Constructed Stormwater Wetlands

Chapter 6

Due to the different climatic conditions, the design of constructed wetlands in the Coastal Dry Topics differs from the design of wetlands in South East Queensland and southern states. The following design considerations and criteria outlined below are specific to the Coastal Dry Topics and are intended to address key requirements such as maintaining perennial wetland vegetation during the dry season; managing the potential for weed ingress and providing natural means of managing mosquito populations. Constructed wetlands in the form detailed below have not yet been constructed in the Townsville region. Therefore it is recommended that demonstration projects adopting the design guidelines detailed below are constructed and revisions/updates of this Chapter made, where deemed appropriate, to reflect practical learnings and understanding of the performance and sustainability of constructed stormwater treatment wetlands in the Coastal Dry Tropics.

6.1 Introduction

Constructed wetland systems are densely 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 and improved landscape amenity.

Constructed wetlands in the Coastal Dry Tropics will generally consist of an inlet zone (sedimentation basin to remove coarse sediments (refer Chapter 4 – Sedimentation Basins)), deep pools, a deep marsh macrophyte zone (i.e. a heavily vegetated area to remove fine particulates and uptake soluble pollutants) and a high flow bypass channel (to protect the macrophyte zone from scour and vegetation damage). Figure 6-1 and Figure 6-2 show the key elements of constructed stormwater wetland systems.

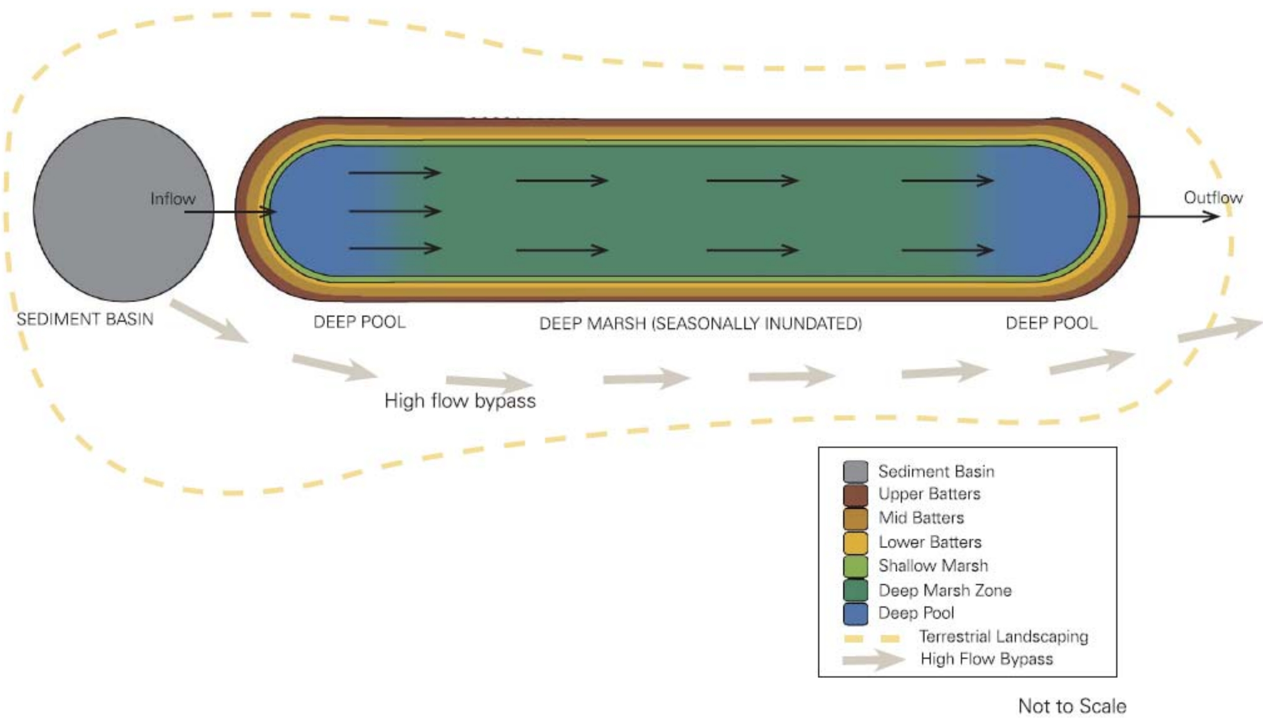


Figure 6-1: Schematic Layout of a Constructed Wetland System

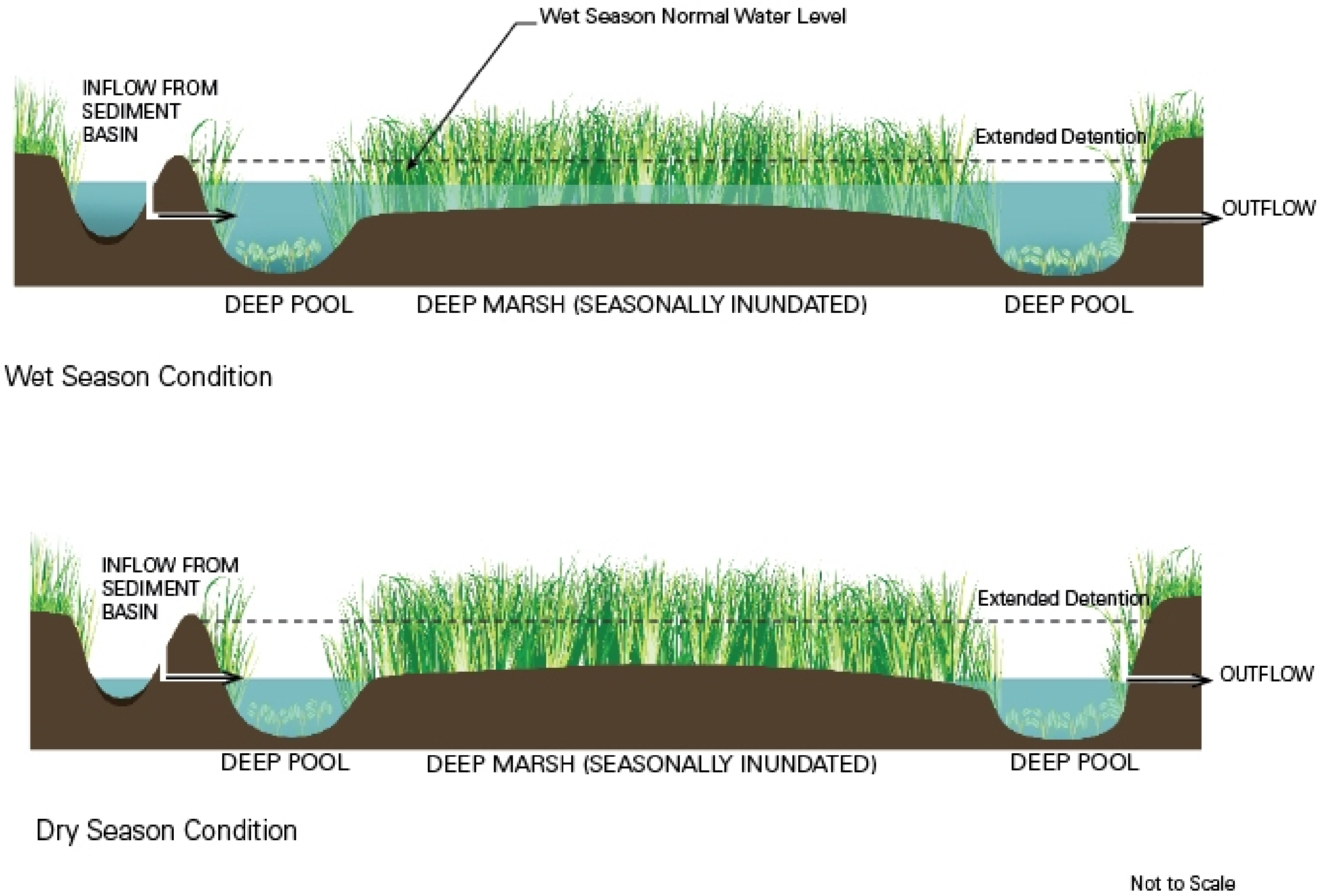


Figure 6-2: Wet and dry season conditions in a Constructed Freshwater Wetland.

Constructed wetlands treat stormwater by capturing runoff and slowly passing it horizontally through a densely vegetated macrophyte zone. Soluble and colloidal (fine particles held in suspension) pollutants are mostly removed by sorption (absorption – '*into*' and adsorption – '*onto*') to biofilms on stems of wetland plants (Figure 6-3). For this reason, dense vegetation is important for effective treatment and vegetation with a large stem surface area provides greatest treatment (i.e. plants with many small diameter stems are able to support more biofilms than plants with fewer, thicker stems). Emergent macrophytes are also important for:

- Transferring oxygen to the sediments (oxygen pumps) thereby facilitating the processing and/or immobilising of pollutants captured and held within wetland sediments;
- Aiding in the treatment of nutrient and heavy metal concentrations, either through direct uptake, or through providing a surface for biofilms and epiphytes that assist with the removal of pollutants;
- Influencing sediment deposition and physically filtering sediment particles from the water column;
- Influencing hydrology and hydraulics by promoting even flow distribution through the wetland;
- Providing shade, decreasing light availability for algal synthesis;
- Decreasing erosion by reducing wave action and flow velocities while binding soil particles with their root systems;
- Providing a basis for wetland food chains and supplying shelter for mosquito predators such as macroinvertebrates and fish.

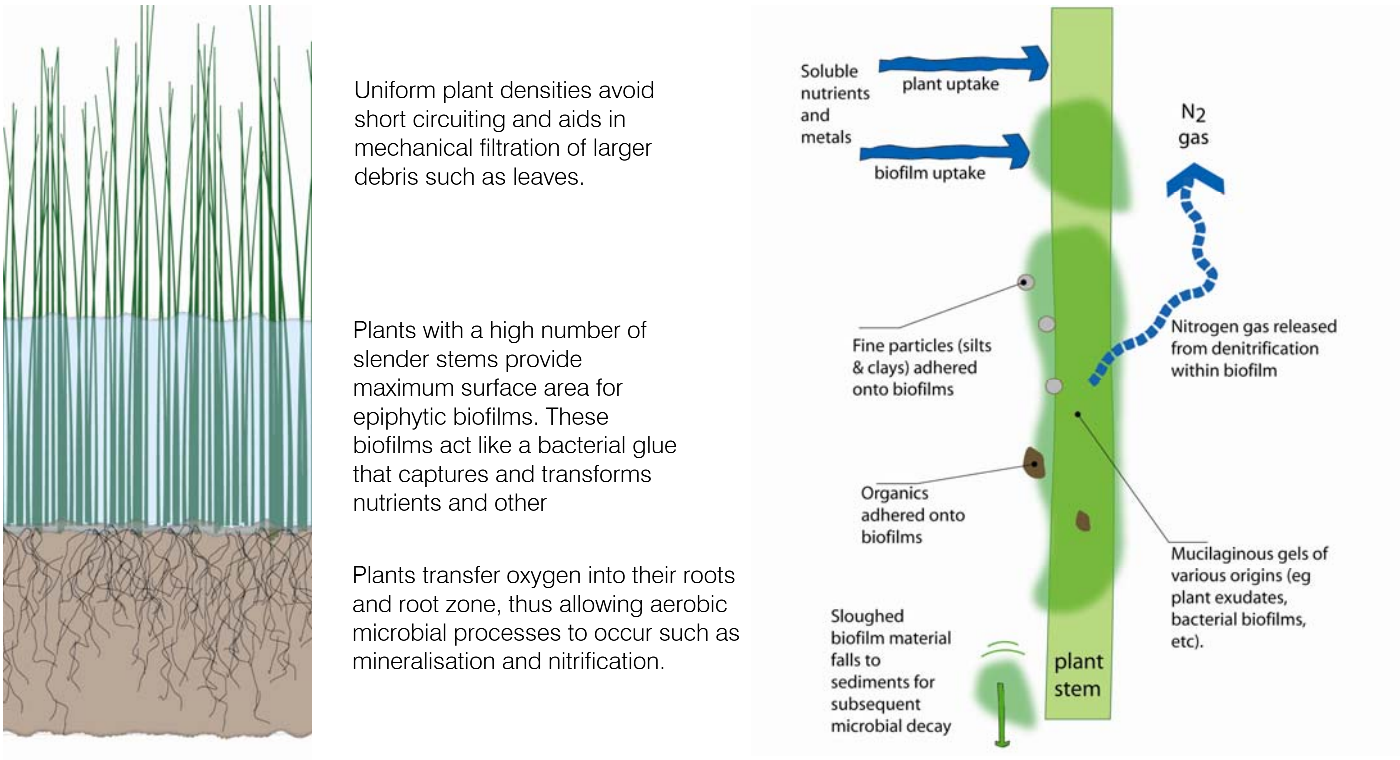


Figure 6-3: Dense emergent macrophytes and biofilms on the plant stems play an important role in nutrient removal in constructed stormwater wetlands (Figure and associated text from the Healthy Waterways WSUD Technical Design Training Notes for South East Queensland - Version 1 June 2007)

6.2 Design Considerations

Due to the different climatic conditions, the design of constructed wetlands in the Coastal Dry Topics differs from the design of wetlands in South East Queensland and southern states. The following design considerations and criteria outlined below are specific to the Coastal Dry Topics and are intended to address key requirements such as maintaining perennial wetland vegetation during the dry season; managing the potential for weed ingress and providing natural means of managing mosquito populations. Constructed wetlands in the form detailed below have not yet been constructed in the Townsville region. Therefore it is recommended that demonstration projects adopting the design guidelines detailed below are constructed and revisions/updates of this Chapter made, where deemed appropriate, to reflect practical learnings and understanding of the performance and sustainability of constructed stormwater treatment wetlands in the Coastal Dry Tropics.

Community acceptance of constructed wetlands will be driven by their aesthetics and landscape amenity value. Poorly designed and/or maintained wetlands are unlikely to gain community support; therefore, it is essential to address potential issues such as pests and weeds starting at conceptual design and continuing through implementation and long-term maintenance.

The operation of constructed wetlands involves the interaction between stormwater runoff, vegetation and hydraulic structures and the successful implementation of constructed wetlands requires appropriate integration into the landscape design. In this regard, the following sections provide an overview of the key design issues that must be considered when conceptualising and designing constructed wetlands.

6.2.1 Landscape Design

Constructed wetlands are often located within accessible open space areas and can become interesting community features. Landscape design aims to ensure that macrophyte 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 6-1: Boardwalk and public Viewing Area on the Edge of a Landscaped Wetland

Terrestrial landscaping provides a visual buffer and framework for the wetland system within the community and native habitat. Native trees can encourage recreational elements such as walking and bird watching. These recreational elements, as well as education in the form of descriptive panels and signs, can increase acceptance of these systems within the community.

6.2.2 Invasive Weed Control

To protect landscape amenity and the stormwater treatment efficiency of the wetland it is important to maintain, throughout the year, the design vegetation communities to avoid excessive colonisation of the wetland by weeds. Weed infestation is a major problem in the Dry Tropics, particularly within ephemeral waterways and stormwater treatment facilities. The wetland design presented in this chapter is based on an ephemeral wetland (i.e. it will dry periodically) and therefore, the design and management of the wetland to manage weed infestation takes on high importance. Management of weeds is achieved as follows (see also Section 6.2.6):

- Designing the macrophyte zone as predominately a deep marsh system (i.e. water depth 0.5m - 0.7m) to maintain the macrophyte vegetation by minimising the frequency and duration of wetland drying, thus permanently occupying the habitat and restricting weed colonisation opportunities.
- Planting dense littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season.
- During the establishment and ongoing maintenance of the wetland, prompt removal of weeds before they spread and/or set seed is of critical importance (see also Section 6.5.5.3).

6.2.3 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 quantitative 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*[1] and wetland hydrologic effectiveness to maximise treatment performance. 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.

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 around 48 hours to remove nutrients

1 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.

effectively from urban stormwater. Optimal hydrologic effectiveness in the Coastal Dry Tropics Region is a balance between minimising overflows in the wet season and sustaining vegetation in the dry season (i.e. sizing the wetland to treat the majority of stormwater runoff while not being too large as to result in water level drawdown and drying in excess of 60–70 days in the dry season). Further discussion on hydrologic effectiveness and sizing of wetlands in the Coastal Dry Tropics is provided in the following sections of this Chapter.

6.2.4 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 6-1.

Table 6-1: 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.	Wetland area and outlet design is critical to achieve the WSUD Objectives (e.g. target pollutant load reduction) as well as ensuring the size is adequate to sustain wetland vegetation (i.e. not too large as to result in excessive water level drawdown and drying in excess of 60 days in the dry season). 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.
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 inflows, measures are to be taken to "protect" the wetland from erosion during periods of high inflow rates.

6.2.5 Inlet Zone Design Considerations

The inlet zone of a constructed stormwater wetland is designed as a sedimentation basin (see Chapter 4) and has two key functional roles. The primary role is to remove coarse to medium sized sediment (i.e. 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 (i.e. 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.

Chapter 4 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 (i.e. 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. The relevant local authority should be consulted to determine if a GPT is required.

Plate 6-2 Inlet zone bypassing major design flows around wetland.

6.2.6 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 (see also Section 6.3.4):

- The preferred extended detention depth is 0.5m. Deeper extended detention depths, up to a maximum of 0.75m, may be acceptable where the wetland has a high hydrologic effectiveness (refer to Section 6.2.3) and where the botanic design uses plant species tolerant to greater depths of inundation.
- The longitudinal bathymetry of the macrophyte zone should grade (min 0.5% grade) smoothly from 0.7m in depth (based on design normal water level) up to a central crest 0.5m in depth and then back down to a maximum of 0.7m in depth. This ensures that isolated pools of water are not created within the macrophyte zone during the dry season when the normal water level slowly draws down due to evapotranspiration.
- The macrophyte zone is to have a flat cross sectional bathymetry only grading up at the edge batters. This facilitates the even distribution of flows to avoid short circuiting, creates a uniform hydraulic conveyance and maximises stormwater contact with macrophyte stems and biofilms.
- The bathymetry of the macrophyte zone should be designed so that the macrophyte zone is connected to deeper open water pools (located at the inlet and outlet of the macrophyte zone) to allow mosquito predators to seek refuge in the deeper open water zones during periods of extended dry weather.
- The deep open water pools should be 2m in depth to ensure that a permanent pool of water is sustained throughout the dry season. This ensures habitat is retained for fish, macroinvertebrates (mosquito predators) and submerged macrophytes.
- The surface area of deep refuge pools (excluding the sediment basin) within the wetland should be between 20% and 30% of the total macrophyte area.
- The constructed wetland is required to retain water permanently and therefore the base must be of suitable material to retain water (e.g. clay). If in-situ soils are unsuitable for water retention, a clay liner (e.g. compacted 300 mm thick) must be used to ensure there will be permanent water for vegetation and habitat.

- 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.
- Dense littoral vegetation around the perimeter of the wetland is required to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season. During extended dry periods (e.g. in excess of 60 days) wetland macrophytes may also require irrigation to sustain dense foliage and prevent habitat opportunities for weed species.
- 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 hours) for a wide range of flow depths. The outlet structure should also include measures to exclude debris to prevent clogging.

6.2.7 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.

6.2.8 Vegetation Types

Vegetation planted in the macrophyte zone has an important functional role in treating stormwater flows, as well as adding aesthetic value. A dense cover of perennial emergent macrophytes is essential for both stormwater treatment function and for the control of weeds. It is necessary for the macrophytes to permanently occupy the wetland habitat to limit weed colonisation opportunities. Dense perennial littoral vegetation is also important to avoid the ingress of weed species into the wetland macrophyte zone. 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, life histories, physiological and structural characteristics, natural distribution, and community groups of the wetland plants. The reader is referred to the Appendix A (Plant Selection for WSUD Systems) for a list of suggested plant species suitable for constructed wetland systems in the Coastal Dry Tropics. 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. The plant species in Appendix A are listed in accordance with the wetland zone/water depth in which they should be planted. The wetland zones are: deep marsh, shallow marsh (wetland edge), lower littoral and upper littoral.

6.2.9 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 permanent pool (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.
- 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 8:1 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 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 if required.
- 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.

6.2.10 Designing for Maintenance Access

Access to all areas of a constructed wetland is required for maintenance. In particular 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 Chapter 4). If sediment removal requires earthmoving equipment to enter the basin, then a stable ramp suitable for heavy plant will be required into the base of the inlet zone (maximum slope 1:10).

To aid maintenance, it is recommended that the inlet zone is constructed with a hard (i.e. rock) bottom. This is important if maintenance is performed by driving into the basin. It also serves an important role by allowing excavator operators to detect when they have reached the base of the inlet zone during desilting operations.

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.

Technical Note:

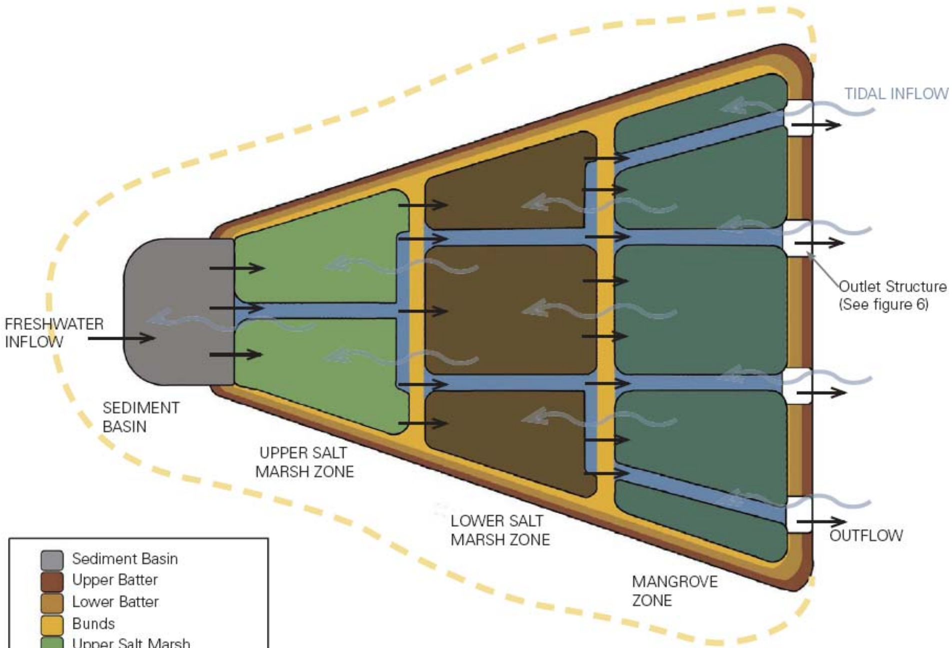
Saline/Brackish Constructed Wetlands

Urban communities in the Dry Tropics are often located near large estuarine river systems. In some locations it may be useful to have an optional estuarine stormwater treatment system. While estuarine systems are typically lower nutrient environments than freshwater stormwater treatment systems, a modified salt marsh community would still have considerable nutrient processing capability and could potentially provide a stormwater treatment capacity in some locations. *This is a new concept that has not yet been tested and therefore should only be considered if other design solutions are not possible or practical.*

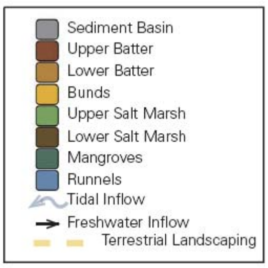
If an estuarine stormwater treatment system was to be trialled/ constructed as a demonstration project, it is recommended that the model would need to consider the following list of features/design elements:

- Drain a large stormwater runoff event over several tidal cycles
- During a runoff event, extended detention depth should not exceed 0.5m, but preferably be lower
- The wetland should consist of a series of cells that would progressively fill and spill during a runoff event
- The initial cell would be a sedimentation pond
- Surrounding the sedimentation pond and throughout the subsequent cells would support salt marsh communities (ranging from herbaceous to woody)
- A dry weather drainage system would allow complete drainage over a single tide cycle
- The wetland would be drained by a series of runnels that would be capable of completely draining the system on a low tide sequence, thus managing potential mosquito breeding habitat
- High tides (exceeding mean high tide) would be allowed to penetrate the entire system
- A salinity gradient would be maintained through the system for most seasons
- A series of berms and chokes would be included to ensure cells progressively fill and spill and that a salinity gradient is created and maintained
- In high tidal range environments particular care will be needed in the design of the hydraulic connection between the perched salt marsh treatment system and the larger and deeper estuarine drainage channels (these environments are highly susceptible to erosion particularly after catchment development)
- An important element in a estuarine system will be the wetting and drying sequence in that this will heighten the capacity to process nitrogen pollutants which are critical pollutants to near shore marine ecosystems

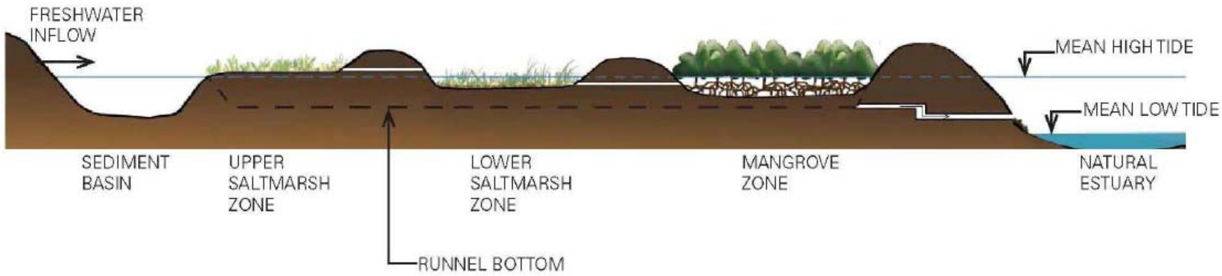
The illustrations on the following page, demonstrate how a saline/brackish wetland may be configured to achieve the above design criteria.

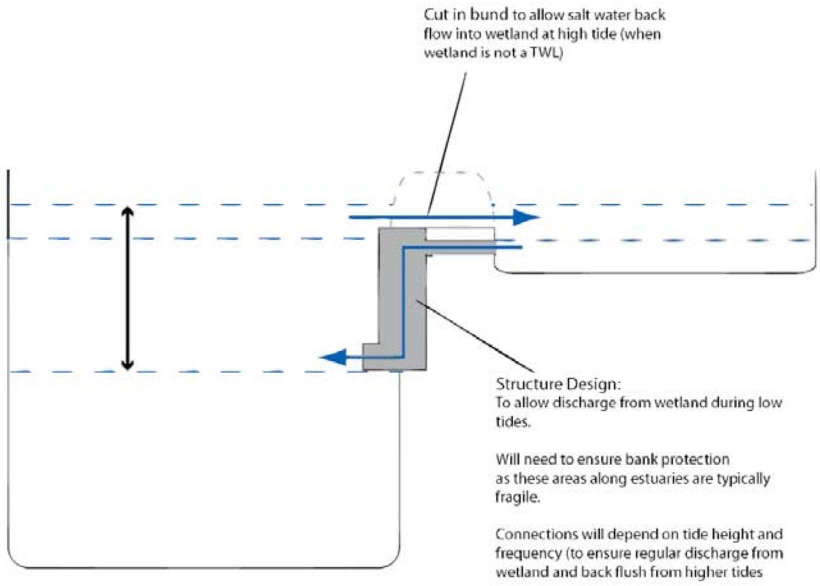


Runnels are small channels or rivulets located throughout the system providing a key hydrologic linkage between treatment zones. The saline/brackish wetland needs to be large enough to drain the runnel volume at all tide cycles, i.e. completely drain during low tide to prevent the creation of mosquito larval habitat. Complete draining will depend on the frequency of inundation. If the system is at the top of the tide height some residual water may be necessary. This may increase the risk of mosquito habitat being created. In addition, the wetlands need to be small enough to retain stormwater inflows and backwater the entire wetland during runoff events. Inundation depth during wet weather flows probably should not exceed 0.5 metres.



Freshwater inflows will first reach the upper salt marsh zone followed by the lower salt marsh zone and finally the mangrove zones. These zones provide a tiered design that mimics natural estuarine environments and creates the appropriate tidal interaction for each habitat type. As with natural estuarine environments, treatment zones will widen and flatten as they approach the Bay. This configuration enhances treatment capacity by providing a diversity of habitat types and vegetation.



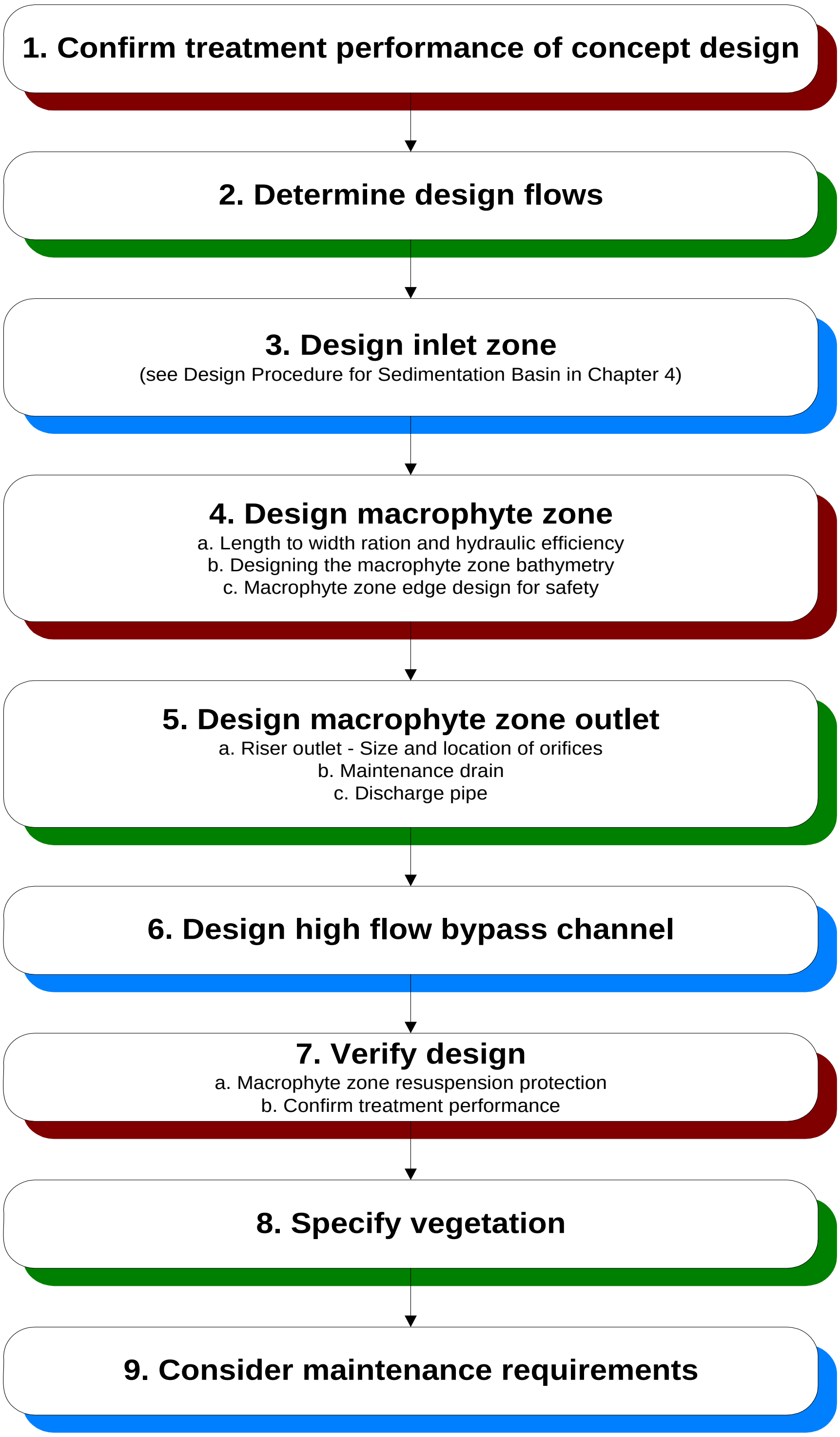


Outlet structures will allow Mean High Tide flows to inundate the estuarine area and freshwater flows to completely discharge during low tide event

Figure 6-4: Possible design features of Saline/Brackish Constructed Wetlands

6.3 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 6.8.

6.3.1 Step 1: Confirm Treatment Performance of Concept Design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the constructed wetland area (i.e. the macrophyte zone surface area) from the concept design is adequate to deliver the required level of stormwater quality improvement. This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. Where possible, this modelling should be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

6.3.2 Step 2: Determine Design Flows

6.3.2.1 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 (i.e. sedimentation basin) and the 'control' outlet structure (i.e. 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 year ARI) – for situations where only the minor drainage system is directed to the inlet zone. Townsville City Council guidelines should be referred to for the required design event for the minor design flow.
    - Major flood flow (50 year ARI) – for situations where both the minor and major drainage system discharge into the inlet zone.

6.3.2.2 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 6.2.7) 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.

6.3.3 Step 3: Design Inlet Zone

As outlined in Section 6.2.5, the inlet zone of a constructed stormwater wetland is designed as a sedimentation basin (refer Chapter 4) 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 6-5, the inlet zone consists of the following elements:

Plate 6-3: 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 Chapter 4) 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 Chapter 4) 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 Chapter 4 Sedimentation Basins. When applying the design procedure outlined in Chapter 4, the following should be used as a guide:

- The inlet zone typically must comprise a deep open water body that operates essentially as a sedimentation basin designed to capture coarse to medium sized sediment (i.e. 125 μm or larger).
- 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.
- The crest of the overflow pit must be set at the normal water level of the inlet zone (which is typically set 0.3 m above the normal water level of the macrophyte zone).
- 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 normal water level and without resulting in any flow over the high flow bypass weir.
- The obvert of the connection pipe can be set below the normal water level of the wetland to conceal the pipe (below the normal water level) during the dry season.
- An energy dissipater is usually required at the end of the pipes to reduce velocities and distribute flows into the macrophyte zone.
- The inlet zone is to have a structural base (e.g. rock) to define the base when desilting and provide support for maintenance plant/ machinery when entering the basin for maintenance.
- The high flow bypass weir ('spillway' outlet) is to be set at the same level as the top of extended detention in the macrophyte zone.

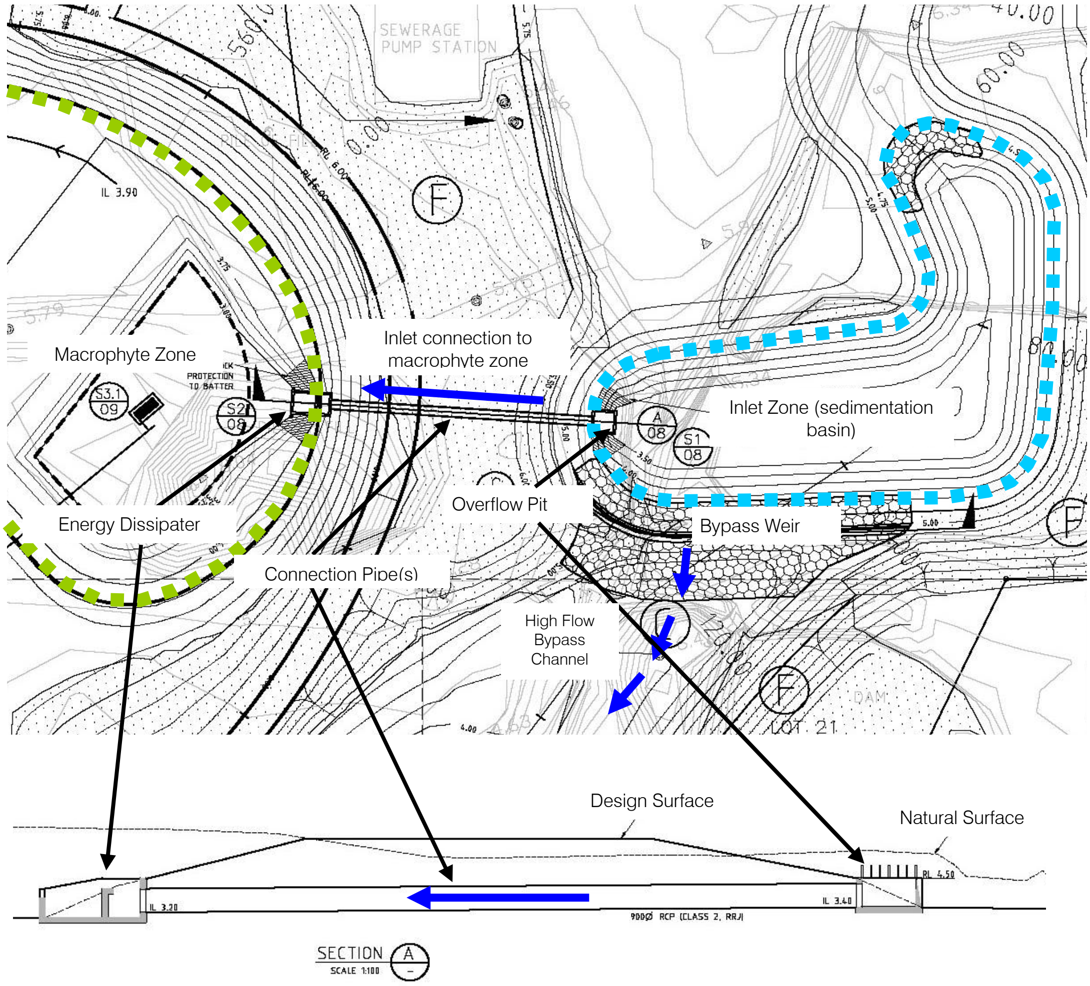


Figure 6-5: Example of Inlet Zone Connection to Macrophyte Zone

6.3.4 Step 4: Designing the Macrophyte Zone

6.3.4.1 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 6-6). 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.

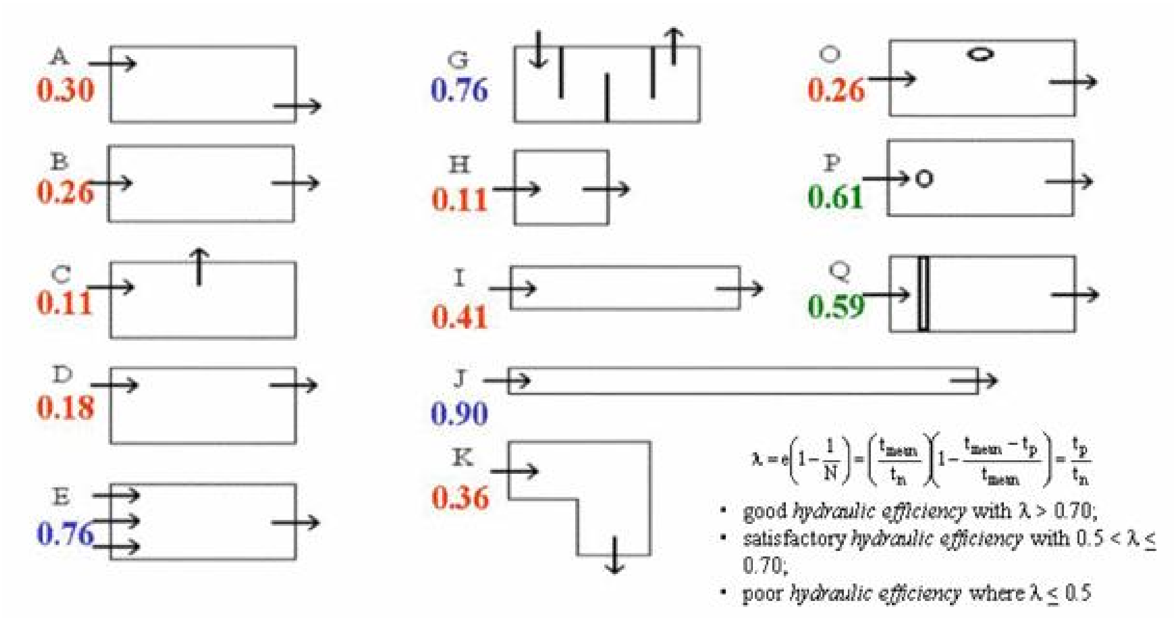


Figure 6-6: Hydraulic Efficiency (λ) Ranges

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).

6.3.4.2 Designing the Macrophyte Zone Bathymetry

The bathymetry of constructed wetlands in the Coastal Dry Tropics are to be designed to ensure that macrophytes can provide adequate pollutant removal during the wet season and also be sustained during the dry season. To achieve this, the longitudinal bathymetry of the macrophyte zone should gently grade (min 0.5% grade) from 0.7m in depth (based on design normal water level) up to a central crest 0.5m in depth and then back down to a maximum of 0.7m in depth. This ensures that isolated pools of water are not created during the dry season when the normal water level slowly draws down due to evapotranspiration. Smaller deep open water permanent pools at the inlet and outlet of the wetland are required to provide habitat for mosquito predators during the dry season (Refer to Figure 6-1 and Figure 6-2). For large wetlands, this bathymetry could be repeated in series (i.e. a deep pool located between two macrophyte zones).

The macrophyte zone is to have a flat cross sectional bathymetry only grading up at the edge batters (Figure 6-). This facilitates the even distribution of flows to avoid short circuiting, creates a uniform hydraulic conveyance and maximises stormwater contact with macrophyte stems and biofilms. This is also assisted by providing banded macrophyte planting perpendicular to the direction of flow (Plate 6-4).

The deep open water pools should be 2m in depth to ensure that a permanent pool of water is sustained throughout the dry season. This ensures habitat is retained for fish, macroinvertebrates (mosquito predators) and submerged macrophytes. Submerged macrophytes are important to provide habitat and for maintaining dissolved oxygen levels and therefore deeper pools (i.e. >2m) should be avoided. A balance pipe connection between the deep pools is necessary to allow inflows in dry conditions to benefit and sustain the deep permanent pools. The surface area of deep refuge pool (excluding the sediment basin) within the wetland should be between 20% and 30% of the total macrophyte area. This ensures the volume of water within the pools is sufficient to maintain permanent water during the dry season but not so large that the macrophyte zone is likely to experience dry periods of greater than 60 days (due to larger inflows required to fill the pools before wetting the macrophyte zone).

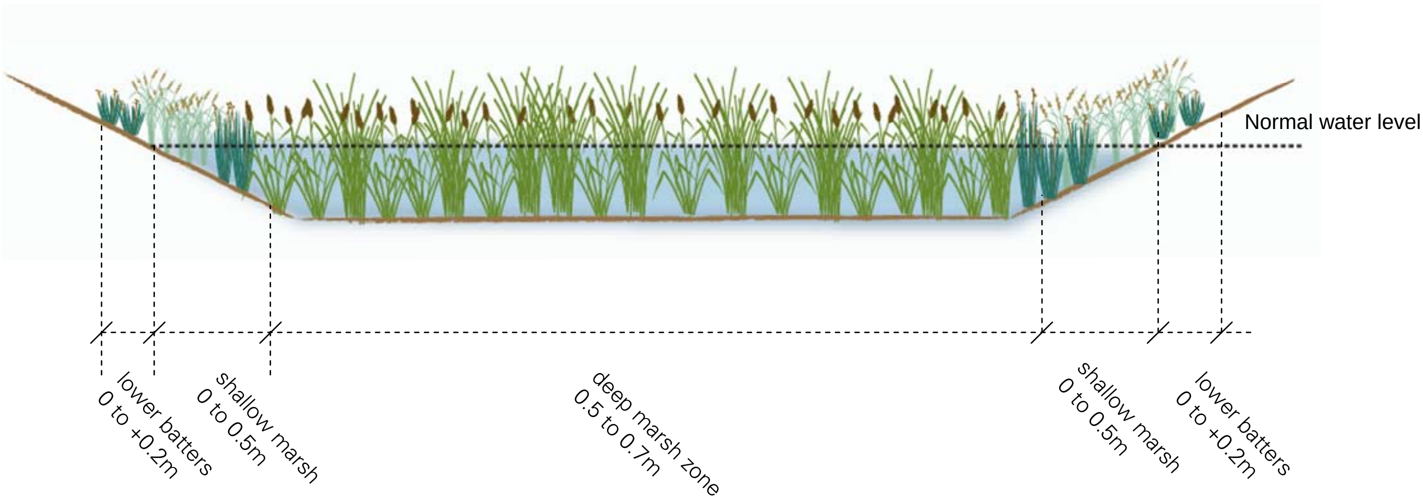


Figure 6-7: Typical cross section of a Constructed Wetland System showing preferred bathymetry and planting zones. Refer to Appendix A for more detail on planting zones and suitable macrophyte species.

Plate 6-4: Macrophyte Zone banded planting (direction of flow is from left to right).

6.3.4.3 Macrophyte Zone Edge Design for Safety

Consideration of public safety is required when wetlands are located in parklands/public open space or any areas readily accessible. Reducing public safety risk can be achieved in a number of ways and the measures adopted should respond to the level of perceived risk given the particular site characteristics.

One method of reducing the risk posed by water bodies is to design batter slopes on approaches and immediately under the normal water level (refer Figure 6-8). 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.

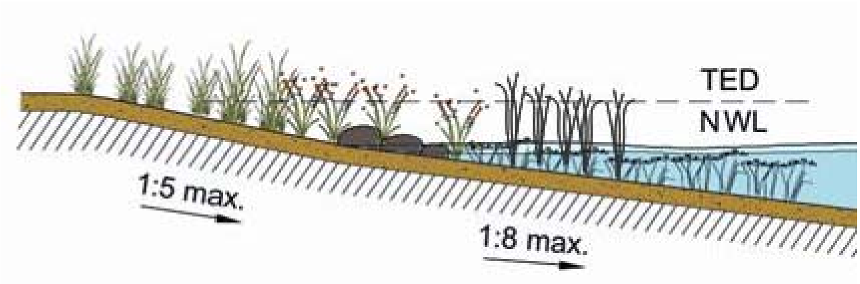


Figure 6-8: Example of a wetland edge design for public safety.

The safety requirements for individual wetlands will vary from site to site and requires careful consideration. The following requirements from the *Sediment Basin Design, Construction and Maintenance Guidelines* (BCC 2001) can be applied to constructed wetland systems:

- For water depths greater than 150 mm and maximum batter slope of 5:1 (H:V) or less, no fencing is required.
- For water depths greater than 150 mm and maximum batter slope greater than 5:1 (H:V) fencing may be required.

In some cases, vertical edges are used for wetlands (refer to Section 6.4). 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 0.5 m 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:

- dense vegetation at least 2 m wide and 1.2 m high (minimum) may be suitable.
- pool fence (or similar) when there is a chance of drowning and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields etc.)

6.3.4.4 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 (e.g. 300 mm thick). Specialist geotechnical testing and advice must be sought.

Wetland plants must be planted into suitable topsoil with a minimum depth of 200mm (see Section 6.5.4). Most terrestrial topsoils provide a good substratum for wetlands, nonetheless laboratory soil testing (using Australian Standard testing procedures, e.g. AS 4419-2003: *Soils for landscaping and garden use*) of topsoil is necessary to ensure the topsoil will support plant and microbial growth and have a high potential for nutrient retention. Careful consideration should be given to the topsoil source and its propensity to contain weed seeds which may be viable in an ephemeral wetland habitat.

6.3.5 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.

6.3.5.1 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 6.1

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 normal water 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 6.8.

$$A_o = \frac{Q}{C_d\sqrt{2 \cdot g \cdot h}}$$ (Small orifice equation) Equation 6.2

Where	C_d	=	orifice discharge coefficient (0.67)
	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

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 6-5 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 6-5: Example Outlet Riser Assemblies with Debris Guards

The pit is connected to the deep 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 normal water level (i.e. pipe obvert a minimum 0.3 m below normal water 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 6-7 and Plate 6-6 shows one possible configuration for a riser outlet pit.

Plate 6-6: Macrophyte Zone Outlet Arrangement

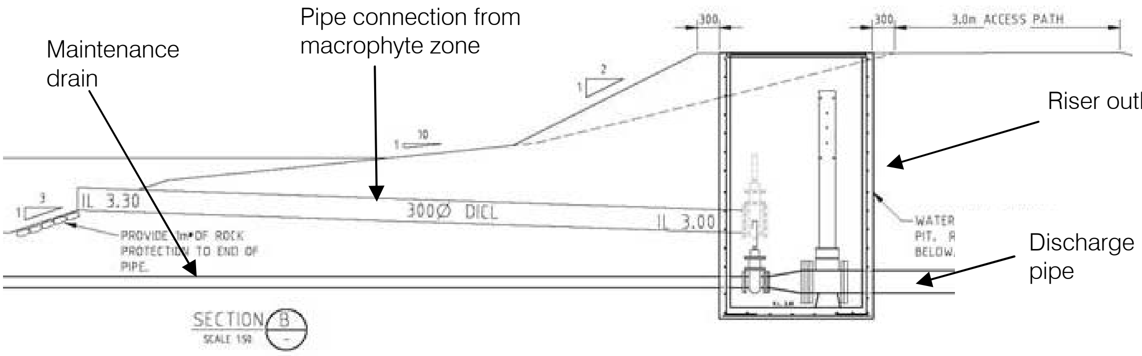


Figure 6-9: Typical Macrophyte Zone Outlet Arrangement

6.3.5.2 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 6-9), which can be operated manually. The maintenance drainage pipe should be sized to draw down the permanent pool within 12 hours (i.e. 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.

6.3.5.3 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 (i.e. maximum discharge from the riser or the maximum discharge from the maintenance drain).

6.3.5.4 Balance Pipe

A balance pipe connection between the deep permanent pools in the wetland is necessary to allow inflows in dry conditions to benefit and sustain all deep pools rather than just the pool located at the inlet. The deep pools are generally 2m in depth and may experience up to 1m of draw down during the dry season. The invert of the balance pipe should therefore be located approximately 1m below the normal water level. A 300mm diameter pipe is typically sufficient for a balance pipe.

6.3.6 Step 6: Design High Flow Bypass Channel

The bypass channel accepts 'above design flow' from the inlet zone (sediment pond) of the wetland via the bypass weir (Section 6.3.3) and conveys these flows downstream around the macrophyte zone of the wetland. The bypass channel should be designed using standard methods (i.e. Manning's Equation) to convey the 'above design flow' (Section 6.3.2) and to avoid bed and bank erosion (see Chapter 2). Typically, a turf finish will provide appropriate protection for most bypass channel applications (but velocities need to be checked). Dense planting can be applied when appropriately designed for in terms of design roughness and management of velocities. Plate 6-7 shows typical high flow bypass channel configurations.

Plate 6-7: Turfed constructed wetland high flow bypass weir configuration.

6.3.7 Step 7: Verify Design

6.3.7.1 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:

$$\frac{Q_{max\ riser}}{A_{section}} < 0.05\text{m/s} \qquad \text{Equation 6.3}$$

Where $Q_{max\ riser}$ = target maximum discharge (defined in equation 6.1) (m^3/s)

$A_{section}$ = minimum wetland cross-section area* (m^2) x 0.5 vegetation blockage factor**

*measured from top of extended detention

**blockage due to tall dense vegetation

6.3.7.2 Confirm Treatment Performance

If the basic wetland parameters established by the conceptual design phase have changed during the course of undertaking detailed design (e.g. 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 a suitable quantitative modelling program.

6.3.8 Step 8: Specify Vegetation

Refer to Section 6.4 and Appendix A for advice on selecting suitable plant species for constructed wetlands.

6.3.9 Step 9: Consider Maintenance Requirements

Consider how maintenance is to be performed on the wetland (e.g. how and where is access available, where is litter likely to collect etc.). A specific maintenance plan and schedule should be developed for the wetland, either as part of a maintenance plan for the whole treatment train, or for each individual asset. Guidance on maintenance plans is provided in Section 6.6.

6.3.10 Design Calculation Summary

Following is a design calculation summary sheet for the key design elements.

CONSTRUCTED WETLANDS DESIGN CALCULATION SUMMARY

	Calculation Task		CALCULATION SUMMARY Outcome	Check
	Catchment Characteristics			
		Catchment area	ha	
		Catchment land use (i.e. residential, commercial etc.)		
		Storm event entering inlet pond (minor or major)		
	Conceptual Design			
		Macrophyte zone area	m^2	
		Normal level of macrophyte zone	m AHD	
		Extended detention depth (0.25-0.5m)	m	
		Notional detention time	hrs	
1	**Confirm Treatment Performance of Concept Design**			
		Total suspended solids	% removal	
		Total phosphorus	% removal	
		Total nitrogen	% removal	
2	**Determine design flows**			
		'Design operation flow' (1 year ARI)	year ARI	
		'Above design flow' (2-50 year ARI)	year ARI	
	Time of concentration			
	Refer to *Handbook for Drainage: Design Criteria* (TCC 2004) and QUDM		minutes	
	Identify rainfall intensities			
		'Design operation flow' - $I_{1\ year\ ARI}$	mm/hr	
		'Above design flow'- $I_{2-50\ year\ ARI}$	mm/hr	
	Peak design flows			
		'Design operation flow' 1 year ARI	m^3/s	
		'Above design flow' 2-50 year ARI	m^3/s	
3	**Design inlet zone**			
	Refer to sedimentation basin (Chapter 4) 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 Chapter 4)	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 by-pass weir			
		Weir Length	m	
		High flow by-pass weir crest level (top of extended detention)	m AHD	
4	**Designing the macrophyte zone**			
		Area of Macrophyte Zone	m^2	
		Aspect Ratio	L:W	
		Hydraulic Efficiency		

CONSTRUCTED WETLANDS DESIGN CALCULATION SUMMARY				
			CALCULATION SUMMARY	
	Calculation Task		Outcome	Check
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 by-pass 'channel'			
		Longitudinal slope	%	
		Base width	m	
		Batter slopes	H:V	
7	Verification checks			
		Macrophyte zone re-suspension protection		
		Confirm treatment performance		

6.4 Landscape Design Notes

Whilst constructed wetlands play a significant role in delivering stormwater quality objectives, they can also play an important role in creating a community landscapes and urban ecology. The following sections outline some of the landscape design issues that should be considered when designing constructed wetland systems.

6.4.1 Objectives

Landscape design of wetlands generally requires consideration of the following objectives:

- 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.
- Achieving dense perennial littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season.
- Ensuring that the wetland planting strategy is based on the wetland design depths/zones, achieves dense perennial emergent macrophyte cover and has the structural characteristics to perform particular treatment processes (e.g. well distributed flows, enhance sedimentation, maximise surface area for the adhesion of particles and provide a substratum for algal epiphytes and biofilms).
- Providing maintenance access to allow for the prompt removal of weeds before they spread and/or set seed.
- Incorporating Crime Prevention Through Environmental Design (CPTED) principles.
- 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. For further guidance refer to the *South East Queensland WSUD Conceptual Design Guidelines* (Healthy Waterways Partnership, 2008)

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.

6.4.2 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, in particular planting types as they relate to the different vegetation communities in the shire.

6.4.3 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 (see Figure 6-10). 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 can be manipulated to provide open spaces that only periodically convey stormwater flows. Further discussion of high flow bypass configuration is provided in Section 6.4.4.3.

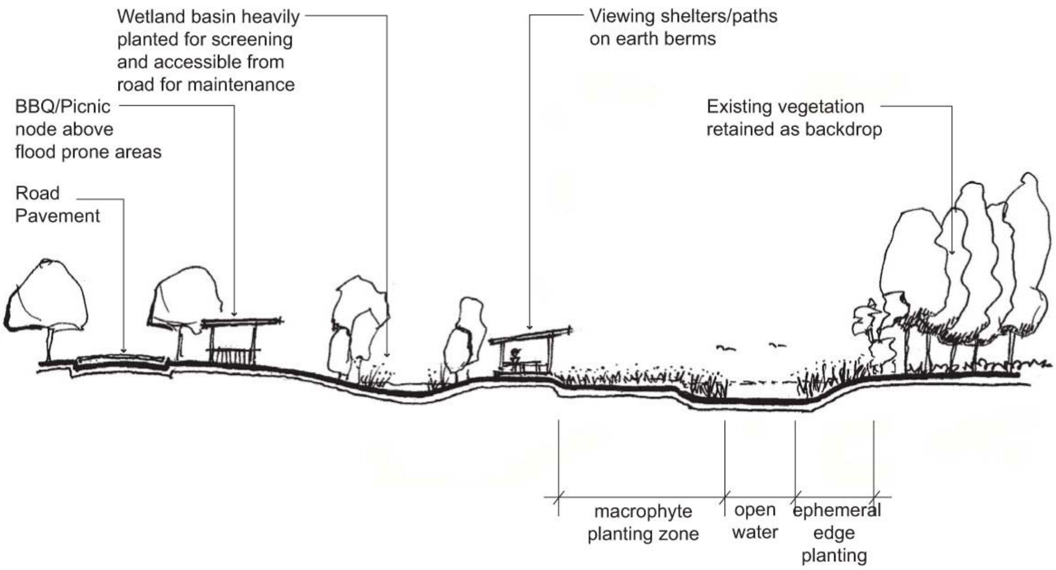


Figure 6-10: Typical landscape treatments to constructed wetlands in open space areas

Plate 6-8: Boardwalk treatment over wetland (right) and integration of urban art with wetland setting (left)

6.4.4 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.

6.4.4.1 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.
- Earth bunds located between the sedimentation basin and macrophyte zone can be used as crossings and can be planted as a shaded walkways.
-

Figure 6-11 illustrates a conceptual earth bund walkway.

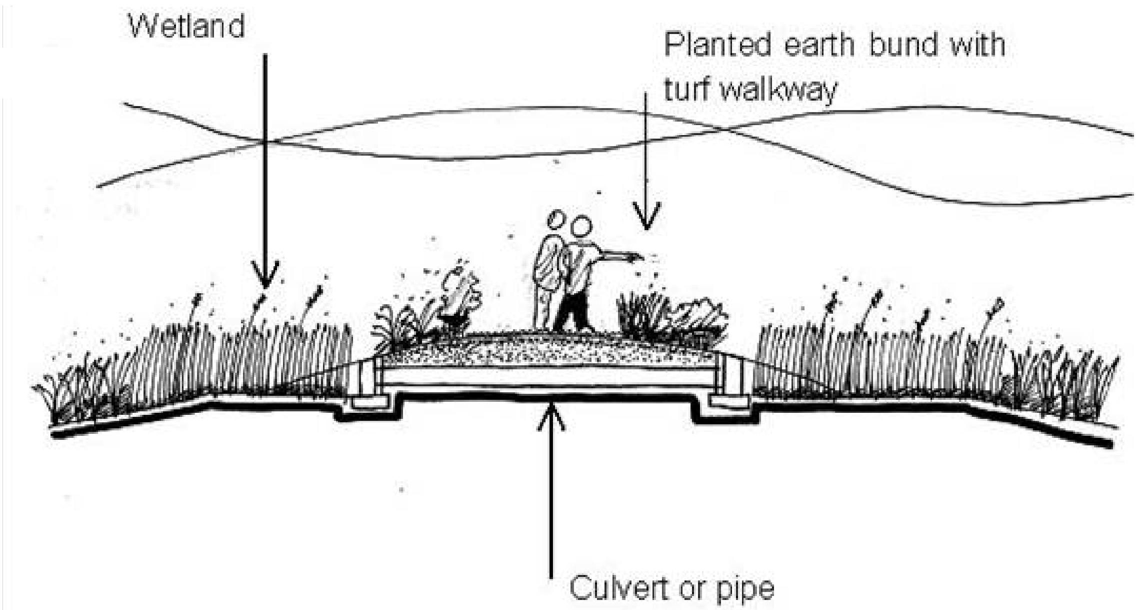


Figure 6-11: Earth Bund Structure as Wetland Crossing

6.4.4.2 Wetland Embankments

The landscape design approach for the wetland embankments is similar to the approach taken for embankments in sedimentation basins. Refer to Chapter 4, Section 4.4.3.3 for guidance.

6.4.4.3 High Flow Bypass Channel

The high flow bypass channel will convey stormwater during above design flow and in some situations can form a large element in the landscape. Therefore the design of the high flow bypass needs to be carefully considered to provide recreational and landscape opportunities during times outside of above design flow events.

The key considerations for design of the high flow bypass area are as follows:

- No major park infrastructure including playgrounds, barbeques and amenity buildings to be located within the high flow bypass areas. Passive recreation infrastructure including seating and picnic tables are suitable provided they are of robust design.
- In many cases, the high flow bypass will be formed through the use of turf and in these cases the opportunity for creating more active spaces should be investigated.
- Designers should 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.
- Where groundcover species other than turf are adopted, plant species should be selected to ensure appropriate response after periodic flooding.
- 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.
- 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 62 (following page) provides an illustration of creation of open spaces through configuration of key wetland components.

6.4.4.4 Macrophyte Zone Outlet Structure

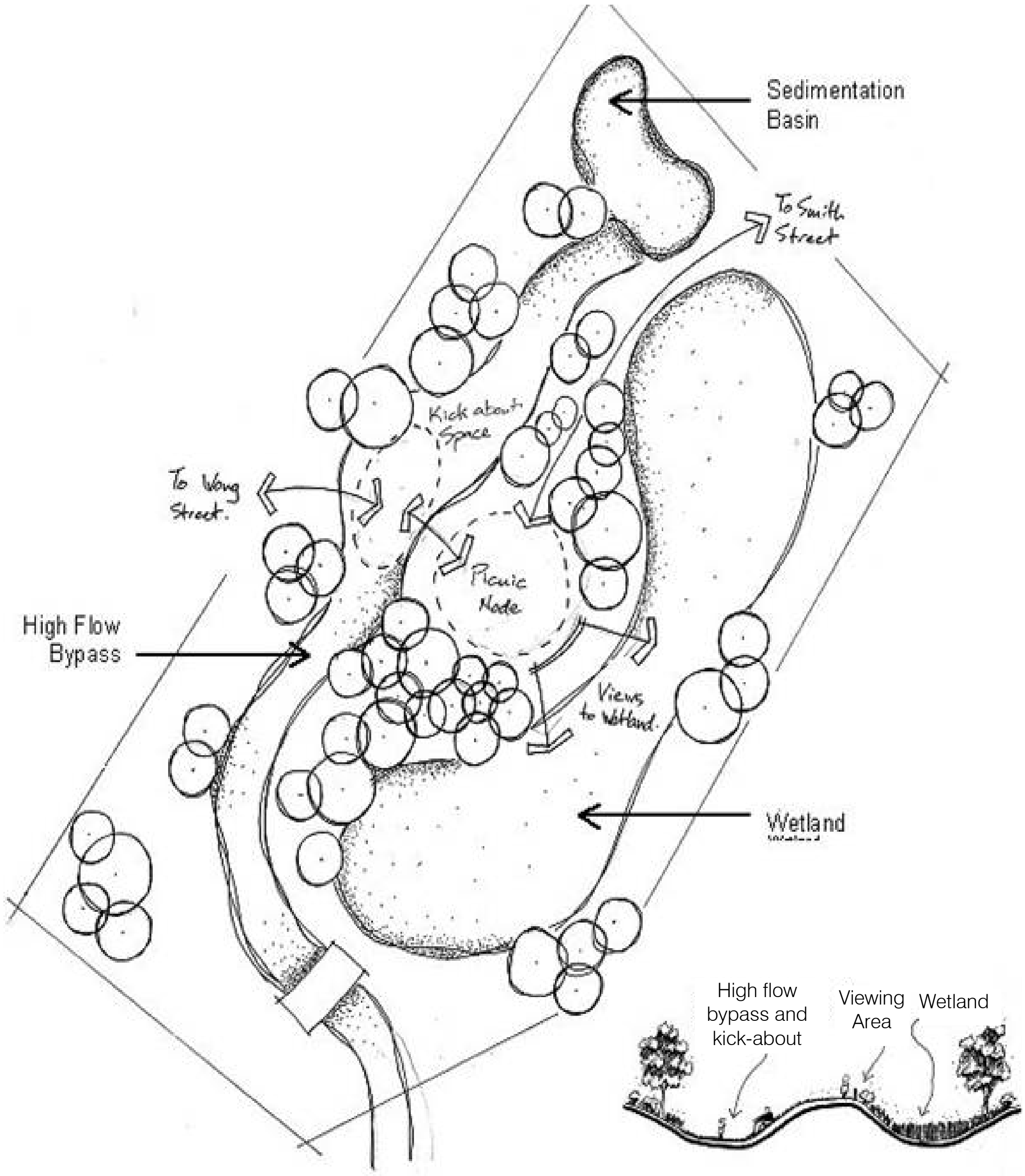
Landscape design approach for the macrophyte outlet zone is similar to the approach taken for overflow pits in sedimentation basins. Refer to Chapter 4, Section 4.4.3.6 for further guidance.

6.4.4.5 Viewing Areas

Refer to Chapter 4, Section 4.4.3.8 for guidance.

6.4.4.6 Fencing

Refer to Chapter 4, Section 4.4.3.9 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 6-12: Example Relationship between High Flow Bypass, Wetland and Basin and the Creation of Open Space

6.4.5 Constructed Wetland Vegetation

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

- Macrophyte zone planting consisting of deep marsh (0.5m – 0.7m in depth at design normal water level) and shallow marsh (edges) (0.5m – 0m in depth at design normal water level)
- Littoral vegetation (embankment) (above design normal water level)
- Terrestrial plants, including existing vegetation, adjacent to the upper littoral edge.

6.4.5.1 Macrophyte Zone Planting (from 1.0 m below to 0.2 m above design water level)

Appendix A 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 planting perpendicular to flow that respond to designed depth zones and local biodiversity.

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.

This is achieved by selecting species with many small diameter vertical leaves or stems and planting the vegetation in bands. When selecting suitable species it is important to also note the ability of some species to be highly self-sustaining. Native macrophytes that distribute themselves across new wetlands quickly by producing large quantities of seed material are great for colonizing and minimizing costs of replacements and weed management. However, these types of plants should only be used if they meet the landscape and stormwater treatment objectives (e.g. are aesthetic and have a suitable structural form) and do not pose an invasive threat to downstream receiving environments. Additionally, littoral planting should provide a dense buffer between the wetland and publicly accessible open space to discourage contact with the water.

6.4.5.2 Littoral Vegetation (above design water level) and Parkland Vegetation

Between the macrophyte zone and the top of the embankment, establishment of trees, shrubs and groundcovers can occur in consideration of the following:

- Selecting groundcovers, particularly for slopes greater than 1 in 3, with matting or rhizomatous root systems to assist in binding the soil surface during the establishment phase.
- Achieving dense perennial littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season.
- Preventing macrophyte zone plants and ground covers 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 wetland 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.

6.4.6 Safety Issues

6.4.6.1 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. Fences can be substituted where possible by using dense edge plantings to deter public access to areas of open water. Dense littoral vegetation that can grow to around 2 m high and 1.5 m wide are effective in deterring public access.

6.4.6.2 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 relevant local government guidelines.

6.4.6.3 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 0.5 m 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 grassed areas requiring mowing abut the asset.

Barriers that may be appropriate are:

- dense vegetation at least 2 m wide and 1.2 m high (minimum) may be suitable.
- pool fence (or similar) when there is a chance of drowning and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields etc.)

Dense littoral planting around the wetland and particularly around the deeper open water pools of the sediment pond (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 (e.g. 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 2 m wide and 1.2 m high (minimum) may be suitable. A temporary fence may be required until the vegetation has established and becomes a deterrent to pedestrians.

An alternative to the adoption of a barrier/ fence is to provide a 2.4 m safety bench that is less than 0.2 m deep below the normal water level around the waterbody. This is discussed in Chapter 4 Section 4.3.3.3 with respect to appropriate batter slopes.

6.5 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.

6.5.1 Staged Construction and Establishment Method

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 (i.e. two years) before the vegetation in the systems has reached its design condition (i.e. 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).

6.5.1.1 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 6-).

- <u>Subdivision Construction</u> - 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.
- <u>Building Phase</u> - Once the Subdivision Construction works are complete and the development plans are sealed then the Building Phase can commence (i.e. 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.

6.5.1.2 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 6-13):

- <u>Stage 1: Functional Installation</u> - Construction of the functional elements of the constructed wetland at the end of Subdivision Construction (i.e. during landscape works) and the installation of temporary protective measures.
- <u>Stage 2: Sediment and Erosion Control</u> – 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.

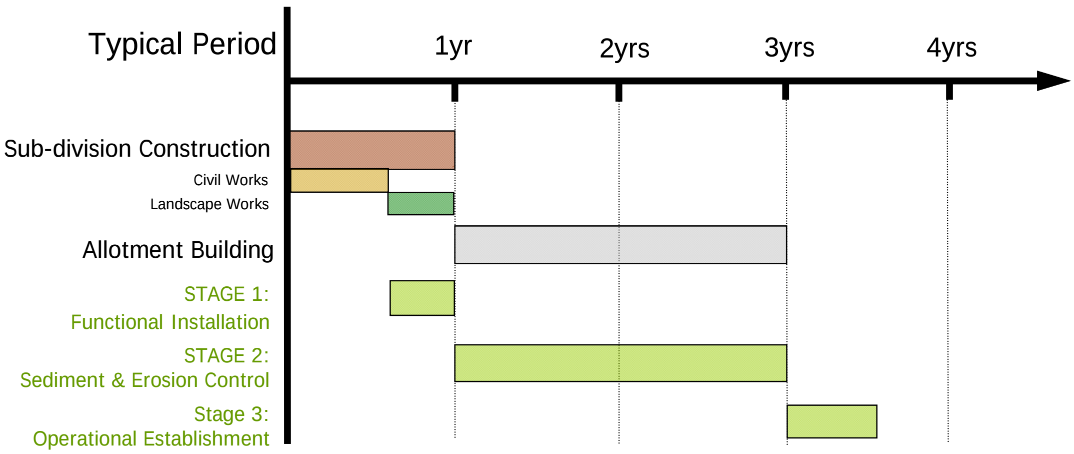


Figure 6-13: Staged Construction and Establishment Method

6.5.1.3 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. Irrigation of edges may be required.
- Planting the littoral zone and providing irrigation to ensure fast establishment of dense vegetation to minimise weed growth.

Plate 6-10: Constructed Wetland Functional Installation

6.5.1.4 Sediment and Erosion Control

During Allotment Building Phases the sedimentation pond can be used to reduce the load of coarse sediment discharging to the receiving environment. The disconnection between the sediment pond and the macrophyte zone 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.

Plate 6-10: Constructed Wetland Sediment & Erosion Control Operation

This means the Macrophyte Zone can be fully commissioned and made ready for operation once the Allotment Building Phase is complete.

6.5.1.5 Operational Establishment

At the completion of the Allotment Building Phase the sediment pond is de-silted, the disconnection between the sediment pond and macrophyte zone is removed and the constructed wetland is allowed to operate in accordance with the design.

Plate 6-11: Constructed Wetland Operation Establishment

6.5.2 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 macrophyte 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.

6.5.3 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 Appendix A 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

'Floral Edges', a system of interlocking plants within one long container is recommended for wetland planting, particularly for the deep marsh zone. The series of plants (usually 5) are grown together in a single 'strip' container. Generally, these 'floral edges' are supplied as more mature plants with developing rhizomes (for rhizomatous species) and 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.

6.5.4 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 (e.g. 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 200mm deep and preferably 300mm in depth for improved dry season moisture retention.

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, e.g. AS 4419-2003: *Soils for landscaping and garden use*) 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.

Careful consideration should be given to the topsoil source and its propensity to contain weed seeds which may be viable in an ephemeral wetland habitat. If a problematic weed bank is likely to be present within the topsoil then importing alternative topsoil should be considered. 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.

6.5.4.1 Topsoil Treatments

The wetland topsoil should be tested in accordance with AS 4419-2003: *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 (i.e. clear water with no aquatic plants competing for resources).

6.5.5 Vegetation Establishment

6.5.5.1 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 (e.g. use of matting or sterile grasses to stabilise exposed batters) should always be used prior to planting.

6.5.5.2 Water Level Manipulation

To maximise the chances of successful emergent macrophyte 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 zone 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 sediment pond and the macrophyte zone (i.e. covering the overflow pit) and opening the maintenance drain. The deep marsh zones should have a water depth of approximately 0.2 m for at least the first 6 - 8 weeks. This will ensure the deep marsh zones of the wetland are inundated to shallow depth and the shallow marsh edges remain moist (muddy) providing suitable conditions for plant establishment. Seedlings planted in the littoral zones of the wetland will require ongoing watering at a similar rate as the terrestrial landscape surrounding the wetland (Section 6.4.6.3). 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.

6.5.5.3 Weed Control

To protect landscape amenity and the stormwater treatment efficiency of the wetland it is important to maintain, throughout the year, the design vegetation communities to avoid excessive colonisation of the wetland by weeds. Weed infestation is a major problem in the Dry Tropics, particularly within ephemeral waterways and stormwater treatment facilities, therefore, the design and management of the wetland to manage weed infestation takes on high importance. Management of weeds is achieved as follows:

- Designing the macrophyte zone as predominately a deep marsh system (i.e. water depth 0.5m - 0.7m) to maintain the macrophyte vegetation by minimising the frequency and duration of wetland drying, thus permanently occupying the habitat and restricting weed colonisation opportunities.
- Planting dense littoral vegetation around the perimeter of the wetland to avoid the ingress of weed species. To maintain dense perennial littoral vegetation, irrigation is likely to be required, particularly during the dry season.
- Maintaining dense macrophyte vegetation in the wetland during prolonged dry conditions is necessary to avoid opening up habitat opportunities for weeds. When the macrophyte zone dries (i.e. the macrophyte zone sediments are exposed) for a period in excessive of 60 days, irrigation of the macrophyte zone may be required to achieve this.

During the establishment and ongoing maintenance of the wetland, prompt removal of weeds before they spread and/or set seed is of critical importance.

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 (e.g. jute mesh).

6.5.5.4 Watering

Regular watering of the littoral vegetation during the plant establishment phase is essential for successful establishment and vigorous 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 (i.e. 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, irrigation will still be required, particularly during the dry season. Watering requirements to sustain healthy dense vegetation should be determined during ongoing monitoring and maintenance site visits.

6.5.5.5 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 (i.e. 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.

6.6 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 Chapter 4). 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:

- irrigation of the littoral zone plants (especially during dry periods) to prevent the ingress of invasive weeds
- prompt removal of weeds before they spread and/or set seed is of critical importance
- desilting the inlet zone following the construction/ building period
- routine inspection of the wetland to identify any damage to vegetation, weed growth, 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
- watering of wetland macrophytes during prolonged dry periods (in excess of 60 days)
- 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 (Step 9). 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 (i.e. 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 the local authority. Refer to the guidelines or direction from the relevant local authority 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 6.7.3. These forms must be developed on a site specific basis as the configuration and nature of constructed wetlands varies significantly.

6.7 Checking Tools

This section provides a number of checking aids for designers and Council development assessment officers. In addition, Section 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).

6.7.1 Design Assessment Checklist

The checklist on page 6-41 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.

6.7.2 Construction Checklist

The checklist on page 6-42 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.

6.7.3 Operation and Maintenance Inspection Form

The example form on page 6-43 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.

6.7.4 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 table on page 6-43 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):

TREATMENT	Y	N
MUSIC modelling performed?		
INLET ZONE	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 normal water level above macrophyte normal water 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)		
Balance pipe connected between deep (refuge) pools		
MACROPHYTE ZONE	Y	N
Extended detention depth of 0.5 m?		
Vegetation bands perpendicular to flow path?		
Appropriate depth of macrophyte vegetation (deep marsh ranging from 0.5 m to 0.7 m with no areas where water can pond)?		
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 (i.e. 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	Y	N
Riser outlet provided in macrophyte zone?		
Notional detention time of 48 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:	
Constructed by:		Time:	
		Weather:	
		Contact During Visit:	

Items inspected	Checked		Satisfactory		Items inspected	Checked		Satisfactory	
	Y	N	Y	N		Y	N	Y	N
DURING CONSTRUCTION									
A. FUNCTIONAL INSTALLATION					Structural components cont				
Preliminary Works					22. Ensure spillway is level				
1. Erosion and sediment control plan adopted					23. Provision of maintenance drain(s)				
2. Limit public access					24. Collar installed on pipes				
3. Location same as plans					25. Balance pipe installed				
4. Site protection from existing flows					26. Protection of riser from debris				
5. All required permits in place					27. Bypass channel stabilised				
Earthworks					28. Erosion protection at macrophyte outlet				
6. Integrity of banks					Vegetation				
7. Batter slopes as plans					29. Vegetation appropriate to zone (depth)				
8. Impermeable (e.g. clay) base installed					30. Weed removal prior to planting				
9. Maintenance access to whole wetland					31.Provision for water level control				
10. Compaction process as designed					32. Vegetation layout and densities as designed				
11. Placement of adequate topsoil					33. Provision for bird protection				
12. Levels as designed for base, benches, banks and spillway (including freeboard)					34. By-pass channel vegetated				
13. Check for groundwater intrusion									
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. Pre-treatment 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)
Irrigation of littoral zone plants required?			
Irrigation of wetland macrophytes require (prolonged dry period)?			
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)?			
Balance pipe not blocked (deep pools of equal water level)?			
Resetting of system required?			

COMMENTS

ASSET TRANSFER CHECKLIST		
Asset ID:		
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 and vegetation dense, healthy and free from weeds?		
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 (e.g. drawings, survey, models) provided?		
Asset listed on asset register or database?		
COMMENTS		

6.8 Constructed Wetland Worked Example

As part of a residential development in Townsville, 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 6-3. 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 (15 lots/ hectare) served by 14 m wide local road reserves. Due to the moderate to steep 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 (50 year ARI) entering via overland flow.

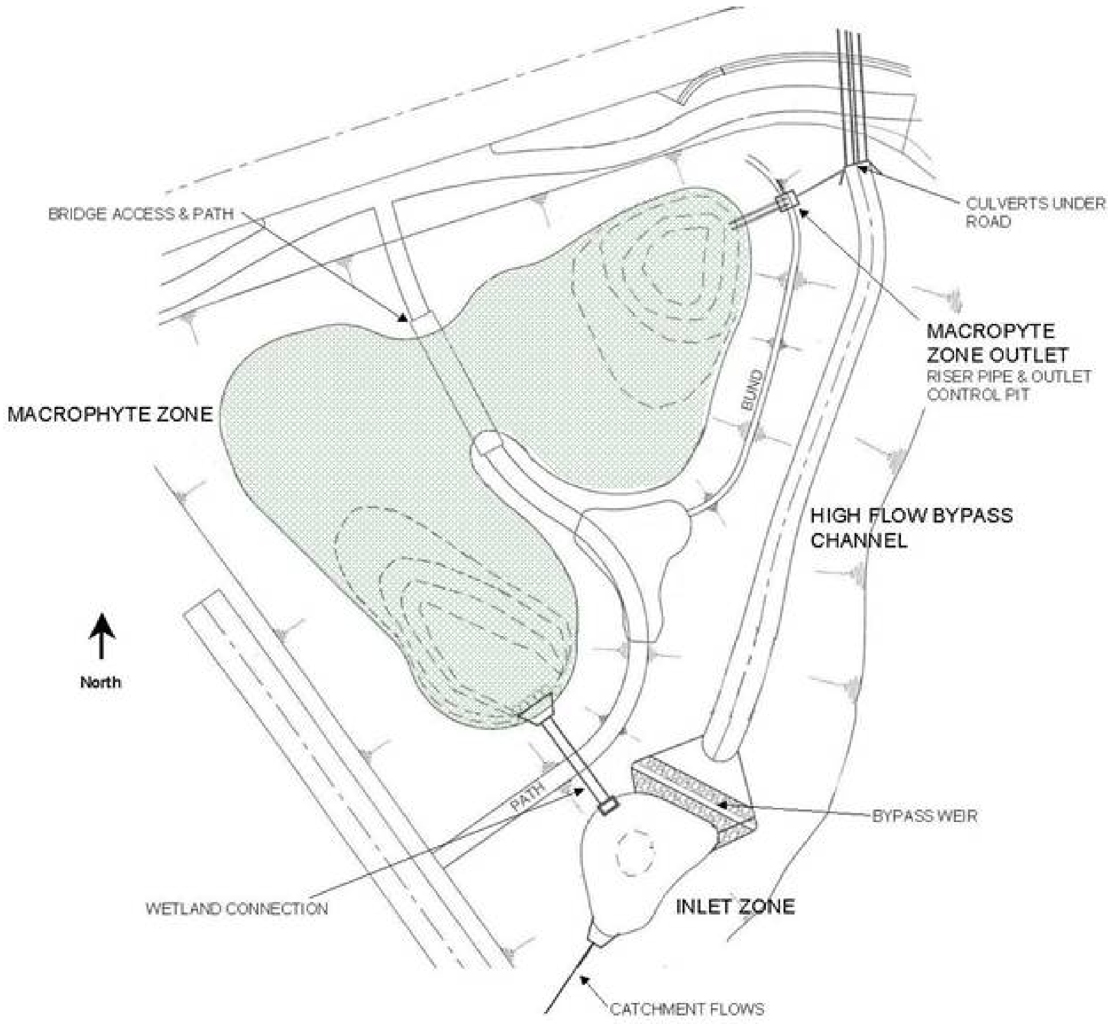


Figure 6-34: Layout of Proposed Wetland System

Site Characteristics

The site has a moderate fall of 2.5 m 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 6-34) established the following key design elements to ensure effective operation:

- wetland macrophyte zone extended detention depth of 0.5 m, normal water level of 11.5 m AHD and an area of 5000 m^2
- inlet zone normal water level of 11.7 m AHD, which is 0.2 m above the normal water level of the macrophyte zone
- bypass weir ('spillway' outlet) level of 12 m AHD set at the top of extended detention in the wetland macrophyte zone and 0.3 m above the inlet zone normal water level
- high flow bypass channel longitudinal grade of 1.5%.

During the conceptual design phase, the configuration described above and shown in Figure 6-3 was modelled using MUSIC to ensure the stormwater discharges from the site comply with Townville City Council water quality objectives (WQOs), being a minimum 65 % reduction in mean annual TSS load; 55 % reduction in mean annual TP load and 35 % reduction in mean annual TN load. To achieve these objectives, the wetland concept required a macrophyte zone area of 5500 m^2, extended detention depth of 0.5 m and detention time of 48 hours.

6.8.1 Step 1: Verify size for Treatment

Quantitative modelling of treatment performance with the input parameters from the concept design above are used to estimate the reduction performance of the constructed wetland system to ensure the design will achieve target pollution reductions. The wetland size to deliver the required load reductions (based on 0.5 m extended detention depth) is 5.5 % of the catchment area, equating to 5500 m^2 (macrophyte zone area). This verifies the quantitative modelling results undertaken during the concept design phase and confirms the wetland conceptual design can be now progressed to detailed design and documentation.

6.8.2 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 (2 year ARI) and the major storm (50 year ARI) flows enter the inlet zone of the wetland. Therefore, the 50 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 using QUDM (DNRW, IPWEA & BCC 1998) and local government guidelines. The time of concentration (t_c) was calculated using the procedures outlined in Section 4.06 of QUDM and found to be 10 minutes. The coefficient of runoff was taken from local government guidelines as follows:

C_{10} = 0.82 (from QUDM)

	C Runoff		
ARI	1	10	50
QUDM Factor	0.85	1	1.15
C_{ARI}	0.656	0.8	0.943

Catchment area, A = 10 ha

Rainfall Intensities, t_c = 10 mins

I_1 = 91.9 mm/hr

I_{50} = 224 mm/hr

Rational Method *Q* = *CIA*/360

'Design operation flow' (1 year ARI) = 1.67 m^3/s

'Above design flow' (50-year ARI) = 5.87 m^3/s

6.8.3 Step 3: Design Inlet Zone

The design of the inlet zone is undertaken in accordance with the design procedures outlined in Chapter 4 with a summary of the key inlet zone elements provided below.

6.8.3.1 Inlet Zone (Sedimentation Basin) Size

An initial estimate of the inlet zone area can be established using the curves provided in Figure 6-15 (showing Figure 4.3 of Chapter 4). Assuming a notional deep pool depth of 2 m and an inlet zone extended detention depth of 0.3 m (i.e. 0.5 m macrophyte zone extended detention depth – 0.2 m level difference between the deep pools), a sedimentation basin area of 360 m^2 is required to capture 90% of the 125 μm particles for flows up to the 'design operation flow' (1 year ARI = 1.67 m^3/s). Confirmation of the sedimentation basin area is provided by using Equation 4.1 in Chapter 4.

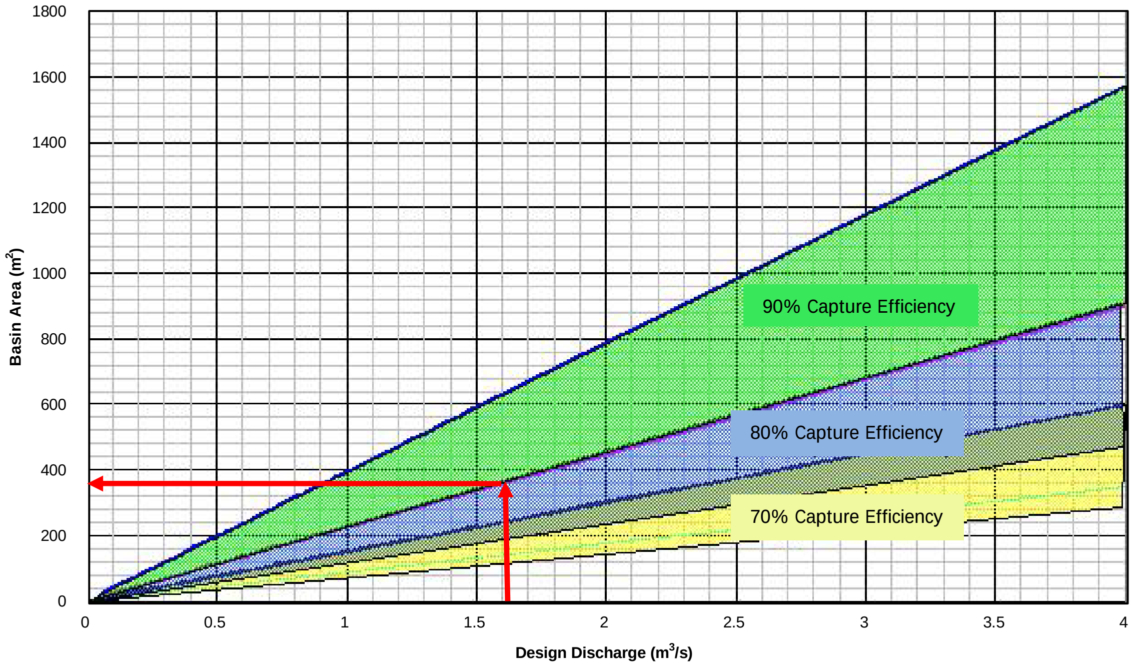


Figure 6-45: Figure 4.3 from Chapter 4 (reproduced for this example)

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 Chapter 4):

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 normal water level the area of the basin at 1 m depth is 153 m^2 and at 2 m depth 17 m^2. Therefore, the sedimentation basin storage volume V_s is 85 m^3.

The volume of accumulate sediments over 5 years ($V_{s:5yr}$) is established using Equation 4.3 from Chapter 4 (using a sediment discharge rate of 1 m^3/Ha/yr):

$$V_{s:5yr} = A_c \quad R \quad L_o \quad F_c \qquad = 10 \times 0.9 \times 1 \times 5 = 45\ m^3$$

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

6.8.3.2 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 = 1.67 m^3/s). As defined by the conceptual design (Section 6.8) the follow design elements apply:

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

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

<u>Overflow Pit</u>

According to Section 4.3.5 in Chapter 4, 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 4.4 (Chapter 4), the required perimeter of the outlet pit to pass 1.67 m^3/s with an afflux of 0.3 m can be calculated assuming 50% blockage:

$$P = \frac{Q_{des}}{B \cdot C_w \cdot h^{3/2}} = \frac{1.67}{0.5 \cdot 1.66 \cdot 0.3^{3/2}} = 12.25\ \text{m}$$

Orifice Flow Conditions

From Equation 4.5 (Chapter 4), the required area of the outlet pit can be calculated as follows:

$$A_o = \frac{Q_{des}}{B \quad C_d \sqrt{2 \quad g \quad h}} = \frac{1.67}{0.5 \cdot 0.6\sqrt{2 \cdot 9.79 \cdot 0.3}} = 2.30\ \text{m}^2$$

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 3100 x 3100 mm pit size is adopted providing a perimeter of 12.4 m which is greater than the 12.25 m 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.

<u>Connection Pipe(s)</u>

As the connection pipe (i.e. 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:

$$A_{pipe} = \frac{Q}{V} = \frac{1.67}{2.21} = 0.756 \text{ m}^2$$

This area is equivalent to two (2) 750 mm reinforced concrete pipes (RCPs). The obvert of the pipes is set 500 mm below the normal water level in the wetland macrophyte zone (11.0 m AHD) meaning the invert is at 10.25 m AHD (to minimise exposure of the pipe obvert in the dry season).

6.8.3.3 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 0.3 m above the normal water level of the inlet pond (sediment pond).

Assuming a maximum afflux of 0.3 m, the weir length is calculated using the weir flow equation (Equation 4.4 in Chapter 4):

$$L = \frac{Q_{des}}{C_w \cdot H^{3/2}} = \frac{5.87}{1.66 \cdot 0.3^{3/2}} = 21.52 \text{ m (adopt 22 m)}$$

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

Inlet Zone Area	= 360 m^2 set at 11.7 m AHD
Overflow pit	= 3000 x 4000 mm with letter box grate set at 11.7 m AHD
Pipe connection (to wetland)	= 2 x 750 mm RCPs at 10.25 m AHD
High flow bypass weir	= 22 m length set at 12.0 m AHD

6.8.4 Step 4: Designing the Macrophyte Zone

6.8.4.1 Length to Width Ratio and Hydraulic Efficiency

A macrophyte zone area of 5000 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 6-3 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 6-6 (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

6.8.4.2 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 a deep marsh zone and a deep open water zone as depicted in Figure 6-5 and described below:

- The bathymetry across the deep marsh zone is to grade gradually over its length, ranging from 0.5 m to 0.7m below normal water level (see Figure 6-16 and Table 6-2).

- The deep refuge pools upstream and downstream of the deep marsh zone is to be connected via the maintenance drain to ensure the upstream deep pool can drain down to 11.5 m AHD following a rainfall event.
- The depth of the deep pool in the vicinity of the outlet structure is to be 2 m below the normal water 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.

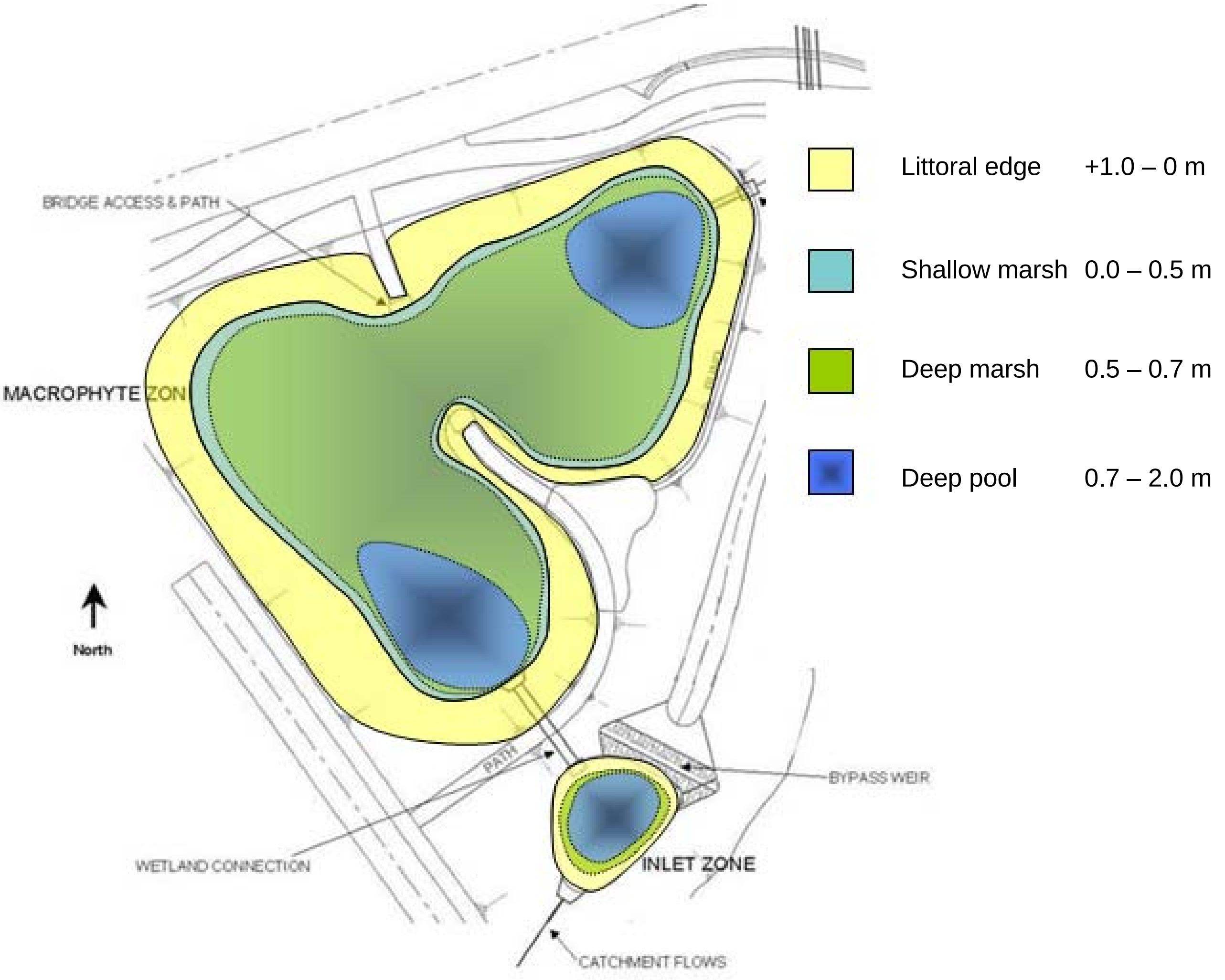


Figure 6-56: Layout of Marsh Zones

Table 6-2: Indicative Break of Marsh Zones

Zone	Depth Range (m)	Proportion of Macrophyte Zone Surface Area (m)
Deep Refuge Pool	0.7-2.0 below normal water level	20%
Deep Marsh	0.5 – 0.7 below normal water level	70%
Shallow Marsh	0.0 – 0.2 below normal water level	10%

6.8.4.3 Macrophyte Zone Edge Design for Safety

The batter slopes on approaches and immediately under the normal 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 0.3 m 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).

Reference is made to the construction drawings in Section 6.3.4.2 for a typical cross section of the macrophyte zone.

6.8.5 Step 5: Design the Macrophyte Zone Outlet

6.8.5.1 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 6.1):

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

Extended detention storage = 5500 m^2 x 0.5 m extended detention

= 2750 m^3

Notional detention time = 48 hrs x 3600 s/hr

Therefore, $Q_{\text{max riser}}$ = 2750/(48 x 3600) = 0.0147 m^3/s = 15.9 L/s

The placement of orifices along the riser and determining their appropriate diameters involves iterative calculation using the orifice equation (Equation 6.2) over discrete depths along the length of the riser.

Equation 6.2 is given as:

$$A_o = \frac{Q}{C_d\sqrt{2 \cdot g \cdot h}}$$ (Small orifice equation)

Where C_d = Orifice Discharge Coefficient (0.67)

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 (48 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 0.125 m intervals along the length of riser at 0 m, 0.125 m, 0.250 m and 0.375 m above the normal water level (11.5 m AHD).
- Two orifice diameters of 30 mm and 40 mm were selected and the numbers required at each level are summarised in Table 6-3 and Figure 6-6 below.

Table 6-3: Iterative Spreadsheet Calculations for Stage-Discharge Relationship

Orifice Positions (m above 11.5m AHD)		0	0.125	0.250	0.0375		
Orifice Diameter (mm)		40	30	30	30		
Number of orifices		3	3	3	2		
Extended Det. Depth (m above 11.5m AHD)	Extended Det. Volume (m3)	Flow at given Ext. Det. Depths (m^3/s)				Total Flow (L/s)	Not. Detention Time (hrs)
0	0	0.00				0.00	
0.125	875	3.96	0.00			3.96	48.3
0.25	1750	5.60	2.23	0.00		7.82	48.8
0.375	2625	6.85	3.15	1.48	0.00	11.49	49.9
0.5	3500	7.91	3.86	2.10	2.23	16.09	47.5

The stage-discharge relationship of the riser is plotted in the chart below (Figure 6.17) 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 Qmax (15 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 with a pipe connection to the deep 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.

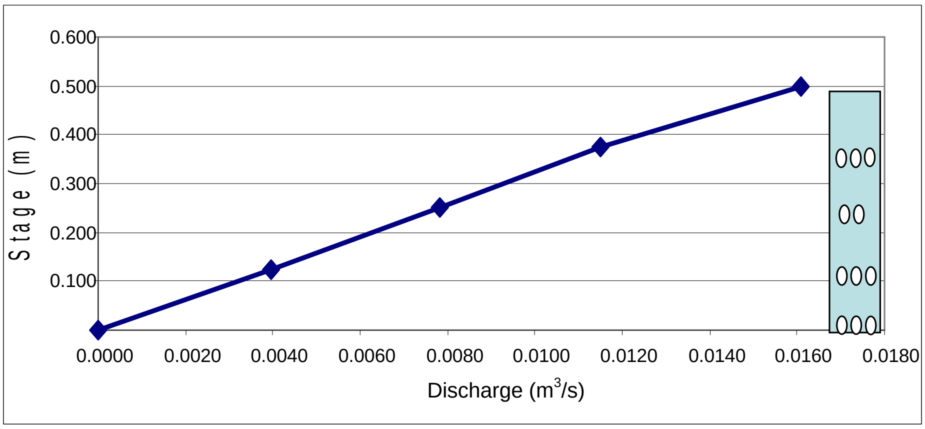


Figure 6-67: Riser Pipe Configuration Showing Discharge Stage Relationship

6.8.5.2 Maintenance Drains

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

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

Wetland Permanent Pool Volume = 5500 m^2 x 0.6 m = 3300 m^3 (assumes 0.60 m nominal depth)

Q = 3300/(12 x 3600) = 0.0764 m^3/s = 76.4 L/s

The size of the 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 305 mm – adopt 300 mm diameter pipe meaning a notional draining time of 13 hrs.

The size of the valve can be established using the orifice equation, assuming the orifice operates under inlet control (Equation 6.2):

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

Where	Q	= 76.4 L/s (0.0764 m^3/s)
	C_d	= 0.67
	h	= 0.67 m (one third of permanent pool depth in open water zones)
So	A_o	= 0.0315 m^2 corresponding to an orifice diameter of 200 mm

6.8.5.3 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 (15.9 L/s) or the maintenance drain (76.4 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 (300 mm pipe at 0.5% as calculated above).

Riser outlet = 300 mm diameter pipe with following orifice detail:

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

Maintenance drain	= 300 mm diameter pipe at 0.5 % grade
Maintenance control	= 200 mm diameter valve
Discharge pipe	= 300 mm diameter at 0.5 % grade

6.8.5.4 Balance Pipe

The maintenance drainage pipe connects the deep refuge pools and is therefore also operating as a balance pipe to sustain equal water levels in the pools. This is particularly important during the dry season when small inflows provide top-up water.

6.8.6 Step 6: Design High Flow Bypass Channel

The bypass channel accepts 'above design flow' (50 year ARI = 5.87 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:

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

Where Q = 'above design flow' (50-year ARI = 5.87 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 0.3 m 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 0.3 m. This ensures flow in the channel does not backwater (i.e. submerge) the bypass weir.

For base width = 11 m, Q = 6.3 m^3/s > 'Above Design flow' (5.87 m^3/s)

High flow bypass channel – Base width of 16 m, batters of 5(H):1(V) and longitudinal slope of 1.5%.

6.8.7 Step 7: Verification Checks

6.8.7.1 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 6.3):

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

Where $Q_{max\ riser}$ = target maximum discharge (defined in equation 6.1) (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) = 34 m (based on the 6 (L) : 1 (W) length to width ratio)

Minimum depth at top of extended detention depth is within the deep marsh = 1 m depth

Giving $A_{section}$ = 34 m x 1m = 34 m^2 x 0.5 (blockage factor)

$Q_{max\ riser}$ = 15.9 L/s (0.0159 m^3/s)

Therefore, $V_{macrophyte\ zone}$ = 0.0159/(34 x 0.5) = 0.0008 m/s < 0.05 m/s (OK)

6.8.7.2 Confirm Treatment Performance

The key functional elements of the constructed wetland developed as part of the conceptual design (i.e. area, extended detention depth) were not adjusted as part of the detailed design. Therefore, the performance check undertaken in Step 1 (see Section 6.3.1) still applies.

6.8.8 Step 8: Vegetation Specification

The vegetation specification and recommended planting density for the macrophyte zone have been adapted from Appendix A and are summarised in Table 6.4 below.

The reader is referred to Appendix A for further discussion and guidance on vegetation establishment and maintenance.

Table 6-4: Worked Example Vegetation List

Zone	Plant Species	Planting Density (plants/m^2)
Upper batters	*Gahnia siberiana* *Lomandra filiformis spp. filiformis*	6 6
Lower batters	*Cyperus tenuispica* *Cyperus digitatus*	8 8
Shallow Marsh	*Cyperus scariosis* *Fimbristylis dichotoma*	6 6
Deep Marsh	*Baumea articulata* *Eleocharis dulcis*	4 4
Deep Pool	*Ceratophyllum demersum* *Myriophyllum dicoccum*	1 1

6.8.9 Step 9: Maintenance Plan

A maintenance plan for the wetland is to be prepared in accordance with Section 6.6.

6.8.10 Design Calculation Summary

The sheet below shows the results of the design calculations.

CONSTRUCTED WETLANDS DESIGN CALCULATION SUMMARY

	Calculation Task		Outcome (CALCULATION SUMMARY)		Check
	Catchment Characteristics				
		Catchment area	10	ha	✓
		Catchment land use (i.e. residential, commercial etc.)	Residential		
		Storm event entering inlet pond (minor or major)	50yr ARI		
	Conceptual Design				
		Macrophyte zone area	5500	m^2	✓
		Normal water level of macrophyte zone	11.5	m AHD	
		Extended detention depth (0.25-0.5m)	0.5	m	
		Notional detention time	48	hrs	
1	Confirm Treatment Performance of Concept Design				
		Total suspended solids	65	% removal	✓
		Total phosphorus	55	% removal	
		Total nitrogen	35	% removal	
	Macrophyte Area		5500	m^2	✓
2	Determine design flows				
		'Design operation flow' (1 year ARI)	1	year ARI	✓
		'Above design flow' (2 – 50 year ARI)	50	year ARI	
	Time of concentration				
	(Refer to relevant local government guidelines and QUDM)		10	minutes	✓
	Identify rainfall intensities				
		'Design operation flow' - $I_{1\ year\ ARI}$	92	mm/hr	✓
		'Above design flow'- I_2 -$I_{50\ year\ ARI}$	224	mm/hr	
	Peak design flows				
		'Design operation flow' - 1 year ARI	1.67	m^3/s	✓
		'Above design flow' – 2-50 year ARI	5.87	m^3/s	
3	Design inlet zone				
	Refer to sedimentation basin (Chapter 4) 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	90	%	
		Inlet zone area (Figure 4.2 in Chapter 4)	360	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	3100 x 3100	L x W	
		Provision of debris trap	Yes		
		Connection pipe dimension	2 x 750	mm diam	✓
		Connection pipe invert level	10.25	m AHD	
	High flow by-pass weir				
		Weir Length	22	m	✓
		High flow by-pass weir crest level (top of extended detention)	12.0	m AHD	
4	Designing the macrophyte zone				
		Area of Macrophyte Zone	5500	m^2	✓
		Aspect Ratio	6:1	L:W	
		Hydraulic Efficiency	0.6-0.7		

CONSTRUCTED WETLANDS DESIGN CALCULATION SUMMARY				
		CALCULATION SUMMARY		
Calculation Task		Outcome		Check
5	Design macrophyte zone outlet			
	Riser outlet			
	Target maximum discharge (Q_{max})	15.9	m^3/s	✓
	Uniform Detention Time Relationship for Riser	Yes		
	Maintenance Drain			
	Maintenance drainage rate (drain over 12hrs)	76.4	m^3/s	✓
	Diameter of maintenance drain pipe	300	mm	
	Diameter of maintenance drain valve	200	mm	
	Discharge Pipe			
	Diameter of discharge pipe	300	mm	✓
6	Design high flow by-pass 'channel'			
	Longitudinal slope	1.5	%	✓
	Base width	11	m	
	Batter slopes	5:1	H:V	
7	Verification checks			
	Macrophyte zone re-suspension protection			✓
	Confirm treatment performance			✓

6.8.11 Worked Example Drawings

Drawing 6.1 at the end of the chapter illustrates the worked example wetland layout.

6.9 References

BCC 2000 (with revisions 2004), Subdivision and Development Guidelines, BCC, Brisbane, http://www.brisbane.qld.gov.au

BCC 2001, Sediment Basin Design, Construction and Maintenance: Guidelines, BCC, Brisbane

Engineers Australia 2006, Australian Runoff Quality, Engineers Australia, ACT, http://www.arq.org.au/

GBLA (Graeme Bentley Landscape Architects) 2004, Preliminary drawings for Mernda Wetland, report for Stockland, GBLA, Victoria

Leinster, S 2006, *Delivering the Final Product – Establishing Water Sensitive Urban Design Systems*, 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design Book of Proceedings, Volume 2, A Deletic and T Fletcher (eds), Melbourne.

LHCCREMS (Lower Hunter and Central Coast Regional Environmental Management Strategy) 2002, Water Sensitive Urban Design in the Sydney Region: 'Practice Note 2 – Site Planning', LHCCREMS, NSW, http://www.wsud.org/downloads/Planning%20Guide%20&%20PN%27s/02-Site%20Planning.pdf

McFarlane A 1997, Successful Gardening in Warm Climates, Kangaroo Press, Sydney

DNRW, IPWEA & BCC (Department of Natural Resources and Water, Institute of Public Works Engineering Australia – Qld Division & Brisbane City Council) 1998, *Queensland Urban Drainage Manual (QUDM) Second Edition*, prepared by Neville Jones & Associates and Australian Water Engineering for DNRW, IPWEA & BCC, Brisbane.

Persson J, Somes NLG and Wong THF 1999, 'Hydraulic efficiency and constructed wetland and ponds', Water Science and Technology, vol. 40 no. 3, pp. 291–289

Standards Australia 2003, AS 4419-2003: Soils for landscaping and garden use, Standards Australia