Chapter 9 **Constructed wetlands**

Constructed wetland in Lynbrook, Victoria.

9.1 Introduction

Constructed wetland systems are shallow, extensively vegetated water bodies that use **enhanced sedimentation**, fine filtration and pollutant uptake processes to remove pollutants from **stormwater**. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically over three days, back to dry weather water levels.

Wetlands generally consist of an **inlet zone** (**sediment basin** to remove coarse sediments), a **macrophyte** zone (a shallow, heavily vegetated area to remove fine particulates and uptake of soluble pollutants) and a high flow bypass channel (to protect the **macrophyte zone**) (e.g. Figure 9.1). They are designed primarily to remove stormwater pollutants associated with fine to colloidal particulates and dissolved contaminants.

Simulations using computer models are often undertaken to optimise the relationship between **detention time**, wetland volume and the **hydrologic effectiveness** of the constructed wetland to maximise treatment given the volume constraints of the wetland site. The relationship between detention time and pollutant removal efficiency is largely influenced by the settling velocity of the target particulate, 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. Detention periods should notionally be about 72 hours to effectively remove nutrients in urban stormwater in Victoria.

The key operational design criteria for constructed wetlands may be summarised as to:

- promote **sedimentation** of particles larger than 125 μm within the inlet zone
- discharge water from the inlet zone into the macrophyte zone for removal of fine particulates and dissolved contaminants through the processes of enhanced sedimentation, filtration, adhesion and **biological uptake**
- ensure that the required detention period is achieved for all flow though the wetland system through the incorporation of a **riser outlet** system

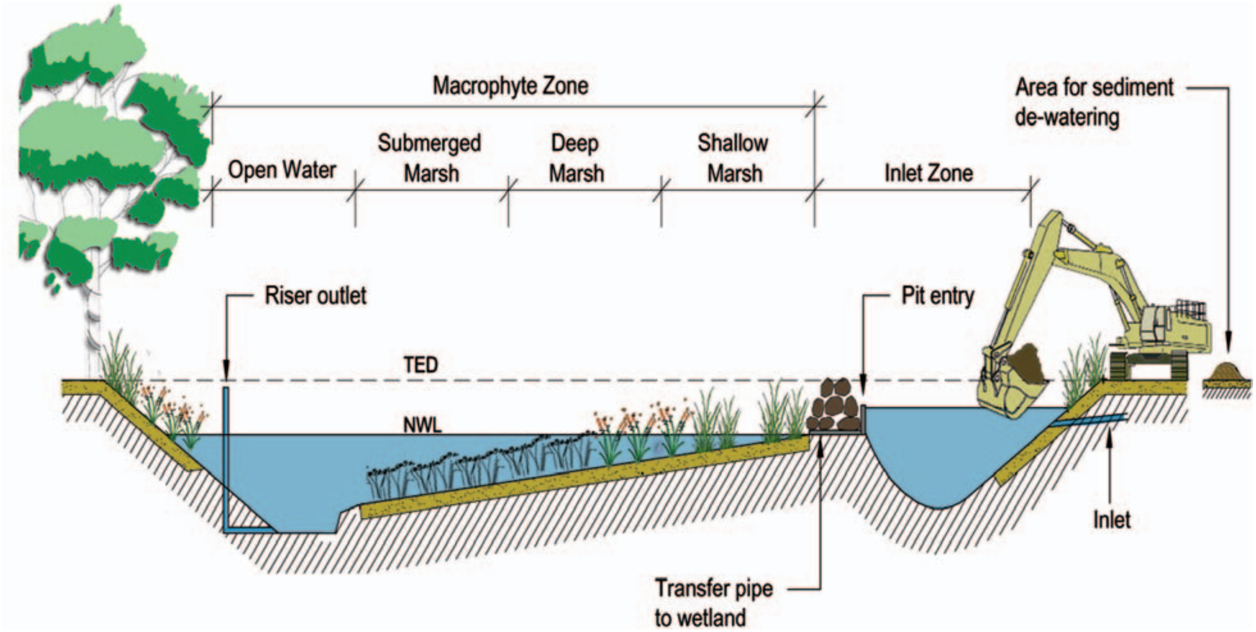

Figure 9.1 Layout of a constructed wetland system.

- ensure adequate flood protection of the macrophyte zone from scouring during above-design conditions by designing for bypass operation when inundation in the macrophyte zone reaches the design maximum **extended detention** depth.

Poor design of constructed wetlands has led to many of these urban wetlands and **ponds** systems becoming a long-term liability to the community. Common problems encountered include:

- accumulation of litter in some sections of the wetland
- accumulation of oil and scum at 'dead zones' in the wetland
- infestation of weeds or dominance of certain species of vegetation
- mosquito problems
- algal blooms
- scouring of sediment and banks, especially during high flows.

Many of the these problems can be minimised or avoided by good engineering design principles. Poor wetland hydrodynamics and lack of appreciation of the stormwater **treatment train** are often identified as major contributors to wetland management problems. A summary of desired hydrodynamic characteristics and design elements is presented in Table 9.1.

In many urban applications, wetlands can be constructed in the base of retarding basins, thus reducing the land required for stormwater treatment. In these situations, the wetland systems will occasionally become inundated to greater depths than the extended detention depth. However, the inundation is relatively short (hours) and is unlikely to affect the vegetation provided there is a safe pathway to drain following flood events that does not scour vegetation or banks.

Key design issues to be considered are:

1. verifying size and configuration for treatment
2. determining design flows
3. designing the inlet zone (see Design Procedure for Sedimentation Basin, Chapter 4)
4. layout of the macrophyte zone
   - zonation
   - longitudinal and cross sections
5. hydraulic structures:
   - macrophyte zone outlet structures
   - connection to the inlet zone
   - bypass **weir** and channel
6. recommending plant species and planting densities
7. providing maintenance.

Table 9.1 Desired wetland hydrodynamic characteristics and design elements

Hydrodynamic characteristics	Design issues	Remarks
Uniform distribution of flow velocity	Wetland shape, inlet and outlet placement and morphological design of wetland to eliminate short-circuit flow paths and 'dead zones'	Poor flow pattern within a wetland will lead to zones of stagnant pools which promotes the accumulation of litter, oil and scum 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	Regular flow throughput in the wetland would promote flushing of the system, thus maintaining a dynamic system and avoiding problems associated with stagnant water (e.g. algal blooms, mosquito breeding, oil and scum accumulation)
	Morphological and outlet control design to match botanical layout design and the hydrology of the wetland	Inadequate attention to the inundation depth, wetness gradient of the wetland and the frequency of inundation at various depth range would lead to dominance of certain plant species especially weed species over time, which results in a deviation from the intended botanical layout of the wetland
		Recent research findings indicate that regular wetting and drying of the substrata of the wetland can prevent releases of phosphorus from the sediment deposited in the wetland
Uniform vertical velocity profile	Selection of plant species and location of inlet and outlet structures to promote uniform 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 increase the potential for algal bloom.
Scour protection	Design of inlet structures and erosion protection of banks	Owing to the highly dynamic nature of stormwater inflow, measures are to be taken to 'protect' the wetland from erosion during high inflow rates

9.2 Verifying size for treatment

The curves (Figures 9.2–9.4) are based on the performance of the system in Melbourne with varying typical extended detention depths and were derived using the Model for Urban Stormwater Improvement Conceptualisation (**MUSIC**) (Cooperative Research Centre for Catchment Hydrology 2003).. To estimate an equivalent performance at other locations in Victoria, the hydrologic design region relationships should be used to convert the treatment area into an equivalent treatment area in Melbourne (reference site) (see Chapter 2). In preference to using the curves, local data should be used to model the specific treatment performance of the system.

The curves were derived assuming the systems receive direct runoff (i.e. no pretreatment) and have the following characteristics:

- the inlet zone forms part of the wetland system sized to retain 125 μm sediment for flows up to the one-year ARI peak **discharge** and with provision for high flow bypass
- notional detention period of 72 hours.

The curves in Figure 9.2 to 9.4 can be used to check the expected performance of the wetland system for removal of Total Soluble Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN). The X-axis on the curves is a measure of the size of the surface of the wetland (measured as the **permanent pool** area), expressed as a percentage of the contributing *impervious* catchment.

9.3 Design procedure: constructed wetlands

Major elements of constructed wetland systems are shown in Figure 9.5.

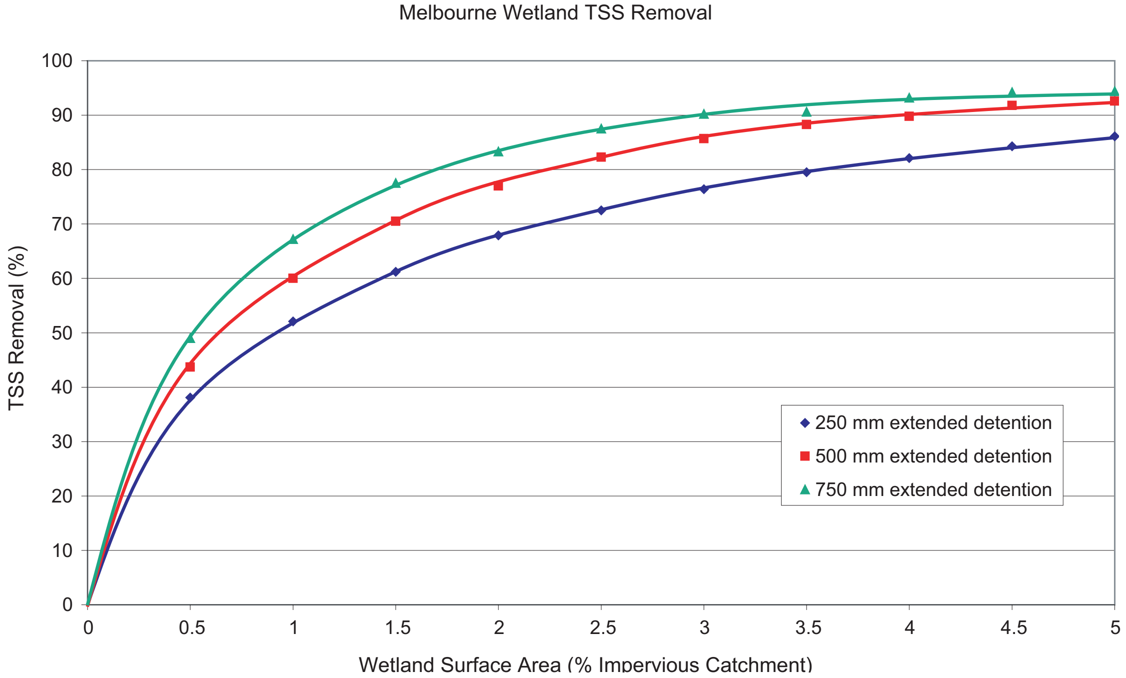

Figure 9.2 Performance of a wetland in removing Total Soluble Solids (TSS) in Melbourne.

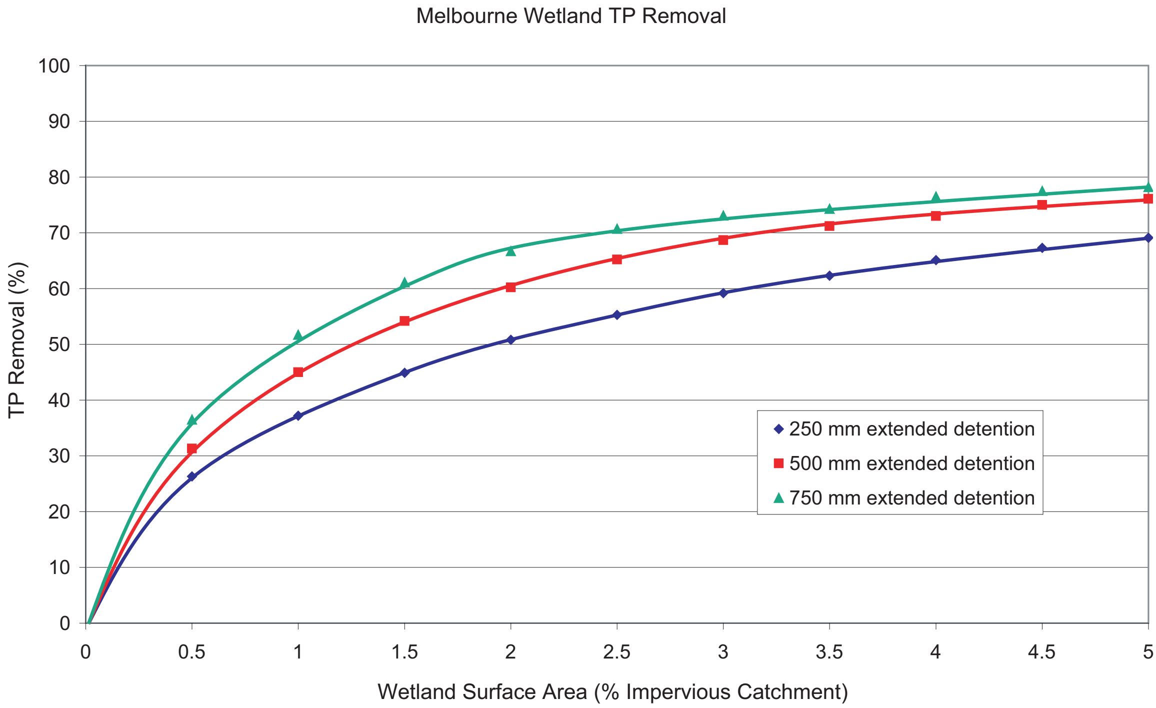

Figure 9.3 Performance of a wetland in removing Total Phosphorus (TP) in Melbourne.

Analyses to be undertaken during the detailed design phase of the inlet zone and the macrophyte zone of constructed wetland system include the following.

1. Design of the inlet zone as a sedimentation basin to target sediment of 125 μm or larger, including the:
   - inlet zone to operate as a flow regulator into the macrophyte zone during normal operation
   - inlet zone to operate for bypass of the macrophyte zone during above-design conditions
   - connection between the inlet zone and the macrophyte zone to be appropriately designed so that inlet conditions provide for energy dissipation and distribution of inflow into the macrophyte zone
- provision for sediment and debris removal.

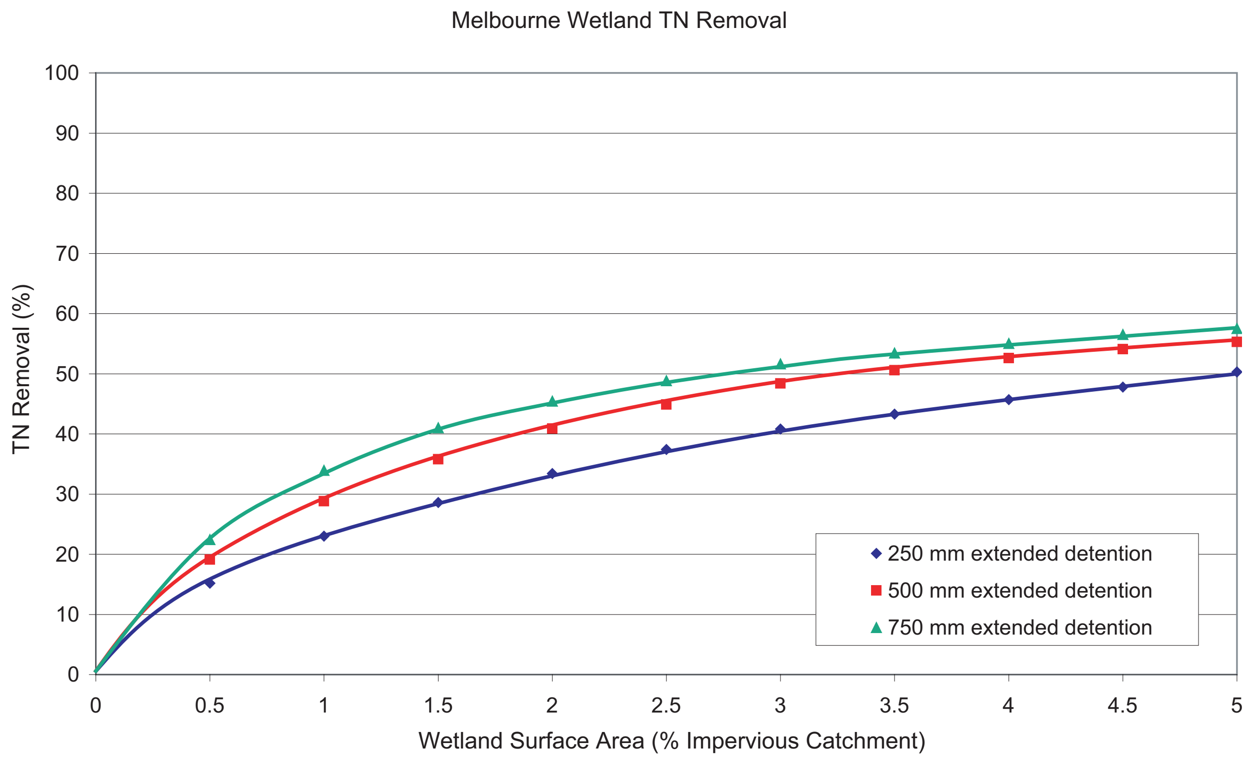

Figure 9.4 Performance of a wetland in removing Total Nitrogen (TN) in Melbourne.

2. Configure the layout of the macrophyte zone to provide an extended detention volume so that the system's **hydraulic efficiency** can be optimised, including design for the:
   - range of suitable extended detention depth to be between 0.25 m and 0.75 m, depending on the desired operation of the wetland and target pollutant
   - **bathymetry** of the macrophyte zone to promote a sequence of **ephemeral**, shallow marsh, marsh and submerged marsh systems in addition to a small, open water system near the outlet structure
   - placement of the inlet and outlet structures, the aspect ratio of the macrophyte zone and flow control features to promote a high hydraulic efficiency within the macrophyte zone, in particular
   - location and depth of permanent pools within the macrophyte zone
   - drainage of the macrophyte zone, if necessary.
3. Design the macrophyte zone outlet structure to provide for a 72 hour **notional detention time** for a wide range of flow depth. The outlet structure should include measures to trap debris to prevent clogging.

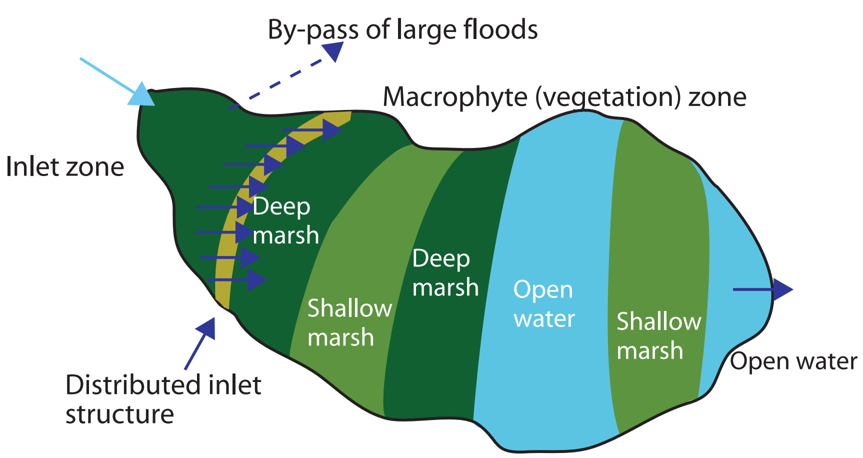

Figure 9.5 Elements of a constructed wetland system.

4. Provide landscape design, which requires:
   - macrophyte zone vegetation (including **littoral zone**)
   - terrestrial vegetation.

The following sections describe the design steps required for constructed stormwater wetland systems.

9.3.1 Estimating design flows

The hydrologic design objectives for the inlet zone are:

1. capacity to convey stormwater inflows up to the peak one-year ARI discharge into the macrophyte zone
2. capacity to convey above-design stormwater inflows to the by-pass system; design discharge capacity for the bypass system corresponds to, for example:
   - the minor system capacity (two-year or five-yearyear ARI) if overland flow path does not direct overland flow into the wetland
   - 100-year ARI peak discharge if the wetland system forms part of the major drainage system.

9.3.1.1 Minor and major flood 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, the use of the Rational Design Procedure should strictly be used only to size inlet hydraulic structures. A full flood routing computation method should be used in sizing the outlet hydraulic structures (e.g. outlet pipe, spillway and embankment height).

9.3.2 Inlet zone

The inlet zone of a constructed stormwater wetland serves two basic functions:

1 the pretreatment of inflow to remove gross pollutants and coarse to medium-sized sediment
2 the hydrologic control of inflows into the macrophyte zone and bypass of floods during 'above-design' operating conditions.

The inlet zone typically comprises a relatively deep, open waterbody (> 1.5 m) that operates essentially as a sedimentation basin. Often it may be necessary to install a **Gross Pollutant Trap (GPT)** at the inlet to this zone 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.

For more information and guidance on the design of the inlet zone, see Chapter 4.

9.3.3 Macrophyte zone layout

9.3.3.1 Size and dimensions

To optimise hydraulic efficiency (i.e. reduce short circuits and dead zones), it is desirable to adopt a high length to width ratio. The ratio of length to width varies depending on the size of the system and the site characteristics. To simplify the design and earthworks smaller systems tend to have length to width ratios at the lower end of the range. This can often lead to poor hydrodynamic conditions within the macrophyte zone. Persson *et al* (1999) used the term 'hydraulic efficiency' to define the expected hydrodynamic characteristics for a range of configurations of stormwater detention systems. Engineers Australia (2003) present expected hydraulic efficiencies of detention systems for a range of notional shapes, aspect ratios and inlet/outlet placements within stormwater detention systems and recommends that the λ value for constructed wetland systems should not be less than 0.5, and should be designed to promote hydraulic efficiencies greater than 0.7 (see Figure 9.6).

The numbers in Figure 9.6 represent the values of λ. In Figure 9.6, 'o' in diagrams O and P represent islands in a waterbody and the double line in diagram Q represents a structure to distribute flows evenly.

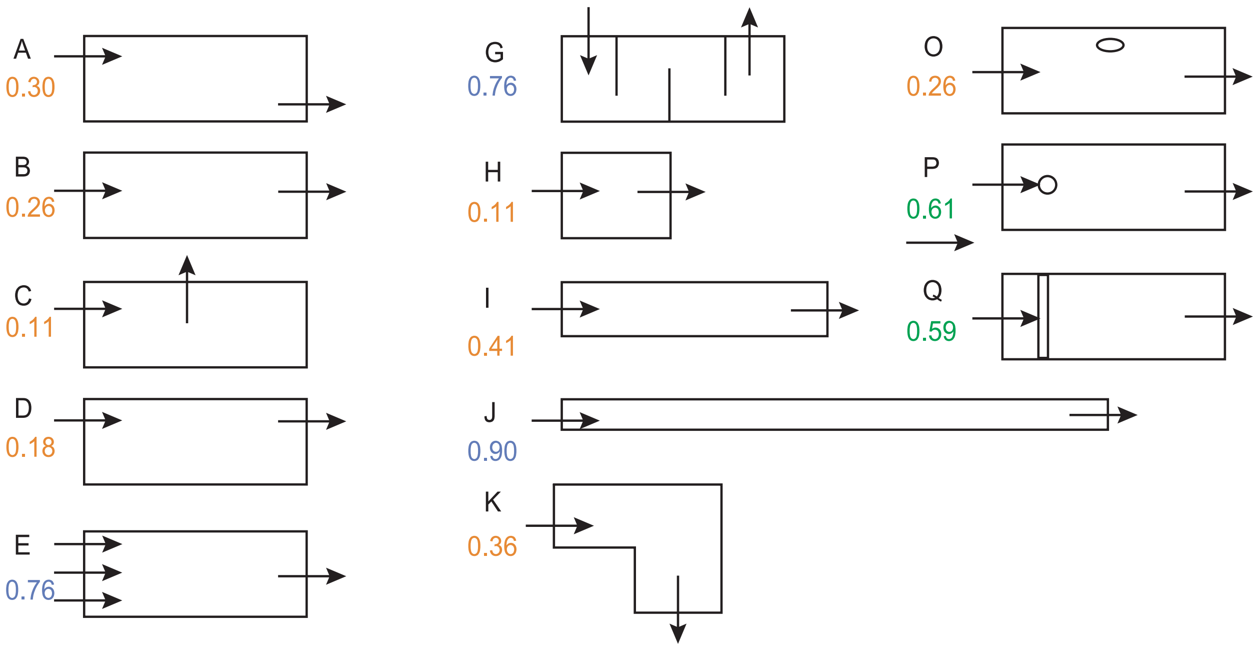

Figure 9.6 Hydraulic efficiency (λ) – a measure of flow hydrodynamic conditions in constructed wetlands and ponds; range is from 0 to 1, with 1 representing the best hydrodynamic conditions for stormwater treatment (from Persson et al, 1999).

9.3.3.2 Zonation

A range of habitat areas within wetlands is needed to support a variety of plant species and ecological niches. The wetland is broadly divided into four macrophyte zones and an open water zone. The bathymetry across the four macrophyte zones is to vary gradually over the depth range, from 0.2 m above the permanent pool level to 0.5 m below the permanent pool level (see Table 9.2). The depth of the open water zone in the vicinity of the outlet structure is to be 1.0 m below the permanent pool level.

To ensure optimal hydraulic efficiency of the wetland for the given shape and aspect ratio, the wetland zones are arranged in bands of equal depth running across the flow path. The appropriate bathymetry coupled with uniform plant establishment ensures the cross section has equivalent hydraulic conveyance, thus preventing short-circuiting.

9.3.3.3 Long section

In defining a long section of a macrophyte zone, it is necessary to provide areas for habitat refuge. For this reason it is desirable to have permanent pools interconnected to prevent fauna being isolated in areas that dry out. This also reduces the piping required to drain the wetland for maintenance purposes.

An example bathymetry of a wetland system is shown in Figure 9.8. It illustrates gradual changes in depth longitudinally to create different vegetation areas as well as consistent zone banding across the wetland.

Figure 9.7 Zonation in wetland systems.

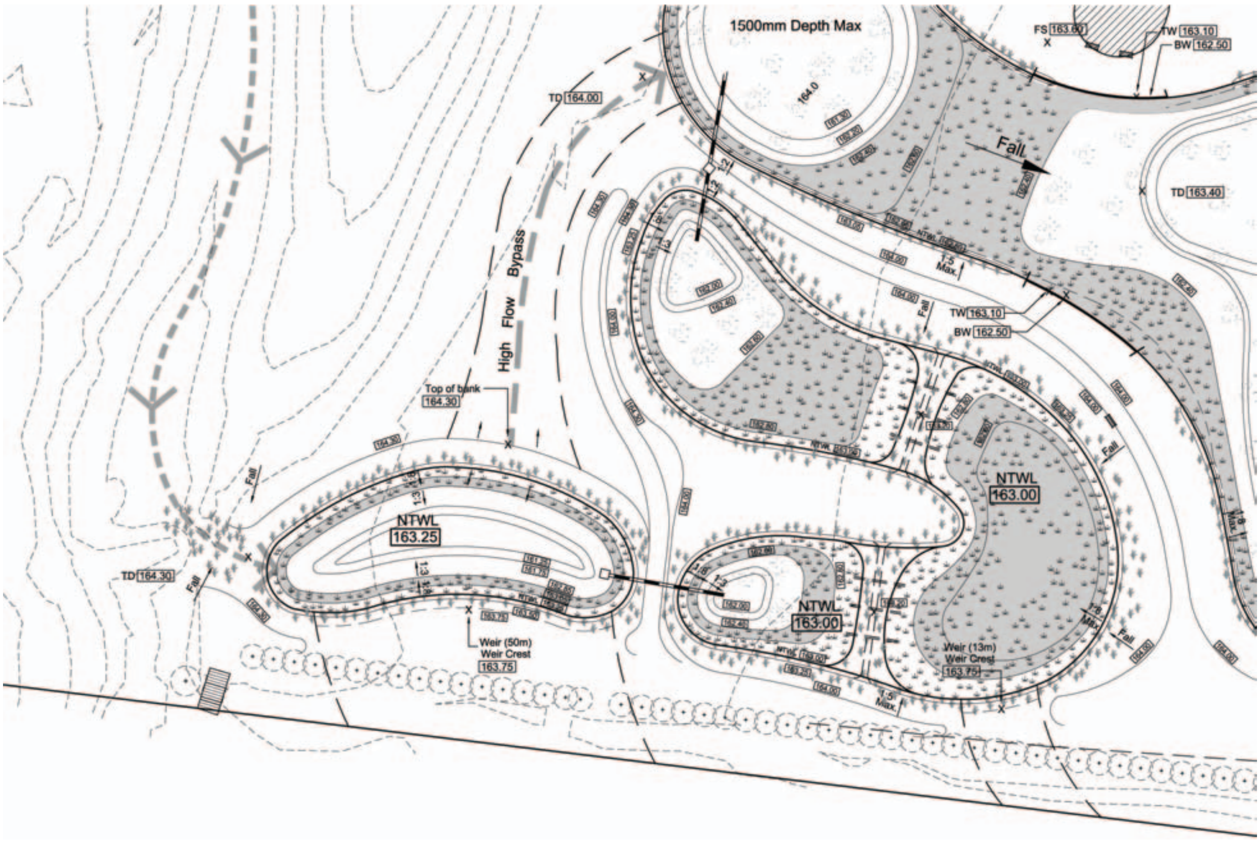

Figure 9.8 Example bathymetry of a constructed wetland system (Graeme Bentley Landscape Architects 2004).

9.3.3.4 Cross sections

The **batter slopes** on approaches and immediately under the permanent water level have to be configured with consideration of public safety (e.g. Figure 9.9).

A gentle slope to the water's edge and extending below the water line should be adopted before the batter slope steepens into deeper areas. An alternative to the adoption of a flat batter slope is to provide a 3 m 'safety bench' that is less than 0.2 m deep below the permanent pool level and built around the wetland.

Safety requirements for individual wetlands may vary from site to site, and it is recommended that an independent safety audit be conducted for each design. Safety guidelines are also provided by some local authorities (e.g. Melbourne Water 2003, and Royal Life Saving Society of Australia 2004) and these should be followed.

9.3.4 Macrophyte zone outlet structure

The macrophyte zone outlet structure forms two purposes. The first is to control discharges from the extended detention storage to ensure the wetland maintains a notional detention time

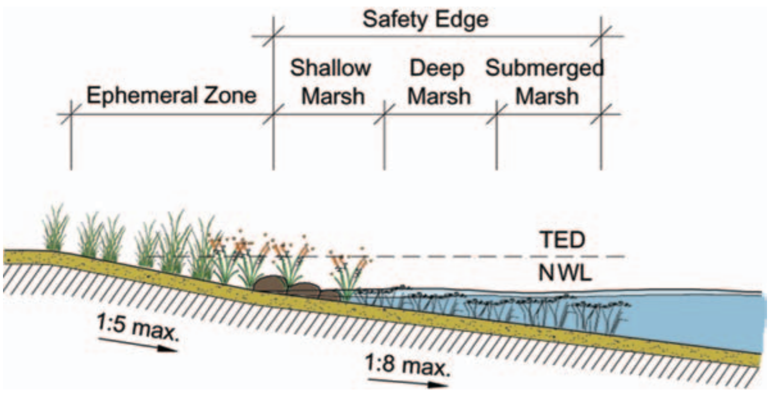

Figure 9.9 Example of edge design to a constructed wetland system.

of 72 hours. The outlet structure also needs to include features to allow the permanent pool to be drained for maintenance.

9.3.4.1 Maintenance drain

The permanent pool of the wetland should be able to be drained with a maintenance drain operated manually. A suitable design flow rate (*Q*) is one which can draw down the permanent pool within 12 hours (i.e. overnight).

The orifice discharge equation (Equation 9.1) is considered suitable for sizing the maintenance drain on the assumption that the system will operate under inlet control with its discharge characteristics determined as follows:

$$A_o = \frac{Q}{C_d\sqrt{2gh}} \qquad \text{(Equation 9.1)}$$

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

9.3.4.2 Riser outlet – size and location of orifices

The riser is designed to provide a uniform notional detention time over the full range of the extended detention depth. The target maximum discharge may be computed as the ratio of the volume of the extended detention to the notional detention time:

$$\text{Target maximum discharge } (m^3/s) = \text{extended storage volume } (m^3) \,/\, \text{detention time (s)} \qquad \text{(Equation 9.2)}$$

The placement of outlet orifices and determining their appropriate diameters is designed iteratively by varying outlet diameters and levels, using the orifice discharge equation (Equation 9.1) applied over discrete depths along the length of a riser up to the maximum detention depth. This can be performed with a spreadsheet as illustrated in the spreadsheet included on the CD.

As the outlet orifices can be expected to be small, the orifices need to be prevented from clogging by debris. Some form of debris guard is recommended (e.g. Figure 9.9).

An alternative to using a debris guard is to install the riser within a pit which is connected to the permanent pool of the macrophyte zone via a submerged pipe culvert. This connection should be adequately sized such that there is minimal water level difference between the water within the pit and the water level in the macrophyte zone. With the water entering into the outlet pit being drawn from below the permanent pool level, floating debris are prevented from entering the outlet pit while heavier debris would normally settled onto the bottom of the permanent pool.

9.3.4.3 Riser outlet – pipe dimension

While conservative, it is desirable to size the riser pipe such that it has the capacity to accommodate the one-year ARI peak discharge operating as a 'glory hole' spillway. Under normal operation, this flow would bypass the macrophyte zone when this zone is already operating at design capacity. Nevertheless, it is good practice to provide a level of contingency in discharge capacity for the riser outlet to prevent any overtopping of the embankment of the macrophyte zone. A minimum of a 0.3 m freeboard for the embankment (i.e. crest level of embankment above the top of the extended detention) is often required.

Significant attenuation of the peak one-year ARI inflow can be expected and some routing of the inflow hydrograph through the storage provided by the macrophyte zone is recommended.

The sharp-crested weir equation (Equation 9.3) can be used in defining the required perimeter (*P*) (and thus dimension) of the riser outlet. A weir coefficient of 1.7 (k_w sharp-crested weir) is recommended:


Figure 9.10 Debris guards on riser outlets.

$$P = \frac{Q_{des}}{C_w \times H^{1.5}} \quad \text{(Equation 9.3)}$$

P = Perimeter of the outlet pit
C_w = Weir coefficient
H = Depth of water above the crest of the outlet pit
Q_{des} = Design discharge (m^3/s).

9.3.4.4 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).

9.3.5 Connection to the inlet zone

The pipe that connects the inlet zone to the macrophyte zone must have sufficient capacity to convey a one-year ARI flow, assuming the macrophyte zone is at the permanent pool level, without resulting in any flow in the bypass system. The configuration of the hydraulic structure connecting the inlet zone to the macrophyte zone would normally consist of an overflow pit connected to one or more pipes through the embankment separating these two zones.

Typical specifications of water and embankment levels are:

- bypass spillway level = top of extended detention in the macrophyte zone
- permanent pool level in inlet zone = 0.3 m above permanent pool level in macrophyte zone.

Velocity checks are to be conducted for when the wetland is full and when it is near empty. Velocities should ideally be less than 0.05 m/s.

The culvert connection between the inlet zone and the macrophyte zone can be sized using standard culvert equations that accounts for energy losses associated with the inlet and exit conditions and friction losses within the culvert. For most applications, the culvert will operate under outlet control with the inlet and outlet of the culvert being fully submerged. With relatively short pipe connections, friction loss is typically small and can be computed using Manning's equation. The total energy loss of the connection is largely determined by the inlet and outlet and outlet conditions and the total losses can be computed using the expression

$$\Delta H = (K_{in} + K_{out})\frac{v^2}{2g} + S_f \times L \quad \text{(Equation 9.4)}$$

where K_{in} and K_{out} are the head loss coefficients for the inlet and outlet conditions (typically, and conservatively, assumed to 0.5 and 1.0 respectively), S_f is the friction slope (which is computed from Manning's equation or the Colebrook-White equation) and L is the length of the culvert (Chadwick and Morfett 1986).

Figure 9.11 Connection inlet zone.

9.3.6 High-flow route and bypass design

To protect the integrity of the macrophyte zone of the wetland, it is necessary to consider the desired above-design operation of the wetland system. This is generally provided for with a high flow route that bypasses the macrophyte zone during flow conditions that may lead to scour and damage to the wetland vegetation. A function of the inlet zone is to provide hydrologic control of inflow into the macrophyte zone (see Section 9.3.2 and Chapter 4). A bypass weir is to be included in the design of the inlet zone, together with a bypass floodway (channel) to direct high flows around the macrophyte zone.

Ideally, the level of the bypass weir should be set at the top of the extended detention level in the macrophyte zone. This would ensure that a significant proportion of catchment inflow will bypass the macrophyte zone once it has reached its maximum operating extended detention level. The width of the spillway is to be sized to safely pass the maximum discharge conveyed into the inlet zone or the 100-year ARI discharge (see Section 9.3.1) with the maximum water level above the crest of the weir to be defined by the top of embankment level (plus a suitable freeboard provision).

9.3.7 Vegetation specification

Vegetation planted in the macrophyte zone (i.e. marsh and pool areas) is designed to treat stormwater flows, as well as add aesthetic value. Dense planting of the littoral berm zone will inhibit public access to the macrophyte zone, minimising potential damage to the plants and the safety risks posed by water bodies. Terrestrial planting may also be recommended to screen areas and provide an access barrier to uncontrolled areas of the stormwater treatment system.

Plant species for the wetland area will be selected based on the water regime, microclimate and soil types of the region, and the life histories, physiological and structural characteristics, natural distribution, and community groups of the wetland plants (see Appendix A). The distribution of the species within the wetland will relate to their structure, function, relationship and compatibility with other species. Planting densities should ensure that 70%–80% cover is achieved after two growing seasons (two years).

9.3.8 Designing to avoid mosquitos

Mosquitos are a natural component of wetland fauna and the construction of any waterbody will create some mosquito habitat. To reduce the risk of high numbers of mosquitos designs should function as balanced ecosystems with predators controlling mosquito numbers. Design considerations that should be addressed include:

- providing access for mosquito predators to all parts of the waterbody (do not have stagnant isolated area of water)
- providing areas of permanent water (even during long dry periods) that mosquito preditors can seek refuge
- maintaining natural water level fluctuations that disturb the breeding cycle of some mosquito species

- providing a bathymetry such that regular wetting and drying is achieved and water draws down evenly so isolated pools are avoided
- providing sufficient gross pollutant control at the inlet such that human-derived litter does not accumulate and provide breeding habitat
- ensuring maintenance procedures do not result in wheel rut and other localised depressions that create isolated pools when water levels fall.

Local agencies guidelines should also be consulted in regard to approaches for avoiding excessive numbers of mosquitos.

9.3.9 Design calculation summary

A *Constructed Wetland Calculation Summary* is included to aid the design process of key design elements of a constructed wetland.

Constructed Wetand	CALCULATION SUMMARY		
CALCULATION TASK	**OUTCOME**		**CHECK**
1 Identify design criteria			
Design ARI flow for inlet zone		year	
Target sediment size for inlet zone		mm	
Notional detention period for macrophyte zone		hrs	
Design ARI flow for bypass spillway		year	
Extended detention volume		m^3	☐
2 Catchment characteristics			
Residential		Ha	
Commercial		Ha	
Fraction impervious			
Residential			
Commercial			☐
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities		minutes	☐
Identify rainfall intensities			
Station used for IFD data:			
100-year ARI		mm/hr	
1-year ARI		mm/hr	☐
Design runoff coefficient			
C_1			
C_{100}			☐
Peak design flows			
Q_1		m^3/s	
Q_{100}		m^3/s	☐
4 Inlet zone			
Refer to *Sedimentation Basin Calculation Summary*			☐
5 Macrophyte zone layout			
Extend detention depth		m	
Area of macrophyte zone		m^2	
Aspect ratio		L:W	
Hydraulic efficiency			
Length		m	
Top width (including extended detention)		m	
Cross section batter slope		V:H	☐
6 Macrophyte zone outlet structures			
Maintenance drain			
Diameter of maintenance valve		mm	
Drainage time		hrs	☐
Riser			
Linear storage-discharge relationship for riser			☐
Discharge pipe			
Discharge capacity of discharge pipe		m^3/s	☐
7 Connection between inlet zone and macrophyte zone			
Discharge capacity of connection culvert		m^3/s	☐
8 Bypass weir			
Discharge capacity of bypass weir			

9.4 Checking tools

Checking aids are included for designers and referral authorities. In addition, advice on construction techniques and lessons learnt from building wetland systems are provided.

Checklists are provided for:

- design assessments
- construction (during and post)
- operation and maintenance inspections
- asset transfer (following defects period).

9.4.1 Design assessment checklist

The *Wetland Design Asset Checklist* presents the key design features that should be reviewed when assessing a design of a **bioretention basin**. 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, the design procedure should be assessed to determine the effect of the omission or error.

In addition to the *Checklist*, a proposed design should have all necessary permits for its installations. The referral agency should ensure that all relevant permits are in place. These can include permits to clear vegetation, to dredge, create a waterbody, divert flows or disturb fish or platypus habitat.

Land 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 Handover Checklist* (see Section 9.4.4).

9.4.2 Construction advice

General advice is provided for the construction of wetlands. It is based on observations from construction projects around Australia.

Protection from existing flows

It is important to protect a wetland system from upstream flows during construction.. A mechanism to divert flows around a construction site, protect from litter and debris is required. This can be achieved by constructing a high flow bypass channel initially and then diverting all inflows along the channel until the wetland system is complete.

High flow contingencies

Contingencies to manage risks associated with flood events during construction are required. All machinery should be stored above acceptable flood levels and the site stabilised as well as possible at the end of each day. Plans for dewatering following storms should also be made.

Erosion control

Immediately following earthworks it is good practice to revegetate all exposed surfaces with sterile grasses (e.g. hydroseed). These will stabilise soils, prevent weed invasion yet not prevent future planting from establishing.

Inlet erosion checks

It is good practice to check the operation of inlet erosion protection measures following the first few rainfall events. These need to be checked early in the system's life, to avoid continuing problems. If problems occur in these events, then erosion protection should be enhanced.

Tolerances

Tolerances are very important in the construction of wetlands (e.g. base, longitudinal and batters) – levels are particularly important for a well-distributed flow path and for establishing appropriate vegetation bands. As water levels reduce (e.g. for maintenance) areas need to drain back into designated pools and distributed shallow pools across the wetland are avoided. Generally a tolerance (plus or minus) of 50 mm is acceptable.

Wetland Design Assessment Checklist					
Wetland location:					
Hydraulics	Minor flood: (m^3/s)		Major flood: (m^3/s)		
Area	Catchment area (ha):		Wetland area (ha)		
Treatment				Y	N
Treatment performance verified from curves?					
Inlet zone				Y	N
Inlet pipe/structure sufficient for maximum design flow (Q_5 or Q_{100})?					
Scour protection provided at inlet?					
Configuration of inlet zone (aspect, depth and flows) allows settling of particles >125 μm?					
Bypass weir incorporated into inlet zone?					
Bypass weir and channel sufficient to convey $>Q_1$ <= maximum inlet flows?					
Bypass weir crest at macrophyte permanent pool level + extended detention depth?					
Bypass channel has sufficient scour protection?					
Structure from inlet zone to macrophyte zone enables energy dissipation/flow distribution?					
Structure from inlet zone to macrophyte zone enables isolation of the macrophyte zone for maintenance?					
Inlet zone permanent pool level above macrophyte permanent pool level?					
Maintenance access allowed for into base of inlet zone?					
Public access to inlet zone prevented through vegetation or other means?					
Gross pollutant protection measures provided on inlet structures (both inflows and to macrophyte zone)					
Macrophyte zone				Y	N
Extended detention depth >0.25 m and <0.75 m?					
Vegetation bands perpendicular to flow path?					
Vegetation bands of near uniform depth?					
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?					
Batter slopes from accessible edges shallow enough to allow egress?					
Maintenance access provided into areas of the macrophyte zone (especially open water zones)?					
Public access to macrophyte zones restricted where appropriate?					
Safety audit of publicly accessible areas undertaken?					
Freeboard provided above extended detention depth?					
Outlet structures				Y	N
Riser outlet provided in macrophyte zone?					
Orifice configuration allows for a linear storage-discharge relationship for full range of the extended detention depth?					
Riser diameter sufficient to convey Q_1 flows when operating as a 'glory hole' spillway?					
Maintenance drain provided?					
Discharge pipe from has sufficient capacity to convey the maintenance drain flows or Q_1 flows (whichever is higher)?					
Protection against clogging of orifice provided on outlet structure?					

Transitions

The detail of earthworks needs to be checked in order to ensure smooth transitions between benches and batter slopes. This will allow for strong-edge vegetation to establish and avoid local ponding (that can enhance mosquito breeding habitat).

Inlet zone access

An important component of an inlet zone (or forebay) is accessibility for maintenance. Should excavators be capable of reaching all parts of the inlet zone an access track may not be required to the base of the inlet zone; however, an access track around the perimeter of the inlet zone is required. If sediment collection is by using earthmoving equipment, then a stable ramp will be required into the base of the inlet zone (maximum slope 1:10).

Inlet zone base

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 by driving into the basin. It also serves an important role for determining the levels that excavation should extend to (i.e. how deep to dig) for either systems cleaned from the banks or directly accessed.

Dewatering collected sediments

An area should be constructed that allows for dewatering of removed sediments from an inlet zone. This area should be located such that water from the material drains back into the inlet zone. Material should be allowed to drain for a minimum of overnight before disposal.

Timing for planting

Timing of planting vegetation depends on a suitable time of year (and potential irrigation requirements) as well as timing in relation to the phases of development. Temporary sediment controls should always be used prior to planting as lead times from earthworks to planting are often long.

Vegetation establishment

During the establishment phase water levels should be controlled carefully to prevent seedlings from being desiccated or drowned. This is best achieved with the use of maintenance drains. Once plants are established, water levels can be raised to operational levels (see Appendix A).

Bird protection

Protection against birds (e.g. using nets) should be considered for newly planted areas of wetlands as birds can pull out young plants and reduce plant densities.

9.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST
Wetlands

INSPECTED BY:
DATE:
TIME:
WEATHER:
CONTACT DURING VISIT:

SITE: ______________________

CONSTRUCTED BY: ______________________

DURING CONSTRUCTION

Items inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
Preliminary works	Y	N				Y	N		
1. Erosion and sediment control plan adopted					18. Concrete and reinforcement as designed				
					19. Inlets appropriately installed				
2. Limit public access					20. Inlet energy dissipation installed				
3. Location same as plans					21. No seepage through banks				
4. Site protection from existing flows					22. Ensure spillway is level				
5. All required permits in place					23. Provision of maintenance drain(s)				
Earthworks					24. Collar installed on pipes				
6. Integrity of banks					25. Low flow channel rocks are adequate				
7. Batter slopes as plans					26. Protection of riser from debris				
8. Impermeable (eg. clay) base installed					27. Bypass channel stabilised				
9. Maintenance access to whole wetland					28. Erosion protection at macrophyte outlet				
10. Compaction process as designed					**Vegetation**				
11. Placement of adequate topsoil					29. Vegetation appropriate to zone (depth)				
12. Levels as designed for base, benches, banks and spillway (including freeboard)					30. Weed removal prior to planting				
					31.Provision for water level control during establishment				
13. Check for groundwater intrusion									
14. Stabilisation with sterile grass					32. Vegetation layout and densities as designed				
Structural components									
15. Location and levels of outlet as designed					33. Provision for bird protection				
16. Safety protection provided					34. By-pass channel vegetated				
17. Pipe joints and connections as designed									

FINAL INSPECTION

1. Confirm levels of inlets and outlets					9. Check for uneven settling of banks				
2. Confirm structural element sizes					10. Evidence of stagnant water, short circuiting or vegetation scouring				
3. Check batter slopes									
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									
7. Maintenance access provided					13. Evidence of debris in high flow bypass				
8. Public safety adequate					14. Macrophyte outlet free of debris				

COMMENTS ON INSPECTION

ACTIONS REQUIRED

1.									
2.									
3.									
4.									
5.									
6.									

9.4.4 Asset handover checklist

Asset Handover Checklist		
Asset location:		
Construction by:		
Defects and liability period		
Treatment	**Y**	**N**
System appears to be working as designed visually?		
No obvious signs of under-performance?		
Maintenance	**Y**	**N**
Maintenance plans provided for each asset?		
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?		

9.5 Maintenance requirements

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

Maintaining vibrant vegetation and adequate flow conditions in a wetland are the key maintenance considerations. Weeding, planting and debris removal are the dominant tasks. 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).

The most intensive period of maintenance is during plant establishment (first two years) when weed removal and replanting may be required (see Appendix A). It is also the time when large loads of sediments could affect plant growth, particularly in developing catchments with poor building controls.

Other components of the system that require careful consideration are the inlet points. Inlets can be prone to scour and build-up of litter. Occasional litter removal and potential replanting may be required.

Maintenance is primarily concerned with:

- flow to and through the system
- maintaining vegetation
- preventing undesired vegetation from taking over the desirable vegetation
- removal of accumulated sediments
- litter and debris removal.

Wetland Maintenance Checklist			
Inspection frequency: 3 monthly	Date of visit:		
Location:			
Description:			
Site visit by:			
Inspection items	**Y**	**N**	**Action required (details)**
Sediment accumulation at inflow points?			
Litter within inlet or macrophyte zones?			
Sediment within inlet zone requires removal (record depth, remove if >50%)?			
Overflow structure integrity satisfactory?			
Evidence of dumping (building waste, oils etc.)?			
Terrestrial vegetation condition satisfactory (density, weeds etc)?.			
Aquatic vegetation condition satisfactory (density, weeds etc.)?			
Replanting required?			
Settling or erosion of bunds/batters present?			
Evidence of isolated shallow ponding?			
Damage/vandalism to structures present?			
Outlet structure free of debris?			
Maintenance drain operational (check)?			
Resetting of system required?			
Comments:			

Vegetation maintenance will include:

- removal of noxious plants or weeds
- replacement of plants that die.

Similar to other types of stormwater practices, debris removal is an ongoing maintenance function. Debris, if not removed, can block inlets or outlets, and can be unsightly. Inspection and removal of debris should be done regularly, but debris should be removed whenever it is observed on the site.

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

9.5.1 Operation and maintenance inspection form

The *Wetland Maintenance Checklist* should be 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 three months for the first year and then six-monthly thereafter. More detailed site specific maintenance schedules should be developed for major wetland systems and include a brief overview of the operation of the system and key aspects to be checked during each inspection.

9.6 Worked example

9.6.1 Worked example introduction

A sedimentation basin and wetland system is proposed to treat runoff from a residential and commercial area located in Shepparton, Victoria. The wetland will consist of an inlet zone designed to treat the larger pollutant sizes. Flow will than pass through into a macrophyte zone where a riser outlet will be used to control the system detention period to settle finer sediment particles. A bypass channel will enable large flood events to bypass the macrophyte zone during

Figure 9.12 Layout of proposed wetland system.

periods when the macrophyte zone is already operating at its design level. This worked example focuses only on the macrophyte zone component of the system with the design of the inlet zone (sedimentation basin) and bypass channel contained in an earlier worked example (see Chapter 4). An illustration of the site and proposed layout of the wetland is shown in Figure 9.12.

The contributing catchment area of the proposed wetland is 10 ha (with percentage imperviousness of 50%). The site is flat with the maximum fall of less than 0.5 m across the site. Stormwater from the catchment is conveyed by conventional stormwater pipes and discharges into the constructed wetland via a single 1000 mm diameter pipe. There are no site constrains with regard to the size of the wetland, as construction can extend into an adjacent park if required.

9.6.2 Design objectives

The design criteria for the wetland system are to:

- promote sedimentation of particles larger than 125 μm within the inlet zone
- optimise the relationship between detention time, wetland volume and the hydraulic effectiveness of the system to maximise treatment given the wetland volume site constraints – simulation using MUSIC has found that a wetland with an extended detention volume of about 650 m^3 will be sufficient to meet best practice water quality objectives, equivalent to a hydraulic effectiveness of 85% for a notional detention period of 72 hours.
- ensure that the required detention period is achieved for all flow though the wetland system by using a riser outlet system
- provide for bypass operation when the inundation of the macrophyte zone reaches the design maximum extended detention depth.
- configuring the layout of the macrophyte zone to provide an extended detention volume of 650 m^3 so that optimum hydraulic efficiency of the system can be achieved – this includes particular attention to the placement of the inlet and outlet structures, the aspect ratio of the macrophyte zone and the need to use bathymetry and other flow control features to promote a high hydraulic efficiency within the macrophyte zone; a key design consideration is the extended detention depth for the macrophyte zoneThis worked example focuses on the design of the macrophyte zone of the wetland system. Analyses to be undertaken during the detailed design phase of the macrophyte zone of the wetland system include the following:
- designing the provision to drain the macrophyte zone if necessary
- designing the connection between the inlet zone and the macrophyte zone appropriately so that inlet conditions provide for energy dissipation and distribution of inflow into the macrophyte zone
- designing the bathymetry of the macrophyte zone to promote a sequence of ephemeral, shallow marsh, and submerged marsh systems in addition to a small, open water system near the outlet structure
- designing the macrophyte zone outlet structure to provide for a 72 hour notional detention time, including a debris trap.

In addition, a landscape design will be need to be provided, including:

- macrophyte zone vegetation (including edge vegetation (littoral zone))
- terrestrial vegetation.

9.6.2.1 Confirming macrophyte zone area

As a basic check of the adequacy of the size of the wetland, reference is made to the performance curves presented in Section 9.2. According to Figures 9.2 to 9.4, the required wetland size to satisfy best practice environment management objectives for stormwater quality (based on 0.5 m extended detention depth) in Melbourne is the larger 2.3% (for 80% reduction in TSS); 1.0% (for 45% reduction of TP) and 2.5% (for 45% reduction of TN) of the impervious area (i.e. 2.5% of the impervious area is the critical size).

According to the **hydrologic region** analysis in Chapter 2, the **adjustment factor** for constructed wetlands in Shepparton is 1.21.

The required wetland area computed using the procedure presented in Chapter 4 is as follows:
Impervious area = 5 ha
Required wetland area (0.5 m extended detention) = 50 000 × 0.025 × 1.21 = 1500 m^2.
Extended detention volume required = 750 m^3 compared to 650 m^3 derived from MUSIC modelling.

The discrepancy between proposed extended detention volume derived from detailed modelling using MUSIC and the value determined from the simple procedure contained in Chapter 2 is within 20% and is considered acceptable.

Proposed required extended detention of 750 m^3 is within the expected size required to achieve best practice environmental management objectives for urban stormwater quality.

9.6.3 Design calculations

9.6.3.1 Estimating design flows

With the catchment area being relatively small, the Rational Method Design Procedure is considered to be an appropriate method for computing the design flows (Q).

Catchment area = 10 ha

$t_c = \sim 10$ min (Institution of Engineers 2001 methods)

Runoff coefficients (C) Institution of Engineers 2001 Book VIII

$^{10}I_1 = 38.2$ mm/hr

$F_{imp} = 0.5$

$C_{10} = 0.55$ ARR 1998

Runoff coefficients from Table 8.6 in Institution of Engineers 2001

$C_1 = 0.44$

$C_{100} = 0.66$

Institution of Engineers 2001 Rainfall intensities (Shepparton) $t_c = 10$ min

$I_1 = 38.2$ mm/hr

$I_{100} = 130$ mm/hr

Rational Method $Q = CIA/360$

$Q_1 = 0.47\ m^3/s$

$Q_{100} = 2.4\ m^3/s$

9.6.3.2 Inlet zone

The procedure for the design of the inlet zone follows that presented in Procedure 1 for sediment basin. In this worked example, design computation for the bypass weir and the connection to the macrophyte zone will be presented.

9.6.3.3 Macrophyte zone layout

Size and dimensions

The wetland has been sized to require an extended detention volume of 750 m^3. An extended detention depth of 0.5 m has been adopted requiring a surface area of 1500 m^2.

In this case it has been chosen to adopt a length (L) to width (W) ratio of 6:1. This aspect ratio represents a shape configuration in between Case G and Case I in Figure 9.6 and the expected hydraulic efficiency is 0.6. This is lower than ideal for a wetland; however, the space constraints of the site limit the available area for the macrophyte zone.

Aspect ratio is **6(L):1(W)**; hydraulic efficiency **~ 0.6**

To calculate the dimensions:

L = 6W

Wetland area = 6W × W = 1500

Proposed dimensions are 95 m × 16 m.

Notional macrophyte zone dimensions are **95 m (L) x 16 m (W).**

Zonation

The wetland is broadly divided into four macrophyte zones, an open water zone and a littoral zone. The bathymetry across the four macrophyte zones is to vary gradually over the depth range outlined below. The depth of the open water zone near the outlet structure is to be more than 1.0 m below the permanent pool level.

Table 9.2 Percentage of wetland surface allocated to macrophyte zones and open water

Zone	Depth range (m)	Percentage of macrophyte zone surface area (m)
Open Water	>1.0 below permanent pool	10%
Submerged Marsh	0.5–1.0 below permanent pool	10%
Deep Marsh	0.35–0.5 below permanent pool	25%
Marsh	0.2–0.35 below permanent pool	25%
Shallow Marsh	0.0–0.2 below permanent pool	25%
Littoral (edges)	+0.5–0.0 above permanent pool	5%

Each zone has varying depths, but within each zone there are bands of equal depth across the flow path. The appropriate bathymetry coupled with uniform plant establishment ensures the cross section has equivalent hydraulic conveyance, thus preventing short-circuiting.

Wetland consists of four macrophyte zones arranged in bands of equal depth running across the flow path.

Long section

Shepparton has a relatively low Mean Annual Rainfall (MAR, 563 mm), with much of the rainfall falling in winter and spring. The region also has high summer evaporation. It is, therefore, likely that water losses during summer will be high and it will be necessary to provide areas of habitat refuge. For this reason it is desirable to have areas of permanent pool interconnected to prevent fauna being isolated in areas that dry out. The proposed long section is for the bed of the wetland to gradually deepen over the four macrophyte zones (i.e. excluding edges). This profile also facilitates draining of the wetland.

Long section of the macrophyte zone is to be gradually deepening over the four macrophyte zones ranging from the permanent pool level (shallow marsh) to 1.0 m below the permanent pool (submerged marsh zone).

Cross sections

The batter slopes on approaches and immediately under the permanent water level have to be configured with consideration of public safety. A batter slope of 1(V):8(H) from the top of the extended detention depth to 0.3 m beneath the water line before steepening into a 1(V):3(H) slope is recommended as a possible design solution (see Figure 9.13). The safety requirements for individual wetlands may vary from site to site, and it is recommended that an independent safety audit be conducted of each design.

Cross section of macrophyte zone is trapezoidal in shape with a **base width of 8 m** and a **top width of 22.0 m**.

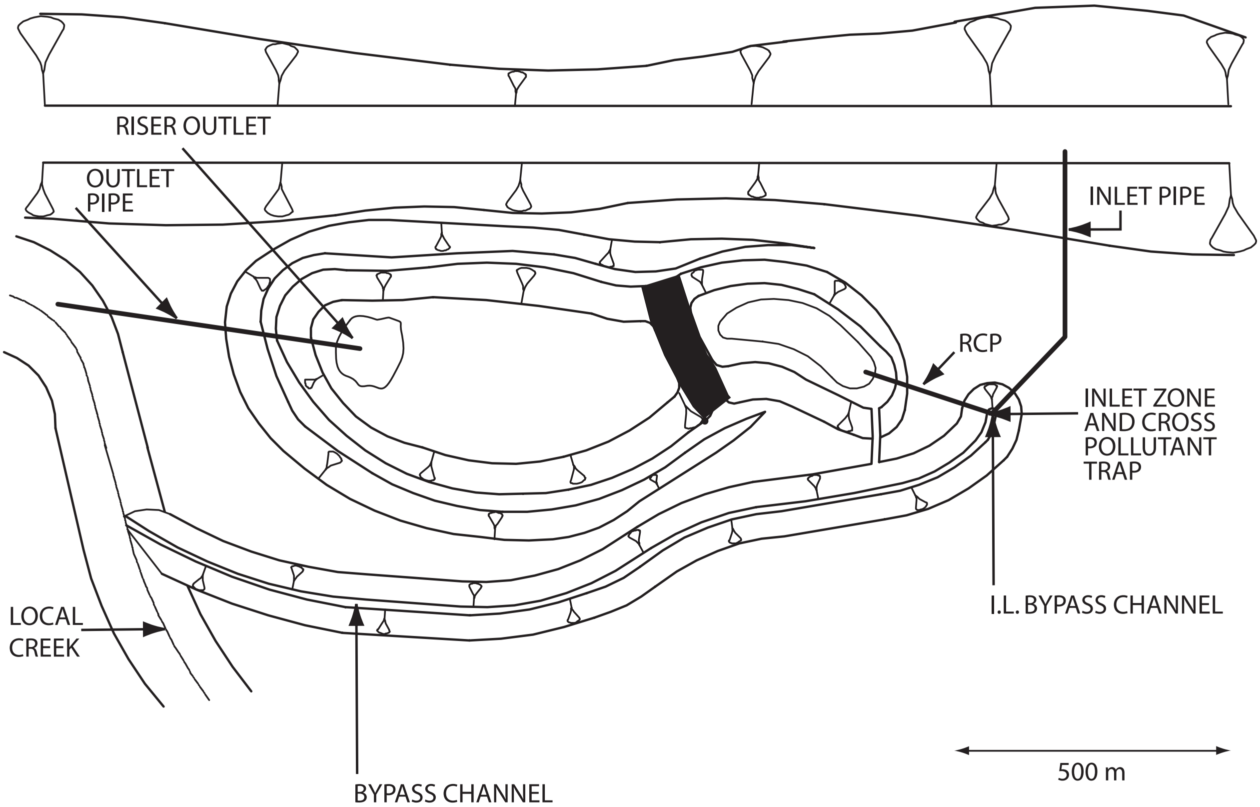

Figure 9.13 Typical cross section of macrophyte zone.

9.6.3.4 Macrophyte zone outlet structure

Maintenance drain

A maintenance drain will be provided to allow drainage of the system. Valves will be operated manually to drain the inlet zone and macrophyte zone independently.

The mean flow rate (Q) for the maintenance drain is selected to draw down the permanent pool over a notional 12 hours and is computed as follows:

Permanent pool volume ~ 375 m^3 (assuming approximate 0.25 m nominal depth)

$$Q = 375/(12 \times 3.6) = 9 \text{ L/s}. \qquad \text{(Equation 9.5)}$$

To determine the area of the orifice for the drain, it assumed that the valve orifice will operate under inlet control with its discharge characteristics determined by the orifice equation (Equation 9.1):

$$A_o = \frac{Q}{C_d\sqrt{2gh}}$$

$Q = 375/(12 \times 3600) = 0.009 \text{ m}^3/\text{s}$
$C_d = 0.6$
$h = 0.33$ m (one-third of permanent pool depth)

Giving $A_o = 0.0018 \text{ m}^2$ corresponding to an orifice diameter of 150 mm – adopt 150 mm.

Pipe valve to allow draining of the permanent pool for maintenance to be **at least 150 mm diameter.**

Riser outlet – size and location of orifices

The riser is designed to provide a uniform notional detention time over the full range of the extended detention depth.

Target Q_{max} = extended storage volume/detention time
= 750/(72 × 3.6) = 2.9 L/s

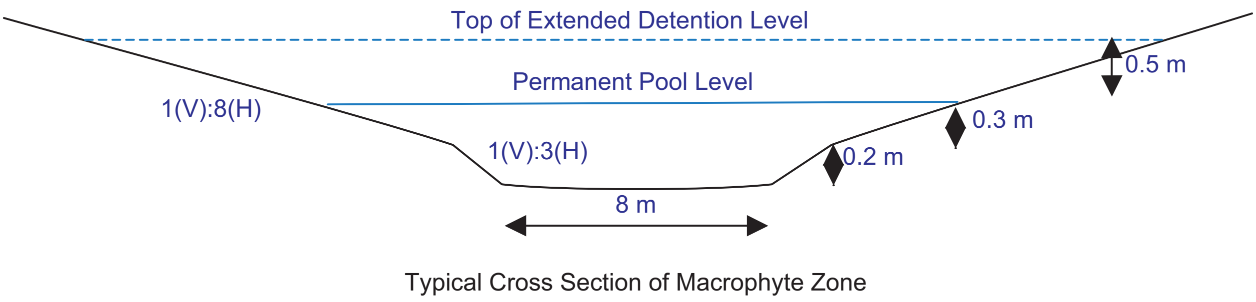

Figure 9.14 Typical cross section.

Outlet orifices along the riser are located at 0.167 m intervals along the length of the riser (i.e. at 0 m, 0.167 m and 0.333 m above the permanent pool level). A standard orifice diameter of 20 mm was selected and the numbers required at each level were determined iteratively using a spreadsheet (Table 9.3) and applying the orifice equation (Equation 9.1) applied over discrete depths along the length of the riser up to the maximum detention depth. The results of the design are summarised in Table 9.3. The stage–discharge relationship of the riser is plotted in Figure 9.14 and shows that the riser maintains a linear stage–discharge relationship.

Table 9.3 Determination of orifice positions

		Q_1	Q_2	Q_3	Total flow (L/s)	Notional detention time (hr)
Orifice positions (invert level)		0	0.167	0.333		
Orifice diameter (mm)		20	20	20		
number		2	1	1		
Water depth (m)	**Volume**					
0	0	0			0	
0.167	139	0.662			0.662	58.16
0.333	317	0.945	0.327		1.272	69.29
0.5	549	1.169	0.475	0.334	1.978	77.09

As the wetland is relatively small, the required orifices are small, and it is necessary to include measures to prevent blocking of the orifices.

The riser is to be installed within an outlet pit with a culvert connection to the permanent pool of the macrophyte zone. The connection is via a 300 mm diameter pipe. The pit is accessed via the locked screen on top of the pit.

The riser pipe should not be smaller than the pipe conveying the outflow from the wetland to the receiving waters (see 'Discharge pipe', p. 178).

Table 9.4 Outlet risers

Outlet riser consist of three rows of orifices of 20 mm diameter located as follows:	
Depth above permanent pool (m)	**No. of 20 mm diameter orifices**
0.000	2
0.167	1
0.333	1

Riser outlet – pipe dimension

As designed, high flows would bypass around the macrophyte zone when this zone is already operating at design capacity (i.e. when the water level in the macrophyte zone reaches the top of its extended detention). A notional riser pipe diameter of 150 mm is thus sufficient.

Riser pipe to be **150 mm diameter.**

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 or the maintenance drain:

- the maximum discharge from the riser = 1.3 L/s
- the maximum discharge through the maintenance pipe occurs for depth of 1.0 m (i.e. depth of open water zone); the maximum discharge through the 90 mm diameter valve is computed to be 17 L/s.

The required pipe diameter for the outlet should thus be larger than 90 mm. Since the diameter of the riser has been selected to be 150 mm, it is appropriate to also use this dimension for the outlet pipe connecting the wetland to the adjoining creek.

Outlet pipe for wetland for discharge to receiving waters (or existing drainage infrastructure) is to be **150 mm** diameter.

9.6.3.5 Connection to the inlet 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 pipe with the capacity to convey the one-year ARI peak discharge of 0.47 m^3/s.

Design specifications:
Bypass spillway level = top of extended detention in the macrophyte zone
Permanent pool level in inlet zone = 0.3 m above permanent pool level in macrophyte zone

In designing the culvert connecting the inlet zone to the macrophyte zone, the following conditions apply:
Headwater level = 0.5 m above macrophyte permanent pool level
Tail water level = permanent pool level
Design flow = 0.47 m^3/s.
Assume culvert under outlet control; $K_{in} = 0.5$, $K_{out} = 1$, $n = 0.015$
Try 1 by 450 mm diameter capacity = 0.41 m^3/s Too small
Try 3 Nos 300 mm diameter capacity = 0.55 m^3/s OK.

Culverts connecting inlet zone to macrophyte zone is to be **3** Nos 300 mm diameter.

Velocity checks are to be conducted for when the wetland is full and when it is at permanent pool level. For the velocity checks, the maximum inflow corresponding to the one-year ARI peak discharge is used (i.e. 0.47 m^3/s).
Flow check $V = Q/A$
When full:
$A = 15 \times 0.5 = 7.5$ m^2; $V = 0.06$ m/s no risk of scour
When at permanent pool level:
$A = 15 \times 0.1 = 1.5$ m^2; $V = 0.3$ m/s no risk of scour.

9.6.3.6 High-flow route and bypass design

The bypass weir level at the inlet zone is set to match the top of the extended detention level in the macrophyte zone. The length of the spillway (L) is to be sized to safely pass the 100-year ARI discharge with a water level over the weir of 0.3 m (i.e. top of wetland embankment).
The 100-year ARI peak discharge = 2.4 m^3/s
Crest level = 0.5 m above macrophyte permanent pool
Freeboard (top of wetland embankment) = 0.3 m
$k_w = 1.7$ (sharp-crested weir)

$$\text{Weir flow, } Q = k_w \times L \times H^{1.5} \qquad \text{(Equation 9.6)}$$

Therefore, $L = Q/k_w \times H^{1.5}$

$Q = 2.4$ m^3/s (100-year ARI flow from contributing catchment)
$H = 0.30$ m
$L = 8.6$ m

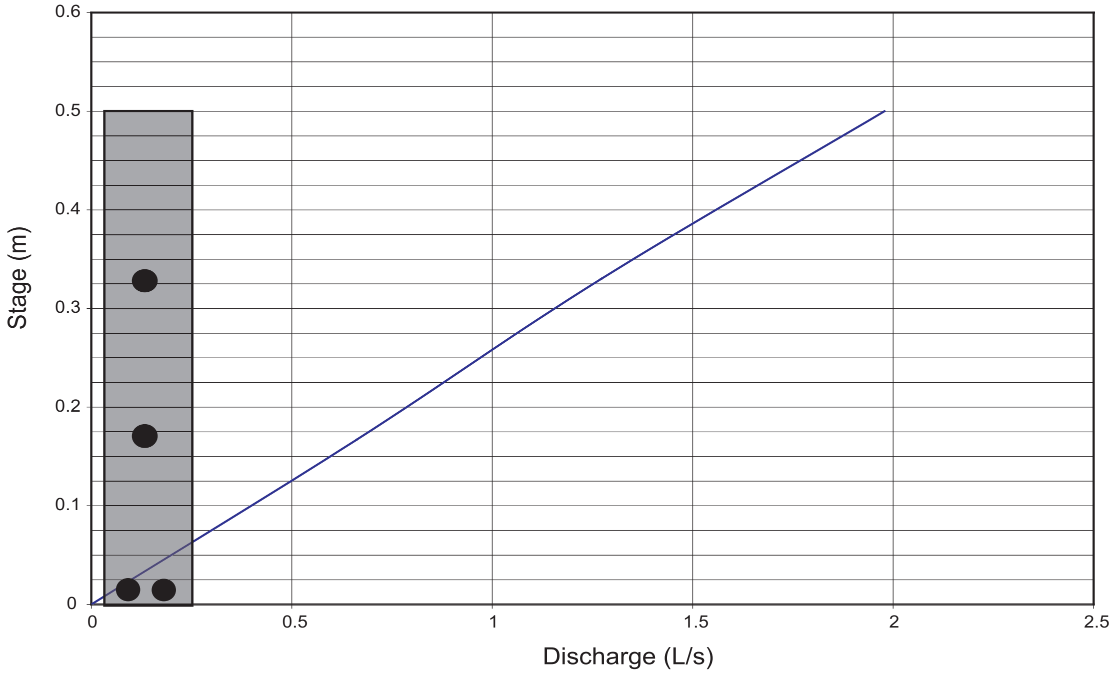

Figure 9.15 Positioning of orifice outlets (see attached CD).

The spillway length is to be 9.0 m set at a crest level 0.5 m above the permanent pool level of the macrophyte zone.

9.6.3.7 Vegetation specifications

The vegetation specification and recommended planting density for the macrophyte zone are summarised in Table 9.5 (see Appendix A for further discussion and guidance).

Table 9.5 Vegetation specifications

Zone	Plant species	Planting density (plants/m^2)
Littoral berm	*Persicaria decipens*	3
Ephemeral marsh	*Blechnum minus*	6
Shallow marsh	*Cyperus lucidus*	6
Marsh	*Bolboschoenus caldwellii*	4
Deep marsh	*Juncus ingens*	8

9.6.4 Design calculation summary

The completed *Constructed Wetland Calculation Summary* shows the results of the design calculations.

Constructed Wetand	CALCULATION SUMMARY		
CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			
Design ARI flow for inlet zone	1	year	
Target sediment size for inlet zone	0.125	mm	
Notional detention period for macrophyte zone	72	hr	
Design ARI flow for bypass spillway	100	year	
Extended detention volume	750	m^3	✓
2 Catchment characteristics			
Residential	7	ha	
Commercial	3	ha	
Fraction impervious			
Residential	0.4		
Commercial	0.7		✓
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities	10	minutes	✓
Identify rainfall intensities			
Station used for IFD data:	Shepparton		
100-year ARI	130	mm/hr	
1-year ARI	38.2	mm/hr	✓
Design runoff coefficient			
C_1	0.44		
C_{100}	0.66		✓
Peak design flows			
Q_1	0.47	m^3/s	
Q_{100}	2.400	m^3/s	✓
4 Inlet zone			
Refer to *Sedimentation Basin Calculation Summary*			✓
5 Macrophyte zone layout			
Extend detention depth	0.5	m	
Area of macrophyte zone	1500	m^2	
Aspect ratio	6(L):1(W)	L:W	
Hydraulic efficiency	0.6		
Length	95	m	
Top width (including extended detention)	16	m	
Cross section batter slope	1(V):8(H)	V:H	✓
6 Macrophyte zone outlet structures			
Maintenance drain			
Diameter of maintenance valve	90	mm	
Drainage time	12	hr	✓
Riser			
Linear storage-discharge relationship for riser			✓
Discharge pipe			
Discharge capacity of discharge pipe	0.75	m^3/s	✓
7 Connection between inlet zone and macrophyte zone			
Discharge capacity of connection culvert	0.55	m^3/s	✓
8 Bypass weir			
Discharge capacity of bypass weir	2.4	m^3/s	✓

9.6.5 Construction drawings

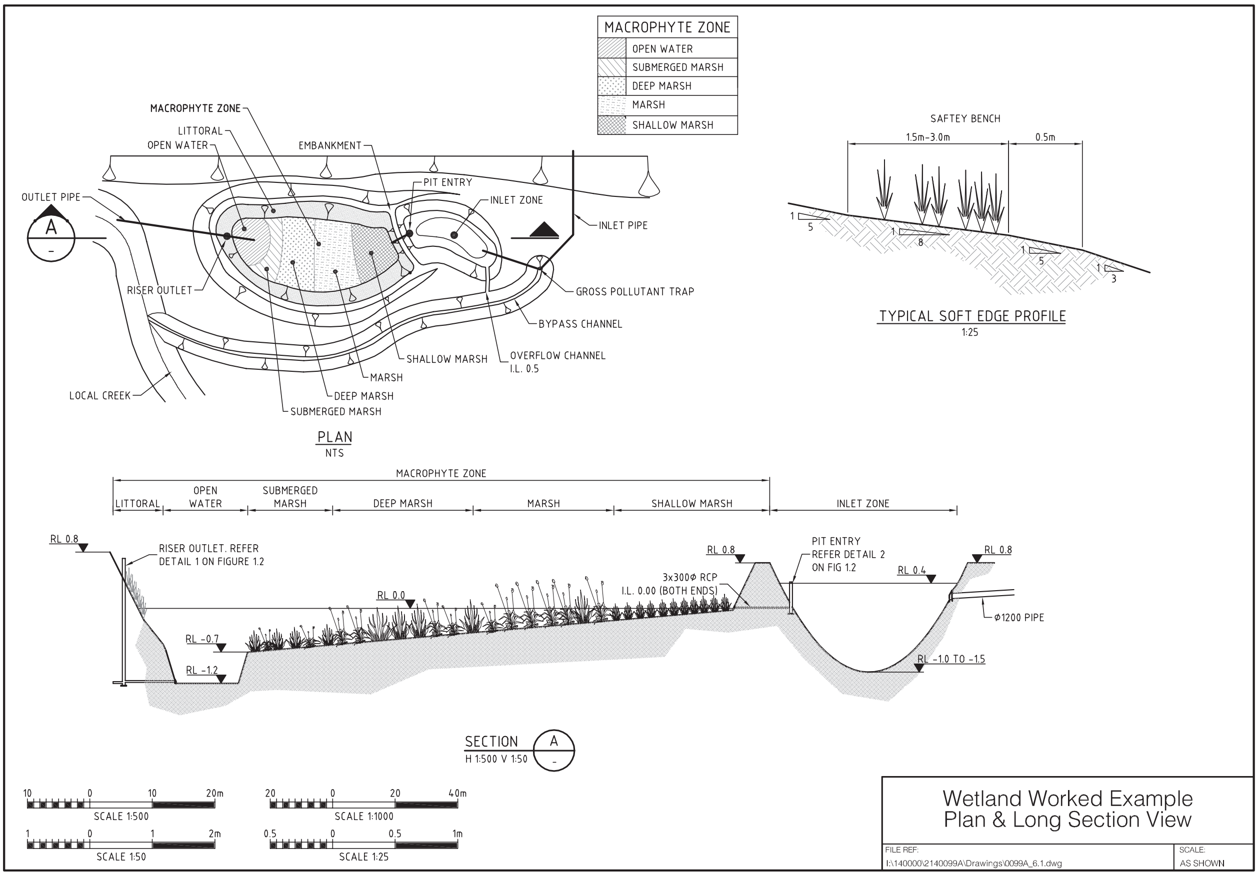

Figure 9.16 Wetland worked example plan and long section view

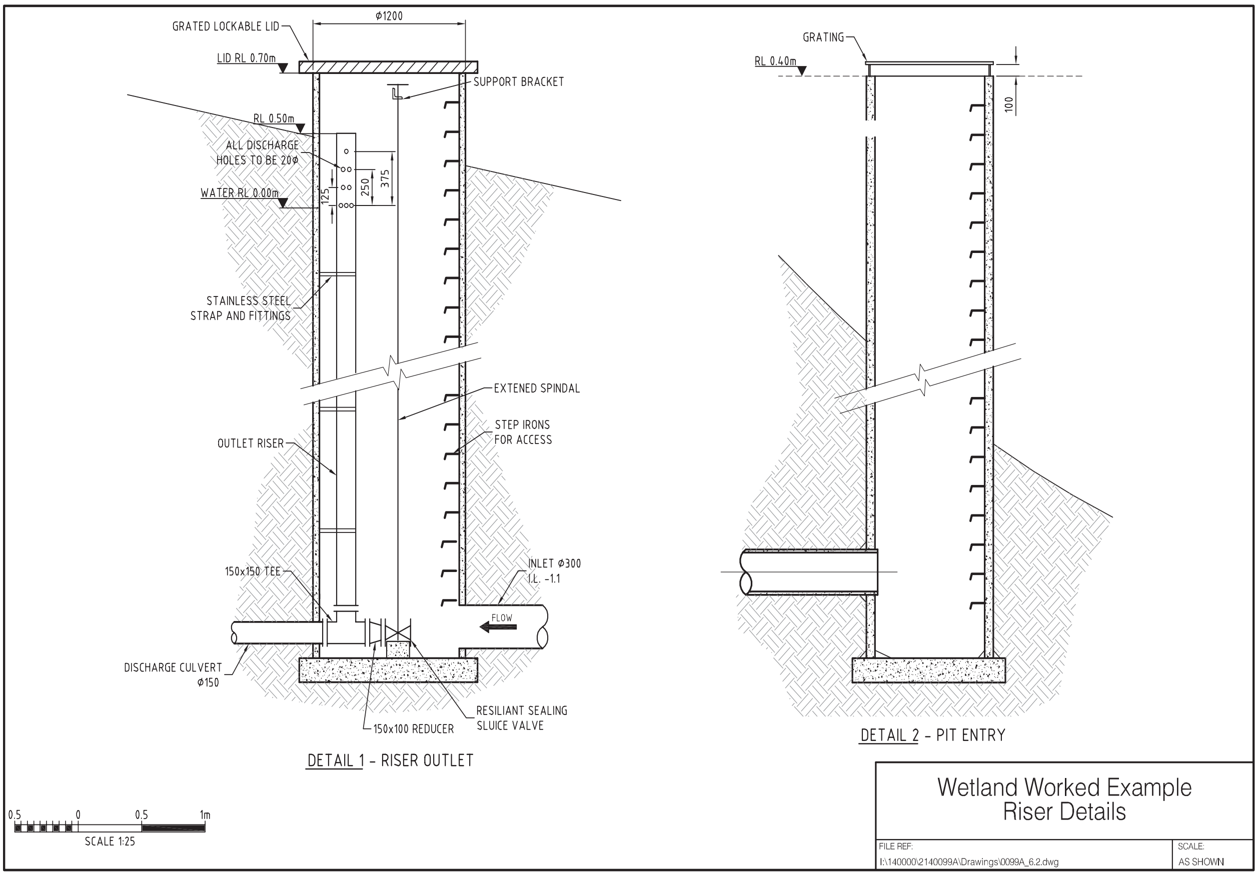

Figure 9.17 Wetland worked example riser details

9.6.6 Example inspection and maintenance schedule

An example inspection and maintenance schedule, the *Wetland Maintenance Checklist*, is included for a constructed wetland showing local adaptation to incorporate specific features and configuration of each individual wetland. The *Shepparton Wetlands Maintenance Form* is an inspection sheet developed for the Shepparton wetland, modified from the generic *Wetland Maintenance Checklist*.

SHEPPARTON WETLANDS – MAINTENANCE FORM	
Location	
Description	Constructed wetland and sediment forebay
SITE VISIT DETAILS	
Site visit date:	________________
Site visit by:	________________
Weather	________________

Purpose of the site visit	Tick Box	Complete Sections
Routine inspection	☐	Section 1 only
Routine maintenance	☐	Section 1 and 2
Cleanout of sediment	☐	Section 1, 2 and 3
Annual inspection	☐	Section 1, 2, 3 and 4

SECTION 1 – INSPECTION	
Depth of sediment:	________ m
Cleanout required if depth of sediment >1.0 m	Yes/No
Any weeds or litter in wetland (If Yes, complete Section 2 – Maintenance)	Yes/No
Any visible damage to wetland or sediment basin? (If Yes, completed Section 4 – Condition)	Yes/No
Inspection comments:	

SECTION 2 – MAINTENANCE	
Are there weeds in the wetland?	Yes/No
Were the weeds removed this site visit?	Yes/No
Is there litter in the wetland or forebay?	Yes/No
Was the litter collected this site visit?	Yes/No

SECTION 3 – CLEANOUT OF SEDIMENT		
Have the following been notified of cleanout date?	Yes	No
Coordinator – open space and/or drainage	☐	☐
Local residents	☐	☐
Other (specify ……………………………………….)	☐	☐
Method of cleaning (excavator or eductor)		
Volume of sediment removed (approximate estimate)	m^3	
Any visible damage to wetland or sediment forebay? (If yes, complete Section 4 – Condition)	Yes/No	

SECTION 4 – CONDITION					
Component	Checked?		Condition OK?		Remarks
	Yes	**No**	**Yes**	**No**	
Inlet weir or pipes					
Outlet riser/s and weir/s					
Sediment forebay					
Bypass channel (if constructed)					
Wetland vegetation					
Wetland banks and batter slopes					
Wetland floor					
Wetland diversion bunds (if constructed)					
Retaining walls					
Surrounding landscaping					
Comments:					

Shepparton Wetlands Maintenance Form

9.7 References

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