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Operation and Maintenance of Stormwater Treatment Devices in the Auckland Region

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	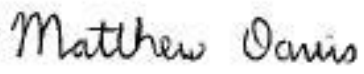
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Stormwater Treatment Device Operation and Maintenance

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1 Introduction

The original Technical Publication 10, "Stormwater Treatment Devices Design Guideline Manual" (TP10), was developed in the early 1990's by the Auckland Regional Council to assist stormwater treatment designers. It has been in use in the Auckland region since October 1992 and in the past five years has been used as the design basis for a number of other New Zealand regions.

A large number of devices installed in Auckland in the mid-to-late 1990's and early 2000's are difficult to operate and maintain, primarily due to poor design and construction. As time has elapsed, many practices in relation to the design and construction of treatment devices have been learnt and applied, and as a result stormwater treatment devices have improved.

Council has obligations under the Resource Management Act (1991) (RMA) for the maintenance and enhancement of the quality of water in waterways and coastal waters. This is done in part by controlling the discharge of contaminants into water, or onto or into land. To assist in this requirement the council has developed plans and guidelines for the management of stormwater. This operation and maintenance technical report forms part of the toolbox of information available for those maintaining stormwater treatment devices in the Auckland region.

TP10 has been subject to only one revision incorporating changes in the philosophy and approach in relation to stormwater treatment devices. The manual provides information on the operation and maintenance of these devices; however its focus was primarily on their design and construction; it was not tailored specifically for operational inspection and maintenance. Consequently, the day to day operation and maintenance of stormwater devices required additional information of relevance to network managers, device owners and maintenance contractors.

The objective of this report is to assist the stormwater industry by providing details and advice on the operation and maintenance of stormwater treatment devices commonly used in the Auckland region. In particular it attempts to provide advice on how to overcome operational and maintenance issues, and how to implement good maintenance schedules that prolong the life and performance of each device.

1.1 Objective

This report aims to provide all the necessary information to operate and maintain a stormwater treatment device effectively. Each chapter focuses on one device and provides specific maintenance information for that device.

The scope of this report is restricted to devices documented in the current TP10 and excludes proprietary devices. Devices included in this report are:

- Stormwater ponds.
- Wetlands.

- Swales and filter strips.
- Rain gardens.
- Tree pits.
- Sand filters.
- Oil and water separators.
- Rain tanks.
- Permeable paving.
- Infiltration trenches and dry wells.
- Living roofs.

While the scale of a treatment device will dictate the detail required, the operation and maintenance manual for any device is the most important source of information for its continued operation. The manual provides the background design and construction information along with maintenance frequencies and methods. This report provides information on developing operation and maintenance manuals, generic maintenance schedules and advice on troubleshooting maintenance issues for each device type listed above.

Stormwater treatment devices, particularly those based on low impact urban design principles, are constantly evolving as knowledge is gained about the urban hydrological cycle and also as the objectives of treatment systems change. The guides described in this technical report are therefore living documents and will be updated periodically as new information becomes available.

It is also recommended that you check with industry associations, experienced contractors, manufacturers and the council for additional advice and improved maintenance methods for stormwater treatment devices, particularly if any issues arise with a device where a solution is not readily apparent.

1.2 Technical Publication No.10

TP10 is a document to assist in the design of stormwater treatment devices. It was originally produced by the Auckland Regional Council in the early 1990's (republished 2003) and was the first real design guide in New Zealand for stormwater treatment devices. TP10 was largely based on overseas experience and design standards.

TP10 sets out the design criteria for a number of treatment devices including:

- Ponds.
- Wetlands.
- Filtration devices (sand filters, rain gardens).
- Infiltration devices (infiltration trenches, permeable paving).

- Swale and filter strips.
- Oil and water separators.
- Rainwater tanks.
- Green roofs.

The publication also outlines operation and maintenance of these devices. This technical report aims to supplement TP10 and expand on operation and maintenance requirements for stormwater treatment devices. The guides therefore incorporate device design criteria as outlined in TP10.

1.3 Target audience

Stormwater treatment devices can be owned or operated by a number of different groups, ranging from the individual property owner, council, developers and crown agencies (New Zealand Transport Authority (NZTA), Watercare, etc). Throughout the process of designing, consenting, constructing and operating a device, a number of stakeholders are involved who often require different levels of information.

The following stakeholders have been identified for the maintenance of stormwater treatment devices along with the documents which may be of most relevance to their requirements.

Table 1
Document target audiences.

Audience/ Stakeholder	Document		
	TP10 – design	Technical report –operation & maintenance (this report)	Operation & maintenance guide
Consulting engineers	✓	✓	
Council engineers	✓	✓	✓
Building inspectors (council & consultants)	✓	✓	✓
Consent officers (council)	✓	✓	✓
Compliance officers (council)	✓	✓	✓
Design engineers	✓	✓	
Network maintenance contractors	✓	✓	✓
Contractors (>50 employees – well structured with hierarchy)			✓
Contractors (<50 employees – one person who undertakes several roles)			✓
Local tradespeople			✓
Device manufacturers	✓	✓	✓
Architects	✓		
Landscape architects	✓	✓	
Developers	✓	✓	
Landowners	✓	✓	✓

1.4 Report structure

This technical report describes operation and maintenance procedures for each device type in a separate chapter using a common format for ease of use. This first section of the technical report (Sections 1 to 3) contains generic information on the maintenance and operation of stormwater treatment devices. It covers applicable standards, acts, and other national and international guidelines which may be helpful. The second section (Sections 4 to 14) of the report details specific operation and maintenance items for each specific device.

2 Technical Guidelines

2.1 National guidelines

Councils publish other guidelines and technical reports which are useful and often necessary reference documents in designing, constructing and maintaining stormwater treatment devices within the Auckland region. While most of these guidelines are not legal documents, reference to them in consent conditions means that certain aspects can become legal obligations for the consent holder. Appendix One outlines some of the more common and referenced technical guidelines and reports in use in the Auckland region and which treatment devices they are applicable to. This is not an all inclusive list of guidelines.

2.2 International guidelines

Stormwater best management practices have been a focus for many municipalities and government departments around the world in an effort to improve water quality. Most district agencies will publish stormwater management manuals and suites of guidance documents that address specific regional concerns and approaches to stormwater management. These can provide new ideas and approaches that can be adapted for managing stormwater in the Auckland region, however regionally specific issues and design parameters may not be fully applicable (e.g. flow calculations which incorporate snow melt).

Maintenance considerations and practices reflect the climatic conditions in which these devices are found and can vary from drought prone (e.g. Australian cities) to flooding concerns (e.g. eastern Washington). Appendix One also includes a table identifying a number of international documents which provide additional information on overseas practice. This list of international guidelines is not a complete review.

2.3 Operation and maintenance manuals

Resource consent conditions will often stipulate that an operation and maintenance manual must be produced, with a copy provided to the council or as a contract supply/construction condition. Whether or not a manual is required will be a reflection of the scale of the device, complexity of its components and connections and sensitivity of the final receiving environment.

It is recommended that each device has an operation and maintenance manual regardless of its size or whether it is a legal requirement. The detail associated with the manual should reflect the device type, scale and complexity.

Operation and maintenance manuals provide invaluable information on the design and construction of the device, maintenance methods specific to the device and site, and records of maintenance activities. The manual should also indicate where specialists are required to complete maintenance work. For example, when a registered drain layer, structural engineer, electrician (particularly for fixing pumps), geotechnical engineer, contractor with confined space entry training and certification, should be engaged. The manual can be used for preparing maintenance contracts and schedules of quantity for tender and assist contractors to price work.

An operation and maintenance manual will typically contain a log book for recording inspections and maintenance activities, technical information on the design and construction of the device, and the maintenance procedures detailing schedules and methods. It is recommended that the technical information section of the operation and maintenance manuals contain:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination spills or flooding.
2. Site location, legal description, how to access the site, site specific health and safety, co-ordinates (NZTM2000).
3. Catchment details which will include information or calculations on design criteria, catchment size and characteristics, other stormwater devices and reticulation within the catchment.
4. Design calculations including peak flows, water quality volume, filtration rates and treatment functions (if written, include a copy of the design report, construction specifications and drawings, and geotechnical and structural reports).
5. Consent information including consent numbers and a summary of obligations that need to be met (like submission of annual maintenance report). Include a copy of consents in the Appendix.
6. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular components that may be buried beneath the ground (e.g. underdrainage systems).
7. As-builts for planting and actual device showing levels and sizes. Depending on the consenting authority a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection may be required.

Reporting or monitoring may be required as a condition of consent or contract key performance indicator. Both should be included as procedures in the manual and the log book should be designed to capture the information needed for reporting or audits.

Listed are some of the key benefits of a site and device specific operation and maintenance manual:

- Design and construction details are useful in troubleshooting performance issues or when refurbishing the device.
- Maintenance methods provide site specific information like access instructions and preferred subcontractors for specialist tasks (e.g. sucker truck operation).

- Records of all inspection and maintenance activities to be referenced in audits and any reporting requirements.
- Site details including legal description, location, access, and co-ordinates (NZTM2000).
- Long-term maintenance responsibilities and contacts are listed, including landowner, maintenance manager, specialist representative (e.g. maintenance contractors, geotechnical engineer, structural engineer), emergency contact representative and site access contact.

For individual landowners the operation and maintenance manual can be as simple as a ring binder with the design specifications, as-built plans, product and material specifications, and instructions from manufacturers, with some blank pages to record maintenance and inspection activities. This is particularly useful in passing on information to new landowners or maintenance contractors for the device and is effectively a single location for information related to the treatment device. Council also has available operation and maintenance manual templates for typical small on-site systems.

Each treatment device chapter contains suggestions for specific information to be included in the device's operation and maintenance manual along with generic maintenance schedules and methodologies to be adapted for specific site requirements.

3 Standards and Other Legal Compliance

3.1 Regulations and legislation

Applicable standards and legal compliance in operation and maintenance activities usually falls under health and safety requirements. Other documents which tend to focus on construction may also be applicable for some maintenance activities, particularly any refurbishments or tasks involving earthworks (e.g. stormwater pond sediment removal, rain garden soil change).

Appendix Two outlines the most relevant Acts followed by standards and technical documents relating to operation and maintenance. These lists of legislation and standards are not exhaustive.

3.2 Compliance auditing and monitoring

Compliance with regulations and legislation is an everyday requirement. In relation to stormwater treatment devices there can also be compliance requirements in contract documents and resource consent conditions.

Health and safety will typically have its own auditing and monitoring needs that will require addressing in maintenance contracts or by those undertaking maintenance work, for example confined space entry or working at height. These aspects can be worked into an overall site auditing and monitoring programme.

Non-compliance with resource consent conditions can range in scale of repercussion from a written enforcement notice to rectify the problem (usually within a given timeframe and accompanied with a monetary fine) to abatement notices with legal ramifications. Repercussions can potentially see site activities shut down. The council can also take further legal action which can be costly and result in a criminal conviction. Non-compliance can result in environmental hazards by releasing untreated run-off into receiving environments.

In the event of an untreated discharge or spill, the ARC Pollution Hotline (09 377 3107) should be called. The emergency spill response procedures identified in the device's operation and maintenance manual should be followed.

Non-compliance with contract conditions will often have implications for key performance areas (and potential bonus payouts) and opportunities for contracts to roll over for subsequent years. Serious non-compliance can result in contract suspension or cancellation, all of which have implications for a company's reputation and profitability. Regular audits and monitoring can assist in ensuring compliance with regulations and contracts. Monitoring can also assist in setting maintenance schedules based on performance of the device in local conditions.

3.2.1 Monitoring

Discharge quality monitoring and permeability of filter media (or soil) is often a condition of consent but can also greatly assist device managers in developing maintenance schedules that maintain optimum efficiency while preventing unnecessary and sometimes expensive maintenance. The first year of operation usually requires the most frequent monitoring as this will set the precedent for how the device should perform, while providing an indication of how local conditions will affect the performance of the device (and subsequently the maintenance schedule).

Ideally all earthworks within the device's catchment will have been completed prior to the device being commissioned. It is acknowledged that this is often not the case, particularly for subdivisions. In these instances, the optimum efficiency of the device may be after the defects liability period for earthworks have been completed and the device refurbished.

3.2.2 Audits

Each treatment device chapter contains suggestions for specific information to be included in the device's operation and maintenance manual along with generic maintenance schedules and methodologies to be adapted for specific site requirements.

Audits are valuable tools for ensuring compliance but also are an opportunity for improvement as concerns are identified or alternative maintenance methodologies are trialed. A due diligence approach is effective in ensuring all data is captured and actual or potential non-compliances are addressed. Audits can be conducted on consent conditions to ensure activities comply and obligations are being met, against maintenance contract specifications, or the operation and maintenance manual itself (which should include consent and contract obligations).

Audits should always be conducted by someone independent from the site with the necessary training and skills and include interviews with field staff who routinely carry out the maintenance activities. Audits should be conducted at least once per year and be filed in the operation and maintenance manual. Audits are often conducted to measure maintenance contractor performance or to ensure health and safety compliance. An audit of the operation and maintenance of a stormwater device can be incorporated into either of these audits and do not need to be completed as a separate task.

4 Stormwater Pond

4.1 Introduction

Stormwater ponds remove sediments and other contaminants from stormwater before discharging to a receiving open water body or piped stormwater system. They provide a flood control and water treatment function as well as creating an aesthetically pleasing habitat that can be used by birds and aquatic life. Ponds have a long life span if maintained correctly and are one of the most common stormwater treatment tools worldwide.

4.2 Device description

The functions of stormwater ponds include holding water to allow for the settling out of sediment, filtering of pollutants, trapping of floating rubbish, and retention of water during flooding. Two types of ponds are generally recognised:

Wet ponds have a standing (permanent) pool of water and are permanent structures providing water quality treatment and flood protection. Wet ponds are not usually located within an existing watercourse (known as offline). Most ponds in the Auckland region are wet ponds.

Dry ponds do not have a permanent pool of water but operate similarly to a wet pond by providing some water quality treatment but mostly flood protection. Dry ponds typically do not provide as much water quality improvement as wet ponds.

In the Auckland region ponds are one of the most widely-used and cost-effective methods of stormwater treatment; however, they require a considerable land area. The components of a wet stormwater pond are identified in the figure below and table.

Figure 1

Typical wet stormwater pond components.

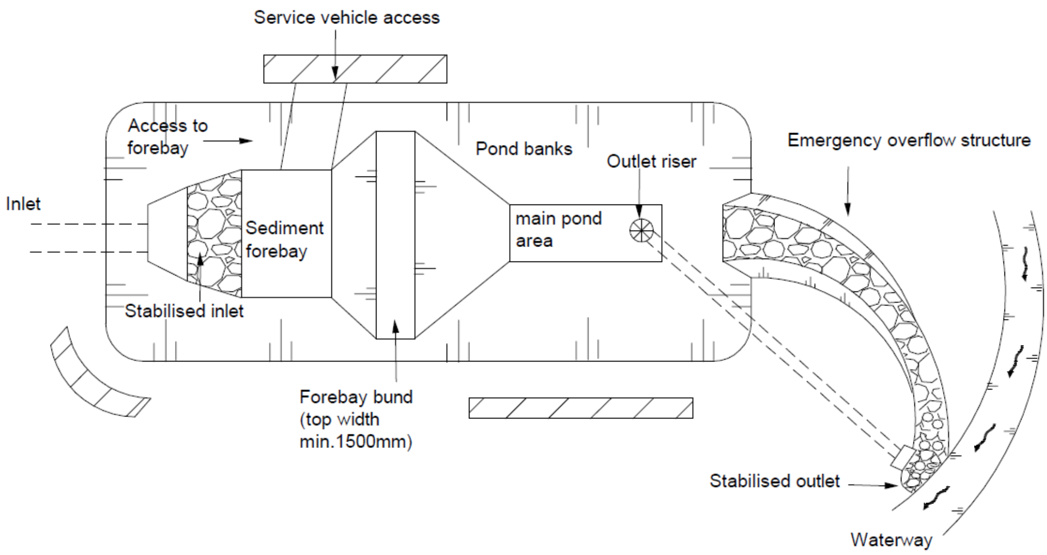


Table 2

Key components of a stormwater pond.

Component	Description
Inlets	Stormwater enters the pond's sediment forebay or directly to the main pond through the inlet. Energy dissipaters, for example rip rap (stones held together with cement), rock aprons, and baffles are used to slow the inflow. Sometimes trash racks or debris screens are used at the pond inlets to stop large debris entering the pond.
Pond banks	Contains the pond and flood extents. For safety reasons banks should not be steeper than 3:1 (horizontal to vertical rise) to allow for easy access for maintenance. Any planting around the banks must allow for easy access of machinery for future maintenance. If the banks are too steep fencing may be required.
Sediment forebay	First stage of treatment, allows coarser sediment and other debris to settle out of the water before being discharged to the main pond either via an outlet pipe or spillway. The forebay is usually shallower than main pond and separated via a bund which can be used as access for maintenance (only if designed to support extra loads from machinery etc). The forebay bund top should be a minimum of 1500 mm wide, while the forebay pond should be sized to approximately 15% of the main pond area.
Main pond area	Larger than the forebay and retains water for longer allowing finer sediments to settle out, and biological and physical processes to break down other pollutants (e.g. oil and grease).

Component	Description
Riser/outlets	The outlet skims treated run-off from the surface of the pond via a riser or weir structure that discharges to either a piped stormwater system or directly to the receiving environment. Scruffy domes are often used to prevent rubbish and debris from entering the receiving environment. Risers can be fitted with a drain-down valve to allow for improved maintenance of the pond. Risers are sometimes fitted with skimmers (or baffles) to prevent smaller debris and wildlife from getting washed into the stormwater system.
Emergency overflow structures	Allows excess water to exit the pond during high rainfall events. They are usually 300 mm lower than the pond bank to prevent bank failure, erosion and damage to downstream property. It is either a separate spillway or included in the riser (hole in grill).

The rate at which stormwater leaves a pond is physically limited by the size of the weir or height of the openings cut into the riser outfall structure. The openings (also called weirs) are usually rectangular or circular in shape. Most ponds have one outlet, but very large ponds may have multiple outlets.

Skimmers (also called baffles or circular baffle plates) affixed to the outside of the outlet structure keeps floating oil, grease and debris in the pond. In their simplest form, skimmers are half-pipes mounted vertically to the outfall structure in front of the weir opening. More complex skimmers wrap around the edge of the outlet structure. Skimmers are becoming more commonly used on ponds in the Auckland region.

4.2.1 Stormwater ponds location

The location of a stormwater pond has a direct impact on the ease of maintenance. The council specifies a preference for "off-line" ponds (not located within a permanent watercourse (stream, river etc). Pond size is determined by the amount of water that needs to be treated from the surrounding catchment. In areas where open space is a premium, pond size is often maximised by creating steeper banks and in some cases using retaining walls. Steep banks or retaining walls can be problematic as the banks are not as easily accessible by machinery for maintenance (e.g. for removal of sediment from the pond bottom). Because the pond's water body is deeper in these situations fencing is often required which can have maintenance implications, particularly for access to the water body.

Wet ponds are suitable in areas where the groundwater is close to the land surface and water does not readily pass through the soil. If a wet pond is used in areas where the groundwater is very deep or the soil is very porous, a waterproof liner should be used, alternatively a dry pond is usually considered. The use of a liner in a pond should be clearly documented and communicated to those undertaking maintenance, as extra care must be taken to prevent stressing or tearing the liner during maintenance activities (e.g. removal of sediment from the pond bottom).

4.3 Operation and maintenance manuals

An operation and maintenance manual will greatly assist in managing the stormwater pond's maintenance. It may also be a condition of consent. The operation and maintenance manual can provide invaluable background information on the ponds design parameters and construction which can assist in troubleshooting issues when the pond needs refurbishing, or for the removal of sediment build up (will show original levels of the bottom of the pond, risers, and outlets), or for dry ponds maintaining structural integrity during extreme dry conditions.

The manual should consist of three main sections; the log book, technical information and procedures.

4.3.1 Log book

The log book section of the manual will contain the log sheets where inspections, maintenance and remedial works that take place are recorded. When designing log sheets it is best to review reporting requirements to ensure the required information can be recorded regularly. This section often informs any reporting requirements which may be part of consents, monitoring, or contract performance. The most effective log sheets can be completed easily with enough flexibility regarding the type of information that could potentially be entered.

Figure 2
Example log sheet for stormwater pond maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Stormwater pond			**File No.** **Date** / /
SITE: AUT pond, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	PM3	Prune plants and replace dead plants	J. Smith
4/5/09	PM2	Remove weeds	J. Smith
6/6/09	PM1	Some erosion around outlet. Stabilised outlet with rip rap	H. Bloggs

4.3.2 Technical information

This section provides all the background information on design and construction of the stormwater pond, including as-builts, calculations for flow and consents associated with the pond.

Typically this section would include the following which is specific to the site:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination, spills or flooding.
2. Site location, legal description, co-ordinates (NZTM2000), how to access the site, site specific health and safety.
3. Catchment details which will include information or calculations on design criteria, catchment size and characteristics, other stormwater devices and connection to reticulation within the catchment.
4. Stormwater pond design calculations including a copy of the design report, geotechnical report and compliance certificates or producer certificates. Other details to include:
    a. Levels to LINZ Auckland datum 1946 (or specify survey benchmark)
        i. Top of dam
        ii. Top of spillway
        iii. Toe of dam
        iv. 2-yr ARI water level
        v. 10-yr ARI water level
        vi. 10-yr ARI water level
        vii. 34.5 mm extended detention water level.
    b. Height of dam in metres to 0.1 m
    c. Maximum water depth to 0.1 m
    d. Contributing catchment area in ha
    e. Maximum pond length in m
    f. Maximum pond width in m
    g. Maximum operating surface area in m^2
    h. Normal operating surface area in m^2
    i. Normal water depth to 0.1 m
    j. Normal storage volume in m^3
    k. Water quality pond volume in m^3
    l. Forebay surface area at normal storage volume
    m. Crest height and width of forebay bund
    n. Total suspended solids removal percentage
    o. Estimated sediment accumulation rate in tonnes per year

p. Spillway details – type and width or diameter

q. Inlet details – type and width or diameter

r. Outlet details – type and width or diameter

s. Drain down valve details (location, drained water depth)

t. Embankment details – type, crest width, upstream slope, downstream slope, vegetation on upstream face, vegetation on downstream face

u. Year of completion.

5. Consent information including consent numbers and a summary of obligations that need to be met (like submission of annual maintenance report). Include a copy of consents in the appendix.

6. Construction drawings and construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is under the water (e.g. pond liners).

7. As-built planting layout and schedule, if applicable.

8. As-built plan, dated and showing maintenance truck access, machinery working pads and temporary working/storage areas.

9. Depending on the consenting authority a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection may be required.

4.3.3 Procedures

The procedures section of the operation and maintenance manual should specify inspections, planned maintenance, methods for carrying out maintenance, and frequency of tasks. Section 4.4 provides a generic maintenance schedule for a stormwater pond. This can be adapted for the specific site and design of the stormwater pond.

Typical maintenance procedures should include:

- Inspections required and frequency.
- Maintenance needs and frequency.
- Details for permanently wet areas.
- Details for the surrounding planted area.
- Recommended control method to eradicate established pests and invasive weeds from both terrestrial and aquatic areas.
- De-watering methodology of the main pond and the forebay.
- De-silting methodology including the main pond and the forebay.

Reporting requirements, whether consent or contract based should be detailed as a procedure (include reporting format, recipient details and frequency). Any monitoring requirements should also be documented. Monitoring will most probably be associated with water quality. The procedures should explicitly describe how to undertake any monitoring, for example how to collect a water sample and from where. Details of parameters to be tested and any trigger levels of contaminants (which may be specified in the resource consent) should also be provided.

The procedures can be grouped by frequency so that tasks can be carried out at the same time and scheduling of maintenance is easier. Unplanned or emergency response procedures should also be documented or referenced if found in other documents.

4.4 Maintenance schedules

The operation and maintenance requirements for stormwater ponds fall into three general categories: functional, aesthetic and safety. Ponds typically have differing catchment sizes, pollutant loads, inflows and other components meaning that they all have different maintenance frequencies. Normally, stormwater ponds have a detailed operation and maintenance plan that is specific to each device and takes these items into consideration. Guidance on recommended maintenance actions and typical frequencies for each action are provided in the Table 3. Visual inspections after storm events are important to repair any damage however it is acknowledged that there may be a delay between the storm event and inspection as the contractor tends to more urgent repairs.

A full inspection of the pond including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the pond and may be done by them directly. Defect liability periods differ across the region so check with the council if unsure.

4.4.1 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, uncontrolled activities within the catchment, or contaminant spills. Depending on the location of the pond there may be some time between the incident occurring, reporting, and remediation. It is important that after storm events the pond is visually inspected promptly so that any damage can be rectified.

Table 3

Typical stormwater pond maintenance schedule.

Component	Recommended action	Frequency: Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Functional maintenance recommendations						
Inlet pipes and structures	Inspect for clogging and build up of debris and rubbish. Debris should not block or threaten to obstruct any stormwater inflow points.	✓				✓
	The area around inlet and energy dissipation (e.g. rip rap) structures should also be inspected for erosion and cracks in the structure. Remove debris and litter and fix cracks and erosion as necessary.		✓			✓
Trash racks and debris screens	If the pond is equipped with trash racks, inspect for build up of gross pollutants including leaves, sticks, branches, litter and other debris. Remove accumulated debris that can hinder stormwater flows into the pond and cause localised flooding. Remove and properly dispose of debris and litter. Check the trash rack for corrosion. Replace excessively corroded racks.	✓				✓
Sediment forebay	Accumulated sediments need to be removed from the forebay more frequently than from the main pond. Dredging needs to occur if sediment build-up threatens operation or if storage volume of the forebay is reduced to about 50% of its design volume (i.e. the depth of the sediment is half of the total depth of the water, check using a stick or survey staff gauge). Sediments should be tested for contaminants (e.g. heavy metals, PAHs) prior to dredging to determine the most appropriate mechanism (e.g. landfill) for disposal of the sediments (contaminated sediment has concentrations higher than natural background levels, refer TP153).				✓	✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Bund	The bund separates the forebay from the main pond and also provides an important access point for maintenance (if designed for to bear equipment). The bund should also be checked for erosion and stability (see Erosion and Bank Stability section below). Any problems with erosion should be quickly repaired.		✓			✓
Risers, control structures, grates, outlet pipes, skimmers, weirs and orifices	Inspect control structures, weirs, orifices, outfall pipes for leaks and blockages. Blockages could be caused by heavy sedimentation, floating debris, trash, etc. or if maintenance has been neglected, control structures could be overgrown with vegetation. If left uncorrected, blockages can cause both local and widespread flooding. Trash and other floating debris should be regularly removed from the pond and disposed of properly. The areas around the control structure should be free of blockages and dense vegetation to maintain an unobstructed flow path for stormwater. A boat may be needed to access the outlet.	✓				✓
	Inspect for evidence of leaky joints or soil piping around outflow pipes. Erosion (washout, scouring) around outflow pipes can be caused by water flowing from the pond and out along the outside of pipe, which can lead to bank failure. In this case, the anti-seep collar around the outflow pipe may need to be repaired or replaced.		✓			✓
	Inspect outfall and water discharge areas for erosion. Restore eroded areas and stabilise as necessary. Check to make sure energy dissipaters are adequate.		✓			✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Emergency overflow or spillway	Inspect and verify that the emergency overflow path is clear of debris and has not been blocked or altered in any way. Correct blockages and alterations as necessary. Check the flow path for erosion and fix as necessary. If problems with the emergency flow path are left unattended, significant flooding and even pond bank failure can occur. Structural repairs must be done promptly to avoid catastrophic failure.	✓				✓
Erosion and bank stability	Check banks for settlement, erosion, scouring, cracking, sloughing, seepage, and rilling etc. Unless specified in the pond's landscape plans, woody vegetation should generally be removed as its root systems can compromise bank strength if the plant should die. They can also impede access of maintenance equipment. If woody plants are present, the plant and root system needs to be removed, replaced with the proper material and compacted to the original bank design specifications (usually 95% of the soil maximum density). Pedestrian and bicycle traffic can compact soils and kill off vegetation cover, thus leading to erosion. Therefore, pedestrian traffic should either be restricted and affected areas closed off and restored, or the affected areas provided with a more erosion resistant ground cover.	✓				✓
Valves and pumps	Inspect for properly functioning valves and pumps, if installed. Mechanical features on ponds should be run through their full range of motion and their proper operation confirmed. Moving parts should be inspected for corrosion and properly lubricated.		✓			

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Main pond	The main pond will also require the removal of accumulated sediments, but not as frequently as the sediment forebay. A permanent silt marker (either a mark on the riser or permanent post) will assist in determining when the main pond will require removal of built up sediment. Dredging of sediment should occur when the build-up reduces the storage volume of the main pond to about 50% of its design volume (i.e. the depth of the sediment is half of the total depth of the water, check using a stick or survey staff gauge). Consideration needs to be given to the noise and costs of pumps for de-watering. Gravity methods of de-watering are often preferred.				✓	
	For dry ponds check vegetation cover. Vegetation must have shallow root systems and not impede flow when the pond is inundated. Remove woody species and dense clumps of vegetation.		✓			
Aesthetic maintenance recommendations						
Landscaping	Banks and surrounding areas need to be regularly cleared of weeds, plants pruned and replaced 3 monthly. Grass areas around the pond need to be mown monthly. Schedules may vary with growth rates and seasons.	✓				
Shallow pond areas (which support wetland type vegetation, also known as littoral zone)	Inspect littoral zones for exotic and invasive/nuisance aquatic vegetation and remove accordingly. Control of invasive vegetation may be done manually or with appropriate herbicide. (Application of herbicides may need to be done by a properly-licensed and registered professional). Inspection frequency may need to be increased during the growing season.		✓			

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Water body	Rubbish and other floating debris need to be removed from the pond's surface and in areas where it collects. Inspect the pond for algal blooms or fish kills, which may signal eutrophication (a condition characterised by a combination of super-dense aquatic vegetation or algae growth and low dissolved oxygen levels in pond water), high nutrient or high pollutant levels in the stormwater run-off. Water quality testing may be needed to help identify causes of algal blooms.	✓				✓
	Check the water body for invasive aquatic weed species which can clog the flow of water through the pond. Species include common cattail, arrowhead, marshwort, hornwort, fringed water lily, and water poppy (refer Regional Pest Management Strategy). Removal of weeds should be carried out through biological control or manual removal (refer Landscape and Ecology Values within Stormwater Management, Boffa Miskell 2009).		✓			
Wildlife	Once established, many stormwater ponds become habitats for birds and aquatic life. Regular inspection is required to ensure that desirable species are not threatened and that pest species are controlled. Open areas for mosquito control should be maintained, avoid stagnant, still water which may require chemical treatment for mosquito control. A visual inspection of the pond area to check for dead or sick birds or the presence of any introduced fish (e.g. carp, catfish, rudd, tench etc) should be carried out in conjunction with other monthly maintenance tasks.	✓				✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Soil	Soil can be eroded from pond banks particularly after heavy rainfall and where vegetation cover is poor. Also, depending on the quality of the soil, fertilisers may be needed to aid plant growth (refer Landscape and Ecology Values within Stormwater Management, Boffa Miskell, 2009). **NB: Fertilisers, herbicides and pesticides should only be used after careful consideration due to proximity to the waterway and because the pond water will ultimately discharge into the stormwater system.**	✓				✓
	When planting is being established or new planting has recently gone in, the soil should be protected with an organic matting such as coconut fibre to prevent erosion.			✓		

Note: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the pond area (e.g. falling trees, or branches). Typically a storm event is >2-year event.

4.4.2 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, uncontrolled activities within the catchment, or contaminant spills. Depending on the location of the pond there may be some time between the incident occurring, reporting, and remediation. It is important that after storm events the pond is visually inspected promptly so that any damage can be rectified.

Typical issues after storm events include floatables, blockages of outlets or inlets, flooding and erosion of banks. The procedures listed above should be used for any corrective maintenance. Details for refurbishment or re-build will be found in the technical information section of the operation and maintenance manual.

Uncontrolled catchment activities relate mainly to earthworks without effective erosion and sediment control measures in place. The increased sediment load in run-off could inundate the pond and cause problems for aquatic life.

A spill response plan should also be included in the operation and maintenance manual (or referenced if located in another document). The primary response will be preventing contamination of downstream receiving environments and relocation or rescue of fauna (e.g. ducks and fish).

4.5 Troubleshooting

There are a number of common problems that arise when a stormwater pond is not maintained or if the use of the land surrounding the pond changes. Listed below are some of these common problems, suggested causes and potential solutions.

Table 4
Stormwater pond troubleshooting.

Symptom	Likely cause	Remedy
Water levels in pond remain high	Clogging of outfall structures and openings.	Inspect outlet structures and openings for blockages by debris or sediments. Clean openings as necessary.
Water levels in dry pond are higher than normal	For normally dry ponds, groundwater levels may have risen.	Check outfall and pipes for clogging. If groundwater tables remain high for long periods of time, this will need to be discussed with the owner of the pond. It may be necessary to retrofit the pond with an underdrain or convert the pond to wet pond.
Wet pond is dry	There are cracks in the pond outfall structure where water is leaking from.	Inspect the outlet structure for cracks and repair cracks as necessary. Inspect for leaky joints between the outlet pipes and outlet structure. Repair leaks as necessary.
	A maintenance drain down valve is open.	Inspect and close drain valves.
	Water levels in wet ponds constructed in areas with fluctuating groundwater tables may become seasonally dry.	Ponds constructed in areas where groundwater levels drop below the bottom of the pond will become dry as long as low groundwater level conditions persist. This issue should have been addressed during the design of the pond and may be a normal part of the pond operation.
	Groundwater levels have dropped.	
	Drought conditions exist.	
	Liner is torn, or inadequately constructed.	Remove sediment, inspect liner, and replace if necessary.
Stormwater exiting the pond is not	The quality of the stormwater exiting the pond should be significantly better than the stormwater entering the pond. If this is not the case there are a number of things to check:	

Symptom	Likely cause	Remedy
clear or appears dirty, muddy or dark.	The forebay may be full of sediment.	Accumulated sediment needs to be removed from the forebay more frequently than from the main pond. Dredging needs to occur if the ability of the forebay to store water is reduced to about 50% of its overall volume.
	Works in the contributing drainage area may have disturbed soils and recent rains may have washed excessive amounts of soils into the pond.	Verify that proper erosion and sediment controls are being used around the construction sites. Repair any erosion control measures. Install additional erosion control measures to prevent further run-off of sediments. Stabilise areas of exposed soil and where erosion has occurred.
	The pond may have been designed with the outlet close to the inlet structure causing a short-circuit and preventing any treatment from occurring.	This is an issue that should have been addressed during the design of the pond. Strategically-located baffles or islands in the pond can manipulate flow to increase the distance that stormwater travels between inlet and outlet points. Islands can also provide habitat and offer visual appeal.
Plants are encroaching into the pond	Pond vegetation is colonising shallow areas of the pond.	Dry ponds would not normally have wetland plants growing in them due to insufficient water cover. Only remove plants if they are affecting the pond function.
	The outlet structure may be clogged.	Inspect the outlet structure openings for clogging (e.g., accumulated debris or vegetation) and remove accordingly.
	Wet ponds will typically have a fringe of wetland plants which can improve the ponds ability to treat water.	
Pond banks are eroding	Water running down pond banks is eroding soils.	Minor erosion can be fixed by replacing eroded soils and re-stabilising the exposed soils with vegetation or other means.
	Stormwater outlet pipes are aimed at pond banks or exit near the top of the pond banks.	More extensive erosion due to strong flows may require more significant erosion protection (e.g. rock rip-rap, geotextile, etc). In this case, the root cause of erosion should be identified and addressed (e.g. pipes may need extended down into the pond) in order to prevent future erosion problems.

Symptom	Likely cause	Remedy
Water is leaking from the pond and through the banks along the pipes.	Leak collars around pipes have either failed or have not been installed correctly during the pond's construction. Failure of pond banks can cause major damage.	Repair or replacement of leak collars should only be attempted by qualified construction contractors. This remedy typically requires draining the pond, excavating the pond banks and fixing the leak collar.
Algal blooms are occurring	Algae are always present in waterways; it is when environmental conditions are right that algal blooms occur. This can look like a yellow, green, red, or blue-green coloured scum on the surface of the water. Algal blooms occur when the water is stagnant or slow flowing, there are high levels of nutrients, and the weather has been sunny and hot for long periods.	There are no proven definitive ways to treat algal blooms, the best approach is prevention of optimum bloom conditions by ensuring the water body is shaded, and flow is maintained. Use of barley straw bales to remove algae has had varying levels of success. Aeration may also decrease algal outbreaks. **Figure 3** Barley straw bales in a Waitakere pond. 

Symptom	Likely cause	Remedy
Bird life is dying off.	The most common cause of death among birds in stormwater ponds is botulism. Botulism is caused in anaerobic conditions by the toxins produced by *Clostridium botulinum* bacteria (Coffield and Whelchel, 2007). Birds carry the bacteria but it is only when they ingest the toxic bacteria that they get sick, often by eating maggots and other invertebrates that have been feeding on the dead animals that are carrying the bacteria.	Botulism occurs most often in mid-to-late summer, when water levels are low and the water stagnates, causing die off of invertebrates. Cases of botulism will often be found when there is a lack of available oxygen in the water which often occurs after algal blooms. Actions include the prompt removal of dead birds and animals from the area, reduce algal blooms, improve shading over the water body and if possible maintain flow through the ponds from alternate water source. **Figure 4** Dead birds removed from a stormwater pond. 
Plants are dying off.	Plants on the edge of a stormwater pond are exposed to both extreme wet and dry conditions.	Selection of plants should take local conditions into account and new plantings should be watered as required. Replace plants if necessary.
Animal pests are a problem.	Dense vegetation and abundant food supply associated with stormwater ponds provides habitat for many animal pests.	Thin out vegetation if possible, set traps and or bait stations throughout the area (ensure correct procedures are followed regarding signs and handling of poisons).
	If mosquitoes are the problem, this could be due to stagnant water and low water levels.	Eliminate mosquito breeding habitat by removing rubbish and areas where water can stagnate in small pools.

Symptom	Likely cause	Remedy
Odour from pond.	Water levels are low and water has stagnated.	Exposed banks and pond floors can have anaerobic soils and so will smell as they dry out. Depending on scale the pond may need to be topped up with water to raise the water levels.
	A significant pollution event has occurred and discharged contaminants into the pond which are causing a strong odour.	Depending on the magnitude of the event and contaminants (to be determined through water quality testing) the pond may need to be cleaned out or more water flushed through the pond.

Older ponds can be constructed using materials and designs that do not aid maintenance. Many stormwater treatment ponds have had to be retrofitted with features to aid maintenance. The construction technical report and construction guides (Supervisors and Field Guide) will provide specific information on how to construct or install these devices.

Some features that have needed to be retrofitted on older ponds include:

- Replacement of timber weirs and timber retaining walls due to decay which compromises bank stability.
- Retrofit anti-seep collars to stop piping and erosion along outlets.
- Retrofit drain down valves or relocation for easy access (e.g. attach float to novacoil pipe).
- The geometry of the pond can cause short circuiting, in extreme circumstances the pond may need to be reshaped to prevent the short circuiting. The creation of islands may help with short circuiting.
- Plants that have grown too large or impede access may need to be removed and replaced with smaller shrubs and ground cover. Review planting plan for future plantings.
- Install a permanent silt marker (preferably timber H6 treated 125x125) in cross-sectional area. The silt marker should be installed in an area accessible for regular monitoring of silt built-up within the forebay and/or main pond.
- Ponds without forebays may have one retrofitted to aid water quality treatment and retention.
- Reconfiguration of the outlet structure to include a scruffy dome or revised outlet weir.

4.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance associated with maintenance contracts, part of consent conditions, or part of legislation such as the Building Act or Health & Safety Act.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the stormwater pond. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts and hazardous or inappropriate practices can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the stormwater pond would tend to focus on discharge water quality. Quarterly sampling of discharge from the pond during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies. The deposition of sediment should also be regularly monitored to determine the cleaning regime. Regular monitoring of water quality and sediment deposition will help to identify any performance issues and enable prompt remediation.

4.7 Photo gallery – stormwater ponds

Figure 5

Connection at outlet riser allowing clearing of sediment forebay using sucker truck. Note access in background. [RDC]

Figure 6

All weather access to pond outlet control structure – enables debris to be cleared at all times. [WCC]

Figure 7

Outlet control structure leading to downstream erosion and undermining of retaining structure. [RDC]

Figure 8

Dry pond showing outlet with scruffy dome and overflow spillway with gabion protection (NSCC).

5 Wetlands

5.1 Introduction

As a result of land development, over 90% of New Zealand's natural wetlands have been drained or filled in. Wetlands provide a number of ecosystem functions, such as improving water quality and flood attenuation. Constructed wetlands mimic the processes found in natural wetlands and provide an important natural water treatment system which can be used for wastewater treatment or stormwater treatment.

5.2 Device description

Constructed wetlands are shallow vegetated ponds designed to utilise the benefits of natural wetland functions and processes to:

- improve the quality of stormwater run-off;
- slow stormwater flows down;
- provide flood control; and
- compensate for loss of natural wetlands.

Wetlands also offer significant wildlife habitat benefits and can be visually pleasing additions to the landscape. Wetlands differ from stormwater ponds in that they are typically dominated by a planted area of aquatic vegetation whereas stormwater ponds (wet ponds) are dominated by large areas of open water. These plants can provide shading to standing water which aids in buffering thermal loads and the temperature of any surface water. Like wet ponds, constructed wetlands are relatively cost-effective methods of stormwater treatment but require considerable land area to function well. Constructed wetlands require a regular supply of water to ensure that they don't dry out.

Constructed wetlands remove nitrogen, phosphates, sediments and heavy metals such as zinc and copper from stormwater run-off, as well as control the flow rates of stormwater. Pollutant removal is achieved by the settling out of sediment from the run-off and sticking to biofilms (layers of microorganisms that coat plants and other surfaces) in the water column. Additionally, dissolved nutrients are removed from stormwater by natural biological processes such as uptake by plant and microbial communities.

Figure 9

Typical stormwater treatment wetland components.

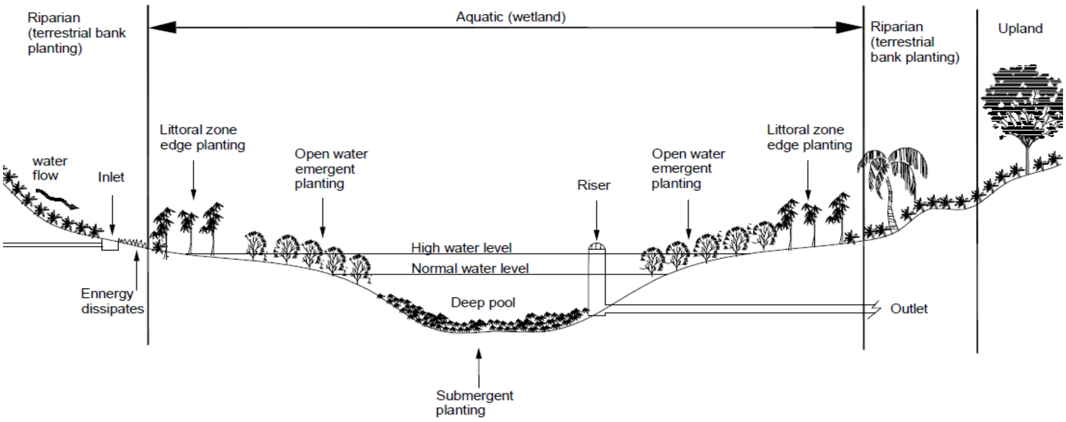


Table 5

Key components of a stormwater treatment wetland

Component	Description
Inlet	Stormwater is piped to the wetland's sediment forebay (if included) or to the main wetland pond. Erosion control measures (energy dissipaters, rip-rap, etc) are usually used to slow the flow of water entering the wetland. Sometimes trash racks or debris screens are used at the wetland inlets to stop large debris entering the wetland.
Sediment forebay (not always included)	Stormwater flows are slowed in the forebay to allow coarse sediments to settle out before this water flows into the wetland component. This extends the life of the wetland as it will not silt up as quickly. The forebay is separated from the main wetland pond by a bund (low dam) which may be used for maintenance access (if specifically designed to sustain equipment loads).
Main wetland pond	The main wetland pond is where the majority of water quality treatment occurs. Water is held here for longer periods and the wetland vegetation assists finer sediments to settle out of the water (aided by biofilms on the wetland plants) and other pollutants such as oil and grease to break down. The wetland pond should be no greater than 1m deep and have variable depths over a wide area.
Littoral shelf (shoreline)	The littoral shelf is the planted area of the wetland. It includes the shoreline of the wetland where the plants are frequently covered with water and are usually quite flat. Natural biological processes uptake nutrients (e.g. nitrogen and phosphorous) typically contained in the stormwater. Wetland vegetation is efficient at slowing down flows and trapping sediments contained in the stormwater.

Component	Description
Plants	Wetlands require specific plant species that are suited to different water levels. There are 5 planting zones each with a recommended list of plant species (TP10, ARC). The zones range from deep water to dry land. Plants used in the wetland should be eco-sourced native varieties, to provide habitat, promote indigenous landscapes, and plant diversity.
Risers/ Outlets	The exit point from the main wetland pond for treated stormwater. Discharges from the main pond water will usually enter either a piped stormwater system, or a natural water course. 'Scruffy domes' (circular grills) are often used on vertical pipes (risers) to prevent large floating debris and rubbish from entering the stormwater system. Outlets can also be weirs. Some riser outlets have a drain down valve fitting to allow the wetland to be partially drained to assist in maintenance. Risers are sometimes fitted with skimmers (or baffles) to prevent smaller debris and wildlife from entering the stormwater system.
Emergency overflow structures	A stormwater treatment wetland must have a structure that allows excess water to safely exit the wetland during extreme heavy rain events, rather than allowing the pond banks to be overtopped. An emergency overflow can be entirely separate and independent of the wetland outlet structure (i.e. built into the bank of the wetland) or it can be incorporated as part of the riser (sometimes just an opening in the outlet grill).

5.2.1 Wetland location

The location of a wetland will have a direct impact on the ease of carrying out maintenance tasks. Wetlands require a regular supply of water which plays a critical role in site selection. Wetland ponds that are located in porous soils or used to treat wastewater require liners to prevent the wetland pond from draining and leachate from wastewater from contaminating groundwater and soils. If a wetland is lined extra care during maintenance is required to ensure the liner is not torn or stressed in any way. Details of the liner should be included in the operation and maintenance manual.

5.3 Operation and maintenance manuals

An operation and maintenance manual will greatly assist in managing the wetland maintenance. It may also be a condition of consent. The operation and maintenance manual can provide invaluable background information on the wetland design parameters and construction which can assist in troubleshooting issues or when the wetland needs refurbishing.

The manual should consist of three main sections; the log book, technical information and procedures.

5.3.1 Log book

The log book section of the manual will contain the log sheets where inspections, maintenance and remedial works that take place are recorded. This section often informs any reporting requirements which may be part of consents or monitoring. The most effective log sheets can be completed easily with enough flexibility regarding the type of information that could potentially be entered.

Figure 10
Example log sheet for wetland maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Wetlands			**File No.**
			Date
			/ /
SITE: AUT pond, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	WT3	Prune plants and replace dead plants	J. Smith
4/5/09	WT2	Remove weeds	J. Smith
6/6/09	WT1	Checked for erosion inlet and outlet. All ok	H. Bloggs

5.3.2 Technical information

This section provides all the background information on design and construction of the stormwater wetland, including as-builts, calculations for flow, and consents associated with the wetland.

Typically this section would include the following which is specific to the site:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination spills or flooding.
2. Site location, legal description, co-ordinates (NZTM2000), how to access the site, site specific health and safety.
3. Catchment details which will include information or calculations on design criteria, catchment size and characteristics, other stormwater devices and reticulation within the catchment.
4. Stormwater wetland design calculations including a copy of the design report, geotechnical report and compliance certificates or producer certificates. . Other details to include:
    a. Levels to LINZ Auckland datum 1946 (or specify survey benchmark)

i. Top of dam.

ii. Top of spillway.

iii. Toe of dam.

iv. 2-yr ARI water level.

v. 10-yr ARI water level.

vi. 100-yr ARI water level.

vii. 34.5 mm extended detention water level.

b. Height of dam in metres to 0.1 m.

c. Maximum water depth to 0.1 m.

d. Contributing catchment area in ha.

e. Maximum pond length in m.

f. Maximum pond width in m.

g. Maximum operating surface area in $m^{2.}$

h. Normal operating surface area in m^2.

i. Normal water depth to 0.1 m.

j. Normal storage volume in m^3.

k. Water quality pond volume in m^3.

l. Total suspended solids removal percentage.

m. Estimated sediment accumulation rate in tonnes per year.

n. Spillway details – type and width or diameter.

o. Inlet details – type and width or diameter.

p. Outlet details – type and width or diameter.

q. Percentage of surface area expected to be vegetated by year 2.

r. Embankment details – type, crest width, upstream slope, downstream slope, vegetation on upstream face, vegetation on downstream face.

s. Year of completion.

5. Consent information including consent numbers and a summary of obligations that need to be met (e.g. submission of annual maintenance report). Include a copy of consents in the appendix.

6. Construction drawing and construction photographs. If photos were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is under the water (e.g. liner).

7. As-builts for planting layout, and wetland. Must be dated and showing maintenance truck access, machinery working pads and temporary working/storage areas.

8. Depending on the consenting authority a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection may be required.

5.3.3 Procedures

The procedures section of the operation and maintenance manual should specify inspections, planned maintenance, methodologies for carrying out maintenance, and frequency of tasks. Section 5.4 provides a generic maintenance schedule for a wetland. This can be adapted for the specific site and design of the wetland.

Typical maintenance procedures should include:

- Inspections required and frequency.
- Maintenance needs and frequency.
- Rubbish accumulation inspection and removal frequency.
- Details for permanently wet areas.
- Details for the surrounding planted area.
- Recommended control method to eradicate established pests and invasive weeds from both terrestrial and aquatic areas.
- De-watering of the main wetland and the forebay.
- De-silting methodology including the main wetland and the forebay.

Reporting requirements, whether consent or contract based, should be detailed as a procedure (include reporting format, recipient details and frequency). Any monitoring requirements should also be documented. Monitoring will most probably be on water quality. The procedures should explicitly describe how to undertake any monitoring, for example how to collect a water sample and from where. Details of parameters to be tested should also be given and any trigger levels (which could be specified in the resource consent).

The procedures can be grouped by frequency so that tasks can be carried out at the same time and scheduling of maintenance is easier. Unplanned or emergency response procedures should also be documented or referenced if found in other documents. Animal and plant pest control methodologies need to be detailed as some methods can add contaminants to the water.

5.4 Maintenance schedules

The operation and maintenance requirements for stormwater treatment wetlands falls into two general categories: functional and aesthetic. All wetlands have different catchment sizes, pollutant loads, inflows and other components meaning that they all have different maintenance frequencies. Normally, wetlands have a detailed operation and maintenance plan that is specific to each site and takes these items into consideration. However, guidance recommended maintenance actions and typical frequencies for each action are provided in Table 6.

A full inspection of the wetlands including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the wetlands and may be done by them directly. Defect liability periods differ across the region so check with the council if unsure.

Table 6
Typical constructed wetland maintenance schedule.

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more years	After storm events
Functional maintenance recommendations						
Inlet pipes and structures	Inspect for clogging and build up of debris and rubbish. Debris should not block or threaten to obstruct any stormwater inflow points.	✓				✓
	The area around inlet and energy dissipation (e.g. rip rap) structures should also be inspected for erosion and cracks in the structure. Remove debris and litter and fix cracks and erosion as necessary.		✓			✓
Trash racks and debris screens	If the wetland or forebay is equipped with trash racks, inspect for build up of gross pollutants such as leaves, sticks, branches, litter and other debris. Remove accumulated debris that can hinder stormwater flows into the wetland and cause localised flooding. Remove and properly dispose of debris and litter.	✓				✓
	Check the trash rack for corrosion. Replace excessively corroded racks.				✓	
Sediment forebay	Accumulated sediments need to be removed from the forebay more frequently than from the main wetland pond. Dredging needs to occur if sediment build-				✓	✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
	up threatens operation or if storage volume of the forebay is reduced to about 50% of its design volume. Sediments should be tested for contaminants (e.g. heavy metals, PAHs) prior to dredging to determine the most appropriate mechanism (e.g. landfill) for disposal of the sediments (contaminated sediment has concentrations higher than natural background levels, refer TP153).					
Bund	The bund separates the forebay from the main pond and also provides an important access point for maintenance. The bund should be checked for erosion and stability (see Erosion and Bank Stability section below). Any problems with erosion should be quickly addressed and fixed.		✓			✓
Risers, control structures, grates, outlet pipes, skimmers, weirs and orifices	Inspect control structures, weirs, orifices, outfall pipes for leaks and blockages. Blockages could be caused by heavy sedimentation, floating debris, trash, etc. or if maintenance has been neglected, control structures could be overgrown with vegetation. If left uncorrected, blockages can cause both local and widespread flooding or cause the dam to breach. Trash and other floating debris should be regularly removed from the pond and disposed of properly. The areas around the control structure should be free of blockages and dense vegetation to maintain an unobstructed flow path for stormwater. A boat may be needed to access the outlet.	✓				✓
	Inspect for evidence of leaky joints or soil piping around outflow pipes. Erosion around outflow pipes can be caused by water flowing from the wetland and out		✓			✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm events
	along the outside of pipe, which can lead to bank failure. If erosion is occurring or there has been a bank failure the anti-seep collar around the outflow pipe may need to be repaired or replaced.					
	Inspect outfall and water discharge areas for erosion. Restore eroded areas and stabilise as necessary. Check to make sure energy dissipaters are adequate.		✓			✓
Emergency overflow or spillway	Inspect and verify that the emergency overflow path is clear of debris and has not been blocked or altered in any way. Correct blockages and alterations as necessary. Check flow path for erosion and fix as necessary. If problems with the emergency flow path are left unattended, significant flooding and even pond bank failure can occur. Structural repairs must be done promptly to avoid catastrophic failure.	✓				✓
Erosion and bank stability	Check banks for settlement, erosion, scouring, cracking, sloughing, seepage, and rilling. Unless specified in the pond's landscape plans, woody vegetation should generally be removed as their root systems can compromise bank strength if the plant should die. If woody plants are present, the plant and root system needs to be removed, replaced with the proper material and compacted to the original bank design specifications (usually 95% of the soil maximum density). Pedestrian and bicycle traffic can compact soils and kill off vegetation cover, thus leading to erosion. Therefore, pedestrian traffic should either be restricted and affected areas closed off and restored, or the affected areas provided with a more erosive resistant ground cover.	✓				✓

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
Littoral zones (the areas supporting wetland vegetation)	Inspect littoral zones for exotic and invasive/nuisance aquatic vegetation and remove accordingly. Control of invasive vegetation may be done manually or with appropriate herbicide. (Application of herbicides may need to be done by a properly-licensed and registered professional). Inspection frequency may need to be increased during the growing season.		✓			
	Check flowpaths through the wetland areas for signs of any short-circuiting (uneven flows). These can reduce retention and treatment times, increase water velocity and lead to erosion or damage to wetland plants. Short-circuiting can also or create stagnant areas within the wetland between storm events. Correct by additional planting or structural repairs to vegetation bands.		✓			
Valves and pumps	Inspect for properly functioning valves and pumps, if so equipped. Mechanical features in wetlands should be run through their full range of motion and their proper operation confirmed. Moving parts should be inspected for corrosion and properly lubricated.		✓			
Wetland Liner	Check liner for leak. Evidence that there may be a leak includes water level in the wetland pond is lower than expected, or there is ponding occurring outside the pond. Fix according to liner manufacturer's or design specifications.			✓		
Aesthetic maintenance recommendations						
Landscaping	Wetland needs to be regularly cleared of weeds, plants pruned and replaced 3 monthly. Grass areas around the pond	✓				

Component	Recommended action	Frequency				
		Monthly	6 monthly	Yearly	Two or more y ears	After storm e vents
	need to be mown monthly. Schedules may vary due to growth rates and seasons.					
Water body	Rubbish and other floating debris need to be removed from the wetland. Inspect the wetland for algal blooms or fish kills, which may signal eutrophication (a condition characterised by a combination of super-dense aquatic vegetation or algae growth and low dissolved oxygen levels in pond water), high nutrient or high pollutant levels in the stormwater run-off. Water quality testing may be needed to help identify causes of algal blooms.	✓				✓
Wildlife	Once established, many wetland ponds become habitats for birds and aquatic life. Regular inspection is required to ensure that desirable species are not threatened and that pest species are controlled. Areas for mosquito controlling organism (e.g. minnows) should be maintained.	✓				✓
Soil	Soil can be eroded from wetland banks particularly after heavy rain and where vegetative cover is poor. Also, depending on the quality of the soil, fertilisers may be needed to aid plant growth. **NB: Fertilisers, herbicides and pesticides should only be used after careful consideration due to proximity to the waterway and because the wetland water will ultimately discharge into the stormwater system. Only herbicides registered for application in aquatic environments should be used (refer New Zealand AgriChemical Handbook etc).**		✓			✓

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the wetland (e.g. falling trees, or branches). Typically a storm event is >2-year event.

5.4.1 Unplanned and emergency maintenance

Unplanned or emergency works can result from storm events, uncontrolled activities within the catchment, or contaminant spills. Depending on the location of the wetland there may be some time between incident, reporting, and remediation. It is important that after storm events the wetland is visually inspected promptly so that any damage can be rectified.

Typical issues after storm events include floatables, blockages of outlets or inlets, flooding and erosion of banks. The procedures listed above should be used for any corrective maintenance. Details for refurbishment or re-build will be found in the technical information section of the operation and maintenance manual.

Uncontrolled catchment activities relate mainly to earthworks without effective erosion and sediment control measures in place. The increased sediment load in run-off could inundate the wetland causing problems for aquatic life.

A spill response plan should also be included in the operation and maintenance manual (or referenced if located in another document). The primary response will be preventing contamination of downstream receiving environments and relocation or rescue of fauna (e.g. ducks and fish).

5.5 Troubleshooting

There are a number of common problems that arise when a wetland is not maintained or if the use of the land surrounding the pond changes. Listed below are some of these common problems, likely causes and potential solutions.

Table 7
Constructed wetland troubleshooting.

Symptom	Likely cause	Remedy
Water levels in wetland remain high	The openings in the wetland's outlet structure may be too small causing water levels to remain elevated after a storm.	Action may not be necessary unless water levels in the wetland remain elevated for more than two days or if flooding is a threat. Talk to your supervisor immediately if this occurs and inform the engineer/designer.
	Clogging of outlet structures and openings.	Inspect outlet structures and openings for blockages by debris or sediments. Clean openings as necessary.
	Invasive plants (such as raupo) could be clogging the ponded area.	Manually remove plants that are the problem. Do not use herbicides.
Wetland is dry	A maintenance drain valve is open.	Inspect and close drain valves.

<table>
<tr><th>Symptom</th><th>Likely cause</th><th>Remedy</th></tr>
<tr><td rowspan="4"></td><td>Wetlands constructed in areas with fluctuating groundwater levels may become seasonally dry.</td><td>Wetlands constructed in areas were groundwater levels drop below the bottom of the pond will become dry as long as low groundwater level conditions persist. This issue should have been addressed during the design of the wetland and may be a normal part of the stormwater system's operation.</td></tr>
<tr><td>Water may be leaking from cracks in the outlet structure.</td><td>Inspect the outlet structure for cracks and repair cracks as necessary. Inspect for leaky joints between the outlet pipes and outlet structure. Repair leaks as necessary.</td></tr>
<tr><td>Water may be leaking from cracks in the berm at the outlet end of the wetland.</td><td>Talk to your supervisor immediately if this occurs and inform the engineer/designer.</td></tr>
<tr><td>Groundwater levels have dropped.
Drought conditions exist.</td><td>Not much can be done to remedy drought conditions. The next wet season should bring water levels back up. This may be a good opportunity to clean accumulated sediments from the forebay and perform inspection and repair work of the stormwater infrastructure.</td></tr>
<tr><td rowspan="4">Stormwater exiting the wetland is not clear or appears dirty, muddy or dark.</td><td colspan="2">The quality of the stormwater exiting the wetland should be significantly better than the stormwater entering the wetland. If this is not the case there are a number of things to check:</td></tr>
<tr><td rowspan="2">Water leaving the wetland may contain high concentrations of sediment, especially fine materials like silt or clay. Finer sediment like clays and silts may take a very long time to settle out of suspension and will likely cloud the water in the wetland. Construction activities in the wetland's catchment may be contributing sediment to the stormwater run-off. Exposed or destabilised soils may be eroding.</td><td>Look for erosion areas within the catchment, including areas where construction works are underway and verify that proper erosion control measures (e.g. silt fences, filter socks, etc.) are in place. Add or repair erosion controls as necessary.</td></tr>
<tr><td rowspan="2">Accumulated sediment needs to be removed from the forebay more frequently than from the wetland's main pond. Dredging needs to occur if the ability of the forebay to store water is reduced to about 50% of its overall volume.</td></tr>
<tr><td>The forebay may be full of sediment.</td></tr>
</table>

Symptom	Likely cause	Remedy
	Works in the contributing drainage area may have disturbed soils and recent rains may have washed excessive amounts of soils into the wetland.	Verify that proper erosion and sediment controls are being used around the construction sites. Repair any erosion control measures. Install additional erosion control measures to prevent further run-off of sediment. Stabilise areas of exposed soil and where erosion has occurred.
	The wetland may have been constructed with the outlet too close to the inlet structure causing a short circuit and preventing any treatment from occurring.	This is an issue that should have been addressed during the design of the wetland. Strategically located baffles, bands or islands in the wetland can manipulate flows to increase the distance that stormwater travels between inlet and outlet points. Islands can also provide habitat and offer visual appeal.
Wetland plants are encroaching into the pond.	Wetland vegetation is colonising shallow areas of the pond.	Constructed wetlands are specifically designed to sustain large fringes of aquatic plants.
		No action is likely needed unless the species are invasive weeds. Aquatic vegetation is part of the wetland's water quality treatment system. Selectively remove plants only if they are affecting the wetland function or are threatening to clog the outlet structure. Periodic thinning of vegetation may be required over time if wetland performance in treating contaminants begins to deteriorate.
Wetland banks are eroding	Water running down wetland banks is eroding soils.	Minor erosion can be fixed by replacing eroded soils and re-stabilising the exposed soils with vegetation or other means. Run-off from the banks could be conveyed into a swale or pipe to reduce water velocities and erosion. Armour areas of concentrated run-off with riprap or appropriate erosion resistant vegetation
	Stormwater outlet pipes are aimed at wetland banks or exit near the top of the wetland banks.	More extensive erosion due to strong flows may require more significant erosion protection (e.g. rock rip-rap, geotextile, etc). In this case, the root cause of erosion should be identified and addressed (e.g. pipes may need extend down into the wetland) in order to prevent future erosion problems.

Symptom	Likely cause	Remedy
Water is leaking from the wetland and through the banks along the pipes	Leak collars around pipes have either failed or have not been installed correctly during the wetland's construction. Failure of wetland banks can cause major damage.	Repair or replacement of leak collars should only be attempted by qualified construction contractors. This remedy typically requires draining the wetland, excavating the wetland banks with heavy machinery, fixing the leak collar and reconstructing the wetland banks to their original design specifications.
Bird life is dying off.	The most common cause of death among birds in stormwater wetlands is botulism. Botulism is caused in anaerobic conditions by the toxins produced by *Clostridium botulinum* bacteria (Coffield and Whelchel, 2007). Birds carry the bacteria but it is only when they ingest the toxic bacteria that they get sick, often by eating maggots and other invertebrates that have been feeding on the dead animals that are carrying the bacteria.	Botulism occurs most often in mid-to-late summer, when water levels are low and the water stagnates, causing die off of invertebrates. Cases of botulism will often be found when there is a lack of available oxygen in the water which often occurs after algal blooms. Actions include the prompt removal of dead birds and animals from the area, reduce algal blooms, maintain flow through the wetlands and improve shading over the water body. **Figure 11** Dead birdlife. 

Symptom	Likely cause	Remedy
Algal blooms are occurring	Algae is always present in water. Algal blooms occur when environmental conditions are right. Specifically, blooms tend to occur when the water is stagnant or slow moving, there are high levels of nutrients, and the weather has been sunny and hot for long periods. Blooms can look like a yellow, green, red, or blue-green coloured scum on the surface of the water.	There are a number of ways (unproven) to treat algal blooms, but the best approach is prevention of optimum bloom conditions by minimising use of fertilisers upstream of the wetland and maintaining flows. Using barley straw bales to remove algae has had varying levels of success. Wetlands that are better shaded should have fewer problems with algal blooms than poorly vegetated wetlands. **Figure 12** Manawa Wetland – barley straw bales. 
Animal pests are a problem	Dense vegetation and abundant food supply associated with stormwater wetlands provides habitat for many animals, including pests.	Thin out vegetation if possible, set traps and or bait stations throughout the area (ensure correct procedures are followed regarding signs and handling of poisons and their use in close proximity to aquatic habitats).
Plants are dying off	Plants on the edge of a stormwater wetland are exposed to both extreme wet and dry conditions.	Selection of plants should take local conditions into account and new plantings should be watered as required. Replace plants if necessary. Inspect the outlet structure to ensure it is not blocked, artificially elevating the wetland water level. Inspect the outlet structure and berm for leaks that may cause the wetland to dry out.

5.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, resource consent conditions, or part of legislation such as the Building Act or Health & Safety Act.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the wetland. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts and hazardous or inappropriate practices can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the wetland would tend to focus on discharge water quality. Quarterly sampling of discharge from the wetland during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies. The deposition of sediment should also be regularly monitored to determine the cleaning regime. Regular monitoring of water quality and sediment deposition will help to identify any performance issues and enable prompt remediation. Wetland sediment can also be examined for heavy metal and other contaminant accumulation.

5.7 Wetland – photo gallery

Figure 13

Northern Gateway Tollbooth wetland shows sediment forebay and main pond.

Figure 14
Mantra Road wetland with scruffy dome outlet structure newly constructed showing staged treatment bays, starting with forebay at the back of the photo. [WCC]

Figure 15
Manawa wetlands, good vegetation cover with rip rap line overflow for erosion control. [WCC]

Figure 16

Wetland by northern motorway (Akoranga exit) showing good plant coverage and easy access around the perimeter of the wetland pond.

Figure 17

Trias Road wetland, good vegetation cover but photo shows established weeds (woolly nightshade).

6 Rain Gardens

6.1 Introduction

Rain gardens (also known as bioretention or bioinfiltration devices) can have the appearance of an aesthetic plant bed with little appreciation for the stormwater treatment function. There are distinct differences between a traditional plant bed and a rain garden. Often, during construction or maintenance, specific features which are essential to raingarden function are not followed as per the design plans due to inexperience and lack of understanding. The following sections will guide you through the maintenance process and explain why certain features are required and what to watch out for when maintaining a rain garden.

6.2 Device description

Rain gardens receive rain water that runs off hard surfaces (inflow) such as roofs and car parks either as sheet flow, or from pipes or overland flow channels (swales). Run-off passes through plant roots and the rain garden media mix which absorbs the water and filters the pollutants before the water is released back to the piped stormwater system or waterway. A properly functioning rain garden should filter run-off from a rain event within 24 hours (i.e. ponding should disappear in 12 to 24 hours).

Rain garden functions:

- Filter stormwater run-off to remove contaminants.
- Detain some storm water to alleviate flooding.
- Return stormwater to the natural environment via infiltration to groundwater and evapotranspiration.
- Aesthetically pleasing i.e. they look good.

Rain gardens are designed to treat stormwater from smaller storms and the initial stormwater flows (first flush) from larger storms (which is when stormwater is most polluted). In heavy downpours, rain gardens can overflow. Excess stormwater exits the ponding area when the water depth reaches a maximum of about 300 mm through a raised overflow structure which will be designed specifically for the local conditions. Rain gardens typically include six main elements in their design. In the order in which stormwater would normally pass through the garden system, the elements are listed in Table 8.

Figure 18
Typical rain garden.

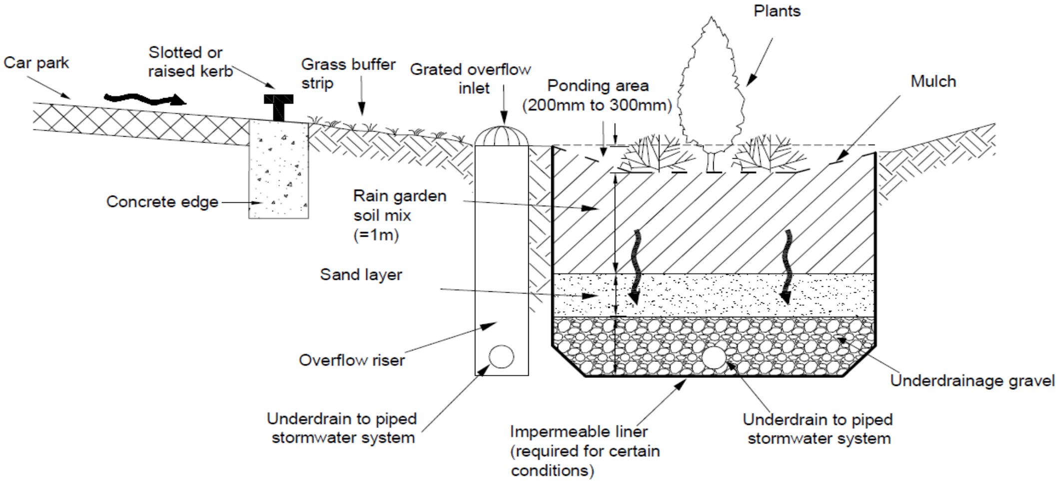


Table 8
Key components of a rain garden.

Device component	Description
Grass buffer strip (not always included) or inlet	Grassed buffer strip between hard surface and garden which is the first stage of filtration removing larger particles and creating run-off sheet flow (so as to avoid erosion). Grass filter strips are not always included in rain garden design, often due to site constraints. It is not an essential component. The inlet to the rain garden will usually be the entire perimeter of the rain garden.
Plants (preferably native)	The plants and planting media mix filter pollutants out of the stormwater run-off and provide a positive aesthetic function (i.e. they look good). Native plants are usually used as they are often better suited to the extreme wet/dry conditions of rain gardens (ponding for up to 24 hrs). Plants with shallow root systems are preferred to prevent ingress to underdrainage.
Ponding area	This area holds stormwater run-off and allows it to seep down through the planting mix and into the underdrain system. The ponding area is usually 200 mm – 300 mm lower than surrounding hard surfaces at its deepest. Ponding areas are essential for raingardens to function correctly. Local authorities may have specific maximum depth and minimum capacity requirements for the ponding area. For safety reasons, the maximum depth of the ponding area should not exceed 300 mm.
Mulch layer	Prevents weeds and helps to prevent the media drying out. Pebbles can also be used, but are not recommended where nitrogen removal is required as a treatment outcome.

Device component	Description
Rain garden media mix	Special media mix to support plant growth and allow water to pass through the garden freely. The media acts as the filter for pollutants in a rain garden. It usually consists of sand, topsoil (<5%), and organic matter to support plant growth.
Sand layer (if included)	Serves as an additional stormwater filter by removing pollutants that may pass through the planting bed. Will also help retain media within the rain garden and stop migration into the drainage layer. A combination of thin (50-100 mm) alternating layers of sand and gravel can also be used.
Underdrain system	Water drains through rain garden media mix to the underdrain where it is piped to the stormwater network or waterways (e.g. stream, open water). Surrounding high permeability (ability to drain) soils may not require an underdrain as run-off will drain through the rain garden into groundwater aquifers.
Overflow system	Structure which removes excess run-off from the rain garden thus preventing flooding and damage to the garden. Typically a riser (vertical drain or raised catchpit) connected directly to the underdrain system. Can be located within the rain garden or adjacent to the rain garden.

6.2.1 Rain garden location

Rain gardens can be found all across the Auckland region and are used to treat stormwater from small drainage areas like driveways, car parks and roads. They are also used to treat run-off from roofs in residential and commercial/industrial areas in accordance with some council consents.

In general, rain gardens are used in areas close to the source of water run-off, e.g. adjacent to the road and away from steep slopes. Rain gardens need to be fully lined in areas where water sits near the surface of the ground (high watertable) and have an underdrain in poorly-draining soils.

The type of plants used in a rain garden will be determined based on expected stormwater flows, rainfall, and amount of sunlight the rain garden will receive. It is also important to review these determinants when replacing dead plants in a rain garden. Trees which can grow into protected species should not be used. If a rain garden requires refurbishment a protected tree within the garden will inhibit any maintenance activities. The council's District Plan will provide guidance on protected plant species.

6.2.2 Life span of rain gardens

Rain gardens filter pollutants from stormwater. These pollutants accumulate in the media of the rain garden and can clog the media so that it no longer operates effectively at removing the pollutants. Every 5 years or so (depending on original construction and activities, such as construction, within the drainage area and contaminant loads) the rain garden may need to be cleaned out and rebuilt. Poorly constructed rain gardens will likely require rebuilding within 2-3 years of initial construction. Refer to the Rain Garden Construction Guidelines for information on how to build a rain garden. Rain garden life spans can be increased to as much as 30 years if properly maintained.

6.3 Operation and maintenance manuals

Operation and maintenance manuals are often required as a condition of consent. Even if they are not, an operation and maintenance manual is very useful in documenting design and construction information of the device and providing methodologies for maintenance procedures.

Typically an operation and maintenance manual should contain a section for the log book to record inspections and maintenance activities, technical information on the design and construction of the rain garden, and a section for all the maintenance procedures which detail methodology and frequency.

6.3.1 Log books

The log book is perhaps the most important tool in managing a rain garden as it provides details on all maintenance activities and inspections. The log should be kept simple so that it can be completed easily and records the necessary information for any reporting required, whether a condition of consent or contractual requirement.

Figure 19
Example log sheet for rain garden maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Rain gardens			**File No.**
			Date
			/ /
SITE: AUT pond, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	RGM3	Check media moisture – okay. Prune plants and replace dead plants.	J. Smith
4/5/09	RGM2	Remove weeds	J. Smith
6/6/09	RGM1	Channelled flow eroding garden. Check levels and remove some mulch and planting mix to get to correct levels.	H. Bloggs

6.3.2 Technical information

This section provides all the background information on the design and construction of the rain garden. If there are any faults with the rain garden and it is not performing, this section can assist in troubleshooting the problem, which could be design related. Typically this section will include:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contaminant spills or flooding.
2. Site location, legal description and details on how to access the site and where key features of the garden are located (situation map, and layout plan are important).
3. Consent numbers and details of issuing agency, include summary of consent obligations and attach copies of consents to the appendices.
4. Design information:
    a. Co-ordinates for the centre of the device.
    b. Levels to LINZ Auckland datum 1946.
    c. Planted surface of device.
    d. Overflow outlet.
    e. Invert of outlet pipe.
    f. Invert of orifice outlet, if any.
    g. Diameter of orifice outlet, if any (mm).
    h. Design ponding water depth (m).
    i. Contributing catchment area (roofs) in $m^{2.}$
    j. Contributing catchment area (paving) in $m^{2.}$
    k. Contributing catchment area (pervious) in $m^{2.}$
    l. Normal operating surface area of device in $m^{2.}$
    m. Nominal depth of planting media (mm).
    n. Year of completion.
5. If required by the consenting authority, a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection.
6. Construction detail plans of the device.
7. Copy of geotechnical report, if applicable.
8. Copy of design calculations.
9. As-built planting layout and schedule, if applicable.

10. As-built plan; dated and showing maintenance truck access, machinery working pads, underdrainage, catch pits, manholes, and temporary working/storage areas.
11. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is buried beneath the garden media (e.g. underdrainage).

6.3.3 Procedures

This section provides the details for inspections and maintenance tasks. Section 6.4 below provides a generic maintenance schedule which can be adapted to the site specific requirements. The maintenance schedule will form the basis of any maintenance contracts that are tendered.

Reporting requirements, whether as a condition of consent or a contract, should be included as a procedure with details of the reporting format, contents and frequency. Any monitoring which is carried out should also be documented with details of how to undertake any sampling or testing and where results should be submitted.

6.4 Maintenance schedules

Rain gardens require regular inspection and maintenance to ensure they continue to operate effectively. One year after construction is complete, a full inspection of the rain garden, including all the operational and visual features, should be conducted. As part of the full inspection, a flow test should be performed to test the underdrain is still working properly and that the rain garden drains down within 24 hours. Council may require a CCTV report for the underdrainage for the full inspection.

Table 9 outlines the typical components of a rain garden and the recommended maintenance actions and frequency. The maintenance frequency is the recommended minimum time. Rain gardens should be inspected after storms to ensure that any damage is fixed immediately. In most cases an operation and maintenance manual that covers detailed maintenance specific to each rain garden will be produced by the designer/owner of the rain garden.

Table 9
Typical rain garden operation and maintenance recommendations.

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm events
Grass filter strip (if included)	Mow grass to a minimum height of 50 mm. Do not mow the grass shorter than this or the effectiveness of the filter strip will decrease. The frequency will vary depending on growth rates and seasons. Re-sow grass as necessary.	Growth rate and season dependent				
	Remove rubbish, leaves and other debris.	✓				✓
	Check grass strip for gouging and eroding flow channels. Repair as necessary.		✓			✓
Ponding area	Check that level of media and mulch stays below the surrounding hard surface areas and overflow (between 200 mm and 300 mm lower). Remove excess mulch/media as required.		✓			
	Remove rubbish, leaves and other debris.		✓			✓
	Test drainage of ponding area by checking the garden 24 hours after rain to ensure there is no water still ponding (after storm event). This can also be done by digging a hole 20 cm wide by 20 cm deep, and pouring 10 L of water into the hole. The water should go down at a minimum rate of approximately 2.5 cm per hour.			✓		✓
	Clear inflow points of build up of sediment, rubbish and leaves. Check that there is no erosion or gouging.		✓			✓
	Check the surface of the rain garden media mix for a crust of fine sediment which can inhibit drainage. Remove if present and rework top layer of rain garden media mix. Top up media and mulch as necessary (ensuring level is below surrounding hard	✓				✓

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm events
	surface an overflow).					
Rain garden media mix	Media needs to be free draining – avoid compaction from planting and filling bed with too much media. Level must be below surrounding hard surface level and overflow grate. Use drainage test as described above. Rain garden media mix should be a mix of 50-60% sand, 20-30% topsoil (no clay) and 20-30% organic material.			✓		
Mulch layer (bark, pebbles, etc)	Remove rubbish, leaves and other debris. After storm events mulch may need to be redistributed or added around inflow points.		✓			✓
	Check the surface of mulch for build up of sediment, remove and replace as required.			✓		
	Check mulch depth to ensure adequate cover, redistribute and replace as required.		✓			
	Mulch may need to be completely replaced periodically to prevent surface clogging				✓	
Plants	Remove weeds (particularly those identified in the council's Regional Pest Management Strategy) – do not use herbicides or pesticides as these chemicals will pollute the stormwater.		✓			
	During extended dry periods the plants may require extra watering, this is particularly important while plants are getting established in the garden when weekly or bi-weekly watering may be required.		✓			
	Check plant health and replace dead plants as necessary. Use native species suitable for the conditions of your garden (e.g. full sun or shaded). **See ARC TP10 for partial list of suitable species.**		✓			
	Periodic pruning of vegetation may be required to ensure lines of sight for traffic are maintained.		✓			

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm events
Underdrain system	Check that garden is draining freely using the drainage test as described above.		✓			
	If underdrain is blocked the rain garden will need to be refurbished by removing plants and rain garden media mix. An inspection well (installed during construction) can be used to verify that the underdrain is working properly or CCTV can show any blockages or collapse. Low pressure backwash may be used to clear any blockages or clogging from fine sediments.				✓	

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

6.4.1 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, vandalism, or uncontrolled activities within the catchment. In either case there can be a delay between incident, reporting and response particularly where the rain garden is located away from public areas. It is important that after storm events the rain garden is inspected promptly so that any damage which could potentially cause flooding or be a hazard can be rectified.

Typical issues after a storm event include blocking of overflow outlets, deposition of sediment and rubbish within the ponding area thus limiting permeability and decreasing the ponding volume, and erosion of the rain garden bed. The procedures listed above should be used for any corrective maintenance. If the damage is extreme then a complete or partial re-build may be required. Details for this will be found in the technical information section of the operation and maintenance manual.

Uncontrolled activities within the catchment can include construction activities (for subdivision or individual property developments), earthworks or road works. All of these activities can contribute increased sediment loads in stormwater run-off and increased contaminants. Unexpected sediment inputs from construction activities can create a layer of sediment within the rain garden which can diminish permeability.

6.5 Troubleshooting

There are a number of common problems that arise when a rain garden is not maintained or if the use of the land surrounding the rain garden changes. A list of common problems, suggested causes and solutions are set out below.

Table 10
Rain garden troubleshooting table.

Symptom	Likely cause	Remedy
Stormwater run-off is bypassing the rain garden.	Earthworks activities in the area can greatly increase the sediment load in run-off hindering the ability of the rain garden to filter the water or raising the surface level of garden.	Ensure that the surface of the rain garden is below the surrounding area. Remove any accumulated sediments and debris from inflow areas and from the top of the rain garden.
	Rubbish and other debris may be blocking the inflow points to the rain garden.	Remove rubbish, leaves and any other debris that could be causing a blockage.
Stormwater and/or mulch are flowing off the rain garden. The rain garden is ponding for longer than 24 hours.	Mulch is floating off the rain garden during storm events.	Replace mulch with a less buoyant material.
	The incorrect blend of media mix has been used.	Replace media mix with the correct rain garden media mix (50-60% sand, 20-30% topsoil, and 20-30% organic material). Commercial rain garden media mix may be available in some areas at local garden centres.
	The media within the garden may have been compacted during construction or other activities.	Loosen the top 500 mm of media by tilling or forking. Restrict vehicle, pedestrian and bicycle access to the rain garden.
	A layer of fine sediment may have settled on the garden surface.	Inspect the top 75-100 mm for fine sediment accumulation and replace if necessary. Remove the fine sediment layer and turn over the top layer of rain garden media mix
	The rain garden may have been filled with too much mulch or media.	Remove excess mulch or media so that level of ponding area is approximately between 200 mm and 300 mm below the surrounding hard surface and overflow.

Symptom	Likely cause	Remedy
	Overflows or discharge pipes may be clogged with sediments or debris.	Inspect clogging and clean overflows and discharge pipes. Backwash underdrain with low pressure water blaster.
	Planting or rain garden media mix may be clogged.	Investigate the surface layers to locate where the clogging is occurring. It may be necessary to remove some of the rain garden media mix and replace with fresh rain garden media mix.
A sulphury smell is coming from the rain garden.	The sulphury smell is a product of anaerobic (without oxygen) respiration. Organic material is likely rotting within the garden.	Inspect rain garden after a rain event and verify that the garden drains within 12 to 24 hours after the storm. See above solutions for rain garden ponding.
	The underdrain is likely clogged and water is not properly draining out of the garden.	
Erosion and gouging is occurring within the rain garden.	Rain gardens require an even sheet flow of water to operate effectively. Kerbs and other hard structures can focus stormwater flow causing erosion and gouging through the media.	Create openings in the kerb at selected intervals to increase the number and width of run-off access points, or replace kerbing with a different design – for example kerbing that is slightly raised off the ground.
	Inflow is being concentrated.	Increase kerb openings by cutting kerbs or replacing with different design. If this is not possible install rip-rap (i.e. stones set into concrete) at the inflow point to reduce erosion. Create a small rip-rap lined stilling basin or forebay to reduce water velocity and internal erosion.
Plants are stressed or dying. Symptoms may include yellowing of leaves, unseasonal leaf fall, wilting, etc.	The plants selected for a rain garden may not be suitable for the location and intolerant of extreme wet/dry conditions.	Select plants appropriate for the proposed location (e.g., full shade, partial shade, full sun, etc.) Native plants are recommended (see ARC TP10 for suggested plant list).
	Ponding or excessively long periods of flooding may cause plants to become stressed and die.	Inspect rain garden after a rain event and verify that the garden drains within 12 to 24 hours after the storm. See above solutions for rain garden ponding.

Symptom	Likely cause	Remedy
	The plants could be poisoned by run-off from a hazardous spill (i.e. fuel, paint, oil, etc)	In the event of a hazardous chemical spill into a rain garden, the entire rain garden should be completely cleaned out, replaced with clean material and replanted.
	The plants could be dehydrated due to extended dry weather conditions. Newly-planted vegetation also needs regular watering until it is established	Check media moisture content and water the plants if media is dry. Plants should be watered when necessary like any normal garden. This is particularly important with new rain gardens where the plants are still maturing.
	The plants may be stressed due to attack by plant pests or diseases. Pests may include insects or animals.	Consult with your local garden centre. Stressed plants may have to be replaced with healthy stock or pest resistant species.
	The rain garden media mix may be overly compacted.	Loosen the top 500 mm of media by tilling or forking. Restrict vehicle, pedestrian and bicycle access to the rain garden.
	The amount of pollutants accumulated in the rain garden has reached a level where they are toxic to the plants.	Collect and have media samples analysed in a laboratory to confirm toxicity. Refurbish the rain garden in accordance with the construction notes.

6.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or part of consent conditions.

Auditing typically implies a compliance requirement, while monitoring will tend to refer to performance of the rain garden. An audit checklist can be developed based on the maintenance schedule. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that shortcuts and hazardous or inappropriate practices can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the rain garden would tend to focus on discharge water quality and permeability of the rain garden media mix. If maintenance frequency for the rain garden is difficult to determine (based on catchment activities and contaminant loads) quarterly sampling of discharges during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies and methods. The permeability of the growing media should be tested within the first month of operation as this should represent optimum permeability. Thereafter permeability should be tested quarterly for the first year of operation and then annually in subsequent years.

Depending on the size of the rain garden the permeability test can be done using the simple falling head test method. The permeability test should be performed on saturated media using a cylindrical cone which is inserted into the media right down to the underdrainage system (ensure the underdrain is not damaged by the cylinder). The cylinder is filled with water to a set level (usually 100-200 mm) and timed until the water drains down.

Depending on the requirements for audits and monitoring reporting of results should be submitted to the owner and the regulatory authority.

6.7 Photo gallery – rain gardens

Figure 20

Paul Matthews Road rain garden level spreader can get clogged with sediment and vegetation.

Figure 21

Waitakere Library rain garden, note level of stones and planting mix, coming out of kerb splits.

Figure 22

Waitakere Civic Centre rain garden, note mulch is higher than surrounding drainage area (no ponding area in rain garden).

Figure 23

Waitakere Civic Centre car park rain garden showing good ponding area (garden bed level lower than surrounding ground).

Figure 24

Albany Civic Crescent rain gardens pre-planting, note sand bag protection of inlets during construction

Figure 25

Albany Civic Crescent rain gardens post-planting

7 Tree Pits

7.1 Introduction

Tree pits are relatively new to the suite of treatment devices in the Auckland region. An example of where tree pits have been used is the Albany Civic Centre which has embraced low impact stormwater treatment options, and included tree pits as a feature of the stormwater treatment process.

7.2 Device description

Tree pits perform a similar function to rain gardens, but are generally only used to treat small areas of stormwater run-off from car parks and roadways. The inlet on a tree pit is usually an opening in the kerb and channelling in a car park or roadway. The outlet is an underdrainage system connected to the piped stormwater system or soakage pit. Run-off is filtered through the plant media mix absorbing stormwater run-off and filtering the pollutants before the water is released back to the piped stormwater system.

Unlike rain gardens, tree pits do not generally have filter strips and receive sheet flow directly from the kerb and channel via the kerb outlet. A properly functioning tree pit should filter run-off from a rain event within 24 hours (i.e. ponding should disappear in 24 hours).

Tree pits are designed to treat stormwater from smaller storms and the initial stormwater flows from larger storms (which is when stormwater is most polluted). In heavy downpours, stormwater either bypasses the tree pit and flows to the conventional stormwater system, or ponds in the roadside kerb and channel. Due to the ability of the stormwater to bypass a tree pit during large events, overflow structures are often not required (this is entirely dependent on the design).

Figure 26

Tree pit components.

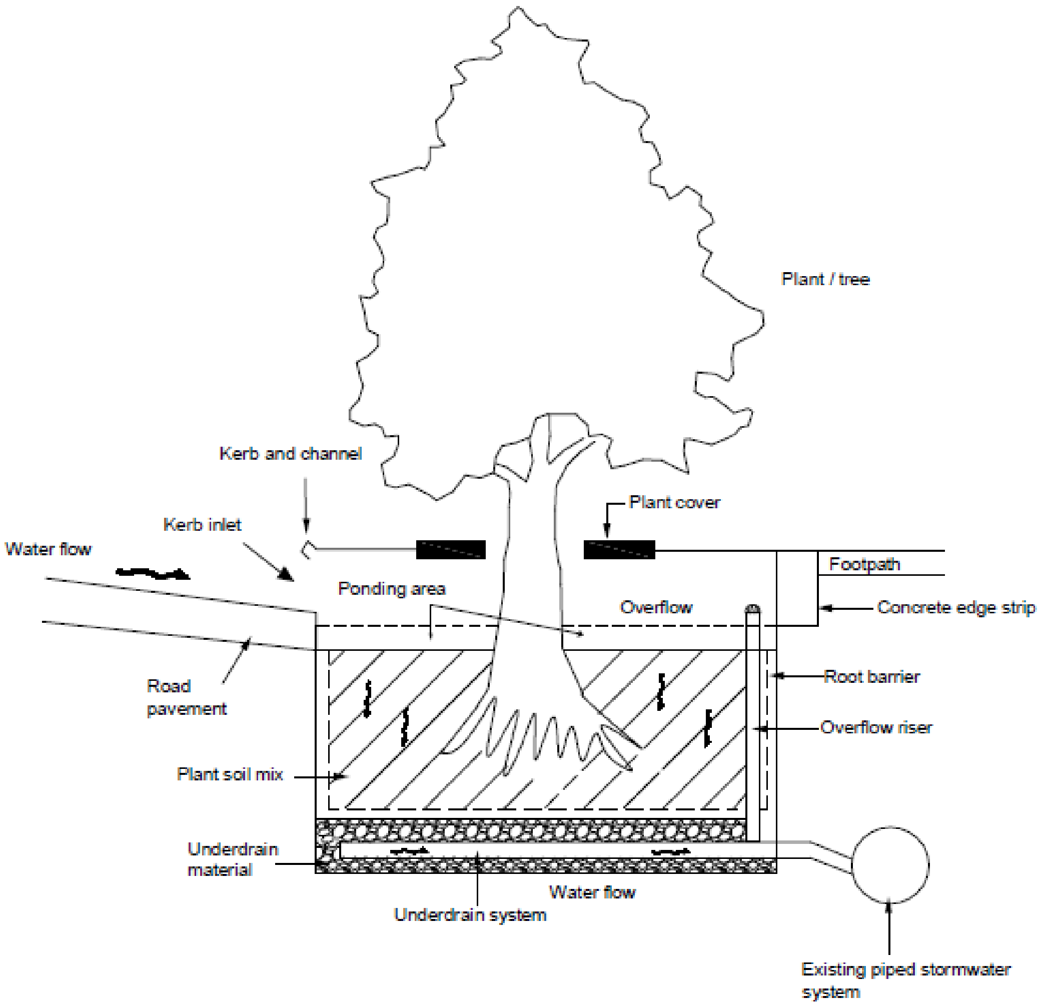


Table 11

Key components of a tree pit.

Component	Description
Kerb and channel	Kerb and channel is used on roads and in car parks to direct stormwater run-off away from the trafficked areas to the tree pits.
Kerb inlet	The kerb inlet is a large opening in the side of the kerb through which water is directed into the tree pit. Often the kerb inlet is a side entry splay pit which is built into the footpath and kerb next to roads.
Plant covers	Covers used around the base of the tree or shrub to ensure the root structure is not damaged (either by vehicles or pedestrians travelling across the media and compacting it).

Component	Description
Plants	In tree pits, these are usually limited to a single specimen and are generally large plants such as shrubs or trees. The shrubs or trees enhance performance by filtering pollutants from the water, reducing water volumes through evapotranspiration and provide amenity value, particularly along roadways.
Ponding area	Surface area beneath the plant cover which is 200 mm to 300 mm lower than surrounding hard surfaces where the water ponds prior to filtering through the media.
Mulch layer (may not be included)	Prevents weeds and helps to prevent the media drying out. Because most tree pits are below the level of the road surface and therefore are not as susceptible to drying out, a mulch layer is sometimes not needed. Mulch can also aid in removing contaminants like oil and grease from the stormwater.
Plant media mix	Special media mix to allow water to pass through the garden freely. The media acts as the filter for pollutants. It usually consists of sand, topsoil (minimal clay 0-5%), and organic material (e.g. peat). A rain garden media mix can also be used sparingly (too much can leach nutrients to the stormwater discharge) and is now available at some retail garden centers.
Root barrier (may not be included)	The root system (root ball) of the trees and shrubs used in tree pits can grow to a point where roots extend outside of the tree pit area, causing damage to car parks, road ways or footpaths and other utilities. The root barrier is a specially manufactured permeable fabric to ensure that tree or shrub roots do not extend beyond the extent of the tree pit. They line the outside of the tree pit, and are generally fixed in place with stakes at selected intervals around the edges of the tree pit, or are fixed to a metal strip around the top of the tree pit below the plant covers. Root barriers are not necessary in concrete box type tree pits as the concrete itself acts as a root barrier.
Underdrain system	Excess water drains through plant media mix to the underdrain where it is collected by perforated pipes and directed to the stormwater network or water body.
Overflow system	In some cases an overflow system (either by a standpipe or channel grate) is provided to direct flows greater than what the tree pit is designed to cope with to the piped stormwater network. These are not always included.

7.2.1 Siting tree pits

Tree pits are generally found in car parks and alongside roadways as they provide additional benefits for stormwater run-off while providing amenity value as street trees. They are now used reasonably extensively throughout the Auckland region.

Unlike rain gardens, tree pits are not designed to collect large volumes of run-off. Run-off is collected via an opening in the kerb and channelling. Due to their location in trafficked areas, the trees should be single trunk specimens and will require regular pruning to ensure they do not obstruct traffic views.

7.3 Operation and maintenance manuals

Operation and maintenance manuals are often required as a condition of consent. Even if they are not, an operation and maintenance manual is very useful in documenting design and construction information of the device and providing methodologies for maintenance procedures. An operation and maintenance manual for tree pits can be written to cover a number of tree pits for a particular development.

Typically an operation and maintenance manual should contain a section for the log book to record inspections and maintenance activities, technical information on the design and construction of the rain garden, and a section for all the maintenance procedures which detail methodology and frequency.

7.3.1 Log books

The log book is perhaps the most important tool in managing a tree pit as it provides details on all maintenance activities and inspections. The log should be kept simple so that it can be completed easily and records information necessary for any reporting required, whether a condition of consent or contractual requirement. Permeability testing and monitoring should also be recorded in the log book. An example of a log for tree pits is provided below.

Figure 27
Example log sheet for tree pit maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Tree pit			**File No.**
			Date
			/ /
SITE: AUT pond, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	TP3	Prune plants and replace dead plants.	J. Smith
4/5/09	TP2	Remove weeds	J. Smith
6/6/09	TP1	Checked overflow pipe for blockages, replaces missing cap.	H. Bloggs

7.3.2 Technical information

This section provides all the background information on the design and construction of the tree pit. If there are any faults with the tree pit and it is not performing, this section can assist in troubleshooting the problem, which could be design related. Typically this section will include:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contaminant spills or flooding.

2. Site location, legal description and details on how to access the site and where key features of the garden are located (situation map, and layout plan are important).

3. Consent numbers and details of issuing agency, include summary of consent obligations and attach copies of consents to the appendices.

4. Design information:

   a. Co-ordinates for the centre of the device.

   b. Levels to LINZ Auckland datum 1946 (or specify survey benchmark).

   c. Planted surface of device.

   d. Overflow outlet.

   e. Invert of outlet pipe.

   f. Invert of orifice outlet, if any.

   g. Diameter of orifice outlet, if any (mm).

   h. Design ponding water depth (mm).

   i. Contributing catchment area (roofs) in $m^{2.}$

   j. Contributing catchment area (paving) in $m^{2.}$

   k. Contributing catchment area (pervious) in $m^{2.}$

   l. Normal operating surface area of device in $m^{2.}$

   m. Nominal depth of planting media (mm).

   n. Year of completion.

5. If required by the consenting authority, a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection.

6. Construction detail plans of the device.

7. Copy of geotechnical report, if applicable.

8. Copy of design calculations.

9. As-built planting layout, species planted and schedule, if applicable.

10. As-built plan, dated and showing maintenance truck access, machinery working pads and temporary working/storage areas.

11. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is buried within the tree pit (e.g. underdrainage).

7.3.3 Procedures

This section provides the details for inspections and maintenance tasks. Section 7.4 below provides a generic maintenance schedule which can be adapted to the site specific requirements. The maintenance schedule will form the basis of any maintenance contracts that are tendered.

Reporting requirements, whether as a condition of consent or a contract, should be included as a procedure with details of the reporting format, contents and frequency. Any monitoring which is carried out should also be documented with details of how to undertake any sampling or testing and where results should be submitted.

7.4 Maintenance schedules

Tree pits require regular inspection and maintenance to ensure they work effectively at treating stormwater run-off. A flow test should be performed to test that the tree pit is continuing to operate correctly, by inundating the tree pit with water and observing 24 hours later. If the tree pit functions correctly, all water will drain away within this time.

Generally an operation and maintenance manual that covers detailed maintenance specific to each set of tree pits will be produced by the designer/owner of the tree pit as a condition of consent. However, this is not always available. Table 12 outlines the components of tree pits and recommends typical maintenance actions and frequency. Note that the maintenance frequency is the recommended minimum time. As the majority of tree pits are located alongside the road carriageway or within car parks, it is essential that adequate traffic management is in place during maintenance of the tree pits when persons or machinery are on the road carriageway or car park.

A full inspection of the tree pit including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the tree pit and may be done by them directly.

Table 12

Typical tree pit maintenance schedule.

Component	Recommended action	Frequency					
		Monthly	3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
Plants	Check tree/shrub health. During extended dry periods the trees/shrubs may require extra watering, this is particularly important while trees/shrubs are getting established in the garden.	✓					
	If necessary (for tree health or where the planting impedes vehicular vision or pedestrian movement), prune seasonally in accordance with arborist requirements or contract an appropriate arborist to undertake the work. Remember that there are special council rules relating to the pruning of trees. Check with your local council before pruning.			✓			
	Trees may be staked to support them until they are mature. Inspect stakes, support structures and ties. Repair or replace where required.		✓				
Kerb and channel	Remove rubbish, leaves and other debris. Note any kerb and channel defects. Pass on defect information (such as cracking, loose concrete, etc) to the owner of the tree pit (e.g. local council) for remedial action.		✓				✓
Kerb outlet	Ensure that the kerb outlet is not blocked. Clean out any rubbish, leaves and other debris.		✓				✓

Component	Recommended action	Frequency					
		Monthly	3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	Ensure that the kerb outlet and associated tree pit structure appears structurally sound by checking for cracks and damage. Repair or report to local council for remedial action.				✓		
Plant covers	Check the plant covers for any damage. Repair if possible. Depending on the ownership of the tree pit and maintenance arrangement relating to it, either purchase and fit, or report the need for new covers, to the tree pit owner.				✓		
Ponding area	Check the inside of the tree pit visually either through the plant covers (if possible) or through the kerb outlet (a torch and/or mirror may be required). If the ponding area is covered with sediment, rubbish, leaves or other debris then remove plant covers and clean out manually or use a vacuum system to remove the debris.			✓			✓
	Remove the plant covers and inspect the ponding area is functioning correctly by: • Checking that the level of media and mulch stays below the kerb outlet level. Remove excess mulch/ media as required. • Checking the surface of the plant media mix for a crust of fine sediment which can inhibit drainage. Remove if present and rework top layer of plant media mix. Top up media and mulch as necessary (ensuring level is below surrounding hard surface and overflow).				✓		

Component	Recommended action	Frequency					
		Monthly	3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	• Testing the drainage of the ponding area by checking the garden 24 hours after rain to ensure there is no water still ponding. This can also be done by completely inundating the tree pit with water from a hose or hydrant.						
Mulch layer (if present)	It is unlikely that the tree pit will develop extensive weed intrusion, but over time weeds may establish themselves. Remove weeds – do not use herbicides or pesticides as these chemicals will pollute the stormwater. The plant covers may need to be removed to undertake this.		✓				
Plant media mix	The tree pit planting media needs to be free draining – avoid compaction from planting and filling bed with too much media. Remove excess or top up to desired level. Media should consist of sand, topsoil (minimal clay 0 - 5%) and organic material. Use drainage test as described above.				✓		
Underdrain system	Check that tree pit is draining freely using drainage test as described above. • If the tree pit has an overflow pipe connected to it, then the underdrain may be able to be cleared by inserting a low pressure water blaster hose down the overflow pipe. DO NOT use high pressure as this will damage the underdrainage system. • If an overflow pipe is not present, the tree pit may need to be completely refurbished by removing plants, mulch layer (if present), plant media mix and				✓		

Component	Recommended action	Frequency					
		Monthly	3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	underdrainage system and reconstructing the tree pit.						
Overflow pipe (if present)	Ensure that the overflow pipe or grate is clear of debris.		✓				✓
	Check that overflow pipe is not blocked by filling with water (about 1L) and ensuring this drains away. If necessary the overflow pipe may need to be cleaned out with a hose or manually cleaned out.			✓			

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

7.4.1 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, vandalism, or uncontrolled activities within the catchment. In either case there can be a delay between incident, reporting and response particularly where the tree pit is located away from public areas. It is important that after storm events the tree pit is inspected promptly so that any damage which could potentially cause flooding or be a hazard can be rectified.

Typical issues after a storm event include blocking of overflow outlets, deposition of sediment and rubbish within ponding area thus limiting permeability and decreasing the ponding volume, and erosion of tree pit bed. The procedures listed above should be used for any corrective maintenance. If the damage is extreme then a complete or partial re-build may be required. Details for this will be found in the technical information section of the operation and maintenance manual.

7.5 Troubleshooting

There are a number of common problems that arise with tree pits that are similar to that of rain gardens. If replacing tree specimens due to death or sickness, do not replace with a protected species as this can inhibit ability to conduct future maintenance, particularly within the drip line of a protected tree. Listed below are some of these common problems, suggested causes and solutions.

Table 13
Tree pit troubleshooting.

Symptom	Likely cause	Remedy
Stormwater run-off is bypassing the tree pit.	Rubbish and other debris may be blocking the kerb outlet (entrance to the tree pit).	Remove rubbish, leaves and any other debris that could be causing a blockage.
	The plant media mix and/or mulch level is too high and does not allow water to enter the kerb outlet and/or pond.	Remove plant covers and remove excess mulch and/or plant media mix. Reshape to form ponding area and cart excess material off-site.
	The kerb outlet has been damaged or has not been constructed correctly and water cannot enter the tree pit (i.e. kerb and channel not shaped correctly, kerb outlet too small, part of outlet covered by road carriageway or paved area, levels incorrect, etc).	Contact owner of tree pit (e.g. local council) to report issue.
Stormwater is ponding outside the front of the tree pit (possibly extending into the car park or roadway). If a mulch layer is used, mulch may also be flowing off the tree pit.	Earthworks activities in the area can greatly increase the sediment load in run-off hindering the ability of the tree pit to filter the water or raising the surface level of garden.	Ensure that the surface of the tree pit is below the surrounding area. Remove any accumulated sediments and debris from inflow areas and from the top of the tree pit.
	A layer of fine sediment may have settled on the garden surface.	Remove fine sediment layer and turn over and examine the top layer (75 – 100 mm) of plant media mix for fine sediment accumulation.
	The incorrect blend of media mix has been used.	Replace media mix with the correct plant media mix (sand, topsoil, and compost).
	The media within the garden may have been compacted during construction or other activities.	Loosen the top 500 mm of media by tilling or forking.
	The tree pit may have been filled with too much mulch or media.	Remove excess mulch or media so that level of ponding area is approximately between 200 mm and 300 mm below the surrounding hard surface and overflow.
	The overflow or discharge pipes may be clogged with sediments or debris.	Inspect clogging and clean overflows and discharge pipes.

Symptom	Likely cause	Remedy
	Planting or plant media mix may be clogged.	It may be necessary to remove some of the plant media mix and replace with fresh plant media mix.
A sulphury smell is coming from the tree pit.	The sulphury smell is a product of anaerobic (without oxygen) respiration. Organic material is likely rotting within the garden.	Inspect tree pit after a rain event and verify that the pit drains within 12 to 24 hours after the storm. See above solutions for tree pit ponding.
	The underdrain is likely clogged and water is not properly draining out of the garden.	
Trees or shrubs are stressed or dying. Symptoms may include yellowing of leaves, unseasonal leaf fall, wilting, etc.	The trees or shrubs selected for a tree pit may not be suitable for the location and intolerant to extreme wet/dry conditions.	Select plants appropriate for the proposed location (e.g. full shade, partial shade, full sun, etc.). Consider non-deciduous (i.e. trees that do not die off in winter) as these will reduce leaf fall which may lead to blocking and clogging of the tree pit.
	Ponding or excessively long periods of flooding may cause the trees or shrubs to become stressed and die.	Inspect tree pit after a rain event and verify that the garden drains within 12 to 24 hours after the storm. See above solutions for tree pit ponding.
	The trees or shrubs could be poisoned by run-off from a hazardous spill (i.e. fuel, paint, oil, etc).	Check media and mulch for evidence of heavily polluted run-off (rainbow slick, coloured mulch, etc). If contamination is bad the tree pit may need to be cleaned out and completely re-built. Consult with the tree pit owner and/or arborist to determine whether a complete re-build is required.

Symptom	Likely cause	Remedy
	The trees or shrubs could be dehydrated due to extended dry weather conditions. Newly-planted vegetation also needs regular watering until it is established.	Trees should not require additional watering but this may be required during excessive dry periods. Check media moisture content and water if media is dry. Routine watering may be required when the trees or shrubs are still maturing.
	The trees or shrubs may be stressed due to attack by plant pests or diseases. Pests may include insects or animals.	Consult with your local garden centre or arborist. Stressed trees or shrubs may have to be replaced with healthy stock or pest resistant species.
	The plant media mix may be overly compacted.	Loosen the top 500 mm of media by tilling or forking.
	The amount of pollutants accumulated in the tree pit has reached a level where they are toxic to the tree.	Refurbish the tree pit in accordance with the construction notes and operation and maintenance manual.

7.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or part of consent conditions.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the tree pit. An audit checklist can be developed based on the maintenance schedule. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts, and hazardous or inappropriate practices, can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the tree pit would tend to focus on discharge water quality and permeability of the tree pit media mix. If maintenance frequency for the tree pits is difficult to determine (based on catchment activities and contaminant loads) quarterly sampling of discharge during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies and methods. The permeability of the growing media should be tested within the first month of operation as this should represent optimum permeability. Thereafter permeability should be tested quarterly for the first year of operation and then annually in subsequent years.

Depending on the size of the tree pit the permeability test can be done using the simple falling head test method. The permeability test should be performed on saturated media using a cylindrical cone which is inserted into the media right down to the underdrainage system (ensure the underdrain is not damaged by the cylinder). The cylinder is filled with water to a set level (usually 100-200 mm) and timed until the water drains down.

Depending on the requirements for audits and monitoring reporting of results should be submitted to the owner and the regulatory authority.

7.7 Photo Gallery – tree pits

Figure 28
Tree Pit Waitakere City.

Figure 29

Tree pit constructed at Botanic Gardens.

Figure 30

Albany Civic Crescent tree pit showing energy dissipation at inlet and geotextile under flow path (photo taken before mulch laid).

8 Swales and Filter Strips

8.1 Introduction

Swales and filter strips (also known as infiltration or biofiltration strips) treat and convey stormwater run-off to the stormwater system or open receiving environment. Swales and filter strips are trafficable by mowers (for maintenance), people, and in some instances driveways so they provide a value for money and durable option for stormwater treatment. The principal difference between swales and filter strips is that swales accept concentrated flows, while filter strips accept flows as distributed or sheet flow.

8.2 Device description

A swale is a channel that transports and treats stormwater. Vegetation, either grass or other dense ground cover plants, slow the water flow to allow the water to filter through the vegetation and soil to remove pollutants including clay and silt (sediment), dissolved nutrients and metals (e.g. nitrogen, phosphorous and zinc). Stormwater flow is designed to collect concentrated flow into the vegetated swale channel. It then travels down the swale to the outlet.

Filter strips intercept stormwater as distributed or sheet flow 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 and some run-off may infiltrate into the ground.

Council requires the water flow in swales to take at least 9 minutes to pass along the swale in order to be treated. Rock lined swales are also used and the rocks slow stormwater flows down to allow for filtration.

Pollutant removal is dependent on the length of time water stays in the swale and the depth of water relative to the height of vegetation. Filter strips and swales can be readily incorporated into a treatment train (e.g. swales drain to a larger stormwater pond or a rain garden) to enhance the overall performance of a site's stormwater treatment system.

The components of a typical infiltration swale (most common in Auckland) are outlined in Table 14.

Figure 31

Typical swale components.

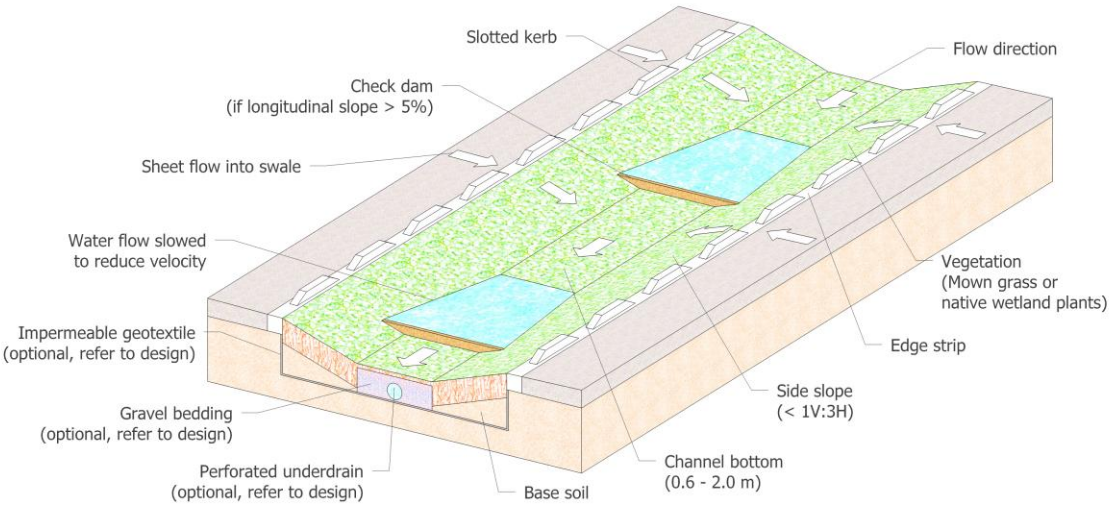


Table 14

Key components of swales.

Component	Description
Inflow points	Where the stormwater enters the swale or filter strip (e.g. stormwater pipe outlet, or surface run-off from surrounding car parks or open space).
Side slopes (Swales)	Defines the channel through which the stormwater flows and can form a point of entry to the swale bottom e.g. sheet flow from car parks (see figure above). Slope should not exceed 3H:1V for mower access and to prevent scour due to high velocities.
Longitudinal slope	A slope topography of less than 5% is typically required for swales and filter strips to allow sufficient residence time, limit water velocities and prevent erosion.
Channel bottom (Swales)	Flow is concentrated at the base of the channel (min 600 mm, max 2 m width) and is sometimes reinforced with gravel or rip rap where erosion may be expected. Base of channel must be at least 600 mm wide for mower access.
Underdrain (not always present)	Buried under the swale channel or filter strip to capture filtered stormwater run-off (usually a perforated pipe such as Novacoil) and connects directly to the catch pit or stormwater manhole.
Vegetation and soil	Vegetation and permeable soil in the swale bottom and on the surface of the filter strip provides a means to slow flows and to physically filter particles from stormwater run-off. Vegetation also prevents erosion of soils.

Component	Description
Outlet	Exit for filtered stormwater to either the piped system (swales) or waterway (swales or filter strips). For swales, outlets are usually a catch pit with flat grate or a 'scruffy dome', while outlets for filter strips are typically more diffuse or may even drain to a swale. Outlets are also used to capture water from storms that exceed the design capacity of the swale.
Design enhancements (check dams, spreaders, etc)	Slow water flow down to allow run-off to filter though vegetation and soil and/or spread the flow of water evenly across the width of the channel. Often used in swales with slope greater than 5%.

8.2.1 Device locations

Swales and filter strips are part of a site's drainage system and usually follow the site contours and natural overland flow paths. A suitable drainage area is less than four hectares. Swales and filter strips are often located on property boundaries or next to hard surfaces (car parks, driveways etc). They are frequently used in rural and semi-rural areas in place of road side kerb and channel drainage.

Swales and filter strips may also be components of a treatment train where they are just one part of a larger stormwater treatment system. For instance a vegetated swale receiving run-off from a roadway can be used to direct the flow to a wetland pond where the run-off receives additional treatment.

8.3 Operation and maintenance manuals

Operation and maintenance manuals are often required as a condition of consent. Even if they are not, an operation and maintenance manual is very useful in documenting design and construction information of the device and providing methodologies for maintenance procedures. If the swale or filter strip is part of a treatment train then the operation and maintenance manual should cover all devices and explain the interdependence of treatment systems.

Typically an operation and maintenance manual should contain a section for the log book to record inspections and maintenance activities, technical information on the design and construction of the swale or filter strip, and a section for all the maintenance procedures which detail methodology and frequency.

8.3.1 Log books

The log book is perhaps the most important tool in managing a swale or filter strip as it provides details on all maintenance activities and inspections. The log should be kept simple so that it can be completed easily and records information necessary for any reporting required, whether a condition of consent or contractual requirement.

Figure 32
Example log sheet for swale maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Swale			**File No.**
			Date
			/ /
SITE: Henderson Valley Road, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	SWM3	Prune plants and replace dead plants.	J. Smith
4/5/09	SWM2	Remove weeds	J. Smith
6/6/09	SWM1	Checked overflow pipe for blockages, replaces missing cap.	H. Bloggs

8.3.2 Technical information

This section provides all the background information on the design and construction of the swale or filter strip. If there are any faults with the swale and it is not performing, this section can assist in troubleshooting the problem, which could be design related. Typically this section will include:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination spills or flooding.
2. Site location, legal description and details on how to access the site (situation map, and layout plan are important).
3. Consent numbers and details of issuing agency, include summary of consent obligations and attach copies of consents to the appendices.
4. Design information:
    a. Co-ordinates for the centre of the device.
    b. Levels to LINZ Auckland datum 1946 for planted surface of device.
    c. Longitudinal slope.
    d. Bottom width (swale) or strip width (filter strip) (m).
    e. Side slopes (swales).
    f. Lateral slope.
    g. Design residence time (minutes).
    h. Design enhancements (check dams etc).
    i. Overflow outlet.

j. Invert of outlet pipe.

k. Invert of orifice outlet, if any.

l. Diameter of orifice outlet, if any (mm).

m. Catchment area serviced.

n. Contributing catchment area (roofs) in $m^{2.}$

o. Contributing catchment area (paving) in $m^{2.}$

p. Contributing catchment area (pervious) in $m^{2.}$

q. Normal operating surface area of device in $m^{2.}$

r. Nominal depth of planting soil (mm).

s. Year of completion.

5. If required by the consenting authority, a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection if required by the local consenting authority.

6. Construction detail plans of the swale or filter strip.

7. Copy of geotechnical report, if applicable.

8. Copy of design calculations.

9. As-built planting layout and schedule, if applicable.

10. As-built plan, dated and showing underdrainage and connections to stormwater reticulation if applicable.

11. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is buried in the swale or filter strip (e.g. underdrainage).

8.3.3 Procedures

This section provides the details for inspections and maintenance tasks. Section 8.4 below provides a generic maintenance schedule which can be adapted to the site specific requirements. The maintenance schedule will form the basis of any maintenance contracts that are tendered.

Reporting requirements, whether as a condition of consent or a contract, should be included as a procedure with details of the reporting format, contents and frequency. Any monitoring which is carried out should also be documented with details of how to undertake any sampling or testing and where results should be submitted.

8.4 Maintenance schedules

Swales and filter strips are relatively low maintenance if they are constructed properly. The most frequent maintenance requirement is to mow the grass and control weeds. Table 15 describes typical maintenance and the frequency required for a swale or filter strip.

A full inspection of the swale or filter strip including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the device and may be done by them directly.

Table 15
Typical swale and filter strip maintenance schedule.

Component	Recommended action	Frequency		
		Monthly	Two or more years	After storm events
Inflow points	Remove rubbish and debris.	✓		
	Visually inspect for scouring, channeling and erosion; repair as necessary.			✓
Side slopes	Visually inspect for scouring, channeling and erosion; repair by adding soil and replanting as required.			✓
Channel bottom	Visually inspect for scouring, channeling and erosion; repair by adding soil and replanting as required.			✓
	Visually inspect for boggy patches and pools of water. Check soil for compaction, aerate as necessary or top up any dips in channel bottom.		✓	
Vegetation and soil	If grass is used in the swale channel or filter strip it will need to be mown to maintain a height which is not too short or too long (between 50 mm to 150 mm) for stormwater treatment. Grass cover should be dense and bare patches re-seeded to maintain cover. Use a catcher to remove grass clippings.	✓		
	If plants are used these too should be densely planted and any gaps filled with new plants.	✓		
	Weeds should be removed manually or selective non-toxic weed spraying should be used (e.g. hot water weed control). Bare patches must be re-seeded with grass.	As required		

Component	Recommended action	Frequency		
		Monthly	Two or more years	After storm events
	Watering may be required to maintain dense cover during extended dry periods and especially immediately after installation.	As required		
	Inspect the swale or filter strip to ensure stormwater is filtering through the soil. Either check after a storm event or run water over the swale.		✓	✓
	Aerate soil to combat natural compaction (similar to coring on sports fields and lawn bowls greens).		✓	
Outlet (and pipes under traffic crossings)	Remove rubbish and debris from outlet grate, stormwater catch pit, or pipes under traffic crossings.	✓		
	Visually inspect around the outlet to ensure there is no scouring or erosion. Repair as necessary.			✓

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

8.4.1 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, vandalism, or uncontrolled activities within the catchment. In either case there can be a delay between incident, reporting and response particularly where the swale or filter strip is located away from public areas. It is important that after storm events these devices are inspected promptly so that any damage which could potentially cause flooding or be a hazard can be rectified.

Typical issues after a storm event include blocking of overflow outlets, deposition of sediment and rubbish within swale channels, and erosion of swale or filter strip slopes. Uncontrolled catchment activities can include uncontrolled discharge of sediment laden run-off from earthworks, discharge of contaminant spills, filling in by neighbouring property owners, or compacted from vehicle parking or traffic. The procedures listed above should be used for any corrective maintenance. If the damage is extreme then a complete or partial re-build may be required. Details for this will be found in the technical information section of the operation and maintenance manual.

8.5 Troubleshooting

There are a number of common problems that arise when a swale or filter strip is not maintained or if the use of the land surrounding the device changes. Listed below are some of these common problems, suggested causes and potential solutions.

Table 16
Swale troubleshooting.

Symptom	Likely cause	Remedy
Water is not draining and is ponding on the surface for more than 24 hrs.	Soil is compacted – often from vehicles driving over the swale or very high pedestrian traffic.	Aerate the soil with a garden fork or rotating aerator; install bollards or other measures to prevent vehicle traffic accessing the swale; or construct small pedestrian overbridge to direct foot traffic.
	Soil has become clogged with fine sediments.	Remove top layer of soil and replace with fresh soil. Turn the soil over and revegetate.
	Check at outlet – see if water is coming out after rain and underdrain (if present) could be blocked.	Re-build. If underdrain is present a low pressure backwash can be used to clear any blockages or clogging.
	The swale or filter strip was not graded correctly to allow complete flow through the device.	Re-grade slopes and revegetate.
Water is flowing straight down the swale to the outlet.	Soil is not free draining (see above).	Aerate the soil with a garden fork, remove top layer of soil and replace, or replace soil with free draining mix.
	The slope is too steep causing the water to flow too fast.	If slope is greater than 5% construct check dams to retain water in the swale for longer.
	Vegetation is not dense enough.	Leave grass longer, re-seed to increase density. May need to change mowing frequency – e.g. decrease over dry periods.
Scouring and channels are developing.	Inflow is being concentrated at certain points.	Remove any blockages, including rubbish and build up of sediment. Fill as necessary.
Grass is dead or dying	Swale vegetation is being mowed too low.	The grading of the swale is uneven and the mower may "scalp" the grass. Set the mower to a higher clearance.

Symptom	Likely cause	Remedy
	Lack of water or soil is not free draining.	Reseed or sod damaged areas, irrigate as appropriate. Check grading at the base of channel to ensure drainage is maintained.

8.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or part of consent conditions.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the swale. An audit checklist can be developed based on the maintenance schedule. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that shortcuts and hazardous or inappropriate practices can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the swale or filter strip would tend to focus on discharge water quality and residence time of water in the device. Sampling of discharge during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies and methods. The residence time of water in the device will indicate whether the swale or filter strip is performing correctly and allowing the water to filter through the vegetation and thus remove contaminants. Water residence time should be tested within the first month of operation to provide optimum performance results and then periodically thereafter.

Depending on the requirements for audits and monitoring reporting of results should be submitted to the owner and the regulatory authority.

8.7 Photo gallery – swales and filter strips

Figure 33

Northern Gateway swale showing damaged base of swale in background and erosion protection in foreground.

Figure 34

Northern Gateway swale showing die back of grass probably from spraying.

Figure 35
Road side urban swales.

Henderson Valley Road swales clogged with leaves and built up with sediment, note sides of swale would be difficult to access with a mower

Henderson Valley Road swales newly constructed showing grated channels for driveway crossings

Figure 36
Goodlands Estate greenfield development roadside swale.

Figure 37

Kerbless road draining to grassed filter strip, Goodlands Estate.

9 Sand Filters

9.1 Introduction

Sand filters are used to attenuate peak stormwater flows, and treat stormwater to reduce (or remove) contamination by using different types of filter media. Sand filters are often used in built up commercial or industrial areas because they are underground and do not take up valuable surface land.

9.2 Device description

Sand filters are usually multi-chamber structures designed to treat stormwater run-off through sedimentation (settling of heavier particles from the water column) and filtration (run-off passes through the sand to filter out pollutants). Stormwater run-off from hard surfaces including roofs, car parks and roads is normally collected by a series of roadside drains (kerb and channel to catchpits) or spouting (downpipes for roof run-off). The stormwater is then conveyed by a piped stormwater system to the sand filter for treatment.

Sand filters can be made up of a number of buried chambers, above ground chambers or a combination of the two. Many sand filters arrive on-site as prefabricated units pre-drilled for the connection with all of the internal components already installed (except the filter media) and require only a connection to the inlet, outlet and joining of the chambers where there is more than one chamber.

The sand filter media is often made up of a mix, or layered with sand and other materials like peat to increase the removal of heavy metals. In industrial situations the sand is often replaced with specially designed media such as ZPG (zeolite, perlite and granulated activated carbon) to increase the removal of heavy metals and other additional pollutants.

Sand filters include five main elements in their design as listed in Table 17.

Figure 38

Cross-section of sand filter showing components.

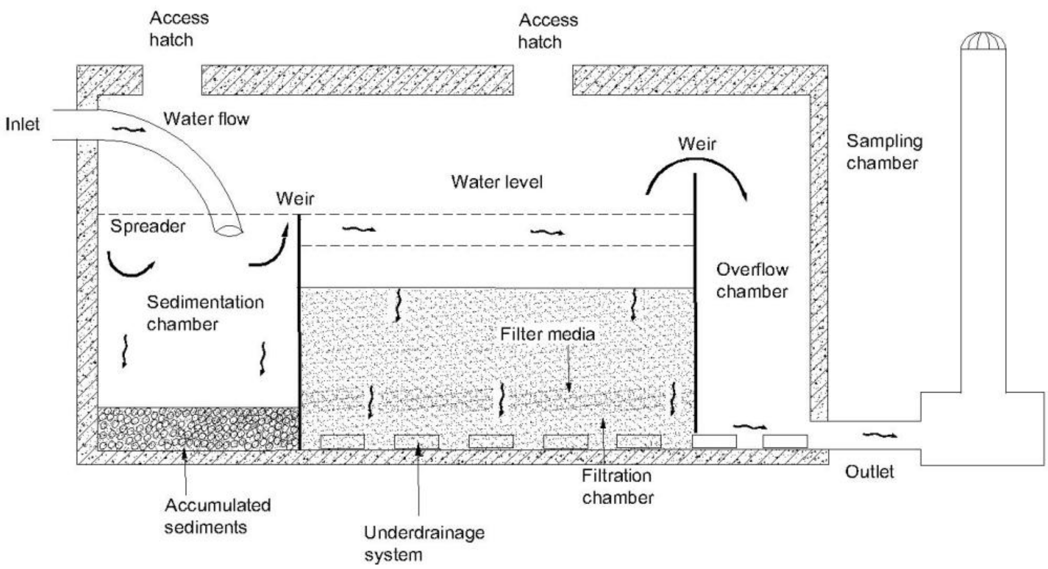
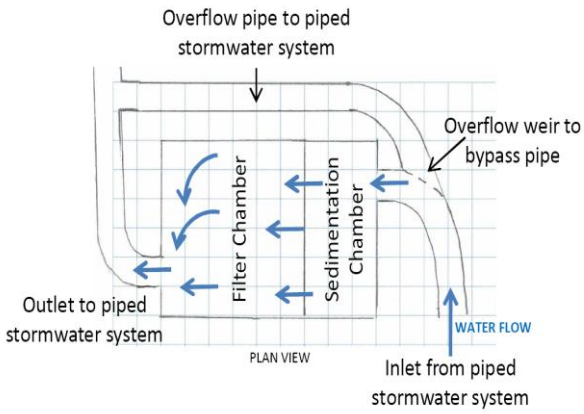


Table 17

Key components of a typical sand filter.

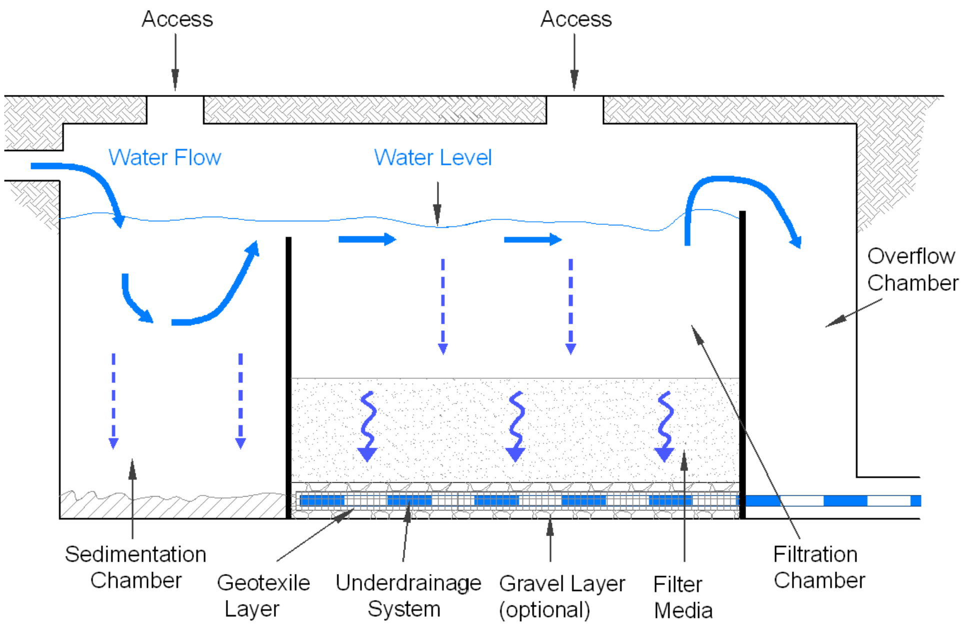
Component	Description
Inlet	Stormwater run-off enters the sand filter from a piped stormwater reticulation system passing through an inlet manhole where a diversion weir is located (so that during larger storms the sand filter is safely bypassed). 
Sedimentation chamber	The first chamber in the sand filter slows stormwater run-off so that the coarser, heavier particles contained in the run-off drop out. Sometimes this is assisted by baffles (small walls or plates) at the bottom of the chamber. Baffles are also often included in the top of the sedimentation chamber to trap floatables (e.g. litter, hydrocarbons). They are usually 25% of the area of the filtration chamber.

Component	Description
Filtration chamber	Run-off enters the filtration chamber via a weir from the sedimentation chamber. The run-off drains down through the sand filter media to the under drainage system. A spreader may be in place between the sedimentation and filtration chamber to ensure the flows distribute evenly over the filter bed and do not erode the top of the filter bed. The filter media is normally 400 mm deep with a ponding area above at a minimum of 400 mm deep.
Underdrainage system	Located beneath the sand filter, the under drainage system collects the treated water via perforated pipes and conveys this to the outlet.
Outlet	Collects flows from the under drainage system and discharges them to either a piped system or directly to the receiving environment (i.e. waterways, streams, the coast, etc). For most sand filters, the outlet is piped to an outlet manhole.
Overflow system	Usually consists of pipes located above the normal operating level of the sand filter (i.e. above the sand filter bed and ponded water level). Flows during the larger storms overflow from the sand filter through the pipes to the stormwater reticulation system.

The 'Washington' sand filter is the most common type installed in the Auckland region. Delaware sand filters are often used around service stations or loading bays. Austin sand filters are usually open sand filters and are not extensively used in the Auckland region. The following figures provide a brief description of each type of sand filter.

Figure 39

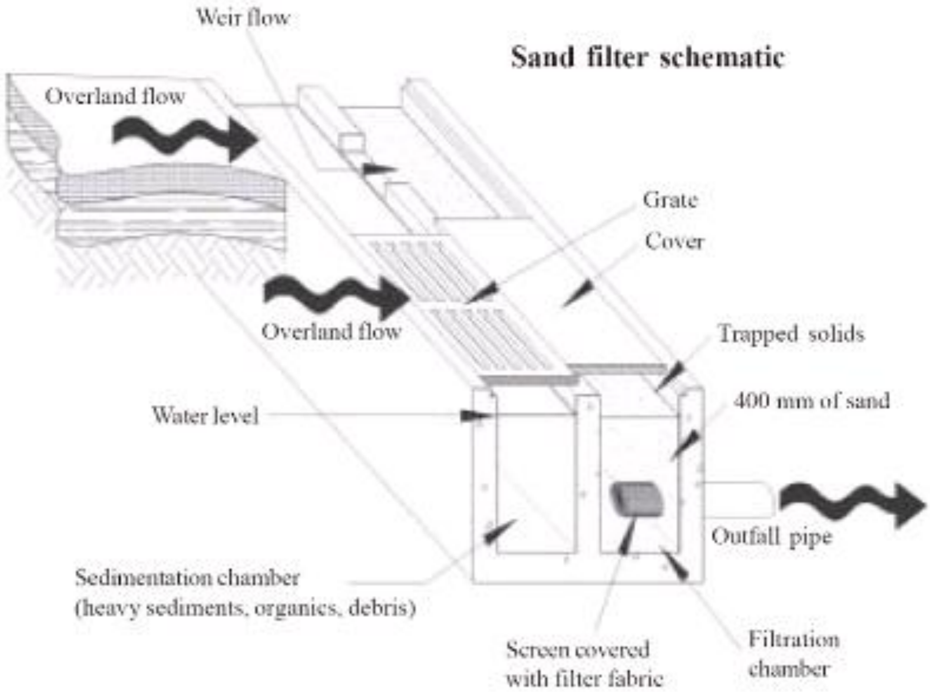
Typical Washington sand filter.



The Washington sand filter consists of a sedimentation chamber followed by the sand filter media bed. They are completely enclosed, often pre-cast underground concrete units. Manufacturers include Hynds and Humes. Pre-fabricated units treat smaller impervious areas (usually up to 5000 m^2). Larger areas are normally serviced by a number of sand filter units, or made to specific specifications. It is also known as an 'Underground Sand Filter' or 'Vault Sand Filter'.

Figure 40

Typical Delaware sand filter (Source: ARC, TP10).



Delaware sand filters are typically used for direct pavement run-off (from roads, car parks or forecourts). They are generally not very wide but extend along the main drainage path and collect flows via a series of grated covers (such as a dish channel). Water then overflows, usually by a series of weirs, or single long weir to a layer of sand through which stormwater is filtered before entering an outlet pipe. They are also called 'Perimeter Sand Filters' because they are often located at the edge of paved areas.

Figure 41

Austin sand filter: Upper Harbour Highway, Hobsonville [NZTA].

The Austin sand filter has an inlet bay (sometimes with energy dissipaters), sedimentation basin and a characteristic 'jagged' weir to distribute flows evenly on the sand filter bed. The sedimentation chamber is usually enclosed but the sand filter bed is not. They are usually constructed on-site.

9.3 Operation and maintenance manuals

The operation and maintenance manual is an essential tool for managing your sand filter. Most sand filters are buried structures so the operation and maintenance manual will provide important details on where to find particular components for maintenance and emergency works. It is an important tool in troubleshooting any issues related to the performance and functioning of the sand filter. An operation and maintenance manual should consist of a log book for recording all inspections and maintenance activities, a technical information section which provides design details and construction information, and a procedures section with documents the methodologies and frequency of maintenance activities.

9.3.1 Log book

Logs books document inspections and maintenance activities that take place. The log book should be developed with any reporting requirements in mind as they will often form the basis of any maintenance reports which may be required as a condition of consent or contract obligation. Permeability testing and monitoring should also be recorded in the log book.

Figure 42

Example logs sheet for general operation and maintenance of a sand filter.

<table>
<tr><td colspan="3" rowspan="4">OPERATION & MAINTENANCE – FIELD LOG SHEET
Sedimentation chambers & sand/peat filters</td><td>File No.</td></tr>
<tr><td></td></tr>
<tr><td>Date</td></tr>
<tr><td>/ /</td></tr>
<tr><td colspan="4">SITE: Great Stuff Industries, 21 Tree Road, Penrose</td></tr>
<tr><td>Date</td><td>Procedure number</td><td>Comments/Actions</td><td>Name</td></tr>
<tr><td>eg 4/5/09</td><td>SFP5</td><td>Permeability test showed dogging. Top 100 mm of media replaced.</td><td>J. Smith</td></tr>
<tr><td>4/5/09</td><td>SFP3</td><td>Chambers inspected after large storm event – all appears okay.</td><td>J. Smith</td></tr>
</table>

Figure 43

Example log sheet for permeability testing of sand filter.

<table>
<tr><td colspan="3" rowspan="4">PERMEABILITY TEST – FIELD LOG SHEET
Sand/peat filters</td><td>File No.</td></tr>
<tr><td></td></tr>
<tr><td>Date</td></tr>
<tr><td>/ /</td></tr>
<tr><td colspan="2">SITE: Great Stuff Industries, 21 Tree Road, Penrose</td><td colspan="2">PROCEDURE NO: SFP5 – permeability test</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Date</td><td>Procedure number</td><td>Comments/Actions</td><td>Name</td></tr>
<tr><td>eg 4/5/09</td><td>SFP5</td><td>Permeability test showed dogging. Top 100 mm of media replaced.</td><td>J. Smith</td></tr>
<tr><td>4/5/09</td><td>SFP3</td><td>Chambers inspected after large storm event – all appears okay.</td><td>J. Smith</td></tr>
</table>

Figure 44
Example log sheet for stormwater quality monitoring of sand filter.

<table>
<tr><td colspan="6">STORMWATER MONITORING – FIELD LOG SHEET
Sand/peat filters</td><td>File No.</td></tr>
<tr><td colspan="6"></td><td></td></tr>
<tr><td colspan="6"></td><td>Date</td></tr>
<tr><td colspan="6"></td><td>/ /</td></tr>
<tr><td colspan="3">SITE: Great Stuff Industries, 21 Tree Road, Penrose</td><td colspan="4">PROCEDURE NO: SFPM1 – stormwater monitoring</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="2">Date</td><td rowspan="2">Sample time (HH:MM)</td><td rowspan="2">Location (inlet or outlet)</td><td colspan="2">Laboratory results analysis</td><td rowspan="2">Comments/ Actions</td><td rowspan="2">Name</td></tr>
<tr><td>Date received</td><td>Filed in O&M Manual section 1.5</td></tr>
<tr><td>eg 4/5/09</td><td>10:20</td><td>Inlet</td><td>20/05/09</td><td>Yes</td><td>Emailed supervisor.</td><td>J. Smith</td></tr>
<tr><td>4/5/09</td><td>10:35</td><td>Outlet</td><td>20/05/09</td><td>Yes</td><td>As above.</td><td>J. Smith</td></tr>
</table>

9.3.2 Technical information

This section is perhaps the most important for understanding how the sand filters were designed and constructed. This section is invaluable when troubleshooting problems or if the sand filter needs to be refurbished. Typically this section would include information on:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, emergency contact information in case of contaminant spills or flooding, and details of suppliers.
2. Site location, legal description, co-ordinates (NZTM2000), details on how to access the site, site specific health and safety.
3. Catchment details which will include information or calculations on design criteria, catchment size and characteristics, other stormwater devices and reticulation within the catchment.
4. Sand filter design calculations including peak flows, water quality volume, filtration rates and treatment functions (if written, include a copy of the design report, construction specifications and drawings, and geotechnical report).
5. Consent information including consent numbers and a summary of obligations that need to be met (like submission of annual maintenance report). Include a copy of consents in the appendix.
6. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in

particular components inside the chambers and buried beneath the ground (e.g. underdrainage system).

7. As-builts showing levels to LINZ Auckland datum 1946 and manufacturers specifications (particularly of filter media for replacement and top up).

8. Depending on the consenting agency, a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection.

9.3.3 Procedures

This section of the operation and maintenance manual provides the 'how to' and 'when'. Procedures should include detailed methodology for each specific task, frequency and notification of any hazards that may be associated with the specific task. Section 9.4 contains a generic maintenance schedule which can be adapted for the specific site and sand filter that has been installed. Manufacturers will also provide guidance on maintenance specific to their filters which will need to be incorporated into the procedure methodologies.

Monitoring requirements should be listed as a procedure with details regarding how to collect samples, when to collect them, and where to submit results. Any maintenance reporting requirements, whether as a condition of consent or contractual arrangement, should also be documented in the procedures. Include details on report format, who is responsible for preparing the report(s), and who to submit it to.

9.4 Maintenance schedules

Sand filters perform very well when maintained at routine intervals. The frequency of maintenance will be dependent on the size of the filter, the type of filter media used, the amount of stormwater run-off the filter treats and the amount and type of pollutant it is treating. Generally, an operation and maintenance manual that covers detailed maintenance specific to each sand filter will be produced by the designer/owner of the sand filter. However, this is not always the case and so recommended actions and frequencies for the operation and maintenance of most sand filters is given in Table 18.

Note that the maintenance frequency is the recommended time for a typical sand filter with moderate pollutant loads. The actual frequency may be increased or decreased depending on the type and size of the filter and the catchment which it serves (because of varying quantities of stormwater run-off and pollutant loads contained in the stormwater run-off).

A full inspection of the sand filter including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the sand filter and may be done by them directly.

The sand filter should also be inspected after storms to ensure that any damage or potential clogging is fixed immediately.

Note: The underground sand filter chambers are a CONFINED SPACE and are therefore extremely dangerous to work in. Only people fully certified for confined spaced entry should enter the chambers for inspections and maintenance.

Table 18
Typical sand filter maintenance schedule.

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
Mow around filter (if applicable)	Mow the upstream catchment area and land surrounding the sand filter. Ensure that all clippings are captured and removed off-site.	As required (usually under other maintenance contracts).				
Inlet weir (if applicable)	If the system contains an inlet weir, inspect to make sure this is not blocked. If necessary, clean out debris.	✓				✓
Sedimentation chamber	Inspect the sedimentation chamber via the hatch for floatables (litter and debris). If present, remove manually or using a sucker truck.	✓				✓
	Inspect sediment level in the sedimentation chamber. If the sediment level is more than half the height of the weir (usually >200 mm) between the sedimentation and filtration chamber, then remove using a sucker truck.		✓			✓
Filter bed	Inspect the surface of the filter bed for rubbish and debris, including organic material such as leaves. If present, remove.	✓				✓

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	Inspect the surface of the sand bed for vegetation including weed/vegetation growth and algae. Remove weeds and vegetation manually. Remove algae by removing the top layer of sand (using a rake and shovel or if possible with a sucker truck). Top up with fresh filter media to the level of the weir between the sedimentation and filtration chamber. Do not spray as this will contaminate the stormwater and downstream waterways.		✓			
	Inspect the level of the filter bed. This should be level with the weir between the sedimentation chamber and the filtration chamber. Where this is not the case, erosion of the filter bed may be occurring. Top up with fresh filter media as per the specification given in the operation and maintenance manual.		✓			✓
	Check filter for clogging Check that the filter is draining down – either after rainfall events or manually by introducing water at the inlet manhole (if possible) or by overfilling the sedimentation chamber so it spills over to a minimum depth of 200 mm (above the sand filter). When full, the sand filter is designed to drain down within 48 hours. If it takes longer than this, this may indicate either the filter media is clogged, contaminated or that the underdrain is blocked. Follow the procedures in the Troubleshooting section for ponding.		✓			✓
	Inspect filter In the first instance, inspect the filter bed visually for clogging. A crust of fine sediment may be present. Rake off and remove. Dig down into the filter media. If the bed is clogged with contaminants (you should be		✓			✓

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	able to see how far this extends by the darker pollutants), remove manually with shovels or with a sucker truck. A minimum of 50 mm of filter media should be removed. Replace with fresh filter media as per the specification given in the operation and maintenance manual. Re-test. If the filter is still not draining down in the required time, check the underdrainage.					
	Check underdrainage CCTV could be used via the outlet manhole to inspect the underdrainage for blockages (or if installed via an inspection well). If the underdrain is blocked, attempt to clear manually using cleaning rods or low pressure backwash. If the inlets to the underdrainage system (i.e. perforations in the pipes or geotextile) are blocked a low pressure hose may be used to try and backwash the filter by inserting the hose into the underdrainage system (this will flush large contaminants back up through the filter to the top where they will need to be removed). Do not use high pressure jets. Re-test. If the filter is still not draining, refurbishment of the filter bed may be required.		✓			✓
	Filter bed refurbishment Follow the procedures for the structural inspection – drain down and removal of filter media. Remove the geotextile from around the underdrainage. While the filter bed has been removed, it is worth undertaking a structural inspection of the filtration chamber and underdrainage system. Repair any defects. Follow the guidance given in the construction		✓			✓

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
	guideline for the re-instating the filter bed, including testing.					
Weir and spreader (if included)	Inspect the weir and spreader (if present) between the sedimentation and filtration chambers. Remove any debris.	✓				✓
Inlet and outlet pipes	Inspect the inlet and outlet pipes as well as inlet and outlet manholes visually during rainfall events. Ensure that there are no blockages (i.e. the full pipe bore is utilised during these events). Arrange to have pipes cleaned out if necessary. It is important to make sure that any debris cleared during cleaning does not flow through the filter or downstream of the outlet – use a sucker truck where necessary.			✓		
	Where the outlet drains directly to a waterway, ensure that no erosion is occurring at the outlet. Replace or repair energy dissipation such as rip-rap and geotextile if required. Repair any erosion damage.		✓			
Hinges, covers and lids	Inspect any hinges, covers and lids and ensure that they are in good working order. Oil hinges and remove rust where necessary. Ensure covers are able to be removed easily (lift and place back). Locks may be required to secure the sand filter and prevent unsupervised entry to the device.			✓		

Component	Recommended action	Frequency				
		3 monthly	6 monthly	Yearly	Two or more years	After storm e vents
Structural inspection	**Drain down** This procedure should be undertaken during dry weather. Where possible this should be undertaken when a full sand media replacement or other works requiring the clean out of the sand filter is required. Block off the incoming and outgoing lines to the filter. Pump out the sedimentation chamber. If present, use the drain down valve to drain down the sand filter bed, if not remove as much of the water ponding above the filter as possible				✓	
	Remove filter media Remove the sand filter bed carefully so as to not damage the underdrain system. The bed should be able to be removed using a sucker truck but may require turning over with a shovel to break up the filter media and assist in removal. If necessary clean out the outlet and any other components of the sand filter. The geotextile around the underdrainage may need to be removed for the inspection.				✓	
	Inspection Inspect the inside of the filter including the base, walls, weirs, spreader, baffles, etc for any cracking or damage. If the damage appears minor (hairline cracks) then repair and report to the owner of the sand filter. If the damage appears excessive, this may indicate issues relating to the underlying foundations of the sand filter. An inspection by a structural engineer will be required. Report the damage to the owner of the sand filter so that they can engage a structural inspection. It is important that this be undertaken in a timely manner as the sand filter will be offline until the inspection is completed and the damage is repaired.				✓	

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

NOTE: Material removed from a sand filter during maintenance or reconditioning is likely to be contaminated with material filtered during storm events. Disposal of this sediment should be to registered landfill, not cleanfill.

9.4.1 Unplanned or emergency maintenance

Unplanned or emergency works can result from storm events, uncontrolled activities within the catchment, or contamination spills. It is important that after storm events the sand filter is inspected promptly so that any damage can be rectified. Uncontrolled catchment activities relate mainly to earthworks without effective erosion and sediment control measures in place. The increased sediment load in run-off can blind the filter media, preventing filtration.

Typical issues after storm events include floatables, blockages of outlets or inlets, deposition of sediment and rubbish blinding the filter media, and preferential flow channels forming in the filter media. Uncontrolled catchment activities can include uncontrolled discharge of sediment laden run-off from earthworks and discharge of contaminant spills. The procedures listed above should be used for any corrective maintenance. If the filter media is completely clogged it may need to be replaced. Details for refurbishment or re-build will be found in the technical information section of the operation and maintenance manual.

9.5 Troubleshooting

There are a number of common problems that arise when a sand filter is not maintained or if the use of the land surrounding the filter changes. Listed below are some of these common problems, suggested causes and solutions.

Table 19
Sand filter troubleshooting.

Symptom	Likely cause	Remedy
Stormwater run-off is bypassing the sand filter.	If a diversion weir is located in the inlet manhole, this may be blocked.	Remove rubbish, leaves and any other debris that could be causing a blockage.
	Rubbish and other debris may be blocking the inlet to the sand filter.	
Water is not draining through the sand filter and/or the overflow from the filter operates continuously during small storms.	Debris is lying on top of the filter (such as leaves, rubbish, litter, grass clippings).	Remove debris or sediment crust. This may require raking the top level of filter media, removing it and topping up with fresh media if necessary.
	A layer of fine sediment may have settled on the filter media surface.	
	The filter bed is compacted.	Rake or till the top of the filter to a minimum depth of 50 mm and re-level.
	The filter bed is clogged with contaminants.	Dig down into the filter media. If the bed is clogged with contaminants (you should be able to see how far this extends), remove manually with shovels or with a sucker truck. A minimum of 50 mm of filter media should be removed. Replace with fresh filter media as per the specification given in the operation and maintenance manual.
	The underdrain or geotextile around the underdrain is blocked.	CCTV may be able to be used via the outlet manhole to inspect the underdrainage for blockages (or if installed via an inspection well). If underdrain is blocked attempt to clear manually using cleaning rods or low pressure backwash. If the inlets to the underdrainage system (i.e. perforations in the pipes or geotextile) are blocked a low pressure hose may be used to try and backwash

Symptom	Likely cause	Remedy
		the filter by inserting the hose into the underdrainage system (this will flush any large contaminants back up through the filter to the top where they will need to be removed). Do not use high pressure jets. Re-test. If the filter is still not draining, refurbishment of the filter bed may be required.
The inlet is submerged and/or the water level in the filter is more than usual.	The overflow system may be blocked.	Clear the overflow system of any debris.
A sulphury smell is coming from the sand filter.	The sulphury smell is a product of anaerobic (without oxygen) respiration. Organic material is likely rotting within the filter or algae is present in the filter.	Rake and remove any debris on the surface of the filter. It may also be necessary to rake or till the surface of the bed down to a minimum depth of 50 mm and re-level. If the smell does not disperse over subsequent visits, the top 50 mm of material may need to be removed and replaced with fresh media, alternatively the bed may require a complete refurbishment.
Erosion of the filter bed is occurring.	The flow splitter is blocked creating unequal flow across the filter.	Remove any debris.
	The filter media is no longer the level of the weir between the sedimentation and filtration chamber.	Top up with fresh media as specified.
	Part of the underdrainage system may be blocked creating preferential flow through the filter.	Follow the procedures above for blocked underdrains.
	The filter bed is not level creating preferential flow through the filter.	Top up and re-level the filter bed.

9.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or part of consent conditions, or part of legislation such as the Building Act or Health & Safety Act.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the sand filter. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that shortcuts, and hazardous or inappropriate practices, can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the sand filter would tend to focus on discharge water quality and permeability of the filter media. If maintenance frequency for the sand filter is difficult to determine (based on catchment activities and contaminant loads) quarterly sampling of discharge during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies. The permeability of the filter media should be tested within the first month of operation as this should represent optimum permeability. Thereafter permeability should be tested quarterly for the first year of operation and then annually in subsequent years to determine optimum maintenance frequency.

The permeability test can be performed by blocking the inlet, overflow outlet and outlet, and filling the chamber with water until it is 440 mm above the filter media, mark this on the side of the chamber (note confined space training is required before entering the sand filter) in the first permeability test and remove the outlet bung (this height above the filter media will differ depending on the designed water quality volume). Check the sand filter after 24 hours and make a note of the water level (record this in the log book). If the water level is >150 mm above media level reinspect the filter after 48 hours. The filter should have drained down completely after 48 hours (water level <50 mm above filter media). If it takes longer than this, it may indicate either the filter media is clogged, contaminated or that the underdrain is blocked. Remedy by replacing the blinded media and/or clearing of the underdrains.

9.7 Photo gallery – sand filters

Figure 45
Crust on Austin sand filter media will impede filtration of stormwater, remove crust and top up with fresh media.

Figure 46
Sand filter (SF1250) showing baffle wall, filter media, filter cloth, and outlet.

Figure 47

Sand filter lid placement showing chamber connections.

Figure 48

Austin filter dissipation chamber clogged with moss and algae.

Figure 49

Inside sand filter showing debris on filter bed and in dispersion channel, and filter media blinded by fine sediment from storm event.

Figure 50

Large sand filter with weeds growing on filter bed surface.

10 Oil Water Separators

10.1 Introduction

Oil and water separators are only found on commercial or industrial sites and are designed to meet the specific requirements of the site. Contractors involved in installing an oil and water separator tend to be experienced installers with a good understanding of the functions.

10.2 Device description

Oil and water separators remove petroleum based oil and grease commonly referred to as total petroleum hydrocarbons (TPH) from stormwater and small spills in areas where hydrocarbon products are handled (e.g. substations, petrol stations, airports, refuelling zones, storage terminals, industrial areas and workshops). TPH in the environment can be present in a variety of forms including:

- Free oil – removed by separation through an oil and water separator.
- TPH associated with solids: gravity separation for coarser sediments and filtration for finer sediments.
- Emulsified oils – oils that have been associated with a detergent making it effectively soluble in water. Difficult to remove, typically requires biological activity or caustic reactions.
- Mechanically solubilised oil - Mechanical action like vehicle movements and tyre traffic, breaks oils into particles so small that they do not behave according to Stokes law but are governed by electrostatic attraction and brownian motion. To remove this form of oil requires very long-term settling, electro or chemical coagulation or filtration methods.

Oil and water separators are generally buried underground structures and can come as package treatment plants or specifically designed for the site. Above-ground devices are also available. Oil and water separators work by slowing down the inflow of contaminated stormwater to allow oil droplets to rise to the surface. As the oil droplets combine they rise faster (oil is less dense than water). Laminar flow (slow non-turbulent flow) is required for optimum performance, so a critical component is the inlet baffle or screen which reduces the speed of the water. Once the oil collects on the surface of the water, the clean water at the bottom of the device is directed to the outlet by baffles and is then discharged from the device. The oil collected on the surface of the device is generally removed by vacuum during device maintenance.

Oil and water separators function by:

- Slowing down stormwater flows from a small treatment area (e.g. service station, refuelling depot, workshop) to allow oils, greases and other hydrocarbons to become trapped and improve discharge water quality.

- Removes 90 to 95% of oil and grease to 15 mg L^{-1} of oil and grease when properly sized.
- Underground devices can be used in built up areas, industrial areas and car parks.
- Above ground devices can be installed or retrofitted to pre-existing infrastructure.

Figure 51
Key components of an oil/water separator.

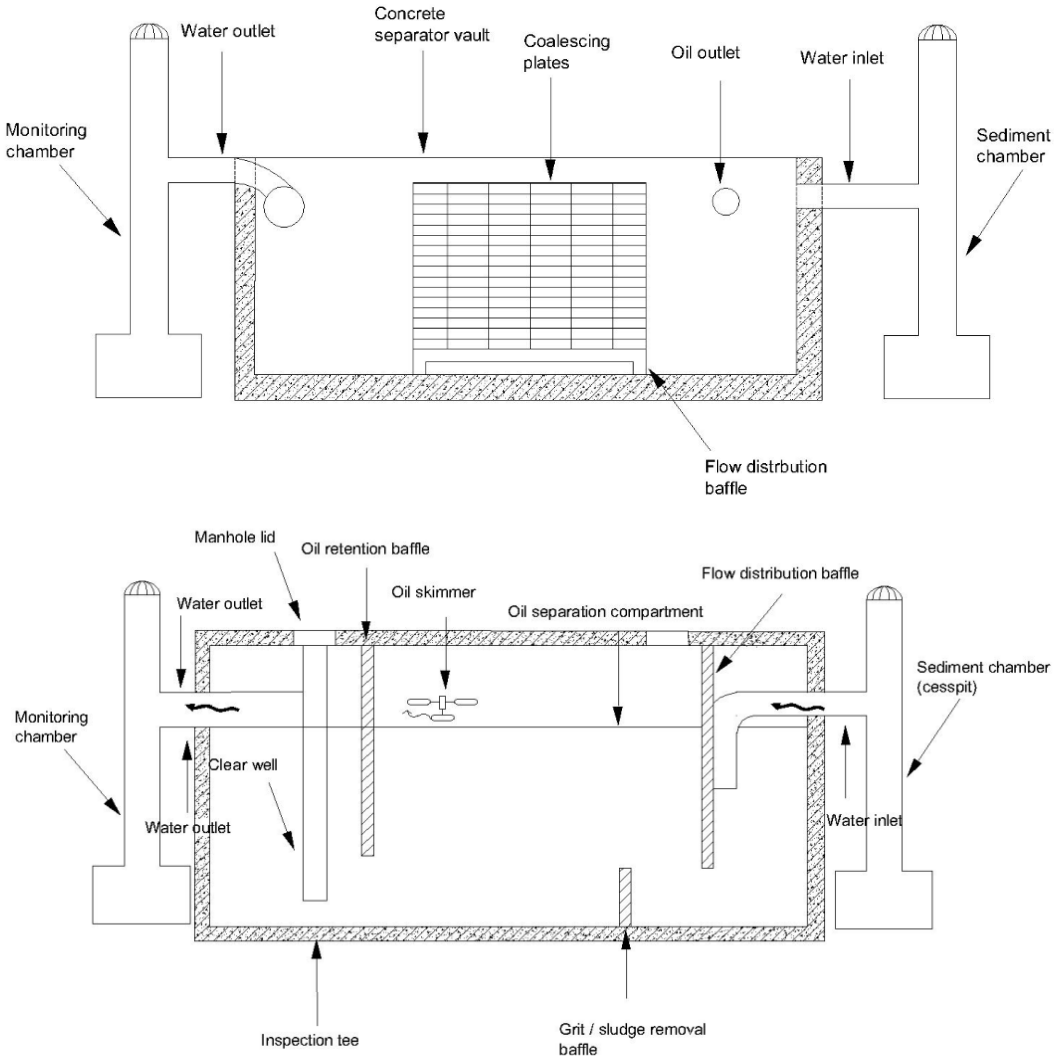


Table 20

Key components of a typical oil and water separator.

Device component	Description
Inlet forebay chamber with baffle	Stormwater run-off enters the oil and water separator from the treatment area only (via piped stormwater system). This chamber is where the stormwater run-off is slowed down to allow the oil to start rising. The forebay can also collected coarse sediment and sediment attached hydrocarbons settled out from the stormwater.
Collection chamber	Oil collects on the surface, and in the case of the plate separator, is where the plate pack is located.
Sediment baffle	Sediment baffle is approximately 300 mm high from the base of the collection chamber and located prior to the oil retaining baffle. It makes sure sediment stays in the collection chamber to allow free flow of treated water under the oil retaining baffle.
Plate pack (plate separator only)	Plate packs are made of oleophilic materials that attract oil droplets to their surface but do not adhere to them. As the oil droplets become attracted, they collide and coalesce into bigger droplets which increases the rate at which they separate from the water and rise to the surface of the device.
Oil retaining baffle	The oil retaining baffle is a vertical plate which leaves a 300 mm gap at the bottom of the chamber to allow clean stormwater to pass under it. This ensures all oil is retained within the collection chamber.
Shut-off valve	The valve controls the flow of stormwater exiting the separator. It can be closed to trap spills and allow for maintenance work on the unit.
Outlet chamber and outlet pipe	This chamber collects the clean stormwater and discharges it to either additional treatment as part of a treatment train (e.g. sand filter), to a piped system or directly to the receiving environment.
High flow bypass (optional)	Allows water to bypass the oil and water separator during high flows to prevent oil collected in the device from being "blown out" by high volumes of water. Bypasses typically still allow for capture of "first flush" water that would contain the majority of hydrocarbons present.

All Auckland Regional Council (ARC) approved oil/water separators can be categorised as one of the following:

API (American Petroleum Institute) Separators – the API device slows the incoming water to allow time for the oil in the water to rise to the surface. Baffles keep the oil on the surface of the storage section. Clean water passes under the baffle and out the outlet pipe.

Coalescing Collection Plate Separators (also simply called Plate Separators) – the plate separator device slows the incoming water to a slow speed to allow time for the oil to rise toward the surface. The contaminated water passes over a pack of closely spaced (10 mm) plates that capture the oil. Oil droplets stick or attach to the surface of the plate and then rise to the surface of the tank where they settle out and are captured by baffles or skimmers. Treated water passes under a baffle to ensure floating oils are retained within the storage chamber.

Figure 52
Typical API separator (Source: ARC, 2003)

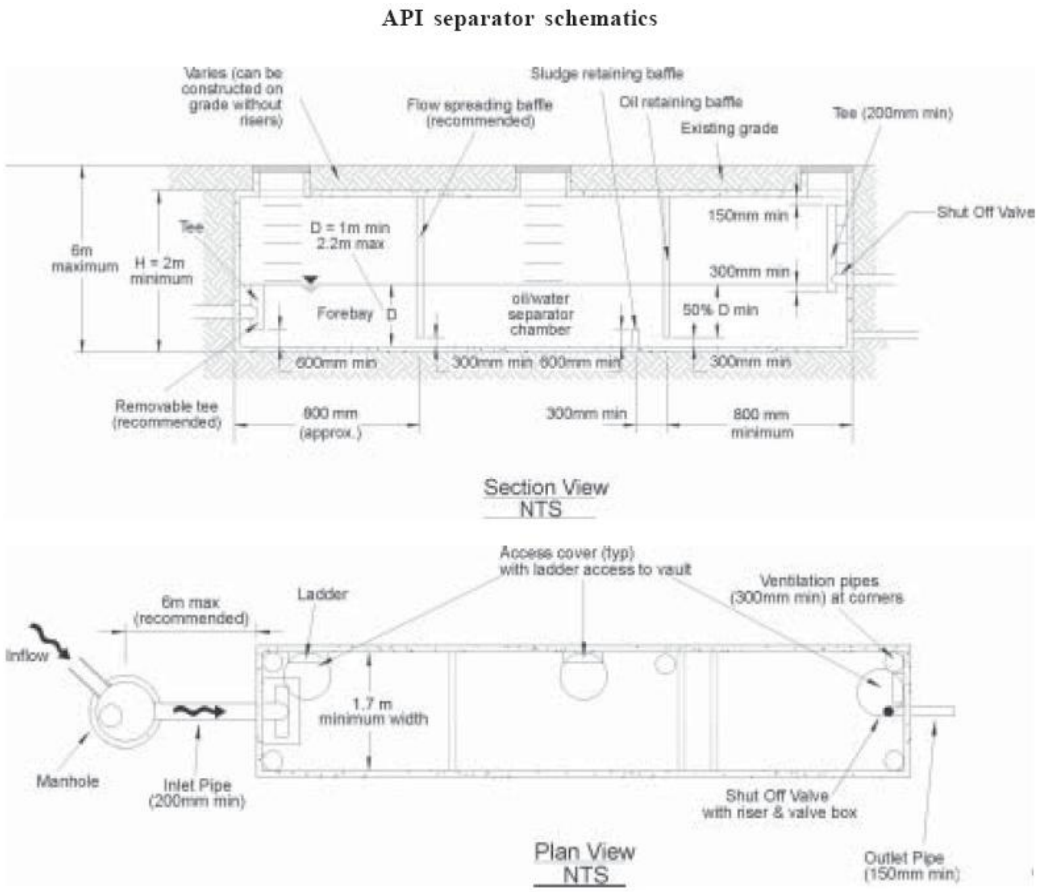


Figure 53
Typical plate separator: Example 1 (Source: Mbeychok, 2007).

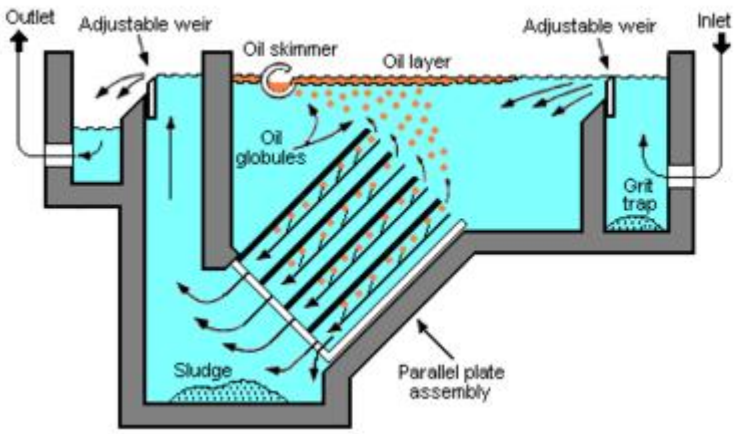
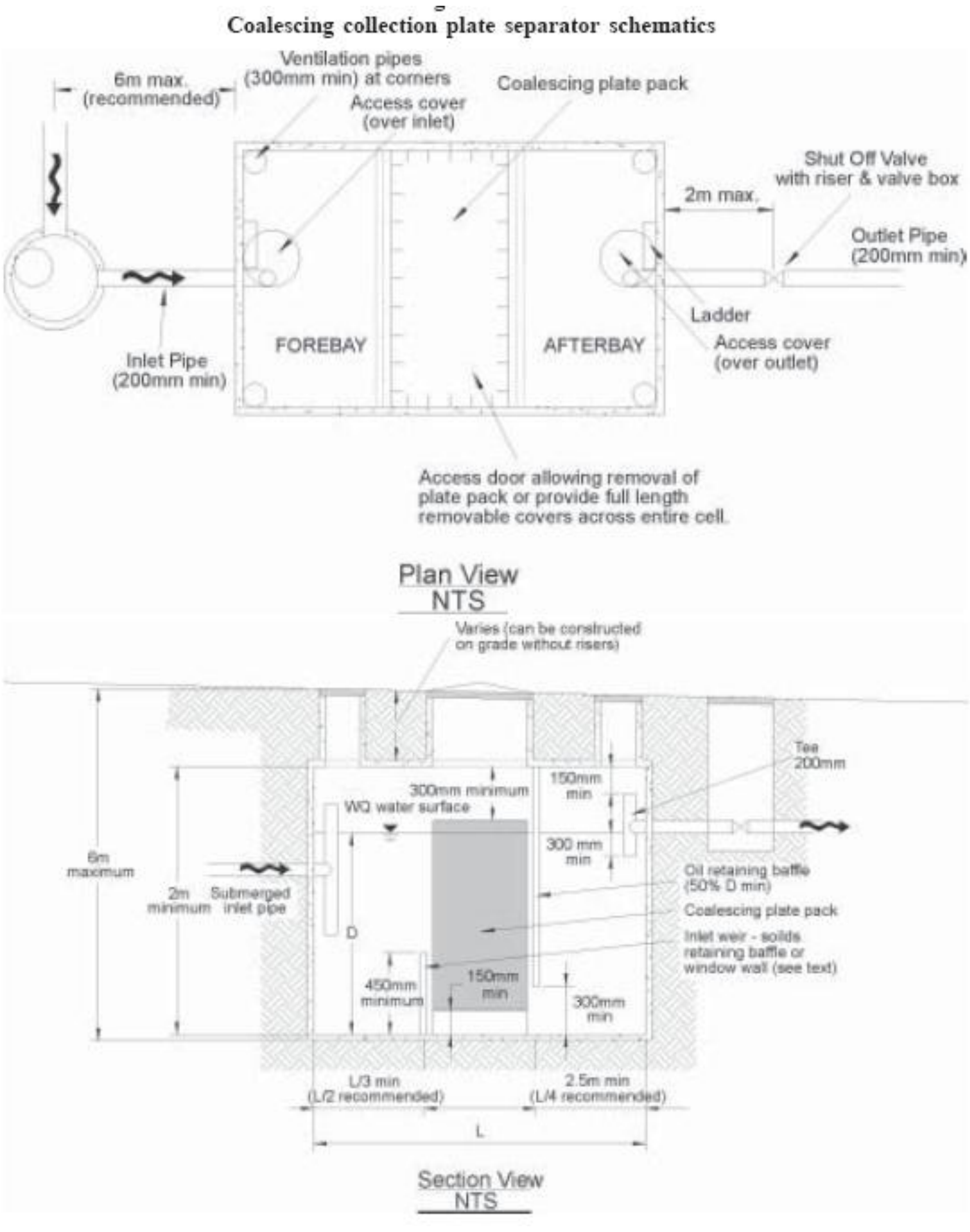


Figure 54

Typical plate separator: Example 2 (Source: ARC, 2003).



10.3 Operation and maintenance manuals

Oil and water separators are usually designed specifically for the site and the purpose for which they are being applied. Due to the potential for discharges to exceed accepted contamination levels, particularly for hydrocarbons, oil and water separators need to be regularly maintained and inspected. Oil and water separators are usually prefabricated units so the manufacturers will provide guidance on suitable maintenance methodologies and frequency. However it is strongly advised to develop your own comprehensive operation and maintenance manual for the specific site. This is often a condition of consent as is regular reporting on maintenance activities.

The operation and maintenance manual will not only provide details on how to carry out maintenance tasks and their frequency but should also provide background information on the design parameters and calculations, construction specifications, and as-builts. This background information is particularly useful for troubleshooting performance issues or if a unit requires upgrading or refurbishing. The operation and maintenance manual will also include a log book for all inspections and tasks to be recorded. This would include any monitoring of discharges and performance of the unit.

10.3.1 Log book

Maintenance reporting is often a resource consent condition or a requirement as part of a maintenance contract. The log book will form the basis of any reporting and should be structured to meet the information requirements for reporting.

Figure 55
Example log sheet for oil water separator maintenance.

<table>
<tr><td colspan="4" rowspan="4">OPERATION & MAINTENANCE – FIELD LOG SHEET
Oil water separator</td><td>File No.</td></tr>
<tr><td></td></tr>
<tr><td>Date</td></tr>
<tr><td>/ /</td></tr>
<tr><td colspan="3">SITE: Substation, 21 Tree Road, Auckland</td><td colspan="2">MODEL: Plate separator 1234</td></tr>
<tr><td>Date</td><td>Procedure number</td><td>Depth of oil in separation chamber (mm)</td><td>Comments/Actions</td><td>Name</td></tr>
<tr><td>eg 4/5/09</td><td>OWM1</td><td>0.5</td><td>Checked for blockages – all okay.</td><td>J. Smith</td></tr>
<tr><td>4/5/09</td><td>OWM2</td><td>1</td><td>Shut-off valve closed and opened, re-greased.</td><td>J. Smith</td></tr>
<tr><td>6/6/09</td><td>OWA1</td><td>3</td><td>Oil removed by sucker truck and plate park cleaned.</td><td>H. Bloggs</td></tr>
</table>

The log book should also keep a record of waste removal manifests from contractors cleaning out the oil and water separator. Removal of waste solids or slurry needs to be carried out by a trained operator with temporary spill management measures in place (e.g. boom around sucker truck and work area, emergency spill kit at the ready). The operation and maintenance manual should provide a list of contractors who are approved by the owner and qualified to complete the work.

Figure 56

Example manifest log sheet for oil water separator maintenance.

WASTE REMOVAL MANIFEST LOG Oil water separator			**File No.**
			Date
			/ /
SITE: Substation, 21 Tree Road, Auckland		**MODEL:** Plate separator 1234	
Date	**Name of contractor/carrier**	**Manifest number**	**Volume removed**
eg 4/5/09	Joe's Sucker Truck	AE 33453	6 m^3

10.3.2 Technical information

The technical information section of the operation and maintenance manual provides the background and technical details for the system and how it connects to the stormwater network. Typically this section would include:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination spills or flooding.
2. Site location, legal description and details on how to access the site and where key features of the system and connections are located (situation map, and layout plan are important).
3. Specific site health and safety requirements, e.g. personal protective equipment, prohibited activities.
4. Consent numbers and details of issuing agency, include summary of consent obligations and attach copies of consents to the appendices (both building and resource consents).
5. Catchment details including size, land use activities, and reticulation network.
6. Design criteria for the oil water system (include a copy of the design report in the appendices):
    a. Treatment flow rate.
    b. Tank size (m^3).
    c. Oil specific gravity.
    d. Influent hydrocarbon concentration.
    e. Maximum oil storage volume.
    f. Sludge storage volume and forebay sludge storage volume.

g. Plate size, spacing and inclination.

7. Construction specifications and drawings, construction photo log of stages (particularly valuable for buried components), and as-builts of the system (including connections to stormwater network).

10.3.3 Procedures

This section of the operation and maintenance manual provides the 'how to' and 'when'. Procedures should include detailed methods for each specific task, frequency and notification of any hazards that may be associated with the specific task. Section 10.4 contains a generic maintenance schedule which can be adapted for the specific site oil and water separator unit that has been installed. Manufacturers will also provide guidance on maintenance specific to their unit which will need to be incorporated into the procedure methods.

Monitoring requirements should be listed as a procedure with details regarding how to collect samples, when to collect them, and where to submit results. Any maintenance reporting requirements, whether as a condition of consent or contractual arrangement, should also be documented in the procedures. Include details on report format, who is responsible for preparing the report(s), and who to submit it to.

10.4 Maintenance schedules

Oil and water separators perform well only when maintained at routine intervals. Failure to maintain them will mean that they will not operate correctly and may result in oil bypassing the device and being discharged to the environment. Perhaps one of the most important tasks is to regularly visually inspect the unit, at least once a month and after storm events, to check oil levels and to check for clogging or blockages.

Note that the maintenance frequency is the recommended time for a typical oil/water separator with moderate pollutant loads. The actual frequency may be increased or decreased depending on the type and size of the separator and the catchment which it serves (i.e. because of varying quantities of stormwater run-off and pollutant loads).

A full inspection of the oil/water interceptor including all operational and visual features should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects liability period for the contractor who constructed the oil/water interceptor and may be done by them directly. The oil/water separator should also be inspected after storms to ensure that any damage or potential clogging is fixed immediately.

Note: The underground chambers are a CONFINED SPACE and are therefore extremely dangerous to work in. Only people fully certified for confined spaced entry should enter the chambers for inspections and maintenance.

Table 21

Oil water separator generic maintenance schedule.

Component	Recommended action	Frequency					
		API separator			Plate separator		
		Monthly	6-monthly	After storm events	Monthly	6 monthly	After storm events
Visual inspection of all components	Remove the access lid and check components for damage or blockage. Collect a sample from the chamber in a glass jar and check that the oil layer does not exceed 3 mm depth, if it does have the oil removed and the device cleaned.	✓		✓	✓		✓
Sampling	Remove sample from stored water in outlet chamber. Have the sample checked to ensure outflow has less than 15 mg L^{-1} of oil.	✓			✓		
Removal of oil	As required based on visual inspection. Typically removal of oil will occur once the film on the surface is 3 mm. This normally happens approximately every 2-3 months. If the depth of oils exceeds 3 mm during this period, increase the frequency of removal. Smaller quantities of oil can be cleaned out with absorbent pillows, larger quantities will need to be cleaned out using a sucker truck. All waste (liquid and solid) must be disposed of either through the trade waste system or approved hazardous substance landfill.	As required.			As required.		
Check shut-off valve	Inspect the valve regularly to ensure it can be accessed and is free from debris that may prevent prompt closure. Fully close then re-open valve. Grease and oil if necessary. Undertake any necessary repairs.	Coincide with removal of oil.			Coincide with removal of oil.		
Empty tank and remove	Sludge should be removed when it exceeds 150 mm. The frequency of		✓			✓	

Component	Recommended action	Frequency					
		API separator			Plate separator		
		Monthly	6-monthly	After storm events	Monthly	6 monthly	After storm events
sludge	removal will be site specific but is generally every 6-8 months.						
Clean plates	Remove plate pack and clean off excess oil after all oil has been removed from the device. Reinsert plate pack.			✓			
Structural inspection Requires full emptying of chamber and access to device.	1. Full internal structural inspection Inspect the inside of the device including the base, walls, plates, etc for any cracking or damage. If the damage appears minor (hairline cracks) then repair and report to the owner of the device. If the damage appears excessive, this may indicate issues relating to the underlying foundations of the device. An inspection by a structural engineer will be required. Report the damage to the owner of the device so that they can engage a structural inspection. It is important that this be undertaken in a timely manner as the separator will be offline until the inspection is completed and the damage is repaired. 2. Inspect inlet and outlet pipes Inspect the inlet and outlet pipes as well as inlet and outlet manholes visually during rainfall events. Ensure that there are no blockages (i.e. the full pipe bore is utilised during these events). Arrange to have pipes cleaned out if necessary. It is important to make sure that any debris cleared during cleaning does not flow through the separator or downstream of the outlet – use a sucker truck where necessary.	Bi-annually.			Bi-annually.		

Component	Recommended action	Frequency					
		API separator			Plate separator		
		Monthly	6-monthly	After storm events	Monthly	6 monthly	After storm events
	3. Check covers and lids Inspect the covers and lids and ensure that they are in good order and able to be removed easily (lift and place back). Repair where necessary.						

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be washed into the oil water separator (e.g. rubbish, or leaves). Typically a storm event is >2-year event.

10.4.1 Unplanned or emergency maintenance

If an unexpected spill does occur the Emergency Spill Response Plan for the device should be followed. This plan should include the following steps:

1. CLOSE the shut-off valve. This is usually located in a Toby box where the separator is located.
2. Inform management and council Pollution Hotline (09 377 3107) that the spill has occurred.
3. The valve should remain closed until the spill has been removed from the device, usually via a sucker truck.
4. The device should be thoroughly cleaned prior to re-commissioning.
5. After re-commissioning open the shut-off valve and leave it open.

10.5 Troubleshooting

There are a number of common problems that arise when an oil and water separator is not maintained or if the use of the land surrounding the separator changes. Listed below are some of these common problems, suggested causes and solutions.

Table 22
Oil/water separator troubleshooting.

Symptom	Likely cause	Remedy
Stormwater run-off is bypassing the device.	Inlet may be blocked.	After a storm event, check oil build-up and ensure design flows will continue to be treated.
	Oil build-up may be excessive.	Remove oil build-up.
Water level at inlet is very high.	Inlet or outlet may be blocked.	Inspect the inlet and outlet for signs of blockage. Inspect the separator for blockage (i.e. litter etc). Remedy as required.
Discolouration in outflow (surface slick).	Oil is bypassing the device.	Inspect entire device to identify cause. Remedy as required.
	The collection of oil has reached capacity.	Arrange for removal of oil.
Oil is not collecting on the water surface in the collection chamber (or oil slick looks irregular).	Foreign contaminant may be present (e.g. detergent).	Identify the source of contamination and prevent it from occurring again (e.g. wash water containing detergents etc) Clean out the oil and water separator. Remove waste collected to secure landfill.
Permanent water level drops.	Leak present.	Full structural inspection required.

10.6 Compliance auditing and monitoring

Most maintenance contracts will require regular auditing of maintenance activities. The nature and frequency of these audits will be detailed in contract documents. Resource consent conditions will also specify monitoring or maintenance reporting requirements.

Monitoring will focus on discharge quality to ensure that the oil and water separator is removing the quantity of oil it is designed to remove. It is advised that on top of visual inspections sampling should be conducted monthly (particularly within the first year of operation).

Audits would assess the maintenance schedule and correlate this to the log books to ensure that each task is being completed at the stated frequency. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts, and hazardous or inappropriate practices, can be stopped. Audits should be conducted at least once a year.

10.7 Photo gallery – oil water separators

Figure 57

Oil separator showing plate chamber.

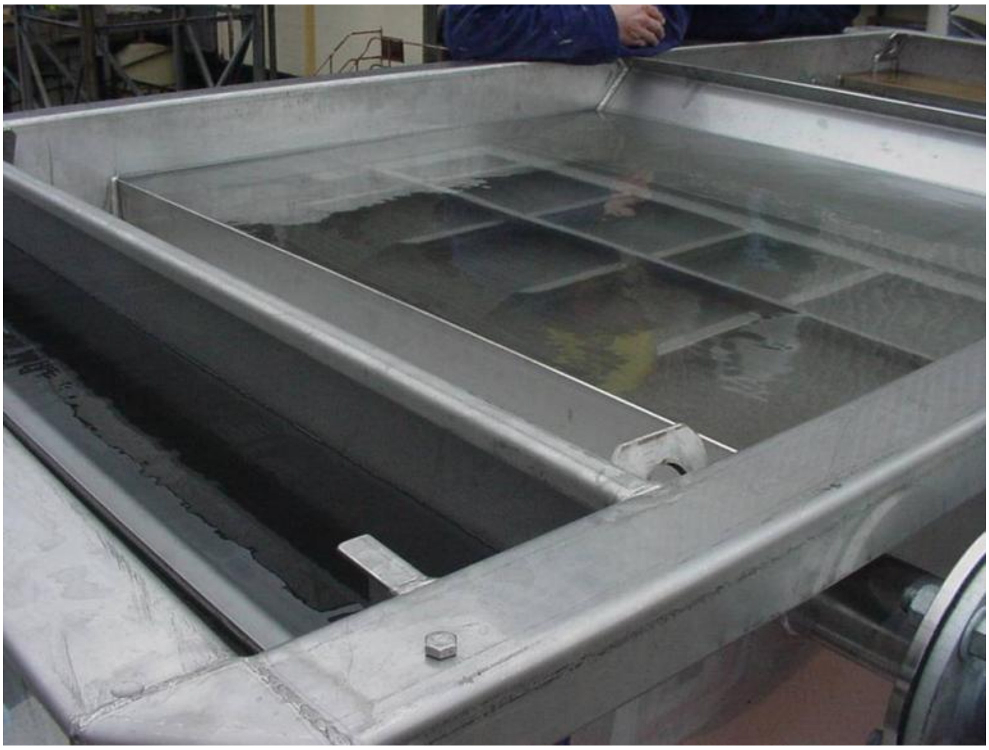
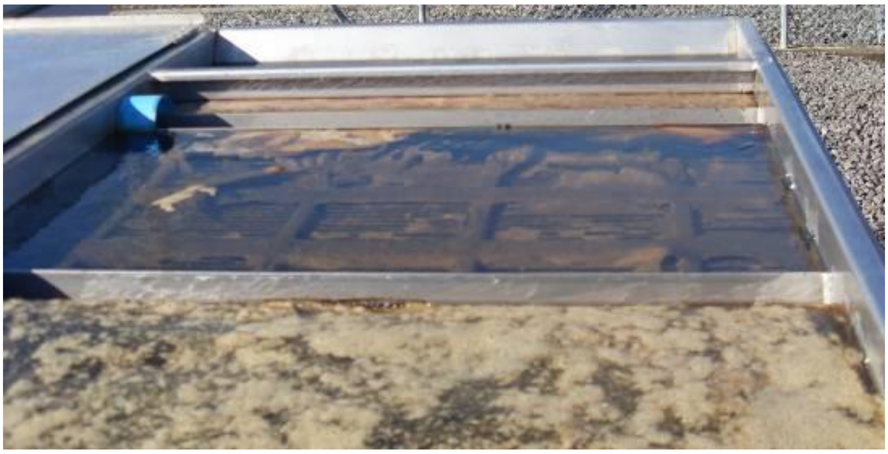


Figure 58

SEPA oil separator unit showing decanting.

Figure 59

SEPA oil separator showing compartments and plates in centre chamber.



11 Permeable Paving

11.1 Introduction

There is an increasing range of porous surfaces becoming commercially available, including concrete blockpavers, porous concrete blocks, porous concrete, porous asphalt and resin-bound aggregate. The use of these porous surfaces for permeable paving systems is relatively new in New Zealand, therefore maintenance techniques and material specifications are constantly being improved based on experience and lessons learnt. Check with manufacturers and experienced contractors when completing any maintenance work on a permeable paving system to ensure that techniques and materials used are the most appropriate, given any new developments. Gobi blocks or interlocking open cell concrete blocks are far more common than the porous blocks.

11.2 Device description

Permeable paving is a paving system that is specially designed to remove pollutants and decrease peak stormwater run-off from hard surfaces (impervious surfaces). They are designed to allow run-off to filter through a coarse graded pavement to an underlying gravel layer where treated run-off is temporarily stored before draining slowly through to the ground or via a collection pipe to the local stormwater system.

In New Zealand permeable paving is generally constructed of modular pavers or blocks. The use of porous asphalt or porous concrete is increasing. Porous surfaces are typically used for small drainage areas (catchments) only in low volume traffic areas such as low trafficked car parks, driveways, footpaths and sidewalks. Due to its potential to clog with sediments, porous surfaces are not appropriate for high-traffic areas or in areas subject to heavy sediment loads.

Permeable paving is commercially available in a number of different configurations, shapes, colours and brand names. The paver blocks can be of an open-cell design (commonly known as modular blocks) so that when placed they resemble a honeycomb pattern and the spaces in between filled with sand or pea gravel and is often grassed (e.g. Gobi blocks). They can also form a tighter interlocking design (e.g. porous blocks or paver blocks). These interlocking concrete blocks are either solid blocks (which rely on the water filtering through the gravel filled gaps between the blocks), or porous blocks (where the water filters through the actual block).

Table 23 outlines the key components of a typical permeable paving system. Variations may occur depending on local conditions and site constraints. The components are listed from the base of the system to the top.

Figure 60

Typical permeable pavement arrangement.

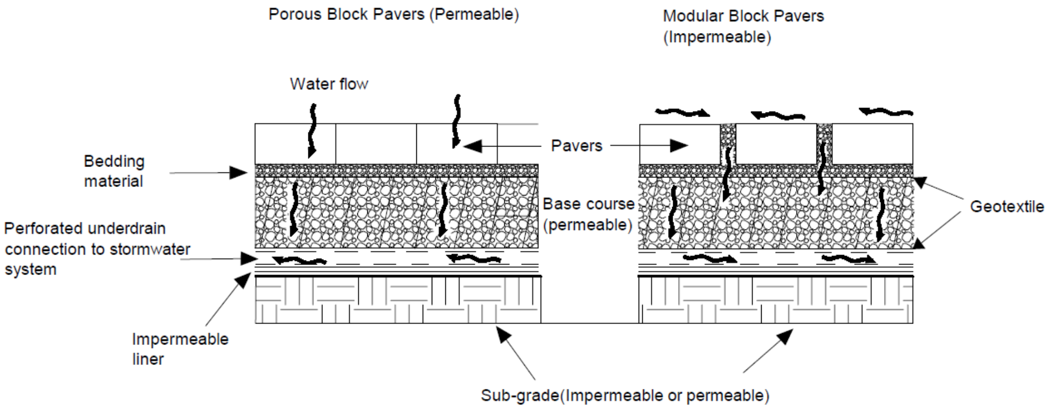


Figure 61

Permeable pavement system showing connection to catch pit and underdrainage system.

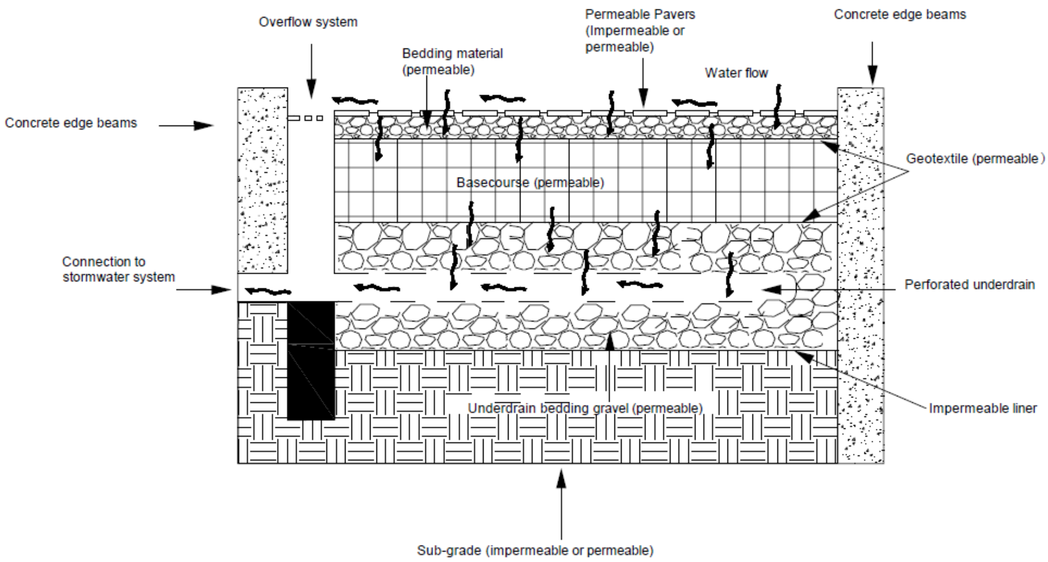


Table 23

Key components of a permeable paving system.

Device component	Description
Sub-grade	The sub-grade must be of sufficient strength and durability to not degrade with the wetting and drying action over the life of the pavement.

Device component	Description
Impermeable liner	Impermeable liners are required in geotechnically sensitive areas where water cannot be allowed to infiltrate through into the sub-grade, or where the structural integrity of the pavers (due to traffic load) requires it. In clay, low permeability sub-grades, or when an impermeable liner is used, an underdrain is required to collect and discharge the water to the local stormwater system. Most paving systems in the Auckland region will have an impermeable layer and underdrain system.
Geotextile	Geotextile is placed between layers to prevent the movement of fine sediment and aide filtration. Geotextile must be secured at edges of paving area and all joins overlapped. Note the geotextile layer can lead to internal clogging and reduced permeability and should only be used when additional tensile strength is required.
Base course	High voids ratio (up to 30% voids for water storage) basecourse material that will not breakdown with the wetting and drying action over the life of the pavement must be used.
Bedding material	This is a high permeability material varying between a coarse sand to fine gravel size (2 to 5 mm) depending on the type of paving system. Fine gravel (~5 mm) is generally preferred to improve permeability.
Pavers	Permeable pavers can be separated into three broad categories: Open cell pavers – a concrete or plastic grid with spaces in between filled with sand or pea gravel and is often grassed (e.g. Gobi blocks) Solid block interlocking pavers – which rely on the water filtering through the gravel filled gaps (generally 6 to 8 mm wide) between the blocks Porous interlocking blocks or porous concrete – which rely on the water filtering through the porous block or concrete itself.
Edge beams	Edge beams (e.g. 300 mm x 300 mm concrete) should be provided around all edges of the permeable paving to prevent pavers from getting displaced.
Overflow system	Overflow systems (e.g. catchpits etc.) need to be designed into the system to take excess flows during large storm events and as a precautionary measure in case the pavers block up with silt over time.

11.3 Operation and maintenance manuals

An operation and maintenance manual will greatly assist in managing the permeable paving system to ensure optimum efficiency. There are a few methods traditionally used in pavement cleaning that can ruin or drastically reduce the efficiency of a permeable paving system. For example high pressure water blasting should not be used; instead a mechanical suction brushing (i.e. wet vacuum) is the best method. This is so the bedding sand doesn't get washed away, yet sediment on the surface of the pavers can be cleared. Some maintenance techniques like wet vacuuming will require immediate remedial action to replace fill gravel removed from the voids during the maintenance procedure.

The operation and maintenance manual will also provide design and construction information so that if there are any problems where pavers need to be re-laid or underdrainage fixed, the as-built information will be at hand. The manual should consist of three main sections; the log book, technical information and procedures.

11.3.1 Log book

The log book section of the manual will contain the log sheets where inspections, maintenance and remedial works that take place are recorded. This section often informs any reporting requirements which may be part of consents or monitoring. The most effective log sheets can be completed easily with enough flexibility regarding the type of information that could potentially be entered.

Figure 62
Example log sheet for permeable paving maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Permeable paving			**File No.**
			Date
			/ /
SITE: Unitec Sports Centre car park, Entrance 3, Carrington Road, Mt Albert			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	PPM3	Sweep whole car park with wet vac truck. Top up bedding sand in south west corner (5 kg).	J. Smith
4/5/09	PPM2	Hot water treatment for weeds.	J. Smith
6/6/09	PPA1	Car flooded. Uplifted paver re-laid and bedding sand topped up.	H. Bloggs

11.3.2 Technical information

This section provides all the background information on design and construction of the permeable paving system, including as-builts, calculations for flow and consents associated with the device.

Typically this section would include the following which is specific to the site:

1. Co-ordinates for the centre of the device.
2. Levels to LINZ Auckland datum 1946.
3. Site location, legal description, how to access the site, site specific health and safety.

4. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contaminant spills or flooding.

5. Catchment details which will include information or calculations on design criteria, catchment size and characteristics, other stormwater devices and reticulation within the catchment.

6. Permeable paving design calculations including peak flows, water quality volume, storage volume (where detention is required), filtration rates and treatment functions (if written, include a copy of the design report, construction specifications and geotechnical report).

7. Outlet details (size, location, connection with stormwater network).

8. Consent information including consent numbers and a summary of obligations that need to be met (like submission of annual maintenance report). Include a copy of consents in the appendix.

9. Construction photographs. If these were taken it is a good idea to include them in the operation and maintenance manual as they will show the construction stages and in particular what is buried beneath the pavers (e.g. underdrainage system).

10. Year of completion.

11.3.3 Procedures

The procedures section of the operation and maintenance manual should specify inspections, planned maintenance, methods for carrying out maintenance, and frequency of tasks. Section 11.4 provides a generic maintenance schedule for a permeable paving system. This can be adapted for the specific site and design of the permeable paving system. The procedures may vary based on manufacturer's recommendations and the type of paver used.

Reporting requirements, whether consent or contract based, should be detailed as a procedure (include reporting format, recipient details and frequency). Any monitoring requirements should also be documented. Monitoring will often be related to permeability, water quality and structural integrity. The procedures should explicitly describe how to undertake any monitoring, for example how to perform a permeability test and what rates of permeability are acceptable (this methodology and acceptable rates are dependent on the type of paver used, e.g. porous blocks vs. Gobi blocks).

The procedures can be grouped by frequency so that tasks can be carried out at the same time and scheduling of maintenance is easier. Unplanned or emergency response procedures should also be documented or referenced if found in other documents.

11.4 Maintenance schedules

The three key maintenance issues with permeable paving are:

1. Initial settling in of the paving blocks placed over the bedding and base course materials.

2. Reduction of permeability due to sediments and growth of weeds clogging the pavers, bedding sand, or gravel base course.

3. Stains on the surface of the pavers associated with fluid leaks.

If there are any planned earthworks within the catchment of the permeable paving area, the pavers should be protected with geotextile. Once the earthworks are complete and the site is stabilised the geotextile cover can be removed.

The following table outlines guidance relating to operation and maintenance of permeable pavers. A full inspection of the permeable paver system, including all operational and visual features, should be carried out one year after construction is complete. Ideally this will coincide with the end of the defects and liability period for the contractor who constructed the permeable paver system and may be done directly by them.

Table 24
Typical maintenance requirements for permeable pavers.

Component	Recommended action	Frequency			
		Monthly	6 monthly	Yearly (plus)	After storm events
Permeable pavers	Pavers should be swept with a wet vacuum sweeper to prevent clogging from build up of sediment and debris. Manufacturer or consent conditions may specify frequency of sweeping		✓		
	In areas where significant initial settling (e.g. 2.5 to 3 cm) has occurred, lift the blocks, re-level the bedding material and replace the blocks to final elevations.	As required			
	Within first year visually inspect the paving and drainage areas looking for build up of sediment, settlement, rutting and activities within the drainage area that may clog the paving (e.g. construction). If sediment accumulation is occurring, identify the source of the sediment and implement erosion control measures. Notify the owner/manager of the land disturbing activity.	✓			
	Collect rubbish, sweep up leaves and remove weeds.	✓			
	Remove stains using biodegradable stain removers as required.	✓			

Component	Recommended action	Frequency			
		Monthly	6 monthly	Yearly (plus)	After storm events
	Mow grass (if used in open cell pavers). Re-sow as required.				
Joint/Bedding material	After cleaning with wet vacuum sweeper check joint material and top up as necessary.		✓		
	The initial permeability of newly installed paving must be 10 times or more than the permeability before the first re-jointing, in order to get a reasonable period (say 5 years) between full re-bedding.			✓	
Gravel base course	Visually inspect that water drains away after heavy rain events. Ponding may indicate clogging of paving system.				✓
Inspection chambers	Inspection chambers can be placed in the permeable paving system to monitor water levels in the basecourse during and after storm events.			✓	✓
Underdrainage	If inspection wells are installed check the underdrainage for blockages. If no wells are present visually inspect the area after a rain event to ensure the water drains away and water is discharging through the outlet. If water is ponding on the surface or there is no flow (or very little) from the outlet back wash the underdrain with a low pressure pump or mechanical suction brush.			✓	✓

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

11.4.1 Unplanned or emergency maintenance

It is important to schedule regular visual inspections of the permeable paving area to remedy any damage or problems which may not have been reported. Inspections are particularly important after storm events to ensure that the system is operating effectively. Due to the system design any major issues relating to performance will probably require uplifting pavers and re-constructing base layers. This is where the technical information section of the operation and maintenance manual is vital to provide the design and construction information. Any uncontrolled sediment discharges from construction activity within the permeable paver drainage field can significantly affect performance and may require major emergency maintenance to reinstate permeability.

Permeable pavers are often used in car parks and access ways where vehicles are present. Therefore oil or petrol spills (versus minor leaks or drips) are potential hazards which need to be addressed in the procedures section of the operation and maintenance manual. The site or maintenance vehicles (if located in a public space) should have oil spill kits to respond to these situations. It is acknowledged that there can be a delay between incident, reporting and response particularly where the permeable paving is located in areas with less pedestrian or vehicle traffic.

As a guide the following steps should be undertaken in the case of a spill:

1. Notify the council pollution hotline and the owner of the site (if not already notified).
2. If the response is fast and the spill is still ponding on the surface the discharge and overflow outlets should be plugged to prevent contaminated run-off entering the stormwater reticulation network or receiving environment.
3. The surface oil or petrol should be absorbed using pads or absorbent material specifically designed for hydrocarbon spills. Sawdust or other granular material is not advised with permeable pavers as particles can filter into the permeable paving system.
4. In all instances the pavers directly impacted by the spill will need replacing as will the bedding material and potentially the base course. If it is a localised spill the depth of contamination should be obvious due to staining of materials (filter cloth, gravel, sand etc). If necessary, testing of bedding and base course material should be carried out to determine the extent and depth of the spill.

   Any potentially contaminated material should be tested by a trained technician and strict health and safety protocols followed to avoid harm to anyone in the area. Portable meters (such as a photoionisation detector (PID)) can be used onsite to determine 'real time' concentration of contaminants.
5. The area which is being refurbished after a spill should be protected by a boom or sock to prevent run-off entering the contaminated zone until all contaminated material is removed and disposed of offsite at a secure landfill.

11.5 Troubleshooting

There are a number of common problems that arise when permeable pavers are not maintained correctly. Some of the problems relate to design and construction errors and can only be remedied by re-laying the pavers, such as slope of site (graded during construction) and settling due to incorrect base material.

Table 25

Permeable paving troubleshooting.

Symptom	Likely cause	Remedy
Water is ponding on surface of pavers or running off to other roadside drainage.	Pavers and or drainage gaps are clogged with fine sediment or decaying organic matter.	Use a wet vacuum sweeper to clean sediment and debris build up from surface. Replace gravel or fill sand lost during the vacuum process.
	Check slope of paved area if too steep water will just drain off the permeable paving area.	Lift pavers and re-lay gravel and sand at a gentler slope.
Pavers are lifting and rutting. Uneven surface and pedestrian tripping hazard.	Settling of sub-grade, gravel or sand has caused pavers to become uneven.	Lift pavers and re-grade sub-layers adding more material where required.
	Gravel loss from drainage gaps. Differential settling of fill aggregate can be a tripping hazard.	Replace gravel or fill sand lost
	Heavy vehicles are using the area and exceed the design load.	Prevent access by heavy vehicles.
	The underlying water table is higher than expected.	Reassess suitability of permeable paver stormwater treatment.
Pollutants are passing through system untreated or contaminants are found downstream (indicated by sampling).	There is a rip or hole in the permeable liner or underdrain or the filter bed has become short-circuited.	Lift pavers to check impermeable liner and underdrain for leaks or channelisation. Fix as required.
	The quantity of pollutants in the drainage area are too high to be filtered out of the run-off.	Install a primary stormwater treatment device (such as a swale or rain garden) to remove higher levels of pollutants before run-off reaches the permeable pavers.
	The material used may not be suitable to capture contaminants of concern.	Replace media with a material better suited to remove contaminants of concern. Replace with a finer grade as an option to improve removal efficiencies.

Symptom	Likely cause	Remedy
Grass growing in the pavement (where not designed for).	Fine sediment or organic matter has accumulated in the drainage gaps	Use a wet vacuum sweeper to clean sediment and debris build up from surface. Replace gravel or fill sand lost during the vacuum process.
Pavers have unsightly stains.	Fluid drips from motor vehicles	Clean using biodegradable detergents if stains require removal.

11.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or resource consent conditions.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the permeable paver system. An audit checklist can be developed based on the maintenance schedule. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that shortcuts and hazardous or inappropriate practices can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the permeable paving system would tend to focus on discharge water quality to show performance of the system and indicate any problems with clogging or blockages. If maintenance frequency for the permeable pavers is difficult to determine (based on catchment activities and contaminant loads), quarterly sampling of discharges during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies.

11.7 Photo gallery – permeable paving

Figure 63

Unitec Sports Complex car parking, Gobi block permeable paving.

Figure 64

Permapave porous permeable paving.

Figure 65

Thomas Bloodworth Park permeable paving in reserve car park (open cell).

Figure 66

Open cell permeable paving.

12 Rain Tanks

12.1 Introduction

Rain tanks are used in rural areas for household water supply but are not as prevalent in urban areas. This is mainly due to the public health issues associated with using unfiltered tank water for potable supply. In previous years rain tanks have been discouraged or require permits if there is a mains potable water supply. However with the advent of a more sustainable approach to stormwater management and particularly water supply rationing, rain tanks are increasing in popularity for non-potable use and rainwater detention including for industrial use as wash water or other process water.

12.2 Device description

Rain tanks collect rainwater that runs off hard surfaces free of substantial amounts of sediment and debris (inflow) including roofs and car parks via a pipe network. The rain tank then stores the rainwater temporarily or permanently to reduce stormwater run-off flows. Stormwater collected can be used as a non-potable water supply (non-drinking water uses such as toilet, laundry and outdoor uses). Rain tanks do not treat stormwater to remove contaminants to any great extent but relieve potential flooding problems by holding the stormwater flow back, and reduce storm water volumes through reuse. Some treatment is achieved through settlement of material at the bottom of the tank. Rain tanks can be located above or below ground. Rain tanks are commonly used for potable water in rural and semi-rural areas not yet serviced by the city's mains water supply.

Figure 67
Typical rain tank components.

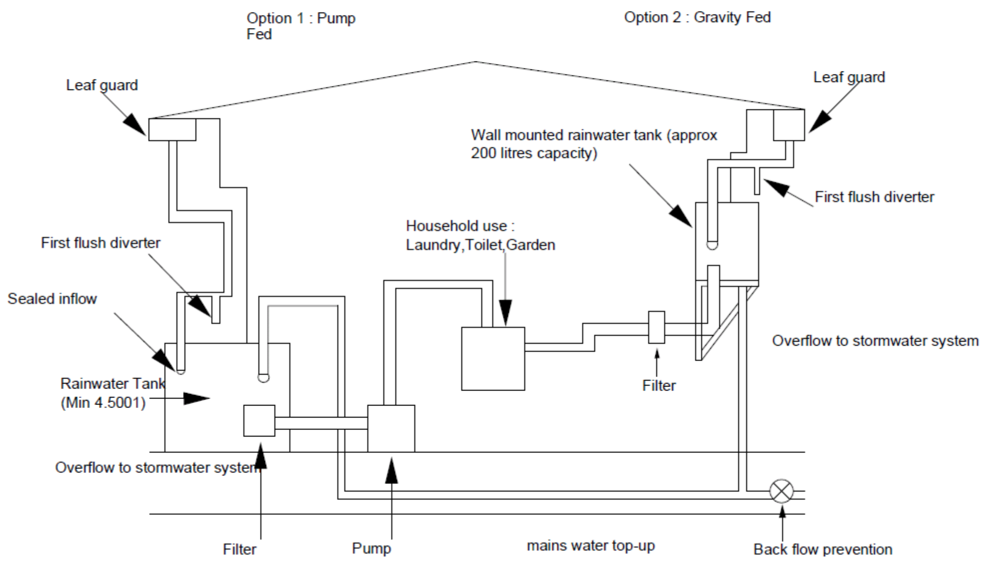


Table 26
Key components of rain tanks.

Device component	Description
Collection system and pre-treatment	Collection systems can be gutter systems or may be kerb and channeling, or traditional stormwater piping, if collecting run-off from ground surfaces such as car parking areas. The collection system may be fitted with: • Leaf guards and debris diverters. • First flush diverters (to divert the 'dirty' initial run-off that falls on the roof). • Insect screens. • Sediment traps (for non-roof hard surfaces such as parking areas). • Controlled tank inlets (to prevent stirring up of bottom sediments).
Tank	Above or below ground; concrete, steel or polyethylene; and specifically designed tanks (i.e. for architectural purposes).
Plumbing	Piped systems that supply non-potable water to the household, including: • Pumps (in most cases). • Water supply outlet (where water exits the tank). • Backup water supply connection (connection to the existing reticulated water supply that tops up the tank during periods of low rainfall, usually activated by a float switch). • Filtration (a filter that removes any debris from the run-off/tank but is not normally required).
Overflow system	Piped overflow from tank that usually discharges to the local stormwater system (often 80-100 mm in diameter), when the tank is full.
Orifice	Small diameter outlet which restricts the outflow from the tank. Only used where detention is provided.

12.2.1 Different types of rain tanks

There are three different types of rain tanks – detention, single-purpose and dual-purpose. Most tanks have a design life of 20 years or more. Regular removal of sediment from the bottom of the tank will extend the life of the tank and fixtures.

12.2.1.1 Detention tank systems

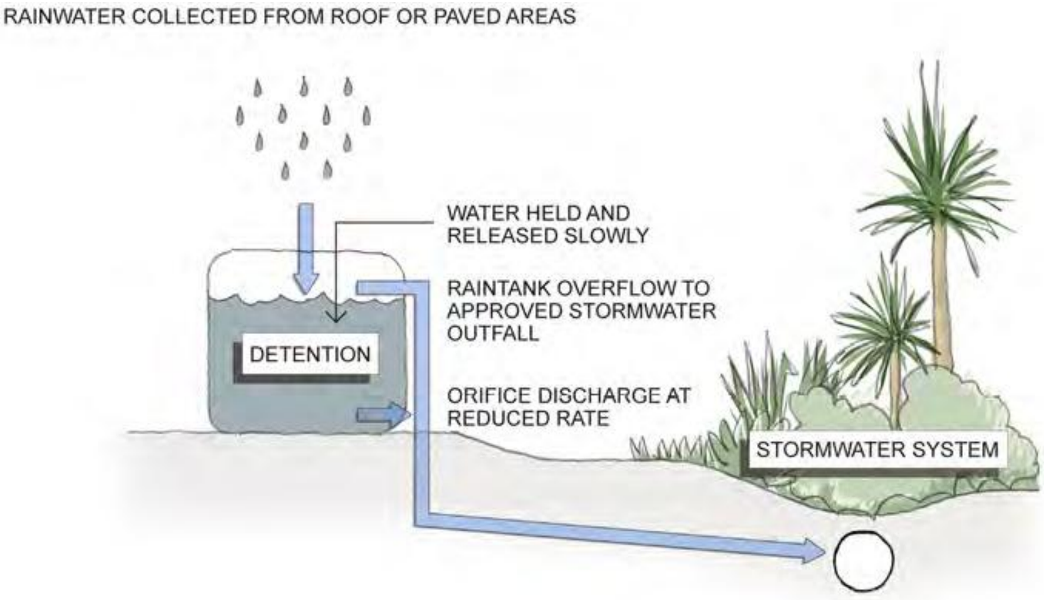
Detention tanks systems reduce peak stormwater run-off by storing rainwater from the roof or other hard surface (parking areas, etc), then slowly releasing the rainwater through a small diameter discharge orifice. The detention tanks have one inlet pipe which transports the collected water to the tank. The tanks have two outlet pipes.

One outlet pipe is a small diameter orifice between 10 to 35 mm. This outlet is located near the bottom of the tank, and slowly releases the water from the tank into the local stormwater system. Underground detention tanks should have debris screens in front of the orifices.

The second outlet is a large diameter overflow pipe near the top of the tank. It is usually between 80 to 100 mm in diameter and connected into the local stormwater system. When the tank is full, additional run-off overflows to this pipe and is discharged to the local stormwater system.

Figure 68

Detention tank schematic (Source: NSCC, 2008. Raintank Guidelines).



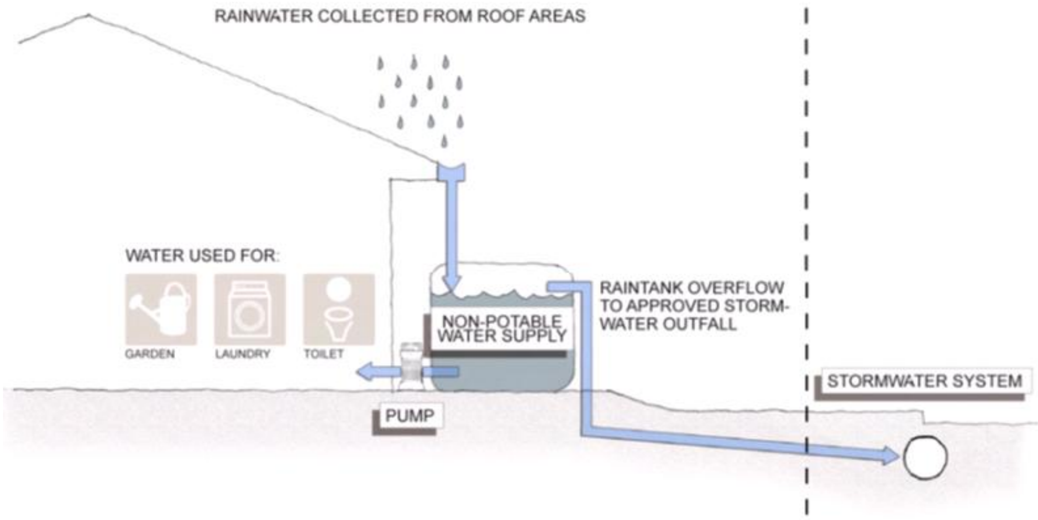
12.2.1.2 Single-purpose rain tank

The single-purpose rain tank provides a non-potable water supply. It collects rainwater from roof areas only and supplies rainwater for non-potable (non-drinking) household uses (i.e. toilet, laundry and outdoor use). They are not used to collect run-off from ground surfaces such as parking areas because the run-off includes pollutants/sediment, which are not suitable for household non-potable water use.

Single-purpose rain tanks have one inlet pipe which transports the collected water to the tank. The tank has two outlet pipes. The tank's first outlet pipe is a large diameter (80 to 100 mm diameter) overflow pipe near the top of the tank. The second outlet pipe is a small (up to 25 mm) water pipe located near the bottom of the tank which feeds the rainwater to a pump and then to household non-potable water use. All of the water stored in the tank is used for non-potable water use.

Figure 69

Single-purpose rain tank schematic (Source: NSCC, 2008. Raintank Guidelines).



12.2.1.3 Dual-purpose rain tank

These provide a non-potable water supply **and** reduce peak stormwater run-off flows. They collect water from roof areas only. The system combines collection for non-potable use and detention into one tank by locating the small diameter orifice part way up the side of the tank. The volume below the orifice is 'permanently' stored for use as household non-potable water and volume above the small diameter orifice is 'temporarily' stored and released through the orifice during and after each rainfall event.

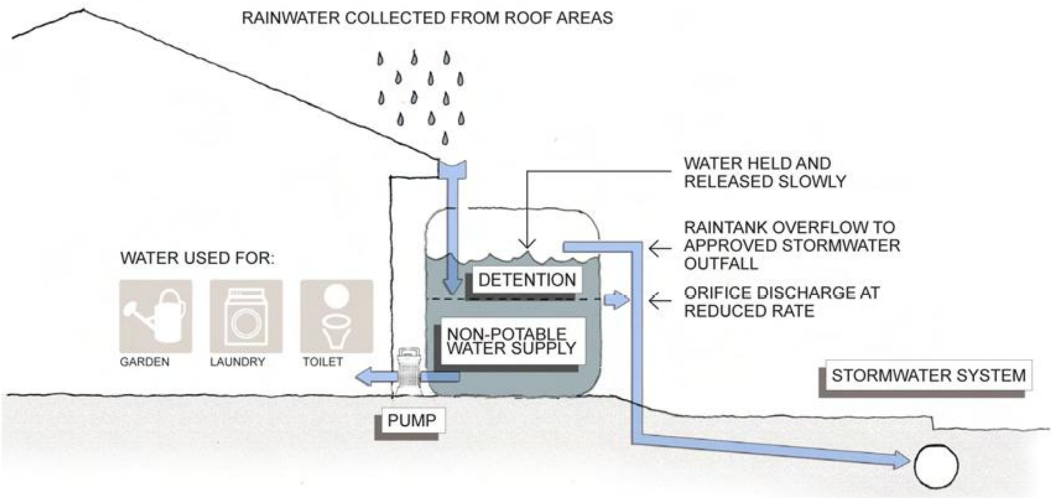
Dual-purpose rain tanks comprise one inlet which transports the collected water to the tank, and three outlet pipes. One of the outlet pipes is a small diameter orifice (between 10 to 35 mm) located midway down the side of the tank. This outlet slowly releases the top section of water (detention) from the tank into the local stormwater system.

The second outlet pipe is a small (up to 25 mm) water pipe located near the bottom of the tank which feeds the rainwater to a pump and then to household non-potable water use.

The third outlet pipe is a large diameter (80 to 100 mm diameter) overflow pipe near the top of the tank.

Figure 70

Dual-purpose rain tank schematic (NSCC, 2008, Raintank Guidelines).



12.2.2 Additional components and further information

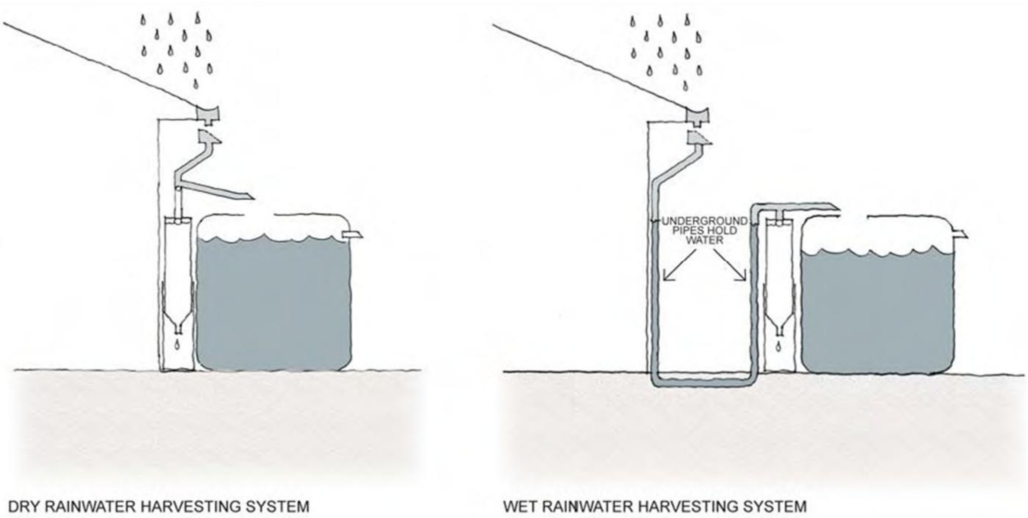
The following is a selection of additional components that are sometimes included in the rain tank collection system.

12.2.2.1 Wet and dry systems

A 'wet system' is where the pipe connecting the roof to the tank is in a 'U' shape and remains full of water between rainfall events. A 'dry system' is where all the piping has a positive slope and drains out between rainfall events.

The advantages of the wet system are that much of the pipe work is below ground and is therefore less obtrusive and can be better suited when the tank is located some distance from the house. A dry system on the other hand provides better water quality (as the water, and sediment, is not always sitting in the bottom of the 'U'), is easier to maintain and does not provide opportunities for mosquito breeding. An outlet 'cap/valve' should be installed at the bottom of the 'U' in wet systems so the standing water can be flushed out at regular intervals to enhance water quality, or a 'first-flush' diverter installed to continually drain out the water standing in the 'U'.

Figure 71
Dry vs. wet rainwater harvesting system (NSCC, 2008, Raintank Guidelines).



12.2.2.2 Gutter systems

Make sure all gutters have a positive slope towards the inlet into the tank with no raised connections that may result in standing water. Ensure the joints are sealed with no leaks and the guttering has no holes. One of the most important issues with gutters is how to prevent the build up of leaves and debris. The use of gutter screens (either placed over or inside the gutter) improves the quality of water collected and reduces the cleaning requirement.

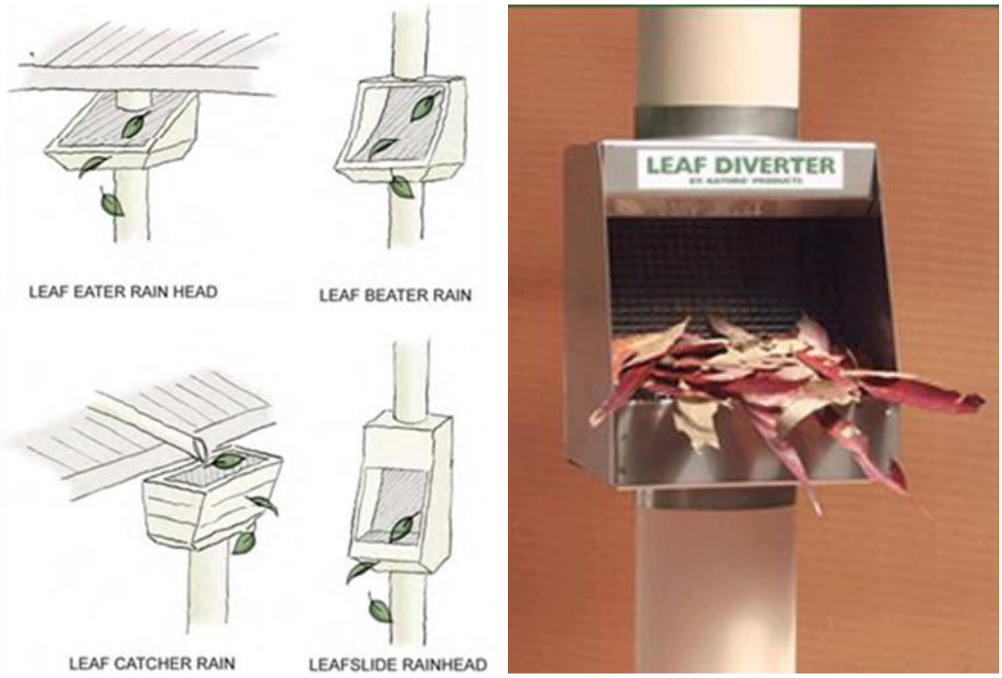
Figure 72
Gutter guards and screens (NSCC, 2008; Gutter Supply).

12.2.2.3 In-line leaf and debris diverters

These devices are placed in the piping between the roof and the tank. There are many different types which block the passage of debris (and are self cleaning) while allowing the water to flow through.

Figure 73

In-line leaf and debris diverters (NSCC, 2008; Kathro Products).



12.2.2.4 First flush diverters

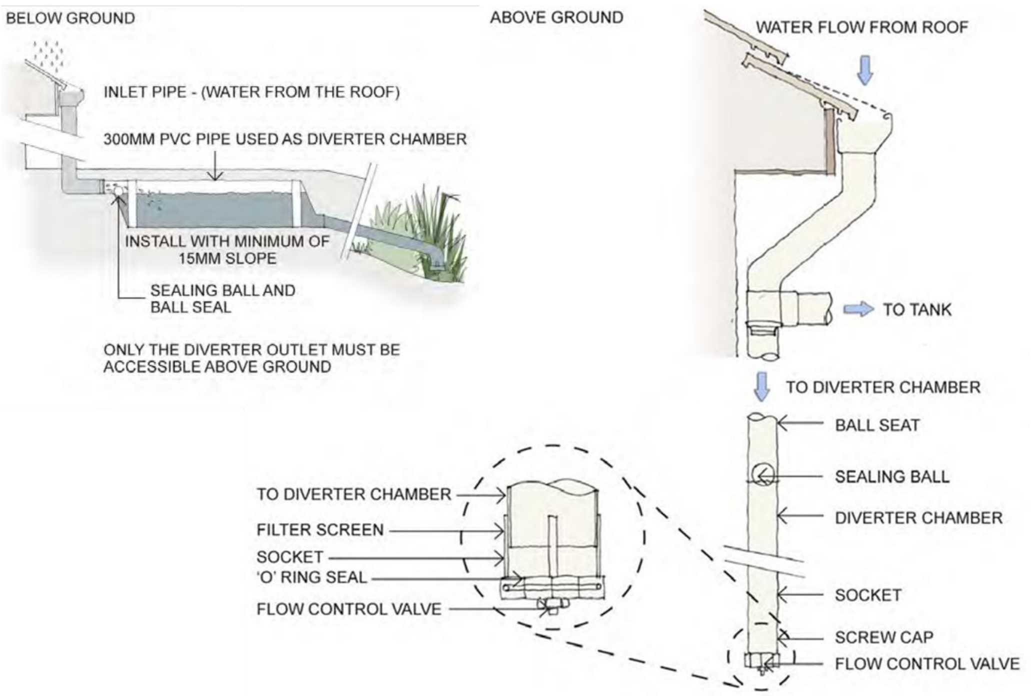
First flush diverters divert the initial 'dirty water' from the 'first water' that falls on the roof. This water carries away the contaminants that have collected on the roof during the dry period since the last rainfall event. Typically this is the first 40 litres of roof run-off for every 100m² of roof area.

This 'first flush' is diverted into a small chamber separate from the rain tank. Once filled, the rest of the rainwater flows past into the tank.

A small diameter valve at the base of the first flush chamber allows it to empty before the next rain event.

Figure 74

First flush diverters: below and above ground systems (NSCC, 2008).



12.2.2.5 Insect screens

Insect proof screens (mesh covers) which prevent insects from entering the tank while at the same time allowing air to circulate i.e. mesh covers should be installed. Sometimes these are called vector screens. They can form part of an in-line leaf & debris diverter, or could be in the form of flap valves.

Figure 75

Examples of insect screens (Rain Harvesting, 2010).

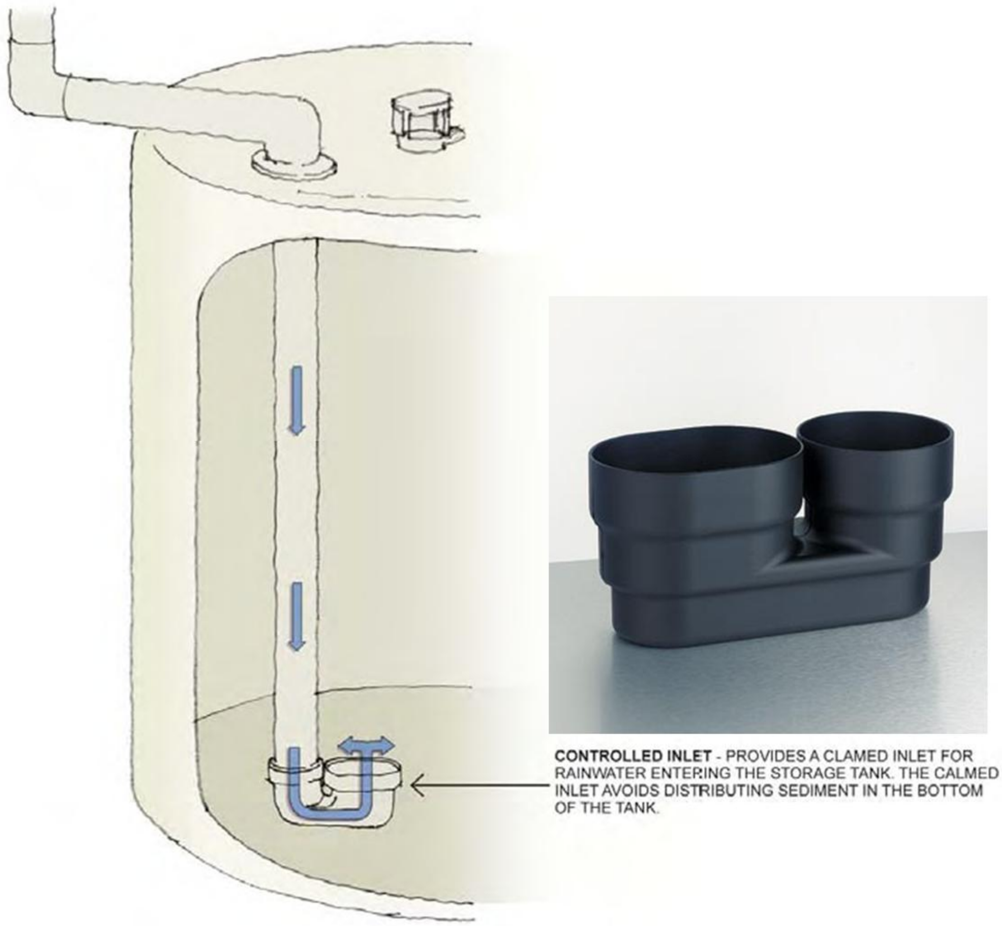
12.2.2.6 Sediment traps

Sediment traps capture sediment generated from non-roof surfaces like car parks (detention only tanks). It is important to ensure that sediment and debris are excluded from a detention tank as these are likely to block the small diameter outlet orifice draining the tank.

12.2.2.7 Controlled tank inlets

Also called 'calmed inlets'. All rain tanks are required to provide dead storage at the base of the tank for sediment to accumulate. High flows into the tank, especially when the water is low, will stir up this sediment resulting in poor water quality. To minimise this, the inlet pipe can be extended to the bottom of the tank with a 'U' fitting, to discharge the inflow in an upward direction minimising sediment disturbance.

Figure 76
Examples of controlled tank inlets (NSCC, 2008; Stark Environmental).



12.2.2.8 Pumps

There are a wide variety of pumps available. Selecting the correct pump requires the input from a qualified pump hydraulics person and/or from any professional pump dealer.

Figure 77

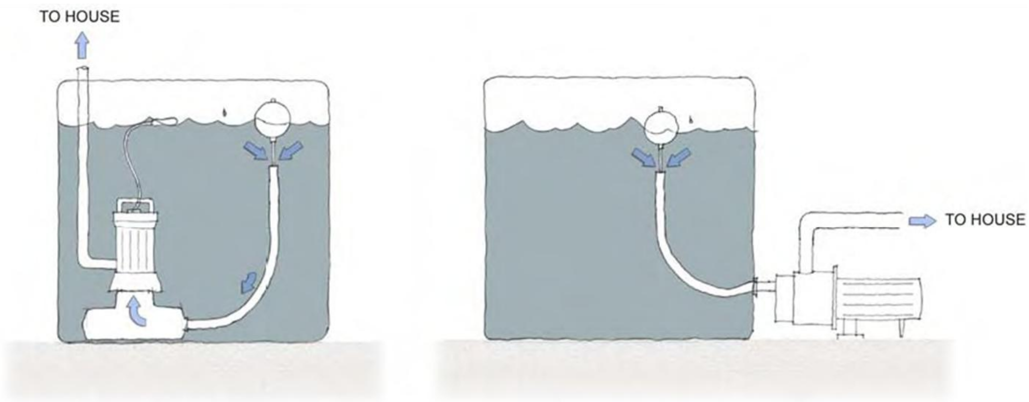
Rain tank pump (Smart Turf and Irrigation, 2009).

12.2.2.9 Water supply outlet

The water supply outlet should be located at least 50 mm above the bottom of the tank to allow for sediment and fine debris build up in the tank. For improved water quality, the outlet can be fitted with a floating inlet which floats 50 mm below the surface of the water in the tank.

Figure 78

Tanks with floating inlets (NSCC, 2008).



12.2.2.10 Backup water supply

This provides a reliable and constant 'low water level' through dry periods when there is no rainfall by providing a mains water supply only when the water gets below a defined low level inside the tank. This ensures continuous supply of non-potable water during dry periods. There are a number of different options available, requiring different backflow prevention devices (devices that prohibit backflow of the rain water into the drinking water back up). Expert advice should be sought from experienced plumbers and equipment suppliers.

Figure 79

Typical backup water supply configuration: top-up via solenoid controlled mains connection (NSCC, 2008).

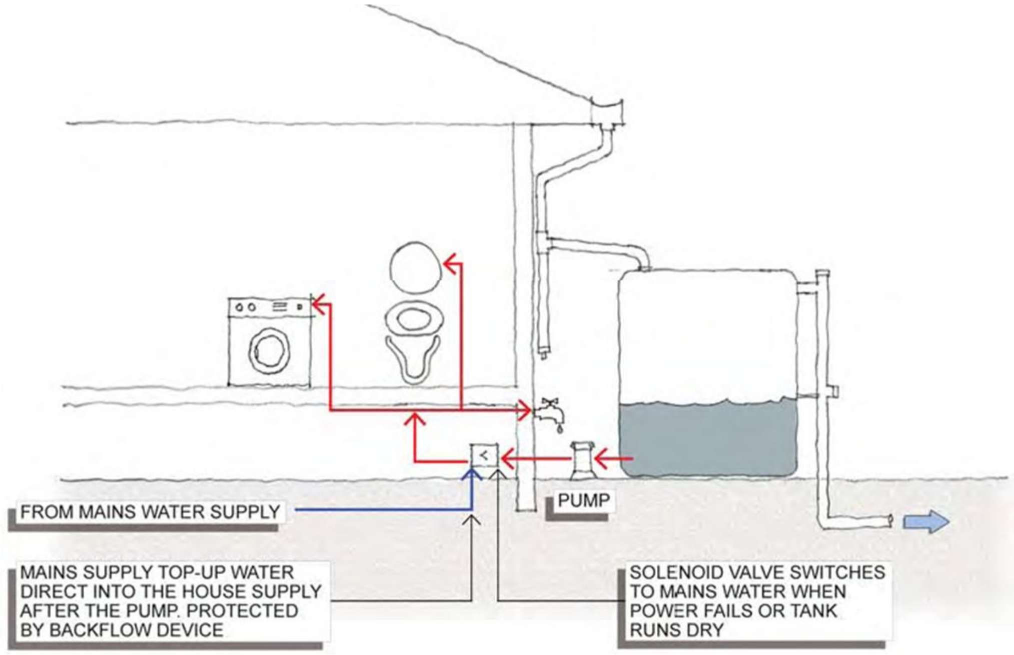
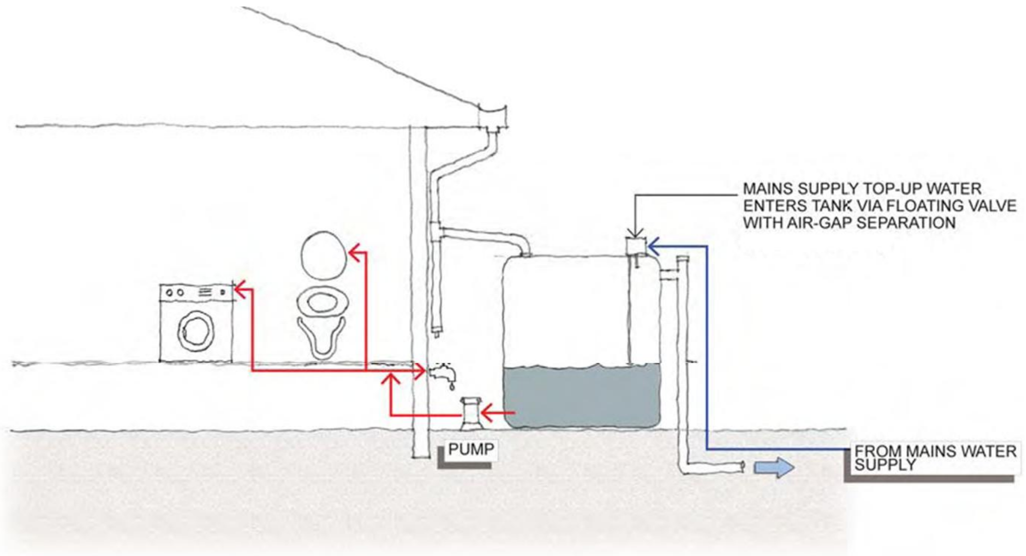


Figure 80

Typical backup water supply configuration: top-up to tank via float valve (NSCC, 2008).



12.2.2.11 Filtration

There are a wide range of filter systems available but these are generally not required for non-potable water uses, depending on the level of contamination on the roof, other leaf and debris screens and the sensitivity of the fixtures. If in doubt, seek advice from experienced plumbers and equipment suppliers.

Figure 81

Typical cartridge filter and housing.

12.2.2.12 Signage

When a building has dual plumbing consisting of a potable water supply from the mains-water supply and a non-potable supply from a single- or dual-purpose rain tank, then all taps and outlets supplying non-potable water must be labelled "Not suitable for drinking" with a suitable diagram as shown to comply with the Building Code. Other signage will also be required if backflow prevention devices or filters are installed.

Figure 82

"Not suitable for drinking" sign (NSCC, 2009, Practice Note 05).

12.2.2.13 An approved outfall

All rainwater discharged from the tank must be directed to a council approved local stormwater collection system.

12.2.2.14 Small diameter orifices

It is recommended to install inspection caps on all small diameter orifice discharge pipes to allow for inspections and cleaning as they can be susceptible to clogging.

12.2.2.15 'Tank Vac' system

The 'Tank Vac' system can be installed to assist in the cleaning of debris from the bottom of the tank. The system has a pipe laid along the bottom of the tank with holes to 'suck' up the bottom sediment when the tank overflows, and then breaks the suction so that only a small volume of water is discharged during each tank overflow event.

12.3 Operation and maintenance manuals

An operation and maintenance manual for a rain tank is a vital reference for what can be a complex device, particularly a dual-purpose rain tank which provides non-potable water supply. This manual is particularly important for rain tanks whose designs can be highly variable and often unique. The details of plumbing connections and complimentary devices (for example, first flush diverters, and back flow preventers) should be detailed in the manual so that if any problems arise with the system, the components and connections are known.

Operation and maintenance manuals typically have three sections. The log book allows for all inspections and maintenance activities or changes to the system to be documented in one place. The technical information section provides all the background information including as-builts and design calculations. The final section details the maintenance procedures which detail exactly how maintenance is to be carried out and when. Some council's have a standard template to be used for rain tank operation and maintenance manuals.

A copy of the operation and maintenance manual should be retained by the owner and an additional copy should be submitted to council for inclusion with the property records.

12.3.1 Log book

Log books should be simple, easily updated log sheets which provide enough information for any reporting requirements, whether consent or contract based, or tracking when and how maintenance was undertaken. If the tank is located at a residential property it is strongly advisable to keep a log book of maintenance.

Figure 83
Example log sheet for rain tank maintenance.

<table>
<tr><td colspan="4">OPERATION & MAINTENANCE – FIELD LOG SHEET
Rain tank</td><td>File No.

Date
/ /</td></tr>
<tr><td colspan="3">SITE: Substation, 21 Tree Road, Auckland</td><td colspan="2">TANK: Located under the deck at rear of property</td></tr>
<tr><td>Date</td><td>Procedure number</td><td>Depth of oil in separation chamber (mm)</td><td>Comments/Actions</td><td>Name</td></tr>
<tr><td>eg 4/5/09</td><td>RTM1</td><td>1.0</td><td>Access hatched checked and inlet and outlets cleared (filters washed).</td><td>J. Smith</td></tr>
<tr><td>4/5/09</td><td>RTA1</td><td>1.2</td><td>Branches overhanging roof pruned and gutters cleaned out.</td><td>J. Smith</td></tr>
<tr><td>6/6/09</td><td>RTA2</td><td>3.2</td><td>Pump checked by electrician – electrical warrant of fitness issued.</td><td>H. Bloggs</td></tr>
</table>

12.3.2 Technical information

The technical information section provides all the background information regarding the design and the construction of the rain tank. This section should contain as-builts, design calculations and consents for the rain tank.

Typically the following information would be included:

1. Long-term maintenance responsibilities including contact details for owner, maintenance manager, site access contact, and emergency contact information in case of contamination spills or flooding.
2. Site location, legal description and details on how to access the site and where key features of the tank and plumbing are located (situation map, and layout plan are important).
3. Consent numbers and details of issuing agency, include summary of consent obligations and attach copies of consents to the appendices (both building and resource consents).
4. Tank design details:
    a. Impermeable area – roofs $m^{2.}$
    b. Impermeable area – paving $m^{2.}$
    c. Permeable area (m^2).
    d. Nominal tank size (litres).
    e. Detention volume (litres).

f. Single orifice diameter (mm)

g. Single orifice height above base (mm).

h. Second/upper orifice diameter, if any (mm).

i. Second/upper orifice height above base (mm).

j. Tank material (Concrete, steel, plastic, fibreglass, other).

k. Vendor/supplier information.

l. Above/below ground installation.

m. Kerb outlet – yes/no.

n. Year of completion.

5. Include a list of non-potable outlets connected to the tank, e.g. all toilets, laundry tub, washing machine cold water supply, garden taps and locations.

6. Details of extra components, e.g. first flush diverter, back flow preventer, pumps, which should include manufacturer's specifications and contact details, and service requirements.

7. Design calculations and criteria for water volumes (design storms, flow rates and water quality volumes).

8. As-built plans for tank structure including retaining walls, and plumbing connections.

9. Copies of supporting reports, for instance, geotechnical report, or structural report, construction photos (these can be useful to look back on for troubleshooting particularly for components that are buried or hidden), and construction drawings.

12.3.3 Procedures

This section outlines methodology and frequency for maintenance of the rain tank. The primary concerns regarding tank maintenance are:

- To keep roofs and collection areas free of overhanging trees to reduce organic litter and prevent access by rodents, cats and possums. Inlets and overflows should be screened and access hatches kept closed.
- To prevent run-off from other areas not within the design catchment area (like driveways and car parking areas) from entering the tanks.

Section 12.4 provides typical maintenance procedures and their frequency. These can be adapted for a specific site and the specific set-up. Manufacturers and suppliers will probably have specific advice regarding the maintenance of their products so these should be included in the operation and maintenance manual.

12.4 Maintenance schedules

Tank owners should periodically inspect their property's plumbing and drainage system for leaks and faults. As these systems age, joints can loosen and begin to separate, resulting in leaks. Similarly the rainwater tank and associated non-drinking water supply system requires periodic inspection and maintenance.

Most actions are relatively simple to perform and may easily be carried out by the property owner. Some actions such as pruning branches overhanging roofs, servicing the pump, de-silting the tank and repairs to top-up valves and backflow prevention devices may require professional assistance.

The following tables set out the recommended inspection and maintenance actions for detention tanks and single/dual-purpose rainwater tanks.

Note: The installed system may not be provided with all of the components listed and may have additional features not covered below. If in any doubt, contact a qualified plumber for advice.

> **Note:** Rain tanks are a CONFINED SPACE and are therefore **extremely dangerous to work in.** Only people **fully certified for confined spaced entry** should enter the tanks for inspections and maintenance.

Table 27
Typical detention tank maintenance schedule.

Component	Recommended actions	Frequency				
		Monthly	Quarterly	6 monthly	Annually	2 plus years
Surrounding area	Trim or clear overhanging branches to minimise leaf litter and eliminate potential roosting points for birds. This also reduces opportunities for access to the roof by rodents, cats and possums.				✓	
	Check any inlet and overflow screens that prevent access by small animals and birds into the tank. Ensure access hatches are closed.			✓		
	Check that the entry of surface water run-off from areas other than the roof into buried single and dual-purpose tanks is prevented as the run-off tends to carry high sediment loads which can clog		✓			

Component	Recommended actions	Frequency				
		Monthly	Quarterly	6 monthly	Annually	2 plus years
	the system. Check for signs of development or organic debris in the catchment that may increase loads to the device.					
Tank hatches & covers	Inspect for correct fit and seal. Particularly important to prevent entry by children. Ensure locks are in place to prevent public access to larger devices.				✓	
Overflow, outlet pipes & orifices	Inspect to ensure that all orifice and overflow outlets are clear and drain freely.		✓			
Roofs, gutters, downpipes, gutter guards, leaf guards, and sediment traps	Inspect and remove debris and accumulated sediment and prune any overhanging branches. If the roof and gutters need to be cleaned, the inlet to the detention tank should be temporarily diverted to prevent ingress of dirty water to the tank. Check and clean sediment traps. Check that pipe fittings are still secure and have not separated.				✓	
Tank	Inspect the tank for leaks, sediment build up and structural integrity (particularly if the tank is 20 years old or more). Clean out if sediment >200 mm (use a ruler/stick to measure the depth). A professional tank cleaning contractor should be employed to clean out the tank as necessary. Note confined entry health and safety requirements may be necessary for maintenance of larger tanks.				✓	

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

Table 28

Typical single- and dual-purpose rain tank maintenance schedule.

Component	Recommended actions	Frequency				
		Monthly	Quarterly	6 monthly	Annually	2 plus years
Surrounding area	Trim or clear overhanging branches to minimise leaf litter and eliminate potential roosting points for birds. This also reduces opportunities for access to the roof by rodents, cats and possums.				✓	
	Check that any inlet and overflow screens prevent access by small animals and birds into the tank. Ensure access hatches are closed.			✓		
	Check that the entry of surface water run-off from areas other than the roof into buried tanks is prevented. Check for signs of development or organic debris in the catchment that may increase loads to the device.			✓		
Backup water supply	Inspect all pipes and valves for leaks.				✓	
	Float operated top-up valves are prone to leakage which may result in constant filling of the tank to overflow. This may go unnoticed until the next water meter reading. Check these valves regularly to ensure that they are closing properly and not leaking. Seek professional assistance if necessary.				✓	
	With the 3-way solenoid valve option check that the valve is switching to tank water supply rather than mains supply when tank water is available. Confirm by listening for the pump and noting drawdown in the tank when tank water is used.				✓	
Tank hatches & covers	Inspect for correct fit and seal. Particularly important for underground tanks to prevent ingress of contaminated surface water run-off and entry by children. Ensure locks are in place to prevent public access to larger devices.				✓	
In-line filter	It is advisable to keep a spare filter cartridge. Swap filter cartridges and clean the old cartridge ready for the next replacement.			✓		

Component	Recommended actions	Frequency				
		Monthly	Quarterly	6 monthly	Annually	2 plus years
First flush device	Inspect and remove any debris and accumulated sediment. Refer to the manufacturer's instructions.		✓			
Overflow, outlet pipes & orifices	Inspect for blockage and clean if necessary. Flush when the tank is cleaned		✓			
Roofs, gutters, downpipes, gutter guards & leaf guards	Inspect and remove debris and accumulated sediment and prune any overhanging branches. If the roof and gutters need to be cleaned, the inlet to the rainwater tank should be temporarily diverted to prevent ingress of dirty water to the tank. Check for leaks or loose fittings.			✓		
Tank	Inspect the tank for leaks, sediment build up and structural integrity. A professional tank cleaning contractor should be employed to clean out the tank when the sludge level gets close to the pump inlet.				✓	
	Most rainwater tanks have a design life of 20 years or more. Clean out if sediment >200 mm (use a rule/stick to measure the depth). Tanks older than this should be regularly assessed and replaced if necessary. Note confined entry health and safety requirements may be necessary for maintenance of larger tanks.				✓	
Backflow prevention valve	Check by qualified person.				✓	
Pump	Pumps should be professionally inspected and/or serviced every few years. Refer to the pump service manual or contact a local service provider.					✓
Non-return valve	Check operation when the pump is serviced.					✓

12.5 Troubleshooting

Most of the troubleshooting problems are related to the single/dual-purpose rain tank systems and their pumping and supply of non-potable water to the building. Listed below are some of these common problems, suggested causes and solutions.

Table 29
Detention tank troubleshooting.

Symptom	Likely cause	Remedy
Mosquitoes in and around tank.	Access to standing water outside or inside the tank.	Ensure all connections and entries to the tank are sealed.
		Check that gutters are not holding water.
		Clean out mesh screens on inlet filters, leaf slides and gutter guards.
		Ensure access hatches and covers are closed at all times.
Tank full of water most of the time.	The small orifice draining the tank is clogged or too much sediment has settled at the bottom of the tank.	Clean out drainage orifice, and clean out accumulated debris from the bottom of the tank.

Table 30
Single- and dual-purpose rain tank troubleshooting.

Symptom	Likely cause	Remedy
Mosquitoes in & around tank.	Access to standing water outside or inside the tank.	Ensure all connections and entries to the tank are sealed.
		Check that gutters are not holding water.
		Clean out mesh screens on inlet filters, leaf slides and gutter guards.
		Ensure access hatches and covers are closed at all times.
Tank full of water most of the time.	The small pipe draining the tank is clogged or too much sediment has settled at the bottom of the tank.	Clean out drainage pipe, and clean out accumulated debris from the bottom of the tank.

Symptom	Likely cause	Remedy
Discoloured water.	Commonly caused by build up of leaves in the gutters, inlet system and tank or by the stirring up of sediment in the bottom of the tank.	If discolouration appears to be caused by leaf tannins consider: • Cleaning the gutters and inlet system. Installing leaf guards, a leaf slide, inlet filter or first flush device if one is not installed. • Prune overhanging trees that drop leaves on the roof. • Clean out the tank.
		If discolouration appears to be caused by sediment consider: • Installing a bottom inlet system. • Installing an in-line filter. • Cleaning out the tank.
No water getting to the toilet or laundry.	Lack of water in the tank.	If the water level is below the pump inlet, the top-up valve may be blocked or the mains water supply may be turned off.
	Leak in the system	Check all connections for leaks and repair if found.
	Water supply valve from tank to the pump is turned off.	Turn valve on.
	Power outage.	During a power outage the pump will not operate and hence the toilet (or laundry) will need to be filled manually until the power comes back on. When the power comes back on the pump may need to be "re-set". If a proprietary 3-way solenoid valve is installed this should automatically switch over to mains supply in the event of a power outage.
	Pump not working.	Check that power supply to pump turned on.
		Check the pump circuit breaker.
		Try "re-setting" the pump. Follow pump manufacturer's instructions or seek advice from local pump supplier/dealer.
	Pump working but no water coming out.	Check the pump inlet is not blocked.
		Check the in-line filter is not blocked.
Excessive mains water use.	Leakages or malfunctioning tank switching device.	Check that the float operated rainwater tank top-up valve is closing correctly and is not leaking.

Symptom	Likely cause	Remedy
		Check that the proprietary 3-way solenoid valve is switching over to tank supply when tank water is available.

12.6 Compliance auditing and monitoring

Compliance in regards to rain tanks will be based on resource consent conditions and/or building consent conditions. Rain tank monitoring involves a series of visual inspections performed under the maintenance schedule (Section 12.4).

Auditing typically implies a compliance requirement. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that shortcuts, and hazardous or inappropriate practices, can be stopped. Audits should be conducted at least once a year.

12.7 Photo gallery – rain tanks

Figure 84
Glencourt Place rain tank with difficult access.

Figure 85

Waitakere Hospital rain tanks

Figure 86

Rain tank filter showing leaf litter and organic debris.

Figure 87

Inside a rain tank showing sediment on bottom of tank.

Figure 88

Rain tanks behind house with retaining wall.

13 Living Roofs

13.1 Introduction

Living roofs are gaining in popularity, with property owners either modifying existing buildings (retrofitting) or including them at the outset of design for new buildings. Living roofs are also referred to as green roofs, eco-roofs, vegetated roofs or roof gardens. Living roofs can be designed to assist in a building's stormwater management, air quality, building insulation, roof longevity and reduction of the heat island effect.

13.2 Device description

Living roofs are built on top of a human-made structure (e.g. house, office building, or underground car park) and can be located below, at, or above ground. Living roofs have been categorised into three basic types: extensive, semi-extensive, or intensive, depending on their substrate depth, design characteristics and core purpose. Table 31 provides definitions targeted to a stormwater engineering audience from an international task committee on living roofs for stormwater control, which falls under the umbrella organisation of the American Society of Civil Engineers (ASCE).

The key components of a living roof system are presented in Figure 89 and described in Table 32.

Table 31
Broad categorisation of living roof systems

Living Roof Type	Description[1]
Extensive	• Low profile with thinner layers (drainage, substrate, and plants) than semi-extensive and intensive living roofs • Low growing plants are established in 20–150 mm of substrate • Usually less expensive and lower maintenance when compared to other types of living roofs • Roof structural requirements are lower than other living roof types, with saturated weights reported from 70–170 kg m^{-2} • Thin substrate depth limits how much water can be retained in the system, and hence the diversity and height of plants that can be grown in the absence of irrigation • Generally not meant to support foot traffic, other than for occasional

[1] See Auckland Regional Council Technical Report 2012/012, Living Roofs review and design recommendation for stormwater management for more detail

Living Roof Type	Description[1]
	maintenance • Focus on function over form
Semi-extensive	• Designed to be low maintenance, but with deeper layers (drainage, substrate, and plants) than extensive roofs but not as deep as intensive roofs • Typical substrate layers range from 100–200 mm • Larger variety of plants can grow on this roof type when compared to an extensive roof • Irrigation is typically infrequent or absent • Provide function plus a wider plant biodiversity, but are not typically for occupied spaces
Intensive	• Have the deepest layers (drainage, substrate, and plants) and a wider plant variety, including herbaceous plants to shrubs or trees • Substrate is typically >200 mm, which promotes deeper potential root depth, and hence accommodates a wider height and variety of plant species • Associated high saturated weight (300–1000 kg m-2) requires significant structural support for the roof • Regular irrigation is usually a required design element • Many intensive roofs are designed to be at least partially accessible, hence design emphasises form and accessibility
Rooftop Garden	• Accessible areas on the roof with containerised plants instead of layers of membranes and growth media that are installed directly on the roof deck • May sometimes be considered intensive living roofs • Usually irrigated, where aesthetic requirements are high or particularly important

Figure 89

Typical living roof.

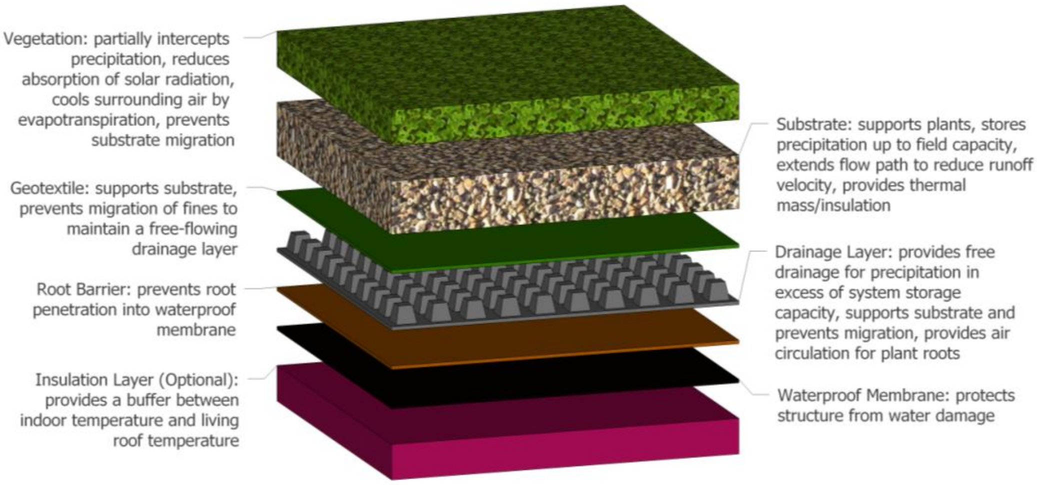


Table 32

Key components of a living roof system.

Device component	Description
Plants	Species selected to withstand extreme climatic conditions including solar radiation, wind, drought, and rain.. The primary role of the vegetation is to ensure the surface of the substrate is stable – resistant to rain, wind and animals. Stems and leaves physically protect the surface from impact while roots bind and hold the substrate in place. Vegetation also reduces absorption of solar radiation and provides stormwater attenuation volume by direct interception of rainfall and through uptake of water from the substrate, then release to the atmosphere via evapotranspiration.
Growing media/ substrate	Usually composed of 80-90% light weight aggregate (eg. pumice or zeolite) and up to 20% organic material. The growing medium should be stable (resistant to rot, shrinkage etc) and well draining to promote ongoing plant health and structural integrity. The use of fertiliser shall be minimised, however if necessary shall only be applied as per landscaping plan. The growth medium supports plants both physically and nutritionally, stores precipitation up to field capacity, extends flow path to reduce runoff velocity, and provides thermal mass/insulation.

Device component	Description
Root barrier/ geotextile material	The geotextile (filter fabric) physically supports the substrate, separating it from the drainage layer and preventing migration of substrate fines, to maintain a free-flowing drainage layer. It can be either a separate layer, or attached to a commercially available drainage layer. A root barrier is required to prevent root penetration into the waterproof membrane. There are a number of options for this including chemical compositions in the water proof membrane or geotextile, or a laminated layer. Some root barriers contain chemicals toxic to fish – these should **not** be used for living roof applications.
Drainage layer	The drainage layer provides free drainage for rainfall in excess of the system storage capacity and provides air circulation for plant roots. When using an aggregate drainage layer, the drainage layer should extend to the surface around the roof for a width of ≥200 mm. When using a drainage mat, a gravel edge should be included, extending from the drainage mat to the surface, around the perimeter of the living roof (and around any protrusions) for a width of ≥200 mm. This provides additional drainage, fire control and a visual cue for maintenance access.
Insulation layer	An optional insulation layer may be included in the living roof design.
Waterproof membrane	At least a double-ply waterproofing membrane of high quality is strongly recommended. Alternatively, a purpose-made living roof heavy-duty single ply membrane with felt layer can be used. Care must be taken during installation to prevent any damage to the waterproof membrane (by footwear, installation tools etc). Particular care must also be taken around protrusions/penetrations (roof vents, air-conditioning units etc), typical waterproofing problem areas. It is recommended to install gravel edging around protrusions for protection and easy identification for maintenance.
Outlet	Excess water in the drainage material is directed to the outlet. Access is required for regular maintenance; gravel edging should be installed around the outlet for ease of identification and access.

13.2.1 Living roof locations

Living roofs are used around the world in developed urban environments and can take on many forms. Living roofs can be utilised as an effective source control in various commercial, industrial, and residential applications – from high rise commercial or residential buildings, through to suburban residential garages. Depending on the type of living roof, maintenance may require extra health and safety measures due to the height and pitch of the roof. Appropriate harnesses, restraints and/or barriers, in addition to appropriate training for working at height, may be required.

13.2.2 Living roof functions

Living roofs reduce the overall impervious coverage of a site, which results in a number of benefits. In a stormwater management context, living roof systems provide volume reduction and peak flow attenuation. By converting a usually impervious roof into a permeable area the volume of stormwater reaching the outlet during a rainfall event is greatly reduced compared to that from a conventional rooftop. Water is intercepted by the vegetation, stored within the porous substrate and returned to the atmosphere via evapotranspiration. In addition, the path water must take through the living roof system to exit the rooftop results in greatly reduced peak flow rates. Additional environmental, economic, amenity and aesthetic benefits are also provided by living roof systems:

- Reduced energy consumption
  - Enhance building insulation (when dry) and thermal mass (when wet)
  - Improve air conditioning efficiency and reduce operational cost were vents are located above the vegetation, as intake air temperature is cooler than ambient air
- Extend the useful life of a roof surface by protecting it from damaging UV rays which cause mechanical breakdown of surfaces
- Mitigate the "urban heat island effect" (i.e. lower ambient temperatures)
  - Reduce the amount of solar energy absorbed by building materials
  - Create a cooling microclimate by evapotranspiration
  - Reduce reflected heat
- Create urban habitat
  - Mitigate removal of habitat from modifying existing land use
  - Provide "green corridors"
- Absorb and filter airborne pollutants, including dust, while releasing oxygen
- Reduce sound/noise transmission
- Provide amenity value as a recreational space
- Provide aesthetic value and/or blend a building into a sensitive landscape.

The relative degree of each benefit from an individual living roof varies dependant on system configuration (substrate depth, composition, and vegetation characteristics).

13.3 Operation and maintenance manuals

The operation and maintenance manual provides important information on how to maintain the living roof as well as provides background information like copies of consents, as-builts, and design specifications which can help when troubleshooting maintenance issues. It is also a valuable document for correcting any aspects that do not work in the design of the living roof.

The document should be made up of sections that can easily be added to. These sections are often titled 'Log books', 'Technical information' and 'Procedures'. The following sections provide a description of what information should be entered to these sections.

13.3.1 Log books

Log books are essential tools in keeping track of work or inspections undertaken and often form the basis of consent report requirements. The most basic log will record when the roof was inspected, what areas were checked and what action if any was undertaken. Depending on consent conditions or purpose of the living roof there may be permeability and/or water quality monitoring undertaken which should also be recorded in the log book.

Figure 90
Example log sheet for living roof maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Living roof			**File No.** **Date** / /
SITE: University of Auckland, 20 Symonds St, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	GRM3	Outlet partially blocked, debris cleared.	J. Smith
4/5/09	GRM2	Weeds removed and plants trimmed.	J. Smith
6/6/09	GRA1	Water seeping into ventilation unit, waterproof membrane checked – OK. Engineer called to check unit.	H. Bloggs

13.3.2 Technical information

This section is perhaps the most important for understanding how the living roof was constructed and what the design parameters are. Typically this section would include information on:

1. Long-term maintenance responsibilities including contact details for landowner, maintenance manager, design engineer, emergency contact details, and site access contact.
2. Location of the living roof including street address, legal description, co-ordinates (NZTM2000), how to access the site, and site specific health and safety (includes location maps and layout plans).
3. Regional and local council consent numbers (with copy of consents in appendices) – a summary of obligations under the consent conditions would be useful if there are numerous requirements.

4. Levels to LINZ Auckland datum 1946 of the planting level, overflow outlet, invert of outlet pipe, and invert of orifice outlet.

5. Design information:

    a. Substrate (planting media) specifications for:

        i. dry bulk density in kg m^{-3}

        ii. permeability in mm h^{-1}

    b. Total system weight (including drainage later, substrate and vegetation):

        i. at field capacity in kg m^{-3}

        ii. when saturated in kg m^{-3}

    c. Diameter of orifice outlet (mm).

    d. Contributing catchment area (roof size) in m^2.

    e. Contributing catchment area (impermeable areas) in m^2 (if any).

    f. Normal operating surface area of living roof in m^2.

    g. Description of and nominal depth of substrate (mm) *include manufacturer and supplier of substrate if applicable.*

    h. Year of completion.

    i. Copy of design calculations (design storms, flow rates, permeability etc).

6. Construction detail plans of the living roof.

7. Copy of structural report for building.

8. Copy of design report.

9. As-built planting layout and schedule.

    a. Include a pictorial list of plants on the specific living roof to ensure desired plants can be recognised by contractors carrying out maintenance.

10. As-built plan, dated and showing maintenance access.

13.3.3 Procedures

This section will specify what inspections, checks and maintenance should be carried out and the frequency for maintenance. Section 13.4 below provides a generic maintenance schedule which can be added to and altered for a specific site. Maintenance procedures can be grouped by frequency to make it easier to carry out all monthly inspections at the same time.

Reporting should be a specific procedure documented in the operation and maintenance manual. Consent conditions will often require annual or on request reporting, as will maintenance contracts. The log sheets will form the basis of this reporting as all inspections and physical works carried out should be itemised here. It is a good idea to assess reporting requirements at the outset and design the log book to capture this information.

13.4 Maintenance schedules

13.4.1 Establishment period

Most extensive living roof installations take 12–18 months to establish a high vegetative cover (>85%) and this is the critical time for maintenance as it impacts the long-term success of the roof. However, many of the maintenance requirements are the same as for any landscaping project.

Plants should be watered immediately following installation and then watered for the first few weeks or months unless ample rainfall occurs. It is then possible to reduce irrigation frequency. After the first summer, irrigation may not be necessary depending on the local environment, the plant species chosen, the substrate depth, and aesthetic requirements.

For the establishment period, monthly visits should occur for the first six months with quarterly visits thereafter. The key tasks will be weeding and plant replacement, if required, to encourage rapid establishment of the living roof plant species and to prevent weed establishment.

13.4.2 Ongoing maintenance

After the establishment period, maintenance commitments for the living roof will typically reduce. Ultimately, living roof maintenance is dependent on local rainfall conditions, the species of plants used, and the proposed final aesthetic and function of the roof. Desired aesthetic may range from a maintenance intensive "lush" living roof with a structured design, to an extensive living roof design purely for function with minimal maintenance requirements. As a guide Table 33 outlines some of the typical operational and maintenance tasks.

Table 33
Typical living roof maintenance schedule.

Component	Recommended action	Frequency			
		3 Monthly	6 Monthly	Yearly	As required
Plants	Remove weeds. Herbicides, fungicides, and insecticides should be avoided. If absolutely necessary, they should be used sparingly as they have the potential to hasten degradation of the roof membrane and contaminate runoff. Care must be taken to prevent generating favourable	✓			

Component	Recommended action	Frequency			
		3 Month ly	6 Monthly	Yearly	As required
	conditions for germination of more weeds i.e. avoid disturbing the substrate too much				
	Check substrate moisture content. Irrigate plants if required. Most likely to be required Dec–Mar. Irrigation may not be necessary depending on local environment, plant species, and substrate depth				✓
	Remove dead foliage Depends on how manicured the roof is required to be and the types of plants used. Dead foliage can help provide nutrients to the roof assisting in a self sustaining system and prevent the need for frequent fertiliser use. If grasses leave significant volumes of dead material, removal may be required to prevent fire risk.			✓	
	Replace dead plants Best time of year to replace plants is Apr–Sep			✓	
	Remove or trim any vegetation that has grown into the edging surrounding protrusions and/or roof equipment (i.e. air vents or air conditioning units).			✓	
	Test substrate chemistry to identify if fertilisation is required. If so, restrict supplemental fertilisation to slow-release fertiliser. Plants must be actively growing with suitable substrate moisture and temperature conditions to ensure plants are able to uptake and use nutrients. Typically Sep and Apr, if required.		✓		
Substrate	Check substrate depth to verify no media loss from the roof			✓	
	Test permeability to ensure adequate drainage through the substrate, must meet design specifications			✓	
Inspect outlet	Ensure outlet is clear of debris. Check after any major storm event to ensure material has not been washed off the roof causing outlet blockages	✓			✓
Perimeter drain inspection	Ensure all perimeter drainage material is free from plant litter and plants.			✓	
	Ensure downpipes are clear of any litter. Check perimeter pipes are clear of fine silt and blockages.	✓			✓

Component	Recommended action	Frequency			
		3 Monthly	6 Monthly	Yearly	As required
Waterproof membrane	Undertake a full visual inspection for sign of leaks. This may require a qualified building inspector. If potential leaks are identified, test thoroughly using electric field vector mapping (EFVM) or equivalent.			✓	
	Check membrane is completely covered to prevent UV degradation and damage from footwear or equipment		✓		

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

Weeding ultimately determines the success of a living roof with a weedy roof being a common reason for public perception of a 'failed' green roof. However, the definition of a weed depends on the objectives of the living roof, and on the potential for plants to establish on the living roof, or move from the roof into neighbouring areas. Without a weeding programme the vegetation composition of nearly all roofs will change over time; in Auckland, as in Europe, roofs are likely to become dominated by grasses that die off in summer.

On all roofs, 'weeds' include plants with aggressive root systems or high biomass that may impact waterproofing layers either by root invasion, or by exposure of the drainage mat when they topple over. Most tree species will fail to establish on extensive living roofs, as they die in summer, however those that are not dead by autumn will need removing. In Auckland, aggressive weed species identified include pampas (*Cortaderia* species), cotoneaster and butterfly bush (*Buddleja davidii*). A Waitakere roof studied[2] is adjacent to a source of native shrubland species. Self-established plants that were removed due to stability concerns included *Coprosma robusta*, cabbage tree (*Cordyline australis*), and kanuka *Kunzea ericoides*. Annual early-autumn visits are usually adequate to ensure removal of such weeds before they set seed or become a risk to the roof.

Roofs designed specifically for stormwater mitigation, not aesthetics, can allow a wide range of adventive species to establish. On these roofs weeding focuses on removing aggressive adventive species that have the potential to smother planted vegetation, then die to leave large bare patches on the roofs. The bare patches reduce stormwater mitigation. Adventive legumes (*Trifolium repens* white clover, *Lotus pedunculatus* and *L. suaveolens*, hairy trefoil among others) were consistently weeded from Auckland living roofs[3] designed for stormwater management. Other adventive plants were not controlled; these generally had an upright growth form and were annuals, for example *Senecio vulgaris*, *Epilobium ciliatum*, *Euphorbia peplus* and the cosmopolitan native species *Pseudognaphalium luteoalbum*.

[2] See Auckland Regional Council Technical Report 2010/018, Extensive Green Roofs for Stormwater Mitigation: Part 2 Performance Monitoring for more detail
[3] See Auckland Regional Council Technical Report 2010/017 and Technical Report 2010/018 for more detail

Maintenance, particularly in the first 12 to 24 months until a high vegetation cover is established, must be frequent enough to allow removal of undesirable weeds before they set seed. Removal of plants with stolons that root at each node, or underground rhizomes, e.g. *Trifolium repens* and kikuyu grass can be very time consuming once they are established. Visits may need to be as frequent as two-monthly during the growing season (typically April to November) if significant bare areas, suitable for weed establishment are present. Required weeding effort decreases as vegetation cover increases, and the roof is established enough to be subjected to the drought-stress that inhibits establishment of adventive plants.

The highest weeding intensity is required for young 'roof gardens' where there is low tolerance for any adventive plants. Some roofs have vegetation that requires removal of dead flower and seed stalks, or regular biomass removal (e.g. trimming of some tussocks) to maintain high aesthetic values. Removal of dead leaves may also be important for roofs in locations with potential fire hazard, and may be used to enhance biodiversity in sod or meadow roofs by reducing the competition of grasses with orchids, herbs and annual species.

Testing of substrate chemistry and visual assessment of plant growth will identify if fertilisation is required. If so, supplemental fertilisation should be restricted to a slow-release fertiliser, and generally one low in phosphorus. The aim is to match nutrient availability to plant growth and avoid stimulating a 'flush' of soft foliage that can be susceptible to wind and drought. Typically a low rate will be broadcast when substrate moisture and temperature ensures plants are actively growing, so able to uptake the nutrients.

Use of herbicides, fungicides (particularly copper), and insecticides (including slug and snail poisons) should be avoided if possible, as most roof runoff is connected to stormwater systems that ultimately discharge to surface waters. Any spraying must take into account the high potential for impacting adjacent environments due to the windy, elevated nature of rooftops; if herbicides are used, adopt practices that avoid drift (e.g. weed wands, wicks or brushes). Some chemicals have the potential to hasten degradation of the roof membrane.

All activities occurring on a living roof, whether associated with vegetation management or not, must be done by people who are fully aware of the need to protect and maintain the integrity of the plants, drainage, and waterproofing. People should be kept off vegetation as much as possible; paths should be defined around plant rooms and key access points; the use of 200 to 300 mm high, grated walkways allows vegetation to grow undamaged by foot traffic. Cutting or sharp tools, equipment, or footwear should never come into contact with the waterproofing membrane.

13.4.3 Emergency or unplanned maintenance

Emergency or unplanned maintenance may be required after heavy rainfall, storms with high winds, and earthquakes. It is important to check a living roof after storm events for loss of plants and media, and ensure that the waterproof membrane has not been compromised. Debris and rubbish can also be blown onto the roof and will need to be collected and removed.

Emergency contact details for service professionals should be available in the O&M Manual to undertake any assessments that may be needed after a storm event. Service professionals include structural engineer and mechanical engineer (for air conditioning or vents).

Any inspections or emergency works associated with an event should be logged in the O&M Manual Log Book.

13.5 Troubleshooting

A variety of problems may arise when a living roof is not maintained. These can have significant consequences on the building structure or living roof function. Listed below are some of these problems, suggested causes and potential solutions.

Table 34
Living roof troubleshooting.

Symptom	Likely cause	Remedy
Water leaking into building.	Waterproofing membrane compromised.	Identify leak and remediate. If the leak is significant, it may be necessary to replace the membrane completely and re-build the living roof. EFVM can typically be used post construction to identify leaks, reducing the need to disturb the entire living roof for repairs.
Roof is sagging.	Roof media is too heavy for the structural capacity.	Have the roof assessed by a structural engineer to determine appropriate action.
Regular surface runoff during rainfall events (Water is not reaching outlet by filtration through the drainage material).	Substrate does not meet design specifications for permeability.	Test substrate to confirm permeability is as detailed in design specifications. Replace as necessary with correct growing media.
	Drainage layer is not level, preventing drainage and causing water to pond.	Re-level drainage layer in areas of ponding.
	Drainage layer blocked by build up of sediment or organic material.	Identify the source of sediment or organic material. Check filter cloth is installed correctly. Remediate if necessary and clear out drainage layer.
Ponding is occurring near the outlet, or gutters are overflowing	Outlet is blocked	Identify cause of blockage and remediate

Symptom	Likely cause	Remedy
Plants are not thriving.	Reassess living roof purpose – plant health varies based upon the time of year and the purpose of the roof	Stormwater management: At times of the year (such as summer) the plants may not be thriving (i.e. browned plants) but the roof will still be in an acceptable condition. Only need to ensure the plants do not reach a drought state sufficient to kill them. Purely aesthetic: Definite need to ensure plants are thriving at all times.
	Plants are drought stressed	Test substrate moisture, irrigate plants if necessary
	Plants are nutrient stressed	Test chemical composition of the substrate, apply a slow release fertiliser if required
	Water is not draining away from the drainage layer properly.	The drainage layer could be blocked. Inspect and clear if possible.
	Lack of sufficient growth media.	Modify growth media, re-level or replace any lost material.
	Plants may be subjected to extreme sun/ wind/cold/frosty conditions, beyond what they can tolerate.	Replace plants with hardier specimens or consider installing a protective erosion mat/net to affected areas (ensuring it is securely fastened). Increase planting density to improve coverage.

13.6 Compliance auditing and monitoring

There can be many requirements for compliance from different regulating sources. These can be performance areas in maintenance contracts, or part of consent. Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the living roof. An audit checklist can be developed based on the operation and maintenance manual. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts, and hazardous or inappropriate practices, can be stopped. Audits should be conducted at least once a year. Maintenance contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the living roof would tend to focus on permeability of the substrate and plant establishment and health. If maintenance frequency for the living roof is difficult to determine, quarterly sampling during the first year of operation will provide a good indication of performance and assist in reviewing maintenance frequencies. The permeability of the growing media should be tested within the first month of operation as this should represent optimum permeability. Thereafter permeability should be tested quarterly for the first year of operation and then annually in subsequent years.

In-situ permeability testing will vary from the design permeability tests, which are typically based upon FLL methodology[4]. A modified double ring infiltrometer test should be used[5]. As the double ring method was developed to measure vertical permeability only, the method is applicable to a living roof, where unimpeded flow is provided below the substrate by a separate, free draining layer. Rings should be inserted into the substrate by gently pressing and twisting (rather than the standard hammering), due to the limited substrate depth and to prevent damage to the geotextile below.

13.7 Photo gallery – living roofs

Figure 91
University of Auckland living roof: ~1 month after initial planting (Sep 2006).

[4] See ARC TR2010/017 and FLL. (2008). "Guidelines for the Planning, Execution, and Upkeep of Green-Roof Sites." *3253115*, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e V., Bonn
[5] Bouwer, H. 1986 Intake rate: cylinder infiltrometer pp.835-836. In Klute, A. (Ed) 1986 Methods of soil analysis. Part 1 Physical and mineralogical methods. Second Edition. ASA & ASSS Madison, Wisconsin.

Figure 92

University of Auckland living roof: plants in optimum health, late spring 2007.

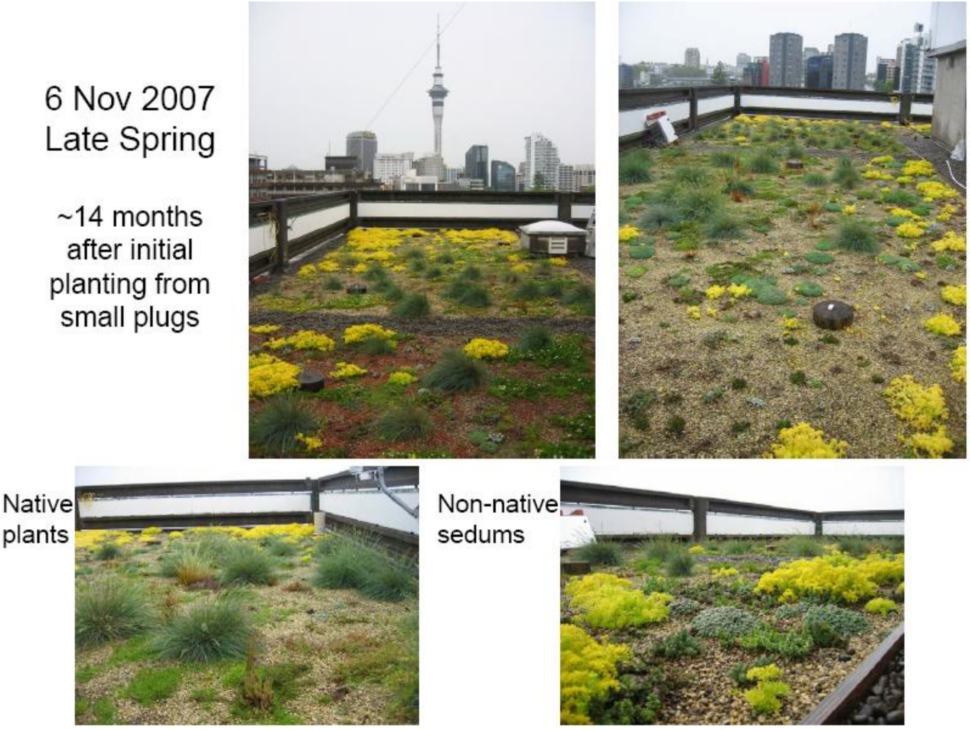


Figure 93

University of Auckland living roof: plants water stressed, late summer 2008, note significant variation in appearance between seasons, yet living roof is still functional.

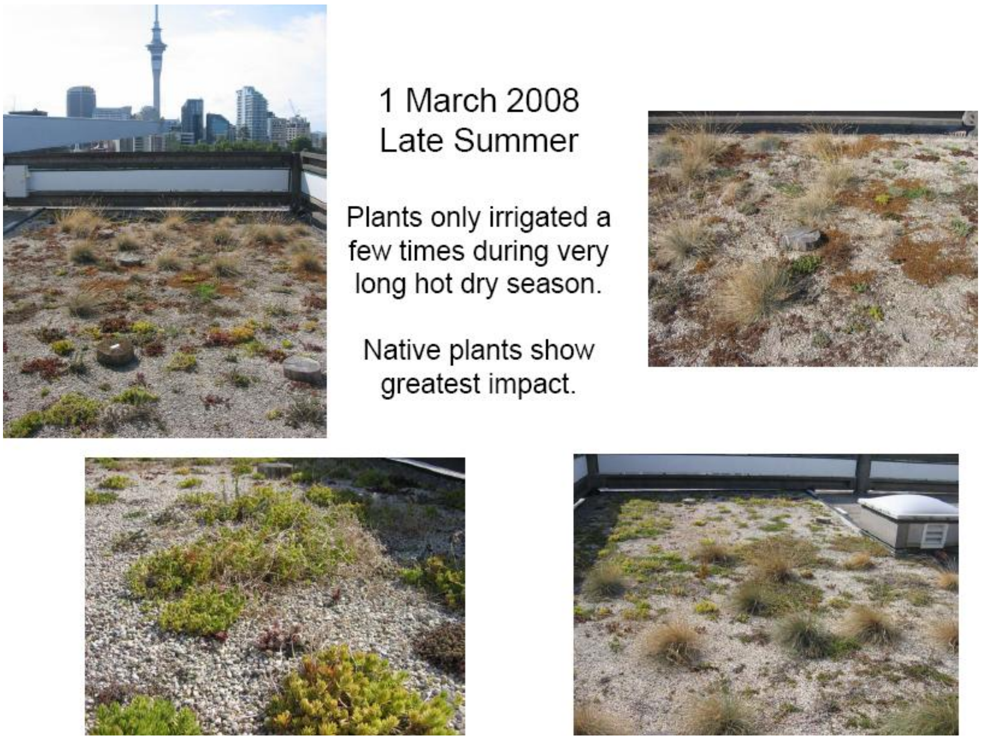


Figure 94

NZI Building living roof.

Figure 95

Suburban residential living roof.

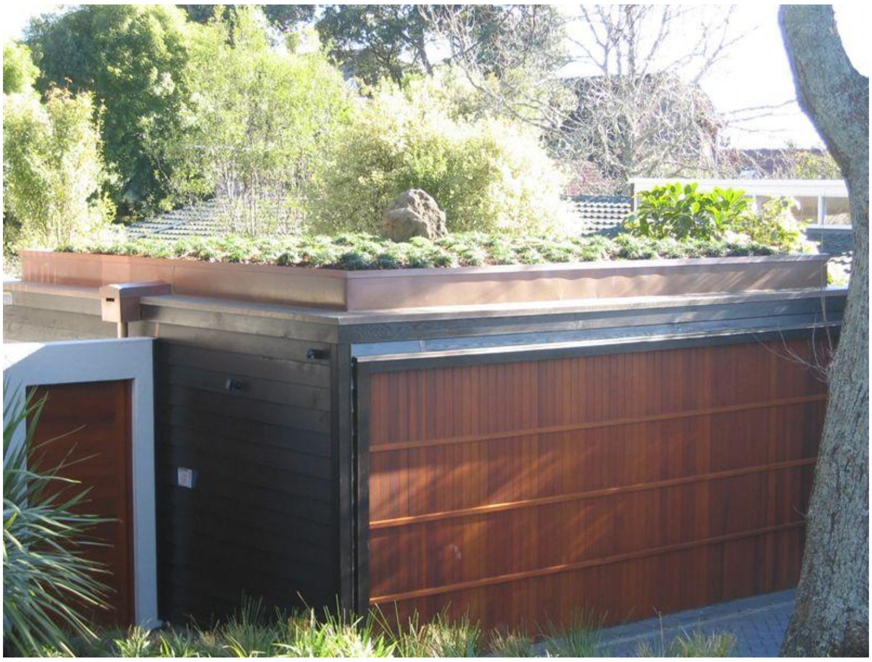


Figure 96

A simple living roof to maintain; the succulent based plant palate has low water and nutrient requirements, clearly defined paths identify the walkable areas and the parapet defines the edge of the building

Figure 97

A difficult living roof to maintain; the grass planting has significant nutrient and water requirements to remain lush, and the steep slopes make even nutrient and moisture distribution difficult; however, access is straightforward and safe

Figure 98

A difficult to maintain living roof: the grass planting has significant nutrient and water requirements, access to mow the grass is difficult and the lack of balustrade is a safety issue.

Figure 99

A difficult to maintain living roof: the vegetation is overgrown, it is difficult to get onto the roof to check outlets and waterproofing etc, and once on the roof the edge is not clearly visible causing safety concerns

Figure 100

The need for positive drainage and maintenance: (a) Edinburgh, Scotland; (b-d) Waitakere City Civic Centre roof drains in need of maintenance; only (b) shows a living roof drain, (c-d) demonstrate even conventional roof gutters require maintenance.

(a)  (b) 

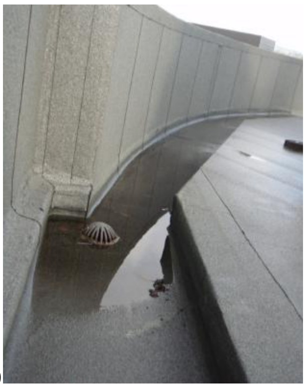
(c)  (d) 

Figure 101

Well constructed and maintained outlets and edging free from vegetation and debris

Figure 102

Requirement to check edging is installed: (a) edging material between the barrier and substrate would protect the drainage layer from substrate migration; (b) edging material around all protrusions provides protection from UV or other physical damage and ease of identification.

(a)  (b) 

Figure 103

Slumping of substrate on a steeply pitched roof, exposing the retaining battens. Roof requires additional substrate and plants, which should then be held in place with an erosion control mat.

14 Infiltration Trenches and Dry Wells

14.1 Introduction

Infiltration devices are often known as soakholes. There are vast array of infiltration devices in use in the Auckland region, often designed for specific site and geological conditions. Soakholes and larger public infiltration systems are often made of precast concrete chambers with perforations allowing water to percolate to the next chamber and ultimately the surrounding ground. Some also include bores that extend into underlying aquifers to maximise soakage and disposal rates. This chapter only looks at infiltration trenches and dry wells, which are also known as private soakage.

Rain gardens, swales and permeable paving systems can also be constructed for infiltration of stormwater rather than discharge to stormwater reticulation systems.

14.2 Device description

All infiltration devices direct stormwater run-off to the underlying geology and ultimately groundwater. The key function of infiltration devices is to reduce the volume of stormwater run-off, reduce surface water contaminant loadings, and extend baseflow in streams. Run-off is stored in chambers or the void space between the storage medium (aggregate) and slowly permeates into the surrounding ground where natural biological processes can improve water quality. Infiltration devices are most effective in permeable natural soils with water tables a minimum of 1 m below the base of the device.

Infiltration devices can have high failure rates if careful consideration is not given to site selection and maintenance. Catchment characteristics, particularly potential sources of pollution (e.g. oil, grease, high sediment loads) need to be identified and suitable pre-treatment included in the design of the infiltration device. There is also significant risk of polluting groundwater if run-off is not sufficiently treated prior to infiltration. The volume of water infiltrated also requires consideration as too much water can cause geotechnical failure of the infiltration field.

Infiltration trenches: Trenches can be buried and receive inflow either from pipes or surface drains that collect sheet flow run-off. Pre-treatment is essential to prevent the trench from clogging. Infiltration rates should be between 3 mm hr^{-1} and 1 m hr^{-1} in order to achieve attenuation and treatment, and their suitability is therefore highly dependent on geology. Trenches with a piped inflow point often have a dispersion pipe the length of the trench to evenly disperse run-off. In this situation a trench may be grassed, however clear delineations are required to protect the trench from any activities which could compact the soil and trench (e.g. vehicle or pedestrian traffic).

Dry wells: Operate by receiving run-off from roofs only. Pre-treatment is not required, however gutter guards and screens are essential to prevent organic material entering the dry well. Dry wells are also known as private soakage.

14.2.1 Infiltration trench and dry well locations

An infiltration device can only be located in geotechnically stable regions with suitable geology for infiltration and deep water tables. Careful consideration needs to be given when locating infiltration devices near hard surfaces (e.g. car parks), building foundations and groundwater supply bores. This is to reduce the risk of subsidence to building foundations or the seal of car parks. The pre-treatment device will often require more maintenance than the infiltration device itself as the pre-treatment device will accumulate sediment at a faster rate than the infiltration device.

Figure 104

Typical infiltration trench components (cross-section and long-section).

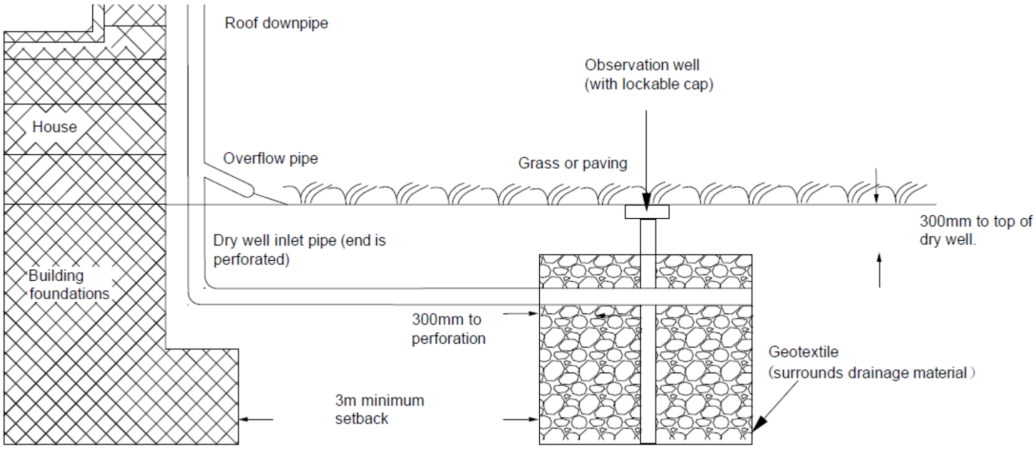


Figure 105

Typical dry well components (cross-section).

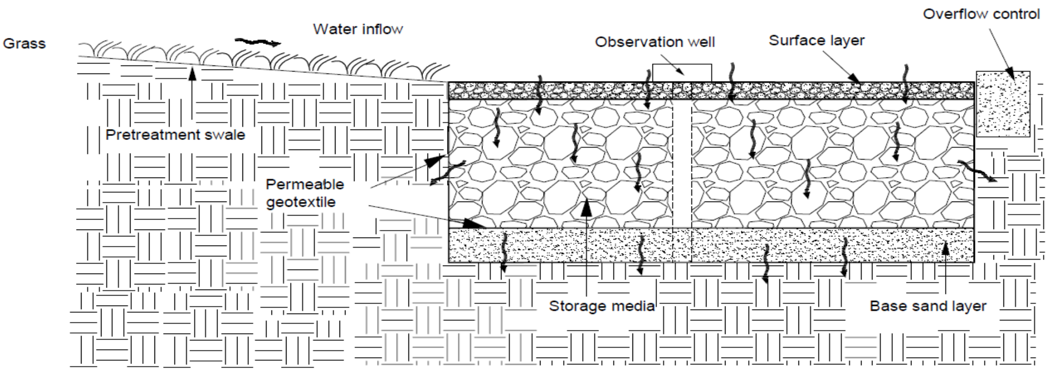


Table 35
Key components of infiltration trenches and dry wells.

Component	Description
Pre-treatment	Pre-treatment is strongly recommended to remove larger sediments as this helps prevent clogging of the infiltration media and geotextile. For example swales, forebay type structures or surface sand filters are often used. Dry wells do not normally require pre-treatment as they only accept roof run-off, however gutter guards or an in-line leaf/debris diverter are essential to prevent organic material entering the dry well (organic material is a source of contamination).
Inflow points	Where the stormwater enters the infiltration trench or dry well. **Trench:** inflow can be piped or via a swale or other pre-treatment device. **Dry well:** inflow via a pipe, usually downpipe from roof.
Overflow controls	Piped inflows will have an overflow pipe which will discharge directly to the stormwater system or overland flow paths. Trenches that receive inflow from the surface may have an overflow weir on the downstream side of the trench. When the weir is overtopped run-off will flow to a nearby catch pit or overland flow path. Overflow must be diverted safely to prevent flooding and erosion of surrounding land.
Observation well	A vertical perforated PVC pipe that is anchored to the bottom of the trench or dry well, with lockable cap (100-200mm diameter). Allows for maintenance inspections (to check infiltration rates) and if necessary to remove standing water that may indicate clogging or high groundwater levels. Larger trenches may require an inspection entry portal, however confined space health and safety measures should always be adhered to before entering the portal for inspection.
Surface layer	Visible surface of the infiltration trench or dry well. **Trench:** this layer is often pea gravel (depth of 300 mm) and the first stage of filtration. **Dry Well (or buried trench):** this layer will be topsoil and grass or paving (depth of 300mm) with no function other than aesthetics.
Dispersion pipe	A perforated horizontal pipe that runs the length of the trench or the width of the well. Disperses run-off from a piped inlet to the whole area. The dispersion pipe is covered by a filter sock to prevent clogging of storage media.
Geotextile	Non-woven geotextile material lines the walls and base of the trench or dry well to prevent migration of surrounding soil into the infiltration device and blinding of the surrounding soil by fine sediments. Geotextile can also be used between layers of media (e.g. sand and gravel) and to cap the dry well or trench before finishing the surface (e.g. grass, pavement). A non-woven geotextile is preferred due to its filtration ability and it is less likely to 'open' with pressure from aggregates or sediment.

Component	Description
Storage media	The component of the trench or dry well that provides storage of run-off (depth typically 1-2 m). Usually aggregate, run-off is stored in the voids which are usually 30%-40% of the total volume. Aggregate size will vary with the necessary infiltration rate but are often graded between 25 to 75 mm.
Base sand filter	At the bottom layer of the trench (not usually present in dry wells) and provides enhanced treatment of run-off. Depth of 150 mm to 300 mm. Can add fibric or hemic peat to target particular contaminants, however the addition of peat will reduce infiltration rates so must be considered during design phase. Geotextile should be used between the sand and the storage media.

14.3 Operation and maintenance manuals

Operation and maintenance manuals are often required as a condition of consent. Even if they are not, an operation and maintenance manual is very useful in documenting design and construction information of the device and providing methodologies for maintenance procedures. The maintenance manual for an infiltration device should include the pre-treatment device(s).

Typically an operation and maintenance manual should contain a log book section to record inspections and maintenance activities, technical information on the design and construction of the infiltration device, and a section for all the maintenance procedures which detail methodology and frequency.

14.3.1 Log books

The log book is perhaps the most important tool in managing an infiltration device as it provides details on all maintenance activities and inspections. The log should be kept simple so that it can be easily completed and record all necessary information that may be required as a condition of consent or contractual requirement.

Figure 106
Example log sheet for infiltration device maintenance.

OPERATION & MAINTENANCE – FIELD LOG SHEET Infiltration trench			**File No.**
			Date
			/ /
SITE: Henderson Valley Road, Auckland			
Date	**Procedure number**	**Comments/Actions**	**Name**
eg 4/5/09	ITM3	Pre-treatment swale mown; rubbish collected from top of the infiltration trench.	J. Smith
4/5/09	ITM2	Observation well checked after storm event (occurred 2/5/09) – only 100 mm of water base of well.	J. Smith

14.3.2 Technical information

This section provides all the background information on the design and construction of the infiltration device. If there are any faults with the infiltration device and it is not performing as planned, this section can assist in troubleshooting the problem, which could be design-related. Typically this section will include:

1. Long-term maintenance responsibilities including contact details for the owner, maintenance manager, site access contact as well as emergency contacts in the event of contamination spills or flooding.
2. Site location, legal description and details on how to access the site (situation map, and layout plan are important).
3. Consent numbers and details of issuing agency, including a summary of consent obligations and copies of consents.
4. Design information:
    a. Co-ordinates for the centre of the device.
    b. Levels to LINZ Auckland datum 1946.
    c. Type and infiltration rate of natural soil (form infiltration tests).
    d. Seasonal groundwater level information.
    e. Water quality volume.
    f. Design infiltration rate of infiltration device.
    g. Details of outlet structure and invert level.
    h. Diameter of orifice outlet, if any (mm).

i. Contributing catchment area (roofs) in m^{2}.

j. Contributing catchment area (paving) in m^{2}.

k. Contributing catchment area (pervious) in m^{2}.

l. Normal operating surface area of device in m^{2}.

m. Nominal depth of infiltration trench and media (mm).

n. Year of completion.

5. If required by the consenting authority, a detailed scale plan of the total contributing catchment with the same information in GIS shape file, DXF or DWG file format in NZTM projection.

6. Construction detail plans of the infiltration device.

7. Copy of geotechnical report, if applicable.

8. Copy of design calculations.

9. As-built plan, dated and showing dispersion pipe, observation well and connections to stormwater reticulation if applicable.

10. Construction photographs, if available. These are useful as they show the construction stages and in particular what is buried in the infiltration device (e.g. infiltration layers, dispersion pipe).

14.3.3 Procedures

This section provides the details for inspections and maintenance tasks. Section 15.3 below provides a generic maintenance schedule which can be adapted to the site specific requirements. The maintenance schedule will form the basis of any maintenance contracts that are tendered.

Reporting requirements, whether as a condition of consent or a contract, should be included as a procedure with details of the reporting format, contents and frequency. Any monitoring which is carried out should also be documented with details of how to undertake sampling or testing and where results should be submitted.

14.4 Maintenance schedules

Many infiltration trenches or dry wells fail soon after construction because of clogging. Maintenance and regular inspection of the device are essential in order to detect and rectify problems early, before more significant damage is done, such as completely clogging the device. Another issue is if a device is not functioning correctly there is a significant risk of contaminating groundwater.

A full inspection of the infiltration device is required annually, including full inspection of the pre-treatment device. Ideally a full inspection one year after construction should be carried out coinciding with the end of the defects liability period for the Contractor who constructed the infiltration device and may be done by them directly. Dry wells on private property should also be inspected to ensure run-off is not being diverted and that blockages or clogging have not occurred.

Table 36

Typical infiltration trench and dry well maintenance schedule.

Component	Recommended action	Frequency			
		Monthly	6-Monthly	Yearly	After storm events
Pre-treatment	REFER TO RESPECTIVE DEVICE CHAPTER DEPENDING ON TYPE OF PRETREAMENT USED E.g. swale, oil/water separator, sand filter				
	Remove rubbish, and sediment build up from pre-treatment device as required. Check and repair scouring and preferential flows into infiltration trench (if surface trench).	✓			✓
Inflow	Infiltration Trench: For surface trenches check for scouring and preferential flows into infiltration trench. Repair by leveling surface aggregate. In some instances a level spreader may need to be added to promote sheet flow.	✓			
	Dry Well: Check gutters and downpipes are clear of leaves and other debris. Clean any debris traps or screens.	✓			
Observation Well	Use the observation well to check that water is draining within the required amount of time (less than 48 hours).		✓		✓
	If the device is not draining use the observation well to vacuum the water out (sucker truck or other pump system). Note that water removed from an infiltration device may not be suitable for direct discharge to the stormwater system or surface water bodies without treatment. If no treatment is able to be provided the water should be treated as wastewater. If water needs to be removed on a regular basis, the infiltration trench may be clogged and require reconstruction.	As required			

Component	Recommended action	Frequency			
		Monthly	6-Monthly	Yearly	After storm events
Surface Layer	Trench: Check surface aggregate for sediment build up and remove trapped debris. If sediment built up, remove surface aggregate, wash and return to trench or replace (may be up to 300 mm). Depending on local soil suitability gypsum can be used to break up minor clay sediment deposition		✓		
	Geotextile Layer: If present, check for sediment accumulation and replace if necessary.		✓		
	Dry Well/Buried Trench: Mow grass and keep area free of rubbish. Use light weight hand mower so as not to compact surface.	✓			
Storage Media and Geotextile	If infiltration device is not draining, dig down through aggregate along one wall of the trench or well. Check aggregate for evidence of sediment build up and check geotextile for blinding by fine sediments. If sediment has built up remove aggregate to depth of build up, wash and return to trench. If geotextile is blinded try washing with a low pressure water blaster taking care not to puncture the geotextile. If this is unsuccessful the geotextile material will need to be replaced.	As required			

NOTE: A storm event is any heavy rain event or prolonged rainfall period where by flooding can occur or debris can be blown into the device (e.g. falling trees, or branches). Typically a storm event is >2-year event.

14.4.1 Unplanned or emergency maintenance

The need for unplanned or emergency works can result from storm events, vandalism, or uncontrolled activities within the catchment. Wind-blown dust from neighbouring catchment developments can also reduce the effectiveness of infiltration trenches as the fine dust typically not trapped in pre-treatment devices settles over the drainage area. In either case there can be a delay between incident, reporting and response particularly where the infiltration device is located away from public areas. It is important that the infiltration device is inspected after storm events so that any damage that could potentially cause flooding or be a hazard can be rectified.

Typical issues after a storm event include blocking of overflow outlets, deposition of sediment and rubbish within the infiltration device, and erosion of the pre-treatment device (e.g. swale).

Uncontrolled catchment activities can include uncontrolled discharge of sediment laden run-off from earthworks, discharge of contaminant spills, compaction of surrounding soils from vehicle parking or traffic. The procedures listed above should be used for any corrective maintenance. If the damage is extreme then a complete or partial re-build may be required. Details for this will be found in the technical information section of the operation and maintenance manual or the construction chapter for infiltration devices.

If a contaminant spill occurs, measures should be implemented to prevent the discharge reaching groundwater. Measures may include a boom or sock to prevent discharge from the spill area to the infiltration device, use of absorbent pads for surface spills, and removal of water out of the infiltration device from the observation well. Depending on the type of contaminant released and the extent of the spill, the infiltration trench or dry well storage media may require replacement.

14.5 Troubleshooting

There are a number of common problems that arise when an infiltration device is not maintained or if the use of the land surrounding it changes. Listed below are some of these common problems, suggested causes and potential solutions.

Table 37
Infiltration trench and dry well troubleshooting.

Symptom	Likely cause	Remedy
Water is not draining and is ponding in the infiltration device.	Storage media has become clogged with sediment.	Check catchment for sediment generating activities. Stop these or put in place diversion measures before attempting to fix the device. The only way to fix an infiltration device once clogged is to refurbish/renew it. Remove excess water via the observation well and a sucker truck. Wash or replace all aggregate, repair or replace geotextile material and re-lay.
	Fine sediments have clogged geotextile material.	Remove aggregate overlaying the geotextile fabric, replace the fabric and re-cover with aggregate. Follow operation and maintenance manual for correct installation.
Surrounding soil is spongy and waterlogged.	Soil has become compacted.	Aerate the soil with a garden fork, rotating aerator or ripper. If compaction is due to vehicle or pedestrian traffic install bollards or other measures to prevent access to the area.

Symptom	Likely cause	Remedy
	Change in site groundwater flows and levels.	Could be a seasonal high water table or groundwater flows may have changed due to other land uses or activities within the area. Investigation required. Location may no longer be suitable for infiltration.
Scouring and channels are developing.	Inflow is being concentrated at certain points.	Remove any blockages, including rubbish and build up of sediment. Fill as necessary. Construct a level spreader to distribute flows more evenly through the trench.

14.6 Compliance auditing and monitoring

Different regulatory authorities can have varying requirements for compliance depending on their jurisdiction. These can be performance areas in maintenance contracts, or part of consent conditions.

Auditing typically implies a compliance requirement while monitoring will tend to refer to performance of the infiltration device. An audit checklist can be developed based on the maintenance schedule. One of the first tasks in an audit is to correlate the log book with the maintenance schedule to determine if inspections and planned maintenance are taking place at the required frequencies. Audits should also look at the maintenance methodology as an opportunity for improvement and to ensure that short cuts and hazardous or inappropriate practices can be stopped. Audits can also identify maintenance trends that may help identify design improvements. Audits should be conducted at least once a year. Maintenance Contractors often undergo auditing for contract performance and health and safety compliance. The operation and maintenance audit can be conducted in conjunction with these audits.

Monitoring of the infiltration device would tend to focus on infiltration rates of run-off through the infiltration device. Infiltration rates can be monitored by checking the observation well and drain down after storm events. Infiltration devices should drain within 48 hours.

Reporting of results should be submitted to the owner and the regulatory authority or as stipulated in the auditing and monitoring schedule for the device.

14.7 Photo gallery – infiltration trenches and dry wells

Figure 107

Buried infiltration devices showing inspection/access ports (ACC, 2003, Soakage Design Manual).

Figure 108

Surface infiltration trench

Figure 109

Surface infiltration trench along roadway (ARC, 2007, Infiltration Trenches).

Figure 110

Infiltration soakholes, surface and interior view examples.

15 Appendix One: Technical Guidelines and Reports

15.1 Regional technical guidelines and reports

ACC	Auckland City Council
ARC	Auckland Regional Council
LTSA	Land Transport Safety Authority
MCC	Manukau City Council
NSCC	North Shore City Council
NZWERF	New Zealand Water Environment Research Foundation
RDC	Rodney District Council
WCC	Waitakere City Council

Publisher	Title	Description
ACC	On-site Stormwater Management Manual (December 2002)	Section 11 describes the requirements for operation and maintenance and monitoring of devices including owner's obligations, generalised operation and maintenance/monitoring requirements, and device-specific operation and maintenance plans.
ARC	TP10 Stormwater management devices: Design guidelines manual	These guidelines provide a commonly accepted design approach for stormwater management practices that will provide both water quantity and water quality benefits.
ARC	TP90 Erosion and Sediment Control Guidelines for Land Disturbing Activities in the Auckland Region	These guidelines outline the principals of erosion and sediment control and control measures that should be used.
ARC	TP124 Low Impact Design Manual for the Auckland Region	Approaches to site design and development from a stormwater management context, primarily applicable for residential land development.

Publisher	Title	Description
ARC	TP109 Dam Safety Guidelines	Advice on the health and safety issues around dams and other temporary dam structures (e.g. sediment retention ponds). This may be applicable to large ponds and wetlands.
ARC	Technical Report 2009/084 Fish Passage in the Auckland Region – a synthesis of current research	Updated version of TP131 and incorporates the most current research on fish passage issues and offers a range of options for the construction of fish-friendly in-stream structures.
ARC	TP153 Background Concentrations of Inorganic Elements in Soils from the Auckland Region	Provides background total recoverable levels of selected trace elements from major soil groups in the Auckland region. These can be used when determining if soils from rain gardens or sediment removed from ponds etc is contaminated.
ARC	TR 2009/083 Landscape and Ecology Values within Stormwater Management (Boffa Miskel, 2009)	Review of TP10 Chapter 14 and provides recommendations for landscape and ecology for each stormwater management device in TP10. Includes specifications for soil, planting and pest control.
ARC	TR 2010/017 Extensive Living Roof Design and Construction	The guide documents research into developing living roof design specifically for stormwater management. The research centers around design and retrofit of an extensive living roof constructed on the roof of the University of Auckland Faculty of Engineering building.
LTSA	Integrated Stormwater Management Guidelines for the New Zealand Roading Network	Provides guidance on a range of issues relating to the management of stormwater run-off from state highways and local roads in New Zealand.
MCC	Manukau City Council Stormwater Ponds	Applicable to Stormwater Ponds only. Sections of this document address maintenance requirements including a schedule and inspection checklists. Specifies contents of operation and maintenance manuals for ponds.
NSCC	Infrastructure Design Standards – Section 4: Stormwater	Section 4.17 provides details on the requirement for Operation & Maintenance Manuals for all public and private stormwater devices.
NSCC	Permeable Pavement Design Guidelines (September 2004)	Section 11 outlines maintenance and monitoring requirements of permeable paving systems.

Publisher	Title	Description
NSCC	Rain Tank Guidelines (July 2008)	Appendix B specifies contents for operation and maintenance manuals and provides example Owners Manuals for Rain tanks and Detention Tanks.
NSCC	Bioretention Guidelines (July 2008)	Section 8 provides information on the maintenance of bioretention devices (rain gardens, stormwater planters, tree pits, and bioretention swales).
NSCC	NSC05 Single-purpose Rain Tanks, NSC06 Dual-purpose Rain Tanks	Practice note giving general information on the minimum design requirements and maintenance of single and dual-purpose rain tanks to collect water from the roof and store for non-potable use.
NSCC	NSC07 Detention Tanks	Practice note developed to give general information on the minimum design requirements and maintenance of detention tanks for both residential and non-residential activities.
NSCC	NSC10 Bio-Retention	Practice note to provide guidance in meeting the minimum requirements proposed in Plan Change 22 for bio-retention for applicants seeking to follow a permitted or controlled activity route for on-site stormwater management.
NSCC	NSC11 Pervious Paving	Practice note to provide information on the design of pervious paving systems. Section 11.7 refers to maintenance requirements.
NSCC	NSC12 Green Roofs	Practice note to give information on the design of green roofs as one of the acceptable on-site stormwater mitigation measures for both residential and business zones.
NSCC	LB101 What you need to know	Description of the Long Bay stream protection areas and the required practice notes for different types of activities.
NSCC	LB102 On-Site Stormwater Mitigation	Practice note to assist choice of appropriate, cost effective stormwater management solutions and explains how to select pre-approved solutions using a stormwater migration factor or proposed alternative technologies.
NSCC	LB103 Rainwater Harvesting	Practice note to assist with the design of rainwater tanks in the Long Bay area.
NSCC	LB104 Management of Driveway Run-off	Practice note to assist with the management of driveway run-off in the Long Bay area including specific requirements for stream protection areas.

Publisher	Title	Description
NSCC	LB105 Erosion and Sediment Control Lot Level	Practice note to assist with erosion and sediment control, includes appropriate controls, consent requirements at the individual lot level.
NSCC	LB106 Landscape Protection Areas	Practice note defining landscape protection areas and their requirements.
NSCC	LB107 Long Bay Water Supply Systems	Practice note to be used in conjunction with NSCC Infrastructure design standards for the design and construction of the Long Bay water supply system.
NSCC	LB108 Improved traditional Wastewater System	Practice note to be used in conjunction with NSCC Infrastructure design standards to provide standards for an "improved traditional" wastewater system.
NSCC	LB109 Primary and Secondary Stormwater Systems	Practice note for design of primary and secondary overland flowpaths.
NSCC	LB110 Other Technologies	Practice note based on the ARC's TP10, describing requirements for alternative technologies to meet the Long Bay water quality and quantity management objectives.
NSCC	LB201 Minimising Impervious Areas	Practice note providing ideas for minimising impervious areas.
NSCC	LB202 Bush Revegetation	Practice note detailing the benefits of bush revegetation to reduce volumes of stormwater run-off from site.
NSCC	LB203 Pervious Paving	Practice note describing the benefits and considerations for design and construction of pervious paving.
NSCC	LB204 Rain Gardens	Practice note describing the benefits and site considerations for rain gardens used to treat stormwater from small catchment areas.
NSCC	LB205 Swales Filter Strips	Practice note for the design requirements for swales and filter strips in Long Bay, including some pre-approved designs.
NSCC	LB206 Flow Dispersers	Practice note describing flow dispersers, these are used to ensure the effectiveness of other treatment devices and to prevent erosion.
NSCC	LB207 Bio-filtration Trench	Practice note detailing construction techniques for bio-filtration trenches, Long Bay is assumed to be not conductive for infiltration.
NSCC	LB208 Green Roofs	Practice note with a brief description of considerations for the installation of green roofs.

Publisher	Title	Description
NSCC	LB209 Worked Examples	Some worked examples showing the steps for design of stormwater management devices such as filter strips and rain gardens.
NSCC	LB301 Stormwater Treatment for Roads	Practice note describing the on-site mitigation of stormwater run-off that must be incorporated into roading design to meet the rules of the Long Bay Structure Plan Area.
NSCC	LB302 Conditioning of Surface Soil	Practice note providing guidance on conditioning surface soils in the Long Bay area to produce soil profiles that more closely resemble original natural surface soils.
NSCC	LB303 Erosion – Sediment Control Subdivision	Practice note providing guidance on the requirements and descriptions of erosion and sediment control practices at the subdivision level.
NSCC	LB401 Riparian Management	Practice note detailing best practice and regulatory options and the desired outcomes for the Long Bay catchment to assist with selecting the best options for riparian planting.
NSCC	LB405 Fish Habitat Management	Practice note outlining best practice and regulatory and desired objectives for maintaining passage and spawning grounds for fish in the Long Bay area.
NSCC	LB403 Spring and Seepage Management	Practice note detailing guidance for spring and seepage management including retaining springs and seepages, preventing stock and human access to springs and seepages etc.
NSCC	LB 404 Stream bank Management	Practice notes detailing the benefits and considerations of stream bank management to reduce loss of land and prevent destabilisation of assets.
NSCC	LB405 ephemeral Stream Management	Practice note describing the benefits of ephemeral streams to catchment ecosystems and guidance on ephemeral stream management.
NSCC	LB406 Managing your Stream Project	Practice note giving information on how to get started on stream restoration including defining goals and concept plans.
NZWERF	Onsite Stormwater Management Guideline (October 2004)	Appendix D gives information on models for delivery of O&M of treatment devices, general O&M practices, and device specific O&M checklists.

Publisher	Title	Description
RDC	Rodney District Council Standards for Engineering Design and Construction (23 April 2009)	Section 4 specifies requirements for operation and maintenance manuals.
RDC	Management of Stormwater in Countryside Living Zones (Rural and Town) (2005)	Section 10 outlines the maintenance and monitoring requirements for stormwater treatment devices.
WCC	Code of Practice for City Infrastructure and Land Development (August 2005)	Section 4 provides information on O&M requirements specifically contents of O&M Manuals.
WCC	Countryside and Foothills Stormwater Management Code of Practice (2005)	Section 10 outlines the maintenance and monitoring requirements for stormwater treatment devices.

15.2 International technical guidelines and reports

Organisation	Title	Description
California Department of Transportation (CALTRANS)	Stormwater Quality Handbook: Project Planning & Design Guide	Extensive information on stormwater management, design of treatment devices and project delivery (e.g. construction contracts).
California Department of Transportation (CALTRANS)	Stormwater Quality Handbooks: Construction Site Best Management Practices Manual	Focus on erosion and sediment control at construction sites.
ACT Government – Territory and Municipal Services	ACT Government Design Standards for Urban Infrastructure	Urban infrastructure standards for all infrastructures (e.g. roads, parks, pipelines).
Moreton Bay Waterways and Catchments Partnership	Water Sensitive Urban Design Technical Design Guidelines for South East Queensland	Low impact urban infrastructure design guidelines with information on construction and operations and maintenance.

Organisation	Title	Description
Tim D. Fletcher, Ana B. Deletic & Belinda E. Hatt Department of Civil Engineering & Institute for Sustainable Water Resources, Monash University	AWA Water Conservation & reuse research program – A review of stormwater sensitive urban design in Australia	Research into performance of low impact urban stormwater design, and review of case studies, including construction and maintenance.
Gold Coast City Council, Queensland Australia	Land Development Guidelines – Section 13 Water Sensitive Urban Design Guidelines	Water sensitive urban design guidelines from concept through to construction and maintenance
Department of Ecology, State of Washington, United States of America	Stormwater Management Manual for Eastern Washington	Guidance in stormwater design and management for eastern Washington. Includes construction BMPs.
Department of Environmental Conservation, New York State	Construction Stormwater Toolbox	Suite of documents to assist with compliance with the General Permit for Construction Activities includes erosion and sediment control and stormwater design specifications and performance.

16 Appendix Two: Regulations and Standards

Act	Description
Health and Safety in Employment Act (1992)	Details the various duties of persons who are responsible for work and those who do the work. Also defines hazards and harm in a comprehensive way so that all hazards and harm are covered.
Resource Management Act (1991)	The main piece of legislation that sets out how we should manage our environment. It's based on maintaining the sustainable management of our resources, and it encourages planning for the future of our environment.
Building Act (2004)	Regulates constructing, altering, demolishing and maintaining new and existing buildings throughout New Zealand. It sets standards and provides procedures for people involved in building work to ensure buildings are built properly first time.
Hazardous Substances and New Organisms Act (1996)	Provides information to be used in preventing or managing the adverse effects of hazardous substances and new organisms.
Health Act (1956)	Aims to improve, promote, and protect public health by specifying responsibilities, reporting requirements, risk assessment and management, and imposing obligations. Including pollution of water courses, drinking water supply and refuse and waste management.
Auckland Metropolitan Drainage Act (1960)	This Act empowers Watercare Services Limited (then the Auckland Metropolitan Drainage Board) to manage the regions sewerage systems and enable pipeline maintenance and emergency works. Includes trade waste, stormwater and discharges to open water.
North Shore Drainage Act (1963)	This Act empowers the North Shore City Council (then the North Shore Drainage Board) to manage the District's sewerage systems and enable pipeline maintenance and emergency works.
Local Government Act (2002); and Local Government (Auckland Council) Act (2009)	States the purpose of local government and empowers local authorities' framework and powers to decide which activities they undertake and the manner in which they will undertake them. Promotes the accountability of local authorities to their communities. Provides for local authorities to play a broad role in promoting the social, economic, environmental, and cultural well-being of their communities and taking a sustainable development approach.

16.1 Standards and codes

Title	Description
Guidelines for the Provision of Facilities and General Safety in the Construction Industry	Relevant sections of the Health and Safety in Employment Act (1992). Guidelines based on standards contained in former legislation and generally accepted good practice.
Code of Practice for Manual Handling	Explains how the Health and Safety in Employment Act (1992) applies to manual handling tasks.
Building Code	The Building Code provides acceptable solutions that, if followed, mean that a building will automatically comply with the Building Code. They also contain Verification Methods that provide a means of testing that a building complies with the Building Code. The Building Code Handbook contains information on how the building controls regulatory framework works, current definitions, lists of all standards referenced in the Compliance Documents, Building Code Clauses and a current index for Compliance Documents.
NZS 3910:2003 Conditions of contract for building and civil engineering construction	Provides a standard form of general conditions of contract for incorporation into construction contract documents. Usually with this contract form the Contractor constructs the works in accordance with the design provided by the Engineer, however, it may also be suitable for contract works for which the Contractor, wholly or partly, has design responsibility.
NZS 3915:2005 Conditions of contract for building and civil engineering construction (where no person is appointed to act as engineer to the contract)	Provides a New Zealand standard contract form for incorporation in building and construction contract documents, in situations where the client (Principal) administers the contract directly. Also includes conditions of tender and forms for special conditions, contract agreement and bonds for contractors and principals. Provides a range of disputes resolution procedures. The intent and content of this Standard has been aligned with NZS 3910:2003 and the provisions to the Construction Contracts Act 2002.
NZS 6802:2008 Acoustics – Environmental Noise	Sets out procedures for the assessment of noise for compliance with noise limits, and provides guidance for the setting of noise limits for consent conditions, rules or national environmental standards.

Title	Description
NZS 6803:1999 Acoustics – Construction Noise	Covers the measurement and prediction of noise from construction, maintenance and demolition work, and the assessment of such noise to determine whether action is required to control it. Includes the normal hours of work.
Proposed Auckland Regional Plan: Air, Land and Water	The Proposed Auckland Regional Plan: Air, Land and Water (ALW Plan) has been prepared in order to achieve the purpose of the Resource Management Act (1991).
SNZ HB 2002:2003 Code of Practice for Working in the Road	This Handbook deals with aspects of the roles and responsibilities of Road Controlling Authorities, principal providers, utility operators and contractors; consents and work approvals; and details of construction requirements; for the purpose of installation and maintenance of utilities within the road corridor.
Department of Labour: Approved Code of Practice for Excavations and Shafts for Foundations	Part One covers trenches and excavations. This section also includes recommendations intended to assist engineers who may be involved in the design of shoring. Part Two covers shafts, drives and the construction of large-diameter shafts for piling, where persons enter for inspection or other work purposes.
Department of Labour Approved Code of Practice for the Safe Handling, Transportation and Erection of Pre-Cast Concrete	This code of practice refers to design issues specific to the safe handling, transportation and erection of precast concrete elements. The design and construction of all precast elements must be in accordance with the overall building design, and shall comply with the requirements of the New Zealand Building Code.
Department of Labour Approved Code of Practice for the Provision of Facilities and General Safety in the Construction Industry	These general guidelines apply to all construction workplaces. They contain relevant sections of the Health and Safety in Employment Act (1992) and regulations, generally accepted good practice and references to further information.
Department of Labour Approved Code of Practice for Operator Protective Structures on Self-Propelled Mobile Mechanical Plant	This code of practice has been prepared jointly by the Occupational Safety and Health Service and the New Zealand Contractors' Federation, in consultation with the construction and forestry industries. It provides best practice measures for employers to consider when managing mechanical plant roll over hazards in a way that meets the requirements of the Health and Safety in Employment Act and Regulations.
Department of Labour Approved Code of Practice for Manual Handling	This Code sets a process that may be used to identify, assess and control hazards associated with manual handling. This is likely to include serious back injuries, acute low back pain and other work-related musculoskeletal disorders such as disorders of the neck, shoulders, knees, arms and hands.

Title	Description
Department of Labour Best Practice Guidelines for Working at Height in New Zealand	These guidelines provide practical guidance to all engaged in work associated with working at height on how they can meet their obligations under the Health and Safety in Employment Act 1992 and its associated Regulations. Adherence to these Best Practice Guidelines is recommended.
Department of Labour Safe Working in a Confined Space	Set of 11 information sheets provide general, non-technical information on safe working in a confined space, and includes examples of accidents. It is intended to supplement Australian Standard 2865: 1995 Safe working in a confined space.
Drinking Water Standards (DWS) (2005)	The DWS 2005 details how to assess the quality and safety of drinking water using the revised water quality standards and compliance criteria. The drinking water standards apply to drinking water, that is, water intended to be used for human consumption, food preparation, utensil washing, oral or personal hygiene.