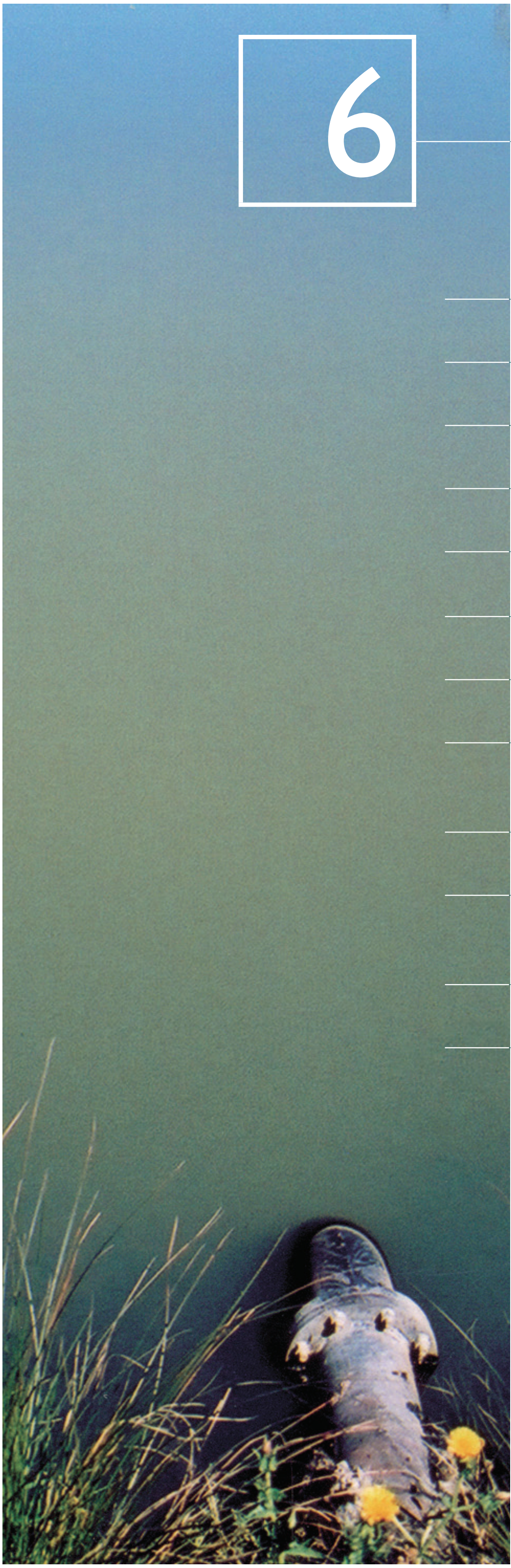


Stormwater Treatment Systems


View of the outlet structure for the Wigram detention/treatment basin

6.1 Introduction

Stormwater treatment systems installed along the waterways and drainage network of Christchurch, have to date focused on sediment retention. Systems range from small-scale on-site interceptors located near the source of the specific contamination, to large-scale ponds and basins located downstream of large urban catchments. The first generation of large-scale stormwater treatment systems in Christchurch, misnamed 'silt traps', were installed after severe sediment deposition in the Heathcote/Ōpāwaho River and its tributaries. This was largely a result of erosion from the Port Hills that occurred during extreme storms in the mid 1970s. While such structures may have been useful to reduce sedimentation during development, their ability to efficiency in remove chemical contaminants from stormwater in mature urban catchments is limited. Further, their utilitarian form is no longer an acceptable solution.

Notwithstanding the functional requirements of any treatment system, acceptable solutions today must also meet additional "values" criteria such as landscape, recreation, ecology, etc. The Wigram detention basin is a good example of a values approach, as it incorporates amenity and ecological values. Current research into stormwater treatment is also identifying other, less traditional methods for stormwater treatment, such as the use of constructed wetlands.

In determining what is an appropriate stormwater treatment system for any catchment, it should be understood that whilst sediment is the primary contaminant during the early stages of any urban development, it becomes a lesser concern as urban developments mature. Chemical contaminants however, do become more important as the intensity of urban contaminant sources (buildings, roads, vehicles, etc) increase. These chemical contaminants are either in dissolved form or bound to particulate matter, with bound contaminant concentrations being higher for fine particles than coarse particles.

The primary aim of stormwater treatment for mature urban catchments (i.e. those that are not major sources of sediment) should therefore be to:

- Remove the highly contaminated fine particulate matter. This cannot be achieved without also removing the coarser particulate matter, so requires the removal of both fine and coarse particulates.
- Reduce dissolved contaminant concentrations, particularly during rainfall events.
- Reduce bioavailability of residual (after whatever treatment is used) dissolved contaminants.

Adsorption of contaminants onto the surface of suspended particles, sediment, organic matter, and vegetation, is a principle mechanism for removal of dissolved contaminants and contaminants bound to fine particulate matter (Leersnyder, 1993).

Properly functioning treatment facilities, such as Wigram wet pond, remove an average of 75% of the incoming contaminant load on an annual basis; the exact figure differing for different contaminants (Brown *et al*. 1996). Stormwater treatment of this type is referred to as the 'best practicable option' (BPO) or best management practice (BMP). BPOs reduce the contaminant load as much as practically possible. Note that they may not, however, ensure that specific standards for environmental protection are met. Recent New Zealand research indicates that even with BPOs in place, in the long term, toxic contaminants in stormwater are still likely to accumulate in the sediments of receiving environments (the waterways and estuary), to levels that will harm aquatic life. Caution is therefore required in their implementation.

Stormwater treatment systems must be considered on a case by case basis. In a landmark case before the Environment Court in 1996, the Auckland Regional Council successfully argued that the North Shore City Council should not extend the metropolitan limits of Auckland into the hitherto undeveloped catchment of the Okura Estuary. The decision in the case accepted the evidence that the current BPO treatment devices could not guarantee that ecological and environmental values would be maintained when the catchment was developed.

Because urban development will degrade the water quality of receiving waters, even with BPOs in place, proposals should always place significant emphasis on controlling contaminants at their source and by protecting unmodified tracts of land. The control of contaminants at source can include:

- Decreasing point source contaminant inputs in residential areas from such things as the illegal disposal of household chemicals, biocide residues, and used engine oil, as well as the cleaning of cars. The Ministry for the Environment (MfE) have published tips for reducing point source contamination in residential areas, which can be found on their web site: www.mfe.govt.nz
- Improving industrial practices that currently cause contamination of stormwater and therefore streams (e.g. improper disposal of cement, acid, alkali, resin forming chemicals, detergents, nutrients and timber treatment chemicals). MfE have published guidelines for developing safe water discharge from sites with petroleum products (MfE 1998), available from their web site www.mfe.govt.nz

- Reducing the sediment load created from construction work during development from entering stormwater systems and waterways. This requires special consideration. For practical guidelines refer to Environment Canterbury's Erosion and Sediment Control Guidelines (Environment Canterbury, 2007).

Stormwater treatment is an evolving subject, with councils throughout New Zealand (including Christchurch) developing frameworks. For example, Waitakere has a particularly comprehensive draft plan (Waitakere City Council, 2000). The Christchurch City Council has also developed a "Surface Water Strategy 2009–2039" for Christchurch (Christchurch City Council, 2009). This can be accessed through Council's website www.ccc.govt.nz (search name: surface water strategy 2009–2039).

6.1.1 Stormwater Contaminants

Urban stormwater contains contaminants that can be broadly divided into five groups: suspended solids, nutrients, hydrocarbons, metals, and microbes. The potential impact of these contaminant groups on receiving waters is presented in Table 6-1. Table 6-2 is a guide to likely discharge concentrations in certain modified catchments for some of these stormwater contaminants, drawn from various New Zealand data. Also provided are ANZECC (2000) trigger levels; conservative figures that need to be supplemented by actual tests of runoff, estimates of the bio-availability of the contaminants, and toxicological data for the receiving environment.

Table 6-1: Urban storm contaminants and their potential impacts on receiving waters. Refer to Chapter 2.2.5: Reduction in Water Quality, for more detailed information.

Contaminant	Impact on Environmental Values
Suspended Solids	Reduced light levels, and smothering of the bed substrate (when suspended solids settle out). Increased Biochemical Oxygen Demand (BOD) from organic materials.
Nutrients	Nuisance plant growth (if no other factors are limiting), and increased BOD.
Hydrocarbons	Oxygen depletion of waters (Chemical Oxygen Demand, COD).
Metals	Impact on the physiology of plants, chronic and acute effects on animals.
Microbes	Potential impacts on human health.

Table 6-2. Dishcarge concentrations of some stormwater contaminants for different land use categories in New Zealand and ANZECC (2000) trigger levels.

Site	Total Suspended Solids	Cadmium	Copper	Lead	Zinc	Nitrogen TN	Phosphorous TP
	g/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3
Urban (10%ile)[1]	50	–	15	–	90	1300	200
Urban (50%ile)[1]	170	–	40	–	260	2500	420
Mature New Urban (75%ile)[2]	70	–	7	4	80	1000	–
Mairangi Bay (residential)[3]	–	0.09	8	2.5	80	–	–
Pakuranga (residential)[4]	–	0.06	15	–	444	–	–
Hayman Park (commercial)[5]	30	–	38	–	249	–	140
Riccarton Main Drain (residential)[6]	62	–	–	–	400	1000	250
Milnes Drain (flat rural/residential)[6]	128	–	–	–	200	1800	400
Wigram Detention Basin (mixed)[7]	101	1.30	14	33.0	412	–	–
Tranzlink Pond (industrial/commercial)[8]	95	–	31	19.8	673	3688	–
ANZECC (2000) trigger level (90% protection)[9]	(25)[10]	0.4	1.8	5.6	15	–	–
ANZECC (2000) trigger level (for lowland rivers)	–	–	–	–	–	614	33

[1] Williamson (1993); [2] Brough *et al.* (2012); [3] Opus (2000, cited in Kingett Mitchell *et al.* 2001); [4] Auckland Regional Council (1992); [5] Leersnyder (1993); [6] Main (1994); [7] Brown *et al.* (1996); [8] McMurtrie & Lerner (2009); [9] Trigger values are for a water hardness of 30 g/m^3 $CaCO_3$, and must be adjusted if hardness varies. [10] There are no ANZECC (2000) guidelines for Total Suspended Solids, with values relating to visual clarity instead. In the absence of any guideline value the CCC considers that anything under 25 g/m^3 is acceptable, but this must be considered in context with other guidelines or standards for visual clarity.

6.2 The Treatment System Selection Process

There are several steps involved in choosing the most appropriate treatment system for effectively reducing contaminant levels and controlling flood flows for any specific catchment. These steps involve the following, which are outlined in the specified sections:

1) Follow the current Christchurch City Council practices and objectives for stormwater treatment systems:
    - *Section 6.2.2: Current Council Practice for Stormwater Treatment Systems.*
2) Determine the likely contaminant levels for the catchment:
    - *Section 6.2.3: Determining Contaminant Levels.*
3) Become familiar with the current treatment systems and treatment train options, and their operation and maintenance requirements:
    - *Section 6.2.1: General Considerations*
    - *Section 6.2.4: Types of Stormwater Treatment Systems*
    - *Section 6.3: Pretreatment devices (MPTs and swales)* (see also *Section 5.2.1.1 Vegetated Swales*)
    - *Section 6.4: First Flush Interception*
    - *Section 6.5: Soakage Systems*
    - *Section 6.6: Detention Basins*
    - *Section 6.7: Constructed Wetlands*
    - *Section 6.8: Detailed Design for Detention Basins and Wetlands*
    - *Section 6.9: Operation and Maintenance.*
4) Consult the provided selection tools, which outline the capabilities and limitations of various treatment systems:
    - *Section 6.2.5: Selection Tools.*

These steps should be followed to make an informed decision as to the most appropriate treatment system for the development. All designs shall provide for operation and maintenance requirements.

Refer to S*ection 6.10: Planning, Design, and Operation Checklist,* for additional guidance on the steps involved in designing and building an efficient stormwater treatment system which has regard to the six values approach to surface water management.

The decision process should always be discussed and approved by the Council Asset Owner prior to any formal adoption of treatment systems.

6.2.1 General Considerations

Design and implementation of stormwater treatment systems is a complex issue that can only be adequately addressed by considering whole catchments, and seeking input from an experienced multi-disciplinary team. Designers must consider stormwater treatment for any development with the understanding that the effectiveness of any treatment system will be dependent upon catchment characteristics and good environmental design. The long term success of new stormwater treatment systems will also depend on good attention to operation and maintenance details.

General guidelines for an effective treatment train, which incorporates soakage systems, detention basins, and constructed wetlands include:

- Keep the mitigation close to the source of the problem.
- Reproduce the pre-development hydrological conditions, and determine base flows.
- Consider catchment short term and long term needs.
- Take advantage of natural contours.
- Understand the natural topography in order to situate the treatment system in the appropriate place.
- Provide effective stormwater pretreatment (e.g. silt traps, swales, macro-pollutant traps, debris traps)
- If space is limited, focus on first flush capture and treatment (minimum requirement).

  Note: Council requires full treatment with greenfield developments.
- Understand the local groundwater level regime and design accordingly.
- Clearly decide whether the feature is to be "wet" or "dry" during dry weather and design accordingly.
- Apply life cycle design principles. For example, target sustainable maintenance regimes, and provide for infrequent maintenance events such as sediment removal, liner repair, plant harvesting, and plant replacement.
- Consider the need for a large storm event bypass (which can also serve as a bypass during maintenance work).
- Provide emergency spillway and secondary flow path.
- Design total capacity to allow for plant growth within the treatment system.
- If possible, co-location with other reserves can give an improved community asset.
    - 'Bigger is better'
    - Avoid locating facilities like wetlands that have potential nuisance issues associated with them, close to high density residential areas

Include Natural Values

In the past stormwater treatment systems have been designed in a very utilitarian way, often constrained by adequate provision of land. The Christchurch City Council now requires such artificial facilities to follow natural drainage processes and be designed and managed for a full range of values. For example:

- Large-scale stormwater treatment systems such as constructed wetlands, soakage systems, and basins should be designed for a range of values, including ecological, recreational, cultural, landscape, heritage and drainage values, and in a way that considers public safety (Figure 6-1). Maintenance is often minimised with large scale naturally functioning systems.
- Small-scale, on-site stormwater treatment systems require an effective maintenance regime set in place when they are installed. Unfortunately in many instances this has not been implemented.

6.2.2 Current Council Practice for Stormwater Treatment Systems

In assessing water quality and management issues associated with any development, certain objectives should be considered. Any water management or treatment system shall:

- Make special provision to protect waterways from high short term sediment discharge in any new development with significant earthworks. Refer to Environment Canterbury's Erosion and Sediment Control Guidelines (Environment Canterbury, 2007) for useful, practical mitigation measures.
- Reproduce as near as practicable, the existing hydrological conditions in flows from the site. This will require an assessment of runoff flows including base flow.
- Provide a system for pollutant removal to reduce (or at least not increase) existing pollutant concentrations in the receiving environment. Critical pollutants need to be identified and receiving water targets known. This will be defined in the Stormwater Management Plan (SMP), or draft SMP for the catchment area, when operative, and may require pre-design monitoring and assessment of the expected annual pollutant load from the new development area using the 'simple method' outlined below (*Section 6.2.3: Determining Contaminant Levels*).
- Be consistent with any SMP or draft SMP for the catchment area. Where an SMP is not available for the catchment area, consult with the Council Asset Owner representative on how to best achieve an integrated approach that considers the development in context of the greater catchment area.
- Have a system and design that is appropriate for the site, given physical constraints.
- Be cost-effective, provide for easy and practical maintenance, and have an acceptable future maintenance burden that includes considering the need for ongoing monitoring requirements.
- Where integration with a wider catchment scheme is not possible, have a minimum of first flush capture (*Section 6.4: First Flush Interception*) to treat stormwater from paved areas. This recognises constraints such as site and economics, which may

Figure 6-1: Large-scale stormwater treatment systems, such as the Wigram Detention Basin, have been designed to incorporate additional values, such as ecology and landscape, as well as stormwater treatment and drainage.

prevent the creation of a larger system.

- Have a positive, or at least a neutral impact on the natural and human environment.
- Incorporate a 'six values' approach, which includes ecology, landscape, recreation, heritage, culture, and drainage values, with careful consideration to safety.

6.2.3 Determining Contaminant Levels

Simple Method for Estimating Annual Urban Contaminant Loads from Developing Areas

As a preliminary design step, designers must determine likely stormwater contaminant levels from their development, and the degree of treatment required to meet the downstream receiving water requirements.

To bring a degree of objectivity, and for the purpose of comparison in water quality assessment of any new development, the use of this 'simple method' (Schueler, 1991) for estimating urban pollutant loads is recommended.

The simple method outlined below is intended for individual development sites that are less than 250 hectares. Despite its simplicity and generality, it is currently considered reliable enough for non-point pollution management decisions at the site level. Urban pollutant export (L) in kilograms per year can be determined by the following equation:

$$L = \varphi\, P\, C\, K_p\, A/100{,}000 \quad \text{(kg/yr)} \qquad \text{Eqn (6-1)}$$

where
- P = Rainfall depth (mm/year). Adopt mean annual rainfall depth given in Figure 21-4 (typically 650 mm).
- φ = A correction factor for P for storms that produce no runoff. Adopt 0.85 for Christchurch.
- C = Catchment runoff coefficient for the site. Refer to *Chapter 21.3.4: Runoff Coefficient.*
- K_p = Flow-weighted mean concentration of pollutant in urban runoff (mg/m^3). Use values in Table 6-3.
- A = Total area of site (ha).

The adopted provisional values of K_p (Table 6-3) rely on borrowed data from other cities/countries that seem appropriate for Christchurch conditions. K_p values will be adjusted as, and when, more reliable local data is obtained through monitoring.

Exercise care when relying on 'simple method' estimates of pollutant loads, because:

- The simple method only estimates pollutant loads generated during storms. Any pollutants associated with base flows should be considered separately. Typically these will be low or close to natural background levels.
- It should only be used for developed catchments.
- Care is needed in determining pollutant load for any undeveloped catchment where proposed development area will only contribute a small impervious area to the total catchment.
- Special consideration is needed for pollutant loadings under certain conditions; site disturbances during construction, heavy industrial sites, heavily travelled highway, and undeveloped areas.

6.2.4 Types of Stormwater Treatment Systems

There are many stormwater treatment devices for improving water quality. The typical Christchurch approach to date has included the following.

Pretreatment Devices:

- macropollutant traps (MPT) *(Chapter 13.4: Grills in Waterways)*
- swales *(Chapter 5.2.1.1: Vegetated Swales)*

Soakage Systems:

- soakage swales *(Chapter 5.2.1.1: Vegetated Swales)*
- infiltration chambers
- soakage basins (soil adsorption basins).

Table 6-3: Recommended provisional mean concentrations of pollutants in urban runoff (K_p values) for Christchurch (Schueler, 1991). Data are from other cities, but seem appropriate for Christchurch conditions.

Urban Pollutant	Flow Weighted Mean Concentration (K_p) Factor g/m^3	Flow Weighted Mean Concentration (K_p) Factor mg/m^3
Suspended solids		
less than 10 ha	33	33,000
greater than 10 ha	33-200	33,000-200,000
construction	4000	4×10^6
Total Phosphorus		260
Total Nitrogen		2500
Chemical Oxygen Demand (COD)		35,600
Biochemical Oxygen Demand (BOD)		7000
Zinc		400
Copper		50
Lead		75
Hydrocarbons		500

Detention Basins:

- wet ponds
- dry basins.

Constructed Wetlands:

- surface flow wetlands
- subsurface flow wetlands.

The treatment systems are summarised in Table 6-4, along with their specific function and additional values. The ability of these systems to both treat stormwater and ameliorate flood flows, as well as specific design considerations, are discussed in the following sections.

These systems can be considered as stand-alone, however best practice will usually dictate they be considered in combination as outlined in Table 6-5. Individual treatment systems are effective at removing different types of contaminants, so the incorporation of several treatment systems will ensure more efficient contaminant removal. For example, Figure 6-2 illustrates the different contaminants removed and the processes that occur in a treatment combination incorporating a detention basin and wetland.

Any stormwater treatment system should therefore be viewed as a treatment train. The more carriages or treatment components included in the train, the better the performance of the system. The type of treatment train will depend on the receiving environment.

In Greenfield development where soakage to ground is not feasible the Council's preference is for dry first flush basins, followed by secondary treatment through constructed wetlands. Constructed wetlands are on the list of 'most preferred' stormwater mechanisms to achieve water quality goals in the Council's Surface Water Strategy, 2009–2039 (Christchurch City Council, 2009).

6.2.5 Selection Tools

To aid the choice of treatment train for a site, a series of selection tools are presented in Tables 6-6 to 6-9 that can be used to compare the capabilities and limitations of various systems.

The selection tools consider:

- representative removal capability of treatment systems for a number of urban pollutants
- common restrictions on treatment systems
- comparative stormwater benefits
- natural or human amenity values that can be achieved with the treatment system.

Physical constraints of the site, such as contributing catchment size and soil conditions should also be considered when choosing a treatment system.

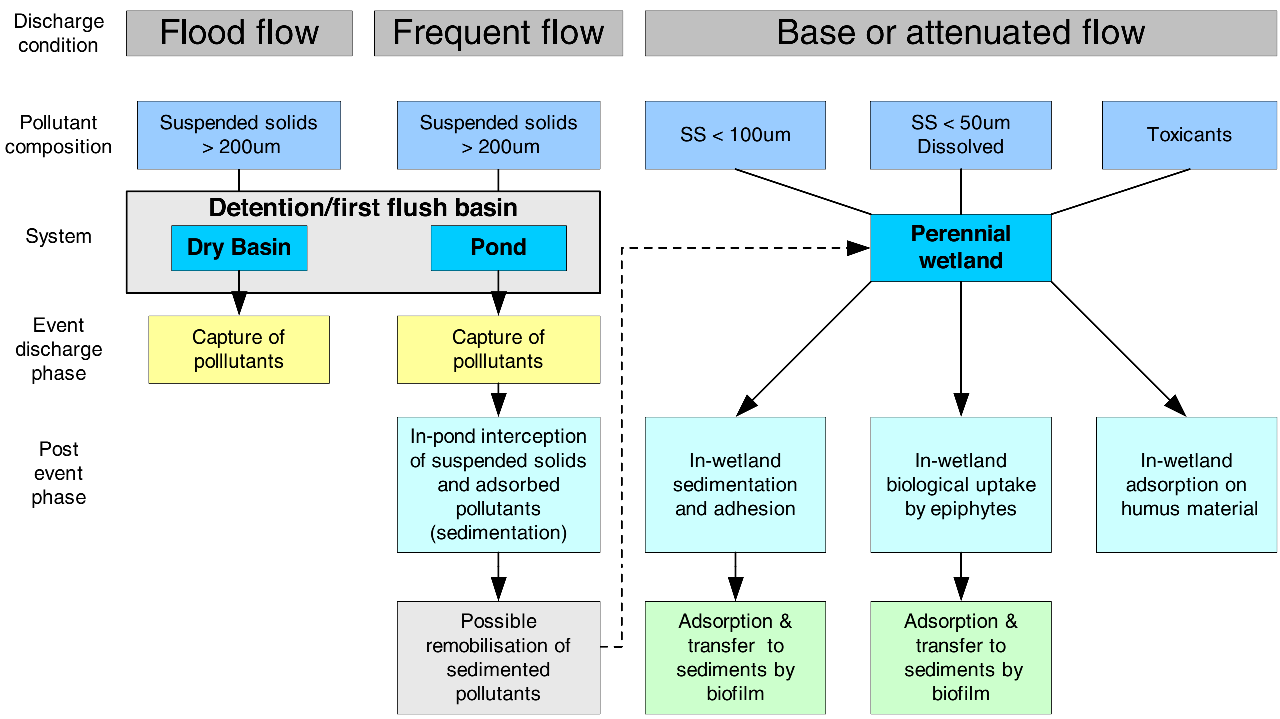
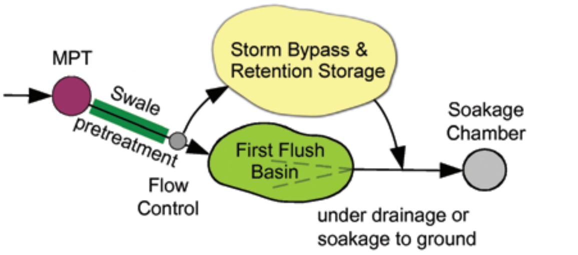
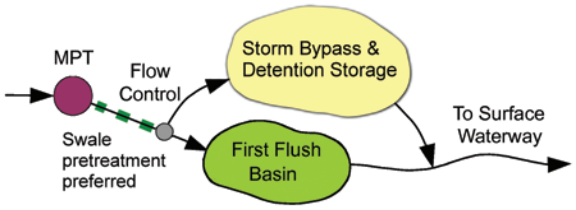
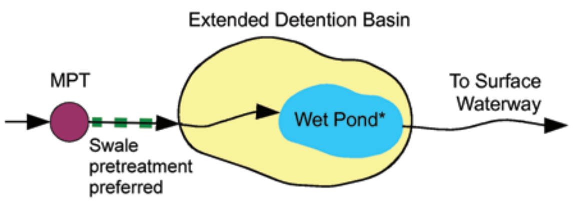
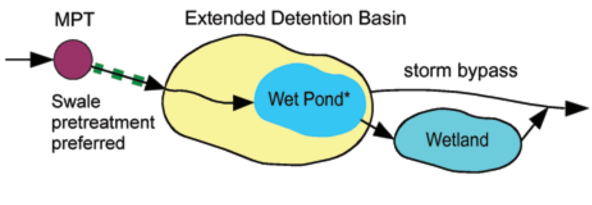
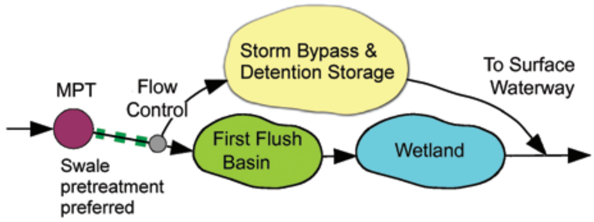


Figure 6-2: The treatment process for a treatment train incorporating a detention basin (or first flush basin) and wetland. Adapted from Lawrence & Breen (1998).

Table 6-4: Examples of different stormwater treatment systems, including their specific functions and additional values.

System Type and Illustration	Facility and Ownership	Specific Function	Additional Values
Pretreatment Devices	**Macropollutant Traps (grates, sumps, grills, debris racks)**		
	Private or public system Grates, grills: *Chapter 13.4: Grills in Waterways*	Trap coarse sediment and macro-pollutants	Protection against block-age Safety
	**Swales** Small scale on-site pri-vate or public system See *Chapter 5.2.1.1: Vegetated Swales*	Temporary stormwater detention Some filtration Trap sediment	Streetscape Avoids sumps and traps Conveyance
Soakage Systems	**Rapid Infiltration Chambers**		
	On-site private system or communal public system	Stormwater retention Stormwater treatment	Groundwater recharge
	**Soakage Basins** Public system	Stormwater retention Filtration, denitrification, and phosphorus removal	Groundwater recharge Landscape Recreation
Detention Basins	**Wet Ponds**		
	Public system	Temporary stormwater detention Removal of coarse to fine particles	Wildlife Landscape Recreation
	**Dry Basins** (mostly dry except dur-ing and after storms) Public system	Temporary stormwater detention Removal of coarse to me-dium particles	Landscape Recreation Adds to reserve areas
Constructed Wetlands	**Surface/Subsurface Flow** (can be ephemeral)		
	Public system	Removal of dissolved con-taminants and fine particles Medium-term stormwater detention Filtration and denitrification	Encourages a more natural functioning system Increases plant diversity Groundwater recharge Landscape Cultural

Table 6-5: A stormwater treatment system should be designed as a treatment train, which incorporates individual treatment systems. The choice of treatment train will depend on the receiving environment and pollutant levels, but the developer should always aim for the highest level of treatment.

Treatment System and Treatment Train Option	Treatment	Where to Use
	First flush interception and treatment Particle settlement (coarse to fine) Filtration Soil adsorption	Small to medium urban catchments with excellent soil permeability Low ground water Groundwater recharge required Discharge constraints in surface waterways
	First flush interception and treatment Particle settlement (coarse to medium)	Small to large urban catchments Nearby surface waterway Low permeability soils High water table
	Particle settlement (coarse to fine) Biofilm adsorption with baseflow	Flood attenuation needed Suitable where single large basins serve large urban catchments Use as basis for core habitat
 Treatment process outlined in Figure 6-2	First flush interception and treatment Particle settlement (coarse to fine) Removal of dissolved contaminants in baseflow and first flush Biofilm adsorption Filtration and denitrification	Flood attenuation needed Continuous baseflow treatment needed Suitable for large urban catchments Use as basis for core habitat
 Treatment process outlined in Figure 6-2	First flush interception and treatment Particle settlement (coarse to fine) Removal of dissolved contaminants in baseflow and first flush Biofilm adsorption Filtration and denitrification	Suitable for large catchments with limited space Continuous baseflow treatment needed

MPT = Macro-pollutant trap. These trap coarse and macro litter and debris, and typically include grates, sumps, grills, and debris racks.

* Wet ponds should preferably be used upstream of, and in conjunction with, a wetland system. Where a wet pond is not followed by wetland, a dry first flush basin should be used. The use of a wet pond with no other treatment system should be questioned.

All base flow and first flush passes through the treatment systems however, provision can be made to bypass permanent base flows. Ponds and wetlands here are schematic only. For more effective operation, ponds and wetlands should be multi-celled with diffusers between each cell.

Where possible swales should be incorporated into treatment trains for conveyance upstream of, and between, systems for pretreatment.

6.3 Pretreatment Devices

6.3.1 Macropollutant Traps (MPT)

Despite any at-source litter interception, provision should always be made for MPTs placed upstream of any treatment system to intercept litter, larger rocks and stones, vegetation, and woody debris. MPTs typically include grates, sumps, grills, and debris racks.

Litter Interception

Although litter traps are often installed in waterways, litter control closer to its source is preferred, to encourage better litter disposal practices. Interception should certainly be no further downstream than immediately above the point of stormwater outfall to the waterway. The creation of systems to achieve this is encouraged.

Potential trouble spots for extensive litter accumulation during storm flows need to be identified, with access for maintenance. Litter transport into waterways is a significant problem, particularly in industrial and commercial areas. Side-entry sumps are therefore unacceptable in these zones.

On-site (Private) Interceptors

On-site requirements for stormwater treatment systems, such as special sumps and filters, are governed by the Building Act and its regulations.

6.3.2 Swales

Vegetated swales having gently sloping sides (typically flatter than 6H:1V) and flat longitudinal grades, are primary channels designed to intercept, convey, and provide inline primary treatment of stormwater. They are generally used to transport runoff from its point of origin to a secondary stormwater treatment system (soakage system, detention basin, constructed wetland) or surface outfall. (See also *Chapter 5.2.1.1: Vegetated Swales*). Figure 6-3 shows an example of a vegetated (grassed) swale.

In general swales:

- provide storage, which attenuates the peak flows entering a secondary treatment system. Additional storage can be obtained by "choking" swale flows and utilising road and yard storage during more significant events.
- should flow at low velocities so that the grass acts as a filter, to remove suspended sediments by adsorption, filtration, and settlement.
- May in some instances provide soakage along their length, if designed for this.
- prolong the life of the main soakage basin filter or other treatment system, by reducing the amount of sediment reaching the basin.
- are good substitutes for piped and concrete channel systems in areas that are close to the source of stormwater (i.e. where catchment areas are small and peak flows are manageable).
- Refer to *Chapter 5.2.1.1: Vegetated Swales,* for design considerations.

Figure 6-3A: Macropollutant traps (MPT) are a useful pretreatment device to trap litter closer to its source, before it can enter a waterway. Debris rack in Alderson Reserve.

Figure 6-3B: Vegetated swales slow stormwater flow and remove some sediments by adsorption, filtration and settlement. Grassed swale along QEII Drive.

Table 6-6: Representative removal capability of treatment systems for a number of urban pollutants of concern. Adapted from Auckland (Hartwell & Silyn-Roberts 2002) and international (Schueler 1987) data.

Treatment System	Pollutant Removal Efficiency (%)						Comment
	Solids	Phosphorus	Nitrogen	BOD	Trace Metals	Bacteria	
Grassed Swale	20–60	20–40	20–40	20–40	20–60	20–40	High potential for re-suspension of sediment with any storm flow.
Soakage Basin	60–100	40–80	40–80	20–60	40–100	60–100	Dependent on extent of overflow permitted.
Dry Detention Basin	40–80	40–60	20–40	20–40	20–60	0–40	Efficiency in trace metal reduction is reduced for more soluble elements.
Extended Detention Wet Pond	60–80	40–80	40 –60	20–60	40–80	40–80	Sizing relative to runoff is volume dependent. Bacteria removal dependent on bird population for the system.
Wetlands	60–80	40–80	20–60	20–40	40–80	60–100	Removal includes soluble trace metals. Bacteria removal dependent on bird population attached to the system.

Note: The level of pollutant removal will be subject to the level of provision of treatment system volume or surface areas relative to catchment runoff. As a general rule, the higher the concentration of in-flowing pollutants, the greater the degree of removal.

Table 6-7: Common restrictions associated with various treatment systems.

Treatment System	Slope	High Water Table	Close to Bedrock	Space Consumption	Maximum Depth	High Sediment Input	Thermal Impact Downstream
Grassed Swale	☹	☹	😐	😐	☹	☹	☺
Soakage Basin	😐	☹	☹	😐	😐	☹	☺
Dry Detention Basin	☺	😐	😐	☹	😐	😐	☺
Extended Detention Wet Pond	☺	☺	😐	☹	😐	😐	☹
Wetlands	☹	☺	☺	☹	☹	😐	☹

☺ generally not a restriction

😐 can be overcome with careful site design

☹ may preclude the use of the treatment system.

Table 6-8: Comparative stormwater benefits of various stormwater treatment systems.

Treatment System	Peak Discharge Flow			Volume Control	Ground Water Recharge	Stream Bank Erosion Control
	2 yr Storm	10 yr Storm	100 yr Storm			
Grassed Swale	🙂	🙁	🙁	😐	😐	🙁
Soakage Basin*	🙂	🙂	😐	🙂	🙂	🙂
Dry Detention Basin*	🙂	😐	😐	🙁	🙁	🙂
Extended Detention Wet Pond*	🙂	😐	😐	😐	😐	🙂
Wetlands	🙂	🙁	🙁	🙁	🙁	😐

* first flush capture will not usually suppress peak discharge flow from storm events greater than a 2 year frequency.

🙂 usually provided

😐 sometimes provided with careful site design

🙁 seldom or never provided.

Table 6-9: Natural or human amenity values that can be achieved with the various stormwater treatment system.

Treatment System	Low Flow Maintenance	Streambank Erosion Control	Aquatic Habitat Creation	Wildlife Habitat Creation	Landscape Enhancement	Recreational Benefits	Hazard Reduction	Community Acceptance
Grassed Swale	😐	🙁	🙁	😐	😐	😐	🙂	😐
Soakage Basin	😐	🙂	🙁	🙂	😐	😐	🙂	😐
Dry Detention Basin	🙁	🙂	🙁	🙂	😐	😐	😐	😐
Extended Detention Wet Pond	🙁	🙂	🙂	🙂	🙂	🙂	😐	😐
Wetlands	🙁	😐	🙂	🙂	🙂	😐	😐	😐

🙂 usually achieved

😐 sometimes achieved

🙁 seldom achieved.

6.4 First Flush Interception

Stormwater from hard standing areas should be treated by first flush capture and preferably also by subsequent treatment. Many of the contaminants accumulated on surfaces (e.g. roofs, roads, etc) are removed by a relatively small amount of rainfall, where intensity is sufficient. Provided a treatment system can be located close to the stormwater source, simply sizing a system that can cope with the stormwater volume from a 'first flush' may be sufficient for treatment (although there may still be flood routing requirements to consider). Stormwater later in the storm event is much less contaminated and can be diverted around the treatment system without undue risk to the downstream receiving environment.

Even for stormwater from catchments up to around 50 ha, the affect of first flush capture will be apparent, so long as the rainfall is reasonably intense and of large enough volume. The effect becomes blurred however in stormwater from large catchments where the flow times from different parts of the catchments vary widely. This can result in the mixing of dirty first flush runoff and the cleaner later runoff. For the same reason, the first flush may not be prominent in urban streams where there are several widely-spaced contributing upstream sources.

The treatment efficiencies of first flush systems will be lower than those of large full-flow systems but over a whole catchment, multiple smaller first flush systems could improve the retention of stormwater contaminants. This is because their smaller size would improve the feasibility of treating highly contaminated stormwater close to its source. Irrespective of this, the complete removal of the chemical contaminants in stormwater is seldom necessary. There are thresholds for the toxic effects of most chemicals, and dilution of dissolved contaminants as well as the mixing of contaminated with uncontaminated sediments often reduce concentrations below these thresholds. The primary attribute of the first flush concept is that it maximises the ratio of treatment efficiency to treatment system area; a critical consideration in urban catchments.

The Christchurch City Council recommends as best practice the capture of runoff from the first 25 mm of storm rainfall depth, but not less than 12.5 mm. The capture of runoff from at least the first 25 mm of storm rainfall depth is a requirement for 'green fields development'.

From the Botanic Gardens rain gauge record it has been determined that 25 mm first flush interception will achieve treatment of 78% of the rainfall depth falling on the recipient catchment in an average year and that 12.5 mm first flush interception will achieve treatment of 58% of annual rainfall depth (Figure 6-4).

Average detention time prior to discharge to surface waters should be at least 24 hours. Outlet control devices which delay the first half of the first flush volume longer proportionally to the second half first flush volume are also recommended. Detention time in wetlands and wet ponds should be longer to effectively treat dissolved pollutants.

Capture can be achieved by a range of systems including pipes and channels, but should always incorporate vegetated swales for at least 50 m upstream of the soakage area.

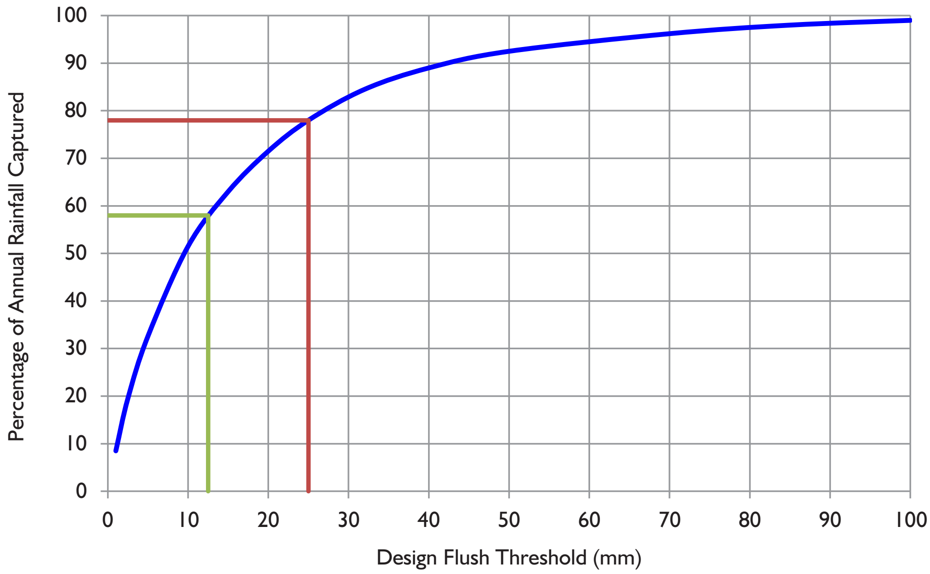


Figure 6-4: Botanic Gardens rain gauge percentage of annual rainfall captured for design flush depth. The highlight lines show 58% capture for a rain depth threshold of 12.5mm and 78% capture for a 25mm threshold.

Where first flush treatment alone is permitted, subsequent flows may bypass detained water and discharge to ground or to surface waters, but via flood routing systems if necessary.

Care should be exercised in considering stormwater runoff or base flows that have high concentrations of dissolved metals. Any dissolved contaminants that have particulate forms, (e.g. metals), don't always show a first flush effect because their concentrations usually depend simply on the presence, not the amount, of their particulate forms. However, for particulate contaminants in small stormwater catchments, the first flush effect will usually be pronounced. If a treatment system can be constructed close to a stormwater source, only the first flush need be captured and treated.

A critical component of the first flush system is the bypass for stormwater in excess of the first flush volume. This bypass operates in all moderate to large rainfall events and must be capable of preventing flows in excess of the treatment volume from entering the treatment system, particularly wetlands. If this were to occur, the high velocities through a treatment wetland would destroy the fragile biofilms (50 mm/s should be the target maximum velocity for stable biofilms) and resuspend deposited sediment. The contaminants retained from previous rainfall events would be flushed downstream thus undoing the prior achievements of the treatment system.

6.4.1 Determination of First Flush Volume

The first flush volume coefficients are based on capturing just the runoff from the storm leading edge—typically 25 mm depth from hard standing areas—which assumes insufficient time for pervious surface contribution.

Calculate the first flush volume using the coefficient C_{ff} of Table 6-10 as follows:

Determination of First Flush Volume, V_{ff}

$$V_{ff} = 10 \times C_{ff} \times A_{total} \times d_{ff} \quad (m^3) \qquad \text{Eqn (6-2)}$$

where C_{ff} = Composite First Flush coefficient (from Eqn 6-3 or Table 6-10)

A_{total} = Full catchment area (ha)

d_{ff} = First flush rainfall depth (mm)

25 mm is recommended and is required in 'green fields' development

Not less than 12.5 mm

Determination of the Composite First Flush Coefficient, C_{ff}

$$C_{ff} = im\% \times C_{eff} \times C_D \qquad \text{Eqn (6-3)}$$

where im% = Catchment percent impervious area. Typical values are shown in Table 6-10. The pervious catchment area is ignored as it rarely contributes to the first flush volume.

C_{eff} = Percent of total impervious area contributing

C_D = Discharge coefficient

A discharge coefficient (C_D) of 0.9 assumes 2.5 mm ponding storage.

Note that C_D yields a volume discharge for the purpose of determining the first flush volume whereas the coefficients of Chapter 21 yield peak discharge rates for events of less than 1 hour or flood detention volumes, after allowing for both losses and attenuation, for storm events generally greater than 12 hours.

Table 6-10: Zone average impervious area percentages and composite first flush coefficients.

District Zone	Effective impervious area (im %)	Impervious % Contribution C_{eff}	Discharge Coefficients C_D	Composite FF Coefficients C_{ff}
L1	50%	90%	0.9	0.41
L2	55%	90%	0.9	0.53
L3, L4, L5	70%	100%	0.9	0.63
LH	45%	95%	0.9	0.38
Business	90%	100%	0.9	0.81

Schools : Seek advice from CCC
Rural and Park: Not considered to contribute to first flush

6.5 Soakage Systems

The principal objective of stormwater soakage (infiltration) systems is to retain stormwater in the hydrological cycle via the processes of infiltration, percolation, and evapotranspiration. More conventional stormwater drainage (the discharge of stormwater directly to waterways) adversely affects surface waters by increasing storm runoff and peak flows, introducing contaminants to the stream environment and depleting the in-ground reservoirs feeding stream flows. The discharge of (nominally clean) roof or treated stormwater to ground soakage recharges groundwater while mitigating flooding and surface water quality problems. It provides a means of sustainably managing the stormwater resource in a way that minimises the effects of urban development on the natural environment.

Well-designed public facilities provide opportunities to enhance amenity and environmental values within a neighbourhood by creating or adding to green corridors and landscaped basins. Small utilitarian "bath tubs" scattered throughout the catchment are, however, not acceptable.

Christchurch's free-draining alluvial soils, to the south and west, provide opportunities for surface water management by soakage. However, in the free draining surface strata of the western city, the aquifer system is particularly vulnerable to contamination. Consequently, any stormwater soakage system must incorporate safeguards and treatment prior to its discharge to soakage. Harmful contaminants include suspended or dissolved chemicals and bacterial pollution. Potential hydrocarbon or chemical spillages are of particular concern.

High sediment loads in stormwater can preclude the use of soakage systems unless effective pretreatment is included. In all situations where soakage systems are employed pretreatment using MPT's and swales should be installed.

Soakage systems range in scale and complexity from single soakage chambers accepting roof runoff from individual buildings, to more comprehensive public facilities comprising of roadside soakage swales, soakage chambers, rapid infiltration chambers, and overflow soakage areas. The Christchurch City Council strongly favours community soakage systems on public land with local purpose utility reserve status, rather than private facilities on individual properties (with the exception of soakage of roof runoff from commercial zones). The Council can assume responsibility for maintaining community facilities, so that the gradual clogging associated with poorly maintained soakage systems is managed.

All treatment options need to be considered carefully at the land-use planning stage of development, whether it is green field development or major site redevelopment. Designs that incorporate more than one treatment system or soakage option may provide superior stormwater quality and quantity control than one single system. Unless there is an applicable global consent, a resource consent is required for any stormwater soakage system.

6.5.1 Types of Soakage Systems

Soakage systems can be public or private, and include the following:

- soakage and rapid infiltration chambers
- on-site roof water soakage systems
- soakage swales
- soakage basins.

The components of a soakage (or soil infiltration) system are illustrated in Figure 6-5.

Soakage and rapid infiltration chambers

- provide direct discharge to groundwater, or free draining strata, at soakage rates greater than 50 mm/m^2/hr.
- occupy a small footprint compared with direct surface soakage systems, but are used only for treated first flush stormwater, or clean storm by-pass water after first flush.

On-site Roof Water Soakage Systems

- On-site soakage chambers or pits can be used for roof water from commercial buildings in approved areas, and for roof water from private dwellings isolated from an approved outfall. Refer to Figure 6-6 and Figure 6-7 for typical private soak pit configurations.
- Roof stormwater is considered to be relatively clean and can be disposed of via soakage to ground via a sealed system that excludes all other stormwater. Discharge occurs via soakage chambers or trenches.
- Discharge of roof water to soakage via a sealed system is permitted by Environment Canterbury, subject to certain conditions.
- Current Council policy however, favours community soakage systems on public land to better ensure effective long term maintenance.
- In areas where soil type and groundwater levels preclude soakage to ground there is the option to retain roof water for garden watering.

Soakage swales

Swales at reduced grades in permeable ground can treat stormwater via soakage to ground. See also *Section 6.3.2: Swales* and *Section 5.2.1.1: Vegetated Swales.*

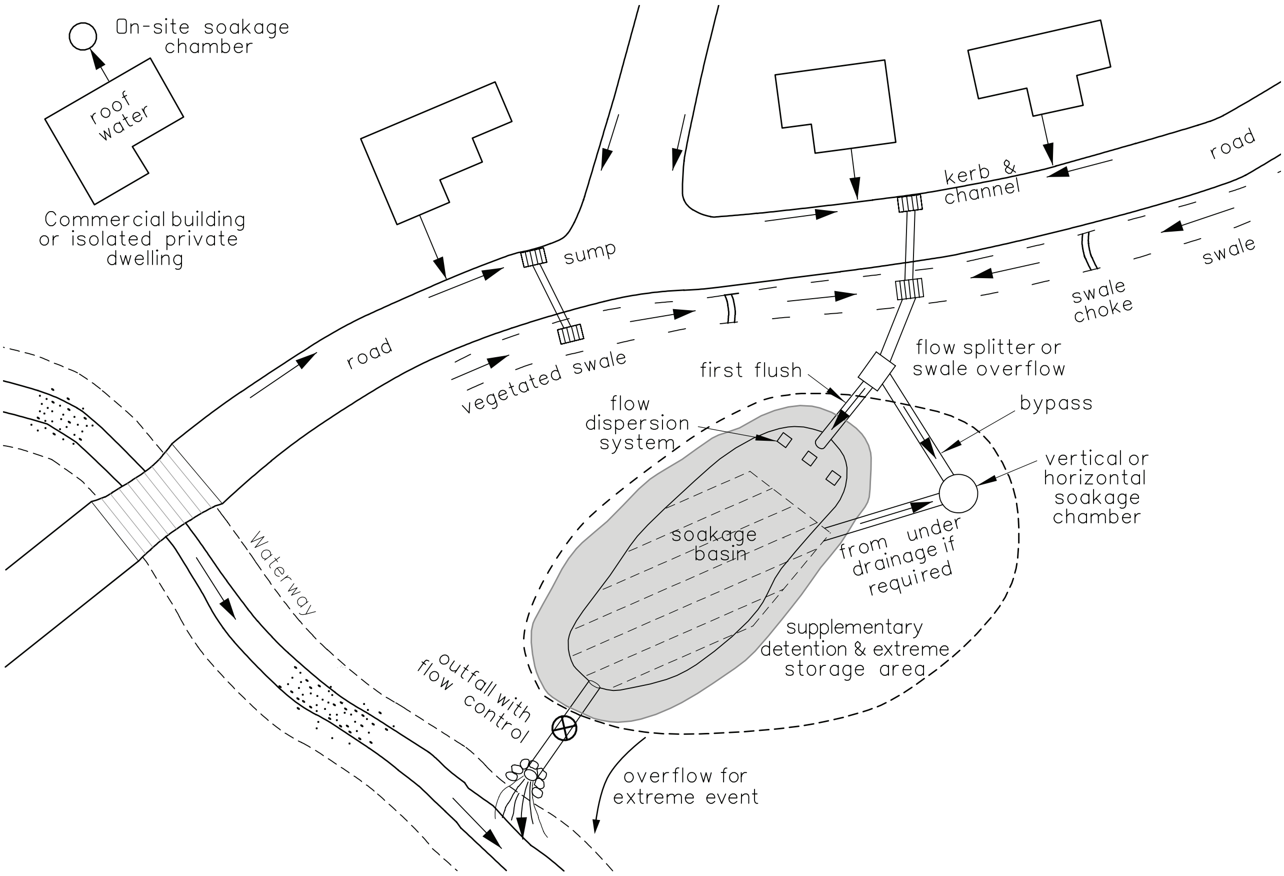


Figure 6-5: General schematic of a soakage system providing surface water quantity and quality control for a neighbourhood via a system of private roof water soakage, roadside swales, soakage basins, and extended storage areas.

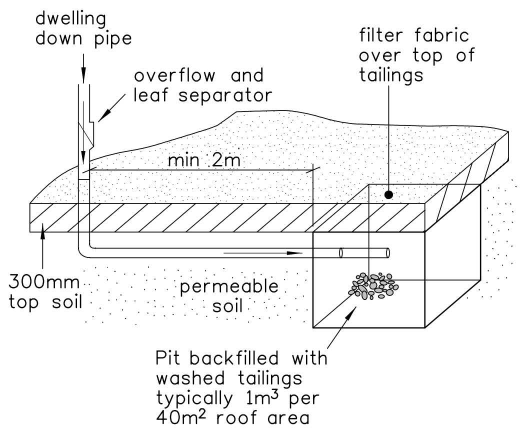


Figure 6-6: Soak pit for a private dwelling.

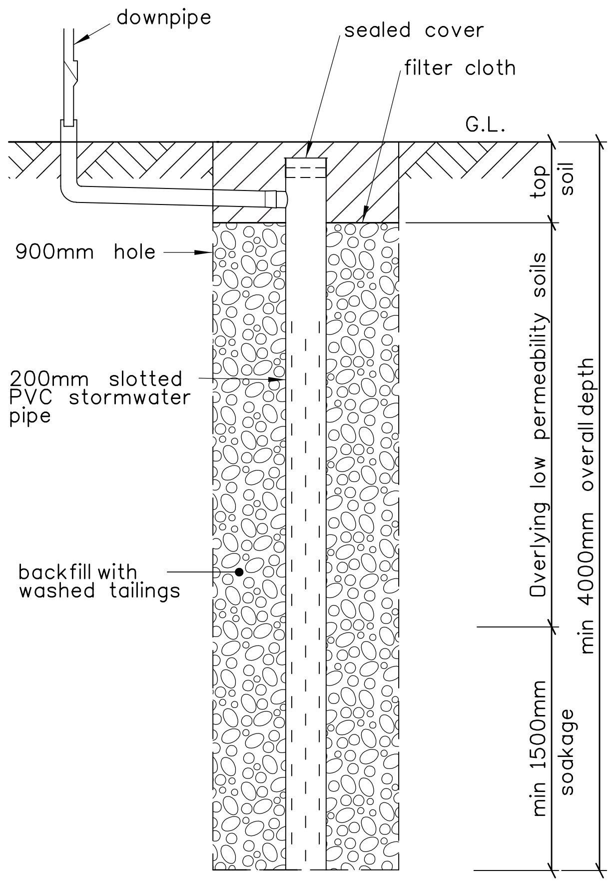


Figure 6-7: Vertical soakage shaft for a private dwelling.

Soakage Basins

Soakage basins can provide both water quality and quantity control. They are generally public systems. Often referred to as soil adsorption basins, they provide a storage area for stormwater from where it can pass at a pre-determined rate through a filter bed designed to remove contaminants. Contaminants successfully reduced include hydrocarbons, suspended sediment and attached metals. The filtered runoff then percolates down to the water table or via an under drainage system to surface water or a soakage chamber.

Vegetation helps to catch sediment, slow the flow of water and maintain porosity of the soils. Percolation rates within soakage basins should not exceed 75 mm/hr (determined by infiltrometer test) to ensure adequate treatment of stormwater is achieved. Soil mix design for the upper infiltration media can be critical to successful infiltration basin design. For advice on soil mix check with the Christchurch City Council.

Soakage basins require storage for at least the first flush rainfall component. Reserve storage or an adequate overflow system are also required. Each soakage basin can be designed to provide a unique and aesthetically pleasing landscape element, which ideally will be adjacent to a larger reserve (Figure 6-8).

Soakage basins could be co-located with reserves (Figure 6-8), which, subject to Council approval, may be used as secondary storage areas for extreme stormwater overflows. Some minor recontouring in the reserve may be required to maximise storage potential, and merge the basin with the reserve.

Figure 6-8: Soakage basins retain stormwater and allow soakage of stormwater through a filter bed, which removes contaminants. If appropriately designed, planted and placed in a reserve they can become a pleasing landscape element. Soakage basin in a local park along Roydon Drive.

6.5.2 Current Soakage System Models

Upper Heathcote Model

The "Heathcote River Floodplain Management Strategy" (Christchurch City Council, 1998), which has been adopted by both the Christchurch City Council and Environment Canterbury, promotes the use of ground soakage as the key mitigation measure for further residential development in the Upper Heathcote catchment. Consent has been granted to the Council to install comprehensive public soakage systems throughout the upper Heathcote River/Ōpāwaho catchment. The adopted approach for treatment and disposal of Upper Heathcote stormwater involves the following key aspects:

- roof stormwater directly to ground soakage
- vegetated swales as pretreatment
- soakage basins (with a percolation rate not greater than 75 mm/hr from infiltrometer testing or 50 mm/hr from live tests of the facility)
- rapid infiltration chambers, or trenches, for overflow after 'first flush' capture.

Similar facilities are recommended elsewhere, as long as soil and groundwater conditions are suitable.

Brooklands/Spencerville Model

The stormwater drainage system for the Brooklands and Spencerville residential areas incorporates a soakage system. This concept allows for the fact that much of the area is low lying and was adopted to preserve the open character of the neighbourhoods, as well as to reduce the cut and fill earthworks and pipe diameter necessary to provide drainage by conventional means.

The Brooklands and Spencerville residential areas are located on flat, low lying sandy soils. Roof stormwater discharges to a soakage chamber (refer to standard drawing SD8024) located near each property frontage. Road runoff collects in roadside swales. Groundwater levels alongside roads are controlled by subsoil drains (*Chapter 5.3.1.2: Subsoil Drains*), which are located under swales and discharge into small diameter stormwater mains. The drainage design standard is low at 24 mm/day (2.78 l/s/ha), and effective area drainage relies on storage above and below ground. Drained subsoils absorb water during a storm with slow release to the subsoil drains after each event.

An integral component of this scheme is the City Plan rules, which require a minimum lot area of 1000 m^2 and limit site coverage so that the soakage system concept is not compromised.

6.5.3 Site Investigations

Several factors can preclude the use of soakage as an effective stormwater disposal option. The suitability of ground conditions and effects on groundwater must be carefully considered in:

- initial site selection
- on-site testing.

6.5.3.1 Site Selection

Before deciding on the placement of any soakage system, consideration must be given to site conditions, and if necessary, a study on an appropriate scale should be undertaken.

Desirable sites for public soakage systems have the following characteristics:

- not located at former landfill sites
- further than 800 m up-gradient and 200 m in any other direction from shallow public reticulated water supply wells
- co-located with or adjacent to open space, although small community sub-surface soakage systems for 'clean' roof water may be located within road reserves (Note: small, isolated, standalone soakage basins are not acceptable.)
- located in the middle to lower part of any sub-catchment
- gravel strata within 5 m of the ground surface and a water table deeper than 1 m
- site slope of 5% or less
- good access for future maintenance.

The following information should be gathered for any potential site. This can be done prior to the on-site testing and can provide valuable information for the selection of possible testing sites:

- soils descriptions from soil maps, reports, and local knowledge
- location of contaminants, e.g. abandoned refuse pits
- groundwater levels (including seasonal variation)
- depth to gravels
- location of any impervious soils.

Refer to *Part A, Chapter 3.6: Developing Visions,* for additional factors to consider when undergoing any site selection.

6.5.3.2 On-site Testing

The selection of sites for soakage basins and rapid infiltration chambers must be accompanied by an investigation of soakage characteristics to confirm the ability to operate as a successful stormwater disposal area. The investigation must cover the following aspects:

Site Infiltration Characteristics

Soakage basins should be constructed with an engineered soil lining to ensure that controlled percolation rates are maintained. However, the underlying permeability of the ground (*Appendix 6*) will be dictated by natural conditions, which must be sufficiently free draining to effectively dispose of all stormwater. These drainage characteristics must be proven by site specific testing prior to the design and construction of the basin.

The infiltration characteristics can be assessed by the following measures:

- detailed geological logging of test pits and/or investigation boreholes
- monitoring of existing stormwater soakage systems in equivalent and nearby settings
- the installation and testing of trial infiltration devices
- in situ infiltration measurements in test pits, using a double ring infiltrometer (Figure 6-9), Guelph permeameter, or other appropriate means.

In situ infiltration measurements should be taken at the points of interest. Care must be taken with the results of testing, especially when using them to describe infiltration rates for the site as a whole. The two types of infiltration tests used for in situ testing of soils are surface testing and sub-surface testing.

Surface testing is used where the soil profile remains unmodified.

- Surface testing is generally carried out using a double ring infiltrometer (Figure 6-9, *Appendix 6*), and is done prior to construction to satisfy the designer that the soils are suitable. Environment Canterbury has set a maximum infiltration rate

Figure 6-9: Double ring infiltrometer testing for measuring surface soil infiltration rates.

for the system to provide adequate groundwater protection; this rate is 75 mm/hr.

- Infiltration measurements will be made after the construction of the surface infiltration system to ensure that the average infiltration rate of the basin soils does not exceed the maximum set out in the resource consent conditions.
- Refer to *Appendix 6* for the double ring infiltrometer method.

Sub-surface testing is used for measuring the infiltration rates of soils along the full depth of the proposed system.

- The test is usually carried out at the proposed location of the new soakage system. The inverse augerhole method (Figure 6-10, *Appendix 6*), a pump test, or other suitable testing procedure may be used.

The Department of Building and Housing Verification method E1/VM1 (Department of Building and Housing, 2010) describes a site testing method suitable for onsite soak pits (titled Disposal to Soak Pits). This procedure is repeated in *Appendix 6*.

Depth to Water Table

An indication of the long-term range of water table fluctuations must be determined from consideration of the following information sources:

- long-term groundwater level data held by the Council and Environment Canterbury

Figure 6-10: Inverse augerhole method for measuring surface and sub-surface soil infiltration rates.

- installation of on-site monitoring boreholes to measure groundwater levels (which can then be correlated to longer term records)
- logging of test pits to identify soil mottling areas.

Proximity of Nearby Bores

For each disposal area a survey must be undertaken to identify existing water supply bores in the vicinity of the site. This must involve a review of the following information sources:

- a print out of bore locations and bore details from the Environment Canterbury bore database
- information from the Christchurch City Council water supply section detailing the location of existing and proposed supply bores.

Where these information sources identify any potentially sensitive bores within 1 km of the site vicinity, then surveys must be carried out to confirm exact locations and usages of these bores.

6.5.4 Design Considerations

Function

Ensure that the risk of contaminating the underlying groundwater is minimised. In general:

- Only roof water and stormwater from impervious areas with very low contamination risk can be disposed of by rapid infiltration devices .
- Any stormwater from residential and industrial paved areas requires treatment before disposal to groundwater. This could be attained by passing the stormwater through a soil filter in soakage basin, or by another suitable treatment system. Vegetated swales and detention basins can provide pre treatment of stormwater by filtering sediments, and can improve the performance of a soakage system by removing much of the sediment load and providing temporary storage.
- Industrial sites must have emergency systems for diversion and containment, to minimise the risk of chemical spills entering the community soakage system.
- Advice should always be sought from Environment Canterbury consent officers on whether a site-specific discharge permit is required.

With any new development that will rely on soakage for stormwater disposal, some means of silt trapping upstream of the soakage system should be put in place during construction to ensure that the system does not become unduly silted during the construction phase. Silt trapping should also be installed upstream of any soakage system as a matter of course to prolong its life. Include means of monitoring silt build-up and some practical method of silt removal before silt impedes operation of the chamber.

Form

Traditional design of soakage structures has focused on hydraulic capacity and structural integrity, and on making the structure safe. While these criteria are important, the design should also be appropriate for the existing landscape:

- Materials must be appropriate for the site, be durable, and reflect the landscape and natural materials of the area.
- Soakage structures could be used as features or even works of art in the landscape.
- Where conditions limit the choice of materials and their consequent appearance, thought should be given to integrating the structure with the landscape. Methods include appropriate plantings to screen or soften the appearance of any visually obtrusive structures.
- The form of the basin should be functional but not utilitarian or bathtub-like in appearance.
- Ensure that there is a suitable setback distance around the basin area, typically an average width of 5 m that will allow for sufficient planting, access and safety factors.
- Consider having qualified landscape architects collaborate with engineers in order to realise this.

Sizing

Infiltration system sizing will consider flow continuity (Eqn 6-4) using the storm runoff rate and rate of infiltration, from which the excess flow (Q_S) that must go to storage can be determined.

$$Q_{RO} = Q_i + Q_S \qquad \text{Eqn (6-4)}$$

where Q_{RO} = storm runoff rate
Q_i = rate of infiltration
Q_S = rate of accumulation to storage

At storm end, some or all of the runoff will have infiltrated to ground, with any excess flow contained by storage.

By considering the conservation of volume, (Eqn 6-5) can be assessed to determine the requirement for V_S.

$$V_{RO} = V_i + V_S \qquad \text{Eqn (6-5)}$$

where V_{RO} = storm runoff volume
V_i = infiltration volume
V_S = storage volume

For small catchments this assessment is quite straightforward, but does require consideration of a range of storm durations to determine the critical case. Short duration storms tend to govern storage requirement whereas infiltration volume is more critical for long duration storms. Note that Council will require a minimum storage volume with all soakage systems to ensure no undue reliance on rapid infiltration to ground with any facility (Refer to *Chapter 6.5.5: Soakage Basin Sizing* for minimum storage sizing requirements).

For catchments with somewhat more complex runoff characteristics, the infiltration and storage flow rates will require summation over a fixed time step (t) to determine the volume in storage. From this tabulation the peak storage requirement will be apparent:

$$V_S = \Sigma Q_S \, \Delta t \qquad \text{Eqn (6-6)}$$

where Q_S = rate of accumulation to storage (can be positive or negative)
= can be obtained from Eqn (6-4)

On-site Soakage chambers and Pits

The Department of Building and Housing Verification Method E1/VM1 (Department of Building and Housing 2010) includes a design procedure to determine soak pit volume (Disposal to Soak Pit).

Placing filter cloth around the outer limits of any soakage chamber prevents migration of finer particles into the surrounding strata. This means that only the chamber/boulder pit backfill needs to be removed during reconstruction, and prevents the need to excavate any of the surrounding strata.

Soakage Basins

Soakage systems will be designed to dispose of stormwater for the critical storm duration of the return period considered appropriate for the type of system, its location in the catchment, and for the consequences of the system failing, or being overwhelmed.

Where surface soakage systems are designed for both stormwater treatment and detention, attenuation storage combined with overflow chambers (Figure 6-11 and Figure 6-12), will be designed to dispose of all stormwater that follows 'first flush' from the critical storm for the catchment. Storm bypass should occur upstream of the basin via overflow weirs or a splitter box arrangement (Figure 6-5 and Figure 6-13) or similar.

A soil infiltration rate not exceeding 75 mm/hour, determined by infiltrometer test (50 mm applied in a live test), and not less than the rate required to empty the basin within 5 days of any storm, is considered appropriate to achieve effective treatment of contaminants. However, a value of 20 mm/hour should be used for design purposes in sizing basins to allow for a reduction in infiltration rate over time. New basins should be able to achieve close to the maximum rate when first commissioned.

Where the natural strata underlying the basin are not free draining then the filtered runoff can be collected by an under-drain system (Figure 6-5, Figure 6-14 or Figure 6-15) and passed to a vertical soakage chamber (Figure 6-11) where it is put to groundwater via a soakage chamber. The free draining strata should not be more than 5 m below ground level.

Basin inlets should ensure the early dispersal of inflows to 'sheet' flow over the basin bed.

Basins should be appropriately shaped and landscaped to merge in with the surrounding landscape. Side slopes should not be steeper than 4H:1V and 'first flush' depth not greater than 1 m.

Adequate riparian margins shall be provided around basins with average width no less than 5 m.

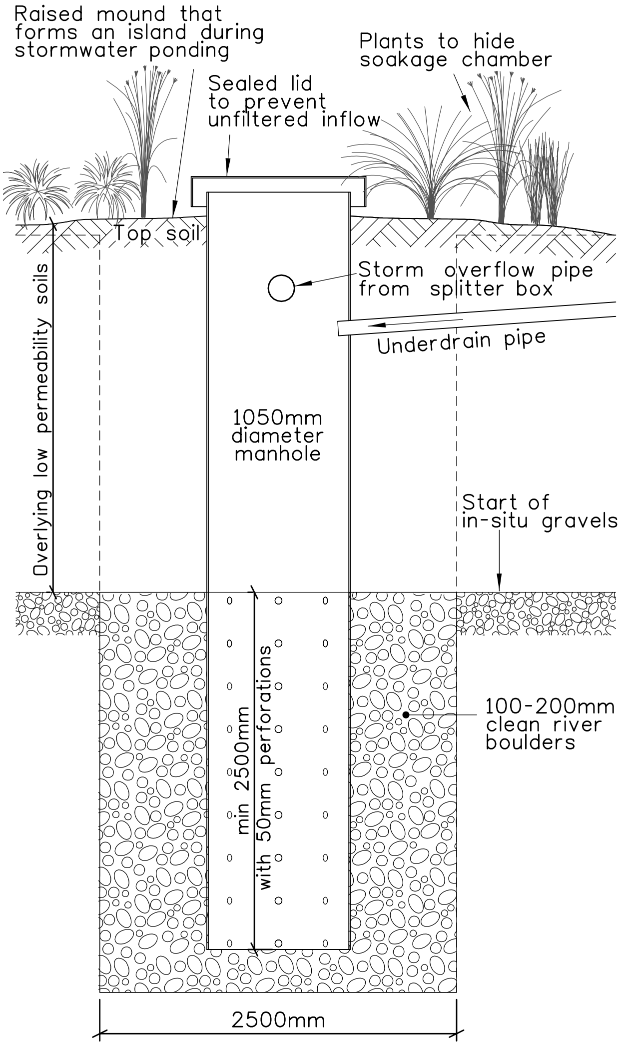


Figure 6-11: Vertical soakage chamber used for areas with overlying low permeability soils.

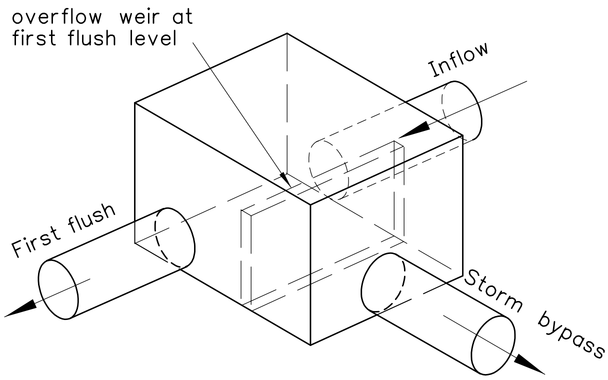


Figure 6-13: Bypass splitter box installed upstream of a basin to divert cleaner later stormwater flow directly to an overflow chamber.

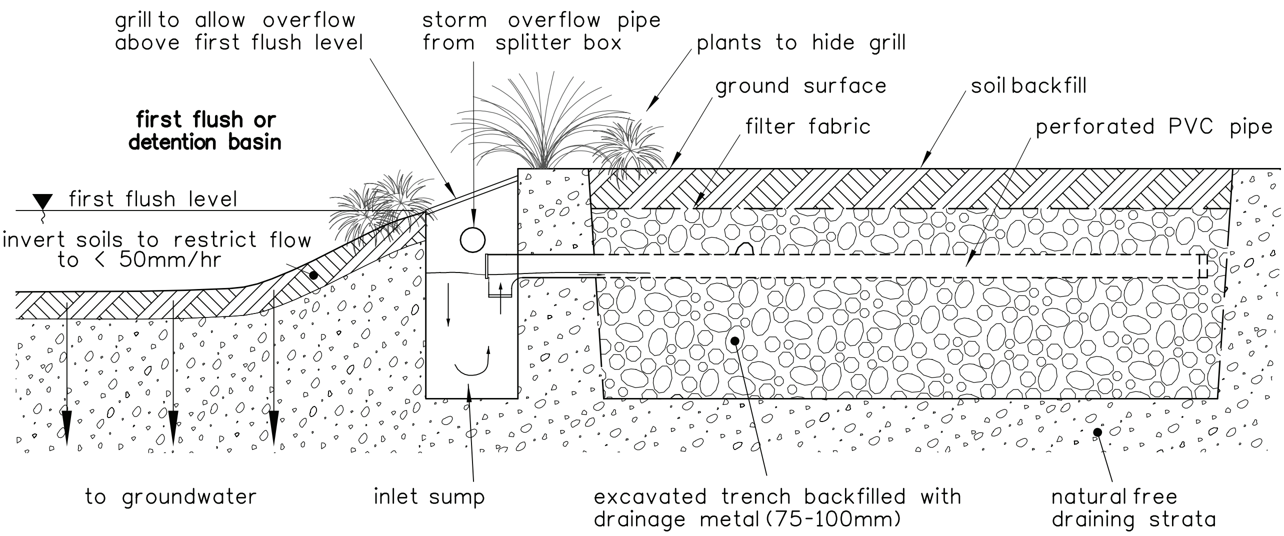


Figure 6-12: Horizontal soakage chamber used where permeable soils are close to the surface.

Overflow to Rapid Infiltration Chambers

Chambers accepting overflow introduce a risk of groundwater contamination and their use should be restricted as much as possible. If alternative overflow storage capacity (e.g. within an adjacent reserve) is sufficient, infiltration chambers may not be necessary, except for extreme events.

The crest level of overflow chambers should be set to ensure all available storage capacity is used before overflows commence.

To prevent mixing of the more contaminated first flush stormwater within soakage basins a bypass splitter box or overflow bund should be installed upstream of the basin to divert the cleaner later stormwater inflow directly to an overflow chamber (Figure 6-13).

Overflow chambers should be fitted with a tamper-proof lid with underflow weir to minimise entry of gross floatable contaminants (e.g. hydrocarbons, debris). The lids should also be designed to allow complete closure in the event of a chemical spill.

For design purposes the inflow capacity should assume some long term clogging. It is also desirable to provide a secondary system of some sort, in order to provide for short term shutdown to clear or replace the system.

6.5.5 Soakage Basin Sizing

The procedures described in this section are for the determination of required basin storage volume for a given catchment, and include a method for determining the number of soakage chambers for the design return period *(Chapter 20: Inundation Design Performance Standards)*.

1) Determine First Flush Volume, V_{ff}

First flush volume (V_{ff}) is a function of contributing catchment area and rainfall depth. Refer to *Section 6.4: First Flush Interception,* for the recommended calculation procedure.

2) First Flush Basin Water Surface Area, A_{ff}

$$A_{ff} = V_{ff}/y_{ff} + 8\sqrt{(V_{ff}\, y_{ff})} \quad (m^2) \qquad \text{Eqn (6-7)}$$

where y_{ff} = soakage basin first flush depth (m)

$8\sqrt{(V_{ff}\, y_{ff})}$ = an approximation for 1:4 side batters

3) Storm Average Runoff Flow Rate, Q_{avg}

$$Q_{avg} = 2.78\ C\ i\ A/1000 \quad (m^3/s) \qquad \text{Eqn (6-8)}$$

where: C = rational method runoff coefficient

i = rainfall intensity (mm/hr)

A = full catchment area (ha)

C and i are both determined by the requirements and procedures of *Chapter 20: Inundation Design Performance Standards,* and *Chapter 21: Rainfall and Runoff.*

4) Basin Floor Infiltration Flow Rate, Q_{if}

$$Q_{if} = A_{if}\ f \quad (m^3/s) \qquad \text{Eqn (6-9)}$$

where: A_{if} = first flush basin infiltration area (m^2)

f = floor infiltration rate (m/s)

A_{if} will vary with basin water level but a good result can be obtained by adopting a mean value for A_{if} as the area at 2/3 y_{ff}.

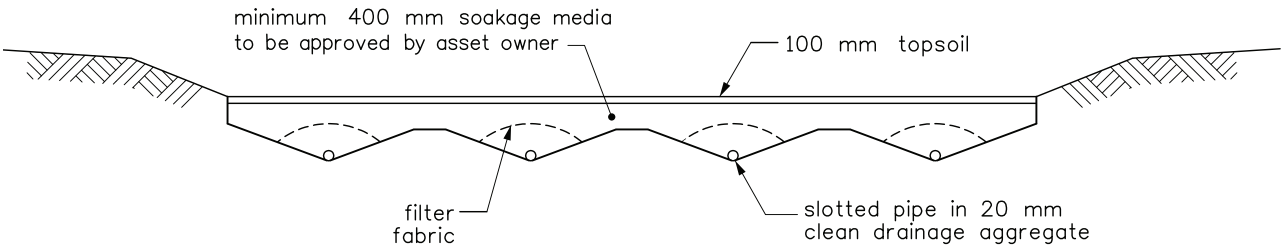


Figure 6-14: Underdrain layout.

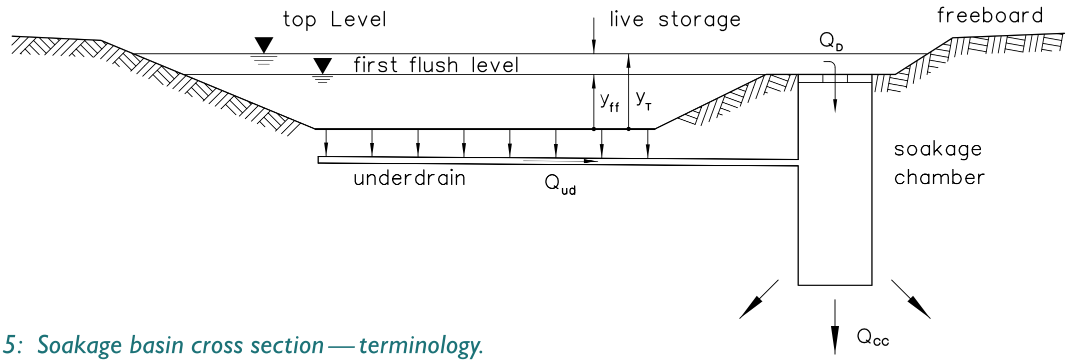


Figure 6-15: Soakage basin cross section — terminology.

5) Underdrain Flow rate, Q_{ud}

Conservatively assume that all basin floor infiltration is intercepted by the under-drains, so:

$$Q_{ud} = Q_{if} \quad (m^3/s) \qquad \text{Eqn (6-10)}$$

6) Storm Total Volume, V_S

$$V_S = Q_{avg}\, D \quad (m^3) \qquad \text{Eqn (6-11)}$$

where D = storm duration (sec)

begin by assuming:

D = time of concentration (T_C)

7) Basin Live Storage Volume, V_{LS}

(Note, Council require a minimum storage volume determined by the catchment runoff from a 10% AEP, 18 hour storm.)

$$V_B = V_{ff} + V_{LS} \quad (m^3) \qquad \text{Eqn (6-12)}$$

where V_B = basin full volume
V_{ff} = first flush volume

$$V_S = V_B + V_{If} \quad (m^3) \qquad \text{Eqn (6-13)}$$

where V_S = storm total runoff volume
V_{If} = infiltration volume

and $V_{If} = Q_{ud}\, D$ Eqn (6-14)

Therefore:

$$V_S = V_{ff} + V_{LS} + Q_{ud}\, D$$

$$V_{LS} = V_S - V_{ff} - Q_{ud}\, D \qquad \text{Eqn (6-15)}$$

where Q_{ud} = underdrain flow rate (m^3/s)

Test various storm durations (D) to determine the critical duration (D_C) and required critical basin full volume (V_B). Check that V_B is not less than the runoff volume from a 10% AEP, 18 hour storm.

For each trial storm duration, further trial and error is required to determine basin dimensions and the related value for live storage volume (V_{LS}). It should be noted that this procedure assumes no direct entry to the soakage chambers. Direct inflow (Q_D) can be considered where live storage is limited.

8) Basin Total Surface Area, A_B

To determine approximate basin surface area, A_B

$$A_B = V_B/y_T + 8\sqrt{(V_B\, y_T)} \quad (m^2) \qquad \text{Eqn (6-16)}$$

where y_T = basin full depth (m)

Note that a separate detention basin is generally required to limit live storage over the first flush basin to no more than 300 mm.

9) Number of Soakage chambers

Size the soakage chambers to dispose of the peak underdrain flow rate (Q_{ud}; Eqn (6-17a)) or, if there is limited live storage, for the direct inflow (Q_D; Eqn (6-17b)). A capacity reduction factor (φ) is included to provide some spare capacity and a reduction in chamber soakage capacity over time.

$$\#\ \text{Chambers} = Q_{ud}/(\varphi\, Q_{CC}) \qquad \text{Eqn (6-17a)}$$

$$\#\ \text{Chambers} = Q_D/(\varphi\, Q_{CC}) \qquad \text{Eqn (6-17b)}$$

where j = capacity reduction factor; typically assume a value of 0.3
Q_{CC} = a single chamber infiltration rate (m^3/s)
Q_D = direct inflow (m^3/s)

Refer to Figure 6-14 for soakage basin cross section terminology.

Procedure Summary

Determine the following:

A, im %, A_{eff}, d_{ff}, V_{ff}, y_{ff}, A_{ff}, C, f, T_C, and Q_{CC}

Then, for each trial D, tabulate the following:

i, Q_{avg}, V_S, V_{LS}, V_B y_T, A_B, and # Chambers.

Definitions Summary

A	=	full catchment area (ha)
A_{eff}	=	effective first flush catchment area (ha)
A_{if}	=	first flush basin infiltration area (m^2)
A_B	=	basin full area (m^2)
C	=	rational method runoff coefficient
d_{ff}	=	first flush rainfall depth (m)
D	=	storm duration (sec)
D_C	=	critical storm duration for specific return period (sec)
f	=	basin floor infiltration rate (m/s)
i	=	storm rainfall intensity (mm/hr)
im %	=	catchment % impervious
Q_{avg}	=	storm average runoff flow rate (m^3/s)
Q_{CC}	=	single chamber infiltration flow rate (m^3/s)
Q_D	=	direct inflow (m^3/s)
Q_{if}	=	basin floor infiltration rate (m/s)
Q_{ud}	=	underdrain flow rate (m^3/s)
T_C	=	time of concentration
V_S	=	storm runoff volume (m^3)
V_B	=	basin full volume (m^3)
V_{LS}	=	live storage (m^3)

V_{if} = infiltration volume (m^3)
V_{ff} = first flush volume (m^3)
y_{ff} = first flush basin depth (m)
A_{ff} = first flush basin area (m^2)
y_T = basin full depth (m)
φ = capacity reduction factor

Figure 6-16A: Detention basins that are completely dry between rainfall events are called dry basins. They can be grassed or vegetated (as pictured here at Wrights Road).

Figure 6-16B: Detention basins that retain a permanently wetted area are called wet ponds. Tranz Rail first flush wet pond, Matipo Street.

6.6 Detention Basins

For the purpose of this Guide, 'detention basins' are defined as artificially constructed depressions that store water temporarily to attenuate flood flows and potentially improve water quality by settling out sediment. They gradually discharge floodwaters through an outlet control structure into receiving waters downstream, or to a further downstream treatment system (such as a wetland), in the overall treatment train. Thus detention basins can provide both water quantity and quality control (although with certain limitations).

There are two types of detention basin:

- those that are totally dry between rainfall events, referred to as dry basins, or dry detention basins (Figure 6-16A)
- those that retain a wetted area, referred to as wet ponds (Figure 6-16B).

The Christchurch City Council has constructed several stormwater detention basins in the city to attenuate flood flows and improve stormwater quality. These range from earlier utilitarian concrete structures of questionable efficiency (often inappropriately called silt traps, Figure 6-17), to more recent basins that also incorporate amenity and other values (Figure 6-16).

Stormwater detention in its wider context is an important feature of Christchurch's land drainage system. Some of the larger, natural ponding areas play an important role in controlling peak discharges from major tributary catchments (e.g. Henderson's Basin).

Figure 6-17: First generation stormwater systems, called silt traps, have a limited ability to treat stormwater and are very utilitarian in structure; making them unacceptable in today's standards. Penruddock Rise silt trap.

Constructed detention basins, however, require careful consideration. There will be many circumstances where they are not effective; some where their use could increase flooding downstream, and some where the cost of construction and ongoing maintenance cannot be justified. The efficiency of contaminant removal is also variable. Drainage authorities generally avoid a 'blanket' policy for these reasons.

Dry detention basins only effectively remove coarse sediments. Therefore to achieve the required level of water quality treatment they will often need to be incorporated with other treatment systems in a treatment train. Placing a detention basin upstream of another stormwater treatment system (such as a wetland) to ensure removal of coarse sediment will prolong the life of the downstream treatment system.

On-site detention for subdivisions and industrial areas can be useful in particular circumstances, such as:

- when the drainage system that is immediately downstream has capacity limits
- in combination and upstream of other stormwater treatment systems such as a constructed wetland or soakage to groundwater system
- in combination with a surface water environment enhancement scheme.

6.6.1 Effectiveness of Detention Basins

Where detention basins are only required for water quality, the requirements of the Christchurch City Council will typically call for "first flush" capture and also off-line detention. Extending the detention time of dry or wet basins is the key to maximise settling; the primary pollutant removal mechanism (that is sometimes aided by natural or artificial flocculation). If stormwater is detained for 24 hours or more (i.e. with staged low flow controlled discharge), a considerable percentage of particulate pollutants removal is possible (see *Appendix* 7). However, the removal of suspended particles less than about 100 microns is very inefficient, and is effectively zero for particles less than about 20 microns due to persistent disturbance from wind, solar thermal effects, and horizontal though-flow.

Wet ponds can only provide limited removal for soluble pollutants, and unfortunately some of the "mature urban" pollutants of greatest concern occur primarily in soluble form (e.g. nitrate and ortho-phosphorous). Additionally, the selective removal of coarse sediments, and the flow-through of finer particles can be potentially damaging to downstream environments. The concentrations of stormwater contaminants are typically higher on fine particulate matter than they are on coarse particulate matter. As a consequence, if the coarser particles are selectively removed (e.g. in a wet pond), then although the load (kg/day) of total suspended solids reaching the downstream deposition area is reduced, the mean particle size is smaller and the particulate contaminant concentrations in sediments deposited downstream are higher. There is also the potential for the sediment in the downstream environment to become anaerobic closer to the sediment surface due to lower oxygen permeability (in comparison to less polluted areas). The actual effect in a particular depositional area will depend on how the fine sediment disperses and settles and how it mixes with other less contaminated sediment. These factors will be different for each lake, river and estuary.

Removal of soluble pollutants can be somewhat enhanced with detention basins if extended detention is achieved. Detention of stormwater for extended periods (i.e. in the provision of a wet pond with large permanent storage volume relative to typical stormwater inflow) will often allow some removal of dissolved pollutants through uptake by, and absorption to, phytoplankton (Figure 6-18). Retention of contaminants is then achieved by deposition within the pond of dead phytoplankton. However, the retention time needs to exceed the life span of the plankton. Even then, such removal is not very effective because of the limited plankton biomass able to be produced between rainfall events and the small amounts of uptake and adsorption of the main contaminants of concern. If a new inflow of stormwater occurs during the plankton growth phase then no removal occurs and the contaminants are flushed from the pond, although in a less bio-available particulate form.

Another process that influences the ability of wet ponds to retain contaminants like metals is "redox cycling". Particulate metals are usually bound to iron and manganese oxides on the particle surfaces. In the water column, adsorption to these particles controls dissolved metal concentrations and given enough time (very unusual in detention wet ponds) the dissolved concentrations will be reduced to very low levels. These particles with their adsorbed metals sink to form the pond bed sediments. Provided the bottom waters in stormwater detention ponds remain aerated, the iron and manganese oxides on the sediment will remain stable and will retain the adsorbed metals. If, however, the bottom waters lose their oxygen (as frequently happens in deeper ponds during extended periods with little wind during summer), the oxides dissolve and release their adsorbed metals into the water column.

These now dissolved metals can be taken up by, or adsorbed to, phytoplankton and re-adsorbed to new oxides that form when the dissolved iron and manganese meet aerated surface waters. If, however, this uptake, adsorption, and settling is not complete before the next rainfall event, then the pond can become a source of both dissolved and particulate metals. Redox cycling also affects the retention of phosphorus by the same mechanism.

As mentioned above, the settling of particulate matter, sometimes aided by natural or artificial flocculation, is the only significant contaminant removal process in stormwater detention ponds. As the particle size decreases this process becomes less efficient. Except when the volume of stormflow from a rainfall event is less than that of the pond and there is a period of several days before the next rainfall event, the settling of particles less than about 50 microns will usually be incomplete, and particles less than about 20 microns may not settle to any significant extent before they are flushed from the pond.

Due to the rather questionable ability of detention basins to treat stormwater, they should preferably be included as part of a treatment train. For example, the inclusion of a detention basin upstream of wetlands or very large permanent wet ponds are more effective at total contaminant control.

6.6.2 Design Considerations

Basin design and implementation is a complex issue that can only be adequately addressed by considering the catchment in its entirety. Basins can be designed to fulfil multiple functions, including flood retention, water quality, and wetland habitat. Appropriate design criteria for the various functions must be discussed with and agreed to by Council.

Where basins are installed as part of a subdivisional approval, basin design and long term management needs to be both checked and approved by the Environmental Services Subdivisions Engineer (who will consult with the asset manager). In order to satisfy the financial objectives of subdividers and the resource management objectives of the Christchurch City Council, a collaborative design approach involving both developer and Council is recommended. Invariably, a multi-disciplinary design team that includes an engineer, ecologist, and landscape architect will be required. Normally a Council asset owner representative must be willing to accept any community system. The system will often be prescribed through an SMP for the greater catchment.

As detention basins reliably remove only coarse particles, they typically should not be used as the only means of stormwater treatment. The use of wet ponds and constructed wetlands downstream can significantly improve water treatment capability by also dealing with dissolved pollutants. A note of caution is raised however in the use of wet ponds that are not part of a wetland treatment system.

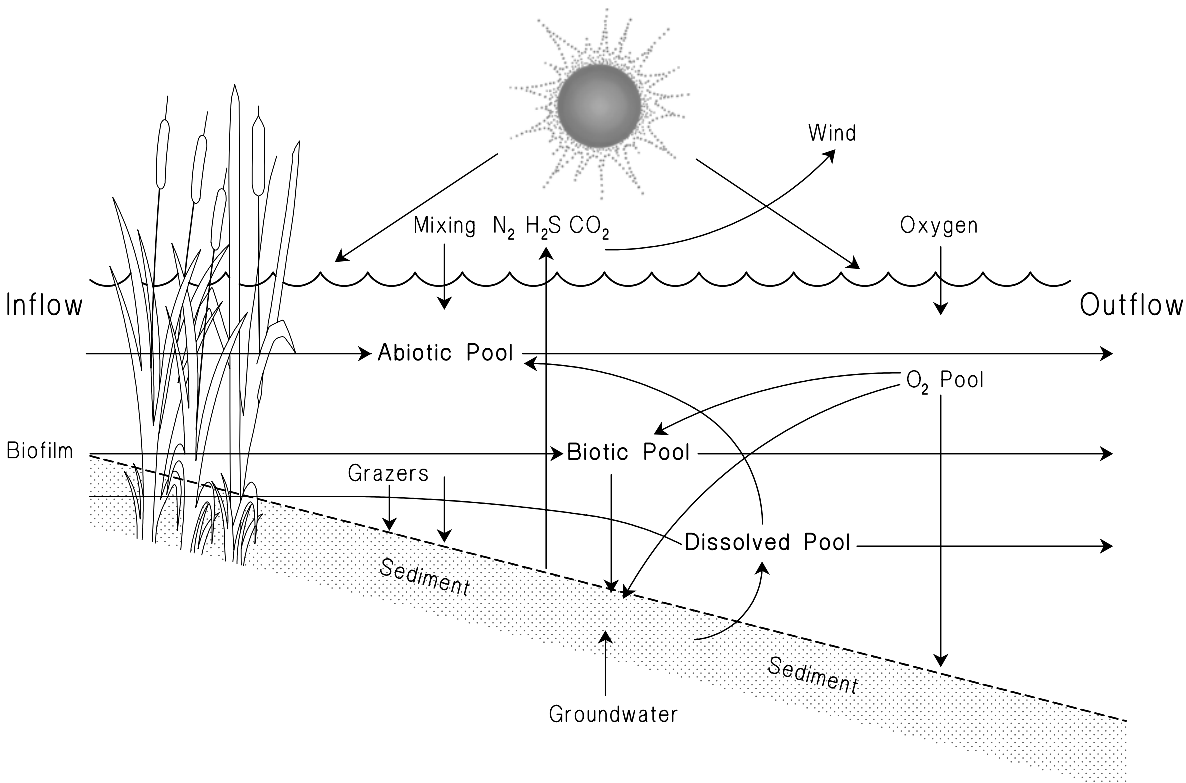


Figure 6-18: Diagrammatic representation of the main water quality processes that occur in wet ponds. Modified from Lawrence & Breen (1998).

Question the Need for any Wet Pond

If a proposed wet pond cannot meet sufficient stormwater treatment levels or cannot provide for additional values such as drainage, landscape, ecology, and recreation then do not proceed with it. There are many examples of small wet ponds that become stagnant and unpleasant during summer months, and likely do little to protect the downstream environment from stormwater contaminants.

Flood Detention

An appropriately designed detention basin will reduce downstream flood flows significantly. This benefit will dissipate with distance downstream from the basin.

Designers should check with Council whether a suitable computerised hydrological model is already available for the catchment. If not, the use of a recognised hydrological model is recommended. These hydrological modelling techniques are well established and will facilitate the design of a basin with the required characteristics.

Hydrology

Assess groundwater levels for at least one year and correlate these with groundwater levels in nearby wells that have long term data. This allows for an accurate picture to be gained of the groundwater regime at a particular site.

Consider storms of different durations. Then in context of the catchment of the receiving waterway, determine the critical storm (peak storm) for sizing storage, and entry and exit structures. The critical storm for storage may be related to the critical storm of the receiving waterway. e.g. the critical storm for the Upper Heathcote River/Ōpāwaho is 36 hours.

Upstream reticulation systems including pipes, swales, waterways and secondary overland flows must be designed to match basin performance criteria (i.e. all flow must be routed to basin). The downstream spillway or overflow system must be designed to pass the critical 1% AEP (1 in 100 yr) hydrological event, with allowance for the effect of wave runup or overtopping.

The Council Asset Owner can provide specific performance criteria that are based on the maximum detention time required to route peak discharge to suit downstream reticulation capacity.

Design must consider consequences of blockage and the effects of prolonged detention of stormwater.

Structures

Physical works must be able to perform satisfactorily under design flood conditions that meet specific performance criteria. The physical integrity of any structure shall not be compromised by flood events up to this level of performance.

Specific regard shall be given to embankment stability, spillway, downstream erosion, and inlet and outlet structures.

Structures should be in harmony with or add to the landscape values of the basin.

Outlets should be designed to prevent 'floatables' from passing downstream and if appropriate, consideration given to a control to fully detain waters in the event of a chemical spillage upstream. Figure 6-19 illustrates a submerged outlet design that will help ensure the prevention of floatables from passing out of the detention wet pond.

Maintenance and Safety

Ensure all maintenance requirements are considered and provided for, including access for, and the consequences of, eventual debris clearance and sediment removal.

Basins have a finite functional life for drainage or wetland values. The buildup of sediment will need to be monitored and the removal of trapped sediment planned for. Consider multiple cells for areas of high sediment deposition.

Where access to permanent water by children is possible, provide bed and bank zones of moderate slope (e.g. 6H:1V or flatter).

Provide maintenance and landscape buffers around basins of at least 5 m average width.

Detention Basins within Parks and Reserves

The Council may permit detention of rare events within reserves or over sports fields. Such permission is more likely in established catchments were space is limited. This consideration acknowledges that within an urban environment there is an increasing pressure on open space and greater pressure to maximise benefit from such areas. In greenfield development ponding should occur on purpose built utility reserves.

Specific approval to use reserve areas for flood detention must be obtained from the Council Asset Owner prior to any design work. General design considerations include the following:

- no inundation shall exceed 24 hours duration
- an adequate slope and outlet capacity shall be provided to rapidly draw down flood waters after the storm event
- developers should provide appropriately designed

and landscaped basins to accommodate the 20% AEP (1 in 5 year) event

- sports fields may be flooded for more frequent storm events if specific drainage systems are incorporated in the field's surface layers
- consider safety issues, especially where the public can gain access to the basin
- children's play areas may only be inundated if surface slopes into the pond water are no steeper than 10H:1V (horizontal to vertical)
- provide sufficient space around the basin for maintenance access and safety considerations
- for grass cover, side slopes should be flatter than 4H:1V (horizontal to vertical), whereas steeper banks must be planted out in shrubs and trees
- structures must not detract from the overall visual amenity of the park or reserve
- where the detention basin provides for drainage of the reserve, consider the effect of 'local' drainage on the reserve when the pond has water in it
- Consider the consequences of blockage and provide safe secondary flow paths.

Improving Water Quality Treatment Efficiency

Detention basins will typically only remove heavy sediment and associated contaminants, while smaller particles and associated contaminants continue to pass through the system. In mature catchments, or catchments where significant quantities of fine sediments are generated, this can represent a significant proportion of stormwater pollutants. Thus, to increase the ability of detention basins to improve water quality, consider the following:

- The proliferation of relatively small structures that serve individual subdivisions is strongly discouraged when a single large structure could be shared. Larger facilities can cater more readily for a wider set of values (ecology, recreation, and heritage; Figure 6-20). They usually function more effectively in terms of water quality control and minimise nuisances. Where first flush detention only is considered, check carefully the respective first flush inflow times with any large basin/pond serving several smaller catchments.

Figure 6-20: Wigram Detention Basin is a 3.5 ha flow-through wet pond that treats water from a 350 ha catchment in the Hornby district. Its large size and the surrounding reserve area has enabled the creation of a treatment facility with significant additional values.

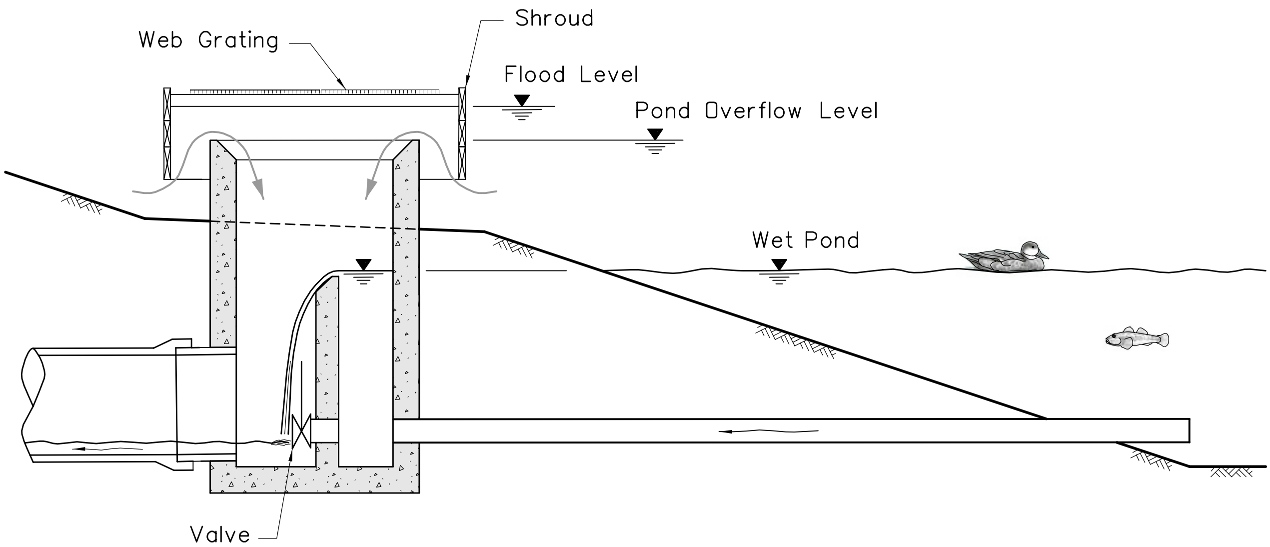


Figure 6-18: Design schematic for a submerged and shrouded outlet from a wet pond, that will ensure floatables are retained within the wet pond and not carried downstream.

- Use detention basins in conjunction with, and generally upstream of, other stormwater treatment systems. A detention basin upstream of a constructed wetland will greatly improve the life of the wetland and improve efficiency of contaminant removal (see *Section 6.7: Constructed Wetlands*).
- The tendency of the lighter hydrocarbons and some debris to float on the water's surface offers an opportunity for additional treatment. It is recommended that a submerged outlet (refer back to Figure 6-19) or similar floatable trapping device be installed just upstream of the detention pond outlet. A submerged outlet prevents floatables moving downstream and enables some hydrocarbons to evaporate and/or be broken down by UV exposure.
- Maximise the length of the flow path between the inlet and the outlet and prevent short-circuiting during storm events by incorporating islands, peninsulas and planting in the design. Also design inlet and outlet structures to minimise short-circuiting during periods of in-pond stratification.
- Ensure the organic loading in the ponds is enough to avoid the development of low sediment redox conditions, which can result in the release of pollutants trapped in the sediments.
- Depth of temporary ponded water should be sufficient to avoid resuspension of sediments from surface water disturbance but not too deep to slow sedimentation time. About 1 m is a maximum desirable depth for dry basins and live storage over wetponds. Note that for basins used solely for water quantity mitigation, a greater storage depth may be acceptable.
- Negotiations with adjoining landowners and the Christchurch City Council are encouraged to achieve these benefits.

There are other issues associated with wet ponds within detention basins that need to be addressed during the design phase. For example, the Wigram wet pond is subject to phytoplankton growths which, when discharged, can cause a reduction in water clarity in the Heathcote River/Ōpāwaho into which the wet pond discharges. In addition to this, strong winds are able to resuspend sediment at times, adding to the turbidity of the discharge. Nuisances such as midges and safety issues also need to be considered in the design of basins.

Habitat/Landscape/Planting

With careful planning, detention basins can provide opportunities for delivering on many values, including ecological, recreational, cultural, landscape, heritage and drainage values:

- Detention basin design must provide for landscape features (diversity of shape, size and form) and where possible the enhancement of terrestrial and wetland habitats, without conflicting with the functionality of the basin (Figure 6-21). Planting of appropriate species provides opportunities to enhance bird habitats (although see below); for dry basins such planting may be beneficial to woodland bird species. An attractively landscaped basin can also provide good opportunities for passive and active recreation.
- For wet ponds, landscaping should be designed so as to discourage significant waterfowl densities, as high numbers may jeopardise water quality objectives. Heavy planting and steeper banks are preferable as they are not as suitable for mallard ducks, which prefer gentle grassed slopes.
- Ensure a suitable setback distance around the basin area for sufficient planting and safety factors.
- Consider if the basin is to be dry or wet and follow the appropriate streamside planting guideline *(Chapter 11: Riparian Planting)*.
- Design to minimise mosquito habitat, or include operational measures to disrupt the larval stage of their life cycle, e.g. raising and lowering of water levels. Refer to *Chapter 18: Mosquitoes and Other Insect Pests.*

Figure 6-21: The dry basin within Cardigan Bay Reserve (corner of Wrights and Lincoln Road) was initially a grassed depression (left). After planting it has become a significant landscape feature and provides habitat for birds (right).

6.7 Constructed Wetlands

There is an increasing international trend to use constructed wetlands for water quality treatment. The gradual shift from detention ponds to wetlands, or a combination of the two, is a reflection of how much of our urban catchment is now considered as 'mature' with lower sediment loadings but still significant amounts of contaminants. Constructed wetlands are often preferred to ponds or detention basins as a means of water treatment because of their robust effectiveness over a wide range of hydrological conditions, and potentially high landscape and ecological values. Constructed wetlands are considered as being 'most preferred' of the Christchurch City Council's 'Preferred Stormwater Mechanisms' (to achieve water quality goals), as documented in the Surface Water Strategy, 2009–2039 (Christchurch City Council, 2009).

There are wetlands throughout New Zealand that receive stormwater, but in most cases stormwater is either a small proportion of the inflow, or is from an industrial or mixed rural/residential catchment source. There are very few, if any, wetlands that have been constructed specifically for treating stormwater from mature, predominantly residential catchments. The Tranz Link stormwater treatment system in Addington, Christchurch (Figure 6-22), combines an upstream intermittent free water surface (IFWS) wetland with two downstream ponds. This system receives stormwater of mixed origin from the Tranz Link yards and upstream business zone catchment. The performance of this system is currently being assessed.

A good example of a pond-wetland system treating stormwater from an industrial area is that at the Fletcher Building Steel Group premises in Auckland (Figure 6-23). During the second year after its construction this system achieved just over 80% removal of total zinc (Leersnyder, 1993) although it was treating only half the design catchment area. The system has now been fully operational for several years and the removal efficiency for zinc is close to 90% (personal communication, Martin Fryer, Environmental Systems Manager, Fletcher Building).

The design of constructed wetlands for stormwater treatment is still a relatively new science, and new information is continually being published. The following documents contain a large proportion of the information needed to apply constructed wetlands to the treatment of urban stormwater:

- IWA (2000): Reviews all aspects of wetland design and treatment of effluents, including stormwater, although the section on stormwater is short. Is the most recent, comprehensive source of information available, and probably contains the most up-to-date, complete list of references.
- Wong *et al.* (1999): This is an industry guide for the use of constructed wetlands in stormwater treatment. Provides relatively concise descriptions of stormwater treatment in wetlands.
- Lawrence & Breen (1998): This document provides a more general description of wetland use for stormwater treatment.
- Department of Land and Water Conservation (1998a, b): A two-volume document that contains information on constructed wetland function and design. This is probably the best 'local' choice.

Figure 6-22: The Tranz Link constructed wetland system. Stormwater enters the intermittent free water surface (IFWS) wetland at the bottom of the photos and then enters two wet ponds, the first of which is visible at the top of the right photo.

Mike Timperley, Niwa

Figure 6-23: The pond and FWS wetland system at the Fletcher Building Steel Group industrial site, Auckland. Stormwater enters the pond from the bottom left, flows around the end of the "U" shaped system (centre right) and passes through the wetland, exiting at the left.

6.7.1 Types of Constructed Wetlands

Constructed wetlands fall into two general categories; surface flow (SF) and subsurface flow (SSF) wetlands.

Surface Flow (SF) Wetlands

SF wetlands are constructed to more or less mimic natural wetlands. The processes occurring in each (i.e. natural and constructed wetlands) are much the same, although the balance between the processes can be altered in constructed wetlands. There are two types of SF wetlands:

Intermittent Free Water Surface (IFWS) wetland:

- designed to have free water only during rainfall events.

Free Water Surface (FWS) wetland (Figure 6-24):

- designed to have permanent surface water
- advantage is the longer retention time of water in the FWS wetlands, which maximises the efficiency of contaminant removal processes (except for contaminant adsorption to bed sediment), and allows for some sediment retention by settling
- ideally, the free water surface area should be concentrated in a pond that is upstream from the vegetated section of the wetland
- this type of constructed wetland system is, at present, preferred by the Christchurch City Council.

The mechanisms operating in a SF wetland for retaining chemical contaminants include:

- settling of suspended sediment in areas of quiescent standing water (mostly in FWS wetlands)
- the trapping of suspended particles, including phytoplankton by filtration through biofilms attached to macrophytes and bed sediments (this is the main advantage of wetlands over ponds)
- the uptake of some dissolved contaminants by macrophytes, benthic algae, and phytoplankton (in FWS wetlands)
- adsorption of dissolved metals onto oxidised bed sediments (mostly in IFWS wetlands)
- a wetlands' high production of dissolved organic matter enables the complexing of metals and binding to organic compounds, which reduces the bio-availability of chemical contaminants.

Sub-Surface Flow (SSF) Wetlands

SSF wetlands can operate in either horizontal flow or vertical flow modes (Figure 6-24). These wetlands are constructed with a vegetation cover able to tolerate frequent wet-dry cycles, a soil layer and an underlying permeable gravel stratum.

Contaminant removal mechanisms include those of SF wetlands (except for the settling of sediments), but in addition the gravel substrate in SSF wetlands acts as a physical filter. These wetlands can be highly efficient in the early stages of use but have the substantial disadvantage of a low initial hydraulic loading (mm/day), which can decrease quite rapidly over time as the substrate becomes blocked with plant roots and bacterial films.

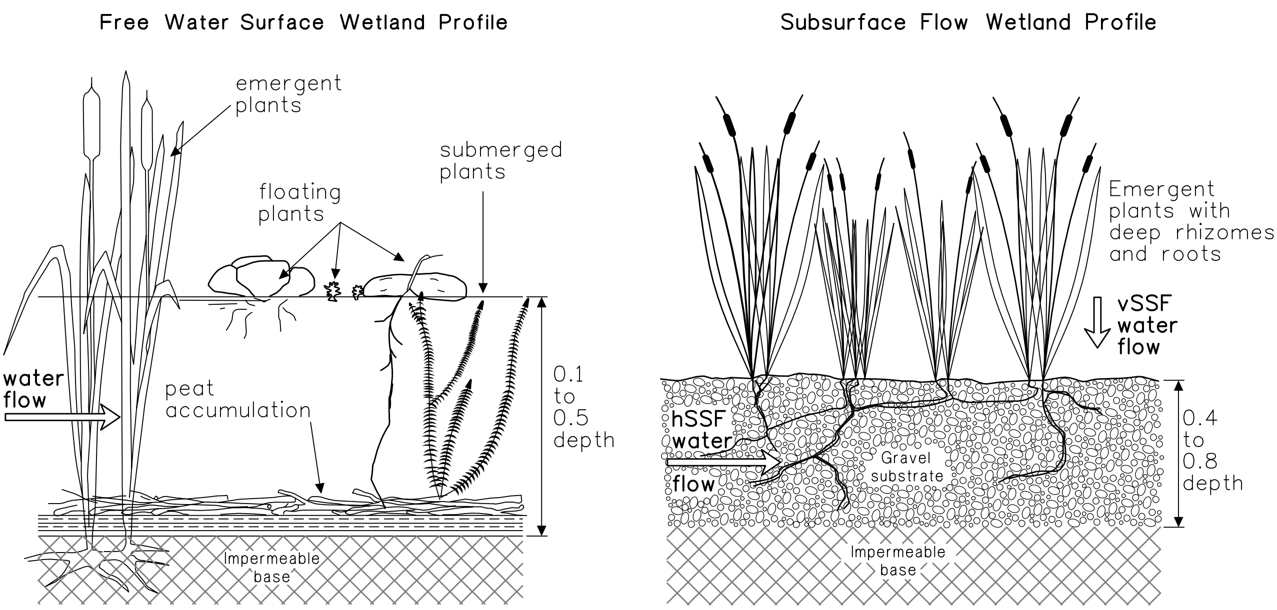


Figure 6-24: Illustration of two constructed wetlands; a free water surface (FWS) wetland (left), and a subsurface flow (SSF) wetland (right). ⇩ ; flooded zone and likely movement of water through the system, hSSF; horizontal flow mode, vSSF; vertical flow mode. Adapted from Department of Land and Water Conservation (1998b).

In general, SSF wetlands do not appear to be suited to the treatment of urban stormwater for which minimal maintenance is an important requirement. Where space is severely limited, however, SSF wetlands and simpler variations (e.g. small vegetated sand filters), are ideal for treating stormwater and particularly road runoff, close to its source. The trade-off is that the efficiency of treatment for dissolved and fine particulate contaminants may be low and periodic maintenance might be required in order to restore the permeability of the filter substrate.

6.7.2 Design Considerations for Surface Flow (SF) Wetlands

Choosing the Best Constructed Wetland Systems

The type of treatment system used for stormwater contaminant removal is site-specific and depends on the balance between dissolved and particulate contaminants. Therefore this is, in effect, a matter of contaminant "size", as even dissolved contaminants have a finite size.

A simple guideline is that as the size of the contaminant decreases, the optimum treatment system should change from a detention basin, to a pond-wetland, and finally to a wetland where the stormwater contains negligible particulate matter greater than about 100 microns. Note however, that even in the latter situation, a pond upstream of the wetland, and thus as part of a treatment train, is desirable for first flush capture and for balancing flow into the wetland.

In mature urban catchments erosion is only a small contributor of sediment to stormwater. Road gravel and sediment are often the major contributor and this can be controlled to some extent by minimising the amounts of free gravel on the roads and by efficient operation and maintenance of roadside sumps.

Despite the relative lack of sediment in mature catchments, for general application to stormwater the ideal treatment train consists of an initial dry basin draining directly into a SF wetland (Figure 6-25). The basin will allow first flush capture, balance of flows to the wetland, and also act as an initial sediment trap.

Sizing Constructed Wetlands for Stormwater

As stated above, wetlands added to a stormwater quality treatment train will greatly assist in the removal of sub 100 micron particulate matter and dissolved chemicals.

Despite the fact that wetlands often have to treat highly variable flows of stormwater, at this time the design parameters have to be inferred from the performance of wetlands treating relatively constant flows of wastewater. IWA (2000) contains the following statements about total suspended solids (TSS) removal in SF wetlands:

- "The value of k_T for TSS is theoretically the same as the settling velocity of the incoming particles....".
- "Intersystem performance (the performance difference between different systems) is not strongly sensitive to hydraulic loading rates because many wetlands are over-designed with respect to solids removal."
- "Treatment wetlands are typically efficient in bringing about a net decrease of TSS, with removal efficiencies often in the 80–90% range."

As the first statement indicates, it is assumed that the sole removal process in wetlands is settling. The filtering and trapping of fine sediment by wetland plants and bio-films is ignored. This is normal practice (see Lawrence & Breen, 1998) although it is generally acknowledged that trapping by vegetation is a significant removal process. Lawrence & Breen (1998) discuss the role of vegetation in particle interception but note that "the particular role of vegetation is not well documented". They refer to several studies that have demonstrated the contribution of vegetation to the trapping of TSS but as is apparent from the IWA (2000) statement, this trapping process has not been sufficiently well quantified for it to be included in models of wetland performance.

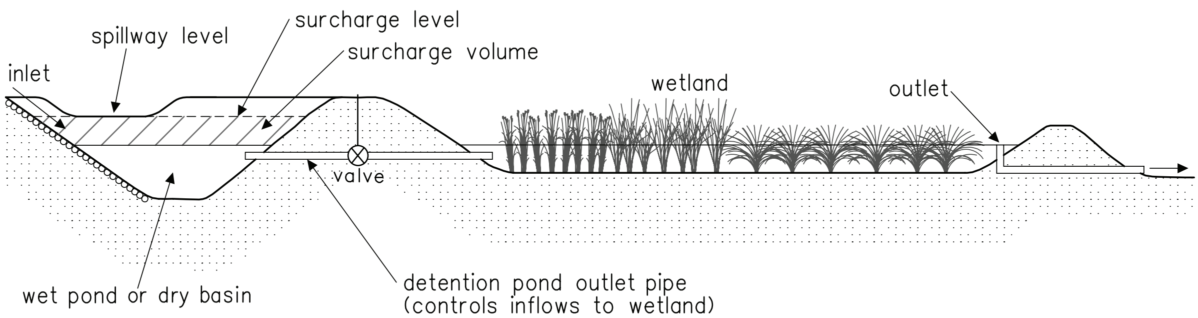


Figure 6-25: An ideal stormwater treatment system consists of a wet pond detention basin upstream of a constructed wetland (in this case a free water surface flow wetland). The wet pond captures stormwater flows and slowly releases water into the wetland via a restricted submerged outlet over a period of time that corresponds to the design flow rate of the wetland. Adapted from Department of Land and Water Conservation (1998b).

Current design guidelines typically result in wetlands being over-designed for TSS removal, and so as a consequence achieve high removal efficiencies. This over-design for TSS removal occurs as wastewater wetlands are designed to also remove BOD, plant nutrients, and sewage microorganisms. These all require several days retention for efficient treatment and in the meantime high removal of TSS occurs by both settling and filtration.

It should be noted however that wetlands generate their own TSS from the physical and biological breakdown of plant tissues and biofilms. Therefore, a wetland achieving 80 % net removal of incoming TSS as determined from inflow and outflow monitoring, might, in fact, be removing 100 % of the incoming TSS, perhaps in a small area of the wetland near the inflow, while generating the 20 % TSS in the outflow.

This leaves the efficient design of SF wetlands for removing TSS from urban stormwater somewhat uncertain at the present time. Currently wetland design for stormwater treatment follows the design for wastewater treatment.

Three methods for sizing constructed wetlands for wastewater treatment are detailed in Department of Land and Water Conservation (1998b)

- rule-of-thumb approach
- Reed's method (Reed *et al.*, 1995)
- Kadlec-and-Knight method (Kadlec & Knight, 1996).

The "rule-of-thumb" method used in the UK is simply 10–20 m^2 of wetland area per m^3 of effluent per day.

Both the Reed's and Kadlec-and-Knight methods consider wetlands as attached growth biological reactors, and therefore use first order plug flow kinetic models as the basis for their performance equations. First order kinetics simply means that the rate of removal of a particular component is directly proportional to the remaining concentration of that component. There are two idealised mixing theories that enable an approximation to be made of the remaining concentration at any point within the wetland cell:

- completely mixed; at any point, the concentration is the same as the effluent concentration
- plug flow; the concentration decreases along the length of the flow path.

The main difference between Reed's method and the Kadlec-and-Knight method is that Reed *et al.* (1995) considers available volume of wetland and the average water temperature, whereas Kadlec & Knight (1996) assume an areal rate reduction basis, so that the rate constant is related only to the surface area of the wetland, with temperature changes considered significant only for nitrogen removal.

Both models assume that the limiting design factor is the pollutant that requires the largest land area for its removal, and that all other pollutants will be adequately removed within this area.

The general form of equation for Reed's method for BOD, NH_4 and NO_3 removal is shown below in Eqn (6-18). Note that the equation for TSS, pathogen, and phosphorus removal takes a different form to that given below.

$$\ln\left(\frac{C_i}{C_o}\right) = k_T t \qquad \text{Eqn (6-18)}$$

where $t = A_S yn/Q$ Eqn (6-19)

$= $ hydraulic residence time

C_i = the inflow concentration

C_o = the outflow concentration

k_T = the first order reaction rate constant at temperature T

= 0.38 for BOD removal at 10 °C

A_S = the treatment area of the wetland

y = water depth within the wetland

n = porosity or effective water space left in a heavily planted wetland

Q = average flow into the wetland

The general form of the Kadlec-and-Knight equation is as follows:

$$\ln\left(\frac{C_o - C^*}{C_i - C^*}\right) = -\frac{k}{q} \qquad \text{Eqn (6-20)}$$

where $$q = \frac{365Q}{A_S} \qquad \text{Eqn (6-21)}$$

C_i = the inflow concentration

C_o = the outflow concentration

C^* = background pollutant concentration

k = areal reaction rate constant

q = hydraulic loading rate

A_S = treatment area of the wetland

Q = average flow into the wetland

For a given flow, inflow concentration and desired outflow concentration, the area of the wetland depends on the value of 'k': the larger the value of 'k' the smaller the area required and vice versa.

For both methods it is assumed that the concentration of the contaminant decreases exponentially with time in the wetland.

Christchurch City Council Simplistic Method for Wetland Sizing

Given the current uncertainty in Christchurch of surface flow wetland performance for stormwater treatment, a simplistic approach using Reed's method (Reed *et al.*, 1995) for flat urban Christchurch is suggested.

Using Eqn (6-18) it has been calculated that, for an average water temperature of 10°C and typical BOD inflow concentration of about 5000 mg/m^3, a through wetland hydraulic residence time (flow travel time) of 2 days will provide a satisfactory level of treatment prior to release to downstream receiving waters.

Upstream stormwater detention, incorporating pre-treatment by sedimentation with a detention basin, is required followed by wetland treatment as follows:

- hydraulic residence time (t): 2 days minimum
- operating water depth (y): 0.25 m
- a wetland shape aspect ratio: 10 L:1 W
- wetland vegetation porosity (n): 0.75

Note, although operating water depth (y) has been set here to 0.25 m, intermittent, deeper open water should be included in the final design and a deeper forebay flow attenuation zone should be included. Overall wetted area should however, be based on an average depth of 250 mm.

First determine the storm runoff volume to be treated. As a minimum this should be the first flush volume determined by the procedure of *Section 6.4.1: Determination of First Flush Volume*.

For a typical urban development the catchment effective first flush runoff area (Aeff) is given by:

$$A_{eff} = im\% \times C_{eff} \times A \text{ (ha)} \qquad \text{Eqn (6-22)}$$

where im% = catchment percent impervious area

C_{eff} = impervious percent contribution

A = full catchment area (ha)

For example in an L1 zoned urban development of 10 hectares, and 25 mm first flush rainfall depth, from Table 6-10 im% = 50% and C_{eff} = 90% from which the catchment effective first flush runoff area (A_{eff}) is:

$$\text{So} \quad A_{eff} = 50\% \times 90\% \times 10 \text{ ha} = 4.5 \text{ ha}$$

Then, from Eqn (6-3), first flush volume (V_{ff}) is:

$$V_{ff} = 10\, A_{eff} d_{ff} \text{ (m}^3\text{)} \qquad \text{Eqn (6-23)}$$

where d_{ff} = first flush rainfall depth (mm)

$$= 10 \times 4.5 \times 25$$

$$= 1125 \text{ m}^3$$

If that volume is detained in either a detention basin/wet pond or combination detention basin and wetland forebay detention zone and slowly released to the wetland over 4 days, with two days flow travel time through the wetland, then average flow rate through the wetland:

$$Q = 1125 \text{ m}^3/4 \text{ days}$$

$$= 280 \text{ m}^3/\text{day } (= 3.3 \text{ l/s})$$

Thus by rearranging Eqn (6-19) to the form of Eqn (6-22), the wetland treatment area (A_S) required is:

$$A_S = \frac{Qt}{yn} \text{ (m}^2\text{)} \qquad \text{Eqn (6-24)}$$

where Q = the average flow rate through the wetland (m^3/day)

t = hydraulic residence time (days)

y = water depth within the wetland (m)

n = porosity or effective water space left in a heavily planted wetland

$$A_S = \frac{280\text{m}^3/\text{day} \times 2 \text{ days}}{0.25\text{m} \times 0.75}$$

$$= 2990 \text{ m}^2$$

Thus, typically, an effective wetland treatment system with flow attenuation through a first flush basin/wet pond will require about 3000 m^2 of wetland area per 10 hectares of urban development; say 17 m width × 176 m length, for which mean velocity is 0.8 mm/s. Note that additional area will be required for maintenance access, internal bunding and landscape buffers. For this example, the final area requirement could be up to 5000 m^2. Such a system could reduce the TSS to less than 20 g/m^3 and BOD to less than 2000 mg/m^3 for typical urban stormwater runoff with first flush detention pretreatment (based on the Reed method). Greater wetland area would reduce the need for, or duration of upstream detention, just as lesser wetland area would require greater upstream detention volume, or duration.

Designers should note that a combined detention basin/wetland area, with buffers, will typically require 5 to 8% of the urban catchment to provide treatment to target standards and meet acceptable facility criteria.

6.8 Detailed Design for Detention Basins and Wetlands

This section should be read in conjunction with the individual design consideration sections of this chapter, along with *Section 6.10: Planning, Design, and Operation Checklist. Chapter 9.3.2.2: Design Considerations for Ponds,* contains further design guidelines for wet ponds.

6.8.1 Detention Basins

Depth

For water quality basins maximum first flush depth should not exceed 1.0–1.2 m to better facilitate sedimentation. Avoid shallow depths to minimise resuspension of deposited sediments.

For water quantity dry basins, detention depth should not exceed an average of 1.5 m. For very large dry basins, where the depth to width ratio is very low, several metres of detention depth may be acceptable. Advice should be sought from Council's Asset Owner on what would be acceptable.

Duration

A design average 24 hours detention (full release over 48 hours) is required, with provision to prevent immediate release of smaller runoff events that might normally pass through the basin quickly. An average minimum of six hours detention should be given to all minor flows (runoff from up to 5 mm storm events). A stage outfall system will allow longer detention time, proportionally, for lesser storms. Where contributing catchments present a risk of accidental chemical spillage to the basin, provision shall be made for full first flush containment to allow for clean up. Gate valves are Council's first preference for discharge control. They permit easy adjustments to outflow rates and better facilitate containment.

Two Stage Design

A two-stage basin design is recommended where extended detention for flood routing, or greater water quality treatment is sought from detention basins. The lower stage will store first flush with slow release of water detained. this lower level release should also be staged (refer to the 'Duration' clause above). The lower bed should be graded at 50H:1V minimum slope close to the outlet or low flow channel within the basin, steepening up to 75H:1V .

The upper stage will be sized and graded (100H:1V minimum slope) to enable dryout soon after the storm event and possibly have separate discharge point near the basin inlet position to minimise disturbance of detained water by more severe storms.

Inlet Control

Slow incoming water velocities to reduce scour and resuspension within the basin. Consider using two or more cells in larger basins to achieve this.

Extended Detention Control Device

For dry basins, a vertical and internally controlled extension of a low flow orifice, with floatable excluders, can withstand partial clogging and gradual sediment accumulation. It can also offer two-stage discharge rate control and full first flush.

Subsoil drains can also offer first stage discharge control and help keep a basin bed dry during rainfall events. Such systems will require above ground extensions to facilitate clean out. All basin pipe outlets through embankments shall have anti-seep collars, or be backfilled with low permeability stabilised fill.

Storm Bypass and Overflows

An extreme storm bypass channel or overflow, such as a splitter box or overflow bund, is essential to minimise the risk of resuspension of sediments in the basin and their uncontrolled overflow downstream. The bypass or overflow should be located at the inlet end of the basin and designed to provide for at least a 2% AEP (1 in 50 yr) critical short duration event (i.e. hydraulic sizing must be for at least the maximum flow rates generated by a 2 % AEP event).

Access

The detention basin must provide good access for maintenance and future sediment removal. Permanent survey reference points should be installed to allow easy monitoring of sediment build up.

Maximum side slope of 3H:1V are recommended, or 4H:1V and flatter if mowing is required. Minimum bed slopes of 50H: 1V to 100H:1V (refer to the 'Two Stage Design' clause above), are also recommended to assist drawdown and drying for dry basins. Access slopes for maintenance vehicles should not exceed 12H:1V for trucks and 5H:1V for excavators.

Sediment Storage

Sediment storage capacity of 5% of the total first flush volume is required within the detention basin. Some means to easily check sediment buildup shall also be provided. A flat concrete slab 1 m square cast in the basin invert, with a level indicator post has been used for this purpose.

Freeboard and Wave Bands

A minimum of 200 mm freeboard above first flush water level is required. A greater requirement may be necessary where significant hydraulic head is required to activate any storm bypass, such as a weir or channel overflow, or where wave buildup on an expansive reach of water is anticipated. Should wave action be considered an issue, erosion control may be necessary. Given the relatively short duration time for impounded waters within any dry basin however, wave erosion should not generally be an issue.

Buffers and Basin Layout

A minimum 5 m average width buffer around detention basins is required for access and landscaping. Where public access is intended, greater buffer width may be required at 'corner' boundaries with private land. A landscape plan shall be required for all basins and should only be prepared in consultation with Council's Asset Parks and Waterways staff. Basin layout shall fit the surrounding landform and not be utilitarian in appearance.

As much as possible, basins should be sited alongside or within reserves to maximise green space. Co-location may bring benefits from infrequent extended detention within the Reserve.

6.8.2 Wet Ponds and Wetlands

Sizing

Wetlands serving mature flat urban catchments, with adequate pretreatment of stormwater, shall be sized for water quality treatment in accordance with *Section 6.7.2: Design Considerations for Surface Flow (SF) Wetlands,* to provide at least two days detention time within the wetland. Further design work will be required for industrial or hillside catchments using the references provided. Allowance can be made for up to 500 mm average detention storage depth over the water quality volume, for more extreme storm events.

Wet pond volume shall be based on the detention time required to achieve 75% sediment removal. For current Christchurch practice this roughly equates to the runoff volume generated by a 15 mm rainfall first flush event (25 mm for all Greenfield development). It should be understood that the first flush detention requirement is additional to the required wet pond volume (Figure 6-26).

As a proliferation of small wet ponds is not considered by Council to be desirable, wet ponds should only be considered for contributing urban sub-catchments greater than 10 hectares per facility.

Approval will be required from Council for all wet pond proposals.

Shape

Wet ponds shall be wedge shaped, narrowest at the inlet with a minimum length to width ratio of 3L:1W. Irregular shorelines are preferred.

Wetlands should have an aspect ratio of approximately 10 L:1W to better simulate plug flow (Figure 6-27).

Substrate

Correct substrate is critical to successful wetland vegetation growth. In surface flow (SF) wetlands substrates need to be provided for vegetation to be planted into. The substrate should be selected to satisfy the following criteria:

- sourced from an area with low weed populations
- chemically stable (e.g. non dispersive)
- able to support plant growth, and suitable for the particular vegetation that will be planted
- needs to contain sufficient nutrient levels for plant growth (but it is not recommended that fertiliser be used to promote growth).

For wetlands ensure the substrate is not overworked by machinery or over compacted, as this will lead to

Figure 6-26: First flush detention area in relation to the wet pond area. For determining wet pond volume, the first flush detention requirement is additional to the required wet pond volume.

Figure 6-27: Constructed wetlands should have a length:width ratio of 10 L:1W to simulate plug flow. Tranz Link wetland, Matipo Street. The white line represents the wetland base area.

a decline in substrate structure. Also ensure the wetland bed is able to be properly drained to help disrupt mosquito larval life cycles.

Refer to the Department of Land and Water Conservation (1998a, b) for further information on substrate selection.

Soils and Groundwater

Ensure the site's soils and seasonal groundwater fluctuations are considered carefully in any final design.

Open soils may require a lining be applied to the basin to limit percolation of untreated waters to groundwater. Highly erodible loess soils will require stabilisation with lime in areas of high inflow/outflow. High seasonal water tables could lead to embankment seepage/slumping and necessitate an underdrainage system in the basin floor to keep the basin dry between storm events.

Plug Flow

Flow through a wetland must be controlled and consistent with no short-circuiting or channelization of the flow path. To achieve this, and to provide for future extreme maintenance, wetlands shall be constructed in cells of length not exceeding 6 hours transit time, or in two or more parallel channels.

The cells or bays shall have inlet/outlet provision to bypass or isolate individual cells or bays. With a cell structure the separation of cells allows for interception of the entire flow, remixing and redispersion.

Inlet Control

Inlets shall be designed to rapidly disperse and slow down incoming water velocities. A wet pond forebay of deep water in any wetland may be necessary to disperse and help attenuation of flow through the wetland.

Water Depth

Wetland average water depth should not be greater than 250 mm, but provision can be made for short sections of open water surface with depths up to 1.0 m lying between shallow vegetated zones. Average depth in a multi-depth wetland should be calculated from volume divided by area.

Wet pond depth can be up to 2 m, typically averaging 1 to 1.5 m with shallow underwater safety benches on the pond perimeter where access is possible.

First flush basins may have up to 0.3 m detention storage on top of the first 25 mm of rainfall. These are dry basins that drain by either infiltration or controlled outlet

Wetlands may have up to 0.5 m of detention storage, from post-first-flush runoff, over the water quality volume (250 mm average depth). Typically this detention storage should only be used for the more extreme storm events beyond the 20% AEP storm event.

Side Slopes

Below the water surface, wetland banks should be near vertical. Above water level, banks should be no greater than 4H:1V and vegetated.

Wet pond side slopes should not exceed 4H:1V with at least 6H:1V where access is provided. For safety, a gently sloping underwater bench at least 3 m into the water shall be provided where access is possible.

Geotechnical advice should be sought where deep ponds are located close to services or development.

Landscape and Buffers

Like all ponds and basins, wetlands shall be designed to be in harmony with their location and preferably be part of a larger reserve area. A minimum 5 m buffer around wetlands and wet ponds shall be provided for access and landscaping. A landscape plan shall be required for all ponds/wetlands, prepared in consultation with Council Parks and Waterways staff.

Flood Flows

Whilst wetland performance is dependent upon attenuated inflows and separation from flood flows, it is permissible to design for periodic flooding (minimum 5 year return period) where floodwaters come from ponding, not through flow (i.e. velocities are kept very low).

Access and Maintenance

Access is required for routine and possible future extreme maintenance, which may require complete removal of vegetation and sediments. Multiple channels or cells are required in any design to provide for this eventuality. Loss of storage through sedimentation can be minimised, or delayed, by the provision of adequate pretreatment measures.

Freeboard and Storage

Freeboard or additional depth in any wet pond will delay the need remove sediment accumulation. Freeboard and erosion control may also be necessary for wave action. Refer to *Chapter 9.3.2.2: Design Considerations for Ponds,* for more detail.

Habitat Control

Design to minimise mosquito habitat, or include operational measures to disrupt the larval stage of their life cycle. Provision for regular rapid raising or lowering of water levels shall be provided. Consider carefully the consequences of long dry periods on any wet pond or wetland. The designer will need to demonstrate that sufficient flow through of any wet pond or wetland can be achieved to ensure that a healthy water body is maintained.

6.9 Operation and Maintenance

6.9.1 General Considerations for Operation and Maintenance Manuals

An operation and maintenance manual is required as a condition of subdivision or development for all stormwater treatment systems. The manual should provide a brief overview of the system layout, mode of operation, design objectives and how the objectives are met by both the design and operation of the structure. This must be prepared by the designer of the system and referred to the Council Asset Owner for acceptance.

The contents of the manual need to include the following general aspects, as well as specific aspects outlined in the relevant sections of this chapter. In addition, designers need to use the checklist provided in *Chapter 19.2: Operations and Maintenance Manual Checklist*, to ensure all issues are addressed.

Purpose

- Detail whether the basin or area is for stormwater detention purposes, water quality maintenance, base flow augmentation, stormwater to ground soakage, or protection and continuance of an existing wetland. Also state whether it will cater for recreation and landscape values, or as wildlife habitat.
- Identify the key design criteria, e.g. pond design parameters and capacity, secondary flow paths stipulated, etc.

Operational Philosophy

- Describe the intended hydrologic and hydraulic operation of the facility.
- State if there is to be a permanent body of water or whether the pond will dry out.
- State whether the facility's invert will be planted out with shrubs and other such vegetation, or grassed, and whether the planting is matched to the proposed environment. Also state the intended purpose of the vegetation.
- Identify the intended form of maintenance, such as mown berms only, or mown berms and invert.
- Describe how any bypass, secondary flow path or emergency spillway should operate.
- What legal provisions exist for off-line discharges? Any secondary flow path across private property needs to be protected by way of easement in favour of the operator.
- What provision is made for controlled drawdown of water for extraordinary maintenance, such as sediment removal or liner repair? Consultation with an ecologist is essential prior to drawdown in such situations.
- Describe outlet operation in the event of a contaminant spillage upstream, so that the contamination can be contained and treated.

Maintenance

- State whether the facility is totally within a 'local purpose drainage reserve', recreation reserve or other reserve, and with whom the future maintenance responsibilities will lie. (i.e. Council or private).
- State when the Contractor's maintenance responsibilities end and when the Council's commence. It would be preferable for Council's responsibilities to commence at the beginning of July each year, in order to tie in with that fiscal year.
- Before the facility is to be transferred to Council responsibility it should have passed through one complete winter cycle, and with all design criteria and Resource Consent requirements having been met.
- Give an overview of the maintenance schedule, including plant loss replacement.
- Include a contact person responsible for the maintenance contract.
- Identify any specific items that require regular inspection or cleaning. For example, submerged pipes that will require regular silt removal, grate, and inlet/outlet structures, etc, that will need regular inspections and maintenance.

Transfer of Operating Responsibilities

- What resource consents have been granted for the construction of the facility. Will the consent is to be transferred to the Council, and if so, at what stage and under what circumstances it will be transferred.
- State if any ongoing monitoring is required and whether the facility's performance has to be measured to fulfil a resource consent condition.
- List health and safety issues.
- Identify if notification of works to private owners, utility operators or the community is required.
- If necessary, a site visit to the facility should be arranged between the designer and the Council Asset Owner to discuss any specific requirements or problems before Council responsibility is acknowledged and accepted.
- Any transfer should include easements.

6.9.2 Operation and Maintenance Manual for Soakage Systems

Any operation and maintenance manual shall address (but is not limited to) the following issues:

- embankment maintenance
- establishment of plant species within basins, swales, and wetlands
- soakage chamber maintenance/reconstruction where appropriate
- sediment removal/dredging
- safe disposal of sediment
- spill response and clean-up procedures
- maintenance/reconstruction of filter bed where appropriate
- monitoring programme.

Maintenance of soakage systems will require regular maintenance of the filter bed. This will eventually involve partial reconstruction (i.e. removing the top layer) or total reconstruction of the filter beds to prolong the life of the system. Mixing and relaying of the filter material is not generally acceptable.

Soakage Basins

The management objective for soakage basins is to maintain both their infiltration and storage characteristics. Maintenance of soakage systems will require regular maintenance of the filter bed. This will eventually involve partial reconstruction (i.e. replacing the top layer) or total reconstruction of the filter beds to prolong the life of the system. Mixing and relaying of the filter material is not generally acceptable. This will be achieved through the following measures:

- Mowing of grass and pruning of vegetation: this will be carried out to maintain a tidy appearance of the basin. All cuttings will be removed from the area. However, if possible, reduce the amount of vegetative maintenance by planting appropriate species and providing sufficient space for plant growth.
- Control of pests and weeds: minimal applications of fertilisers and pesticides will be used. Any applications will be timed to avoid any runoff effects.
- Inspections: these will coincide with regular maintenance and will assess erosion of soil or vegetation, accumulation of litter and general basin function and appearance. Tidy up measures will be implemented as required.
- Maintenance of infiltration rate: maintenance of the infiltration rate is likely to require some occasional tilling or discing and aeration of the soil to prevent clogging. The timing of these maintenance works will be based on monitoring of the infiltration rate, achieved during storm events where ponding occurs.
- Sediment removal: removal of sediment may be required at some point due to the clogging of infiltration pathways or accumulation of chemical residues. The requirements for any such sediment removal will involve skimming off the surface layer where fine-grained deposits have accumulated during stormwater inflows.
- Machinery access: basins will be sited and designed to allow easy access for equipment required for tilling, discing and soil removal.

Overflow Chambers

The management objective for overflow chambers is to maintain a rapid infiltration rate. This will be achieved by maintaining the integrity of the inlet features of the chambers, namely:

- a continuous cover over the top of the chamber to prevent litter and debris entering the chamber
- an underflow weir and grill inlet around the circumference of the chamber to prevent inflow of floating debris.

If infiltration rates in the chambers reduce over time, as evidenced by prolonged ponding, maintenance would involve cleaning out the base of the chamber by either suction tanker or drilling rig, or re excavation of horizontal soakage trenches.

Emergency Response to Spillages

A strategy must be in place for responding to any spillages of hazardous substance within a catchment using ground soakage. Refer to *Chapter 19: Operation and Maintenance*, for a checklist.

6.9.3 Operation and Maintenance Manual for Detention Basins and Ponds

- For dry basins refer to *6.6.2 General Considerations*.
- For ponds see also the maintenance requirements in *Chapter 9.3.2.2: Design Considerations for Ponds.*

6.9.4 Operation and Maintenance for Constructed Wetlands

Wetlands require most attention during the vegetation establishment phase to ensure that growth occurs where it is needed and to control weeds. As the desired plants become established the effort required for vegetation maintenance decreases. Pest control can sometimes be needed. These general requirements are well explained in both Kloosterman & Tanner (2001), and Tanner (2000, 2001).

The primary maintenance consideration is the loss of hydraulic performance due to either sediment accumulation or excessive vegetation growth. Excessive sediment accumulation usually only occurs in the following circumstances:

- where the wetland is either directly receiving stormwater from an eroding catchment (i.e. a young or partially urbanised catchment or one with unstable stream channels)

- where the upstream pond is not performing adequately (i.e. is too small or too shallow, possibly as a result of sediment accumulation).

The solution is to either install a pond or improve the performance of the existing pond.

Excessive vegetation growth is a relatively common problem and thinning, at intervals of several years, may be required.

Loss or change of the vegetation cover can require substantial effort to correct. The vegetation cover is selected to thrive in the water regime expected for the wetland—either free water surface (FWS) or intermittent free water surface (IFWS). If an IFWS wetland changes to a FWS wetland because of blockage, or the reverse change occurs because of sediment aggradation, then the vegetation may be unable to cope with the new environment. Either of these changes can occur because of poor design. However, in normal operation, blockage by plant debris, etc., is a matter for routine maintenance, whereas aggradation is prevented by maintaining the sedimentation capacity of the upstream wet pond.

Operation and Maintenance Manual for Constructed Wetlands

Refer to *Chapter 6.9.1: General Considerations*

6.9.5 Monitoring

6.9.5.1 Monitoring of Soakage Systems

Monitoring could be required as a condition of consent, and will normally be the responsibility of the consent holder.

For soakage basins that will vest with the Council, developers shall discuss proposed monitoring conditions with Council staff, prior to applying to Environment Canterbury for resource consents. The Council may require payment of a lump sum to cover the costs of future monitoring and analysis, after the basin has vested to the Council. The value of the lump sum will be determined by the amount and type of monitoring required.

Typical monitoring by the consent holder may include:

- measurements of infiltration rates (using double ring infiltrometer tests) in soakage basins and in contributing swales where ground soakage is utilised
- composite sampling of soils in the top 50 mm of basin inverts shall be undertaken as required by consent, with samples typically analysed for the determinants shown in Table 6-11.

Frequency of Monitoring

Background measurements should be taken prior to commissioning of the soakage basin. Typically, sampling will be repeated one year after commissioning. Thereafter, monitoring frequency will be determined by a number of factors, including but not limited to: the nature of the catchment, previous monitoring results, other available data for similar basins or catchments.

Direct Soakage chambers

Where direct soakage chambers are permitted, monitoring of inflows, particularly during the first flush, may be required.

Typically, samples will be analysed for:

- total petroleum hydrocarbons
- acid soluble zinc
- dissolved zinc
- acid soluble and dissolved lead
- acid soluble and dissolved copper
- faecal coliforms
- suspended solids.

Frequency of Monitoring

Where monitoring is required, the frequency of monitoring will be determined by the catchment characteristics, previous monitoring results, and available data for similar systems, or SMP requirements for the catchment.

6.9.5.2 Monitoring of Wet Ponds and Wetlands

The extensive monitoring discussed below would not typically be required with most stormwater treatment train systems. The Christchurch City Council will however identify key sites for such monitoring, and

Table 6-11: Soakage monitoring determinants from Canterbury Regional Council consent requirements.

Determinants	Maximum Acceptable Concentration (dry weight)
Total lead	300 mg/kg
Total copper	130 mg/kg
Total zinc	300 mg/kg
Total petroleum hydrocarbons (TPH)	C7 to C9* – 500 mg/kg C10 to C14* – 1700 mg/kg

* these values refer to carbon chain length.

work with developers to better evaluate the long-term performance and benefit of such systems.

Monitoring of wetland and wet pond performance is complicated by the highly variable nature of stormflow events. Performance is normally evaluated in terms of reductions in sediment load and chemical contaminant load, typically as the difference in concentration between inlet and outlet. Loading is the product of concentration and mass flow rate (kg/s), therefore both of these quantities have to be monitored. Since rainfall intensity and the resulting stormflow cannot normally be predicted, continuous flow recording and automatic samplers triggered by the flow recorders are required for reliable results. Obviously both the inlet and outlet need to be monitored. If travel to the wetland or wet pond is a significant cost, telemetry can be a viable alternative for detecting a sampler initiation. Permanent survey reference points should be installed to allow easy monitoring of sediment buildup.

Telemetry is a particularly useful option if the variables to be determined are not stable and cannot be adequately preserved, such as with *Enterococci*, BOD, etc. Degradation of unpreserved samples can be a serious problem during warm weather. It is seldom practical to refrigerate samples. Samples for plant nutrients can be preserved by adding a small amount of a mercury salt to the sample containers before sampling but the mercury is likely to interfere with other analyses (e.g. metals). There is no preservative that is compatible with all the variables listed below.

Wetland/wet pond performance can vary markedly over time and a meaningful evaluation of performance is only possible with monitoring that:

- spans summer and winter
- includes several events covering a range of volumes and intensities of rainfall, and different lengths of antecedent dry period.

These factors change the state of the wetland and the composition of the stormwater.

Typical contaminants of concern in stormwater are:

- dissolved metals: usually copper and zinc from residential catchments plus lead, cadmium, chromium, nickel, arsenic and sometimes mercury if the catchment contains industrial activities
- particulate forms of these metals
- suspended sediment
- petroleum hydrocarbons
- polycyclic aromatic hydrocarbons (PAHs)
- ammonia
- other plant nutrients such as nitrate, dissolved organic nitrogen, dissolved reactive phosphorus, dissolved organic phosphorus
- indicator organisms: usually *Enterococci* for discharge to saline waters, and *E. coli* for discharge to freshwaters.

This is an extensive list and, depending on the nature of the stormwater, which can usually be inferred from the catchment land use, it is often possible to reduce the number of variables to be measured and still satisfy the monitoring objectives. For example, the performance of the wetland for one dissolved metal is often a good indicator of its performance for the other dissolved metals. Similarly, the results for total petroleum hydrocarbons give a good indication of the likely performance for PAHs (by far the most expensive variable to test in the above list).

Note that if the facility is situated in a catchment for which an SMP has been agreed, there will be monitoring quidelines/requirements in that document to follow.

Another option for reducing the analytical cost is to collect composite samples. So long as the compositing period is only a few hours in length then degradation of the sample is not likely to be a problem and preservation is usually unnecessary. Over collection periods of several days, however, only total metals from the above list can be collected without preservation. Nutrients and total suspended solids must be preserved by appropriate means although, if samples are kept dark, the error introduced to the suspended solids result after a day or two should be quite small. Composite sampling is not reliable for organic contaminants (e.g. petroleum hydrocarbons and PAHs) and is impossible for BOD and any other measure of organic carbon and indicator organisms.

The vegetation cover and the bed level of the wetland will change over time. The state of the vegetation can be monitored using standard survey methodology such as transects or quadrats, for species composition and biomass. The simplest approach for monitoring bed level changes are with permanently fixed level gauges. For this purpose stainless steel rulers have been found to be quite useful.

6.10 Planning, Design, and Operation Checklist

Treatment system design and operation should follow the checklist below.

Catchment Hydrology

- ❑ Determine runoff flows
  - ❑ Base flow, summer and winter
  - ❑ Frequent events, say 5 times per year
  - ❑ Rare flood events
  - ❑ First flush volume

Selection of Catchment Management Measures

- ❑ Determine flood detention objectives
- ❑ Determine water quality objectives
- ❑ Estimate the pollutant discharges (dissolved, suspended, and floating)
- ❑ Identify critical pollutants and receiving water reduction targets

Pre design monitoring:

- ❑ Design a monitoring/sampling program
  - ❑ Select sites for monitoring
  - ❑ Assess instrumentation needs

Treatment train selection:

- ❑ Review types of stormwater treatment systems
- ❑ Make the treatment train selection based on objectives
- ❑ Adopt at least first flush offline treatment

Siting the facilities:

- ❑ Look at physical constraints
- ❑ Consider landscape and other values

Design Principles

- ❑ Look at litter trapping measures
- ❑ Set preliminary basin/pond/wetland depth and shape
- ❑ Carry out flow routing for:
  - ❑ Base flow
  - ❑ Frequent events
  - ❑ Rare flood events
  - ❑ First flush diversion
- ❑ Look at water treatment of:
  - ❑ Base flow
  - ❑ Frequent events
  - ❑ Rare flood events
  - ❑ First flush volume
- ❑ Determine likely sediment removal effectiveness
  - ❑ Assess particle sedimentation efficiency
  - ❑ Look at ability to retain settled particles
- ❑ Consider recreation and aesthetic functions
- ❑ Refine basin/pond/wetland depths and shape
- ❑ Resolve inlet and outlet configurations
- ❑ Select aquatic and riparian plants and design the planting
- ❑ Look at likely impacts of water quality on ecology
- ❑ Design structural elements
  - ❑ Look at soil substrates, groundwater, and percolation
  - ❑ Carry out embankment design
  - ❑ Design the shoreline of the structure for wave, water current, aesthetic, and ecological needs
  - ❑ Design outlet control structures, allowing for water level control and full drawdown
  - ❑ Carry out spillway design
  - ❑ Review all components for maintenance requirements including access
- ❑ Assess and resolve Health and Safety issues

Operation and Maintenance

- ❑ Produce an Operation and Maintenance manual (Refer to *Chapter 19*)
- ❑ Pond and/or wetland performance assessment
- ❑ Design a monitoring/sampling program
  - ❑ Select sites for monitoring
  - ❑ Assess instrumentation needs

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