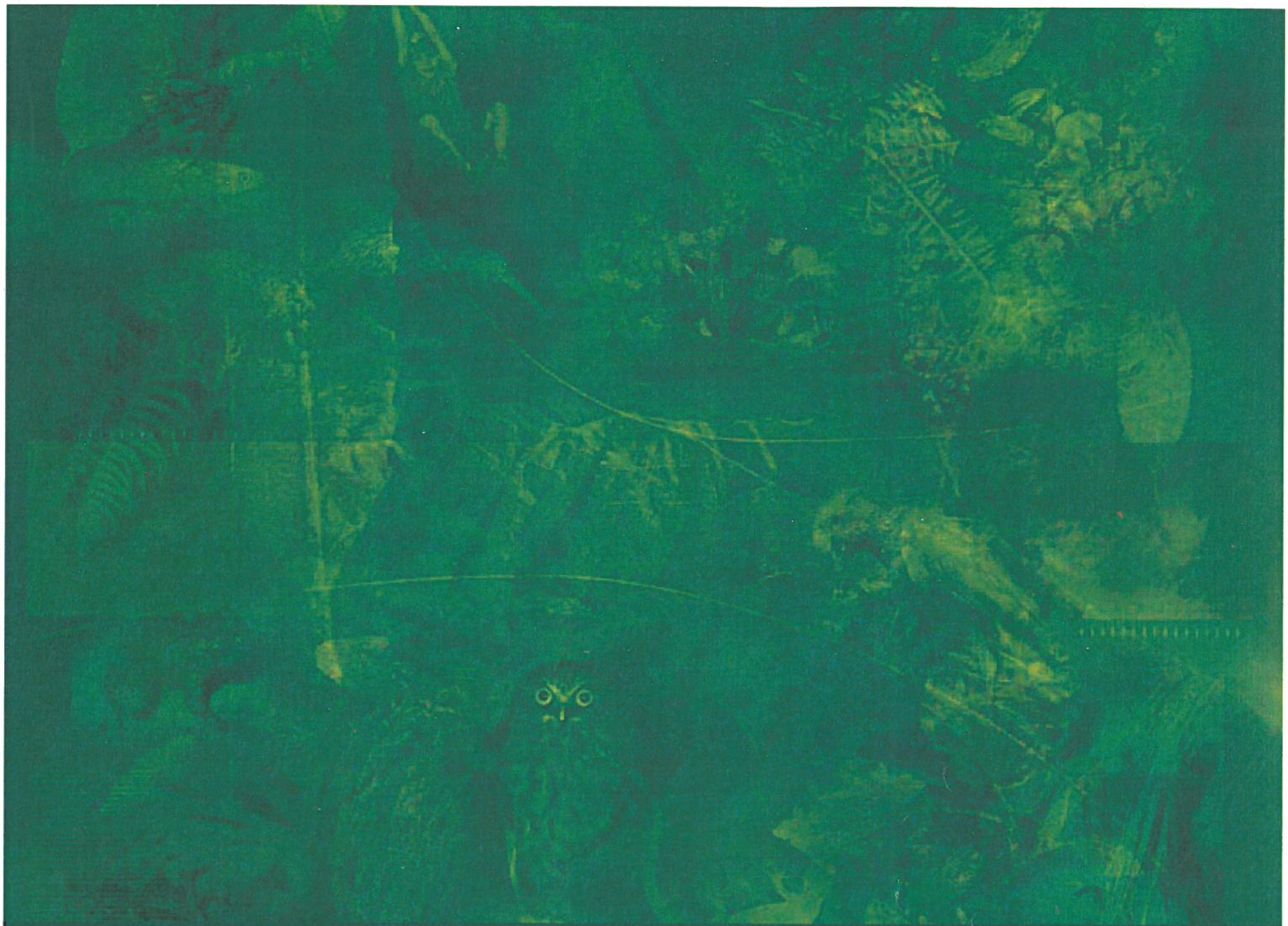

Stormwater management devices: Design guidelines manual

Second edition, May 2003

Whatatepea te kō, kia kotahi We're in it together 09 366 2000 www.arc.govt.nz

Auckland Regional Council
TE RAUHITANGA TAIAO

Forward

Introduction

Human land-based activities generate contaminants. In fresh and saline receiving waters these contaminants can and do cause problems for ecological and human health. Stormwater runoff is a major transport mechanism of land-derived contaminants into aquatic receiving environments. Overseas and New Zealand specific information indicates that serious and widespread adverse effects can result from inputs of stormwater-borne contaminants into receiving waters. In addition, increased quantities of stormwater may impact on downstream flood levels and stream channel physical structure.

Stormwater management can help reduce these impacts. Stormwater management involves careful application of site design principles, construction practices, and maintenance operations to prevent sediment and other contaminants from entering surface water, groundwater, or our coastal environments.

Objective of the manual

The objective of this manual is to provide a commonly accepted design approach for stormwater management practices that will provide both water quantity and water quality benefits, thus benefiting the wider environmental issues we face. Individual development sites may at times present unique issues and the use of standardised design approaches may not be entirely appropriate but most sites will find that the approaches detailed in the manual will help meet Resource Management Act objectives.

Development of the manual

The original Technical Publication #10, “Stormwater Treatment Devices Design Guideline Manual” (TP 10) had been used since October 1992 in response to issues related to stormwater runoff quality. It has provided design guidance for a decade and that decade has seen a number of changes in programme philosophy and evolution in approach and design. In addition, with the advent of Technical Publication #108, “Guidelines for Stormwater Runoff Modelling in the Auckland Region” (TP 108), a revision to more align the manual with the hydrological approach was considered advantageous.

Key revisions

The design approach is more transparent from the context of design input (catchment area, permeability, slope, land use, etc.) generating practice sizing than was the original TP 10 The format and organisation of the manual attempts to make it more “user friendly”.

New manual components relate to outfall protection, landscaping and the approval process for innovative practices. The innovative practices chapter is seen as very important in light of new proprietary products that seem to increase in availability every day. Many of these products have value when correctly applied but it is important to have a rigorous testing regime to ensure that stated performance has been verified.

Technical material has been updated as our knowledge of impacts and methods of control has improved. We have updated the manual to include new information and standards that, we believe, are more effective. Design engineers, planners, landscape architects, resource managers, and government agencies who are involved with the design, regulation and maintenance of stormwater drainage will hopefully find the manual useful.

Tangata Whenua Statement

The Auckland Regional Council (ARC) has consulted with Tangata Whenua on the development of this Guidelines Manual but the opportunity for specific input was, to some degree, limited. This does not in any way diminish the positive contribution that Tangata Whenua can make in the implementation of this document.

Various iwi and hapu have developed or are developing policies and planning documents which contain provisions relating to water management issues. It is important to consider these policies and plans not just for their statutory importance but also for the value they add to a wider cultural understanding of environmental management issues.

Contact information

Questions and comments are welcomed verbally, or in writing, to anyone on the ARC stormwater/sediment team. Please feel free to contact the team at the following address.

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The environmental problems that an urban society creates are not going to "just go away". It has taken 150 years for the problems we have created to manifest to their current level. We have to work together to arrest the rate of decline and ensure that the world we leave our children is not worse than the one we have inherited from our parents.

Please give a careful attention to the manual, understand the context for much of the document, and help us today to make the Auckland Region a better place tomorrow.

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Chapter 1
Introduction

1.1 Objectives of these guidelines

The primary objective of these guidelines is to outline and demonstrate the ARC's preferred design approach for structural stormwater management devices. Specifically this includes design guidance for water quality and water quantity ponds, wetlands, filtration practices, infiltration practices, biofiltration practices and other practices that may be used.

The guidelines also have the following secondary objectives:

1. To provide the reader with a summary of the principles of stormwater management including an outline of environmental effects and management concepts;
2. To outline the statutory process and introduce the rules in the Auckland Regional Council (ARC) Proposed Regional Plan: Air, Land, and Water (which detail when a Stormwater Discharge Permit is required);
3. To provide a resource guideline for those involved with the design, construction and operation of stormwater management devices; and
4. To minimise adverse environmental effects of stormwater discharges through appropriate design, construction and operation of stormwater management practices.

1.2 What is the effect of impervious area on stormwater runoff?

Development of the Auckland Region has changed the character of the natural landform by covering the land with impervious surfaces. Houses, shopping centres and office buildings provide places to live and work. Car travel between buildings is facilitated and encouraged by a complex network of roads and carparks. This infrastructure allows the successful operation of the city and Region and encourages social and economic development.

However, this change from natural landforms and vegetative cover to impervious surfaces has two major effects on stormwater:

> Water quantity (urban hydrology)
> Water quality (non point source pollution)

1. <u>Urban hydrology</u>

Roofs, roads, parking lots, and other impervious areas stop water soaking into the ground, diverting it across the surface and increasing the quantity and rate of water discharging to streams and harbours. Impervious surfaces, compaction of soils and the absence of vegetation reduce the

Plate 1-1: Flood flows in an urban environment

"sponge like" storage capacity of the ground surface, reducing infiltration and the volume of underground water that feeds groundwater resources and stream baseflows. These changes in the hydrological cycle cause flooding, stream erosion , sedimentation and loss of water for abstraction. Flooding and erosion can have direct effects on public safety, while erosion and sedimentation can affect the habitat of aquatic resources.

2. Non-point source pollution

Particles from car exhausts, tyres and brakes, silt, fertilisers, oils, litter and other by-products of urban life fall and collect on impervious surfaces. Many of these small particles adhere onto sediment which stormwater runoff transports to streams, estuaries and harbours. Where the water is still, these contaminants settle out and accumulate. Other contaminants dissolve as rain passes over them and change the physical-chemical composition of stormwater. The accumulation of sediment, contaminants and changes to the chemical make-up of stormwater affect water quality and can then have significant effects on the viability of aquatic resources.

These effects will be detailed further in Chapter Two.

1.3 Managing stormwater

Stormwater management aims to protect human and ecological values by preventing or mitigating the adverse effects of stormwater quality and quantity on the human and aquatic environment.

Stormwater management techniques are generally divided into:

> non-structural practices (which prevent changes to the quality and quantity of stormwater by low impact designs, management practices or planning regulations), and

> structural practices (which reduce or mitigate changes that have already occurred to stormwater by constructed treatment devices).

Non-structural practices may be further categorised into:

> site design practices which reduce the quantity of stormwater runoff, and

> contamination control practices which minimise the risk of contaminants coming into contact with stormwater.

Structural, or treatment, practices assume that the increase in runoff or contamination of stormwater has already occurred and attempt to reduce the contaminants in the stormwater or hold runoff to reduce flooding and erosion.

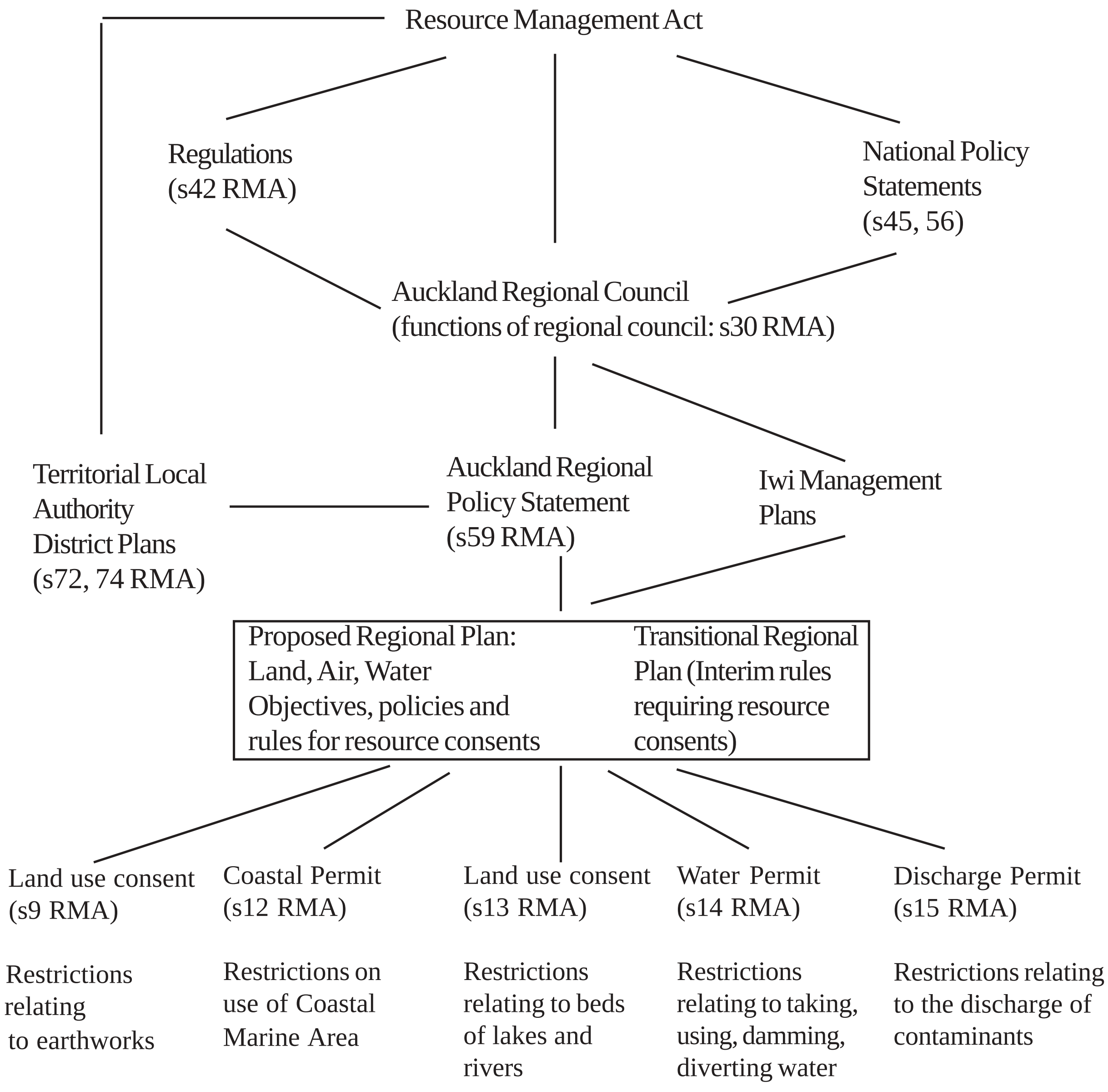
1.4 Regulatory framework

The Resource Management Act (RMA) sets up the statutory framework requiring stormwater discharge permits and is shown in Figure 1-1. Stormwater Discharge Permits are issued under section 15 of the RMA which controls the discharge of "contaminants or water into water". Activities which do not meet the permitted activity criteria of the Transitional Regional Plan and the proposed Regional Plan: Air, Land, and Water (ALW) require resource consents.

Permitted activities allow the discharge of water to any land or water body from any development which has an impermeable surface area of less than 1000 square metres.

When considering a resource consent application, the ARC must have regard to the policy set down in the Regional Plan: Air, Land, and Water and the Auckland Regional Policy Statement. The ALW Plan requires the "best practicable option" (BPO) to be implemented with respect to minimising the effects of stormwater discharges. The BPO will vary depending upon the discharge quality, site conditions, opportunities for mitigation, the downstream receiving environment values and technical and financial constraints. The RMA defines BPO as:

Figure 1-1: Regulatory framework



> *"Best Practical Option means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to*
>
> *(a) the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and*
>
> *(b) the financial implications, and the effects on the environment, of that option compared with other options; and*
>
> *(c) the current state of technical knowledge and the likelihood that the option can be successfully applied."*
>
> *s2(1) Resource Management Act, 1991*

To protect the human and ecological values attributed to receiving waters and to guide the selection of the BPO, the ARC uses three categories of stormwater management objectives which are set out in the proposed Regional Plan. These are:

- water quantity objectives,
- water quality objectives and
- aquatic resource protection objectives.

Water quantity objectives generally relate to the protection of public safety from the flooding and erosion effects of stormwater. Water quality objectives protect downstream receiving waters from the physical-chemical effects associated with the accumulation of stormwater contaminants. Where the discharge is to a watercourse with high ecological value, aquatic resource protection objectives such as hydrological erosion control requirements or additional water quality measures may also be required.

1.5 Technical Objectives

This manual provides guidelines on the selection and design of structural stormwater management devices. The primary objectives therefore relate to the removal of contaminants from stormwater, reducing peak discharges, and reducing site runoff by volume control. However, prevention is better than cure. To fully meet stormwater objectives set by the ARC will require stormwater management solutions which are integrated with development and all opportunities should be taken to prevent and minimise stormwater effects.

The ARC has outlined some preventative methods in the "Low Impact Design" manual (TP124) and the "Environmental Operating Procedures" manual. The Low Impact Design manual presents an alternative approach to residential site design and development from a stormwater management perspective. The Environmental Operating Procedures manual presents a methodology for businesses to assess their environmental impacts and then eliminate and prevent pollution.

The ARC's objectives for managing stormwater are:

1.5.1 Water quantity

The primary water quantity objective of treatment devices is to match the pre-development and post-development peak flow rates for the 50%, 10%, and 1% Annual Exceedence Probability (AEP) rainfall events.

Where significant aquatic resources are identified in a freshwater receiving environment, additional water quantity requirements may be required.

1.5.2 Water quality

The primary water quality objective of the treatment devices in this manual is to remove 75% of total suspended sediment on a long term average basis. Removal of sediment will remove many of the contaminants of concern, including; particulate trace metals, particulate nutrients, oil and grease on sediments and bacteria on sediments.

1.5.3 Aquatic resource protection

Aquatic resource protection is primarily concerned with maintaining the physical structure of the receiving system while promoting practices that provide habitat conditions conducive to a healthy ecosystem in receiving environments.

Physical structure is maintained by designing for by the detention, storage, and release of the first 34.5 mm of rainfall over a 24 hour period.

Other practices include riparian vegetation maintenance or enhancement and a reduction in the volume of runoff through revegetation and use of roof runoff for domestic water purposes.

It is important to note that these are objectives only. They are not standard requirements. There will be situations where alternative approaches or design requirements may be appropriate.

Their application depends upon whether the stormwater issue they address is present and the degree of implementation depends upon site and catchment circumstances as determined by the Best Practicable Option. For example water quantity objectives are unlikely to be required where stormwater is discharged to an open coastal environment where erosion, sedimentation and flooding issues are not present. While water quality is a significant issue in urban areas, the degree to which the water quality objectives are implemented depends on the practices which are able to be retrofitted into the available space. The same issues also apply to aquatic resource protection.

In addition, the approval by the ARC of a catchment management plan for specific catchment that has been submitted by a TA may provide for alternative requirements that have been defined through a catchment-wide analysis. Proposed individual developments should investigate whether an approved comprehensive catchment plan exists for a given catchment, and if so, should ensure that development is in accordance with that plan.

1.6 Structure of these guidelines

These guidelines replace ARC Technical Publication 10: Stormwater Treatment Devices, Design Guideline Manual, October 1992. This document is divided into the following chapters as follows:

Chapter One:	Introduction
Chapter Two:	Effects of land use on stormwater
Chapter Three:	Stormwater management concepts
Chapter Four:	Choosing a stormwater management device
Chapter Five:	Pond design, construction and maintenance
Chapter Six:	Wetland design, construction and maintenance
Chapter Seven:	Filtration design, construction and maintenance
Chapter Eight:	Infiltration design, construction and maintenance
Chapter Nine:	Swale and filter strip design, construction and maintenance
Chapter Ten:	Oil and water separator design, construction and maintenance
Chapter Eleven:	Rain tank design, construction and maintenance
Chapter Twelve:	Greenroof design, construction and maintenance
Chapter Thirteen:	Outlet protection
Chapter Fourteen	Landscaping guidance for stormwater practices
Chapter Fifteen	Innovative stormwater management practices

Chapters 1 - 4 aim to provide all users with an introduction to the regulatory framework, effects of stormwater and the range of management concepts applicable to the Auckland Region.

Chapters 5 -13 describe different practices. Each will provide guidelines for the design, construction and operation and maintenance phases of development.

Chapter 12 discusses a new technology (at least for New Zealand) on the use of vegetated roofs for stormwater benefits. The discussion in that chapter is more to acquaint people with the concept than to function as a design chapter. Depending on interest, the Chapter will be expanded in the future to provide more design assistance.

Chapter 14 provides discussion on landscaping to enhance site appearance and public acceptability.

Chapter 15 relates to new practices and establishes a framework for the assessing performance expectations of new practices and the level of testing that is required for their widespread use in the Region.

1.7 Statement of intent

Applicants may propose alternative designs that meet the requirements of the ALW Plan, and the ARC will assess whether the design will achieve the Plan's goals and objectives.

In addition, this guideline is being distributed primarily in digital format. One reason for that approach is the recognition that updates may be necessary due to increased knowledge relating to investigations or criteria changes both here and overseas. It is the intent of the ARC to update this manual whenever changes are warranted. Distribution can then be done more easily by posting changes on the ARC website.

Plate 1-2: The key to stormwater management is outside the pipe: site design, source control and management practices should be the primary tools for stormwater management.

Chapter 2
Effects of land use on stormwater runoff

2.1 Urbanisation

2.1.1 The hydrological cycle

Water moves constantly between the atmosphere, ground and waterbodies in an ongoing, worldwide cycle, the hydrological cycle. Processes such as rainfall, infiltration and runoff, evaporation, freezing, and melting, continually move water between different physical phases, across regions, between fresh and saline waters and into the atmosphere. Some processes, such as freezing in polar areas or deep infiltration to slow aquifers, may keep water in one part of the cycle for long periods of time. All the time though, water is moving through the cycle.

The total volume of water in the cycle is finite. The amount of water vapour in the atmosphere plus the amount of rainfall, freshwater, ground water, sea water and ice on the land is constant. Over time, physical factors such as climate or landform may change the volume of water at each stage in the cycle, or sub-cycles, but in total no water leaves or enters the cycle.

Plate 2-1: Typical phases of urbanisation - bush, pasture, subdivision, and mature urban

Restricting the movement of water in one stage of the hydrological cycle will proportionally increase it's movement in another. This occurs during urbanisation. The photographs above show the typical phases of urbanisation; through bush, pasture, subdivision and mature urban. In a natural state, a catchment is covered by bush, trees and grass, which intercept rainfall and let it infiltrate into the ground. Urbanisation creates impervious surfaces which reduces vegetative interception, depression storage, infiltration and surface roughness (flow retardation). The excess water now runs off more quickly and increases the flow rate and volume of stormwater for a given storm event.

Plate 2-2: 100% site imperviousness

To illustrate these changes, Table 2-1 gives estimates of the proportion of movement by each process before and after development. These figures represent proportions for the non-volcanic soils of the Auckland Region.

Table 2-1
Components of the hydrological cycle in Auckland

Component	Pre-development	Post-development
Annual rainfall	1200mm	1200mm
Total runoff	320mm	700mm
Deep infiltration	60mm	10mm
Shallow infiltration	300mm	100mm
Evaporation/transpiration	520mm	390mm

2.1.2 Non-point source pollution

Impervious surfaces also collect contaminants derived from everyday urban life. These could be anything from litter, dust, decomposing vegetation or oils, to exhaust emission particles. Roads, in particular, collect by-products from vehicle wear and tear and combustion by-products. In the context of stormwater management and this manual, these by-products are all termed "contaminants."

Stormwater runoff moves contaminants off impervious surfaces, through drainage pipes and into waterbodies. Litter and larger particles are washed off directly while the (very small) contaminant particles attach more to fine silt and clay particles and become readily transportable. Heavier particles drop out of suspension close to the ends of stormwater pipes while finer silts settle and accumulate further away in still, sheltered sections of water. This accumulation of contaminants from wide areas of developed urban land is termed "non point source" pollution.

Plate 2-3: Non point source contaminants

The effects of non-point source pollution are diverse. Persistent contaminants such as metals and toxic organics accumulate in sediment and have toxic ecological effects. Other contaminants such as sediment physically affect habitat, for example by smothering.

In some cases, these contaminants occur naturally in the environment. However, it is important to remember that impervious surfaces and stormwater pipes collect contaminants together, transport them and allow them to accumulate in places that they would not normally end up, and in much higher volumes and concentrations.

2.2 Key effects

Many of the effects of stormwater are only significant when considered cumulatively. The water quality and flooding effects of stormwater from an individual site may be relatively minor. If we consider a 10% increase in peak flow from a 1 hectare site, downstream flood levels may only increase 1 mm or less. However, allowing an increase in flood levels on an individual site basis is an ad hoc approach which neglects the sum total of all potential development in a catchment. Therefore, in addition to any site specific effects, stormwater effects must be considered on a cumulative basis.

The three key effects of urban stormwater on the environment are:

1. Water quantity - flooding and erosion risks to humans and their property from altered hydrology and development too close to existing watercourses.
2. Water quality - threats to human health and receiving systems from changes to the physical-chemical nature of water and sediment.
3. Aquatic resources - loss of freshwater aquatic resources due to both altered hydrology and non point source pollution. In particular, this considers the physical effects of stormwater on the freshwater environment.

2.3 Water Quantity

2.3.1 General

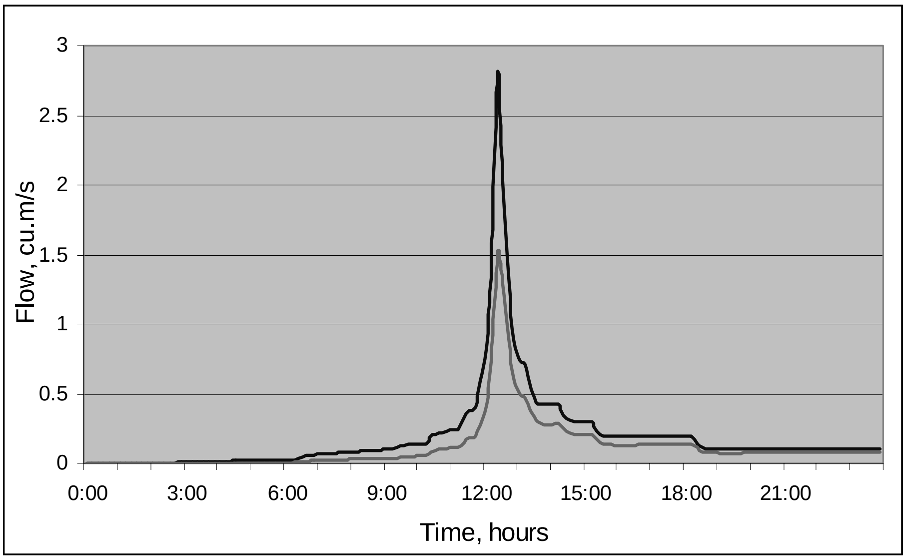
Stormwater drainage systems are generally designed for a moderate level of risk and adopt approximately a 10% AEP event for pipe sizing. However, the importance of more severe, less frequent events is acknowledged and allowance is made for overland flow paths for events up to 1% AEP. These two systems are termed the primary and secondary drainage systems. To protect the public and their property, habitable building floor levels are required to have a contingency freeboard above the 1% AEP flood levels.

Flooding adjacent to waterways naturally occurs but urbanisation can increase flood potential due to either a gradual increase in peak flows (as a result of upstream development described in the example below), or, where a constriction in the drainage channel (culvert, pipe drainage system) or stream channel reduces the flow capacity. However, the safe passage of flood flows is not always a case of "making the pipes big enough." Water flow changes with the location along the channel due to changes in topography, channel dimensions, roughness, pools and other factors. The flood level at a given point is therefore determined by how quickly upstream conditions deliver water and how quickly downstream conditions allow it to get away. The equilibrium sets the flood level. However, the flow rate also changes with time, as the flood passes down a catchment. The flood level will therefore constantly change as both the physical- spatial factors and the variation of flow with time balance.

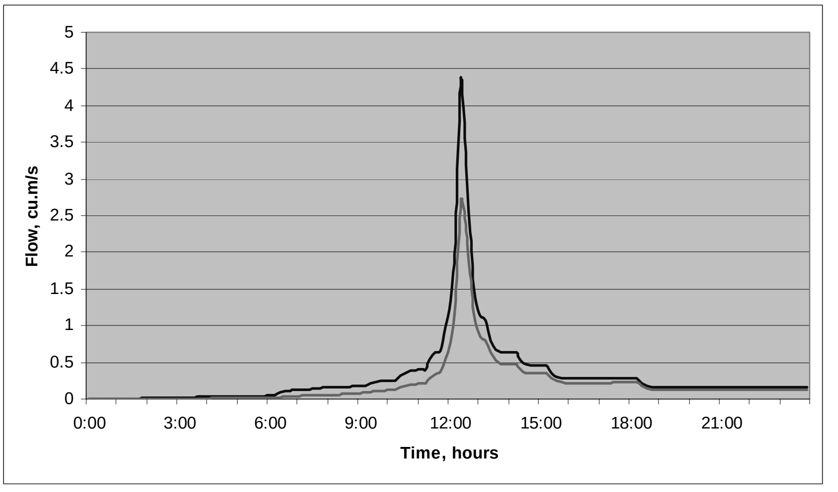
2.3.2 Case study:

Figure 2-1 sets out the predevelopment and post development 50% and 10% AEP hydrographs for a 27.7 hectare residential development, which was previously pasture. The site changed from two houses to 297 lots of about 600 square metres. For average sized houses, garages and driveways and subdivision roading, the imperviousness increases from less than 1% to 54%.

Figure 2-1
Pre-and post-development 50% and 10% hydrographs



The hydrographs show that the peak flow rate for the 50% AEP event increases from 1.51 m^3/sec to 2.80 m^3/sec and for the 10% AEP event increases from 2.7 m^3/s to 4.37 m^3/s. The volume of stormwater runoff for the 50% AEP event increases from 10,200 m^3 to16,800 m^3.



Stormwater from the development discharges to a stream. The extra peak flow in the watercourse raises the flood level. The flood level equivalent to the predevelopment 50% AEP event, now occurs more frequently, resulting in more frequent bankfull flows. This results in more stream bank erosion.

2.3.3 Examples of effects

1. Extent of flooding

Flood levels are determined by equating the rate of inflow, outflow and available storage. Where the outflow is smaller than the inflow, levels rise. In Plate 2-4 the flooding has risen above the stream channel and spread across large sections of land - the natural floodplain.

Increased imperviousness upstream and loss of storage volume, by filling in the flood plain, would make the flood level higher still.

Plate 2-4

2. Channel constrictions

Channel constrictions such as culverts and bridges are potential flooding points. Constrictions usually include an overland flow path to pass events more severe than the design event and make allowance for blockage.

The risks to the property in Plate 2-5 are multiple, including development greater than expected upstream, debris in the flood channel, weakening of foundations and an event greater than the design flood.

Plate 2-5

3. Lack of freeboard

To calculate freeboard and allow for the safe passage of flood flows, the ultimate development scenario upstream must be considered.

The consequences of getting it wrong are evident in Plate 2-6. A further rise in flood level will cause the bridge to become a constriction and raise upstream flood levels significantly.

Plate 2-6

4. Channel erosion

As bankfull flows increase in frequency with development, the channel erodes to become stable for the increased flow and velocity. As shown in Plate 2-7, this often results in a wider, "U" shaped channel, the most efficient shape for transporting the flow. During this process, aquatic habitat is lost.

Plate 2-7

5. Bank slumping

Stream flows are generally deepest and fastest on the outside of a bend. When flow velocities increase, the toe of a bank is often eroded, removing bank support. Eventually, the bank slumps. The recent slump is also susceptible to erosion and, unless stabilised, can keep retreating as shown in Plate 2-8.

Plate 2-8

6. Channel Incision

Plate 2-9 shows a stream where high velocity and frequent high flows erode the channel base. The clay channel invert here has been cut down 0.5 m to 1.0 m

Channel erosion is a significant source of sediment which affects water quality and downstream habitat.

Plate 2-9

2.4 Water Quality

2.4.1 General

Evidence of the effects of urbanisation on water quality may be direct but is often indirect. When considered from a number of perspectives, a clearer picture of effects emerges. Three common methods for observing water quality effects include visual assessment, contaminant level measurement, and biological surveys.

A very simple way to note stormwater effects is to walk along an urban stream and note the changes as the land use changes. Areas with greater levels of imperviousness discharge higher quantities of contaminants and water volumes which quickly change the structure and quality of the stream. Effects are particularly evident where the upper reaches of a catchment are undeveloped. A visual survey can document comparative downstream changes, such as channel erosion locations, fish pass blockages, and areas of sedimentation.

Plate 2-10

Urban stream where stability issues cause economic effects

Measuring water or sediment quality chemical parameters for comparison against accepted threshold values can also indicate effects on organisms. A number of studies of such urban runoff have been carried out in Auckland to monitor water quality effects. In addition, a number of biological studies have monitored chemical parameters in situ and attempted to correlate the contaminant levels against the observed species condition and abundance. There is increasing evidence that catchment development strongly impacts on aquatic resources.

This section presents an introduction to common stormwater contaminants and includes an overview of visual and biological effects that are linked to development and non point source pollution. The ARC has carried out a significant amount of work on quantifying water quality effects and this information is available through a number of ARC technical publications. A summary of available information was collated in 1995 in ARC TP 53 - "The environmental impacts of urban stormwater runoff".

2.4.2 What are the contaminants?

(a) Suspended sediments: These are soil, organic particles, and breakdown products of the built environment entrained in stormwater flow. They can be silt sized (63 *u*m) or smaller. Sediments reduce light transmission through water, clog fish gills, affect filter feeding shellfish, smother benthic organisms, change benthic habitats and fill up estuaries. Larger soil particles above silt sized are also contaminants, but typically exhibit different physical characteristics and settle much more quickly. These particles are sometimes termed "bed load" sediment.

For the purposes of TP 10, the definition of suspended sediments is that provided in the ALW Plan.

(b) Oxygen demanding substances: These are soil organic matter and plant detritus which reduce the oxygen content of water when they are broken down by chemical action and by bacteria. Chemical oxygen demand (COD), total organic carbon (TOC) and biological oxygen demand (BOD) are three measures of the consumption of oxygen in water. Fish generally neet at least 5 gO_2/m^3 to stay alive. A large proportion of fish kills in the Region are caused by spills and oxygen demanding substances such as sewage.

(c) Pathogens: Pathogens are disease-causing bacteria and viruses, usually derived from sanitary sewers. Organisms such as faecal coliform and enterococci are often used as indicators of the presence of pathogenic organisms. However, the presence of an indicator organism does not necessarily prove a pathogen is present; merely that the risk is higher.

Concentrations of indicator organisms in stormwater in the pipe before discharge may exceed Ministry of Health guidelines for contact recreation and shellfish collection. However, dilution with receiving waters will usually mean public health criteria are not exceeded.

(d) Metals: A variety of trace metal compounds are carried in stormwater in both solid and dissolved forms. The most commonly measured metals of concern are zinc, lead, copper and chromium. Metals are persistent; they don't decompose and they accumulate in sediments, plants and filter feeding animals such as shellfish. Elevated levels of metals cause public health issues and organisms avoid the affected habitat area (leading to a reduction in the number and diversity of fauna.) At higher levels still, intergenerational deformities and tumours may occur, as has been recorded overseas.

(e) Hydrocarbons and oils: The hydrocarbons in stormwater are generally those associated with vehicle use. They may be in the form of a free slick, oil droplets, and oil emulsion, and in solution or absorbed to sediments.

(f) Toxic trace organics and organic pesticides: A large range of trace organic compounds has been found in stormwater in Auckland. Polyaromatic hydrocarbons (PAHs) are one major group. PAHs are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil, and gas. Soot is a good example of a PAH. Organo- chlorine pesticides such as dieldrin, Lindane and Heptachlor constitute another main class of toxic organics.

(g) Nutrients: Nutrients in stormwater are usually nitrogen and phosphorus compounds that stimulate plant and algal growth. This can cause daily fluctuations in oexyen concentrations, including phases of aerobic decomposition, which removes dissolved oxygen from the receiving waters.

(h) Litter: Litter in stormwater is often referred to as gross pollution. It has a high visual and amenity impact, but limited effect on public health and ecological standards.

In addition to the above contaminants, stormwater discharges have other physical and chemical effects which affect aquatic organisms and change how contaminants react. These include changes to temperature, pH, dissolved oxygen, alkalinity, hardness and conductivity.

2.4.3 Measurement of water quality effects

The concentration of contaminants in stormwater varies during a storm, from storm to storm, and from catchment to catchment. The event mean concentration (EMC) is a measure of the average pollutant concentration during a storm. It is the pollutant load for the storm divided by the volume of runoff and will vary from storm to storm. The variation of pollutant concentration with time through a storm is termed a pollutograph.

When comparing concentrations with water quality criteria, it should be borne in mind that individual samples may exceed the EMC by a large factor. Exceeding water quality guidelines does not necessarily lead to effects on the environment. An EMC value in stormwater may exceed water quality guidelines "in pipe" but may not following dilution in receiving water. Water quality criteria are therefore more often used as an indicator of receiving environmental health rather than a regulatory standard.

Once contaminated sediments accumulate, their effect depends on factors such as spatial distribution, duration of exposure, dilution from deposition with cleaner sediments, and the rate at which the contaminants are assimilated (or bioavailability) by organisms in the receiving environment.

Pollutant toxicity is described as chronic (effects are the result of a gradual accumulation over time) or acute (effects are the result of a sudden pulse).

2.4.4 Examples of effects

The following photographs illustrate the issues discussed.

1. Stream contaminants

Plate 2-11 shows the urban stream water and sediment quality in an inner city stream. Effects include litter, inorganic material, some turbidity in the water column, vegetative detritus, and sediments.

Plate 2-11

Plate 2-12 is a close-up of the same environment.

Plate 2-12

2. Sediment

Sediment from urban land uses and stream channel erosion often settles in estuaries. Low velocities and the saline environment assist particulate settling. Continual sediment delivery reduces light penetration and prevents plant food sources growing in the estuary, thereby affecting bottom dwelling organisms such as worms, crabs and shellfish, the base of the marine food web.

The sediments in the upper and right of plate 2-13 are predominately coarse sand and gravel sized particles transported from nearby roads.

Plate 2-13

3. Litter

Stormwater systems typically receive inflow via a catchpit. “Back entry” catchpits have a slot set into the kerb behind the grate to improve the hydraulic capacity. However, the size of the slot (50 mm minimum) is sufficient to pass pieces of litter into the stormwater system and waterbodies. Plate 2-14 shows a gross pollutant trap to catch litter.

Litter will then travel downstream from where it is generated and is an obvious example of how far stormwater pollutants may travel. Litter affects recreational amenity values and may compromise species habitat.

Plate 2-14

4. Benthic community health

Benthic species are creatures living in aquatic bottom sediments. Figure 2-2 gives an indication of benthic community health in a number of urbanised estuarine areas around Auckland by looking at the species diversity and frequency. Big Muddy Creek can be thought of as a control site as most runoff is from the water supply catchments west of Laingholm. Sites adjacent to the urbanised parts of the region have fewer number of species and a corresponding higher level of metal and organic chemical sediment contamination.

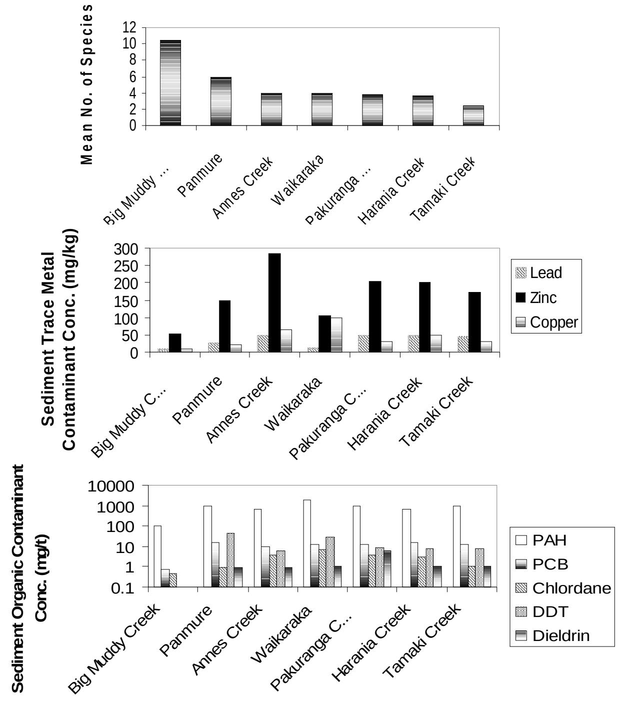


Figure 2-2

5. Tamaki River contamination gradient

Figure 2-3 shows a possible relationship between oyster contamination and body condition. Commercial oysters were taken from the Mahurangi Estuary and deposited in locations along the Tamaki River for a twelve month period. The level of contamination is worst in the reaches of the river with greatest contamination (Panmure Basin) and decreases toward the open coastline. The condition of oysters in the upper reaches of the Tamaki River is significantly worse than those in the lower reaches. This is thought to be due to increased flushing characteristics of the river as the tidal influence increases.

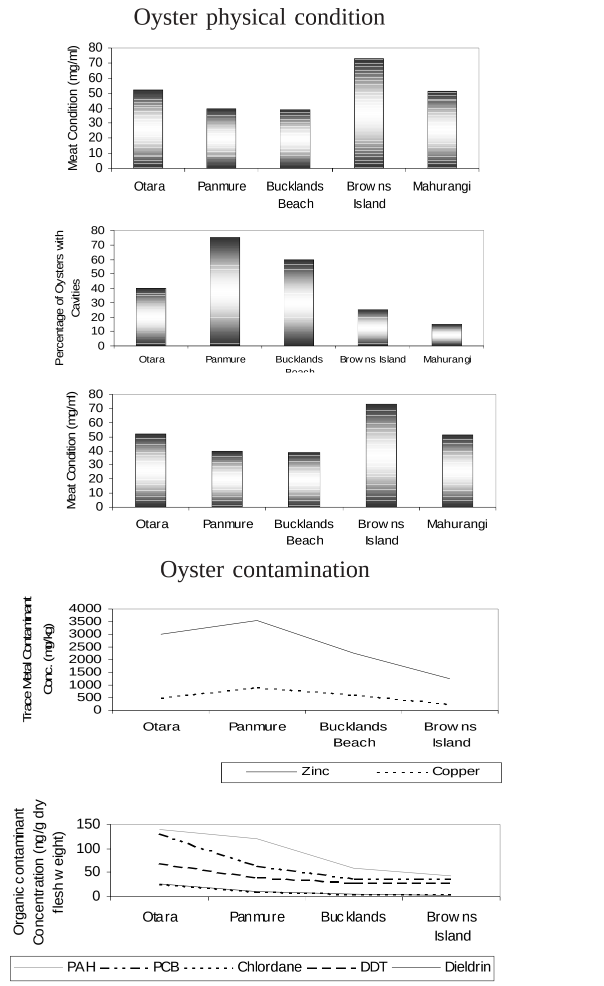


Figure 2-3

2.5 Aquatic habitat

2.5.1 General

Stream health is affected by all the water quality and water quantity factors that have been discussed in the previous sections. Hydrological factors are thought to be key factors in causing sedimentation and erosion of physical stream structure. However, it is very difficult to identify the combination of different factors that cause specific problems in stream health. Surrogate indicators are therefore used to indicate stream health.

One form of life that exists in streams is macroinvertebrates. Macroinvertebrates are aquatic insects that include grazers, shredders, collectors/browsers, piercers, suckers, and filter feeders on detritus and predators. The presence of a diverse macroinvertebrate community indicates consistently good water quality and a stable stream structure (available habitat). Any alteration of either of these parameters will be reflected in the macroinvertebrate community. So where they are present, they are extremely valuable.

Fish are another barometer of health with their absence or presence providing a picture of the overall health of a stream. Typical fish found in Auckland streams include banded kokopu, inanga, common bully, as well as eels and freshwater crayfish.

The increased frequency and magnitude of peak flows destabilises stream banks and increases sedimentation. Sedimentation can smother stable and productive aquatic habitats such as rocks, logs, and aquatic plants. The roots of large trees are undercut and fall into the stream while new growth has less opportunity to become established. Deliberate removal of vegetation exposes soil on stream banks, a common feature of urban streams that makes them more vulnerable to erosion. The structural stability of the stream channel has a significant effect on the health of the aquatic ecosystem.

The effectiveness of structural practices at protection of stream aquatic resources was assessed by Horner, (2001) from a catchment-wide perspective. Horner makes a number of interesting statements although they need to be further documented. Key findings were:

- Until catchment total impervious area exceeds 40%, biological decline was more strongly associated with hydrologic fluctuation than with chemical water and sediment quality decreases. Accompanying hydrologic alteration was loss of habitat features, like large woody debris and pool cover, and deposition of fine sediments.
- Structural BMPs at current densities of implementation demonstrated less potential than the non-structural methods (riparian buffers, vegetation preservation) to forestall resource decline as urbanisation starts and progresses. There was a suggestion in the data, though, that more thorough coverage would offer substantial benefits in this situation. Moreover, structural BMPs were seen to help prevent further resource deterioration in moderately and highly developed catchments. Analysis showed that none of the options is without limitations, and widespread landscape preservation must be incorporated to retain the most biologically productive aquatic resources.
- Structural BMPs can make a substantial contribution to keeping stream ecosystem health from falling to the lowest levels at moderately high urbanisation and, with extensive coverage, to maintaining relatively high biotic integrity at light urbanisation.

The following pictures and text detail aquatic resource impacts related to stream channel modification, barriers to migration, and sedimentation.

1. Stream structure

Urban streams are often straightened and "improved" to increase the hydraulic capacity as seen in Plate 2-15. This process removes habitat such as stream meanders, pool/ riffle structures. Food sources from in stream vegetation and sediments are lost.

Plate 2-15

2. Barriers

Culverts, weirs and other in-stream structures form barriers to fish passage. This culvert is above the base flow water level preventing fish migration. Climbing fish species cannot pass through the culvert because it overhangs the stream and the shallow depth of water inside the pipe gives high velocities. The culvert shown in Plate 2-16 has also caused channel and stream bank erosion, producing turbulence which discourages migration by slow swimming fish species.

Plate 2-16

3. Sedimentation

Low flowing sections of streams are susceptible to sedimentation as seen in Plate 2-17. This can remove habitat in a similar way to channel lining, by infilling pool and riffle stream stretches and smothering food sources and bottom dwelling animals.

Plate 2-17

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Chapter 3
Stormwater management concepts

3.1 Introduction

This chapter presents a guide to the following stormwater management concepts of:

> - site design,
> - contamination control and treatment;
> - common structural stormwater management practices and
> - a summary of treatment mechanisms that they utilise.

3.2 Stormwater management concepts

3.2.1 Overview

As we saw in Chapter Two; water is in a constant dynamic cycle between the land, water bodies and the atmosphere. Development alters the rate of water's progress through the cycle, resulting in hydrological and water quality effects. The most effective forms of stormwater management try to redress this disruption by avoiding it as much as possible in the design phase. Where this is not possible, stormwater effects must be managed by constructed mitigative methods such as detention ponds and water quality treatment devices. Unfortunately, attempts at mitigation are usually only partially successful, as they control a limited proportion of contaminants and are restricted by technical and financial constraints.

Prevention is better than cure. Stormwater management solutions that fundamentally reduce the risk of stormwater effects are more successful as the potential effects are never generated. Even partial prevention is more useful than mitigation, in that the scale of mitigation required is reduced. Prevention is best achieved by integrating careful site design and contamination control measures.

The RMA outlines the multi- faceted, integrated approach to managing effects; Section 17 states: "*Every person has a duty to* ***avoid, remedy or mitigate*** *any adverse effect on the environment arising from an activity* ..." In the context of stormwater management, the 'avoid, remedy or mitigate' concept matches three stormwater management concepts -

'Avoid' - Site design - practices which prevent stormwater becoming contaminated by reducing runoff or removing contaminant sources, e.g., use of non-zinc roofing materials, reduction of impervious area by porous paving.

'Remedy' - Contamination control

Source control - practices which contain contaminants or prevent them from contacting stormwater runoff, e.g. separation of stormwater and oil spills by bunding.

Management practices - work practices that avoid or reduce the potential for runoff to become contaminated, e.g. improved street sweeping practices, training staff in chemical handling procedures.

'Mitigate' - Treatment devices - constructed practices to reduce the quantity of contaminants in stormwater or retard the volume of flow e.g. constructed wetlands, detention ponds.

The purpose of this manual is to provide design guidance for treatment devices, and therefore primarily deals with the mitigative section of stormwater management tools. However, avoiding effects by careful site design and remedying effects by source control and management practices is a vital tool in the control of contaminants. Any one stormwater management tool, on it's own, is unlikely to achieve the stormwater management objectives for any given development. For this reason it is necessary to consider the objectives early in the design process while competing demands can be carefully balanced and an integrated solution achieved. The need for, and size of, treatment devices is then minimised as is their installation and maintenance costs. The combination of a number of different tools or practices to achieve an overall stormwater management objective is called "The Treatment Train" and is discussed further in Chapter Four: Choosing of a stormwater management device.

Many of the effects of stormwater are, by themselves, very small. However when considered on a catchment basis, their cumulative effect is substantial - such as in the case of flooding due to gradual increases in upstream impervious areas. To manage these effects, we need to understand them on a catchment basis, where the effects are discernible, but prevent them on an individual site basis, where the physical changes to the hydrological cycle are made. This is the role of catchment management plans. They are a key tool for integrated stormwater management and are a range of the above approaches to achieve overall catchment objectives.

3.2.2 Site design

Site design, or runoff control practices, aim to fundamentally reduce the impact of development on the hydrological cycle by attempting to mimic pre-development rates of runoff, infiltration, and evapo-transpiration. To achieve this, we must carefully evaluate the components of a development proposal and identify how they will change the existing hydrological regime. Reduced infiltration, increased runoff and reduced evapotranspiration will result from the development. But, with careful design and control of construction processes, we can minimise the changes.

To manage the effect of development on runoff hydrographs, several defining rainfall events need to be considered to approximate predevelopment conditions as closely as possible to those post development. The 50%, 10% and 1% AEP events have been chosen for this purpose. The ARC considers that changes to the hydrological cycle are minimised by matching the pre and post development peak flow rates and minimising changes to the volume and duration for these events. This usually requires a mixture of site design practices and structural treatment practices.

Four techniques for runoff control are outlined below- further detail is contained in the Auckland Regional Council Technical Publication No. 124 : Low impact design manual for the Auckland Region.

3.2.3 Existing site features

A natural site contains an existing drainage network with features such as watercourses, depressions, floodplains, wetlands, vegetation and permeable areas that contribute to the current balance in the hydrological cycle. By identifying, preserving, and integrating these features with the development where appropriate, changes to the cycle are minimised. the residual changes are thus easier (and cheaper) to manage.

3.2.4 Reduce imperviousness

Impervious surfaces affect water cycle processes by reducing infiltration and increasing runoff. By reducing imperviousness, the overall percentage of hard surfaces can be reduced and the permeability of the required hard surfaces increased. Using pervious channels or infiltration practices at the start of the treatment train for onsite infiltration or to collect and transfer stormwater to a downstream treatment practice reduces the effective impervious area of the development. In either case, the amount of runoff is reduced, which will subsequently reduce the necessary volume of stormwater treatment devices on site.

Some methods to reduce impervious areas:
- Reduce road widths to suit actual traffic densities instead of generic minimum widths
- Make lots closer to the main roading network to minimise accessway lengths
- Use grass swales for drainage to reduce concentration times and encourage infiltration
- Use porous pavements, gravel or grass for low density accessways and parking areas
- Place footpaths on only one side of a street
- Reduce parking requirements to a minimum

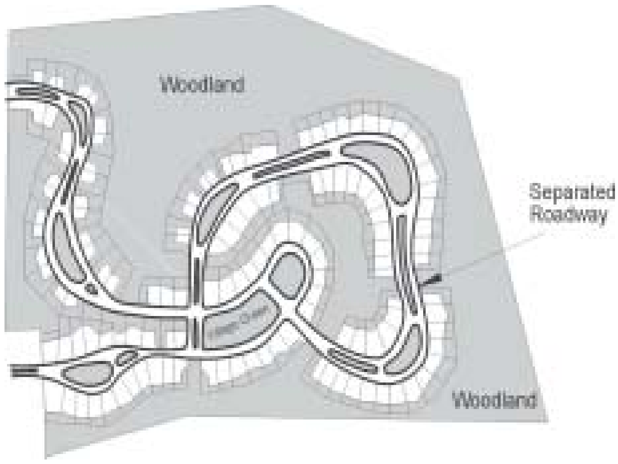


Figure 3-1 Cluster development

3.2.5 Clustering/lot configuration

Subdivisions traditionally require significant amount of earthworks to produce flat sites with house lots of very similar sizes. Typically, each will have a house, front yard, back yard and separate access to the road. All streams, vegetation and site features are lost to maximise the number of lots. However, by clustering houses, as shown in Figure 3-1, together with smaller lot sizes, existing site features may become common recreational resources. Overall site imperviousness is then reduced and the existing stormwater channels are retained.

Some methods to change the lot configuration include using:
- Smaller lot densities with common recreational areas
- Duplex or terrace housing configurations instead of single family lots
- The same accessways to service multiple lots

3.2.6 Minimise site disturbance

Earthworks compaction produces high strength but high density soil with reduced permeability. Even when not sealed with impervious surfaces, this reduces infiltration and increases runoff. To prevent changes to the hydrological cycle, it is therefore very important to avoid earthworks on areas that are to be retained as permeable.

Existing vegetation also plays an important role in maximising infiltration and promoting evapotranspiration. Organic litter beneath trees and smaller vegetation acts a sponge by capturing rainfall and holding it while it slowly infiltrates into the ground. By analysing the existing topography and natural site features and carefully planning around them, it is possible to integrate the development with the environment and minimise the areas of vegetation and earthworks disturbance.

Some methods to minimise site disturbance include:
- Minimise bulk earthwork areas during construction
- Avoid earthworks on future permeable areas
- Maintain riparian margins of watercourses
- Maintain vegetated areas to promote long term infiltration
- Replant vegetation on slopes

3.2.7 Contamination control

Source control and management procedures attempt to reduce or avoid contaminants getting entrained in stormwater runoff. These practices assume that the contaminant source is necessary for the successful operation of the business or activity, and seek to control the release of contaminants or remove them before they come into contact with stormwater. For example, service stations inherently use trade oils and petrol as their main business activity, but, they are required to cover the service area and shut off stormwater pipes during tanker deliveries to prevent the discharge of petroleum products to the environment via stormwater drains.

The ARC advocates that businesses that handle chemicals or produce wastewater carry out an environmental self audit to identify actual and potential contaminant sources. An action plan should then be developed to eliminate any actual pollution and minimise the risk of potential pollution. The reduction of potential pollution sources is set out in 3.2.8 or 3.2.9. Further information is available in the ARC's "Environmental Operations Plan" manual.

Plate 3-1: Chemical roof and bunding

3.2.8 Source control

Source control practices identify contaminant sources and construct physical works to prevent them coming into contact with stormwater. The classic example is the above ground storage tank with a bund constructed around the tank. The bund volume is slightly greater than the volume of the storage tank.

Other examples include:

- Physical control structures such as bunding, spill containment
- Covering stockpiles of soil, waste products
- Directing washwater to sanitary sewer
- Covering "dirty" work areas such as truck washes or oil changing bays

3.2.9 Management practices

Numerous procedures can be designated as management practices, from council initiatives to regularly remove gutter dusts before they get entrained in stormwater to industrial protocols for handling chemicals. The common factor is that there is a process to be followed that minimises the risk of contaminant transfer to stormwater.

Council initiatives include:

- Street vacuuming
- Education initiatives
- Recycling

Industry initiatives include:

- Refuelling procedures
- Chemical handling procedures
- Staff training re proper disposal areas for wastes, chemicals etc.
- Proper storage for chemicals, fuel etc. i.e. not outside, forgotten

3.2.10 Treatment

Treatment practices attempt a difficult task; the removal of contaminants entrained in stormwater flows. Significant proportions of contaminants are dissolved in stormwater, and many others are attached to fine particles of silt which do not easily settle. Removing these contaminants needs a complex combination of processes such as sedimentation, adsorption, and filtration. When site size constraints and limited financial resources to implement treatment are also considered, the complete removal of contaminants from stormwater is basically not achievable. This is why the ARC emphasizes that opportunities for good site design practices and contamination control must be incorporated as a necessary precursor to effective treatment practices. This will produce a better overall result for treating the effects of stormwater.

The time of installation and the maintenance of treatment devices are important issues. Much of the impact of development occurs in the early stages of construction when the significant changes occur to the hydrological regime and large quantities of sediment are discharged during earthworks. The early installation of stormwater management facilities is the best defence to these changes and also provides a backup to earthworks controls. After development, stormwater devices require ongoing maintenance to ensure that inlets and outlets are not blocked and the full treatment volume is available to remove contaminants.

The remainder of this section provides an introduction to the different types of treatment practices. Following the section, a number of photographs illustrate the various types of stormwater management practices.

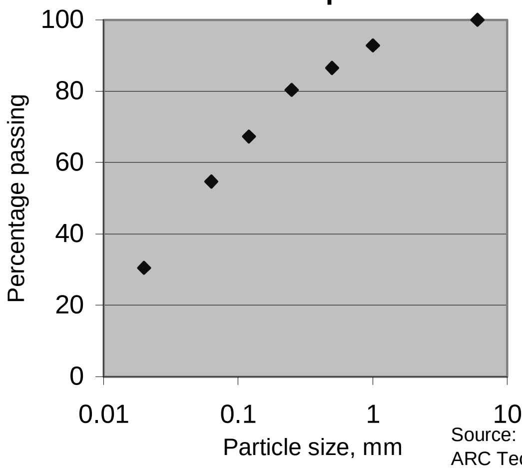
(a) Sedimentation

Most particles suspended in stormwater are less than 120 *u*m diameter. Coarser fractions, above 120 *u*m tend to remain in gutters or get caught in catchpits. However, contaminants attach to particles less than 20 *u*m in disproportionately high numbers, meaning that effective removal devices must target these very small clay particles.

Sediment coarser than medium silt (approx. 20 *u*m) settles rapidly, but much longer settling times are required for finer particles to settle. Particles less than 10 *u*m tend not to settle discretely according to Stokes Law but must flocculate before settling. The particle shape, density, water viscosity, electrostatic forces and flow characteristics affect settling rates.

Figure 3-2

Stormwater suspended solids



Source: Table A2.5: ARC Tech Pub 5

Particle size distribution and laboratory settling rates for residential stormwater in Pakuranga are presented in Figure 3-2.

The proportion of sediment and contaminated sediment removed can be improved by the following measures:

- longer detention times
- larger surface area for settling
- promoting laminar flow and reducing turbulence
- promotion of coagulation

(b) Aerobic and anaerobic decomposition

Microorganisms reduce soluble BOD (biological oxygen demand) and break down nutrients and organic compounds by aerobic and anaerobic oxidation. Once the aerobic microorganisms have taken up contaminants they die, and settle to the bottom of ponds where further anaerobic oxidation may take place. In anaerobic conditions, microorganisms can remove nitrogen by de-nitrification. This is an importance process in constructed wetland function.

Aerobic:
Organic matter + bacteria + O_2 => new cells + CO_2 + NH_3 + H_2O

Anaerobic:
Organic matter + bacteria => new cells + alcohols/acids + bacteria =>
new cells + CH_4 + H_2S + NH_3 + CO_2 + H_2O

(c) Filtration and adsorption to filter material

As sediment particles pass through a filter bed or through soil, they may be removed by the following filtration processes:

- settling into crevices
- enmeshment in interstices (sieving)

> impingement onto filter particles followed by sticking onto particles (by electrostatic or other bonding)

Adsorption is the accumulation of dissolved substances on the surface of a media such as plants or filters. Dissolved substances can also be removed by adsorption to filter material and biological uptake by microorganisms living among the filter material.

(d) Biological uptake

Plants take up nutrients or metals from stormwater via absorption processes. However they may also re-release them to the water column when they die and decay.

(e) Biofiltration

A variation to the filtration mechanism is to use plants as the filter media. Contaminants adhere to plant surfaces or are absorbed into vegetation. This mechanism is a combination of filtering, reduced settling time and adhesion.

(f) Precipitation

Colloidal particles may, under the right physical-chemical conditions, flocculate and settle out, enabling sedimentation devices to sometimes remove apparently dissolved trace metals. The precipitation process may be slow, requiring large detention times, but may be assisted by mechanical flocculation or chemical additives.

3.3 Typical stormwater management practices

3.3.1 Water quality ponds

Ponds detain stormwater inflows to allow suspended solids to settle. There are two main types; wet ponds and detention ponds. Wet ponds as shown in Plate 3-2 have a permanent pool with very slow flow through the pond. Detention ponds have a temporary pool formed by capturing and releasing stormwater at a slow rate. Sedimentation is promoted by slow flows which give longer detention times and minimise turbulence. Aerobic decomposition and adsorption of contaminants on to plants provide secondary treatment benefits by removing some nutrients and further sediment.

Plate 3-2

3.3.2 Wetlands

Wetlands, as shown in Plate 3-3, detain flows to allow sediments to settle, but also remove a significant proportion of contaminants by adhesion to vegetation and aerobic decomposition. Vegetation is an integral component of the wetland system and assists each of the treatment mechanisms. It reduces velocities and turbulence, provides significant surface area for silt adhesion and reduces dissolved metals and nutrients through biological uptake. Wetlands also have the potential to provide hydrological benefits in a similar fashion to detention ponds.

Plate 3-3

Plate 3-4

3.3.3 Detention practices

Detention ponds and tanks intercept stormwater flows, store it and release it at a reduced rate. Their volume is determined according to flood routing principles for a range of rainfall events. Plate 3-4 shows a dry detention pond that functions only during or jsut after rainfall/runoff.

Their primary function is to reducing flooding and erosion of the downstream channel, but they also contribute to water quality by retaining water, thereby giving silt particles some opportunity to settle out of suspension.

Plate 3-5

3.3.4 Filtration

Sand, topsoil or even compost are filter media that can remove contaminants when stormwater is passed through them. Coarse sediment particles are generally removed by sedimentation (right hand chamber in Plate 3-5) and then silt and attached contaminants are removed by sieving and adhesion to filter media (large left hand chamber). Underdrains collect water at the base of the filter media and discharge to the outlet. Filters generally only service a small catchment area and therefore only give limited hydrological benefit from flow attenuation on a catchment basis.

Plate 3-6

3.3.5 Infiltration

Infiltration practices collect and hold water below ground for disposal to the groundwater table. Sediments are removed by filtering in the stone reservoir or by in situ soils adjacent to the excavation where the stormwater is stored. Practices include infiltration trenches, soakage pits and porous block pavements. Soils must be permeable enough to disperse stormwater in a reasonable time and ensure the practice is ready to receive further inflow. Consequently, infiltration practices are more often used in areas with volcanic soils. Infiltration practices can have significant hydrological benefits by assisting groundwater recharge.

Plate 3-7

3.3.6 Rain gardens

Rain gardens, as shown in Plate 3-7, are a combination of an infiltration and filtration device. Water is directed to a local hollow where it soaks into a organic filter medium such as topsoil or compost. Some water soaks into the ground while the remainder is collected and piped to the stormwater drainage system.

Plate 3-8

3.3.7 Biofiltration

Passing stormwater through vegetation removes sediment particles by adhesion to the plants and organic material as it filters through them. Dense vegetation, low water velocity and a long exposure time through the vegetation are required to ensure reasonable effectiveness. Biofiltration practices may have multiple benefits by reducing impermeable area, assisting groundwater recharge and increasing hydrological response times.

Vegetative swales such as that in Plate 3-8 are well suited to collecting and treating non-point source flows from long impermeable surfaces such as roads and carparks.

Plate 3-9

3.3.8 Vegetative filters

Vegetative filter strips are another biofiltration practice. They rely on distributed flow to produce a thin layer of water passing through the vegetation to ensure reasonable treatment. They are generally only used in conjunction with another stormwater treatment practice (both upstream and down).

Plate 3-10

3.3.9 Gross pollutant traps

GPTs are often placed at the inlets to stormwater practices to catch large pieces of litter and vegetation. Collection of litter at a single point allows easier maintenance and better performance of downstream stormwater management devices.

3.4 Design basis of treatment practices

The following design concepts form the basis for the stormwater management practices in the rest of this manual. Specific regulatory and technical objectives are set out in Chapter Four

3.4.1 Resource consent applications

The ARC advocates that applications for resource consents for the diversion and discharge of stormwater made from the beginning of the year 2000 should be supported by calculations of peak flows, volumes and hydrographs using ARC's TP108, "Guidelines for stormwater runoff modelling in the Auckland Region", April 1999. The ARC recommends HEC-HMS as a suitable model for doing such calculations. HEC-HMS is available as freeware, and may be downloaded from the Internet.

The ARC suggests that there are advantages in continuing to use TP108 in undertaking calculations associated with stormwater quality treatment. The following sections relate to the use of TP108 in design. If a HEC-HMS model has been set up with pervious and impervious areas separately modelled, it can also be used for stormwater quality treatment calculations. Otherwise hand calculations are required.

3.4.2 Water quality design

This manual describes the required sizing of various stormwater treatment devices to achieve the required level of suspended solids removal. Compliance with the Water Quality Volume, WQV, and the checklist requirements set out in the practice chapters is deemed to produce a design that will achieve the water quality objective.

Water quality treatment practices in this manual are sized on the Water Quality Volume (WQV). This is an empirical measure based on the stormwater quality design storm, S_d and the Areas of Development (be they impervious and/or pervious), draining to the water quality treatment device and the associated Curve Numbers relating to those contributing areas.

The Areas of Development contributing to the Water Quality Treatment Practice are those areas, be they impervious or pervious, that contribute runoff whether or not it needs to be treated.

The Curve Numbers represent runoff from various surfaces or land uses overlying various soil types and are obtained from TP108 Table 3.2 "Hydrological Soil Classifications for prevalent Auckland Soils" and Table 3.3 "Curve Numbers for typical Auckland Conditions".

TP108 provides rainfall charts and worksheets. The use of HEC-HMS or similar mathematical model is recommended, especially as the use of this method and models will have already been set up and used in the prediction of peak flows and volumes of stormwater runoff from the proposed development.

Section 3.4.3 and 3.4.4 outline how to use TP108 for obtaining the Water Quality Volume, WQV.

3.4.3 Stormwater quality design storm, S_d

ARC TP4's analysis of rainfall from the rain gauge at the Botanic Gardens at Manurewa arrived at a rainfall depth of 25 mm for S_d. In order to make allowance for the differences in location, the rainfall depth corresponding to the site location is obtained from Figure 3-3, the 2 Year ARI Daily Rainfall Depth.

S_d = (2 year 24-hour rainfall depth at site) /3

This rainfall depth is to be applied on a 24-hour event using TP 108 (with the temporal rainfall pattern set out in Section 2 of TP 108).

3.4.4 Water Quality Volume, WQV

The Stormwater Quality Design Storm, S_d, is the rainfall depth chosen from hydrological analysis of a rain gauge located in the Auckland Region that enables 80% of the runoff volume of all storms to be captured and treated. This gives 75% removal of total suspended solids on a long term average basis. The choice of this objective is justified in ARC Technical Publication No. 4 "Selection of Stormwater Treatment Volumes for Auckland". This study found that the removal of 75% TSS is at the marginal point of return for sediment removal versus device size, i.e. aiming for a higher degree of removal would require an undue increase in treatment device size and therefore cost.

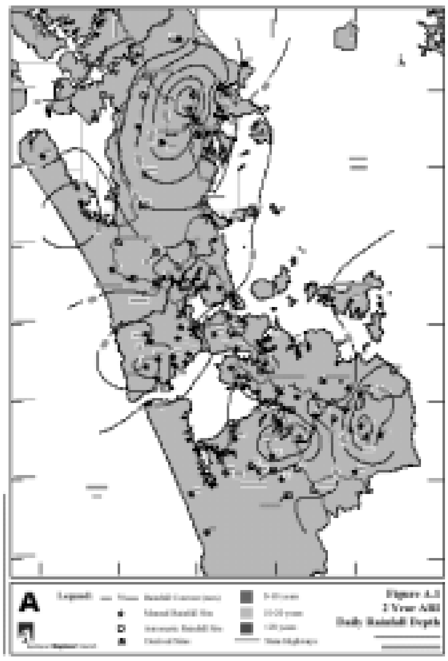


Figure 3-3
2 year rainfall depth image

Section 3.5 shows how to calculate the water quality volume WQV. Two methods are described below:

- The first (Modelling Method) being based on the assumption that the designer has already undertaken calculations for the development using TP108 Guidelines for Stormwater Runoff Modelling in the Auckland Region, and
- The second (Manual Method) being based on the manual method of TP108. It is recommended that designers hold a copy of TP108 Guidelines for Stormwater Runoff Modelling in the Auckland Region.

It is important, regardless of which method is used (modelling or manual) that calculations be done separately for pervious surfaces and impervious surfaces to calculate the total volumes associated with water quality and extended detention (34.5 mm). This approach provides a more accurate and more consistent calculation for volume. Grouping them together for the analysis tends to under-predict volumes associated with those storms. On the other hand, peak discharges for the 2, 10, and possibly 100 year events can be grouped for consideration of timing and peak discharges.

3.5 Modelling Method

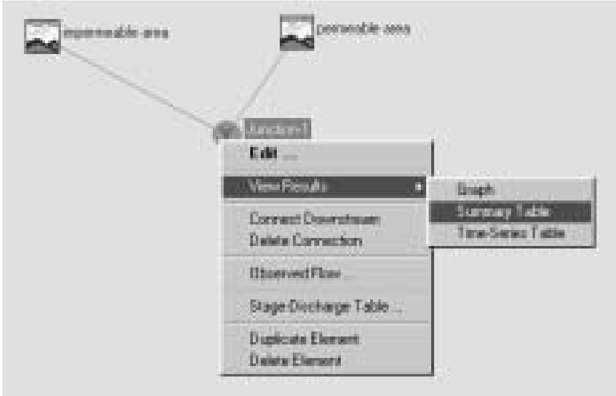


Figure 3-4
Summary of results

When modelling for water quality, extended detention, 2, and 10 year peak control, consider the catchment (or site) to be heterogeneous. Heterogeneous catchments should be modelled by division into separate homogeneous sub-catchments, connected by hydraulic elements.

For the water quality and extended detention storms, issues such as timing or response time are not important as for most devices. Vegetated swales and filter strips are designed for a peak flow rate, but because they serve very small catchments the catchment response time can be ignored and the peak 10 minute rainfall rate used (minus losses).

For 2 and 10 year peak determination timing is important. The procedure outlined in TP 108 should then be used to complete the analysis.

WQV is the "Total Outflow" obtained from the Summary of Results screen for the point of interest. An example of the output screens is presented in Figure 3-4.

<u>3.5.1 Manual Method</u>

This may be the easier approach for determining the water quality and extended detention volumes. It is directly based on using TP108 and the designer is referred to that document.

Rainfall

Use TP108 Figure A.1 to obtain the rainfall depth associated with the 2 year event being studied.

Stormwater Quality Design Storm, S_d

Use TP108 Figure A.1 - 2 Year ARI Daily Rainfall Depth
Find rainfall depth for the site location,
S_d = rainfall for site / 3

Runoff Curve Numbers

Identify the soil type for the site and its associated land cover to select the associated curve number.
Use TP108 Table 3.3 for Curve Numbers
Impervious coverage has a curve number of 98.

Initial Abstraction

I_a = 5 mm for pervious areas
I_a = 0 for impervious area

Calculate storage individually for both the pervious and impervious area

$S = ((1000/CN) - 10)25.4 =$ mm
calculate separately for pervious and impervious areas

Runoff depth

Runoff depth, $Q_{24} = (P_{24} - I_a)^2/((P_{24} - I_a) + S)$
this is done separately for pervious and impervious areas

Runoff Volume

Runoff volume, $V_{24} = 1000Q_{24}A =$ m^3

Calculate this separately for pervious and impervious areas

Water quality volume is the summation of both V_{24}'s

Designers are also referred to ARCs TP108: for worked examples:

> Section 5. Worked Example for setting up a model and undertaking the calculations using HEC-HMS, and
> Section 6. Graphical Method for Peak Flow Rate

3.6 Alternative methods of design

The ARC prefers designers to use TP108 methodology for design calculations. The ARC also prefers the use of mathematical models such as HEC-HMS because it reduces chance of mathematical error. The use of TP108 will also ensure that comparative results are obtained by the use of the standard input parameters. It will also ensure consistency in analyses within a catchment.

Whilst the ARC does not encourage the use of other methods for calculations, we recognise that there are other methods of calculation and other sources of data. If these are used, the applications need to be well supported with full sources of alternative data, full copies of calculations and all appropriate references to support the application.

The primary situation where alternative methods of design may be used, with ARC concurrence, is when catchment-wide analyses are done. This may be the situation where characteristics of the catchment or management approach may be better considered through a modelling technique that is more appropriate for that specific catchment. Situations where that could occur include enclosed system analysis or continuous simulation (where adequate rainfall data exists). Communication between the individual proposing an alternative method of design and the ARC should be done prior to modelling being initiated to ensure there are no disagreements on the methods of analysis.

3.7 Relative levels of removal efficiencies

In some situations where the treatment device to achieve the required removal cannot fit within a specific site, a lower level of treatment will result. Similarly, if additional land and volume is available, improved efficiency can also be provided. Table 3-1indicates approximate levels of treatment achieved by devices having greater or less volumes than those detailed in Section 3.4.

Table 3-1
Relative levels of removal efficiency

Practice Volume	Efficiency
150% of WQV	82%
100% of WQV	75%
75% of WQV	70%
50% of WQV	60%
25% of WQV	50%
10% of WQV	40%
5% of WQV	30%

The expected removal efficiency is simply the available WQV divided by the WQV detailed in Section 3.4. If that analysis indicates that the required WQV is 2,000 m^3, and the available volume is 1,500 m^3, then the practice efficiency will be approximately 70%.

3.8 Use of rainfall station data

Where more extensive site rainfall is available, e.g. long term instantaneous data, that data may be analysed independently to give a more accurate estimate of the 2 year ARI daily rainfall depth at that location, or a long term part of the record may be used directly as input into a routing model. Such an approach will need full justification for that approach and the results obtained will need to be fully supported by calculations, identification of the rainfall station and results of the statistical analysis of the rainfall data.

3.8.1 Rainfall depth for stream bank protection

The ARC is concerned about erosion in watercourses. A study "Stream Erosion – A Hydrological Basis for Management" has been undertaken by BCHF. The report has two main recommendations for the protection of streams, one for stable streams and the second for unstable streams.

The recommendation for stable streams is that post development peak flows should not exceed predevelopment peak flows. This recommendation requires a stringent analysis relating bankfull flow to shear stress. If the stream has frittering of banks, landslides, bank collapse or streambed undermining then the stream is not considered as being stable. Since almost all streams in the Auckland Region have one or more of the conditions mentioned, this scenario is not being pursued, especially in an urban or urbanising environment. We are therefore considering all streams as unstable.

For unstable streams the interim recommendation is for detention ponds to be designed for the discharges from a 2 year ARI 24 hour storm from post development conditions, such that no more than 30 mm of runoff occurs over the 24 hour period, or that the maximum peak outflow is 7.5 l/s per hectare of the site.

The initial BCHF information has been modified for greater consistency with the design approach used in TP 10 which aims to store and release the first 34.5 mm of rainfall over a 24 hour period.

3.9 Water quantity design

Controlling water quantity control requires matching the post and predevelopment hydrological conditions as closely as possible. Stormwater management practices are often sized to match peak flows for the 1%, 10% and 100% AEP events. The outflow conditions and required storage volumes are then determined by hydrological routing for these events.

Hydrological modelling should be carried out in accordance with ARC Technical Publication 108: Guidelines for Stormwater Runoff Modelling in the Auckland Region.

3.10 Summary

Minimising the effects of stormwater requires an integrated, catchment wide approach to stormwater management. Site design, contamination control and treatment practices all have a role to play. This chapter has provided an introduction to site design and contamination control concepts, but other ARC publications such as the Environmental Operating Procedures manual and the Low Impact Design approach deal with these in more detail.

Water quality treatment is based on the Water Quality volume defined in Section 3.4 and the specific requirements for each practice outlined in chapters 5-14. Water quantity control requires control practices also defined in those chapters. Both of these methodologies are developed in the following chapter, Choosing of a Stormwater Management Devices.

3.11 Good practice guidelines

When implementing the stormwater management concepts outlined in this chapter, the following guidelines for designing and implementing stormwater management practices will be helpful and cost effective:

1) Prevention is better than cure, so implement source control as much as possible.
2) Consider the site in the context of the catchment management plan.
3) Consider stormwater management objectives early in the design process to achieve an integrated approach within the site constraints.
4) Consider the treatment train concept and incorporate a suite of practices to achieve the stormwater management objectives.
5) Preserve natural watercourses and minimise works in and around watercourses to preserve aquatic resources.
6) Maintain riparian margins and vegetative buffers around watercourses and wetlands to preserve stream health and encourage natural processes to remove contaminants.
7) Minimise the impervious area of the development and maximise infiltration on site storage/detention to minimise changes to the water cycle.
8) Separate discrete pollution sources from the general stormwater system. Provide additional treatment or dispose of wastes from those sources to the sanitary sewer if necessary.
9) Develop management practices to reduce the risk of contamination during hazardous operations.
10) Institute earthworks controls before starting construction.
11) Institute stormwater management practices before development so they are working from Day One. This also acts a backstop for sediment control during earthworks.

3.12 Bibliography

ARC, Selection of Stormwater Treatment Volumes for Auckland, Technical Publication 4, 1992.

ARC, An Assessment of Stormwater Quality and the Implications for Treatment of Stormwater in the Auckland Region, Technical Publication 5, 1992.

ARC, Environmental Operations Plan, Do It yourself Environmental Checklists for a clean safe and profitable business, 1999.

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ARC, 2000, Technical Publication 124, Low impact design manual for the Auckland Region

Beca Carter Hollings & Ferner Ltd., Stream Erosion - A Hydrological Basis for Management, prepared for the Auckland Regional Council, December 2001.

McCuen, Richard H., et. al., Policy Guidelines for Controlling Stream Channel Erosion with Detention Basins, Department of Civil Engineering, University of Maryland, December 1987.

Chapter 4
Choosing stormwater management devices

4.1 Introduction

Stormwater management involves controlling either or both the quantity and quality of runoff. Quantity control practices regulate the peak flow rate and, depending on the practice, the total volume of runoff. Water quality control practices prevent the initial release of contaminants into receiving systems, or once they are released, reduce the quantities that enter surface or groundwaters. Completely recapturing released contaminants is impossible, and there is a pronounced diminishing of the rate of return on higher levels of capture. Prevention is more efficient and cost-effective. This Chapter will discuss runoff quantity and quality control and show how a number of different practices achieve these.

It is important to realise that stormwater practices do <u>not</u> all perform the same functions. A pond may be excellent at reduction in suspended solids, but and not as effective at capturing hydrocarbons. It is important to recognise the potential effectiveness of different stormwater practices on the contaminants generated on a specific site. As such, land uses and their associated contaminants are an important consideration in determining which stormwater practice or practices are appropriate for a given site.

4.2 Regulatory objectives

Stormwater management regulatory requirements can be categorised in a number of ways. A simple way is to define what purpose the practice is serving. For this manual, there are three broad regulatory categories which define the stormwater management universe:

> Water quantity control,
> Water quality control, and
> Aquatic ecosystem protection.

All three categories will not necessarily be addressed on each site, but rather they shall be used as needed. Examples could include:

> Discharge to tidewater (saline water) will not generally require peak control. The main focus will be water quality treatment.
> Discharge into a concrete (open or enclosed) system having adequate capacity for additional flows will only be considered for water quality treatment as the conveyance system is sized to handle peak flows.
> A project in the top part of a catchment not having downstream flooding problems will have to consider control of the 2 and 10 year storm, storage and release of the first 34.5 mm of rainfall over a 24 hour period, and 75% reduction in suspended solids.

<u>4.2.1 Water quantity control</u>

Water quantity control comprises those practices that detain stormwater runoff to regulate its rate of release to receiving waters or to infiltrate runoff into the ground so it does not become surface flow. Water quantity control can be further subdivided into three categories.

> Flood control

- Stream channel protection
- Infiltration or low stream flow augmentation

Flood protection

Historical efforts to prevent increases in downstream flood levels involved construction of stormwater management ponds to temporarily hold large volumes of stormwater during extreme events and releasing them over a longer time period than would have occurred normally. Current ARC requirements for downstream flood protection are generally that site post-development peak discharges for the 2 and 10 year storm events shall not exceed predevelopment peak discharges for those events. If there are existing flooding problems downstream, management may include control and release of the 100 year post-development peak discharge at the predevelopment peak discharge release rate. Section 5.4.1 provides more information on this topic for pond designers.

Stream channel protection

It is increasingly recognised that urbanisation causes increased stream channel instability as flows are increased in volume and frequency. This is achieved by storage and release of an initial volume of runoff, which for regulatory purposes is defined as the runoff associated with the first 34.5 mm of rainfall over a 24 hour period. This can significantly reduce or eliminate downstream channel erosion as a result of urban alteration of the hydrologic cycle. There is more detail in Chapter 5, Section 5.4.1, Channel protection objectives.

Infiltration or low stream flow augmentation

Urbanisation, through increased impervious surfaces and greater soil compaction, reduces groundwater recharge. A reduction in groundwater recharge lowers groundwater levels and can reduce or eliminate base stream flow. Maintaining, to the degree possible, groundwater recharge, can be an important element in protection of perennial stream flow. There are so many uncertainties in the methods for estimating groundwater levels and soil recharge rates to justify setting a required level of recharge. However, applicants should itemise opportunities have been considered to maximise recharge given the intended land use.

4.2.2 Water quality control

Water quality control applies to those practices that remove contaminants having the potential to be in or that are already in stormwater runoff. There is a wide range of water quality practices. Roofing an area that can generate stormwater contamination if exposed to rainfall is a water quality practice. Stormwater runoff from a parking lot cannot generally be treated at each location where vehicles travel or park so a water quality control practice may be most appropriate at a point to which stormwater flow can be directed. Consideration of water quality control can generally be broken into two categories: source control and treatment practices or measures.

Source control

Specific pro-active actions can prevent rain entraining potential sources of contamination and carrying them into the stormwater drainage system. A good resource document is the ARC's "Environmental Operations Plan - Do-It-Yourself Environmental Checklists For A Clean, Safe and Profitable Business".

Source control practices are often divided into structural and nonstructural groups. Nonstructural practices mainly embrace preventive actions that do not require building anything, such as management and source control practices. Structural practices are those which involve construction of some form of protection to prevent rainfall coming into contactwith contaminants.

While TP 10 is primarily devoted to the design, construction, and maintenance of stormwater quantity and treatment practices, we reinforce the importance of source control when considering site development and usageand urge applicants to incorporate it as one of the components of an effective stormwater management system during site development.

Treatment practices

While quality control can be nonstructural (policies to retain natural soil and vegetation cover), it generally involves building a facility such as a detention pond. The general criterian for constructed water quality treatment devices is a 75% reduction in suspended solids leaving the site. That general requirement may be expanded to other contaminants depending on the land use (see table 4-6). Treatment practices into two main categories: vegetative and structural.

The water quality benefits of vegetative practices derive from two main principles: filtering of contaminants by the vegetation, and infiltration of stormwater into the ground. Most vegetative practices consist of filter strips and swales. Others such as rain gardens rely upon filtering and infiltration, but for the purposes of this document those practices are considered as structural.

A suite of structural water quality treatment practices involve a variety of treatment processes. Water quality treatment can be provided by settlement of contaminants, filtering of contaminants by the passage of stormwater through a filter media or into the ground, or gravity flotation for oil and litter.

There are other treatment mechanisms such as attachment to plant material, biological uptake, bacterial decay, and precipitation, but those processes are secondary and their effectiveness at contaminant reduction is not easily quantified.

Flocculation for sedimentation is one practice increasingly popular. Colloidal particles, may, under the right chemical and flow conditions, flocculate and settle out. This process is becoming more common in sedimentation ponds through the use of aluminium sulfate or poly-aluminium chloride (PAC). Sediment removal rates of over 90% has been achieved in sediment ponds treated by flocculation.

4.2.3 Aquatic ecosystem protection or enhancement

Aquatic ecosystem protection or enhancement is an emerging issue of concern in the Region, and is dependent on addressing both water quantity and water quality. Maintaining the physical structure of streams as much as possible is just as important as maintaining good water quality.

Physical structure

If stream ecosystem protection is important then water quantity must be considered in terms of the following:

- limiting the increase in peak rates of runoff,
- reducing to the extent possible the increased volume of stormwater discharged,
- attempting to limit the erosive duration of stormwater flows, and
- thermal impacts.

Water quality

Contaminants affect aquatic life in a number of ways. The most obvious cause and effect is smothering of bottom dwelling organisms by sediment or sediments filling in riffle pool areas to deprive organisms of habitat. Sediment also reduces light penetration, clogs gills, and causes any number of other adverse side effects.

Contaminants other than sediment also have impacts on aquatic organisms. Acute and chronic toxicity can stress local populations or cause mortality. Toxicity can impact at a particular level of the food chain which can disrupt the overall diversity and abundance of an aquatic ecosystem. Impacting on macroinvertebrates can adversely affect the fisheries population in a given stream or reach of stream.

4.3 Stormwater practices

Stormwater quantity and quality control practices can be grouped in various ways. One classification is:

* Storage practices
    - ponds
    - vaults and tanks
    - American Petroleum Institute (API) separators
* Vegetative practices
    - swales
    - filter strips
    - wetlands (natural and constructed)
    - landscape management
* Infiltration practices
    - bores and tunnels
    - basins
    - trenches
    - porous pavements
* Filtration practices
    - sand filters
    - leaf compost filters
    - other

Storage practices can benefit quantity control, quality control, or both. In a number of instances, one mode of operation (storage, vegetative treatment, or infiltration) predominates but the practice incorporates other modes.

The trend is to combine the capabilities of two or more options by establishing "treatment trains" of complementary practices to achieve in series overall stormwater management benefits.

4.4 Site constraints

The success of any management practice depends on selecting the appropriate options for the site's control objectives and conditions at an early stage. The objectives must be clearly delineated at the outset and site conditions investigated in enough detail to match the practice to the site so as to meet the objectives. Decisions need to be made whether quantity control, quality control, or for ecosystem protection or enhancement, both are provided, as well as what contaminants need to be treated and how.

Deciding whether a practice is relevant means looking at the catchment area, soils, hydrogeologic conditions, circumstances of the receiving water and nearby properties, cost, land ownership, and so on. Each practice's constraints for implementation are discussed in its specific chapter. This discussion overviews the process of weighing up various practices when initiating the site design process.

4.4.1 Catchment area

Stormwater practices are only effective when they are used in the right place. A major consideration is the catchment area that drains to the practice. Some practices, due to treatment or hydrologic factors are more appropriate to smaller or larger catchment areas. Practices that rely on vegetative or filter media filtering of runoff are more appropriate for smaller catchment areas, as large flows may overwhelm their ability to filter the runoff. Ponds, on the other hand, are more appropriate for larger catchment areas.

Table 4-1
Stormwater management practice versus catchment area for water quality treatment

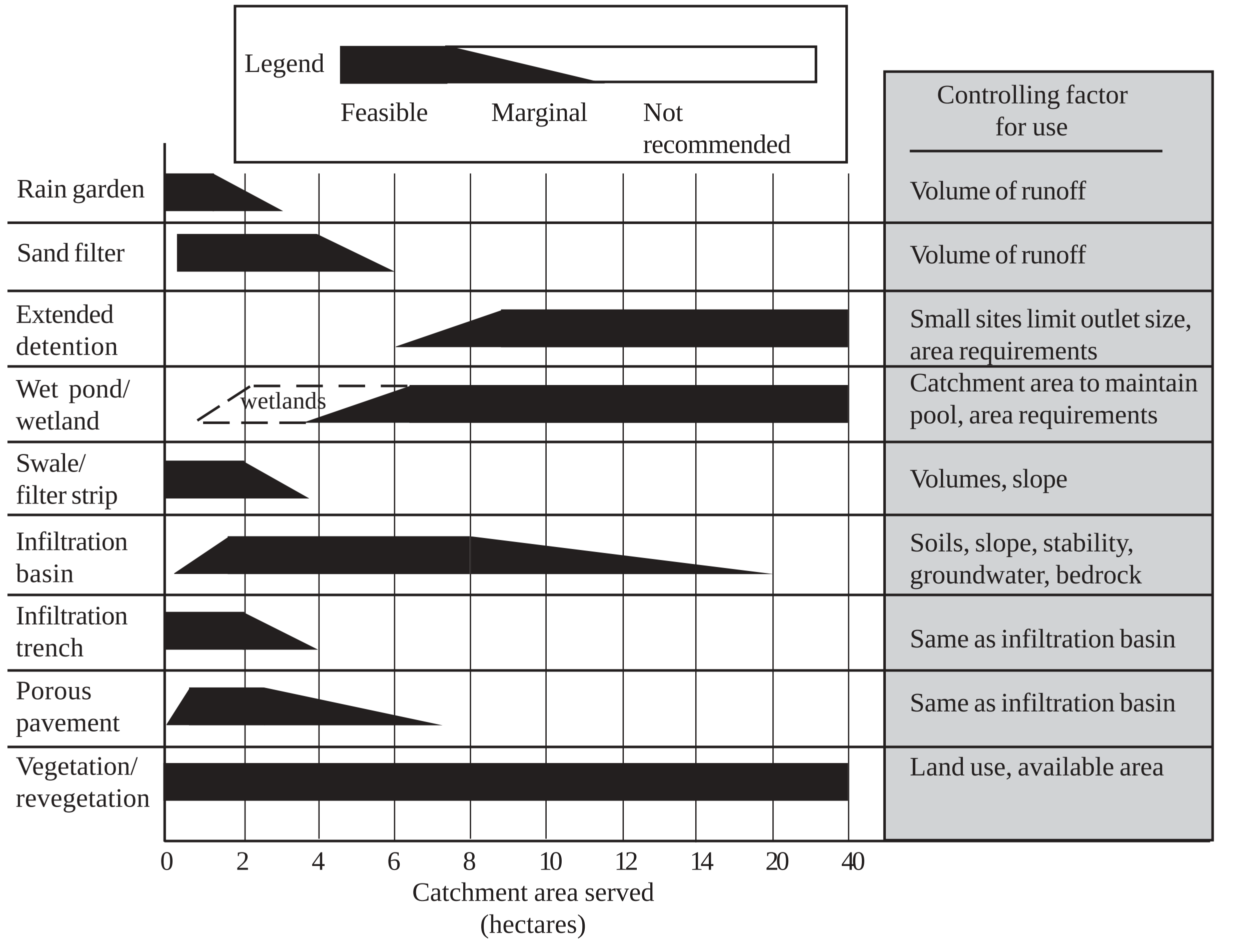


Table 4-1 shows the catchment areas for which various practices are most appropriate.

4.4.2 Soil type

The function of stormwater practices is very dependent on the underlying soils. More permeable soils can enhance the operation of some practices, but adversely affect that of others. For example, wet ponds or wetlands, rely on a pool of water or saturated subsoils to provide the basis for water quality treatment. Permeable soils would prevent the retention of a normal pool of water unless a liner was installed.

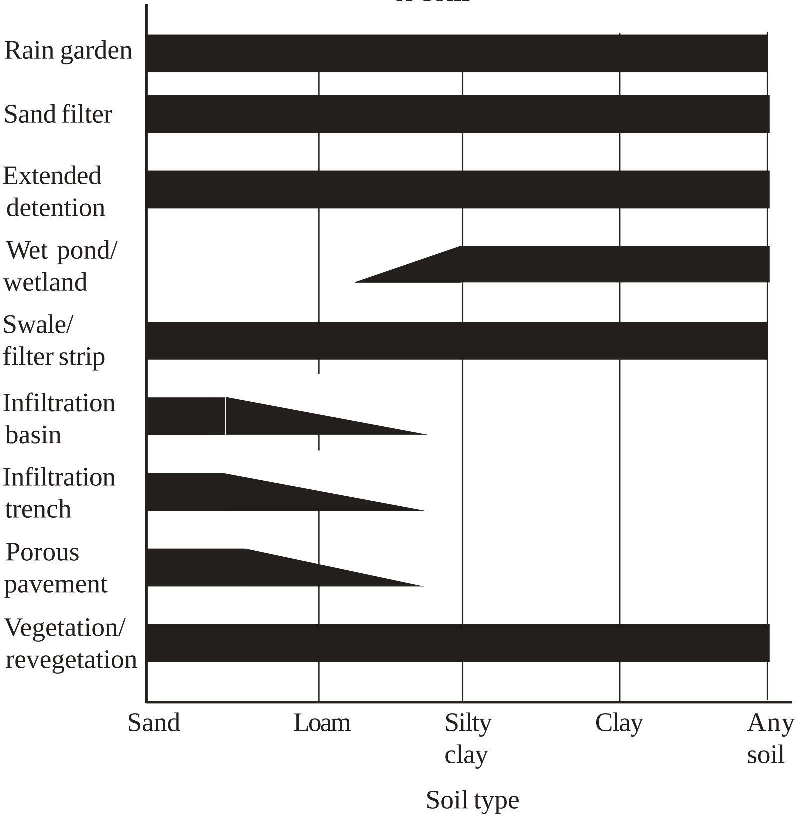
On the other hand, infiltration practices rely on the passage of water through the soil profile and more permeable soils transmit greater volumes of water. Some practices, such as filtration or biofiltration, do not rely upon site soils for proper function, although their performance may be enhanced by the water passing over and through coarser soils. Filtration practices rely on the permeability of the filter material to provide for water quality treatment, while biofiltration relies upon the passage of water through vegetation to provide contaminant capture. Table 4-2 overviews the suitability of stormwater practices to various soil conditions.

4.4.3 Slopes

Slope is an important consideration when choosing a practice. Steeper slopes may eliminate some practices from consideration, may require other practices to be modified from a more desired approach, or have little impact on the use of others.

Ponds provide temporary or permanent storage of water, with certain minimum surface area or storage volume requirements to achieve a minimum level of treatment. It becomes increasingly difficult to meet these

Table 4-2
The suitability of stormwater management practices related to soils

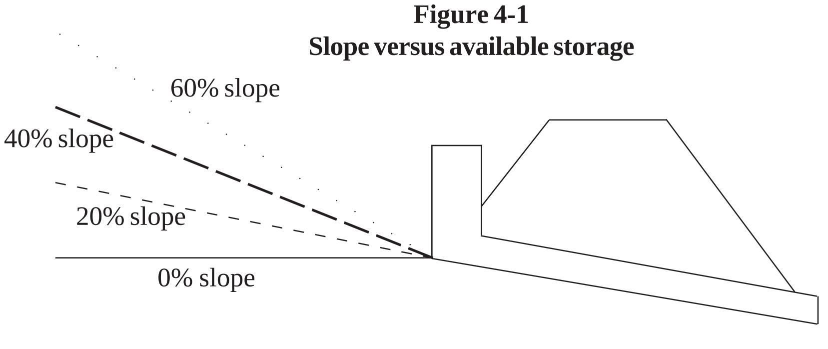


requirements as slope angle steepens. An example of the loss of storage ability versus slope is shown in Figure 4-1.

Other practices such as vegetated swales may be adapted for steeper slopes if the swales are placed along the contours rather than up or down the slope. Performance of biofiltration practices depends on the residence time of stormwater flows through the swale. Steep slopes result in high velocities of flow and reduced residence time. Filter strips, on the other hand, cannot generally be placed along the contour so their use is restricted to gentler slopes. Actual slope limitations for biofiltration practices are given in the detailed discussion of those practices.

Infiltration practices are also limited to gentle slopes for two reasons. Infiltration practices, similar to ponds, must provide storage of runoff until the water can soak into the ground. Steeper slopes reduce the potential storage volume and reduce the water quality benefits. In addition, infiltration of water into a slope may cause saturation further down, which could cause slope instability or re-ermergence of stormwater.

Figure 4-1
Slope versus available storage



Slope (%)	Area of storage available (bottom to crest) in m^2
0	7.5
20	5.0
40	2.8
60	1.9

Depending on the design and approach, filtration practices, including rain gardens, may or may not be sensitive to slope. Prefabricated filter chambers that service small areas may be placed on steeper slopes with little problem.

Revegetation as a stormwater management practice can be used on any slope, and In fact offer better benefits on steep slopes. The sediment yield from a slope triples as the slope doubles, so revegetation of steeper slopes provides a proportionatly greater benefit then for lesser slopes.

4.4.4 General constraints on treatment practices

As well as slope, soil type and catchment area, a number of other constraints may affect the applicability of a specific treatment device in a specific context. Table 4-3 provides guidance on various BMPs and the constraints to their use.

Table 4-3
Constraints on use of stormwater treatment practices

BMP	Steep slopes	High water table	Close to bedrock	Slope stability concerns	Space consumption limitation	Maximum depth limitation	High sediment input	Thermal impacts
API separator	~	~	>	~	~	-	-	~
Extended detention pond	>	~	>	>	-	~	>	~
Wet pond/ wetland	-	~	>	-	-	-	>	-
Vegetated swale/filter strip	>/-	>	>	>	>	~	-	~
Infiltration practices	-	-	-	-	>	-	-	~
Filtration practices	~	>	~	~	~	~	~	~

~ Generally not a restriction
> Can be overcome with careful site design
- May preclude the use of a BMP

4.5 Contaminant generation and removal process

In the past, the ARC has focused on suspended solids as the key contaminant of concern. This focus will remain for stormwater treatment. Suspended solids smother bottom dwelling organisms, reduce light penetration in water, destroy aquatic habitat and adversely affect aquatic organisms. There are, however, other environmental contaminants generated from human activities. Table 4-4 presents typical loadings for a number of contaminants and land uses. Although it does show a range of measurement values greater variation may be probably from year-to-year at the same place. The general order of contaminant production, from highest to lowest is:

industrial and commercial > motorway > higher density residential >
lower density residential > farm land > forest

Although not listed in the sequence above, the construction phase can produce far higher loadings of solids than any finished land use. However, from established land uses metals and synthetic organics are of particular concern because of their potential for toxicity to human consumers of water and to aquatic life. They make up most of what are generally considered as priority contaminants. Table 4-5 lists priority contaminants most frequently detected in urban runoff samples as reported in the United States Environmental Protection Agency (USEPA) National Urban Runoff Program (NURP) monitoring project in 23 cities in the early 1980s.

Three metals (lead, zinc, and copper) were found in almost all samples, and four additional metals were detected in approximately half. Phthalate, the most common synthetic organic was found in only 22 percent of the samples. Present in 10 to 19 percent were three chlorinated hydrocarbons (two pesticides and a wood preservative) and four polynuclear aromatic hydrocarbons (PAHs). As can be seen, urban stormwater runoff is a multifaceted and complex problem to manage.

Synthetic organics are an exceptionally large and diverse category of chemicals. They include hundreds of

Table 4-4
Contaminant loading ranges for various land uses
Figures are in kg/ha/yr except for FC (no./ha/yr)

Land use	TSS	TP	TN	Pb (median)	Zn	Cu	FC	COD
Road	281-723	.59-1.5	1.3-3.5	.49-1.1	.18-.45	.03-.09	1.8E+08	112-289
Commercial	242-1369	.69-.91	1.6-8.8	1.6-4.7	1.7-4.9	1.1-3.2	5.6E+09	306-1728
Residential (low)	60-340	.46-.64	3.3-4.7	.03-.09	.07-.20	.09-.27	9.3E+09	NA
Residential (high)	97-547	.54-.76	4.0-5.6	.05-.15	.11-.33	.15-.45	1.5E+10	NA
Terraced	133-755	.59-.81	4.7-6.6	.35-1.05	.17-.51	.17-.34	2.1E+10	100-566
Bush	26-146	.10-.13	1.1-2.8	.01-.03	.01-.03	.02-.03	4.0E+09	NA
Grass	80-588	.01-.25	1.2-7.1	.03-.10	.02-.17	.02-.04	1.6E+10	NA
Pasture	103-583	.01-.25	1.2-7.1	.004-.015	.02-.17	.02-.04	1.6E+10	NA

specialised products for industrial and commercial uses, as well as compounds produced incidentally through chemical reactions. Examples of the latter are the polynuclear aromatic hydrocarbons. These by-products of fossil fuel combustion appear in vehicle exhausts, lubricants and smokestack emissions. New chemicals can also be formed through environmental reactions after the release of a material.

Table 4-4 summarises the frequency of detection of contaminants from various land uses. Because different land uses generate different contaminants, when a new site is being developed or stormwater management is being implemented, the contaminants kikely to arise from the future land use or uses must be considered in

Table 4-5
Frequently detected priority contaminants of samples in NURP sites

Inorganics	Organics
Detected in 75% or more of samples	
94% Lead 94% Zinc 91% Copper	None
Detected in 50-74% of samples	
58% Chromium 52% Arsenic	None
Detected in 20-49% of samples	
48% Cadmium 43% Nickel 23% Cyanides	22% Bis(2-ethylhexyl)phthalate 20% α-Hexachloro-cyclohexane
Detected in 10-19% of samples	
13% Antimony 12% Beryllium 11% Selenium	19% α-Enfosulfan 19% Pentachlorophenol[a] 17% Clordane[a] 15% Lindane[a] Pyrene[b] 14% Phenol 12% Phenanthrene[b] 11% Dichloromethane 10% 4-Nitrophenol 10% Chrysene[b] 10% Fluoranthene[b]

a Chlorinated hydrocarbon
b Polynuclear aromatic hydrocarbon

any stormwater management strategy. This is particularly important when the contaminants are not attached to sediments. As commercial and industrial land use produces a disproportionate level of contamination of a

Table 4-6
Industrial activity and commonly found contaminants

Activity	Contaminant
Wood preserving activities	Arsenic, Copper, TSS, Oil and Grease
Industrial inorganic chemicals	Aluminium, Iron, Nitrate + Nitrite
Plastics, synthetic resins	Zinc
Soaps, detergents, cosmetics, perfumes	Nitrate + Nitrite, Zinc
Agricultural chemicals	Nitrate + Nitrite, Lead, Iron, Zinc, Phosphorus
Asphalt paving and roofing materials	TSS, Zinc, TPH
Concrete products	TSS, Iron, pH
Steel works	Aluminium, Zinc
Iron and steel foundaries	Aluminium, TSS, Copper, Iron, Zinc
Landfills	Iron, TSS, Aluminium, Cadmium, COD, Copper, Cyanide, Lead, Magnesium, Nitrate + Nitrite
Automobile dismantler yards	TSS, Aluminium, Iron, Lead, Oil and Grease, Zinc, Cadmium
Scrap recycling	Copper, Aluminium, Iron, Lead, Zinc, TSS, COD, Cadmium, Arsenic, Magnesium, Selenium
Fabricated metal products except coating	Iron, Aluminium, Zinc, Nitrate + Nitrite
fabricated metal coating and engraving	Zinc, Nitrate + Nitrite

variety of constituency, it is beneficial to list various commercial and industrial activities and the contaminants that are generally found in those activities. Table 4-6 lists a number of industrial activities that the USEPA, through monitoring, has found frequently exceed water quality standards for the contaminants listed in the table. Other contaminants may exist on those sites but the ones listed frequently exceed standards.

To properly specify, design and operate treatment practices, one needs to understand the precesses that can operate to prevent contaminants from entering receiving waters. Table 4-7 lists all the main processes that can capture, hold and transform various classes of contaminants in urban stormwater runoff and factors that enhance the operation of each process to improve water quality.

A key factor in the effectiveness of all processes is time. The likelihood of settling a solid particle is directly related to the time provided to complete sedimentation at the particle’s characteristic settling velocity. Time is also a crucial determinant of the degree to which chemical and biological processes operate. Characteristic rates of chemical reactions and biologically mediated processes must be recognised and designed for in order to obtain their treatment benefits. For all of these reasons, water residence time is the single most basic and important variable to consider when designing treatment practices that will be cost-effective.

The designer and operator have a high degree of control over many of the processes that promote favourable water quality outcomes (possibly excluding soil). More specific objectives require more intervention, such as developing some desired soil condition.

4.6 Appropriate practice(s) for stormwater quantity/water quality/aquatic ecosystem goals

In many cases, a given BMP can provide both effective water quantity and quality control for a given site. However in some situations, this may not be possible and multiple practices may have to be used to achieve stated objectives or consent requirements. For example, ponds may provide water quantity and quality control, but the constraints of a particular site may prevent their use. Sand filtration, on the other hand, provides for water quality treatment but has very limited ability to provide any water quantity control. Table 4-8 details the general capability of various stormwater management practices to provide for water quantity control.

In addition to water quantity performance, stormwater practices also vary in the level of water quality

Table 4-7
Summary of contaminant removal mechanisms

Mechanism	Contaminants affected	Promoted by
Physical sedimentation	Solids, BOD, Pathogens, Particulate COD, P, N, Metals, Synthetic Organics	Low turbulence
Filtration	Same as sedimentation	Fine, dense herbaceous plants, constructed filters
Soil incorporation	All contaminants	Medium-fine texture
Chemical precipitation	Dissolved P, metals	High alkalinity
Adsorption	Dissolved P, metals, synthetic organics	High soil Al, Fe high soil organics, circumneutral pH
Ion exchange	Dissolved metals	High soil cationic exchange capacity
Oxidation	COD, petroleum hydrocarbons, synthetic organics, pathogens	Aerobic conditions
Photolysis	Same as oxidation	High light
Volatilisation	Volatile petroleum hydrocarbons and synthetic organics	High temperature and air movement
Biological microbial decompostion	BOD, COD, petroleum hydrocarbons, synthetic organics, pathogens	High plant surface area and soil organics
Plant uptake and metabolism	P, N, metals	High plant activity and surface area
Natural die-off	Pathogens	Plant excretions
Nitrification	NH_3-N	Dissolved oxygen > 2 mg/l low toxicants, temperature > 5-7^{0}C, circumneutral pH
Denitrification	NO_3+NO_2-N	Anaerobic, low toxicants temperature > 15^{0}C
Features that help achieve any objective	**Features that help achieve metals control**	**Features that help achieve organics control**
increasing hydraulic residence time low turbulence fine, dense herbaceous plants medium-fine textured soil	high soil organic content high soil cation exchange capacity circumneutral pH	aerobic conditions high light high soil organic content low toxicants circumneutral pH

performance they can achieve. Water quality performance must also be considered in terms of the contaminants of concern. A water quality practice that is effective at reducing suspended solids may not provide

Table 4-8
Water quantity effectiveness of stormwater management practices

Practice	Peak discharge control 2- yr. storm	10-yr. storm	100-year storm	Volume control	Groundwater recharge/low flow maintenance	Streambank erosion control
API separators	-	-	-	-	-	-
Extended detention dry pond	+	+	+	-	-	+
Wet pond	+	+	+	-	-	+
Constructed wetland	+	+	+	>	>	+
Infiltration practices	+	>	-	+	+	+
Revegetation	+	-	-	+	+	>
Sand filter	+	-	-	-	-	-
Biofiltration (swale, filter strip, rain garden)	>	-	-	>	>	-
Water reuse	>	-	-	+	>	+

\+ Usually provided
\> Sometimes provided with careful design
\- Seldom or never provided

much reduction in oil and grease. Table 4-9 details the potential contaminant reduction capability of various stormwater management practices.

In addition to how well different stormwater management practices can achieve specific objectives such as water quantity or water quality control, some have secondary impacts.

An example of a negative impact would be a stormwater management pond that has a normal pool of water. While being good at removing contaminants, the pond may be a source of thermal contamination of down-stream receiving waters. The pond water, if there is no base flow into or out of the pond, may become heated by bright sunlight on a warm summer day. If there are aquatic organisms downstream which are sensitive to stream temperature changes the ongoing discharge from the pond may have adverse impacts downstream even though the pond is providing water quality treatment. Table 4-10 provides an overview of the potential secondary impacts of stormwater treatment devices.

Positive secondary effects often include amenity and passive recreational benefits such as walking around the perimeter, picnicking, and so on.

4.7 Which device or devices to choose

This chapter has provided information that helps to lead a stormwater management plan designer to select appropriate practices. Figure 4.2 provides a decision path for design whereby a project can be evaluated and a decision can be arrived at based on the key variables. Practice evaluation and selection should be based on collection of information in conjunction with a logical progression of thought and analysis. A brief example demonstrates an appropriate approach.

Table 4-9
Potential contaminant removal effectiveness of stormwater management practices

Practice	Suspended Solids	Oxygen Demand	Total Lead	Total Zinc	Total Phosphorus	Total Nitrogen	Bacteria
API separators	-	o	o	o	o	o	o
Extended detention dry pond	+	>	+	>	>	-	o
Wet pond	+	>	+	>	>	-	o
Constructed wetland	+	+	+	+	+	+	o
Infiltration practices	+	+	+	+	+	>	+
Revegetation	+	+	+	+	>	>	-
Sand filter	+	-	+	+	>	-	>
Biofiltration (swale, filter strip, rain garden)	+	-	+	>	-	-	o

+ High potential for removal **>** Moderate potential for removal
- Low potential for removal **o** Insufficient knowledge

4.7.1 Example problem

Site and catchment conditions

Type of development::	Commercial shopping centre
Size:	3 hectares
Soils:	Waitemata silts and clays
Slope:	8%
Site stability:	good
Receiving system:	typical degraded urban catchment, freshwater stream draining to estuary

Design considerations

Contaminants of concern:	total suspended solids, metals, possibly nutrients
Stormwater issues:	water quantity (10 yr., 100 yr.) and water quality
Catchment area/appropriate practices:	vegetation, sand filter, infiltration practices
Secondary issues:	public health and safety
Maintenance:	property owner responsibility

Practice consideration

Applicable practices for contaminant removal	dry and wet pond (TSS, lead, zinc), wetland (TSS, lead, zinc, phosphorus), infiltration (TSS, lead, zinc, phosphorus), revegetation (TSS, lead, zinc), sand filter (TSS, lead, zinc), biofiltration (TSS, lead)

Table 4-10
Potential secondary impacts of stormwater treatment practices

Practice	Aquatic habitat creation	No temperature increase	Landscape enhancement	Recreational benefits	Public safety	Community acceptance
API separator	-	+	-	-	+	+
Extended detention dry pond	-	+	>	>	>	>
Wet pond	+	-	+	+	>	+
Constructed wetland	+	>	>	>	>	>
Infiltration practices	-	+	-	-	+	+
Revegetation	+	+	+	>	+	>
Sand filter	-	+	-	-	+	+
Biofiltration (swale, filter strip, rain garden)	-	+	>	-	+	>
Water reuse	-	+	-	-	+	>

+ Usually provided
> Provided with design modification
- Seldom provided

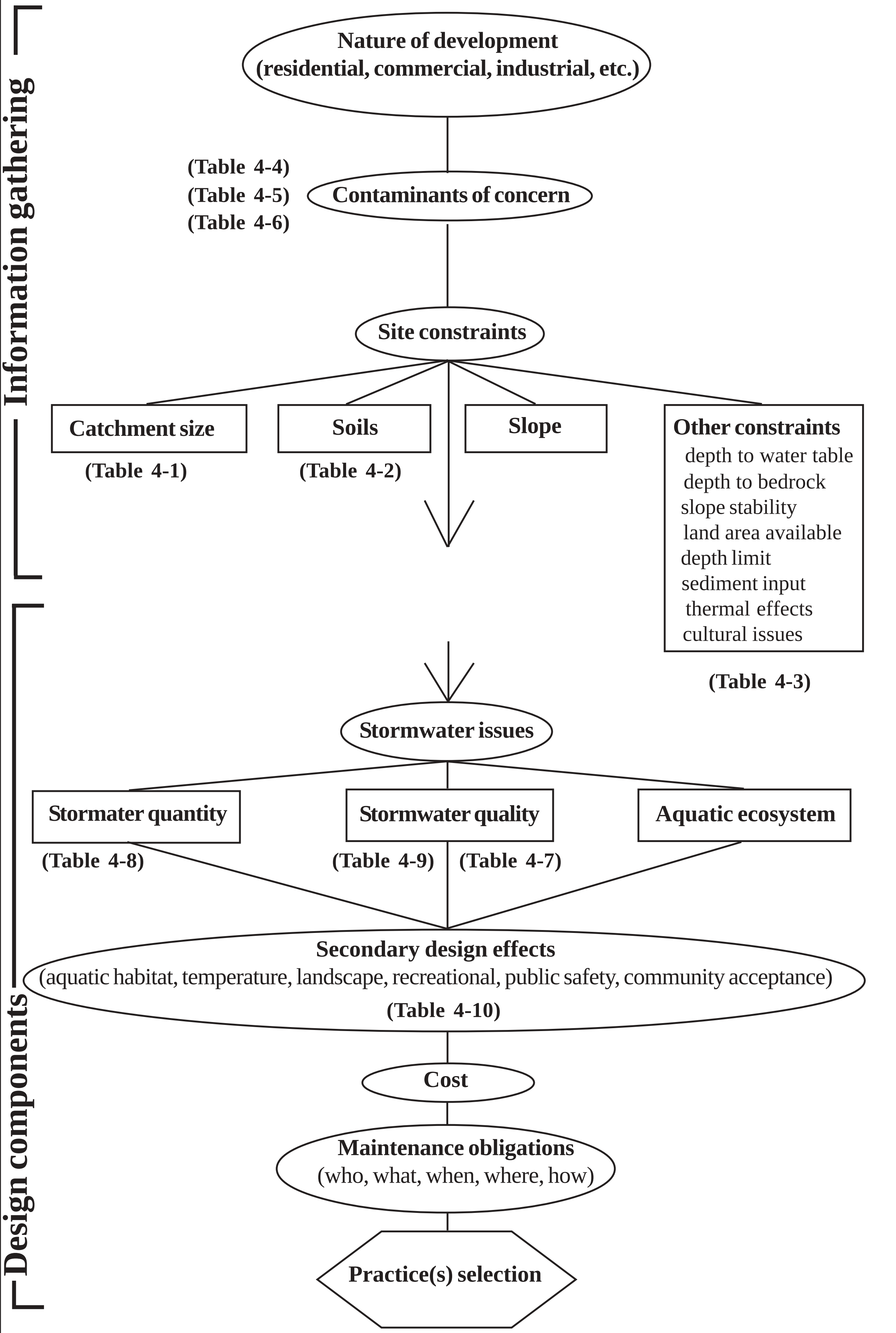
Applicable practices for water quantity	ponds, wetlands
Treatment practice for 3 ha. catchment area	rain garden, sand filter, infiltration, biofiltration
Treatment practice related to clay soils	rain garden, sand filter, ponds, swale, revegetation
Aquatic ecosystem	not a concern on this project (goes into reticulation)
Landscape	attractive
Public health and safety	important

Choosing practices

The example case study indicates that both water quantity and water quality are issues of concern. The appropriate practice(s) then relates back to the site and catchment conditions, design considerations, and practice considerations.

As the example shows, it is difficult to address both water quantity and water quality issues with one single practice. It would be best to conceptually select an approach that addresses both issues and then integrate the practices as needed for final design.

Figure 4-2
Process of stormwater management practice evaluation and selection



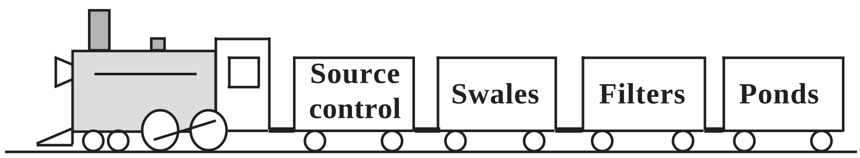
Water quantity practices involve the storage of stormwater and release over a longer period of time to manage downstream flooding. Stream channel stability is not an issue so that the storage and release of the first 34.5 mm of rainfall over a 24 hour period is not an issue. What can be considered is a dry stormwater detention pond whose purpose is to reduce outflow rates to pre-development levels. This does not address water quality, which will need to be considered with a separate practice.

Water quality control needs to consider total suspended solids and metals. Nutrients are not considered to be critical for this catchment. Ponds are not considered as practical for this site as the total site area precludes consideration of a wet pond. With this site, parking is an important issue and biofiltration may be the most practical option. Swales in between parking spaces having kerb cuts to allow water entry into the swale is the selected option. If used, swales would have to follow site contours and meet the residence requirement time.

For this site, stormwater quantity control requires a dry detention pond in one corner of the property while water quality control is provided by vegetated swales. Another option could be to design and construct a constructed wetland that addresses both quantity and quality issues.

4.8 The treatment train: which suite of practices suit your site

Stormwater treatment train



As the example shows, it may be difficult for one practice to provide for multiple benefits. The ARC will place more emphasis on the "Stormwater Treatment Train" concept where several types of stormwater practices are used together and integrated into a comprehensive stormwater management system. Although this is obvious when multiple issues are considered (such as stormwater quantity, quality, and aquatic ecosystem protection), it is also sometimes needed when considering a single issue. For example, stormwater quality may include a variety of contaminants to manage, but processes that facilitate one type of contaminant in one practice may not facilitate removal of a contaminant in another phase (liquid versus particulate). The treatment train approach to stormwater management will become increasingly important to reduce overall stormwater impacts of the urban environment.

4.9 Device operation and maintenance

As well as land use and site location, another element that should be considered during the design phase is operation and maintenance. Presented below are two recommended techniques to assist in consideration of operating conditions, costs of selected practices and other responsibilities throughout the design process. They can either be used as review techniques following completion of a practice design or, ideally, be incorporated into the overall design process and used continually during it:

> Spend a mental year at the practice
> Who, what, when, where, and how

4.9.1 Spend a mental year at the practice

To use this technique, the stormwater designer simply imagines conditions at the completed practice throughout an entire year. This should not only include rainy and sunny weather, but also light rain showers. Other site conditions may include hot, dry weather or drought, when vegetation is stressed or dead. Finally, for safety purposes, the designer should also imagine what the system will be like at night.

As these conditions are visualised, the designer should also imagine how they may affect not only the operation of the system itself, but also the people that will maintain it or otherwise interact with it. Will the outlet structure's trash rack be prone to clogging from vegetation floating in the stormwater runoff? Is there a safety issue with small children?

What about night conditions? Will the constructed wetland next to the office parking lot that is attractive during summer lunch hours become a safety hazard to workers leaving the office at night?

At first, it may be exasperating to realise that the number of possible site conditions and circumstances can be as numerous and varied as the number of possible practice types. But then again, that is the point of this exercise. It is intended to help the designer consider and design for all possible conditions at the practice, not just the 1 in 2 or 10 year storm event. In doing so, the practice designer will not only meet the letter of the RMA requirements but also the spirit of the entire stormwater programme.

4.9.2 Who, what, when, where, and how

The second recommended review technique a practice designer may employ is to simply focus on one or more operation and maintenance characteristics or functions of the practice and then ask (and answer) the following questions:

> *Who will perform it?* Does the stormwater practice's design require operation and maintenance specialists or will someone with general maintenance equipment and training be able to do the job?
>
> *What needs to be maintained?* Preparing a list of all practice components included in the design may prompt a revised design with a shorter operation and maintenance list.
>
> *When will maintenance need to be performed?* Once a day? A week? A year? Remember, the recurring costs of practice maintenance can be substantial. In addition, can maintenance only be performed during dry weather? If so, what happens during the lengthy time periods of wet, rainy weather. What happens when repairs need to be made or debris removed during a major storm event? In terms of effort and possible consequences, it is easier for the designer to find answers to these questions now, than for maintenance or emergency personnel to scramble for them later.
>
> *Where will maintenance have to be performed?* Will the maintainer be able to get there? Once there, will they have a stable, safe place to stand and work? In addition, where will such material as sediment, debris, and trash removed from the practice be disposed of? Before answering that question, do you know how much there might be and what it might contain? Are there toxic or hazardous materials in the sediment or debris? If so, is the place you originally intended to use for disposal still suitable? Once again, it is easier to address these questions now than when the dump truck is loaded.
>
> *How will maintenance be performed?* The simple instruction to remove the sediment or harvest the vegetation can become rather complicated if there hasn't been any provision made to allow equipment to get to the bottom of the practice or even into the site. Mowing the grass can be dangerous on steep, long slopes. How will you explain to your client why the stormwater management practice they have invested in has become a liability to themselves and their community?

Similar to the mental year review technique, the questions raised in this technique are intended to make the designer more aware of all the possible impacts the facility may have and, further, to encourage the designer to address those impacts now, during the design phase, rather than leave them for others, particularly maintenance personnel, to cope with later. Even if the designer cannot completely answer all of the questions, he or she will be able to advise the others of any unavoidable needs or problems that will be inherent in the practice and allow them time to adequately prepare.

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Watershed Management Institute, Operation, Maintenance, and Management of Stormwater Management Systems, August 1997.

Chapter 5
Pond design, construction, and maintenance

5.1 Introduction

Stormwater management ponds have been used in the Auckland Region for years, initially for water quantity control, but more recently also for water quality control. They have been, and are expected to remain, important components in the ARC stormwater effort to minimise adverse impacts associated with urban land use. This Chapter reviews ponds that are either normally dry or normally wet. Both forms of pond can and may possibly have an extended detention component to them. This Chapter does not include discussion of wetland ponds. Wetland ponds, while having much in common with deeper ponds are being considered separately within Chapter 6, a more detailed discussion of the additional functions that they provide.

Ponds are defined as:

Dry pond - A permanent pond that temporarily stores stormwater runoff to control the peak rate of discharges and provide water quality treatment, primarily through the incorporation of extended detention. These ponds are normally dry between storm events.

Wet pond - A permanent pond that has a standing pool of water. These ponds can, through their normal storage of water, or or in conjunction with extended detention, provide water quality treatment. They can, also in conjunction with extended detention, provide protection of downstream channels from frequent storms.

Stormwater ponds are used for three primary purposes:

- Reducing downstream flood potential,
- Providing water quality treatment, and
- Minimising, to the extent possible, downstream channel erosion.

It may not be necessary in every situation to address all three purposes, but there will be sites, as discussed later in the Chapter, where all three functions will be included in the design.

5.2 Water quantity/quality performance

Ponds detain runoff, typically from a design storm, and then discharge it, usually at the pre-development peak discharge rate.

Traditionally ponds, especially dry ones, have been used primarily for flood protection. They normally detain runoff and then discharge it at a specified rate, reducing the potential for downstream flooding by delaying the arrival of runoff from upper parts of a catchment. More recently, wet and dry pond designs have been modified to extend the detention time of runoff thereby increasing particulate contaminant settling and minimising downstream channel erosion. Wet ponds are normally designed to have a permanent pool for storage of a specified water quality volume, in the Auckland Region, this is 1/3 of the 2 year frequency storm. Wet ponds also have an outlet design that increases residence time and flow path.

5.2.1 Contaminant removal mechanism

The primary contaminant removal mechanism of all pond systems is settling or sedimentation. However, the effectiveness may vary to some degree depending on the type of detention system (dry or wet).

Flood detention ponds have limited effectiveness at providing sedimentation as detention times may be several hours only, so only the coarser particles can be removed from the water column.

Extended detention ponds that are normally dry also rely on sedimentation during shore periods of live storage only although they typically hold flows for longer than flood detention ponds.

The best approach for particulate removal is the combination of extended detention in conjunction with a normal wet pool. The pool allows for displacement of water previously stored and the extended detention allows for better sedimentation of excess storm flows.

5.2.2 Expected performance

Ponds can be effective at reducing peak discharge rates. Depending on their design and their location within a catchment, they may also be effective in reducing downstream channel erosion, downstream flood levels and flooding.

Effectiveness at contaminant removal depends on the type of pond system. In general, they can be ranked, from least to most effective, in their ability to remove stormwater contaminants: dry detention, extended dry detention, and then wet detention.

Unlike dry detention ponds, wet ponds provide mechanisms that promote the removal of dissolved stormwater contaminants, and not just particulates. Table 5-1 illustrates expected contaminant reduction.

Table 5-1
Expected contaminant reduction range of ponds (in %)(WMI, 1997)

Contaminant	Dry (flood)	Dry (ext. det.)	Wet
Total suspended solids	20-60	30-80	50-90
Total phosphorus	10-30	15-40	30-80
Total Nitrogen	10-20	10-40	30-60
COD	20-40	20-50	30-70
Total Lead	20-60	20-70	30-90
Total Zinc	10-50	10-60	30-90
Total Copper	10-40	10-50	20-80
Bacteria	20-40	20-60	20-80

Data from the Auckland Region for TSS removal efficiencies from three wet stormwater management ponds (Pacific Steel, Hayman Park and Unitech) is in Table 5-2:

Table 5-2
Stormwater treatment pond monitoring in Auckland

Pond	Reference	Monitoring period	Number of events monitored
Pacific Steel, Otahuhu	Leersnyder (1993)	3-1/2 months	6
Hayman Park, Manukau	Leersnyder (1993)	1-1/2 months	4
Unitech, Mount Albert	McKergow (1994)	1 month	6

The water quality volume and expected sediment reduction for each pond were determined in accordance with the design procedures from the previous version of TP 10. The relevant design parameters, expected TSS removal efficiencies, and the monitored sediment inflow and outflow average event mean concentrations (EMC) of TSS removal are summarised in Table 5-3.

Table 5-3
TSS removal efficiencies for Auckland pond studies

Pond	Catchment area (ha)	Imperviousness (%)	Average pond depth (m)	TP 10 design volume (m^3)	Actual pond volume (m^3)	TSS removal efficiency
Pacific Steel	9.7	approx. 100	0.71	1455	4750	78
Hayman Park	6.3	61	0.57	550	1757	71
Unitech	41.5	60	1.00	5380	5000	83

As can be seen from the local data, only a small number of events were monitored so they do not necessarily indicate long term removal efficiency. This would require a long term monitoring programme to achieve a reasonable degree of confidence. The results are only indicative of the pond's TSS removal capability.

5.2.3 Constraints on the use of ponds

Dry ponds

> Need fairly porous soils or subsurface drainage to assure that the bottom stays dry between storms
> Not suitable in areas with high water tables or shallow depth to bedrock
> Not suitable on fill sites or steep slopes unless geotechnically checked
> May not be suitable if receiving water is temperature sensitive as detention ponds do not detain water long enough to reduce temperatures from impervious surfaces.

Wet ponds

> Not suitable on fill sites or near steep slopes unless geotechnically checked
> May need supplemental water supply or liner system to maintain permanent pool if not dug into the groundwater
> Minimum contributing drainage area of 2 - 3 hectares is needed to maintain the permanent pool
> Not feasible in very dense urban areas or areas with high land costs due to large surface area needs
> May not be suitable if receiving water is temperature sensitive due to warming of pond surface area.
> Safety issues need to be addressed, depending on normal pool depth

Dry flood detention ponds are not normally recommended for stormwater management systems. They have ongoing maintenance needs because standing water in areas where positive drainage is impeded may cause mosquito problems, and their overall performance for water quality treatment is less than than provided by wet ponds. A study in the U.S. (DNR. 1986) indicated that over 70% of the dry ponds in a given jurisdiction were not functioning as designed. In addition, dry ponds tend to have less aesthetic appeal than wet ponds.

5.3 Pond component disclaimer

The ARC's Technical Publication #109, Dam Safety Guidelines, has a general discussion of dam components. The technical safety criteria for dam design and construction that are beyond the scope of this document include:

> Minimum dam top width
> Embankment side slopes
> Seepage control
> Foundation standards
> Foundation cutoff
> Outlet protection
> Access and set aside area for sediment drying

Plate 5-1: Innovative service outlet design where pond is a community amenity

Two issues that will be discussed in this Chapter are minimum spillway capacity, as spillway design will affect the duration of detention and therefore stormwater quantity and quality control, and pond forebay areas and capacity. These will be discussed in the Design Procedure section.

A typical wet pond is shown in Figure 5-1.

5.4 Design approach

5.4.1 Objectives

Water quantity objectives

Urbanisation has dramatic impacts on the amount of stormwater runoff that is generated from a catchment. Examples of the level of impact can be seen in the case studies chapter of the Low Impact Design Manual for the Auckland Region (TP 124). On the three case studies, peak rates of discharge were increased from 70 - 90 percent from pre-development to post-development for the two year storm and the total annual volume of runoff increased approximately 300 percent. Ponds, when properly sized, can be a primary quantity control practice.

ARC criteria for water quantity control depend on the receiving environment. If the receiving environment is a piped stormwater reticulation system with adequate capacity for the increased runoff or tidal (either estuarine or marine), then water quantity control is not an issue and a number of practices can be used to achieve water quality goals. If the receiving environment is a stream, then control of peak rates of runoff may be a requirement, and ponds become a primary option for controlling discharge rates.

ARC policy is to ensure that post-development peak discharges for both the 2 and 10 year storms remain at their pre-development peak rates for those storms. The intent of peak discharge control of storms of two different frequencies is to achieve benefits for a range of discharges. Controlling the peak rates for the 2 and 10 year storms provides control of storms between those intervals and also will provide management for a percentage of peak flows from storms of greater magnitude (Maryland, 1982).

Where there are downstream flooding issues, peak discharges for the post development 100 year 1% AEP storm event may need to be managed to ensure that downstream flood levels are not increased. Depending on the catchment, the number of tributaries and the location of the project in a catchment, timing of flow discharges may be an issue. If so, a catchment wide study may be necessary to ensure that downstream flood risks are not increased. If there is no catchment-wide study, work done by Manuakau City Council and overseas has indicated that limiting the peak discharge of the 100 year storm to not exceed 80% of the pre-development 100 year storm will reduce downstream flood increase concerns. The 80% peak discharge rate reduces potential for coincidence of elevated flow downstream by extended release of the flows. The ARC will accept this approach as an alternative to a catchment wide study.

Water quality objectives

Water quality objectives aim for 75% removal of TSS. Ponds are not as appropriate for dissolved contaminants (refer to Chapter 4 for land use versus contaminants generated). They are more appropriate where sedimentation can achieve stated goals.

Where possible, water quality ponds ponds need a bypass for larger flows. Because all flows travel through the pond, water quality performance during larger events will be reduced as first flush contaminants are carried through it. Ideally, larger flows should bypass the pond in order to avoid a drop in water quality performance, albeit at the expense of its ability to provide peak flow reduction for larger storms.

In those situations, it may be best to use a treatment train approach to stormwater where other practices provide primary water quality treatment while the pond is primarily used for water quantity control. Although desirable, this approach may not always be possible due to site constraints.

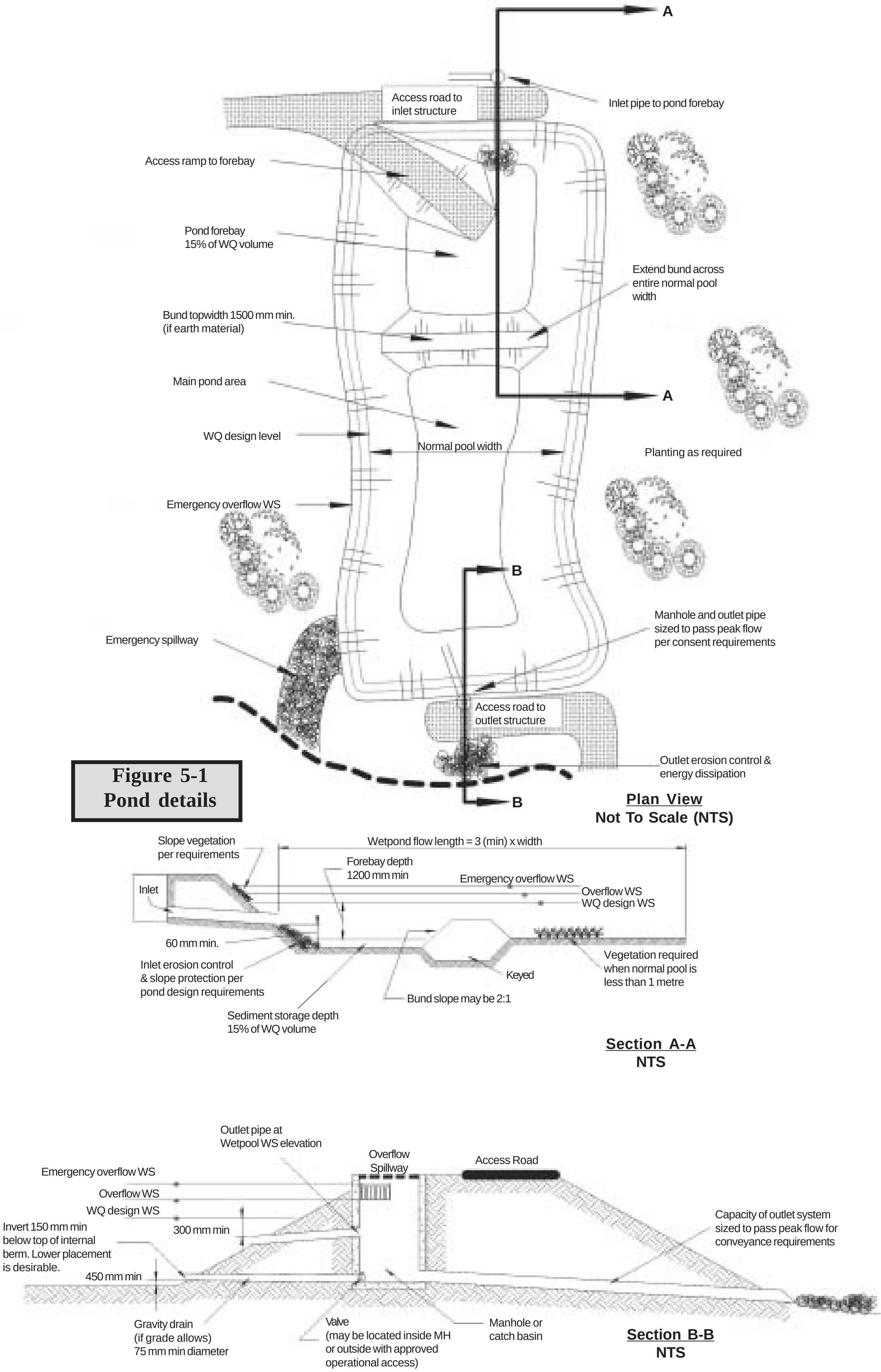


Figure 5-1
Pond details

There is a direct linkage between water quality treatment and flow control. If catchment considerations necessitate peak controls, it is recommended that 50% of the calculated water quality volume be placed as dead storage while 50% of the water quality volume can be live storage and released as part of the 34.5 mm rainfall capture and release requirement (as discussed in the next section). This water quality credit can only be provided when storage and release of the runoff from the 34.5 mm rainfall is required. The permanent storage will reduce flow velocities entering the pond, while the extended detention will facilitate (in addition to the wet pool) settlement of particulates. If there is no requirement for either extended detention or peak control, the entire water quality volume can be stored within the permanent pool level.

Channel protection objectives

Urban development has the effect of increasing the frequency and magnitude of floods, particularly during frequent small storm events. As a consequence streams can suffer an increase in erosion, as channels enlarge to cope with the increased storm response. The objective of criteria related to channel protection is to maintain or improve the in-stream channel stability to protect ecological values of the stream and reduce sedimentation downstream.

A study (BECA, 2001) done for the ARC recommends that the pond outlet should be designed to convey the volume generated by the first 30 mm of runoff over the total catchment area and release that volume over a 24 hour period from a 2 year frequency storm event. However, because more extensive impervious surfaces upstream require more storage to achieve the discharge target, the ARC requires the runoff from a rainfall event of 34.5 mm to be stored and released over a 24 hour period to minimise potential for stream channel erosion.

This provision is in addition to normal stormwater quality and flow attenuation requirements. However, by using extended detention for some of the stormwater quality treatment rather than a full wet pond, the treatment and erosion attenuation volumes may be partially combined, reducing total pond volume. Section 5.5 summarises all the relevant design requirements.

Ponds in series

The ARC does not generally recommend the use of ponds in series instead of a single pond with an equivalent surface area. If the single pond were divided into two ponds in series then each of the two ponds would have approximately 1/2 of the surface area of the single one. Each pond then has half the detention time, so the first pond takes out the coarser sediment. The flow is then remixed in the channel between ponds, and the second pond is too small to take out the finer fractions. Therefore ponds in series may be less efficient than single large ponds of equivalent volume.

However, sometimes site constraints make it necessary to use two or more treatment ponds in series rather than one larger single pond. To offset the reduction in sediment removal, where two or more ponds in series are necessary they should be sized at 1.2 times the volume specified in this document for a single pond. Where there are no specific site constraints, a single pond is preferred.

5.4.2 Preferences

Preferences for wetlands versus ponds

While TP 10 is a ‘toolbox’ of available stormwater management practices, constructed wetlands are preferred to open water ponds because they provide better filtration of contaminants, including dissolved ones due to densities of wetland plants, incorporation of contaminants in soils, adsorption, plant uptake, and biological microbial decomposition (more in depth discussion in Chapter 6). In addition, wetlands, being shallow water bodies do not have the safety issues associated with deeper water ponds. For these reasons, the ARC has a preference for shallow wetland ponds where ponds are used.

On-line versus off-line

As clearly stated in the Air, Land, and Water Plan the ARC has preference for 'off-line' placement of ponds rather than 'on-line'. Off-line ponds are considered to be those ponds not physically located in perennial watercourses. They can be in gullies or upland areas. On-line ponds are located on streams having perennial flows and their impact to the stream itself can be significant. On-line ponds alter geomorphic and biological character of streams and these alterations may adversely impact on the streams natural character and function.

However, while off-line ponds are a preference, it is not a hard and fast rule. Within the Metropolitan Urban Limits (see Auckland Regional Policy Maps) on-line ponds may be the only option to provide downstream benefits if there is already a high level of development that exists in a catchment. In those areas, on-line ponds would have to be considered on a case-by-case basis to determine suitability.

There may be mitigation requirements placed on on-line ponds to compensate for the loss of stream habitat when an on-line pond is accepted for a specific location.

Dry ponds versus wet ponds

Dry ponds are not normally recommended. They need more maintenance and have a lower water quality performance than wet ponds. In terms of preference when ponds are the selected options, constructed wetlands are a first choice, followed by wet ponds, and finally dry ponds.

Maintenance responsibility

Maintenance issues will be discussed later in this Chapter but the issue of ensuring an entity is responsible for maintenance must be considered as an issue to determine whether ponds are applicable in a given situation. Ponds are expensive and require routine and non-routine maintenance to ensure proper long-term performance or failure of the pond system can occur. While a swale can fill in or a sand filter clog, pond failure can have significant effects, such as property damage and potential loss of life. Ponds must therefore be regarded as small dams, and evaluated in the context of best practice for dam operation. If maintenance responsibility cannot be defined during the design phase, ponds should not be selected for a given site.

5.4.3 Safety features

Depth

Deeper ponds can be attractive to children who like open water. Historically, ponds have been 1 - 3 metres deep, sometimes over anyone's head. Stormwater ponds should not be deeper than 2 metres, if at all possible. If water quality volume requirements and site limitations limit pond area, then use a wetland and extended detention live storage to achieve the water quality volume.

Benches

A reverse slope bench or slope break should be provided 300 mm above the normal standing water pool (where there is a normal pool) for safety purposes. All ponds should also have a shallow bench 300 mm deep that extends at least three metres from the shoreline, before sloping down to the pond floor. This shallow bench will facilitate the growth of emergent wetland plants and also act as a safety feature.

In addition to the benches, the steepness of the pond slope down to the invert of the pond should not exceed 4 horizontal to 1 vertical. Steeper slopes will make it very difficult for someone who is in the pond to get out of it.

The reverse slope above the waterline has at least three functions. It:

1. Reduces erosion by rilling that normally would be expected on longer slopes.

2. Intercept particulates traveling down the slope and conveys them to the pond inflow.

3. Provides an additional safety feature to reduce the potential for children running or riding uncontrolled down the slope and falling into the pond.

Plate 5-2: Example of a safety bench (above water) in conjunction with a shallow bench (note: normal pool level has been lowered to allow for planting of shallow bench)

Fences

The ARC does not require fencing of ponds, because we consider that use of natural features such as reverse benching, densebank planting, and wetlands buffers (which consists of a dense stand of vegetation) will provide a similar level of protection. Territorial authorities retain their own discretion about fencing.

5.4.4 Aesthetics

Aesthetics must be considered as an essential pond design component. Ponds can be a site amenity if properly designed and landscaped or can be a scar on the landscape. The developer and designer should consider the pond as if they themselves were to be living in the development. Small items can have a big influence on the livability of a given area to residents and the best time to consider the issue is during the design phase. There is a greater discussion of landscaping in Chapter 14.

5.5 Design procedure

5.5.1 Approach

Pond sizes are determined to remove 75% of the incoming sediment load on a long-term basis. The development of this sizing rationale and size versus performance curves are presented in an earlier report (ARC, TP 4) whose results are incorporated into this manual.

Pond design tasks, in order, include the following:

1. Determine the need for water quantity control. In normal situations if it is required, that requirement will be to limit post-development peak discharges for the 2 and 10 year frequency storms to their pre-development peak discharge release rates.

   If downstream flooding is documented, the post-development 100 year storm peak discharge rate may also need to be limited. In this case, a catchment analysis may be necessary or, as an option to the catchment analysis, limiting the 100 year peak discharge to 80% of the the pre-development release rate.

2. Protect channel form in receiving environment. If the discharge enters a perennial natural stream channel, its channel will need to be protected from erosion.In such cases the runoff from a rainfall event of 34.5 mm shall be stored and released over a 24 hour period.

3. Determine the need for water quality control. Calculate the water quality volume (1/3 of the 2 year-24 hour rainfall, as shown in Chapter 3) that needs to be treated when detention is required, and provide

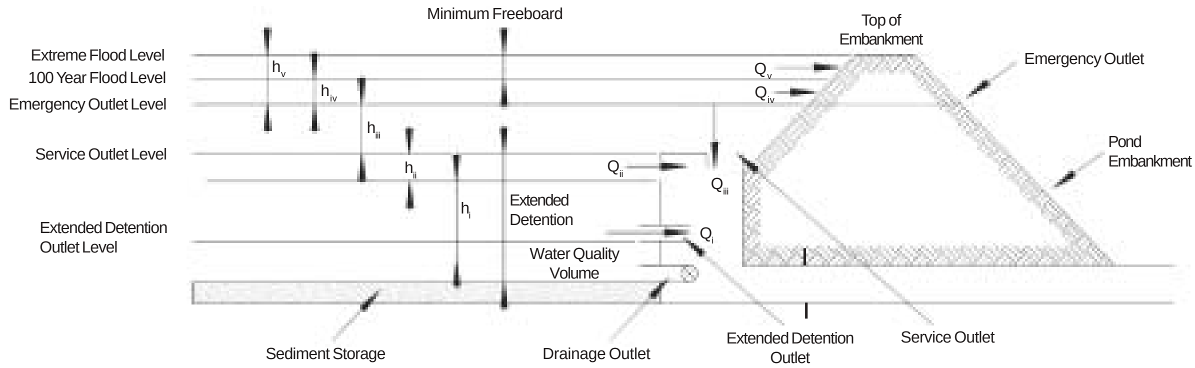
at least 50% of that volume as permanent pond storage. The other 50% stores and releases runoff from the 34.5 mm of rainfall over a 24 hour period.

A TP 108 analysis is needed for up to five rainfall events including the 2 year, 10 year, possibly 100 year, 34.5 mm rainfall, and 1/3 of the 2 year rainfall. The 2, 10, and 100 year events must be done for both pre- and post-development while the 34.5 mm (erosion protection) and 1/3 of the 2 year rainfall (water quality treatment) events are based on the post-development condition.

5.5.2 Spillways and outlet capacity

There are two primary outlets from a pond: the service outlet and the emergency outlet. They will be discussed in the context of their sizing. Figure 5-2 illustrates the various outlet elements and components. The terms detailed in the figure are those used in the Hydraulic Flow discussion of this chapter.

Figure 5-2
Schematic pond levels



Service outlet

The service outlet should be designed to at least accommodate the flows from the primary drainage system entering the pond. The service outlet will normally convey the flow from the extended detention orifice, the 2 year storm and the 10 year storm. In addition, the service outlet should also have a gate valve at the invert of the normal pool to allow for drainage of the pond during maintenance.

When an extended detention orifice is required, that orifice shall not be less than 50 mm in diameter (or 50 mm wide if a slot). If calculations indicate an orifice (or slot) of smaller size, the 50 mm shall be used and attention must be given to implementation of protective measures such as cover plate or other means, to prevent blockage of the orifice. It is important to consider blockage on all outlet devices but the extended detention outlet will be susceptable to blockage unless specifically designed for.

Emergency spillway

The emergency spillway will convey flows beyond the service spillway’s capacity. It should be designed to convey at least the 100 year storm with a freeboard of at least 300 mm.

The emergency spillway should be located in natural ground and not placed on fill material unless it is armoured to prevent scour of the embankment. Operating velocities must be calculated for spillways in natural ground in order to determine the need for additional armouring. If the emergency spillway is placed on fill, the embankment should be constructed higher than the final design to allow for settlement.

In situations where embankment failure may lead to loss of life or extreme property damage (see TP 109, Dam Safefy Guidelines, Hazard Analysis), the emergency spillway must be able to:

> Pass an extreme flood, which may be the Probable Maximum Flood (PMF), with no freeboard (after

post-construction settlement) and with the service outlet blocked. The PMF is defined in TP 109 as the largest probable flood event that could occur at the site, or the theoretical upper limit to flood magnitude. The extreme flood (Q_v) is defined as detailed in NIWA Science and Technology Series No. 19, “A Guide to Probable Maximum Precipitation in New Zealand”, June 1995. For high risk dams as defined in Tp 109, discussion with the ARC is essential to determine the needed factor of safety.

> Pass the full Q_{iv} (the 1% AEP event flow) assuming the service spillway is blocked with at least 0.5 metres of freeboard (after construction settlement).

5.5.3 Forebay

A forebay must be provided for all wet ponds. The sediment forebay is intended to capture only coarse sediments and is the location where most frequent sediment clean will be needed because coarser particles comprise the highest proportion of incoming sedments in terms of total volume. Thus the more frequent cleanout of the forebay area.

The forebay should meet the following criteria:

1. The volume of the forebay should be at least 15 % of the water quality volume (or 30% of the adjusted volume when extended detention is required). It should be cleaned out when filled in to about 50% of its design volume.

2. Flow velocities from the forebay during the 1 in 10 year storm must be less than 0.25 m/s, in order to avoid resuspension of sediment. In some cases this may necessitate more than the minimum forebay volume. The recommended depth of the forebay is 1 metre or more, to reduce velocities.

5.5.4 Hydraulic flow characteristics

1. Calculate the water quality volume to be treated using 1/3 of the 2 year-24 hour rainfall event and separately calculated for pervious and impervious areas (as in Chapter 3, Section 3.5). Time of concentration should be at least 0.17 hours.

2. Take a minimum of 50% of that volume for normal pool (dead) storage (when detention is required).

3. Use the 34.5 mm rainfall for the TP 108 analysis to determine the depth of runoff that is to be stored and released over a 24 hour period.

4. Conservatively assume that the entire extended detention volume is in the pond at one time even though this will not actually be the case since the outlet orifice will be sized to release this volume over a 24 hour duration.

   > Use an elevation - storage table to estimate the elevation required to store the full extended detention volume

   > Calculate the average release rate (equal to the volume/duration) = Q_{avg}

   > At the full extended detention design elevation, the maximum release rate is assumed to be $Q_{max} = 2(Q_{avg})$

   > Calculate the required low flow orifice size: $Q_i = 0.62A(2gh_i)^{0.5}$ by trialing various orifice sizes.

   > h_i = elevation difference = the elevation at extended detention - the elevation at normal pool + d/2.

   Other devices may be suitable for extended detention design, and all are based on a similar approach to the orifice opening approach. Those designs can include:

> Multiple orifices at the same elevation (n orifices, A area each) $Q_i = n\ 0.62A(2gh_i)^{0.5}$

> Vertical slot extending to water surface (width w) $Q_i = 1.8\ w\ h_i^{3/2}$

> Vertically spaced orifices (situated h_1, h_a, h_b from surface of pond filled to the WQ volume. Each orifice area A) $Q = 0.62A(2gh_1)^{0.5} + 0.62A(2gh_a)^{0.5} + 0.62A(2gh_b)^{0.5}$

> Pipe (area A) $h = (1.5Q_i^2/2gA^2) + h_f$ where h_f is pipe friction loss

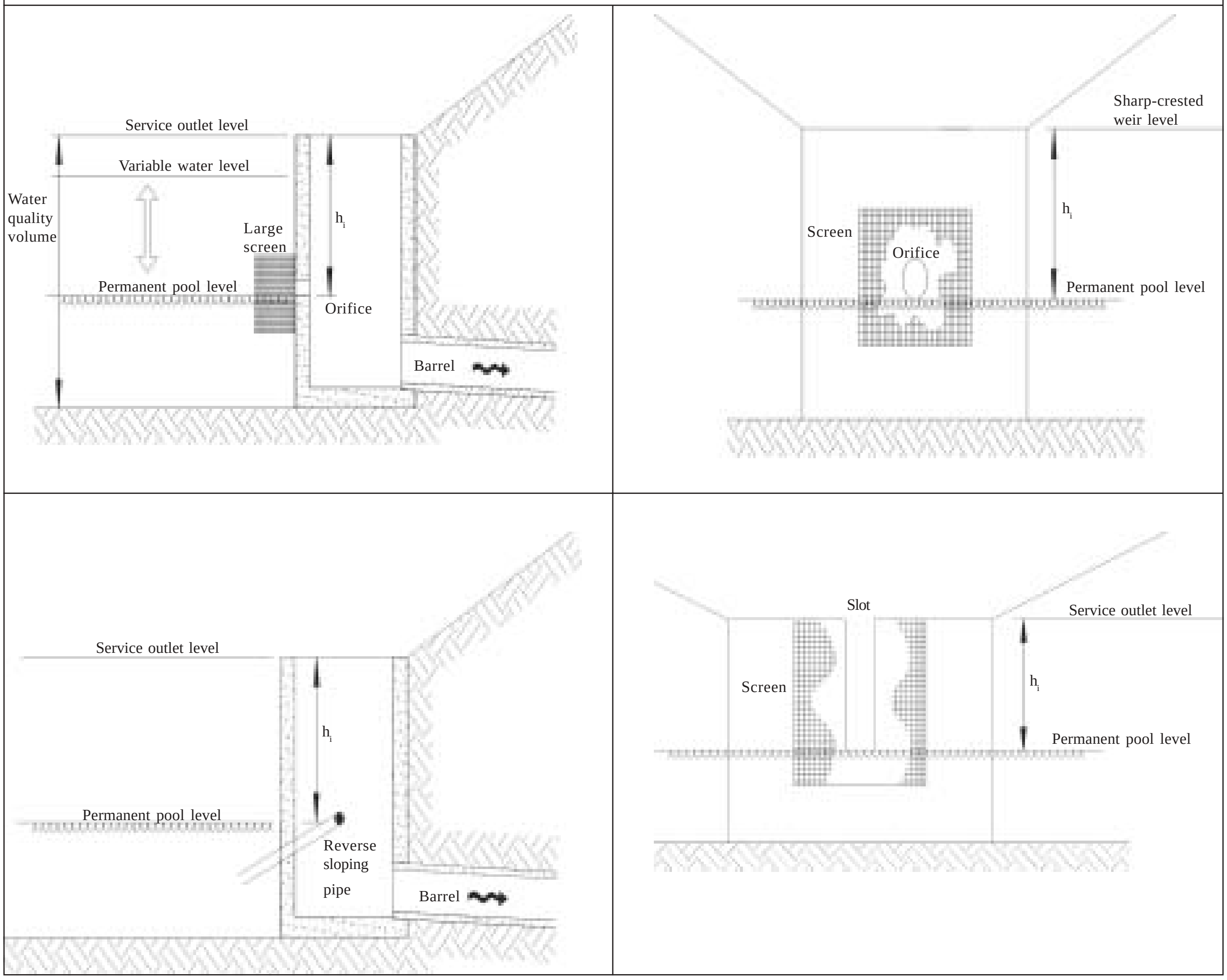
A number of different outlet designs for extended detention are detailed in Figure 5-3.

5. 2 and 10 year stormwater management

Set the invert elevation of the 2 year release point at the extended detention water surface elevation (based on the elevation - storage table mentioned in step 4)

The service outlet may consist of a drop inlet structure, a broad crested weir, a cascade weir or a weir leading to an open channel. As peak control requirements call for both 2 and 10 year frequency storms to be controlled, the discharge is clearly defined in terms of the following equations.

Figure 5-3
Types of extended detention outlets



Drop inlet

For moderate flows, the top of the drop shaft acts as a circular sharp weir. For a circular drop inlet, the energy head above the weir lip, (h_{ii}) can be used to calculate the flow according to:

$$Q_{ii} = 3.6\pi R\ h_{ii}^{3/2} \quad \text{(SI units)}$$

Where R is the radius of the inlet.

For a box weir:

$$Q_{ii} = 7.0wh_{ii}^{3/2}$$

where w is the length of the side of the square box, on the inside.

These equations apply only for $h_{ii}/R \leq 0.45$ (or, for a box inlet, $h_{ii}/w \leq 0.45$). For $h_{ii}/R > 0.45$, the weir becomes partly submerged, and for $h_{ii}/R > 1$ the inlet is fully submerged and the flow resistance is equal to the inlet resistance of a pipe, typically:

$$h_{ii} = k(v^2/2g)$$

where v is the velocity at flow Q_{ii} and k is typically 0.5 to 1.0, depending on the details of the inlet.

For a circular inlet:

$$v = Q_{ii}/\pi R^2$$

Starting with the design flow and the chosen pipe radius, the head (h_{ii}) can be found by using the appropriate formula for the h_{ii}/R value. If this head is higher than desired, a large outlet can be used.

Aeration of the flow over the weir should be considered if the flows are so high that inadequate ventilation may cause damage to the drop structure. In general, adequate ventilation will be provided by appropriate sizing of the outlet pipes. It is recommended that the outlet pipe be sized so that when the emergency spillway is operating at maximum flow (Q_v), the outlet discharges at 75% full. Standard pipe friction and pipe outlet loss calculations can be performed to determine the required outlet size (USBR, 1977).

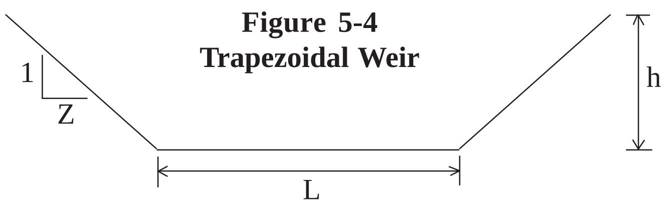
The entry to the outlet should be protected by a screen or grid cage to collect debris.

Broad crested weir

In this case, a weir narrower than the emergency weir is used. The weir could be situated away from the emergency weir, or if sufficient erosion protection is provided, in a lowered section of the emergency spillway.

The flow may pass down a single chute into a small plunge pool or appropriately lined area. Alternatively, a series of small cascades or a stepped spillway may be used. To size the weir, the change in pond elevation (h_{ii}) at the service design flow is found by solution of the following equation (see Figure 5-4):

Figure 5-4
Trapezoidal Weir



$$Q_{ii} = 0.57(2g)^{1/2}(2/3Lh^{3/2} + 8/15zh^{5/2})$$

As an approximation, the following formula may be be used for a broad-crested weir:

$$Q_{ii} = 1.7\ L\ h_{ii}^{3/2}$$

Weir with channel

This design will be useful for shallower ponds, where the channel can be easily constructed by making a cut in the embankment.

The outflow is controlled by the weir. Appropriate texts may be consulted for refined weir calculations, but the following may be used as an approximation for a sharp-crested weir:

$$Q_{ii} = 1.8Lh_{ii}^{3/2}$$

where Q_{ii} is the service design flow, h_{ii} is the head over the weir when the emergency spillway starts operation and L is the length of the weir. The outlet channel should be sufficiently large that the water level is below the water level (h_{ii}) at the service design flow (to avoid backwater effects). The channel may require covering for safety reasons.

6. Emergency spillway design

The emergency spillway section is normally designed as a trapezoidal channel whose sizing is based on trial and error to the following equation:

$$Q = 0.57(2g)^{1/2}(2/3Lh^{3/2} + 8/15Zh^{5/2})$$

where:
Q = discharge through the spillway
L = horizontal bottom width of the spillway
h = depth of flow at design flow
Z = horizontal/vertical side slope (recommended to be 3)

5.5.5 Designs to avoid short-circuiting

Dead zones and short-circuiting are undesirable because they reduce effective pond detention times. The flow path length must be at least twice the pond width, and preferably three times the width (but not much greater). The narrower the flow path, the greater the velocity and the less settling will occur . The designer should minimise dead zones and short-circuiting to improve the treatment performance of the pond.

5.5.6 Oil separation

Stormwater will, in most situations, contain oils and greases. Having an extended detention outlet similar to the reverse sloping pipe shown in Figure 5-3 will allow water to be discharged from below the surface and encourage volatilisation of the hydrocarbons on the surface.

5.5.7 Debris screens

Screens are used to trap rubbish and organic debris, which is unsightly, especially if trapped in vegetation. Screens should be used to protect extended detention outlets from clogging. Screens may be installed at the inlet to the pond or at the outlet from the pond. Various outlets are detailed in Figure 5-3.

5.5.8 Ease of maintenance

Ease of maintenance must be considered as a site design component. Access to the stormwater management pond or wetland must be provided for in the design, and land area adjacent to the pond must be set aside for drying out of sediments removed from the pond when maintenance is performed. The land set aside for pond maintenance must be sized as follows:

1. The set aside area shall accommodate at least 10 percent of the stormwater management pond volume at a maximum depth of one metre, and
2. The slope of the set aside area shall not exceed 5 percent, and
3. The area and slope set aside may be modified if an alternative area or method of disposal is approved on a case by case basis.

5.6 Pond and site design

5.6.1 Pond shape

The design of pond shape should consider engineering constraints, design parameters to achieve treatment, and the existing topography. For a given catchment the design parameters include water volume, surface area, depth, water flow velocity and detention period. In addition, it is recommended that the length to width ratio be 3 horizontal to 1 vertical or greater to facilitate sedimentation. These parameters should be considered in light of the existing topography. Generally, a pond will look more natural and aesthetically pleasing if it is fitted into existing contours.

5.6.2 Pond contours

Pond contour profiles are critical to the design of a pond: they determine available storage, the range of plants that can be grown and the movement of water through the pond. The safety features of shallow slopes and reverse slopes will help provide areas suitable for a variety of plants.

5.6.3 Edge form

Edge form influences the appearance of a pond, increases the range of plant and wildlife habitats and has implications for pond maintenance. Edges can include sloping margins where water level fluctuations cause greater areas of wet soils. Generally, sloping margins require a more sophisticated management approach to ensure growth of plants. Areas of gradually varied wetness should be identified and specific planting strategies should be developed for these areas. Such gradually sloping areas can appear a more natural part of the landscape than steep banks, and they provide opportunities for a greater range of plants and habitat.

5.6.4 Islands

Islands, properly located, can be used to manipulate flow characteristics, to increase the distance that water travels and to help segregate first flush inflow from later flows within a storm event. They also increase the extent of planted margin and can provide a wildlife habitat that offers some protection from domestic animals or people, as well as offering additional aesthetic appeal.

5.7 Landscaping

Design of a stormwater pond system should ensure that the pond fits in with the surrounding landscape. General landscape design principles will apply. The area should develop a strong and definite theme or character. This might be generated from particular trees, or views from the site, topographical features, or the cultural character of the surrounding neighbourhood. The landscape design for the area will provide a setting for the pond so that the pond will appear a natural component of the overall setting.

5.8 Construction

In addition to the information provided in this chapter, dam builders and owners should refer to TP 109, Dam Safety Guidelines has information on monitoring of dams during and post- construction.

Most of the information on wet systems is directed towards ponds where the normal pool of water is established by the construction of an embankment. Excavated ponds typically do not have the same safety concerns related to embankment failure.

When constructing wet ponds, it is very important to regularly inspect for seepage through the embankment. Detention ponds with a normal pool of water develop a zone of saturation through the embankment, which can increase failure potential in the future.Concerns regarding this zone of saturation (frequently detailed on plans as the area below the phreatic line) are alleviated by good quality control during construction.

The risk of a potential hazard is reduced by requiring, during design, safety features in the embankment which reduce the movement of water through the embankment. These safety features include anti-seep collars, diaphragms, core trenches, and clay cores. These features are not visible once construction is completed. Their construction and quality of construction must be verified by the inspector during their installation. Failure to inspect these features at critical times may result in embankment failure in the future.

Detention or retention practices which are normally dry do not develop a zone of saturation (which results from standing water), and internal water seepage is not a critical concern.

<u>5.8.1 Important inspection aspects related to design</u>

When certain site conditions are encountered or where the design has an unusual aspect, it is important to keep in regular communication with the consent agency (ARC, TA) to avoid some common mistakes. Examples of items which should be discussed include:

1. Encountering sandy soils when building a wet pond designed with a normal pool of water when the plan does not specify a pond liner.
2. Stormwater inlets too near the intended outfall, thereby creating a short-circuit flow path. While this may be acceptable from a stormwater quantity perspective, the short circuiting will reduce treatment and lessen water quality benefits.
3. Steep slopes into the pond with no slope breaks (benches) can increase the hazard potential and erosion of side slopes.
4. Failure to include on the plans essential components normally associated with ponds, such as anti-seep collars, trash protection for low flow pipes, service and emergency spillways.
5. Failure to include a draw down mechanism in wet ponds. Wet detention ponds should have a means to draw the water level down should draining the pond become necessary. From an inspector's viewpoint, a wet detention pond without a drawdown mechanism should be brought to the attention of the consent agency. Where groundwater provides the permanent water pool, a drawdown mechanism won't be available. The inspector should know the expected or design ground water elevations at a site, especially the seasonal high level. This information should be on the approved plans.

Refer to the checklist at the end of the chapter.

<u>5.8.2 Important inspection aspects related to construction</u>

This section highlights important things to inspect during the construction of ponds. At the end of the chapter is an example of a Sediment/stormwater management pond construction checklist. This checklist, adapted as needed, should be used by inspectors during construction of stormwater management ponds.

1. A major cause of pond failure is soil piping - water traveling along the outside of the service spillway. It generally occurs along a metal or concrete pipe where water which is under pressure from the

depth of water in the pond causes erosion of soil adjacent to the pipe. Erosion of this material causes the pond embankment to be weakened at that point and failure of the embankment results. This failure is much more likely to occur in wet detention ponds than in normally dry ones because they have a permanent pool of water next to the embankment. Water will soak into the embankment and seek a lower elevation. Failure potential can be prevented by proper installation of anti-seep collars or diaphragms, in conjunction with proper compaction of soils adjacent to the service spillway and collars or diaphragms.

2. The general minimum standards for construction work also apply to the construction of stormwater ponds. Does the construction comply with local material and equipment requirements for earthwork, concrete, other masonry, reinforcing steel, pipe, water gates, metal, and woodwork?
3. Are interior side slopes no steeper than 3:1(horizontal to vertical) and exterior side slopes no steeper than 2:1? The reason most stormwater embankment ponds remain stable is that the mass of earth in the embankment is heavy enough to prevent slippage of material caused by water pressure on the upstream slope. Steep side slopes are not only more dangerous to the general public, but they also reduce the total mass of earth material in the embankment. This can increase the potential for embankment failure.
4. Are elevations relatively accurate and according to the approved plans? An inspector should carry a simple Locke level to determine whether a given location is at proper elevation. The invert elevation of a service spillway must be lower than the elevation of the pond embankment or trouble can be expected. A Locke level provides a quick, moderately accurate, means to verify field implementation.
5. Are inlet and outlet areas stabilised to prevent erosion? Relying only on vegetative practices for stabilisation is generally inadequate since it takes time for the vegetation to become well established. Some form of additional stabilisation technique is generally necessary to protect soil until vegetation is established. This can include erosion control matting, riprap, gabions, and the like.
6. Are safety features provided? These may include the shallow bench surrounding the pond edge, barrier plantings to discourage approach by children, and/or fencing where required.
7. A sequence of construction must be established and followed. It is just as important that construction be done in the correct order as it is to have good quality construction. The sequence of construction includes preconstruction meetings, temporary erosion and sediment control, core trench, and so on. An example of a typical pond sequence of construction is presented at the end of the chapter.
8. Upon completion of construction, a final inspection should be performed. This inspection provides written documentation to the developer/contractor of the satisfactory completion of the facility. Depending on regional or local council requirements, this inspection augments the submission of an As-built plan.

5.8.3 As-built plans

Where consent conditions require, there may be a requirement for an As-Built Plan to verify that construction was done in accordance with the approved consent.

As-built plans should detail:

1. A section along the crest of the dam
2. A cross-section of the emergency spillway
3. A section along the centreline of the emergency spillway
4. A section along the centreline of the principal spillway extending at least 20 metres downstream of the fill
5. The elevation of the principal spillway crest
6. The elevation of the principal spillway conduit invert (inlet and outlet)
7. The diameter, length, thickness and type of material for the riser
8. The diameter, length and type of material of the conduit
9. The size and type of anti-vortex and trash rack device and its elevations in relation to the principal spillway crest
10. The number, size, and location of the anti-seep collars
11. The diameter and size of any low stage orifices or drain pipes

12. The length, width, and depth of contours of the pond area so that design volumes can be verified
13. Any erosion control measures at inflow and outflow points
14. Notes and measurements to show that any special design features were met
15. Statement on seeding and fencing (as appropriate)
16. Notes on site clean up and disposal
17. Sign and date check notes to include statement that practice meets or exceeds plans and specifications

5.9 Pond safety

The most important concern of stormwater management detention and retention ponds is safety. Failure to act in some situations may cause structural failure. Inspections must be made at least annually to ensure the safety of a stormwater pond. If there is any concern that the facility is unsafe, the pond owner must seek advice from a dam safety expert. Failure to take action when confronted with a potential problem can increase liability if a failure occurs.

Complete failures of stormwater management ponds generally do not occur overnight. They start as small problems and increase gradually, hence the importance of regular maintenance.

Ponds are unique among stormwater practices. If filtration, biofiltration, or infiltration practices fail or clog, their reduced performance generally will not result in downstream safety concerns. Ponds provide effective water quality performance, but that performance is gained at the cost of increased safety concerns. They must be designed correctly, built satisfactorily and actively maintained. A failure in any one of these three aspects of ponds could result in significant problems. Ponds are a valuable tool in controlling stormwater runoff, but care must be taken to ensure their long term effectiveness.

5.10 Operation and maintenance

In addition to the information provided in this Chapter, dam builders and owners should refer to TP 109, Dam Safety Guidelines for information on monitoring of dams during and post - construction.

5.10.1 Aesthetic and functional maintenance

Maintenance falls into a number of different categories, but the two main areas are:

> Aesthetic/nuisance maintenance and
> Functional maintenance.

These two areas can overlap at times. They are mutually and equally important. Functional maintenance includes routine (preventive) and corrective maintenance and is important for performance and safety reasons. Aesthetic maintenance is important primarily for public acceptance of stormwater facilities, and because it may also reduce needed functional maintenance activities.

Both forms of maintenance are needed and both must be combined into an overall stormwater management system maintenance program. Both forms of maintenance are included in the checklists in the back of this Chapter.

Aesthetic maintenance

Aesthetic maintenance primarily enhances the visual appearance and appeal of a stormwater pond. An attractive stormwater pond will more easily become an integral part of a community. Aesthetic maintenance is obviously more important for those ponds that are very visible. The following activities can be included in an aesthetic maintenance program:

> *Graffiti removal*

The timely removal of graffiti will improve the appearance of a stormwater pond. Timely removal will also tend to discourage further graffiti or other acts of vandalism.

> *Grass trimming*

Trimming of grass around fences, outlet structures, hiker/biker paths, and structures will provide a more attractive appearance to the general public. As much as possible, the design of stormwater ponds should incorporate natural landscaping elements which require less cutting and/or trimming. However, there often are areas where mowing will be necessary to maintain attractiveness.

> *Control of weeds*

In situations where vegetation has been established, undesirable plants can be expected. These undesirable plants can adversely impact the aesthetics of a stormwater pond and send the wrong signals to the public about weed control. This can also apply to wet detention littoral zones, which may be invaded by undesirable aquatic plant species. These undesirable plants can be removed through mechanical or chemical means. If chemicals are used, the chemical should be used as directed and according to territorial council requirements and left over chemicals disposed of properly.

> *Miscellaneous details*

Careful and frequent attention to performing maintenance tasks such as painting, tree pruning, leaf collection, debris removal, and grass cutting (where intended) will allow a stormwater management pond to maintain an attractive appearance and help maintain its functional integrity.

Functional maintenance

Functional maintenance is necessary to keep a stormwater management system operational at all times. It has two components:

> Preventive maintenance
> Corrective maintenance

Preventive maintenance

Preventive maintenance is done on a regular basis as detailed in the checklists contained at the end of this chapter. Tasks include upkeep of any moving parts, such as outlet drain valves or hinges for grates or maintenance of locks. It can also include maintenance of vegetative cover to prevent erosion. Examples of preventive maintenance include:

1. Grass mowing

   Actual mowing requirements at a pond should be tailored to the specific site conditions and grass type.

2. Grass maintenance

   Grass areas require limited periodic fertilising and soil conditioning in order to maintain healthy growth. Provisions may have to be made to reseed and re-establish grass cover in areas damaged by sediment accumulation, stormwater flow or other causes.

3. Vegetative cover

   Trees, shrubs, and other landscaping ground cover may require periodic maintenance, including fertilising, pruning, and weed pest control.

4. Trash and debris

   A regularly scheduled program of debris and trash removal will reduce the potential for outlet structures, trash racks, and other pond components from becoming clogged and inoperable during storm events. In addition, removal of trash and debris will prevent possible damage to vegetated areas and eliminate potential mosquito breeding habitats. Disposal of debris and trash must comply with all local and regional control programmes. Only suitable disposal and recycling sites should be used.

5. Sediment removal and disposal

   Accumulated sediments should be removed before they threaten the operation or storage volume of a stormwater management pond. Disposal of sediments also must comply with local and regional requirements especially if they are contaminated. Only suitable disposal areas should be used.

6. Mechanical components

   Valves, sluice gates, pumps, fence gates, locks and access hatches should remain functional at all times. Regularly scheduled maintenance should be performed in accordance with the manufacturers' recommendations. All mechanical components should be operated during each maintenance inspection to assure continued performance.

7. Elimination of mosquito breeding habitats

   The most effective mosquito control programme is one which eliminates potential breeding habitats, or, in the case of open water ponds, ensures that optimal conditions are maintained for the survival of mosquito control organisms. Any stagnant pool of water can become a mosquito breeding area within a matter of days. Ponded water in open cans, tyres, and areas of sediment accumulations or ground settlement can become mosquito breeding areas.

8. Pond maintenance programme

   A maintenance programme for monitoring the overall performance of the stormwater management pond should be established. Wet detention ponds are especially complex environments. They require a healthy aquatic ecosystem to provide maximum benefits and to minimise maintenance. It is important to remember that potentially large problems can be avoided if preventive maintenance is done in a timely fashion.

Corrective maintenance

Corrective maintenance is required on an emergency or non-routine basis to correct problems and to restore the intended operation and safe function of the pond. Corrective maintenance is done on an as-required, not on a scheduled basis. Failure to promptly address a corrective maintenance problem may jeopardise the performance and integrity of the pond. It may also present a potential safety problem to those living by or below it. Corrective maintenance activities include:

1. Removal of debris and sediment

   Sediment, debris, and trash which threaten the ability of the pond to store or convey water should be removed immediately and properly disposed of in order to restore proper pond function. A blocked inlet or outlet means that stormwater will travel in an area that was not normally designed as a flow path. In the case of an inlet, the stormwater could travel over a kerb onto a grassed area and scour it. If the outlet is blocked, water will back up in the pond and may travel through the emergency spillway. These areas are not designed for frequent flow and may become eroded. If sediments are clogging a pond component, the lack of an available disposal site should not delay removal of the sediments. Temporary arrangements should be made for handling the sediments until a more permanent arrangement is made.

2. Structural repairs

   Repairs to any structural component of the pond should be made promptly. Equipment, materials, and personnel must be readily available to perform repairs on short notice. The immediate nature of the repairs depends on the type of damage and its effects on the safety and operation of the pond. Where structural damage has occurred, the design and conduct of repairs should be undertaken only by qualified personnel.

3. Dam, embankment and slope repairs

   Damage to dams, embankments, and slopes must be repaired quickly. Typical problems include settlement, scouring, cracking, sloughing, seepage and rilling. A common concern in embankments with outflow pipes through them is seepage around the outside of the barrel. This can also cause movement of embankment soils, which can weaken the embankment. Repairs need to be made promptly. Other temporary activities may be needed, such as drawing down the water level in the pond in order to relieve pressure on a dam or embankment or facilitate repairs. Crack repair in a concrete structure may necessitate draining the pond and cleaning before repair. If the pond is to be dewatered, pumps may be necessary if there is no drain valve.

4. Elimination of mosquito breeding areas

   If neglected, a stormwater pond can become a mosquito breeding area, especially where normally dry ponds do not completely drain and dry out. Corrective action may be needed if a mosquito problem exists and the stormwater pond is the source of the problem. If mosquito control in a pond becomes necessary, the preventive maintenance programme for mosquitoes should be re-evaluated, and more emphasis placed on control of mosquito breeding habitats.

5. Erosion repair

   Vegetative cover is necessary to prevent soil loss, maintain the structural integrity of the pond and maintain its contaminant removal benefits. Where a reseeding program has been ineffective, or where other factors have created erosive conditions (such as pedestrian traffic, concentrated flow or the like), corrective steps should be taken to prevent further loss of soil and any subsequent danger to the performance of the pond. Corrective action can include erosion control blankets, riprap, sodding or reduced flow through the area.

6. Fence repair

   Fences can be damaged by any number of factors, including vandalism and storms. Timely repair will maintain the security of the site.

7. Elimination of trees or woody vegetation

   Woody vegetation can present problems for dams or embankments. The root system of woody vegetation can undermine dam or embankment strength. If the vegetation dies and the root system decomposes, voids can be created in the dam or embankment which weaken the structure. Preventive maintenance can avoid this problem. However, when preventive maintenance programmes are deficient, steps must be taken to eliminate the problem. Vegetation, including root systems, must be removed from dams or embankments and the excavated materials replaced with proper material at a specified compaction (normally 95% of the soil’s maximum density).

8. General facility maintenance

In addition to the above elements of corrective maintenance, general corrective maintenance should address the overall pond and it's associated components. If algal growth becomes a problem for ponds, steps must be taken to re-establish its original performance. Stormwater ponds can be very complex systems. They will work only as long as each individual element functions correctly. If one pond component is undergoing corrective maintenance, other components should be inspected at the same time to see if they also need maintenance. This may yield cost savings if equipment is already on site.

5.10.2 Other maintenance activities

Maintenance activities for dry and wet ponds have many similarities, but there also are some differences in the types of maintenance that are needed. Dry detention systems have more lawn areas, that must be mowed at least once per year to prevent the growth of woody vegetation on the embankment. Monthly or more frequent mowing is necessary if good turf grass cover is expected or desired.

Dry detention ponds frequently have pilot or low flow channels to convey smaller flows. Concrete pilot channels may become undermined, and stone ones may become choked with vegetation and require chemical treatment to reestablish flow conveyance ability. Maintenance efforts for pilot channels will be done on an "as needed" basis. Careful inspection of concrete pilot channels is essential, as their undermining will jeopardise its structural integrity.

Wet detention ponds, with their normal water pool, are effective at converting inorganic nitrogen to organic nitrogen. Consequently, this may create algal problems unless littoral zones are planted and maintained with aquatic vegetation. Wet detention ponds also commonly have forebays to remove heavier sediments. Forebay maintenance is therefore an important issue for wet detention ponds, and must be considered. Frequency of forebay maintenance depends on the incoming contaminant load and the forebay size.

Both dry and wet detention ponds have the potential for debris clogging of inlet and outlet structures. Residential communities generate a surprising amount of debris, while commercial facilities can expect debris of all sorts. Inspections for debris should be made on a monthly basis or after rain events to ensure that all components of the stormwater ponds are operating as required.

Coarser sediments can be expected to be found close to the pond inlet, with finer sediments expected to be deposited closer to the pond outfall. The coarser sediments will occupy a greater volume and maintenance schedules should include more frequent removal. Forebays can be more easily and more often cleaned out extending the storage life of the rest of the pond.

To remove sediment from a wet pond drain the water down to the lowest possible level, leaving a small pool of water to provide habitat if there is a desirable resident fish population. This avoids disturbing fines and causing significant turbidity downstream. Sediments removed from the pond should be placed where they can dry before final placement. Sediment control provisions must be included in maintenance costs, to prevent downstream increases in contaminant loadings or to prevent removed sediments from re-entering the pond.

Sediment removal from dry detention ponds is more straightforward. Since they are normally dry, sediments can be removed by an appropriate means and disposed of in one operation. Experience has shown that it is easier and more effective to remove sediments when they are dry and cracked, and thereby more easily separated from the vegetation. Sediment control during maintenance is necessary to prevent rainfall mobilising stockpiled materials or eroding exposed soils.

Erosion problems can occur with either dry or wet detention ponds. For the most part they start as small problems which, if uncorrected, can grow into large problems and possibly threaten the integrity of the detention pond. Inspections to locate erosion problems should be done at least annually or after major storms. Evidence of significant foot or bike traffic in areas where vegetation has died indicate potential erosion areas in the future. These areas should be protected from traffic or provided with a more erosive resistant ground cover.

Periodic maintenance of structural components must be done to ensure their continued operation. This includes inspecting any joints for possible leakage or seepage. Areas should also be checked for corrosion, valves should be manipulated and lubricated when needed, and all moving parts inspected for wear and tear.

Plate 5-3: Outlet Structure Showing Multiple Storm

5.11 Case study

Case study is a residential site, 7.5 hectares in size, with no off-site drainage passing through it..
Waitemata series silts and clays
Gentle site slopes of 2.5%
Predevelopment land use pasture

Post-development land use residential
Average lot size 470 m^2
Number of lots 100

Downstream flooding is not an issue but the site drains into a stream so peak criteria is required for the 2 and 10 year storms in addition to extended detention for channel protection and water quality requirements

TP 108 analysis provided the following information:

2 year rainfall = 70 mm/24 hours
10 year rainfall = 130 mm/24 hours

<u>5.11.1 Pre-development condition</u>

CN pre-development = 74
I_a = 5 mm
Channelisation factor = 1
Catchment length = 0.17 km
Catchment slope = 0.04 m/m
t_c = 0.17 hrs. (minimum as per TP 108)

2 year storm peak flow rate = 0.389 m^3/s, runoff depth = 27.39 mm, runoff volume = 2054 m^3
10 year storm peak flow rate = 1.03 m^3/s, runoff depth = 72.93 mm, runoff volume = 5470 m^3

<u>5.11.2 Post-development condition</u>

CN of pervious areas = 74
CN of impervious areas = 98
Percentage impervious cover = 67% (see Table 2-2a of TP 108)
Average CN = 90

I_a = 1.65 mm
Channelisation factor = 0.6
Average runoff factor = 90/(200-90) = 0.82
Catchment length = 0.2 km
Catchment slope = 0.034 m/m
t_c = 0.17 hrs. (minimum as per TP 108)

2 year storm peak flow rate = 0.66 m^3/s,
Runoff depth - pervious areas = 27.4 mm, runoff volume - pervious areas = 678 m^3
Runoff depth - impervious areas = 65.2 mm, runoff volume - impervious areas = 3275 m^3
Total runoff volume = 3954 m^3

10 year storm peak flow rate = 1.42 m^3/s,
Runoff depth - pervious areas = 72.9 mm, runoff volume - pervious areas = 1805 m^3
Runoff depth - impervious areas = 125 mm, runoff volume - impervious areas = 6282 m^3
Total runoff volume = 8087 m^3

5.11.3 Water quality volume

The WQV is based on 1/3 of the 2-year rainfall depth of 70 mm, equalling 23.3 mm.

TP 108 calculations for the post-development catchment give:
Runoff depth - pervious areas = 3.1 mm, runoff volume - pervious areas = 77 m^3
Runoff depth - impervious areas = 19.1 mm, runoff volume - impervious areas = 959 m^3
Total runoff volume = 1037 m^3 = WQV

Since extended detention will be required as an overlay, the extended detention will provide 50% reduction in the WQV that must be held as permanent standing water.
Thus the required permanent WQV for this example is 518 m^3.

The forebay volume should be at least 10% of the required WQV, or 52 of m^3 storage.
This storage is based on the adjusted water quality volume rather than the total volume. In addition, the volume is increased by an additional 50% to allow for deposition.
The total forebay volume requirement is therefore 78 m^3.

5.11.4 Extended detention volume (EDV)

The EDV is based on 34.5 mm of rainfall.

TP 108 calculations for the post-development catchment give:
Runoff depth - pervious areas = 7.3, runoff volume - pervious areas = 182 m^3
Runoff depth - impervious areas = 30.0 mm, runoff volume - impervious areas = 1507 m^3
Total runoff volume = 1689 m^3 = EDV

5.11.5 Pond outlet design

The pond can now be sized, with knowledge of the site contours and the above volume requirements. Let us suppose that, in this case, the pond chosen has the following storage volume/stage relationship:

Table 5-4
Stage storage relationships

Water Level	Stored volume (m^3)
14.5	0
15.0	518
16.0	2207
17.0	4200
18.0	6700
19.0	8700

Extended detention outlet

The lowest outlet is the extended detention outlet, whose invert is set at a level that impounds the required permanent WQV. In this case the invert is set at RL 15.0, to impound 518 m^3.

The extended detention outlet is sized to release the EDV over a 24-hour period. To do this, the outlet is sized so that when the pond is holding the full EDV the release rate is that which would release the EDV over 12 hours. (Because the release rate decreases as the pond empties, this sizing approximates complete release of the EDV over 24 hours).

Q_i = 1689 m^3/24 hours = 0.02 m^3/s.

At the full EDV elevation, the maximum release rate is assumed to be Q = 2(Q_i)
Q_{max} = 2(0.02) = 0.04 m^3/s

Calculate the low flow orifice.

Assuming an orifice is used for this outlet, its required cross-sectional area A is given by:
$Q = 0.62A(2gh)^{0.5}$
where in this case $Q \leq Q_{max} = 0.04\ m^3/s$, h = 16 - (15 + D/2) and D is the orifice diameter.

Try a 125 mm diameter orifice:
h_i = 16 - (15 + 0.125/2) = 0.937
$Q = 0.62(0.0123)(2 \times 9.8 \times 0.937)^{0.5} = 0.033\ m^3/s$
This is less than 0.039 m^3/s and is therefore adequate.

Weir for 2-year and 10-year events

It is common to use a rectangular weir to provide the appropriate outflow rate for the 2-year and 10-year events. Peak outflows for these events should not exceed the pre-development rates, 0.39 m^3/s and 1.03 m^3/s respectively. Sometimes a weir sized for the 10-year flow will also keep the2-year post-development flow below the pre-development value.

To size the weir precisely, the inflow hydrograph should be derived using TP 108 and HEC-HMS, and should be routed through the pond, and the weir dimensions determined by trial-and-error. The pond routing can be included as part of the HEC-HMS model.

A conservative approximation can be made by ignoring outflow that occurs during the rainfall and sizing the weir so that the entire runoff volume can be held with the outflow rate not exceeding the pre-development peak flow.

2-year event
Pond volume required for teh post-development event
= 518 m^3 (standing water) + 3953 m^3 (2-year volume) = 4471 m^3.

Ponded water level is therefore 17.12 m (by interpolation from stage / volume table)
Weir invert level is the level at which the full EDV of 1689 m^3 is impounded, RL 16.0 m.
Ouflow from extended detention orifice $Q_i = 0.62A(2gh_i)^{0.5}$

where $h_i = 17.12 - (15 + 0.125/2) = 2.057$ m

$Q_i = 0.048\ m^3/s$

Outflow over weir $Q_{ii} = 1.7\ L_{ii}h_{ii}^{1.5}$

where L_{ii} is the weir width and $h_{ii} = 17.12 - 16.0 = 1.12$ m

Try $L_{ii} = 0.17$ m, then $Q_{ii} = 0.343\ m^3/s$
Total outflow $Q_i + Q_{ii} = 0.39\ m^3/s$ or approximately the pre-development flow rate

10 year event
Pond volume required for the post-development event
= 518 m^3 (standing water) + 5470 m^3 (2-year volume) = 5988 m^3

Ponded water level is therefore 17.73 m (by interpolation from stage / volume table
Weir invert level is the level at which the 2-year event is impounded, RL 17.12 m
Outflow from extended detention orifice $Q_i = 0.62A(2gh_i)^{0.5}$

where $h_i = 17.73 - (15 + 0.125/2) = 2.67$ m

$Q_i = 0.055\ m^3/s$

Outflow for 2-year weir $Q_{ii} = 1.7\ L_{ii}h_{ii}^{1.5}$

where $h_{ii} = 17.73 - 16 = 1.73$ m (L_{ii} from 2-year calculations)

$Q_{ii} = 0.66\ m^3/s$

Outflow for 10-year weir $Q_{iii} = 1.7\ L_{iii}h_{iii}^{1.5}$

where L_{iii} is the weir width and $h_{iii} = 17.73 - 17.12 = 0.61$m

Try $L_{iii} = 0.39$ m

$Q_{iii} = 0.32\ m^3/s$

Total outflow $Q_i + Q_{ii} + Q_{iii} = 1.03\ m^3/s$, approximately the pre-development flow rate

It is common to combine the 2-year and 10-year weirs into a single stepped weir. The upper weir width in this case will then be 0.39 + 0.17 = 0.56 m.

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Inspection forms and checklists for ponds

1. Example Preconstruction meeting topics
2. Typical embankment pond sequence of construction for developers and contractors
3. Sediment/stormwater management pond construction checklist
4. Stormwater pond operation and maintenance inspection checklist

Example preconstruction meeting topics

1. General information

    1. Attendance
    2. Purpose of project and background information
    3. Emergency telephone numbers
    4. Construction photograph requirements
    5. Project sign requirements
    6. Starting date
    7. Field office requirements
    8. Responsibility for notification of affected property owners and residents
    9. Chain of command or responsibility for communications and correspondence
    10. Construction schedules
    11. Key personnel and their degree of involvement in the project (inspector, owner, engineer, agencies, etc.)

2. Police and Fire Service concerns

    1. Traffic control
    2. Barricades and signs conforming to the standards
    3. Noise considerations
    4. Working hours, including weekend and holidays
    5. Vandalism and preventative measures
    6. Flagmen and traffic control staff
    7. Equipment storage and vehicle parking
    8. Emergency vehicle access
    9. Underground tank locations and precautionary construction procedures
    10. Storage and use of hazardous materials

3. Utilities

    1. Utility locations
    2. Coordination of utility relocations
    3. Emergency phone numbers of utility companies

4. Change orders and extra claims

    1. Requirements for additional work and submittal of change orders
    2. Procedures and schedule for review and recommendations of change orders
    3. Procedures for negotiating extra claims and change orders

E. Construction access and set-aside areas

    1. Set aside locations and maps
    2. Responsibility for locating and staking set aside areas
    3. Available survey data for the site
    4. Access requirements and staging areas
    5. Set aside restrictions and restoration requirements

5. Construction details

    1. Unique or complex aspects of the project

2. Testing laboratories and sampling procedures
3. Cold and hot weather protection measures
4. Blasting requirements
5. Clean fill location for construction related materials
6. Revised drawing requirements and review procedures
7. Specific construction techniques and procedures
8. Review of technical section of the specifications

6. Consents and permits

   1. Status of all required regional and local permits
   2. Permit or consent restrictions and conditions
   3. Start-of-work notifications

Typical Sequence of Construction for Stormwater/Sediment PondEmbankment Ponds with Riser/Barrel Outlet Structures for Developers and Contractors

1. Notify plan review/compliance agency as required

    a. Arrange the preconstruction meeting
    b. Clear up any questions regarding the approved plan

2. Pre-construction meeting with compliance agency

    a. Review the site plan and layout and discuss any problems or changes needed to the plan
    b. Obtain approvals for the plan changes from the appropriate compliance agency
    c. Discuss the stages of construction which notification to the compliance agency is needed

3. Site layout

    a. Make sure site layout agrees with the plan. Seek approval for a plan change if necessary.
    b. Check elevation of the proposed outfall structure
    c. Physically mark any areas not to be disturbed, such as limit of disturbance, wetlands, property lines, etc.

4. Install perimeter erosion and sediment controls

    a. Install sediment controls at the downstream perimeter wherever sediment may leave the site during the clearing and grubbing for the pond.

5. Install temporary channel diversion

    a. Divert clean water flow away from pond area
    b. Stabilise the diversion

6. Clear and grub the pond area

7. Remove topsoil from the pond area

    a. Stockpile the soil in an approved location
    b. Stabilise the stockpile area

8. Facility stakeout

    a. Stakeout centreline of embankment, outside and inside toe of slopes

9. Core trench/emabankment area

    a. Arrange to meet the inspector to discuss need for location of core trench
    b. If core trench is needed, determine where material will come from before trench is opened.
    c. Make arrangements for de-watering of the core trench if necessary
    d. Excavate for core trench
    e. Fill core trench with suitable material to assure proper compaction to existing ground elevation

10. Construct outfall channel

    a. Protect rock outlet with filter cloth
    b. Constructed and stabilize remaining channel

11. Install barrel with anti-seep collars

    This should be done BEFORE any embankment work

    a. Prepare the bedding for the barrel
    b. Place barrel and anti-seep collars (ensure pipe grade is accurate)
    c. Check the pipe connections are watertight
    d. Backfill barrel, with particular attention to the compaction requirements. Ensure structural backfill is completely free of rocks and other unsuitable material

12. Riser placement

    a. Check riser structure for conformance to specifications
    b. Check elevation of structure
    c. Set riser and pour concrete riser base

13. Install any erosion control structures required

14. Construct remaining core and embankment

    a. Impervious material placed in core of embankment
    b. Check and approve material for suitability
    c. Compact the embankment according to specifications
    d. Check UNSETTLED elevation and top width of embankment
    e. Stabilise embankment

15. Divert flows into pipe system

16. Construct emergency spillway

    a. If earth spillway, construct in undisturbed ground
    b. Check elevation of control section and exit channel

17. Install inflow channels

    a. Stabilise according to plan including pipe outfalls into pond

18. Complete excavation of pond to final grade

19. Vegetatively stabilise all disturbed areas

20. Complete pond conversion

    a. Obtain approval of inspector to convert pond from sediment to stormwater control
    b. Properly de-water the pond in an approved manner as per TP 90
    c. Remove accumulated sediment and restore pond to design grade. Complete final stabilisation
    d. Make any structural modifications to the riser for permanent function

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (**Under Section 332 of the Resource Management Act 1991)**	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SEDIMENT / STORMWATER MANAGEMENT POND CONSTRUCTION CHECKLIST	:	Needs immediate attention	V	Okay	;	Clarification Required	
	9	Not Applicable					

Pond Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory
MATERIALS AND EQUIPMENT	Y	N		
Pipe & appurtenances on-site prior to construction and dimensions checked.				
1. Material (including protective coating, if specified)	Y	N		
2. Diameter	Y	N		
3. Dimensions of riser or pre-cast concrete outlet structure	Y	N		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans	Y	N		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope	Y Y	N N		
6. Number & deminsions of prefabricated anti-seep collars	Y Y	N N		
7. Watertight connectors and gaskets	Y	N		
8. Outlet drain valve	Y	N		
9. Appropriate compaction equipment available, including hand & small power tamps	Y	N		
10. Project benchmark near pond site	Y	N		
12. Equipment for temporary de-watering	Y	N		
SUBGRADE PREPARATION				
13. Area beneth embankment stripped of all vegetation, topsoil, and organic matter	Y	N		
14. Cut-off trench excavated a minimum of 1 metre below subgrade and minimum 1 metre below proposed pipe invert, with side slopes no steeper than 1:1	Y	N		
15. Impervious material used to backfill cut-off trench	Y	N		
PIPE SPILLWAY INSTALLATION	Y	N		
16. Method of installation detailed on plans	Y	N		
17. Bed Preparation	Y	N		
i) Installation trench excavated with 1:1 side slopes	Y	N		
ii) Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have to defined steps before proceeding with installation)	Y	N		
iii) Invert at proper elevation and grade	Y	N		
18. Pipe placement – Metal / Plastic pipe	Y	N		
i) Watertight connectors & gaskets properly installed	Y	N		

Items Inspected	Checked		Satisfactory	Unsatisfactory
ii) Anti-seep collars properly spaced & having watertight connections to pipe	Y	N		
iii) Backfill placed & tamped by hand under "haunches" of pipe	Y	N		
iv) Remaining backfill placed in max. 200mm lifts using small power tamping equipment until 600mm cover over pipe is reached	Y	N		
19. Pipe placement – Concrete pipe	Y	N		
i) Pipe set on blocks or concrete slab for pouring of low cradle	Y	N		
ii) Pipe installed with rubber gasket joints no spalling in gasket interface area	Y	N		
iii) Excavation for lower half of anti-seep collar(s) reinforcing steel set	Y	N		
iv) Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other	Y	N		
vi) Low cradle & bottom half of anti-seep collar installed	Y	N		
vii) Upper half of anti-seep collar(s) formed with reinforcing steel set	Y	N		
viii) Concrete for collar of an approved mix & vibrated into place (Protected from freezing while curing, if necessary)	Y	N		
ix) Forms striped & collar inspected for honeycomb prior to backfilling. Parge if necessary	Y	N		
20. Pipe placement - Backfilling				
i) Fill placed in maximum 200mm lifts	Y	N		
ii) Back fill taken minimum 600mm above top of anti-seep collar elevation before traversing with heavy equipment	Y	N		
RISER / OUTLET STRUCTURE INSTALLATION				
21. Pre-cast concrete structure				
i) Dry and stable subgrade	Y	N		
ii) Riser base set to design elevation	Y	N		
iii) If more than one section, no spalling in gasket interface area: gasket or approved caulking material placed securely	Y	N		

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Items Inspected	Checked		Satisfactory	Unsatisfactory
iv) Watertight & structurally sound collar or gasket joint where structure connects to pipe spillway	Y	N		
22. Poured concrete structure				
i) Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set	Y	N		
ii) Structure formed to design dimensions, with reinforcing steel set as per plan	Y	N		
iii) Concrete of an approved mix & vibrated into place (protected from freezing while curing, if necessary)	Y	N		
iv) Forms stripped & structure inspected for "honeycomb" prior to backfilling. Parge if necessary	Y	N		
EMBANKMENT CONSTRUCTION				
23. Fill material				
i) Soil engineer's test	Y	N		
ii) Visual test by inspector	Y	N		
24. Compaction				
i) Soil engineer's test	Y	N		
ii) Visual test by inspector	Y	N		
25. Embankment				
i) Fill placed in maximum 200mm lifts & compacted with appropriate equipment	Y	N		
ii) Constructed to design cross-section, side slopes & top width	Y	N		
iii) Constructed to design elevation plus allowance for settlement	Y	N		
IMPOUNDED AREA CONSTRUCTION				
26. Excavated/grade to design contours & side slopes	Y	N		
27. Inlet pipes have adequate outfall protection	Y	N		
28. Forebay(s)	Y	N		
29. Wet pond requirements				
i) 1.3 metre reverse slope bench 100mm above normal pool elevation	Y	N		
ii) 2.3 metre wide level bench 300mm below normal pool elevation	Y	N		
EARTH EMERGENCY SPILLWAY CONSTRUCTION				
30. Spillway located in cut or structurally stabilised with riprap gabions, concrete...	Y	N		
31. Excavated to proper cross-section, side slopes & bottom width	Y	N		

	Checked		Satisfactory	Unsatisfactory
32. Entrance channel, crest, & exit channel constructed to design grades & elevation	Y	N		
OUTLET PROTECTION				
33. End section securely in place & properly backfilled	Y	N		
34. Endwall				
i) Footing excavated or formed on stable subgrade, to design dimensions & reinforcing steel set, if specified	Y	N		
ii) Endwall formed to design dimensions with reinforcing steel set as per plan	Y	N		
iii) Concrete of an approved mix & vibrated into place (protected from freezing, if necessary)	Y	N		
iv) Forms stripped & structure inspected for "honeycomb" prior to backfilling. Parge if necessary	Y	N		
35. Riprap outlet / channel				
i) Outlet / channel excavated to design cross-section with proper transition to existing ground	Y	N		
ii) Filter fabric in place	Y	N		
iii) Stone sized as per plan & uniformly placed at the thickness specified	Y	N		
VEGETATIVE STABILISATION				
36. Approved seed mixture or sod	Y	N		
37. Proper surface preparation & required soil amendments	Y	N		
38. Excelsior mat or other stabilisation materials, as per plan	Y	N		
MISCELLANEOUS				
39. Toe drain	Y	N		
40. Temporary dewatering device installed as per plan with appropriate fabric, stone size & perforation if included	Y	N		
41. Drain for ponds having a permanent pool	Y	N		
42. Trash rack / anti-vortex device secured to outlet structure	Y	N		
43. Trash protection for low flow pipes, orifices, etc	Y	N		
44. Fencing (when required)	Y	N		
45. Access road	Y	N		
46. Set aside area for clean-out maintenance	Y	N		

OFFICERS REMARKS:

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ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____

1st Notice: ____

2nd Notice: ____

Submit plan modifications as noted in written comments by ________________________________

Notice to Comply issued ____

Final inspection, project completed ____

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: ________________________________

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Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (**Under Section 332 of the Resource Management Act 1991)**	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

STORMWATER POND OPERATION & MAINTENANCE INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

	"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
	"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
	"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Pond Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
EMBANKMENT & EMERGENCY SPILLWAY	Y	N	Y	N	**A,S**		Y	N	Y	N	
1. Is the spillway level?						20. Concrete/Masonry condition					
2. Adequate vegetation & ground cover?						Riser and barrels:					
3. Appropriate plants / weeds?						a) Cracks or displacement?					
4. Adequate freeboard?						b) Minor spalling (,0.25mm)?					
5. Embankment erosion evident?						c) Major spalling (rebars exposed)?					
6. Cracking, bulging or sliding of dam						d) Joint failures?					
a) Upstream face						e) Water tightness adequate?					
b) Downstream face						21. Pond drain valve:					
c) At or beyond toe upstream						a) Operational / exercised?					
d) At or beyond toe downstream						b) Chained and locked?					
e) Emergency spillway						22. Slope protection or rip-rap failures?					
7. Pond & toe drains clear & functioning?						23. Other?					
8. Evidence of animal burrows?						**PERMANENT POOL (WET POND)**					**M**
9. Seeps/leeks on downstream face?						24. Undesirable vegetative growth?					
10. Vertical & horizontal alignment of top of						25. Removal of floating debris required?					
dam as per As-Built plans?						26. Visible pollution?					
11. Emergency spillway clear of obstructions						27. Evidence of 'edge' erosion?					
& debris						28. Other?					
12. Provision of access for maintenance?						**DRY POND**					**M**
a) By hand?						29. Adequate vegetation cover?					
b) For machinery?						30. Presence of undesirable vegetation /					
13. Other?						woody growth?					
RISER & SERVICE SPILLWAY					**A**	31. Standing water or wet spots?					
Type: Reinforced concrete						32. Sediment and/or trash accumulation?					
Metal pipe						33. Low flow channels unobstructed?					
Masonry						34. Other?					
14. Low flow orifice obstructed?						**SEDIMENT FOREBAYS**					
15. Low flow trash rack:						35. Is sediment accumulation > 50%					
a) Is debris removal necessary?						(maintenance req'd immed. If Yes)					
b) Is corrosion evident?						36. Provision of access for maintenance:					
16. Weir trash rack maintenance						a) By hand?					
a) Is debris removal required?						b) For machinery?					
b) Is corrosion evident?						**OUTFALLS INTO PONDS**					**A,S**
17. Is there excessive sediment						37. Riprap failures?					
accumulation inside the riser?						38. Condition of endwalls / headwalls	Good		Fair		Poor
18. Metal pipe condition	Good		Fair		Poor	39. Evidence of slope erosion?					
19. Outfall channels functioning?						40. Condition of any inflow pipes.	Good		Fair		Poor
						41. Other?					

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Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
OTHER	Y	N	Y	N	**M**	**CONSTRUCTED WETLAND AREAS**	Y	N	Y	N	**A**
41. Encroachments on pond or easement area?						45. Vegetation healthy and growing?					
42. Complaints from residents?						46. Evidence of invasive species?					
43. Aesthetics						47. Excessive sedimentation in wetland area?					
a) grass mowing required?											
b) graffiti removal needed?											
c) other (specify)?											
44. Any public hazards (specify)?											

Inspection Frequency Key **A = Annual, M = Monthly, S = After monthly storm**

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ____________________________

Chapter 6
Wetland design, construction and maintenance

6.1 Introduction

Wetlands are complex natural shallow water environments that are dominated by hydrophytic (water loving) vegetation. This distinguishes them from deep water habitats that are dominated by large areas of open water. Our current scientific knowledge regarding their functions and values has developed during just the last 40 years. Until very recently, the filling and draining of wetlands was accepted practice to "improve" the land. We now know that wetlands provide many important benefits including the attenuation of flood flows, maintenance of water quality, and support for aquatic life and wildlife. Around most urban areas, wetlands have been drained for land development activities and for enhanced agricultural purposes. Approximately 90% of New Zealand's pre-European wetlands do not exist today.

Constructed wetlands are shallow vegetated ponds designed to utilise the benefits of natural wetland functions and processes for various purposes. The four principal purposes identified by Kadlec and Knight (1996) are:

> To compensate for and help offset the rate of loss of natural wetland as a result of agriculture and urban development. (constructed habitat wetlands)
> To improve water quality. (constructed treatment wetlands)
> To provide flood control. (constructed flood control wetlands)
> Produce food (constructed aquaculture wetlands)

Constructed wetlands have become increasingly popular in recent years for the second purpose identified above to treat urban stormwater to remove contaminants that would be potentially detrimental to the receiving water ecosystem. Multiple use constructed wetlands, which combine a number of purposes and benefits, are becoming more common in urban situations. Wong et al (1999) list the following purposes and benefits which are commonly combined:

> Flood protection
> Flow attenuation
> Water quality improvement
> Landscape
> Recreational amenity
> Provision of wildlife habitat.

A major consideration in the use of constructed wetlands for stormwater management purposes is to replace, to some degree, the wetlands that have already been lost. Wetlands are nature's natural "kidney" system and the loss of this filtering function of wetlands can be correlated, at least in part, with the decline in the quality of our water resources systems. Protecting existing wetlands, in conjunction with increasing the total extent of wetlands through wetlands restoration, creation, or construction for new developments, forms part of an effective strategy for downstream aquatic resource protection.

6.2 Objectives

This chapter:

> Demonstrates the advantages of constructed wetlands over unvegetated ponds
> Presents design principles of constructed wetlands intended to treat urban stormwater in the

Auckland Region,

- Discusses the physical, chemical and biological processes which are utilized to treat stormwater
- Gives guidelines for construction and maintenance of constructed wetland systems.

A key focus is how to optimise constructed wetland design for both treatment and stormflow detention by identifying the minimum dimensions that will achieve the required 75% treatment performance. Constructed wetlands are intended for use close to the source of urban stormwater, before the stormwater enters the receiving environment.

Other features and benefits of constructed wetlands are not included in the proposed design because their provision would require additional site area. These include provision of open water, increased habitat diversity and aesthetic amenity features such as islands and irregular shorelines. These can be added to the proposed design as needed or desired, provided the sizing and hydraulic control and treatment features of the design are not compromised.

Brown et al (1998) present a good outline of the chemical, biological and physical processes which influence treatment of urban stormwater in constructed wetlands.

A brief summary is presented in Table 6-1.

6.3 Advantages of constructed wetlands over unvegetated pond systems

A monitoring study of the treatment performance of an existing Auckland urban stormwater treatment constructed wetland was carried out and the results are detailed. The results of both local and overseas monitoring studies show that constructed wetland are better than detention ponds for urban stormwater treatment (ARC, 2001).

Vegetated wetlands offer better than unvegetated, deeper treatment ponds, mainly because of the dense vergetation which:

- Reduces the speed of water within the pond, promoting settlement of suspended solids
- Reduces wave action which in unvegetated ponds can inhibit deposition of solids and cause resuspension of fine solids
- Reduces wind induced water mixing
- Filters litter, floatables and silt particles
- Provides surfaces (substrates) for the growth of a variety of microorganisms which take up soluble contaminants (including nutrients and metals) and promote aggregation and settlement of colloidal particles; resulting in their deposition into the bottom sediment. Microrganisms are important as catalysts for most contaminant transformations in wetlands (Kadlec and Knight, (1996)
- Provides natural organic material which adsorbs organic and inorganic contaminants and results in their deposition into the bottom sediments
- Provides organic matter to bottom sediments and promotes conditions in which nitrification (NO_2^- to NO_3^-) and denitrification (N_2) occur, resulting in removal of nitrogen from the aquatic system. Organic soils maximise denitrification
- Takes up nutrients and some contaminants (although a proportion are later released when the plants decay)
- Increases organic bottom sediments that have a high cation exchange capacity for contaminants such as metals, phosphorus salts and organics

Wong et al (1998) list the advantages of vegetation in a constructed wetland stormwater treatment system as follows:

During baseflow the vegetation provides for the following benefits over unvegetated ponds:

> Provides surface area for sediments to adsorb onto biofilms growing on plants.
  Sediments attach to these biofilms and then settle to the bottom as part of the sloughed biofilm in a short term process occurring over hours to weeks.
> Takes up nutrients from the sediment.
  Nutrients in the sediment are transformed into plant biomass in a medium term process occurring over weeks to years.
> Transforms absorbed materials into less available contaminant forms.
  Plant biomass is returned to the sediment for storage as low-level biodegradable macrophyte litter in a long term process occurring over years to decades.
> Controls surface sediment redox (oxidation and reduction of chemical substances).
  Plant root zones generally help maintain an oxidised sediment surface layer that prevents undesirable chemical transformation of settled contaminants.

During storm events vegetation also provides the following physical benefits:

> Increases hydraulic roughness
> Promotes uniform flow
> Enhances sedimentation of particles through filtering.
> Provides more surface area for small-particle adhesion
> Protects sediments from erosion.

Table 6-1
Overview of stormwater contaminant removal mechanisms of constructed wetlands. (adapted from Mitchell 1996).

Contaminant	Removal processes
Organic material	biological degradation, sedimentation, microbial uptake
Organic contaminants (e.g. pesticides)	adsorption, volatilisation, photosynthesis, and biotic/abiotic degradation
Suspended solids	sedimentation, filtration
Nitrogen	sedimentation, nitrification/denitrification, microbial uptake, plant uptake, volatilisation
Phosphorus	sedimentation, filtration, adsorption, plant and microbial uptake
Pathogens	natural die-off, sedimentation, filtration, predation, UV degradation, adsorption
Heavy metals	sedimentation, adsorption, plant uptake

Wong et al (2001) compared suspended solids reduction in a vegetated and an open water channel. The data demonstrated that concentrations in the vegetated channel fell more rapidly than in the open water channel..

Monitoring data from an existing vegetated wetland at UNITEC Carrington campus in the Auckland Region were compared with the results from the same pond before the vegetation had developed into a significant treatment component. Results demonstrated improved performance by the vegetation for treatment of a number of stormwater contaminants, including total and dissolved metals (ARC, 2001).

6.4 Water quantity performance

Constructed wetlands can be sized to control the peak rate of runoff from storm events, and an additional consideration from a downstream erosion control perspective is provided by dead storage and control and release of the first 34.5 mm of rainfall over a 24 hour period for smaller storms. This storage capacity reduces peak flows, velocities, and reduces the loadings of contaminants which are delivered to downstream waters during small runoff events. The attenuated peak flows and velocities minimize erosional forces within the stream channel and further protect and maintain downstream water quality.

Organic matter accumulates in wetlands primarily through the growth and decay of vascular plants and algae. Organic soils have a higher porosity and thus a lower density and higher water holding capacity than mineral soils: organic soils have about a tenth of the density of mineral soils; 1.0 to 2.0 grams/cm^3 for mineral soils compared to 0.2 to 0.3 grams/cm^3 for organic soils. This allows the wetland soils to store more water than mineral soils. While this function is less effective during high runoff events, it enables wetlands to noticeably reduce the volume of water and the loadings of contaminants discharged during small runoff events.

6.5 Water quality performance

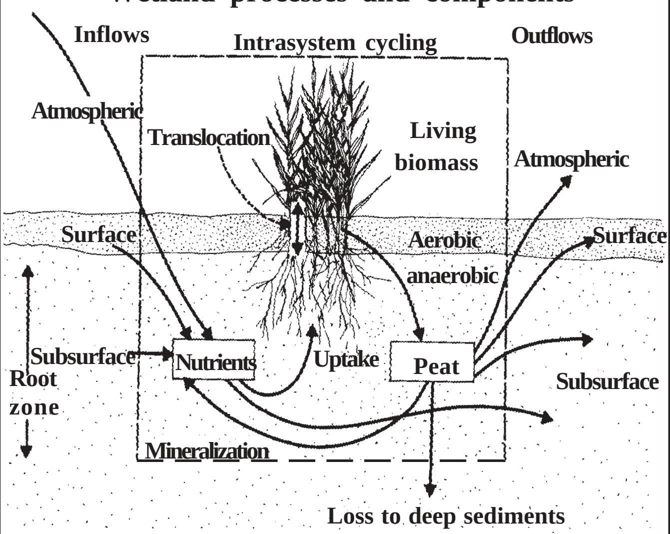
Natural wetland systems have complex mechanisms, as shown in Figure 6-1, for cycling elements and compounds into different forms and between the air, water, soil, plant and animal media. The figure aims not to show all wetland processes, but to indicate their complexity. Discussion of wetland water quality processes is further complicated by the variety of wetland types and their characteristics.

Stormwater contaminants generally fall into three categories; sediment, nutrients (phosphorus and nitrogen) and toxicants (including metals and organics). The form and fate of a particular contaminant is influenced by the type of wetland, geographic location, time of year, hydrologic condition and other factors. When it comes to wetlands and water quality, there are no simple relationships.

Brown et al (1998) note that wetland processes are influenced by:

- diurnal changes in water temperature and dissolved oxygen, and
- seasonal changes associated with changes in daylight hours, water temperature, growth of wetland vegetation, microbiological activity and chemical reactions.

Figure 6-1
Wetland processes and components



This means that the treatment efficiency achieved by a particular wetland varies widely for different contaminants. In areas with a marked seasonal variation in water temperature, treatment efficiency for a particular contaminant may also vary seasonally.

Wetland maturity also affects treatment efficiency for some contaminants, with new wetland soils sometimes having a higher assimilation capacity for phosphorus and nitrogen than older wetland soils.

The accumulation of organic matter from dead plant material also removes contaminants more rapidly. High density wetland vegetation is likely to achieve higher treatment efficiency than lower density because the larger surface contact area supports more microorganisms, which mediate contaminant removal processes.

6.5.1 Sediments

Plate 6-1: Small Well Landscaped Constructed Wetland

Although the sedimentation process is better understood for open water ponds (the longer that water remains in a pond system, the greater the degree of sediment retention) constructed wetlands can also be designed to maximise the detention times.

The sedimentation removal rate in constructed wetlands is very closely related to the removal of numerous other contaminants, especially phosphorus and metals, because they tend to bind to sediments. Removing sediments from the water column will thus tend to remove a number of other contaminants. Approximately 50% of phosphorus can be expected to be in particulate form, and should thus be removed with the sediments.

The removal of soluble contaminants can also be significant. It depends on the residence time, which in turn depends on the total volume of dead water storage, the inter-event dry period and the design rainfall volume.

The organic soils in constructed wetlands are an important sink for nutrients and other contaminants that would otherwise enter downstream waters. Thus, constructed wetlands designed to keep sediments in place will provide for long-term storage of contaminants. For example by minimising disturbance of wetland sediments and dispersing flow through the wetland rather than by channelising it.

6.5.2 Toxicity and biofilms

Timperley et al (2001) show that urban stormwater contaminants such as the metals copper, lead, and zinc may be present in very high concentrations in fine particulate matter that is difficult to settle and retain in open pond treatment systems. It is then trapped in biofilms in receiving water habitats where it can be ingested by grazing organisms. The accumulation of toxic contaminants such as metals and persistent toxic organics in sediments in both freshwater and marine areas is of major concern in the Auckland area.

Urban stormwater toxicity is generally associated with the heavy metals copper, lead and zinc, and hydrocarbons including petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH). Toxic persistent organic compounds including pesticides, herbicides and industrial chemicals may also be present in some stormwater.

Vegetated wetlands are significantly more effective than ponds in removing soluble contaminants. The reduction of toxic substances should be a high priority for vegetated wetland design for most of the Auckland area.

Timperley et al (2001) state that biofilm trapping in wetlands and shallow macrophyte ponds is an effective mechanism for removing fine particulate matter from storm and wastewaters. The very large surface areas of submerged vegetation and the associated microorganisms provide effective systems for the removal of fine particulate matter.

6.5.3 Nutrients

The design of vegetated wetlands for reduction of phosphorus in stormwater has received considerable attention in New South Wales and Victoria in Australia because many of the receiving waters in those areas have very long detention times and are sensitive to nutrient enrichment. Wiese (1998) identifies the need to reduce dissolved phosphorus in order to protect the quality of receiving waters as the critical parameter determining wetland size in southeast Australia.

The slow removal rate of dissolved phosphorus by urban stormwater wetlands means they need long detention times in order to achieve the desired outflow quality.

In the Auckland area most freshwater receiving waters are small fast-flowing streams which have short flow paths to the coast, and have very short detention times. Those receiving waters are not highly sensitive to nutrient enrichment. The marine receiving waters in the Auckland area are not generally sensitive to nutrient enrichment, with the exception of temporary empoundments of tidal water such as the Orakei Basin and Onehunga Bay lake. The few lakes in the Auckland area are much more sensitive to nutrient enrichment.

Vegetated wetlands are capable of achieving significant reductions in nitrogen and phosphorus nutrients, but design to achieve desirable discharge standards requires relatively long detention times. Nutrient reduction will not generally be a high priority for vegetated wetlands in the Auckland area, but could be required where the receiving waters are known to be sensitive to high nutrient inputs.

6.5.4 Contaminant removal efficiency

Table 6-2 presents summary data for the 1994 and 2002 studies at the Carrington Unitech pond/wetland. Sixteen types of PAH were monitored in the 2001-2002 study. Concentrations were generally low in inflows and very low in outflows. Results indicated a high degree of removal by the vegetated wetland.

Table 6-2
Mean concentrations for the combined volumes of storms on 13/11/01, 22/11/01, 11/12/01, 04/01/02, and 05/02/02, compared with 1994 study mean concentrations.

Constituent	Units	Inflow Concentration		Outflow Concentration		% Removal	
		1994	2002	1994	2002	1994	2002
Suspended solids	g/m^3	81.2	27.6	13.5	15.2	83.3	44.9
Chemical oxygen dmd	g/m^3	57.4	43.9	39.1	32.3	31.8	26.4
Ammonia nitrogen	g/m^3	0.021	0.046	0.058	0.050	-176	-8.6
Nitrate nitrogen	g/m^3	0.601	0.376	1.453	0.056	-141	85.1
Nitrite nitrogen	g/m^3	0.009	0.005	0.022	0.003	-144	40.0
Total nitrogen	g/m^3		0.994		0.668		32.7
Organic nitrogen	g/m^3		0.567		0.559		1.4
Copper total	g/m^3	0.0258	0.0155	0.0049	0.0032	81.0	79.3
Copper soluble	g/m^3	0.0056	0.0050	0.0032	0.0019	42.8	62.0
Lead total	g/m^3	0.0947	0.0204	0.0057	0.0005	93.9	97.5
Lead soluble	g/m^3	0.0024	0.0004	0.0011	0.0004	54.1	0
Zinc total	g/m^3	0.225	0.161	0.071	0.023	68.4	85.7
Zinc soluble	g/m^3	0.097	0.089	0.052	0.012	46.3	86.5

It is unlikely that persistent contaminants in stormwater can be reduced to zero by wetland treatment systems. It was noted during the 2002 UNITEC wetland monitoring study that inflow suspended solids and organic nitrogen were almost certainly retained within the wetland, and that suspended solids and organic nitrogen in the outflow were almost certainly derived from detrital material generated within the wetland.

At this stage the 2002 outflow concentrations for suspended solids, total and soluble metals and PAH are considered to be achievable standards for optimised constructed wetland treatment systems for stormwater.

Further work to determine seasonal changes in nitrogen and phosphorus nutrient removal will be necessary to determine the overall performance of constructed wetland treatment systems in the Auckland Region.

6.5.5 Constructed wetland design criteria

It is important to specify the contaminants that an urban stormwater treatment wetland is designed to treat, as effective treatment of different contaminants can require markedly different detention times within the treatment wetland.

Suspended solids are at one end of the treatability spectrum and require a relatively short detention time to achieve a high degree of removal, although it should be noted that fine particulate matter, which makes up a small proportion of suspended solids, is much more difficult to remove. At the other end of the treatability spectrum are nitrogen and phosphorus nutrients. Given sufficient space and time, wetlands are capable of removing nutrients to very low levels (for nitrogenous compounds down to around 0.5 mg/L, and for phosphorus down to about 0.1mg/L), but like any other waste treatment system, their efficiency depends on their design and waste characteristics.

Designs that remove toxic substances will also achieve good aesthetic outcomes as well as meeting desirable discharge targets and some reduction of nutrients and human pathogens. It is desirable to reduce mass discharges of metals and persistent organic contaminants into the coastal marine area where they become concentrated in sediments.

For receiving waters with high contact recreation values design to remove pathogens will be desirable, but at this stage the requirements for effective pathogen removal do not appear to be known. Kadlec and Knight (1996) give an areal rate constant for removal of faecal coliform, but this is unlikely to be applicable to an optimised constructed wetland treatment system and therefore not be a priority for the Auckland Region.

The most common design priority for vegetated wetlands for the treatment of urban stormwater in the Auckland area will be the removal of:

- Sediments,
- Toxic substances including hydrocarbons and dissolved metals, and
- Other toxic substances associated with fine particulate matter.
- Nutrient limitation of stormwater discharges into freshwater lakes or coastal water empoundments

6.6 Applicability

As detailed in Chapter 4, wetlands are most appropriate on sites that meet or exceed the following criteria.

- Catchment area more than approximately 1 hectare
- Soils that are silty through clay
- No steep slopes or slope stability issues
- No significant space limitations

Hydrology is the single most important criterion for determining the success of a constructed wetland system. They should therefore only be used in areas that have enough inflow from rain, upstream runoff or groundwater inflow to ensure the long-term viability of wetland processes.

The Auckland Region averages around 1200 mm of rainfall per year with some seasonal variation in rainfall. It rains on the average of every 2 to 8 days. Table 6-3 summarises rainfall data for the Auckland Region. The data summary is for a 10 year period between 1990 and 2000 and includes all storms of more than 2mm. Rainfall events are separated if there were 3 or more hours without rainfall. Storm events which spanned parts of two calendar months were assigned to the month in which most of the rain fell.

Table 6-3 shows that while more rain occurs in winter (June – August) rain is distributed throughout the year, with the average period between rainstorms being between 5 – 8 days in summer (Dec – Feb), and at 2 – 2.5 days in winter. The summer rainfall interval allows the maintenance of wetland treatment systems by avoiding their drying out in summer.

Table 6-3
Summary of storm rainfall for Auckland
(Data for Ranitopuni at Walker Rd 1990-2000)

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average rainfall (mm)	64	59	89	98	117	161	195	150	126	98	108	82
Number of storm events per month	5.4	4.4	7.1	9.2	10.1	13.1	13.6	13.9	12.1	9.6	9.6	6.4
Average rainfall per storm (mm)	9.1	11.4	11.8	10.2	11.3	10.6	14.4	10.4	10.4	9.2	11.3	11.6
Average storm duration (hrs)	3.5	4.4	4.6	4.3	5.0	6.5	6.5	5.6	5.3	5.2	5.5	5.1
Av. int betw storms (hrs)	165	183	114	77	85	49	50	59	63	85	82	123
% rain in storm class												
<5mm	12.5	7.9	8.0	13.5	13.2	14.2	10.4	14.1	11.0	14.5	12.5	10.5
5-10mm	12.4	22.1	17.9	17.9	17.3	18.9	11.5	17.1	23.5	17.6	12.6	12.8
10-20mm	31.0	37.4	16.5	24.2	28.5	27.2	17.5	34.1	28.4	42.1	29.5	26.0
20-40mm	30.1	25.4	24.3	26.2	16.1	10.7	29.2	14.5	18.7	19.2	23.2	20.0
>40mm	14.0	17.2	35.3	18.2	25.9	29.0	41.4	20.2	18.4	6.6	22.5	30.9

The average rainfall per storm, average storm duration, and the distribution of total rain in different storm size classes are remarkably constant throughout the year. This is beneficial to the hydrologic performance of the wetland treatment system. (Note that the high proportion of rainfall in the >40mm storm class for July is attributable to large storms which occurred in July 1998 and July 2000).

Constructed wetlands are feasible for almost any drainage area if the site soils are impermeable enough to allow for ponding with little exfiltration. Few problems are likely in the establishment and propogation of vegetation, even in periodic droughts. Wetland plants are tolerant of fluctuating water levels and some periodic fluctuation would enhance biological diversity. Soils analyses should be done during the site design phase to ensure that the soils can maintain a wetland environment. As the wetland evolves, loss of water should become negligible as the soils on the floor of the basin become more organic, reducing the potential for exfiltration.

Special circumstances may indicate the need to construct an ephemeral wetland. That should be done using specific guidelines and using plants that can adapt to periodic wetting and drying.

6.7 Design approach

Chapter 5 details extended detention design for water quality volumes based on 1/3 of the two year rainfall event (defined in Chapter 3, Section 3.5), the first 34.5 mm of rainfall, and peak flow requirements such as the 2 and 10 year storms depending on where the project is being constructed. The same design approach also applies to constructed wetlands.

Where water quantity control is not required due to the location of the project within a catchment or the outfall of the project enters tidewater, consideration should be given to a an upstream diversion weir to divert the first 1/3 of the 2 year rainfall event into the constructed wetland. Flows exceeding the water quality storm would overtop the diversion weir and bypass the constructed wetland to the site outlet, providing for enhanced water quality treatment of the dirtiest runoff when surface runoff initiates. By capturing the contaminants built up during dry weather a significant portion of the annual contaminant load can be captured. Separating this initial runoff also reduces turbulence and mixing, allowing further removing of contaminants..

6.7.1 Outlet structures

Potential procedures and designs for the outlets from constructed wetlands are the same as for ponds and are discussed in Chapter 5, Section 5.5.2. As with all ponds having a normal pool of water, there is a potentially major problem with outlet clogging where small orifices are needed for extended detention.

Below surface withdraw structures may reduce or eliminate the problem. This approach establishes a normal pool elevation by the outfall pipe having a negative slope. Although having the pipe inlet below the normal pool elevation reduces the potential for clogging by floating debris, it makes it difficult to see any clogging of the pipe. Maintenance shcedules detailed in Chapter 5 may overcome this.

6.7.2 Depths

The design water level and depth are important considerations for constructed wetlands. These shallow water systems do not contain the large volume of water per surface area as do wet ponds.

The proposed depth ranges and areas for a vegetated wetland treatment system with banded bathymetry (Figure 6-2) in the Auckland Region are estimated below. Note that the actual percentage of storage at various depths will vary depending on catchment area served, because smaller systems have a reduced deeper section.

Banded bathymetry (preferred design)	% total wetland wet pool area
Dead storage banded bathymetry at 0.5 -1m depth	40
Dead storage at 0 – 0.5m depth	60

Trapezoidal bathymetry (uniform bottom slope)	% total wetland area
dead storage at 1m depth	20
dead storage at 0-1m depth	80

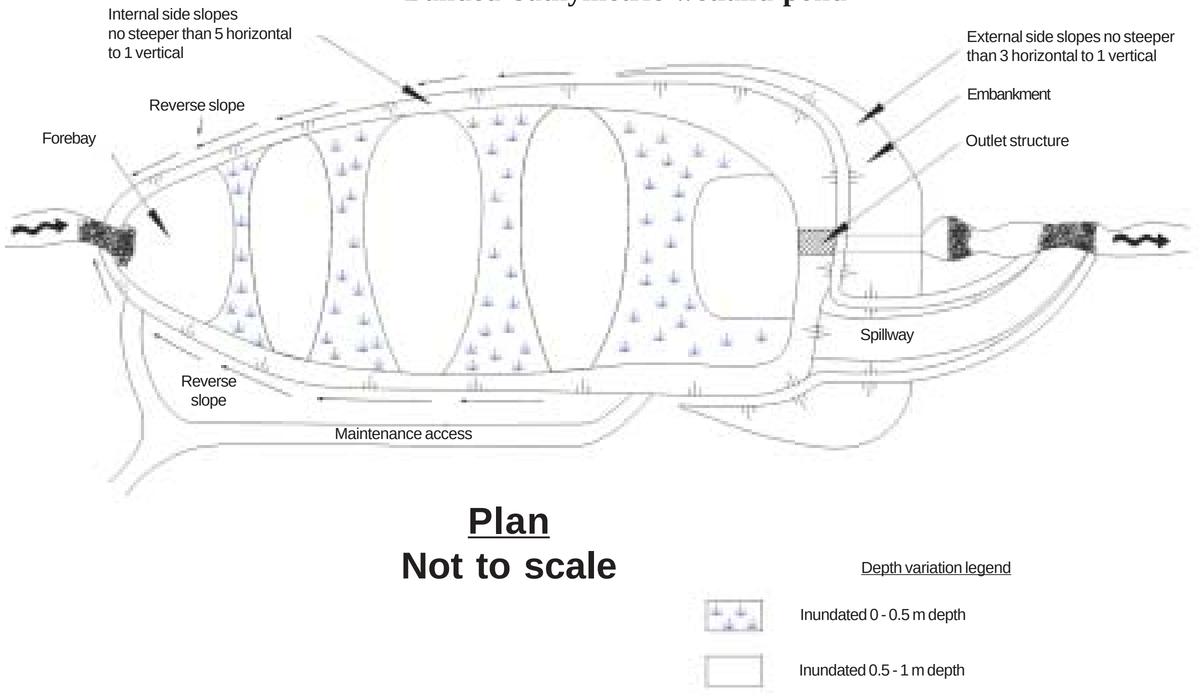
The banded bathymetry design is recommended over the trapezoidal bathymetry design because the configuration provides a better expectation of uniform flow throughout the wetland. The trapezoidal design may have vegetation developing in a unevenly and allow for short-circuiting.

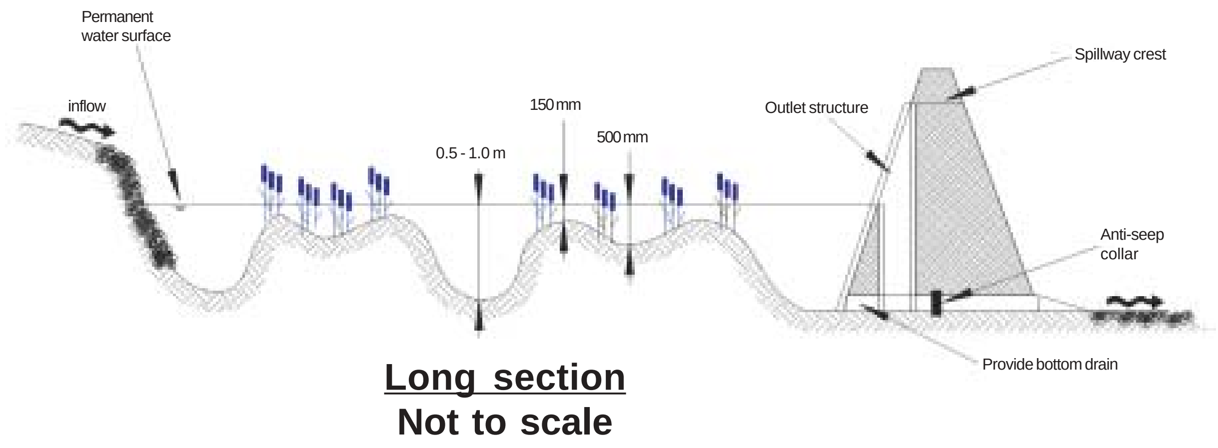
Because constructed wetlands promote the growth and propogation of emergent wetland plants, no areas other than the forebay or around the outlet structure of the pond should be more than 1 metre.

The reverse slope should be in the form of a swale which directs overland flow back into one of the controlled inlets. The vegetation in the swale also will enhance the trapping of particulates before they enter into the constructed wetland.

As well as providing an environment of intense biologic activity, the shallow nature of wetlands reduce liability. The very shallow fringe areas promote dense vegetation growth which act as a natural barrier to small children trying to get into the pond. This is much safer than the steep sides of many deeper ponds which make it harder to get out. The wilder appearance of constructed wetlands and their minimal areas of open water will also tend to discourage casual use by swimming or boating.

Figure 6-2
Banded bathymetric wetland pond





6.7.3 Surface area and water quality storage requirements

The surface area of a constructed wetland reflects the water quality storage requirements. The wetland pond surface area is the same as the deeper pond surface area would be but the overall volume may be significantly less.

To find the surface area snd storage requirements for a constructed wetland:

1. Calculate the water quality volume as detailed in Chapter 3.
2. Using the pond design approach in Chapter 5, calculate the pond surface area using site topography and water quality volumes to be stored. That area will depend on whether there is an extended detention as well as a water quality requirement. Ensure wetland depths are consistent with the provisions of Section 6.6.2 (ie. no deeper than 1 m except at forbay and outlet).
3. Find the volume associated with that surface area to determine the final wetland dimensions and surface area. If a shallower wetland is desired for safety reasons, depth can be reduced but not volume. A greater surface area will then be needed (depending on available land) to provide the required volume.

6.7.4 Forebay

Purpose

The purpose of the forebay is to capture those sediments that are in the sand and gravel size range and which, from a volume standpoint, constitute the largest sediment load from a stabilized catchment. The capture of these larger sediments will reduce the frequency of cleanout from the wetland portion of the basin.

The forebay shall:

- > Constitute approximately 15% of the reduced water quality volume (increased 50% from 10% for sediment deposition), and
- > Shall have a maximum water depth of 2 metres.
- > Shall have a surface length to width ratios should be between 2:1 and 3:1
- > No live storage that would reduce the depth of the normal pool

The forebay will be the deepest component of the wetland pond. Where there are multiple inlets to the constructed wetland, the total volume of all the forebays shall be 15% of the water quality volume with the individual inlet forebays sized with respect to their percentage of contributing flow.

The use of stone riprap, as shown in Figure 6-3 will reduce the velocities of flow into the wetland portion of the basin and minimize resuspension of the deposited sediments in the forebay.

An access to the forebay should be provided for excavation equipment to facilitate cleanout of the forebay. It is an integral component of the constructed wetland and is critical in long term function of the wetland. All inflow points must enter a forebay.

The forebay inlet structure must provide for energy dissipation and even distribution of inflow into the forebay.

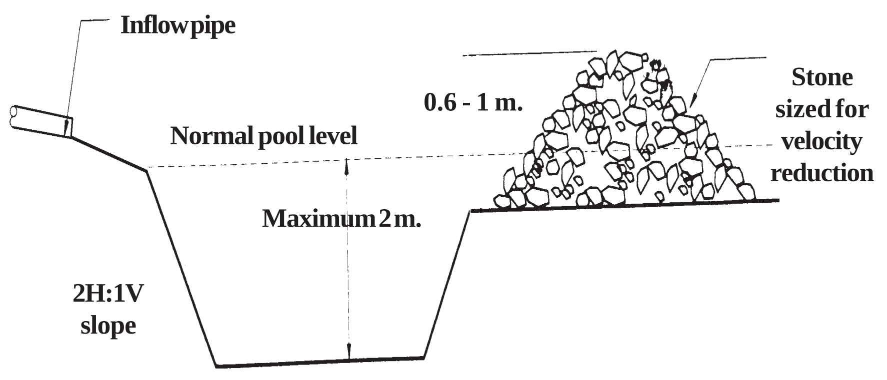
Outlets

The forebay outlet structure should provide water level control and optimum flow through the forebay. An overflow weir or weirs with a total length equal to at least 50% of the forebay width is desirable to maintain a shallow surface discharge and avoid concentration of the outflow.

An excess flow bypass is to be provided around both the forebay and the vegetated wetland. Flow velocities during the 1 in 5 year storm are required to be less than 0.25 m/s to avoid resuspension of sediment. In some cases this may necessitate the use of a forebay which is larger than the minimum forebay volume.

This forebay design, with a permanent pool, offers better water quality treatment between storms and for the first flush of runoff. The pond will operate in a displacement mode with the clean, lower density dead storage water being displaced through the outlet as the dirty incoming stormwater of higher density sinks to the bottom of the dead storage areas.

Figure 6-3
Crosssection of the forebay of a constructed wetland



Debris screens

Ideally the inflowing stormwater should be screened for removal of rubbish prior to the forebay. Screen clogging can be a problem, and designs should ensure that clogged screens do not interfere with the functioning of hydraulic controls.

Self cleaning screen designs should be considered.

6.8 Design procedure for a constructed wetland

The design includes the following:

1. Calculate water quality volume as discussed in Chapter 3.
2. Take 15% of the reduced volume for the sediment forebay.
3. Determine whether the pond requires peak control and stream channel extended detention.
4. Based on that decision, size a wet pond using site topography and required water quality volumes to be stored to calculate the surface area
5. Using that surface area, define your wetland boundaries
6. Set the depths of permanent pool as in Chapter 6.7.2 and Figure 6-2.
7. Do calculations similar to those in the pond design chapter for the outlet structure releases and size the storage volumes as for wet ponds (Chapter 5.5.2).
8. Define bathymetry of the wetland from Figures 6-2 and 6-3 with depth as in Chapter 6.7.2 and Figure 6-2.

6.9 Plants

6.9.1 Main wetland pond

The wetland treatment basin is to be densely vegetated throughout. The optimum treatment configuration is a wetland densely vegetated with species that provide a high density of stems in the submerged zone and thereby maximize the contact between the water and the surfaces on which microorganisms grow, while providing uniform flow conditions with no short circuiting.

Preferred vegetation

Following is a list of the preferred vegetation and it's "normal depth" for the optimized vegetated wetland.

Deep zone 0.6 – 1.1m

- Baumea articulata
- Eleocharis sphacelata
- Schoenoplectus validus
- Typha orientalis (raupo)
- Myriophyllum propinqum (water milfoil)
- Potamogeton cheesemanii (manihi)

Shallow zone: 0.3-0.6m

- Baumea articulata
- Bolboschoenus fluviatilus
- Eleocharis sphacelata
- Eleocharis acuta
- Carex secta
- Schoenoplectus validus
- Typha orientalis
- Isolepis prolifer
- Juncus gregiflorus

Wet margin 0-0.3m

- Baumea teretifolia
- Baumea rubiginosa
- Carex secta
- Eleocharis acuta
- Juncus gregiflorus
- Carex virgata
- Cyperus ustulatus (giant umbrella sedge)
- Phormium tenax (flax)

Live storage zone (periodically inundated)

Syzygium maire (swamp maire)
Carex virgata
Carex lessoniana (rautahi)
Carex dissita (flat leaved sedge)
Cyperus ustulatus
Juncus articulatus
Juncus pallidus
Dacrycarpus dacrydioides (kahikatea)
Cordylina australis (cabbage tree)
Baumea rubiginosa
Phormium tenax (flax)
Coprosma tenuicaulis (swamp coprosma)
Blechnum novae-zelandiae (swamp kiokio)

Land edge:

Coprosma robusta (karamu)
Phormium tenax
Cordyline australis
Carpodetus serratus (putaputa weta)
Laurelia novae-zelandiae (pukatea)
Leptospermum scoparium (manuka)
Schefflera digitata (pate)
melicytus ramiflorus (mahoe)
Pneumatopteris pennigera (gully fern)
Dacrycarpus dacrydioides (kahikatea)
Cortaderia fuluida (toetoe)

For reed beds less than 100m length, the gradient should be flat. For longer reed beds, the introduction of bed slope will compensate for the hydraulic gradient, and allow easier draining. Access to the reed bed is required for planting and maintenance. Access areas need to be identified on plans.

The main potential drawback to an overall densely vegetated system would be the reduction of dissolved oxygen in the near bottom water and the surface sediment layer. Marked stratification of dissolved oxygen concentration occurs in natural vegetated wetland systems, with high DO saturation at the surface and very low DO saturation near the sediment. The presence of anaerobic sediment is desirable for denitrification, but it is not clear if densely planted systems can reduce DO so low that adverse effects can occur in freshwater receiving systems. This matter appears to have attracted little comment in the literature although the chemical changes that occur in anaerobic (anoxic) conditions are well understood.

The removal of nitrogen is less critical in the Auckland Region than in other parts of the country where receiving waters are particularly sensitive to nitrogen enrichment.

Because Auckland's area rainfall is distributed fairly evenly throughout the year, the degree of development of anaerobic conditions in near bottom waters in treatment wetlands is likely to be less than in areas with long dry periods. The ARC hopes to investigate the dissolved oxygen regime in stormwater treatment wetlands in the Auckland Region, and the possible implications for contaminant treatment over time.

6.9.2 Forebay

Vegetation is not necessary in the wet forebay provided the forebay is of good hydraulic design. that said, there are benefits.

The use of densely planted robust vegetation such as the rushes *Eleaocharis sphacelata* and *Schoenoplectus validus* in the forebay pond will increase its sediment removal performance, and also reduce the risk of resuspension of settled sediment during high flow periods, particularly in situations where an ideal hydraulic design could not be achieved.

Plate 6-2: Larger wetland providing stormater and wildlife benefits

The inlet design would need to ensure that water speeds during design maximum flow conditions did not erode the vegetation (suggested velocity <0.25 m/sec).

Dense vegetation in a forebay pond could be beneficial to human safety, and could also be considered for aesthetic reasons.

The disadvantage of vegetated forebays would be the additional maintenance requirement with potentially large volumes of vegetation to be removed in addition to the accumulated sediment.

6.10 Construction

Many parts of the discussion in Chapter 5 are applicable to constructed wetlands, Which are often considered a subset of wet detention ponds. However, they merit their own separate discussion because of the complexities of their design and construction, and their dependence on the establishment and propagation of emergent wetlands plants to provide water quality benefits.

6.10.1 Important inspection aspects related to design

Clay or geotextile liners

The shallowness of wetland stormwater treatment systems means that even a small alteration in water level can significantly affect the health of the aquatic plant community. It is therefore important to ensure that water levels remain as consistent as possible, apart from storm events. This may necessitate the use of a clay or geotextile liner to maintain water levels.

Final pre-construction design plans must show how water levels in the constructed wetland are to be maintained; whether by:

- Continual stream baseflow,
- High ground water levels, or
- In-situ clay soils or installation of a liner.

The combination of a periodically high water table in conjunction with impermeable liners will present a potential problem that must be designed for, possibly by use of underdrains.

Organic soil conditions

The quickest way of meeting wetland plants and organisms essential elements for growth and propagation is to place organic soils on the constructed wetland floor. The final design plans should specify any more complex provisions for placement of organic soils.

Organic soils are not a standard requirement, but their inclusion is highly recommended to facilitate plant growth. Not having organic soils on the constructed wetland floor results in slower growth and spread of the wetland plants and often also leads to the invasion by nondesirable aquatic plant pioneer species which can out-compete more desirable plants.

Shallow depth and slight grades

Unlike deeper detention systems, shallow constructed wetlands need to have exact grades in the inundated pool area. Most of their area comprises emergent aquatic plants whose establishment and propagation typically depend on water depths under one metre. To have a diverse plant community, varying depths are needed since different plants are best suited for various water depths. The plans should detail design elevations throughout the ponded area where wetland plants will be established. They should also clearly identify where each type of plant should go, as in Section 6.91.

Establishment of forebays

Being shallow water systems, constructed wetlands are very susceptible to filling in by sediments generated upstream. All principal inflow points must be provided with forebays designed to trap the largest volume of suspended solids and provide a readily accessible location for allow periodic removal of accumulated sediments.

Plans should detail the location, size, and proposed grades of designed forebay areas, along with dedicated access for maintenance equipment. See the pond design chapter 5.5.3 for guidance on these aspects.

Converting sediment ponds into constructed wetlands systems

Because they are shallow water systems, the long term performance of constructed wetlands can be significantly reduced by sedimentation. The final design plan should indicate whether the constructed wetland will be used as a sediment pond during the construction phase of the project, and if so, should detail how the sediment pond will be converted into a constructed wetland.

If the constructed wetland was not previously used for sediment control, the plans should specify:

- Project phasing for overall site construction, with a timetable for construction of the wetland
- How the constructed wetland will be protected from sediment entry while its catchment area is unstabilised
- When sediment must be removed from the forebays or constructed wetland
- That the wetland will not be planted until site earthworks stabilization is complete

Reduced need to provide for saturated embankment problems

Most constructed wetlands have a shallow depth of permanent water against the embankment, although, some wetland designs specify a deep water zone adjacent to the embankment. The shallow water reduces water pressure adjacent to the embankment and reduces the number of anti-seep collars needed to prevent piping along the outlet from the principal spillway. At least one anti-seep collar on the principal spillway is still required, but stability concerns are lower than for deeper wet detention systems.

Reduced safety features

Constructed wetlands present much less of a safety concern than deeper ponds due to their denser vegetation, more gradual side slopes, and the shallow water depth. Specific safety barriers therefore may not be required. Individual territorial authorities may still require barrier fences.

Establishing and maintaining plantings

There are three approaches to establishing aquatic plants in constructed wetlands:

- Plantings of aquatic plants which facilitates rapid plant growth
- Providing proper hydrology and soil conditions to promote colonisation of the system by local vegetation
- Installing soil having vegetative plant roots or rhizomes

These are not mutually exclusive, and proper conditions must be provided to sustain plantings.

The design must detail which approach is used. If wetland plantings are to be used, the plan should specify:

- the plant species.

- the number of each species.
- where the plants will be located.
- if the pond water level will be lowered to facilitate planting.
- a timetable for planting to occur.
- Access points to maintain reed beds and other vegetation

6.10.2 Important inspection aspects related to construction

If the constructed wetland is to be used as a sediment control pond during construction, there are a number of items which must be considered:

- Outlet structure must be modified by installation of a temporary dewatering or decant device.
- Final grades are not important to establish at this time,
- The minimum volume needed for sediment control must be provided for construction generated sediment.

Regular sediment removal is needed to maintain the wetland's ongoing ability to remove suspended solids. When sediment cleanout is required, the removed materials should be placed upstream of any sediment trapping practices to prevent their movement downstream. An inspection programme will generally determine when sediment cleanout is needed and the final design plan should specify where the removed sediments are to be placed.

The importance of accurate grade establishment in shallow constructed wetland ponds cannot be overstated. During construction, survey stakes must be placed to accurately establish cuts and fills. The final grades must be accurate for successful plant establishment and propagation. Final grades should be established before the pond fills. Once the bottom and side soils have become saturated, the movement of earth material becomes much more difficult and the basin may have to be dewatered and dried before final grades can be established.

Site earthworks must be stabilised before wetland planting if site runoff passes through the wetland pond. Excess sedimentation can smother the plants and change wetland elevations which would alter planting success and plant composition. Optimally, the planting should be done several months after site stabilisation to further reduce sediment entry into the wetland, if construction scheduling permits.

Ideal times for successful establishment of plantings are in the spring when plants are emerging from dormancy and in the late autumn when plants are just entering dormancy. Time frames for planting must be established early in construction and be consistent with consent conditions, if specified.

6.11 Operation and maintenance

Operation and maintenance for wetlands incorporates all of the items detailed in Chapter 5. Other requirements are:

1. Wetlands should be inspected at least twice per year during the first three years during both growing and non-growing seasons to observe plant species presence, abundance, and condition, bottom contours, and water depths relative to plans, sediment, outlet, and buffer conditions.
2. Plants may require watering, physical support, mulching, weed removal, or replanting during the first three years.
3. Nuisance plant species should be removed and desirable species should be replanted.

6.12 Case study

A case study for wetlands design is not considered necessary as the hydrological approach is detailed in Chapter 5.

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Chapter 7
Filtration design, construction and maintenance

7.1 Introduction

Filtration includes a diverse group of practices for treating stormwater runoff. The common factor is that each uses some kind of filtering media such as sand, soil, gravel, peat, or compost to filter out contaminants. They are especially suited for small catchment areas, are primarily water quality practices and they generally have little water quantity control benefit.

Although diverse, stormwater filters have several common design components.

> inflow regulation
> pretreatment
> filter media
> outflow mechanism

This chapter discusses sand filtration and rain gardens.

Sand filters can be either surface or underground, and their designs are similar. Sand filters work by sedimentation and filtration, generally with an inflow point to a sedimentation chamber and an underdrain in a subsequent filtration chamber that discharges filtered stormwater.

The ARC is investigating the use of alternative filter media over the next year for enhanced contaminant reduction, especially of soluble contaminants.

Rain gardens are generally surface depressions with key elements including a grass filter, a sand/loam soil mixture, shallow ponding, plantings of trees and shrubs, and an underdrain.

7.2 Water quality performance

Filtration practices have:

> an excellent ability to remove suspended solids
> a variable ability to reduce phosphorus
> low nitrogen removal in sand filtration systems but a moderate ability in rain gardens
> higher ability to remove bacteria, metals and hydrocarbons than other practices such as ponds

Filters reduce contaminants by a variety of chemical, physical, and biological processes. The dominant process will vary from site to site and between contaminants. In some cases the contaminants are transformed (decomposition, decay) and in other cases they simply accumulate in the filer media. The removal processes include:

> sedimentation
> adsorption
> volatilisation
> filtration
> biological processes

Plate 7-1: Unitec sand filter under construction showing various components

Sedimentation
Sedimentation is one of the principal mechanisms for the removal of many contaminants from the water column. Sedimentation is important for the removal of suspended solids, particulate nitrogen, hydrocarbons and heavy metals.

Adsorption
Adsorption of contaminants onto the surface of suspended solids is the dominant mechanism for dissolved contaminants. Adsorption occurs through three main processes:

- electrostatic attraction,
- physical attraction and
- chemical reaction.

Adsorption is important for removing ammonium ions, phosphorus, viruses and heavy metals.

Precipitation, dissolution, and complexation

Many metals dissolve or precipitate in response to changes in water chemistry. Metals form insoluble sulphides under reducing conditions and insoluble oxides and hydroxides under oxidising conditions.

Volatilisation

Contaminants may enter the atmosphere by evaporation and aerosol formation under windy conditions. Common contaminants removed by volatilisation include oil, chlorinated hydrocarbons and mercury.

Filtration
This occurs as particulates are mechanically filtered through a filter media, vegetation and biota. Dense vegetation and low velocities promote greater removal efficiencies. Organic matter, phosphorus, bacteria, and sediments are effectively removed by infiltration through the soil.

Biological processes

Vegetation offers high contaminant absorption and biological uptake potential as well as providing an environment for significant microbial activity.

Rain gardens utilise additional processes that can further improve water quality function. Mulch has been found to be very effective in removing heavy metals through organic complexing with the hydroxyl and carboxyl sites on the organic molecules. Soil bacteria can metabolise (use as a carbon energy source) oil, grease, and petrol into CO_2 and water in the presence of adequate nutrients and oxygen. Plants are known to uptake, transpire, accumulate and detoxify heavy metals and many other toxic compounds.

In summary, the overall contaminant removal of stormwater filter systems is on a par with that for other practices with higher removal for some contaminants, and lower removal for others. Table 7-1 provides expected removal efficiencies for sand filters. Also included in the table is a comparison of removal expectations and results from monitoring efforts at the Unitec sand filter.

Table 7-1
Contaminant removal expectations (%)

Contaminant	Removal expectations	Unitec site
Sediment	>75	92
Total lead	>75	98
Total zinc	>75	93
Total copper	>75	90
Hydrocarbons	>75	not done

While the results of the Unitec monitoring are extremely good, the monitoring period was of short duration (two months) and the largest storm monitored was 7.7 mm of total rainfall. The results therefore should be considered indicative as opposed to absolute. Overseas data does support the range of results that have been obtained in the ARC study and show sand filters to be effective at contaminant removal.

In addition to the water quality performance, peak discharge rates were reduced significantly between inflow and outflow. For all storms, the mean reduction in peak flow was 64%. The greater the inflow peak, the greater the reduction in peak discharge. For the top 25 percentile of peak inlet flows (i.e. > 11.5 l/s), the flow reduction averaged 90%. These results were for small storm events. It is expected that discharges beyond the filters design specification (water quality storm) would have diminishing benefits.

7.3 Design approach

7.3.1 Objectives

1. To reduce coarse sediments, metals, nutrients, PAH, bacteria and gross contaminants from stormwater runoff from low and high levels of imperviousness for residential, commercial, and industrial site.

2. These practices are primarily water quality treatment practices and consideration must be given to larger flows.

Rain gardens are used primarily in residential areas but can, with careful design and a good maintenance programme, be used on commercial sites. Components of a rain garden include a grass pretreatment area, temporary ponding, planting soil, sand mixing with the soil, an organic layer, and plant material. Infiltration can be a component depending on soil conditions.

Plate 7-2: Example of a rain garden used in a parking lot

Figure 7-1
Typical detail of a flow diversion structure

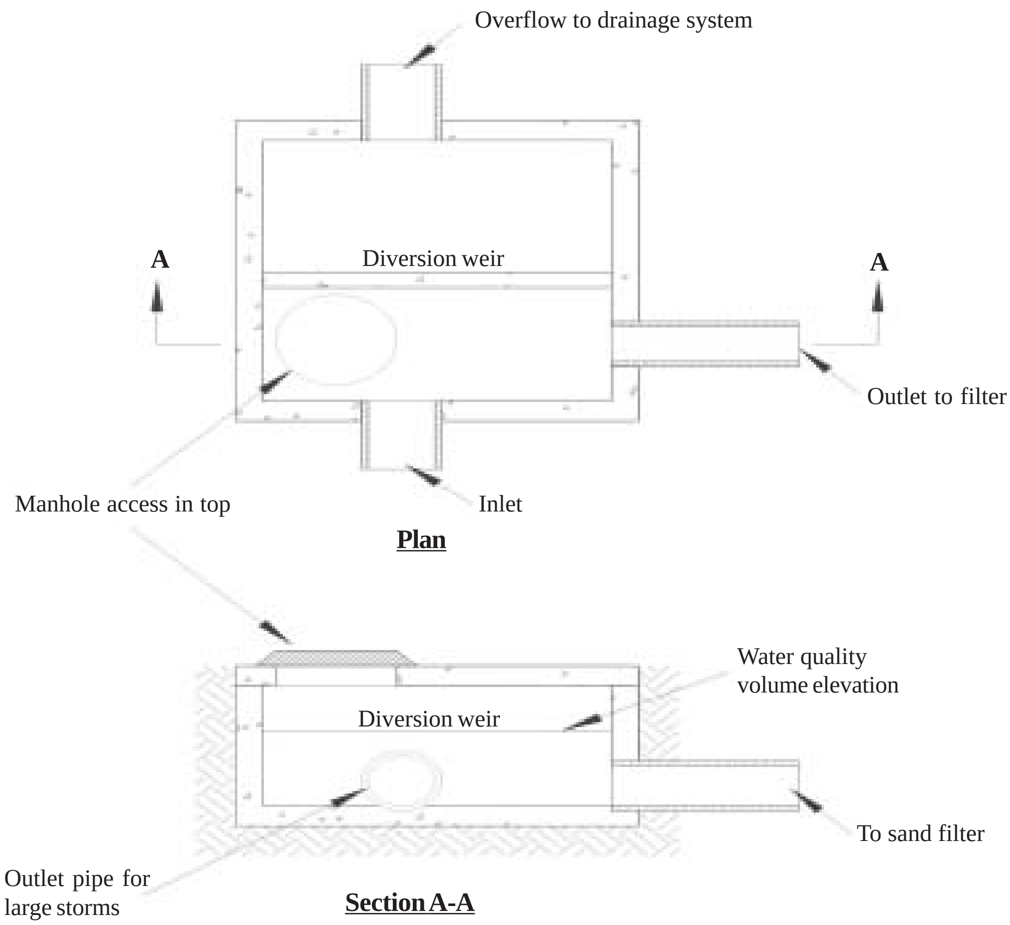


Figure 7-1 provides a typical detail of a flow diverter which can be used primarily for concentrated flow into a sand filter. Rain gardens should have an overflow spillway set above the water quality storm or an overland flow path for larger events.

7.3.2 Applicability

Sand filters are primarily used for high percentages of impervious surfaces where the majority of sediments are in the coarse fraction. When used, they should have a forebay or sedimentation chamber for capture of the coarser sediments and a filtration chamber, having an underdrain, for removal of finer suspended solids, hydrocarbons, and metals. A major component of a sand filter is temporary ponding over the sand. The major limitation is catchment area. Filters are most suited for catchments less than four hectares.

Sand filters can be used in most residential, commercial and industrial developments and are most applicable in areas where impervious surface percentage is high. Specific applications include:

- parking lots for commercial and industrial sites
- service stations
- high density residential housing
- roadways
- bridges

Filters are best located off-line and are suited for retrofits with space constraints and new developments. When considering using a sand filter, designers need to assess:

> the loading rate
> filter loading capacity
> the minimum maintenance frequency

Most street and road particulate matter is in coarser fractions, roughly in sand and gravel equivalent sizes. However, most stormwater contaminants are associated with fine particles. As sand filters have two chambers, the sedimentation chamber is more effective at removing the sand and gravel component. The finer silts and clays are more effectively captured by the filtration component.

As mentioned in the Objectives section, rain gardens are ideally suited for residential developments but can be used on other land uses if pre-treatment is provided to reduce potential clogging. They are ideally suited for small catchments of less than one hectare. They are generally on-line practices with an overflow provided for larger storms.

7.4 Design procedure

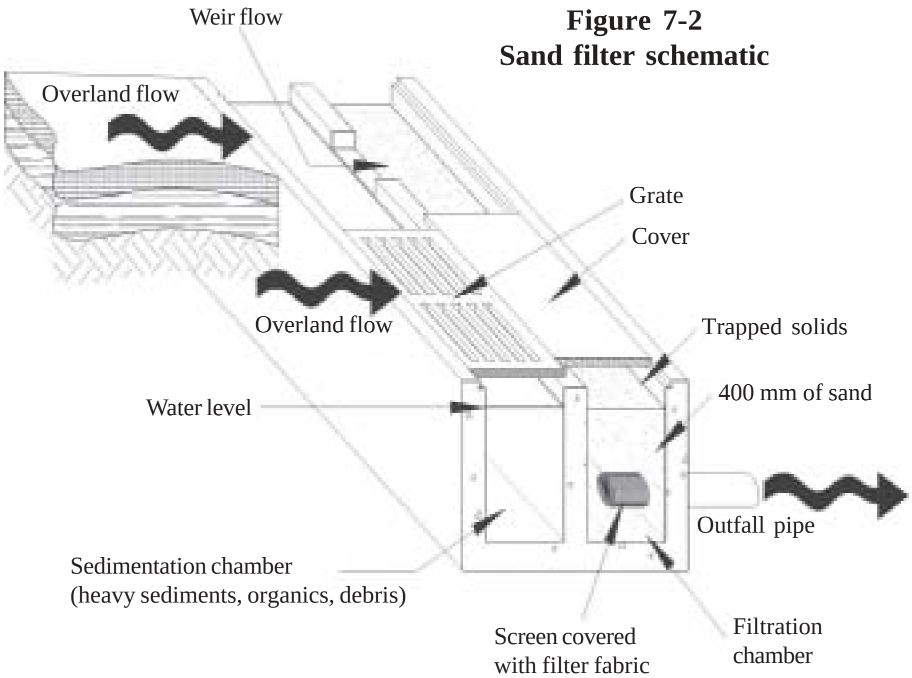
The design approach for sand filters and rain gardens is somewhat different and will be discussed individually. Both rely on treating the runoff from the water quality storm and the use of filter media for treatment. However the rain garden approach is a bit more complicated as the flow must travel through an organic/sand media, not just sand.

7.4.1 Sand filter design procedure

For the most part, sand filters will be used to treat stormwater runoff from impervious surfaces so the calculation of water quality storm volume is relatively simple. Figure 7-2 shows a perimeter sand filter so that the design approach can be visualised.

Design steps

Figure 7-2
Sand filter schematic



1. Calculate the water quality volume to be treated using 1/3 of the 2 year-24 hour rainfall for a given location using TP 108. The water quality calculations should be done by considering the pervious and impervious areas separately.

   Capture and isolate the water to be treated by diversion baffles and weirs. A typical approach to isolate the water quality volume is to construct a diversion weir in the stormwater channel or pipe. When additional runoff greater than the water quality volume enters the diversion weir area, it will spill over the weir, and mixing with water stored in the filter will be minimal.

2. A minimum of 37% of the water quality volume must be available as live storage to ensure that the total water quality volume passes through the filter without bypass.

3. The sand filtration chamber should be sized by the following equation:

$$A_f = \frac{I_a H d_f}{k(h+d_f)t_f}$$

where

A_f = surface area of sand bed in (m^2)
I_a = impervious drainage area contributing runoff (m^2)
H = runoff depth to be treated (m)
d_f = sand bed depth (m)
k = coefficient of permeability for sand filter in metres per day
h = average depth of water (WQ storm) above surface of sand in metres (1/2 max. depth)
t_f = time required for runoff to pass through the filter media in days

The following values should be used:

$I_a H$ = the water quality volume in cubic metres
t_f = 2 days (maximum)
k = 1 metre per day
d_f = 0.4 metres (minimum)

Key filtration chamber design specifications:

(a) The minimum filter bed depth is 0.4 metres
(b) Sand specifications are:

Sieve size (mm)	Percentage passing
9.5	100
6.3	95-100
3.17	80-100
1.5	50 - 85
0.8	25 - 60
0.5	10 - 30
0.25	2 - 10

No locally available sand grades fall within the desired specifications. However, a number are close to the lower limit and can be used. It is important to meet as closely as possible the specified limits as coarser aggregate will allow for more contaminant migration and finer aggregrate will clog more quickly.

(c) An underdrainage system shall be provided. The system usually consists of perforated lateral pipes that feed a collector pipe. The perforated lateral pipes shall be covered by a geotextile fabric that retains sand but does not provide excessive flow resistance. Laterals and mains should be sized to pass the design filter flow at the pipe gradient.

(d) If the system is ‘on-line’ an overflow needs to be provided in order to pass flows greater than the water quality design storm.

3. Design the sedimentation chamber

Key sedimentation chamber design specifications:

(a) Inflow into the chamber must not cause resuspension of previously deposited sediments
(b) The sedimentation chamber outlet delivers flow to the filtration chamber as sheet flow

(c) The sedimentation chamber must be at least 25% of the filtration area detailed in step 2
(d) Flow velocities in the sedimentation area are required to be below 0.25 m/s
(e) The sedimentation chamber must have a permanent pool with a minimum depth of 0.4 metres to reduce resuspension of trapped sediments
(f) The sedimentation chamber should be configured to avoid short-circuiting of the flow. This requires a long narrow pool or tank, the use of baffles to lengthen the flow path or baffles to provide flow resistance at the inlet.

7.4.2 Rain garden design

Rain garden design, as shown in Figure 7-3, differs from sand filter design only slightly. Where sand filtration relies on water quality treatment via passage of stormwater through sand, rain gardens incorporate plants and soils for removal of contaminants. Rain gardens may have aesthetic benefits not provided by sand filter systems, are more appropriate for residential implementation, and provide greater water quality benefits for a wider range of contaminants as a result of additional biological processes provided by plants.

The main components of a rain garden include:

- Grass filter strip
- Ponding area
- Planting soils
- Ground cover or mulch layer
- Plant material
- Underdrain system

Where sand filters tend to have (but don't necessarily require) impermeable linings, rain gardens generally interface with natural ground. This has both advantages and disadvantages.

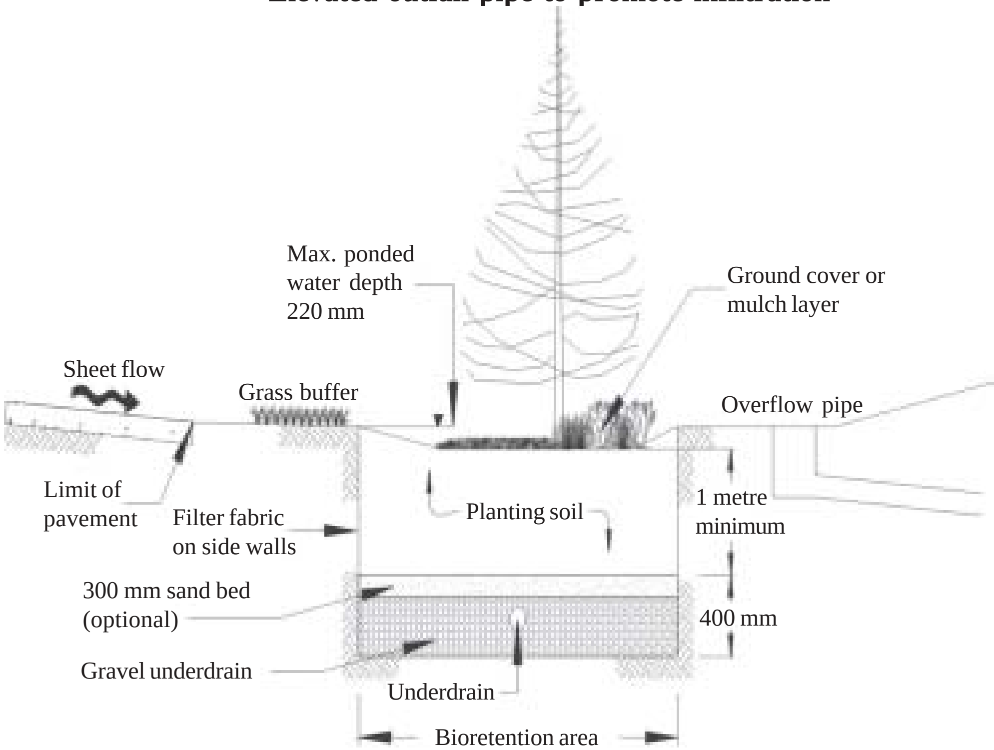
Advantages of a design similar to Figure 7-3 include an elevated underdrain that will promote groundwater recharge where soils and geology allow.

The disadvantages relate to areas where the natural slopes and soils are unstable. In those areas Figure 7-4 can be used, where the rain garden has an impermeable lining with the underdrain pipe located at the bottom to prevent water standing in the bottom.

An underdrain must always be used in both designs.

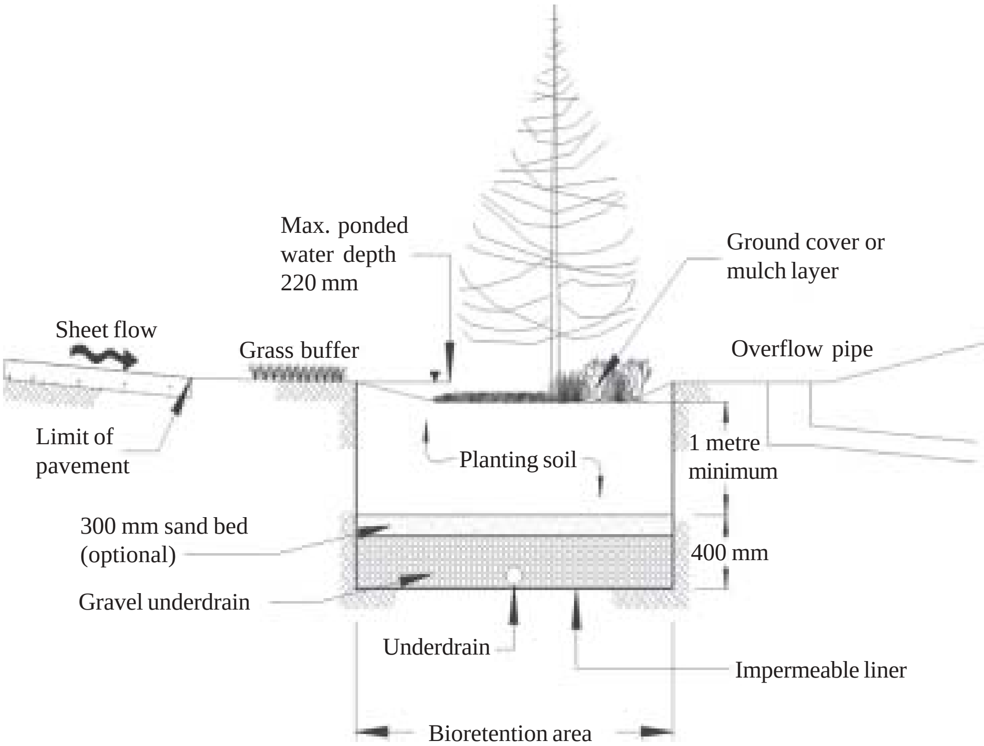
Both designs also allow for an optional sand layer at the bottom with a gravel

Figure 7-3
Elevated outfall pipe to promote infiltration



underdrain system. It is not recommended that a filter cloth be placed between the planting soil, sand bed and gravel underdrain because the fabric represents an area of potential clogging. A small amount of soil migration may be expected but the system will stabilise. Filter fabric (open weave in stable soils; impervious in unstabile soils) should be used, at least on the side walls, to prevent migration of adjacent soil particles into the rain garden.

Figure 7-4
Outfall pipe located at the bottom of the raingarden



The gravel underdrain will collect and distribute treated excess runoff. A properly designed underdrain system helps keep the soil from becoming saturated. The underdrain system consists of a gravel layer with a 100 - 150 mm perforated piping system. There should be a minimum of 50 mm of gravel cover over the perforated pipe.

Rain Garden Design Approach

1. determine water quality storage volume – use 1/3 of the 2 year-24 hour rainfall for site location per TP 108. The calculations shall be done considering the pervious and impervious catchment areas separately and their totals then summed.

   Calculate volume using TP 108. Minimum time of concentration is 0.17 hours.

2. Minimum live storage volume shall be 40% of the WQV.

3. Calculate the required surface area of the filter.

$$A_f = \frac{(WQV)(d_f)}{k(h+d_f)(t_f)}$$

A_f	= surface area (m^2)
WQV	= treatment volume (m^3)
d_f	= planting soil depth (m)
k	= coefficient of permeability (m/day)
h	= average height of water (m) = ½ max. depth
t_f	= time to pass WQV through soil bed (use one day to be conservative)

The following values shall be used:

d_f = planting soil depth (m) one metre
k = coefficient of permeability (m/day) = 0.3 m/day
h = average height of water (m) = 0.11 metres
t_f = time to pass WQV through soil bed (use one day for residential and up to 1.5 days for non-residential to be conservative)

General comments on rain gardens

1. The 220 mm depth of water on the rain garden is an approximate amount, the live storage ability is important to maintain. If less depth is used, the area of storage must be increased so the same volume of live storage is provided. Where the full depth cannot be provided (based on agreement with the ARC) A_f as calculated shall then be multiplied by the ration of the normal depth (1 metre) divided by the actual depth.

$$A_f\text{/actual depth} = \text{revised surface area requirement}$$

2. Keep drainage areas small and avoid the temptation to size them for too large a catchment area. As a general rule, keep their contributing catchments less than 1000 m^2. It is better to have more rain gardens than larger ones.
3. Place them in areas where they will not interfere with the normal use of the property.
4. Design them as off-line systems.
5. Make them look attractive so property owners will continue to maintain them.
6. The one day time to drain for residential properties is important so that property owners don't perceive that there is a drainage problem due to standing water.

Composition of planting soil

The characteristics of planting soils are very important. The soil must be permeable enough to allow runoff to filter through the media, while being able to promote and sustain a vegetative cover. Soils must balance soil chemistry and physical properties in order to support biotic communities above and below ground.

The best planting soil should conform to the following specifications:

- a sandy loam, loamy sand, loam, or a loam/sand mix (35-60% sand)
- clay content should be less than 25%
- permeability should be at least 0.3 metres per day
- free of stones, stumps, roots, or other woody material over 25 mm in diameter
- free of brush or seeds from noxious plants
- placed in lifts of 300 - 400 mm and loosely compacted (tamped lightly with a backhoe bucket)

Having a mulch layer on the surface of the ground can play an important role. The mulch layer assists in maintaining soil moisture and avoids surface sealing, which reduces permeability. Mulch helps prevent erosion and provides a micro-environment suitable for soil biota at the mulch/soil interface. The mulch should be:

- standard landscape type shredded wood mulch or chips
- well aged and free of other materials such as weed seeds, soil, roots, etc
- applied to a maximum depth of 75 mm.

7.5 Plant material

Consider the following when making planting recommendations:

1. Native plant species should be specified over exotic or foreign species
2. Appropriate vegetation should be selected based on their hydric tolerance

Table 7-2
Trees and shrubs

Trees and shrubs	
Brachyglottis repanda **rangiora**	Coastal shrub or small tree growing to 4m+. Large attractive pale green leaves with white fuzz on underside.
Coprosma acerosa **sand coprosma**	Grows naturally in sand dunes. Yellow, interlaced stems and fine golden foliage. Forms a tangled shrubby ground cover. Tolerates drought and full exposure. Prefers full sun.
Coprosma robusta / C. lucida **karamu, shining karamu**	Shrubs or small trees growing to 3m+, with glossy green leaves. Masses of orange-red fruit in autumn are attractive to birds. Hardy plants.
Cordyline australis **ti kouka, cabbage tree**	Palm-like in appearance with large heads of linear leaves and panicles of scented flowers. Sun to semi-shade. Prefers damp to moist soil. Grows eventually to 12m+ height.
Cordyline banksii **ti ngahere, forest cabbage tree**	Branching from the base and forming a clump. Long strap-shaped leaves with red-orange coloured veins. Prefers good drainage and semi-shade.
Corokia buddleioides **korokio**	Bushy shrub to 3m, with pale green leaves with silvery underside. Many small bright yellow starry flowers are produced in spring. Prefers an open situation but will tolerate very light shade.
Entelea arborescens **whau**	Fast growing shrub or small tree (to 5m height) with large bright green heart-shaped leaves. Spiny seed capsules follow clusters of white flowers in spring. Handsome foliage plant
Geniostoma rupestre **hangehange**	Common forest shrub with pale green glossy foliage, growing to 2-3m. Tiny flowers give off strong scent in spring. Looks best in sunny position where it retains a bushy habit, and prefers well drained soil.
Hebe stricta **koromiko**	Shrub or small tree growing to 2-5m in height. Natural forms have white to bluish flowers. Many cultivars and hybrids available with other colours, but unsuitable for use near existing natural areas. Full sun.
Leptospermum scoparium **manuka**	Shrub or small tree growing to 4m+ in height. Natural forms have white to pinkish flowers. Many cultivars and hybrids available with other colours, but unsuitable for use near existing natural areas. Hardy and tolerant of difficult conditions.
Metrosideros robusta **rata**	Eventually forms a large tree. Flowers bright red in summer. Will tolerate dryness and exposure. Full sun.
Pittosporum cornifolium **tawhirikaro**	A slender branched shrub grown for its attractive fruiting capsules which are brilliant orange when split open. Sun or semi-shade.
Pittosporum kirkii	A small tree with dark green leaves and large yellow flowers in the summer. Prefers shade
Pseudopanax crassifolius **horoeka**	Very narrow rigid and leathery leaves in its juvenile form. Stunning in amongst bold leaved plants. Sun or semi-shade.

Table 7-3
Grasses, ground covers, and other plants

Grasses, ground covers, and other plants	
Arthropodium cirratum **Rengarenga, renga lily**	A lily with fleshy pale green – greyish leaves and white flowers. Ground cover in semi shady situation
Asplenium bulbiferum **mouku, hen and chicken fern**	A robust fern with small plantlets produced on the fronds. Tolerates dryness and prefers shade
Asplenium oblongifolium **huruhuruwhenua, shining spleenwort**	Fern with large shiny fronds. Tolerates dryness. Prefers shade
Astelia banksii **kowharawhara, coastal astelia**	Clump forming plant up to a metre high with flax-like leaves. Requires semi-shade. Tolerates full exposure. Frost tender
Astelia solandri **kowharawhara, perching astelia**	An epiphytic plant in natural situations. Long drooping bright green leaves. Tolerates dryness. Prefers shade
Carex flagellifera **manaia, Glen Murray tussock**	Sedge up to 70cm high with reddish-brown spreading foliage. Prefers damp soil and full sun. Tolerates exposure
Carex testacea **sedge**	Coastal sedge up to 40cm high with shiny orange foliage. Prefers full sun and exposure. Tolerates dry soil conditions
Cortaderia fulvida **toetoe**	Branching from the base and forming a clump to 4m high. Long strap-shaped leaves with red-orange coloured veins. Prefers good drainage and semi-shade
Dianella nigra **turutu**	Lily with reddish leaves, and striking violet-blue fruit. Ground cover; prefers open well-drained situation
Disphyma australe **glasswort**	Fleshy leaved ground cover with mauve flowers in the spring. Tolerates drought and full exposure. Frost tender
Doodia media **pukupuku, rasp fern**	Hardy fern growing to 25cm. Young fronds coloured bright red when in full sun. Sensitive to frost
Libertia grandiflora* & *L. ixioides **mikoikoi, native iris**	Clump forming native irises with narrow, upright leaves. Small white flowers in spring. Sun or shade
Phormium cookianum **wharariki, mountain flax**	Clump-forming flax with yellow –green drooping leaves, to 2m. Full exposure and sun
Phormium tenax **harakeke, flax**	Clump-forming flax with large stiff leaves, to 3 m. Full exposure and sun

3. Species layout should generally be random and natural
4. A canopy should be stabilised with an understory of shrubs and herbaceous plants
5. Woody vegetation should not be specified in the vicinity of inflow locations
6. Trees should be planted primarily along the perimeter of the rain garden area
7. Stressors (wind, sun, exposure) should be considered when developing the planting plan
8. Noxious weeds should not be specified
9. Aesthetics and visual characteristics should be a prime consideration
10. Traffic and safety issues must be considered
11. Existing and proposed utilities must be identified and considered
12. Consider using native plants that already exist on the site that otherwise would be removed during site construction.

Recommended plant species for rain gardens includes trees, shrubs, grasses, ground covers, and other plants as shown in the following tables 7-2 and 7-3

7.6 Construction

7.6.1 Sand filters

Sand filters may involve reinforcing steel, concrete and significant site preparation and excavation before construction. The approved plans should be reviewed and discussed for any concerns at the preconstruction meeting. The following construction times and items are important to recognise during the site inspection.

1. Stake out the filtration facility location.
2. Generally, do not use filters for sediment control during construction.
3. Pre-fabricated structural components should be available on-site to verify adequacy of materials. Reinforcing bars should meet design specifications as should all other structural components such as any pipes, aggregate material and filter fabric.
4. Clear foundation areas of any organic material which could cause uneven settlement as the material decomposes. Unsuitable foundation material should be removed and replaced with suitable material.
5. Compact the foundation area to sustain the load placed on it by the filtration system. Level the foundation as detailed on the plans to ensure proper drainage of the facility.
6. Ensure the ARC or TA inspector is on site when the facility has been formed up with reinforcing bars in place but before pouring the concrete so pouring can be observed.
7. During concrete pouring, the inspector must verify that the concrete meets design specifications for the design load.
8. If the filtration practice is composed of prefabricated units, the inspector must approve the means of joining the sections and the steps taken to prevent leakage from between the prefabricated units.
9. Before backfilling, fill the filters with water once the concrete has set (or joints on prefabricated units have been sealed) and allowed to sit for 24 hours and observe whether the unit has any leaks.
10. When installation has been completed to meet size and volume requirements, has no leakage and the contributing catchment areas have been stabilised, place the underdrains on the proper slope and wrap them in filter fabric to prevent migration of the filtration material out of the facility.
11. Place the filter material in the facility. The material should meet criteria specified on the design plans. The sand should be clean, washed aggregate. Other materials, such as peat or compost, may become more accepted if their performance demonstrates their value.
12. Conduct a final inspection to verify that the filter material is placed correctly and the first sedimentation chamber is clean of any accumulated sediments or other construction debris. Site inspection forms are at the end of the Chapter.

7.6.2 Rain gardens

1. Ideally, defer building the rain garden until after the contributing drainage area has been stabilised.
2. Do not use the area excavated as a sediment ponding area during site construction, as finer sediments may seal the bottom before it starts operation.
3. Stake out the general location of the rain garden so that location and dimensions can be considered in terms of site suitability.
4. Excavate the rain garden and connet the underdrains to the stormwater drainage system. If there is no stormwater system, the underdrain should be connected to a flow distribution system to avoid concentrated flows downstream. Impervious lining or filter fabric should be placed at this time.
5. Place gravel backfill, sand backfill and planting soil in excavation. Verify composition of materials and compaction.
6. Plant vegetation, lay mulch and complete site stabilisation.

7.6.3 As-built plans

Consent conditions may require an As-built plan to verify that construction was done in accordance with the approved consent.

The As-built plan must verify the:

1. Dimensions and materials of the filtration system or rain garden match the design dimensions
2. Filter material is per specification
3. Inlets and outlets are constructed correctly
4. Underdrains are installed to grade
5. Prefabricated joints are sealed (filtration practice)
6. 24 hour water test verified no leakage of filtration chamber (filtration practice)

7.7 Operation and maintenance

7.7.1 Sand filters

As is the case with all stormwater practices, the frequency of maintenance depends on the contaminant loadings entering the practice.

Two major components of sand filters include:

> a sedimentation chamber
> a filtration chamber

Sedimentation chamber

The sedimentation chamber settles and stores coarser sediments and debris mainly by gravity. Maintenance inspectors should ensure that the depth of stored materials is below the level where they will migrate to the filtration chamber. This depth is relatively easy to measure.

Maintenance of the sedimentation chamber is generally not needed more than every two to ten years. Sedimentation chambers are normally wet, so the accumulated material is easily removed with vacuum type equipment. Volumes to be removed are generally fairly, reflecting the smaller catchment areas these practices serve. This makes vacuuming a practical method.

Access must be provided to the sedimentation chamber for entry and performance of maintenance.

Filtration chamber

Maintenance of filter chambers depends on the magnitude of the incoming contaminant loadings, but filters generally require cleanout every 6 - 12 months.

The finer sediments may be raked from the surface of the sand and removed, or a flat bottom shovel may skim off the surface of the sand to re-establish sand permeability.

Filtration chambers are more sensitive than sedimentation chambers to clogging by fine sediments and other fine grained materials, such as oils and greases. While the sedimentation chamber functions primarily through gravity settling of the incoming materials, the filtration chamber is where filtering of contaminants occurs. This chamber will be more effective at removal of the finer sediments, which are retained primarily in the top 50 mm of the filter media.

Filtration chambers need more frequent maintenance than sedimentation chambers. If the sand filter is in an area with a significant contaminant loading, filter maintenance may be needed at least twice per year to ensure that the design flows travel through the practice. Diminished permeability of the sand will result in more frequent overflows into the conventional drainage system with less stormwater treatment. It will be fairly easy to see the depth of penetration of the contaminants and how much filter media needs removal. Usually, it is not necessary to replace all of the filter media, only the top layer.

When portions of the filter media must be replaced, only materials which meet the stormwater programme's filter specifications should be used. There is research being done with alternative filter media such as compost, zeolite, fly ash, activated carbon, alum, and so on. If the ARC allows or specifies an alternative filter media as a replacement, this should be documented in the inspection and owner's files as a departure from the approved plans.

Vandalism

As with all stormwater management facilities, there is always the potential for vandalism. This can include damage to the practice itself, theft of practice components or illegal dumping of waste products such as waste oil. Planning is essential in order to enable prompt remedial action.

A primary method to reduce vandalism is a community education program explaining stormwater contaminant generation, the importance of stormwater practices such as filter systems and the need to limit contaminant entry into BMPs. One component of this education program could be stenciling of the inlets to the filter. This may prevent some misuse resulting from ignorance of the facility's purpose.

Other maintenance concerns such as scour, leakage, spalling of concrete or cracks in concrete and grates need to be addressed when they are discovered. If the normally wet sedimentation chambers become dry, there is leakage, and the leakage must be stopped for the facility to function correctly. If the leaking area cannot be identified, a dye test may be necessary to track the flow of water in the leaking chamber. In addition, concrete will deteriorate over time, especially if subject to live loads. The concrete must be routinely inspected, and repaired when necessary.

7.7.2 Rain gardens

Rain gardens treat runoff by filtering it through vegetation and then passing it vertically through an organic soil which filters the runoff. Besides vegetative filtration, treatment may, if designed for, rely upon infiltration of runoff into underlying soils or to an underdrain.

Therefore, maintenance is primarily concerned with:

- Maintenance of flow to and through the biofilter
- Maintaining planted vegetation and preventing undesired overgrowth vegetation from taking over the area
- Removal of accumulated sediments
- Debris removal

Vegetation

Vegetation enhances rain garden performance for stormwater treatment and then requires close attention. Maintenance includes fertilising plants, removing noxious plants or weeds, re-establishing plants that die and maintaining mulch cover.

Regular inspections by the responsible entity (TA, ARC, maintenance organisation) must be done to ensure that the desired vegetation remains and is not overtaken by invasive undesirable plants. In some situations the replacement of the planted vegetation by a volunteer species may be beneficial, but only if the invasive species provides equal or increased water quality benefits and is accepted by the owners of the site.

Sediment

Sediments accumulate in rain gardens and their removal may be the most expensive aspect of rain garden maintenance. Removal should occur when surface ponding lasts significantly longer than the one day drain time, which indicates surface clogging. When sediments are to be removed, it is essential to restore the vegetation and soil conditions to the originally constructed condition. Sediment removal will necessitate disturbance of the vegetation, so steps will have to be taken to re-establish the vegetation upon completion of sediment removal. Erosion control in the contributing drainage area also will be necessary to prevent scour and excessive sedimentation in the rain garden until there is once again a dense stand of vegetation.

Sediment may also impede effective performance of a rain garden by clogging the soil surface and preventing design storms from being treated. If stormwater backs up into the upstream drainage area, overflow may occur and bypass the treatment area.

Debris

Similar to other types of practices, debris removal is an ongoing maintenance function at all rain garden systems. Debris, if not removed, can block inlets or outlets, and can be unsightly if located in a visible location. Inspection and removal of debris should be done on a monthly basis, with debris also removed whenever it is observed on site.

Just as it is important to know when a rain garden needs to be maintained, it is important to know when maintenance does not have to be done. The original plan for the site provides the best information at that time on the design and construction of the rain garden. Over time the facility may change in appearance and function. These changes may not necessarily be bad. Having a knowledgeable inspector conduct regular inspections may be one way to allow a rain garden to evolve into an improved facility with reduced maintenance costs.

7.8 Case studies

7.8.1 Case study 1 - sand filter

A sand filter is to be constructed for a 2000 m^2 carpark. Being a carpark, the impervious surface is 100% of the total area.

2-year 24-hour rainfall = 75 mm

1. Water quality storm extrapolation 75 mm for 2-year, 24 hour storm = 25 mm (75/3)
2. From TP 108, the required water quality volume - WQV = 41.4 m^3
3. Live storage provide = (0.37)(41.4) = 15.3 m^3
4. Surface area of filter

$$A_f = \frac{I_a H d_f}{k(h+d_f)t_f} = \frac{(41.4)(0.4)}{1(0.5+0.4)(2)} = 9.2\ m^2$$

5. Sedimentation area = 9.2/4 = 2.3 m^2

7.8.2 Case study 2 - rain garden

A rain garden is to be constructed on a residential property that is located in Kumeu. The total catchment draining to the rain garden is 1000 square metres of which 200 square metres is impervious surface.

1. Water quality storm extrapolation 81 mm of rainfall for 2 year, 24 hour storm = 27 mm
2. From TP 108, calculated separately, the required water quality volume - WQV = 8.01 m^3
3. Live storage to be provided = (0.4)(8.01)

3.
$$A_f = \frac{(WQV)(d_f)}{k(h+d_f)(t_f)}$$

$A_f = (8.01\ m^3)(1m)/(0.3\ m/day)(0.11m+1m)(1day)$
$A_f = 24.0\ m^2$

7.9 Bibliography

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Filtration system Inspection forms

Construction inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

FILTRATION FACILITY OPERATION & CONSTRUCTION INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Filtration Facility Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
Pre-construction	Y	N			**Completed Facility Components**	Y	N		
1. Runoff diverted					13. 24 hour water filled test (if applicable)				
2. Facility area cleared									
3. Facility location staked out					14. Contributing area stabilised				
Excavation					15. Filter material per specification				
4. Size and Location									
5. Side slopes stable					16. Underdrains installed to grade				
6. Foundation cleared of debris									
7. Foundation area compacted					**Final Inspection**				
Structural Components					17. Dimensions				
8. Dimensions and materials					18. Structural Components				
9. Forms adequately sized					19. Proper outlets				
10. Concrete meets standards					20. Effective site stabilisation				
11. Prefabricated joints sealed									
12. Underdrains (size, materials)									

OFFICERS REMARKS:

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ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ______________________________

1st Notice: ______________________________

2nd Notice: ______________________________

Submit plan modifications as noted in written comments by ______________________________

Notice to Comply issued ______________________________

Final inspection, project completed ______________________________

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ______________________________

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Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

RAIN GARDEN CONSTRUCTION INSPECTION FORM	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Rain Garden Construction Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory	**STRUCTURAL COMPONENTS**	Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION					11. Inflow & outlets installed correctly	Y	N		
1. Runoff diverted	Y	N			12. Overflow system installed correctly	Y	N		
2. Facility area cleared	Y	N			13. Pretreatment devices installed	Y	N		
3. Facility location staked out	Y	N			**VEGETATION**				
4. Contributing drainage are stabilised	Y	N			11. Complies with planting specification	Y	N		
EXCAVATION					12. Topsoil adequate in composition & placement	Y	N		
5. Size & location	Y	N							
6. Excavated to appropriate grade	Y	N			13. Mulch laid	Y	N		
7. Appropriate liners placed as required	Y	N			**FINAL INSPECTION**				
UNDERDRAINS & FILTER MEDIA					14. Dimensions	Y	N		
8. Perforated underdrain installed correctly	Y	N			15. Proper outlet	Y	N		
					16. Effective stand of vegetation & stabilisation	Y	N		
9. Storm drain system installed & connected	Y	N			17. Construction generated sediments removed	Y	N		
10. Gravel, sand, & planting soil back backfilled	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ______________________________

1st Notice: ______________________________

2nd Notice: ______________________________

Submit plan modifications as noted in written comments by ______________________________

Notice to Comply issued ______________________________

Final inspection, project completed ______________________________

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ______________________________

Filtration system
Inspection forms
Operation and maintenance

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** **(Under Section 332 of the Resource Management Act 1991)**	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

FILTRATION FACILITY OPERATION & MAINTENANCE INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

	"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
	"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
	"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Filtration Facility Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**6M**	**SEDIMENT DEPOSITION**	Y	N	Y	N	**A**
1. Contributing areas clean of debris						11. Filtration chamber clean of sediment					
2. Filtration facility clean of debris						12. Water chambers not more than ½ full of Sediments					
3. Inlets and outlets clear of debris						**STRUCTURAL COMPONENTS**					**A**
VEGETATION					**3M**	13. No evidence of structural deterioration					
4. Contributing drainage area stabilised						14. Any grates are in good condition					
5. No evidence of erosion						15. No evidence of spalling or cracking of structural parts					
6. Area mowed and clippings removed						**OUTLETS / OVERFLOW SPILLWAY**					**A**
OIL AND GREASE					**3-6M**	16. Good condition, no need for repair					
7. No evidence of filter surface clogging						17. No evidence of erosion (if draining into a natural channel)					
8. Activities in drainage area minimise oil & grease entry						**OVERALL FUNCTION OF FACILITY**					**A**
WATER RETENTION WHERE REQUIRED					**6M**	18. No evidence of flow bypassing facility					
9. Water holding chambers at normal pool depth?						19. No noticeable odours outside facility					
10. No evidence of leakage											

Inspection Frequency Key **A = Annual, M = Monthly, 3M = Three monthly, 6M = Six Monthly, 3-6M = Three to Six Monthly**

Warning: If filtration facility has a watertight cover; be careful regarding the possibility of flammable gases within the facility. Care should be taken lighting a match or smoking while inspecting facilities that are not vented.

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OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: ______________________________

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Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

RAIN GARDEN MAINTENANCE INSPECTION CHECKLIST	:	Needs immediate attention	V	Okay	;	Clarification Required	
	9	Not Applicable					

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Rain Garden Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**	**OUTLETS/OVERFLOW SPILLWAY**	Y	N	Y	N	**A, AMS**
1. Rain gardens and contributing areas clean of debris						13. Good condition, no need for repair					
2. No dumping of yard wastes into rain garden						14. No evidence of erosion					
3. Litter (branches, etc) have been removed						15. No evidence of any blockages					
VEGETATION					**M**	**INTEGRITY OF BIOFILTER**					**A**
4. Planting height not less than design water depth						16. Rain garden has not been blocked or filled inappropriately					
5. Fertilised per specifications						17. Mulch layer still in place					
6. No evidence of erosion						18. Noxious plants or weeds removed					
7. Is plant composition still according to approved plans											
8. No placement of inappropriate plants											
DEWATERING AND SEDIMENTATION											
9. Rain garden dewaters between storms											
10. No evidence of standing water											
11. No evidence of surface clogging											
12. Sediments should not be > than 20% of swale design depth											

Inspection Frequency Key A = Annual, M = Monthly, AMS = After Major Storm

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OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ____________________________

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Chapter 8
Infiltration design, construction and maintenance

8.1 Introduction

Infiltration practices direct urban stormwater away from surface runoff paths and into the underlying soil. In contrast to surface detention methods, which are treatment or delay mechanisms that ultimately discharge all runoff to streams, infiltration diverts runoff into groundwater. Of all the traditional stormwater management practices, infiltration is one of the few practices (together with revegetation and rain tanks) that reduce the overall volume of stormwater being discharged.

Infiltration practices comprise a suite of different practices, including:

- trenches
- dry wells
- modular block porous pavement
- to a certain extent, rain gardens, swales and filter strips that are considered separately.

Infiltration practices are used for three primary purposes:

- reducing the total volume of stormwater runoff,
- reducing the contaminant loadings downstream, and
- low streamflow augmentation.

Plate 8-1: Infiltration trench treating roadway runoff

The use of infiltration practices for water quality treatment must be considered with caution. Infiltration practices are much more sensitive to clogging than are ponds or filters. As much as possible, sediment should be prevented from entering these practices.

Infiltration trenches receive runoff in a shallow excavated trench that has been backfilled with stone to form a below-grade reservoir. Water then enters the underlying subsoil according to its infiltration rate.

Dry wells function in a similar fashion with the excavated subgrade being filled with stone and relying upon the void spaces to provide for stormwater storage until the runoff infiltrates into the soil.

Modular block porous pavement permits precipitation to drain through paving blocks with a pervious opening. Paving blocks are appropriate only for areas with very light or no traffic or for parking pads. They are laid on a gravel subgrade and filled with sand or sandy loam turf but can also be used with grass in the voids which may require irrigation and lawn care during the summer months.

8.2 Water quality performance

Infiltration systems do not have underdrains, so the design and soil characteristics determine how much runoff is captured and how efficient the treatment.

Among the various runoff treatment options, only soil infiltration systems have been reliable in removing soluble phosphorus. This result likely applies to other relatively soluble contaminants as well. Dissolved contaminant reduction is incomplete but is still higher than with any other treatment method. Table 8-1 estimates runoff contaminant removals.

Table 8-1
Long-term contaminant removal rates

Contaminant	Sized based on Runoff from 25 mm rainfall	2-year storm runoff volume
Total suspended solids	90	99
Total Phosphorus	60-70	65-75
Total Nitrogen	55-60	60-70
Metals	85-90	95-99
BOD	80	90
Bacteria	90	98

With capture of the runoff from taking 1/3 of the 2 year-24 hour rainfall as per TP 108, approximately 80 percent of the total runoff volume would be captured, depending on the soil and the amount of impervious area. If it were possible to apply infiltration on a widespread basis in a catchment, summer stream baseflows would remain within approximately 90 percent of predevelopment conditions.

8.3 Applicability

Soil permeability is the most critical consideration for the suitability of infiltration practices. Practices are generally built in the native soil; but when this is inappropriate, a soil system can be constructed with media such as sand, peat, or a combination. Table 8-2 provide information on the suitability of various soils for infiltration. Infiltration practices normally convey most runoff directly into the soil to eventually enter the groundwater. Constructed soil systems usually require underdrains.

Table 8-2
Infiltration rate from soil textural class

Texture class	Minimum infiltration rate (f) in mm/hr
Sand	210
Loamy sand	61
Sandy loam	26
Loam	13
Silt loam	7
Sandy clay loam	4.5
Minimum allowable rate - 3mm/hr	
Clay loam	2.5
Silty clay loam	1.5
Sandy clay	1.3
Silty clay	1.0
Clay	0.5

The next most crucial considerations for the suitability of infiltration practices, are:

- avoiding clogging
- avoiding potential to contaminante groundwater.

Plate 8-2: Infiltration trench with a swale for pretreatment

Infiltration practices should be constructed in medium textured soils. They are generally unsuitable for clay because of restricted percolation and for gravel and coarse sands because of the risk of groundwater contamination (unless effective pretreatment is provided).

Any impermeable soil layer close to the surface may need to be penetrated. If the layer is too thick, underdrains may be required. As a minimum measure to prevent clogging, infiltration trenches should require a pretreatment device to settle larger solids and reject runoff from eroding construction sites. Infiltration dry wells accept only roof runoff so pretreatment is not expected, Pretreatment is not possible for modular paving either.

The following guidance is applicable to design and implementation of all infiltration practices.

8.3.1 Site characteristics

Site characteristics relate to whether the infiltration practice is intended for quantity control alone or for both quality and quantity control. While quantity control is best achieved with a rapid percolation rate, this rate could be too fast to provide sufficient contact with the soil for contaminant capture, if the groundwater table is relatively close to the surface.

Consequently, the ARC:

- specifies a maximum and a minimum percolation rate to protect groundwater and attain contaminant capture objectives. Infiltration rates greater than 1 m/hr may indicate a direct link to a very permeable aquifer while slower than 3 mm/hour is too slow
- requires runoff pretreatment to meet water quality objectives before the pretreated runoff is infiltrated for quantity control or base streamflow augmentation

The following criteria aims to reduce the substantial risks of failure and groundwater contamination, and to achieve the desired urban stormwater management benefits:

- The invert of the infiltration practice should be at least one metre from the seasonal high water table, bedrock, or relatively impermeable soil layer
- The percolation rate should be at least 3 mm/hr.
- The soil should not have more than 30 percent clay or more than 40 percent clay and silt combined
- If the infiltration practice is to function for primary water quality treatment, infiltration rates must not be greater than that given for sand. Injection into basalts must be preceeded by water quality treatment prior to injection
- Infiltration practices must not be constructed in fill material
- Infiltration practices must not be constructed on slopes exceeding 15 percent

- Catchments draining to infiltration practices must not exceed four hectares, but preferably not more than two hectares
- Infiltration basins, while listed as a practice in Chapter 4, are not encouraged for use unless approved on a case-by-case basis because their long term historical performance has not been good, mainly as a result of surface clogging

8.3.2 Pretreatment

The use of vegetative filters as a pretreatment BMP to improve long term performance of infiltration practices cannot be stressed enough.

Of primary importance to the long term function of infiltration practices is the need to keep all contributing catchment areas stablised. Sediment loadings into the practice must be kept to a minimum. All inspections of these practices must include inspection for site stabilisation. All areas draining to the infiltration practice must be stabilised or premature clogging of the facility will result. The infiltration practice checklists recommend annual inspections for sediment accumulation. The frequency of actual maintenance activities depend on loadings from contributing catchment areas.

8.4 Objectives

Because infiltration practices are the only traditional stormwater management practice that reduces the total volume of runoff, objectives relate to:

- peak flow reduction
- contaminant removal
- low stream flow augmentation

Due to the sensitivity of infiltration practices to clogging, they are best utilised to augment low stream baseflow, with pretreatment to reduce contaminant loads so that the cleaner water infiltrates to maintain groundwater levels and maintain low stream flow.

If long term responsible maintenance can be assured, infiltration is appropriate as a water quality treatment practice

8.5 Design approach

There are a number of items that should be considered when infiltration practices are used.

8.5.1 Site characteristics

A site characterisation must be done to determine the following:

- Topography within 150 metres of the proposed infiltration practice
- Site use
- Location of any water supply wells within 150 metres of the proposed infiltration practice
- Local site geology to gain understanding of soil and rock units likely to be encountered, the groundwater regime and geologic history of the site.
- For infiltration trenches, at least one test pit or test hole per 15 metres of trench length and 2.5 times deeper than the invert depth of the trench.
- For dry wells, at least one test pit for each dry well. The test pit should be 2.5 times deeper than the invert depth of the dry well.
- For modular porous pavement, there must be one test pit per 500 m^2 of infiltrating surface and the test pit should be 2.5 times deeper than the invert depth of the filter bed.
- The depth, number of test holes or test pits and sampling should be increased, if, in the judgement of

the geotechnical engineer, the conditions are highly variable and increasing the depth or the number of explorations is necessary to accurately estimate the performance of the infiltration practice. In addition, the number of explorations may be decreased if, in the opinion of the geotechnical engineer, the conditions are relatively uniform and the borings/test pits omitted will not influence the design.

- Detailed logs for each test pit or test hole must be prepared along with a map showing the location of the test pits or holes. Logs must include at a minimum, depth of pit or hole, soil description, depth to water, depth to bedrock or impermeable layer, and presence of stratification.
- Install ground water monitoring wells (unless the highest ground water level is far below the infiltration practice) to monitor the seasonal ground water levels at the site.

8.5.2 Procedure for conducting an infiltration test

The required approach consists of a relatively large-scale infiltration test to better approximate infiltration rates for design of infiltration practices. This approach reduces some of the scale errors associated with relatively small-scale double ring infiltrometre or "stove pipe" infiltration tests.

1. Excavate the test pit at least 1.5 metres below the bottom of the proposed infiltration practice. Lay back the slopes sufficiently to avoid caving and erosion during the test.
2. The surface area of the bottom of the test pit shall be at least 1 square metre.
3. Install a vertical minimum 1.5 metre long measuring rod marked in 10 mm increments in the centre of the pit bottom.
4. Use a rigid 150 mm pipe with a splash plate on the bottom to convey water to the bottom of the pit and reduce side-wall erosion or excessive disturbance of the ponded bottom.
5. Add water to the pit at a rate that will maintain a water level of between 1 - 1.25 metres above the bottom of the pit. A rotametre can be used to measure the flow rate into the pit.
6. Every 15-30 minutes, record the cumulative volume and instantaneous flow rate in litres per minute necessary to maintain the water level at the same point on the measuring rod.
7. Add water to the pit for a minimum of 17 hours or until one hour after the flow rate into the pit has stabilised (constant flow rate) while maintaining the same ponded level.
8. After 17 hours or one hour after the flow rate has stabilised, turn off the water and record the rate of infiltration in mm/hour from the measuring rod data, until the pit is empty.
9. Based on partial clogging, reduce the derived infiltration rate by a factor of 0.5 and reduce this reduced rate in the design calculations.

8.5.3 Site data analysis

- Determine representative site infiltration rate from soil test results and the stratification identified during the site investigation.
- Determine the textural class from the U.S. Department of Agriculture (USDA) textural triangle in Figure 8-1. Sand is defined to have a diameter between 2000 um and 50 um while clay has a diameter of less than 2 um. Once the texural class has been determined, the infiltration rates can be found.
- Determine infiltration rates by taking direct in-situ measurements of soil infiltration rates.
- Long term infiltration rates greater than one metre per hour (as per steps 8 and 9 above) are considered too

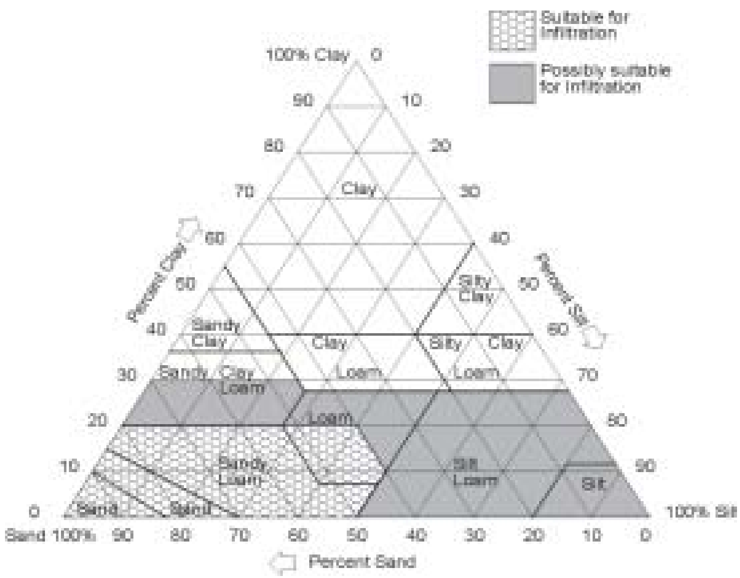


Figure 8-1
USDA. soil textural triangle

rapid to allow significant water quality treatment to occur and pretreatment will have to be provided.

8.6 Design procedure

This approach relies on the use of Darcy's Law, which expresses flow through a porous medium. The resulting equations for the surface area (A_s) and infiltration practice volume (V_t) are:

1. Determine water quality storm - take 1/3 of the 2 year-24 hour rainfall at the site location using the separated approach for pervious and impervious surfaces detailed in Chapter 3, Section 3.5.
2. Use TP 108 to calculate the water quality volume
3. Size the practice area to allow complete infiltration within 48 hours, including rainfall falling directly onto the practice. To do this, use the following equation:

$$A_s = \frac{WQV}{((f_d)(i)(t) - p)}$$

where:

A_s	=	Surface area of practice (m^2)
WQV	=	Water Quality Volume (m^3)
f_d	=	Percolation rate (m/hour); measured rate multiplied by 0.5 for factor of safety
i	=	Hydraulic gradient (m/m) assumed to be 1
t	=	Time to drain from full condition (hours) - maximum time 48 hours
p	=	Rainfall depth for water quality storm (m)

4. Size the practice depth to provide storage for 37% of the volume required to infiltrate.

$$V_t = 0.37(WQV + pA)/V_r$$

where:

V	=	Practice volume required with aggregate added
V_r	=	Void space ratio of stone, normally .35 (scoria is rated at .50)

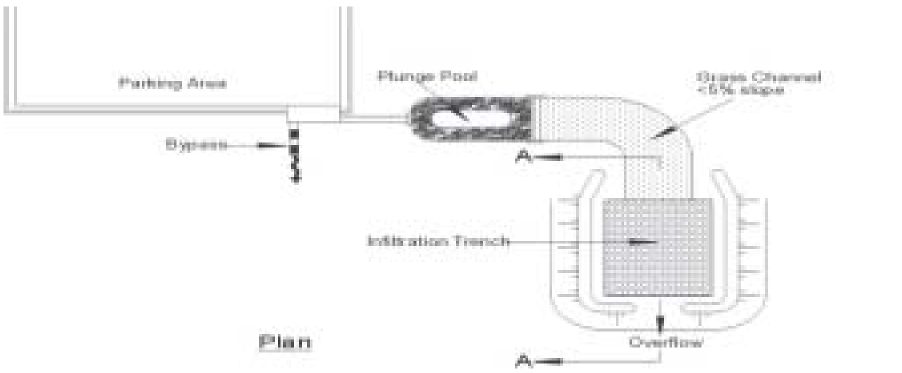


Figure 8-2
Infiltration trench standard detail and shown with a pretreatment swale

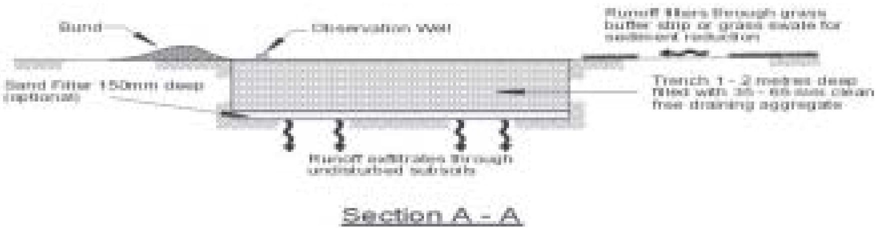


Figure 8-3
Typical application for an infiltration trench

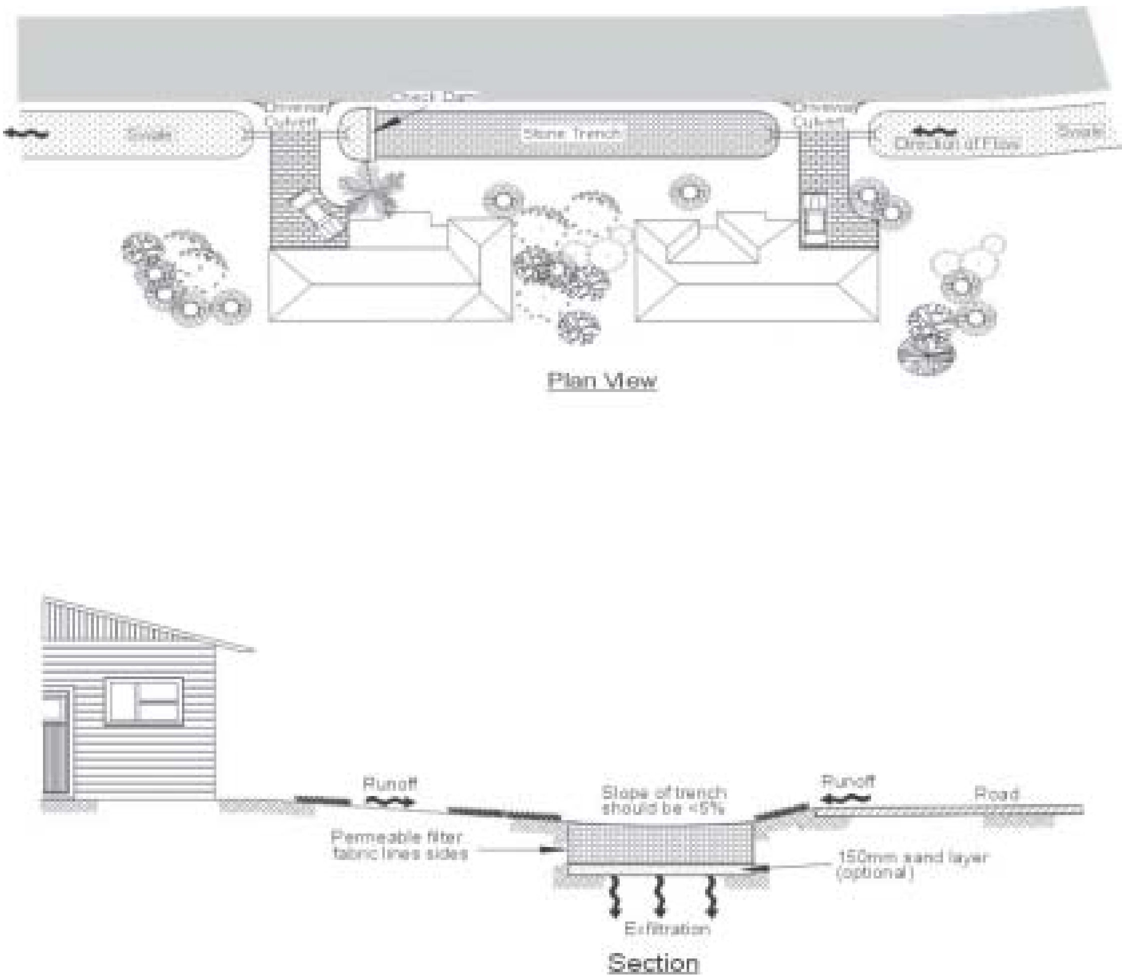
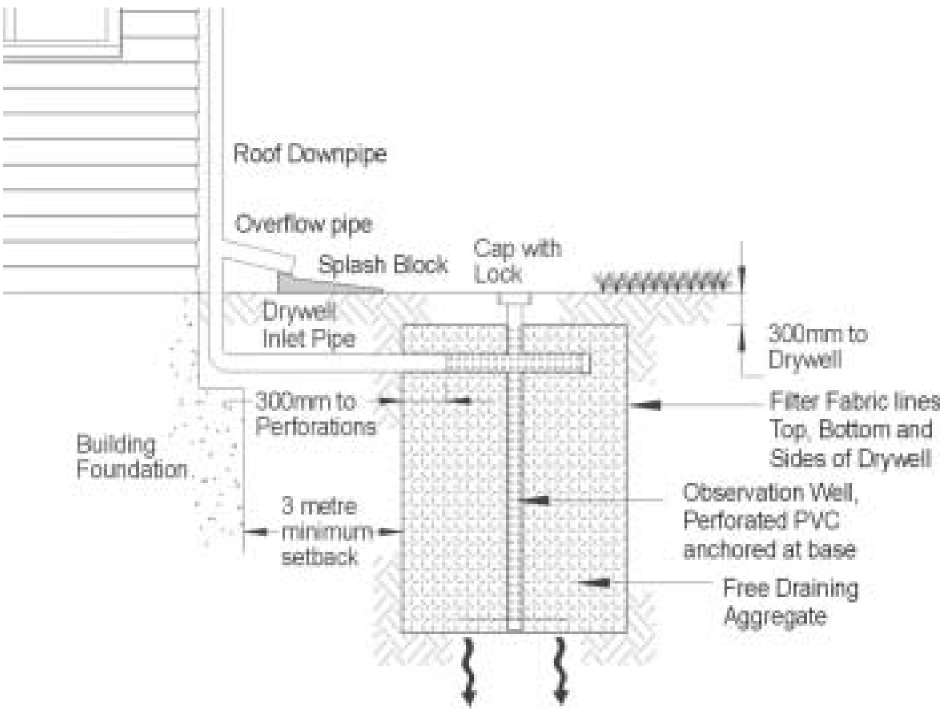


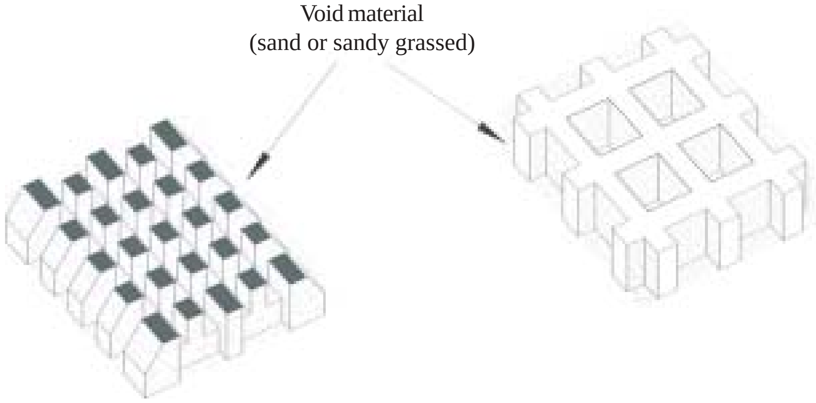
Figure 8-4
Typical detail for an infiltration drywell



Standard details for trenches, dry wells, and modular pavements are provided in Figures 8-2, 8-3, 8-4, 8-5, and 8-6.

As can be seen, infiltration is assumed to occur only out of the bottom of the practice and not the sides. With concerns about partial clogging of infiltration practices and the limited extent of exfiltration that can be expected out of the side walls, it is appropriate to use bottom area only in calculations.

Figure 8-5
Examples of modular paving



8.7 Construction

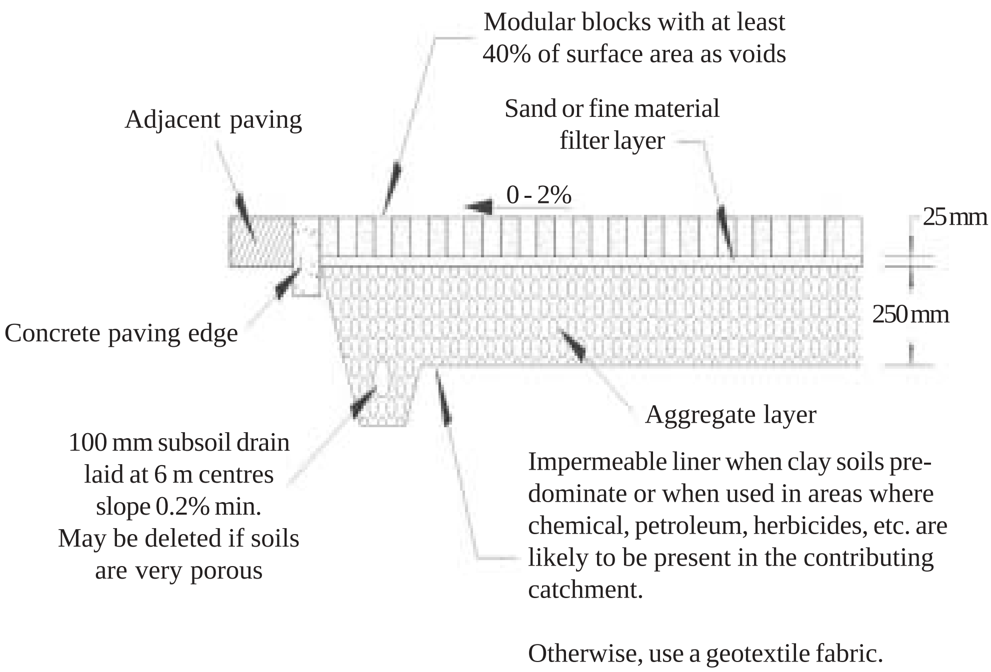
The proper construction of infiltration practices is very important if long term performance is to be expected. These practices are very susceptible to clogging by site generated sediments. It is vital to prevent sediment-laden runoff from construction to enter the practice. There is also a time period after site stabilisation during which excess sediment loads still are transported downstream from revegetated areas before they build up organic material and higher plant density. This is why pretreatment of runoff before it enters the infiltration practice is needed.

The following general guidelines apply to the construction phase of all infiltration practices.

1. Infiltration practices should not be constructed until after permanent stabilisation and permanent erosion control of areas draining to the facilities has been accomplished.

2. Infiltration practices should not be used for temporary sediment ponding during construction. If an infiltration practice must be used for sediment control, the bottom of the practice should be placed at

Figure 8-6
Standard detail for modular paving



least 300 mm above the design bottom elevation. If the practice develops a normal pool of water due to bottom clogging by finer sediments, it should be dewatered and allowed to dry before excavation to final design bottom elevations. If the material is removed while wet, there will be the potential for the water to become turbid and for finer sediments to remain in the water column. This will reduce soil permeability at the final bottom elevation.

3. Other than infiltration dry wells and modular block porous pavement, all infiltration practices shall be designed so that the stormwater runoff first passes through a pretreatment system to remove suspended solids before the runoff enters the infiltration practice.

4. The location of infiltration practices should be clearly marked at the site to prevent vehicle traffic across this area. The traffic will compact the soils and reduce soil infiltration rates.

8.7.1 Characteristics of individual infiltration practices that warrant specific attention

Although grouped together due to their common goals, infiltration practices also are very different in their construction and site utilisation. Consequently, they will be discussed separately to provide specific guidance to an inspector.

Infiltration trenches

Infiltration trenches tend to to be deep, with a large length to width ratio. Filled with stone, scoria, gravel or sand aggregate, they are generally used in areas where space available for stormwater management is limited. Runoff is stored in the voids of the aggregate material, which are normally is between 30 and 40% of the total volume. Scoria has a higher void space ratio of approximately 50%. The stored runoff then exits the trench through the side and bottom walls into the soil profile. Construction inspection should include the following items:

A. Verify the infiltration trench dimensions and location on site before trench construction. Verify distance to foundations, septic systems, wells, and so forth.
B. Excavate the trench using a backhoe or a ladder type trencher. Front-end loaders or bulldozers should not be used, as their blades can seal the infiltration soil surface. Place excavated materials far enough away from the sides of the excavated area, in order to minimise the risk of sidewall cave-ins and prevent migration of the soils back into the trench after the stone, gravel, or sand aggregate has been placed.
C. Inspect the trench bottom and side walls and remove objectionable material such as tree roots that protrude and could possibly puncture or tear the filter fabric.
D. Line the sides and bottom with filter fabric. The side wall fabric will prevent migration of soil particles from the side walls into the trench. The bottom fabric will prevent sealing of the aggregate soil interface.
E. Lay the fabric with sufficient length to overlap the top of the trench. Covering the trench after

Plate 8-3: Infiltration trench under construction showing observation well, footplate, and fabric

placement of the aggregate will protect the completed practice by preventing excess site sediment from entering it.

F. Install an observation well in the aggregate so that future inspections can determine whether the practice is functioning as designed. The observation well should consist of a perforated PVC pipe, 100 - 200 mm in diameter and have a footplate and a cap. The footplate will prevent the entire observation well from lifting up when the cap is removed during future inspections.

G. Inspect the aggregate material before placement to ensure that it is clean and free of debris. The size of the material should be as specified on the approved plans.

H. Upon completion of trench construction, the adjacent areas should be vegetatively stabilised. Direct the trench overflow to a non-erosive outlet channel.

I. Install a pretreatment device such as a biofiltration swale or other approved method before the runoff enters the trench in order to remove suspended solids.

J. Cap the observation well and measure and record the initial depth measured and noted on the inspection checklist.

Infiltration drywells

Similar to infiltration trenches, drywells are excavated areas that are filled with an aggregate material. The main difference is that drywells accept runoff only from roofs. They therefore receive lower loadings of suspended solids loadings than that expected from ground surface runoff.

Plate 8-4: Infiltration dry well

The major concern with infiltration drywells is that, by serving roof areas, they must be located in the vicinity of building foundations. Careful consideration must be given to the correct placement of drywells so that building foundation problems do not result. A big advantage of a drywell over other runoff controls is that the drywell is underground and does not represent a loss of site area to the land developer. Construction inspection should include the following items:

A. Verify the infiltration drywell dimensions and location onsite before drywell construction. Verify distance to foundations, septic systems, wells, and so forth.

B. Excavate the drywell using a backhoe or ladder type trencher. Front-end loaders or bulldozers should not be used as the equipment blades may cause excessive compaction of the drywell bottom.

C. Place excavated materials a sufficient distance from the sides of the excavated area to minimise the risk of sidewall cave-ins and to prevent migration of the soils back into the trench after the stone, gravel, or sand aggregate has been placed.

D. Inspect the drywell bottom and side walls and remove objectionable material such as tree roots that protrude and could possibly puncture or tear the filter fabric.Schedule the work so that the drywell can be covered in one day to prevent wind-blown or water carried suspended solids from entering the drywell.

E. Line the sides and bottom with filter fabric. The side fabric placement will prevent migration of soil particles from the side walls into the trench. The bottom filter fabric will prevent sealing of the aggregate soil interface.

F. Once the aggregated has been placed, place filter fabric over the drywell and final site grading should be done.

G. Install an observation well in the aggregate to allow future inspections to determine whether the practice is still functioning. The observation well should consist of a perforated PVC pipe, 100 - 200 mm in diameter and have a footplate and a cap. The footplate will prevent the entire observation well from lifting up when the cap is removed during future inspections.

H. Inspect the aggregate material before placement to ensure that it is clean and free of debris. The size of the material should be as specified on the approved plans.

I. Install a debris and grit trap consisting of fine-mesh screen covering the downspout (roof leader) to prevent objectionable materials from entering the aggregate subbase through the inflow pipe. Install roof gutter screens to protect gutters and grit traps from clogging due to wash-off of leaves, pine needles, etc. from the roof area.

J. Cap the observation well and measure and record the initial depth measured and noted on the inspection checklist.

Plate 8-5: Modular paving at the Auckland zoo

Modular block porous paving

These practices create road and parking lot surfaces that allow for stormwater runoff to travel through the surface into the ground. Under the porous surface, an aggregate material serves as a reservoir base for temporary storage of the runoff until the water infiltrates into the ground. Their best applications are in areas where there is a low volume of traffic or where overflow parking is needed on a periodic basis, and where subsoils have not been so compacted as to reduce the infiltration rate to below 3 mm/hr..

Lattice block is a modular unit which is generally placed in square sections. It is concrete with large void areas which are filled with a porous material, such as sand or pea gravel. Lattice block still should have filter course, reservoir course and filter fabric lining, prior to entry into the soil. Construction inspection should include the following items:

A. To help preserve the natural infiltration rate of the subgrade soils prior to excavation, prevent soil compaction of the infiltration paving area by heavy construction equipment. The area should be marked off and traffic kept off it to the greatest extent possible.

B. Verify the infiltration paving dimensions and location on site before construction. Verify distances to foundations, septic systems, wells, and so forth.

C. Carefully excavate the area of the paving to prevent excessive compaction of the soils during the subgrade preparation. All grading should be carried out using wide tracked equipment.

D. Once the subgrade has been reached, place filter fabric on the bottom. The type of fabric should be specified on the approved plans.

Plate 8-6: Example of a porous block parking area

E. Once the fabric has been placed, place the reservoir course to the design depth. This course should be clean, washed stone having a void ratio between 30 and 40%. Lay the reservoir course in 300 mm lifts and lightly compact it. Spread aggregate uniformly.

F. Place the aggregate filter on the reservoir course using clean washed stone ranging in size from 10 - 20 mm This stone provides a uniform base for the lattice course.

G. Never let sediments enter the infiltration paving construction area.

H. Lay the surface course. Fill the void areas of the lattice block with the appropriate specified material.

8.7.2 As-built plans

Where consent conditions require, there may be a requirement for an As-Built Plan to verify that construction was done in accordance with the approved consent.

The As-built plan should verify that:

1. Dimensions of the practice meet design dimensions
2. Filter fabric meets specifications
3. Aggregate material is sized as specified
4. Observation well is installed as required
5. Required pretreatment practice is in place
6. Contributing catchment is stabilised
7. Aggregate filter course is placed as required for modular paving
8. Porous surface course is installed properly for modular paving
9. Where appropriate, lattace area is backfilled correctly

8.8 Operation and maintenance

Maintenance issues are generally related to one of two major concerns:

> clogging
> standing water

Clogging of these practices can occur when sediments enter the facility and seal the soil surface, preventing infiltration of runoff. Clogging can also occur if excess oils and greases enter the practice, or from microorganism growth which results when water stands too long in the facility. Whatever the reason, clogging will cause failure of infiltration practices creating long term problems.

Infiltration practices must dry out between storm events to provide maximum stormwater management benefits. Clogging means less runoff is infiltrated and more goes into the overflow system on a more frequent basis. Clogging may also mean that water is permanently present in the facility, which can then become a mosquito breeding area.

Standing water can also result from seasonal high water tables or ground water mounding in the vicinity of the facility. If either of these problems occur, the practice's performance will depend on exfiltration out of the sides instead of the bottom.

Maintenance inspections must identify if there is standing water during a period of time when it hasn't rained. If so, then the cause must be determined whether clogging of the facility, seasonal water table conditions or ground water mounding. This analysis is crucial for determining the next steps. If clogging is the reason, maintenance activities will need to be performed to restore desired infiltration rates.

If the problem is caused by a high water table or mounding or persistent clogging, an entire new strategy will be needed to correct the problem. This could include conversion of the infiltration practice to a practice which includes a permanent pool of water such as a wet detention or constructed wetland system, or providing the practice with a structural outlet to prevent seasonal or permanent water pooling. If either of these options are necessary, the appropriate inspection and/or approval agency should be contacted to ensure approval of the modifications. In such cases, future inspections will be based on the modifications rather than maintaining expectations associated with the originally approved and constructed facility.

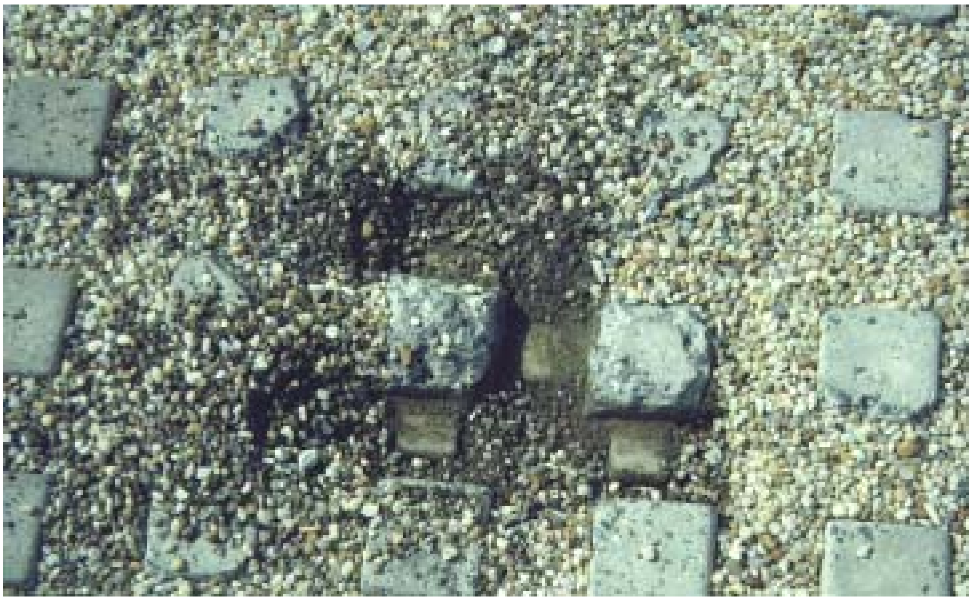


Plate 8-7: Modular paving with pea gravel filler

If the practice is totally clogged, correction is much more difficult. The practice should be drained and allowed to dry out before removing sediments. If sediment removal is attempted while water is standing in the practice, the finer sediments will become suspended and not be removed. These suspended sediments are responsible for the initial clogging of the practice, and their resuspension will last only until quiescent conditions allow for resettlement. The practice will never achieve the desired re-establishment of infiltration rates.

Safeguards should be installed during construction to reduce maintenance concerns. However, even with design and construction being sensitive to future maintenance, maintenance problems will occur as they do for all stormwater management practices. For example, to facilitate maintenance, rock filled infiltration trenches should be designed to have filter fabric placed approximately 300 mm below the surface of the practice. This fabric is a design point of failure which allows the underlying stone to remain clean. If standing water persists on the surface of the practice, the top 300 mm of stone should be removed and the filter fabric removed and replaced. This design prevents the need to replace the entire stone reservoir base.

Lattice block systems are unique. Pretreatment for reduced maintenance cannot be designed into them as for other infiltration practices by using biofiltration, fabrics or forebays. Design options to reduce maintenance for infiltration paving are predominantly limited to

- using them in areas of low traffic, where paving is still necessary
- specifying a certain frequency of inspection, infiltration rate verification and block removal and sediment cleanout..

Education is especially important in reducing maintenance requirements of infiltration paving practices. It is very important that owners are aware of the pervious nature of the paving surface. A common approval condition may be to require that signs be placed around the parking area to notify all users that the surface is pervious, and that sediment tracking needs to be minimised. Covenents also alert owners of the need for in-kind replacement of the pervious pavement, if needed.

Lattice block paving can include filter fabric under the blocks to facilitate future maintenance. When maintenance is necessary, the lattice block can be lifted up in individual sections, the filter fabric under the block replaced, and the blocks restored to their original places. However, some form of maintenance will probably be necessary on an annual basis.

8.9 Case study

The development is a 1/2 hectare commercial site that is 50% impervious and 50% grassed with a loam soil. The water quality storm is 27 mm of rainfall. The measured infiltration rate is 14 mm/hr. Use 1/2 of that rate for factor of safety = 7 mm/hr. Soil is a silt loam.

1. Water quality storm is 1/3 of the 2 year - 24 hour rainfall - in this case 27 mm of rainfall
2. Water quality volume is determined by use of TP 108: calculations for the post-development catchment give:
   Runoff depth from pervious areas = 4.4 mm
   Runoff volume from pervious areas = 11 m^3
   Runoff depth from impervious areas = 22.7 mm
   Runoff volume from impervious areas = 57 m^3
   Total runoff volume = 68 m^3 = WQV
3. Size the practice area

$$A_s = \frac{WQV}{((f_d)(i)(t) - p)} \qquad = 68\ m^3/\ ((.007\ m/hr)(1)(48\ hr) - .027\ m) = 220\ m^2$$

4. Size the storage volume

$$V_t = 0.37(WQV + pA)/V_r = 0.37((68\ m^3 + (.027\ m)(220\ m^2))/0.35 = 78\ m^3$$

   The required minimum depth of trench is therefore 78 m^3/220 m^2 = 0.355 m

8.10 Bibliography

Ferguson, Bruce, Stormwater Infiltration, CRC Press, Inc., Boca Raton, Florida, U.S.A., 1994

Horner, R., Skupien, J., LIvingston, E., Shaver, E., Fundamentals of Urban Runoff Management: Technical and Institutional Issues, Terrene Institute, August, 1994.

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Infiltration practice Inspection forms

Construction inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SEDIMENT / STORMWATER MANAGEMENT DRY WELL CONSTRUCTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Pond Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION					10. Clean / washed material	Y	N		
1. Runoff diverted	Y	N			11. Placed properly	Y	N		
2. Area stabilised	Y	N			**OBSERVATION WELL/ROOF LEADER**				
EXCAVATION									
3. Size & Location	Y	N			12. Pipe size	Y	N		
4. Side slope stable	Y	N			13. Removable cap/footplate	Y	N		
5. Soil Permeability	Y	N			14. Initial depth = _____m	Y	N		
6. Groundwater / Bedrock	Y	N			**FINAL INSPECTION**				
FILTER FABRIC PLACEMENT					15. Pretreatment facility in place	Y	N		
7. Fabric specification	Y	N			16. Debris / gutter screens	Y	N		
8. Placed on bottom, sides, & top	Y	N			17. Stabilisation	Y	N		
AGGREGATE MATERIAL					18. Outlet	Y	N		
9. Size as specifed	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____________________

1st Notice: ____________________

2nd Notice: ____________________

Submit plan modifications as noted in written comments by ____________________

Notice to Comply issued ____________________

Final inspection, project completed ____________________

Officers signature: ____________________

Consent Holder/Engineer/Agent's signature: ____________________

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

INFILTRATION TRENCH CONSTRUCTION INSPECTION FORM	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Infiltration Trench Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION					10. Clean / washed material	Y	N		
1. Runoff diverted	Y	N			11. Placed properly	Y	N		
2. Area stabilised	Y	N			**OBSERVATION WELL**				
EXCAVATION					12. Pipe size	Y	N		
3. Size & location	Y	N			13. Removable cap / footplate	Y	N		
4. Side slope stable	Y	N			14. Initial depth = _______m	Y	N		
5. Soil Permeability	Y	N			**FINAL INSPECTION**				
6. Groundwater / Bedrock	Y	N			15. Pretreatment facility in place	Y	N		
FILTER FABRIC PLACEMENT					16. Stabilisation	Y	N		
7. Fabric specification	Y	N			17. Outlet	Y	N		
8. Placed on bottom, sides, & top	Y	N							
AGGREGATE MATERIAL									
9. Size as specified	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____________________

1st Notice: ____________________

2nd Notice: ____________________

Submit plan modifications as noted in written comments by ____________________

Notice to Comply issued ____________________

Final inspection, project completed ____________________

Officers signature: ____________________

Consent Holder/Engineer/Agent's signature: ____________________

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (**Under Section 332 of the Resource Management Act 1991**)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

INFILTRATION MODULAR PAVING CONSTRUCTION INSPECTION FORM	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required	

Infiltration Modular Paving Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION					10. Clean / washed material	Y	N		
1. Runoff diverted	Y	N			11. Placed properly	Y	N		
2. Area stabilized	Y	N			**AGGREGATE FILTER COURSE**				
EXCAVATION					12. Size as specified	Y	N		
3. Size & location	Y	N			13. Clean / washed material	Y	N		
4. Side slope stable	Y	N			14. Place properly	Y	N		
5. Soil Permeability	Y	N			**POROUS SURFACE COURSE**				
6. Groundwater / Bedrock	Y	N			15. Proper installation	Y	N		
FILTER FABRIC PLACEMENT					**FINAL INSPECTION**				
7. Fabric specification	Y	N			16. Lattace area backfilled correctly	Y	N		
8. Placed on bottom, sides, & top	Y	N			17. Final stabilization	Y	N		
AGGREGATE BASE COURSE									
9. Size as specified	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____

1st Notice: ____

2nd Notice: ____

Submit plan modifications as noted in written comments by ____

Notice to Comply issued ____

Final inspection, project completed ____

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: _________________________________

Infiltration practice
Inspection forms
Operation and maintenance inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

INFILTRATION DRY WELL MAINTENANCE INSPECTION CHECKLIST	:	Needs immediate attention	V	Okay	;	Clarification Required	
	9	Not Applicable					

	"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
	"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
	"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Infiltration Dry Well Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**	**INLETS**	Y	N	Y	N	**A**
1. Roof drains & downspouts clean						6. Good condition of down spouts					
VEGETATION ON TOP OF DRY WELL						7. No evidence of deterioration					
2. Mowing done when needed					**M**	8. Roof gutters drain correctly into dry well					
3. Fertilised per specifications						**OUTLETS / OVERFLOW SPILLWAY**					**A**
4. No evidence of erosion					**M**						
DEWATERING						9. Good condition, no need for repair					
5. Dry well dewaters between storms											
						10. No evidence of erosion					

Inspection Frequency Key A = Annual, M = Monthly

OFFICERS REMARKS:

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OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ____________________________

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Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

INFILTRATION TRENCH MAINTENANCE INSPECTION CHECKLIST	:	Needs immediate attention	V	Okay	;	Clarification Required
	9	Not Applicable				

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Infiltration Trench Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**	**INLETS**	Y	N	Y	N	**A**
1. Trench surface clear of debris						13. Good condition					
2. Inlet areas clear of debris						14. No evidence of erosion					
3. Inflow pipes clear of debris						**OUTLETS/OVERFLOW SPILLWAY**					**A**
4. Overflow spillway clear of debris						15. Good condition, no need for repair					
SEDIMENT TRAPS, FOREBAYS, OR PRETREATMENT SWALES					**A**	16. No evidence of erosion					
5. Obviously trapping sediment						**AGGREGATE REPAIRS**					**A**
6. Greater than 50% of storage volume remaining						17. Surface of aggregate clean					
VEGETATION					**M**	18. Top layer of stone does not need replacement					
7. Mowing done when needed						19. Trench does not need rehabilitation					
8. Fertilized per specifications						**VEGETATED SURFACE**					**M**
9. No evidence of erosion						20. No evidence of erosion					
DEWATERING					**M**	21. Perforated inlet functioning adequately					
10. Trench dewaters between storms						22. Water does not stand on vegetative surface					
SEDIMENT CLEANOUT OF TRENCH					**A**	23. Good vegetative cover exists					
11. No evidence of sedimentation in trench											
12. Sediment accumulation does not yet require cleanout											

Inspection Frequency Key A = Annual, M = Monthly

OFFICERS REMARKS:

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OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: _______________________________

Consent Holder/Engineer/Agent's signature: _____________________________

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Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

MODULAR PAVING MAINTENANCE INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Modular Paving Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS ON INFILTRATION PAVING PARKING AREA	Y	N	Y	N	**M**	**DEWATERING**	Y	N	Y	N	**M**
1. Paving area clean of debris						5. infiltration paving dewaters between storms					
VEGETATION (ANY BUFFER AREA OR PREVIOUS AREAS IN DRAINAGE AREA					**M**	**SEDIMENTS**					**M**
						6. Area clean of sediments					
						STRUCTURAL CONDITION					**A**
2. Mowing done when needed						7. No evidence o f surface deterioration					
3. Fertilised per specification											
						8. No evidence of rutting or spalling					

Inspection Frequency Key A = Annual, M = Monthly

OFFICERS REMARKS:

L:\Lr\stormwater\Revised Templates for Inspection\Maintenance Inspection Forms\Modular Paving Maintenance.doc

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ____________________________

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Chapter 9
Swale and filter strip design, construction and maintenance

9.1 Introduction

Swales and filter strips use vegetation in conjunction with slow and shallow-depth flow for stormwater runoff treatment. As runoff passes through the vegetation, contaminants are removed by the combined effects of filtration, infiltration, adsorption, and biological uptake. Vegetation also decreases the velocity of flow and allows for particulates to settle.

The principal difference between swales and filter strips is that swales accept concentrated flow while filter strips accept flow as distributed or sheet flow.

Contaminant removal depends on the residence time of water through the swale or filter strip and the depth of water relative to the height of vegetation. Good contact with vegetation and soil is required to promote the operation of the various mechanisms that capture and transform contaminants, so spreading flow in minimal depth over a wide area is best.

Water residence time depends on the:

- volume of runoff
- the velocity at which it travels
- the length over which it flows

Velocity is a function of the area of flow, the slope and the friction imparted by the vegetation. Swale and filter strip performance depends on a number of geometric, hydrologic and hydraulic variables including:

- swale or filter strip width and length
- flow depth and velocity
- volumetric flow rate
- slope
- vegetation characteristics including density and height

Any or all of these variables can theoretically be manipulated to maximise water residence time and contact and achieve a desired level of performance.

The design guidance provided here enables swales and filter strips to achieve compliance with Regional Plan requirements for water quality. If a specific site does not allow for optional design, smaller swales and filter strips may still provide significant benefit if implemented in conjunction with other practices to provide pre-treatment as part of a treatment train component.

9.2 Water quality performance

The passage of stormwater through vegetated swales utilises a number of physical, chemical, and biological factors to reduce stormwater contaminants.

Physical factors include:

- reduction of flow speed by the vegetation to improve settlement

> filtration by the dense vegetation
> the rough nature of the soil/vegetation interface which improves retention of settled material and reduces resuspension
> infiltration, which in suitable soils can be a major contaminant removal and volume reduction mechanism.

Chemical factors include:

> contact between stormwater contaminant and the abundant organic matter in swales which can result in complexing and adsorption
> chemical conversion of soluble contaminants to insoluble forms.

Biological factors include:

> microorganisms which degrade organic contaminants
> uptake of nutrients and contaminants by swale vegetation
> the provision of large surface areas of vegetation to which contaminants become absorbed

Plate 9-1: Example of a well designed and maintained swale

9.2.1 Suspended solids

Khan et al (1992) showed that a 60 m long swale used to treat runoff from a 6 hectare suburban catchment achieved an average suspended solids concentration reduction of 83% for six storms.

Yousef et al (1987) reported mass reductions that were much higher than concentration reductions, indicating the importance of infiltration in the systems they studied.

Barrett et al (1998) reported a TSS load removal of 86% in field monitoring of storm events in Texas USA. Yu et al (2001) recorded mass removal of TSS averaging 94%.

Wong, (undated) states that reported removal efficiencies of suspended solids range from 25% to 80% depending on the grading of the suspended solids in the stormwater.

Fletcher (2002) reported TSS concentration reduction of 73-94% (mean 83%) and mass reduction of 57-88% (mean 69%) for a synthetic stormwater with TSS concentration of 150 mg/L. Fletcher (2002) showed that the reduction in TSS concentration during passage through the swale was lower at higher hydraulic loadings. Larger TSS particles were found to settle out rapidly, while smaller particles remained in suspension. Fletcher (2002) concluded that swale length (as a measure of hydraulic loading or detention time) has a significant impact on TSS removal performance, particularly if fine particles are present. In cases where fine material is of specific concern and available swale length is limited, other measures such as bioretention systems or wetlands may be required.

The ARC funded a monitoring project of an existing grassed swale that was not designed in accordance with these guidelines to get a rough estimate of performance. The swale selected was adjacent to the Albany to Orewa motorway approximately one kilometre south of the Silverdale interchange, adjacent to the south-bound lanes of the motorway. The results were highly vaiable (20 storms total) with results between -100% and 76% reduction. The ratios of suspended solids to turbidity for inflow and outflow samples were significantly different, although there was no obvious reason why the outflow suspended solids and turbidity were often higher than inflow suspended solids and turbidity.

9.2.2 Heavy metals

Khan et al (1992) showed that stormwater-borne metals attached to particulates such as lead, zinc, iron and aluminium were reduced by 63-72% during passage through a 60 metre swale. Metals less attached to particulates such as copper and dissolved metals, had generally low removals.

In the motorway monitoring project, passage of the motorway stormwater through the trial swale achieved consistent removals of total copper (average removal 60%), total lead (average removal 90%) and total zinc (average removal 80%).

9.3 Applicability

Swales and filter strips may be used in a variety of land uses including residential, commercial, and industrial. They are typically located on property boundaries or adjacent to impervious surfaces where they can substitute for kerb and gutter. When used, they should be incorporated into site drainage, street drainage and drainage planning. As they are effective for lower and velocities and volumes, the size of the contributing catchment (under 4 hectares) and the associated volume of runoff need to be limited.

Swales and filter strips are aesthetically pleasing than concrete and are generally less expensive to construct.

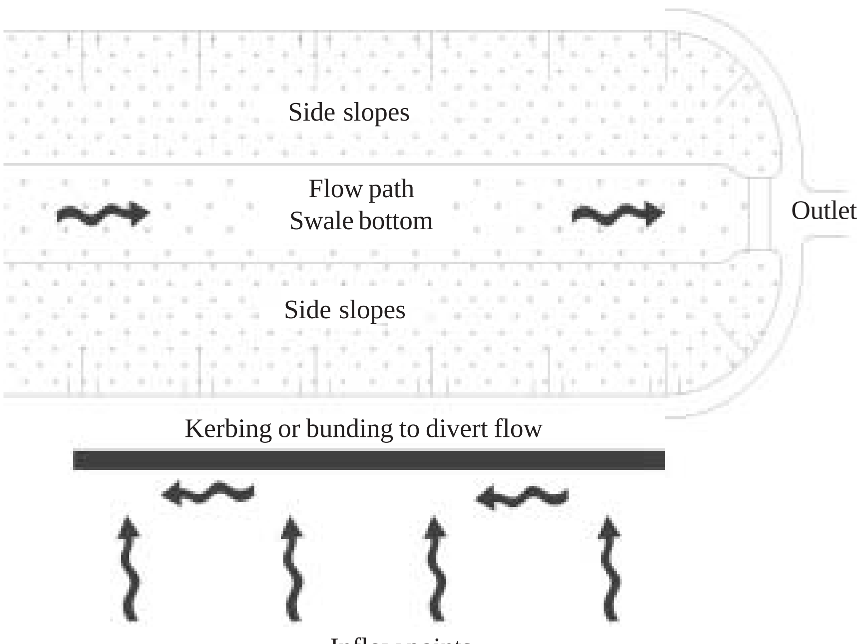
Dense grasses reduce flow velocities and protect against erosion during larger storm events.

Swales and filter strips can be used as the pretreatment or polishing segment of a treatment train, or for basic treatments for contaminated stormwater runoff from roadways, driveways, car parks and highly impervious ultra-urban areas. In cases where hydrocarbons, high TSS or debris are present in the runoff, such as high use sites, a pretreatment (or post treatment) system for those components would be necessary.

Swales or filter strip design needs to consider paths for flows that exceed water quality storms. To protect receiving environment water quality, it is better for larger flows to bypass swales or filter strips, as flow velocities would reduce water quality performance. However most higher flows will travel through them, and velocities for these larger events must be considered, less for water quality performance than for erosion control. If a 10% storm is passed through swales or check dams, the velocity of flow should not exceed the maximum velocities shown in Table 9-1 in order to prevent resuspension of deposited sediments.

Inflow points are another consideration for swale performance. A swale accepting inflow of stormwater throughout its length will not provide the necessary residence time to provide treatment for all the inflow. For proper treatment, all inflow must be diverted to an inlet point that gives a long enough flow path flow to achieve the appropriate residence time as shown in Figure 9-1.

Figure 9-1
Swale with flow diversion to inlet



9.4 Objectives

Swales and filter strips have different objectives.

9.4.1 Vegetated swales

Vegetated swales can take the place of conventional stormwater conveyance systems. Piped systems such as kerb and channel with catchpits provide no water quality function and may worsen receiving system impacts by increasing flow velocities and erosive forces. Although vegetated swales vary in their intended objectives and design, their overall objective is to slow stormwater flows, capture some contaminants and reduce the total volume of runoff.

Plate 9-2: Swale monitoring location south of Silverdale

Swales act in two ways to affect stormwater flows:

> Conveyance of water in a swale decreases in the velocity of flow as compared with conventional storm drainage because as the water passes over and through the vegetation, it encounters resistance.
> Water quality can also be affected by passage through vegetation. Physical, chemical, and biological processes occur that reduce contaminant delivery downstream.

Table 9-1 provides some general guidance on swale and filter strip design.

Table 9-1
Design criteria

Design parameter	Swale	Filter strip
Applicable longitudinal slope	1% - 5%	1% - 5%
Maximum velocity	0.8 m/s (WQ storm)	0.4 m/sec (WQ storm)
Maximum water depth above vegetation (WQ storm)	100 mm	25 mm
Manning coefficient	See equations in Section 9.6.2	
Maximum bottom width	2 m	NA
Minimum hydraulic residence time	9 minutes	9 minutes
Maximum catchment area served	4 hectares	4 hectares
Minimum length	30 m	sufficient to attain residence time
Maximum side slope	3H:1V (shallower if possible for mowing purposes)	NA
Maximum drainage flowpath	NA	50 m
Maximum longitudinal slope of contributing area	NA	5% unless energy dissipation is provided
Maximum lateral slope	0%	2%

9.4.2 Filter strips

Plate 9-3: Detail of a swale check dam

Filter strips intercept stormwater flows before they become concentrated and then distribute the flow evenly across the filter strip. As the water travels across the filter strip it slows down due to frictional resistance of the vegetation to flow. Some of the runoff may infiltrate into the ground.

Redirecting stormwater runoff from impervious surfaces to filter strips could be termed 'hydrologic disconnection', with the objective being to minimise volumes of stormwater diverted to reticulation. In these cases, footpaths and driveways and other impervious features are designed to drain evenly onto adjacent areas, not into a piped system.

An excellent example of a filter strip is the riparian buffer zone, where a sensitive stream system is buffered from stormwater off adjacent developed areas. Although the full range of functions provided by the riparian buffer zone are more complex than the filter strip, conceptually the riparian buffer zone is an elaborate filter strip.

9.5 Design approach

Several swale and filter strip design factors can increase or decrease their performance for water quality treatment.

9.5.1 Factors that increase performance

- low slopes
- permeable soils or underdrainage
- dense grass cover
- longer lengths
- use in conjunction with other practices
- use of check dams for swales

9.5.2 Factors that decrease performance

- compacted soils
- short residence time
- large storm events
- short grass heights

Plate 9-4: Swale level spreader to maintain dispersed flow in swale bottom

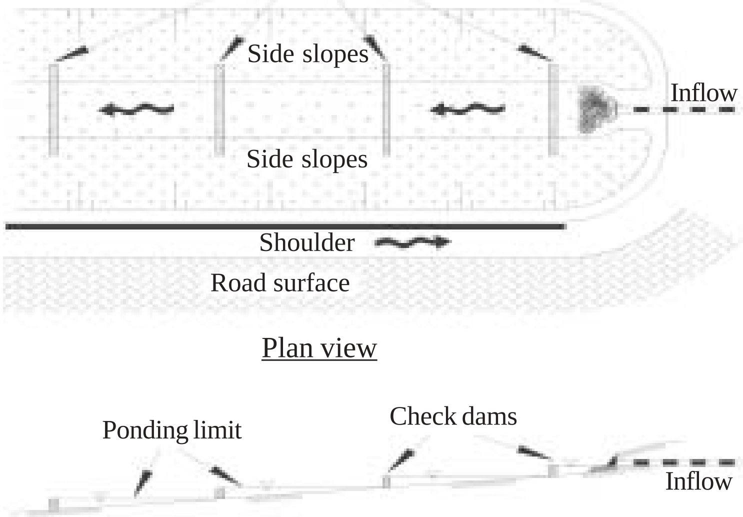
> steep slopes
> high runoff velocities
> dry weather flow
> damage from vehicles

Swales with slopes of less than 2% need a perforated pipe underdrain.

Slopes greater than 5% need check dams to reduce flow velocities. Check dams are installed so that the crest of the downstream dam is at the same elevation as the toe of the upstream dam.

Level spreaders must be installed at the head of any swale greater than a 5% slope and every 15 metres to ensure flow uses the entire swale bottom. The level spreaders can be used to also meet checkdam requirements. A detail of swales with check dams is provided in Figure 9-2.

Figure 9-2
Swale with check dam detail



9.6 Design procedure

The procedures for swale and filter strip design are basically the same. The steps are given in full for swales, and notes are included to allow the procedure to be applied to filter strips.

9.6.1 Initial steps

1. Estimate runoff flow rate for the water quality storm. Use 1/3 of the 2-year 24-hour rainfall as the water quality storm and calculate the runoff according to TP 108, with separate calculations for pervious and impervious areas.

   Swales are practicable only for small catchments for which TP 108 sets the time of concentration (t_c) to 10 minutes, and it is therefore possible to replace part of the TP 108 calculation routine with a formula. An example is provided in the case study.

   The calculation steps are then:

   (a) Determine the water quality storm depth $P_{24} = P_{24,2\text{-year}}/3$, obtaining $P_{24,2\text{-year}}$ from Fig. A1 of TP 108.

   (b) Calculate the peak rainfall rate = $16.2xP_{24}/24$ hours

   (c) Calculate Storage (S) for pervious surfaces from eq. 3.2 in TP 108:
   S = 25.4(1000/CN-10).

   (d) Calculate the peak runoff rate from the pervious surfaces, with I_a = 5 mm:
   Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/P_{24} - 2I_a + 2S)^2$
   Peak runoff rate = P_{24} x Pervious area x (Runoff/Rainfall)

   (e) Repeat the last two steps for impervious surfaces, using CN = 98 (so that S = 5.2 mm) and $I_a = 0$

   (f) Add the two peak runoff rates to get the peak runoff rate for the catchment.

(g) Multiply by 0.89 to allow for peak dampening due to the 10 minute time of concentration. The result is the peak outflow from the catchment and the design flow rate for the swale or filter strip.

2. Establish the slope of the swale or filter strip

3. Select a vegetation cover

<u>9.6.2 Design steps</u>

1. Select the type of vegetation and design depth of flow

2. Select a value of Manning's n (equations developed from swale study project, 2003)

   For 150 mm grass and $d < 60$ mm $n = 0.153\ d^{-0.33} /(0.75 + 25s)$
   $d > 60$ mm $n = 0.013\ d^{-1.2} / (0.75 + 25s)$

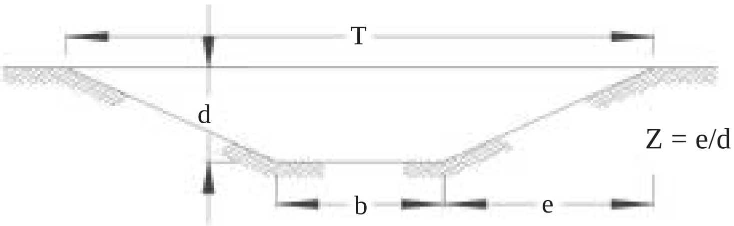
   For 50 mm grass and $d < 75$ mm $n = (0.54\text{-}228\ d^{2.5}) / (0.75 + 25s)$
   $d > 75$ mm $n = 0.009d^{-1.2} /(0.75 + 25s)$

   Where:
   d = depth of flow (m) for water quality storm
   s = longitudinal slope as a ratio of vertical rise/horizontal run (m/m)

3. Select a swale shape (trapezoid or parabolic) from Figure 9-3.

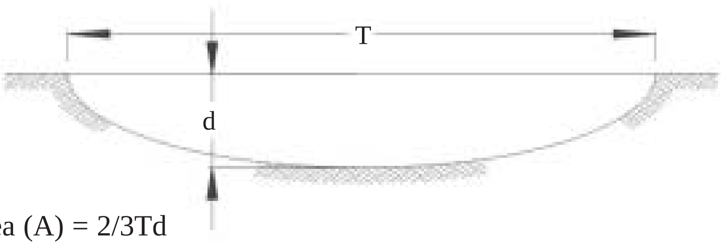
4. Use Manning's equation and first approximations relating hydraulic radius and dimensions for the selected shape (use a trapezoidal shape for a swale or a rectangular shape for a filter strip) to obtain a working value of a swale or filter strip width dimension

Figure 9-3
Channel geometry



Cross sectional area (A) = $bd + Zd^2$
Top width (W) = $b + 2dZ$

$$\text{Hydraulic radius (R)} = \frac{bd + Zd^2}{b + 2d\,(Z + 1)^{1/2}}$$



Cross sectional area (A) = 2/3Td
Top width (W) = 1.5A/d

$$\text{Hydraulic radius (R)} = \frac{T^2d}{1.5T^2 + 4d^2}$$

$Q = AR^{0.67}s^{0.5}/n$ (1)

$A_{rectangle} = Td$ (2)

$R_{rectangle} = Td/(T+2d)$ (3)

Where:

Q = design runoff flow rate (m^3/s, cms)
n = Manning's n (dimensionless)
s = longitudinal slope as a ratio of vertical rise/horizontal run (m/m so dimensionless)
A = cross-sectional area (m^2)
R = hydraulic radius (m)
T = top width of trapezoid/parabolic shape or width of a rectangle
d = depth of flow (m) for water quality storm
b = bottom width of trapezoid (m)

If equations (2) and (3) are substituted into equation 1 and solved for T, complex equations result that are difficult to solve manually. However, approximate solutions can be found by recognising that T>>d and z^2>>1, and that certain terms are nearly negligible. The approximation solutions for rectangular and trapezoidal shapes are:

Rrectangle = d   Rtrapezoid = d   Rparabolic = 0.67 d   Rv = 0.5d

Substituting Rtrapezoid and Atrapezoid = bd+Zd^2 into equation (1), and solve for the bottom width b (trapezoidal swale)

$b = (Qn / d^{1.67}s^{0.5}) - Zd$

For a trapezoid, select a side slope Z of at least 3. Compute b and then top width T, where T = b + 2dZ.

b for a filter strip can be as great as uniform flow distribution can be assured. For a parabolic swale configuration, refer to figure 9-3.

5. Calculate A:

$A_{rectangle} = Td$ or $A_{trapezoid} = bd + Zd^2$

$A_{filter\ strip} = Td$

6. Calculate the flow velocity at design flow rate:

$V = Q/A$

If V > 0.8 m/sec (or V > 0.4 m/sec. for filter strip), repeat steps 1 - 6 until the condition is met. A greater velocity will flatten grasses and reduce filtration. A velocity lower than this maximum value will allow a 9 minute hydraulic residence time. If the value of V suggests that a longer swale or filter strip will be needed than space permits, investigate how Q can be reduced, or increase d and/or T and repeat analysis.

7. Calculate the swale length (L, metres)

L = Vt (60 sec/min)

Where t = hydraulic residence time (min)

Use t = 9 minutes for this calculation.

If, from the analysis, the length is less than 30 metres, increase it to 30 metres (the minimum allowed).

8. If there is still not enough space for the swale or filter strip, the following solutions should be considered:

   > divide the site drainage to multiple swales or filter strips
   > increase vegetation height and design depth of flow (the design must ensure that the vegetation remains standing during the design storm).
   > reduce the developed surface area to gain space
   > increase the longitudinal slope
   > use the swale or filter strip in conjunction with another stormwater practice.

9.6.3 Check for stability

If runoff from events larger than the water quality design storm goes through the swale or filter strip, perform a stability check for the 10 year, 24 hour storm using TP 108. Estimate Q for that event as recommended in item 1 of the Initial Steps. For the 10 year storm, the flow velocities are required to be less than 1.5 m/sec, although higher velocities may be allowed if erosion protection is provided.

9.7 Plant material

Vegetative cover in a swale or filter strip generally consists of a continuous and dense cover of relatively long grass. In swales the grass should be maintained at heights of typically 150 mm and not less than 100 mm and should stay at these heights with minimal care. In filter strips, grass can be shorter (50 mm) since flow depths over the filters are generally small. Dense and well developed grass reduces the water velocity and improves performance.

9.7.1 Wetting

Grass species should be able to withstand periodic wetting, including total submergence for short periods in summer, and continued wetting and periods of total submergence in winter. Mowing will be restricted during the winter due to wet conditions.

9.7.2 Species

The most common grass used for swales in the Auckland Region is perennial rye grass species.

9.8 Wetland swales

Plate 9-5: Wetland swale

A wetland swale is a variation of a basic swale for use where the longitudinal slope is slight, water tables are high, or continuous low base flow is likely to result in saturated soil conditions. If soil is saturated for more than about two weeks, typical grasses will die.

The geometry of wetland swales is the same as that of normal swales except for the following modifications:

> The maximum bottom width may be increased to 7 metres, but a

length-to-width ratio of 5:1 must be provided. The minimum swale length remains at 30 metres.

- If longtitudinal slopes are greater than 5%, the wet swale must be stepped so that the slope within the stepped sections averages less than 5%.
- A high-flow bypass is required for flows greater than the water quality storm, to protect wetland vegetation from damage.
- Flows will be more protracted than in normal swales and more like flow in streams. Since vegetation growing in streams is often less dense, an increase in treatment area is needed to ensure that equivalent contaminant removal is achieved.

9.9 Construction

A key requirement of any vegetative treatment system is to obtain a stand of vegetation that can effectively filter runoff. Ideal vegetation characteristics include a dense, uniform growth of fine-stemmed plants that can tolerate soil saturation and the climatological, soil, and pest conditions of the area. Drainage areas are generally fairly small, less than 4 hectares.

It is essential to maintain proper hydraulic conditions to avoid uneven, channelised flows through the swale or filter strip. Uneven flow across its width reduces contaminant removal because runoff bypasses vegetation, shortening treatment time. Channelised flow also may erode swales or filter strips, exacerbating the downstream water quality problems that they were intended to mitigate.

9.9.1 Important inspection aspects related to design

Design of swales and filter strips is fairly straight forward. Their primary treatment process is filtering runoff through vegetation. It is important to note the following important design aspects of swales and filter strips.

1. The bottom width of swales should be no less than 600 mm if it is to be mowed and no greater than 2 metres to prevent concentration of flow.
2. Sequence of construction for overall site development and construction of the swale and filter strip.
3. Do the post-development drainage patterns resemble the pre-development ones? Placement of swales and filter strips along natural flow paths and contours should be detailed on the approved plans.
4. To assure even sheet flow in a swale or filter strip and avoid channelized flow, the bottom must be flat with no lateral slope across the bottom of the swale or vegetative filter strip.
5. The design of inflow to the swale or filter strip should quickly dissipate runoff velocity to minimise erosion potential. Dissipation practices such as riprap pads and level spreaders should be used.
6. Outflow from swales and filter strips should either be diffuse (to avoid erosion damage to downstream facilities or water bodies) or into a stable conveyance system. Swales should be equipped with raised storm drain outlets to prevent erosion.
7. Generally, swales should be longer than 30 metres to reduce short circuiting, with their total length depending upon the flow and the 9 minute minimum required residence time. No minimum width has been established for filter strips since this is a very site specific design parameter. These dimensions must be specified on the approved plans.
8. Longitudinal slopes should be fairly slight, with maximum slopes of 5% (can be greater with use of check dams if the check dams reduce slope to 5%).
9. Plant specifications must be on the approved plans. Grasses tend to be the superior choice of vegetation as they are resilient, somewhat stiff, dense, provide abundant surface area and can sprout through thin deposits of sand and sediments.
10. Pretreatment should be provided when high sediment inputs to swales or filter strips are likely.

9.9.2 Important inspection aspects related to construction

Construction activities should be phased to ensure the greatest practical amount of plant cover during the course of construction. If permanent swales and filter strips are installed during site construction, they either must be protected from construction site runoff or restored for long term use once site construction is completed. The following important aspects of construction should be noted:

Plate 9-6: Swale needing maintenance due to high sediment loads

1. Stake out site location for the swale or check dam to allow for dimensions, shapes, and slopes to be verified per the design plans.
2. Ensure that lateral slopes are completely level to avoid any tendency for the flow to channelize.
3. Ensure that inlets, outlets, and other auxiliary structures such as check dams or flow bypasses, are installed as specified.
4. Make sure that vegetation complies with planting specifications. Ensure that vegetation becomes uniformly dense for good filtration and erosion protection. Grass can be established by seeding or using sod. Seeding is generally preferred due to its lower cost and the greater flexibility it allows in selecting grass species. The method of vegetative stabilization should be discussed and approved at a preconstruction meeting.
5. Place the swale or filter strip so that no portion will be in the shade of buildings or trees throughout the entire day, as this will cause poor plant growth.
6. Make sure that construction runoff is not entering the swale or check dam. If it is, require removal of sediments and re-establish vegetation upon the completion of construction.
7. Ensure that measures are in place to divert runoff while vegetation is being established. If runoff is probable and cannot be diverted, ensure that adequate erosion control measures are in place.
8. Inspect liners, underdrains, riprap, and check dam spacing, if these are included in the approved plan.
9. Make sure that any level spreaders are completely level and stable enough to remain level during their operation.
10. Check for proper installation of pretreatment devices, if required.
11. Ensure that kerb cuts and their locations are as specified.

9.9.3 As-built plans

Where consent conditions require, there may be a requirement for an As-Built Plan to verify that construction was done in accordance with the approved consent.

The As-built plans should verify that:

1. Dimensions of the swale(s) match the design dimensions
2. Check dams and level spreaders constructed according to plan and are level
3. Inlets and outlets are constructed correctly
4. Lateral slopes are completely level
5. Longitudinal slopes are within design range
6. Flow bypasses are installed correctly.
7. Kerb cuts are installed correctly
8. Vegetation complies with planting specification and is suitably dense
9. Topsoil is adequate in composition and placement

9.10 Operation and maintenance

Plate 9-7: Woody vegetation may reduce grass filtering effectiveness

Physical filtration by vegetation is an important contaminant removal mechanism of swales and filter strips. Another may also be infiltration of stormwater runoff into the surrounding surface and subsurface soils.

Swales and filter strips are mainly susceptible to impaired performance from excess sediment smothering vegetation. Oils and greases can also be a serious concern as they can kill vegetation. These impacts could occur very quickly if large amounts of these contaminants are introduced in a short time frame.

Because the effectiveness of swales and filter strips depends on vegetative filtering of dispersed flow, as well as on infiltration of runoff into underlying soils, their maintenance focuses on:

- maintaining dispersed flow through the swale or filter strip
- maintaining a thick growth of vegetation
- preventing undesired overgrowth vegetation from taking over the site
- removal of accumulated sediments
- debris removal

Maintenance of dispersed flow through the swale or filter strip is critical for its ongoing treatment effectiveness. Concentrated flow travels at a higher velocity than does dispersed flow, and may transport contaminants straight through the practice instead of being removed by it.

Maintaining a dense growth of vegetation to enhance swale or filter strip performance requires periodic vegetation mowing by owners or operators. This must be correctly done. Mowing grass too short will damage the grass, increase runoff flow velocities, and thereby decrease pollutant removal effectiveness. If the grass grows too tall, it may be flattened during storms, also decreasing treatment effectiveness. Mowing during winter months when soils may be saturated could rut the swale or filter strip and concentrate flows.

Inspections must be done to ensure that the desired vegetation remains in the facility. The invasion of undesired vegetation can occur if site conditions promote its growth. In some situations the replacement of the planted vegetation by a volunteer species may be beneficial, but only if the invasive species provides equal or increased water quality benefits and is accepted by the property owners. If site slopes are very flat, the swale or filter strip could become dominated by wetland plants. The dense growth of wetland plants may be desired for stormwater treatment and also will reduce the typical mowing costs associated with them. In this situation, the maintenance file should document the shift in the plant community and provide guidelines for how to take care of the modified site condition.

Sediments accumulate in swales and filter strips and their removal may be their most expensive maintenance aspect. After sediment removal, it is essential to restore the slope and elevations to the originally constructed condition and re-establish the vegetation. Erosion control in the contributing drainage area will be necessary to prevent scour of the facility until there is once again a dense stand of vegetation.

Sediment may also impede effective performance by clogging inlets and preventing the entry of design storms into the practice. If stormwater backs up into the upstream drainage area, it may overflow to an area not intended to accept additional flow and may cause erosion and site instability.

As with other practices, debris removal is an ongoing maintenance need for all swales and filter strips. Debris, such as vegetative cuttings or garden/yard dumpings, if not removed can block inlets or outlets, cause flow to become concentrated and can be unsightly. Inspection and removal of debris should be done on a monthly basis, but debris should be removed whenever it is observed on site.

It is also important to know when you don't have to do maintenance. The original plan for the site provides the best information at that time on the design and construction of the swale or check dam, but over time the facility may change in appearance and function. These changes may not necessarily be bad. Having a knowledgeable inspector conduct regular inspections may be one way to allow a practice to evolve into an improved facility with reduced maintenance costs. The emergence of wetland plants in a swale or filter strip or the growth of native vegetation may improve its value and performance.

9.11 Case study

A swale is to be constructed in a road median strip in a residential subdivision that is located in Kumeu. The catchment area at the bottom of the swale is 2.0 hectares. The imperviousness is 40%, and the soils are clay.

Hydology

Water quality design storm is 1/3 of the 2 year-24 hour rainfall (81 mm) = 27 mm

Peak flow calculation:

Peak rainfall rate = 16.2 x 27 mm/24 hours = 18.2 mm/hour

Impervious area:

$I_a = 0$ and $S = 25.4(1000/CN - 10)$ mm = 5.2 mm

At peak rainfall, Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/P_{24} - 2I_a + 2S)^2 = 0.923$

Peak runoff rate = 18.2 mm/hour x 0.923 x 0.8 hectares = 0.037 m^3/s

Pervious area:

$I_a = 5$ mm and $S = 25.4(1000/CN - 10)$ mm = 89.2 mm

At peak rainfall, Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/(P_{24} - 2I_a + 2S)^2 = 0.264$

Peak runoff rate = 18.2 mm/hour x 0.264 x 1.2 hectares = 0.016 m^3/s

Combined peak runoff flow rate = 0.037 + 0.016 = 0.053 m^3/s

Correction for attenuation in the catchment:

Peak flow rate in swale = 0.89 x 0.053 m^3/s = 0.047 m^3/s

Design steps

1. Vegetation cover - grass, 50 - 150 mm tall, slope - 4%, design depth of flow 100 mm for water quality storm
   $d > 60$ mm $n = 0.013\, d^{-1.2} / (0.75 + 25s)$

2. Mannings n = 0.118

3. swale shape - trapezoidal with side slope Z = 3

4. Calculate the bottom width
   n = 0.118 d = 100 mm
   Q = .047 m^3/s s = .04
   Z = 3
   $b = (Qn / d^{1.67} s^{0.5}) - Zd$
   b = 1.2 m

calculate top width

$T = b + 2dZ$
$T = 1.3$ m

5. Calculate the cross-sectional area A

$A = bd + Zd^2$
$A = .15\ m^2$

6. Calculate the flow velocity

$V = Q/A$
$V = 0.31$ m/s which is less than the maximum allowed 0.8 m/s - good

7. Calculate the Swale length

$L = Vt$ (60 sec/min)(9 min.)
$L = 168$ metres for full water quality treatment

Since b is less than the maximum value, it may be possible to reduce L by increasing b. If reducing L to 100 metres is desired, then:

$V = L/60t = 0.185$ m/s
$A = Q/V = 0.25\ m^2$
$b = (A - Zd^2)/d = 2.2$ metres which is slightly greater than the allowable 2 m
If L was increased to 110 m, the bottom width would be allowable at the maximum 2 m width.

Once the water quality treatment calculations have been completed the design can be adjusted to accommodate additional flow from larger storms if the swale is to accept those events. This will necessitate increasing the freeboard of the swale. Calculate the Q for the larger event and ensure that flow velocities are less than 1.5 m/sec. unless erosion protection is provided.

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Swale and filter strip Inspection forms

Construction and operation and maintenance inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (**Under Section 332 of the Resource Management Act 1991)**	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SWALE & FILTER STRIP CONSTRUCTION INSPECTION FORM	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Swale & Filter Strip Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION	Y	N			12. Flow bypasses installed correctly	Y	N		
1. Runoff diverted	Y	N			13. Pretreatment devices installed	Y	N		
2. Facility area cleared	Y	N			14. Curb cuts installed per plans	Y	N		
3. Facility location staked out	Y	N			**VEGETATION**	Y	N		
4. Facility not in heavily shaded area	Y	N			15. Complies with planting specification	Y	N		
EXCAVATION					16. Topsoil adequate in composition & placement	Y	N		
5. Size & location	Y	N							
6. Lateral slopes completely level	Y	N			17. Adequate erosion control measures in place	Y	N		
7. Longitudinal slopes within design range	Y	N			**FINAL INSPECTION**				
CHECK DAMS & LEVEL SPREADERS					18. Dimensions	Y	N		
					19. Check Dams & level spreaders	Y	N		
8. Dimensions, spacing, & materials	Y	N			20. Proper outlet	Y	N		
9. Compaction	Y	N			21. Effective stand of vegetation & stabilisation	Y	N		
10. Level spreaders are completely level	Y	N			22. Construction generated sediment removed	Y	N		
STRUCTURAL COMPONENTS									
11. Inlets & outlets installed correctly	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ______________________________

1st Notice: ______________________________

2nd Notice: ______________________________

Submit plan modifications as noted in written comments by ______________________________

Notice to Comply issued ______________________________

Final inspection, project completed ______________________________

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ______________________________

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SWALE AND FILTER STRIP FACILITY MAINTENANCE INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required	

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Swale And Filter Strip Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**	**CHECK DAMS / ENERGY DISSIPATORS / SUMPS**	Y	N	Y	N	
1. Swales and filter strips and contributing areas clean of debris											
2. No dumping of yard wastes into swales or filter strips											
3. Litter (branches, etc) have been removed											
VEGETATION					**M**						
4. Plant height not less than design water depth											
5. Fertilised per specifications											
6. No evidence of erosion											
7. Grass height not greater than 250mm											
8. Is plant composition according to approved plans											
9. No placement of inappropriate plants											
DEWATERING					**M**						
10. Swales and filter strips dewaters between storms											
11. No evidence of standing water											

Inspection Frequency Key A = Annual, M = Monthly

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N   In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N   Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: ______________________________

Chapter 10
Oil and water separators

10.1 Introduction

Oil and water separation devices are applicable for treating stormwater runoff from areas where hydrocarbon products are handled (e.g. petrol stations, airports, storage terminals) or where small spills routinely fall on paved surfaces exposed to rain. Treatment should be as close to the source of the hydrocarbon products as possible to retain the oil in a floatable, non-emulsified form. Oil separators are not usually applicable for general urban runoff, because by the time the oil reaches the device it has emulsified or coated sediment in the runoff and is too difficult to separate.

The objective of oil and water separators is to treat most of the flow (90 to 95%) from the catchment to an acceptable degree (15 mg/l oil and grease) and to remove free floating oil, so as not to produce a discharge that causes an ongoing or recurring visible sheen in the stormwater discharge or in the receiving water.

Oil and water separators are not primarily designed to remove suspended sediment. Sites that generate both TSS and hydrocarbons will need separate treatment systems. The sediment laden runoff from other areas can be routed away from the separator and treated for sediment and other contaminant removal using other stormwater practices discussed in this manual.

Oil and water separators have significant benefits for spill containment. Spills enter the separator and mix with the water, then the oil in the spill will rise to the surface. All separators should hold the 2500 litres of oil that is the standard that has been agreed upon by the oil industry.

10.2 Types of oil and water separators

This manual only accepts API and plate separators achieving the goal of removal of oil and grease down to approximately 15 mg/l. Historical practices such as the triple interceptor tank (TIT) are no longer accepted by the ARC as meeting water treatment expectations.

API tanks are shown in Figure 14-1 and separators which contain packs of closely separated coalescing collection plates, are shown in Figure 14-2. These devices are designed to remove oil droplets from runoff, and hence provide more treatment than other practices. API tanks which use baffles were designed by the American Petroleum Council for use in refinery applications.

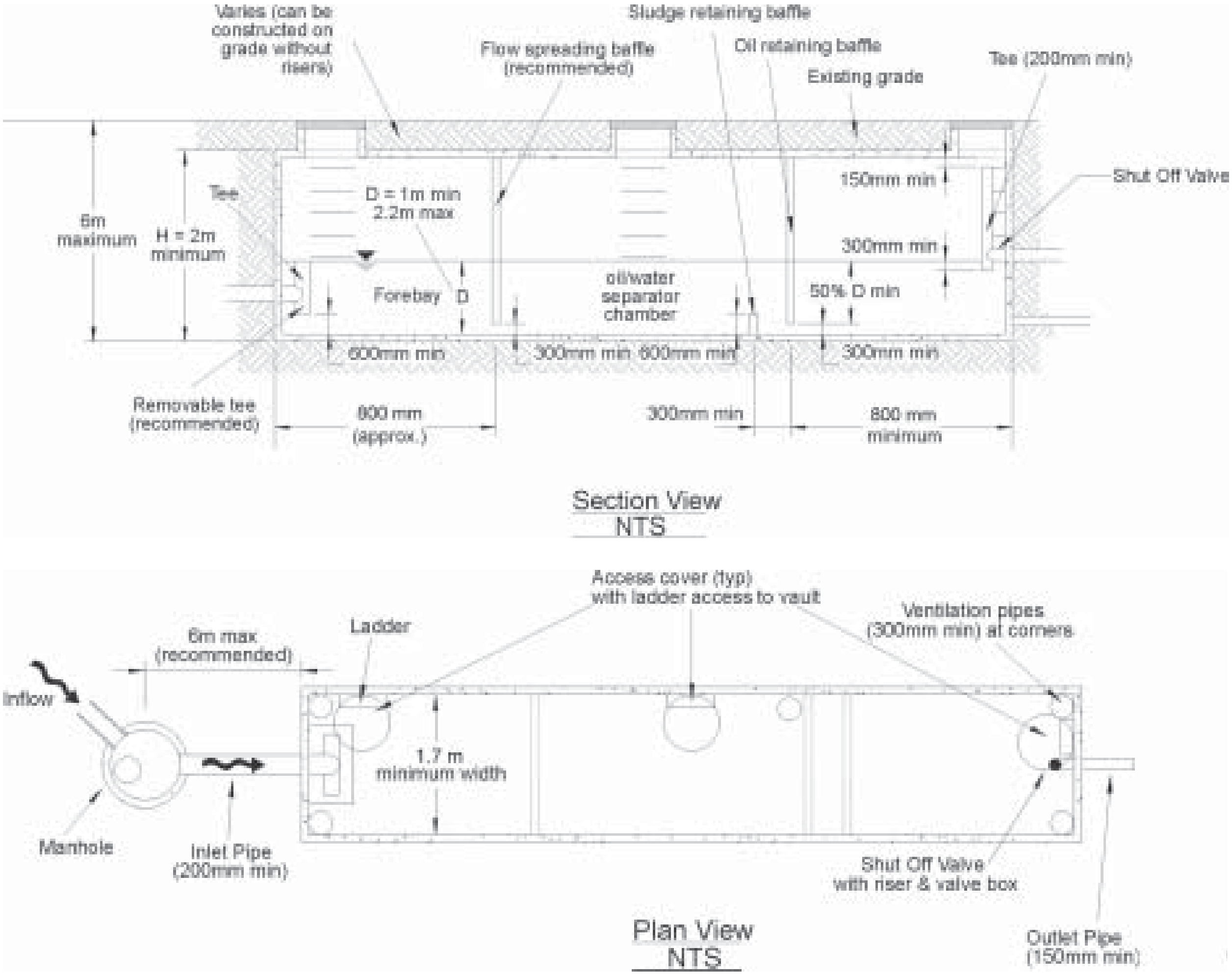
Plate separators contain packs of plates, typically spaced at 10-20 mm centres. The plates increase the effective surface of the device. Viewed another way, the close spacing of the plates reduces the height that an oil droplet must rise before it reaches a collecting surface. Therefore, to achieve the same degree of treatment as an API tank, a smaller device can be used.

The flow through the plate pack may be either downward (against the direction of the rising droplets) or across (where the flow is not biased in the direction of either sediment or droplets).

10.3 Water quality performance

There is concern that oil and water separators used for stormwater treatment have not performed to expectations (Schueler, Shepp, 1993) due to poor design or the need for very frequent maintenance (which is not

Figure 10-1
API separator schematics



done). Therefore, emphasis must be given to proper application, design, operation and maintenance and prevention of plugging. Other treatment systems, such as sand filters should be considered for the removal of insoluble oil and TPH.

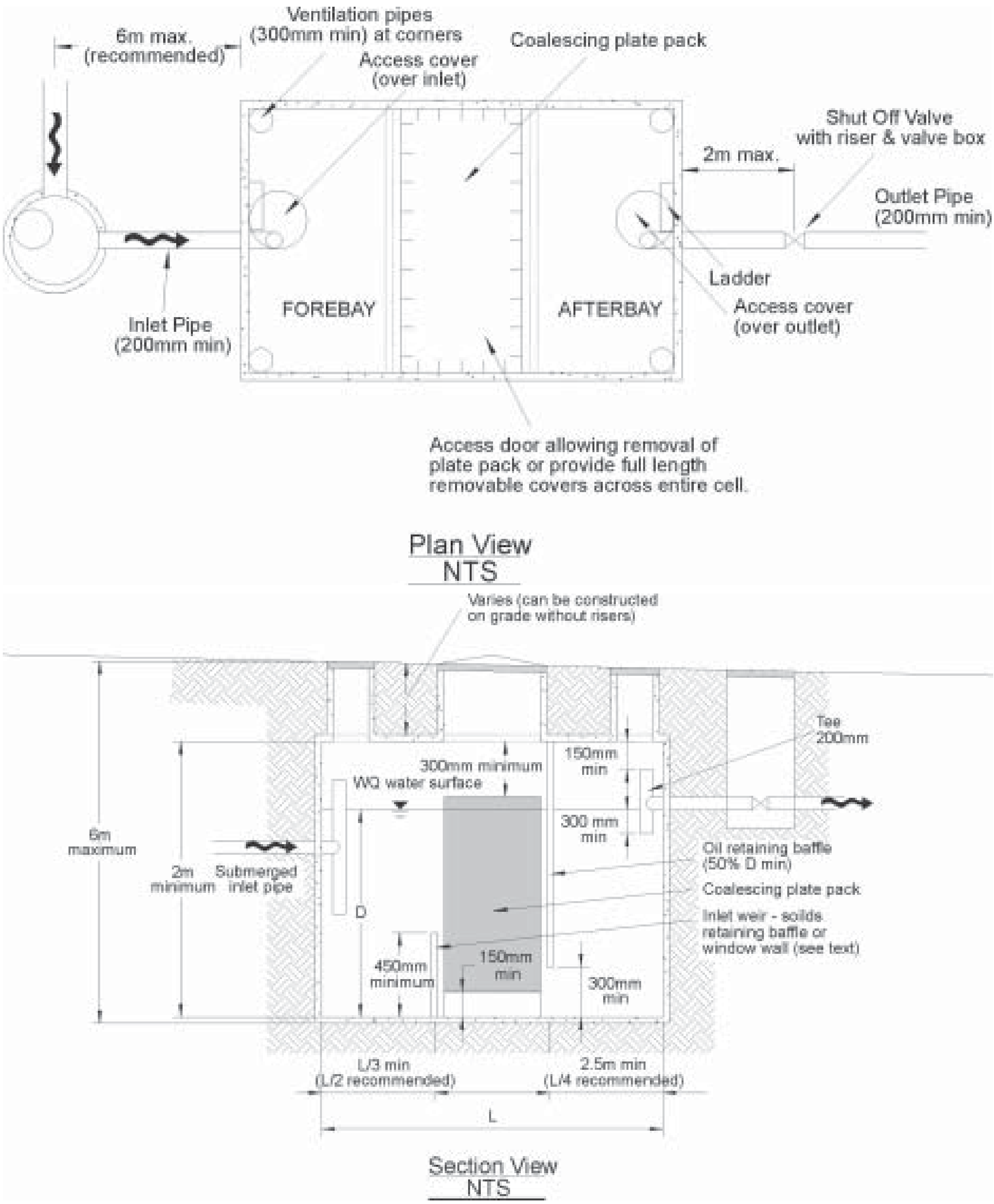
Certain contaminant "hotspots" or areas of significant contaminant generation in the urban environment produce significantly greater loadings of hydrocarbons and trace metals than other areas. Hotspots are often linked to places where vehicles are fuelled and serviced, such as petrol stations, bus depots, and vehicle maintenance areas. Others occur where many vehicles are parked for brief periods during the day (dairies, fast food restaurants, etc.) or where large numbers of vehicles are parked for a long time.

Hotspots are evident in data collected for urban cities in the U.S. (Schueler and Shepp, 1993). Their survey of oil and water separators showing the differences in the quality of pool water and trapped sediments in separators draining five different land uses is summarised in Table 10-1. Petrol stations and dairies (convenience markets) had much higher levels of hydrocarbons and metals both in the water column and the sediments. Streets and residential parking lots, on the other hand, had lower hydrocarbon and metal concentrations.

Petrol stations were found to be an extremely significant hotspot for hydrocarbons. Composite priority contaminant scans at the service station sites revealed the presence of 37 potentially toxic compounds in the sediment and 19 in the water column. Many compounds were polycyclic aromatic hydrocarbons (PAHs) that are harmful to humans and aquatic organisms.

Pitt and Field (1990) monitored metal and PAH levels in runoff from a number of sites in Alabama including

Figure 10-2
Coalescing collection plate separator schematics



vehicle service areas, parking lots, salvage yards, landscaped areas and loading docks. Although their monitoring data was variable, they reported that many of the maximum PAH and metals concentrations in runoff samples were found at vehicle service areas and parking lots, as opposed to ordinary street surfaces. Of greater concern was that nearly 60% of the hotspot runoff samples were classified as moderately to most toxic, according to their relative toxicity screening procedure.

Oil and water separators can be designed to remove oil and TPH down to 15 mg/l at any time. Their performance depends on a systematic, regular maintenance programme. Without that programme, oil and

Table 10-1
Sediment and pool water quality found in oil and water separators at various locations

Parameter	Petrol stations	Dairies	All day parking lots	Streets	Residential parking
Comparative sediment quality (reported in mg/kg of sediment)					
Total P	1,056	1,020	466	365	267
TOC	98,071	55,167	37,915	33,025	32,392
Hydrocarbons	18,155	7,003	7,114	3,482	892
Cadmium	35.6	17	13.2	13.6	13.5
Chromium	350	233	258	291	323
Copper	788	326	186	173	162
Lead	1,183	677	309	544	180
Zinc	6,785	4,025	1,580	1,800	878
Comparative pool water quality (reported in *u*g/l)					
Total P*	0.53	0.50	0.30	0.06	0.19
TOC*	95.51	26.8	20.6	9.9	15.8
Hydrocarbons*	22.0	10.9	15.4	2.9	2.4
Cadmium	15.3	7.9	6.5	ND	ND
Chromium	17.6	13.9	5.4	5.5	ND
Copper	112.6	22.1	11.6	9.5	3.6
Lead	162.4	28.8	13.0	8.2	ND
Zinc	554	201	190	92	ND

ND - Not detected   * in units of mg/l

water separators may not achieve oil and TPH removal to the required level. Pretreatment for TSS may be necessary if the inflow has sediment levels that would cause clogging or otherwise impair the long-term performance of the separator, such as from sites with high sediment loads from heavy vehicle traffic over metalled rather than from sealed areas

10.4 Design approach

In light of overseas experence that oil and water separators used for stormwater treatment have not performed to expectations, proper application, design, proper construction, prevention of coalescing plate fouling and plugging, and operation and maintenance are essential. Other treatment systems, such as sand filters or other emerging technologies should be considered for removal of insoluble oil and TPH.

The following general design criteria should be followed:

> If practicable, determine oil/grease and TSS concentrations, lowest temperature, pH, and empirical oil rise rates in the runoff, and the viscosity and specific gravity of the oil. Also determine whether the oil is emulsified or dissolved. Do not use oil and water separators for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols and alcohols.

> Locate the separator off-line and bypass flows in excess of the water quality storm flow rate.

> Use only impervious conveyances for oil contaminated stormwater.

> Oil and water separators are not accepted for general stormwater treatment of TSS.

10.5 Design Procedure

Grease and oil which is not emulsified, dissolved or attached to sediment will be present as oil droplets of different sizes or as a surface slick.

No data are available on the size distribution of oil droplets in stormwater from commercial or industrial areas, but some data are available for petroleum products storage terminals. These data indicate that about 80% of droplets (by volume) are greater than 90 *u*m and 30% are greater than 150 *u*m in diameter.

Traditionally, 150 *u*m separation has been used, which typically results in an effluent oil and grease concentration of 50 - 60 mg/l. Typically, standards for industrial discharges in Australia are 10 - 20 mg/l, which generally corresponds to the removal of droplets larger than 60 *u*m.

Separation of the 60 *u*m droplet will be adopted as the basis for design for devices in Auckland, which corresponds to the lower tail of the droplet size distribution and should result in an effluent quality of 10 - 20 mg/l at the design flow.

The rise velocity for a 60 *u*m droplet can be calculated, given the water temperature (which affects the viscosity of the water) and the density of the oil. This rise velocity is then used in the sizing calculations for the device. At 15^{o}C and for an oil specific gravity of 0.9, the rise velocity of a 60 *u*m droplet is 0.62 m/hr and this is the recommended value for Auckland.

The use of oil specific gravity of 0.9 is considered appropriate for general use as diesel has a specific gravity of 0.85, kerosene of 0.79, and gasoline has a specific gravity of 0.75.

For other conditions, the rise velocity may be calculated according to:

$$v_r = (gD^2(1-s)) / 18\upsilon$$

where:

s	= specific gravity of the oil
D	= droplet diameter
υ	= kinematic viscosity of the water
g	= gravitational acceleration

10.5.1 Design Flow Rate for Oil and Water Separators

The required design flow rate for separators is from a rainfall intensity of 15 mm/hr. If this flow (and smaller flows) are passed through the device, then 93% of the total runoff from the catchment will be passed through the device.

The design storm intensity of 15 mm/hr was determined by analysis of 10 minute average rain intensities from the Botanic Gardens rain gauge in Auckland. The results of that analysis are given in Table 10-2 which shows the fraction of total rain depth corresponding to various rain intensities, which in turn indicates what fraction of the runoff would be passed through or captured by a separator designed to treat the runoff from a given rainfall intensity. The table shows that increasing the design intensity from 10 mm/hr to 15 mm/hr would increase the capture by 6%, while increasing from 15 mm/hr to 20 mm/hr will result in only a 2% improvement in capture. The design value of 15 mm/hr is therefore reasonable, and will result in 93% of the runoff being treated. This analysis does not take first flush effects into account, so is somewhat conservative, that is, it is expected that more than 93% of the oil in the runoff from the catchment will be passed through the separator.

The required treatment flow rate, Q_d, (the flow from 15 mm/hr of rain) can be calculated according to the rational formula:

$$Q_d = CiA_c$$

where Q_d is in m^3/hr, C is the storm runoff coefficient (1 for paved areas), A_c is the catchment area (in m^2)

Table 10-2 Fraction of total rain depth corresponding to various rain intensities	
Rain intensity (10 minute average, mm/hr)	**Fraction of total rain depth**
5	73
10	87
15	93
20	95
25	97
30	98

Note: Fraction of total rain depth is $\frac{\sum \min(i_j, I)}{\sum i_j}$

where *i* is the rainfall intensity for the *jth* record of a long set of rainfall intensity measurement, and I is the intensity of interest (the intensity in the left hand column of the table).

and i is the rainfall intensity in m/hr (i.e. 0.015 m/hr). For service stations, the catchment areas should include an allowance for rain which manages to get under the canopy by including in the site a 1 m strip under the canopy along its longest face.

10.5.2 API (American Petroleum Institute) tank sizing

The API area (A_d) is based on the rise velocity (V_r) and design flow rate (Q_d), according to the formula

$$A_d = (FQ_d)/V_r$$

Based on plug flow, the above relationship ensures that a droplet with rise velocity V_r will rise to the surface during its passage through the tank. The required rise velocity is 0.62m/hr. as discussed earlier. The factor F (dimensionless) accounts for short-circuiting and turbulence effects which degrade the performance of the tank. The factor depends on the ratio of horizontal velocity (U) to rise velocity (V_r) as shown in Table 10-3.

Table 10-3
F factor for APIs

U/V_r	F factor
15	1.64
10	1.52
6	1.37
3	1.28

The volume and area determined from this tank sizing refer to the dimensions of the main compartment of the tank. Additional volume should be allowed for inlet and outlet sections in the tank.

Other sizing details:

- $U \leq 15 V_r$
- $0.3 W \leq d \leq 0.5W$ (typically d = 0.5W
- 1.5 m < W < 5 m
- 0.75 m < d < 2.5 m

where d is the depth and W is the width of the tank.

Some of these dimensions will not be appropriate for smaller catchments, and may be relaxed. It is necessary, however, to keep the length at least twice the width, the depth at least 0.75 m and $U < 15V_r$ at the design flow.

To avoid re-entrainment of oil and degradation of performance, it is required that the maximum horizontal flow velocity in the main part of the tank be less than 25 m/hr.

10.5.3 Coalescing collection plate sizing

Plate separator suppliers can provide an approximate size of device to achieve 60 *u*m droplet separation at the chosen design flow rate (Q_d). As an approximation, the plan area of each plate can be calculated from the following equation.

$A_{plan} = Q_d/v_rN$ where there are N plates in the pack

Some increase in size should be allowed, to account for short-circuiting.

10.5.4 Other design considerations

Flow Bypass

The catchments draining to oil and water separators will be small and it is not recommended that larger flows bypass them. In the event of a spill, having a bypass increases the potential for spilled material to bypass the separator and enter the receiving system.

Oil retention baffles

As there is no bypass system, an inlet baffle is not required. If, for some specific reason, there is a bypass system prior to flow entering the oil and water separator, an inlet baffle must be installed. This will ensure that oil collected in the tank does not pass back into the bypass and then off-site.

Flow spreading baffles

To achieve even flow distribution across tanks at the inlet, baffled inlet ports or other devices are used. The sizing of the inlet ports or baffles should be such that some head loss is provided to spread the flow. It is recommended that velocities should be less than 0.5 m/s, at the maximum separator flow to avoid oil emulsification.

Access

Ease of access for maintenance and inspection is required. In particular, lids should be kept as lightweight as practicable.

10.6 Construction inspection

These units are prefabricated and delivered onsite as one unit. As such, construction concerns relate to the following:

1. Compaction of foundation to ensure that uneven settling will not occur
2. Elevations are correct to ensure inflow and outflow pipes are at the proper elevation

There is no requirement for an As-built plan.

10.7 Operation and maintenance

It is important to prepare, regularly update and implement an operation and maintenance plan for oil and water separators. They should be inspected monthly to ensure proper operation, and during and immediately after a large storm event (greater than 25 mm over a 24 hour period).

10.7.1 Surface oil removal

The oil which collects in the separator must be removed before the oil layer exceeds 3 mm depth. Oil may be removed after each storm in cases where it is important to remove the oil layer, but more generally oil removal may be on a regular (for example, bimonthly) basis. If it is expected that water will be drawn into the oil outlet, an auxiliary separator may be used. Also Oil may be removed by the following means:

1. Pumping or decanting of the surface oil layer in the dry period between storms, when there is no flow through the device. The invert of the orifice or slotted pipe used to withdraw the oil can be set at the separator outlet weir crest level. Since there will be no flow in the separator when the oil layer is being removed, and the oil outlet is set at the appropriate level, there should be minimal withdrawal of water as the oil is being removed.
2. Removing by decanting through an outlet (such as an orifice or slotted pipe) which is always open. The invert of the oil outlet may be set at the water level, when the separator is operating at the design flow Q_d. If the oil outlet invert is set lower, then water will be drawn into the oil outlet, (the orifice invert may be below the bottom of the oil layer, and the oil outlet is always open). If the oil outlet is set lower, then the water drawn into the outlet may be separated in an auxiliary separator.
3. Using oil absorbent pads. These will soak up some oil, which then cannot be re-entrained into the flow. Such pads will have a limited uptake capacity, and may present a disposal problem.

10.7.2 Sludge removal

Sludge deposits should be removed when the thickness exceeds 150 mm.

Sludge will collect at the base of the separator and must be removed. Such sludge may be allowed to collect in the tank until it is removed. Solids may be pumped out as a slurry.

10.7.3 Vapours

Since an oil layer may sit in the tank for some time, consideration should be given to appropriate venting for safety reasons. The Dangerous Goods Act Regulations contains further information on venting.

10.8 Case study

A service station is to be fitted with an oil separator. Runoff from the covered forecourt roof and other site areas are to be routed away from the oil and water separator and treated at an overall site stormwater management practice. The oil and water separator will have a catchment area of 300 m^2 draining to the device.

1. The separator design flow is the flow from 15 mm/hr of rain which, from the equation provided earlier, is.

$$Q_d = CiA_c$$
$$= (1.0)(300)(0.015)$$
$$= 4.5 \text{ m}^3/\text{hr}$$

2. The separator will be sized for a rise velocity of 0.62 m/hr. First an API will be considered. The maximum design flow velocity (U) for separation at the separator design flow is 15 V_r = 15 (0.62 m/hr) = 9.3 m/hr. Therefore the flow cross section (depth times the width) is $Q_d/U = 0.48$ m^2. The depth is chosen to be half the width, which gives a depth of 0.49 m and a width of 0.98 m.

   This depth is smaller than recommended, so a depth of 0.75 m (the minimum recommended depth) and width of 1.5 m (twice the depth) is chosen, giving $U = Q_d/A$ = 4 m/hr = 6.5 V_r at the design flow. An F of 1.4 (from Table 10-3) is then used to calculate A_d, giving:

$$A_d = (FQ_d)/V_r = (1.4)(4.5)/0.62$$
$$= 10.2\ m^2$$

With this plan area and the width of 1.5 m, the length is 6.8 m. The volume of the main chamber of the tank will be 7.65 m^3 (excluding inlets and outlets). The tank will actually be longer to allow for an inlet chamber and an outlet section, which, as an approximate guide, could add an additional 20% to the total tank volume.

3. As a comparison, a 5 m^3/hr plate separator has a footprint of 2.0 m^2 (compare to, say 12.5 m^2 for the API tank) and a height of 0.56 m, which demonstrates the reduction in size for a plate separator.

4. A plate separator is therefore adopted in this example.

10.9 Bibliography

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Chapter 11
Rainwater tanks
design, construction and maintenance

11.1 Introduction

Rainwater tanks are primarily water quantity management devices. There are minor water quality benefits, depending on the amount of atmospheric deposition in a given area, but their primary function is for quantity management and to supply on-site water use.

Rainwater tanks are not a stand alone solution for quality and quantity issues in a catchment, but they can be implemented as a part of an integrated approach for reducing:

> stormwater volumes entering the receiving waters, through the use of stormwater captured and used on-site
> flows into downstream stormwater treatment practices or if roof runoff is separated from ground runoff
> peak stormwater flows from the sub-catchment by providing permanent or temporary storage
> sanitary sewer overflows by reducing the rates and volumes of stormwater that enters directly or indirectly into sanitary sewers
> roof-generated contaminants entering water bodies
> demand from mains water supply leading to more effective use of water resources,

Peak runoff reduction is limited to any sub-catchment for which tanks are specifically designed. Depending on the rate of slow release and their relative position in a catchment, all devices that store and release stormwater at a slower rate from a selected sub-catchment.have the potential to increase the peak flow rate further downstream.

A catchment-wide approach is essential to verify the effects of flow retarding devices in a sub-catchment (on downstream catchment areas). This is particularly important for catchments with existing and potential downstream flooding issues.

Rainwater tanks have been in use for centuries for supplying household and agricultural water. With the emergence of high quality, low cost community water supply systems, rainwater tank systems became limited to non-urban areas. In recent years, however, there has been a greater interest in rainwater harvesting in urban areas with wider recognition of their environmental and infrastructural benefits.

These guidelines deal only with non-potable use of rainwater.

Plate 11-1: Rainwater tank on a residential property

If potable use of rainwater is intended, several health and safety related issues are involved, including treating and disinfecting the rainwater to appropriate water standards and avoiding cross connections. Professional advice is required for this.

11.2 Limitations of tanks for stormwater quantity management

As with all stormwater practices, rainwater tanks have some limitations in some situations. Their primary limitations relate to their effectiveness for water quantity management, although they have some water quality applications.

The current perception is that roof runoff is relatively clean. Historic approaches have tended to treat runoff from impervious surfaces other than roofs, allowing roof runoff to bypassing treatment systems. Future research will provide better information on roof runoff, but water quality limitations on tank water use cannot be established until there is more information on the need for roof runoff treatment.

What is clear is that particulates from roof runoff are extremely small and sedimentation may not be an effective removal process. Use of roof runoff for domestic non-potable use will reduce contaminant discharge into receiving waters because whatever contaminants are present, some of the runoff will enter wastewater treatment systems or be discharged on to permeable surfaces such as lawn or garden.

This chapter discusses the water quantity benefits of roof water tanks. It does not promote the blanket use of water tanks throughout a catchment, because the timing of storm flows through the catchment when the tanks are primarily used as detention tanks may result in potential increases downstream. A catchment-wide analysis of the sensitivity of timing may need to be done in some catchments but general guidelines may also provide assistance in the absence of a catchment plan.

This chapter allows the roof area to compensate, from a water quantity perspective, for other small impervious surfaces. Roof areas cannot compensate for too many additional impervious surfaces.

The issue is further complicated by household water use. Using roof water for partial water supply (i.e.. non-potable water uses such as laundry and toilet) reduces the total volume of runoff that may be discharged during a storm event compared with use for total water supply (both non-potable and potable water uses), because tanks are more likely to be emptier at the start of a storm. .

Water tank limitations for water quantity management include:

> the catchment time of concentration to the point where the water tank discharges to the receiving system cannot exceed 20 minutes
> tanks cannot compensate forother impervious areas exceeding 120 m^2
> flows from water tanks will bypass downstream treatment systems
> where there are documented downstream flooding problems, only partial credit should be given to use of water tanks, as follows:
  - partial use systems (approximately 300 l/day) will receive a credit for up to 150 square metres of impervious surfaces, including roof areas
  - full use systems (potable and non-potable - approximately 500-600 l/day) will receive a credit for up to 250 square metres of impervious surfaces (including roof areas)

11.3 Performance

11.3.1 Water quality credit through water use

When tank water is used for non-potable purposes, the contaminants in roof runoff are redirected to sanitary sewers and planted areas, accordingly reducing the load entering receiving environments. The percentage contaminant reduction depends on the percentage of water captured for use.

Reduced runoff volumes may also decrease stream channel erosion, conferring additional water quality benefits (Tremain 2001). These additional channel erosion water quality benefits have not been quantified or included in the water quality credit given in this chapter.

Table 11-1 compares typical roof runoff contaminant concentrations with the relevant water quality guidelines for protection of aquatic ecosystems.

Table 11-1
Typical roof runoff quality

Parameter	Typical levels in roof runoff	Water quality guidelines	Reference
pH	6.7	6.5 – 9.0	ANZECC 1992
Suspended solids (g/m^3)	29	-	-
Cadmium (mg/m^3)	0.26	2.2*	USEPA 1999
Copper (mg/m^3)	25	9.0*	USEPA 1999
Lead (mg/m^3)	17.6	2.5*	USEPA 1999
Zinc (mg/m^3)	315	120*	USEPA 1999
Faecal coliforms (cfu/100mL)	2	200	DoH 1992
Enterococci (cfu/100mL)	15	35	MoH 1999

* at hardness of 100 g/m^3
Source Gadd et al (2001)

It is very difficult to quantify water quality benefits of roof runoff capture as contaminant vary according to geography and roofing materials. Any benefits will largely depend on whether water is used for on-site purposes or whether the tank functions primarily as a peak control device.

Airborne sediments deposited on roofs are extremely small, and will not settle out in the tank.

If the tank is used for on-site water use, the actual reduction in contaminant loading will also depend on the percentage of time during the year that the tank is full when a rainfall event occurred. If the tank is full at the start of a rainfall event then none of the rainfall event will be stored (and later used) and hence will confer little water quality benefit. The number of days the tank is full at the start of a rain event is a function of the antecedent rainfall, roof area, tank size and water use.

11.3.2 Water quality credit

For the purposes of estimating the water quality benefits from rainwater tanks, a water quality credit is calculated based on the percentage of water used multiplied by a water quality factor. The percentage of water used is based on Table 11-2 and the water quality factor is taken as 0.75. The water quality factor of 0.75 takes into account the number of rain days that the tank is full at the start of a rainfall event. The water quality credit is not given for other impervious surfaces for which a quantity credit is given. Runoff from non-roof areas must be treated.

Model runs using long-term (up to 20 years) daily rainfall records indicate that the percentage of rain days a tank is full varies from 15% to 35% for a typical range of roof areas and water use rates. The average tank full days is approximately 25%, so the water quality factor of 0.75 has been taken as a value for the Auckland Region.

11.3.3 Peak flow and extended detention attenuation

The degree of peak flow attenuation that can be achieved depends on the roof area, other impervious areas, storm characteristics, tank size and outlet orifice size. Note that the tank can control runoff from the roof catchment area only. If there is an increase in other impervious areas, such as footpaths and paving areas, the roof catchment area needs to be proportionately big enough to compensate for the runoff from those areas. Once paved areas exceed 30% - 60% of the roof area, the incremental increase in roof runoff attenuation storage volumes becomes limted. This contributes to the rationale for the 120 m^2 limitation on non-roof impervious areas.

Rainwater tanks can be designed to perform the following functions (refer Figure 11-1 for commonly used components of a rainwater tank):

> non-potable water use, with a consequent benefit of quality improvement by reducing contaminant load into receiving waters. This requires long-term storage in the tank supplying the demand points (e.g. toilet flush, garden tap, laundry) either by gravity or via a small pump

> peak flow attenuation, which requires temporary storage emptied through an orifice that is sized to limit the tank outflow rate to an approved maximum rate. This manual does not encourage providing a rainwater tank solely for the purpose of flow attenuation without a quality improvement component. However, territorial au-

Table 11-2
Percent water capture

150 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Captured from Roof					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	15%	25%	25%	30%	30%	30%
225	20%	35%	45%	45%	50%	50%
325	25%	40%	55%	60%	65%	72%
500	35%	50%	65%	70%	80%	100%
600	40%	50%	70%	75%	95%	100%
1000	45%	55%	75%	80%	100%	100%

200 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Captured from Roof					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	10%	20%	20%	20%	20%	20%
225	20%	25%	35%	35%	35%	35%
325	20%	30%	40%	45%	50%	55%
500	30%	40%	55%	60%	70%	80%
600	30%	45%	60%	65%	75%	85%
1000	35%	45%	65%	70%	80%	90%

250 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Captured from Roof					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	10%	15%	20%	20%	20%	20%
225	10%	20%	30%	30%	30%	30%
325	15%	25%	35%	40%	40%	45%
500	25%	35%	45%	50%	60%	65%
600	35%	40%	50%	55%	65%	80%
1000	40%	40%	55%	60%	70%	85%

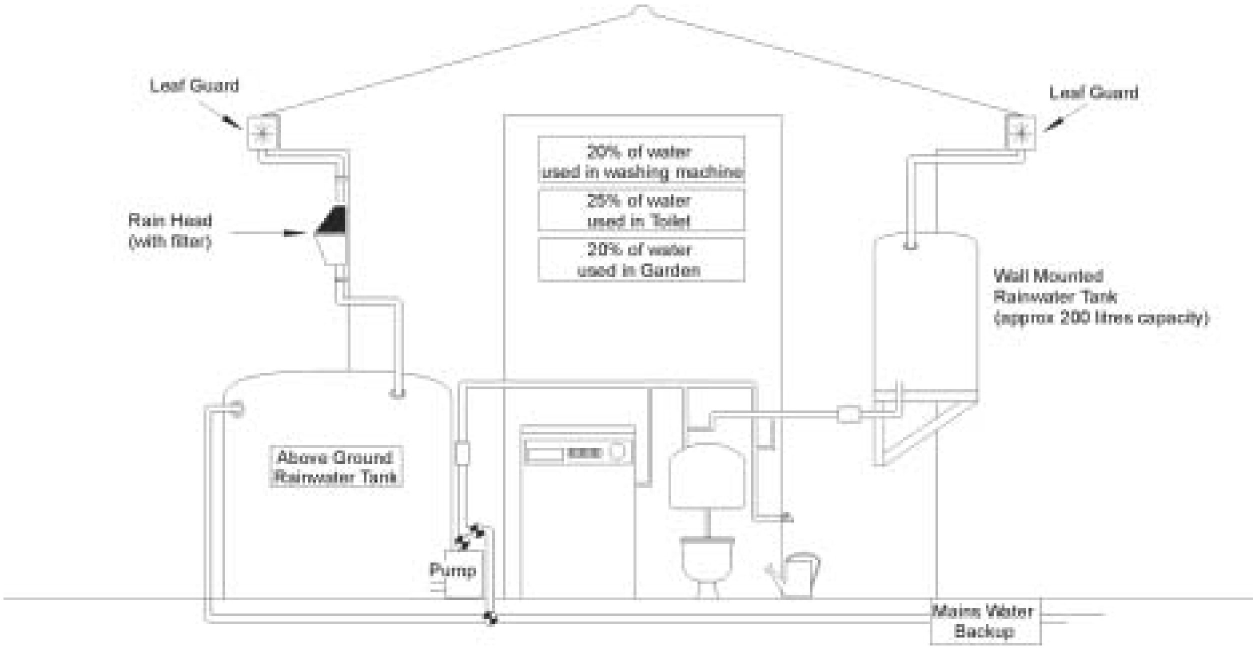
300 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Captured from Roof					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	10%	10%	15%	15%	15%	15%
225	10%	20%	25%	25%	25%	25%
325	15%	20%	30%	35%	35%	35%
500	20%	30%	40%	45%	50%	55%
600	25%	30%	45%	50%	55%	65%
1000	30%	35%	50%	55%	55%	70%

500 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Captured from Roof					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	5%	5%	5%	5%	5%	5%
225	5%	10%	10%	10%	15%	15%
325	10%	15%	15%	20%	20%	20%
500	10%	15%	15%	20%	25%	30%
600	15%	20%	25%	30%	35%	40%
1000	20%	25%	35%	40%	50%	60%

Figure 11-1
Commonly used components of a water tank



thorities may allow or require such tanks in order to manage existing stormwater network capacity

- combined water use and peak flow attenuation, which require long-term storage capacity in the lower part of tank and a temporary storage capacity in the upper part of the tank

For peak discharge control:

- in areas with stormwater reticulation, select 1 in 10 year 24 hour storm as defined by TP 108. This Annual Recurrence Interval (ARI) is chosen for reticulated systems because the infrastructure management objective in this case is to manage stormwater within the existing system capacity, and the majority of the existing systems in the region were designed for 1 in 10 year stormwater service level.
- in areas with no stormwater reticulation, select 1 in 2 year 24 hour storm as defined by TP 108. This ARI is chosen to control intermediate sized storms.

For downstream channel protection:

- Partial credit for control and release of 34.5 mm of rainfall over a 24 hour period is provided by using both of the following equations.

  Volume adjustment = 0.5 (storage tank size (m^3))
  Volume adjustment = 7.5 (daily use (m^3))

  Use the smaller of the two calculated volumes for the volume credit

  The individual volume calculated for each roof is then summed to obtain the total rain tank volume credit for all of the houses on the site. This volume is then subtracted from the total site extended detention volume requirement to calculate the storage volume needed.

The temporary storage for 2 year ARI is generally larger than that for 10 year ARI, for two reasons:

- the outlet orifice of the former is smaller
- the percentage increase of peak from pre-developed to developed is greater for 2 year event than for 10 year event (ARC, 2000)

11.4 Design approach

11.4.1 Objectives

Rainwater tanks should be designed to achieve the following objectives:

> a percentage rainwater capture through water use agreed with the TA or the ARC, as appropriate. The percentage water capture depends on several variables including:

- catchment roof area
- water use rate
- tank capacity
- long-term rainfall characteristics of the area

> temporary runoff storage of a target level should be agreed with the TA or the ARC, as appropriate. The level of required storage depends on several variables including:

- impervious areas,
- tank capacity, and
- storm characteristics of the area.

The default value is either 1 in 10 year ARI or 1 in 2 year ARI for the selected sub-catchment (e.g. a property, a subdivision), depending on whether it is served by a reticulated or stream system.

11.4.2 Applicability

Rainwater tanks can be used in residential, commercial and industrial developments. The applications include the following:

> with water use, to treat roof runoff and accordingly reduce the size of the downstream treatment devices. In this case, the roof runoff, after storage in the tank system, would enter the receiving waters separately, while the ground runoff would be routed via the downstream treatment practice. Examples include industrial or commercial sites where the roofs are treated by tanks while parking areas are treated by rain gardens or swales or high-density subdivisions where roofs are addressed by tanks and the rest of the area treated by wetlands

> in infill developments for managing stormwater within existing system capacity (e.g. existing 1 in 10 year capacity). There are different types of rainwater tanks to suit the available space and required volume, as shown in plate 11-2

> in conjunction with other practices, in order to work towards hydrological neutrality in order to mitigate adverse effects of a development

Plate 11-2: Different types of rainwater tanks

> as multipurpose devices to provide treatment, peak attenuation and non-potable water supply benefits. They become financially self-supporting for reasonably large non-potable water demands when coupled with adequate roof areas

This chapter covers roof areas of up to 500 m^2 and paved areas of up to 120 m^2. The 120 m^2 area is the maximum allowed additional area at this time unless a specific situation warrants an increase. Also, limitations are provided on maximum impervious areas for partial (150 m^2) or full water use (250 m^2)

11.5 Design procedure

11.5.1 Water quality credit through water use

Water quality benefits from rainwater tanks have been based on the water quality credit derived from volume reduction through using the water as a non-potable water source rather than conventional stormwater quality treatment technologies.

Step 1: Determine required percentage runoff capture

The required percentage runoff capture is a function of the required percentage water quality treatment (this should be determined in consultation with the TA or ARC). As shown in Table 11-3, if the total required treatment couldn't be achieved by the tank then a proportionate roof area should be included in the catchment area of downstream treatment devices, based on the following table.

Table 11-3
Proportionate roof area to be treated by downstream treatment devices

% Roof Runoff Captured by Tank System	% Roof Area to be included in the Catchment Area of the Downstream Treatment Devices(1)
90%	33%
75%	44%
50%	63%
40%	70%
30%	78%
20%	85%
10%	93%
0%	100%

Note (1): % Roof Area to be included is calculated based on a "water quality factor" of 0.75 (refer Performance section). For instance, if 40% of roof runoff is captured by the tank, then the water quality credit is equal to 40% times 0.75 (water quality factor) = 30%, therefore 70% (i.e. 100% - 30%) of roof area should be included in calculations for downstream devices.

Step 2: Assess non-potable water demand

Table 11-4
Estimated typical household water demand based on a total of 500 litres/day for a 3 member household

Water Use	Average litres/day
Bathroom	125
Toilet	125
Laundry	100
Gardening	100
Kitchen	50
Total	**500**

If used for non-potable household uses like toilet, laundry and gardening, rainwater needs little or no treatment at all. As shown in Table 11-4, approximately 65 % of household water demand can be met from rainwater collected from roofs. Based on a total water demand of 500 l/d, an average 3-member household would be able to use 325 l/d of rainwater.

For industrial and commercial developments, it would be necessary to assess the non-potable water demand on a case by case basis. Non-potable water usage in some industries and for floor and vehicle washing can be estimated from water audits, where available for similar activities, and by consulting the process engineers of the industry for which the rainwater tanks are to be designed.

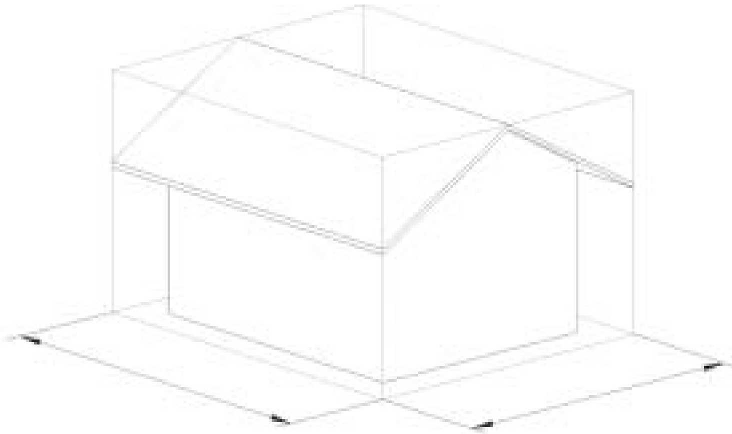
Step 3: Measure roof catchment area

Roof catchment area is the plan area of the roofs that are to be drained to the tanks, for example:

> for existing roofs, measure the plan (horizontal) area of the roof at ground level below the edges of the roof (including eaves)

> for proposed buildings this area can be calculated from the architectural plans. Figure 11-2 provides detail on calculating catchment area.

Figure 11-2
Method to calculate roof catchment area



When figuring catchment area, measure at ground level below edges of the roof, including eaves

Step 4: Use design tables given in this Chapter

Use Tables 11-2 and 11-5 to determine tank size, percentage runoff capture and percentage water supplied.

These Tables were developed using a computerised model that uses long-term (up to 20 years) daily rainfall records to perform water balance analysis.

One point that must be stressed is that water use in litres/day is really “anticipated” water use as opposed to “actual”.

Worked examples are given at the end of the chapter to illustrate the use of these Tables.

If percentage water supplied is estimated to be less than 100%, this means the system is unable to supply the full non-potable water demand throughout the year. Augmentation from mains water would be needed to meet the deficit. Even if the percentage water supplied is estimated to be 100%, it is recommended that mains water be available as a stand-by to counter any problems.

Step 5: Multiply by the factor for the area

For a given roof area and percentage capture, required tank size varies around the Auckland Region, reflecting variations in rainfall. Tank sizes were therefore estimated for three locations; Warkworth (northern extremity), North Shore (central) and Pukekohe (southern extremity). The variations between these three locations were < 10% and did not merit the development of separate Tables for each location. The variations were minor (≤10%), which is within the error margin of the modelling carried out to prepare the Charts. Comparisons of % water captured and % water supplied for Warkworth, Pukekohe, Henderson and the Waitakere Foothills are summarised in Figure 11-3, Comparison for 150 m^2 Roof and Figure 11-4, Comparison for 300 m^2 Roof.

<u>11.5.2</u> <u>Peak flow attenuation</u>

Step 1: Determine required ARI

> for areas where tanks overflow into reticulated stormwater systems, the 1 in 10 year rainfall is to be used

> for areas where tanks overflow to stream, the 1 in 2 year rainfall is to be used.
> Where a reticulated system drains into a stream without flow restriction prior to entry into the stream, criteria should be based on 1 in 2 year ARI.

Step 2: Measure roof catchment area and other impervious areas

The roof catchment area is measured similar to Step 3 for water quality.

The other impervious areas include roof areas that are not connected to the tank and paved areas such as driveways and carparks. Off-site impervious surfaces cannot be included.

Step 3: Use design charts given in this chapter

The next step is to use Figure 11-5 Charts 1 or 2 and Charts 3 or 4 or Charts 5 and 6 to determine tank size, outlet orifice size, and the remainder of any impervious area that would not be mitigated by the tank system.

These Charts for 2.2 m diameter and 3.4 m diameter tanks were developed using the reservoir function of the HEC-HMS Version 2.0.3 and runoff assessment guidelines contained in TP 108. Worked examples are given at the end of the Chapter to illustrate the use of these Charts.

11.5.3 Combined quality and attenuation

It is anticipated that combined quality and peak attenuation tanks would be the most preferred because they provide highest value for money in terms of environmental and water use benefits. Combined tanks also encourage regular homeowner maintenance as they are using the tanks for water supply.

Table 11-5
Percent water supplied

150 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Supplied					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	50%	80%	95%	100%	100%	100%
225	40%	65%	85%	90%	100%	100%
325	35%	50%	70%	80%	90%	100%
500	25%	40%	55%	60%	70%	75%
600	25%	35%	50%	50%	60%	60%
1000	20%	30%	35%	35%	50%	55%

200 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Supplied					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	55%	85%	95%	100%	100%	100%
225	40%	65%	85%	95%	100%	100%
325	35%	55%	75%	85%	95%	100%
500	25%	45%	60%	65%	80%	90%
600	25%	40%	50%	60%	70%	80%
1000	20%	30%	40%	40%	50%	60%

250 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Supplied					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	55%	85%	100%	100%	100%	100%
225	40%	65%	90%	95%	100%	100%
325	35%	60%	80%	85%	95%	100%
500	25%	45%	65%	70%	85%	95%
600	25%	45%	60%	65%	75%	90%
1000	20%	35%	45%	50%	60%	70%

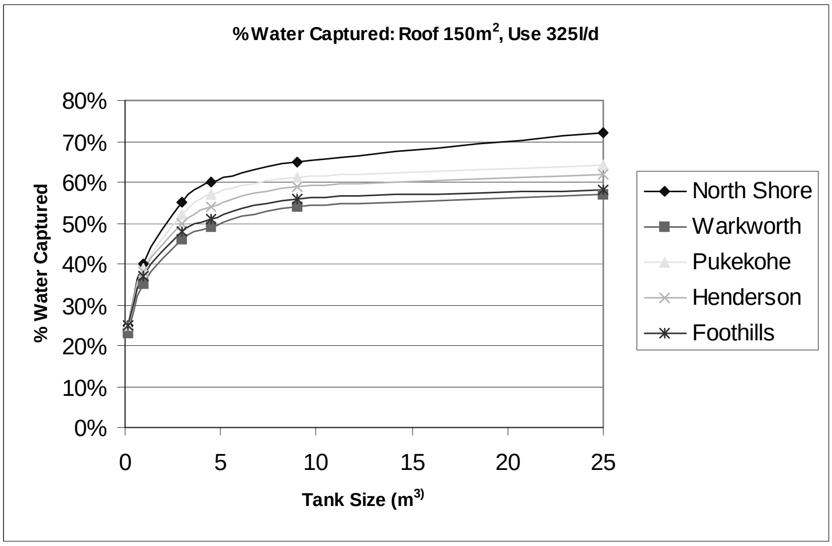
300 m^2 Roof Area

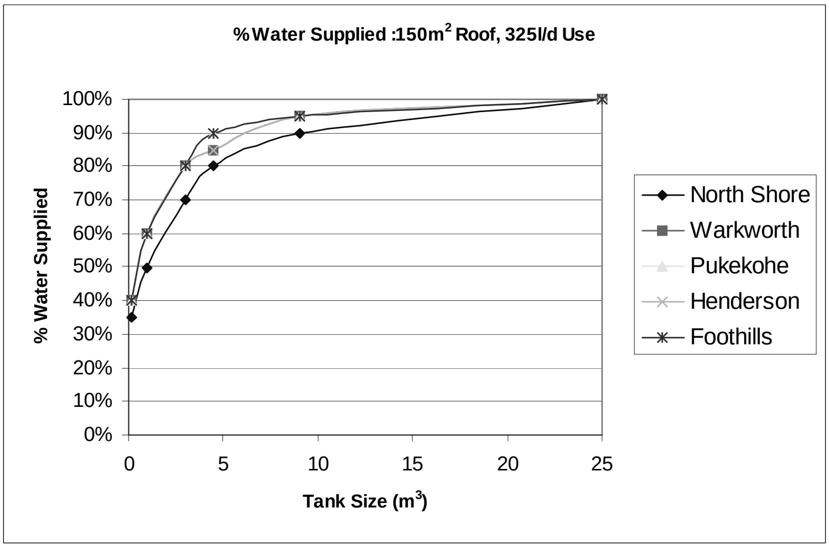
Water use in litres per day	Average Yearly % of Water Supplied					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	55%	85%	100%	100%	100%	100%
225	40%	70%	90%	95%	100%	100%
325	35%	60%	80%	90%	95%	100%
500	25%	45%	70%	75%	85%	95%
600	25%	45%	60%	70%	80%	95%
1000	20%	35%	55%	60%	65%	70%

500 m^2 Roof Area

Water use in litres per day	Average Yearly % of Water Supplied					
	Rain Tank Capacity (Litres)					
	200	1000	3000	4500	9000	25000
125	55%	85%	100%	100%	100%	100%
225	45%	85%	90%	95%	100%	100%
325	40%	75%	85%	90%	95%	100%
500	30%	55%	75%	80%	90%	95%
600	30%	45%	65%	75%	85%	95%
1000	25%	35%	55%	60%	75%	85%

Figure 11-3
Comparison for 150 m² roof





Step 1: Assess the water quality credit volume

The water quality credit volume is assessed using the methodology described in Section 11.5.1.

Step 2: Assess attenuation volume

The attenuation volume is assessed using the methodology described in Section 11.5.2.

Step 3: Assess combined volume

Combined volume is the arithmetical sum of quality and attenuation volumes.

Combined volume = Quality (water use) volume + Attenuation volume

Quality (water use) volume would occupy the lower part of the tank, which is connected via a pump or by gravity (depending on the elevation) to non-potable water demand points.

Attenuation volume should occupy the upper part of the tank, with its outlet orifice placed immediately above the quality (water use) volume.

It is possible that the combined tanks would provide more benefit than estimated. For example, a higher level of attenuation may be achieved, in some instances, when the tank water level is lower than the orifice level, water use, at the start of a storm. These benefits are difficult to estimate and are therefore ignored. This does, however, ensure a conservative design.

It is also possible that the water level in the tank is higher than the orifice level when the critical storm starts, due to a previous storm or a multi-peak storm, resulting in lower than anticipated attenuation. This possibility is considered low, given that the storm pattern of TP 108 is specifically developed for the Auckland Region to represent the most critical case in terms of peak flows.

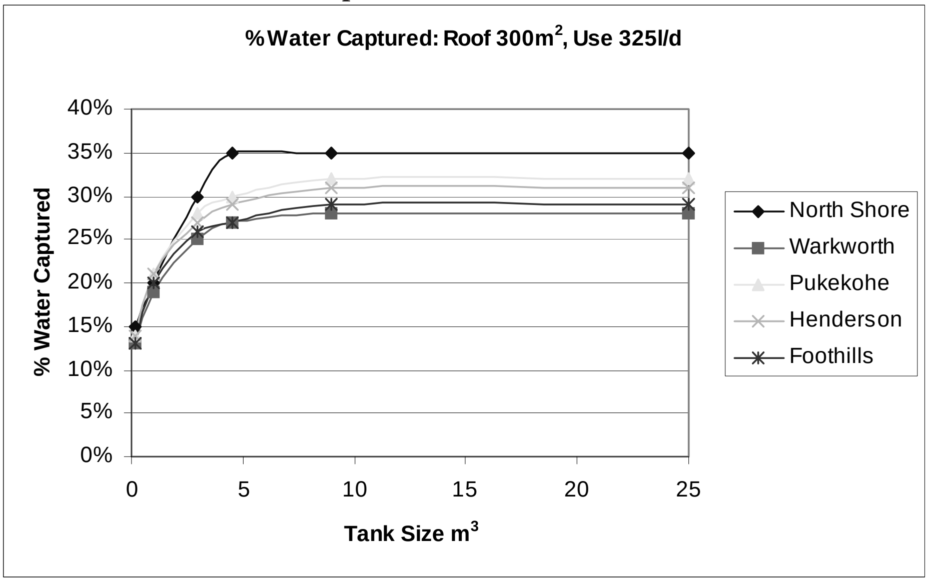
11.5.4 Aesthetics and optimum use of space

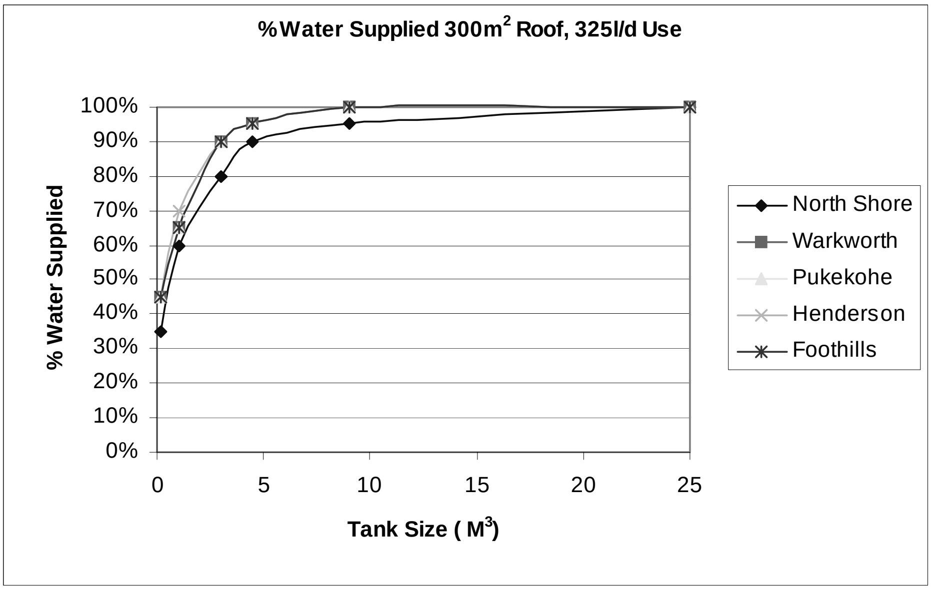
Rainwater tanks, along with other stormwater management needs, should be considered at the conceptual stage of a development project. This would enable the optimum use of space and an aesthetically co-ordinated overall design. Tanks need to be included in this in order to minimise visual intrusion and unnecessary use of space.

There are various types of tanks for installation above or below ground or wall mounted mini tanks just under the gutter for gravity feeding demand points.

For retrofits the space for the tank and the type of the tank should be selected to minimise visual impact and space use. As in the case of new developments, major refurbishments should consider rainwater tanks at the conceptual stage.

Figure 11-4
Comparison for 300 m^2 roof





11.5.5 Other design considerations

These include:

- roofing materials
- gutters and downspouts
- Primary screening
- Water treatment for non-potable use

Roofing materials

Metal roofing, clay tiles or slates are appropriate for quality rainwater harvesting. No lead or copper is to be used as roof flashing or as gutter solder as the slightly acidic quality of rain can dissolve the lead or copper and contaminate water supply. Composite asphalt, shingles and some painted concrete tile roofs can leach contaminants into the rainwater affecting quality, colour and taste.

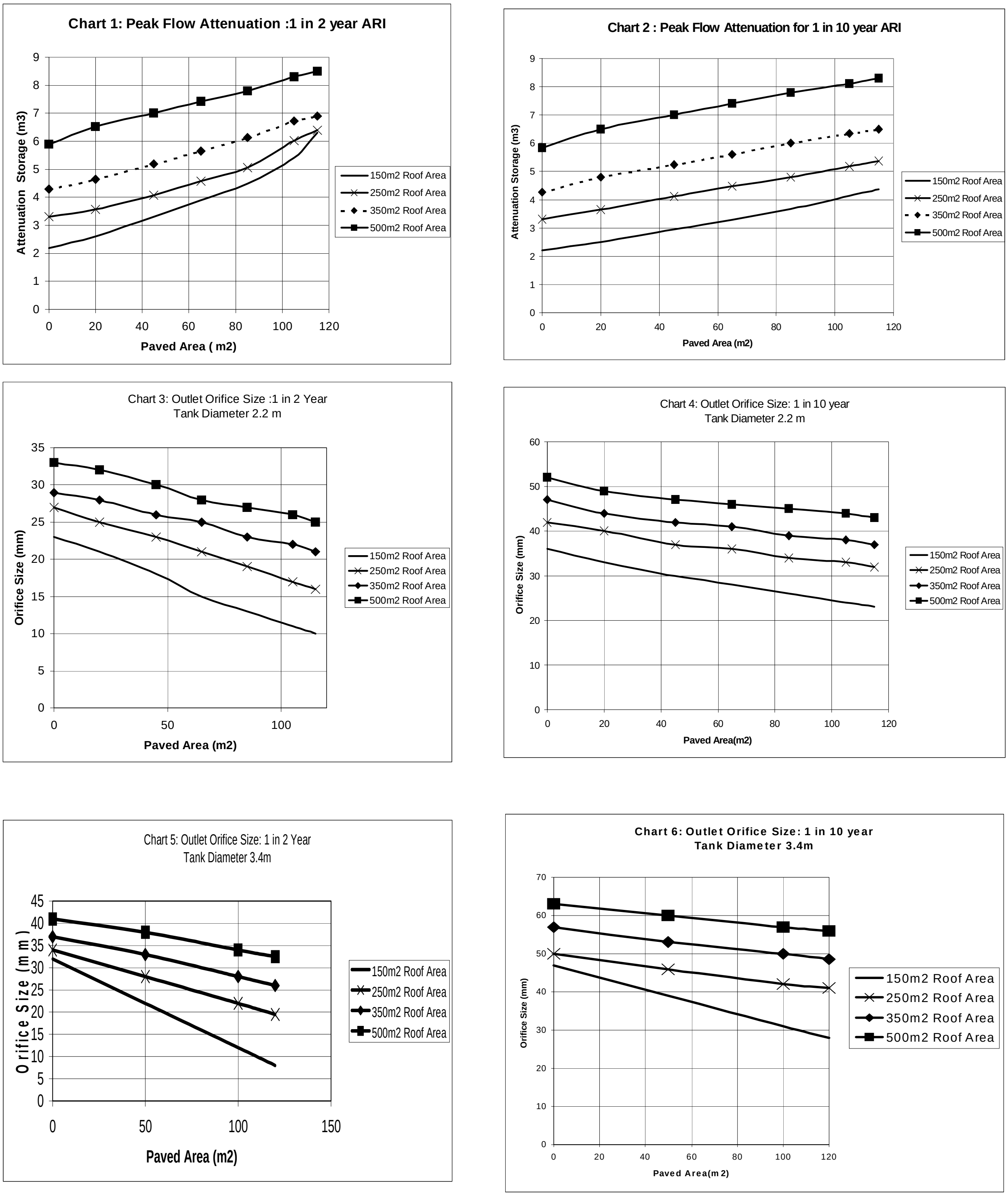
Gutters and downspouts

Seamless extruded aluminium, galvanised steel or PVC are the commonly recommended material for gutters and downspouts. The roofing and gutter material should not contain substances that impair water or are hazardous to health (e.g. asbestos, solder, lead-based paint). Gutters and downspouts must be properly sized, sloped and installed to maximise the quantity of harvested rain. The connection between the downspout and the storage tank is generally constructed of an appropriate grade of PVC pipe.

Primary screening and first flush diverters

Primary screening devices are used to prevent leaves and other debris from entering the tank. Typical primary screening devices are shown below in Figure 11-6. First flush devices are designed to divert the first part of the rainfall that picks up most of the dirt and debris away from the rain tank.

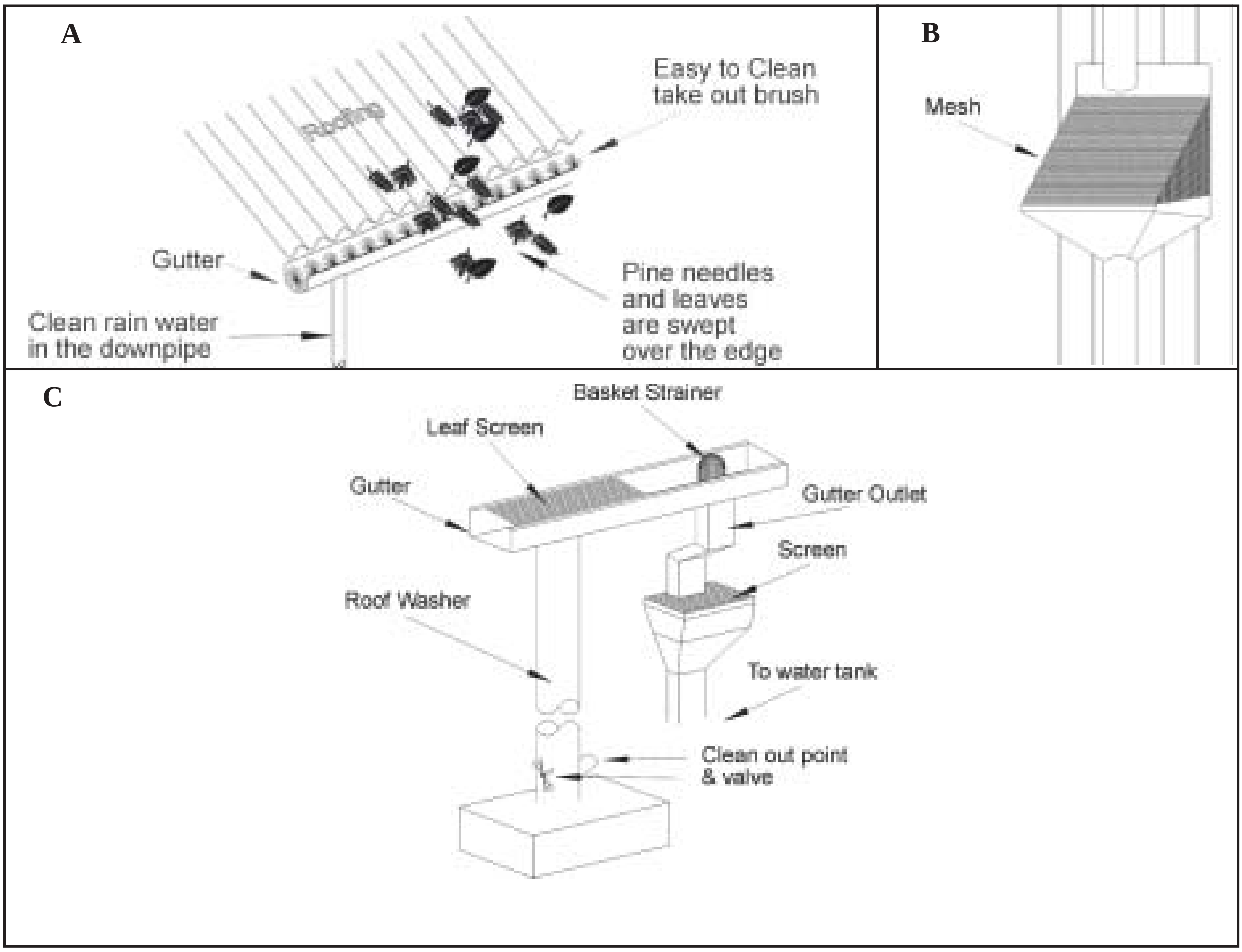
Figure 11-5
Design charts



Primary screening devices often have a 6 mm wire mesh leaf screen in a metal (or plastic) frame installed near the downspout. If there are trees nearby and leaves pose a problem, a leaf screen may be installed along the entire length of the gutter.

The first flush picks up most of the dirt, debris, and contaminants (e.g. bird droppings) that collect on the roof after each storm. The system is commonly designed so that at least the first 40 litres of roof runoff are diverted into a separate small chamber for every 100 m^2 of roof area. Once the chamber has filled, the rest of the water flows to the downspout connected to the rainwater tank. The chamber has a small tube at the

Figure 11-6
Screening devices and first flush diversion

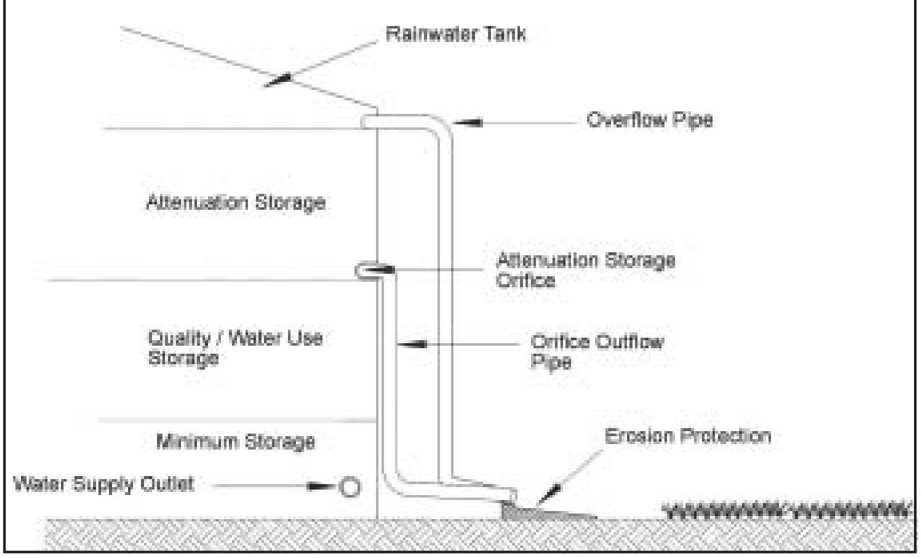


bottom that empties on to the ground after a storm event so it is empty before the next rain event. Figure 11-7 shows a typical first flush device.

Water treatment for non-potable use

Dirt, rust, scale, bird and rodent faeces and airborne bacteria may still enter the tank even when primary screener and first flush diverters are in place. Water can also be unsatisfactory without being unsafe. Although there is some sedimentation of suspended solids inside the tank, even for non-drinking uses, further filtration is often a good idea. Cartridge filters or those used for domestic swimming pools or spa pools may be used (e.g. 50 micron washable filters or similar).

Figure 11-7
Schematic arrangement at the attenuation storage orifice



11.6 Construction

11.6.1 Storage tanks

The tank should have a durable, watertight, opaque exterior and a clean, smooth interior. Available tank materials include plastic, steel, concrete and fibreglass.

A tight fitting top cover is necessary to prevent evaporation, mosquito breeding and to keep insects, rodents, birds and children from entering or falling into tanks. The tank should be located in a cool place and sunlight should not penetrate to prevent growth of algae.

Tanks, as shown in Figure 11-8, should have a suitable overflow outlet or outlets and should be able to be easily cleaned. Erosion protection measures for the overflow should be provided as necessary.

The tank should be placed high enough for gravity feed or pumped to convey water supply.

11.6.2 Attenuation storage outlet

For the controlled emptying of the temporary attenuation storage, an orifice should be drilled immediately above the long-term storage (quality/water use) volume. The edges of the orifice should be strengthened to prevent fraying. A pipe from the orifice should lead the outflow to a swale or a pipeline. Erosion protection measures should be provided as necessary.

11.6.3 Conveying

Poor plumbing can lead to inefficient collection and low water quality due to high loss and debris or pollutants getting into the tank. It may also result in contamination of individual household or mains water supply (e.g. if debris are not diverted or backflow preventers are not installed). Therefore, all plumbing should be done by a qualified plumber certified / registered by the TA. All plumbing work must conform to the relevant NZ standards including AS/NZS 3500.5:2000, and Building Industry Authority (BIA) approved documents G10, G12, and G14.

11.6.4 Backflow prevention

Backflow preventers must be installed to prevent possible mains water contamination.

11.6.5 Minimum water level

It is possible to provide a mains connection to the rainwater tank to maintain a minimum water level during prolonged dry spells. Such connection should have a 25 mm minimum air-gap separation to the maximum overflow water level of the tank.

The minimum water level is usually 100 mm above the water supply outlet. Mains water supply is opened, for trickle feed, and shut by a float-activated valve with its float at the minimum water level.

When a mains augmented minimum water level is provided, the design quality volume should be provided above this level.

11.6.6 Water supply outlet

The water supply outlet should be placed 150 mm to 200 mm above the tank base. The dead storage below the water supply outlet would accumulate any debris that settles within the tank. This dead storage should be cleaned out at regular time intervals.

Note that when mains augmented minimum water level is not provided, the design quality volume should be provided above the water supply outlet level.

11.6.7 As-built plans

There is no requirement for submission of an As-Built plan upon construction completion.

11.7 Operation and maintenance

Proper operation and regular maintenance of the rainwater tank system is necessary to achieve the design objectives.

Regular maintenance includes:

- inspection of the tank (at least annually), clean-out of dead storage and repairs as necessary
- inspection of the orifice outlet and pipework (no greater than annually) and repairs as necessary.
- inspection of the overflow pipework (at least annually) and repairs as necessary.
- where applicable, inspection for erosion damage of areas receiving flow from the orifice and overflow and repairs as necessary (after unusually severe storms)
- water supply pumps and associated electrical work maintenance as per manufacturer's requirements
- inspection of the backflow preventer by a certified inspector and repairs as necessary every 5 years
- maintenance and replacement of the filters as per instruction manual
- inspection of first flush device at least annually and repairs as necessary, along with cleaning of screens in gutters and downspouts

11.8 Design examples

Example 1

A proposed housing project would involve the development of a 600 m^2 greenfield site to have a roof area of 150 m^2 and a paved area of 65 m^2. In order to minimise the effects of the project on the stream system, the TA requires:

- 55% roof runoff capture, (TA has a downstream pond which can treat 60% of the roof area runoff)
- developed 2 year peak flow not to exceed the pre-developed 2 year peak flow;

Calculate the long-term and temporary storages required and orifice size. Select the tank and find the orifice position.

(1) Runoff capture would require non-potable water use from rainwater tank.
Estimate the daily demand rate = 325 L/d (for an average household, Table 11-4, toilet laundry and gardening)

(2) From Table 11-2, long-term storage = 3000 L (for 150 m^2 roof, 325 L/d water use, and 55% runoff capture
From Table 11-5, percentage water supplied = 70%. Therefore mains augmentation would be necessary.

(3) From Figure 11-5 Chart 1, temporary storage = 4000 L (for 150 m^2 roof, 65 m^2 paved area)
From Figure 11-5 Chart 3, orifice size = 15 mm diameter.

(4) Position of water supply outlet:
Tank height (say) = 2000 mm; tank diameter 2200 mm (refer manufacturer's data)
Select: water supply outlet height from base = 200 mm (refer water supply outlet section)
Select: minimum water level with mains augmentation = 300 mm from base (refer Minimum Water Level Section and Figure 11-4)
Calculate: storage below minimum water level = 9000 L (volume for size tank) / 2000 mm x 300

mm = 1350 L
Check: storage available above minimum level = 9000 L - 1350 L = 7650 L. This is satisfactory because it is greater than the required 7000 L (i.e. 3000 + 4000)

(5) Position of orifice (refer Figure 11-8):
Calculate: height of long-term storage = 2000 mm / 9000 L x 3000 L = 667 mm
Add: height of minimum storage = 667 mm + 300 mm = 967 mm
Drill the orifice between 965 mm and 985 mm

<u>Example 2</u>

A proposed housing project would involve the development of a 600 m^2 greenfield site to have a roof area of 200 m^2 and a paved area of 100 m^2. The TA requires that the developed 10 year peak flow should not exceed the pre-developed 10 year peak flow in order to minimise the effects of the project on the reticulated system. Calculate the temporary storage required and orifice size.

(1) From Figure 11-5 Chart 2
Read the required temporary storage from the graph for 150 m^2 = 4.0 m^3
Read the required temporary storage from the graph for 250 m^2 = 5.1 m^3
Interpolate to find the required temporary storage for 200 m^2

= 4.0 + (5.1-4.0)/(250-150) x (200-150) = 4 + (1.1/100) x 50 = 4.55 m^3

(2) From Figure 11-5 Chart 4:
Read the orifice size from the graph for 150 m^2 = 25 mm
Read the orifice size from the graph for 250 m^2 = 33 mm
Interpolate to find the orifice size for 200 m^2

= 25 + (33-25)/(250-150) x (200-150) = 25 + 8/100 x 50 = 29 mm

<u>Example 3</u>

A proposed housing project would involve the development of a 600 m^2 greenfield site to have a roof area of 250 m^2 and a paved area of 150 m^2. The TA requires that the developed 2 year peak flow should not exceed the pre-developed 2 year peak flow in order to minimise the effects of the project on the stream system. Assess whether this condition can be met by providing roof rainwater tank temporary storage, and explore other possible options.

(1) From Figure 11-5 Chart 1:
Read the required temporary storage from the graph for 250 m^2 roof
Paved area 150 m^2 is out of the range of this graph
Therefore, it is not possible to meet the TA or ARC requirement by providing roof rainwater tank only. (120 m^2 paved area has been set as a standard maximum. Specific design, on a case by case basis, is required for paved areas greater than 120 m^2)

(2) Consider other options
(2.1) Reduce the paved area
Try a paved area of 100 m^2
It is within the Chart 1 graph for 250 m^2 roof
Required attenuation volume = 8500 L
(2.2) Keep 150 m^2 paved area. Provide a rain garden in addition to roof tank.
Select temporary storage = 6 m^3 (by trial and improvement) from Chart 1 and read the corresponding paved area = 100 m^2
Calculate excess paved area = 150 - 100 = 50 m^2
Design the rain garden to mitigate runoff from 50 m^2 (refer to Chapter 7)

Example 4

A proposed housing project would involve the redevelopment of a 600 m^2 site to have a roof area of 350 m^2 and a paved area of 70 m^2. Prior to the redevelopment the site has a 150 m^2 roof and a 30 m^2. paved area. The TA requires that the developed 10 year peak flow should not exceed the current 10 year peak flow in order to minimise the effects of the project on the reticulated system. Calculate the temporary storage required and orifice size.

(1) Calculate the additional roof area and paved area
(a) Additional roof area = 600 - 350 = 250 m^2
(b) Additional paved area = 70 - 30 = 40 m^2
Note: If (b) is negative, then the effective additional roof area would be equal to the actual additional roof area less the difference in paved areas, and the effective additional paved area would be taken as zero

(2) Based on the effective additional areas, calculate the temporary storage and orifice size:
From Figure 11-5 Chart 2, temporary storage = 4000 L (for 250 m^2 roof, 40 m^2 paved area)
From Figure 11-5 Chart 4, orifice size = 37 mm diameter

11.9 Bibliography

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URS New Zealand Ltd, Countryside and Foothills Stormwater Management Code of Practice, February 2001

Design Calculation Report Form

(To be produced by the Developer for the approval of City/District/Regional Council)

Date: ______________________

Project: ____

Location: ____

Owner: ____

Developer: ____

Designer: ____

1. Development Type (tick appropriate box):	
Greenfield to Developed	
Lower intensity to higher intensity development	

2. Land Use	Type	Current Area (m^2)	Developed Area (m^2)

3. LNO Design Requirement (tick appropriate box):

Hydraulic neutrality (tick appropriate box) Note that LNO may require greenfield flows, depending on the existing system capacity, even if the site is currently developed	Greenfield – 1 in 2year	
	Greenfield – 1 in 10year	
	Current land use – 1 in 2year	
	Current land use – 1 in 10year	

Roof runoff percentage capture. State the LNO approved percentage.	%

Design Calculation Report Form

(To be produced by the Developer for the approval of City / District Council)

4. Quality / water use storage calculation

5. Attenuation storage and orifice size calculation

6. Total tank size, and position of water use outlet and orifice

Designer: ________________________ Approver (LNO): __________________

Date: _______________ Date: _______________

Rain tanks
Inspection forms
Construction and operation and maintenance inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

RAIN TANK CONSTRUCTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Rain Tank Construction Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
1. Inspector should sight Approved Design Calculation Report (tick to confirm)	Y	N			7. Backflow preventer	Y	N		
					8. Attenuation storage	Y	N		
					9. Orifice position	Y	N		
Observation					10. Overflow pipe	Y	N		
2. Extent of roof catchment conforms to disign	Y	N			11. Maintenance access	Y	N		
					12. Erosion protection	Y	N		
3. Extent of paved (other impervious) area conforms to design	Y	N							
4. Quality / water use storage	Y	N							
5. First flush device, screens and tank cover	Y	N							
6. Water use outlet position, pump and plumbing	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____

1st Notice: ____

2nd Notice: ____

Submit plan modifications as noted in written comments by ______________________________

Notice to Comply issued ____

Final inspection, project completed ____

Officers signature: ______________________________

Consent Holder/Engineer/Agent's signature: ______________________________

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

RAINWATER TANK MAINTENANCE INSPECTION CHECKLIST	: / 9	Needs immediate attention / Not Applicable	V	Okay	;	Clarification Required

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Rainwater Tank Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
OBSERVATION	Y	N	Y	N		5. Backflow preventer (once in five years)	Y	N	Y	N	
1. Extent of roof catchment conforms to design						6. Orifice	Y	N	Y	N	
2. Extent of paved (other impervious) are conforms to design	Y	N	Y	N		7. Overflow pipe	Y	N	Y	N	
						8. Maintenance access	Y	N	Y	N	
3. First flush device, screens and tank cover	Y	N	Y	N		9. Erosion protection	Y	N	Y	N	
4. Water pump and plumbing	Y	N	Y	N							

Inspection Frequency Key **A = Annual, M = Monthly, 3M = Three monthly, 6M = Six Monthly, 3-6M = Three to Six Monthly**

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans?   Y / N   In accordance with As Built plans?
Y / N

Maintenance required as detailed above?   Y / N   Compliance with other consent conditions?
Y / N

Comments: ____

Dates by which maintenance must be completed: /   /

Dates by which outstanding information as per consent conditions is required by: /   /

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: _____________________________

Chapter 12
Greenroof design, construction and maintenance

12.1 Introduction

Greenroofs reintroduce vegetation on areas previously considered unavoidably impervious. They reduce overall site imperviousness and the resulting stormwater runoff. The vegetative cover on a greenroof can:

> improve air quality
> provide habitats for bird and insects
> help retain higher levels of humidity in city areas
> yield significant structural and cost benefits including reducing the expansion and contraction of roof membranes and insulating buildings against temperature extremes

12.2 Design approach

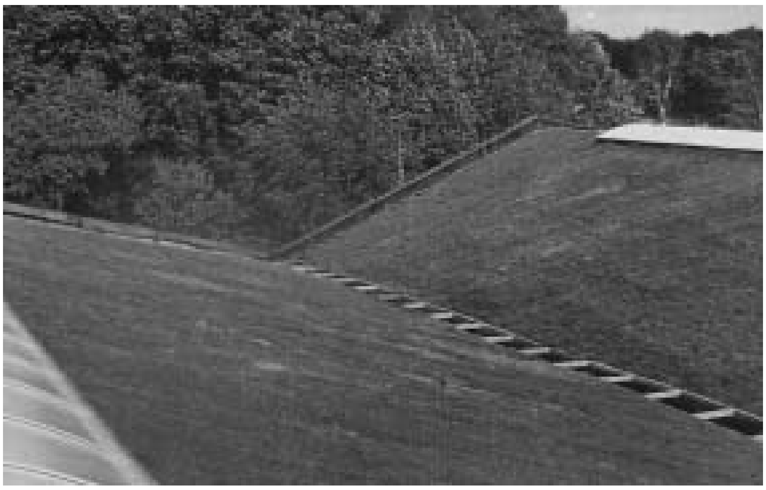
Typically, as shown in Figure 12-1, the cross section of a greenroof consists of:

> a waterproof membrane
> a root barrier
> an insulation layer (optional)
> a drainage layer
> filter fabric
> the engineered growing medium or soil substrate
> the plant material
> usually some form of a biodegradable wind blanket, such as a jute or coco liner-type mesh, is placed over the new plants to stabilise establishing roots

Successful greenroof installation requires an appreciation and consideration of plant biology, hydraulic engineering and architecture. Greenroofs are thoroughly engineered systems which address all the critical aspects of design, including:

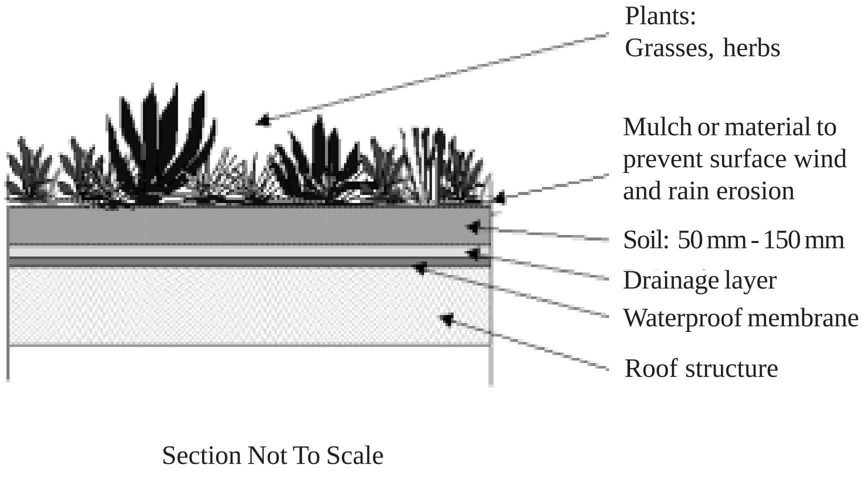
> the saturated weight of the system and load bearing capacity of the underlying roof deck
> moisture and root penetration resistance of the waterproofing membrane
> resistance to wind shear, management of drainage
> the suitability of the proposed plant material

Plant 12-1: Example of a green roof



Ideally, even thin systems work optimally with two layers, separated by a geotextile fabric. The lower level is commonly very light-weight granular mineral material (usually a fired clay). Plant roots will

Figure 12-1
Greenroof standard detail



penetrate through the geotextile and concentrate along the bottom of this layer where they find the best conditions for survival (cool temperatures and more consistent moisture). When roots are encouraged to grow higher up in the profile, they are much more vulnerable to the effects of varying temperature and moisture, consequently, if irrigation is used, water is introduced into this granular layer. If the substrate is chosen to have good water retention qualities, this greenroof will support a variety of plants without irrigation.

12.3 Applicability

Greenroofs can be used on a variety of roof types and on any property size, as their installation will not require the use of additional land. In Auckland's temperate climate, greenroofs should not be limited by the ability to establish and maintain vegetative cover.

<u>12.3.1 Roof Slope</u>

Generally the construction effort and cost of greenroofing increase with slope. Minimal slopes slow down water flow, and above 5^{o} or more it is necessary to prevent rapid runoff by increasing the retention capacity of the substrate. Light soils and water retaining substrates make it possible to vegetate sloping roofs up to 30^{o}.

However, roofs with a slope of 20^{o} or more require:

- steps to prevent soil slippage and erosion
- possible additional support with cross battens
- a raised grid structure to secure the plants' growing substrate.

<u>12.3.2 Additional support considerations</u>

The additional load of materials comprising and water held in a greenroof must be taken into account when accommodating the building's structural load. The calculation must be based on its saturated state. Below are some values from March, 1998 brochure from ZinCo International 3/98. These are calculated in accordance with the German National Standard DIN 1055 - Design Load for Buildings and give examples of roof covers and their approximate saturated weights for comparison:

- > Normal roofing
- > Gravel Surface 90 - 150 kg/m^2
- > Paving Slabs 160 - 220 kg/m^2
- > Vehicle Surface From 500 kg/m^2
- > Greenroof 60 - 150 kg/m^2

For greenroofs with projected live loads of higher than 815 pascals, consultation with a structural engineer is required. Additional soil depths and larger plants will need more structural support, and a greater layer build-up of the greenroof system. Deeper planting beds can be constructed over internal columns and walls to provide a higher overall loading capacity.

12.3.3 Cost

The extra capital cost of a greenroof relates directly to the increased loading on the structure. An American report suggests a landscaped rooftop may cost about one third more than the same roof without vegetation. However, taking into account energy savings from insulation and a longer roof lifespan, the cost calculated as an annual figure over the lifetime of the greenroof may only be half that of a conventional roof.

Any costing should include structural, safety, irrigation and maintenance requirements.

12.4 Water quality performance

Wind, insulation and evapotranspiration create the extreme drying conditions on roof tops mean that runoff from a greenroof is often negligible. The vegetation and soil system provides similar treatment to that achieved by other soil filtration systems such as rain gardens, greenroofs provide both water quantity and water quality benefits. Greenroof runoff is accepted as having 75% suspended solids removal.

From a hydrologic standpoint the curve number for a greenroof can be calculated as 61 when considering an overall site curve number in the TP 108 analysis.

12.5 Greenroof components

Development of a greenroof requires careful consideration of each of the following system components:

- > waterproof membrane
- > insulation layer (optional)
- > drainage layer
- > filter fabric membrane
- > water storage and irrigation
- > soil growth medium
- > plant material

Plate 12-2: Greenroof in an industrial area

12.5.1 Waterproof membrane system

Greenroof systems contain several layers of protective materials to convey water away from the roof deck.

The waterproofing layer may consist of a liquid-applied membrane or specially designed sheet membrane(s). Some believe the liquid-applied membrane provides a superior waterproofing and easier maintenance (McDonough + Partners, 1999). Because it is applied as a liquid, it must be installed directly on the roofing deck, so any existing roofing must be completely removed. With certain limitations, sheet membranes may be installed over existing roofing, although manufacturers prefer that existing roofing be removed. Many of the oldest greenroofs are waterproofed with mastic asphalt, but bitumen sheets with polyester carriers and SBS modified coatings are becoming more common.

Root resistance is achieved either by a laminated upper layer (usually copper) or by chemical additives in the coating. To ensure drainage capacity, the support to the waterproofing layer should have a slope of at least 1.5% (Hendriks and Hooker, March, 1994). Since plant roots discharge acids, the waterproof membrane must also be able to withstand this.

Correct application of the waterproof membrane is essential to the viability of the greenroof. Quality control is assured through knowledgeable roofing procedures and a water impermeability test immediately following membrane application, with a minimum duration of 24 hours (48 hours preferred).

Design standards that are applicable to waterproofing systems include:

- ASTM C981
- ASTM C898
- ASTM STP 1084
- the Architectural Graphic Standard
- the NRCA Roofing and Waterproofing Manual (RCI's Greenroof Workshop, August 6, 2001)

Water leakage from poor drainage or possible root puncture could lead to interior damage if the correct waterproofing membrane system, root barrier, and drainage layer are not selected. Vulnerable areas where leakage is possible include:

- abutting vertical walls
- roof vent pipes
- outlets
- air conditioning units
- perimeter areas.

Plate 12-3: Close up view of varied vegetation on a greenroof

A thorough water flood test needs to be conducted for leaks after installation of the waterproofing membrane to ensure quality control, certainly before the other layers are applied.

12.5.2 Insulation layer (optional)

The insulation layer is an optional component of a greenroof that prevents

Plate 12-4: Wetland on a roof

the water stored in the system from extracting heat energy from the underlying building. They are generally applied on existing roofs in retrofitting projects that may require an increase in the building's insulation value.

12.5.3 Drainage layer

Every greenroof must have a drainage layer to carry away excess water. On very shallow greenroofs the drainage layer may be combined with the filter layer. Unimpeded drainage is assured in greenroof systems because the drainage layer is applied over the entire roof area. A drainage layer is not always necessary on sloped roofs due to gravitaty drainage, but it is recommended to avoid ponding. The drainage layer can be made of gravel, rockwool or plastic.

Drainage can be used to partition the roof surface into compartments so that in the event of damage to the waterproofing, leaks can be easily found. The drainage layer serves the dual purpose of keeping the soil well aerated and in somes cases also acts as a water retention layer.

Drainage capacity must increase closer to the rainwater outlets, so a separation barrier 500 mm wide of large rounded pebbles should be installed along the eaves and near outlets. These rainwater outlets need to be accessible for seasonal cleaning (Hendriks and Hooker, 1994). Additionally, a shallow layer of gravel or pebbles placed approximately 400mm from the outside perimeter of the roof is recommended, providing additional drainage, fire control and access to the roof for maintenance.

12.5.4 Filter fabric membrane

The main function of the filter fabric/membrane is to hold the soil in place and prevent soil particles, plant debris and mulch, from entering and clogging the drainage layer below. Air and water are thus permitted to flow through, while the drainage layer and the actual drains are protected. Careful placement is required with overlaps of at least 100 mm to 160mm wide along vertical edges up to the plant material layer, finished with a strip of self-adhesive bitumen membrane. Typical materials are lightweight water-resistant polyester fiber mats or polypropylene-polyethylene mats (Hendriks and Hooker, 1994). These filter fabrics are the relatively inexpensive typical non-woven, non-biodegradable landscape fabric types found at most garden/home improvement stores.

It is essential to mark the position of the roof outlets before installing the protection layer, so that they can be located easily and the root barrier and protection mat cut accordingly. Protection of the membrane from these components could include 10mm of granular rubber (Hendriks and Hooker, 1994). Reliable detailing at penetration and perimeter areas with durable protection is critical. Any expansion joints which are not extended up through the waterproofing should remain free of plants. They can, for example, be covered by gravel or paving slabs so that they can be easily located and remain accessible at all times.

12.5.5 Water storage and irrigation

Plate 12-5: Greenroof as an aesthetic feature

Greenroofs must be able to store water and not dry out too quickly. If the soil substrate/ drainage system cannot hold a certain amount of free water, then additional forms of water storage may be necessary and can be supplied by several methods. Certainly, the most ecologically correct and economically sustainable systems would require no or little human intervention.

An optional reservoir board layer, available from some companies, can be installed to retain and store small amounts of water. Additionally, either a simple automatic drip irrigation system with a manifold delivering water at the base of the profile can be installed. A more complete (and heavy and costly) irrigation system can be incorporated into any greenroof design.

Base level irrigators introducing water directly to the root zone are favoured for several reasons:

- Roots are encouraged to grow down into the deepest portion of the cover where temperature and moisture conditions are most stable
- a dry surface cover is maintained, discouraging the germination of weed seeds
- water losses due to evaporation are minimised

12.5.6 Soil / growth medium

Because natural soils are heavy, particularly when wet, greenroofs often involve the use of lightwieght soil mixes of high quality compost and recycled materials. These materials need to:

- be water permeable
- be water and air retentive
- be reistent to rot, heat, frost and shrinkage
- have good nutrient status
- provide an excellent rooting medium.

As plants appropriate for greenroofs favour poor soils, substrates that improve soil structure without enriching it are best. While grasses can be grown on lightweight rockwool or growing media as shallow as 10-25cm in depth, it is generally desirable to have as large a volume and depth of media as possible to contribute to wind stability, offset high drying rates and protect the roots from frost damage.

Plant material

Careful and regionally specific vegetative planning is critical to the long term success of any greenroofing project within the Auckland Region. Characteristics of vegetation typically used on greenroofs include:

- shallow root systems
- good regenerative qualities
- resistance to direct radiation, drought, frost and wind
- compatibility with the local range of temperature, humidity, rainfall, and sun/shade exposure
- drought tolerant

Most importantly for the artificial environment of a greenroof, plants need to be reviewed for their tolerance of drought conditions, as most systems are designed to be low maintenance and extensive irrigation is expensive and requires additional design.

The closest natural environment matching conditions found on greenroofs are coastal plant communities, or arid, rocky regions.

12.6 Design procedure

12.6.1 Initial steps

1. Estimate rainfall using TP108 for your site location.
2. Calculate pre- and post- site development curve numbers using a CN of 61 for the roof area.

Stormwater management will still need to be provided for overall site control but the roof area will not require treatment and use of the 61 CN will have a beneficial effect on overall site runoff (peak flow and volume).

12.6.2 Design steps

The following issues need to be addressed in addition to careful consideration of each layer of the greenroof system.

Windproofing

What is the speed and direction of winds blowing across the roof? How do they change daily and with the seasons? Is there a need to provide shelter from the wind?

Shade requirements

How do sun angles change daily and with the seasons as the sun moves across the roof? Where are the cool shaded spots, lightly shaded spots and full sun areas? Is overhead shading necessary?

12.7 Operation and maintenance

Thorough design of a greenroof system should reduce the need for maintenance. Due to the return of organic matter to the soil, additional fertilising is not usually necessary. Mowing and pruning or trimming of plants may sometimes be desirable for aesthetic reasons but correct choice of low growing, or limited size plants should reduce the need for this.

12.8 Case study

Roof area: 400m^2
Roof slope: 10%
Region: Auckland
Two layer profile

Design parameters
Waterproof membrane:
Soil depth: 0.10m
Irrigation required: no
Water storage required: no
Plant type: native grasses, succulents, herbs
Drainage system:
Saturated loading (to be incorporated into roof loading design):

12.9 Bibliography

Web resources:
www.greenroofs.com
www.cmhc-schl.gc.ca/en/imqualf/himu/wacon/wacon_088.cfm
www.Ecoroofs.com
www.portphillp.vic.gov.au
www.construction.ntu.ac.uk

Chapter 13
Outlet protection

13.1 Introduction

Erosion at pipe or channel outlets is common. Determination of the flow condition, scour potential and channel erodibility should be a standard component of stormwater management design. The only safe procedure is to design the outfall on the basis that erosion at the outlet and downstream channel is to be expected. A reasonable procedure is to provide at least minimum protection, and then inspect the outlet channel after major storms to determine if the protection must be increased or extended. Under this approach, the initial protection against channel erosion should be sufficient to provide some assurance that extensive damage would not result from one runoff event.

Two types of erosion result from stormwater discharges:

> Local scour in the vicinity of pipe or channel outfall
> General channel degradation further downstream

Local scour is the result of high velocity flow at the pipe outlet. It tends to have an effect for a limited distance downstream. Natural channel velocities are almost universally less than pipe outlet velocities, because the channel cross section, including the floodplain, is generally larger than the pipe flow area while the frictional resistance of a natural channel is less than the frictional resistance of a concrete pipe. Thus, flow eventally adjusts to a pattern controlled by the channel characteristics.

Channel degradation represents a long term lowering of the stream channel which may proceed in a fairly uniform manner over a long length or may be evident in one or more abrupt drops. Most stream channels in the Region are degrading as a result of increased stormwater runoff volumes from changed land use, initially from forest to rural use and further from rural to urban use. Consideration of instability issues of the waterway into which stormwater systems discharge is an essential part of overall stormwater management design.

Outlet protection for culverts, stormwater outfalls or ditches is essential to prevent erosion from damaging downstream channels and receiving environments. Outlet protection can be a channel lining, structure or flow barrier designed to lower excessive flow velocities from pipes and culverts, prevent scour, and dissipate energy. Good outlet protection will significantly reduce erosion and sedimention by reducing flow velocities.

Plate 13-1: Example of riprap at a stormwater outfall

13.2 Objective

Outlet protection aims to protect outfall areas from local scour. It is necessary whenever discharge velocities and energies at the outlets of pipes or ditches are sufficient to erode the downstream reach.

When an outfall is sited in a coastal environment, it is essential to also consider wave energy in determining appropriate rock sizing.

13.3 Design approach

Key design elements include:

- pipe grade
- outlet velocity
- riprap aprons
- engineered energy dissipators
- flow alignment and outfall setback in freshwater receiving environments
- erosion control in coastal environments

These are summarised below.

13.3.1 Pipe grade

To minimise the complexity of analysis and design of outlet protection structures, the first step to look for was to reduce the need for outlet protection by laying the pipe at as low a grade as possible, for example by using a drop structure in the pipe a short distance above the outfall.

13.3.2 Outlet velocity

In order to identify the need for further outlet protection, it is useful to compare outfall velocities with the velocities that natural channels can tolerate without accelerated erosion, as shown in Table 13-1.

The design and analysis of riprap protection, stilling basins, and other types of outlet structures can be a complex task to accomplish. The first step is to look for ways to reduce the need for outlet protection by laying the pipe at a grade no steeper than possible (possibly using a drop structure in pipe). When considering outfall velocities, there is value in considering what velocities that natural channels can tolerate prior to eroding. Table 12-1 provides those values.

The primary consideration in selecting the type of outlet protection is the outlet velocity for pipes or channels, which is dependent on the flow profile associated with the design storm.

Pipe flow may be controlled by:

- the type of inlet
- the throat section
- the pipe capacity or
- the type of outlet.

The type of control may change from outlet control to inlet control depending on the flow value.

For inlet control, the outlet velocity is assumed to be normal depth as calculated by Manning’s equation.

For outlet control, the outelt velocity is found by calculating the channel flow from Manning’s equation with the calculated tailwater depth or the critical flow depth of pipe, whichever is greater.

Table 13-1
Maximum permissible velocities for unlined channels

Fine Sand, colloidal	0.4
Sandy loam, noncolloidal	0.5
Silt loam, noncolloidal	0.6
Alluvial silts, noncolloidal	0.6
Ordinary firm loam	0.8
Volcanic ash	0.8
Stiff clay, very colloidal	1.1
Alluvial silts, colloidal	1.1
Shales and hardpans	1.8
Fine gravel	0.8
Graded loam to cobbles, noncolloidal	1.1
Graded silts to cobbles, colloidal	1.2
Coarse gravel, noncolloidal	1.2
Cobbles and shingles	1.5

13.3.3 Riprap aprons

Outlet protection can take the form of riprap placement with the stone sizing being done as part of the storm drainage design, and using these guidelines. Riprap outlet protection is usually less expensive and easier to install than concrete aprons or energy dissipators. A riprap channel lining is flexible and adjusts to settlement; it also serves to trap sediment and reduce flow velocities.

Riprap aprons should not be used to change the direction of outlet flow: an impact energy dissipator is more appropriate for this. Riprap aprons aim to manage the transition of piped stormwater into a stream channel primarily by their higher Manning's roughness coefficient, which slows the water velocityl.

Riprap aprons should be constructed, where possible, at zero percent grade for the specified length.

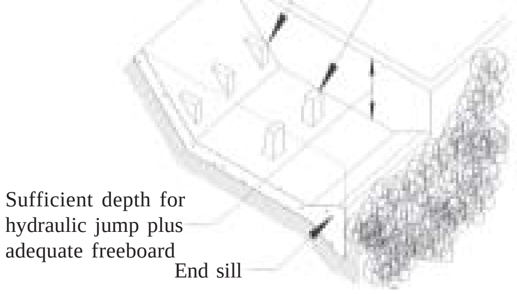
Grouted riprap may be subject to upheaval from periodic saturation of clay subgrades and is therefore not generally recommended for outlet velocity protection. Upheaval can crack the grout resulting in undersized riprap size for the velocities of flow. In general ungrouted, properly sized riprap provides better assurance of long term performance.

Laying riprap directly on soils can allow the water to hit soil particles, dislodging them and causing erosion. Filter cloth laid between the soil and riprap will assist this. Filter cloth is graded on the thickness and permeability characteristics. A qualitative judgement is usually made on the appropriate grade to prevent erosion and prevent puncture by riprap.

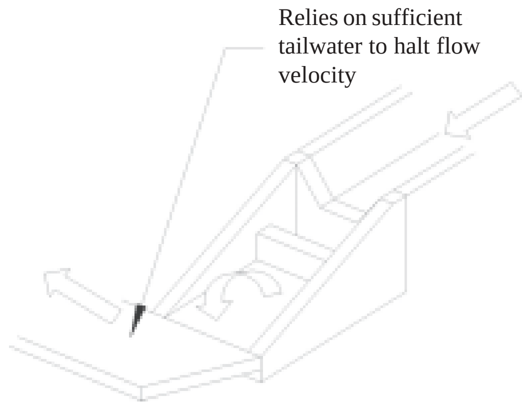
13.3.4 Engineered energy dissipators

There are many other types of energy dissipators. Auckland City has a design detail for a concrete energy dissipation structure in its Development and Connection Standards. An older document is the Culvert Manual, Volume 1 done by the Ministry of Works and Development in August, 1978. There have been many types developed over the years. Commonly used varieties include stilling basins, baffle blocks within a headwall and impact energy dissipators.

Engineered energy dissipaters including stilling basins, drop pools, hydraulic jump basins or baffled aprons are required for outfalls with design velocities more than 6 metres per second. These should be designed using published or commonly known techniques found in such references as *Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC 14, September 1983, Metric Version*. This design approach can be downloaded from the internet at www.fhwa.dot.gov/bridge/hydpub.htm.



Typical Stilling Basin



Typical Impact Energy Dissipater

13.3.5 Flow alignment and outfall setback in freshwater receiving environments

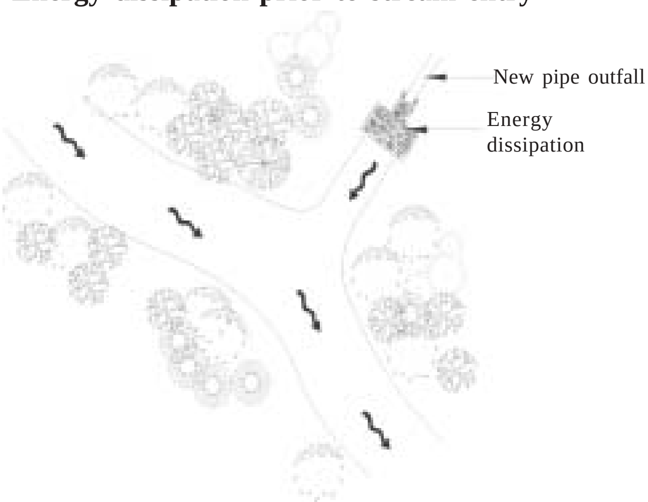
Depending on the location and alignment of the pipe outfall and the receiving stream, outfall structures can have a significant effect on receiving channels. Alignment at a right angle to the stream will force the flow to make a 90^o angle to the direction of flow. This can cause scour of the opposite stream bank in as well as causing significant turbulence at the point of entry.

The preferred approach is to align the pipe flow at no more than a 45^o angle to the stream.

If the pipe outfall must be directly into the stream channel, riprap must be placed on the opposite stream channel boundary to a depth of 300 mm above the elevation of the pipe crown. This is in addition to a riprap apron at the pipe outfall.

The impact of new pipe outfalls can be significantly reduced on receiving streams by locating them further back from the stream edge and digging a channel from the outfall to the stream. This would allow for energy dissipation before flows enter the stream, as shown in Figure 13-1. At a minimum, the pipe outfall should be located far enough back from the stream edge to prevent the energy dissipater intruding on the channel.

Figure 13-1
Energy dissipation prior to stream entry



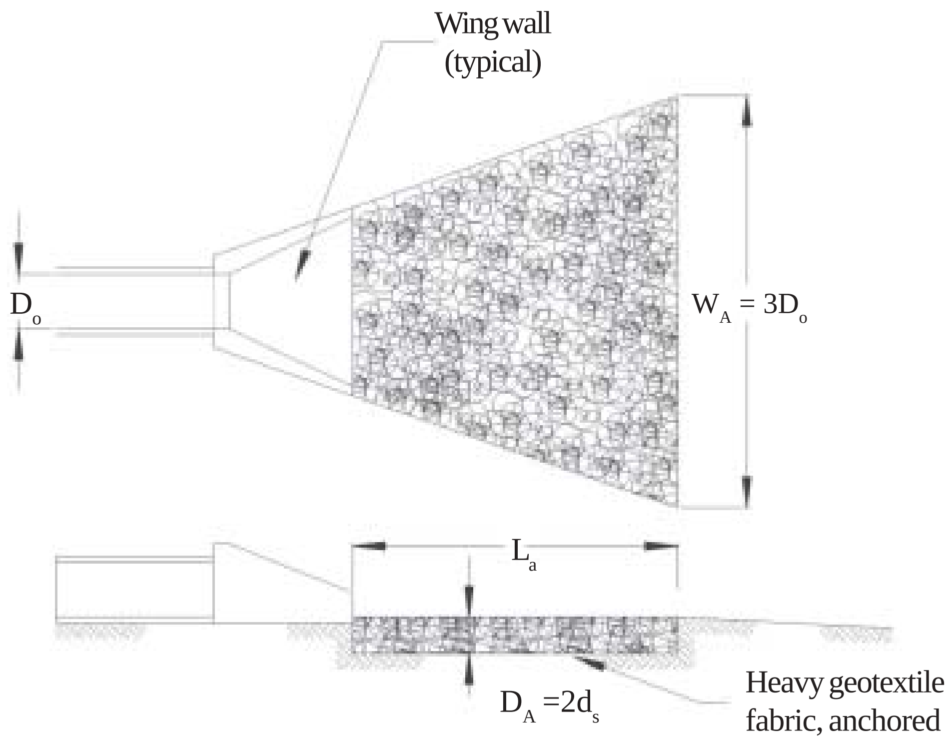
13.3.6 Erosion control in coastal receiving environments

Discharges and outlet structures may give rise to a number of adverse effects on the coastal environment if they are constructed of inappropriate materials and/or are poorly sited. For example, a discharge may cause or exacerbate erosion of a beach or an outlet may detract from the natural character or amenity value of the coastal environment or impede public access to, from and along the coast.

Before locating a discharge in the coastal marine area particular consideration should be given to the following matters to avoid/minimise any adverse effect on the natural character, amenity or public access values of the coastal environment:

1. Discharging in such a location that will not unnecessarily cause or exacerbate erosion, particularly of

Figure 13-2
Schematic of outfall protection



beach materials. For a discharge to a beach, this may involve locating the point of discharge away from the active beach system, e.g. at or near an adjacent headland.

2. Where there are more than one points of discharge to a beach system, consideration should be given to combining discharges to a common point of discharge, including via a common structure.
3. Ensuring the visual form and appearance of the outlet does not detract from its immediate surrounds and the natural character of the coastal environment, e.g. ensuring the structure is assumed into its locality rather than contrasts with that environment. The use of locally sourced rock and/or coloured and sculpted concrete forms may be appropriate.
4. Keeping the "footprint" of the structure to a minimum.
5. Incorporating the discharge pipe into another structure, e.g. a boat ramp, to minimise the number of structures in the coastal environment.
6. Locating the outlet and discharge in such a position as to not create an abstacle to public access to, from or along the coastal marine area.

13.4 Detailed design

The design of outlet protection can be done in two ways. The most accurate approach is that in *Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC 14, September 1983, Metric Version*. This is widely used by design professionals and is recommended by the ARC.

The second approach is a simplified approach, which is conservative in order to ensure that adequate channel protection is provided. The approach still requires that velocities for the design discharge to be calculated and inputted into the equations. The design approach based on Figure 13-2 is:

1. Determine the discharge velocity for the design storm. For stormwater management structures the design storm is the maximum flow that can be carried by the pipe. This will normally be the 10 year design flow.

2. Enter that value into the following equation to determine the equivalent diameter of the stone.

$$d_s = 0.25 \times D_o \times F_o$$

where

d_s = riprap diameter (m)
D_o = pipe diameter (m)
F_o = Froude number = $V/(g \times d_p)^{0.5}$
d_p = depth of flow in pipe (m)
V = velocity of flow in pipe (m/s)

3. The thickness of the stone layer is 2 times the stone dimension. $D_A = 2d_s$
4. The width of the area protected is 3 times the diameter of the pipe. $W_A = 3D_o$
5. The height of the stone is the crown of the pipe + 300 mm.
6. The length of the outfall protection is determined by the following formula.

$$L_a = D_o(8 + 17 \times \text{Log } F_o)$$

Where

L_a = Apron length (m)
g = 9.8 m/sec^2

As can be seen from the equations, any reduction in the discharge velocity will reduce the stone size and apron length. Mechanisms to reduce velocity prior to discharge from the outfall are encouraged, such as drop manholes, rapid expansion into pipes of much larger size, or well up discharge designs.

13.5 Construction

Construction of the outfall protection must be done at the same time as construction of the pipe outfall itself. In terms of environmental protection and timing of construction, it is best to construct the outfall unit from the bottom up, to prevent concentrated flows from being discharged into an unstabilised location. If construction of the outfall system is done from the top end first, the entrance to the system should be blocked off to prevent flow from travelling through the pipe until the outfall protection is completed.

Outfall structures associated with stormwater management ponds shall be done in a similar fashion. Once the embankment has been completed and the pipe outfall structure installed, the outfall erosion protection must be constructed.

It is important that a sequence of construction be established and followed, such as, for example:

1. Clear the foundation area of trees, stumps, roots, grass, loose rock, or other unsuitable material.
2. Excavate the cross-section to the lines and grades as shown on the design plans. Backfill over-excavated areas with moist soil compacted to the density of the surrounding material.
3. Ensure there are no abrupt deviations from the design grade or horizontal alignment.
4. Place filter cloth and riprap to line and grade and in the manner specified. Sections of fabric should overlap at least 300 mm and extend 300 mm beyond the rock. Secure the filter cloth at the edges via secure pins or a key trench.
5. Ensure the construction operations are done so as to minimuse erosion or water contamination, with all disturbed areas vegetated or otherwise protected against soil erosion.
6. For coastal sites, undertake construction at periods of low tide.

13.6 Operation and maintenance

Key tasks are:

- inspect outlet protection on a regular basis for erosion, sedimentation, scour or undercutting
- repair or replace riprap, geotextile or concrete structures as necessary to handle design flows
- remove trash, debris, grass, or sediment

Maintenance may be more extensive as smaller riprap sizes are used, as children may be tempted to throw or otherwise displace stones or rocks.

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Chapter 14
Landscaping guidance for stormwater practices

14.1 Introduction

Landscaping is critical to improving both the function and appearance of stormwater management practices. It has aesthetic, ecological and economic value that is often not recognised during site design and construction. In almost all cases, compliance with regulatory requirements is the key driver and the issue of how a stormwater practice fits into the local landscape can be overlooked.

Moreover, where the initial developer is not the eventual property owner, there may not be a long term interest in landscaping.

Where the local territorial authority assumes the maintenance responsibility for the practice and/or becomes the owner of the practice, landscaping issues must become a standard asset management cost in the Council's financial plans.

If the practice is considered an eyesore, property values will go down and the general public response to stormwater management will be negative. The stormwater practice must be an integral part of the development and given the same landscape attention as other parts of the site.

Plate 14-1: Example of a stormwater pond with little attention given to landscaping

14.2 Objective

The objectives of landscaping stormwater management practices are to:

> improve their aesthetics
> improve their water quality and ecological function
> increase the economic value of the site

A good landscape plan will consider all three objective. This means involving a professional landscape architect with experience in natural system design.

Considerations include:

> site soils
> slopes
> hydrologic conditions
> water quality/ecological benefits.

The following discussion expands on the three objectives.

14.2.1 Improve the aesthetic appeal of stormwater practices

Aesthetics is a subjective yet very important aspect of everyday life. It is a concept that is difficult to define quantitatively. Something that is good aesthetically tends to be considered tasteful, pleasing, appropriate and fitting for its location. Tastes differ, and disagreement about what is aesthetic is common. The goal of this section is to ensure that stormwater practices are designed as an asset to the property owner and to the overall community.

14.2.2 Improve the water quality and ecological function of the practices

Attention to landscaping as a component of a stormwater management practice can have a significant positive effect on water quality and ecological function. Shading of practices can reduce thermal impacts on receiving systems. Vegetated buffer zones (woody or grassed) can reduce sediment entry, and natural vegetation promotes local ecological diversity.

Landscaping plans should consider:

- chemical use reduction
- contaminant source reduction
- impervious surface mitigation.

Projects should be designed to minimise the need for toxic or potentially contaminating materials such as herbicides, pesticides, and fertilisers within the stormwater management practice area.

Materials that could leach contaminants or pose a hazard to people or wildlife should not be used as components of a stormwater practice (examples can include chemically treated wood or galvanised metals).

Good landscaping can also reduce impacts of impervious surfaces by incorporating swales by paths and accessways.

14.2.3 Increase the economic value of the site

A number of studies demonstrate the economic benefits of properly landscaped stormwater systems:

- study in Maryland in the U.S. found that properly designed stormwater management ponds increased adjacent property values by 10 - 15 %
- the U.S. EPA's literature review of the impacts of urban runoff ponds on property values is available on EPA's website at www.epa.gov/OWOW/NPS/runoff.html
- City of Christchurch has been engaged in natural stream restoration and has identified significant monetary benefit to property values for properties abutting the restored stream channels

14.3 Use of native species

This stormwater management manual encourages the use of native plants in stormwater management practices, where they are appropriate. Native plants are defined as those species found in the Auckland Region before European migration.

Native species have distinct genetic advantages over non-native species for planting. As they have evolved here naturally, indigenous plants are best suited for our local climate. This translates into greater survivorship when planted and less replacement and maintenance during the life of a stormwater management practice. Both of these attributes provide cost savings for the practice owner.

People often plant exotic species for their ornamental value. While it is important to have aesthetic stormwater management practices for public acceptance and the maintenance of property value, it is not necessary to introduce foreign species for this purpose. There are a number of native species that are aesthetically pleasing and can be used as ornaments.

14.4 General landscape guidance for all stormwater practices

there are several components of a landscape plan. They should be considered individually and together to ensure implementation of a successful landscape plan. The components include the following:

- stormwater practice area
- landscape screening
- soils
- site preparation
- planting
- general guidance

14.4.1 Stormwater practice area

The practice area includes the stormwater management practice itself, maintenance accessways, fencing and a minimum buffer around these elements. The buffer ensures that adequate space is available for landscaping. Other site elements can be located within the buffer if the need arises. The landscape plan should designate the practice and buffer area.

Plate 14-2: Stormwater management pond with significant landscaping

14.4.2 Landscape screening

Practice elements such as chain link fences, concrete headwalls, outfall pipes, riprap, gabions, steel grates, steep side slopes, manhole covers, and so on. can be screened from general public view with plant materials. Landscape screens of shrubs and trees could have a significant beneficial effect on public perception if used effectively.

14.4.3 Soils

It is necessary to test the soil in which you are about to plant in order to determine the following:

- pH
- major soil nutrients
- minerals
- seasonal wetness and water-retention capacity

The soil samples should be analysed by a qualified professional who will explain the results and their implications for plant selection.

14.4.4 Site preparation

Construction areas are often compacted, so that seeds wash off the soil and roots cannot penetrate it. No material storage or heavy equipment should be allowed in the stormwater practice or buffer area after site clearing has been completed, except to excavate and grade the stormwater management area. All construction and other debris must be removed before topsoil is placed.

For planting success, soils should be loosened to a depth of approximately 150mm. Hard clay soils will require disking to a deeper depth. The soil should be loosened regardless of the ground cover. This will improve seed contact with the soil, increase germination rates and allow the roots to penetrate the soil.

Providing good growing conditions can prevent poor vegetative cover. This saves money as vegetation will not need to be replanted.

<u>14.4.5 Planting</u>

In selecting plants, consider their desired function in the landscape. Is the plant needed as ground cover, soil stabiliser or a source of shade? Will the plant be placed to frame a view, create a focus or provide an accent? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be provided to serve some function in addition to any aesthetic appeal.

Certain plant characteristics are obvious but may be overlooked in the plant selection, especially:

- size
- shape

Tree limbs, after several years, can affect power lines. A wide growing shrub may block an important line of sight to oncoming vehicular traffic. A small tree, when full grown, could block views. Consider how these characteristics can work today and in the future.

It is critical that selected plant materials are appropriate for soil, hydrological conditions and other practice and site conditions. More information on adequacy of specific plant species is provided in the individual practice chapters.

<u>14.4.6 General guidance</u>

- Trees, shrubs, and any type of woody vegetation are not allowed on a dam embankment.
- Check water tolerances of existing plant materials prior to inundation of area.
- Stabilise aquatic and safety benches with emergent wetland plants and wet seed mixes.
- Do not block maintenance access to structures with trees or shrubs
- To reduce thermal warming, shade inflow and outflow channels as well as northern exposures of ponds.
- Shading of standing water reduces undesirable algae blooms
- Avoid plantings that will require routine or intensive chemical applications.
- Test the soil to determine if there is a need for amendments
- Use low maintenance ground cover to absorb stormwater runoff
- Plant stream and water buffers with trees and shrubs where possible to stabilise banks and provide shade
- Maintain and frame desirable views. Take care not

Plate 14-3: A well landscaped stormwater management pond

to block views at road intersections or property entrances. Screen unattractive views into the site.
- Use plants to prohibit pedestrian access to ponds or steeper slopes.
- Consider the long-term vegetation management strategy of the stormwater practice, keeping in mind the maintenance obligations of the eventual owners.
- Preserve existing bush areas to the extent possible.

14.5 Specific landscape provisions for individual stormwater management practices

Plate 14-4: Example of a pond having a good shape but no provision for landscape planting

In addition to the general guidance presented above, more specific guidance is given below for individual stormwater practices (this guidance is subject to variation from site to site).

14.5.1 Ponds and wetlands

Chapters 5 and 6 provide design guidance for ponds and wetlands. Ponds and wetlands have several defined elements that affect landscaping, including:

- pond shape
- pond topography
- zones of water inundation and periodic saturation.

Pond shape

Pond or wetland shape strongly influences public reaction. A rectangular pond is not seen as a 'natural' site feature and offers little in terms of amenity value. A pond with an irregular shoreline or one that apparently fits in with natural contours is more attractive. In addition, an irregular shape has a longer edge than a rectangular pond and allows for more planting, both above and below the water line. The ARC strongly recommends an irregular shoreline or one that follows existing contours. A minimum recommended buffer area around the pond is five metres above the shoreline where a reverse safety bench, as detailed in Chapters 5 and 6, and plantings can be established.

Pond topography

Topography has a major effect on the range of plants that can be grown, the movement of water through the pond or wetland and public safety. Steep side slopes can be dangerous for people slipping into a pond and will have affect the types of plants that can be used.

The ARC recommends a 300 mm deep three metre wide level bench below the normal pool level. This is recommended for safety reasons and for growth of emergent wetland plants. The plants will act to restrict public access to deeper water.

Plate 14-5: Example of a dry extended detention pond with good landscaping

Islands, effectively placed, can also be used for multiple benefits. They can increase stormwater flow paths, provide additional landscaped areas and provide wildlife habitat. Islands also increase edge lengths and vegetated areas.

Zones of water inundation and periodic saturation

Normal pond and wetland function will result in a number of zones becoming established, each providing different landscaping opportunities.

Zone 1 Periodic flooding zone
Sometimes flooded, but usually above the normal water level
This zone is inundated by floodwaters that quickly recede in a day or less. Key landscaping objectives may be to stabilise steep slopes and establish low maintenance natural vegetation.

Zone 2 Bog zone
Apart from short periods in the summer, the soil is saturated

This encompasses the pond or wetland shoreline. The zone includes the safety bench and may also be periodically inundated if storm events are subject to extended detention. Plants may be difficult to establish in this zone as they must be able to withstand inundation of water during storms or occasional drought during the summer. These plants assist in shoreline stabilisation and shading the shoreline, contaminant uptake and limiting human access. They also have low maintenance requirements.

Zone 3 0 - 150 mm deep of normal pool depth

This is a transition zone between the bog zone and the 150 - 500 mm ponded depthin which the water level sometimes drops and the area becomes a bog. Plants in this area must be able to tolerate periodic (but not permanent) saturated soil conditions.

Plate 14-6: Well landscaped rain gardens in a commercial parking area

Zone 4 150 - 500 mm deep
This is the main zone where wetland plants will grow in stormwater ponds and wetlands. Plants must be able to withstand constant inundation of water and enhance contaminant uptake.

Plants will stabilise the bottom and edge of the pond, absorbing wave impacts and reducing erosion. They will slow water velocities and increase sediment deposition rates along with reducing resuspension of sediments.

Zone 5 500 - more than 1000 mm deep
This zone is not generally used for planting because there are not many plants that can survive and grow in this zone.

14.5.2 Infiltration and filter practices

Infiltration and filter practices either take advantage of existing permeable soils or create a permeable medium such as sand. When properly planted, vegetation will thrive and enhance the functioning of the practices. For example, pretreatment buffers will trap sediments. Successful plantings provide aesthetic value and wildlife habitat, making the facilities more acceptable to the general public.

Planting around infiltration or rain garden practices for a 5 - 10 metre distance will cause sediments to settle out before entering the practice, thus reducing the frequency of maintenance clean out. As a planting consideration, areas where soil saturation may occur should be determined so that appropriate plants may be selected. Shrubs or trees must not be planted in areas where maintenance access is needed.

Plate 14-7: A well vegetated riparian corridor amenity to the community, amenity to the stream

14.5.3 Swales and filter strips

Key considerations include:

- soil characteristics
- plant interaction
- effects on stormwater treatment
- riparian buffers

The characteristics of the soil are perhaps as important as practice location, size, and treatment volume. The soil must be able to promote and sustain a robust vegetative cover.

Plant interaction is also important. Planting woody vegetation next to a swale or filter strip may shade the swale intolerant grass species in it.

The landscape plan will have to consider the effects that overall landscaping will have on stormwater treatment.

Riparian buffers are an excellent example of filter strips with high ecological, water quality and aesthetic value. Whan appropriately designed, they can treat dispersed runoff from adjacent land. The buffer, as plate 14-7 shows, can be an amenity to the community and increase economic value of adjacent lands.

14.6 Bibliography

City of Portland, Stormwater Management manual, Adopted July 1, 1999, revised September 1, 2000.

Maryland Department of the Environment, 2000 Maryland Stormwater Design Manual, Volumes I & II

Chapter 15
Innovative stormwater management practices

15.1 Introduction

As the stormwater programme continues to mature, alternative technologies will be proposed to meet water quality design goals. These innovative practices may be developed where site or catchment development intensity make it difficult to achieve desired water quality treatment levels with conventional systems, or provide a level of treatment that is not possible with conventional approaches.

The development of innovative, cost-effective stormwater management technologies is encouraged, subject to approval by the ARC through the consent process. Approval will depend on submission of objective, verifiable data that supports the claimed efficiency, although a single pilot site may be approved for purposes of data collection to document performance .

Innovative practices tend to be new technologies that have not been evaluated using approved protocols, but for which preliminary data indicate that they may provide a desirable level of stormwater contaminant control. Some innovative practices have already been installed or are proposed in the Region as parts of treatment trains or as a stand-alone practice for a specific project. In some cases, innovative practices may be necessary to remove metals or hydrocarbons. Innovative practices can also be used for retrofits and where land availability does not permit larger conventional practices.

15.2 Objective

This chapter outlines the information that should be submitted to evaluate the performance of alternative technologies whose operating parameters have not yet been verified to the satisfaction of the ARC.

This chapter deals with stand alone and pretreatment/retrofit practices.

15.2.1 Stand alone practice

An innovative practice should not be used for new development sites unless there are data indicating that its performance is expected to be reasonably equivalent to that provided by conventional practices, or as part of a treatment train. In retrofit situations, the use of any practices that make substantial progress toward the specified environmental objectives is encouraged.

Any alternative stand alone practice must generally comply with the 75% TSS removal goal in the ALW Plan.

Specific contaminant issues may warrant use of an alternative system that may be less effective at TSS reduction while providing enhanced reduction in other contaminants such as hydrocarbons. Performance at specific contaminant reduction will be monitored appropriately.

Water quantity issues may also affect practice acceptance, depending on location in a catchment.

15.2.2 Pretreatment or retrofit

Individual practices that are not capable of providing desired water quality treatment may nevertheless play a useful pretreatment supplementary role together with other approved stand alone practices.

A practice proposed for pretreatment of flows into another practice may, for example:

> remove coarse sediments, in order to reduce the frequency of maintenance of the primary stormwater treatment practice
> provide water quantity control
> reduce stream erosion.

Retrofit of a site or catchment for water quality treatment depends on land availability, specific contaminants of concern and cost. Water quality goals must be tempered by what can realistically be accomplished in a catchment. It is in these situations where innovative practices have a potentially significant role to play.

15.3 General information required from an applicant for approval of innovative systems

Innovative systems are being introduced on a routine basis. Current ones include:

> storm drain inserts
> underground vaults
> hydrodynamic structures
> on-line storage in the storm drain network.

This subsection summarises the basic information that should be submitted with any request for approval in a specific application in order to promote consistency in the submission of information for approval of an innovative practice. Consistency provides surety for a product manufacturer, a consent applicant and the general public that implementation of an innovative practice is based on the best information available. The ultimate goal is clean water and implementation should be based on an estimation of the best practice being used in a given situation.

It is important to be cautious with using innovative technologies for new development and retrofits. Before selecting an innovative practice for a limited application, available information should be evaluated using an acceptable protocol.

For these reasons, submission of an innovative practice in a given situation or for general compliance should include a description of the innovative technology or product including:

> Whether the operating parameters of the system have been verified.
> Existing or proposed monitoring data (detailed in Section 15.4)
> Documentation of processes by which TSS and other contaminants will be reduced (physical, chemical, biological).
> Documentation and/or discussion of potential causes of poor performance or failure of the practice.
> Key design specifications or considerations
> Specific installation requirements
> Specific maintenance requirements
> Data to support the claimed TSS removal efficiency. If the technology is new or the existing data is not considered reliable, a detailed monitoring programme to assess the TSS removal may be required
> Ownership issues that could influence use of innovative practices on individual sites. Examples of this issue could be refusal of a TA to accept responsibility for operation and maintenance.

15.4 Information needed to judge adequacy of existing or proposed monitoring data

The following summaries the detailed information that is needed to properly judge the adequacy of existing or propsed monitoring data to evaluate performance compliance of an innovative practice, from catchment related information, practice related information and water quality information.

15.4.1 Catchment parameters

The context in which the practice helps define situations where an innovative practice is (or is not) appropriate by assessing collection sites for known or new data. This in turn helps to determine the data's applicability to other locations.

It is also important that monitoring be done in the field, as opposed to the laboratory, as field monitoring better reflects actual practice performance.

Key catchment parameters include:

- catchment area served
- % impervious area
- total impervious area
- hydraulic connectivity
- baseflow or storm generated runoff only
- catchment land use and expected contaminants

15.4.2 Practice design parameters (where applicable)

Detailing specific elements of the innovative practice provides a clear understanding of the water quality treatment processes that occur in the various components of the practice. If the practice has a standard design based on catchment size or maximum flow rate, that information should be clearly stated in the discussion of practice parameters as detailed in the general discussion.

Key practice parameters include:

- basic shape (length/width, volume, importance of local topography)
- any permanent pool elevation and levels of service
- surcharge elevation
- forebay characteristics
- inlet/outlet locations and relative elevations
- water level control options
- 'on-line' or 'off-line'
- age of practice where monitoring has been or will be done
- specifications for practice components (filter media, sieve sizes, geotextile specifications, etc.)

15.4.3 Water quality analysis

Analyses detailed here are primarily for those done in the Auckland Region. Recognising that many innovative practices are being developed overseas, all information may not be available. In those situations a degree of judgement is involved regarding the relative importance of specified criteria. The ARC will consider the submission of overseas data as full or partial fulfilment of the water quality analyses, depending on the applicability of the collected data to the Auckland situation. Compliance assurance may necessitate water quality analysis on a more limited basis only for those parameters where gaps exist.

The following analyses are to be done for practice performance documentation:

- flow weighted composite samples used to determine the TSS concentrations in the influent and effluent of the device
- general water quality constituents for monitoring include TSS, pH, conductivity, DO, enterococci and total hydrocarbons
- total zinc should also be monitored as a 'keystone' contaminant for trace metals
- the performance of the practice or system should be based on the sampling results from at least 10 storms representative of those normally occurring in the Region. Depending on the relative variation in results, additional monitoring may be necessary to better understand expected performance
- at least one storm event must be greater than 20 mm of rainfall
- there must be at least three days of dry weather between storms sampled
- the samples must be collected and handled according to established procedures that are included in the monitoring plan
- the laboratory selected for analysis of the samples is recognised as technically proficient
- the efficiency of the device is calculated for individual events and is also based on the total TSS load removed for all monitored events
- the monitoring must be conducted in the field as opposed to laboratory testing
- depending on the processes involved in treatment, the practice or system may need to be in the ground for at least six months at the time of monitoring

15.5 Discussion

While the level of information requested may seem onerous to someone developing or wanting to use an innovative practice, it is essential that programme implementation and overall success be underpinned by good technology. With millions of dollars being spent on design, implementation and operation, it is important that we get our money's worth and that we are achieving the environmental objectives required.

Ultimate programme success rests on stormwater strategies, approaches and practices achieving a certain level of performance. We must have confidence that a practice will achieve stated goals and a good understanding of practice strength, limitations, and performance if we are to meet our obligations under the RMA and public expectations.