35 CONSTRUCTED PONDS AND WETLANDS

35.1 PURPOSE AND DEFINITION

The treatment systems described in this Chapter tend to be either predominantly open water systems ("ponds") with associated macrophyte zones, or predominantly macrophyte systems ("wetlands") with some open water. Extended detention basins, which are not strictly ponds at all, are also described. The choice of one of these measures reflects differences in pollutant forms and flow and loading conditions.

Water quality control ponds ("wet ponds") can have both water quality control and flood control functions. It is economically advantageous to combine both functions in a single pond. This Chapter covers the design principles for the water quality component of the pond or wetland. The designer should refer to the relevant sections of Chapter 20 for design of the flood storage component within community and regional detention ponds.

The emphasis in the first part of this Chapter is on simple sizing and design principles that can be used for preliminary sizing during the planning phase of a project. However, detailed design of constructed ponds and wetlands is a complex process, which if not done properly, will result in poor performance. Designers should refer to Section 35.5 for a discussion of detailed design procedures.

The pond design charts and procedures in this Manual are partly based on overseas data as there is a lack of experience with ponds and wetlands for water quality control in Malaysia. It is expected that the procedures will be subject to revision as more local knowledge is accumulated.

35.2 PLANNING CONSIDERATIONS

35.2.1 Site Selection

Refer to Section 20.2 in this Manual.

35.2.2 Protection from Sediment Load

Wet ponds or wetlands must be protected by upstream sediment traps and/or gross pollutant traps or other devices to reduce sediment load (see Chapter 34). In general, 'SBTR' type gross pollutant traps are preferable on urban drains where there are a range of pollutants possibly including litter, oil and chemicals. Ponds receiving runoff from highways, parking areas or heavy industrial areas are particularly vulnerable. Proprietary traps may also be suitable for some applications.

Sediment traps (without a trash rack) may be suitable for ponds that are being used as off-line flood storage and water quality control on rivers with mainly non-urban catchments. Sediment traps are to be designed to maximise deposition of coarse sediments. A hard floor (for example, concrete) with vehicle access should be provided to facilitate maintenance.

WEF (1998) recommend that the sediment trap should have an area of 10% of the permanent pool area, however this will depend on the local hydrology. Alternative design guidelines for sediment traps and SBTR-type gross pollutant traps under Malaysian conditions are given in Chapter 34.

35.2.3 Multiple Uses

Wet ponds can have multiple uses. They provide:

- Flood management – temporary flood storage to reduce downstream flow peaks;
- Water quality improvement – by sedimentation and natural biological processes;
- Landscape and recreational value;
- Water supply – ponded water may be suitable for lawn watering, irrigation and other purposes (however it is usually not suitable for potable water); and
- Conservation – restoration or provision of habitats for flora and fauna.

35.2.4 On-line or Off-line

Ponds and wetlands can be either on-line, meaning that they are located on a main watercourse or flow path, or off-line. Some of the common alternatives are shown in Figure 35.1; other arrangements are also possible.

The choice of an on-line or off-line pond design is usually governed by site characteristics. On-line ponds are generally used for small catchments up to 5 to 10 km^2 in area as they will tend to be more economical. However, an off-line design can also be used for small catchments to suit the site. An example is where an open space reserve or playing field is located beside a drain.

For large catchments, the size of the necessary outlet structure and spillway generally makes an on-line design very costly. For this reason an off-line design is preferred. However there are also exceptions, such as where it is desired to build a pond in a river valley to make use of the natural topography. In this case the outlet will normally be in the form of a small dam.

Where there is a risk of occasional high-discharge events, constructed wetlands should be located off-line.

35.3 POND AND WETLAND TYPES

35.3.1 Zonation

Ponds should be designed with a combination of deep and shallow water. The design concept involves three main zones in which different assimilation processes dominate, and different design conditions apply. Typical arrangements of these zones are shown in Figure 35.2.

(a) Inlet Zone

The function of the inlet zone is to remove larger particles, including sediment, and to distribute flow across the pond. The installation of sediment traps or GPTs helps in the function of this zone.

(b) Macrophyte Zone

Macrophytes are large aquatic plants. Beds of macrophytes filter out finer particles, and directly take up contaminants. They enhance sedimentation and the absorption of pollutants onto sediments.

The macrophyte zone should be provided around the pond edges downstream of the main inlets to filter out sediment, nutrients and toxicants, to disperse the inflowing waters and to reduce its velocity. Macrophyte zones should be from 25-50% of the total pond area. Plantings should be on the perimeter, arranged so that there is opportunity for water in the open pond zone to circulate through the macrophyte zone.

(c) Open Water Zone

An open water zone is a deeper area that allows time for fine particles to flocculate to the bed, and allows sunlight to kill bacteria. Decomposition and grazing of organic matter will occur in this zone. Periodic algal growth may occur here and this will also trap dissolved nutrients and allow them to enter the food chain or to settle to the bed of the pond.

A minimum depth of 2.4 m is recommended for open water zones. The open water zone has the potential for some recreational activity, especially in the larger ponds and urban lakes. Water quality however will generally be unsuitable for body contact recreation.

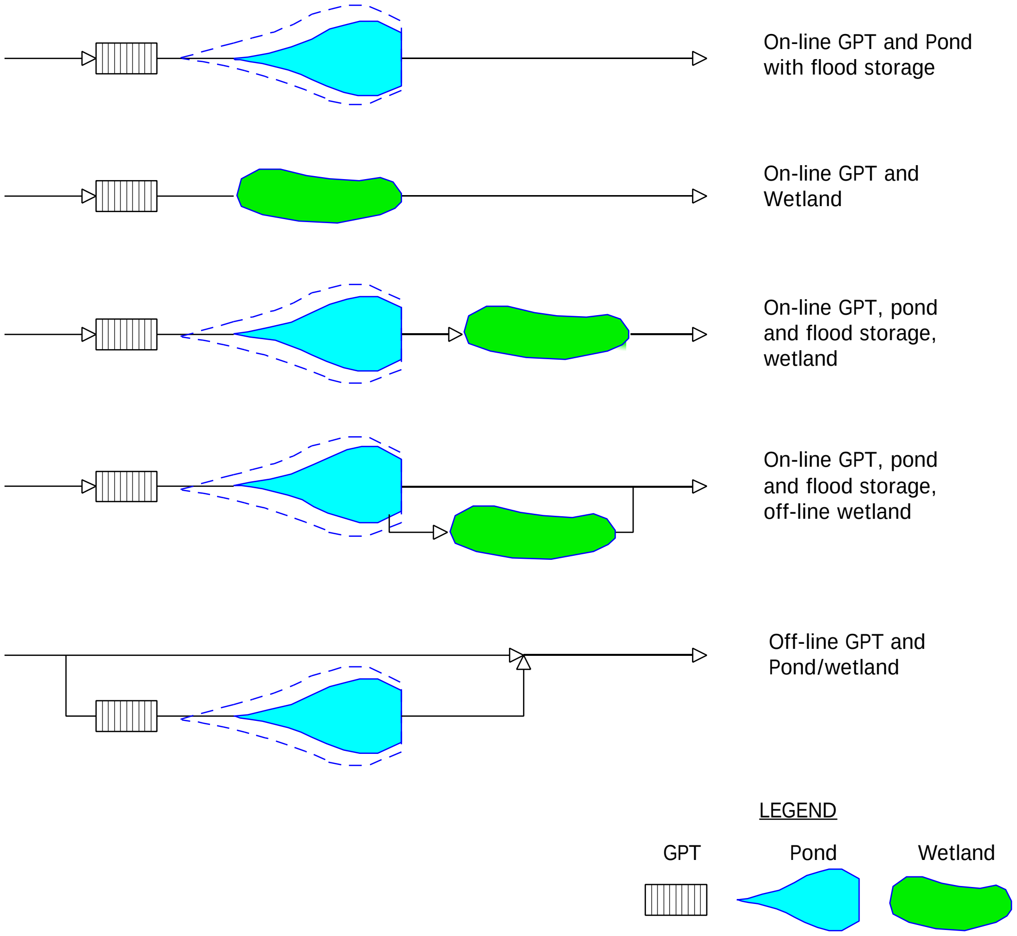


Figure 35.1 Alternative Pond and Wetland Layouts

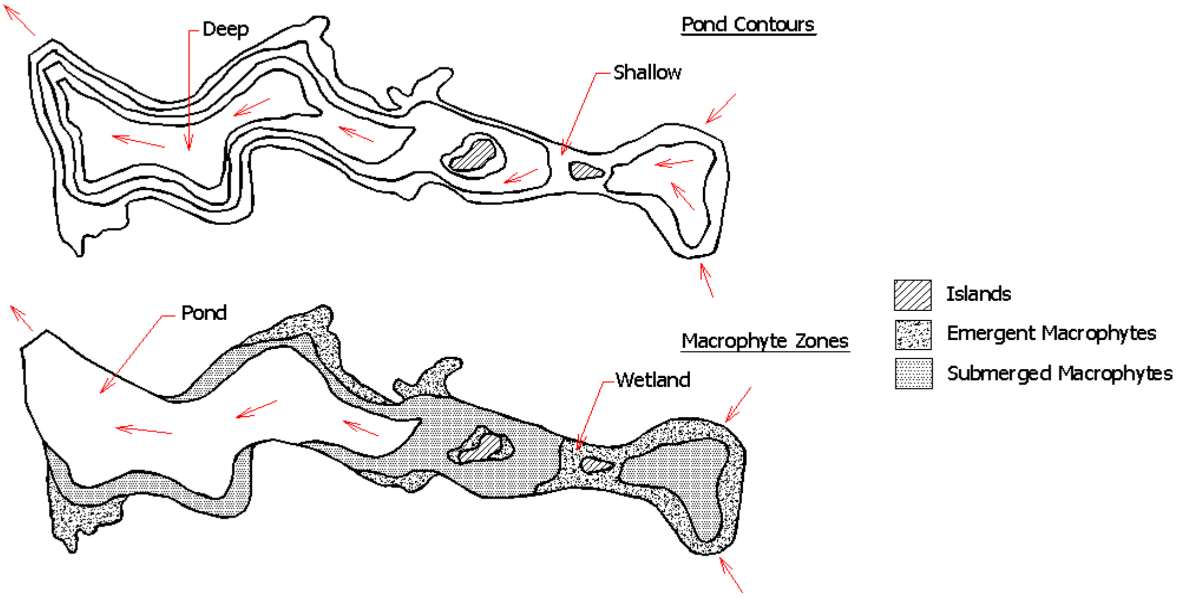


Figure 35.2 Pond Configurations

35.3.2 Wet Ponds

Wet ponds remain permanently full. The ponds are generally vegetated around the fringes and may include islands and wetland vegetation.

Wet ponds are likely to be widely used in Malaysia due to the soil types and aesthetic appeal. Difficulties will arise in obtaining sufficient land in areas that have already been developed.

When sized adequately, wet ponds can provide good sediment removal (up to 75% of load, on an annual basis). Aquatic plants and microbiota improve the treatment performance, especially with regard to nutrients.

Ponds can be provided with different outflow controls to also promote flow attenuation. Slotted or v-notched weirs and multi-staged outlets are common practice in overseas countries. These types of devices provide a smooth transition from the case where attenuation is only provided for the water quality design storm, to also providing a measure of flood control in frequent events. This transition is required in order to protect the downstream ecosystem from the increased peak flows in frequent events (small ARIs).

If maintained properly, wet ponds are attractive and socially acceptable. They are likely to enhance the appeal of surrounding properties and to serve as a focus for recreation. Wet ponds can provide a habitat for birds and fish. The wetland plants themselves are an environmental amenity.

A permanent pond cannot be maintained with very permeable soils (e.g. sandy soils) unless a liner is used.

In the initial establishment period, care in planting and regular maintenance are required in order to encourage plant growth. After this period, pond vegetation and surrounds must be maintained and sediment must be removed periodically from the pre-settling trap or GPT. Maintenance requirements are in general, no greater than for other stormwater systems.

35.3.3 Extended Detention (ED) Basins

The practice has developed in some overseas countries with temperate climates, of designing a basin so that the runoff from a storm is retained over an extended period of several days or longer. This extended detention allows for greater removal of certain pollutants, especially nutrients, by biological action.

Extended detention (ED) basins are designed to fill during a storm, and to empty completely between storms. There is generally no permanent pool of water, but a small pool or wetland may be included within the basin area. Runoff from small storms is attenuated. Extended detention basins are also referred to, rather inaccurately, as "dry ponds". The minimum recommended catchment area is 2.5 ha for commercial or industrial landuses or 3.5 ha for residential landuses.

Extended detention basins designed purely for improving the water quality do not have sufficient storage to attenuate large storm flows – dual purpose basin/ponds are required in that case.

The basin area is often dry between events, so the land can be used as a recreational area, although the land may become boggy if surface and subsurface drainage is not provided.

When sized and designed appropriately with an appropriate draw-down time, extended detention basins can provide the required sediment capture. There is little biological uptake due to there being little vegetation and only short detention times. Sediment re-entrainment may occur if the basin is subjected to high flows. Further, the outlet is usually at the bottom of the basin, so murky sediment-laden water may flow out the outlet. This will degrade the treatment performance of the device. Therefore, unless flow attenuation is designed, ponds which are permanently full (wet ponds) are preferred.

Other issues to consider are:

- Extended detention basins will attenuate small storms, but due to the size and lower release rates, will not provide significant peak flow attenuation for large storms.
- Due to the low amount of vegetation and the absence of permanent water, the habitat value is not high. Extended detention basins may have less visual appeal than ponds, which are permanently full.
- The high probability of repeated storms within the detention period will make it difficult to achieve full emptying.
- Periodically inundated areas are often wet and boggy, so it may be difficult to mow and walk on and create favourable conditions for mosquito breeding. It may be difficult to maintain wetland vegetation because the water level changes may be large and frequent.
- High sediment and debris loadings in many areas of Malaysia will create a serious risk of blockage of the small outlets that are typically used for extended detention.

These issues require careful consideration by the designer under Malaysian conditions. However, there may be particular situations where extended detention would be appropriate. For example, they may be used in areas where pervious soils would preclude the use of a permanently full pond.

35.3.4 Combined Wet/Extended Detention Ponds

Combined wet/ED ponds are something between a wet pond and an extended detention pond. Part of the pond is maintained as a permanent pool. The volume above the permanent pool fills during a storm and slowly empties.

Combined ponds share some of the advantages and disadvantages of wet and extended detention ponds. Small storms are captured and treated in the permanent pool. There is also some biological uptake in the permanent pool. Water level changes are not as large as with an extended detention pond, so wetland plants are easier to grow. A more diverse range of plants will probably be established compared with a wet pond. Some attenuation of small storm flows will be provided. The minimum recommended catchment area is 3.5 ha for residential landuse or 2.5 ha for industrial or commercial landuse.

A combined pond will require a more complicated outlet than for a wet pond. Outlet structures are discussed in Section 35.6.2.

35.3.5 Constructed Wetlands

There are only small changes in pond elevation, to drive flow over the outlet structures. Wet ponds therefore provide minimal flow attenuation.

Issues to consider when choosing constructed wetlands include the following:

- Wetlands have a mostly limited depth, ranging from zero at the shore to 1.0 m in the deepest areas. The average depth of the emergent vegetation zone is typically 0.5 m.
- The change in water level is usually kept small (less than 0.6 m) as most wetland plants are not tolerant of greater changes. These figures are for the water quality design storm. Wetlands which are associated with ponds that are also used for flood control can tolerate submergence to depths between 1 m and 2 m, provided that velocities are low enough to avoid flattening and that the duration of submergence is not more than a few hours.
- Wetlands differ from ponds in having greater biological uptake. Well designed perennial wetlands intercept dissolved and colloidal forms of pollutants. The benthic biofilm adsorbs pollutants and transfers them to the sediments, while dissolved nutrients are primarily taken up by benthic and epiphytic algae. Adhesion of fine particles onto vegetative surfaces may also play a part in pollutant interception.
- Although the water level changes are usually small, the large areas provide some volume for attenuation of small storm flows. In general, wetlands should not be used for extreme flood attenuation due to the potential damage to the wetland plants.
- Wetland areas provide educational benefits and some passive recreation (e.g. walking track) benefits. They can have a high visual appeal, and add to the natural landscape. Wetlands provide a good habitat for birds and fish. In all ponds, and in wetlands in particular, mosquitoes are likely to be a concern of the public.

The control of mosquitoes is discussed later in this Chapter.

- Wetland planting, establishment and maintenance is usually necessary and can be costly.

35.3.6 Dual Purpose Ponds

Dual-purpose ponds consist of a stormwater quality control pond (with volume equal to the Water Quality Volume) and an additional volume above, for flood attenuation. Flow is usually detained in the flood attenuation volume only enough to reduce peak flows (typically a few hours) which does not allow for much treatment of flood flows. The net effect of the pond is similar to the effect of a wet pond in series with a flood detention pond.

The provision of flood storage in a dual-purpose pond is discussed in Chapter 20. Flood storage is not treated in detail in this section, as the main focus here is on stormwater quality control. The designer should be aware that the two functions can be catered for in the same pond, and that incorporating the two functions in one pond will be more cost-effective than creating two separate ponds (a treatment pond and a flood detention pond).

35.4 PRELIMINARY SIZE ESTIMATION

35.4.1 Introduction

A number of pond design procedures are proposed in the literature. This field of knowledge is rapidly evolving, and new procedures are likely to be developed during the lifetime of this Manual. This section provides a recommended preliminary design procedure suitable for general application in Malaysia. Detailed design requires specialised design procedures that are discussed in Section 35.5.

35.4.2 Data Collection

Design of water quality control ponds (wet ponds) requires data on:

- Catchment area;
- Hydrology of inflows;
- Survey details, including depths, of existing ponds;
- Hydraulic conditions at the pond outlet, which may create tailwater;
- Soil type;
- Estimates of sediment loads and other pollutant loads from the catchment; and
- Chemical analysis of the existing pond water and sediment, if there is a risk of chemical contamination. This task is essential when an ex-mining pond is proposed to be used.

35.4.3 Design Criteria

The criteria for design of a water quality control pond (wet pond) will usually take one of the following forms:

1. a requirement to remove a specified percentage removal of pollutants, and/or
2. a requirement to include flood storage, and/or
3. to suit an available site area or utilise an existing pond.

Ponds should form part of a treatment train (see Section 35.4.6. For a complete treatment train serving new development, the overall objective is removal of 70% of suspended solids load (see Table 4.5 in Chapter 4). Some of this removal will occur in the settling trap or GPT, and some in the pond or wetland.

Where the pond or wetland is being installed as part of land redevelopment, the suggested design target for the pond or wetland is a reduction of 50% of the existing pre-development SS load (see Table 4.5).

In existing developed areas, site constraints and economic considerations will govern the size of the pond and the degree of pollutant removal achievable. In some locations existing mining ponds may be able to be used.

35.4.4 Recommended Sizing Guideline

The length of time that water is retained in a pond is the main variable in determining how effective the pond will be in trapping pollutants. Increasing the volume and hence, retention time allows for more sedimentation of particles, and more assimilation of pollutants.

The Pond Efficiency Curves in Appendix 35.A give preliminary estimates of pollutant removal efficiency for on-line ponds. The curves show estimated removal efficiency of *a 2.0 m deep on-line pond* as a function of the Area Ratio, where:

$$Area\ ratio = \frac{Pond\ surface\ area}{Catchment\ area} \qquad (35.1)$$

and the pond surface area and the catchment area are expressed in the same units. An average depth of 2.0 m was chosen to represent the recommended depth range for ponds (CRCFE 1998). Removal efficiency curves are shown for the most commonly considered pollutants: sediment, SS and TP.

The curves have been derived for several representative locations in peninsular Malaysia. For other locations, calculations can be carried out by using the process shown in the flowchart for the preliminary design of ponds, Figure 35.3. This method takes into account local rainfall statistics.

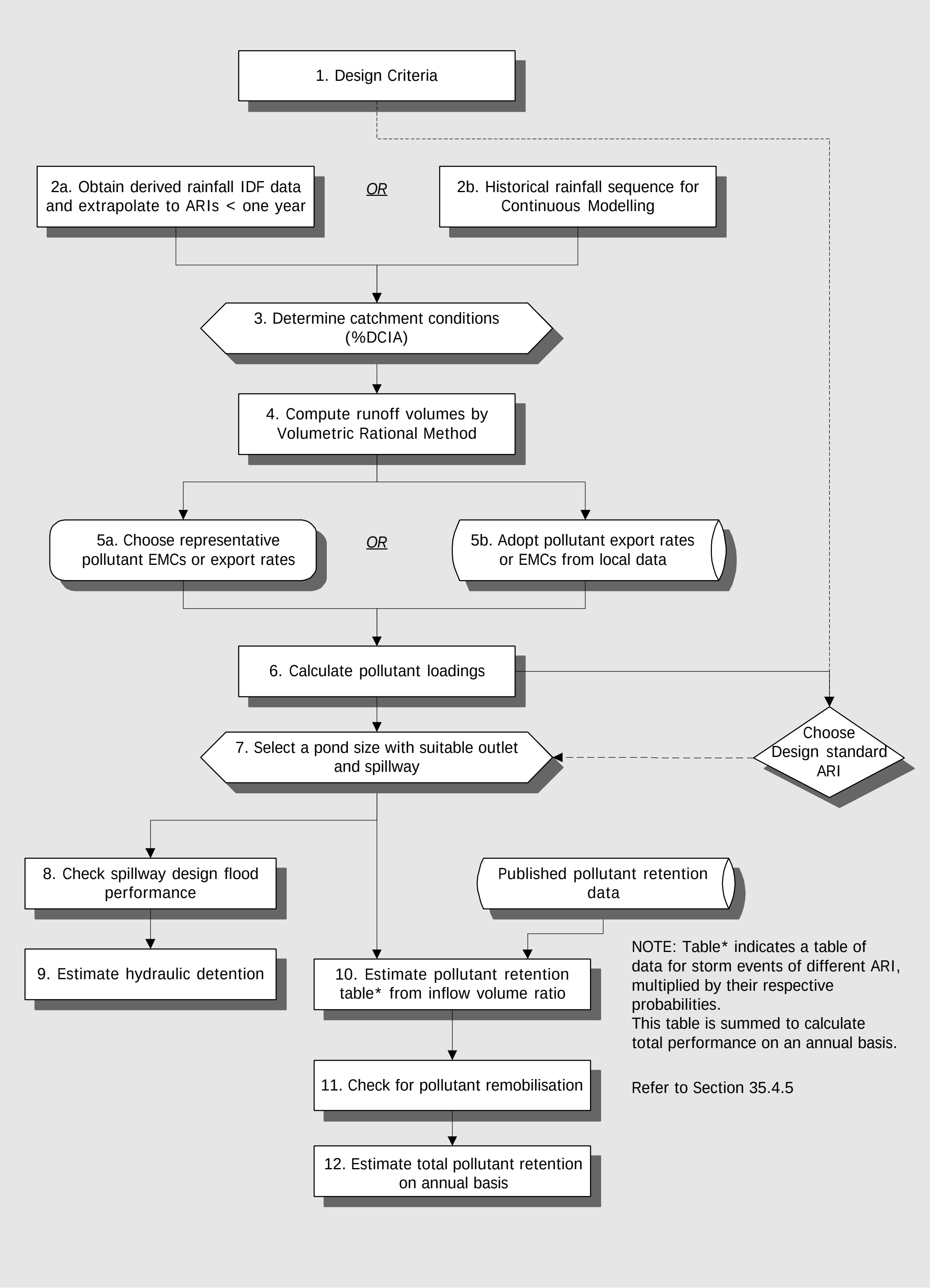


Figure 35.3 Flowchart for Preliminary Pond Sizing

A worked example of the method is given in Appendix 35.B.

The pond design curves are suitable for preliminary size estimates. More detailed calculations are required for detailed design, as discussed in Section 35.5.

35.4.5 Sizing of Off-line Ponds

It is not practical to present typical design curves for off-line ponds because of the range of possible site conditions and diversion characteristics. Therefore, the design of such ponds should always be undertaken using a storage routing computer program.

In general the pollutant removal of an off-line pond will be less than that of a similarly-sized on-line pond, because of the lower percentage of total flow that is captured in the pond.

35.4.6 Multiple Ponds and Treatment Trains

There are opportunities to use sets of adjoining ponds to create optimised treatment trains. It is generally an advantage to have several ponds in series to maximise retention. The designer is able to optimise the outlets of ponds in series to improve both their flood detention and water quality improvement capabilities. This optimisation should be done as part of the detailed design procedure.

Where adjoining ponds differ markedly in depth and/or condition, it may be more advantageous to create a pond/wetland system. In general a deep pond should be located upstream of an on-line wetland. This helps to reduce the peak flood flows and velocities, which would otherwise damage the biological processes. Alternatively, a shallow wetland can be located off-line with only limited inflow (restricted by an inlet pipe) or even arranged to recirculate flow back into a pond.

35.5 DETAILED DESIGN PROCEDURES

35.5.1 Introduction

The preliminary pond sizing guidelines given in Section 35.4 have been generalised across Malaysia. They will need to be adjusted by local Authorities to suit local hydrologic conditions. Further research is recommended in order to derive suitable guidelines for local conditions.

The sizing criteria use empirical pollution interception/retention models based upon limited monitoring of a small number of existing ponds, mainly in temperate climates. As noted by CRCFE (1998) the value of this type of model is limited because the climate, hydrology, soil and other characteristics of the project site may be very different to that at the monitored ponds. Therefore, detailed design should always involve a continuous simulation study of the pond or wetland using local rainfall data and a pond process model. This will require the application of spreadsheet or computer modelling methods. The stage-discharge relationship of the outlet will need to be calculated and used in the model.

Appendix 35.C gives a worked example of detailed design calculations for an off-line pond/wetland for a sample urban catchment that also receives highway runoff.

35.5.2 Process Modelling

As a result of ongoing research it is now possible to describe and model the dominant pollutant interception and retention processes. These models have the potential to supplement and to some extent replace the empirical sizing guidelines. However it must be pointed out that the models require specialist expertise which may not be readily available among local authorities and designers.

CRCFE (1998) provides a range of background material and diagnostic tools, which can be used to assess the performance of existing ponds. The Guidelines will enable the designer to pinpoint the primary factors contributing to under-performance, and the modification options relevant to reducing or removing these factors (Lawrence, 1999).

A number of pond and wetland process models are available which can be used for more detailed design studies. Examples are the models PDMOD and WMOD described in CRCFE (1998). These spreadsheets are available in the public domain as EXCEL spreadsheets.

In the CRCFE models, the transfers and transformations of pollutants are described by physical, chemical, biological and microbial equilibria and rates. Because of the interdependence of these factors all pond compartments have to be analysed concurrently.

A Continuously-Stirred Tank Reactor approach is used. The model also computes losses and gains over time, with a daily computational step. Transfers between the water column and sediment, algal and atmospheric compartments are all included.

The spreadsheet model requires input of daily inflows. The inflows could either be gauged data, or a synthetic time series generated from a hydrological model such as XP-AQUALM. Computer runs should be carried out for at least a year of continuous flow data, in order to obtain a representation of long-term pond performance.

The model also requires input of the pond initial conditions. These conditions should be generated iteratively by running the model for a representative period such as one month, and then using the final results as the initial conditions for a subsequent run. Successive iterations should converge within two or three runs, and the results can then be used for the 'design' runs.

Figure 35.9 shows the major processes represented in some process-based pond and wetland models.

Other models are also available. Information on other process-based models will be added to the Manual as they become available.

35.5.3 Pond Retention

Several process-based models use pond retention curves. These curves are empirical, compiled from observed pond and wetland performance.

Insufficient data is available at present to derive retention curves for Malaysian conditions. Until more data are available, Design Chart 35.4 should be used to define pollutant retention for SS, TP, FC and TN. The pollutant retention data for suspended solids and total phosphorus were adopted from Willing & Partners (1995). The pollutant retention data for faecal coliform and total nitrogen were adopted from the Clean Waterway Programme of Sydney Water Corporation, Australia.

35.5.4 Transformation and Remobilisation of Settled Pollutants

When calculating the pond size, the designer should check for release of deposited material back into the pond (or wetland) as a result of *reducing conditions* (CRCFE, 1998). Reducing conditions may occur as a result of the decomposition of organic sedimented material.

Benthic microbes normally feed on decomposing organic material at the bottom of the pond or wetland. Their growth depletes dissolved oxygen levels and if organic material remains after the oxygen has all been used up, further microbial growth leads the transformation of a number of trapped pollutants (such as nitrate, ferric iron, sulphate) and their release back into the water or atmosphere in such forms as ammonium ions, nitrogen, phosphate, or hydrogen sulphide.

This action is most likely to occur if ponds are too small and hence overloaded, or if the BOD load is excessive or not well distributed across the pond. Stratification (the formation of layers of different density and/or temperature) increases the probability that reducing conditions will occur.

The following, based on CRCFE (1998), is a method of checking for remobilisation of deposited pollutants:

1. Calculate a BOD load per unit area for a storm event, using the methods in Chapter 15.
2. Adjust the BOD load per unit area by a factor F to account for BOD distribution.
3. Estimate the aeration rate, from Table 35.1.
4. Determine the Total P release rate from the empirical relations in Design Chart 35.5.
5. Adjust the sizing calculation in the Spreadsheet Method (Figure 35.3) to account for the TP release.

Table 35.1 Pond Aeration Rates

Mixing Condition	Oxygen Transfer ($g/m^2/day$)
Stratified	0.6
Diurnal mixing	1.0
Fully mixed	1.5

Source: CRCFE (1998)

If the predicted amount of release is significant, the designer should:

- reduce the BOD loading by improved catchment management; or
- increase the size of the pond; or
- increase the area of macrophyte planting; or
- introduce a mixing mechanism, such as recirculation pumps to prevent stratification.

35.5.5 Pond Shape and Design Features

The complexity and requirements for detailed data makes circulation modelling impractical for most small ponds. However, the use of lake and pond circulation models should be considered for the design of large, important lake features.

Ponds should be long relative to their width in order to provide optimum circulation. Length to width ratios should be in the range of 3 to 5 (CRCFE, 1998). Islands or baffles can be incorporated to prevent short-circuiting. Islands can provide valuable aesthetic and environmental benefits (for example, wildlife habitat). For safety the tops of islands should be located above design flood level.

From an aesthetic point of view, it is important to select plantings that enhance the visual quality of the facilities. The designer should consider the alignment and treatment of edges to create variety and interest by, for example, using small embayments in preference to straight edges. Deep embayments should be avoided unless they will have their own stormwater inlets, as they may create zones of poor mixing and lead to poor water quality. An embayment with its own inlet should be subjected to the same criteria as a separate pond.

Pond depth has been discussed in Section 35.3.1. Very deep ponds (> 4 m) should be avoided because they may be prone to thermal stratification.

35.6 EMBANKMENT AND OUTLET DESIGN

The water-retaining embankments for ponds may have the characteristics of small dams, and should be designed as such. Even when existing mining ponds are used, some form of water-retaining embankment may be required.

There are many different types of dams, including concrete, rockfill, and earthfill. Earthfill dams are by far the most commonly used for detention facilities in urban development projects. Regardless of the size or location of a proposed facility, or the similarity to other projects nearby, the design of the pond or wetland, and especially the embankment, should always be based on site-specific information.

35.6.1 Geotechnical Design Considerations

(a) Embankment

Normally, the design will include an embankment to impound the permanent pond and create flood storage. In some cases where an existing mining pond is being used, an embankment may not be required.

The actual subsurface conditions for the particular site and the fill materials intended for use as the embankment must be tested for bearing capacity, seepage, and stability. The structural integrity should not arbitrarily be assumed just because of the proximity or superficial similarities to another pond. In most cases, professional geotechnical advice must be obtained.

The selection of construction materials should take into account the range of immersion depths and flow velocities that is predicted to occur. Embankments are typically constructed from roller-compacted earth. Suitable material must be selected so that it can be compacted to the required standard, so that it will provide an impermeable barrier, and to provide the stability needed to resist hydraulic forces under the design storm.

The embankment should be constructed to control the amount of seepage through the dam in order to prevent piping, which could lead to dam failure. Depending on the availability of suitable material, the dam may be designed as either a homogeneous or a zoned embankment. Figure 35.4 shows a typical dam embankment.

As the name implies, a homogeneous dam embankment is constructed entirely of one type of fill material. Preferably, the material will be sufficiently impervious to inhibit seepage. Because some seepage can be expected for wet pond earthfill dams, homogeneous dams should not be constructed of highly erodible materials, such as silts or fine sands, which could be carried away by water seeping through the embankment (piping).

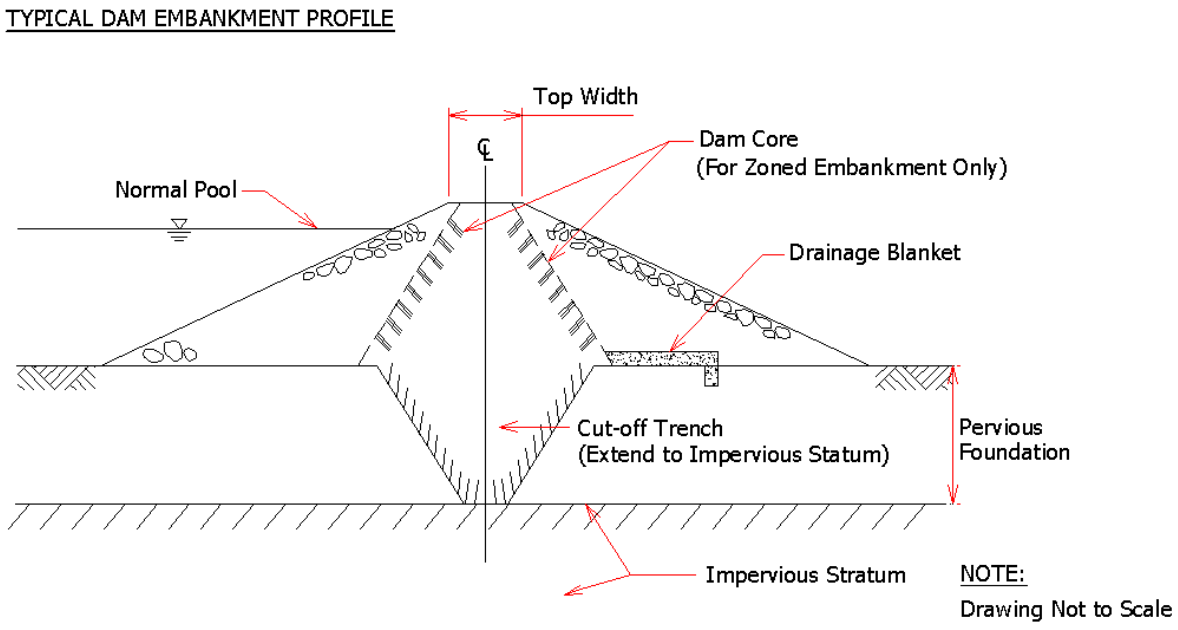


Figure 35.4 Typical Dam Embankment Profile

A zoned type embankment may be preferred if sufficient impervious material is not available to construct the entire embankment, or if the material requires additional measures to prevent slope failure or erosion. For this alternative, two or more zones of different fill material are used to construct the embankment, with one zone, called the dam core, constructed of impervious material. The other zone(s) may be constructed of more pervious materials, such as sand, gravel, and cobbles, and may provide structural stability for the embankment.

If impervious material is not available, an impervious liner may be placed over the embankment to prevent seepage. The liner may consist of clay, possibly mixed with bentonite, or it may be a manufactured synthetic liner. Special care must be taken to ensure that the liner does not crack or puncture. The liner should extend from above the normal pool of the pond to the pond bottom and some additional distance upstream that depends on the imperviousness of the foundation. For very pervious foundation materials, the entire pond may require a liner.

(b) Drainage Blankets

The purpose of a drainage blanket is to allow any seepage through the embankment to drain in a controlled way, thereby minimising embankment erosion. A drainage blanket consists of a layer of sand, gravel, or other pervious material surrounded by appropriate filter material to prevent particles, or fines, from passing from the embankment into the blanket. The filter material may be either a fine-grained pervious material or a synthetic filter fabric. The filter material must be able to filter out particles based on the grain size of the embankment material.

The blanket is placed under the downstream side of the embankment, downstream of the dam core. If the drainage blanket is at the toe of the embankment, water may drain from the blanket into a trench drain along the toe of the dam. If a trench drain is not used, a toe drain consisting of a perforated pipe embedded in the toe of the drainage blanket can be used to carry water into the outfall channel.

(c) Cutoff Trench

A cutoff trench is usually recommended under the embankment to prevent seepage from passing through the foundation and exiting on the downstream side of the dam when the foundation material immediately below the dam is more pervious than the core material. A cutoff trench is excavated into the foundation soil and back-filled with the same impervious material used for the dam core. The cutoff trench should extend through the pervious stratum to rock or some less pervious stratum.

The cutoff trench should be located at or upstream of the centreline of the crest of the dam, but not so far upstream that the cover over the trench provides less resistance to seepage than the trench itself. It should extend the full length of the dam. From the U.S. Bureau of Reclamation publication, *Design of Small Dams*, the width of the cutoff trench may be determined by the equation:

$$W = H - d \tag{35.2}$$

where,

W = bottom width of the cutoff trench (m)
H = reservoir head above ground surface (m)
d = depth of the cutoff trench below ground surface (m)

The slopes of the embankment must be such that the allowable foundation pressure is no exceeded, but flat enough to prevent sloughing. Generally, 4(H):1(V) slopes are adequate and are flat enough that maintenance (mowing, etc.) can be accomplished.

Recommended top widths for earthen dam embankments are provided in Table 35.2.

Table 35.2 Recommended Top Widths for Earth Embankments (USDA, 1982)

Height of Embankment (m)	Top width (m)
< 3	2.4
3 to 4.5	3.0
4.5 to 6	3.6
6 to 7.5	4.2

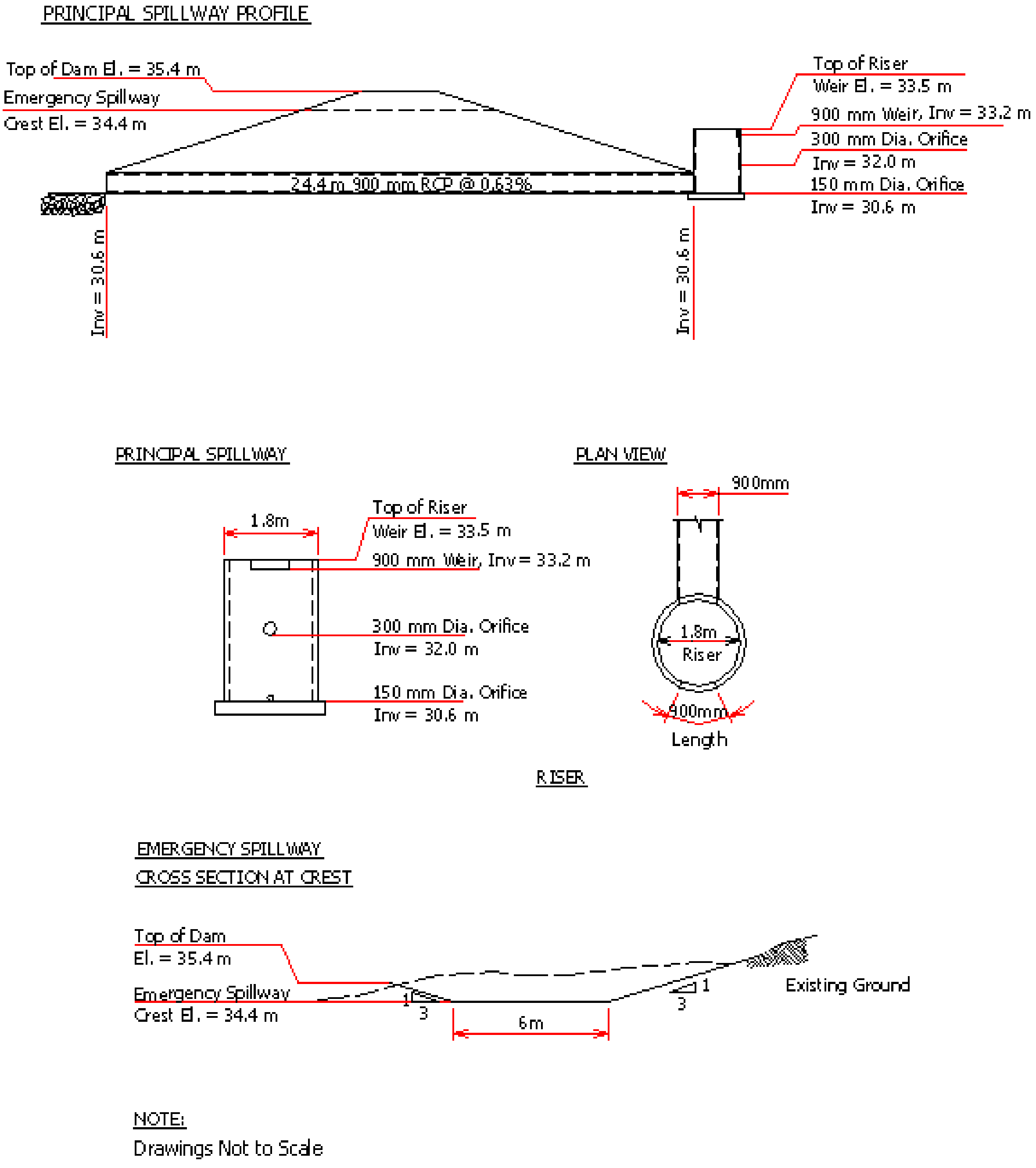
35.6.2 Outlet Works

A normal outlet is provided in order to regulate flows from the pond, and to control water levels. In many cases it is also necessary to maintain a regular baseflow downstream. The designer should investigate whether there are any downstream water users, and the amount of baseflow they require. In environmentally sensitive areas, consideration should be given to providing an environmental baseflow to meet the needs of fish, plants and wildlife. The design of outlets for flood control is discussed in Chapter 20.

The outlet should be arranged to drain the design flood event within 24 hours. This should ensure that the active flood storage is empty before the next storm event.

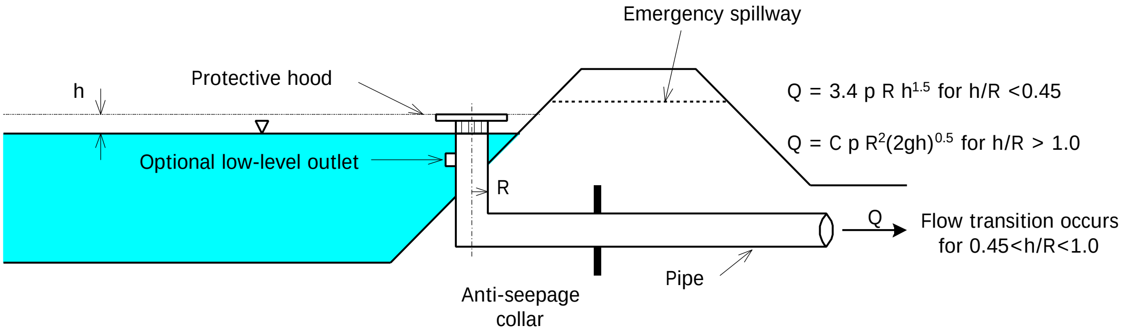
Outlet pipe arrangements commonly comprise a small diameter pipe through an abutment or spillway, or a fixed weir (Figure 35.5). If a fixed weir is used, a pipe with a cap or valve should be provided for trickle flows. The outlet works should be designed to allow the pond water level to be controlled and adjusted to facilitate the establishment and growth of macrophytes. If feasible, provision should be made to allow the pond to be completely drained by gravity for maintenance. For existing mining ponds it is not practicable to make this provision. If a gravity draining provision is made the control valve must be secured in a locked enclosure.

Some other possible outlet arrangements and the applicable discharge equations are shown in Figure 35.6 (based on Auckland Regional Council, 1992).

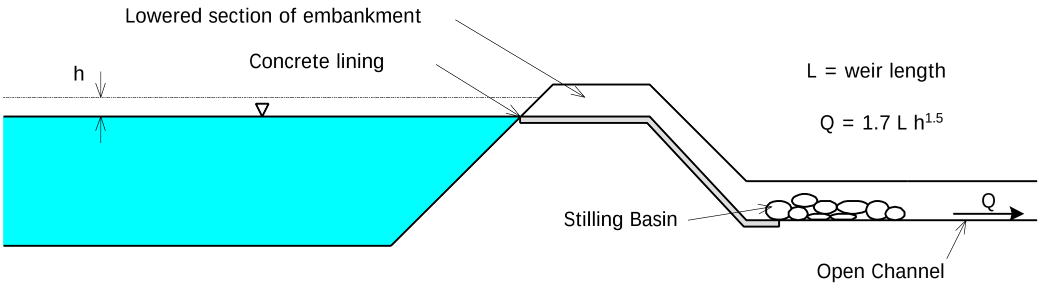


NOTE:
Drawings Not to Scale

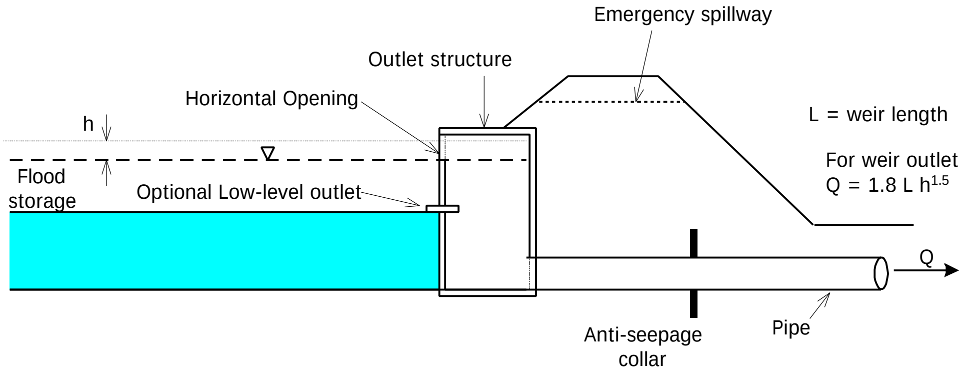
Figure 35.5 Typical Small Dam Spillway and Outlet



(a) Drop Outlet



(b) Broad-crested Weir Outlet



(c) Letter-box Outlet

Figure 35.6 Alternative Pond Outlet Arrangements and Discharge Equations

As can be seen from the equations, a drop outlet has different discharge-head relationships to a weir outlet. This will affect the behaviour of the pond storage during flood flows. A drop outlet is better for maximising ponding, whereas a weir outlet is preferable where the rise in flood levels must be limited due to upstream constraints.

(a) Protection of Outlet Pipe

A potential seepage path is along the contact between the outside surface of an outlet pipe and the embankment. The compaction of the embankment fill around an outlet pipe must be at least equivalent to that elsewhere in the embankment.

Anti-seepage collars have been used extensively in the past to lengthen the seepage path along the pipe. If they are used, it is essential that proper compaction around the collars is achieved. An alternative to anti-seepage collars is a “drainage diaphragm”, which is a layer of drainage material such as sand or gravel surrounded by a filter layer. The diaphragm is designed to allow water to drain out of the embankment but trap any soil particles and prevent them from being washed away. If a drainage blanket is also used, the drainage diaphragm should be designed in conjunction with the blanket.

Extended detention is normally achieved by modifying the pond outlet to reduce the discharge at low heads. Typical extended-detention outlets include small-diameter pipes, a series of pipes at different levels, or a vertical slot. Care must be taken to ensure that the resulting outlets are not prone to blockage. They must be protected by screens, hoods or other devices.

35.6.3 Overflow and Emergency Spillway

Spillways are required to accommodate the design flood, whether or not the pond is intended to provide flood control. Spillways provide a controlled discharge, protecting the earth embankment from being overtopped and washed away by the flood.

For large ponds, spillway safety is a major consideration and designs need to be checked for rare floods. In Malaysia DID (1975) requires that all embankments be checked for stability in the inflow flood resulting from the Probable Maximum Precipitation (PMP). Overseas practices vary depending on the height of the embankment, the volume of the storage and the risk to downstream residents and property. For example in Australia ponds with embankments that are > 10 m in height and hold 20,000 m^3 storage; or are > 5 m high and hold 50,000 m^3 storage, are classified as large dams and must be referred to the state or territory's dam safety officer for assessment.

All ponds should be provided with a spillway able to safely discharge at least the 1 in 100 year ARI flood. For on-line ponds, this will be the flood in the river after taking into account storage routing caused by the flood storage in the pond. For off-line ponds, the emergency spillway need only cater for the diversion flow plus any local catchment inflow. One of the advantages of off-line ponds is that the emergency spillway requirements are much smaller and simpler than for an in-line pond.

If the pond is also intended to have a flood storage component, the form of the emergency spillway becomes important as it will affect the stage-discharge relationship. In this case the spillway should be designed as part of the normal outlet. A fixed weir set at the permanent pond water level provides a suitable outlet. The design of outlets for flood control is described in Chapter 20.

Preliminary spillway calculations are carried out using the weir formula,

$$Q = C \times L \times d^{1.5} \tag{35.3}$$

where the coefficient of discharge $C = 1.7$.

The weir length should be computed so that it can discharge the design flood discharge allowing for storage routing, at the design flood storage level. Because the weir characteristic affects the storage routing, the design calculations must be checked using a storage-routing computer model.

Some other items to be considered in designing a spillway structure include the following:

- Reinforced concrete outlet pipes are recommended, and must be of sufficient strength to support the embankment fill.
- All joints in the riser and outlet pipe should be made watertight. This is especially important for a wet pond, but also good practice for a dry pond.
- The riser should be designed to withstand buoyant forces, with a minimum safety factor of 1.3.
- Vortex action at the top of riser should be controlled. An anti-vortex plate or a headwall may be used to prevent a vortex from forming as the water enters the riser. Anti-vortex devices can often be incorporated with a trash rack.
- Trash racks or other debris control devices should be used to prevent the spillway from becoming clogged. Trash racks can also be used to discourage children from playing inside risers and pipes. The trash rack should be designed such that, for the range of design flows, the average velocity of flow through the trash rack is 1.0 m/s maximum. An alternative criterion is to design the trash rack with a surface area of ten times the cross-sectional area of the riser or outlet pipe opening.
- The outfall channel downstream of the spillway should be protected from erosive velocities of flow exiting the

spillway. Riprap lining or energy dissipaters may be necessary.

35.6.4 Dam Safety

Regardless of how careful a dam is designed and how well it is built, there is always the potential for a dam to be breached, either due to overtopping or to erosion from seepage or piping through or around the embankment. One of the important considerations in pond design is the potential for a failure of the dam embankment, and the potential hazard to downstream features if such an event occurs. If a dam fails, the volume of water stored in the reservoir can be released downstream, posing a risk to roads, buildings, homes and other property, as well as human lives.

Many overseas regulatory agencies have developed classifications systems regarding the hazard potential for damages due to a dam failure. The Soil Conservation Service's classification system is presented below (excerpted from TR-60, *Earth Dams and Reservoirs*, revised October 1985).

Class (a)

Dams located in rural or agricultural areas, where failure may damage farm buildings, agricultural land, or township and country roads.

Class (b)

Dams located in predominantly rural or agricultural areas, where failure may damage isolated homes, main highway or minor railways, or cause interruption of use or service of relatively important public utilities.

Class (c)

Dams located where failure may cause loss of life and serious damage to homes, industrial and commercial buildings, important public utilities, main highways, or railways.

To assist in determining the dam classification, a dam breach analysis may be necessary. This is a procedure where the outflow hydrograph resulting from a dam breach is routed down the river valley below the dam to determine the area that may be inundated.

Two types of analysis may be required. The first is sometimes called a “sunny day” dam failure, where the dam is assumed to fail due to water seeping or piping through the embankment, with no additional precipitation. The normal pond water volume is then routed downstream to determine the breach floodplain. The second type of analysis assumes the dam failure occurs as a result of being overtopped by a large storm (that exceeds the spillway capacity). Once the pond water level reaches a specified depth above the top of the dam, the dam is assumed to be breached and the total pond water volume is routed downstream.

35.7 OTHER POND DESIGN FEATURES

The pond designer has to take into account a wide range of factors. It is desirable to have a multi-disciplinary design team including specialists in landscaping and vegetation as well as engineering.

35.7.1 Slopes

For safety, stability and to promote the growth of macrophytes, slopes within the pond shoreline area should be in the range of 1 in 6 to 1 in 8. After reaching a depth of 1 metre, the slope can be increased. The maximum slope is set by the angle of repose of the saturated soil.

Side slopes above water level should also be gentle, both for safety reasons and to limit the potential for erosion. However, the slope should not be so flat that it creates ponding areas. A minimum side slope of 1 in 10 to 1 in 20 is recommended for a distance of 5 metres from the pond edge, to allow maintenance access.

Ponds that are also intended for flood control will be subject to variable water levels. This creates problems around the water edge due to alternate wetting and drying of soil, making it difficult to establish or maintain grass. In this situation grass is not suitable and a hard edge, lined with rock gabions or a low concrete wall, is preferable where visibility and public access are provided. For those parts of the pond, which are inaccessible, emergent plants such as reeds, which will tolerate water level changes, can be used.

35.7.2 Water Balance

The designer should check that the permanent pond will not dry out during extended dry periods. This can be done by means of a continuous water balance calculation, allowing for evaporation and infiltration over a period of least 12 months. Computer programs such as XP-AQUALM can be used for this calculation. If excessive infiltration is likely it may be necessary to specify an impermeable lining, either with clay or a synthetic liner.

In the humid tropical climate of Malaysia the risk of a pond drying out is less likely than in drier climates.

35.7.3 Erosion and Sediment Control

Erosion and sediment controls should be provided during construction. Erosion of the surroundings and deposition of sediment into the pond will drastically reduce its effectiveness.

The pond should be planned to minimise the area of earthworks required. This will reduce costs as well as help to minimise sediment movement. Areas of existing vegetation should be retained wherever possible. For example, an existing high point with established vegetation could be retained as an island within the ponding area.

If excavation or construction is carried out close to a river for an in-line pond, the flow must be diverted around the site.

Other guidelines for construction activity controls are given in Part H of this Manual.

35.7.4 Landscaping and Planting

Urban ponds and wetlands represent important open space and recreation facilities in urban areas, and are greatly valued by local communities.

If the ponds or wetlands are provided primarily for stormwater management, recreation will normally be limited to secondary uses such as fishing and boating, and passive recreation. The designer will need to accommodate water quality and habitat requirements for fish and other freshwater species such as turtles, as well as aesthetic values (freedom from rubbish, odour and scum).

The pond surroundings should be planted with suitable selected species as quickly as possible, to reduce erosion and provide shade. Local advice should be obtained from, for example, the DBI on suitable species.

Other information on Landscaping is provided in Chapter 42. Aquatic planting in macrophyte zones and wetlands is discussed in Section 35.8.

35.7.5 Health and Safety

In law, the owner of the pond is responsible for ensuring that it does not cause a risk to public health or safety.

Mosquito-borne diseases are a serious concern in tropical areas. The pond design should minimise the risk that mosquitoes will breed there. Mosquito control strategies include:

- Interception of water-borne rubbish which creates a mosquito breeding environment;
- Selection of plants, which provide a breeding ground for predator insects, such as dragonflies that feed on mosquitoes;
- Encouragement of fish breeding;
- Shaping of ponds to avoid stagnant areas with poor circulation;
- Shaping of pond edges to avoid the trapping of water in depressions as the pond water level changes;
- Providing a mechanism to regulate pond levels in order to disturb any breeding larvae; and
- Selection and control of aquatic plants to avoid the creation of habitats favoured for mosquito breeding.

The pond itself can present a hazard to small children. The designer should concentrate on avoiding serious safety hazards such as:

- Sudden drops into deep water (see Section 35.7.1);
- Sudden changes in flow velocities or water levels; and
- Raised structures that children can fall off.

Inlet and outlet structures can be particularly dangerous because of the high flow velocities that occur there. It may be desirable to fence off the inlet and outlet structures. Such fencing should be designed so that it does not interfere with the hydraulics of the flow structure.

35.8 CONSTRUCTED WETLANDS

Constructed wetlands, like ponds, can be used to improve water quality. The extensive wetlands recently constructed at Putrajaya were designed for this purpose. Both ponds and wetlands are best used as a final or 'polishing' treatment, downstream of other structural water quality control works.

Ponds and wetlands are complementary. The pollutant removal efficiency of a pond can be increased by including an area of wetland.

35.8.1 Treatment Processes

The pollutant retention efficiency of a constructed wetland systems appears to be related to factors such as the nature of the inflows (particularly the sediment grading and geochemistry), the ionic composition of the wetland waters, and the geometry and macrophyte planting scheme of the wetland (NSW EPA, 1997). There are currently insufficient data available to quantify these influences. The design guidelines given here are preliminary and are based on current knowledge and operational experience.

A complex variety of treatment processes occur in a typical wetland, as shown in Figure 35.7. Scientific understanding of these processes is increasing, but is still limited.

Preliminary information on treatment processes and design guidelines for the wetlands at Putrajaya is provided in Angkasa GHD (1998). Those guidelines focus to a large extent on wetlands only. Generally, a stormwater management system should contain both ponds and wetlands and the role of open water in promoting sedimentation should also be considered.

35.8.2 Design Principles

CRCFE (1998) suggest several alternative approaches to the sizing of wetlands, depending on the flow conditions:

(a) Steady or Attenuated Flows

This condition applies when upstream flows are constant or only slightly varying, due perhaps to the wetland being off-line or downstream of a detention storage or wet pond.

In this case, size is simply determined on the basis of Equation 35.4:

$$A = 100 \cdot Q \cdot C_{in} \cdot \frac{R}{(r_b \cdot t_r)} \qquad (35.4)$$

where,

A = wetland area (ha)

Q = volume of event discharge (ML)

C_{in} = inflow concentration of the target pollutant (mg/L)

R = level of reduction (interception) required (%)

r_b = daily adsorption rate of the target pollutant by biofilm

t_r = retention time or average time between storm events (days)

(b) Ephemeral Wetlands

Ephemeral wetlands are the opposite to case (a), in that they are designed to collect runoff only infrequently and then dry out. In ephemeral wetlands the pollutants are intercepted mainly by adhesion to vegetation surfaces, sedimentation, and retention (infiltration and evaporation). The wetting and drying cycle are central to the pollutant removal processes in ephemeral wetlands.

There is little published research on which to base a model for determining the size of an ephemeral wetland. Size is related to the volume of the storm event to be captured and, in general, should be such as to fully capture the chosen design storm.

(c) Combined Wetland Facility

A combined facility must be able to handle both steady inflows, and high flows due to stormwater runoff. Under high flow conditions, the large volume of fast-flowing water and reduced light will place at risk the fragile epiphytes and biofilm systems that are fundamental to treatment of colloids and dissolved pollutants.

The designer must be guided by the frequency of storm events, and by their peak discharge rates. The volume and cross-section area of the wetland should be determined such that velocities do not exceed 0.05 to 0.1 m/s more than once per year.

The design of a combined facility will involve a series of compromises, but may be the only viable option where land availability is limited.

(d) Use of Ephemeral Wetland Zones in Pond or Wetland

This case is essentially a combination of (a) and (b). Shallow ephemeral zones tend to have greater species diversity and to have more plant surface area per unit area than permanent wetlands. They also help to improve performance by acting as hydraulic controls, allowing high flows to spread out and reduce velocity.

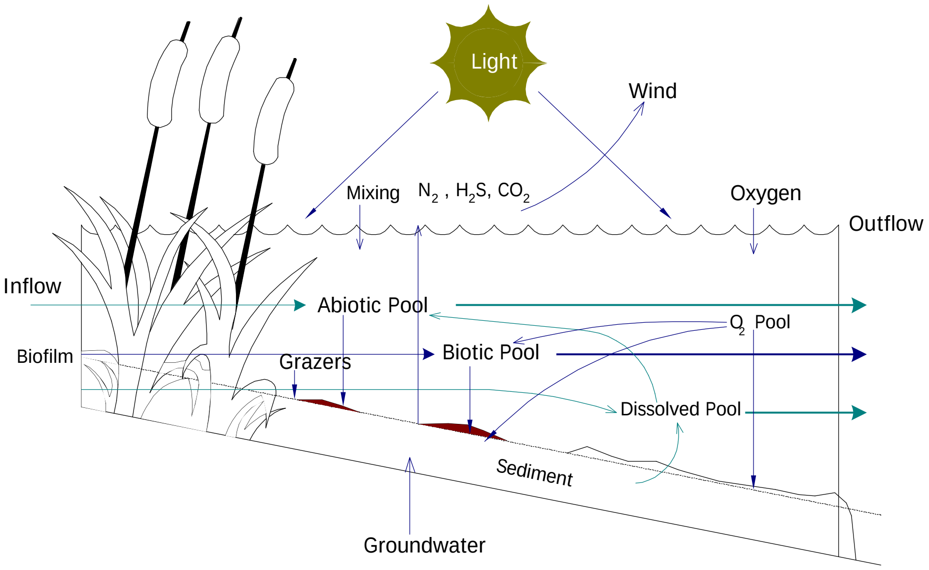


Figure 35.7 Water Quality Processes in Ponds and Wetlands (CRCFE, 1998)

Sizing principles for the permanent and ephemeral wetland zones correspond to those listed in (a) and (b) respectively, above. Ephemeral wetland zones should not be continuously wet, but should have well-defined wet and dry periods. A low-flow bypass may be necessary to achieve this variation.

(e) Recycling of Pond Water through an Off-line Wetland

As an alternative to the composite design, the designer can arrange to recycle water through a separate wetland compartment or a physically separated embayment of a pond. This allows better control of the treatment processes. The recirculation can be by means of a pump, which has the added benefit of inducing mixing to reduce stratification.

35.8.3 Hydrologic Regime

The principal function of the storage in a constructed wetland is to provide a variable wetting-drying cycle, which encourages growth and diversity of macrophytes. A depth range of 0.5 m to 1.0 m and a hydraulic residence time of less than 3-5 days for a design storm may be suitable (EPA NSW, 1997). This depth range is tolerated by most emergent macrophyte vegetation.

An important aspect of the hydrologic regime of the wetland is the frequency of inundation at different depths. This is a function of the outlet design as well as of local climatic conditions. Water depth is a fundamental factor controlling the growth of plants. Different species will have preferences for different depth and inundation regimes. The designer should evaluate the hydrologic regime by means such as a continuous-simulation computer model (see Section 35.5).

35.8.4 Wetland Outlet Design

The use of a riser-type outlet is generally more suitable for controlling the water level regime in a wetland than a weir because it gives more control over the stage-discharge relationship. However there is scope for the design of innovative outlet arrangements such as proportional weirs to suit Malaysian conditions.

Figure 35.8 shows a schematic view of a typical riser pipe outlet design for a constructed wetland. In this example the riser pipe has a hood and screen to prevent blockage by the floating material which is commonly found in wetlands. Anti-seepage collars should be installed along outlet conduits passing through or under the dam embankment.

It is desirable to provide an adjustable outlet so that the water depth can be adjusted if necessary. This is particularly so during the early stage of plant establishment. Some examples of adjustable outlets can be wooden weirs, which can be mounted at different levels and removed when not required; or piped low-flow outlets, which can capped off when not required.

An emergency spillway must be provided to protect the embankment surrounding the wetland. Design principles for the spillway are the same as those for ponds, described in Section 35.6.3.

35.8.5 Flow Distribution

Wetlands must be designed to provide an even flow distribution and avoid short-circuiting (direct flow from inlet to outlet). A long, narrow shape is recommended for this reason. Urbonas and Stahre (1993) proposed that the ideal shape is an extended oval, with inlet and outlet at opposite ends.

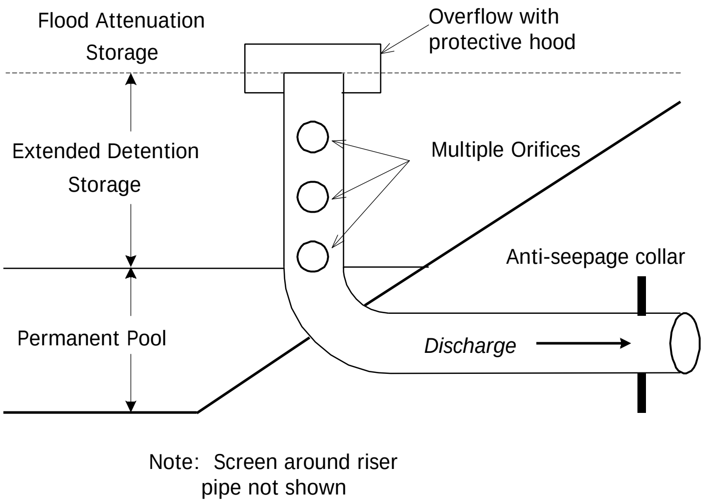


Figure 35.8 Typical Riser Pipe Wetland Outlet (W&RC, 1998)

Inlet structures should be designed to spread the flow as much as possible. This may involve providing flow baffles or a weir.

35.8.6 Planting

The following criteria should be used when selecting plants for a particular pond site:

- the proposed plant must be able to establish and grow at the site.
- the plant should be unlikely to spread outside or downstream of the pond.
- the maximum height of plants must be consistent with the desired visual characteristics of the pond.
- plants must not grow to a density that provides habitats for mosquito or other pest breeding.

Suggested planting lists suitable for Malaysian conditions are given in Chapter 42.

35.8.7 Saline Wetlands

The preceding text relates to freshwater ponds and wetlands. It is also possible to construct saline wetlands in tidal areas. Such wetlands mimic the natural tidal wetlands, which occur in some estuarine and coastal areas. As these ecosystems are often under threat from development, the re-establishment of saline wetlands or the construction of new saline wetlands can have significant environmental value.

There is little data available on the water quality improvement benefits of saline wetlands (for a discussion, see for example, Willing & Partners 1997). However it is assumed that they would have worthwhile benefits. Coupled with their environmental value and potential as fish breeding areas, a significant case can be made for constructing such wetlands.

The design of a saline wetland involves specialised biological and other considerations, including assessment of tide levels and water circulation (see Chapter 46).

35.9 OPERATION AND MAINTENANCE

35.9.1 General Maintenance

As with any constructed facility, ponds require regular ongoing operation and maintenance. General maintenance including lawn mowing, rubbish removal, and inspection should be carried out at regular intervals not exceeding once every two weeks.

Structures such as GPTs, embankments, inlets, outlets, spillways and culverts must be routinely inspected for serviceability, safety, and cleaning and removal of trapped rubbish and sediment. Safety measures such as fences, booms and warning notices must be routinely inspected to ensure that they are in working order.

General guidelines for operation and maintenance of ponds and detention storages are given in Chapter 20 of this Manual.

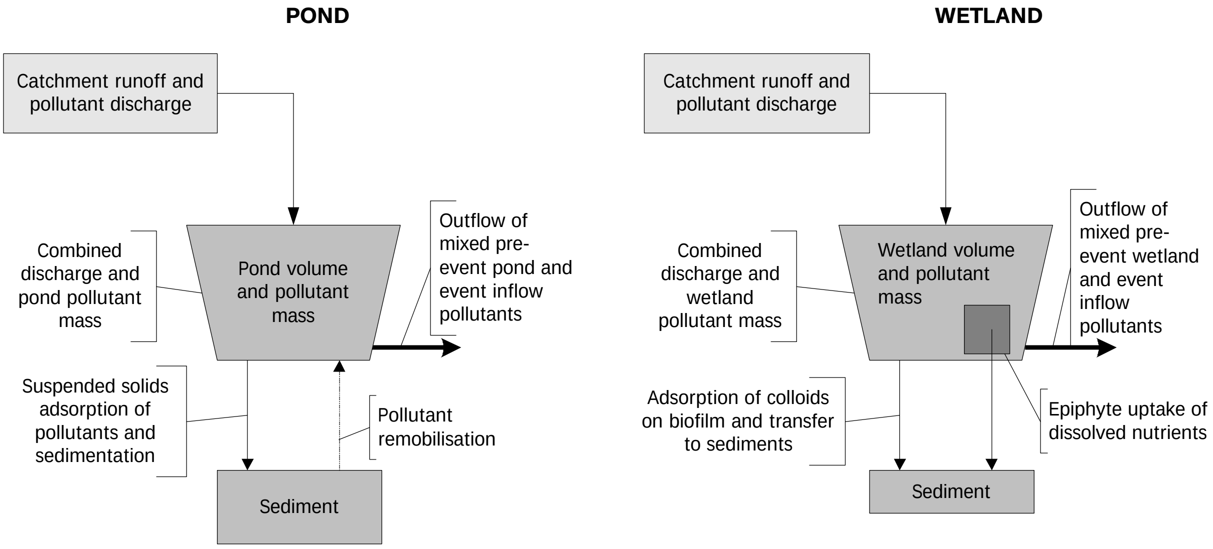


Figure 35.9 Major Components of Pond and Wetland Process Models (CRCFE,1998)

35.9.2 Aquatic Vegetation

Maintenance during the plant establishment phase is critical because it is during this phase that plants are most vulnerable to damage. Low water level, weed invasion, and damage by animals are possible causes of problems. Plants should be inspected at least weekly during the initial phase in order to detect any damage and allow corrective action.

Aquatic plants should be inspected periodically to control pest species and to promote the desired mix of plants for conservation and landscape purposes. Occasional replanting may be necessary to maintain the desired mix of species.

The consensus of scientific opinion, mainly from temperate climates, is that it is not appropriate to regularly harvest macrophytes (see CRCFE, 1998). The disturbance created by the harvesting process introduces the risk of remobilising sediments and nutrients, and introducing weed species. The validity of this conclusion in tropical countries such as Malaysia needs to be established by further research.

35.9.3 Eutrophication and Other Problems

Under certain climatic conditions, nutrient enrichment of pond water can cause abundant plant and algal growth. The resulting algal blooms are unsightly and damaging to public health and can cause fish kills and episodes of poor water quality.

The following conditions are most likely to encourage eutrophication:

1. excessive nutrient loadings in inflows,
2. high average temperatures and abundant sunshine,
3. still water, and
4. clear water (low turbidity).

Pond designers should try to avoid these conditions. For example, it may be inappropriate to locate a pond downstream of an oxidation pond discharge, which is rich in nutrients. In many parts of Malaysia the high turbidity of surface waters helps to prevent eutrophication by preventing sunlight penetration.

However, high turbidity promotes another problem, which is water column stratification. Heated surface waters become lighter than the bottom waters, effectively preventing any mixing. The resulting physical barrier prevents oxygen transfer to the bottom layers, which typically become deoxygenated. Deep mining ponds may be prone to stratification.

There is a rapidly increasing body of scientific knowledge of both of these problems and there are methods, such as mechanical mixing, to overcome them. If any ponds are found to be subject to these problems specialised technical advice should be sought.

APPENDIX 35.A POND DESIGN CHARTS

35.A.1 Pond Design Charts

Preliminary pond design charts for use in Peninsular Malaysia are shown on the following pages.

Design Charts 35.1, 35.2 and 35.3 respectively show average annual pollutant removal of on-line ponds as a function of the Pond Area Ratio, where:

$$\text{Pond Area ratio} = \frac{\text{Pond surface area}}{\text{Catchment area}}$$

For a desired pollutant removal (%), these charts can be used to select the required pond area as a function of directly connected impervious area percentage for the catchment (DCIA) and mean annual rainfall (MAR). Intermediate values should be interpolated. When pollutant removal is specified for more than one pollutant, the largest area ratio so calculated will govern the design.

Pond removal efficiency is a function of the hydraulic detention, which depends on catchment hydrology as well as pond size. The charts have been derived using rainfall data for Ipoh (mean annual rainfall = 3000 mm) and Temerloh (mean annual rainfall = 1600 mm). For other locations or DCIA values, values can be interpolated between the curves. However, the designer must bear in mind and critically examine the assumptions used in deriving the curves.

The curves are valid for an average pond depth of 2.0 metres, as recommended in the text. They should not be used for other pond depths.

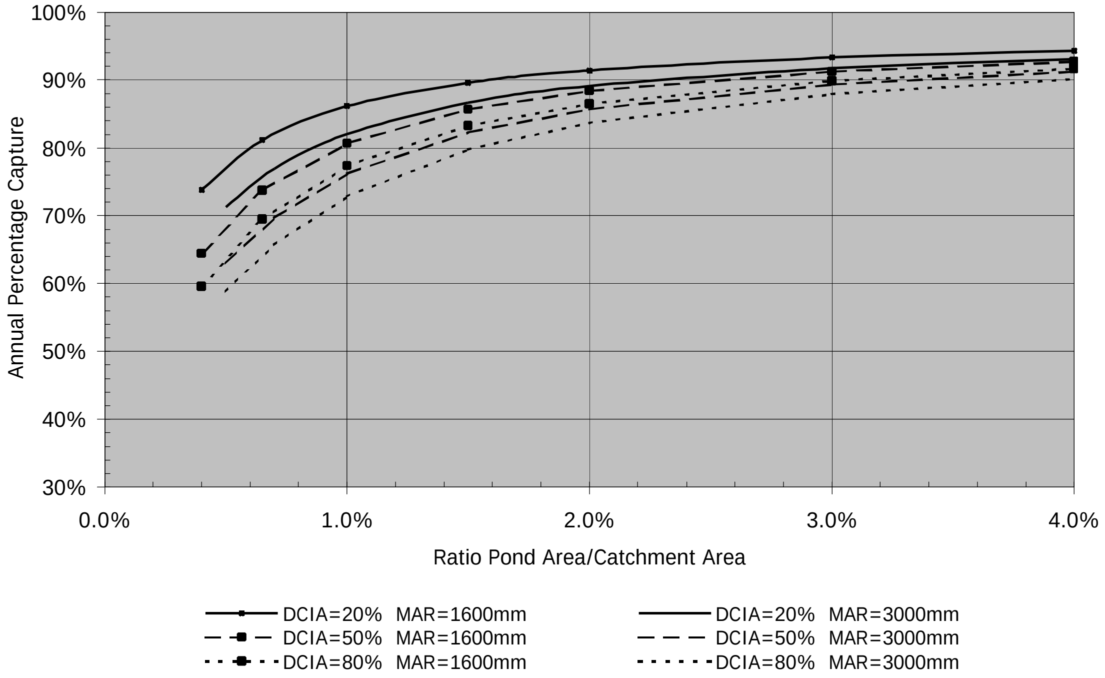
Final designs must always be carried out using a more precise method, such as computer modelling with local rainfall data.

35.A.2 Derivation of Design Charts

The curves were derived following the method given in CRCFE (1998) and outlined in Figure 35.3. This method uses rainfall IDF statistics to estimate the average event retention time and pollutant removal. Suitable assumptions were made in order to apply the method for Malaysian conditions, as described below.

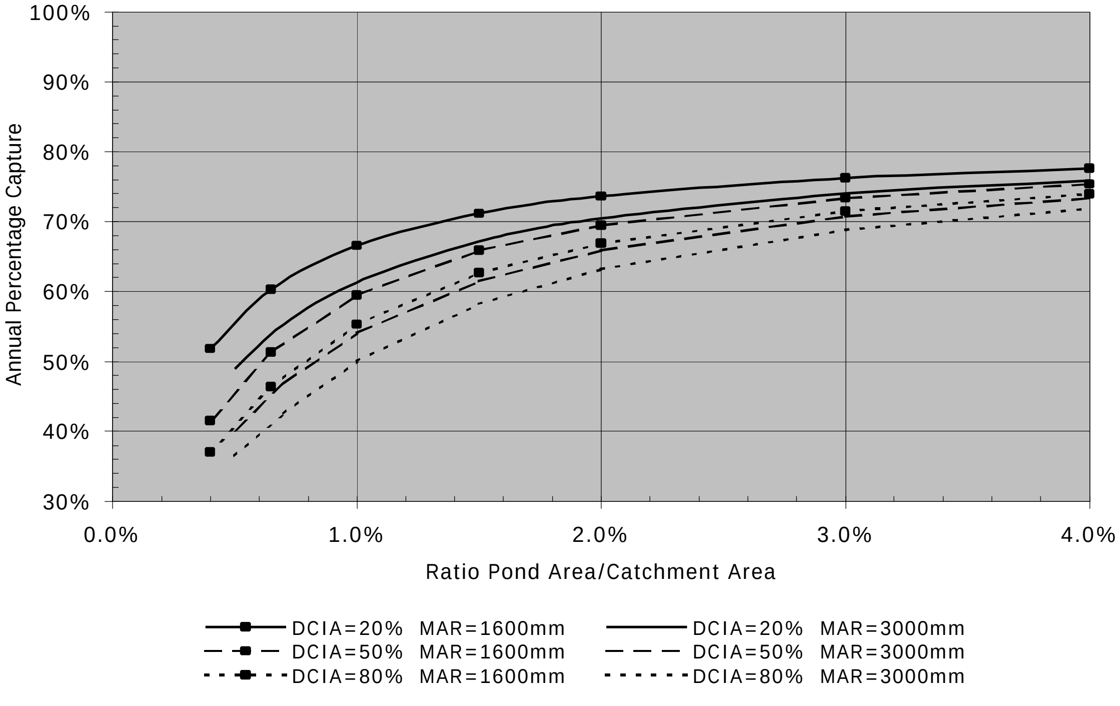
Pollutant retention was calculated using the method based on CRCFE (1998). This is a trial and error procedure as it is necessary to estimate the ratio of concentrations C_{in}/C_{pond}. This ratio is then checked using the in-pond retention curves in Figures 3.4 and 3.5 of the Reference to calculate C as the ratio 1/(1-R). Equations were fitted to these curves for use in the remainder of the design procedure. From Ipoh climate data it is estimated that the average number of dry days between events is 3. The weight of pollutant retained per event is then totalled over the calculation period.

Total loads are computed from the expected number of events and summed to obtain a grand total. The cumulative percentage removal is the load removed in all storms equal to or less than the nominated storm, as a percentage of the total load. Pollutant removal is calculated from Design Chart 35.4. The Pollutant Capture Curves were derived by repeating the spreadsheet calculations for different pond sizes and surface areas, in order to derive the points on the curve.

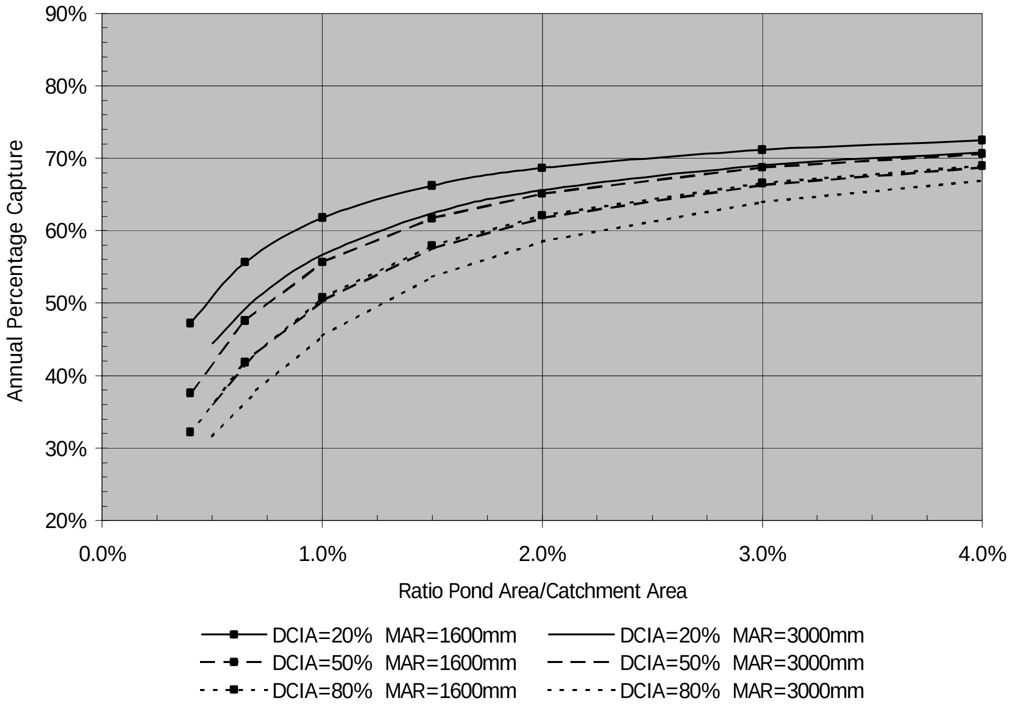


Design Chart 35.1 Annual Pollutant Capture Curve for Sediment as a Function of Pond Area Ratio

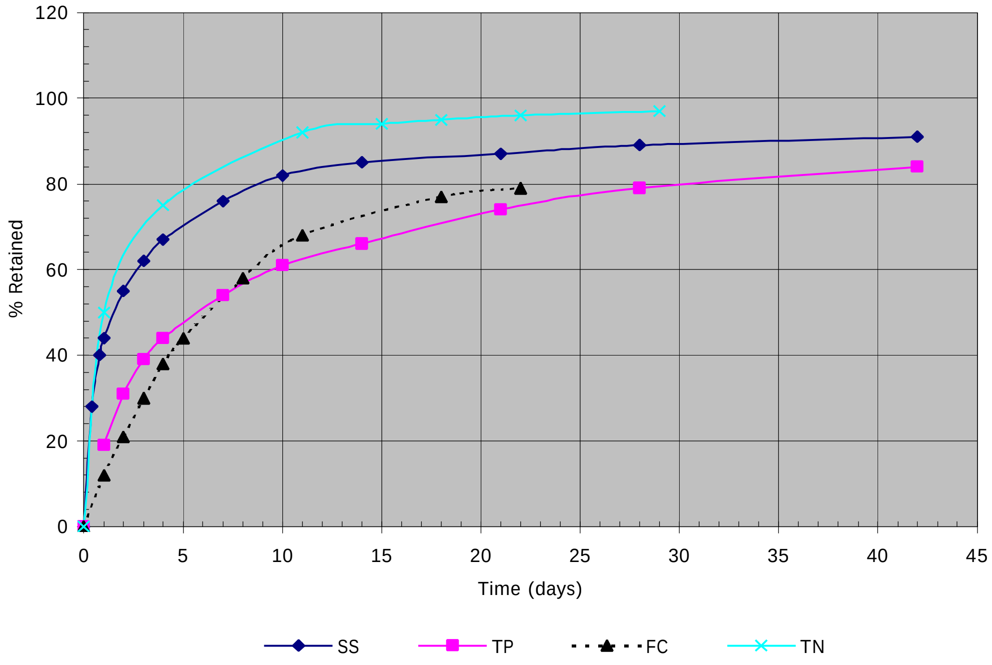
Note: DCIA - Directly connected impervious area and MAR - Mean annual rainfall



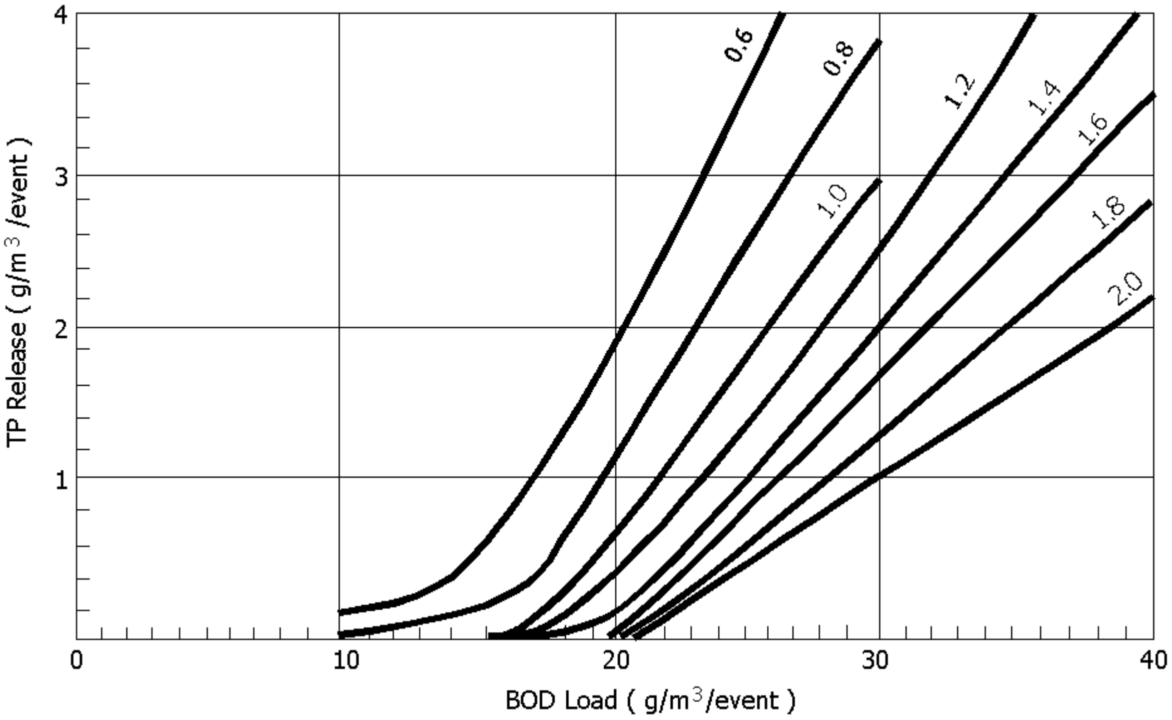
Design Chart 35.2 Annual Pollutant Capture Curve for SS as a function of Pond Area Ratio



Design Chart 35.3 Annual Pollutant Capture Curve for TP as a Function of Pond Area Ratio



Design Chart 35.4 Pollutant Retention (Australian Data)



Design Chart 35.5 Sediment TP Release vs. BOD Load (CRCFE 1998)

Note: Numbers on Curves are Aeration Rates (g/m^2/day)

APPENDIX 35.B WORKED EXAMPLE OF PRELIMINARY POND SIZING

Problem:

Prepare preliminary size estimate for a pond to be located downstream of the GPT in the Sg. Rokam example, Example 16.A in Chapter 16.

Solution:

Step 1 Determine required pond removal efficiency for the selected key pollutants.

The pond is part of a treatment train with an upstream GPT. The DCIA of the catchment is known to be 50%.

From Example 16.A.3 we see that the pond pollutant removal required as part of the treatment train is 65% for sediment and 40% for SS and TP.

Step 2 Determine required pond area ratio for the targeted pollutant removal efficiencies.

Sediment: from Design Chart 35.A1, 65% removal corresponds to an area ratio A_p / A_c of 0.6 %.

SS: from Design Chart 35.A2, 40% removal corresponds to an area ratio A_p / A_c of 0.5 %.

TP: from Design Chart 35.A3, 40% removal corresponds to an area ratio A_p / A_c of 0.65 %.

The largest ratio must be selected therefore adopt an area ratio of 0.65%.

Step 3 Calculate required pond size knowing the catchment area.

The catchment area at node 6F1/2 is 1.19 km^2. Ignore the small local catchment for node 6F1/1, which will drain downstream of the pond.

The required pond area is:

$$1.19 \text{ km}^2 \times \frac{0.65}{100} = 0.78 \text{ hectares.}$$

The required pond volume is:

$$0.78 \text{ ha} \times 2.0 \text{ m} = 15{,}600 \text{ m}^3.$$

Step 4 Select pond configuration.

By examining the available site, which is an open space reserve, it is determined that a single pond with a length: width ratio of at least 3:1 and a surface area of 0.78 hectares can be fitted within the available site area.

APPENDIX 35.C WORKED EXAMPLE OF DETAILED DESIGN OF WETLAND

Problem

A new bridge crossing and associated approach roadworks are to be built across a river (Figure 35.C1). In conjunction with these works, permanent stormwater quality control measures are to be designed to treat runoff from the new bridge and approaches. Prepare concept designs for these stormwater treatment facilities and associated works.

The works are intended to meet statutory requirements with regard to water quality. Special emphasis is to be placed on providing facilities which address the problems of pavement surface contaminants such as oil, grease and particulate matter washed off the pavement surface by stormwater runoff while also addressing the possibility of spills of chemicals or other hazardous materials.

Solution: The design was carried out in the following steps.

1) Design Criteria

The primary objectives of the design are to meet the statutory requirements with regard to water quality and also to be seen as sensitive to the environment and proactive in meeting community expectations.

Adopted Criteria

The bridge and roadworks form part of a land redevelopment (Figure 35.C1).

No overall Strategic Planning study of the receiving river has been carried out as yet. In accordance Section 4.7.1, the targeted average annual pollutant load reductions were adopted from Table 4.5 as follows:

Floatables	90% reduction
Suspended solids	40% reduction
Total phosphorus	30% reduction
Total nitrogen	30% reduction

Achievement of these targets may not be practicable because the resulting works would have unacceptable landtake or environmental impact.

The current Best Management Practice (BMP) for this situation is considered to involve the provision of a treatment train comprised of a litter trap and/or GPT to remove litter and coarse sediment, followed by a wetland with extended detention. The size of the wetland is constrained by the available site area. Provision to trap oil spills is also included in the system. The proposed wetland layout is shown in Figure 35.C2.

2) Modelling Approach

It was decided to use XP-AQUALM water quality model to undertake the pollutant estimation and retention calculations. A continuous simulation for one year of rainfall data will be carried out.

The development of the water quality model was undertaken in the following steps:

- available catchment information was collected and reviewed;
- the catchment was subdivided into three landuse categories in accordance with existing catchment conditions;
- representative rainfall/runoff and pollutant export parameters were identified and tested;
- the model was run using historical rainfall data;
- the model was used to assess the performance of the proposed GPTs and wetlands.

3) Catchment Conditions

Catchment Data

The topography of the general area is characterised by steep slopes on both sides of the river. In some areas valley slopes are in excess of 20%. Catchment landuse is shown in Table 35.C1.

Table 35.C1 Catchment Area and Landuse

Catchment	Landuse	Area (hectare)	
		Existing Pre-development	Post-development
Pit AA7	Urban	7.60	7.60
	Forest	2.78	1.25
	Highway	-	1.53
Wetland	Forest	0.10	0.10

Rainfall

A daily rainfall record was input for 1986. This is considered to be an 'average' year, with an annual rainfall of 1,230 mm. Design rainfall intensity-frequency-duration data was derived using the procedures set out in Chapter 13.

Evaporation

Mean monthly pan evaporation rates at a nearby site were obtained and used in the catchment based water quality model. These are given in Table 35.C2.

Table 35.C2 Monthly Evaporation (mm)

Month	Evaporation	Month	Evaporation
JAN	172	JUL	53
FEB	122	AUG	56
MAR	115	SEP	94
APR	92	OCT	129
MAY	48	NOV	123
JUN	46	DEC	171

Geotechnical Data

Geotechnical investigations have been undertaken at the site for the design of the proposed bridge piers and abutments. These investigations indicate that the proposed bridge abutments are located within an area underlain by sandstone with only thin cover of overburden. Soils in the study area were derived from sandstone and are generally sand, low in nutrients and organic content and highly erodible.

Sediment grading curves are given in Table 35.C3.

Table 35.C3 Sediment Gradings

Particle size (mm)	Percent finer than
0.01	3
0.07	10
0.2	20
0.5	52
1.0	64
3.0	90

Drainage System Data

The area affected by the proposed bridge and eastern approach road will drain to a new stormwater pipe system as shown on Figure 35.C2. This system was modelled in XP-RatHGL. Road pavements are taken to be 100% impervious with an 'n' value of 0.018. The catchment areas draining to Pit AA7 have the landuses shown in Table 35.C1.

Drainage design plans and cadastral plans were obtained from the Local Authority. Catchment areas, levels, slopes and impervious percentages were estimated from 1:4000 scale orthophotomaps and aerial photographs. Proposed drainage systems on the eastern approach were analysed using information from the bridge design drawings.

Bridge Deck Drainage Systems

The bridge deck roadway surface will be 11.6 m wide for most of its length, and will have a one-way cross fall of approximately 6%. The bridge design drawings show drainage inlets provided at intervals on the low side alongside the edge kerb. Pipes will connect each of these to longitudinal drainage pipes located inside the box girder of the bridge superstructure. The depth of the box girder section and the longitudinal profile of the bridge dictates the lengths over which these longitudinal pipes can be graded.

At the pier location the longitudinal drainage system will be terminated and water will be piped through the bottom of the box girder to the top of the pier, and then via a downpipe inside the pier.

4) Runoff Calculation

Design Flows

The XP-RatHGL urban drainage package is a steady-state pipe stormwater design and analysis package. The model uses Rational Formula Hydrology and Hydraulic Grade Line calculations. The resulting system is completely balanced taking into account full flow conditions, backwater effects and user defined design constraints.

The XP-RatHGL model cannot directly handle piped drainage diversions. Instead, the relevant pipes were modelled as overflow diversions. This preserves the hydrologic continuity of the model and ensures that the correct flows are calculated. Pipe sizes for these diversions were then checked using standard pipe design charts.

Pipe configuration, sizes, and levels were adopted from the bridge design drawings. Pit inlet capacities were assessed from data in Chapter 24. Where multiple pits were represented by a single pit in the simplified model, a large value was entered for pit capacity so that it would not be a constraint in the model. Pit losses were assessed from guidelines provided in the XP-RatHGL manual.

A full Hydraulic Grade Line (HGL) analysis was carried out for the 1, 5, 20 and 100 year ARI design storms. The 1 year ARI flows were used for the sizing of diversions, the HumeCeptor GPTs and pond/wetland inlets and outlets. The drainage system performance was checked for the other return periods to verify that it would perform as intended.

Detailed results of the RatHGL stormwater drainage analysis are given in Table 35.C4.

Table 35.C4 Design Flows (m^3/s)

Design case	Pit C14	Pier 2 drainage
1 yr ARI	0.54	0.06
5 yr ARI	1.76	0.13
20 yr ARI	1.93	0.19
100 yr ARI	1.94	0.27

The discharge from Pit C14 is directed to a diversion structure (AA7) located on the Reserve access road near Pier 2 (Figure 35.C1). This structure is arranged to dissipate some of the energy of the incoming flow and direct flows up to the 1 year ARI through drainage Line AB to a GPT and wetland. Flows in excess of this are directed via another outlet directly to the river. This high flow outlet pipe discharges to the river through an energy dissipator on the river bank. The discharge from Pier 2 joins Line AB at Pit AB3.

Continuous Simulation

Continuous simulation was done using the XP-AQUALM model. Model parameters were adopted from a previous study in which the model had been calibrated for flow. The adopted model parameters are provided in Table 35.C5.

Table 35.C5 XP-AQUALM Rainfall/Runoff Model Parameters

Parameter	Urban	Natural	Highway
Initial Soil Store Value (mm)			
C_p	0	0	0
D_r	0	0	0
U_s	40	60	0
Soil Store Capacities (mm)			
$C_{p\ Max}$	5	2	0
$D_{r\ Max}$	30	40	0
$U_{s\ Max}$	55	60	0
a	0.22	0.15	1
b	-0.15	-0.04	0
d	0.7	0.7	0.7
K_t	0.15	0.2	0
e	0.005	0.04	0
f	0	0.1	0
g	0	0.03	0

5) Pollutant Exports

Estimation of pollutant loads was based on equations of the form:

$$PE = a R^{b}$$

where a = calibrated coefficient
b = calibrated exponent
PE = pollutant export rate (load/unit area)
R = runoff (mm/day)

For different landuses, the pollutant export coefficients for key pollutants were adopted for this Example from a search of relevant published literature. The pollutant export relationships adopted for the three broad landuses are presented in Table 35.C6.

Table 35.C6 Pollutant Export Relationships

Pollutant	Units	Urban	Natural	Highway
Suspended Solids (SS)	(kg/km^2)	38.4 R	9.6 R	38.4 R
Total Nitrogen (TN)	(kg/km^2)	$0.85\ R^{1.2}$	$0.25\ R^{1.25}$	$0.45\ R^{1.2}$
Total Phosphorus (TP)	(kg/km^2)	$0.34\ R^{0.8}$	$0.04\ R^{0.57}$	$0.18\ R^{0.8}$
Faecal Coliform (FC)	$(10^{10} CFU/km^2)$	$7.0\ R^{1.1}$	$2.5\ R^{0.95}$	0.0 R
Cadmium (Cd)	(kg/km^2)	0.009 R	0.0 R	0.01 R
Lead (Pb)	(kg/km^2)	0.24 R	0.0 R	0.6 R
Copper (Cu)	(kg/km^2)	0.02 R	0.0 R	0.12 R
Zinc (Zn)	(kg/km^2)	0.525 R	0.0 R	1.1 R

6) Pollutant Loadings

The existing pollutant loadings were calculated by running XP-AQUALM for the representative year, with the pollutant export equation option.

7) Alternatives Considered

Two scenarios were considered:

Scenario 1 provides for the runoff from the bridge and approach roads to be collected and passed through water quality treatment facilities. It also provides for the runoff from an adjacent urban area to be intercepted by the drainage system on the proposed approach roads and passed through the same facilities.

Scenario 2 provides for the runoff from the bridge and approach roads to be collected and passed through water quality treatment facilities. It also provides for the runoff from part of the adjacent urban area to be intercepted by the drainage system on the proposed approach roads and passed through the same facilities.

The treatment train in both cases is proposed to be a GPT to intercept sediments and hydrocarbons, followed by a wetland to provide further treatment before discharge to the River. As Scenario 1 involved the treatment of runoff from a larger catchment, the wetland area required was found to be correspondingly larger.

Investigation of potential sites for a constructed wetland found that the parkland is the only practical site.

Scenario 1 provides for the treatment of runoff from a larger catchment than Scenario 2. This would be achieved at the cost of the loss of almost all of the existing land in the Reserve to create an artificial wetland and at a greater construction costs. These additional costs are not warranted to achieve the objectives of treatment of runoff from the proposed new bridge and approach roads. Accordingly, Scenario 2 was selected as the preferred alternative for design.

Stormwater Drainage Configuration

Bypass

Preliminary studies indicated that the available wetland sites would be of insufficient size to treat annual runoff from the urban catchment. For this reason a bypass is provided to reduce the pollutant loads on the proposed wetland. Flows in excess of the 3 month ARI event will be diverted to the river, and the wetland constructed "off-line".

Oil and Litter Control

During design it was decided to adopt the HumeCeptor proprietary GPT, which also incorporates oil storage facilities (see below). Additional emergency oil storage is provided in the inlet control structure of the wetland and in the wetland itself.

Litter control in the stormwater drainage system will be provided by a Humes In-Line Litter Separator (ILLS). The eastern drainage system drains urban areas as well as the main road. While the road pavement may generate some litter, the urban areas are expected to be the major source.

GPT

The chosen stormwater treatment system for the eastern abutment is a process train comprising a gross pollutant trap, inlet trap, and wetland with extended detention. A GPT is required upstream of the wetland.

The HumeCeptor trap was selected for use because of its ability to retain oil, including oil spills. The effective catchment area, which would be treated by the GPT would be 2.3 ha. The HumeCeptor™ has an oil holding capacity of almost 3,000 L which would provide for the small quantities of oils and fuels in normal runoff and for a small accidental spill. Cleaning should be carried out by a licensed waste disposal contractor using an eductor truck. It is not necessary for personnel to enter the trap during the cleaning process.

Wetland

Water would be piped from the GPT to a wetland located in the park at the Reserve. The wetland is arranged so that it is compatible with the park and landscaped to suit. After passing through the wetland, the treated water would be discharged to the river at the northern end of the Reserve.

The outlet arrangement of the wetland would be designed with a baffle such that in the event of a major oil or fuel spill, the pollutants which are carried through the GPT and onwards to the wetland are retained in the wetland for later removal and not discharged to the river. This would cause some damage to the wetland, which would require rehabilitation after the clean-up is completed. This is considered to be an acceptable risk on the rare occasion of a major spill.

The wetland arrangement in the Reserve has been chosen to maximise its effectiveness while minimising the impact on open space. The wetland replicates a natural river system with a long, narrow planform with deeper ponds. The wetland/pond areas have been determined by assuming a shallow margin of approximately 0.5m depth and a deeper central section of about 1.0 m depth. Macrophytes would be planted in the shallow sections to assist with water treatment. This and relatively dense plantings of *casuarina* and other trees also form a barrier around the edges of the wetland to discourage people from entering the water.

Macrophyte species should be selected to meet the following requirements:

- native to the area,
- known to be likely to establish and grow under conditions applying at the site,
- a plant must be unlikely to colonise outside the designated area,
- the maximum height of the plants must be consistent with maintaining desirable visual characteristics of the pond, and
- a plant must not grow to a density that would provide suitable habitats for mosquito breeding.

The effective surface area of the wetland is approximately 0.2 ha. Landscaping improvements in the Reserve will preserve and improve its aesthetic and environmental value. A footbridge leading to a viewing platform has been provided to allow the public to view the wetland.

Several alternative arrangements were examined. The adopted design is a long wetland running parallel to the river, between the carpark and the grassed area of the Reserve. This has a volume of approximately 1.67 ML at maximum water level (RL 1.8). Dimensions are listed in Table 35.C7.

Table 35.C7 Wetland Stage-storage Details

Level (m)	Surface area (m^2)	Storage volume (m^3)	Remarks
1.80	1,765	1,660	Maximum Water Level
1.61	1,505	1,330	Level at Start of Extended Detention
1.20	1,155	810	Normal Water Level
1.00	975	590	
0.00	0	0	Base level

The primary function of the Wetland Inlet in the Reserve is to reduce the velocity of flow entering the wetland. The inlet is a concrete structure, which tapers outwards to reduce velocities. A concrete crossbar acts as an energy dissipator. The crossbar will also trap any floating litter, debris or oil which passes through the HumeCeptor™ during high flows. Trapped material will need to be removed periodically by a waste disposal contractor.

Outlet

The main outlet from the wetland is a weir, which has been sized to regulate the water level. The weir has sufficient capacity to pass the 100 year ARI inflow. The wetland will provide extended detention by means of a 50 mm diameter trickle pipe outlet below the level of the outlet weir. This means that, after rain, water levels, which are initially at the weir level, will be drawn down gradually to the normal operating water level over a period of a few days. This extended detention provides additional nutrient removal.

Emergency Spill Containment

In a severe emergency, oil may be spilt on the bridge pavement. Depending on location, the drainage system will carry the flow to downpipes in the bridge pier.

The HumeCeptor Model 14 will retain about 3,000 litres. Excess oil will overflow into the Inlet Trap where it would be retained behind the cross-bar. At an average depth of 200 mm, it is estimated that this trap will retain an additional 3,000 to 4,000 litres. Any further excess will enter and be retained behind a floating boom in the southern part of the wetland. If this happens the oil will have a significant impact on the wetland, which will require a thorough cleaning and possibly re-planting, but the river will still be protected.

Any oil tanker accident on this main road would constitute a major emergency, requiring the attendance of police and emergency vehicles. The drainage system has been arranged so as to facilitate the use of additional control measures such as floating booms by the response crews to minimise or hopefully prevent any water quality impact.

Land Requirements

The gross pollutant traps and associated stormwater pipework are located below ground within public roads or reserves. Although they may not be formally required, it is desirable for drainage easements to be established over the affected land to ensure that the drainage function is maintained.

Construction

The pond will be excavated. Approximately 2,200 m^3 of spoil will be produced from excavation of the wetland. It is proposed that this excess spoil will be used for landscaping in and around the reserve.

Excavation of the wetland will require removal of some trees, mainly *casuarinas*. The design involves replanting of the wetland surrounds with *casuarina* trees to replace the trees lost and to provide shade and a visual screen.

Flooding

The wetland is located on the overbank floodplain of the river. A previous Flood Study indicates that average velocities on the overbank would be negligible.

By its very nature, the wetland contains water-tolerant plants. It is unlikely that there would be any adverse effect from flooding. The most likely impact is deposition of sediment and debris, which should be cleaned up after a flood.

Landscaping

Landscaping options were discussed with the local Authority. The main comments were:

- Re-shaping the wetland to provide greater clearance to the existing children's play equipment in the northern end of the park. This would be compensated by extending the wetland further into the southern corner;
- Provision of 1.2m high 'round top' pool fencing around the play equipment to provide enhanced safety in proximity to the new water body;
- Provision of two gazebos and two electric barbecues to replace the shelters and barbecues which would be removed to construct the wetland;
- Provision of a footbridge over the wetland; and
- Provision of suitable tree planting around the area.

These suggested features have been incorporated into the design.

8) Spillway Design

The pond is located off-line, and inflows to the pond are limited by the capacity of the incoming pipe. The outlet weir has sufficient capacity to pass the 100 year ARI inflow. Therefore, no separate spillway has been provided.

The pond does not fall within the criteria for dam safety considerations.

9) Hydraulic Detention and Water Quality Performance Modelling

Modelling Approach

Estimates of average annual pollutant exports and the trapping of pollutants in the wetland and gross pollutant traps (GPTs) were determined using the XP-AQUALM catchment based water quality model.

The modelling approach was to set up an XP-AQUALM model comprising a daily rainfall-runoff model in conjunction with stormwater runoff - pollutant load correlations developed from similarly developed catchments to estimate pollutant loads and concentrations. The model also includes pollutant removal relationships applicable to wetlands (water quality control ponds) and gross pollutant traps.

Site constraints make it impracticable to construct a wetland of the size required by the Design Charts in Appendix 35.A. The model has been used to predict the performance of the GPT and wetland systems for the adopted design arrangement.

Rainfall/runoff model

A daily rainfall-runoff model was created for the three broad landuses for post-motorway condition for the study area. The structure of the rainfall/runoff model consists of surface and soil moisture stores with allowances for evapotranspiration, surface runoff, and throughflow from soil stores, and losses to groundwater. The rainfall/runoff parameters for three broad landuses calibrated for the Homebush Bay catchment were adopted for modelling purposes. Table 35.C4 summarises the adopted rainfall/runoff parameters.

Pollutant Retention

The XP-AQUALM model estimates pollutant retention in both gross pollutant traps, and wetlands (water quality control ponds). Depending on the pollutant retention is a function of either hydraulic retention time, or of sedimentation.

The pollutant retention curves for suspended solids and total phosphorus were adopted from Design Chart 35.4.

The model calculates hydraulic retention time based on the stage-storage and stage-discharge relationships of the water quality control pond. The stage-storage relationship for the wetland is given in Table 35.C7.

Provision has been made to capture the 'first flush' in designing the wetland. The 'First flush' storage volume of 520 m^3 is estimated to represent the first 8 mm of catchment runoff. This trapped water will then be released through the trickle pipe over an extended detention period of several days.

Retention of suspended solids in the gross pollutant traps was based on the sedimentation relationships in XP-AQUALM. The circular HumeCeptor was approximated by a rectangular trap, 2.4m wide and 4.0 m long. Sediment grading curves are shown in Table 35.C3.

There is little other data on retention relationships for heavy metals such as cadmium, lead, copper, and zinc. As it is likely that these metals will be associated with fine sediment particles, the retention curve for suspended solids was also adopted for metals.

Performance Modelling

The predicted performance of the HumeCeptor was modelled using XP-AQUALM, assuming that the unit could be represented as being equivalent to a rectangular GPT 2.4 m wide and 4.0 m long. It should be noted that although the unit has been sized primarily for its oil storage capability, is also effective in removing suspended solids. The performance of the wetland in improving water quality was also modelled using the XP-AQUALM computer model.

Results

The modelling results for pollutant removal efficiency of the wetland are listed in Table 35.C8. The model predicts retention of 98% of suspended solids, 26% for faecal coliforms and about 50% retention for metals such as cadmium, lead, copper, and zinc.

It is estimated that about 44 % retention will be achieved for TN, and about 41 % retention for total phosphorus (TP). The mean hydraulic residence time is 4.7 days. The model also showed that the average TP concentration which will be discharged into the river will be 0.1 mg/l.

The annual bio-available phosphorus in the proposed wetland will be 3.7 kg, and under this condition the wetland is expected to remain mesotrophic with *chlorophyll-A* concentration less than 20μg/l. Therefore, algal bloom problems are not anticipated.

Adopted Design

Features of the adopted design are shown in Figure 35.C3.

Table 35.C8 Predicted Performance of Wetland

Pollutant	Annual Load (kg)	Retained (kg)	Outflow (kg)	Retention (%)
Suspended Solids	982	961	21.6	98%
Oil *	-	-	-	100%
Faecal Coliforms	4.7E+12	1.2E+12	3.5E+12	26%
Metals - *Cu*	2.98	1.59	1.38	53%
Total Nitrogen	93.9	41.3	52.5	44%
Total Phosphorus	12.5	5.1	7.4	41%

NOTE:

* Oil removal has not been modelled. Predicted retention = 100% up to volume of HumeCeptor storage.
\# Includes flows which bypass the GPT and wetland during high flows