Chapter 6
Wetland design, construction and maintenance

6.1 Introduction

Wetlands are complex natural shallow water environments that are dominated by hydrophytic (water loving) vegetation. This distinguishes them from deep water habitats that are dominated by large areas of open water. Our current scientific knowledge regarding their functions and values has developed during just the last 40 years. Until very recently, the filling and draining of wetlands was accepted practice to "improve" the land. We now know that wetlands provide many important benefits including the attenuation of flood flows, maintenance of water quality, and support for aquatic life and wildlife. Around most urban areas, wetlands have been drained for land development activities and for enhanced agricultural purposes. Approximately 90% of New Zealand’s pre-European wetlands do not exist today.

Constructed wetlands are shallow vegetated ponds designed to utilise the benefits of natural wetland functions and processes for various purposes. The four principal purposes identified by Kadlec and Knight (1996) are:

> To compensate for and help offset the rate of loss of natural wetland as a result of agriculture and urban development. (constructed habitat wetlands)
> To improve water quality. (constructed treatment wetlands)
> To provide flood control. (constructed flood control wetlands)
> Produce food (constructed aquaculture wetlands)

Constructed wetlands have become increasingly popular in recent years for the second purpose identified above to treat urban stormwater to remove contaminants that would be potentially detrimental to the receiving water ecosystem. Multiple use constructed wetlands, which combine a number of purposes and benefits, are becoming more common in urban situations. Wong et al (1999) list the following purposes and benefits which are commonly combined:

> Flood protection
> Flow attenuation
> Water quality improvement
> Landscape
> Recreational amenity
> Provision of wildlife habitat.

A major consideration in the use of constructed wetlands for stormwater management purposes is to replace, to some degree, the wetlands that have already been lost. Wetlands are nature's natural “kidney” system and the loss of this filtering function of wetlands can be correlated, at least in part, with the decline in the quality of our water resources systems. Protecting existing wetlands, in conjunction with increasing the total extent of wetlands through wetlands restoration, creation, or construction for new developments, forms part of an effective strategy for downstream aquatic resource protection.

6.2 Objectives

This chapter:

> Demonstrates the advantages of constructed wetlands over unvegetated ponds
> Presents design principles of constructed wetlands intended to treat urban stormwater in the

Auckland Region,
- Discusses the physical, chemical and biological processes which are utilized to treat stormwater
- Gives guidelines for construction and maintenance of constructed wetland systems.

A key focus is how to optimise constructed wetland design for both treatment and stormflow detention by identifying the minimum dimensions that will achieve the required 75% treatment performance. Constructed wetlands are intended for use close to the source of urban stormwater, before the stormwater enters the receiving environment.

Other features and benefits of constructed wetlands are not included in the proposed design because their provision would require additional site area. These include provision of open water, increased habitat diversity and aesthetic amenity features such as islands and irregular shorelines. These can be added to the proposed design as needed or desired, provided the sizing and hydraulic control and treatment features of the design are not compromised.

Brown et al (1998) present a good outline of the chemical, biological and physical processes which influence treatment of urban stormwater in constructed wetlands.

A brief summary is presented in Table 6-1.

6.3 Advantages of constructed wetlands over unvegetated pond systems

A monitoring study of the treatment performance of an existing Auckland urban stormwater treatment constructed wetland was carried out and the results are detailed. The results of both local and overseas monitoring studies show that constructed wetland are better than detention ponds for urban stormwater treatment (ARC, 2001).

Vegetated wetlands offer better than unvegetated, deeper treatment ponds, mainly because of the dense vergetation which:

- Reduces the speed of water within the pond, promoting settlement of suspended solids
- Reduces wave action which in unvegetated ponds can inhibit deposition of solids and cause resuspension of fine solids
- Reduces wind induced water mixing
- Filters litter, floatables and silt particles
- Provides surfaces (substrates) for the growth of a variety of microorganisms which take up soluble contaminants (including nutrients and metals) and promote aggregation and settlement of colloidal particles; resulting in their deposition into the bottom sediment. Microrganisms are important as catalysts for most contaminant transformations in wetlands (Kadlec and Knight, (1996)
- Provides natural organic material which adsorbs organic and inorganic contaminants and results in their deposition into the bottom sediments
- Provides organic matter to bottom sediments and promotes conditions in which nitrification (NO_2^- to NO_3^-) and denitrification (N_2) occur, resulting in removal of nitrogen from the aquatic system. Organic soils maximise denitrification
- Takes up nutrients and some contaminants (although a proportion are later released when the plants decay)
- Increases organic bottom sediments that have a high cation exchange capacity for contaminants such as metals, phosphorus salts and organics

Wong et al (1998) list the advantages of vegetation in a constructed wetland stormwater treatment system as follows:

During baseflow the vegetation provides for the following benefits over unvegetated ponds:

- Provides surface area for sediments to adsorb onto biofilms growing on plants.
  Sediments attach to these biofilms and then settle to the bottom as part of the sloughed biofilm in a short term process occurring over hours to weeks.
- Takes up nutrients from the sediment.
  Nutrients in the sediment are transformed into plant biomass in a medium term process occurring over weeks to years.
- Transforms absorbed materials into less available contaminant forms.
  Plant biomass is returned to the sediment for storage as low-level biodegradable macrophyte litter in a long term process occurring over years to decades.
- Controls surface sediment redox (oxidation and reduction of chemical substances).
  Plant root zones generally help maintain an oxidised sediment surface layer that prevents undesirable chemical transformation of settled contaminants.

During storm events vegetation also provides the following physical benefits:

- Increases hydraulic roughness
- Promotes uniform flow
- Enhances sedimentation of particles through filtering.
- Provides more surface area for small-particle adhesion
- Protects sediments from erosion.

Table 6-1
Overview of stormwater contaminant removal mechanisms of constructed wetlands. (adapted from Mitchell 1996).

Contaminant	Removal processes
Organic material	biological degradation, sedimentation, microbial uptake
Organic contaminants (e.g. pesticides)	adsorption, volatilisation, photosynthesis, and biotic/abiotic degradation
Suspended solids	sedimentation, filtration
Nitrogen	sedimentation, nitrification/denitrification, microbial uptake, plant uptake, volatilisation
Phosphorus	sedimentation, filtration, adsorption, plant and microbial uptake
Pathogens	natural die-off, sedimentation, filtration, predation, UV degradation, adsorption
Heavy metals	sedimentation, adsorption, plant uptake

Wong et al (2001) compared suspended solids reduction in a vegetated and an open water channel. The data demonstrated that concentrations in the vegetated channel fell more rapidly than in the open water channel..

Monitoring data from an existing vegetated wetland at UNITEC Carrington campus in the Auckland Region were compared with the results from the same pond before the vegetation had developed into a significant treatment component. Results demonstrated improved performance by the vegetation for treatment of a number of stormwater contaminants, including total and dissolved metals (ARC, 2001).

6.4 Water quantity performance

Constructed wetlands can be sized to control the peak rate of runoff from storm events, and an additional consideration from a downstream erosion control perspective is provided by dead storage and control and release of the first 34.5 mm of rainfall over a 24 hour period for smaller storms. This storage capacity reduces peak flows, velocities, and reduces the loadings of contaminants which are delivered to downstream waters during small runoff events. The attenuated peak flows and velocities minimize erosional forces within the stream channel and further protect and maintain downstream water quality.

Organic matter accumulates in wetlands primarily through the growth and decay of vascular plants and algae. Organic soils have a higher porosity and thus a lower density and higher water holding capacity than mineral soils: organic soils have about a tenth of the density of mineral soils; 1.0 to 2.0 grams/cm^3 for mineral soils compared to 0.2 to 0.3 grams/cm^3 for organic soils. This allows the wetland soils to store more water than mineral soils. While this function is less effective during high runoff events, it enables wetlands to noticeably reduce the volume of water and the loadings of contaminants discharged during small runoff events.

6.5 Water quality performance

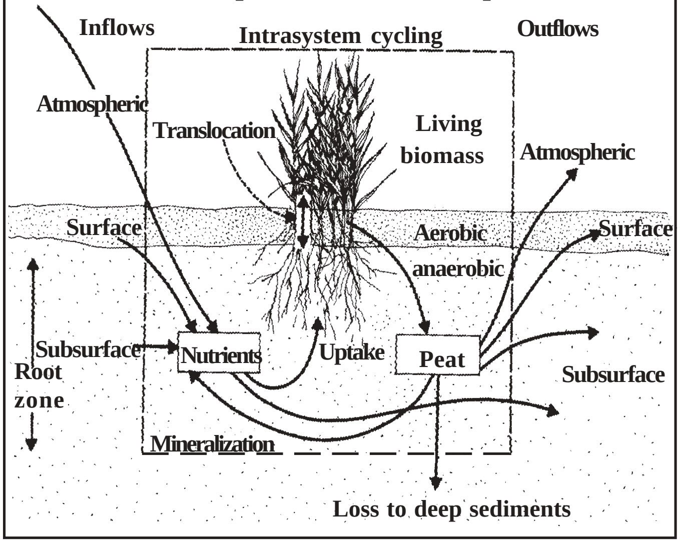
Natural wetland systems have complex mechanisms, as shown in Figure 6-1, for cycling elements and compounds into different forms and between the air, water, soil, plant and animal media. The figure aims not to show all wetland processes, but to indicate their complexity. Discussion of wetland water quality processes is further complicated by the variety of wetland types and their characteristics.

Stormwater contaminants generally fall into three categories; sediment, nutrients (phosphorus and nitrogen) and toxicants (including metals and organics). The form and fate of a particular contaminant is influenced by the type of wetland, geographic location, time of year, hydrologic condition and other factors. When it comes to wetlands and water quality, there are no simple relationships.

Brown et al (1998) note that wetland processes are influenced by:

- diurnal changes in water temperature and dissolved oxygen, and
- seasonal changes associated with changes in daylight hours, water temperature, growth of wetland vegetation, microbiological activity and chemical reactions.

Figure 6-1
Wetland processes and components



This means that the treatment efficiency achieved by a particular wetland varies widely for different contaminants. In areas with a marked seasonal variation in water temperature, treatment efficiency for a particular contaminant may also vary seasonally.

Wetland maturity also affects treatment efficiency for some contaminants, with new wetland soils sometimes having a higher assimilation capacity for phosphorus and nitrogen than older wetland soils.

The accumulation of organic matter from dead plant material also removes contaminants more rapidly. High density wetland vegetation is likely to achieve higher treatment efficiency than lower density because the larger surface contact area supports more microorganisms, which mediate contaminant removal processes.

6.5.1 Sediments

Plate 6-1: Small Well Landscaped Constructed Wetland

Although the sedimentation process is better understood for open water ponds (the longer that water remains in a pond system, the greater the degree of sediment retention) constructed wetlands can also be designed to maximise the detention times.

The sedimentation removal rate in constructed wetlands is very closely related to the removal of numerous other contaminants, especially phosphorus and metals, because they tend to bind to sediments. Removing sediments from the water column will thus tend to remove a number of other contaminants. Approximately 50% of phosphorus can be expected to be in particulate form, and should thus be removed with the sediments.

The removal of soluble contaminants can also be significant. It depends on the residence time, which in turn depends on the total volume of dead water storage, the inter-event dry period and the design rainfall volume.

The organic soils in constructed wetlands are an important sink for nutrients and other contaminants that would otherwise enter downstream waters. Thus, constructed wetlands designed to keep sediments in place will provide for long-term storage of contaminants. For example by minimising disturbance of wetland sediments and dispersing flow through the wetland rather than by channelising it.

6.5.2 Toxicity and biofilms

Timperley et al (2001) show that urban stormwater contaminants such as the metals copper, lead, and zinc may be present in very high concentrations in fine particulate matter that is difficult to settle and retain in open pond treatment systems. It is then trapped in biofilms in receiving water habitats where it can be ingested by grazing organisms. The accumulation of toxic contaminants such as metals and persistent toxic organics in sediments in both freshwater and marine areas is of major concern in the Auckland area.

Urban stormwater toxicity is generally associated with the heavy metals copper, lead and zinc, and hydrocarbons including petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH). Toxic persistent organic compounds including pesticides, herbicides and industrial chemicals may also be present in some stormwater.

Vegetated wetlands are significantly more effective than ponds in removing soluble contaminants. The reduction of toxic substances should be a high priority for vegetated wetland design for most of the Auckland area.

Timperley et al (2001) state that biofilm trapping in wetlands and shallow macrophyte ponds is an effective mechanism for removing fine particulate matter from storm and wastewaters. The very large surface areas of submerged vegetation and the associated microorganisms provide effective systems for the removal of fine particulate matter.

6.5.3 Nutrients

The design of vegetated wetlands for reduction of phosphorus in stormwater has received considerable attention in New South Wales and Victoria in Australia because many of the receiving waters in those areas have very long detention times and are sensitive to nutrient enrichment. Wiese (1998) identifies the need to reduce dissolved phosphorus in order to protect the quality of receiving waters as the critical parameter determining wetland size in southeast Australia.

The slow removal rate of dissolved phosphorus by urban stormwater wetlands means they need long detention times in order to achieve the desired outflow quality.

In the Auckland area most freshwater receiving waters are small fast-flowing streams which have short flow paths to the coast, and have very short detention times. Those receiving waters are not highly sensitive to nutrient enrichment. The marine receiving waters in the Auckland area are not generally sensitive to nutrient enrichment, with the exception of temporary empoundments of tidal water such as the Orakei Basin and Onehunga Bay lake. The few lakes in the Auckland area are much more sensitive to nutrient enrichment.

Vegetated wetlands are capable of achieving significant reductions in nitrogen and phosphorus nutrients, but design to achieve desirable discharge standards requires relatively long detention times. Nutrient reduction will not generally be a high priority for vegetated wetlands in the Auckland area, but could be required where the receiving waters are known to be sensitive to high nutrient inputs.

6.5.4 Contaminant removal efficiency

Table 6-2 presents summary data for the 1994 and 2002 studies at the Carrington Unitech pond/wetland. Sixteen types of PAH were monitored in the 2001-2002 study. Concentrations were generally low in inflows and very low in outflows. Results indicated a high degree of removal by the vegetated wetland.

Table 6-2
Mean concentrations for the combined volumes of storms on 13/11/01, 22/11/01, 11/12/01, 04/01/02, and 05/02/02, compared with 1994 study mean concentrations.

Constituent	Units	Inflow Concentration		Outflow Concentration		% Removal	
		1994	2002	1994	2002	1994	2002
Suspended solids	g/m^3	81.2	27.6	13.5	15.2	83.3	44.9
Chemical oxygen dmd	g/m^3	57.4	43.9	39.1	32.3	31.8	26.4
Ammonia nitrogen	g/m^3	0.021	0.046	0.058	0.050	-176	-8.6
Nitrate nitrogen	g/m^3	0.601	0.376	1.453	0.056	-141	85.1
Nitrite nitrogen	g/m^3	0.009	0.005	0.022	0.003	-144	40.0
Total nitrogen	g/m^3		0.994		0.668		32.7
Organic nitrogen	g/m^3		0.567		0.559		1.4
Copper total	g/m^3	0.0258	0.0155	0.0049	0.0032	81.0	79.3
Copper soluble	g/m^3	0.0056	0.0050	0.0032	0.0019	42.8	62.0
Lead total	g/m^3	0.0947	0.0204	0.0057	0.0005	93.9	97.5
Lead soluble	g/m^3	0.0024	0.0004	0.0011	0.0004	54.1	0
Zinc total	g/m^3	0.225	0.161	0.071	0.023	68.4	85.7
Zinc soluble	g/m^3	0.097	0.089	0.052	0.012	46.3	86.5

It is unlikely that persistent contaminants in stormwater can be reduced to zero by wetland treatment systems. It was noted during the 2002 UNITEC wetland monitoring study that inflow suspended solids and organic nitrogen were almost certainly retained within the wetland, and that suspended solids and organic nitrogen in the outflow were almost certainly derived from detrital material generated within the wetland.

At this stage the 2002 outflow concentrations for suspended solids, total and soluble metals and PAH are considered to be achievable standards for optimised constructed wetland treatment systems for stormwater.

Further work to determine seasonal changes in nitrogen and phosphorus nutrient removal will be necessary to determine the overall performance of constructed wetland treatment systems in the Auckland Region.

6.5.5 Constructed wetland design criteria

It is important to specify the contaminants that an urban stormwater treatment wetland is designed to treat, as effective treatment of different contaminants can require markedly different detention times within the treatment wetland.

Suspended solids are at one end of the treatability spectrum and require a relatively short detention time to achieve a high degree of removal, although it should be noted that fine particulate matter, which makes up a small proportion of suspended solids, is much more difficult to remove. At the other end of the treatability spectrum are nitrogen and phosphorus nutrients. Given sufficient space and time, wetlands are capable of removing nutrients to very low levels (for nitrogenous compounds down to around 0.5 mg/L, and for phosphorus down to about 0.1mg/L), but like any other waste treatment system, their efficiency depends on their design and waste characteristics.

Designs that remove toxic substances will also achieve good aesthetic outcomes as well as meeting desirable discharge targets and some reduction of nutrients and human pathogens. It is desirable to reduce mass discharges of metals and persistent organic contaminants into the coastal marine area where they become concentrated in sediments.

For receiving waters with high contact recreation values design to remove pathogens will be desirable, but at this stage the requirements for effective pathogen removal do not appear to be known. Kadlec and Knight (1996) give an areal rate constant for removal of faecal coliform, but this is unlikely to be applicable to an optimised constructed wetland treatment system and therefore not be a priority for the Auckland Region.

The most common design priority for vegetated wetlands for the treatment of urban stormwater in the Auckland area will be the removal of:

- Sediments,
- Toxic substances including hydrocarbons and dissolved metals, and
- Other toxic substances associated with fine particulate matter.
- Nutrient limitation of stormwater discharges into freshwater lakes or coastal water empoundments

6.6 Applicability

As detailed in Chapter 4, wetlands are most appropriate on sites that meet or exceed the following criteria.

- Catchment area more than approximately 1 hectare
- Soils that are silty through clay
- No steep slopes or slope stability issues
- No significant space limitations

Hydrology is the single most important criterion for determining the success of a constructed wetland system. They should therefore only be used in areas that have enough inflow from rain, upstream runoff or groundwater inflow to ensure the long-term viability of wetland processes.

The Auckland Region averages around 1200 mm of rainfall per year with some seasonal variation in rainfall. It rains on the average of every 2 to 8 days. Table 6-3 summarises rainfall data for the Auckland Region. The data summary is for a 10 year period between 1990 and 2000 and includes all storms of more than 2mm. Rainfall events are separated if there were 3 or more hours without rainfall. Storm events which spanned parts of two calendar months were assigned to the month in which most of the rain fell.

Table 6-3 shows that while more rain occurs in winter (June – August) rain is distributed throughout the year, with the average period between rainstorms being between 5 – 8 days in summer (Dec – Feb), and at 2 – 2.5 days in winter. The summer rainfall interval allows the maintenance of wetland treatment systems by avoiding their drying out in summer.

Table 6-3
Summary of storm rainfall for Auckland
(Data for Ranitopuni at Walker Rd 1990-2000)

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average rainfall (mm)	64	59	89	98	117	161	195	150	126	98	108	82
Number of storm events per month	5.4	4.4	7.1	9.2	10.1	13.1	13.6	13.9	12.1	9.6	9.6	6.4
Average rainfall per storm (mm)	9.1	11.4	11.8	10.2	11.3	10.6	14.4	10.4	10.4	9.2	11.3	11.6
Average storm duration (hrs)	3.5	4.4	4.6	4.3	5.0	6.5	6.5	5.6	5.3	5.2	5.5	5.1
Av. int betw storms (hrs)	165	183	114	77	85	49	50	59	63	85	82	123
% rain in storm class												
<5mm	12.5	7.9	8.0	13.5	13.2	14.2	10.4	14.1	11.0	14.5	12.5	10.5
5-10mm	12.4	22.1	17.9	17.9	17.3	18.9	11.5	17.1	23.5	17.6	12.6	12.8
10-20mm	31.0	37.4	16.5	24.2	28.5	27.2	17.5	34.1	28.4	42.1	29.5	26.0
20-40mm	30.1	25.4	24.3	26.2	16.1	10.7	29.2	14.5	18.7	19.2	23.2	20.0
>40mm	14.0	17.2	35.3	18.2	25.9	29.0	41.4	20.2	18.4	6.6	22.5	30.9

The average rainfall per storm, average storm duration, and the distribution of total rain in different storm size classes are remarkably constant throughout the year. This is beneficial to the hydrologic performance of the wetland treatment system. (Note that the high proportion of rainfall in the >40mm storm class for July is attributable to large storms which occurred in July 1998 and July 2000).

Constructed wetlands are feasible for almost any drainage area if the site soils are impermeable enough to allow for ponding with little exfiltration. Few problems are likely in the establishment and propogation of vegetation, even in periodic droughts. Wetland plants are tolerant of fluctuating water levels and some periodic fluctuation would enhance biological diversity. Soils analyses should be done during the site design phase to ensure that the soils can maintain a wetland environment. As the wetland evolves, loss of water should become negligible as the soils on the floor of the basin become more organic, reducing the potential for exfiltration.

Special circumstances may indicate the need to construct an ephemeral wetland. That should be done using specific guidelines and using plants that can adapt to periodic wetting and drying.

6.7 Design approach

Chapter 5 details extended detention design for water quality volumes based on 1/3 of the two year rainfall event (defined in Chapter 3, Section 3.5), the first 34.5 mm of rainfall, and peak flow requirements such as the 2 and 10 year storms depending on where the project is being constructed. The same design approach also applies to constructed wetlands.

Where water quantity control is not required due to the location of the project within a catchment or the outfall of the project enters tidewater, consideration should be given to a an upstream diversion weir to divert the first 1/3 of the 2 year rainfall event into the constructed wetland. Flows exceeding the water quality storm would overtop the diversion weir and bypass the constructed wetland to the site outlet, providing for enhanced water quality treatment of the dirtiest runoff when surface runoff initiates. By capturing the contaminants built up during dry weather a significant portion of the annual contaminant load can be captured. Separating this initial runoff also reduces turbulence and mixing, allowing further removing of contaminants..

6.7.1 Outlet structures

Potential procedures and designs for the outlets from constructed wetlands are the same as for ponds and are discussed in Chapter 5, Section 5.5.2. As with all ponds having a normal pool of water, there is a potentially major problem with outlet clogging where small orifices are needed for extended detention.

Below surface withdraw structures may reduce or eliminate the problem. This approach establishes a normal pool elevation by the outfall pipe having a negative slope. Although having the pipe inlet below the normal pool elevation reduces the potential for clogging by floating debris, it makes it difficult to see any clogging of the pipe. Maintenance shcedules detailed in Chapter 5 may overcome this.

6.7.2 Depths

The design water level and depth are important considerations for constructed wetlands. These shallow water systems do not contain the large volume of water per surface area as do wet ponds.

The proposed depth ranges and areas for a vegetated wetland treatment system with banded bathymetry (Figure 6-2) in the Auckland Region are estimated below. Note that the actual percentage of storage at various depths will vary depending on catchment area served, because smaller systems have a reduced deeper section.

Banded bathymetry (preferred design)	% total wetland wet pool area
Dead storage banded bathymetry at 0.5 -1m depth	40
Dead storage at 0 – 0.5m depth	60

Trapezoidal bathymetry (uniform bottom slope)	% total wetland area
dead storage at 1m depth	20
dead storage at 0-1m depth	80

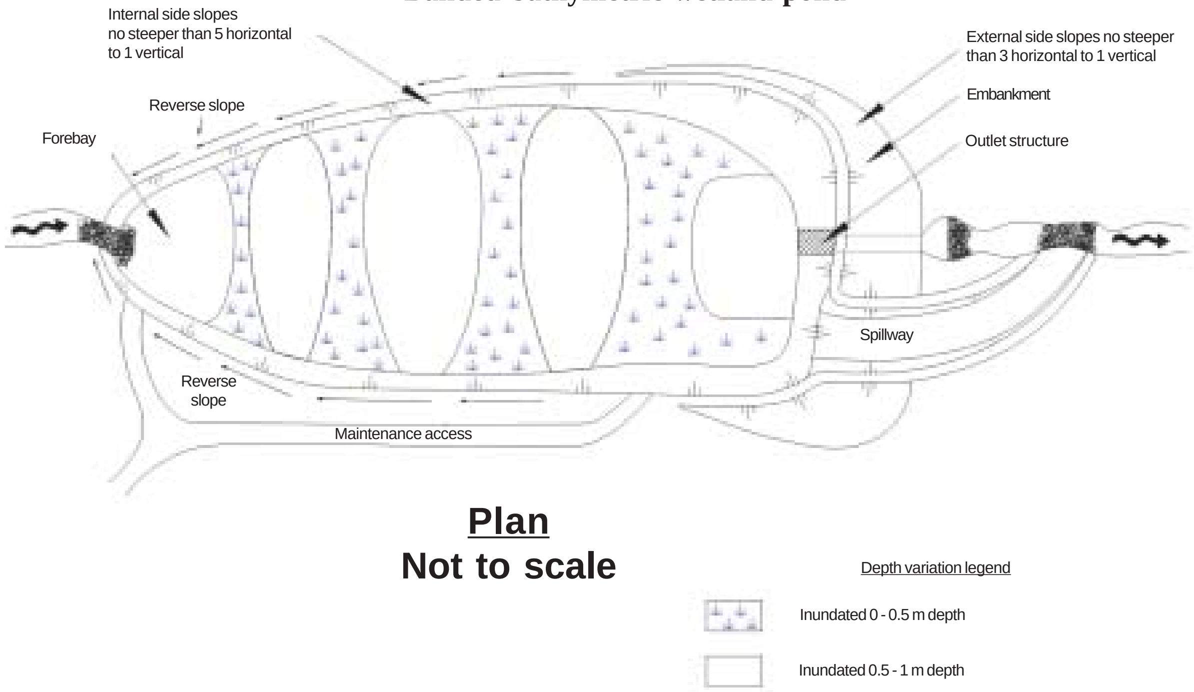
The banded bathymetry design is recommended over the trapezoidal bathymetry design because the configuration provides a better expectation of uniform flow throughout the wetland. The trapezoidal design may have vegetation developing in a unevenly and allow for short-circuiting.

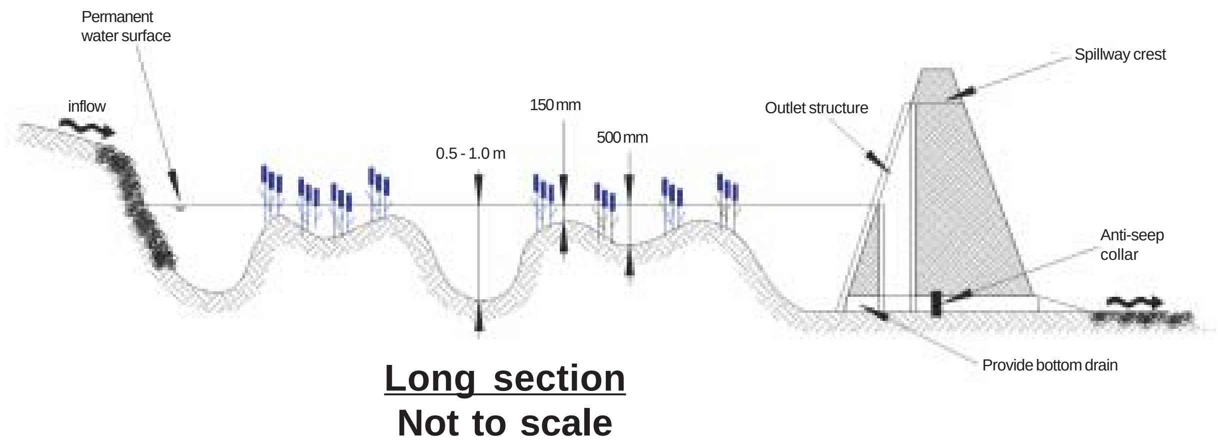
Because constructed wetlands promote the growth and propogation of emergent wetland plants, no areas other than the forebay or around the outlet structure of the pond should be more than 1 metre.

The reverse slope should be in the form of a swale which directs overland flow back into one of the controlled inlets. The vegetation in the swale also will enhance the trapping of particulates before they enter into the constructed wetland.

As well as providing an environment of intense biologic activity, the shallow nature of wetlands reduce liability. The very shallow fringe areas promote dense vegetation growth which act as a natural barrier to small children trying to get into the pond. This is much safer than the steep sides of many deeper ponds which make it harder to get out. The wilder appearance of constructed wetlands and their minimal areas of open water will also tend to discourage casual use by swimming or boating.

Figure 6-2
Banded bathymetric wetland pond





6.7.3 Surface area and water quality storage requirements

The surface area of a constructed wetland reflects the water quality storage requirements. The wetland pond surface area is the same as the deeper pond surface area would be but the overall volume may be significantly less.

To find the surface area snd storage requirements for a constructed wetland:

1. Calculate the water quality volume as detailed in Chapter 3.
2. Using the pond design approach in Chapter 5, calculate the pond surface area using site topography and water quality volumes to be stored. That area will depend on whether there is an extended detention as well as a water quality requirement. Ensure wetland depths are consistent with the provisions of Section 6.6.2 (ie. no deeper than 1 m except at forbay and outlet).
3. Find the volume associated with that surface area to determine the final wetland dimensions and surface area. If a shallower wetland is desired for safety reasons, depth can be reduced but not volume. A greater surface area will then be needed (depending on available land) to provide the required volume.

6.7.4 Forebay

Purpose

The purpose of the forebay is to capture those sediments that are in the sand and gravel size range and which, from a volume standpoint, constitute the largest sediment load from a stabilized catchment. The capture of these larger sediments will reduce the frequency of cleanout from the wetland portion of the basin.

The forebay shall:

> Constitute approximately 15% of the reduced water quality volume (increased 50% from 10% for sediment deposition), and
> Shall have a maximum water depth of 2 metres.
> Shall have a surface length to width ratios should be between 2:1 and 3:1
> No live storage that would reduce the depth of the normal pool

The forebay will be the deepest component of the wetland pond. Where there are multiple inlets to the constructed wetland, the total volume of all the forebays shall be 15% of the water quality volume with the individual inlet forebays sized with respect to their percentage of contributing flow.

The use of stone riprap, as shown in Figure 6-3 will reduce the velocities of flow into the wetland portion of the basin and minimize resuspension of the deposited sediments in the forebay.

An access to the forebay should be provided for excavation equipment to facilitate cleanout of the forebay. It is an integral component of the constructed wetland and is critical in long term function of the wetland. All inflow points must enter a forebay.

The forebay inlet structure must provide for energy dissipation and even distribution of inflow into the forebay.

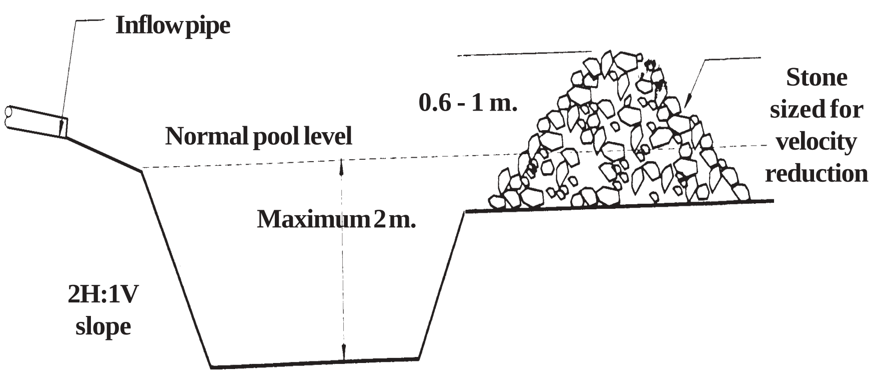
Outlets

The forebay outlet structure should provide water level control and optimum flow through the forebay. An overflow weir or weirs with a total length equal to at least 50% of the forebay width is desirable to maintain a shallow surface discharge and avoid concentration of the outflow.

An excess flow bypass is to be provided around both the forebay and the vegetated wetland. Flow velocities during the 1 in 5 year storm are required to be less than 0.25 m/s to avoid resuspension of sediment. In some cases this may necessitate the use of a forebay which is larger than the minimum forebay volume.

This forebay design, with a permanent pool, offers better water quality treatment between storms and for the first flush of runoff. The pond will operate in a displacement mode with the clean, lower density dead storage water being displaced through the outlet as the dirty incoming stormwater of higher density sinks to the bottom of the dead storage areas.

Figure 6-3
Crosssection of the forebay of a constructed wetland



Debris screens

Ideally the inflowing stormwater should be screened for removal of rubbish prior to the forebay. Screen clogging can be a problem, and designs should ensure that clogged screens do not interfere with the functioning of hydraulic controls.

Self cleaning screen designs should be considered.

6.8 Design procedure for a constructed wetland

The design includes the following:

1. Calculate water quality volume as discussed in Chapter 3.
2. Take 15% of the reduced volume for the sediment forebay.
3. Determine whether the pond requires peak control and stream channel extended detention.
4. Based on that decision, size a wet pond using site topography and required water quality volumes to be stored to calculate the surface area
5. Using that surface area, define your wetland boundaries
6. Set the depths of permanent pool as in Chapter 6.7.2 and Figure 6-2.
7. Do calculations similar to those in the pond design chapter for the outlet structure releases and size the storage volumes as for wet ponds (Chapter 5.5.2).
8. Define bathymetry of the wetland from Figures 6-2 and 6-3 with depth as in Chapter 6.7.2 and Figure 6-2.

6.9 Plants

6.9.1 Main wetland pond

The wetland treatment basin is to be densely vegetated throughout. The optimum treatment configuration is a wetland densely vegetated with species that provide a high density of stems in the submerged zone and thereby maximize the contact between the water and the surfaces on which microorganisms grow, while providing uniform flow conditions with no short circuiting.

Preferred vegetation

Following is a list of the preferred vegetation and it's "normal depth" for the optimized vegetated wetland.

Deep zone 0.6 – 1.1m

Baumea articulata	Typha orientalis (raupo)
Eleocharis sphacelata	Myriophyllum propinqum (water milfoil)
Schoenoplectus validus	Potamogeton cheesemanii (manihi)

Shallow zone: 0.3-0.6m

Baumea articulata	Schoenoplectus validus
Bolboschoenus fluviatilus	Typha orientalis
Eleocharis sphacelata	Isolepis prolifer
Eleocharis acuta	Juncus gregiflorus
Carex secta	

Wet margin 0-0.3m

Baumea teretifolia	Juncus gregiflorus
Baumea rubiginosa	Carex virgata
Carex secta	Cyperus ustulatus (giant umbrella sedge)
Eleocharis acuta	Phormium tenax (flax)

Live storage zone (periodically inundated)

- Syzygium maire (swamp maire)
- Carex virgata
- Carex lessoniana (rautahi)
- Carex dissita (flat leaved sedge)
- Cyperus ustulatus
- Juncus articulatus
- Juncus pallidus
- Dacrycarpus dacrydioides (kahikatea)
- Cordylina australis (cabbage tree)
- Baumea rubiginosa
- Phormium tenax (flax)
- Coprosma tenuicaulis (swamp coprosma)
- Blechnum novae-zelandiae (swamp kiokio)

Land edge:

- Coprosma robusta (karamu)
- Phormium tenax
- Cordyline australis
- Carpodetus serratus (putaputa weta)
- Laurelia novae-zelandiae (pukatea)
- Leptospermum scoparium (manuka)
- Schefflera digitata (pate)
- melicytus ramiflorus (mahoe)
- Pneumatopteris pennigera (gully fern)
- Dacrycarpus dacrydioides (kahikatea)
- Cortaderia fuluida (toetoe)

For reed beds less than 100m length, the gradient should be flat. For longer reed beds, the introduction of bed slope will compensate for the hydraulic gradient, and allow easier draining. Access to the reed bed is required for planting and maintenance. Access areas need to be identified on plans.

The main potential drawback to an overall densely vegetated system would be the reduction of dissolved oxygen in the near bottom water and the surface sediment layer. Marked stratification of dissolved oxygen concentration occurs in natural vegetated wetland systems, with high DO saturation at the surface and very low DO saturation near the sediment. The presence of anaerobic sediment is desirable for denitrification, but it is not clear if densely planted systems can reduce DO so low that adverse effects can occur in freshwater receiving systems. This matter appears to have attracted little comment in the literature although the chemical changes that occur in anaerobic (anoxic) conditions are well understood.

The removal of nitrogen is less critical in the Auckland Region than in other parts of the country where receiving waters are particularly sensitive to nitrogen enrichment.

Because Auckland's area rainfall is distributed fairly evenly throughout the year, the degree of development of anaerobic conditions in near bottom waters in treatment wetlands is likely to be less than in areas with long dry periods. The ARC hopes to investigate the dissolved oxygen regime in stormwater treatment wetlands in the Auckland Region, and the possible implications for contaminant treatment over time.

6.9.2 Forebay

Vegetation is not necessary in the wet forebay provided the forebay is of good hydraulic design. that said, there are benefits.

The use of densely planted robust vegetation such as the rushes *Eleaocharis sphacelata* and *Schoenoplectus validus* in the forebay pond will increase its sediment removal performance, and also reduce the risk of resuspension of settled sediment during high flow periods, particularly in situations where an ideal hydraulic design could not be achieved.

Plate 6-2: Larger wetland providing stormater and wildlife benefits

The inlet design would need to ensure that water speeds during design maximum flow conditions did not erode the vegetation (suggested velocity <0.25 m/sec).

Dense vegetation in a forebay pond could be beneficial to human safety, and could also be considered for aesthetic reasons.

The disadvantage of vegetated forebays would be the additional maintenance requirement with potentially large volumes of vegetation to be removed in addition to the accumulated sediment.

6.10 Construction

Many parts of the discussion in Chapter 5 are applicable to constructed wetlands, Which are often considered a subset of wet detention ponds. However, they merit their own separate discussion because of the complexities of their design and construction, and their dependence on the establishment and propagation of emergent wetlands plants to provide water quality benefits.

6.10.1 Important inspection aspects related to design

Clay or geotextile liners

The shallowness of wetland stormwater treatment systems means that even a small alteration in water level can significantly affect the health of the aquatic plant community. It is therefore important to ensure that water levels remain as consistent as possible, apart from storm events. This may necessitate the use of a clay or geotextile liner to maintain water levels.

Final pre-construction design plans must show how water levels in the constructed wetland are to be maintained; whether by:

- Continual stream baseflow,
- High ground water levels, or
- In-situ clay soils or installation of a liner.

The combination of a periodically high water table in conjunction with impermeable liners will present a potential problem that must be designed for, possibly by use of underdrains.

Organic soil conditions

The quickest way of meeting wetland plants and organisms essential elements for growth and propagation is to place organic soils on the constructed wetland floor. The final design plans should specify any more complex provisions for placement of organic soils.

Organic soils are not a standard requirement, but their inclusion is highly recommended to facilitate plant growth. Not having organic soils on the constructed wetland floor results in slower growth and spread of the wetland plants and often also leads to the invasion by nondesirable aquatic plant pioneer species which can out-compete more desirable plants.

Shallow depth and slight grades

Unlike deeper detention systems, shallow constructed wetlands need to have exact grades in the inundated pool area. Most of their area comprises emergent aquatic plants whose establishment and propagation typically depend on water depths under one metre. To have a diverse plant community, varying depths are needed since different plants are best suited for various water depths. The plans should detail design elevations throughout the ponded area where wetland plants will be established. They should also clearly identify where each type of plant should go, as in Section 6.91.

Establishment of forebays

Being shallow water systems, constructed wetlands are very susceptible to filling in by sediments generated upstream. All principal inflow points must be provided with forebays designed to trap the largest volume of suspended solids and provide a readily accessible location for allow periodic removal of accumulated sediments.

Plans should detail the location, size, and proposed grades of designed forebay areas, along with dedicated access for maintenance equipment. See the pond design chapter 5.5.3 for guidance on these aspects.

Converting sediment ponds into constructed wetlands systems

Because they are shallow water systems, the long term performance of constructed wetlands can be significantly reduced by sedimentation. The final design plan should indicate whether the constructed wetland will be used as a sediment pond during the construction phase of the project, and if so, should detail how the sediment pond will be converted into a constructed wetland.

If the constructed wetland was not previously used for sediment control, the plans should specify:

- Project phasing for overall site construction, with a timetable for construction of the wetland
- How the constructed wetland will be protected from sediment entry while its catchment area is unstabilised
- When sediment must be removed from the forebays or constructed wetland
- That the wetland will not be planted until site earthworks stabilization is complete

Reduced need to provide for saturated embankment problems

Most constructed wetlands have a shallow depth of permanent water against the embankment, although, some wetland designs specify a deep water zone adjacent to the embankment. The shallow water reduces water pressure adjacent to the embankment and reduces the number of anti-seep collars needed to prevent piping along the outlet from the principal spillway. At least one anti-seep collar on the principal spillway is still required, but stability concerns are lower than for deeper wet detention systems.

Reduced safety features

Constructed wetlands present much less of a safety concern than deeper ponds due to their denser vegetation, more gradual side slopes, and the shallow water depth. Specific safety barriers therefore may not be required. Individual territorial authorities may still require barrier fences.

Establishing and maintaining plantings

There are three approaches to establishing aquatic plants in constructed wetlands:

- Plantings of aquatic plants which facilitates rapid plant growth
- Providing proper hydrology and soil conditions to promote colonisation of the system by local vegetation
- Installing soil having vegetative plant roots or rhizomes

These are not mutually exclusive, and proper conditions must be provided to sustain plantings.

The design must detail which approach is used. If wetland plantings are to be used, the plan should specify:

- the plant species.

- the number of each species.
- where the plants will be located.
- if the pond water level will be lowered to facilitate planting.
- a timetable for planting to occur.
- Access points to maintain reed beds and other vegetation

6.10.2 Important inspection aspects related to construction

If the constructed wetland is to be used as a sediment control pond during construction, there are a number of items which must be considered:

- Outlet structure must be modified by installation of a temporary dewatering or decant device.
- Final grades are not important to establish at this time,
- The minimum volume needed for sediment control must be provided for construction generated sediment.

Regular sediment removal is needed to maintain the wetland's ongoing ability to remove suspended solids. When sediment cleanout is required, the removed materials should be placed upstream of any sediment trapping practices to prevent their movement downstream. An inspection programme will generally determine when sediment cleanout is needed and the final design plan should specify where the removed sediments are to be placed.

The importance of accurate grade establishment in shallow constructed wetland ponds cannot be overstated. During construction, survey stakes must be placed to accurately establish cuts and fills. The final grades must be accurate for successful plant establishment and propagation. Final grades should be established before the pond fills. Once the bottom and side soils have become saturated, the movement of earth material becomes much more difficult and the basin may have to be dewatered and dried before final grades can be established.

Site earthworks must be stabilised before wetland planting if site runoff passes through the wetland pond. Excess sedimentation can smother the plants and change wetland elevations which would alter planting success and plant composition. Optimally, the planting should be done several months after site stabilisation to further reduce sediment entry into the wetland, if construction scheduling permits.

Ideal times for successful establishment of plantings are in the spring when plants are emerging from dormancy and in the late autumn when plants are just entering dormancy. Time frames for planting must be established early in construction and be consistent with consent conditions, if specified.

6.11 Operation and maintenance

Operation and maintenance for wetlands incorporates all of the items detailed in Chapter 5. Other requirements are:

1. Wetlands should be inspected at least twice per year during the first three years during both growing and non-growing seasons to observe plant species presence, abundance, and condition, bottom contours, and water depths relative to plans, sediment, outlet, and buffer conditions.
2. Plants may require watering, physical support, mulching, weed removal, or replanting during the first three years.
3. Nuisance plant species should be removed and desirable species should be replanted.

6.12 Case study

A case study for wetlands design is not considered necessary as the hydrological approach is detailed in Chapter 5.

6.13 Bibliography

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