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Guidelines
New Zealand
Constructed Wetland Treatment of Tile Drainage

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Purpose

This guide provides information on how to design and construct wetlands to intercept and treat tile drainage flows from rain-fed grazed pasture in New Zealand. The focus is on removal of nitrate-nitrogen loads. Information to estimate potential nitrogen removal is based on the results of field studies and modelling.

What is the purpose of these guidelines?

The New Zealand Guidelines for Constructed Wetland Treatment of Tile Drainage are intended to guide farmers, farm advisors, rural contractors, and regional council staff to appropriately locate, size, design, and construct effective treatment wetlands. They also provide guidance on wetland planting, weed control, and maintenance in order to achieve effective treatment of tile drainage.

Why build a constructed wetland to treat tile drainage flow?

Tile drainage can act as a significant route for nutrient losses, particularly of nitrogen, from intensively grazed pastures to waterways. Current annual nitrogen losses in tile drainage flows from intensively grazed dairy pastures in New Zealand commonly range from 20–60 kg N per hectare, predominantly as nitrate. This quantity of nitrogen can pose a significant threat to water quality in sensitive receiving streams, rivers, lakes, and estuaries. Alternative design and management of tile drainage systems is required in these situations to integrate environmental goals with traditional agricultural water and soil management goals.

Constructed wetlands offer a potentially cost-effective, practical option for intercepting highly variable tile drainage flows to reduce nutrient losses from pastures, before they reach receiving water bodies. They should ideally be employed in combination with good fertiliser, grazing, and effluent management practices.

Background

Constructed wetlands have been recognised in many countries as an effective technology for treatment of tile drainage waters. As a best management practice, they capitalise on natural processes to reduce pollution from incoming water, while enhancing local biodiversity values.

What information are these guidelines based on?

The recommendations in these guidelines are based on the results of farm-scale trials and modelling carried out by NIWA based on five years of monitoring in the Waikato, and three and four years of monitoring in Northland and Southland, respectively (Sukias, J.P.S. et al. (2006), Tanner, C.C. et al. (2005a), Tanner, C.C. et al. (2005b); Tanner & Sukias, (2010)). In combination with international experience, these results have allowed the quantification of nitrogen removal in relation to wetland size and design, providing realistic guidance on performance expectations for land managers and regulators. The constructed wetland performance predictions presented apply primarily to tile-drained areas of key dairying regions in Northland, Waikato, Bay of Plenty, Taranaki, and Manawatu, with rainfall in the range of 800–1400 mm per year. Estimated differences in performance for Southland and Otago, where there are also significant areas of tile-drained dairy pastures, are also given.

What are constructed wetlands?

Natural wetlands have been called the "***kidneys of the landscape***" because of their ability to store, assimilate, and transform contaminants lost from the land, before they reach waterways. Constructed wetlands attempt to mimic these natural systems to treat through-flowing waters. Generally shallow surface-flow wetlands are the most appropriate type of constructed wetland system for treatment of farm tile drainage. They are similar to natural marshes and swamps, in which water flows through shallow flooded beds of emergent aquatic plants such as raupo (*Typha orientalis*).

In some cases, naturally occurring wetlands on farms can be used to intercept and treat farm drainage. Constructed wetlands have the advantage that they can be created where they are required, avoiding the risk of contamination and degradation of high quality natural wetland habitats.

How do constructed wetlands work?

Flows are dispersed and slowed down when they enter wetlands, promoting settling and deposition of suspended particles. Wetlands are also highly productive environments for plants and beneficial microbes which break down, assimilate and cycle nutrients, organic matter, and associated pollutants, transforming them into less harmful forms. In particular, denitrifying bacteria provide an important means for sustainably removing nitrate-nitrogen by converting it into nitrogen gas that is released back into the atmosphere.

What environmental factors affect performance?

Rainfall patterns, soil water status, groundwater levels, soil properties, drainage system design, and land-management practices affect the flows and contaminant loads generated in farm tile drainage. Consequently, tile drainage flow rates can vary from a trickle to a deluge, and contaminant concentrations fluctuate widely from hour to hour and day to day. Drainage flows can also vary significantly between sites, seasons and years, and across different regions of the country. Depending on the relative size and design of the wetland, the resulting residence time (average amount of time drainage water spends in the wetland) may also vary widely. The biological removal processes operating in wetlands are most efficient when residence times are long and water temperatures are high. Performance tends to be poorer during cold, wet, winter periods. Such factors significantly affect the capacity of wetlands to remove nitrate-nitrogen and other contaminants. Because of this inherent variability, we have focused on providing estimates of long-term annual average percentage removal performance, and indicated the normal range of performance that can be expected in typical dairying regions of New Zealand.

Situations these guidelines ***do not*** *apply to:*

1] Tile-drains conveying irrigated dairy effluent

Tile drains can act as a rapid conduit for irrigated farm dairy effluent. Depending on soil characteristics and preceding soil water status, drainage from such areas may contain high concentrations of organic matter, nitrogen in the form of ammonium, and faecal microbes. Although constructed wetland treatment will likely improve such discharges (Tanner, C.C.; Kloosterman, V.C. (1997)), the sizing, design, and performance estimates provided in these guidelines do not apply to such situations.

2] Large-scale constructed wetlands

The information presented in these guidelines is relevant for constructed wetlands up to 1 hectare (10,000 m^2) in size in low gradient sites and stable soil conditions. For projects larger than this, and any situation where there is potential for land instability or flooding, it is recommended that you seek professional engineering advice.

Compliance with RMA

Please check with your local regional council regarding relevant rules and regulations. Construction of dams, culverts, or earthworks in or near waterways, in particular, may be subject to regional rules and/or require resource consent under the Resource Management Act 1991.

Structural integrity

Use of these guidelines does not in any way negate the need to seek professional engineering advice to ensure sound and appropriate design and construction, particularly for large-scale applications and where there is potential for land instability or flooding.

Getting started

It is critical to plan the implementation of the project, including timing of key stages, BEFORE starting your constructed wetland.

There are five main stages to constructing a wetland:

Stage 1 **Choose location**

Stage 2 **Design**

Stage 3 **Construction**

Stage 4 **Establish plants**

Stage 5 **Maintenance**

Stage 1 Choose location

This section provides guidance for siting the constructed wetland.

What if the area available is limited?

It may be possible to divide the wetland into separate sections with one flowing into another. For example, if a farm track divides the area, a subsurface pipe could link the sections on either side.

A newly installed culvert linking two wetland sections.

Choosing a site to build your constructed wetland will depend on the configuration and existing functions of the available land and where the drainage system can best be intercepted. Likely areas include:

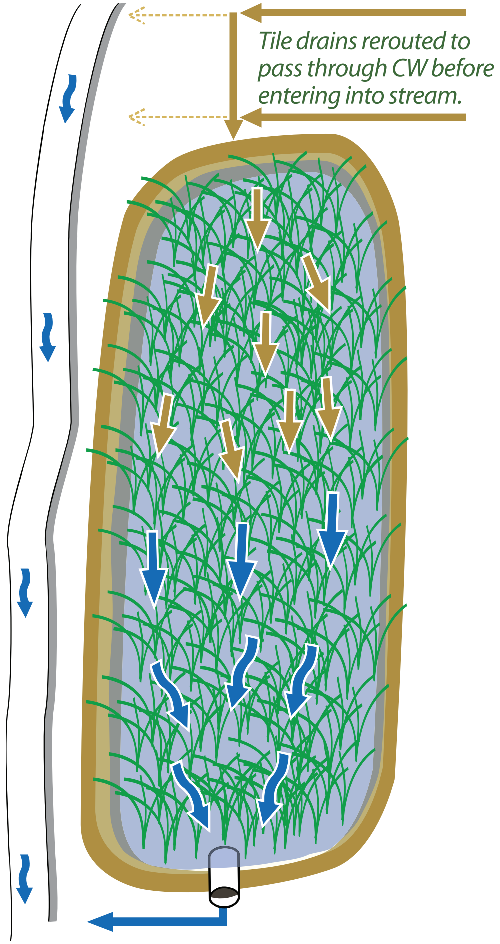
- at the downstream end of tile drains, alongside surface drains and streams,
- at the end of surface drains that are supplied by tile drains.

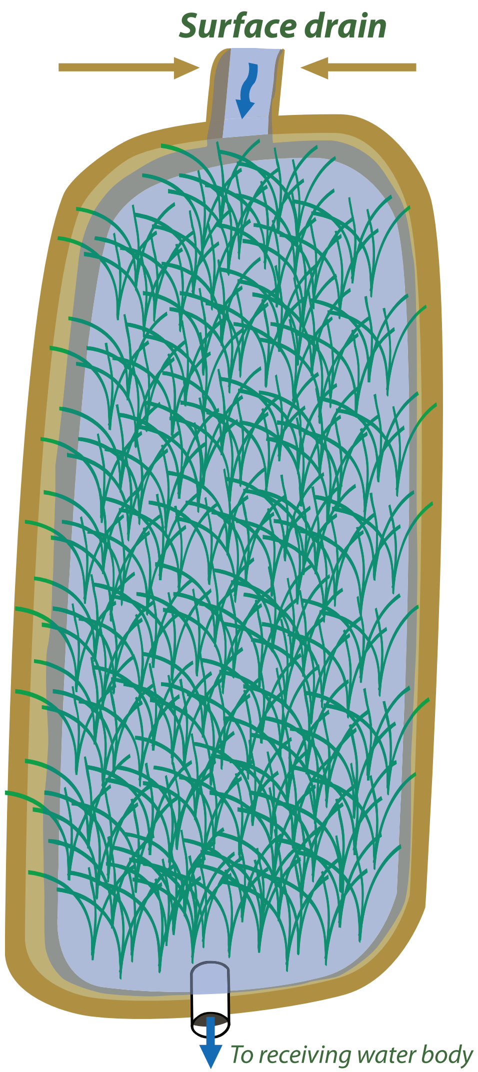
Providing access to the wetland to enable future maintenance is important.

Scenario 1: *End of tile drains, alongside surface drains and streams*

An appropriate place to intercept tile drainage and construct wetlands is alongside receiving drains or streams. This provides valuable wetland habitat closely linked to waterways, and reduces potential interference with farming activities.

Intercepting a buried tile drain.





Scenario 2: *End of surface drains supplied by tile drains*

Constructed wetlands can also be used at the end of surface drains that collect and convey flows from several tile drains. Although predominantly receiving tile drainage, such surface drains are also likely to receive a component of surface drainage with higher particulate loads, particularly during intense rainstorms and extended wet periods. To deal with this additional sediment load from surface drainage, a sedimentation pond comprising an additional 10% of the wetland area should be included at the upstream end of the wetland (see page 21).

Scraping off the turf before constructing a wetland at the end of a surface drain, supplied by tile drains.

Stage 2 Design

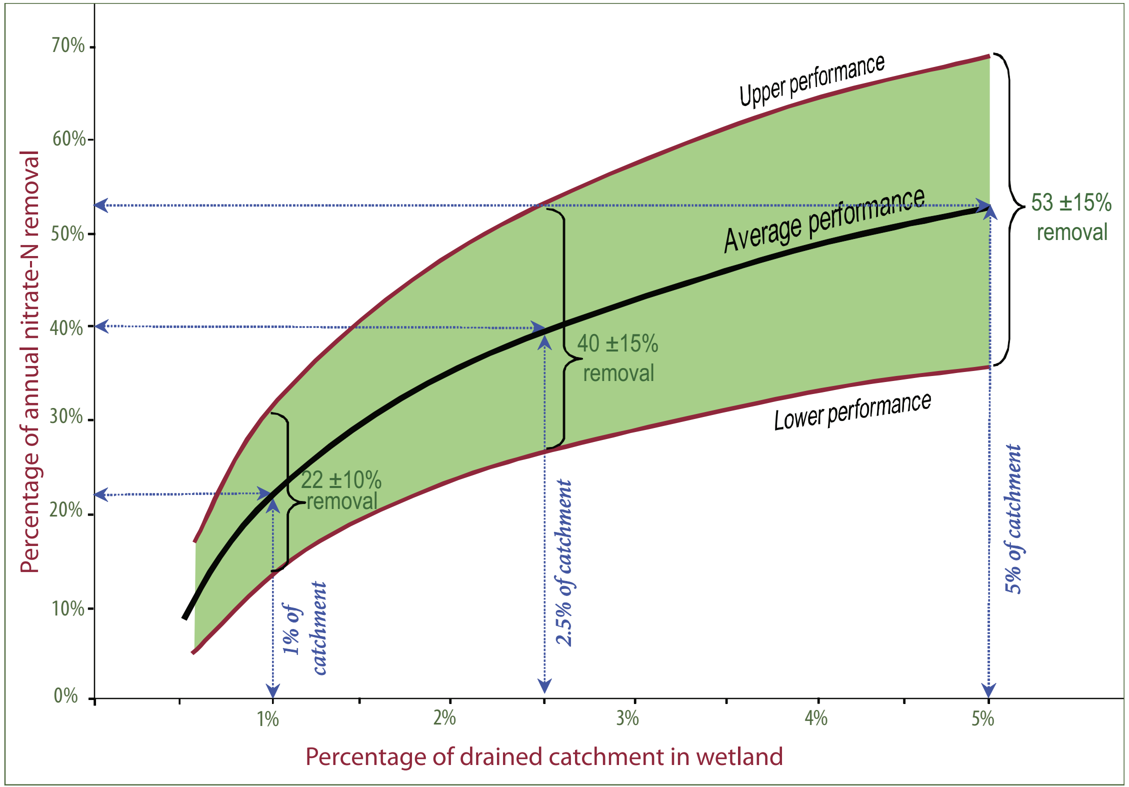
This section provides guidance for sizing and designing the constructed wetland. It has been broken down into nine sections:

A. Size
B. Layout
C. Embankments and sealing
D. Shape
E. Inlet structures
F. Sediment traps
G. Outlet and water-level control structures
H. Outlet protective structures
I. Phosphorus retaining additives

A. Size: *Constructed wetland size and treatment performance*

The size of the constructed wetland depends on your treatment goals and available land area. Generally the bigger the wetland the better the treatment achieved. The following graph, developed from multi-year data from several different dairying regions, provides an estimate of average long-term nitrogen removal in relation to constructed wetland size.

For tile drain flows from grazed pasture in the North Island of New Zealand. (Performance in Southland and Otago expected to be ~ 5–8% lower across range, due to lower average temperatures).



How big do I build it?

Use this chart as a guide for determining how large your wetland needs to be to achieve your target percentage nitrogen removal. Conversely, you can use it to estimate the percentage removal you can expect given your wetland size. The areas of wetland are given as a percentage of the catchment area being treated, therefore, you need to measure the catchment area that will drain into your constructed wetland.

Note: One hectare = 10 000 m². The required 'area' of the constructed wetland applies to the base area of the actual wetland; the embankments are additional to this.

A. Size: *Calculating the wetland area required*

Catchment area (ha)	x	% of catchment	x	100	=	Required wetland area (m^2)
1	x	2.5	x	100	=	250 m^2

The chart below provides examples of wetland surface area for various catchment sizes:

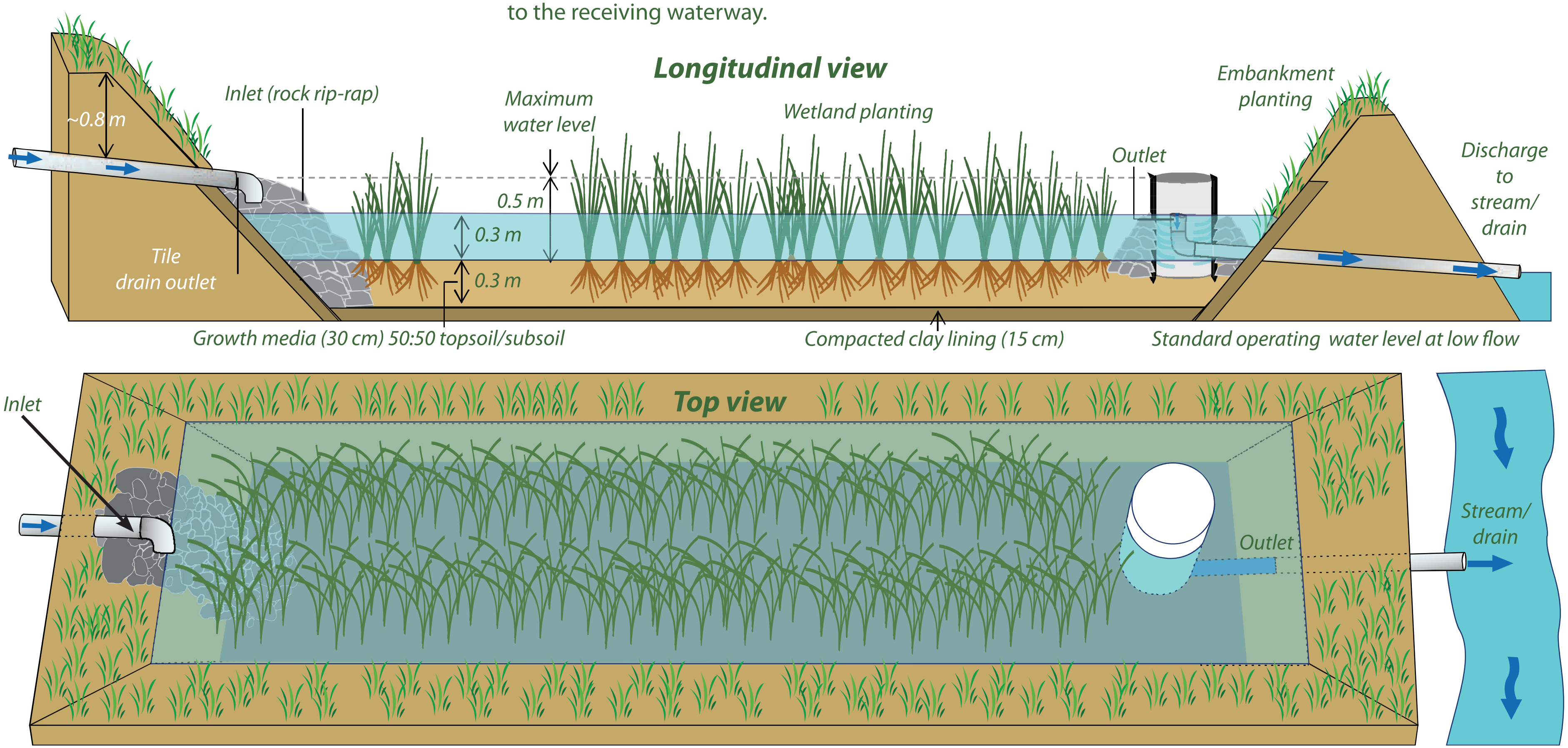
Catchment area (ha)	% of catchment	Constructed wetland area (m^2)
1	1	100
1	2.5	250
1	5	500
5	1	500
5	2.5	1250
5	5	2500
10	1	1000
10	2.5	2500
10	5	5000
20	1	2000
20	2.5	5000
20	5	10000

A recently excavated, two stage, 250 m² constructed wetland, with a mix of topsoil and subsoil returned into the base as the plant growth media.

The same wetland planted with raupo (Typha orientalis) after two seasons' growth.

B. Layout

The drawings below show a simple constructed wetland layout. An inlet structure distributes the inflow water which then flows through the planted area before finally exiting through the outlet structure and discharging to the receiving waterway.



C. Embankments and sealing

Why do we need to seal the base of the constructed wetland?

To retain sufficient water to keep the wetland vegetation alive and maintain its treatment functions.

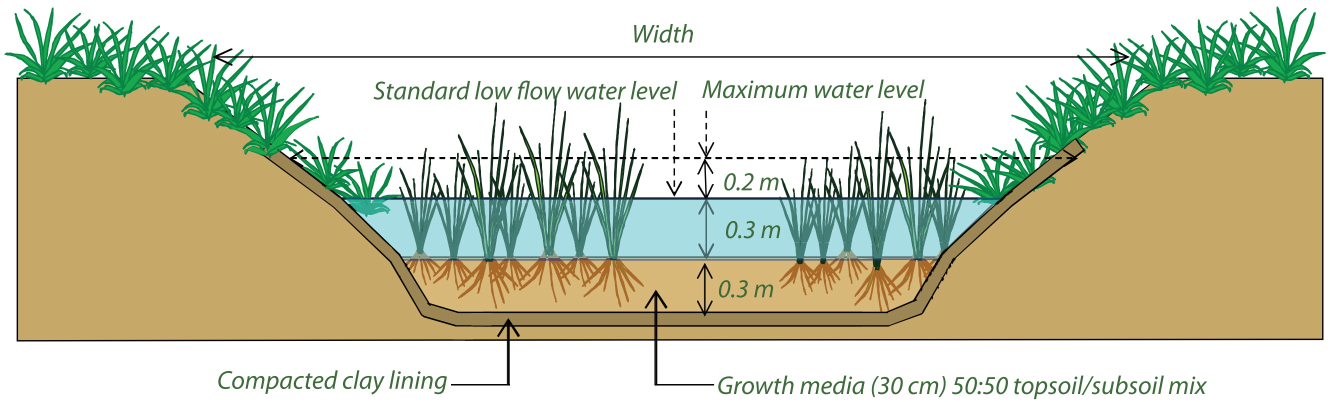
Plastic liner used to make wetland water-tight in porous soils.

The embankment walls should be graded to provide a stable slope that will not erode or slump. This will generally require a slope between 2:1 and 1:2 length-to-width ratio depending on soil structural properties. Appropriate vegetation of the embankments will help stabilise the banks.

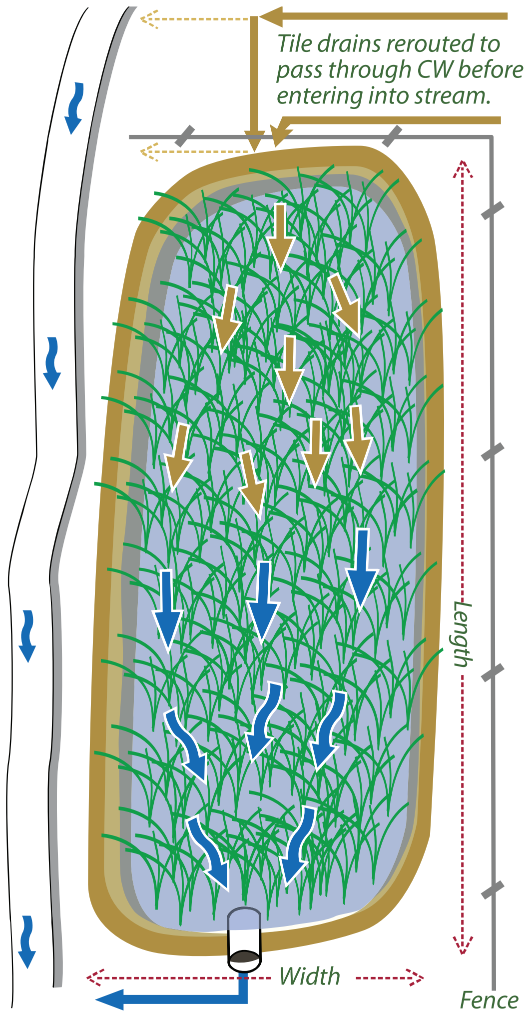
The base and lower 0.5 m of the embankments need to be sealed to retain the treated water and maintain sufficient moisture for survival of wetland vegetation. This can generally be achieved by compacting existing subsoils where the clay content is more than 10%. Compaction usually requires compression with a machine such as a digger, a sheep-foot roller or similar.

Where clay is not available, suitable clay will need to be imported from off-site or use of a geosynthetic clay or plastic liner (e.g., 250–500 micron low density polyethylene) considered. Plastic liners should be covered by at least 200 mm of soil to prevent root penetration and provide protection from sunlight UV damage. This will require initially excavating to a deeper depth, fitting the liner, and then covering it with soil to form the base of the wetland.

Cross-sectional view



Rectangular shaped wetland



D. Shape: *Constructed wetland shape*

The shape of the wetland needs to provide the required area (see page 10) and length-to-width ratio to achieve effective treatment. An elongated rectangular shape is generally the simplest way to achieve this, but there are a range of other options available to achieve a similar outcome.

Constructed wetland area	Recommended Length:Width ratio
Up to 1000 m^2 (<0.1 ha)	3:1–10:1
Greater than 1000 m^2 (>0.1 ha)	3:1–5:1

Very long narrow wetlands should be avoided because flow velocities will become excessive during high-flow events.

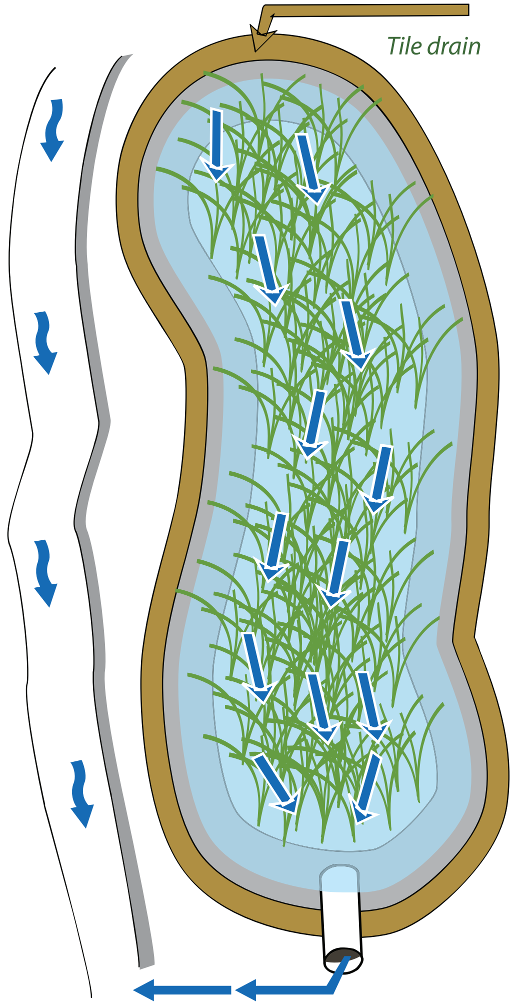
Example of different length-to-width ratios for the same wetland area:

Constructed wetland area	Length	Width	Length:Width ratio
1000 m^2	100	10	10:1
	85	12	7:1
	65	15	4:1

Why is shape important?

An elongated wetland shape with the inflow and outflow at opposite ends will promote even flow through the wetland. This reduces the opportunity for short-circuiting of flow or creation of flow dead-zones, thus ensuring maximum treatment efficiency.

Free-form elongated shape



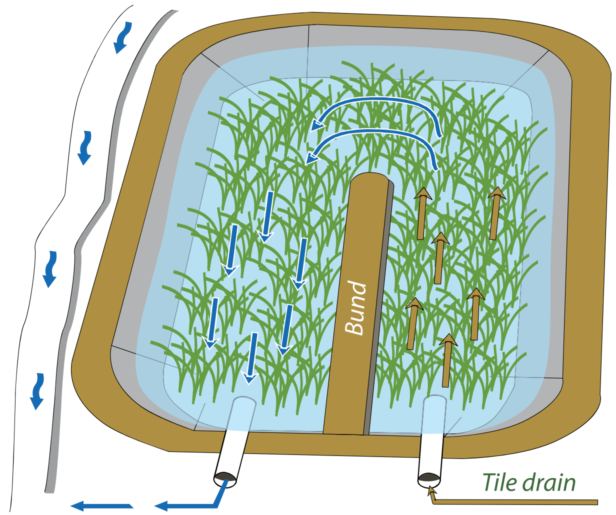
D. Shape: *Alternative constructed wetland shapes*

An alternative way to increase the length-to-width ratio of a wetland is to use internal bunds to create a hairpin flow path.

Highly serpentine designs with multiple internal bunds are not recommended as tight corners tend to cause flow "dead-zones" which reduce the treatment efficiency of the constructed wetland. The shape of constructed wetlands does not need to be rectangular. More natural flowing shapes can fit better into the landscape. However, to maintain good flow along the wetland and avoid dead-zones, we recommend maintaining length-to-width ratios between 3:1 and 10:1, depending on the total area of the constructed wetland (see page 14). Also, the width should not be varied by more than 20% along the length of the wetland.

Free-form shaped constructed wetland receiving multiple inflows, being built between a paddock and a lake.

Hairpin shape



D. Shape: *Constructed wetland layout example*

This constructed wetland is approximately 900 m^2 and receives water from a 4.5 hectare catchment. It is approximately 2% of the catchment area, and has been divided into two sections to utilise the natural lie of the land and enable vehicle passage.

Spring: 8 months after construction and planting.

Autumn: 28 months after construction and planting.

Why are inlet structures important?

Inlet structures help distribute the in-coming water evenly across the constructed wetland. This prevents erosion of soil and plants near the inlet. It also helps prevent preferential flow channels forming. This increases the residence time of water in the wetland, enhancing removal of nitrogen and other pollutants.

Note: In situations where the tile drains flow into a surface flow drain before reaching the wetland, it is recommended that a transverse trench or pond be incorporated at the inlet end of the wetland. This will act as a settling pond for suspended particles transported via the surface drains (see page 21).

E. Inlet structures

The performance of constructed wetlands is best when water flows evenly through the wetland utilising the full area available. Greater effort is required to disperse the inflow when wetland width and size are larger.

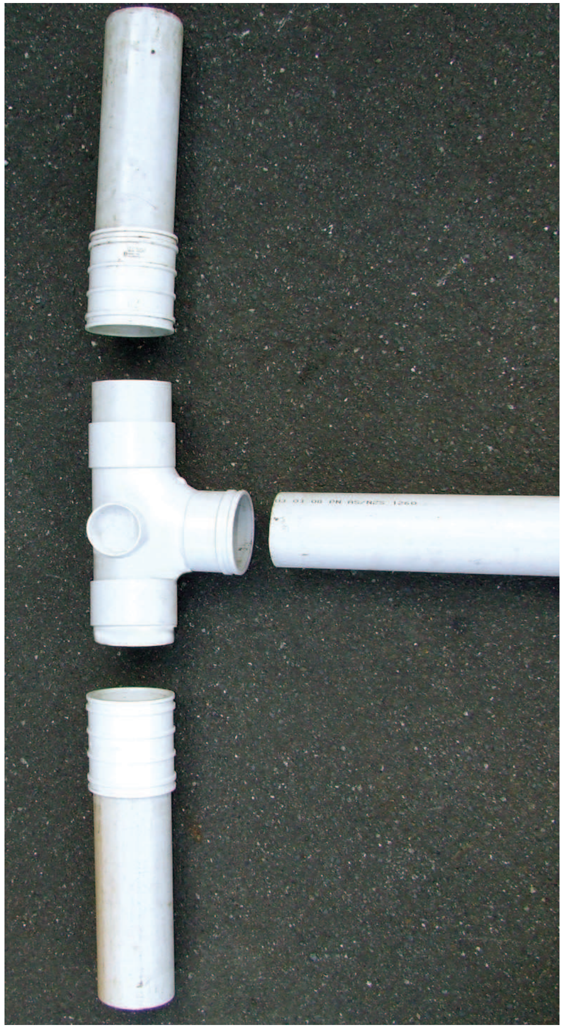
To contain the tile drain flow and provide support for the inlet structure, the final 2 m of the perforated tile drain entering the inlet to the wetland should be rigid PVC pipe.

The table below summarises the recommended inlet structures to provide reasonable dispersal based on the constructed wetland width.

Wetland width	Inlet structure
Up to 8 m	Single central pipe with downward facing bend discharging into pile of coarse rock rip-rap.
8–30 m	Inlet trench with discharge via submerged T-pipe.
More than 30 m	Split flow into two parallel wetlands of lesser width using flow-splitting weir, use combination of above structures.

Schoenoplectus *growing in a constructed wetland.*

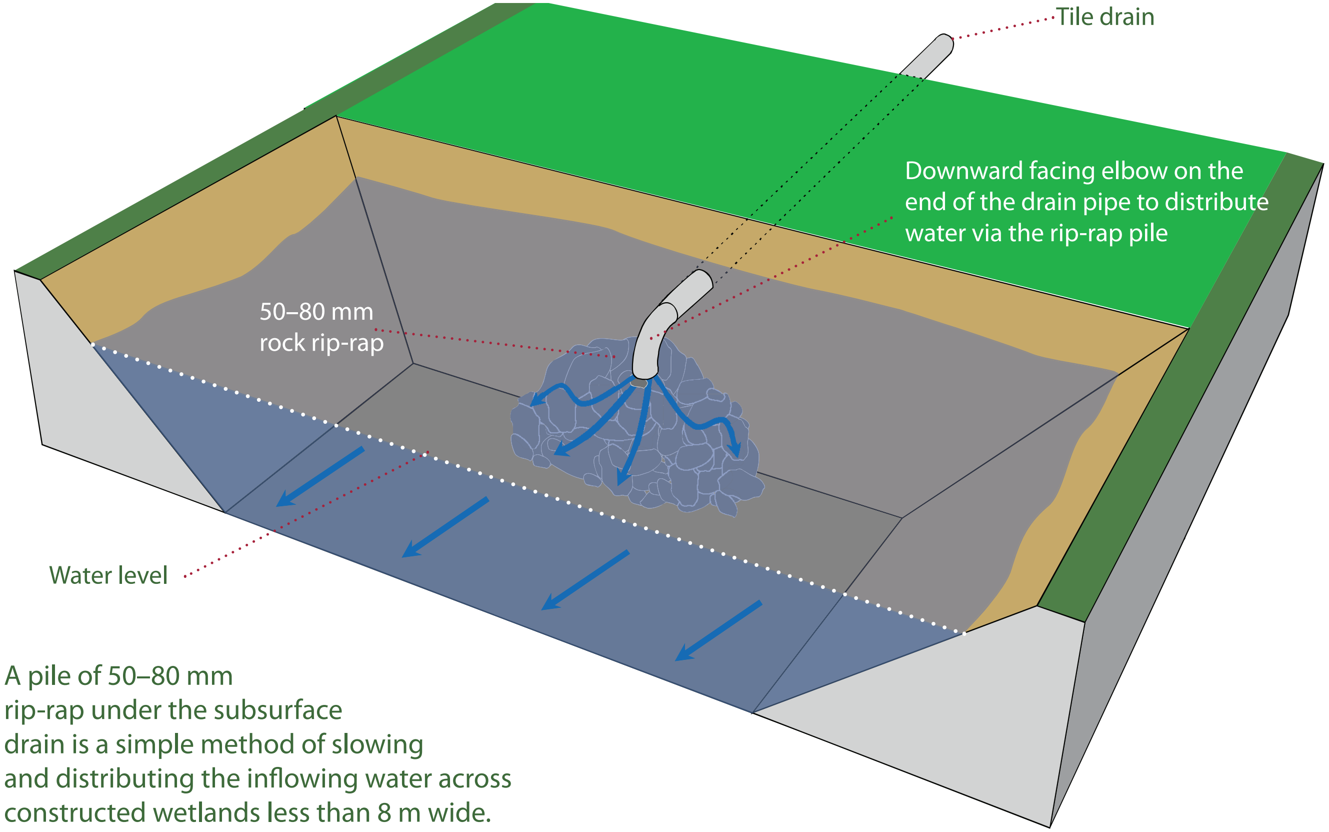
Mature constructed wetland.



Example of a single drain pipe and simple T-pipe, *see page 19.*

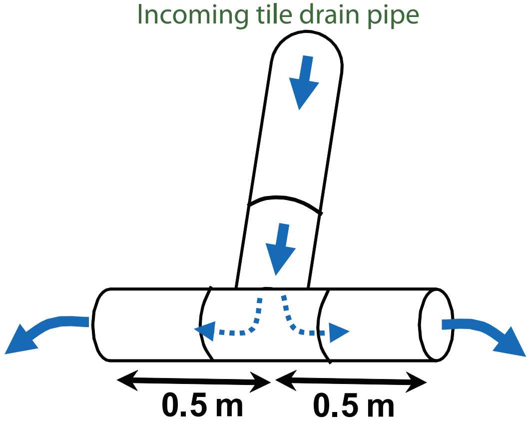
E. Inlet structures: *Wetland width up to 8 m*

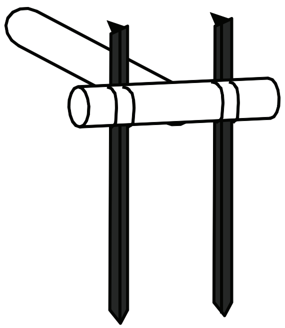
Single pipe draining into pile of rip-rap



A pile of 50–80 mm rip-rap under the subsurface drain is a simple method of slowing and distributing the inflowing water across constructed wetlands less than 8 m wide.

Submerged T-pipe





Warratahs or timber can be used to support the T-pipe. T-pipe must be fixed to supports to ensure even flow from each side.

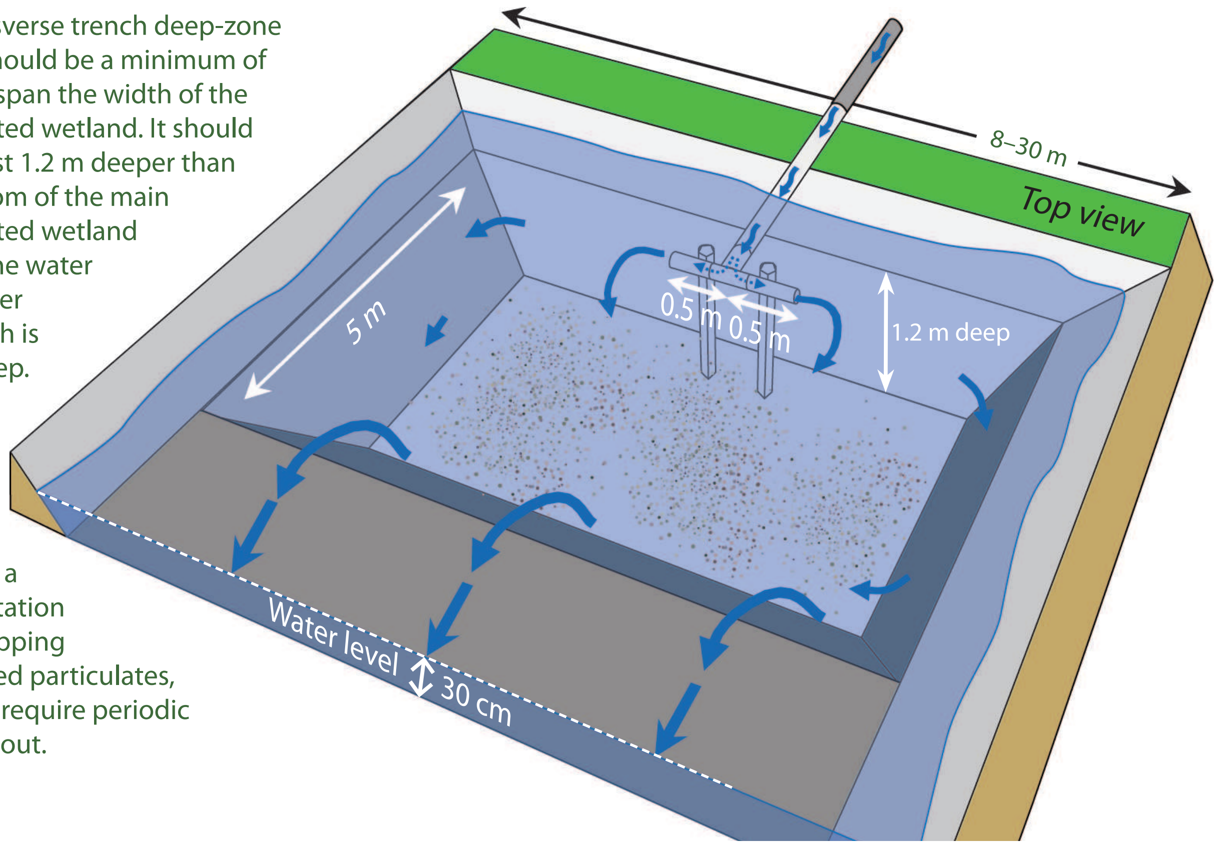
E. Inlet structures: *Wetland width 8–30 m*

A 'T' connector and two 0.5 m pipe extensions should be fitted onto the end of the subsurface drain pipe to deflect flow laterally across an inflow trench or pond.

The transverse trench deep-zone length should be a minimum of 5 m and span the width of the constructed wetland. It should be at least 1.2 m deeper than the bottom of the main constructed wetland so that the water depth over the trench is 1.5 m deep.

The deep zone also serves as a sedimentation pond trapping suspended particulates, and may require periodic cleaning out.

Transverse deep-zone with submerged T-pipe inlet

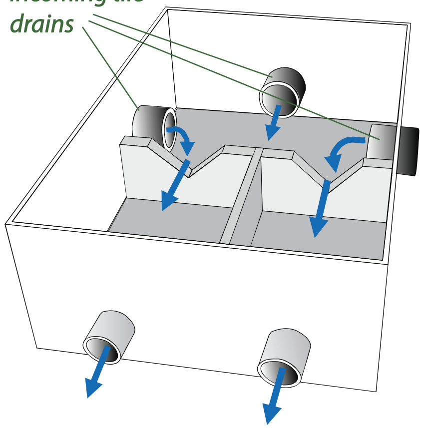


E. Inlet structures: *Wetland width over 30 m*

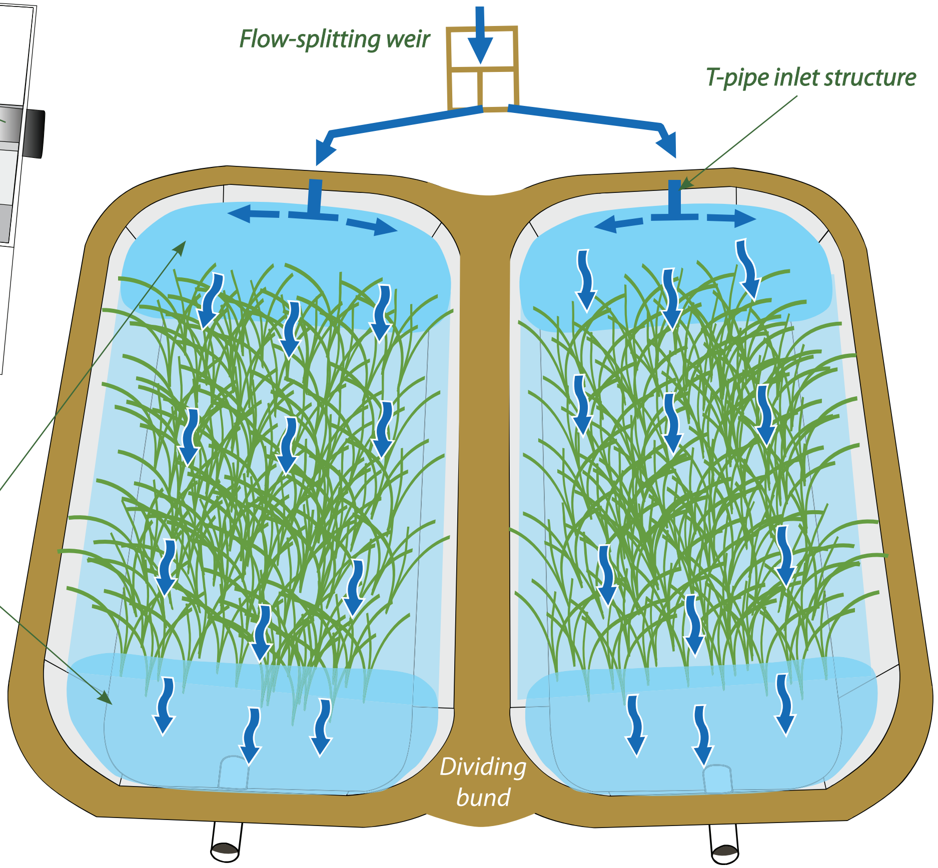
Once wetland widths approach 30 m we recommend they are split into two parallel wetlands by building a central bund to separate the two sides. The bund should be a minimum of 0.8 m high. The inflowing drainage water will need to be split between the two wetlands. A well-designed and maintained flow-splitting weir will be required to provide even flow to each side.

Example of flow-splitting weir set in a sump with lid removed; tile drainage water enters large chamber and is split between the two outlets via V-notches.

Flow-splitting weir



Split flow into two parallel wetland



Why settle out sediments?

Fine soil particles suspended in drainage water increase the turbidity of the receiving waterways. This leads to smothering of the bottom, affecting aquatic organisms and recreational use. Sediments can also be an important source of nutrients such as phosphorus.

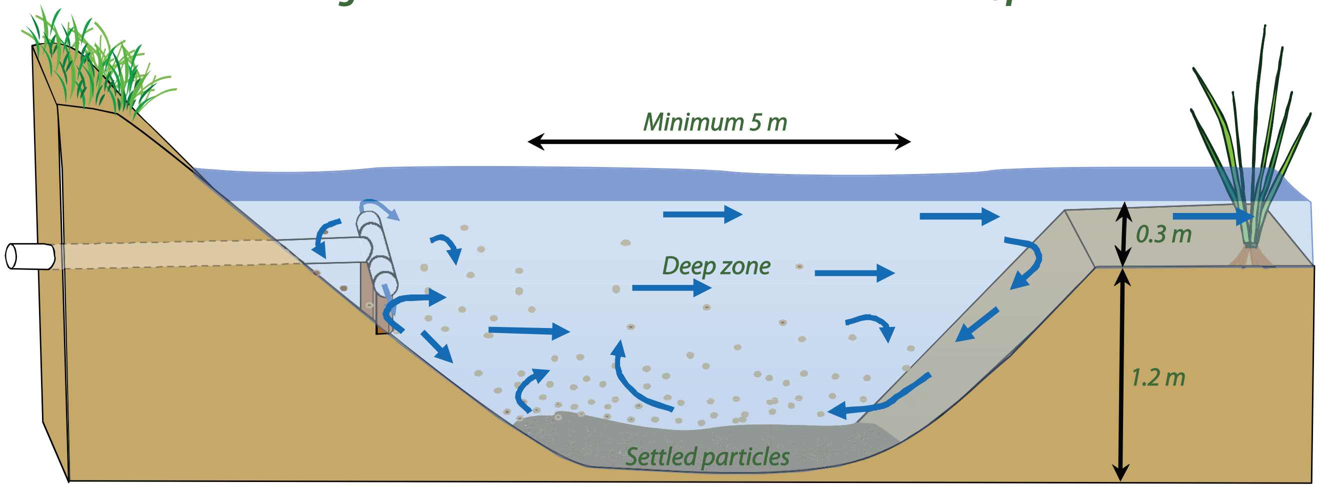
Sediment trap being excavated.

F. Sediment traps:

Where wetland may receive sediment-rich inflows

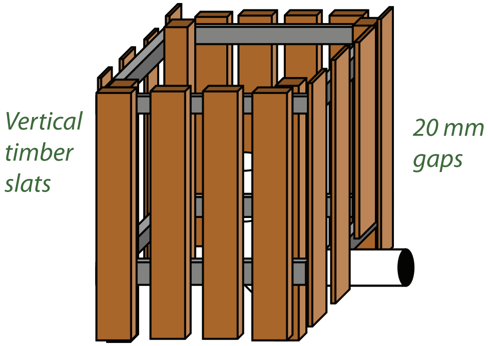
High sediment inputs can silt up shallow wetlands reducing their effectiveness and longevity. If there is potential for the constructed wetland to receive sediment-rich water from surface drains, flood flows, or other sources, an inlet pond is necessary. It should be 1.5 m deep and cover an additional 10% of the surface area of the wetland. The pond plays the same role as a transverse inlet trench, distributing the inflowing water evenly and allowing suspended sediments to be settled out and accumulated for later removal.

Longitudinal section of transverse inlet trench/pond

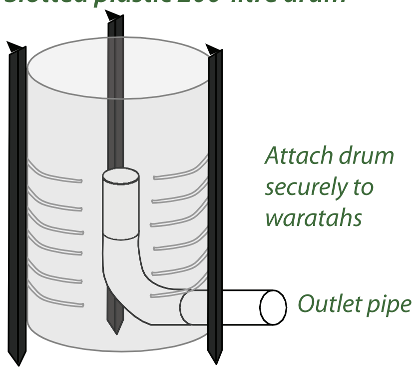


Outlet pipe protective structures

Timber chamber



Slotted plastic 200-litre drum



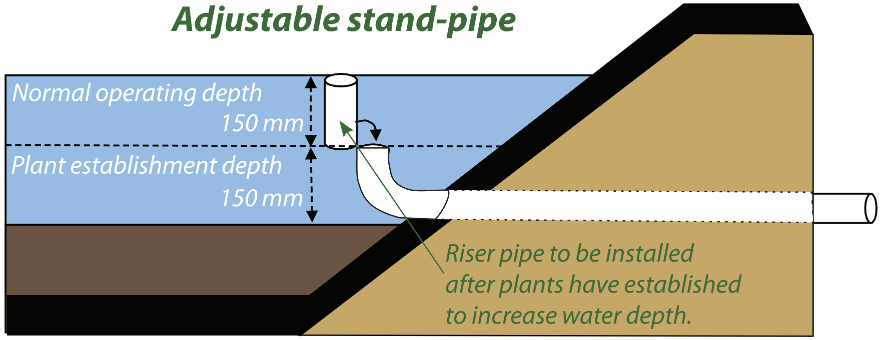
Note: Use lid over structure to block sunlight and thus minimise algal or weed growth on the outlet pipe.

G. Outlet and water-level control structures

Stand-pipe: The height of the outlet structure determines the depth of water retained in the wetland. If the width of the outlet zone is less than 8 m, a single adjustable standpipe, or adjustable weir (see page 23) is generally sufficient. If the width of the wetland at the outlet end is wider than 8 m, a final 5 m-long outlet trench is recommended, similar to those used for the inlet zone. This improves collection and transmission of flows from across the width of the wetland, increasing its hydraulic efficiency. An alternative option is to have multiple outlet pipes or weirs at 6–8 m intervals across the width of the wetland outlet. However, these need to be carefully adjusted and maintained to ensure even outflow. Outlet pipes should be of similar or greater diameter to that of the combined inflow pipes supplying them. This ensures adequate drainage at high inflows, reducing the risk of overflowing the wetland (see note of caution, page 23).

An upturned PVC standpipe with outlet set 150 mm from the bottom is necessary for the first six months of plant establishment. Once the plants have established, an additional 150 mm piece of pipe should be fitted onto the existing one to raise the water to an ideal operating level of 300 mm.

Adjustable stand-pipe



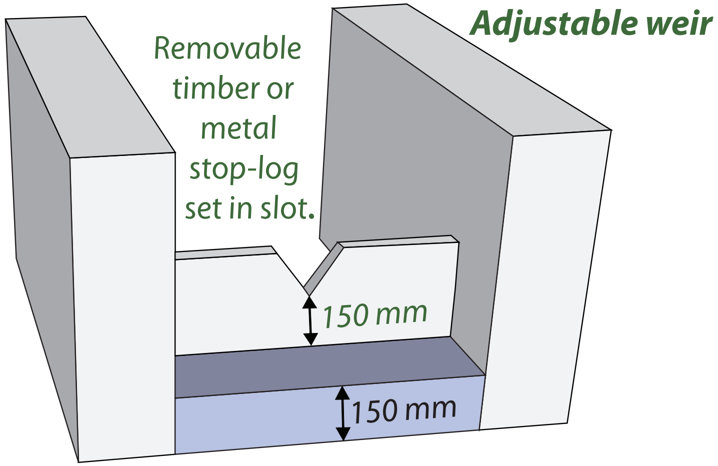
Outlet protective structures: Outlet pipes or weirs should be protected from blockage by plant and other debris. The two methods we recommend for protective structures for a stand-pipe are a slatted timber chamber or a slotted plastic drum. Cut slots or drill multiple holes of 40–60 mm in drum. The structure must be secured to fence posts or waratahs so it does not float away. To further prevent pipe blockage, a 1 m-wide filter zone of rip-rap can be incorporated around the structure. Removing debris from around protective structures is easier than unblocking a pipe.

G. Outlet and water-level control structures

Weir: An alternative to using outflow pipes is to construct adjustable height weirs using concrete and/or treated timber as shown below. Ensure that low water levels can be maintained during plant establishment, and can be adjusted later. Care is needed to ensure stop logs are sealed so that water does not leak out around the edges, leaving the wetland plants dry between flow events. A triangular V-notch can be added in the centre of the weir to enable flow estimates. This requires addition of a staff gauge to measure the height of water behind the weir. For further information see: www.engineeringtoolbox.com/weirs-flow-rate-d_592.html

Why are outlet structures important?

Outlet structures provide control of the water level within the wetland. Water depth is especially important during plant establishment; if it is too deep, the plants will float out or be drowned before they establish.



Wooden outlet weir structure.

Outlet weir with one stop-log in place to control water level.

Note of caution: Overflow is a threat if unusually heavy rainfall occurs that generates inflows that exceed the capacity of the outflow pipe, or the outlet is blocked. The risk of overflow is greater in situations where the constructed wetland receives a significant amount of surface flow as well as tile drainage flow. In these cases you should consider installing a high-flow bypass- an additional higher level outlet pipe or an area of rip-rap on the constructed wetland embankment where the water can safely spill out.

Other P-sorbing materials: A range of P-sorbing materials potentially suitable for improving P retention in constructed wetlands have been identified; these include: allophanic clays, lime, alum, smelter slag, and some volcanic tephras (Ballantine, D.J.; Tanner, C.C. (2010)). These materials are currently being assessed in laboratory trials with a view to field-testing.

Constructed wetland planted with sedges and rushes.

**Note: The use of subsoils with lower organic matter content is likely to reduce N removal performance during the first few years of operation. This will be overcome as wetland plant litter accumulates in the wetland providing a sustainable ongoing supply of organic matter for denitrifying bacteria. Further studies are currently underway and recommendations will be reviewed when further information becomes available.*

**See following website for general distribution of allophanic soils in New Zealand:
http://soils.landcareresearch.co.nz/contents/
and follow links:
Soil Names → Soil classification (NZSC) → Soil Order

H. Phosphorus retaining additives

Reduction of phosphorus (P) losses from farms is also important in many New Zealand waterways. Wetlands are effective at settling out and retaining particulate phosphorus loads. However, in subsurface tile-drain flows, dissolved forms of P generally predominate. The capacity of wetlands to remove these dissolved forms of P is limited, with the main removal mechanisms being adsorption to soil minerals, uptake by plants, and accumulation within organic matter.

Adsorption of P under waterlogged conditions is limited unless additional P-sorptive media are added to the wetland soils and/or used as porous filter materials. There is also potential for P release from constructed wetlands if topsoils with high P status are used as growth media. It is difficult to predict the P release characteristics of normal pasture soils once subjected to water-logged conditions in constructed wetlands. For farms with P-retentive allophanic and pumice soils, P loss via drainage systems is unlikely to be a significant issue and topsoils are likely to be relatively P-retentive under wetland conditions.

Cyperus ustulatus

We recommend the following measures to increase P retention in constructed wetlands treating tile drainage, particularly in P-sensitive catchments:

1. Where possible use a 50:50 mix of subsoil from the B or C horizon mixed with topsoil as the growth media in the base of the wetland. This mix will reduce the overall P status of the wetland soil and introduce more P-retentive material to the soil. If allophanic soils or subsoils can be brought onto the site from nearby areas, these should be used in preference and/or combined with the local soil*.
2. Additionally, incorporate agricultural lime at a rate of 0.5 kg per m^2 into the top 50 mm of soil**.

Stage 3 Construction

This section provides guidance for building the constructed wetland.

Excavating a constructed wetland.

Mix of topsoil and subsoil placed into bottom of excavated constructed wetland.

A. Timeline/planning

Things to consider during the pre-construction stage:

1. Do you need permission? Check with your regional council that this is a permitted activity and for any specific restrictions or rules that need to be followed.

2. Identify: An experienced earthmoving contractor and make sure they know what is required to construct a wetland as outlined in this guide.

3. Make sure conditions are sufficiently dry for earthmoving: The soil should be dry enough for the digger to properly work the soil materials and avoid getting stuck.

4. Pre-order plants: It is wise to identify a supplier of wetland plants and speak to them about the types, quantities and timing of what you need several months in advance. This way they should be available when you need them (see Appendix 1).

5. Purchase: Purchase supplies for building the inlet and outlet structures.

6. Planting: The ideal time to plant is spring/early summer when there is still enough water coming out of the drains to supply the constructed wetland. It also gives the plants a head start to establish themselves before winter, improving their chances of survival.

7. Supplementary water supply: Often the best time of year for construction is in the summer when it is too dry for planting. If this is the case, you must have a supplementary water source available to keep the wetland moist to allow the plants to establish (see Stage 4). Otherwise planting should be delayed until conditions are suitable.


Rectangular constructed wetland planted with raupo.

Digger creating a pile of topsoil for later use as growth media.

B. Construction day and beyond

1. Before the digger arrives, peg out exactly where you want the constructed wetland to be dug.

2. The turf layer should initially be scraped off and disposed of. The topsoil should then be removed and set aside in a separate pile for later return as a growth media.

3. Excavate the wetland to the required depth. If clay is available, compact the base of the wetland, otherwise seal with the appropriate material (see page 13).

4. Once excavated, lined and shaped, cover the base with the set-aside 50:50 mix of topsoil and subsoil to a depth of 30 cm. Ensure that this growth media is only lightly packed down, suitable for planting into.

5. Install the inlet and outlet structures.

6. Plant the plants and flood with the appropriate amount of water (see Stage 4).

Starting excavation of a constructed wetland.

Stage 4 Establish plants

This section provides guidance for planting the constructed wetland including why, what, and how to plant.

When should I organise the plants?

You should start organising the plants early on in your planning. It is likely you will need to order at least a portion of your plants from a specialist wetland nursery which may have to grow them for you. You may also be able to harvest wetland plants for transplanting from existing wetland areas on your farm. Ensure you do not damage valuable natural wetlands, or transfer weeds along with the intended species, particularly in the soil around the plant roots.

A. Role of plants

Constructed wetlands work best with a well-maintained, dense cover of emergent wetland plants. Plants are crucial to the functioning of constructed wetlands because they:

- provide the physical structure that supports the growth of microbial biofilms, which are important in their functioning
- produce litter as a source of organic matter for denitrification and other microbial processes
- shade the water surface to reduce algal growth
- dissipate wind and wave action to reduce erosion
- enhance wildlife and aesthetic values.

Carex *species plants shading constructed wetland surface.*

Schoenoplectus *species dissipate wave action.*

Raupo litter providing organic matter to support denitrification.

Key species* for:

Flooded zone

- Raupo (*Typha orientalis*)
- Kapungawha (*Scheonoplectus tabermontani*)
- Mokuautoto (*Baumea articulata*)
- Kuta (*Eleocharis sphacelata*)

Shallow margins and embankments

- Harakeke, NZ Flax (*Phormium tenax*)
- Toetoe (native *Cortaderia species*)
- Purei (*Carex secta*)

**Maori names for some native plants differ with region. We have attempted to use the most widely recognized name where possible.*

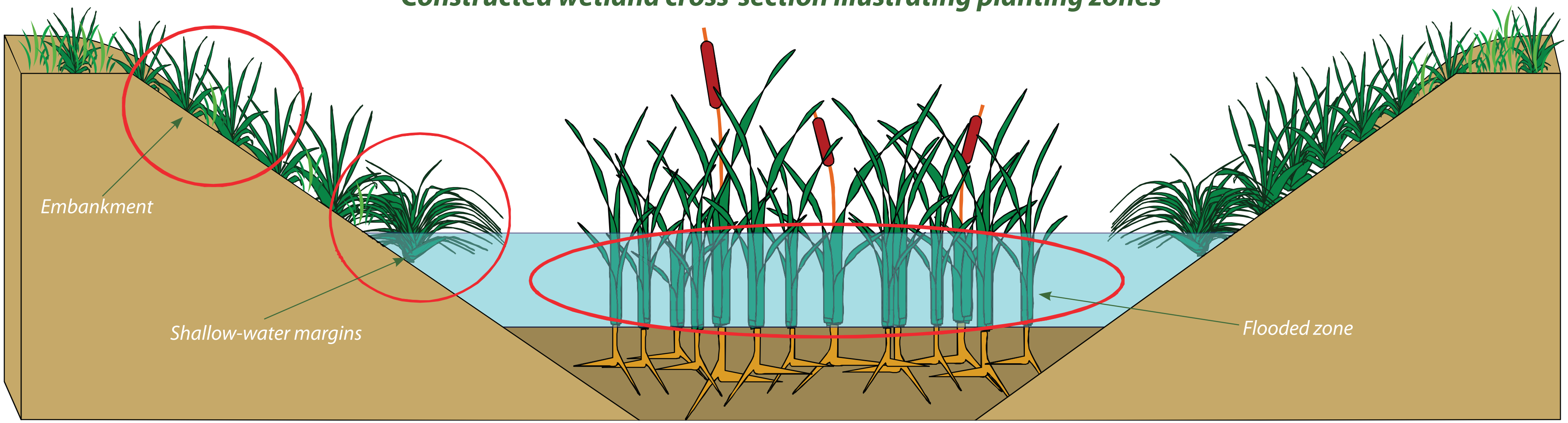
B. Planting zones

There are three main regions within the constructed wetland:

1. the flooded zone
2. the shallow margins
3. the embankments.

Water level is the differentiating factor with the flooded zone being the wettest and the embankment being the driest. The plants in the flooded zone are primarily responsible for water treatment while the plants on the margins and embankment stabilise the edges, help exclude weeds, and promote biodiversity.

Constructed wetland cross-section illustrating planting zones



Baumea articulata *(mokuautoto, jointed twig-rush).*

C. Plant selection: *Key species for the flooded zone*

The tall, emergent plant species listed below grow well within the flooded zone of constructed wetlands. Native species adapted to your locality are recommended. Raupo is the plant of choice for treating farm drainage high in nitrate-nitrogen. It is easy to establish and fast-growing, producing abundant plant litter to stimulate nitrate-removing bacteria. It is relatively resistant to weed invasion and tends to dominate other species under nutrient-rich conditions. Alternatively, plant a combination of the other species as listed below.

Plant species	Common name	Natural range	Description	Depth range
Typha orientalis	raupo, bulrush equivalent to: cumbungi (Aus), reed mace (UK), cattail (N. America)	Throughout New Zealand	1.5–3 m tall. Dull green, erect leaves arising in clumps from green spongy rhizomes. Thick, cylindrical brown seed heads (cat-tails) borne on tall shoots. Leaves die back strongly in winter. Generally dominant emergent wetland plant in fertile lowland New Zealand swamps.	0–0.4 m
Baumea articulata	mokuautoto, jointed twig-rush	From Northland to Levin	1.8 m tall. Green year-round. Dark green, 'leafless', stiff, cylindrical shoots with obvious joints when mature. Red-brown pendulous seed heads borne on separate fertile shoots.	0–0.4 m
Eleocharis sphacelata	kuta, tall spike-rush, spike-sedge	Throughout NZ (common in North Island, uncommon in Canterbury)	0.8–1.3 m tall. Stout, bright green 'leafless', hollow shoots with transverse internal septa, arising from thick rhizome. Seed heads forming at tip of shoots.	0.2–0.6 m
Schoenoplectus tabernaemontani	kapungawha, soft-stem bulrush, lake clubrush	Northland to Westland and Canterbury	0.6–1.8 m tall. Shoots die back over winter, except in northern coastal areas. Erect green to blue-green, 'leafless', cylindrical shoots with white central pith, arising from horizontal rhizome. Brown seed heads form tuft just below the shoot tip. Shoots die back in winter at inland sites.	0–0.4 m

Key flooded zone species: *Typha orientalis* (raupo, bulrush)

Key flooded zone species: *Baumea articulata* (mokuautoto, jointed twig-rush)

Key flooded zone species: *Eleocharis sphacelata* (kuta, tall spike-rush)

Key flooded zone species: *Schoenoplectus tabernaemontani* (kapungawha, soft-stem bulrush)

C. Plant selection: *Key species for shallow-water margins and embankments*

These species are suitable for planting in shallow water and on embankment slopes to reduce bank erosion and weed ingression, and enhance plant and habitat diversity. For identification of these species, see 'Wetland Plants in New Zealand' (Johnson and Brooke, 1989).

Plant species	Common name	Natural range	Description	Planting position	Comments	Photo
Bolboschoenus fluviatillis and *B. medianus*	purua grass, kukuraho, ririwaka, river bulrush, marsh clubrush	Northland to Westland and Canterbury	1–1.8 m tall. Leafy sedges with stems, (triangular in cross-section), emerging from woody, bulbous tubers.	Shallow water to 0.3 m depth.	Common in coastal areas. Fast-growing in spring and early summer, dies back over winter. Provides seasonal diversity.	
Carex secta	purei, makura	Throughout New Zealand	1–1.5 m tall. Drooping harsh tussocks forming trunk-like base when mature. Green year-round.	Moist lower embankments and shallow water to 0.2 m depth.	Establish initially in moist conditions or shallow water, can grow in deeper water if gradually acclimatised. Classic New Zealand plant of wetland and stream margins.	
Other *Carex spp.;* especially *C. germinata, C. lessoniana* and *C. virgata*	rautahi, carex	Throughout New Zealand	0.5–1.5 m tall. Harsh leafy sedges. Green year-round.	Moist lower embankments and shallow water to 0.2 m depth.	Taller-growing species mentioned are likely to be the most robust and able to compete with weeds. Valuable for wildlife.	

C. Plant selection: *Key species for shallow-water margins and embankments*

Plant species	Common name	Natural range	Description	Planting position	Comments	Photo
Cortadera richardii, C. fulvida, C. toetoe	toetoe (New Zealand native species only, not to be confused with introduced pampas grasses)	Different species common in different regions	1.5–3 m tall. Coarse green tussocks, with tall feathery flower heads borne on cylindrical stems.	Upper & lower embankments to water edge and surrounds.	Useful, hardy plant suitable for bank stabilisation and screening. Ensure invasive introduced pampas species are avoided.	
Cordyline australis	ti kouka, cabbage tree	Throughout New Zealand	Tall-growing soft-stemmed tree bearing tufts of fibrous leaves.	Upper embankments and surrounding areas.	Classic New Zealand tree common in wet soils.	
Cyperus ustulatus	toetoe upoko-tangata, giant umbrella sedge	Northland to Canterbury and Fjordland; mainly coastal and lowland	0.5–1 m tall. Harsh pale-green leaves in clumps, with emergent seed-bearing leafy umbells.	Moist lower embankments and shallow water to 0.2 m depth.	Tolerates dry periods. Suitable for wetland margins and embankments, and shallow water.	
Phormium tenax	harekeke, New Zealand flax	Throughout New Zealand	1–3 m tall. Robust clumps of tough robust leaves. Tall dark brown to black flower heads.	Upper & lower embankments to water edge and surrounds.	Does not generally establish well in continuously flooded conditions. An important traditional plant for Maori and important habitat for wildlife.	


Planting Schoenoplectus *into flooded zone.*


Tray of Schoenoplectus *ready to be transplanted.*

D. Planting and establishment

Care is needed to ensure rapid establishment of wetland plants and maximise the survival rate before weeds invade. Below are some tips for successful planting:

1. *Timing of planting*
   Most wetland plants do not grow much during winter and in many the above-ground portions die back over this period (e.g., raupo). Planting should, therefore, ideally take place in spring or early summer (September–December) to promote rapid establishment and enable growth of a tall dense cover that can outcompete weeds. However, planting at this time is often difficult in practice, because ground conditions remain too wet for construction early in the season.

   Later planting in summer (January–February) is possible if larger plant grades are used and a supplementary water source is available to keep the wetland moist. Planting later in the season, or without such supplementary care is not recommended. Instead, it is better to wait until the following spring to undertake planting.

2. *Pre-planting weed and pest control*
   If the area is weedy initially or has been left for any time, it will need manual weeding, or spraying with a translocated herbicide such as glyphosate. If large masses of herbicide-killed plant material are subsequently flooded they will decompose creating de-oxygenated conditions detrimental to plant establishment. It is therefore advisable to control weeds at low levels (to avoid build-up of biomass) and/or physically remove any accumulated dead plants. Useful resources to help identify and control weeds are noted in Appendix 2 and Appendix 3.

   Pukeko and Canada Geese, in particular, can be very destructive to newly planted wetlands and may need controlling during early plant establishment. There are a range of bird deterrents that may be useful including gas bangers and flashing lasers. If you intend to dissuade birds by shooting, you will need a hunting permit from The Fish and Game Council and possibly also a special permit to extend control beyond the open game-bird hunting season, www.fishandgame.org.nz/Site/Regulations/default.aspx.

Large constructed wetland being planted during dry season. Supplementary water will need to be added.

Baumea articulata *plants filling in the flooded zone.*

D. Planting and establishment

3. *Planting*

Select strong hardy plants appropriate to your conditions (see previous section), preferably local ecotypes that grow well in your region. 3–4 plants per square metre (depending on transplant size) are recommended. The transplants should be well firmed into the soil so they do not float out when water levels are raised, or are easily uprooted by waterfowl.

Best establishment and spread is usually achieved using nursery stock grown from seed. Plants with well-developed roots and rhizomes grown up in 1–2 litre pots (PB 1.5–3) are recommended. Some species (e.g., raupo, harakeke/flax, *Schoenoplectus*) can be successfully grown by dividing up wild-grown plants into bare-rooted cuttings, each with 3–5 shoots trimmed to 0.3 m height. Such propagules tend to establish more slowly and are more vulnerable to desiccation and uprooting by waterfowl, so need to be planted early in the season and under ideal conditions to establish effectively. (Collection permits may be necessary for wild-grown plants, except on private land).

4. *Water level control*

Water level during establishment should be maintained at or up to 150 mm above the soil surface. Plants can be planted into dry topsoil (prior to adding drainage water) as long as enough water can be supplied to cover the topsoil immediately after planting. If drainage water is insufficient during the initial establishment period, supplementary water may be necessary.

As a minimum, flooding every 5–10 days or periodic spray irrigation may be used to maintain moist conditions. It is important that the water level is not raised above the height of the establishing plant shoots, as these act much like a snorkel, providing a passage for oxygen to diffuse down to the growing plant. As the plants grow the water level can gradually be raised.


Bare-rooted plant cuttings require ideal conditions to ensure success. Here they have not been planted firmly enough and have floated out of the soil.


Pukeko eating young raupo plants - keep pukeko controlled during establishment.

D. Planting and establishment

5. *Post-planting weed and pest control and care*
   Competition from weeds and disturbance from waterfowl will need to be carefully managed during establishment. Useful resources to help identify and control weeds are noted in Appendix 2 and Appendix 3.

   Once properly established (generally after two growth seasons) tall-growing wetland species should be relatively robust. Plants growing in water-retentive soils should be able to survive normal summer dry periods and recover from moderate periods of drought, regrowing from buried rhizomes. Weed invasion may, however, occur during such episodes requiring additional control and possibly also replanting of badly affected areas.

6. *Get it right first time*
   Wetland plant establishment can be relatively rapid and simple if it is carried out correctly right from the start. However, problems can multiply and become difficult to overcome where plant establishment is compromised by factors such as:

   - planting at the wrong time of the year e.g., too late in the season
   - insufficient or excessive water levels
   - competition and suppression by weeds
   - damage by livestock or waterfowl.

Stage 5

Maintenance

This section provides guidance for maintaining the constructed wetland during plant establishment and thereafter.

Newly planted raupo being flooded.

Raupo established after two years' growth.

A. Requirements during wetland establishment

Fortnightly action list for first three months	
Plants	• Visual inspection of plant health and damage by pukeko or other pests • Check water level and supplement as appropriate (particularly during dry periods or low inflows) • Control weeds in wetlands and surrounds by hand-weeding, careful herbicide application, and/or temporary water level increases
Inlet	• Check for adequate inflow and even dispersal • Identify any blockages or damage
Outlet	• Adjust outlet height so plants are not drowned • Check for blockages and damage • Clear any plants or debris away from outlet
Embankments	• Inspect for weeds, erosion, and damage by pukeko, rabbits or other pests

Ensure stock is properly fenced out of wetland.

Bank erosion can be prevented by planting with appropriate species.

B. Requirements after wetland establishment

Seasonal action list	
Plants	• Visual inspection of plant health, weed and pest problems, take remedial action as necessary
Inlet	• Check for adequate and uniform inflow and identify any blockages or damage
Outlet	• Check for blockages and damage, clear any plants or debris away from outlet • Check water level and outflow quality and quantity
Embankments and fencing	• Where required, control weeds on inner embankments by hand-weeding or herbicide application, mow, or graze with sheep to control grass on embankments and wetland surrounds • Ensure fence and gate are stock-proof

Appendices

Raupo wetland with harakehe (flax) around embankments.

Newly planted constructed wetland.

Appendix 1: *Specialist wetland plant suppliers in New Zealand*

This list only covers suppliers we know of who specialise in large-scale wetland plant propagation and supply. They have been listed from north to south of the country. Other local suppliers may also be able to provide supplies of the wetland plants you require. No endorsement nor discrimination of specific vendors is intended or implied.

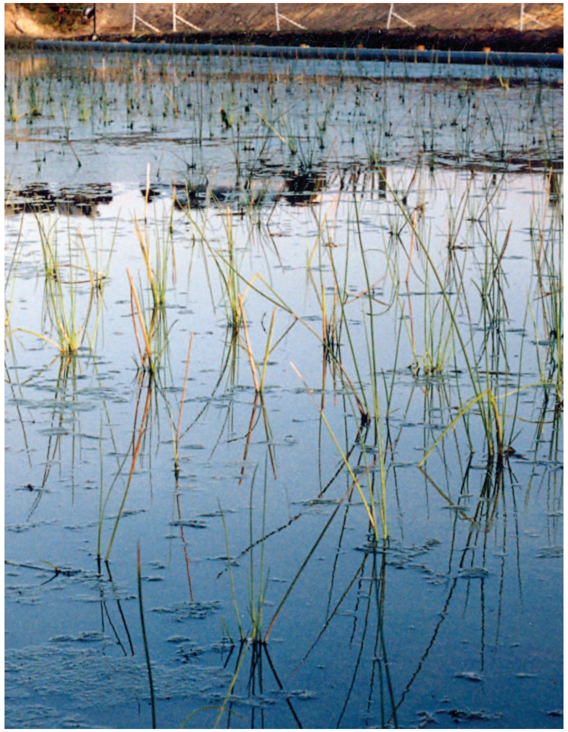
Kauri Park Nurseries Ltd, www.kauriparklimited.co.nz , PO Box 63, S.H. 1, Maungaturoto, 0547, Kaiwaka. Phone: 09 431 2125 and Fax: 09 431 2894.

Oratia Native Plant Nursery, www.oratianatives.co.nz, 625 West Coast Road, Oratia, Auckland 0604. Phone: 09 818 6467.

Naturally Native New Zealand Plants Ltd, www.naturallynative.co.nz, 30 Gamman Mill Road, RD3, Tauranga. Phone: 07 543 1494 and Fax: 07 543 3494. Offices are also located in Auckland and Whakatane.

Taupo Native Plant Nursery, www.tauponativeplant.co.nz, 155 Centennial Drive, Tauhara, Waikato 3378. Phone: 07 378 5450.

Titoki Nursery, www.titokinursery.co.nz, 26 Palmer Road, Waimea West, Nelson. Phone/Fax: 03 542 3421.



New constructed wetland planted with Baumea *and* Schoenoplectus *species.*

Appendix 2: *Resources for wetland plant identification and management*

Roy, B.; Popay, I.; Champion, P.; James, T.; Rahman, A. (2004). *An Illustrated Guide to Common Weeds of New Zealand*. Second Edition. New Zealand Plant Protection Society, Lincoln, New Zealand.

Johnson, P.; Brooke, P. (1989). *Wetland plants in New Zealand*. *DSIR Field Guide.* DSIR Publishing, Wellington. Reprinted by Maanaki Whenua Press.

Tanner, C.C.; Champion, P.D.; Kloosterman, V. (2006). *New Zealand constructed wetland planting guidelines*. National Institute of Water & Atmospheric Research Ltd (NIWA) in association with NZWWA. www.waternz.org.nz/documents/publications/books_guides/constructed_wetland_planting_guide.pdf

Weedbusters website; an alphabetical guide to weeds and their management. weedbusters.co.nz/weed_info/weed_list.asp

New Zealand Novachem Agrichemical Manual. Updated annually. AgriMedia Ltd, Christchurch, New Zealand. www.spraybible.com

Peters, M.; Clarkson, B. (2010). *Wetland Restoration: A Handbook for New Zealand Freshwater Systems*. Manaaki Whenua Press, PO Box 40, Lincoln 7640. www.mwpress.co.nz

Dying Carex secta *due to over-spray, be careful.*

Appendix 3: *Herbicides for weed control during wetland establishment and maintenance*

Target plants to be controlled	Recommended herbicide*	Notes on use
General weed control	glyphosate (e.g., Roundup®)	Non-selective, it will kill most plants. Careful spot application required to avoid impacts on wetland plantings. Generally low toxicity and non-residual, broken down rapidly. Only use formulations recommended for use over water e.g., Roundup Renew, Agpro Green Glyphosate. Also useful for cut stem/stump treatment of woody weeds (e.g., grey willow).
Selective control of grasses	haloxyfop** (e.g., Gallant®)	Generally kills grasses only. Minimal damage to other monocots (cabbage trees, flax, rushes, etc.), but minimise overspray. Does not kill broadleaf plants, ferns, etc. Foliar active with minimal soil activity, moderately low toxicity, short soil residue.
Selective control of woody broadleaf plants (e.g., blackberry and willow)	triclopyr amine (e.g., Garlon® 360)	Kills many broadleaf species including shrubs, vines and trees. Does not kill grasses, but may cause limited damage to sedges, flax or other monocots or ferns. Moderately low toxicity, short soil residue. Also useful for cut stem/stump treatment. Registered for use over water and close to waterways.
	metsulfuron-methyl** (e.g., Escort®)	Kills most broadleaf species including ferns, shrubs, vines and trees except *Solanum* species. Generally not effective on grasses or other monocots (e.g., sedges and flax) unless applied at very high rates. Moderately low toxicity, however, short but very active residue, apply with extreme care, works at very low rates. Also useful for cut stem/stump treatment.

**Mention of specific herbicides does not constitute specific endorsement, nor mean that other products with equivalent active ingredients will not provide similar results.*

***Herbicides not specifically registered for use in waterways. Should only be sprayed on banks, avoiding contamination of waterways, or used under drained conditions, with overflows to waterways avoided for withholding periods of 4–6 weeks. Use all herbicides carefully according to label recommendations.*

Check with local regional council; may require specific consent for use around and in waterways. The New Zealand Novachem Agrichemical Manual provides detailed information on use of all registered herbicides.

References

Ballantine, D.J.; Tanner, C.C. (2010). Substrate and filter materials to enhance phosphorus removal in constructed wetlands treating diffuse farm runoff: A review. *New Zealand Journal of Agricultural Research* (in press).

Sukias, J. P. S.; Tanner, C.C.; Stott, R. (2006). *Management of dairy farm drainage pollution*. National Institute of Water & Atmospheric Research Ltd, Hamilton. NIWA Information Series No. 38.

Tanner, C.C.; Sukias, J.P.S. (2010). Multi-year nutrient removal performance of three constructed wetlands intercepting drainage flows from intensively grazed pastures. *Journal of Environmental Quality* (in review).

Tanner, C.C.; Nguyen, M.L.; Sukias, J.P.S. (2005a). Constructed wetland attenuation of nitrogen exported in subsurface drainage from irrigated and rain-fed dairy pastures. *Water Science and Technology 51(9)*: 55-61.

Tanner, C.C.; Nguyen, M.L.; Sukias, J.P.S. (2005b). Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. *Agriculture*, *Ecosystems and Environment 105*: 145-162.

Tanner, C.C.; Kloosterman, V.C. (1997). *Guidelines for constructed wetland treatment of farm dairy wastewater in New Zealand*. NIWA Science and Technology Series No. 48, National Institute of Water & Atmospheric Research Ltd, Hamilton.

Glossary

Adsorption — The accumulation or adhesion of molecules on a surface, resulting in a high concentration of the molecules on that surface. The accumulating molecules do not actually penetrate the substance they are on.

Allophanic soil — Soil containing *allophane*–naturally occurring clay-sized minerals comprising silica, aluminium oxide and water, usually volcanic in origin. The presence of allophone in soil causes the soil to have very high phosphorous retaining properties.

Ammonium — A reduced form of nitrogen and an essential plant nutrient. It is generally bound within the soil. Bacteria can convert ammonium to the oxidised form of nitrogen called nitrate.

Anaerobic — Reduced conditions that occur in the absence of free oxygen or oxidised compounds such as sulphate and nitrate.

Biodiversity — The variability among living organisms within and between species and within and between ecosystems. Increasing biodiversity within an ecosystem (e.g., a wetland) can increase its resilience to environmental stresses.

Biofilm (slime) — Bacterially generated slimes containing a range of microbes (bacterial, fungal, algal) that form on submerged plant litter surfaces.

Catchment — The area of land or watershed that drains to a stream or water body. For drainage systems it is the area of land that supplies water to the drain.

CW — Abbreviation for constructed wetland.

Denitrification — The anaerobic, bacterially-mediated process whereby microbes remove nitrate from water by converting it to benign nitrogen gas.

Ecotype — Describes a distinct geographic variety or population within a species which is adapted to specific environmental conditions. For example, a raupo adapted to warmer Northland conditions may not thrive if it was transplanted in cooler Southland conditions, despite being the same species.

Geosynthetic clay liner — A woven fabric-like material which incorporates a bentonite or other clay. It has a very low permeability, and therefore, slows the rate of seepage. An alternative to plastic sheet liners.

Hydraulic efficiency — The degree to which through-flowing waters are evenly dispersed and flow through the whole wetland area without short-circuiting.

Hydraulic residence time — The average amount of time water spends occupying a given volume, i.e., the average amount of time it spends in a constructed wetland. The theoretical hydraulic residence time is calculated by dividing the wetland volume at normal depth by the inflow rate (e.g., $m^3/(m^3/day)$). The actual hydraulic residence time is calculated based on tracer studies.

Microbes — Microscopic organisms; bacteria, algae, fungi and protozoa.

Nitrate — An oxidised form of nitrogen that is mobile and can be leached from the soil into ground and surface water. Once it has arrived in receiving waterways, it is considered a pollutant. Most plants can use nitrate as a source of nitrogen. Bacteria can convert nitrate to nitrogen gas (see dentrification).

Organic carbon — Found in organic matter, required by denitrifying bacteria.

Pollutant — A chemical or waste product that is detrimental or toxic to aquatic life or renders the environment or natural resource un-useable or unsafe.

Rhizome — An underground horizontal stem of a plant, often sending out roots and shoots from its nodes.

Rip-rap — Coarse gravel or stones used as foundation or stabilisation in water, soft ground or embankments. Commonly 50–80 mm in diameter.

Sediment — Fine soil particles, usually the clay or silt, that can be suspended from the soil and transported by water.

Sediment load — The quantity of sediment suspended in water.

Sedimentation pond — A pond whose purpose is to slow down the incoming water sufficiently to settle the sediments to the bottom of the pond.

Soil horizon — A distinct layer of soil whose properties and physical characteristics differ from the layers above and beneath. One or more horizons make up the soil profile, the vertical arrangement of distinct layers that is unique to each soil type. The soil profile is subdivided into three major horizons: A-horizon, characterised by the accumulation of organic material, B-horizon, characterised by accumulation of clay, aluminium, iron and organic compounds, and C-horizon, the unaltered original material.

Subsurface drains — A network of below-ground perforated pipes that allow subsurface water to drain from the soil column, maintaining optimum subsurface soil moisture levels.

Tile drains — Common term for subsurface drains. Deriving from traditional use of clay tiles to create drainage conduits in the subsurface of fields.

www.niwa.co.nz

www.niwa.co.nz/our-science/freshwater/tools/tile-drain-wetland-guidelines