Policy 11: Land Development Guidelines

Section 13 Water Sensitive Urban Design (WSUD) Guidelines

13.7 Constructed Wetlands


Constructed Wetland in Residential Areas at Gold Coast

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13.7.1 Introduction

Constructed wetland systems are shallow, extensively vegetated water bodies that use enhanced sedimentation, fine filtration and biological uptake processes to remove pollutants from stormwater. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically over two to three days, back to dry weather water levels. In addition to treating stormwater, constructed wetlands can also provide habitat, passive recreation, improved landscape amenity and temporary storage of treated water for reuse schemes.

Wetlands generally consist of an inlet zone (sedimentation basin to remove coarse sediments (refer **Section 13.5 – Sedimentation Basins**)), a macrophyte zone (a shallow heavily vegetated area to remove fine particulates and uptake soluble pollutants) and a high flow bypass channel (to protect the macrophyte zone from sour and vegetation damage). **Figure 13.7-A** shows the key elements of constructed wetland systems.

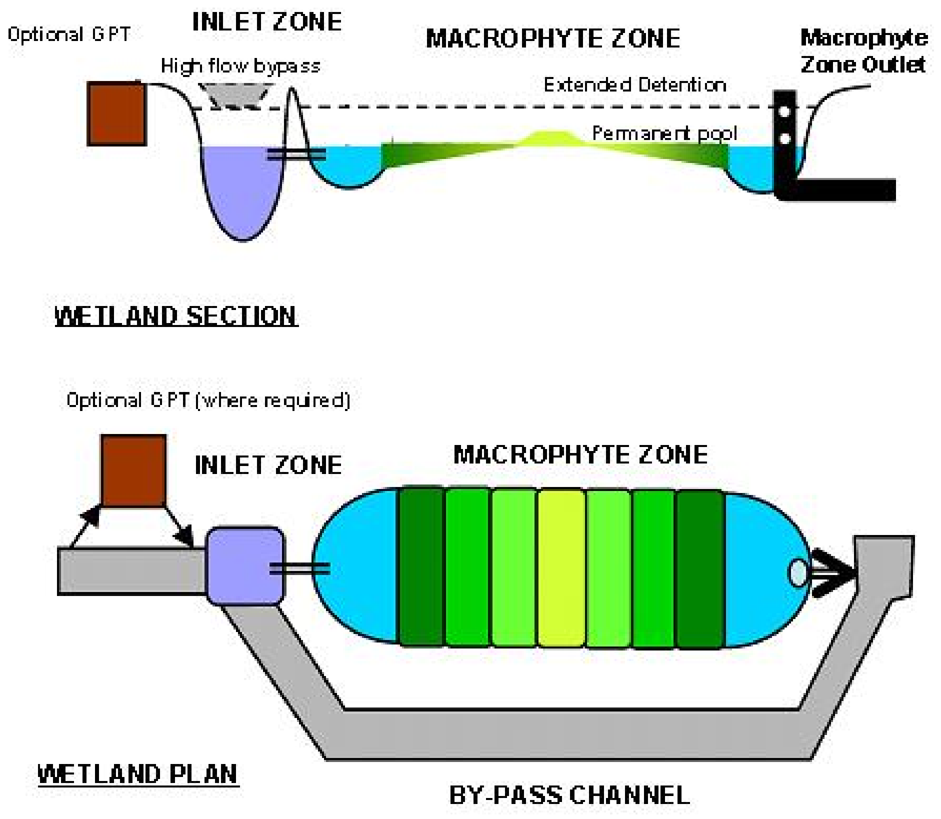


Figure 13.7-A: Schematic Layout of a Constructed Wetland System

13.7.2 Design Considerations

13.7.2.1 Landscape Design

Constructed wetlands are often located within accessible open space areas and can become interesting community features. Landscape design aims to ensure that marsh planting fulfils the intended stormwater treatment function as well as integrating with their surrounds. Opportunities to enhance public amenity and safety with viewing areas, pathway links, picnic nodes and other elements should be exploited. Community education through signage and public art can also be explored. It is important that the landscape of constructed wetlands addresses stormwater quality objectives whilst being sensitive to these other important landscape aims.

Plate 13.7-A: Public viewing area on the edge of a landscaped wetland

13.7.2.2 Detention Time and Hydrologic Effectiveness

Detention time is the time taken for each 'parcel' of water entering the wetland to travel through the macrophyte zone assuming 'plug' flow conditions. In highly constrained sites, simulations using computer models, such as the **Model for Urban Stormwater Improvement Conceptualisation** (**MUSIC**)(**CRCCH 2005**), are often required to optimise the relationship between wetland detention time and wetland hydrologic effectiveness to maximise treatment performance. It should be noted that detention time is rarely a constant and the term notional detention time is used throughout this chapter to provide a point of reference in modelling and determining the design criteria for riser outlet structures. Hydrologic effectiveness is a measure of the mean annual volume of stormwater runoff captured and treated within the wetland and is expressed as a percentage of the mean annual runoff volume generated from the contributing catchment (it should be greater than 80% for well designed wetlands).

The relationship between notional detention time and pollutant removal efficiency is largely influenced by the settling velocity of the target particulates, although defining the settling velocity of fine to colloidal particulates is not a straight forward exercise. Standard equations for settling velocities often do not apply for such fine particulates owing to the influence of external factors such as wind and water turbulence. It is therefore recommended that a notional detention time should preferably be 72 hours (and not less than 48 hours) to remove nutrients effectively from urban stormwater on the Gold Coast.

13.7.2.3 Hydrodynamic Design

Poor wetland hydrodynamics is often identified as a major contributor to wetland operational and management problems. A summary of desired hydrodynamic characteristics and design considerations is presented in **Table 13.7-A**.

Table 13.7-A: Desired Wetland Hydrodynamic Characteristics and Associated Design Considerations

Hydrodynamic Characteristics	Design Considerations	Remarks
Uniform distribution of flow velocity	Wetland shape, inlet and outlet placement and bathymetrical design of wetland to eliminate short-circuit flow paths and poorly mixed zones.	Poor flow pattern within a wetland will lead to zones of stagnant pools which promote litter, oil and scum accumulation as well as potentially supporting mosquito breeding. Short circuit flow paths of high velocities will lead to the wetland being ineffective in water quality improvement.
Inundation depth, wetness gradient, base flow and hydrologic regime	Selection of wetland size and design of outlet control to ensure compatibility with the hydrology and size of the catchment draining into the wetland. Bathymetry layout and outlet control design to compliment the botanical design and the hydrology of the wetland.	Regular flow through the wetland promotes flushing of the system thus maintaining a dynamic system and avoiding problems associated with stagnant water, eg. algal blooms, mosquito breeding, oil and scum accumulation, etc. Inadequate attention to the inundation depth, wetness gradient of the wetland and the frequency of inundation at various depth ranges would lead to sparse vegetation cover and/or dominance of certain plant species (especially weed species over time). This results in a deviation from the intended botanical layout of the wetland and reduced stormwater treatment performance. Recent research findings indicate that regular wetting and drying of the substrata of the wetland can prevent releases of phosphorus from the sediment deposited in the wetland. Therefore, inclusion of ephemeral marsh zones in the bathymetric design is desirable if phosphorus is a targeted pollutant.
Uniform vertical velocity profile	Selection of plant species and location of inlet and outlet structures to promote uniform vertical velocity profile.	Preliminary research findings have indicated that certain plant species have a tendency to promote stratification of flow conditions within a wetland leading to ineffective water pollution control and increasing the potential for algal blooms.
Scour protection	Design of inlet structures and erosion protection of banks.	Owing to the highly dynamic nature of stormwater inflow, measures are to be taken to 'protect' the wetland from erosion during periods of high inflow rates.

13.7.2.4 Inlet Zone Design Considerations

The inlet zone of a constructed stormwater wetland is designed as a sedimentation basin (see **Section 13.5**) and has two key functional roles. The primary role is to remove coarse to medium sized sediment (ie. 125 µm or larger) prior to flows entering the macrophyte zone. 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 second role of the inlet zone is the control and regulation of flows entering the macrophyte zone and bypass of flows during 'above design flow' conditions. The outlet structures from the inlet zone (ie. sedimentation basin) are designed such that flows up to the 'design flow' (typically the 1 year ARI) enter the macrophyte zone whereas 'above design flows' are bypassed around the macrophyte zone. In providing this function, the sedimentation basin protects the vegetation in the macrophyte zone against scour during high flows.

Section 13.5 presents the range of issues that should be considered when designing an inlet zone. Note that when the available space for a constructed wetland is constrained, it is important to ensure that the size of the inlet zone (ie. sedimentation basin) is not reduced. This ensures the larger sediments are effectively trapped and prevented from smothering the macrophyte zone. When the site constrains the size of the constructed wetland it is the macrophyte zone of the wetland that should be reduced accordingly.

Large wetland systems usually require a gross pollutant trap (GPT) as part of the inlet zone to protect the wetland from litter and debris. The decision of whether a GPT is required or not depends on the presence of upstream GPT measures and catchment size. GCCC should be consulted to determine if a GPT is required.

13.7.2.5 Macrophyte Zone Design Considerations

The layout of the macrophyte zone needs to be configured such that system hydraulic efficiency is optimised and healthy vegetation sustained. Design considerations include:

- the range of suitable extended detention depth is 0.25m to 0.5m (providing suitable plant species are selected for deeper extended detention depths), depending on the desired operation of the wetland and target pollutant;
- the bathymetry of the macrophyte zone should be designed to promote a sequence of ephemeral, shallow marsh, marsh and deep marsh zones in addition to small open water zones. The relative proportion of each zone will be dependent on the target pollutant and the wetland hydrologic effectiveness as discussed in **Section 13.7.2.3**;
- the macrophyte zone is required to retain water permanently and therefore the base must be of suitable material to retain water (eg. clay). If *in-situ* soils are unsuitable for water retention, a clay liner (eg. compacted 300 mm thick) must be used to ensure there will be permanent water for vegetation and habitat;
- the bathymetry of the macrophyte zone should be designed so that all marsh zones are connected to a deeper open water zone to allow mosquito predators to seek refuge in the deeper open water zones during periods of extended dry weather;
- particular attention should be given to the placement of the inlet and outlet structures, the length to width ratio of the macrophyte zone and flow control features to promote a high hydraulic efficiency within the macrophyte zone;
- provision to drain the macrophyte zone for water level management during the plant establishment phase should also be considered.

The macrophyte zone outlet structure needs to be designed to provide a notional detention time (usually 48 to 72 hours) for a wide range of flow depths. The outlet structure should also include measures to trap debris to prevent clogging.

13.7.2.6 Wetlands Constructed within Retention (or Detention) Basins

In many urban applications, wetlands can be constructed in the base of retention basins, thus reducing the land required for stormwater treatment. In these situations, wetland systems will occasionally become inundated to greater depths than the extended detention depth; however, the inundation duration is usually relatively short (hours) and is unlikely to affect the wetland vegetation provided there is a safe pathway to drain the wetland following flood events which avoids scour of the wetland vegetation and banks.

When designing a wetland within a retention basin, the outlet control structure of the retention basin (typically culverts) should be placed at the end of the wetland bypass channel. This ensures flood flows 'backwater' across the wetland thus protecting the macrophyte vegetation from scour by high velocity flows.

13.7.2.7 Vegetation Types

Vegetation planted in the macrophyte zone has an important functional role in treating stormwater flows, as well as adding aesthetic value. Dense planting of the littoral zone will inhibit public access to the macrophyte zone, minimising potential damage to wetland plants and reducing the safety risks posed by water bodies.

Plant species for the wetland area will be selected based on the hydrologic regime, microclimate and soil types of the region, and the life histories, physiological and structural characteristics, natural distribution, and community groups of the wetland plants. The reader is referred to the **Section 13.13 – Plant Selection for WSUD System**s for a list of suggested plant species suitable for constructed wetland systems in the Gold Coast area. The planting densities recommended in the list should ensure that 70 – 80% cover is achieved within two growing seasons (2 years). The distribution of the species within the wetland will relate to their structure, function, relationship and compatibility with other species.

13.7.2.8 Designing to Avoid Mosquitoes

To reduce the risk of high numbers of mosquitoes, there are a number of design features that can be considered. Not all of these will be feasible in any one situation, but they include:

- providing access for mosquito predators, such as fish and predatory insects, to all parts of the water body (avoid stagnant isolated areas of water);
- providing a deep sump of permanent water (for long dry periods or for when water levels are artificially lowered) so that mosquito predators can seek refuge and maintain a presence in the wetland;
- maintaining natural water level fluctuations that disturb the breeding cycle of some mosquito species, but be aware that this may suit other mosquito species;
- where possible, incorporating a steep slope into the water, preferably greater than 30° or 3:1 horizontal to vertical. Note that steep edges may be unacceptable for public safety reasons, and a slope of up to 6:1 horizontal to vertical is generally used;
- wave action from wind over open water will discourage mosquito egg laying and disrupt the ability of larvae to breathe;
- providing a bathymetry such that regular wetting and drying is achieved and water draws down evenly so isolated pools are avoided;
- providing sufficient gross pollutant control at the inlet such that human derived litter does not accumulate and provide breeding habitat;
- providing ready access for field operators to monitor and treat mosquito larvae;
- ensuring maintenance procedures do not result in wheel rut and other localised depressions that create isolated pools when water levels fall;
- ensuring overflow channels don't have depressions that will hold water after a storm event;
- water weeds such as Water Hyacinth and Salvinia can provide a breeding medium for some mosquito species whose larvae attach to these plants under water. These weeds should be removed immediately if encountered.

Each case has to be considered on its own merits. It may be possible that a well established constructed wetland will have no significant mosquito breeding associated with it; however, changes in climatic and vegetation conditions could change that situation rapidly. Maintaining awareness for mosquito problems and regular monitoring for mosquito activity should be considered as a component of the management of these sites. Effective and environmentally sound control products are available for control of mosquito larvae in these situations.

13.7.2.9 Designing for Maintenance Access

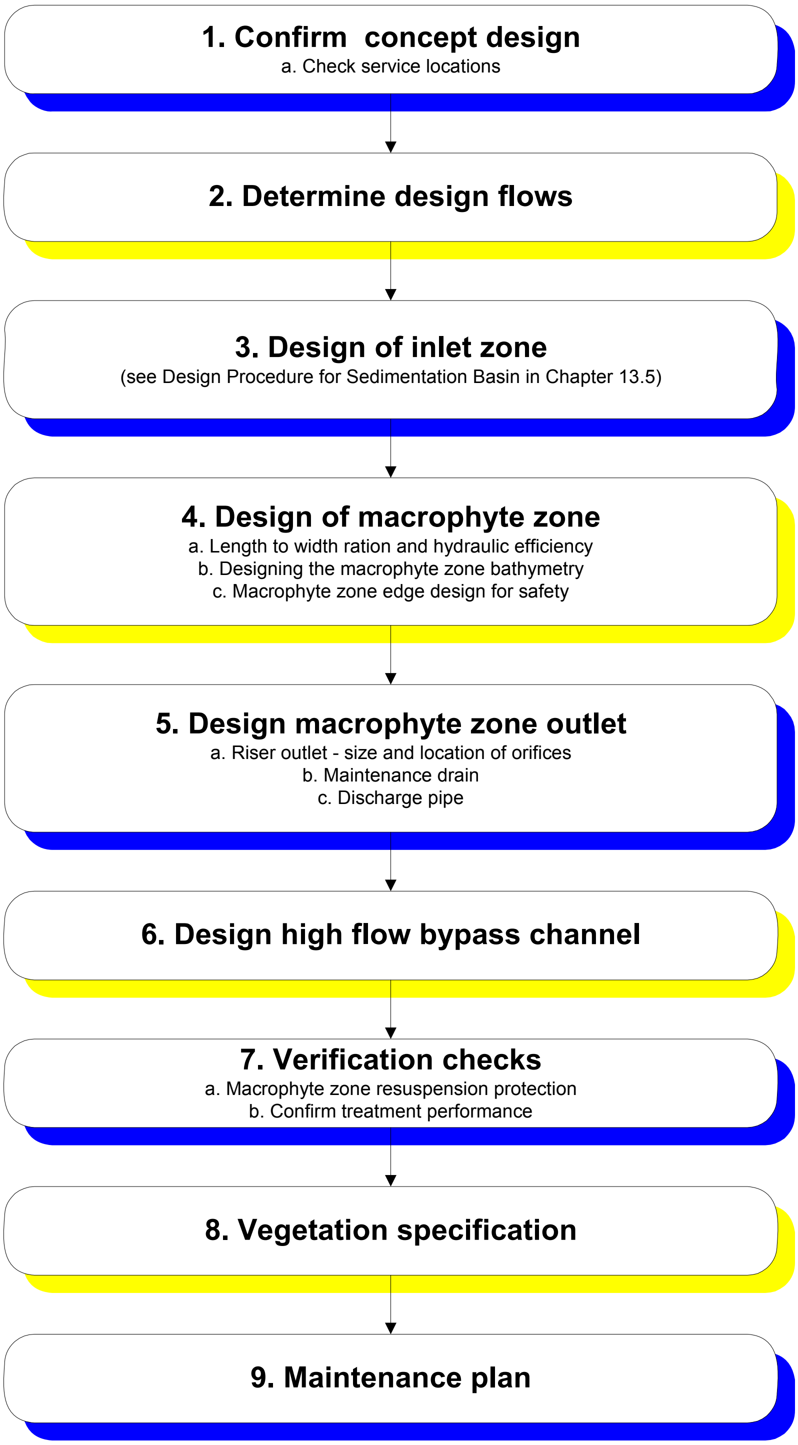
Access to all areas of a constructed wetland is required for maintenance. Inlet zones and gross pollutant traps require a track suitable for heavy machinery for removal of debris and desilting as well as an area for dewatering removed sediments (refer to **Section 13.5**). Macrophyte zones require access to the areas for weeding and replanting as well as regular inspections. Commonly, these access tracks can be incorporated with walking paths around a wetland system. Maintenance access to constructed wetland needs to be considered when determining the layout of a wetland system. A defined hardstand area that provides for 18-28 tonne excavator is to be provided for full access to the inlet and macrophyte zones. It is critical to ensure the outlet for the macrophyte zone is located within easy reach of maintenance access and should not be located too far into the macrophyte zone.

13.7.2.10 Services

Wetlands tend to be located in or adjacent to open space or natural areas. They are usually designed as large scale devices. Where they are located in open space areas, and within urban areas, designers should check the location of existing and proposed services including telecommunications, power, water and sewerage. Conflicts with existing or proposed services are to be avoided and can be addressed by changing the size, configuration and location of the wetland design, or relocating the services.

13.7.3 Wetland Design Process

The key design steps following the site planning and concept development stages are:



Each of these design steps is discussed in the following subsections. A worked example illustrating application of the design process on a case study site is presented in **Section 13.7.8**.

13.7.3.1 Step 1: Confirm Concept Design

Prior to progressing with the detailed design, the designer must review the concept design developed for the site. The concept design must be reviewed to ensure:

- the wetland provides an appropriate level of water quality treatment;
- that a wetland is still appropriate for the site and is appropriately located within a treatment train;
- there are no additional constraints to the location and/or sizing of the wetland.

A **MUSIC** model of the surrounding catchment and 'treatment train' should be developed to provide an initial estimate of the size of wetland required to achieve a given set of WQOs. A full flood routing computation model should also be developed if the wetland is required to achieve a given set of hydraulic retention requirements.

It should be noted that any wetland should form part of the stormwater 'treatment train'. Therefore, other stormwater quality best management practices should be incorporated into the surrounding catchment to augment the stormwater treatment performance of any proposed wetland system.

It should also be noted that if the basic wetland parameters established by the conceptual design phase significantly change during the course of undertaking detailed design (eg. macrophyte zone area, extended detention depth, etc) then the designer should verify that the current design meets the required water quality improvement performance.

a) Check Service Locations

As part of the confirmation of objectives and review of the conceptual design, the designer must check that there are no services (existing or proposed) located in the proposed footprint of the wetland. These include telecommunications, power, gas, water and sewerage.

The designer should liaise with civil designers and GCCC officers to ensure:

- the proposed wetland will no result in water damage to existing services or structures;
- access for maintenance to existing services is maintained;
- no conflicts arise between the location of services and WSUD devices.

Where relevant the detailed design of WSUD measures should show how and where other services are considered.

13.7.3.2 Step 2: Determine Design Flows

a) Design Discharges

To configure the inlet zone and high flow bypass elements of a constructed wetland the following design flows apply:

Design Operation Flow (1 year ARI) for sizing the inlet zone (ie. sedimentation basin) and the 'control' outlet structure (ie. overflow pit and pipe connection) discharging to macrophyte zone.

Above Design Flow for design of the high flow bypass around the macrophyte zone. The discharge capacity for the bypass system may vary depending on the particular situation but will typically correspond to one of the following:

- Minor design flow (2 or 10 year ARI) – for situations where only the minor drainage system is directed to the inlet zone. **Table 3.5B** should be referred to for the required design event for the minor design flow.
- Major flood flow (100 year ARI) – for situations where both the minor and major drainage system discharge into the inlet zone.

b) Design Flow Estimation

A range of hydrologic methods can be applied to estimate design flows. If the typical catchment areas are relatively small, the Rational Method design procedure is considered to be a suitable method for estimating design flows. However, if the constructed wetland is to form part of a retention basin (**Section 13.7.2.6**) or if the catchment area to the wetland is large (> 50 ha), then a full flood routing computation method needs to be used to estimate design flows. Similarly for designs that include structures such as fences and boardwalks, a full hydraulic assessment should be undertaken.

13.7.3.3 Step 3: Design Inlet Zone

As outlined in **Section 13.7.2.4**, the inlet zone of a constructed stormwater wetland is designed as a sedimentation basin (refer **Section 13.5**) and serves two functions: (1) pretreatment of inflow to remove coarse to medium sized sediment; and (2) the hydrologic control of inflows into the macrophyte zone and bypass of floods during 'above design' operating conditions. As depicted in **Figure 13.7-B**, the inlet zone consists of the following elements:

Plate 13.7-B: Inlet zone of a constructed wetland in Brisbane

- sedimentation basin 'pool' to capture coarse to medium sediment (125 µm or larger);
- inlet zone connection to the macrophyte zone (or 'control' structure as defined in **Section 13.5**) normally consisting 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;
- high flow bypass weir (or 'spillway' outlet structure as defined in **Section 13.5**) to deliver 'above design' flood flows to the high flow bypass channel.

For more information and design guidance for each of the inlet zone elements listed above, the reader is referred to **Section 13.5 – Sedimentation Basins**. When applying the design procedure outlined in **Section 13.5**, the following should be used as a guide:

1. The inlet zone typically must comprise a deep open water body (> 1.5 m) that operates essentially as a sedimentation basin designed to capture coarse to medium sized sediment (ie. 125 µm or larger).
2. It may be necessary for a GPT to be installed such that litter and large debris can be captured at the interface between the incoming waterway (or pipe) and the open water of the inlet zone.
3. 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).
4. The dimension of the overflow pit (control structure) should 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).
5. The pipe that connects the sedimentation basin to the macrophyte zone 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.
6. An energy dissipater is usually required at the end of the pipes to reduce velocities and distribute flows into the macrophyte zone.
7. The inlet zone is to have a structural base (eg. rock) to define the base when desilting and provide support for maintenance plant/ machinery when entering the basin for maintenance.
8. 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.

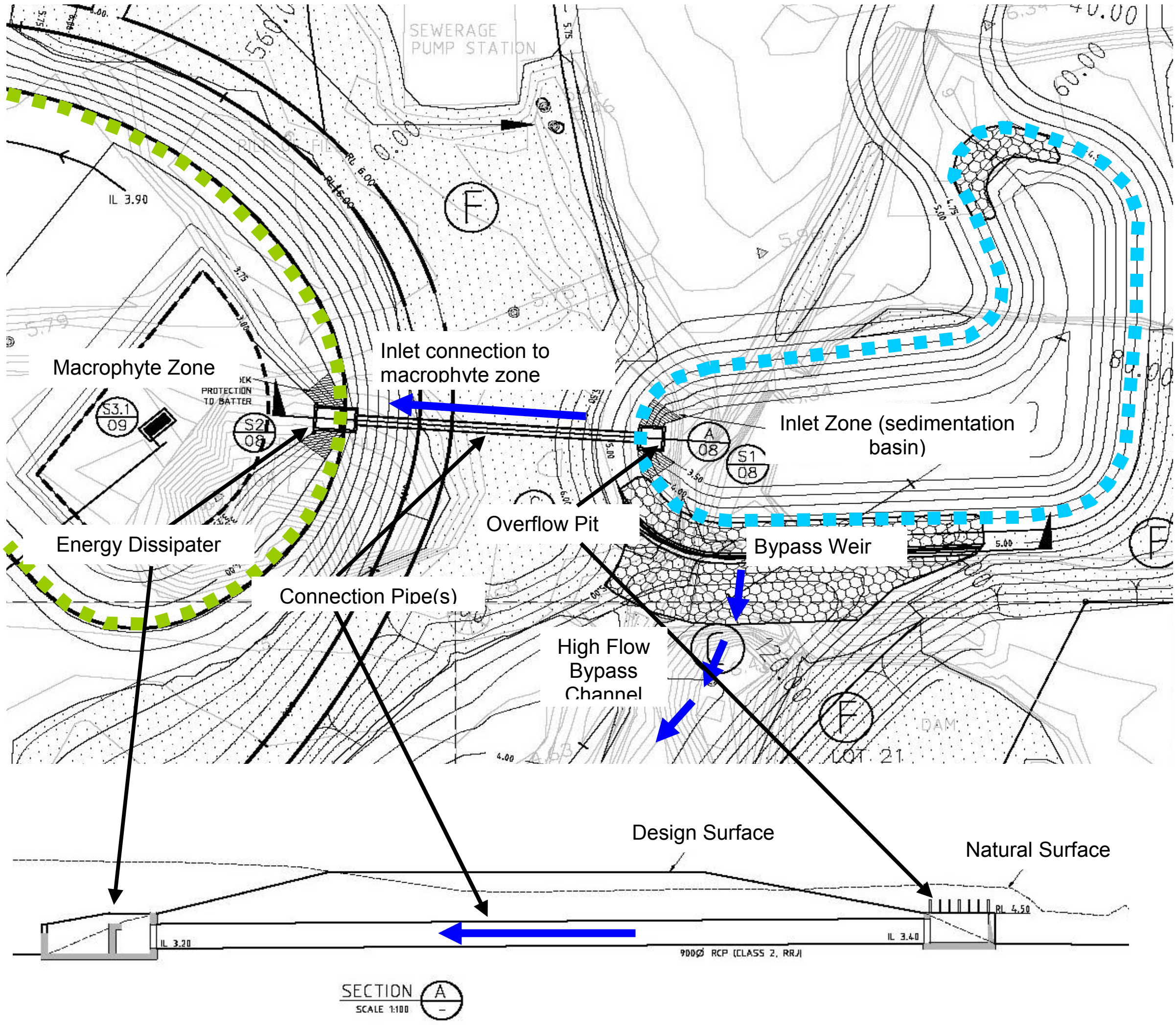


Figure 13.7-B: Example of Inlet Zone Connection to Macrophyte Zone

13.7.3.4 Step 4: Designing the Macrophyte Zone

a) Length to Width Ratio and Hydraulic Efficiency

To optimise wetland performance, it is important to avoid short circuit 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 5 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.

Persson et al. (**1999**) used the term hydraulic efficiency (λ) to define the expected hydrodynamic characteristics for a range of configurations of stormwater detention systems (**Figure 13.7-C**). **Engineers Australia** (**2006**) recommend that constructed wetland systems should not have a hydraulic efficiency (λ) less than 0.5 and preferably should be greater than 0.7.

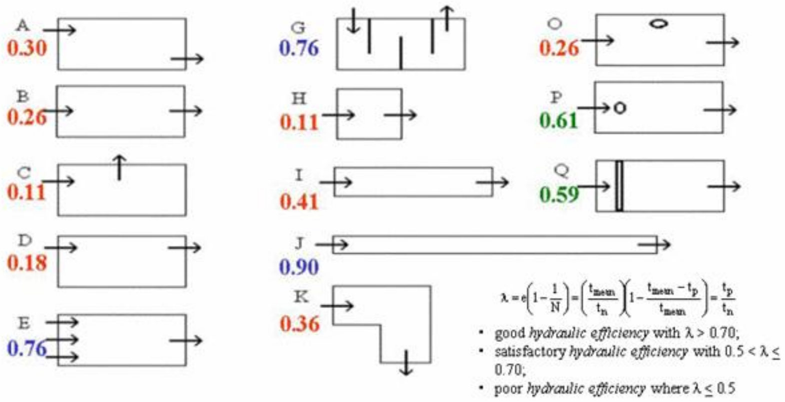


Figure 13.7-C: Hydraulic Efficiency (λ) Ranges

Hydraulic efficiency ranges from 0 to 1, with 1 representing the best hydrodynamic conditions for stormwater treatment. The o in diagrams O and P represent islands in the waterbody and the double line in diagram Q represents a weir structure to distribute flows evenly (**Persson et al. 1999**).

b) 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, ecological niches and 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 four marsh zones are ephemeral marsh, shallow marsh, marsh and deep marsh as depicted in **Figure 13.7-D**. The bathymetry across the four marsh zones is to vary gradually ranging from 0.2m above the permanent pool level (ie. ephemeral marsh) to a maximum of 0.5m below the permanent pool level (ie. deep marsh). **Section 13.13** provides further discussion on the macrophyte plants suited to each marsh zone.

The relative proportion of each marsh zone will be dependent on the specific pollutant(s) being targeted by the wetland. For example, a wetland targeting phosphorus removal would typically have a higher proportion of ephemeral marsh zone where the frequent wetting and drying cycle promotes the 'locking' of phosphorus onto the soil particles within the macrophyte zone substrate. Conversely, if nitrogen is the target pollutant, the macrophyte zone would typically have a higher proportion of marsh and deep marsh. The marsh and deep marsh zones facilitate nitrogen cycling within the aerobic and anaerobic substrate conditions as well as biological processing of soluble nitrogen from the water column by algal epiphytes and biofilms attached to the submerged part of the macrophytes in these zones.

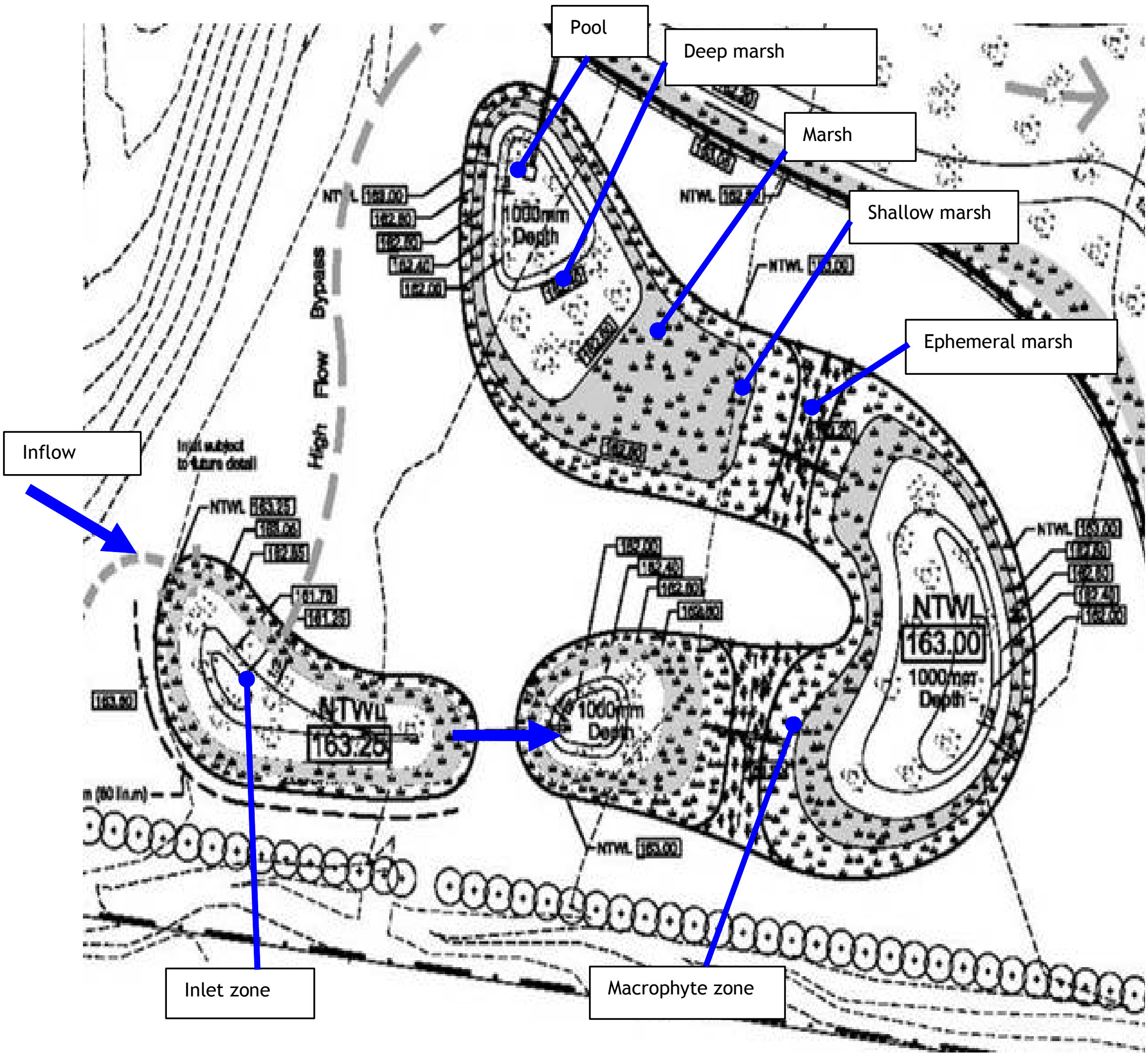


Figure 13.7-D: Example Bathymetry of a Constructed Wetland System (GBLA 2004)

Plate 13.7-C: Macrophyte zone planting and bathymetry

The depth of the open water zones should be not less than 1m below the permanent pool level to avoid colonisation by emergent macrophytes and typically not more than 1.5m depth to allow for colonisation for submerged macrophytes.

To ensure optimal hydraulic efficiency of a wetland for a given shape and aspect ratio, wetland zones are arranged in bands running across (ie. perpendicular) the flow path. The appropriate bathymetry, coupled with uniform plant establishment, ensures the macrophyte zone cross section has uniform hydraulic conveyance, thus reducing the risk of short circuiting.

c) 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 (refer **Figure 13.7-E**). 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.

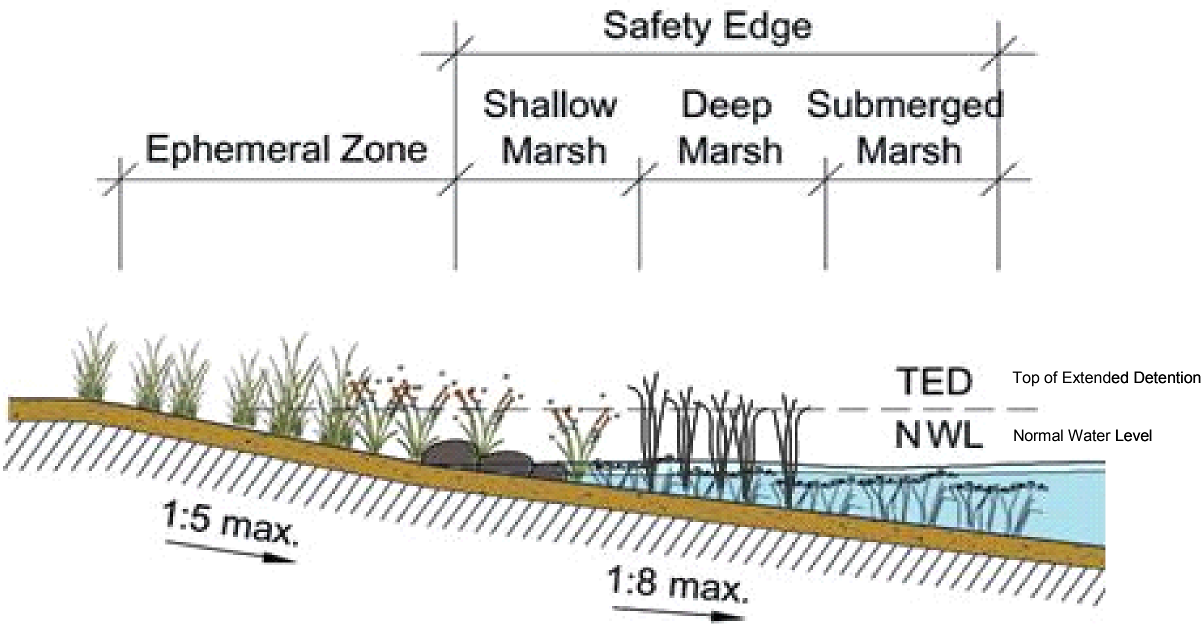


Figure 13.7-E: Example of Edge Design to a Constructed Wetland System

The safety requirements for individual wetlands will vary from site to site and requires careful consideration. The following requirements from **QUDM** (**DPI, IMEA & BCC 1992**) can be applied to constructed wetland systems:

- for maximum batter slope of 6:1 (H:V) or less, no fencing is required, however batters should be 3m wide at a minimum;
- for batter slopes greater than 6:1 (H:V) fencing is required.

Further guidance is also available in **Sediment Basin Design, Construction and Maintenance Guidelines** (**BCC 2001**).

In some cases, vertical edges are used for wetlands (refer to **Section 13.7.4**). When vertical edges are used, a safety fencing/ barrier should be considered on top of concrete or stone walls where:

- there is a risk of serious injury in the event of a fall (over 0.5m high and too steep to comfortably walk up/ down or the lower surface has sharp or jagged edges);
- there is a high pedestrian or vehicular exposure (on footpaths, near bikeways, near playing/ sporting fields, near swings and playgrounds);
- where water ponds to a depth of greater than 300 mm on a constructed surface of concrete or stone;
- where the water is expected to contain concentrated pollutants;
- where mowed grassed areas abut the asset.

The type of fence/ barrier to be considered should be a:

- pool fence when there is a chance of drowning or infection from the asset and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields, etc);
- galvanised tubular handrail without chain wire elsewhere;
- dense vegetation (hedge) at least 2m wide and 1.2m high (minimum) may be suitable if vandalism is not a demonstrated concern.

d) 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 wetland. Where *in-situ* soils are unsuitable for water retention, a compacted clay liner may be required (eg. 300 mm thick). Specialist geotechnical testing and advice must be sought.

13.7.3.5 Step 5: Design Macrophyte Zone Outlet

A macrophyte 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 wetland permanent pool to be drained for maintenance.

The macrophyte zone outlet must be located where it is within easy reach and is accessible for maintenance.

A typical wetland outlet riser is shown in Council's **Standard Drawing N° 05-02-611**.

a) Riser Outlet – Size and Location of Orifices

The riser outlet is designed to provide a uniform notional detention time in the macrophyte zone over the full range of the extended detention depths. The target maximum discharge ($Q_{max\ riser}$) may be computed as the ratio of the volume of the extended detention to the notional detention time as follows:

$$Q_{max\ riser} = \frac{\text{extended detention storage volume } (m^3)}{\text{notional detention time (s)}}$$

Equation 13.7.1

The placement of orifices along the riser and determining their appropriate diameters is an iterative process. The orifice equation (**Equation 6.2**) is applied over discrete depths along the length of the riser starting at the permanent pool level and extending up to the riser maximum extended detention depth. This can be performed with a spreadsheet as illustrated in the worked example in **Section 13.7.8**.

$$A_o = \frac{Q}{C_d\sqrt{2 \cdot g \cdot h}}$$

Where:

C_d	=	orifice discharge coefficient (0.6)
h	=	depth of water above the centroid of the orifice (m)
A_o	=	orifice area (m^2)
Q	=	required flow rate to achieve notional detention time (m^3/s) at the given h
g	=	9.79 m/s^2

Small Orifice Equation – Equation 13.7.2

As the outlet orifices can be expected to be small, it is important that they are prevented from clogging by debris. Some form of debris guard is recommended as illustrated in **Plate 13.7-D** below. An alternative to using a debris guard is to install a riser in a pit located in the embankment surrounding the wetland macrophyte zone (thus reducing any visual impact). A riser within the pit can also be configured with a weir plate (by drilling holes through the plate). An advantage of using a weir plate is that it provides an ability to drain the wetland simply by removing the weir plate entirely. Additionally, shorter weir plates may also be used during the vegetation establishment phase, thus providing more flexibility for water level manipulation.

Plate 13.7-D: Example Outlet Riser Assemblies with Debris Guards

The pit is connected to the permanent pool of the macrophyte zone via a submerged pipe culvert. The connection should be adequately sized such that there is minimal water level difference between the water within the pit and the water level in the macrophyte zone. With the water entering into the outlet pit being drawn from below the permanent pool level (ie. pipe obvert a minimum 0.3m below permanent pool level), floating debris is generally prevented from entering the outlet pit, while heavier debris would normally settle onto the bottom of the wetland. The riser pipe should be mounted upright on a socketed and flanged tee with the top of the pipe left open to allow overtopping of waters if any of the riser orifices become blocked. **Figure 13.7-F** shows one possible configuration for a riser outlet pit.

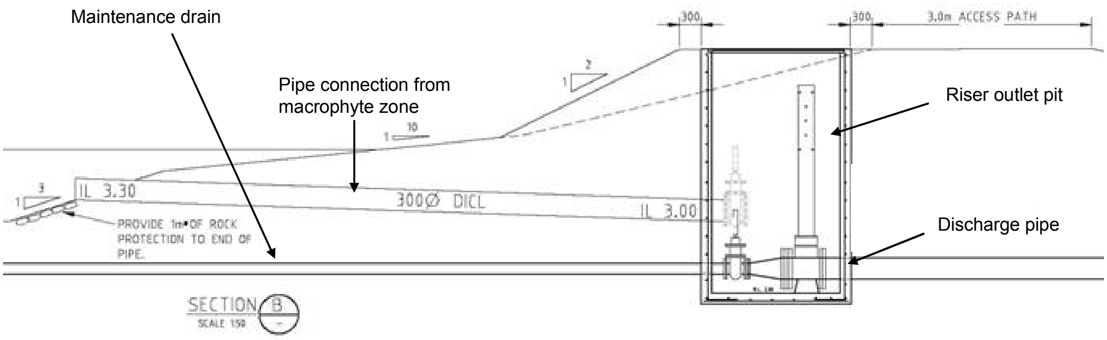


Figure 13.7-F: Typical Macrophyte Zone Outlet Arrangement

b) Maintenance Drains

To allow access for maintenance, the wetland 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 (typically located in the outlet pit as shown in **Figure 13.7-F**), which can be operated manually. The maintenance drainage pipe should be sized to draw down the permanent pool within 12 hours (ie. overnight). If a weir plate is used as a riser outlet, provision should be made to remove the weir plate and allow drainage for maintenance.

Plate 13.7-E: Macrophyte Zone Outlet Arrangement

c) Discharge Pipe

The discharge pipe of the wetland 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 (ie. maximum discharge from the riser or the maximum discharge from the maintenance drain).

13.7.3.6 Step 6: Design High Flow Bypass Channel

The bypass channel accepts 'above design flow' from the inlet zone of the wetland via the bypass weir (**Section 13.7.3.3**) and conveys these flows downstream around the macrophyte zone of the wetland. The bypass channel should be designed using standard methods (ie. Manning's Equation) to convey the 'above design flow' (**Section 13.7.3.2**) and to avoid bed and bank erosion. Typically, a turf finish will provide appropriate protection for most bypass channel applications (but velocities need to be checked). **Plate 13.7-F** shows typical high flow bypass channel configurations.

Plate 13.7-F: Constructed wetland bypass weir and channel configurations

13.7.3.7 Step 7: Verification Checks

a) Macrophyte Zone Resuspension Protection

The principle pathway for biological uptake of soluble nutrients in wetlands is through biofilms (epiphytes) attached to the surface of the macrophyte vegetation. The biofilms, being mostly algae and bacteria, are susceptible to wash out under high flow conditions. Further, wetland surveys indicate that up to 90% of the total nutrients are stored in the sediments, therefore, the key to effective retention of pollutants is managing high velocity flows that could potentially resuspend and remobilise these stored pollutants.

A velocity check is to be conducted for design conditions, when the wetland water level is at the top of the extended detention level and the riser is operating at design capacity, to ensure velocities are less than 0.05 m/s through all zones of the wetland. The following condition must be met:

$$\frac{Q_{max\ riser}}{A_{section}} < 0.05\text{m/s}$$

Where:

$Q_{max\ riser}$ = target maximum discharge (defined in **Equation 13.7.1**) (m^3/s)

$A_{section}$ = wetland cross sectional area at narrowest point*, measured from top of extended detention (m^2)

* Minimum wetland cross-section is used when undertaking this velocity check.

Equation 13.7.3

b) Confirm Treatment Performance

If the basic wetland parameters established by the conceptual design phase have changed during the course of undertaking detailed design (eg. macrophyte zone area, extended detention depth, etc) then the designer should verify that the current design meets the required water quality improvement performance. This can be done by simulating the current design using **MUSIC**.

13.7.3.8 Step 8: Vegetation Specification

Refer to **Section 13.7.4** and **Section 13.13** for advice on selecting suitable plant species for constructed wetlands at Gold Coast.

13.7.3.9 Design Calculation Summary

The following is a design calculation summary sheet for the key design elements.

Constructed Wetlands	Calculation Summary	
Calculation Task	**Outcome**	**Check**
Catchment Characteristics		
Catchment Area	ha	
Catchment Land Use (ie. Residential, Commercial, etc)		
Storm event entering inlet pond (minor or major)		
Conceptual Design		
Macrophyte zone area	m^2	
Permanent pool level of macrophyte zone	m AHD	
Extended detention depth (0.25-0.5m)	m	
Notional detention time	hrs	
1 Confirm Concept Design		
MUSIC modelling performed?		
GCCC WQO's satisfied?		
2 Determine Design Flows		
'Design Operation Flow' – 1 year ARI	year ARI	
'Above Design Flow' – either 2, 10 or 100 year ARI	year ARI	
Time of Concentration		
Refer to **Section 3.5** and **QUDM**	minutes	
Identify Rainfall Intensities		
'Design Operation Flow' – $I_{1\ year\ ARI}$	mm/hr	
'Above Design Flow' – $I_{2\ year\ ARI}$ or I_{10} or $I_{100\ year\ ARI}$	mm/hr	
Peak Design Flows		
'Design Operation Flow' – 1 year ARI	m^3/s	
'Above Design Flow' – 2, 10 or 100 year ARI	m^3/s	
3 Design Inlet Zone		
Refer to **Section 13.5 – Sedimentation Basin** for detailed check sheet		
Is a GPT required?		
Suitable GPT selected and maintenance considered?		
Inlet Zone Size		
Target sediment size for inlet zone	µm	
Capture efficiency	%	
Inlet zone area (**Figure 4.2** in **Section 13.5**)	m^2	
$V_s > V_{s:5yr}$		
Inlet Zone Connection to Macrophyte Zone		
Overflow pit crest level	m AHD	
Overflow pit dimension	L x W	
Provision of debris trap		
Connection pipe dimension	mm diam	
Connection pipe invert level	m AHD	
High Flow Bypass Weir		
Weir length	m	
High flow bypass weir crest level (top of extended detention)	m AHD	

Constructed Wetlands		Calculation Summary	
Calculation Task		Outcome	Check
4	**Designing the Macrophyte Zone**		
	Area of macrophyte zone	m^2	
	Aspect ratio	L:W	
	Hydraulic efficiency		
5	**Design Macrophyte Zone Outlet**		
	Riser Outlet		
	Target maximum discharge (Q_{max})	m^3/s	
	Uniform detention time relationship for Riser		
	Maintenance Drain		
	Maintenance drainage rate (drain over 12hrs)	m^3/s	
	Diameter of maintenance drain pipe	mm	
	Diameter of maintenance drain valve	mm	
	Discharge Pipe		
	Diameter of discharge pipe	mm	
6	**Design High Flow Bypass 'Channel'**		
	Longitudinal slope	%	
	Base width	m	
	Batter slopes	H:V	
7	**Verification Checks**		
	Macrophyte zone re-suspension protection		
	Confirm treatment performance		

13.7.4 Landscape Design Notes

13.7.4.1 Introduction

Constructed wetlands play a significant role in managing some of the WSUD stormwater quality objectives. The landscape design aims to ensure that wetland design fulfils these stormwater quality objectives whilst creating a community and environmental asset.

13.7.4.2 Objectives

Landscape design of wetlands require the following key objectives to meet WSUD strategies:

1. Integrated planning and design of constructed wetlands within the built and landscape environments ensuring that the overall landscape design for the wetland integrates with its host natural and/or built environment.
2. Ensure that a wetland planting strategy based on wetland design depths/ zones addresses stormwater quality objectives and has the structural characteristics to perform particular treatment processes (eg. well distributed flows, enhance sedimentation, maximise surface area for the adhesion of particles and provide a substratum for algal epiphytes and biofilms).
3. Provide appropriate fringe plantings that promote habitat for fauna.
4. Addressing stormwater quality objectives by incorporating appropriate plant species that suit the depth range of a wetland zone and have the structural characteristics to perform particular treatment processes.
5. Incorporating **Crime Prevention Through Environmental Design** (**CPTED**) principles (refer **Section 13.7.4.7**).
6. Providing other landscape values, such as shade, amenity, character and place making.

Comprehensive site analysis should inform the landscape design as well as road layouts, maintenance access points and civil works. Existing site factors such as roads, buildings, landforms, soils, plants, microclimates, services and views should be considered. Landscape design and treatments must be undertaken in accordance with GCCC **Landscape Works Documentation Manual GCCC 2003)**. Another useful reference is **Water Sensitive Urban Design in the Sydney Region: 'Practice Note 2 – Site Planning'** (**LHCCREMS 2002**) for further guidance.

If sited within accessible open space, constructed wetlands can be significant features within the built environment. Landscape design also has a key role in overcoming the negative perceptions that permanent water bodies, like sedimentation basins, have in some communities. In the past this may have been due to legitimate pest and safety concerns that have arisen from poorly designed and/or managed systems, particularly remnant swamps and lagoons. Creative landscape design can enhance the appeal and sense of tranquillity that wetlands provide.

13.7.4.3 Context and Site Analysis

Constructed wetlands can have some impact on the available open space within new developments and considerable landscape planning needs to ensure that a balanced land use outcome is provided. Opportunities to enhance public amenity and safety with viewing areas, pathway links, picnic nodes, interpretive signage/ art and other elements should be explored to further enhance the social context of constructed wetlands.

Landscape treatments should respond to the local context of the site within Gold Coast City, in particular planting types as they relate to the different vegetation communities in the city.

13.7.4.4 Wetland Siting and Shapes

Constructed wetlands need to be arranged to meet hydrological and stormwater quality requirements, but also to integrate effectively into the surrounding existing landscape. The arrangement of wetland, basin and high flow bypass should be designed early in the concept design phase, to ensure that amenity of open space is enhanced.

The final shape of a wetland should provide landscape opportunities to create alternate useable spaces/ recreation areas. Often different shapes to wetland edges can make pathway connections through and around these recreation areas more convenient and enhances the community perception of constructed wetlands. Pathways and bridges across planted earth bunds can be the best way of getting across or around wetlands. The materials on the bridge and pathways are important to be low maintenance and do not impede hydrological flows. Ease of access to the inlet basin for sediment and trash removal is also important to consider.

The area required for the high flow bypass from a hydrological assessment can be manipulated to provide open turfed spaces that only periodically convey flood waters. The key considerations for detailed design of these areas within residential areas are as follows:

- no major park infrastructure including playgrounds, barbeques and amenity buildings to be located within the Q_{100} or high flow bypass areas. Passive recreation infrastructure including seating and picnic tables are suitable provided they are of robust design;
- areas of large revegetation or garden beds that cut through the high flow bypass zone should use thick matting mulch types that bind well to the surface to minimize loss;
- planting species that respond well after periodic flooding should be used primarily, for example *Lomandra* species.

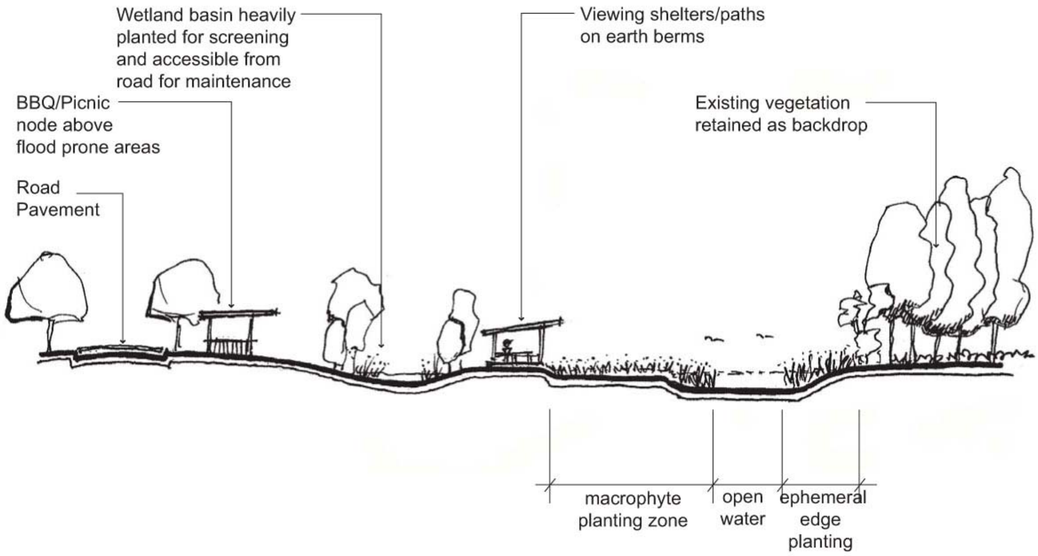


Figure 13.7-G: Typical Landscape Treatments to Constructed Wetlands in Open Space Areas

Plate 13.7-G: Boardwalk treatment over wetland (left) and integration of urban art with wetland setting (right)

13.7.4.5 Specific Landscape Considerations

Numerous opportunities are available for creative design solutions for specific elements. Close collaboration between landscape designer, hydraulic designer, civil/ structural engineer and maintenance personnel is essential. In parklands and residential areas, the aim is to ensure elements are sympathetic to their surroundings and are not overly engineered or industrial in style and appearance. Additionally, landscape design to specific elements should aim to create places that local residents and visitors will come to enjoy and regard as an asset.

a) Crossings

Given the size and location of wetland systems, it is important to consider if access is required across the wetland as part of an overall pathway network and maintenance requirement. Factors that should be considered include:

- the appropriateness of hardwood timber board walks given their life-cycle costs. Where walkway footings are in contact with water, Council will not accept timber piers;
- if boardwalks are used, they should not be located near open water where they could encourage the public to feed wildlife;
- the use of earth bunds as crossings with culverts below. This approach allows some cut material (non-dispersive soils only) to be used on site and can be planted as a shaded walkway. They should be located within the ephemeral marsh zone of constructed wetlands or between the sedimentation basin and first macrophyte zone. Earth bund crossings can be shaped and planted to discourage wildlife feeding. **Figure 13.7-H** illustrates a conceptual earth bund walkway.

Relevant Australian Standards should be referenced for access paths and decks within and around wetlands.

b) Wetland Embankments

The landscape design approach for the wetland embankments is similar to the approach taken for embankments in sedimentation basins. Refer to **Section 13.5** for guidance.

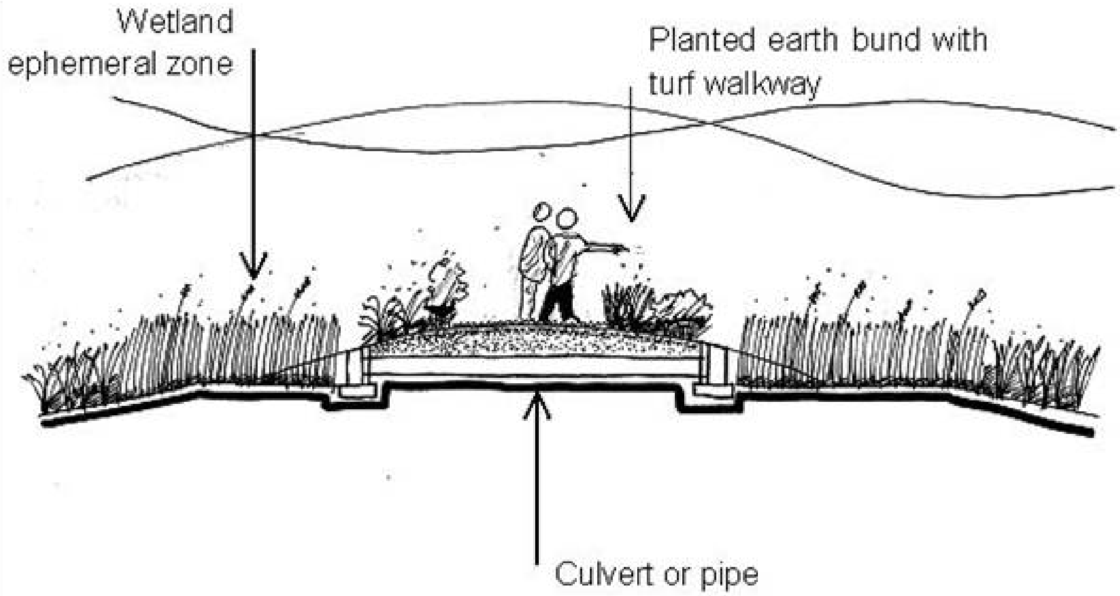


Figure 13.7-H: Earth Bund Structure as Wetland Crossing

c) High Flow Bypass Channel

The high flow bypass channel will convey flood waters during peak storm events. As these elements are generally turfed, it is worthwhile investigating the recreation opportunities offered at times outside of flood events.

Designers should also investigate the opportunities for locating trees and other vegetation types within the bypass channel. Provided hydraulic efficiencies can be accommodated, grassed mounds and landform grading of the embankment edge could also be explored to add variation and interest.

The relationship between the high flow bypass channel and the permanent water bodies should be considered in order to create interesting spaces and forms within the open space. For example, after consideration of site constraints and hydraulic parameters, designers could investigate options to separate the elements from each other or to channel both elements alongside each other. Opportunities should also be sought to achieve balanced cut and fill earthworks. **Figure 13.7-I** provides an illustration of creation of open spaces through configuration of key wetland components.

d) Macrophyte Zone Outlet Structure

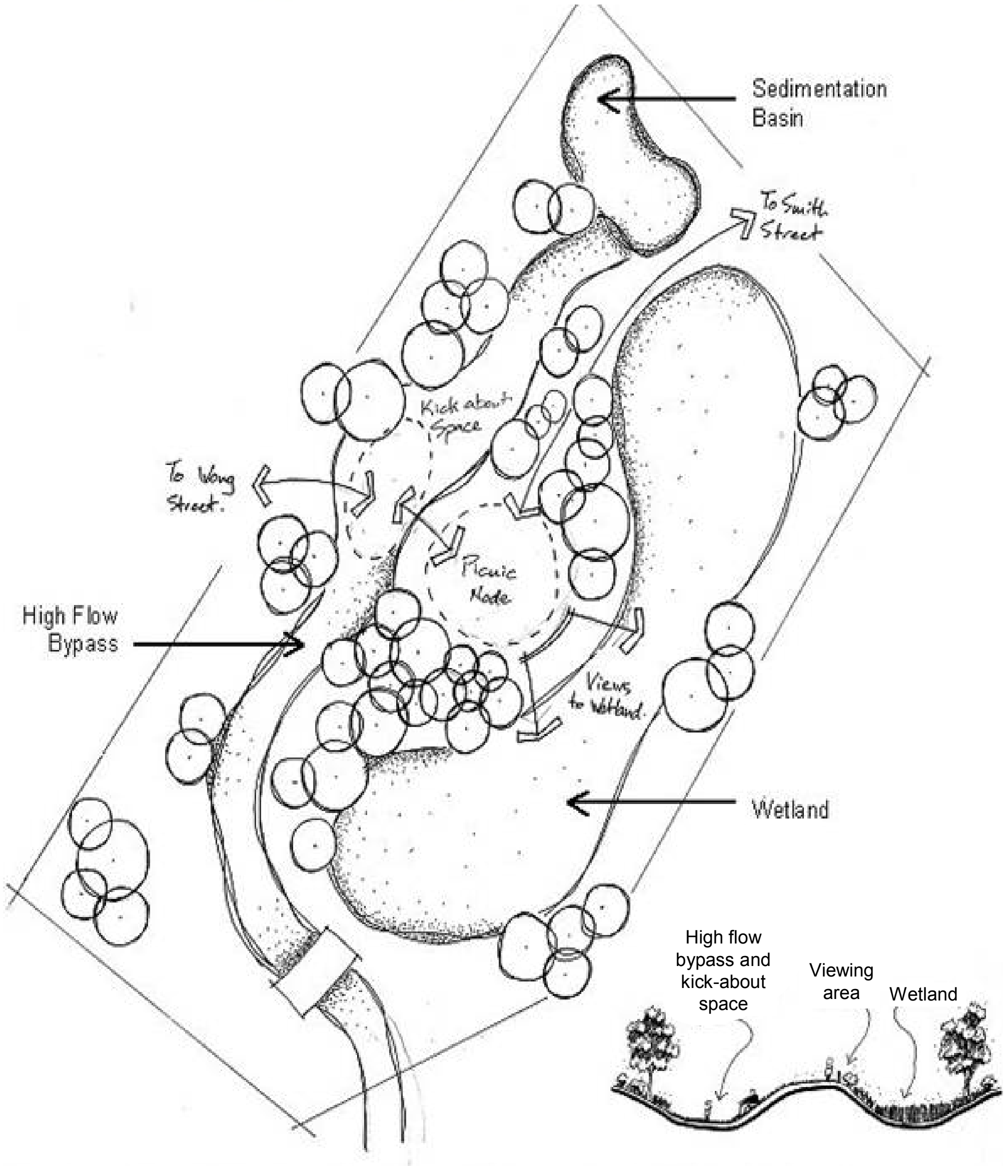
Landscape design approach for the macrophyte outlet zone is similar to the approach taken for overflow pits in sedimentation basins. Refer to **Section 13.5**, **Section 13.5.4.3** for further guidance.

e) Viewing Areas

Refer to **Section 13.5.4** for guidance.

f) Fencing

Refer to **Section 13.5.4** for guidance.



Landscape design should explore options for siting the bypass, wetland and basin and analyse the potential for enhanced amenity. This process should initially take place at the concept development phase and can be refined during the detailed design.

Figure 13.7-I: Example Relationship Between High Flow Bypass, Wetland and Basin and the Creation of Open Space

13.7.4.6 Appropriate Plant Selection

Planting for constructed wetlands systems may consist of up to three vegetation types:

- macrophyte zone planting consisting of ephemeral marsh, shallow marsh, marsh and deep marsh (from 1.0m below to 0.2m above design water level);
- embankment (littoral) vegetation (greater than 0.2m above design water level);
- terrestrial plants, including existing vegetation, adjacent to the embankment edge.

a) Macrophyte Zone Planting (from 1.0m below to 0.2m above Design Water Level)

Section 13.13 provides guidance on selecting suitable plant species and cultivars that deliver the desired stormwater quality objectives for constructed wetlands. Often the most effective way to meet those objectives with the macrophyte planting is to create large bands of single species that respond to designed depth zones and local biodiversity. This reflects natural wetland systems that are often dominated by one single species.

In general, macrophyte vegetation should provide:

- well distributed flows;
- enhanced sedimentation;
- maximum surface area for the adhesion of particles;
- a substratum for algal epiphytes and biofilms;
- habitat and refuge for fauna, both terrestrial and aquatic.

When selecting suitable species it is important to also note the ability of some species to be highly self-sustaining. Macrophytes that distribute themselves across new wetlands quickly by producing large quantities of seed material are great for colonizing and minimizing costs of replacements. Additionally, ephemeral marsh planting should provide a dense buffer between the water body and publicly accessible open space to discourage contact with the water.

b) Embankment (Littoral) Vegetation (greater than 0.2m above Design Water Level) and Parkland Vegetation

Between the macrophyte zone and the top of the embankment trees, shrubs and groundcovers can be selected. Important considerations include:

- selecting groundcovers, particularly for slopes greater than 1 in 3, with matting or rhizomataceous root systems to assist in binding the soil surface during the establishment phase. Example species include *Imperata cylindrica*, *Lomandra sp*. and *Cyndodacton sp*.;
- preventing macrophyte zone plants from being shaded out by minimising tree densities at the water's edge and choosing species such as *Melaleuca* that allow sunlight to penetrate the tree canopy;
- locating vegetation to allow views of the wetland and its surrounds whilst discouraging the public from accessing the water body.

Parkland vegetation may be of a similar species to the embankments littoral vegetation and layout to visually integrate the sedimentation basin with its surrounds. Alternatively, vegetation of contrasting species and/or layout may be selected to highlight the water body as a feature within the landscape. Turf may be considered to achieve this goal.

13.7.4.7 Safety

The design of a wetland must show consideration of all safety aspects below. A competent professional should undertake a risk assessment for a standing/ open water body, assessing the potential hazards associated with a wetland in publicly accessible areas. This assessment should cover the following topics.

a) General

Constructed wetlands need to be generally consistent with public safety requirements for new developments. These include reasonable batter profiles for edges to facilitate public egress from areas with standing water and fencing where water depths and edge profile requires physical barriers to public access. The constructed wetlands can be substituted where possible by using dense edge plantings to deter public access to areas of open water. A dense hedge of around 2 metres high and 1.5 metres wide are effective in deterring public access. Children's playground equipment should not be located close to open water bodies. A minimum setback of 50m is required.

b) Crime Prevention Through Environmental Design (CPTED)

The standard principles of informal surveillance, exclusion of places of concealment and open visible areas apply to the landscape design of wetlands. Where planting may create places of concealment or hinder informal surveillance, groundcovers and shrubs should not generally exceed 1 meter in height. For further guidance on CPTED standards refer to (in the following order):

- GCCC website <www.goldcoast.qld.gov.au> ;
- the GCCC Community Safety Unit (Tel: 5581 6361) for appropriate and current guidelines and standards.

c) Restricting Access to Open Water

Fences or vegetation barriers to restrict access should be incorporated into wetland areas, particularly on top of concrete or stone walls where:

- there is a risk of serious injury in the event of a fall (over 0.5m high and too steep to comfortably walk up/ down or the lower surface or has sharp or jagged edges);
- there is a high pedestrian or vehicular exposure (on footpaths, near bikeways, near playing/ sporting fields, near swings and playgrounds, etc);
- where water ponds to a depth of greater than 300 mm on a constructed surface of concrete or stone. Natural water features are exempt;
- where the water is expected to contain concentrated pollutants;
- where grassed areas requiring mowing abut the asset.

Fences considered appropriate are:

- pool fences (for areas adjacent to playgrounds/ sports fields where a child drowning or infection hazard is present);
- galvanised tubular handrails (without chain wire) in other areas;
- dense vegetative hedges.

Dense littoral planting around the wetland and particularly around the deeper open water pools of the inlet zone (with the exception of any maintenance access points), will deter public access to the open water and create a barrier to improve public safety. Careful selection of plant species (eg. tall, dense or 'spiky' species) and planting layouts can improve safety as well as preventing damage to the vegetation by trampling.

Dense vegetation (hedge) at least 2m wide and 1.2m high (minimum) may be suitable if vandalism is not a demonstrated concern (this may be shown during the initial 12 month maintenance period). A temporary fence (eg. 1.2m high silt fence) will be required until the vegetation has established and becomes a deterrent to pedestrians/ cyclists.

An alternative to the adoption of a barrier/ fence is to provide a 2.4m safety bench that is less than 0.2m deep below the permanent pool level around the waterbody. This is discussed in **Section 13.7.3.4** with respect to appropriate batter slopes.

d) GCCC Grating Guidelines

Inlet and outlet has identified that GPT's represent considerable safety risks if grating of pipeline inlets and/or outlets are not adequately addressed. Refer to GCCC report **Stormwater Inlet/ Outlet Screens ER295/ 249/ 46/ 02**.

13.7.5 Construction and Establishment

This section provides general advice for the construction and establishment of constructed wetlands and key issues to be considered to ensure their successful establishment and operation. Some of the issues raised have been discussed in other sections of this chapter and are reiterated here to emphasise their importance based on observations from construction projects around Australia.

It is important to note that constructed wetlands, like most WSUD elements that employ soil and vegetation based treatment processes, require approximately two growing seasons (ie. two years) before the vegetation in the systems has reached its design condition (ie. height and density). In the context of a large development site and associated construction and building works, delivering constructed wetlands and establishing vegetation can be a challenging task. Therefore, constructed wetlands require a careful construction and establishment approach to ensure the wetland establishes in accordance with its design intent. The following sections outline a recommended staged construction and establishment methodology for constructed wetlands (**Leinster, 2006**).

13.7.5.1 Construction and Establishment Challenges

There exist a number of challenges that must be appropriately considered to ensure successful construction and establishment of wetlands. These challenges are best described in the context of the typical phases in the development of a Greenfield or Infill development, namely the Subdivision Construction Phase and the Building Phase (see **Figure 13.7-J**).

a) Subdivision Construction Phase

Involves the civil works required to create the landforms associated with a development and install the related services (roads, water, sewerage, power, etc) followed by the landscape works to create the softscape, streetscape and parkscape features. The risks to successful construction and establishment of the WSUD systems during this phase of work have generally related to the following:

- construction activities which can generate large sediment loads in runoff which can smother wetland vegetation;
- construction traffic and other works can result in damage to the constructed wetlands.

Importantly, all works undertaken during Subdivision Construction are normally 'controlled' through the principle contractor and site manager. This means the risks described above can be readily managed through appropriate guidance and supervision.

b) Building Phase

Once the Subdivision Construction works are complete and the development plans are sealed then the Building Phase can commence (ie. construction of the houses or built form). This phase of development is effectively 'uncontrolled' due to the number of building contractors and sub-contractors present on any given allotment. For this reason the Allotment Building Phase represents the greatest risk to the successful establishment of constructed wetlands.

13.7.5.2 Staged Construction and Establishment Method

To overcome the challenges associated within delivering constructed wetlands a Staged Construction and Establishment Method should be adopted (see **Figure 13.7-J**):

Stage 1: **Functional Installation**	Construction of the functional elements of the constructed wetland at the end of Subdivision Construction (ie. during landscape works) and the installation of temporary protective measures.
Stage 2: **Sediment and Erosion Control**	During the Building Phase the temporary protective measures preserve the functional infrastructure of the constructed wetland against damage whilst also providing a temporary erosion and sediment control facility throughout the building phase to protect downstream aquatic ecosystems.
Stage 3: **Operational Establishment**	At the completion of the Building Phase, the temporary measures protecting the functional elements of the constructed wetland can be removed along with all accumulated sediment.

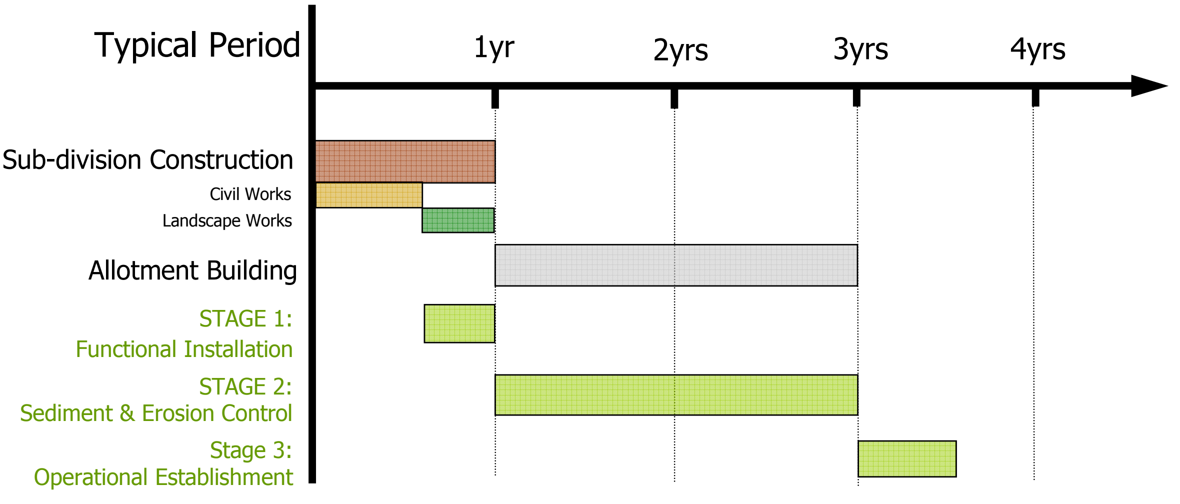


Figure 13.7-J: Staged Construction and Establishment Method

a) Functional Installation

Functional installation of constructed wetlands occurs at the end of Subdivision Construction as part of landscape works and involves:

- earthworks to configure the bathymetry of the wetland;
- installation of the hydraulic control structures including inlet/ outlet control and the high flow bypass weir;
- placement of topsoil, trimming and profiling;
- placement of turf in the High Flow Bypass channel to protect against erosion;
- disconnecting the Inlet Zone from Macrophyte Zone and allowing all stormwater to flow along High Flow Bypass. This effectively isolates the Macrophyte Zone from catchment flows and allows the establishment of wetland plants without the risk of being smothered with coarse sediment during the Subdivision Construction and Allotment Building Phases;
- planting of the Macrophyte Zone once the disconnection is in place. Water level in the Macrophyte Zone can be varied as required by the rate of wetland plant maturity by opening the connection for short periods or opening the outlet control.

Plate 13.7-H: Constructed wetland functional installation

b) Sediment and Erosion Control

During Allotment Building Phases the Inlet Zone will essentially form a sedimentation basin reducing the load of coarse sediment discharging to receiving environment. The disconnection will remain in place to ensure the majority of flows from the catchment continue to bypass the Macrophyte Zone thus allowing the wetland plants to reach full maturity without the risk of being smothered with coarse sediment. This means the Macrophyte Zone can be fully commissioned and made ready for operation once the Allotment Building Phase is complete.

Plate 13.7-I: Constructed wetland sediment and erosion control

c) Operational Establishment

At the completion of the Allotment Building Phase the Inlet Zone is de-silted, the disconnection between the Inlet Zone and Macrophyte Zone is removed and the constructed wetland allowed to operate in accordance with the design.

Plate 13.7-J: Constructed wetland operation establishment

13.7.5.3 Construction Tolerances

It is important to emphasise the significance of tolerances in the construction of constructed wetland systems. Ensuring the relative levels of the control structures (inlet connection to microphyte zone, bypass weir and macrophyte zone outlet) are correct is particularly important to achieve appropriate hydraulic functions. Generally control structure tolerance of plus or minus 5 mm is considered acceptable.

Additionally the bathymetry of the macrophyte zone must be free from localized depressions and low points resulting from earthworks. This is particularly important to achieve a well distributed flow path and to prevent isolated pools from forming (potentially creating mosquito habitat) when the wetland drains. Generally an earthworks tolerance of plus or minus 25 mm is considered acceptable.

13.7.5.4 Sourcing Wetland Vegetation

To ensure the specified plant species are available in the required numbers and of adequate maturity in time for wetland planting, it is essential to notify nurseries early for contract growing. When early ordering is not undertaken, the planting specification may be compromised due to sourcing difficulties, resulting in poor vegetation establishment and increased initial maintenance costs. The species listed in **Table 13.2** (**Section 13.13**) are generally available commercially from local native plant nurseries but availability is dependent upon many factors including demand, season and seed availability. To ensure the planting specification can be accommodated the minimum recommended lead time for ordering is 3-6 months. This generally allows adequate time for plants to be grown to the required size. The following sizes are recommended as the minimum:

Viro Tubes	50 mm wide x 85 mm deep
50 mm Tubes	50 mm wide x 75 mm deep
Native Tubes	50 mm wide x 125 mm deep

A system of interlocking plantings/ containers is recommended for initial wetland planting, particularly for deep marsh and marsh zones. This involves a series of plants (usually 5) grown together in a single ‘strip’ container. Generally, more mature plants with developing rhizomes (for rhizomatous species), are grown together creating interlocking roots. This has been used very successfully in wetland planting previously because the larger more mature plants, often with a thick rhizome system, can survive in deeper water and are more tolerant to fluctuations in water level. The structure of this system slows the movement of water and binds the substrate, helping to reduce erosion. The weight of the interlocking plants also prevents birds from removing them, a common problem encountered during wetland plant establishment. Nurseries require a minimum lead time of 6 months for supply of these systems.

13.7.5.5 Topsoil Specification and Preparation

The provision of suitable topsoil in wetlands is crucial to successful macrophyte establishment and to the long term functional performance of the wetland. Wetland macrophytes typically prefer medium textured silty to sandy loams that allow for easy rhizome and root penetration. Although there are a few plants that can grow in *in-situ* heavy clays (eg. Phragmites), growth is slow and the resulting wetland system will have low species richness, which is undesirable. The wetland must therefore have a layer of topsoil no less than 200 mm deep.

During the wetland construction process, topsoil is to be stripped and stockpiled for possible wetland reuse as a plant growth medium. Most terrestrial topsoils provide a good substratum for wetlands, nonetheless laboratory soil testing (using Australian Standard testing procedures) of the *in-situ* topsoil is necessary to ensure the topsoil will support plant and microbial growth and have a high potential for nutrient retention. Typically, standard horticultural soil analysis, which includes major nutrients and trace elements, is suitable for topsoils intended for wetland use. The laboratory report will indicate the soils suitability as a plant growth medium and if any amendments are required.

If the *in-situ* topsoil is found to contain high levels of salt, extremely low levels of organic carbon (<< 5%), or any other extremes that may be considered a retardant to plant growth, it should be rejected.

If the *in-situ* topsoil is not suitable and soil amendment is considered impractical or not cost effective, sandy loam topsoil should be purchased from a soil supplier. If the local topsoil is suitable but very shallow, mixing with an imported soil will be necessary to reach the required volume to ensure a minimum 200 mm deep topsoil for wetland planting.

Imported topsoils are generally suitable as wetland plant growth medium, however as for *in-situ* soils (above), testing is required to determine the appropriate gypsum or lime dosing rate. If the local topsoil was tested and found to be suitable but then mixed with an imported soil to meet the required volume, laboratory soil testing should be repeated.

Any imported soils must not contain Fire Ants. A visual assessment of the soils is required and any machinery should be free of clumped dirt. Soils must not be brought in from Fire Ant restricted areas.

a) Topsoil Treatments

The wetland topsoil should be tested in accordance with **AS4419-2003: Soils for landscaping and garden use** to ensure it is appropriate for growth of vegetation. If testing finds the topsoil is not appropriate then an alternative source should be found.

Topsoils for wetlands generally do not require fertiliser treatment. Imported foreign loam will contain sufficient nutrients for vegetation growth and local terrestrial topsoil will release nutrients after the wetting process. Submersion of terrestrial soils in water causes a shift from aerobic to anaerobic processes, prompting mineralisation and decomposition of organic matter contained in the soil, thus increasing available nitrogen. When soils become anaerobic, reduction processes cause iron oxides to be released from the surface of soil particles leading to increased availability of phosphorus. The addition of nutrients (fertiliser application) can facilitate the growth of algae (including cyanobacteria (blue-green) algae), particularly when the competing macrophytes and submerged plants are in the early stages of development, increasing the likelihood of algal blooms.

The topsoil within the wetland (macrophyte zones and open water zones) may need to be treated with gypsum or lime. The application of gypsum is standard on most construction sites for the purpose of securing or flocculating dispersive soils if entrained in runoff. The use of gypsum in wetland should only occur within catchments with dispersive soils and applied at a maximum rate of 0.4 kg/ m^2. The application of lime may be required where the **AS4419** (**2003**) soil testing identifies a potential soil pH problem (pH < 5) or where acid sulfate soils (ASS) exist in the vicinity of the wetland. The rate of lime application should be guided by soil test results, an ASS Management Plan and water quality (pH) monitoring of the wetland and inflow.

Gypsum/ lime should be applied about one week prior to vegetation planting. Subsequent application may be required at intervals depending on water quality monitoring. Application of gypsum/ lime too far in advance of planting may lead to aquatic conditions that promote algal growth (ie. clear water with no aquatic plants competing for resources).

13.7.5.6 Vegetation Establishment

a) Timing for Planting

Timing of vegetation planting is dependent on a suitable time of year (and potential irrigation requirements) as well as timing in relation to the phases of development. October and November are considered ideal times to plant vegetation in treatment elements. This allows for adequate establishment/ root growth before the heavy summer rainfall period but also allows the plants to go through a growth period soon after planting, resulting in quicker establishment. Planting late in the year also avoids the dry winter months, reducing maintenance costs associated with watering. Construction planning and phasing should endeavour to correspond with suitable planting months wherever possible. However, as lead times from earthworks to planting can often be long, temporary erosion controls (eg. use of matting or sterile grasses to stabilise exposed batters) should always be used prior to planting.

b) Water Level Manipulation

To maximise the chances of successful vegetation establishment, the water level of the wetland system is to be manipulated in the early stages of vegetation growth. When first planted, vegetation in the deep marsh and pool zones may be too small to be able to exist in their prescribed water depths (depending on the maturity of the plant stock provided). Macrophytes intended for the deep marsh sections will need to have half of their form above the water level, which may not be possible if initially planted at their intended depth. Similarly, if planted too deep, the young submerged plants will not be able to access sufficient light in the open water zones. Without adequate competition from submerged plants, phytoplankton (algae) may proliferate.

The water depth must be controlled in the early establishment phase. This can be achieved by closing off the connection between the inlet zone and the macrophyte zone (ie. covering the overflow pit) and opening the maintenance drain. The deep marsh zones should have a water depth of approximately 0.2m for at least the first 6 – 8 weeks. This will ensure the deep marsh and marsh zones of the wetland are inundated to shallow depth and the shallow marsh zone remains moist (muddy) providing suitable conditions for plant establishment. Seedlings planted in the ephemeral marsh and littoral zones of the wetland will require ongoing watering at a similar rate as the terrestrial landscape surrounding the wetland (**Section 6.4.6.2**). When it is evident that the plants are establishing well and growing actively, a minimum of 6 – 8 weeks following planting, the plants should be of sufficient stature to endure deeper water. At this time, the connection between the inlet pond and the macrophyte zone can be temporarily opened to allow slow filling of the wetland to the design operating water level.

c) Weed Control

Weed management in constructed wetlands is important to ensure that weeds do not out compete the species planted for the particular design requirements. This may also include some native species like Phragmites that naturally can appear in constructed wetlands and out-compete other more important planted species.

Conventional surface mulching of the wetland littoral berms with organic material like tanbark is not recommended. Most organic mulch floats and water level fluctuations and runoff typically causes this material to be washed into the wetland with a risk of causing blockages to outlet structures. Mulch can also increase the wetland organic load, potentially increasing nutrient concentrations and the risk of algal blooms. Adopting high planting density rates and if necessary applying a suitable biodegradable erosion control matting to the wetland batters (where appropriate), will help to combat weed invasion and will reduce maintenance requirements for weed removal. If the use of mulch on the littoral zones is preferred, it must be secured in place with appropriate mesh or netting (eg. jute mesh), or a suitable 'heavy' mulch that forms a heavy interlocking mat must be used. Any non-secured mulch should be located in areas where there is a low risk of being washed away (ie. littoral zones).

d) Watering

Regular watering of the littoral and ephemeral marsh zone vegetation during the plant establishment phase is essential for successful establishment and healthy growth. The frequency of watering to achieve successful plant establishment is dependent upon rainfall, maturity of planting stock and the water level within the wetland. However, the following watering program is generally adequate but should be adjusted (ie. increased) as required to suit site conditions:

Week 1-2	3 visits/ week
Week 3-6	2 visits/ week
Week 7-12	1 visit/ week

After this initial three month period, watering may still be required, particularly during the first winter (dry period). Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

e) Bird Protection

During the early stages of wetland establishment, water birds can be a major nuisance due to their habit of pulling out recently planted species. Interlocking planting systems (ie. where several plants are grown together in a single container such as 'floral edges') can be used, as water birds find it difficult to lift the interlocking plants out of the substrate unlike single plants grown in tubes.

13.7.6 Maintenance Requirements

Wetlands treat runoff by filtering it through vegetation and providing extended detention to allow sedimentation to occur. In addition, they have a flow management role that needs to be maintained to ensure adequate flood protection for local properties and protection of the wetland ecosystem.

Maintaining healthy vegetation and adequate flow conditions in a wetland are the key maintenance considerations. Weeding, planting, mowing and debris removal are the dominant tasks (but should not include use of herbicides as this affects water quality). In addition, the wetland needs to be protected from high loads of sediment and debris and the inlet zone needs to be maintained in the same way as sedimentation basins (see **Section 13.5**). Routine maintenance of wetlands should be carried out once a month.

The most intensive period of maintenance is during plant establishment period (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments could impact on plant growth, particularly in developing catchments with poor building controls. Debris removal is an ongoing maintenance function. If not removed, debris can block inlets or outlets, and can be unsightly if in a visible location. Inspection and removal of debris should be done regularly.

Typical maintenance of constructed wetlands will involve:

- desilting the inlet zone following the construction/ building period;
- routine inspection of the wetland to identify any damage to vegetation, scouring, formation of isolated pools, litter and debris build up or excessive mosquitoes;
- routine inspection of inlet and outlet points to identify any areas of scour, litter build up and blockages;
- removal of litter and debris;
- removal and management of invasive weeds;
- repair to wetland profile to prevent the formation of isolated pools;
- periodic (usually every 5 years) draining and desilting of the inlet pond;
- regular watering of littoral vegetation during plant establishment;
- water level control during plant establishment;
- replacement of plants that have died (from any cause) with plants of equivalent size and species as detailed in the planting schedule;
- vegetation pest monitoring and control.

Inspections are recommended following large storm events to check for scour and damage.

All maintenance activities must be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure. Maintenance personnel and asset managers will use this plan to ensure the wetlands continue to function as designed. To ensure maintenance activities are appropriate for the wetland as it develops, maintenance plans should be updated a minimum of every three years. The maintenance plans and forms must address the following:

- inspection frequency;
- maintenance frequency;
- data collection/ storage requirements (ie. during inspections);
- detailed clean-out procedures (main element of the plans) including:
  - equipment needs;
  - maintenance techniques;
  - occupational health and safety;
  - public safety;
  - environmental management considerations;
  - disposal requirements (of material removed);
  - access issues;
  - stakeholder notification requirements;
  - data collection requirements (if any);
- design details.

An approved maintenance plan is required prior to asset transfer to GCCC. Refer to **Section 9** of these Guidelines for more specific guidance on requirements for asset transfer.

An example operation and maintenance inspection form is included in the checking tools provided in **Section 13.7.7**. These forms must be developed on a site specific basis as the configuration and nature of constructed wetlands varies significantly.

13.7.7 Checking Tools

This section provides a number of checking aids for designers and Council development assessment officers. In addition, **Section 6.6.5** provides general advice for the construction and establishment of wetlands and key issues to be considered to ensure their successful establishment and operation, based on observations from construction projects around Australia. The following checking tools are provided:

- Design Assessment Checklist;
- Construction Inspection Checklist (during and post);
- Operation and Maintenance Inspection Form; and
- Asset Transfer Checklist (following ‘on-maintenance’ period).

Figure 13.7-K below shows the stages of the development approval, construction and establishment, and asset transfer process and which checklists should be used at each stage.

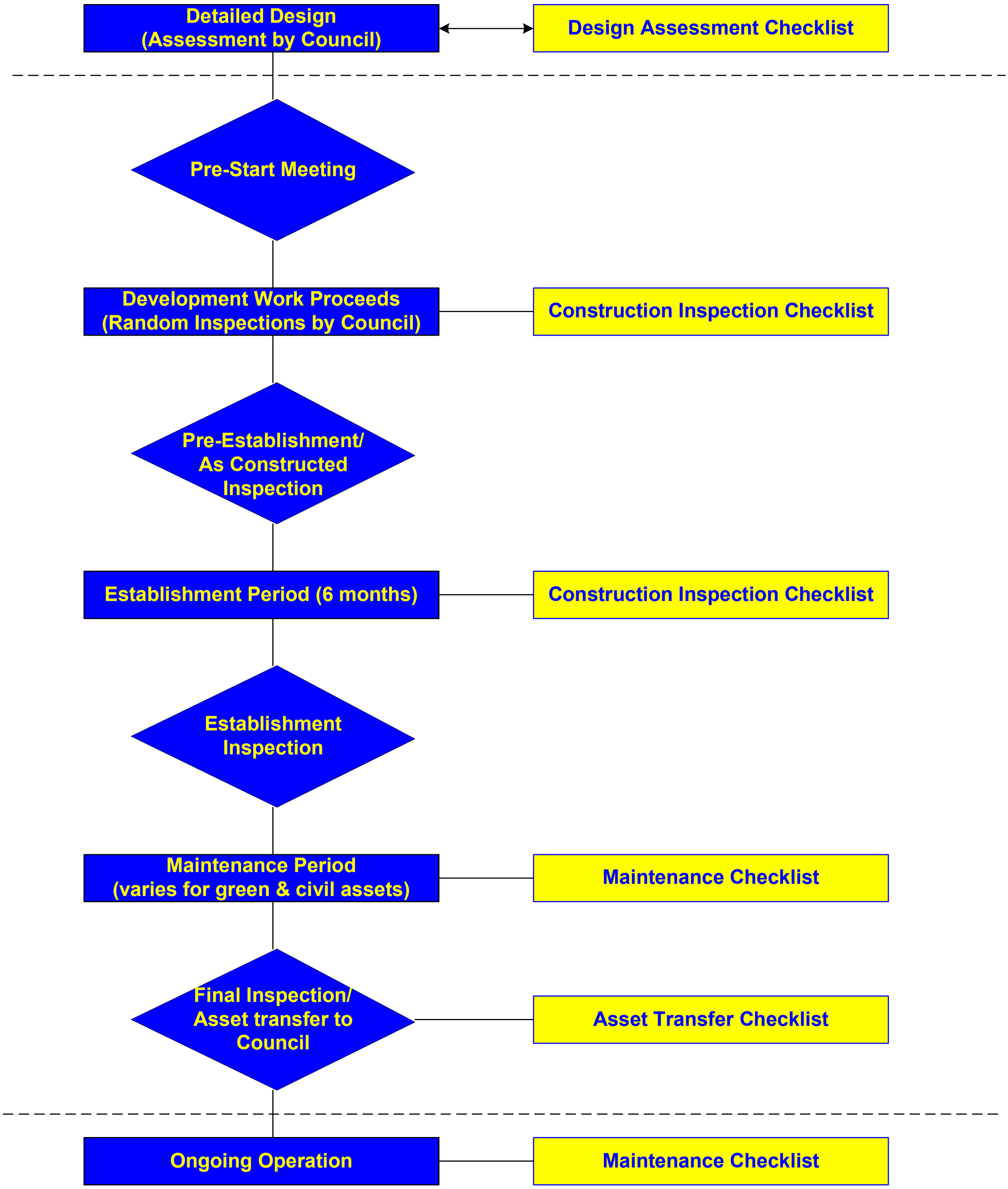


Figure 13.7-K: Development Approval and Handover Stages – Appropriate Checklists

13.7.7.1 Design Assessment Checklist

The design assessment checklist presents the key design features to be reviewed when assessing a design of a wetland. These considerations include configuration, safety, maintenance and operational issues that should be addressed during the design phase. Where an item results in an 'N' when reviewing the design, referral should be made back to the design procedure to determine the impact of the omission or error. In addition to the checklist, a proposed design must have all necessary permits for its installations. Council development assessment officers will require supporting evidence/ proof from the developer that all relevant permits are in place.

13.7.7.2 Construction Checklist

This checklist on presents the key items to be reviewed when inspecting the bioretention basin during and at the completion of construction. The checklist is to be used by Construction Site Supervisors and local authority Compliance Inspectors to ensure all the elements of the bioretention basin have been constructed in accordance with the design. If an item receives an 'N' in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

13.7.7.3 Maintenance Checklist

The example maintenance checklist should be developed and used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 – 6 months depending on the size and complexity of the system. More detailed site specific maintenance schedules should be developed for major constructed wetland systems and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

13.7.7.4 Asset Transfer Checklist

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the asset transfer checklist. The asset transfer checklist provides an indicative asset transfer checklist.

Wetland Design Assessment Checklist			
Asset I.D.			
Wetland Location:			
Hydraulics:	Design Operational Flow (m^3/s):	Above Design Flow (m^3/s):	
Area:	Catchment Area (ha):	Wetland Area (ha):	

Concept Design	**Y**	**N**
MUSIC modelling performed? Refer to **Section 13.7.3.1** for further guidance.		
Service locations assessed and no conflicts?		
Inlet Zone (Refer to Section 13.7.3.2 and 13.7.3.3 for further guidance)	**Y**	**N**
Discharge pipe/ structure to inlet zone sufficient for maximum design flow?		
Scour protection provided at inlet for inflow velocities?		
Configuration of inlet zone (aspect, depth and flows) allows settling of particles >125µm?		
Bypass weir incorporated into inlet zone?		
Bypass weir length sufficient to convey 'above design flow' ?		
Bypass weir crest at macrophyte zone top of extended detention depth?		
Bypass channel has sufficient capacity to convey 'above design flow'?		
Bypass channel has sufficient scour protection for design velocities?		
Inlet zone connection to macrophyte zone overflow pit and connection pipe sized to convey the design operation flow?		
Inlet zone connection to macrophyte zone allows energy dissipation?		
Structure from inlet zone to macrophyte zone enables isolation of the macrophyte zone for maintenance?		
Inlet zone permanent pool level above macrophyte permanent pool level?		
Maintenance access allowed for into base of inlet zone?		
Public safety design considerations included in inlet zone design?		
Where required, gross pollutant protection measures provided on inlet structures (both inflows and to macrophyte zone)		
Macrophyte Zone (Refer to Section 13.7.3.4 for further guidance)	**Y**	**N**
Extended detention depth >0.25m and <0.5m?		
Vegetation bands perpendicular to flow path?		
Appropriate range of macrophyte vegetation (ephemeral, shallow, marsh, deep marsh)?		
Sequencing of vegetation bands provides continuous gradient to open water zones?		
Vegetation appropriate to selected band?		
Aspect ratio provides hydraulic efficiency =>0.5?		
Velocities from inlet zone <0.05 m/s or scouring protection provided?		
Public safety design considerations included in macrophyte zone (ie. batter slopes less than 5(H):1(V)?		
Maintenance access provided into areas of the macrophyte zone (especially open water zones)?		
Safety audit of publicly accessible areas undertaken?		
Freeboard provided above extended detention depth to define embankments?		
Outlet Structures (Refer to Section 13.7.3.5 for further guidance)	**Y**	**N**
Riser outlet provided in macrophyte zone?		
Notional detention time of 48-72 hours?		
Orifice configuration allows for a linear storage-discharge relationship for full range of the extended detention depth?		
Maintenance drain provided?		
Discharge pipe has sufficient capacity to convey maximum of either the maintenance drain flows or riser pipe flows with scour protection?		
Protection against clogging of orifice provided on outlet structure?		
Comments		

Wetland Construction Inspection Checklist

Asset I.D.:		Inspected by:	
Site:		Date:	
		Time:	
Constructed By:		Weather:	
		Contact During Visit:	

Items Inspected	Checked Y	Checked N	Satisfactory Y	Satisfactory N	Items Inspected	Checked Y	Checked N	Satisfactory Y	Satisfactory N
During Construction									
A. Functional Installation									
Preliminary Works					**Structural Components (continued)**				
1. Erosion and sediment control plan adopted					22. Ensure spillway is level				
2. Limit public access					23. Provision of maintenance drain(s)				
3. Location same as plans					24. Collar installed on pipes				
4. Site protection from existing flows					25. Low flow channel is adequate				
5. All required permits in place					26. Protection of riser from debris				
Earthworks					27. Bypass channel stabilised				
6. Integrity of banks					28. Erosion protection at macrophyte outlet				
7. Batter slopes as plans					**Vegetation**				
8. Impermeable (eg. Clay) base installed					29. Vegetation appropriate to zone (depth)				
9. Maintenance access to whole wetland					30. Weed removal prior to planting				
10. Compaction process as designed					31. Provision for water level control				
11. Placement of adequate topsoil					32. Vegetation layout and densities as designed				
12. Levels as designed for base, benches, banks and spillway (including freeboard)					33. Provision for bird protection				
13. Check for groundwater intrusion					34. Bypass channel vegetated				
14. Stabilisation with sterile grass					**B. Erosion and Sediment Control**				
Structural Components					35. Disconnect inlet zone from macrophyte zone (flows via high flow bypass)				
15. Location and levels of outlet as designed					36. Inlet zone to be used as sediment basin during construction				
16. Safety protection provided					37. Stabilisation immediately following earthworks and planting of terrestrial landscape around basin				
17. Pipe joints and connections as designed					38. Silt fences and traffic control in place				
18. Concrete and reinforcement as designed									
19. Inlets appropriately installed					**C. Operational Establishment**				
20. Inlet energy dissipation installed					39. Inlet zone desilted				
21. No seepage through banks					40. Inlet zone disconnection removed				
Final Inspection									
1. Confirm levels of inlets and outlets					8. Public safety adequate				
2. Confirm structural element sizes					9. Check for uneven settling of banks				
3. Check batter slopes					10. Evidence of stagnant water, short circuiting or vegetation scouring				
4. Vegetation planting as designed					11. Evidence of litter or excessive debris				
5. Erosion protection measures working					12. Provision of removed sediment drainage area				
6. Pretreatment installed and operational					13. Evidence of debris in high flow bypass				
7. Maintenance access provided					14. Macrophyte outlet free of debris				

Comments on Inspection

Actions Required

1.
2.
3.
4.

Inspection officer signature:

Wetland Maintenance Checklist			
Asset I.D.:			
Inspection Frequency:	1 to 6 monthly	**Date of Visit:**	
Location:			
Description:			
Site Visit by:			

Inspection Items	**Y**	**N**	**Action Required (Details)**
Sediment accumulation at inflow points?			
Litter within inlet or macrophyte zones?			
Sediment within inlet zone requires removal (record depth, remove if >50%)?			
Overflow structure integrity satisfactory?			
Evidence of dumping (building waste, oils, etc)?			
Terrestrial vegetation condition satisfactory (density, weeds, etc)?			
Aquatic vegetation condition satisfactory (density, weeds, etc)?			
Replanting required?			
Settling or erosion of bunds/ batters present?			
Evidence of isolated shallow ponding?			
Damage/ vandalism to structures present?			
Outlet structure free of debris?			
Maintenance drain operational (check)?			
Resetting of system required?			

Comments

Wetland Asset Transfer Checklist		
Asset I.D.:		
Asset Description:		
Asset Location:		
Construction by:		
'On-Maintenance' Period:		
Treatment	**Y**	**N**
System appears to be working as designed visually?		
No obvious signs of under-performance?		
Maintenance	**Y**	**N**
Maintenance plans and indicative maintenance costs provided for each asset?		
Vegetation establishment period completed (2 years)?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
Asset inspected for defects?		
Asset Information	**Y**	**N**
Design Assessment Checklist provided?		
'As constructed' plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (eg. drawings, survey, models) provided?		
Asset listed on asset register or database?		
Comments		

13.7.8 Constructed Wetland Worked Example

As part of a residential development in Pimpama on the Gold Coast, stormwater runoff is to be delivered to a constructed wetland for water quality treatment. An illustration of the site and proposed layout of the wetland is shown in **Figure 13.7-L**. This worked example describes the design process for each component of the constructed wetland: inlet zone (including the bypass weir), macrophyte zone, macrophyte zone outlet and high flow bypass channel.

Catchment Characteristics

The development is a typical detached housing estate ('Residential A', 15 lots/ hectare) served by 14m wide local road reserves. Due to the moderate to steep (typically greater than 5%) gradient through the contributing catchment (10 ha), stormwater runoff is collected and conveyed to the wetland inlet zone via conventional piped drainage with minor storm (2 year ARI) flows discharged to the wetland inlet zone via a 975 mm diameter pipe and major storm (100 year ARI) entering via overland flow.

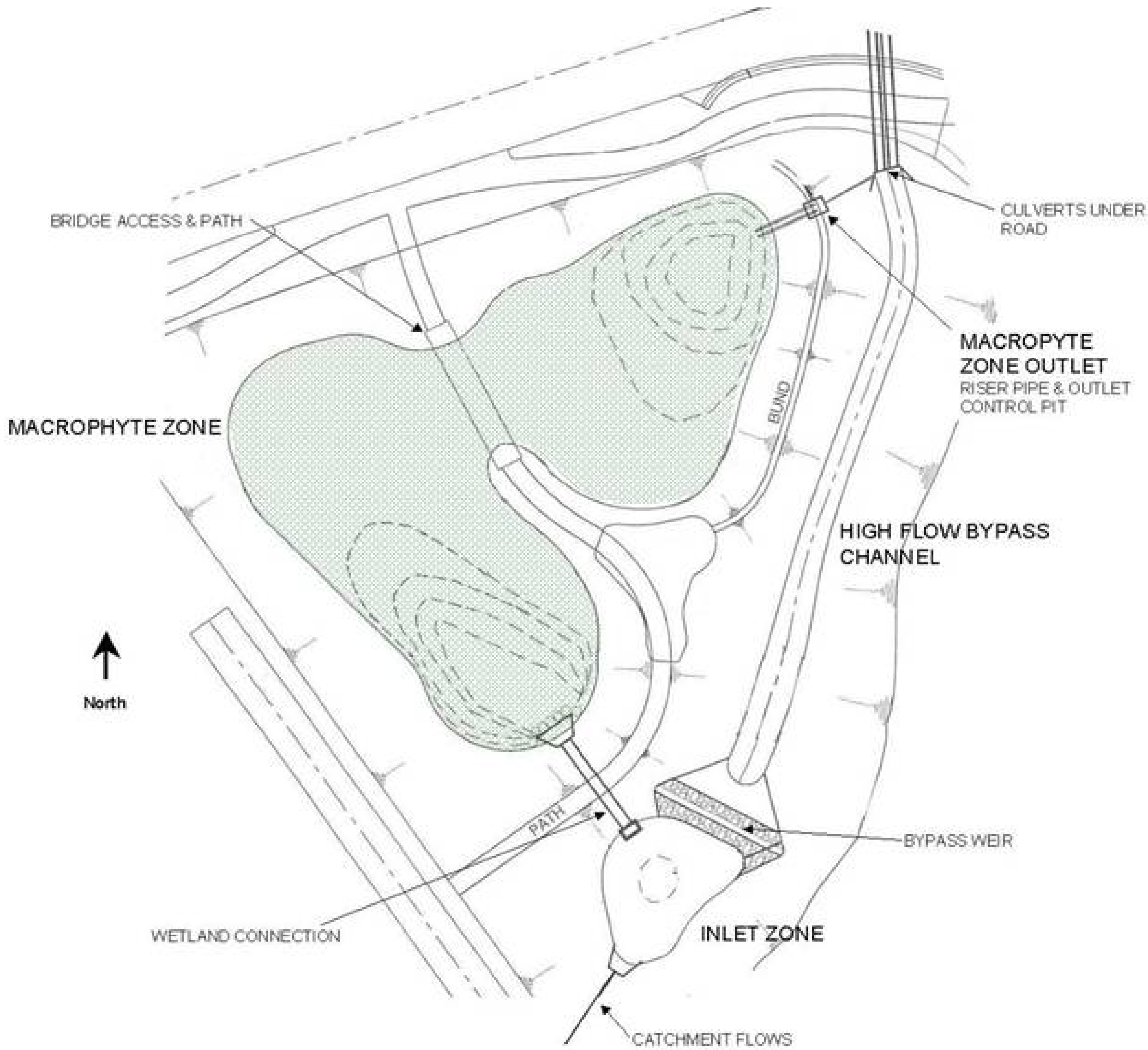


Figure 13.7-L: Layout of Proposed Wetland System

Site Characteristics

The site has a moderate fall of 2.5m from south to north and is constrained by roads to the west and north and by steeper grades to the east. Soils through the site have been classified as clay.

Conceptual Design

The conceptual design of the constructed wetland (as shown in **Figure 13.7-L**) established the following key design elements to ensure effective operation:

- wetland macrophyte zone extended detention depth of 0.5m, permanent pool level of 11.5m AHD and an area of 7000 m^2;
- inlet zone permanent pool level of 11.7m AHD, which is 0.2m above the permanent pool level of the macrophyte zone;
- bypass weir ('spillway' outlet) level of 12m AHD set at the top of extended detention in the wetland macrophyte zone and 0.3m above the inlet zone permanent pool level;
- high flow bypass channel longitudinal grade of 1.5%.

13.7.8.1 Step 1: Confirm Treatment Performance of Concept Design

During the conceptual design phase, the configuration described above and shown in **Figure 13.7-L** was modelled using **MUSIC** to ensure the stormwater discharges from the site comply with GCCC water quality objectives (WQOs). In this case, delivering the GCCC WQOs equates to an 80% reduction in mean annual TSS load, more than 60% reduction in mean annual TP load and 45% reduction in mean annual TN load. To achieve these objectives, the wetland concept required a macrophyte zone area of 7000 m^2, extended detention depth of 0.5m and detention time of 72 hours.

The conceptual design of the stormwater treatment system required of this project has undertaken appropriate modelling using **MUSIC** or alternative techniques to ensure that stormwater discharges from the site comply with GCCC WQOs, a prerequisite of development approval.

13.7.8.2 Step 2: Determine Design Flows

The site has a contributing catchment of 10 ha which is drained via conventional pipe drainage. Both the minor storm (10 year ARI) and the major storm (100 year ARI) flows enter the inlet zone of the wetland. Therefore, the 100 year ARI peak flow sets the 'above design flow'. The 'design operation flow', which is required to size the inlet zone and the inlet zone connection to the macrophyte zone, is the 1 year ARI peak flow.

Design flows are established using the Rational Method and the procedures are provided in **QUDM** (**DPI, IMEA & BCC 1992**) and **Section 3.5**. The time of concentration (t_c) was calculated using the procedures outlined in **Section 5.05** of **QUDM** (**DPI, IMEA & BCC 1992**) and found to be 10 minutes. The coefficient of runoff was taken from **Table 3.5A** of the **Land Development Guidelines** and **Table 5.04.3** of **QUDM** (**DPI, IMEA & BCC 1992**) as follows:

$C_{10} = 0.8$

(**Table 3.5A** of these Guidelines)

	***C* Runoff**		
ARI	1	10	100
QUDM Factor	0.8	1	1.20
C_{ARI}	0.64	0.8	0.96

Catchment area A = 10 ha

Rainfall Intensities for Pimpama (GCCC)

t_c = 10 mins

I_1 = 100 mm/hr

I_{100} = 226 mm/hr

Rational Method Q = $CIA/360$

'Design Operation Flow' (1-year ARI) = 1.78 m^3/s

'Above Design Flow' (100-year ARI) = 6.03 m^3/s

13.7.8.3 Step 3: Design Inlet Zone

The design of the inlet zone is undertaken in accordance with the design procedures outlined in **Section 13.5** with a summary of the key inlet zone elements provided below.

a) Inlet Zone (Sedimentation Basin) Size

The size of the inlet zone required can be established using **Equation 13.5.1** in **Section 13.5**. For this example, the following parameters have been used:

R = 80%

v_s = 0.011m/s (for 125μm, see **Table 13.5.1**)

Q = 1.78 m^3/s ('Design Operation Flow' – 1 Year ARI)

n = 1.12 (From **Equation 13.4.2**, assuming a λ=0.11),

d_e = 0.3m

d_p = 2m

d^* = 1

Iterative calculations were subsequently performed to determine that the required area for the inlet zone is 330m^2. Therefore, an inlet zone area of 330 m^2 is required to capture 80% of 125 μm particles for flows up to the 'Design Operation Flow' (1 year ARI = 1.78 m^3/s).

A further consideration in the design of the inlet zone is the provision of adequate storage for settled sediment to prevent the need for frequent desilting. A desirable frequency of basin desilting is once every five years. To ensure this storage zone is appropriate the following must be met (refer to **Section 13.5**):

Sedimentation Basin Storage Volume (V_s) > Volume of Accumulated Sediment over 5 years ($V_{s:5yr}$)

The sedimentation basin storage volume (V_s) is defined as the storage available in the bottom half of the inlet zone permanent pool. Considering the internal batters of the inlet zone will be 2:1 (H:V) below the permanent water level the approximate area of the basin at 1m depth is 316 m^2 and at 2m depth 304 m^2. Therefore, the sedimentation basin storage volume V_s is 310 m^3.

The volume of accumulate sediments over 5 years ($V_{s:5yr}$) is established using **Equation 13.5.3** from **Section 13.5** (using a sediment discharge rate of 1.6 m^3/Ha/yr):

$$V_{s:5yr} = A_c \cdot R \cdot L_o \cdot F_c$$

$$= 10 \times 0.8 \times 1.6 \times 5 = 64 \ m^3$$

Therefore,

$$V_s > V_{s:5yr}, \text{ hence OK.}$$

b) Inlet Zone Connection to Macrophyte Zone

The configuration of the hydraulic structure connecting the inlet zone to the macrophyte zone consists of an overflow pit (in the inlet zone) and a connection pipe with the capacity to convey the 'design operation flow' (1 year ARI = 1.78 m^3/s). As defined by the conceptual design the follow design elements apply:

- inlet zone permanent pool level (overflow pit crest level) = 11.7m AHD which is 0.2m above the permanent pool level of the macrophyte zone;
- bypass weir ('spillway' outlet) crest level = 12m AHD which is the top of extended detention for the wetland and 0.3m above the inlet zone permanent pool level.

It is common practice to allow for 0.3m of freeboard above the afflux level when setting the top of embankment elevation.

Overflow Pit

According to **Section 13.5.3.5**, two possible flow conditions need to be checked: weir flow conditions (with extended detention of 0.3 m) and orifice flow conditions.

Weir Flow Conditions

From **Equation 13.5.4** (**Section 13.5**), the required perimeter of the outlet pit to pass 1.78 m^3/s with an afflux of 0.3m can be calculated assuming 50% blockage:

$$P = \frac{Q_{des}}{B \cdot C_w \cdot h^{3/2}} = \frac{1.78}{0.5 \cdot 1.66 \cdot 0.3^{3/2}} = 13.1 \quad m$$

Orifice Flow Conditions

From **Equation 13.5.5** (**Section 13.5**), the required area of the outlet pit can be calculated as follows:

$$A_o = \frac{Q_{des}}{B \cdot C_d \sqrt{2 \cdot g \cdot h}} = \frac{1.78}{0.5 \cdot 0.6\sqrt{2 \cdot g(0.3)}} = 2.4 \text{ m}^2$$

In this case the weir flow condition is limiting. Considering the overflow pit is to convey the 'design operation flow' (1 year ARI) or slightly greater, a 3000 x 4000 mm pit size is adopted providing a perimeter of 14m which is greater than the 13.1m calculated using the weir flow equation above. The top of the pit is to be fitted with a letter box grate. This will ensure large debris does not enter the 'control' structure while avoiding the likely of blockage of the grate by smaller debris.

Connection Pipe(s)

As the connection pipe (ie. between the inlet zone and the macrophyte zone) is to be submerged, the size can be determined by firstly estimating the required velocity in the connection pipe using the following:

$$h = \frac{2 \cdot V^2}{2 \cdot g}$$

Where:

h	=	maximum available head level driving flow through the pipe (defined as the bypass weir spillway outlet crest level minus the normal water level in the macrophyte zone = 0.5 m)
V	=	pipe velocity (m/s)
g	=	9.79 m/s^2

Note: ***The coefficient of 2 in the equation is a conservative estimate of the sum of entry and exit loss coefficients (K_{in} + K_{out}).***

Hence,

V = $(9.79 \times 0.5)^{0.5}$ = 2.21 m/s

The area of pipe required to convey the 1 year ARI is then calculated using the continuity equation by dividing the 1 year ARI flow (Q_2 = 1.60 m^3/s) by the velocity:

$$A_{pipe} = \frac{Q}{V} = \frac{1.78}{2.21} = 0.80 \text{ m}^2$$

This area is equivalent to two (2) 600 mm reinforced concrete pipes (RCPs). The obvert of the pipes is to be set below the permanent water level in the wetland macrophyte zone (11.5m AHD) meaning the invert is at 10.85m AHD.

c) High Flow Bypass Weir

All flows in excess of the 'design operation flow' and up to the 'above design flow' are to bypass the wetland macrophyte zone. This is facilitated by a high flow bypass weir ('spillway' outlet) designed to convey the 'above design flow' (50 year ARI) with the weir crest level 0.3m above the permanent pool of the inlet pond.

Assuming a maximum afflux of 0.3 m, the weir length is calculated using the weir flow equation (**Equation 13.5.4** in **Section 13.5**):

$$L = \frac{Q_{des}}{C_w \cdot H^{3/2}} = \frac{6.03}{1.66 \cdot 0.3^{3/2}} = 22.1\text{m (adopt 23m)}$$

To ensure no flows breach the embankment separating the inlet zone and the macrophyte zone the embankment crest level is to be set at 12.6m AHD (ie. 0.3m freeboard on top of the maximum afflux level over the high flow bypass weir).

Inlet Zone Area	= 330 m^2 set at 11.7m AHD
Overflow pit	= 3000 x 4000 mm with letter box grate set at 11.7m AHD
Pipe connection (to wetland)	= 2 x 600 mm RCPs at 10.80m AHD
High flow bypass weir	= 23m length set at 12.0m AHD

13.7.8.4 Step 4: Designing the Macrophyte Zone

a) Length to Width Ratio and Hydraulic Efficiency

A macrophyte zone area of 7000 m^2 was established as part of the conceptual design and verified as part of **Step 1**. The layout of the wetland as presented in **Figure 13.7-L** represents a length (L) to width (W) ratio of 6 to 1. This aspect ratio represents a shape configuration in between Case G and Case I in **Figure 13.7-B** (but closer to Case G). Thus, the expected hydraulic efficiency (λ) is 0.6-0.7.

Aspect Ratio	= 6(L) to 1(W)
Hydraulic Efficiency	~ 0.6-0.7

b) Designing the Macrophyte Zone Bathymetry

Being a typical residential catchment, the wetland macrophyte zone has been configured to target sediment and nutrient capture. Therefore, the macrophyte zone of the wetland is divided into four marsh zones and an open water zone as depicted in **Figure 13.7-M** and described below:

- the bathymetry across the four marsh zones is to vary gradually over the length of the macrophyte zone, ranging from 0.2m above the permanent pool level (ephemeral zone) to 0.5m below the permanent pool level (see **Figure 13.7-M** and **Table 13.7-B**). The ephemeral marsh zone is to be located adjacent to the pathway and bridge crossing mid way along the wetland;
- the permanent pools upstream and downstream of the ephemeral zone are to be connected via the maintenance drain to ensure the upstream permanent pool can drain down to 11.5m AHD following a rainfall event;
- the depth of the open water zone in the vicinity of the outlet structure is to be 1m below the permanent pool level;
- the marsh zones are arranged in bands of equal depth running across the flow path to optimise hydraulic efficiency and reduce the risk of short-circuiting.

Table 13.7-B: Indicative Break of Marsh Zones

Zone	Depth Range (m)	Proportion of Macrophyte Zone Surface Area (m)
Open Water (Pool)	>1.0 below permanent pool	10%
Transition	0.5 – 1.0 below permanent pool	10%
Deep Marsh	0.35 – 0.5 below permanent pool	20%
Marsh	0.2 – 0.35 below permanent pool	20%
Shallow Marsh	0.0 – 0.2 below permanent pool	20%
Ephemeral Marsh	0.2 – 0.0 above permanent pool	20%

Figure 13.7-M: Layout of Marsh Zones

c) Macrophyte Zone Edge Design for Safety

The batter slopes on approaches and immediately under the permanent water level have to been configured with consideration of public safety:

- generally, batter slopes of 1(V):8(H) from the top of the extended detention depth to 0.3m beneath the water line has been adopted;
- the general grade through the wetland below the waterline is 1(V):8(H) or flatter;
- the batters directly adjacent and within the open water zones of the macrophyte are limited to 1(V):8(H).

13.7.8.5 Step 5: Design the Macrophyte Zone Outlet

a) Riser Outlet – Size and Location of Orifices

The riser outlet is designed to provide a uniform notional detention time in the macrophyte zone for the full range of possible extended detention depths. The target maximum discharge from the riser is computed as the ratio of the volume of the extended detention to the notional detention time as follows (**Equation 13.7.1**):

$$Q_{max\ riser} = \frac{\text{extended detention storage volume } (m^3)}{\text{notional detention time } (s)}$$

Extended detention storage = 7000 m^2 x 0.5m extended detention

= 3500 m^3

Notional detention time = 72 hrs x 3600 s/hr

Therefore, Q_{max} = 3500/(72 x 3600) = 0.0135 m^3/s = 13.5 L/s

The placement of orifices along the riser and determining their appropriate diameters involves iterative calculation using the orifice equation (**Equation 13.7.2**) over discrete depths along the length of the riser.

Equation 6.2 (Small Orifice equation) is given as:

$$A_o = \frac{Q}{C_d\sqrt{2 \cdot g \cdot h}}$$

Where:

C_d	=	Orifice Discharge Coefficient (0.6)
h	=	Depth of water above the centroid of the orifice (m)
A_o	=	Orifice area (m^2)
Q	=	required flow rate to drain the volume of the permanent pool in 12 hours

The size of each orifice is sized to achieve the notional detention time (72 hrs) over the full range of extended detention depths. This was performed in a spreadsheet application and the resulting riser configuration can be described as follows:

- Orifices are located at 0.125m intervals along the length of riser at 0 m, 0.125 m, 0.250m and 0.375m above the permanent pool level (11.5m AHD).
- Two orifice diameters of 30 mm and 40 mm were selected and the numbers required at each level are summarised in **Table 13.7-C** and **Figure 13.7-N** below.

Table 13.7-C: Iterative Spreadsheet Calculations for Stage-Discharge Relationship

Orifice Positions (m above 11.5 m AHD)		**0**	**0.125**	**0.25**	**0.375**		
Orifice Diameter (mm)		**40**	**30**	**30**	**30**		
Number of orifices		**3**	**3**	**2**	**2**		
Extended Det. Depth (m above 11.5m AHD)	**Extended Det .Volume** (m3)	**Flow at given Ext. Det. Depths** (L/s)				**Total Flow** (L/s)	**Not. Detention Time** (hrs)
0	0	0.00				0.00	
0.125	875	3.24	0.00			3.24	74.94
0.25	1750	4.89	1.87	0.00		6.67	72.91
0.375	2625	5.96	2.73	1.24	0.00	9.94	73.37
0.5	3500	6.93	3.38	1.82	1.24	13.38	72.68

The stage-discharge relationship of the riser is plotted in the chart below (**Figure 13.7-N**) and shows that the riser maintains a linear stage discharge relationship.

At the top of extended detention the high flow bypass is activated; therefore, the riser pipe has no role in managing of flows greater than the Q_{max} (13.5 L/s) of riser pipe. An upstand riser pipe diameter of 225 mm is selected.

As the wetland is relatively small and the required orifices are small, it is necessary to include measures to prevent blocking of the orifices. The riser is to be installed within an outlet pit, as per **Figure 13.7-F** with a pipe connection to the permanent pool of the macrophyte zone. The connection is via a 225 mm diameter pipe. The pit is accessed via the locked screen on top of the pit.

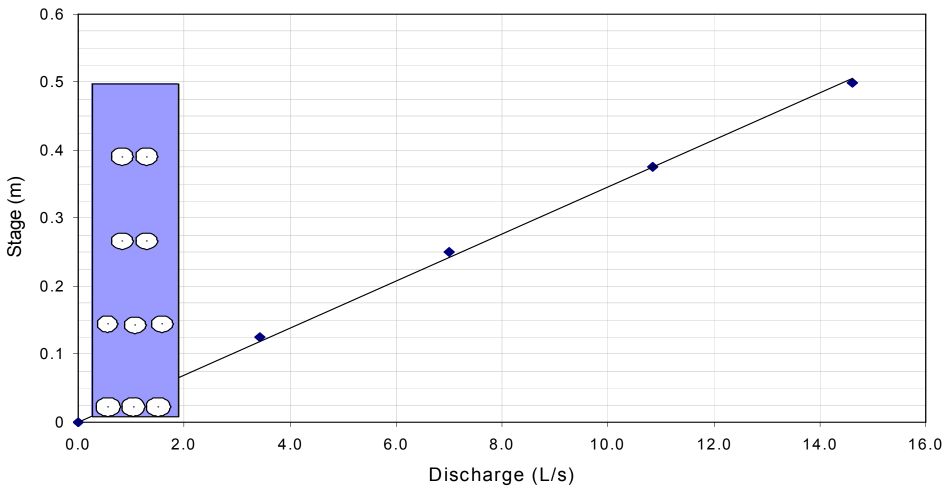


Figure 13.7-N: Riser Pipe Configuration Showing Discharge Stage Relationship

b) Maintenance Drains

To allow access for maintenance, the wetland is to be drained via a maintenance drain (ie. pipe) that connects the low points in the macrophyte bathymetry. The drain must be sized to draw down the permanent pool of the macrophyte zone in 12 hours with allowance for manual operation (ie. inclusion of valve).

The mean flow rate to draw down the macrophyte zone over a notional 12 hour period is as follows:

Permanent Pool Volume ~ 1750 m^3 (assuming approximate 0.25m nominal depth)

Q = 1750/ (12 x 3.6) = 40.5 L/s

The size of the of maintenance drain can be established using the Manning's equation assuming the drain/ pipe is flowing full and at 0.5% grade:

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n}$$

Where:

A	=	cross sectional area of drain (m^2)
R	=	hydraulic radius (m) (pipe area/ wetted perimeter)
S	=	0.5% (0.005m/m)
n	=	0.012

Giving pipe diameter of 240 mm – adopt 225 mm diameter pipe meaning a notional draining time of 14 hrs.

The size of the valve can be established using the orifice equation, assuming the orifice operates under inlet control (**Equation 13.7.2**):

$$A_o = \frac{Q}{C_d \sqrt{2 \cdot g \cdot h}}$$

Where:

Q	=	40.5 L/s (0.0405 m^3/s)
C_d	=	0.6
h	=	0.33m (one third of permanent pool depth)

So,

A_o = 0.0104 m^2

corresponding to an orifice diameter of 115mm – adopt 150mm

c) Discharge Pipe

The discharge pipe of the wetland conveys the outflow of the macrophyte zone to the receiving waters (or existing drainage infrastructure). Under normal operating conditions, this pipe will need to have sufficient capacity to convey the larger of the discharges from the riser (13.5 L/s) or the maintenance drain (30.5 L/s). Considering the maintenance drain flow is the larger of the two flows the discharge pipe size is set to the size of the maintenance drain (225 mm pipe at 0.5% as calculated above).

Riser outlet = 225 mm diameter pipe with following orifice detail:

Level	Orifices	Orifice Diameter
11.5m AHD	3	40 mm
11.625m AHD	3	30 mm
11.75m AHD	2	30 mm
11.875m AHD	2	30 mm

Maintenance drain = 225 mm diameter pipe at 0.5% grade

Maintenance control = 150 mm diameter valve

Discharge pipe = 225 mm diameter at 0.5% grade

13.7.8.6 Step 6: Design High Flow Bypass Channel

The bypass channel accepts 'above design flow' (50 year ARI = 5.80 m^3/s) from the inlet zone (via the bypass weir) and conveys this flow around the macrophyte zone of the wetland. The configuration of the bypass channel can be designed using Manning's Equation:

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n}$$

Where:

Q = 'Above Design Flow' (50-year ARI = 5.80 m^3/s)

A = cross section area (m^2)

R = hydraulic radius (m)

S = channel slope (1.5%)

n = Manning's roughness factor

A turf finish is to be adopted for the bypass channel and a Manning's n of 0.03 is considered appropriate for flow depths more than double the height of the grass.

Assuming there is a 0.3m drop from the bypass weir crest to the upstream invert of the bypass channel and 5(H):1(V) batters, the base width of the bypass channel can be established by setting the maximum flow depth in the bypass channel at 0.3m. This ensures flow in the channel does not backwater (ie. submerge) the bypass weir.

For base width = 12m,

Q = 6.1 m^3/s > 'Above Design flow' (6.03m^3/s)

High flow bypass channel,

Base width of 12m, batters of 5(H):1(V) and longitudinal slope of 1.5%.

13.7.8.7 Step 7: Verification Checks

a) Macrophyte Zone Resuspension Protection

A velocity check is to be conducted for when the wetland is at the top of the extended detention level and the riser is operating at design capacity. This check is to ensure velocities through the macrophyte zone ($V_{macrophyte\ zone}$) are less than 0.05 m/s to avoid potential scour of biofilms from the wetland plants (macrophytes) and resuspension of the sediments (**Equation 13.7.3**):

$$\frac{Q_{max\ riser}}{A_{section}} < 0.05\text{m/s}$$

Where:

$Q_{max\ riser}$ = target maximum discharge (defined in **Equation 13.7.1**) (m^3/s)

$A_{section}$ = wetland cross sectional area at narrowest point*, measured from top of extended detention (m^2)

* minimum wetland cross section is used when undertaking this velocity check.

Wetland width (W) = 34m (based on the 6 (L) : 1 (W) length to width ratio)

Minimum depth at top of extended detention depth is within the ephemeral marsh = 0.3m depth

Giving $A_{section}$ = 34m x 0.3m = 10.2 m^2

$Q_{max\ riser}$ = 13.5 L/s (0.0135 m^3/s)

Therefore,

$V_{macrophyte\ zone}$ = 0.0135/ 0.3/ 34 = 0.0013 m/s < 0.05 m/s (OK)

b) Confirm Treatment Performance

The key functional elements of the constructed wetland developed as part of the conceptual design (ie. area, extended detention depth) were not adjusted as part of the detailed design. Therefore, the performance check undertaken in **Step 1** (see **Section 13.7.3.1**) still applies.

13.7.8.8 Step 8: Vegetation Specification

The vegetation specification and recommended planting density for the macrophyte zone have been adapted from **Section 13.13** and are summarised in **Table 13.7-D** below.

The reader is referred to **Section 13.13** for further discussion and guidance on vegetation establishment and maintenance.

Table 13.7-D: Worked Example Vegetation List

Zone	Plant Species	Planting Density (plants/m^2)
Ephemeral marsh	*Carex appressa* *Isolepis nodosa*	8 8
Shallow Marsh	*Eleocharis equisetina* *Juncus usitatus*	10 10
Marsh	*Schoenoplectus mucronatus* *Baumea rubiginosa*	6 6
Deep Marsh	*Baumea articulata* *Schoenoplectus validus*	4 4

13.7.8.9 Design Calculation Summary

The sheet below shows the results of the design calculations.

Drawings 13.7.1 and **13.7.2** show the principles of this worked example.

Constructed Wetlands		Calculation Summary		
	Calculation Task	Outcome		Check
	Catchment Characteristics			
	Catchment Area	10	ha	✓
	Catchment Land Use (ie. Residential, Commercial, etc)	Residential		
	Storm event entering inlet pond (minor or major)	100 yr ARI		
	Conceptual Design			
	Macrophyte zone area	7000	m^2	✓
	Permanent pool level of macrophyte zone	11.5	m AHD	
	Extended detention depth (0.25-0.5m)	0.5	m	
	Notional detention time	72	hrs	
1	**Confirm Concept Design**			
	MUSIC modelling performed?	Yes		✓
	GCCC WQO's satisfied?	Yes		
	Macrophyte area	7,000	m^2	
2	**Determine Design Flows**			
	'Design Operation Flow' – 1 year ARI	1	year ARI	
	'Above Design Flow' – either 2, 10 or 100 year ARI	100	year ARI	
	Time of Concentration			
	Refer to **Section 3.5** and **QUDM**	10	minutes	
	Identify Rainfall Intensities			
	'Design Operation Flow' – $I_{1\ year\ ARI}$	100	mm/hr	✓
	'Above Design Flow' – $I_{2\ year\ ARI}$ or I_{10} or $I_{100\ year\ ARI}$	226	mm/hr	
	Peak Design Flows			
	'Design Operation Flow' – 1 year ARI	1.78	m^3/s	✓
	'Above Design Flow' – 2, 10 or 100 year ARI	6.03	m^3/s	
3	**Design Inlet Zone**			
	Refer to **Section 13.5 – Sedimentation Basin** for detailed check sheet			
	Is a GPT required?			
	Suitable GPT selected and maintenance considered?	No		✓
	Inlet Zone Size			
	Target sediment size for inlet zone	125	μm	
	Capture efficiency	80	%	
	Inlet zone area (**Figure 4.2** in **Section 13.5**)	330	m^2	
	$V_s > V_{s:5yr}$	Yes		
	Inlet Zone Connection to Macrophyte Zone			
	Overflow pit crest level	11.7	m AHD	✓
	Overflow pit dimension	4000 x 3000	L x W	
	Provision of debris trap	Yes		
	Connection pipe dimension	2 x 600	mm diam	✓
	Connection pipe invert level	10.85	m AHD	
	High Flow Bypass Weir			
	Weir length	23	m	✓
	High flow bypass weir crest level (top of extended detention)	12.0	m AHD	

Constructed Wetlands	Calculation Summary		
Calculation Task	Outcome		Check
4 Designing the Macrophyte Zone			
Area of macrophyte zone	7000	m^2	
Aspect ratio	6 : 1	L:W	
Hydraulic efficiency	0.6 – 0.7		
5 Design Macrophyte Zone Outlet			
Riser Outlet			
Target maximum discharge (Q_{max})	13.5	m^3/s	✓
Uniform detention time relationship for Riser	Yes		
Maintenance Drain			
Maintenance drainage rate (drain over 12hrs)	40.5	m^3/s	✓
Diameter of maintenance drain pipe	225	mm	
Diameter of maintenance drain valve	150	mm	
Discharge Pipe			
Diameter of discharge pipe	225	mm	✓
6 Design High Flow Bypass 'Channel'			
Longitudinal slope	1.5	%	✓
Base width	12	m	
Batter slopes	5 : 1	H:V	
7 Verification Checks			
Macrophyte zone resuspension protection			✓
Confirm treatment performance			✓

13.7.9 References

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