Chapter 5
Pond design, construction, and maintenance

5.1 Introduction

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

Ponds are defined as:

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

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

Stormwater ponds are used for three primary purposes:

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

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

5.2 Water quantity/quality performance

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

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

5.2.1 Contaminant removal mechanism

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

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

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

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

5.2.2 Expected performance

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

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

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

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

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

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

Table 5-2
Stormwater treatment pond monitoring in Auckland

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

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

Table 5-3
TSS removal efficiencies for Auckland pond studies

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

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

5.2.3 Constraints on the use of ponds

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

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

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

5.3 Pond component disclaimer

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

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

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

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

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

5.4 Design approach

5.4.1 Objectives

Water quantity objectives

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

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

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

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

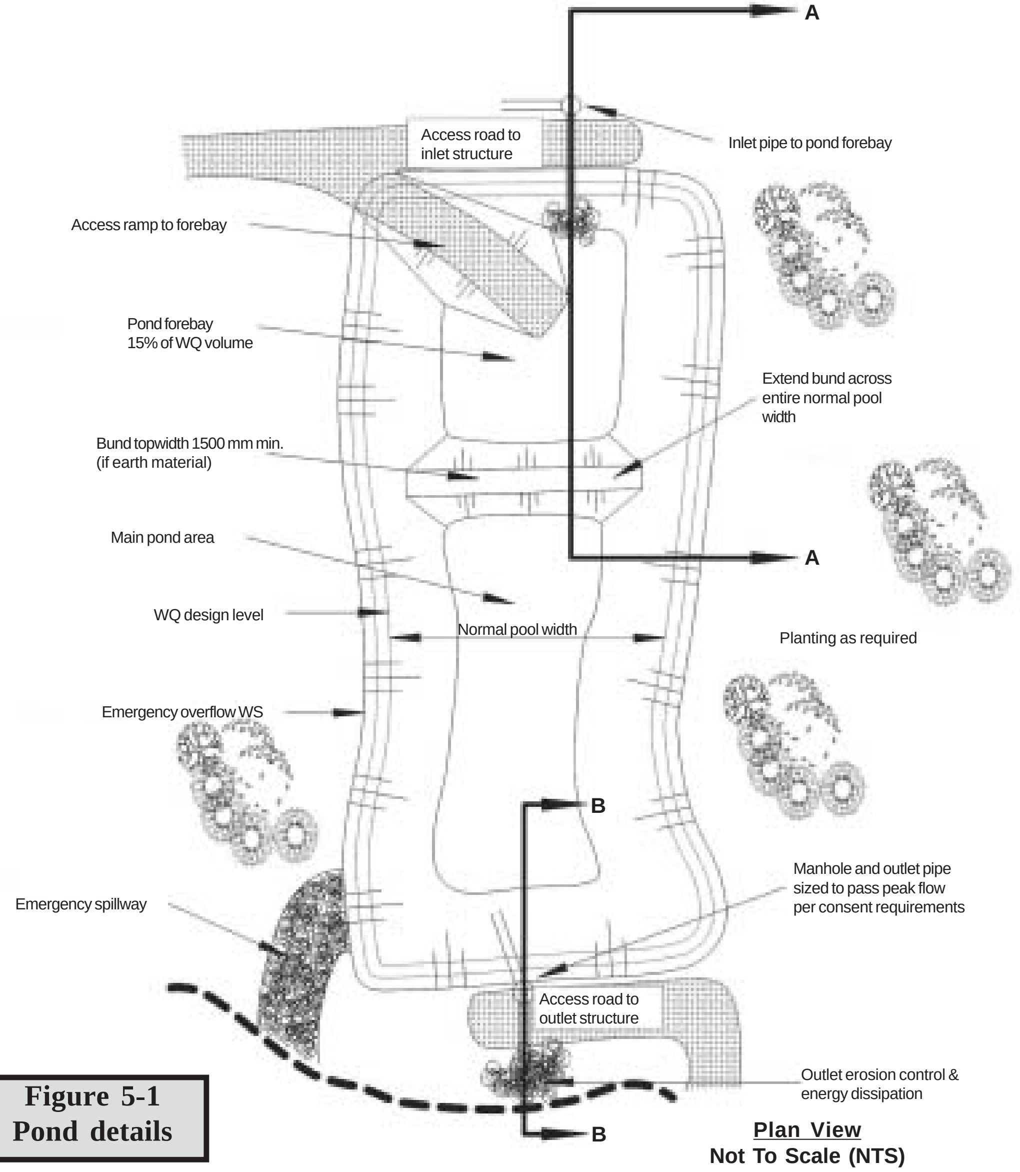
Water quality objectives

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

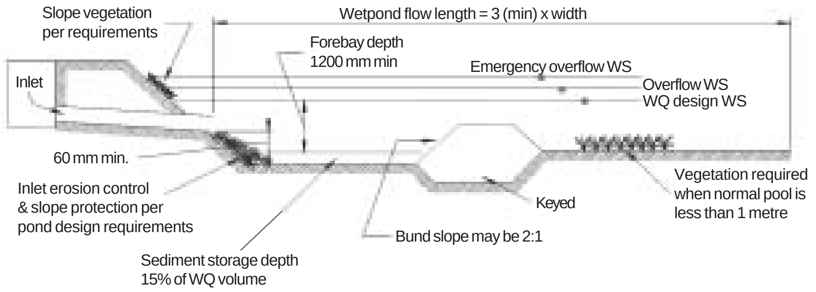
Where possible, water quality ponds ponds need a bypass for larger flows. Because all flows travel through the pond, water quality performance during larger events will be reduced as first flush contaminants are carried through it. Ideally, larger flows should bypass the pond in order to avoid a drop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

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

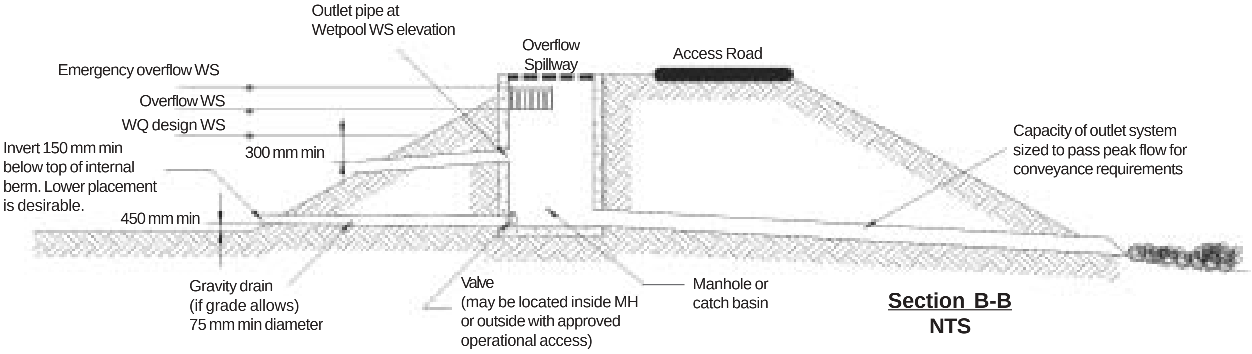
Figure 5-1
Pond details



Plan View
Not To Scale (NTS)



Section A-A
NTS



Section B-B
NTS

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

Channel protection objectives

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

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

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

Ponds in series

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

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

5.4.2 Preferences

Preferences for wetlands versus ponds

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

On-line versus off-line

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

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

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

Dry ponds versus wet ponds

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

Maintenance responsibility

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

5.4.3 Safety features

Depth

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

Benches

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

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

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

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

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

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

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

Fences

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

5.4.4 Aesthetics

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

5.5 Design procedure

5.5.1 Approach

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

Pond design tasks, in order, include the following:

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

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

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

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

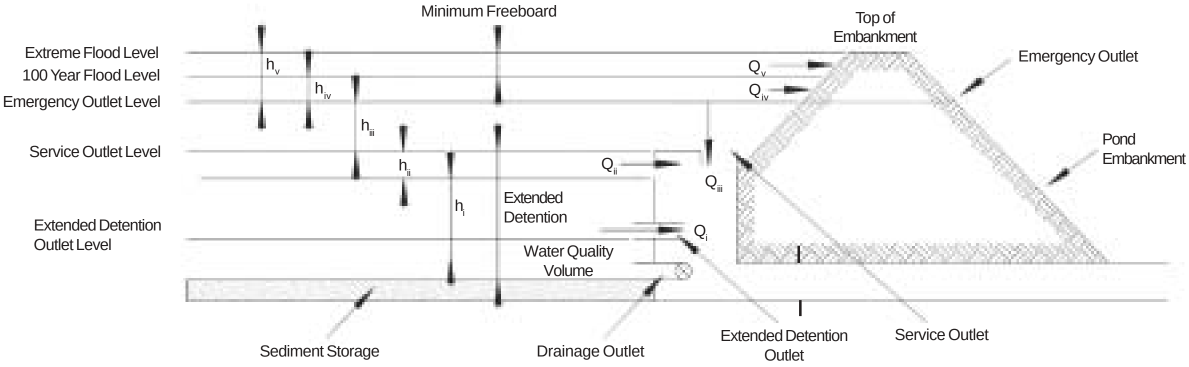
at least 50% of that volume as permanent pond storage. The other 50% stores and releases runoff from the 34.5 mm of rainfall over a 24 hour period.

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

5.5.2 Spillways and outlet capacity

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

Figure 5-2
Schematic pond levels



Service outlet

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

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

Emergency spillway

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

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

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

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

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

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

5.5.3 Forebay

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

The forebay should meet the following criteria:

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

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

5.5.4 Hydraulic flow characteristics

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

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

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

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

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

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

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

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

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

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

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

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

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

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

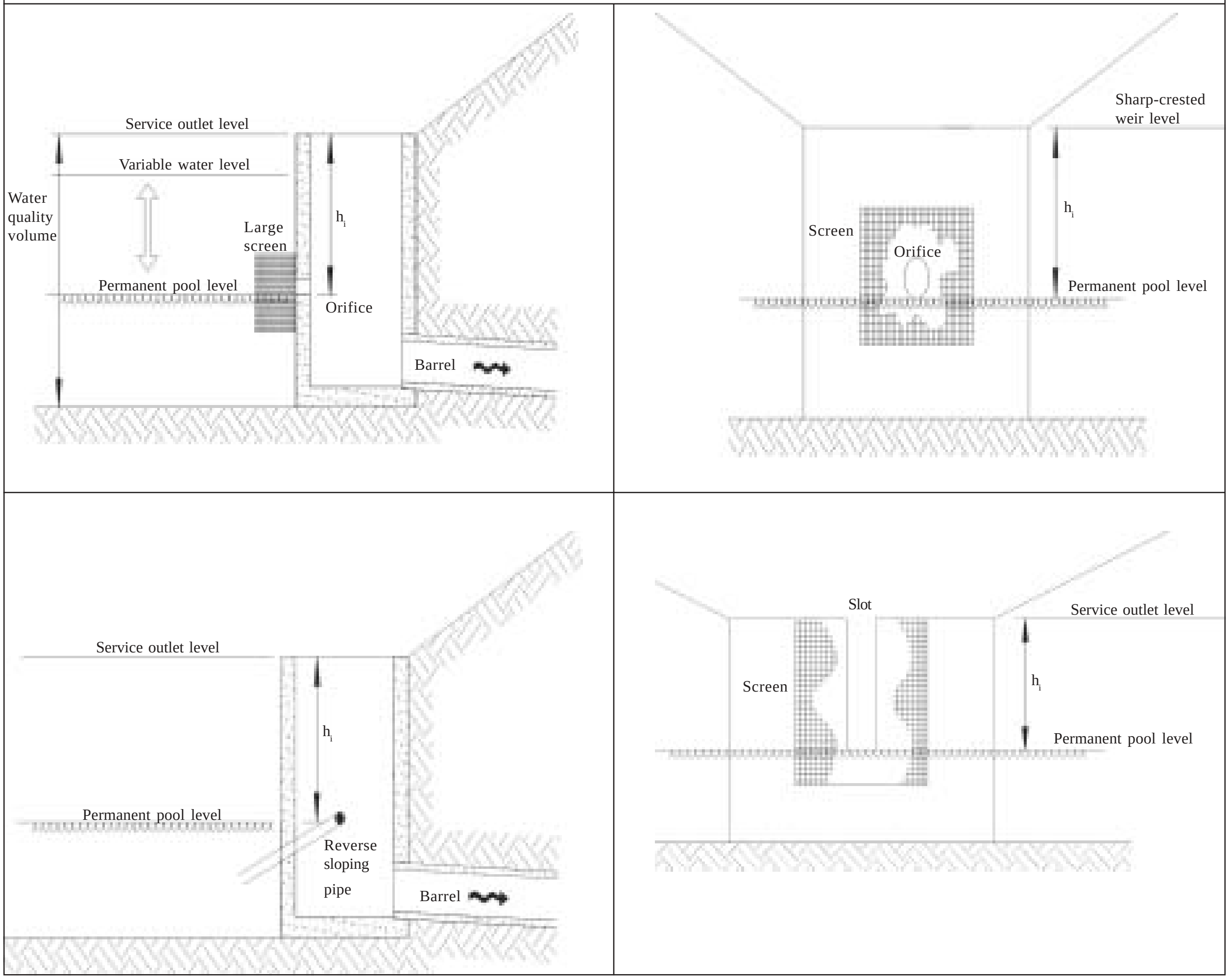
A number of different outlet designs for extended detention are detailed in Figure 5-3.

5. 2 and 10 year stormwater management

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

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

Figure 5-3
Types of extended detention outlets



Drop inlet

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

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

Where R is the radius of the inlet.

For a box weir:

$$Q_{ii} = 7.0 w h_{ii}^{3/2}$$

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

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

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

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

For a circular inlet:

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

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

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

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

Broad crested weir

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

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

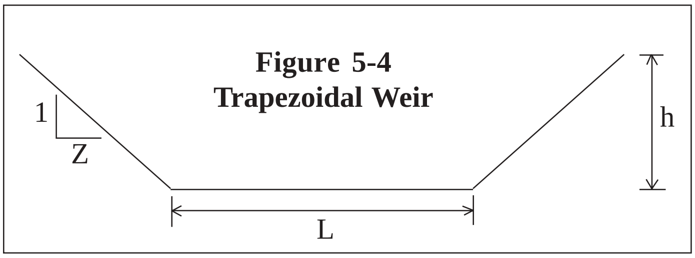


Figure 5-4
Trapezoidal Weir

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

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

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

Weir with channel

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

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

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

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

6. Emergency spillway design

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

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

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

5.5.5 Designs to avoid short-circuiting

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

5.5.6 Oil separation

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

5.5.7 Debris screens

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

5.5.8 Ease of maintenance

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

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

5.6 Pond and site design

5.6.1 Pond shape

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

5.6.2 Pond contours

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

5.6.3 Edge form

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

5.6.4 Islands

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

5.7 Landscaping

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

5.8 Construction

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

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

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

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

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

5.8.1 Important inspection aspects related to design

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

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

Refer to the checklist at the end of the chapter.

5.8.2 Important inspection aspects related to construction

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

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

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

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

5.8.3 As-built plans

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

As-built plans should detail:

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

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

5.9 Pond safety

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

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

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

5.10 Operation and maintenance

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

5.10.1 Aesthetic and functional maintenance

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

- Aesthetic/nuisance maintenance and
- Functional maintenance.

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

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

Aesthetic maintenance

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

> *Graffiti removal*

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

> *Grass trimming*

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

> *Control of weeds*

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

> *Miscellaneous details*

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

Functional maintenance

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

> Preventive maintenance
> Corrective maintenance

Preventive maintenance

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

1. Grass mowing

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

2. Grass maintenance

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

3. Vegetative cover

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

4. Trash and debris

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

5. Sediment removal and disposal

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

6. Mechanical components

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

7. Elimination of mosquito breeding habitats

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

8. Pond maintenance programme

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

Corrective maintenance

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

1. Removal of debris and sediment

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

2. Structural repairs

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

3. Dam, embankment and slope repairs

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

4. Elimination of mosquito breeding areas

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

5. Erosion repair

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

6. Fence repair

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

7. Elimination of trees or woody vegetation

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

8. General facility maintenance

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

5.10.2 Other maintenance activities

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

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

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

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

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

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

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

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

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

Plate 5-3: Outlet Structure Showing Multiple Storm

5.11 Case study

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

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

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

TP 108 analysis provided the following information:

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

5.11.1 Pre-development condition

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

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

5.11.2 Post-development condition

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

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

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

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

5.11.3 Water quality volume

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

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

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

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

5.11.4 Extended detention volume (EDV)

The EDV is based on 34.5 mm of rainfall.

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

5.11.5 Pond outlet design

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

Table 5-4
Stage storage relationships

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

Extended detention outlet

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

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

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

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

Calculate the low flow orifice.

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

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

Weir for 2-year and 10-year events

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

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

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

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

Ponded water level is therefore 17.12 m (by interpolation from stage / volume table)
Weir invert level is the level at which the full EDV of 1689 m^3 is impounded, RL 16.0 m.
Ouflow from extended detention orifice $Q_i = 0.62A(2gh_i)^{0.5}$
where $h_i = 17.12 - (15 + 0.125/2) = 2.057$ m
$Q_i = 0.048\ m^3/s$

Outflow over weir $Q_{ii} = 1.7\ L_{ii}h_{ii}^{1.5}$
where L_{ii} is the weir width and $h_{ii} = 17.12 - 16.0 = 1.12$ m
Try $L_{ii} = 0.17$ m, then $Q_{ii} = 0.343\ m^3/s$
Total outflow $Q_i + Q_{ii} = 0.39\ m^3/s$ or approximately the pre-development flow rate

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

Ponded water level is therefore 17.73 m (by interpolation from stage / volume table
Weir invert level is the level at which the 2-year event is impounded, RL 17.12 m
Outflow from extended detention orifice $Q_i = 0.62A(2gh_i)^{0.5}$
where $h_i = 17.73 - (15 + 0.125/2) = 2.67$ m
$Q_i = 0.055\ m^3/s$
Outflow for 2-year weir $Q_{ii} = 1.7\ L_{ii}h_{ii}^{1.5}$
where $h_{ii} = 17.73 - 16 = 1.73$ m (L_{ii} from 2-year calculations)
$Q_{ii} = 0.66\ m^3/s$
Outflow for 10-year weir $Q_{iii} = 1.7\ L_{iii}h_{iii}^{1.5}$
where L_{iii} is the weir width and $h_{iii} = 17.73 - 17.12 = 0.61$m
Try $L_{iii} = 0.39$ m
$Q_{iii} = 0.32\ m^3/s$
Total outflow $Q_i + Q_{ii} + Q_{iii} = 1.03\ m^3/s$, approximately the pre-development flow rate

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

5.12 Bibliography

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

Seyb, Roger, A Revised Stormwater Treatment Design Methodology for the New TP 10, Second South Pacific Stormwater Conference, Rain - The Forgotten Resource, 27-29 June, 2001.

Department of Natural Resources, Maintenance of Stormwater Management Structures, A Derpartmental Summary, Sediment and Stormwater Division, Water Resources Administration, July, 1986.

State of Maryland, The Effects of Alternative Stormwater Management Design Policy on Detention Basins, 1982.

Water Resources Administration, The Effects of Alternative Stormwater Management Design Policy on Detention Basins, 1984.

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

Auckland Regional Council, Report on Selection of Stormwater Treatment Volumes for Auckland, prepared by Beca Carter Hollings and Ferner Ltd., Environment and Planning Division, Technical Publication #4, 1992.

Auckland Regional Council, Stormwater Treatment Devices Design Guideline Manual, Technical Publication #10, Environment and Planning Division, October 1992.

U.S. Bureau of Reclamation, Design of Small Dams, U.S. Government Printing Office, 1977

Thompson, Craig S, Tomlinson, Alaric I, A Guide to Probable Maximum Precipitation in New Zealand, NIWA Science and Technology Series No. 19, NIWA, Wellington, June 1995.

Inspection forms and checklists for ponds

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

Example preconstruction meeting topics

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

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

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

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

E. Construction access and set-aside areas

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

5. Construction details
    1. Unique or complex aspects of the project

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

6. Consents and permits

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

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

1. Notify plan review/compliance agency as required

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

2. Pre-construction meeting with compliance agency

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

3. Site layout

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

4. Install perimeter erosion and sediment controls

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

5. Install temporary channel diversion

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

6. Clear and grub the pond area

7. Remove topsoil from the pond area

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

8. Facility stakeout

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

9. Core trench/emabankment area

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

10. Construct outfall channel

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

11. Install barrel with anti-seep collars

    This should be done BEFORE any embankment work

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

12. Riser placement

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

13. Install any erosion control structures required

14. Construct remaining core and embankment

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

15. Divert flows into pipe system

16. Construct emergency spillway

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

17. Install inflow channels

    a. Stabilise according to plan including pipe outfalls into pond

18. Complete excavation of pond to final grade

19. Vegetatively stabilise all disturbed areas

20. Complete pond conversion

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

Auckland Regional Council
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STORMWATER COMPLIANCE INSPECTION ADVICE

(Under Section 332 of the Resource Management Act 1991)

Investigating Officer:

Date:

Time:

Weather: Rainfall over previous 2-3 days?

Person contacted during visit:

Page 1 of 2

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

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

Pond Components:

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

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

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

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

OFFICERS REMARKS:

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ACTION TO BE TAKEN:

No action necessary. Continue routine inspections? Y / N

Correct noted site deficiencies by ____

1st Notice: ____

2nd Notice: ____

Submit plan modifications as noted in written comments by ____

Notice to Comply issued ____

Final inspection, project completed ____

Officers signature: __________________________

Consent Holder/Engineer/Agent's signature: __________________________

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STORMWATER COMPLIANCE INSPECTION ADVICE

(Under Section 332 of the Resource Management Act 1991)

Investigating Officer:

Date:

Time:

Weather: Rainfall over previous 2-3 days?

Person contacted during visit:

Page 1 of 2

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

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

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

Pond Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
EMBANKMENT & EMERGENCY SPILLWAY	Y	N	Y	N	**A,S**
1. Is the spillway level?					
2. Adequate vegetation & ground cover?					
3. Appropriate plants / weeds?					
4. Adequate freeboard?					
5. Embankment erosion evident?					
6. Cracking, bulging or sliding of dam					
a) Upstream face					
b) Downstream face					
c) At or beyond toe upstream					
d) At or beyond toe downstream					
e) Emergency spillway					
7. Pond & toe drains clear & functioning?					
8. Evidence of animal burrows?					
9. Seeps/leeks on downstream face?					
10. Vertical & horizontal alignment of top of dam as per As-Built plans?					
11. Emergency spillway clear of obstructions & debris					
12. Provision of access for maintenance?					
a) By hand?					
b) For machinery?					
13. Other?					
RISER & SERVICE SPILLWAY					**A**
Type: Reinforced concrete					
Metal pipe					
Masonry					
14. Low flow orifice obstructed?					
15. Low flow trash rack:					
a) Is debris removal necessary?					
b) Is corrosion evident?					
16. Weir trash rack maintenance					
a) Is debris removal required?					
b) Is corrosion evident?					
17. Is there excessive sediment accumulation inside the riser?					
18. Metal pipe condition	Good		Fair		Poor
19. Outfall channels functioning?					

	Checked		Maintenance Needed		Inspection Frequency
	Y	N	Y	N	
20. Concrete/Masonry condition Riser and barrels:					
a) Cracks or displacement?					
b) Minor spalling (,0.25mm)?					
c) Major spalling (rebars exposed)?					
d) Joint failures?					
e) Water tightness adequate?					
21. Pond drain valve:					
a) Operational / exercised?					
b) Chained and locked?					
22. Slope protection or rip-rap failures?					
23. Other?					
PERMANENT POOL (WET POND)					**M**
24. Undesirable vegetative growth?					
25. Removal of floating debris required?					
26. Visible pollution?					
27. Evidence of 'edge' erosion?					
28. Other?					
DRY POND					**M**
29. Adequate vegetation cover?					
30. Presence of undesirable vegetation / woody growth?					
31. Standing water or wet spots?					
32. Sediment and/or trash accumulation?					
33. Low flow channels unobstructed?					
34. Other?					
SEDIMENT FOREBAYS					
35. Is sediment accumulation > 50% (maintenance req'd immed. If Yes)					
36. Provision of access for maintenance:					
a) By hand?					
b) For machinery?					
OUTFALLS INTO PONDS					**A,S**
37. Riprap failures?					
38. Condition of endwalls / headwalls	Good		Fair		Poor
39. Evidence of slope erosion?					
40. Condition of any inflow pipes.	Good		Fair		Poor
41. Other?					

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

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

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

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

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

Comments: ____

Dates by which maintenance must be completed: / /

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

Officers signature: ________________________________

Consent Holder/Engineer/Agent's signature: ____________________________