

CHAPTER 11 WATER QUALITY POND AND WETLANDS

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11.1 INTRODUCTION

This Chapter contains guidance for the selection and design of water quality ponds and or/wetlands for new or existing developments areas. Guidances provided include descriptions, design criteria and sizing procedures.

If there is a need to design a storage facility for both water quality and quantity control purposes, the water quality pond should be considered and used in conjunction with detention pond design.

11.2 WATER QUALITY POND

11.2.1 Description and Types

Water quality ponds, with extended detention (ED), are effective for removing suspended constituents. Removal rates of solids and many dissolved constituents by wet water quality pond outperform dry type (Iowa Natural Resources Conservation Service, 2008). Dry type water quality ponds provide moderate pollutant removal, particularly soluble pollutants because of the absence of a permanent pool.

A practice has developed in some overseas countries with temperate climates, of designing a pond so that the runoff from a storm is retained over an extended period of several days or longer. This water quality pond allows for greater removal of certain pollutants, such as suspended constituents and nutrients, by biological action and settlement. The water quality pond uses a much smaller outlet than a flood control detention basin, which extends the emptying time for the more frequently occurring runoff events to facilitate pollutant removal (UDFCD, 2008). Runoff from small storms is attenuated.

When sized and designed appropriately with an appropriate drawdown time, water quality pond can provide the required sediment capture. In dry type ponds there is little biological uptake due to the lack of vegetation and relatively shorter detention times. Sediment re-entrainment may occur if the pond is not designed properly when subjected to high flows. Wet type ponds that are permanently full (wet extended detention ponds) are preferred if very high quality effluent is desired. Both dry and wet type water quality ponds can provide extended detention, the latter by having a surcharge water quality capture volume that is released slowly to mitigate some of the erosion effects in downstream waterways.

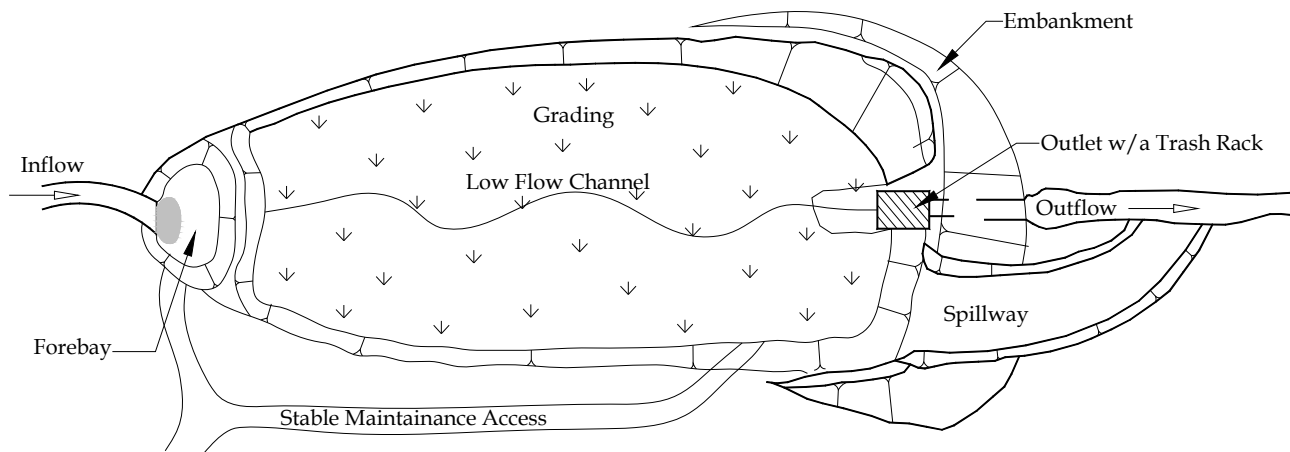
Other issues to be considered are:

- Water quality ponds will attenuate small storms (such as the water quality design storm), but due to their relatively small size and lower release rates, they will not provide significant peak flow attenuation for large storms. However, the water quality pond can be incorporated as the bottom stage of a larger flood control basin that provides flow attenuation for large storms.
- Due to the low amount of vegetation and the absence of permanent water, the habitat value may not be high. Water quality ponds may have less visual appeal than ponds that are permanent pool.
- 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 they may be difficult to mow and walk on and create favourable conditions for mosquito breeding. It may be difficult to maintain wetlands 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.

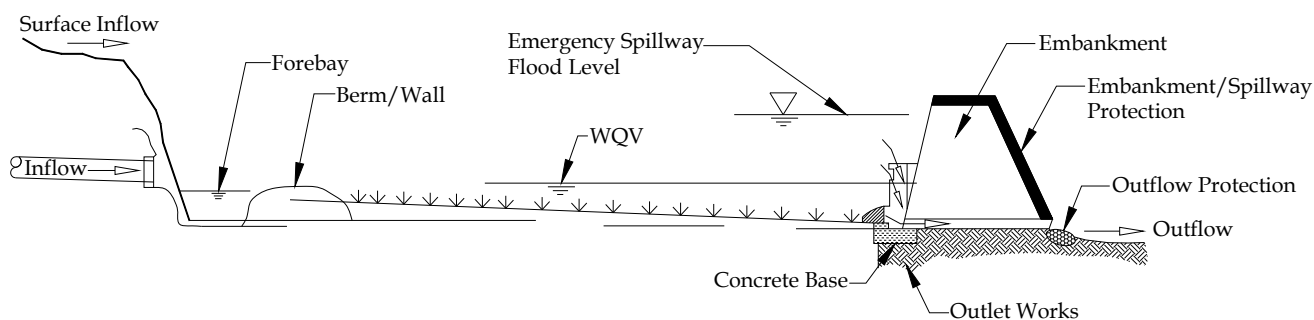
These issues require careful consideration by the designer under Malaysian conditions. There may be particular situations where water quality ponds would be appropriate. For example, they may be used in areas where pervious soils, lack of impermeable liner, lack of adequate inflow during dry weather periods, or low groundwater table would preclude the use of a permanent pool pond. On the other hand, when these conditions can be satisfied, wet detention basins would do a very good job in reducing pollutants leaving the site.

11.2.1.1 Dry Type

A dry type water quality pond is a sedimentation basin designed to totally drain dry after runoff from a storm ends (Figure 11.1). It is an adaption of the detention ponds used for flood control. The primary difference is in the outlet design. The dry type water quality pond uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. A drain time (time to fully evacuate the design volume) of 24 hours to 48 hours is recommended to remove a significant portion of the fine particulate pollutants found in urban stormwater runoff (UDFCD, 2008).



(a) Plan



(b) Profile



(c) Examples (UDFCD, 2008)

Figure 11.1: Dry Type Water Quality Pond (Modified from UDFCD, 2008)

Dry type water quality pond can be used to enhance stormwater runoff quality and reduce peak stormwater runoff rates. If these basins are constructed early in the development cycle, they can also be used to trap sediment from construction activities within the tributary drainage area. The accumulated sediment, however, will need to be removed after upstream land disturbances cease and before the pond is placed into permanent use. Also, a dry type water quality pond can sometimes be retrofitted into existing flood control detention ponds. Dry type water quality pond can be used to improve the quality of urban runoff coming from roads, parking lots, residential neighbourhoods, commercial areas, and industrial sites and are generally used for regional or development-wide treatment (UDFCD, 2008).

Since the dry type water quality pond is designed to drain very slowly, its bottom and lower portions will be inundated frequently for extended periods of time. Grasses in this frequently inundated zone will tend to be stressed, with only the species that can survive the specific environment at each site eventually prevailing. In addition, the bottom will be the depository of all the sediment that settles out in the pond. As a result, unless the inflow, concrete trickle channel and properly designed outlet are provided, the bottom can be muddy and may have an undesirable appearance to some. To reduce this problem and to improve the pond's availability for other uses (such as open space habitat and passive recreation), it is suggested that wet type water quality pond to be provided, in which the settling occurs primarily within the permanent pool.

11.2.1.2 Wet Type

Wet type water quality ponds (Figure 11.2) are very similar to wet detention ponds with the difference that their design is more focussed on attenuating water quality and peak runoff flows from smaller runoff event. Soluble pollutant removals are provided by a permanent ponding area in the bottom of the pond to promote biological uptake.

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11.2.2 Design Considerations and Requirements

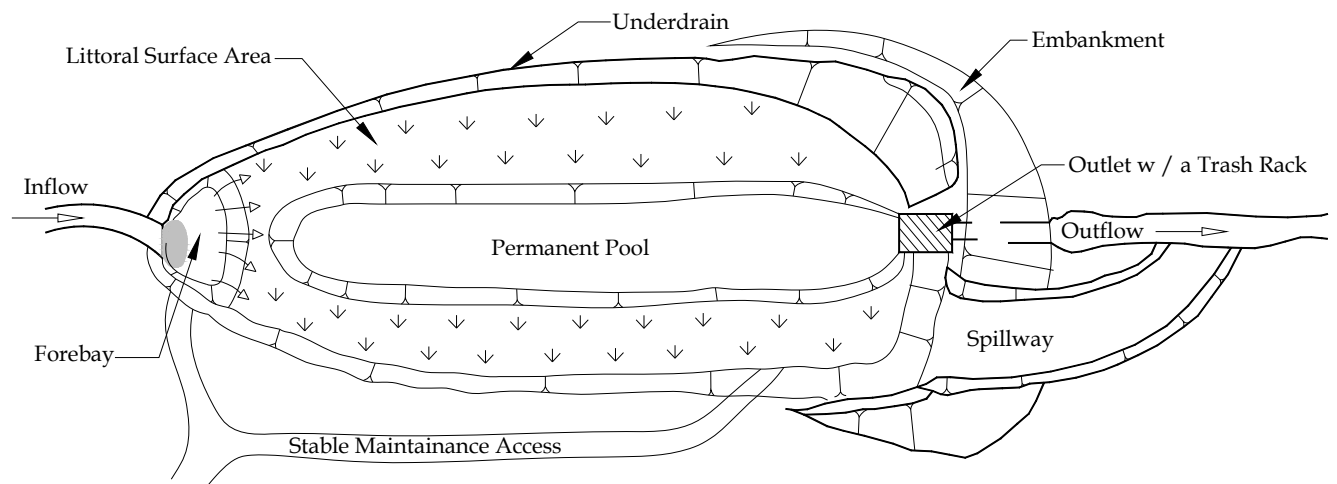
Specific designs may vary considerably, depending on site constraints or preferences of the designer or community.

11.2.2.1 Drainage Area

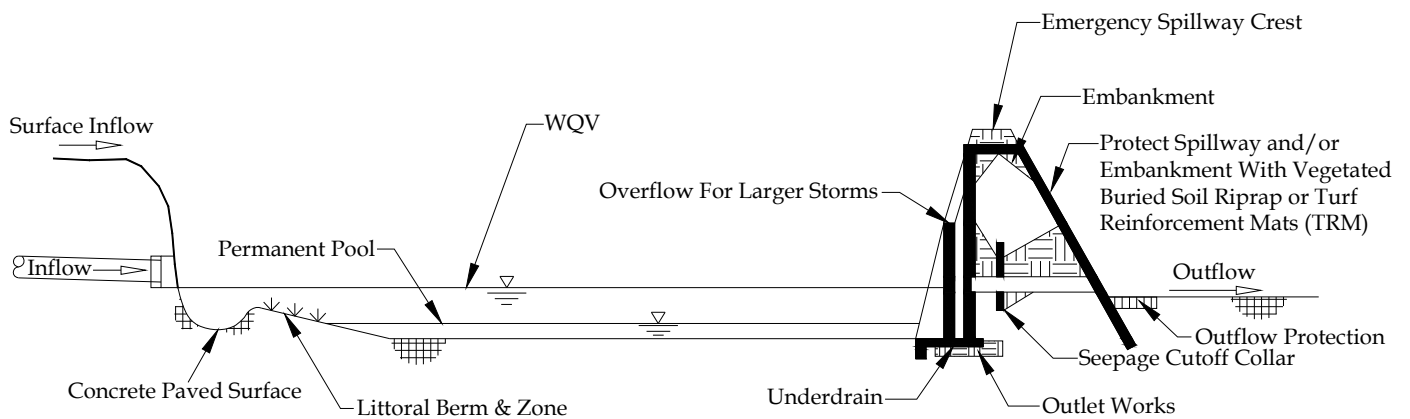
The minimum recommended catchment area is 2.5ha for commercial or industrial landuse and 3.5ha for residential landuse. A single water quality pond shall not have a contributing drainage area less than minimum recommended catchment area unless specifically approved by the local regulatory authority because it may require a very small orifice that would be prone to clogging when sized to allow for complete drawdown of the water quality volume for a specific period.

11.2.2.2 Location and Site Suitability

It is recommended that water quality ponds be located where the topography allows for maximum runoff storage at minimum excavation or embankment construction costs (Iowa Natural Resources Conservation Service, 2008). When locating a water quality pond, planners and designers should also consider the location and use of other land use features, such as planned open spaces and recreational areas, and should attempt to achieve multi-use objectives where these can be safely achieved. Water quality ponds shall not be located on unstable slopes or slopes greater than 15% (Iowa Natural Resources Conservation Service, 2008).



(a) Plan



(b) Profile



(c) Example (Iowa NRCS, 2008)



(d) Example (UDFCD, 2008)

Figure 11.2: Wet Type Water Quality Pond (Modified from UDFCD, 2008)

11.2.3 Design Criteria

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most water quality pond designs.

11.2.3.1 Geometry

Design flow paths shall be designed to minimise potential short-circuiting by locating the outlet as far away from the inlet structures as possible. The recommended length-to-width ratio of a basin should be at least 2:1 (and preferably 3:1).

11.2.3.2 Water Quality Volume

The water quality volume (WQV) shall be determined for a water quality design storm (runoff from a 40mm rainfall depth over the contributing catchment). An effective stormwater enhancement facility has to balance the pond brim-full volume and its drawdown time.

In practice, the drain time is determined by the required pollutant settling time. If sediment characteristics are not known, a 12-hour drawdown time for a wet type water quality pond and a 48-hour drawdown time for dry type water quality pond are recommended for stormwater quality control designs. It was reported that about 80 to 90% sediment removal can be achieved using the above drain times (EPA, 1983). Therefore, it is expected that a large detention volume draining in a short time will not sufficiently remove sediment and the water quality volume shall be determined with the water quality pond design.

The required storage volume for WQV can be obtained using the Equation 11.1 as follows:

$$WQV = C.(P_d).A \quad (11.1)$$

where,

- WQV = Water quality volume (m³);
- C = Volumetric Rational Method runoff coefficient (Refer Table 2.5);
- P_d = Rainfall depth for water quality design storm (m); and
- A = Contributing drainage area (m²).

11.2.3.3 Outlet Works

The outlet works are to be designed to release the water quality volume over a proposed drain time period (Refer to Chapters 2 and 20 pertaining to outlet type: orifice plate or perforated riser pipe; hydraulic structures geometries; grates, trash racks, and screens; and all other necessary components). The number of columns of perforations used should be minimised and the diameter of the perforation hole(s) should be maximised when designing outlets to reduce chances of clogging by accepting the orifice size that will empty the water quality volume in a specified time (UDFCD, 2008).

The outlet works are designed to provide a drawdown of the water quality pond over a specific time. The target average discharge from the outlet works is computed as the ratio of the required storage volume for the WQV to the drawdown time as follows:

$$Q_{ave} = \frac{\text{Required Storage for WQV (m}^3\text{)}}{\text{Drawdown Time (s)}} \quad (11.2)$$

11.2.3.4 Safety

Public safety should be considered, particularly in residential areas. Designers should avoid steep slopes and drop-offs and depths over 1.0m whenever possible. If it is not possible, safety features such as fences shall be provided unless buffered by shallow marshlands (littoral zone) on all sides accessible by the public.

11.2.3.5 Water Quality Volume for Detention Ponds

Wherever possible, it is recommended that water quality pond be incorporated into stormwater quantity detention facilities. This is relatively straight forward for water quality pond, constructed wetlands, wetpond and detention pond. When combined, the 2, 5, 10, and/or 100-year ARI detention levels are provided above the

water quality volume and the outlet structure is designed to control two or three different releases. When a local policy is lacking, the following approach is suggested as a minimum:

- Water quality: The full water quality volume is to be provided according to the design procedures;
- Minor storm: The full water quality volume plus the full minor storm quantity detention volume is to be provided; and
- Major storm (100-year storm or other event): One-half the water quality volume plus the full 100-year (or other major storm event) detention volume is to be provided.

The designer should be aware that the two functions (stormwater quantity and quality controls) can be provided by a same pond, and that incorporating the two functions in one pond will be more cost-effective than creating two separate ponds.

11.2.4 Design Procedure for Water Quality pond

The following design steps are recommended when designing water quality pond:

Step 1: Confirm Treatment Performance of Concept Design.

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the required area from the concept design is adequate to deliver the required level of stormwater quality improvement. This design process assumes a conceptual design has been undertaken. The pollutant reduction curve for water quality pond as a function of catchment impervious area shown in Figure 3.1 can be used to undertake this verification check. The curve is intended to provide an indication only of appropriate sizing and do not substitute the need for a thorough design process.

Step 2: Determine Water Quality Volume.

Designer should determine the runoff coefficient for the catchment area to calculate the WQV and set the permanent pool elevation and water level based on the WQV calculated.

Step 3: Outlet Works.

The outlet works are to be designed to release the WQV (above the permanent pool elevation) over a proposed drain time period (Refer to Chapters 2 and 20 pertaining to outlet type) based on the types of water quality pond.

Step 4: Design Embankment(s) and Spillway.

Designers must calculate the peak of storm water surface elevation and size an emergency spillway to provide a controlled overflow for flows in excess of the design water quality storm. They must then set the top of the embankment elevation.

11.3 CONSTRUCTED WETLANDS

Constructed wetlands, like ponds, are used to improve water quality. The wetlands constructed at Putrajaya and Engineering Campus, Universiti Sains Malaysia (Figure 11.3) were designed for this purpose. Ponds and wetlands are complementary. The pollutant removal efficiency of a pond can be increased by including an area of wetlands.

11.3.1 Description and Components

Wetlands is an area of land where soil is saturated with water either permanently or seasonally. Such areas also need to be covered, at least partially, by shallow pools of water. Wetlands include swamps, marshes and bogs, among others. The water found in wetlands can be saltwater, freshwater or brackish.



(a) Putrajaya

(b) Engineering Campus,
Universiti Sains Malaysia

Figure 11.3: Examples of Constructed Wetlands in Malaysia

Wetlands are considered the most biologically diverse of all ecosystems. Plant life found in wetlands includes mangrove, water lilies, cattails, sedges, tamarack, black spruce, cypress, and many others. Animal life includes many different amphibians, reptiles, birds and furbearers.

Wetland systems can be explicitly designed to aid in pollutant removal from stormwater. Wetlands also provide for quantity control of stormwater by providing a significant volume of temporary water storage above the permanent pool elevation. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically based on the design WQV, back to dry weather water levels. As stormwater runoff flows through the wetlands, pollutant removal is achieved via settlement and biological uptake within the BMPs. Wetlands are among the most effective stormwater BMPs in terms of pollutant removal, and also offer aesthetic value.

Constructed surface flow wetlands systems remove pollutants in stormwater through sedimentation, filtration of fines and biological uptake. The main components of a wetlands are the inlet zone, macrophyte zone and then open water zone (Figure 11.4).

11.3.1.1 Inlet Zone

The function of the inlet zone (sediment basin or forebay) is to encourage settling of coarse to medium sediments from the water column, reduce flow velocities and distribute flow across the wetlands. The installation of sediment traps and trash skimmers helps in the function of this zone.

The inlet zone of a wetlands is designed as a sediment basin and serves two functions:

- Pre-treatment of inflow to remove coarse to medium sized sediment; and
- The hydrologic control of inflows into the macrophyte zone and bypass of floods during 'above design' operating conditions.

The inlet zone consists of the following elements:

- Sedimentation basin 'pool' (or sediment forebay) to capture coarse to medium sediment;
- Inlet zone connection to the macrophyte zone (or control structure) normally consisting of an overflow pit within the inlet zone connected to one or more pipes through the embankment separating the inlet and macrophyte zones; and
- High flow bypass weir (or 'spillway' outlet structure) to deliver 'above design' flood flows to the high flow bypass channel.

11.3.1.2 Macrophyte Zone

Macrophytes are large, emergent aquatic plants. For macrophyte zones to function efficiently, flows that pass through the vegetation must be evenly distributed. Beds of macrophytes filter out fine particles and directly take up contaminants. They enhance sedimentation and the absorption of pollutants onto sediments.

Macrophyte species should be selected from plants provided in Annex 1 and they shall meet the following requirements:

- Native to the area;
- Known to be likely to establish and grow under conditions applying at the site;
- Unlikely to colonise outside the designated area;
- With a maximum height of the plants must be consistent with maintaining desirable visual characteristics of the pond; and
- Not growing to a density that would provide suitable habitats for mosquito breeding.

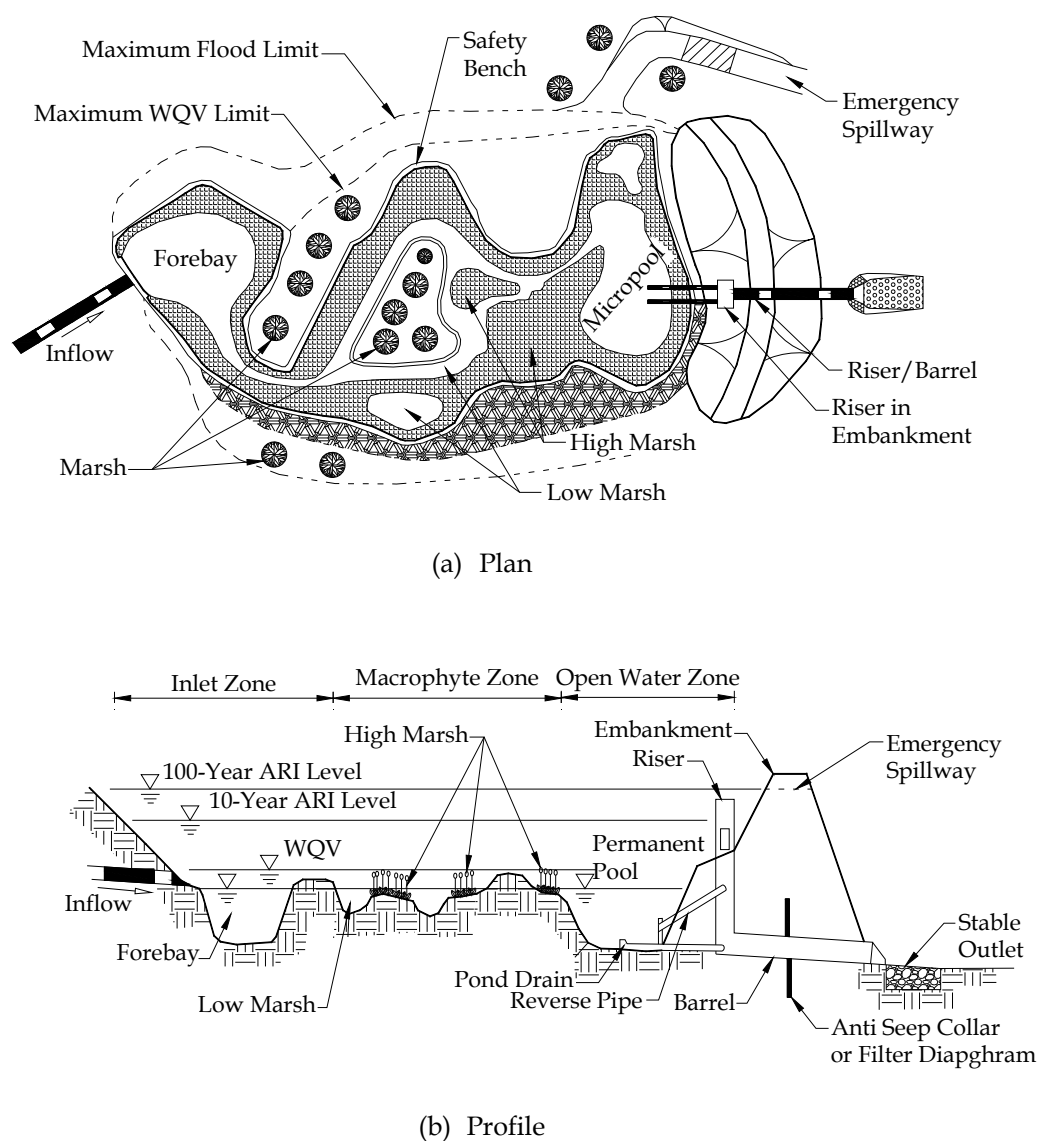


Figure 11.4: Wetlands Component (Modified from MDE, 2000)

11.3.1.3 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.

11.3.2 Design Considerations and Requirements

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wetlands designs.

11.3.2.1 Drainage Area

Wetlands require a positive water balance, through continuous base flow or groundwater seepage, so that permanently wet conditions can be sustained. They are therefore limited to areas where springs or land drainage provides base flow during dry weather (CIRIA, 2007).

11.3.2.2 Space Requirement

At a minimum, the surface area of a wetlands should be no less than 1% of the contributing drainage area. The surface area can be determined from the annual pollutant curve as a function of pond area ratio in Chapter 3.

11.3.2.3 Location and Site Suitability

Wetlands are normally located at a position that can receive all the site runoff (i.e. at the lowest point in the site), generally at minimum excavation (or construction) cost. Where the urban design of an area permits, the location of a wetlands should take account of natural site features that might be used as additional temporary storage areas when the wetlands capacity is exceeded during extreme events. If the wetlands design criteria include protection of the watercourse during floods, then the system should not be located in the floodplain, where there is a risk that the detention storage will be lost through inundation at the critical time. River flood waters also tend to carry high sediment and debris loads, which will necessitate additional wetlands maintenance. Wherever possible, wetlands should be located in, or adjacent to, non-intensively managed landscapes where natural sources of native species are likely to be plentiful (CIRIA, 2007).

11.3.2.4 Site Slope and Stability

Wetlands basin require a near-zero (almost horizontal) longitudinal slope, which can be provided using embankments, if required. Wetlands should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions. Wetlands should not be considered within or over waste fill materials, uncontrolled or non-engineered fill (CIRIA, 2007).

11.3.2.5 Subsurface Soil and Groundwater

The soil below a wetlands must be sufficiently impermeable to maintain wet conditions, unless the wetlands intersects the water table. In permeable strata, a liner (or other impermeable material) will be required to prevent drying out. As the wetlands evolves, loss of water should become negligible as the soils on the floor of the basin become more organic, reducing the potential for exfiltration. Loams soils are needed in a wetlands bottom to permit plants to take root. Assessment of soils should be based upon an actual subsurface analysis and permeability tests (CIRIA, 2007).

In areas with contaminated soils or contaminated groundwater, wetlands can be used providing that the system is fully sealed, preventing exchange of water between the facility and groundwater. Any excavation or earthmoving processes required must be managed to ensure that mobilisation of contamination does not occur. Any permeability of the subsurface soils will require the use of a liner (or equivalent). Where the groundwater table is close to the base of the wetlands, the operation of the outfall should be confirmed for the annual

maximum water table level. The maximum expected groundwater level should be beneath the storage zone (CIRIA, 2007).

11.3.3 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. The constructed wetlands is designed for stormwater pollution control in the project area before discharging into the nearest receiving waterway.

11.3.3.1 Design Storm

The water quality design storm with 40mm rainfall depth over the contributing catchment should be determined at the pre-treatment inlet. If the wetlands is to be constructed offline, then an upstream bypass structure can be used to divert the water quality storm volume into the wetlands.

The principal function of the storage in a wetlands is to provide a variable wetting-drying cycle, which encourages growth and diversity of macrophytes. A depth range of 0.3m to 1.2m and a hydraulic residence time of at least 12 hours for a design storm may be suitable. However, peak flow control and extended detention are achieved by temporarily ponding above the wetlands permanent water level during rainfall events, and then releasing it in no less than 12 hours to 24 hours is recommended for its biological treatment function.

11.3.3.2 Allocation of Surface Area

In general, wetlands designs are unique for each site and application. However, the allocation of surface area and limiting depths for the design of constructed wetlands shall be considered for adequate pollutant removal, ease of maintenance and improve safety. Note that if the surface area criteria is in conflict with the volume allocations, the surface area allocations are more critical for an effective design.

a) *Inlet Zone*

A sediment forebay is designed at the inlet zone to remove incoming sediment from the stormwater flow before runoff enters the wetlands marsh. This ensures the vegetation in the macrophyte zone is not smothered by coarse sediment and allows the macrophyte zone to target finer particulates, nutrients and other pollutants. The forebay shall consist of a separate cell, formed by an acceptable barrier and provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the wetlands facility.

Typically the forebay should be about 15 to 30% of the total wetlands area and around 1.5 to 2.0m deep. A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.

b) *Macrophyte Zone*

The wetlands arrangement in a recreation reserve should be chosen to maximise its effectiveness while minimising the impact on open space. The wetlands replicates a natural river system with a long, narrow plan form with deeper ponds. Macrophytes would be planted in the shallow sections to assist with water treatment. This and relatively dense plantings of macrophytes also form a barrier around the edges of the wetlands to discourage people from entering the water.

The macrophyte zone should be provided around the wetlands edges downstream of the main inlets to filter out sediment, nutrients and toxicants, to disperse the inflowing waters and to reduce their velocity. Plantings should be on the perimeter, arranged such that there is opportunity for water in the open pond zone to circulate through the macrophyte zone. An allocation of 50 to 80% of the total wetlands area and a depth of 0.3 to 1.2m is recommended for the macrophyte zone.

c) *Open Water Zone*

The open water zone attracts plant and wildlife diversity and has the potential to be used for aesthetic and passive recreational activity. Typically, at least 5% of the total wetlands area, a minimum depth of 1.0m and a maximum depth of 2.0m are recommended for the open water zone.

11.3.3.3 Geometry

a) *Length to Width Ratio*

The length of time that water is retained in a pond is the main variable in determining how effective the wetlands will be in trapping pollutants. Increasing the volume and hence, retention time allows for more sedimentation of particles, and more assimilation of pollutants. Wetlands should be long relative to their width in order to provide optimum flow circulation, with minimum length to width ratio (L:W) in the range of 2:1 to 5:1.

b) *Macrophyte Zone Bathymetry*

It is a good design practice to provide a range of habitat areas within the macrophyte zone to support a variety of plant species, ecological niches and perform a range of treatment processes. The macrophyte zone therefore typically comprises of four marsh zones (defined by water depth). The four marsh zones are:

- Ephemeral zone (from 0.20m above the pool or water surface elevation): These areas are located above the permanent pool that are inundated during larger storm events. This zone supports a number of species that can survive flooding.
- High marsh zone (from 0.30m below the pool to the normal pool elevation): This zone will support a greater density and diversity of wetlands species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.
- Low marsh zone (from 0.30 to 0.60m below the normal permanent pool or water surface elevation): This zone is suitable for the growth of several emergent wetlands plant species.
- Deep marsh zone (from 0.60 to 1.2m deep; includes the outlet micropool and deepwater channels through the wetlands facility): This zone supports little emergent wetlands vegetation, but may support submerged or floating vegetation.

The recommended vegetation planting density for the macrophyte zone is summarised in Table 11.1.

Table 11.1: Vegetation Planting Density

Zone	Depth Range (m)	Planting Density (plant/m ²)
Ephemeral zone	0 to 0.20m above permanent pool	8
High marsh zone	0 to 0.30m below permanent pool	10
Low marsh zone	0.30 to 0.60m below permanent pool	6
Deep marsh zone	0.60 to 1.20m below permanent pool	4

c) *Water Depth*

Wetlands should contain a mixture of water depths. Water levels in excess of 1m should not occur over more than 20% of the wetlands pond surface area (preferably limited to the inlet zone and outlet open water zones) as deep water supports relatively less of plant species compared to shallow zones.

Where wetlands are designed for flow attenuation, the depth of temporary storage above the permanent water level should not exceed 1.5m to allow for colonisation for submerged macrophytes. The water depth in the wetlands shall range between 0.1m and 1.2m with an average of 0.6m. Changes in water level shall be limited to

about 0.6m. Wetlands that are associated with ponds used for flood control shall be designed to accommodate submergence to depths between 1m and 2m with the maximum velocity not exceeding 0.1m/s.

d) Slopes

For safety, stability and to promoting the growth of macrophytes, slopes within the wetlands shoreline area should be in the range of 6(H): 1(V) to 8(H): 1(V). After reaching a depth of 1m, 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 10(H): 1(V) to 20(H): 1(V) is recommended for a distance of 5m from the wetlands edge, to allow maintenance access.

Wetlands 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 that are inaccessible, emergent plants such as reeds, which will tolerate water level changes, can be used.

e) Water Balance

The designer should check that the permanent pool will not dry out during extended dry periods. This can be done by means of a continuous water balance calculation, allowing for runoff inputs, evaporation and infiltration over a period of least 12 months. If excessive exfiltration 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 permanent pool drying out is less likely than in drier climates.

11.3.3.4 Water Quality Treatment

a) Pollutant Removal Capabilities

Wetlands design variants are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed wetlands facilities can reduce pollutant removal performance. The pollutant reduction curve in Figure 3.1(c) can be used to check the expected performance of the wetlands system.

b) Water Quality Volume

Pollutants are removed from stormwater runoff in a wetlands through uptake by wetlands vegetation and algae, vegetative filtering, and through gravitational settling in the slow moving marsh flow. Other pollutant removal mechanisms are also take place in a stormwater wetlands, including chemical and biological decomposition, and volatilization. The required storage for WQV of a wetland can be determined from Equation 11.1.

c) Hydraulic Residence Time

The hydraulic residence time is the permanent pool volume, divided by the average outflow discharge rate. The longer the residence time, the higher the pollutant removal.

Using 2 x water quality volume to size the permanent pool means that smaller storms (1 x water quality volume) will displace only half of the pool volume of the wetlands, thus providing for extended residence times. Larger treatment volumes with respect to the watershed size (3 x water quality volume) will provide longer residence times and, therefore, greater efficiencies. In certain situations, using these larger volumes and efficiencies may be desirable, especially where downstream waters may be sensitive to pollutants from urban

runoff. However, the challenge is to provide the recommended minimum surface area allocations for the different depth zones as previously discussed.

11.3.3.5 Inlet and Outlet Configuration

a) *Inlet Design*

When applying the design procedure, the following should be used as a guide (Brisbane City Council, 2005):

- The inlet zone typically must comprise of a deep open water body (1.5m to 2.0m) that operates essentially as a sedimentation basin designed to capture coarse to medium sized sediment
- It may be necessary for a GPT to be installed at the end of incoming waterway (or pipe), so that litter and large debris can be captured before entering the open water of the inlet zone. A floating skimmer installed at the downstream end of the forebay can be used instead to capture the floatable debris.
- The crest of the overflow pit must be set at the permanent pool level of the inlet zone (which is typically set 0.3m above the permanent water level of the macrophyte zone).
- The overflow pit and pipe that transfer flows from an inlet zone, or pond to the macrophyte zone controls the water level in the inlet pond and the maximum level flow rate that can reach the macrophyte zone. This structure needs to have sufficient capacity to convey a 1-year ARI flow, assuming the macrophyte zone is at the permanent pool level and without resulting in any flow over the high flow bypass weir.
- An energy dissipater is usually required at the end of the pipes to reduce velocity and distribute flow into the macrophyte zone.
- The inlet zone is to have a structural base (e.g. coarse rock or cobble) to define the base during removal of silt deposits in its bottom and provide support for maintenance plant/ machinery when entering the basin for maintenance.
- The high flow bypass weir (spillway outlet) is to be set at the same level as the top of extended detention in the macrophyte zone to enable stormwater to safely discharge from the inlet zone around the macrophyte zone in periods of high flow.
- The high flow bypass channel may be used to protect the wetlands from the large, infrequent flows, bypassing excess flows around the wetlands, as well as reducing the risk of damage from erosion, scour and re-mobilisation of pollutants. The design of the high flow bypass channel needs to be carefully considered to provide recreational and landscape opportunities during times outside of the above design flow events.

b) *Outlet Design*

The use of a multiple stage riser-type outlet is generally more suitable for controlling the water level regime in a wetlands 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. However, flow control from a stormwater wetlands is typically accomplished with the use of a concrete or corrugated metal riser and barrel.

The riser is a vertical pipe or inlet structure that is attached to the base of the micropool with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (Figure 11.5). The riser should be located within the embankment for maintenance access, safety and aesthetics. A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality, channel protection, and overbank flood protection runoff volumes. The number of orifices can vary and is usually a function of the pond design (Iowa Natural Resources Conservation Service, 2008).

In the case of an extended detention (ED) wetlands, there is generally a need for an additional outlet (usually an orifice). This additional outlet that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which shall be sized to release the water quality volume no less than 12 hours to 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 0.3m below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next

outlet is sized for the release of the channel protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the water quality volume and is sized to release the channel protection storage volume. However, in most instances trash racks will be needed to avoid the orifice to be clogged by debris. The trash rack design should conform to the design criteria as shown in Chapter 7.

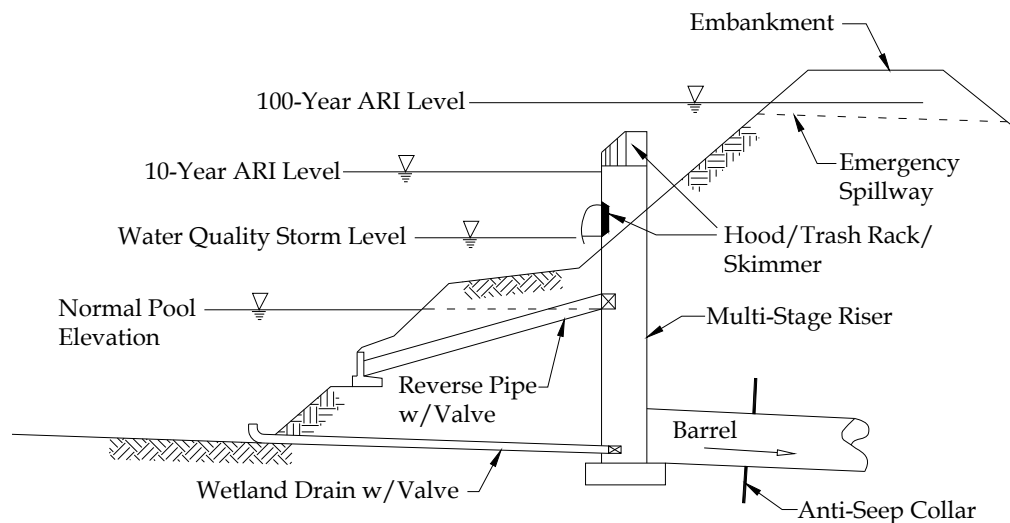


Figure 11.5 Typical Wetlands Facility Outlet Structure (Modified from MDE, 2000)

Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch or proportional weirs, or an outlet pipe protected by a hood that extends at least 0.3m below the normal pool level. After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars shall be installed on the outlet barrel to reduce the potential for pipe failure. Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the outlet of the barrel to prevent scouring and erosion (Iowa Natural Resources Conservation Service, 2008).

If a wetlands facility discharges to a channel with dry weather flow, care should be taken to minimise tree clearing along the downstream channel, and to re-establish a forested riparian zone in the shortest possible distance. If a low flow discharge pipe is used, it should be constructed on a reverse slope and extended into the wetlands below the pool surface elevation but above the bottom elevation. This helps to prevent clogging, since a typical wetlands environment consists of floating plant debris and possible sediment and organic accumulation at the bottom. The wetlands facility must have a bottom drain pipe located in the open water zone with an adjustable valve that can completely or partially dewater the wetlands within 12 to 24 hours. The wetlands drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a hand wheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner (Iowa Natural Resources Conservation Service, 2008).

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

11.3.3.6 Spillway

Spillways are required to accommodate the design flood, whether or not the wetlands 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 wetlands with large pool area, 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 during the inflow flood resulting from the Probable Maximum Precipitation (PMP) storm events.

An emergency spillway is to be included in the stormwater wetlands design to safely pass flows that exceed the largest design storm flows for that facility, whether this be the water quality design storm or the 100-year ARI if the wetlands basin is a multi-purpose stormwater facility. The spillway prevents the flood flows from overtopping the embankment and causing structural damage or catastrophic failure. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. All wetlands should be provided with a spillway able to safely discharge at least the 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 only need to cater all the diverted flows, including any that may be larger than the design ARI due to the capacity of the diversion system and actual diversions entering the diversion system, plus any local catchment inflows. One of the advantages of off-line facilities is that the emergency spillway requirements are much smaller and simpler than for in-line facilities.

If the wetlands 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 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.

In spillway design, it is also necessary to ensure that receiving channel downstream of the structure is sufficiently protected against the erosive flow from the spillway. Riprap lining or energy dissipaters may be necessary.

11.3.3.7 Embankment and Maintenance Access

The water-retaining embankments for the wetlands basin may have the characteristics of small dams, and should be designed as such. 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 wetlands, and especially the embankment, should always be based on site-specific information.

11.3.3.8 Safety

Constructed wetlands need to conform to public safety requirements for new developments. Generally, the owner of the wetlands is responsible for ensuring that it does not pose risk to public health or safety. These include reasonable batter profiles for edges to facilitate public egress from areas with standing water and fencing or railings where water depths and edge profile requires physical barriers to deny public access.

Mosquito-borne diseases are a serious concern in tropical areas. The wetlands design should minimise the risk of mosquito breeding 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;
- Varied depths as described in this chapter, to encourage breeding of fish and other predator species;
- Shaping of wetlands to avoid shallow stagnant areas with poor circulation;
- Shaping of wetlands edges to avoid the trapping of water in depressions as the pond water level changes;
- Providing a mechanism to regulate water 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;
- 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 velocity. 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.

11.3.4 Design Procedure for Constructed Wetlands

The following design steps are recommended when designing wetlands:

Step 1: Confirm Treatment Performance of Concept Design.

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the required wetlands area (i.e. the macrophyte zone surface area) from the concept design is adequate to deliver the required level of stormwater quality improvement. This design process assumes a conceptual design has been undertaken. The pollutant reduction curve for wetlands as a function of catchment impervious area shown in Figure 3.1 can be used to undertake this verification check. These curves are intended to provide an indication only of appropriate sizing and do not substitute the need for a thorough design process.

Step 2: Determine Design Flows.

A design operation flow (based on water quality storm) is required for sizing the inlet zone (i.e. sedimentation basin) and the control outlet structure (i.e. overflow pit and pipe connection) discharging to macrophyte zone.

Water Quality Volume

Next, the designer should calculate the WQV and set the WQV permanent pool elevation based on the volume calculated and the WQV water level.

Step 3: Designing the Inlet Zone.

The design of inlet zone applies the same processes as the procedure for design forebay or sediment basins. Inlet zone connection to the macrophyte zone normally consists of an overflow pit within the inlet zone connected to one or more pipes through the embankment separating the inlet zone and the macrophyte zone. The inlet zone shall be provided with a gross pollutant trap (GPT) to remove larger particles and debris including sediment.

Step 4: Designing the Macrophyte Zone.

Length to Width Ratio and Hydraulic Efficiency

To optimise wetlands performance, it is important to avoid short circuiting of flow paths and poorly mixed regions within the macrophyte zone. One way to minimise this is to adopt a high length to width ratio not less than 2 to 1 for the macrophyte zone. Length to width ratios less than this can lead to poor hydrodynamic conditions and reduced water quality treatment performance.

Designing the Macrophyte Zone Bathymetry

It is good design practice to provide a range of habitat areas within the macrophyte zone to support a variety of plant species (Refer Annex 1) and ecological niches to perform a range of treatment processes. The macrophyte zone therefore typically comprises four marsh zones (defined by water depth) and an open water zone. The bathymetry across the four marsh zones is to vary gradually ranging from 0.2m above the permanent pool level (i.e. ephemeral marsh) to a maximum of 1.2m below the permanent pool level (i.e. deep marsh).

Macrophyte Zone Edge Design for Safety

The batter slopes on approaches and immediately under the permanent water level have to be configured with consideration of public safety. It is recommended that a gentle slope to the water edge and extending below the water line be adopted before the batter slope steepens into deeper areas.

Macrophyte Zone Soil Testing

Constructed wetlands are permanent water bodies and therefore the soils in the base must be capable of retaining water. Geotechnical investigations of the suitability of the in-situ soils are required to establish the water holding capacity of the soils. Where the infiltration rates are too high for permanent water retention, tilling and compaction of in-situ soils may be sufficient to create a suitable base for the wetlands. Where in-situ soils are unsuitable for water retention, a compacted clay liner may be required (typically 300mm thick). Specialist geotechnical testing and advice must be sought.

Step 5: Design Open Water Zone Outlet.

An open water zone outlet has two purposes: (1) hydrologic control of the water level and flows in the macrophyte zone to achieve the design detention time; and (2) to allow the wetlands permanent pool to be drained for maintenance.

Outlet Works – Size and Location of Orifices

The riser outlet is designed to provide a uniform notional detention time in the open water zone over the full range of the extended detention depths. In the case of an extended detention wetlands, there is generally a need for an additional outlet that is sized to pass the water quality volume that is superimposed on top of the permanent pool no less than 12 hours to 24 hours.

Maintenance Drains

To allow access for maintenance, the wetlands should have appropriate allowance for draining. A maintenance drainage pipe should be provided that connects the low points in the macrophyte zone bathymetry to the macrophyte zone outlet. A valve is provided on the maintenance drainage pipe), which can be operated manually. The maintenance drainage pipe should be sized to draw down the permanent pool within 12 hours. If a weir plate is used as a riser outlet, provision should be made to remove the weir plate and allow drainage for maintenance.

Discharge Pipe

The discharge pipe of the wetlands conveys the outflow of the macrophyte zone to the receiving waters (or existing drainage infrastructure). The conveyance capacity of the discharge pipe is to be sized to match the higher of the two discharges (i.e. maximum discharge from the riser or the maximum discharge from the maintenance drain).

Step 6: Design Embankment(s), Spillway and High Flow Bypass Channel.

Designers must next size an emergency spillway, and calculate the peak major storm water surface elevation. They must then set the top of the embankment elevation.

The bypass channel accepts 'above design flow' from the inlet zone of the wetlands via the bypass weir and conveys these flows downstream around the macrophyte zone of the wetlands. The bypass channel should be designed using standard methods (i.e. Manning's Equation) to convey the 'above design flow' and to avoid bed and bank erosion.

Step 7: Specify Vegetation.

Refer to Annex 1 for advice on selecting suitable plant species for wetlands.

Step 8: Design Calculation Summary.

Prepare a design calculation summary sheet and checklist for the key design elements.

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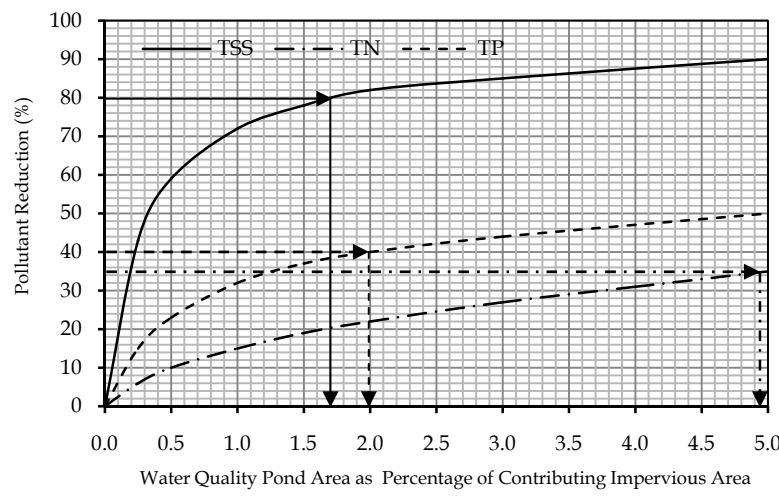
APPENDIX 11.A EXAMPLE - WATER QUALITY POND

Problem:

A water quality pond is proposed for the new development of 2.5 hectare college in Nibong Tebal, Pulau Pinang based on the following assumptions:

- average runoff coefficient, C_{ave} was estimated to be 0.45 based on the imperviousness of the mixed development area
- fraction of impervious area, f_{imp} is estimated to be 0.65

Solution:

Reference	Calculation	Output
Relevant Layout Plan	<u>Development Project Area</u>	
	Catchment area, A	= 2.5ha
Section 11.3.3.4 (a)	<u>Confirm treatment performance of design concept</u>	
Table 1.4	Reduction of total suspended solids, TSS	= 80%
	Reduction of total nitrogen, TN	= 35%
	Reduction of total phosphorus, TP	= 40%
Figure 3.1(b)	<u>Determine required water quality pond area ratio for the targeted pollutant removal efficiencies</u>	
	 <p>The graph plots Pollutant Reduction (%) on the y-axis (0 to 100) against Water Quality Pond Area as Percentage of Contributing Impervious Area on the x-axis (0.0 to 5.0). Three curves are shown: TSS (solid line), TN (dashed line), and TP (dash-dot line). Arrows indicate that 80% TSS removal requires a 1.70% area ratio, 35% TN removal requires a 4.95% area ratio, and 40% TP removal requires a 2.00% area ratio.</p>	
	TSS: 80% removal corresponds to an area ratio of 1.70%.	
	TN: 35% removal corresponds to an area ratio of 4.95%.	
	TP: 40% removal corresponds to an area ratio of 2.00%.	
	The largest ratio must be selected therefore adopt an area ratio	= 4.95%
	<u>Calculate required water quality pond size knowing the catchment area</u>	
	The catchment area	= 2.50ha
	Contributing impervious area = $f_{imp} \times A = 0.65 \times 2.5$	= 1.625ha

Reference	Calculation	Output
<p>Equation 11.1</p> <p>Section 2.3.1.1 11.2.3.2</p>	<p>where: f_{imp} = Fraction of impervious area A = Catchment area</p> <p>The required water quality pond area = $1.625 \times \left(\frac{4.95}{100}\right)$</p> <p><u>Determine WQV</u></p> <p>Required storage for WQV = $C_{ave} (P_d) A$ $= 0.45 \times 0.040 \times 25000$</p> <p>where: WQV = Water quality volume (m³); C_{ave} = Average rational runoff coefficient; P_d = Rainfall depth for water quality design storm (= 40 mm); A = Contributing drainage area (m²).</p> <p><u>Designing Water Quality Pond</u></p>	<p>= 0.080438ha = 804.38m²</p> <p>= 450m³</p>
<p>Section 11.2.3.1</p>	<p><u>Designing Water Quality Pond</u></p> <p>Width, W</p> <p>Length, L</p> <p>Surface area</p> <p>Length to width ratio</p> <p>Extended Detention Depth: Depth (Above the permanent pool water level)</p> <p>Side slope</p> <p>Water quality pond volume = $0.5 \times (20+22.4) \times 0.5 \times (60+62.4) \times 0.4$</p>	<p>= 20m</p> <p>= 60m</p> <p>= 1200m² (>804.38m²)</p> <p>3:1</p> <p>= 0.4m</p> <p>= 1:3</p> <p>= 518.98m³ (>450m³)</p>
<p>Section 11.2.1.4(b)</p>	<p><u>Option 1: Wet Type Water Quality Pond</u></p> <p>Drawdown time</p>	<p>= 12-Hour</p>
<p>Equation 11.2</p>	<p>$Q_{ave} = \frac{\text{Required Storage for WQV (m}^3\text{)}}{\text{Drawdown Time (s)}} = \frac{450}{12 \times 60 \times 60}$</p>	<p>= 0.0104m³/s</p>
<p>Equation 2.6</p>	<p><u>Outlet works</u></p> <p>Outlet sized to discharge the WQV</p> <p>$Q = C_o A_o \sqrt{2gH_o}$</p> <p>where, Q = The orifice flow rate (m³/s); C_o = Orifice discharge coefficient (= 0.60);</p>	<p>= orifice</p>

Reference	Calculation	Output
Section 11.2.1.4(a) Equation 11.2	$A_o = \text{Area of orifice (m}^2\text{), } \pi D_o^2/4;$ $D_o = \text{Orifice diameter (m);}$ $H_o = \text{Effective head on the orifice measured from the centre of the opening (m); and}$ $g = \text{Acceleration due to gravity (9.81m/s}^2\text{)}$	
	Say, Orifice diameter, D_o	= 0.09m = 90mm
	Effective head on the orifice measured from the centre of the opening, H_o	= 0.355m
	$Q = C_o A_o \sqrt{2gH_o} = 0.60 \times \frac{\pi(0.09)^2}{4} \sqrt{2g(0.355)}$	= 0.010m ³ /s (<0.0104m ³ /s)
	Option 2: Dry Type Water Quality Pond	
	Drawdown time	= 24-Hour
	Equation 11.2 $Q_{ave} = \frac{\text{Required Storage for WQV (m}^3\text{)}}{\text{Drawdown Time (s)}} = \frac{450}{24 \times 60 \times 60}$	= 0.00521m ³ /s
	<u>Outlet works</u>	
	Say, Orifice diameter, D_o	= 0.06m = 60mm
	Effective head on the orifice measured from the centre of the opening, H_o	= 0.37m
$Q = C_o A_o \sqrt{2gH_o} = 0.60 \times \frac{\pi(0.06)^2}{4} \sqrt{2g(0.37)}$	= 0.00457m ³ /s (<0.00521 m ³ /s)	
Section 7.4.3	<u>Trash Racks</u>	
	Provide trash racks of sufficient size that do not interfere with the hydraulic capacity of the outlet. Refer Chapter 7 for minimum trash rack sizes.	
	<u>Design for Safety</u>	
	Embankment height	= 0.6m
	Side Slope	= 1 : 4
	An emergency spillway is to be included in the water quality pond design to safely pass the flow larger than water quality design storm. The spillway prevents pond water levels from overtopping the embankment and causing structural damage.	

APPENDIX 11.B EXAMPLE - WETLANDS

Problem:

A constructed wetlands is proposed with the Bio-Ecological Drainage System (BIOECODS) for the new development of engineering campus, Universiti Sains Malaysia in Nibong Tebal, Pulau Pinang. The campus area is 320 acre. However, the total contributing drainage area is 250 acre.

Reference	Calculation	Output
Relevant Layout Plan	<u>Development Project Area</u>	
	Total contributing drainage area, A	= 250 acre = 1,011,714.11m ²
	<u>Confirm treatment performance of design concept</u>	
11.3.3.4 (a)	Reduction of total suspended solids, TSS	= 80%
Table 1.4	Reduction of total nitrogen, TN	= 40%
	Reduction of total phosphorus, TP	= 50%
Figure 3.1(e)	<u>Determine required wetland area ratio for the targeted pollutant removal efficiencies</u>	
	<p>The graph plots Pollutant Reduction (%) on the y-axis (0 to 90) against Wetland Area as Percentage of Contributing Impervious Area on the x-axis (0.0 to 5.0). Three curves are shown: TSS (solid line), TN (dashed line), and TP (dash-dot line). Arrows indicate that 80% TSS removal requires a 4.00% area ratio, 40% TN removal requires a 3.00% area ratio, and 50% TP removal requires a 2.75% area ratio.</p>	
	TSS: 80% removal corresponds to an area ratio of 4.00%	
	TN: 40% removal corresponds to an area ratio of 3.00%	
	TP: 50% removal corresponds to an area ratio of 2.75%	
	The largest ratio must be selected therefore adopt an area ratio	= 4.00%
	<u>Calculate required wetland size knowing the catchment area</u>	
	Total contributing drainage catchment area, A	= 1,011,714.11m ²
	Contributing impervious area = $f_{imp} \times A = 0.30 \times 1,011,714.11$	= 303,514.23m ²
	Where, f_{imp} = Fraction of impervious area A = Catchment area	

Reference	Calculation				Output																
	<table border="1"> <thead> <tr> <th>Catchment Characteristic</th> <th>Area (m²)</th> <th>Area (%)</th> <th>f_{imp}</th> </tr> </thead> <tbody> <tr> <td>Buildings/Lots, Road/Footpath</td> <td>202,342.82</td> <td>20.00</td> <td>0.70</td> </tr> <tr> <td>Green Area</td> <td>809,371.29</td> <td>80.00</td> <td>0.20</td> </tr> <tr> <td>Total</td> <td>1,011,714.11</td> <td>100.00</td> <td>-</td> </tr> </tbody> </table>				Catchment Characteristic	Area (m ²)	Area (%)	f_{imp}	Buildings/Lots, Road/Footpath	202,342.82	20.00	0.70	Green Area	809,371.29	80.00	0.20	Total	1,011,714.11	100.00	-	
Catchment Characteristic	Area (m ²)	Area (%)	f_{imp}																		
Buildings/Lots, Road/Footpath	202,342.82	20.00	0.70																		
Green Area	809,371.29	80.00	0.20																		
Total	1,011,714.11	100.00	-																		
	The required wetland area = $303514.23 \times \left(\frac{4.00}{100}\right)$				= 12,140.57m ²																
Section 11.3.3.2	Allocation of Surface Area																				
	Inlet zone - Not available since design as off-line wetland. Detention pond can design as sediment forebay to reduce incoming sediment stormwater flow before runoff enter wetland.																				
	Macrophyte Zone = 80% x 12,140.57m ²				= 9,712.46m ²																
	Open Water Zone (Micropool) = 20% x 12,444.08m ²				= 2,428.11m ²																
	<u>Determine Design Flows</u>																				
	Design inflow rate (water quality storm), Q_{peak} (Routing result from detention pond)				= 0.275m ³ /s																
	<u>Determine WQV</u>																				
Equation 11.1	Required storage for $WQV = C_{ave} (P_d) A$ $= 0.35 \times 0.040 \times 1,011,714.11$				= 14,164.00m ³																
Section 2.3.1.1 11.2.3.2	where: WQV = Water quality volume (m ³); C_{ave} = Average rational runoff coefficient; P_d = Rainfall depth for water quality design storm (= 40mm); A = Contributing drainage area (m ²).																				
	<u>Designing wetland and bathymetry</u>																				
	Length to Width Ratio:																				
	Width, W				= 50m																
	Length, L				= 250m																
	Surface area				= 12,500m ² (>12,140.57m ²)																
11.3.3.3	Length to width ratio				= 5:1																
	Extended Detention Depth:																				
	Depth (Above the permanent pool water level)				= 1.2m																
	Side slope				= 1:3																
	Wetland volume = $0.5 \times (50+57.20) \times 0.5 \times (250+257.20) \times 1.2$				= 16,311.55m ³ (>14,164.00m ³)																

Reference	Calculation	Output																												
Annex 1 Table 11.2	<u>Designing macrophyte zone</u>																													
	Length to width ratio and hydraulic efficiency:																													
	Width, W	= 50m																												
	Length, L	= 200m																												
	Surface area	= 10,000m ² (>9,712.46m ²)																												
	Length to width ratio	= 4:1																												
	Designing the macrophyte zone bathymetry:	= 10,000m ²																												
	(i) Area:																													
	Deep marsh	= 900m ² (9.0%)																												
	Low marsh	= 6,700m ² (67.0%)																												
	High marsh	= 2,400m ² (24.0%)																												
	(ii) Depth:																													
	Deep marsh	= 1.0m																												
	Low marsh	= 0.6m																												
	High marsh	= 0.3m																												
	Macrophyte zone edge design for safety requirements:																													
	Embankment height	= 0.6m																												
	Side slope	= 1 : 3																												
	Macrophyte zone soil testing:																													
	Provide compacted clay liner (pea gravel and soil mixture) as specified by engineer																													
	Vegetation specifications:																													
		<table border="1"> <thead> <tr> <th>Zone</th> <th>Water Depth (m)</th> <th>Plant Species</th> <th>Planting Density (plant/m²)</th> </tr> </thead> <tbody> <tr> <td>High marsh zone</td> <td>0.3</td> <td>Eleocharis Variegata</td> <td>10</td> </tr> <tr> <td>High marsh zone</td> <td>0.3</td> <td>Eleocharis Dulchis</td> <td>10</td> </tr> <tr> <td>High marsh zone</td> <td>0.3</td> <td>Hanguana Malayana</td> <td>10</td> </tr> <tr> <td>Low marsh zone</td> <td>0.6</td> <td>Lepironia Articulata</td> <td>6</td> </tr> <tr> <td>Low marsh zone</td> <td>0.6</td> <td>Typha Augustifolia</td> <td>6</td> </tr> <tr> <td>Deep mash zone</td> <td>1.0</td> <td>Phragmites Karka</td> <td>4</td> </tr> </tbody> </table>	Zone	Water Depth (m)	Plant Species	Planting Density (plant/m ²)	High marsh zone	0.3	Eleocharis Variegata	10	High marsh zone	0.3	Eleocharis Dulchis	10	High marsh zone	0.3	Hanguana Malayana	10	Low marsh zone	0.6	Lepironia Articulata	6	Low marsh zone	0.6	Typha Augustifolia	6	Deep mash zone	1.0	Phragmites Karka	4
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Reference	Calculation	Output
	<u>Designing open water zone</u>	
	(i) Micro pool area	= 2,500m ² (>2,428.11m ²)
	(ii) Micro pool depth	= 2.0m
	<p>Outlet works</p> <p>After considering design concept and requirements, several factors and constraints of the application Bio-Ecological Drainage System (BIOECODS) in the Enginerring Campus, USM, to allow for tidal effects, one unit of check valve is incorporated into a concrete structure proposed at the recreational pond located downstream of the wetland. The check valve is approximately 0.6 m in diameter.</p>	



Layout

