Constructed Wetland Practitioner Guide

Design and Performance Estimates

NIWA Taihoro Nukurangi
DairyNZ

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1. Getting started

Steps to develop a constructed wetland

1. Consider your goals.

Is nitrogen a big problem in your catchment or is it phosphorus? Do you need to control sediment or slow flood flows? Do you want to improve the aesthetics or biodiversity of your farm, support a particular native species, or connect better with mana whenua? Is a good duck hunting site one of your motivations?

2. Find the expertise you need.

Some organisations offer support for wetland development. Your regional council's land or freshwater management team is a good place to start. Landcare Trust, DairyNZ, Fish and Game or your farm advisor may also be able to help. A good digger driver and nursery that can supply appropriate plants will also be important for a successful project.

3. Identify the location and a basic design concept.

This will give you a good starting point. If you haven't already, connecting with local iwi at this point is a good idea. There may be local considerations or important species to look out for.

4. Check on consenting requirements.

You may need a consent, or ideally, you may be able to avoid triggering one. Some examples of potential triggers for a consent include proximity to watercourses and natural wetlands; the amount of soil you are moving; fish passage requirements; and mana whenua concerns.

5. Develop a detailed plan and costing.

By this point you'll know how big the job is, labour requirements and expertise needed. If you are employing someone to construct your wetland, involve them early to ensure your goals are met.

2. About this guide

Purpose

This guide provides design and performance information for people wanting to establish a surface-flow constructed wetland to specifically reduce contaminant loss (nitrogen, phosphorus and sediment) from subsurface tile drains, shallow groundwater outflows from seeps and springs, and surface drains and small streams in pastoral farming landscapes. Wetlands can also provide a wide range of other benefits, including flood management and habitat for birds, fish, invertebrates and plants. They also enhance the natural beauty of farm landscapes and support cultural values such as mahinga kai and recreational activities such as bird watching and hunting. For further information on incorporating these additional values, see the websites of Department of Conservation, Fish and Game New Zealand, The National Wetlands Trust and your regional council.

The information provided in this guidance is based on advice from water quality scientists, regional councils, non-government organisations, wetland practitioners and farming experts, and draws on NIWA's "Technical guidelines for constructed wetland treatment of pastoral farm run-off" (Tanner et al. 2021) and a review of New Zealand and international performance data (Woodward et al. 2020).

The wetland performance estimates for reduction of sediment, nitrogen and phosphorus have been reviewed and endorsed by a technical advisory group established to help deliver this guide.

A general, high-level overview and summary of surface-flow constructed wetlands and their benefits is provided in DairyNZ (2021). These guidelines do not address protection and restoration of natural wetlands. Further guidance on the contaminant attenuation capabilities of natural seepage wetlands on pastoral land is described in McKergow et al. (2016) and Rutherford et al. (2017). Advice on the protection and restoration of natural wetlands is provided in Peters and Clarkson (2010) and Taura et al. (2017).

Keeping it legal

If you want to construct a new wetland and it involves excavation or damming water, disturbance to waterways, adding structures to waterways and/or water diversion, you may need a resource consent. Always contact your local regional council or rural professional for advice and assistance on the local regulations before any earthworks commence.

Regional or territorial councils have rules regarding earthmoving near natural waterways and wetlands, the height of embankments and dams, the amount of the water impounded and the total volume or area of earthworks. Fish passage may also need to be maintained in natural and modified waterways where suitable habitat exists upstream for these species. Specific resource consent may be required depending on local regulations.

Regional councils can also help you identify potential funding, and ensure your plans are compliant.

3. About surface-flow wetlands

What are they

Surface-flow wetlands are the most common type of constructed wetland (CW) applied to pastoral land because of their simple design and lower-cost relative to other wetland types. Water flows horizontally over the surface of a shallow, vegetated treatment basin before discharge through an outlet structure or weir (**Figure 1**).

They are suitable across a range of farm types and landscapes, are robust under variable flow conditions and can, with the incorporation of appropriate sediment traps, withstand moderate rates of sediment loading. Their ability to remove sediment and nutrients from diffuse agricultural runoff over the long term is also well established (Woodward et al. 2020).

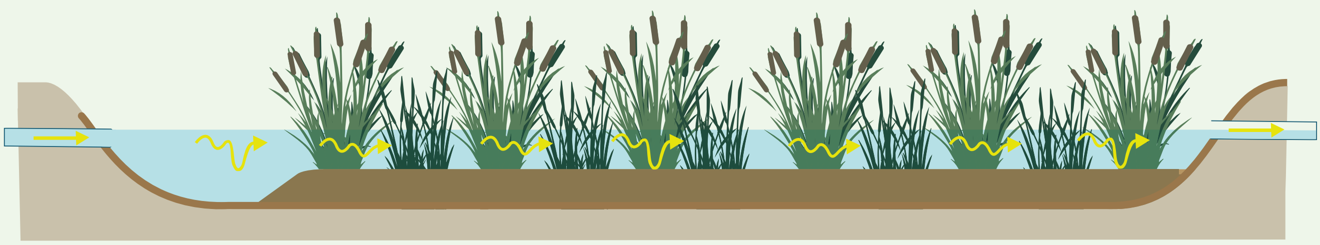


Figure 1. Simple diagram showing surface water flow through a shallow, vegetated wetland basin.

How they function

Constructed wetlands remove contaminants through a combination of physical, chemical and biological processes. A constructed wetland aims to provide an environment in which these processes are optimised to maximise treatment rates. The most important processes are shown in **Figure 2**.

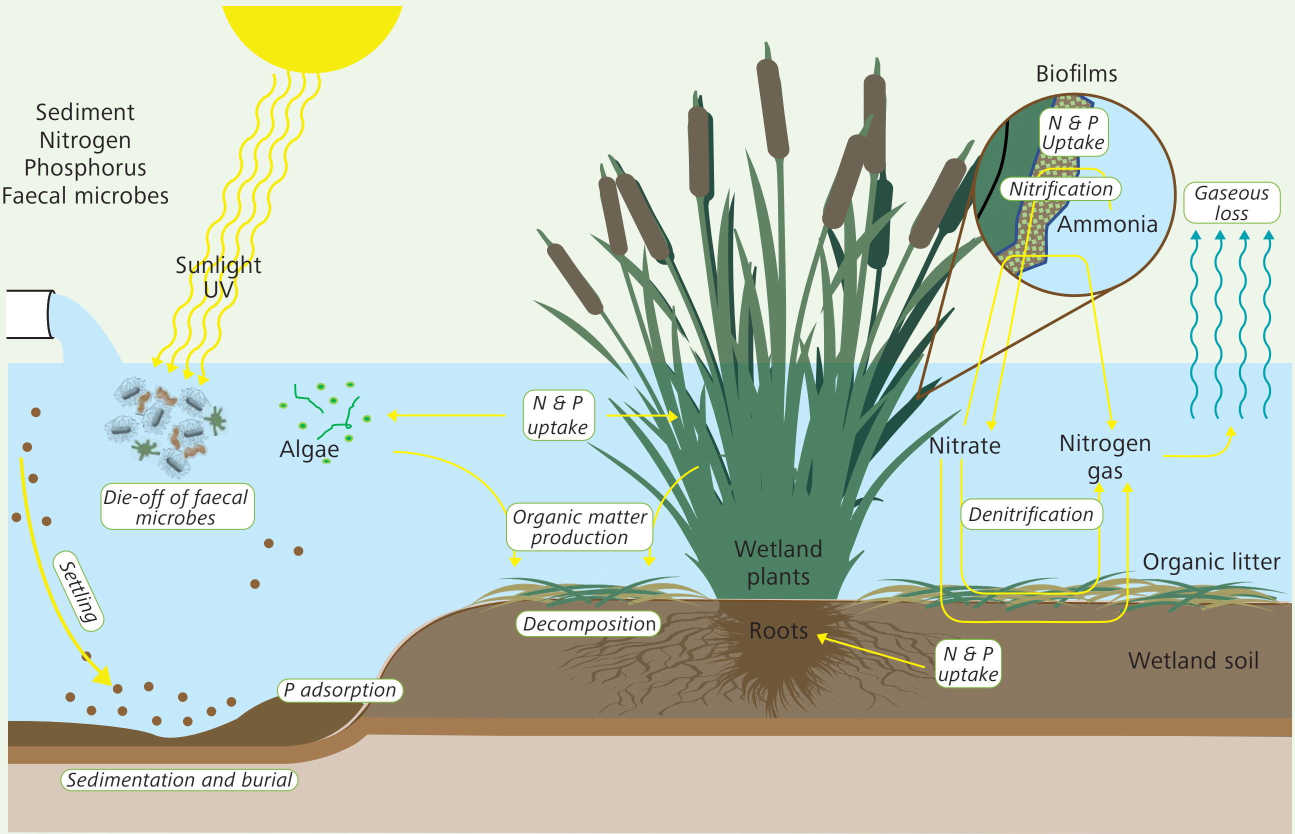


Figure 2. Key contaminant removal processes in surface-flow wetlands.

Wetlands are effective for removing sediment and sediment-bound or particulate contaminants through physical settling processes. Gravitational settling occurs when water velocities are low and hydraulic retention times are long. Fine suspended sediment may also adhere to sticky biofilms that form on plant and litter surfaces underwater and can be filtered from the water column as water flows through wetland vegetation beds. A deep-water column or dense vegetation cover prevents sediment and associated particulate contaminants from being resuspended back into the water column under high flow conditions or as a result of wave action in the wetland.

Microbial denitrification is the key process by which nitrogen (N) is removed in well-established wetlands. In this process, naturally occurring denitrifying bacteria and fungi typically found in wet soils and decomposing vegetation convert nitrate in water into harmless atmospheric nitrogen gas (N_2) as part of their respiration process. A small proportion may be converted to nitrous oxide (N_2O) if the process is incomplete, but recent work by AgResearch has shown that the risk of such pollution swapping (e.g., nitrogen in water being converted to the greenhouse gas nitrous oxide) in wetlands is small (Simon and de Klein, 2021). Wetlands generally provide optimal conditions for denitrification to occur due to permanent waterlogged conditions, low oxygen levels and a good supply of decomposing organic material which acts as a carbon food source for the denitrifying bacteria and fungi.

The uptake of dissolved nitrogen and inorganic phosphorus by wetland plants is also an important nutrient removal pathway, particularly in newly established wetlands, where the environmental conditions for maximising bacterial denitrification processes are not yet optimal. Nutrients taken up by the plant are transformed into plant biomass and are either remineralised or accumulate in wetland soil following decay processes. In some instances, wetlands may act as a source of dissolved phosphorus and work is underway to determine where this is most likely to be a risk. In general, it is best to avoid using P-rich soils in constructed wetlands (further guidance is provided in the wetland design section, see page 17).

Bacterial contaminants are likely to die off naturally in wetlands that have long water retention times or where there is sufficient exposure of microorganisms to sunlight, although wetlands can also be a source of *E.coli* due to the enhanced bird habitat they provide. This can be minimised by avoiding open water zones close to wetland outflows.

4. Contaminant removal performance estimates

There are many reasons to restore and construct wetlands, including: water quality and flood management, wildlife habitat, biodiversity and aesthetics. However, these guidelines focus on the contaminant reduction function of constructed wetlands, in particular removal of nitrogen and sediments. They provide design guidance based on robust scientific research, for the creation of sustainable wetland systems that can effectively reduce pollutant loads.

The performance of different sized constructed wetlands relative to the size of their contributing catchments was assessed by Woodward et al. (2020) using information derived from local and international field-scale monitoring and modelling studies. This information was integrated with expert opinion to derive contaminant reduction estimates for constructed wetlands in the New Zealand context.

Performance estimates were further refined to generate conservative estimates of long-term performance for appropriately designed, constructed, vegetated and maintained constructed wetlands. The performance was assessed and endorsed by a technical advisory group comprising experts from regional and national regulatory agencies and wetland practitioners. Performance estimates were limited to small-scale, edge-of-field and sub-catchment situations; discharge from streams of first-order or less, involving waterways generally smaller than one metre wide and 30cm deep at base-flow, which receive flow from catchments no larger than about 50ha in extent. They assume normal New Zealand pastoral farming conditions and management practices on flat to rolling landscapes (average slopes of 15° or less) with annual rainfall of 800-1600mm. They do not apply to areas with highly permeable soils where groundwater is the dominant flow pathway and therefore hard to intercept on-farm. Some additional limitations are noted below for specific contaminants and flow pathways.

Performance estimates for sediment

Figure 3 shows the expected long-term performance estimates for removal of suspended sediments by a constructed wetland built according to the recommendations in this guidance, including the incorporation of a sediment pond. As relative wetland area increases from 1 to 5% of the catchment area, the long-term average total suspended sediment removal is expected to increase from 50 to 90%. The shaded areas in **Figure 3** show the inter-annual and inter-site range of performance expected.

Sediment which might be transported in surface drains or overland flows (e.g., off raceways) will comprise a range of size fractions from fine clays and silts to larger aggregates of soil and potentially clumps of dung. High intensity rain events will transport larger particles, while low intensity events will mainly transport medium to fine particles. The estimates for removal are based on annual performance of wetlands, thus during high intensity events when lots of large particles are mobilised, high removal rates will occur, but predominantly for the coarse particles. In contrast, during less intense events, less sediment will be mobilised, but greater capture of finer particles will occur. Because of insufficient performance information relevant to catchments dominated by clay soils these performance estimates are only applicable to catchments with soils having < 35% clay content.

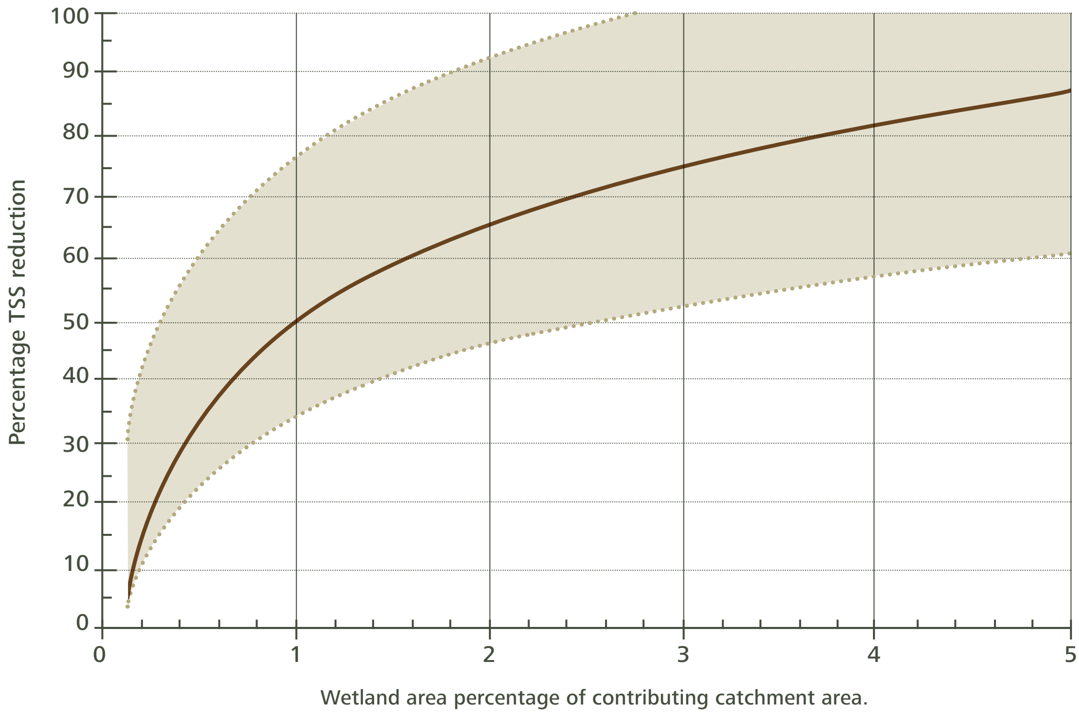


Figure 3: Long-term median annual performance expectations for reduction of total suspended solids (TSS). Performance is for appropriately constructed wetlands receiving surface drainage and run-off from pastoral farmland in New Zealand with catchment rainfall of 800-1600mm/year. Not applicable to areas with clay soils (>35% clay content). Solid line shows expected median. Shaded area shows expected inter-annual and inter-site range of performance.

Performance estimates for nitrogen

Nitrogen in agricultural drainage water is normally present in dissolved nitrate-N form. This is primarily removed in constructed wetlands via biological processes (microbial denitrification and plant uptake). Removal rates generally decrease as temperature decreases. Different performance estimates are therefore provided for warmer (average annual air temperatures ≥12°C) and cooler (average annual air temperature 8-12°C) regions of New Zealand (**Figure 4**).

Based on long-term conditions, the median proportion of total nitrogen (TN) removed from constructed wetlands in warm climate zones increase from 25 up to 50% as relative wetland area increases from 1 to 5% of the catchment area (**Figure 5**). For cool climate zones (e.g., the South Island) the median nitrogen removal rates increase from approximately 20 to 40% for the same relative wetland areas.

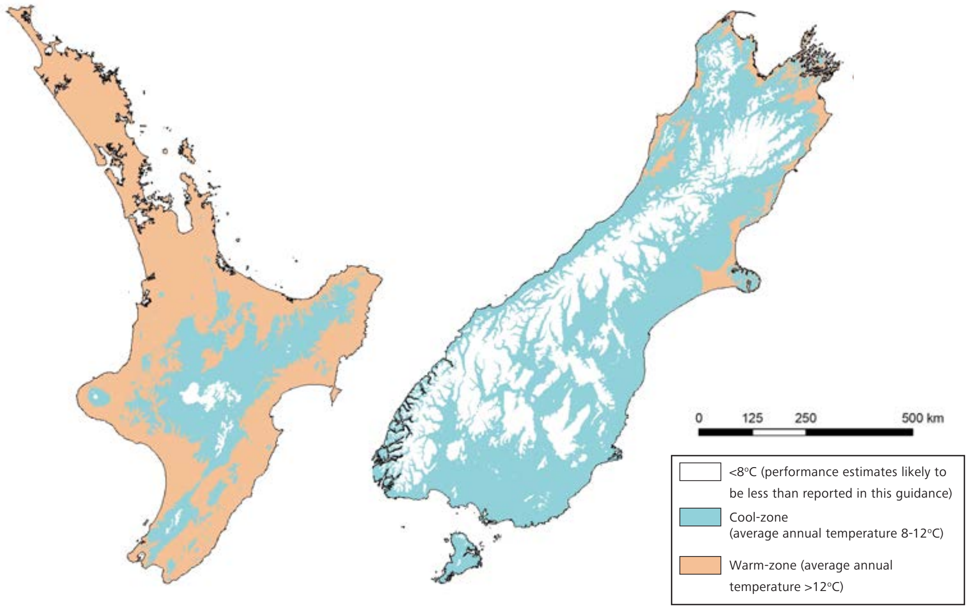


Figure 4. Warm and cool regions in New Zealand. Warmer temperatures support higher rates of N removal.

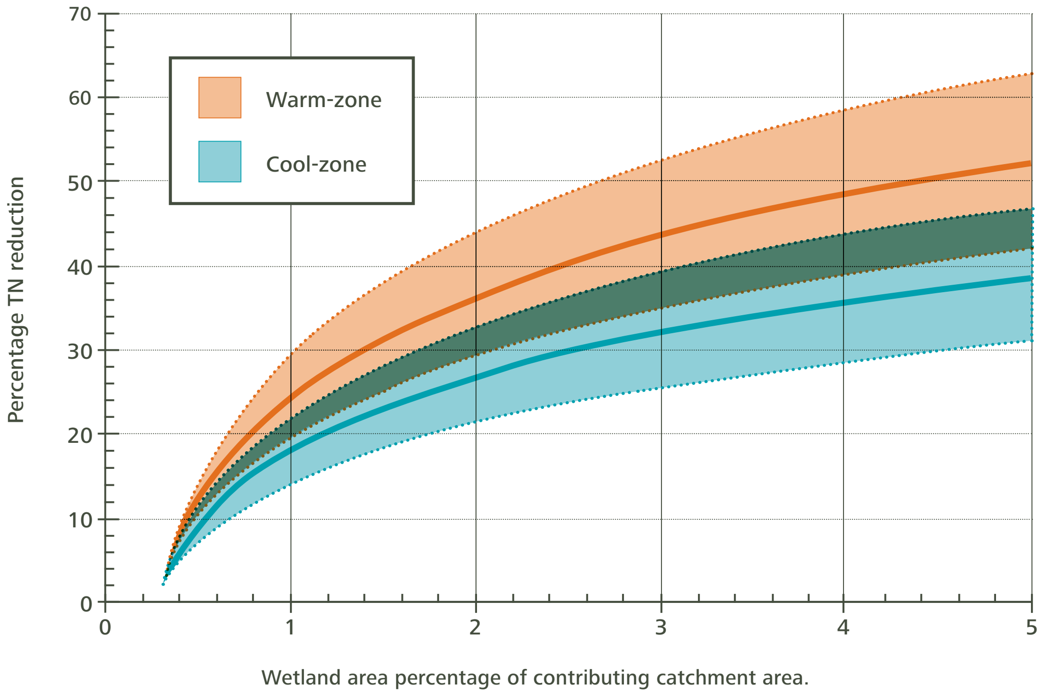


Figure 5. Long-term median annual total nitrogen (TN) reduction performance expectations. Performance is for appropriately constructed wetlands receiving surface drainage and run-off from pastoral farmland for warm (average annual temperature >12°C) and cool (average annual temperature 8-12°C) climatic zones in New Zealand with catchment rainfall of 800-1600mm/year. Solid lines show expected medians for each zone; shaded areas show inter-annual and inter-site range of performance expected.

Performance estimates for phosphorus

Performance estimates for removal of total phosphorus (TP) are applicable to constructed wetlands receiving surface run-off and drainage flows where P is predominantly associated with particulates (suspended sediments), and in catchments not dominated by clay soils (i.e., <35% clay content). The average proportion of phosphorus removed by these wetlands over the long term is estimated to increase from 25 up to 50% as relative wetland area increases from 1 to 5% (**Figure 6**).

Phosphorus in subsurface drainage water is mainly in dissolved forms and its removal is not covered by the treatment estimates provided here. There is potential for dissolved P release from constructed wetlands when P-rich agricultural soils are used as growth media. Therefore, soils with low potential for P release (e.g., allophanic soils) or use of subsoils alone or mixed with topsoil should be selected for use in the base of the wetland. Where Phosphorus reduction is a specific goal or soils are known to have high P status, it is recommended that soil tests are carried out to assess the risk. Information available at present suggests there is significant potential for wetland P release when the soil TP/anion storage capacity ratio is 0.2 or more.

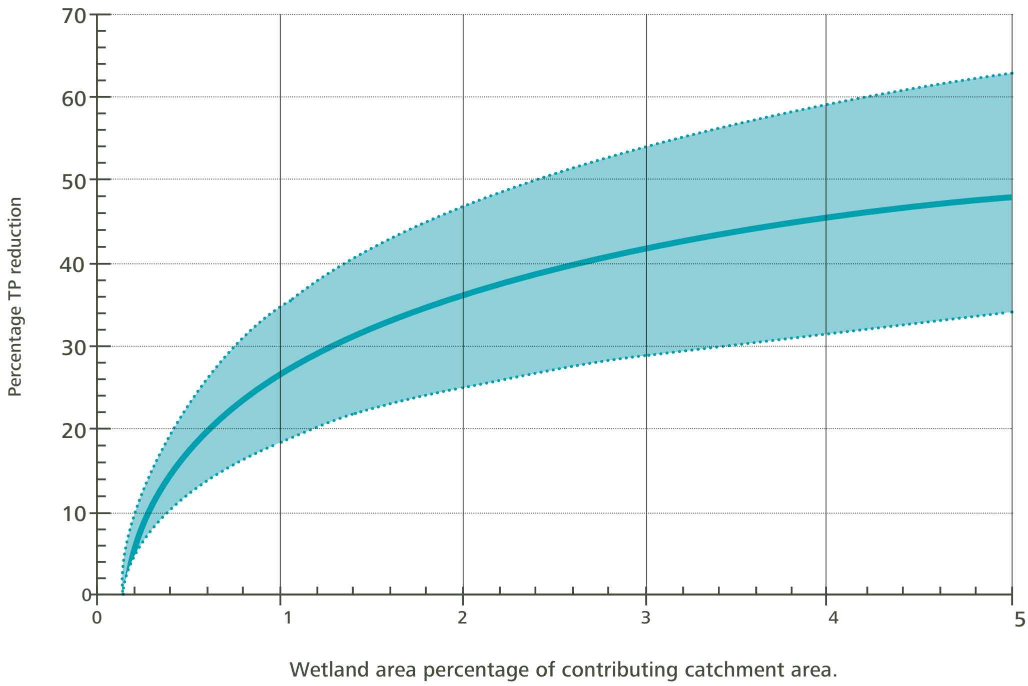


Figure 6. Long-term median annual total phosphorus (TP) reduction performance expectations. Performance is for appropriately constructed wetlands receiving surface run-off and drainage from pastoral farmland in New Zealand with catchment rainfall of 800-1600mm/year. Solid line shows expected median; shaded area shows inter-annual and inter-site range of performance expected. These predictions do not apply for constructed wetlands whose main source of flow is subsurface drainage containing predominantly dissolved forms of phosphorus.

5. Wetland design

Design basics

It is important to emphasise that the contaminant removal estimates shown in the previous section only apply to well designed and maintained wetlands constructed according to the design principles outlined in this guide. To maximise contaminant removal, it is important to target the dominant sources and transport pathways off contaminant loss in the landscape.

The main principles of effective wetland design for managing agricultural drainage and run-off are to:

1. Capture, slow down, spread out, and retain water and contaminant flows in the wetland for as long as possible without compromising upslope drainage and flood risk.
2. Create conditions which mimic those found in a natural wetland, particularly high coverage of emergent wetland plants.
3. Provide co-benefits including flood protection, ecological habitat, plant and animal biodiversity, and mahinga kai.

Diffuse agricultural contaminant flows are highly variable from day-to-day, season-to-season and even year-to-year. The treatment performance of wetlands will vary according to the distribution, intensity, and duration of rainfall and how this interacts with soils, slopes, and vegetation across landscapes to generate surface and subsurface drainage and run-off. Seasonal temperatures also impact both microbial and plant uptake of nutrients in wetlands.

The key components of an effective constructed wetland are:

1. A sedimentation zone.
2. A deep-water inlet (dispersion) zone.
3. A shallow vegetated wetland zone.

These wetland components (or zones) are described in **Table 1** and illustrated in **Figure 7**. Wetlands can either be configured with a separate or integrated sedimentation pond (**Figure 7A and B**, respectively). Wetlands receiving tile drain flows with minimal sediment load may not need sedimentation ponds - check whether the flow goes murky during storm flows. **Figure 8** provides an example of how these wetland components are typically integrated into the landscape and **Figures 9A and B** shows how different configurations can be used to suit natural landscape features and topography. The timeline for the stages of wetland construction are given in **Appendix 1**.

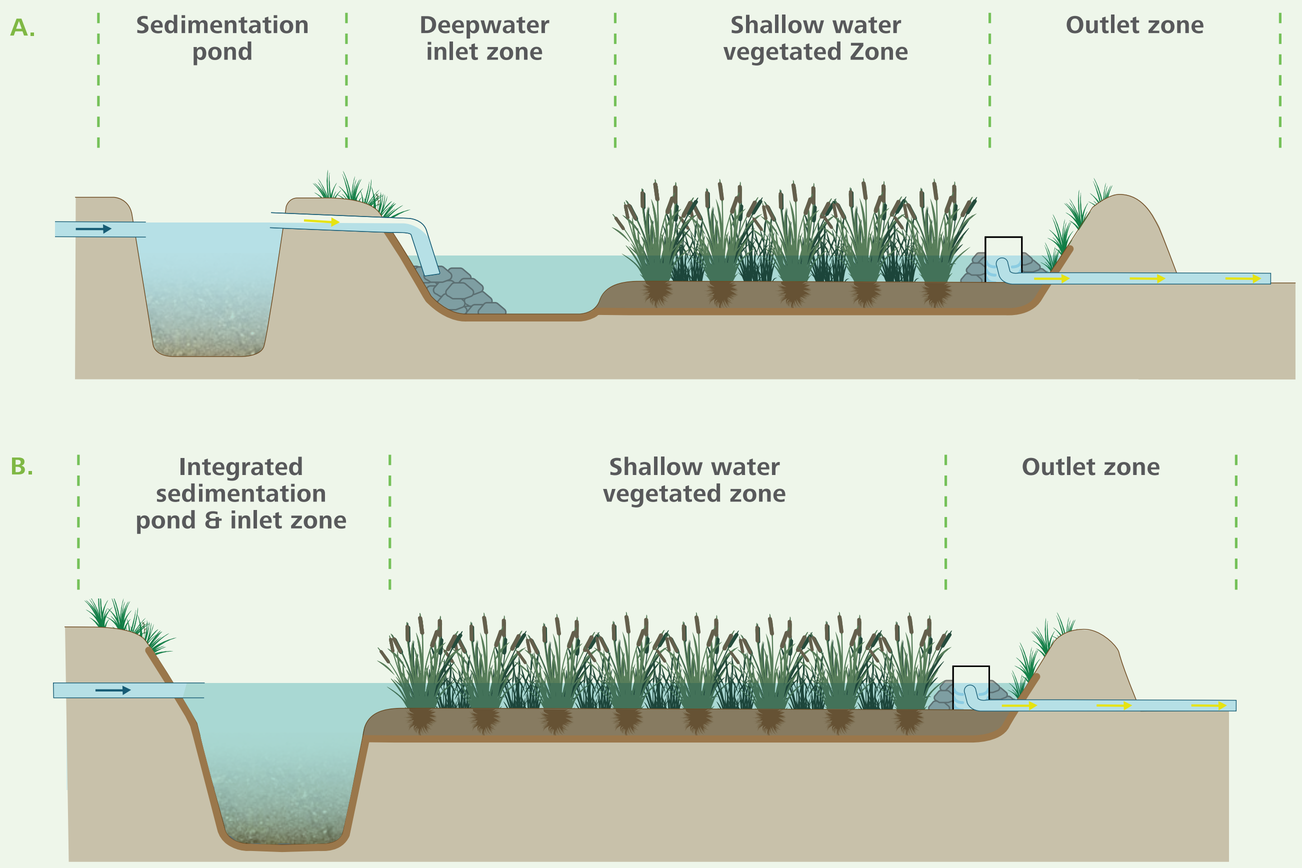


Figure 7. Surface-flow constructed wetland treatment cells in side view. Option (A) features a separate sedimentation pond, deep inlet and shallow treatment/planted basins while (B) integrates these components into a single inlet-sedimentation zone and shallow treatment zone. Note: Embankment slopes are exaggerated.

Table 1. Constructed Wetland design basics for managing pastoral farm drainage and run-off. See Appendix 1 for recommended construction timeline.

SIZE AND SHAPE	
Wetland type	Surface-flow, also known as free-water surface constructed wetlands.
Size	1-5% of contributing catchment area - bigger areas provide greater contaminant reduction. Larger areas (≥2%) are recommended in regions that experience high intensity storm events. Wetland size should be determined at normal water level, not at the top or outside of the embankments.
Shape	Elongated or multi-wetland cell systems with inlet and outlet at opposite ends and overall length:width ratio ideally 5:1 to 10:1 (minimum 3:1).
Performance	A well-designed wetland that is 2% of catchment will typically remove between 46 - 92% of sediment (from soils with low clay content); 28 - 44% of nitrogen in warm zones (22 - 33% in cool zones), and 25 - 46% of particulate phosphorus.
WETLAND COMPONENTS	
Initial deep sedimentation pond (>1.5 m depth)	Should be included wherever there is potential for sediment transport into the wetland. Size up to 20% of the wetland area, taking account of expected peak flows based on local rainfall intensity. Provide for digger access to enable periodic clean-out of accumulated sediment to maintain at least half the original pond depth.
Deep (>0.5m) open water dispersion zone at inlet	Up to 20% of the wetland size located at the inlet of each vegetated wetland zone, and up to 30% of the total wetland area can be deep zones.
Shallow (average 0.3 m depth) densely vegetated zone	At least 70% of wetland area, including the final 20% of wetland area closest to the outlet should be vegetated. This is to reduce the impacts of disturbance and faecal inputs by waterfowl.
PLANTING	
Shallow zones	70% cover of native wetland sedges and bulrushes. Ideally, plant in spring-early summer at 2 - 4 plants/m^2.
Embankments	Hardy riparian plants. Plant in winter-early spring at ~1 - 2 plants/m^2.
Protection	Control weeds mechanically or with an approved herbicide before planting and during initial 18 months of establishment. Protect new plantings from grazing by pūkeko and Canada geese. Fence the wetland to exclude livestock.

A well-functioning wetland should have:

- Low sediment accumulation rates in the main vegetated wetland zone.
- Well-established, flourishing and evenly distributed wetland plants.
- Uniform flow, with no signs of channelisation or short-circuiting.
- Outflow water which is generally clear, with low odour.
- Appropriate water levels for plant survival and treatment function.
- Minimal cover of invasive weedy plants in the vegetated treatment cell.
- Well-maintained embankments and margins – fenced to exclude livestock, without erosion or dominance by weeds.

Figure 8. Features of a surface flow constructed wetland in the landscape: (1) A deep sedimentation pond (more than 1.5m deep), size will depend on rainfall intensity and topography but generally up to 20% of wetland size, (2) Deep (over 0.5m) open water zones at the inlet of each cell to help dispersion and mixing, and even out the flow, (3) shallow (average 0.3m deep), densely vegetated zones (at least 70% of the total area). The shallow zone is where most of the nitrogen removal happens via microbial denitrification, fuelled by decaying plant leaf litter. Sunlight penetration in deep open-water areas can promote die-off of faecal microbes in inflowing waters, but shallow water with dense plantings is recommended in the final 20% of the wetland to limit faecal contamination and sediment disturbance in the final outflow by waterfowl.

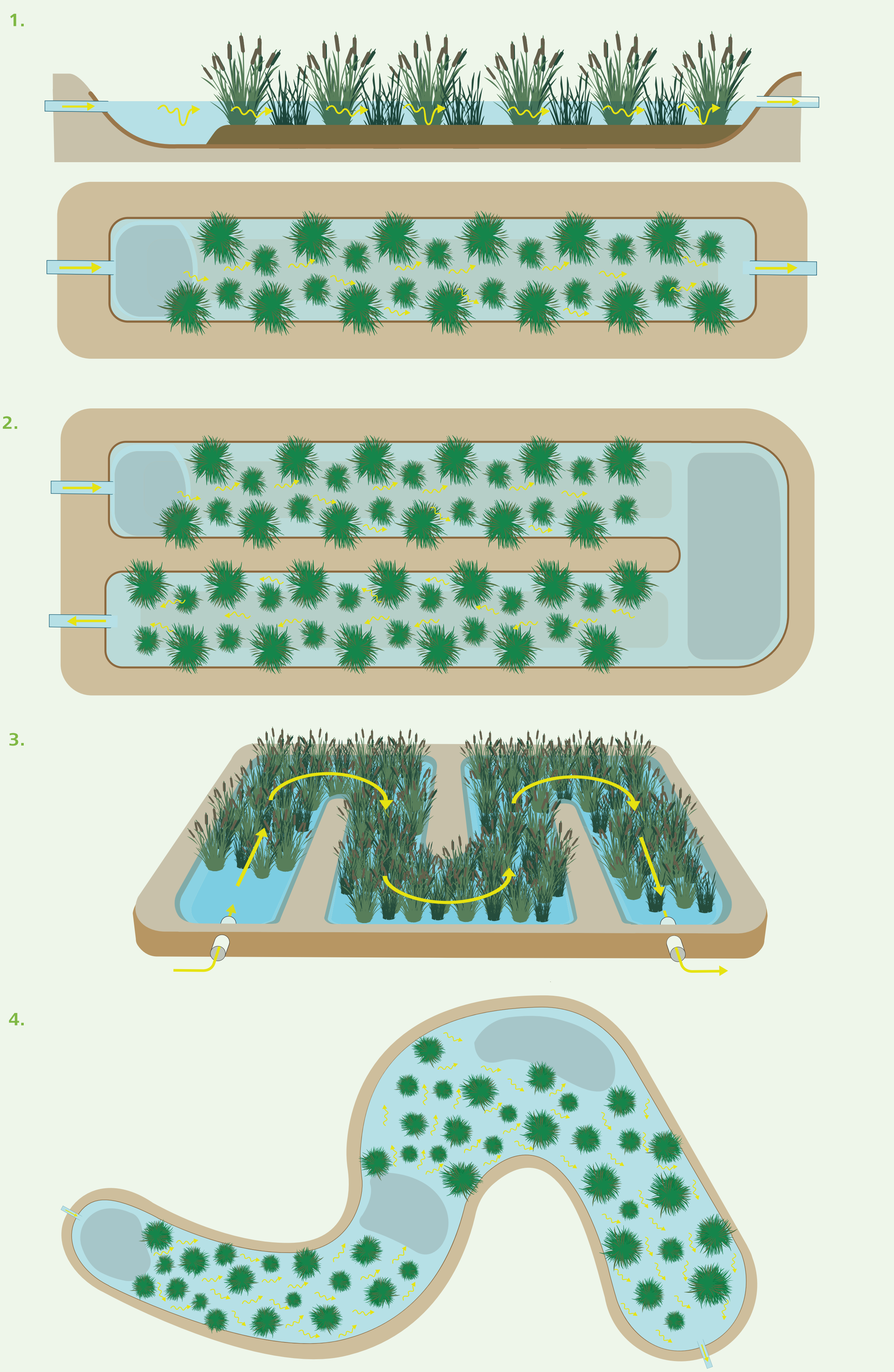


Figure 9A. Different design configurations of surface-flow constructed wetlands for flat land. Wetland length:width ratios can be increased by having multiple cells in series or using bunds to create a serpentine flow path.

Wetland size

Wetlands intercepting agricultural runoff and drainage flows generally need to comprise between 1-5% of their contributing catchment (i.e., 100-500m^2 of wetland per hectare) to meet the expected treatment performance described in **Table 1**. The performance of constructed wetlands depends to a large extent on the residence time of water within them, so larger relative wetland areas will provide higher contaminant removal. Larger areas (≥2% of contributing catchment) are recommended for areas that experience frequent high intensity/duration storm events (e.g., Northland, Bay of Plenty, Gisborne, Nelson, Tasman and the West Coast) to ensure that sufficient residence time is achieved. Graphs of estimated long-term median annual performance in relation to relative wetland size (measured at the normal water surface), and expected range of variability, are provided for sediment, nitrogen and phosphorus in the previous section. Use these performance estimates along with information about your farm nutrient budget and landscape attributes, and water quality targets and limits developed for your catchment to determine the most appropriate wetland size.

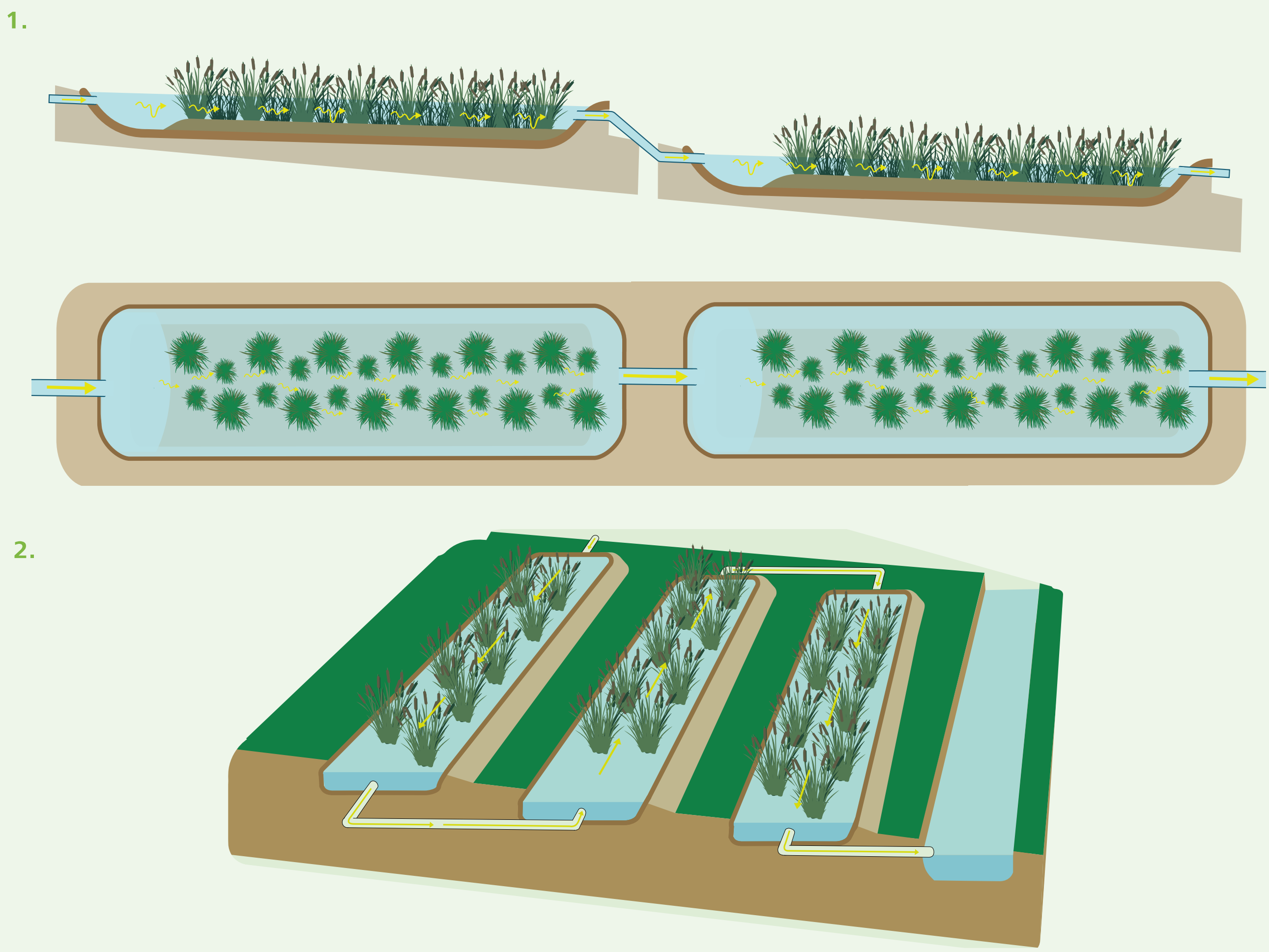


Figure 9B. Different design configurations of surface-flow constructed wetlands for contoured or steeper land. Wetland length:width ratios can be increased by stepping a series of cells down the slope.

Flow path positioning

Depending on the landscape and catchment, surface-flow wetlands can be constructed to intercept a range of different flow paths:

- Sub-surface tile drains prior to discharge into open channels or streams.
- Groundwater seeps or springs (e.g., at the toe-slope of hills).
- Drainage ditches.
- Small streams or creeks, where a proportion of the flow can be maintained in the natural channel for fish passage and a proportion diverted to an off-line wetland constructed adjacent to the water course (**Figure 10B**) or where fish passage can be maintained through the wetland (**Figure 10A**).
- Ephemeral flow paths which receive periodic surface runoff. These typically need to have at least a portion of more permanent inflow from shallow groundwater to sustain wetland plantings.

Focus on flow paths that carry significant contaminant loads. Flows that occur consistently or frequently during wet periods of the year will provide the greatest contaminant reductions and be the most able to sustain a wetland.

Maintenance of fish passage is legally required for rivers, streams and modified natural watercourses. Some artificial drains and canals also provide valuable fish habitat which should be maintained. Consult the Fish Passage Guidelines available on the Department of Conservation (DoC) and NIWA websites for further information (Franklin et al. 2018). Examples of fish-friendly inlet and outlet structures are provided in the wetland outlet and spillway section below. A suitably designed off-line wetland has the benefit of retaining flow along the watercourse to provide for fish passage. It can also be engineered to accept the majority of flow during normal flow conditions, while allowing a proportion of the water to bypass the wetland during higher flow periods. This approach provides more consistent flows to the wetland resulting in stable treatment performance and avoids damage to the wetland during flood flows. However, water and associated contaminants that do not pass through the wetland will not be treated.

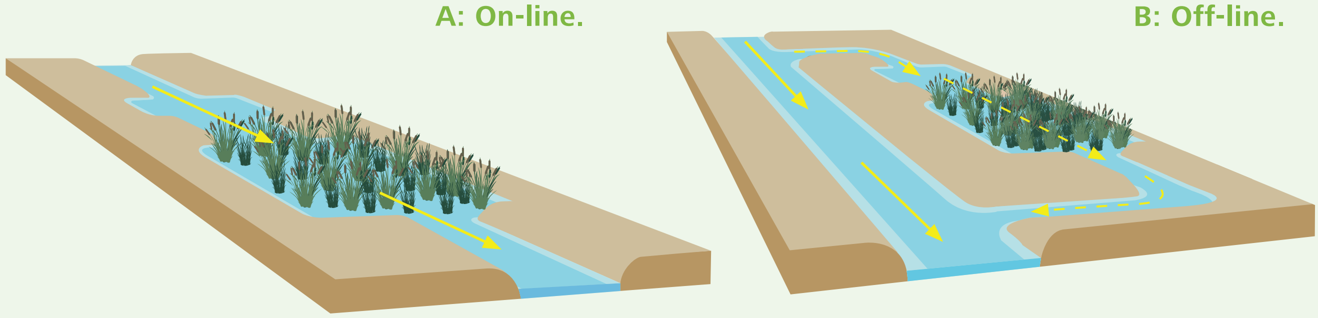


Figure 10. Diagram showing (A) on-line and (B) off-line wetland options.

Wetland shape and arrangement

The shape and form of the wetland should aim to promote uniform flows throughout the treatment beds, so as to avoid dead-zones and maximise the amount of time water spends in the wetland being treated. Often the best location for a constructed wetland is on low-lying areas of the farm where natural wetlands may have existed historically prior to modification of the landscape through drainage, and pastoral production is generally lower.

Contaminant removal performance is influenced by how evenly water flows through the wetland. This means the best shape for a constructed wetland is elongated or with multiple cells to avoid short-circuiting between the inlet and the outlet. Even flow distribution across the full width of a wetland, and consequent wetland treatment effectiveness, is improved where the overall length to width ratio of the wetland channel is between 5:1 and 10:1 (minimum 3:1). Suitable length-to-width ratios can be achieved by a single long and narrow wetland cell (**Figure 9A: 1**), or by using internal bunds to create longer flows path where space is constrained (**Fig 9A: 2 and 3**). More naturalised shapes that fit into the natural landscape can also be used as long as they achieve suitable length to width ratios and avoid creating dead-zones (**Figure 8 and 9A: 4**). Open water areas orientated across the width of the wetland or on the outer edge of corners can be used to redistribute flow and add diversity (**Figure 9A: 4**). Channels oriented along the flow path should be avoided as they promote preferential flow and short-circuiting.

Constructed wetlands can also be split into a series of separate cells to minimise the amount of excavation required on sloping sites. Land slope and site characteristics will generally dictate whether a single (**Figure 9A**) or multi-stage wetland is preferable (**Figure 9B**). It is generally more practical to build a series of smaller wetland cells down a slope, keeping the fall between each cell to no more than ~1-2m to avoid the need for large bunds/embankments and extensive excavation. Where an embankment must be constructed between cells, this should be constructed using well-compacted subsoil with a high clay content, keyed into the substrate beneath.

Sedimentation pond

Including a sediment pond as the first stage of a wetland complex helps capture coarse sediment fractions and extend the lifetime of a wetland (**Figure 11**). Accumulated sediment will need to be mechanically removed periodically from the sedimentation pond, so it is important to maintain digger access. General principles for construction of a sedimentation pond can be found in the Ministry for Agriculture Forestry coarse sediment trap guidelines (Hudson 2002) and are summarised in Tanner et al. (2021). Sizing of sedimentation ponds should consider regional storm frequency and intensity, but a general rule is that the sedimentation pond should comprise 10 to 20% of the size of the wetland and be excavated to a depth of 1.5m below the outlet level. Its length (minimum of 5m) should be greater than its width. Gently sloping the margins of ponds can enhance shallow-water habitat for waterbirds.

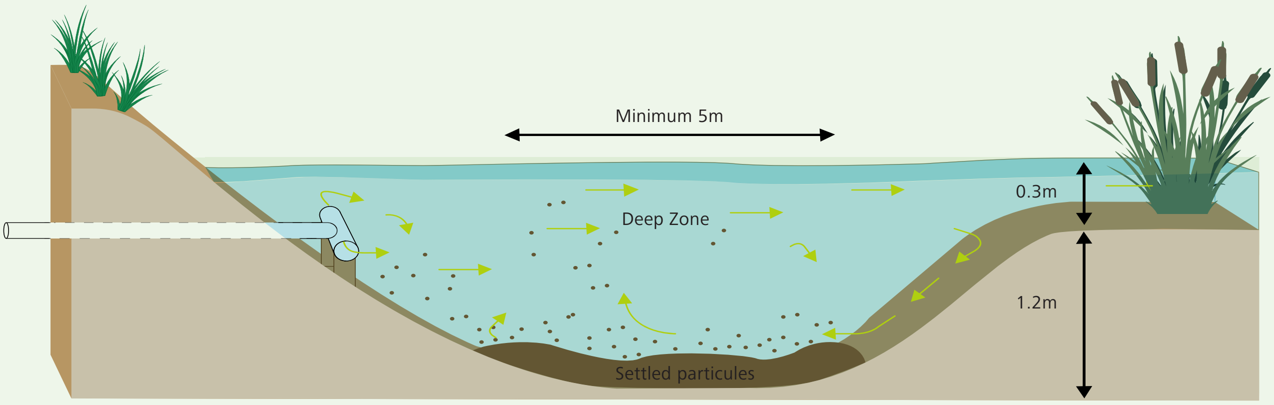
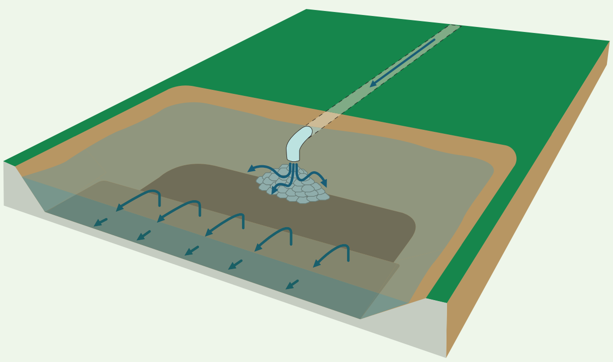


Figure 11. Integrated sedimentation pond configuration and functioning. Sediment ponds can either be separate from the wetland, or integrated into the inlet (as shown), where they also function as the dispersion zone (also refer to Figure 7).

Inlet structure

The performance of constructed wetlands is optimal when water flows uniformly through the wetland to utilise the full available volume. Deeper, non-vegetated, open water zones are recommended in the inlet zone to dissipate the energy of the inflowing plume and distribute it across the width of the wetland. If the inlet enters in a pipe it can be directed downwards using an elbow (**Figure 12A**) or laterally to both sides of the pond-zone using a T-fitting (**Figure 11**). The inlet piping needs to be able to function effectively for long periods without the need for frequent maintenance. An open channel (**Figure 12B**) inflow will be appropriate where fish passage is required through the wetland. Consult **Figures 15** and **16**, and the NIWA/DoC Fish Passage Guidelines for further information on fish passage options (Franklin et al. 2018).

A: Piped inflow.



B: Open channel inflow.

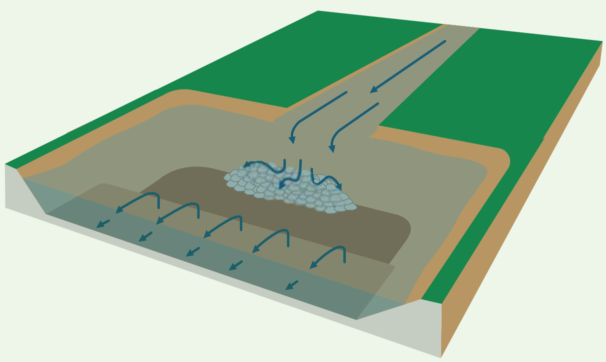


Figure 12. The inlet to sedimentation ponds can be (A) piped (e.g., from a tile drain) or (B) via an open channel. Fish passage should be provided where required; see **Figure 15** for guidance.

Embankment design, lining, and growth media

Where soils in the base of the wetland are highly permeable (e.g., sands) or the wetland receives only intermittent (or ephemeral) flows, a liner may be required in the base of the wetland (e.g., compacted clay or buried plastic sheeting) to reduce water loss and prevent the wetland drying out. Where consistent flows are expected over much of the year and subsoils in the base of the wetland have a clay content of >10%, it is unlikely that leakage will be a problem. Once organic matter has built up in the base of a wetland, nitrate-nitrogen should be very effectively removed in any groundwater seepage through the base or sides of the wetland.

Embankments should be constructed using subsoils compacted in shallow layers, so they are structurally stable and watertight. They need to be keyed into the subsoil and battered at an angle of around 3:1 (2:1 maximum slope) to reduce the potential for bank slumping and erosion. Gently sloping the inner embankments can promote greater plant diversity and shallow-water habitat for wading and dabbling birds.

Some councils have limits on bund height above which professional engineering designs and resource consents may be required. Consenting requirements that relate to specific wetland designs and locations should be identified prior to construction.

In the shallow areas identified for planting, a layer of approximately 0.3m of friable lightly compacted soil is required to promote plant root growth and anchorage (**Figure 13**). Farm topsoil that has received fertiliser for many years is likely to contain high levels of phosphorus which could leach into the water column once the soil is permanently saturated in the wetland. To manage this risk, a 50:50 mixture of topsoil and subsoil is recommended in the shallow planting areas (not required in the sedimentation pond or in deeper, non-vegetated, flow-dispersion zones; see page 9 for further guidance on assessing P-loss risk).

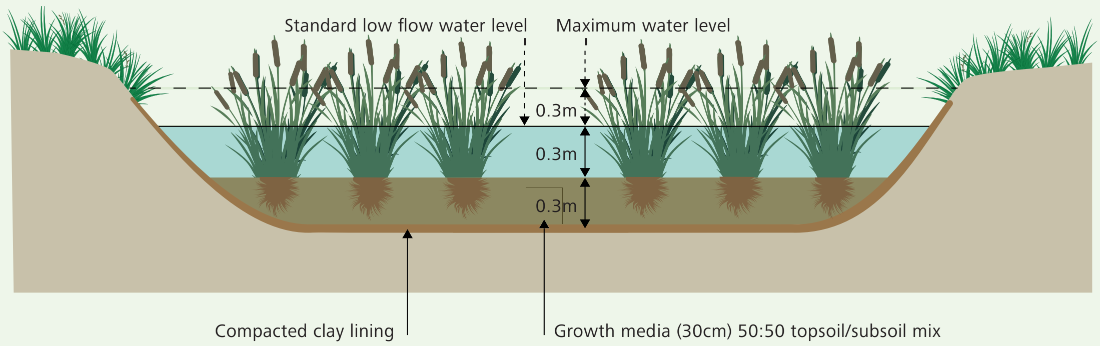


Figure 13. Cross-sectional view of shallow planted zone of a constructed wetland. A compacted clay liner is recommended where the wetland is constructed in permeable soils and/or receives only intermittent flows.

Wetland outlet and spillway

Outlet and spillway structures provide control of water levels within the wetland to maintain treatment functioning and to manage flood risk. Ideal water depth for most emergent wetland plants is around 0.3m. Water depth in the vegetated zones is controlled by the height of the outlet – the interior base of an outlet pipe (known as the invert), or the crest of an outlet weir.

The embankment should be made first to ensure it is properly compacted, and then excavated to fit the outlet pipe or weir structure at the appropriate depth (so that the water level can be adjusted to 0.3m above the wetland base once the topsoil layer has been added to the wetland). Anti-seep collars should be fitted where necessary to stop water leaking around the pipe.

Provision for maintenance of a shallower water level during plant establishment and for future adjustment of the outlet height as sediment and plant material build up in the wetland is also required. For smaller wetlands not requiring fish passage, this can be done by adding a 90° pipe bend that can be swivelled to adjust the level of the outlet (**Figure 14A**) or adding another section to the riser pipe (**Figure 14B**). For larger wetlands, an adjustable outlet weir (**Figure 14C**) or outlet pipes set through the embankment at the establishment water level (that are subsequently able to be capped) are likely to be more practical.

A form of spillway or overflow is required to manage large storm flows and protect the wetland and its embankments against flood damage. The spillway may be configured in the outlet system or comprise a slightly lower, armoured section of the wetland bund, enabling over-topping without damage to the bund. The lip of the spillway needs to be sufficiently wide and shallow to keep flow velocities low to minimise the risk of erosion. The spillway crest, chute and exit need to be suitably armoured with geotextile and rock riprap or concrete to resist erosion and avoid undermining of embankments. In-line wetlands may need a diversion channel to route extreme flows around the wetland or provide an armoured pathway through the wetland.

It is recommended that suitable expertise is sought early in the design process to address potential engineering requirements for the wetland. Fish passage will also need to be considered for some outlet and inlet structures and for where a weir is constructed to divert water into an off-line wetland. **Figure 15** provides guidance on where fish passage structures are required and **Figure 16** provides guidance for maintaining fish passage using gently sloping concrete-lined ramps with rocks inserted as roughness elements. Consult the Fish Passage Guidelines available on the DoC and NIWA websites for detailed design information (Franklin et al. 2018).

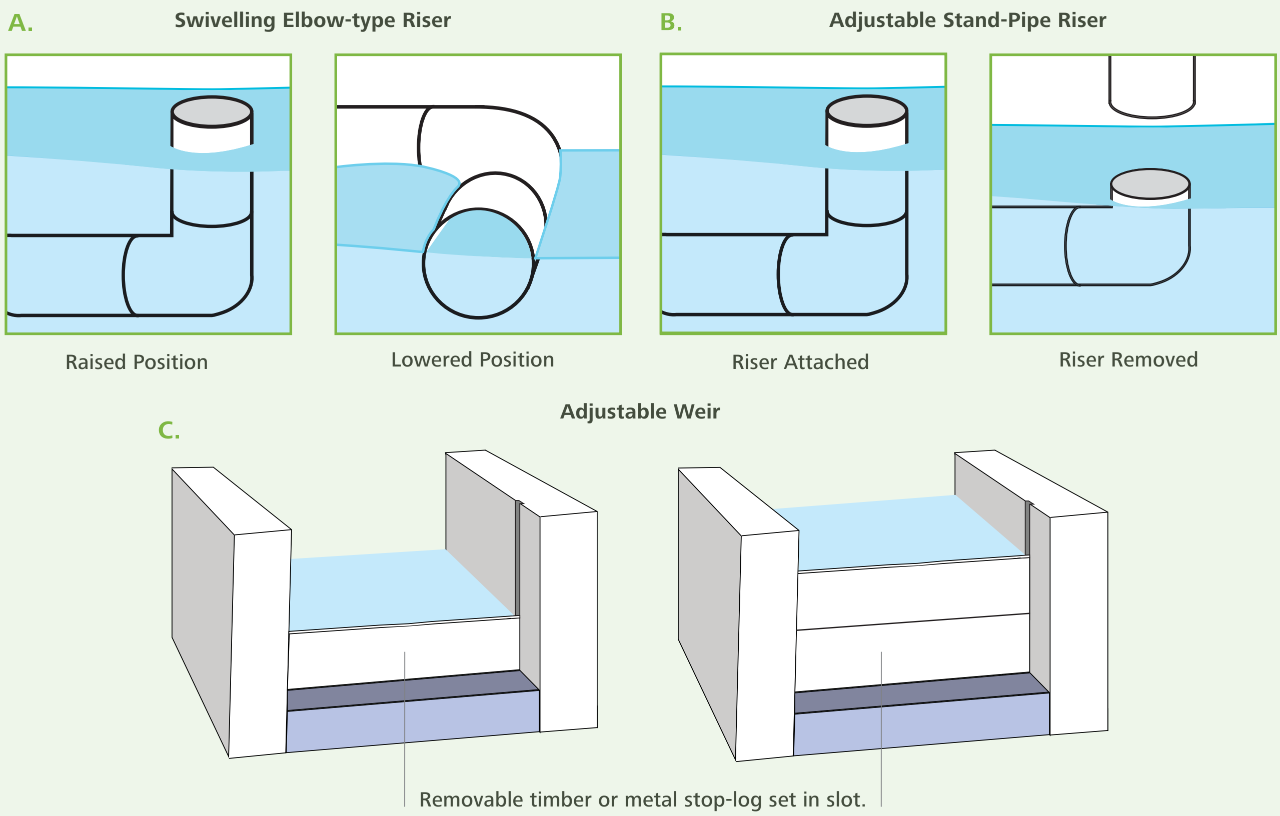


Figure 14. Examples of outlet structure design where providing for fish passage is not required. (A) swivelling elbow-type riser, (B) adjustable riser piper suitable for small wetlands, and (C) adjustable weir suitable for larger constructed wetlands.

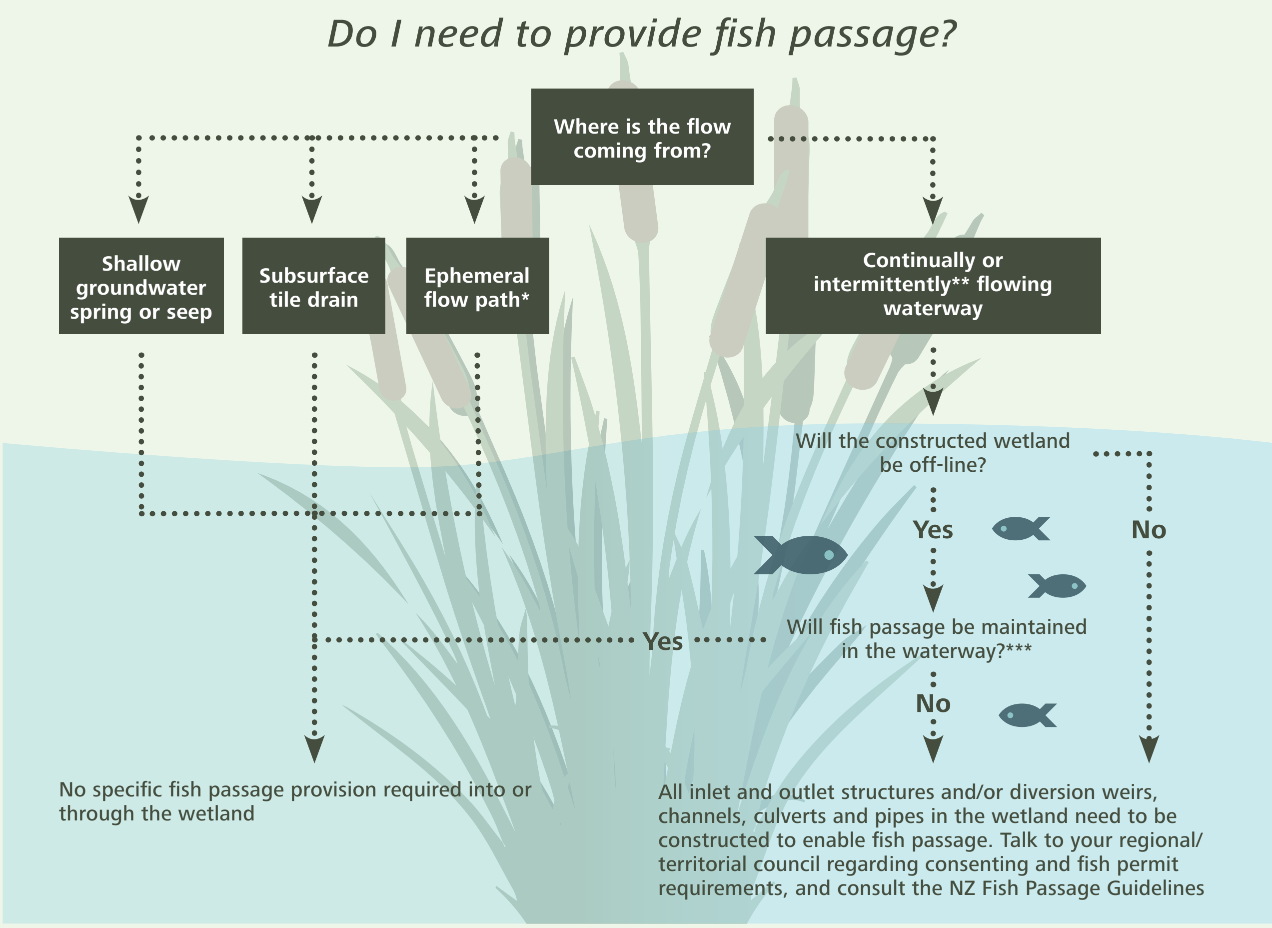
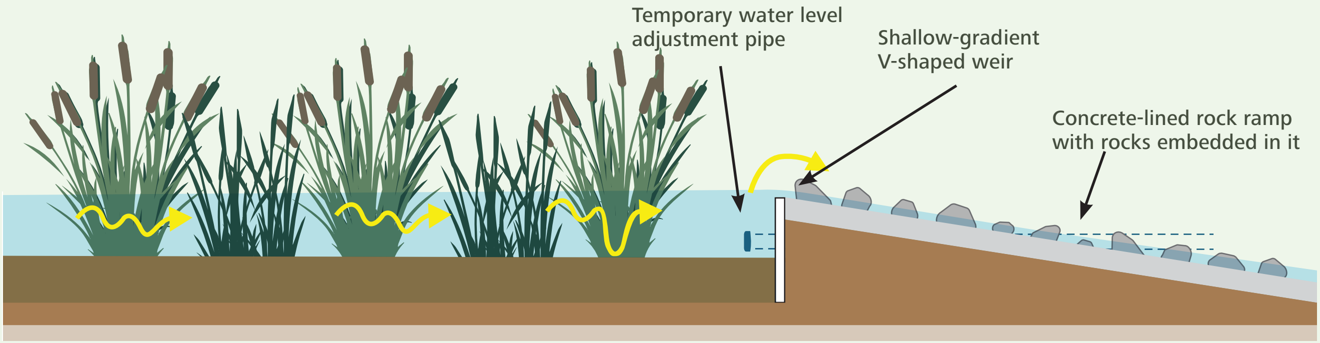


Figure 15. Decision support diagram to help determine whether fish passage is required for inlet and outlet structures of constructed wetlands. *Ephemeral flow paths only flow temporarily after significant rain events (e.g., for 48 hours). **Intermittent flow paths flow seasonally within defined stream banks. ***Fish passage should continue to be maintained under low-flow conditions.



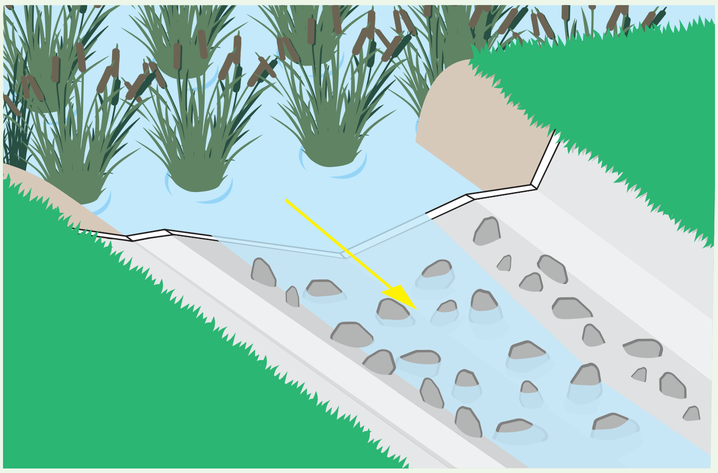


Figure 16. Recommended rock-ramp design to provide fish passage in and out of wetlands and between cells. The water level control weir should be broad, with a shallow V shaped profile (5-10° lateral slope). The rock ramp should have a low gradient (<1:10 for fall heights of ≤1m, <1:15 for heights of 1-4m; and 1:30 for weakly-swimming species such as inanga). Mixed grade rocks (150-200mm diameter) should be securely embedded in the concrete-lined ramp to approximately half their depth to create zones of calmer flow at the margins and a low-flow channel at the centre suitable for the movement of fish. A low level pipe is recommended to enable control of water level during initial plant establishment or wetland maintenance. A swivelling elbow or standpipe can be added to adjust water levels during these periods. This pipe should be capped once the plants are sufficiently grown to cope with deeper water levels (3-4 months).

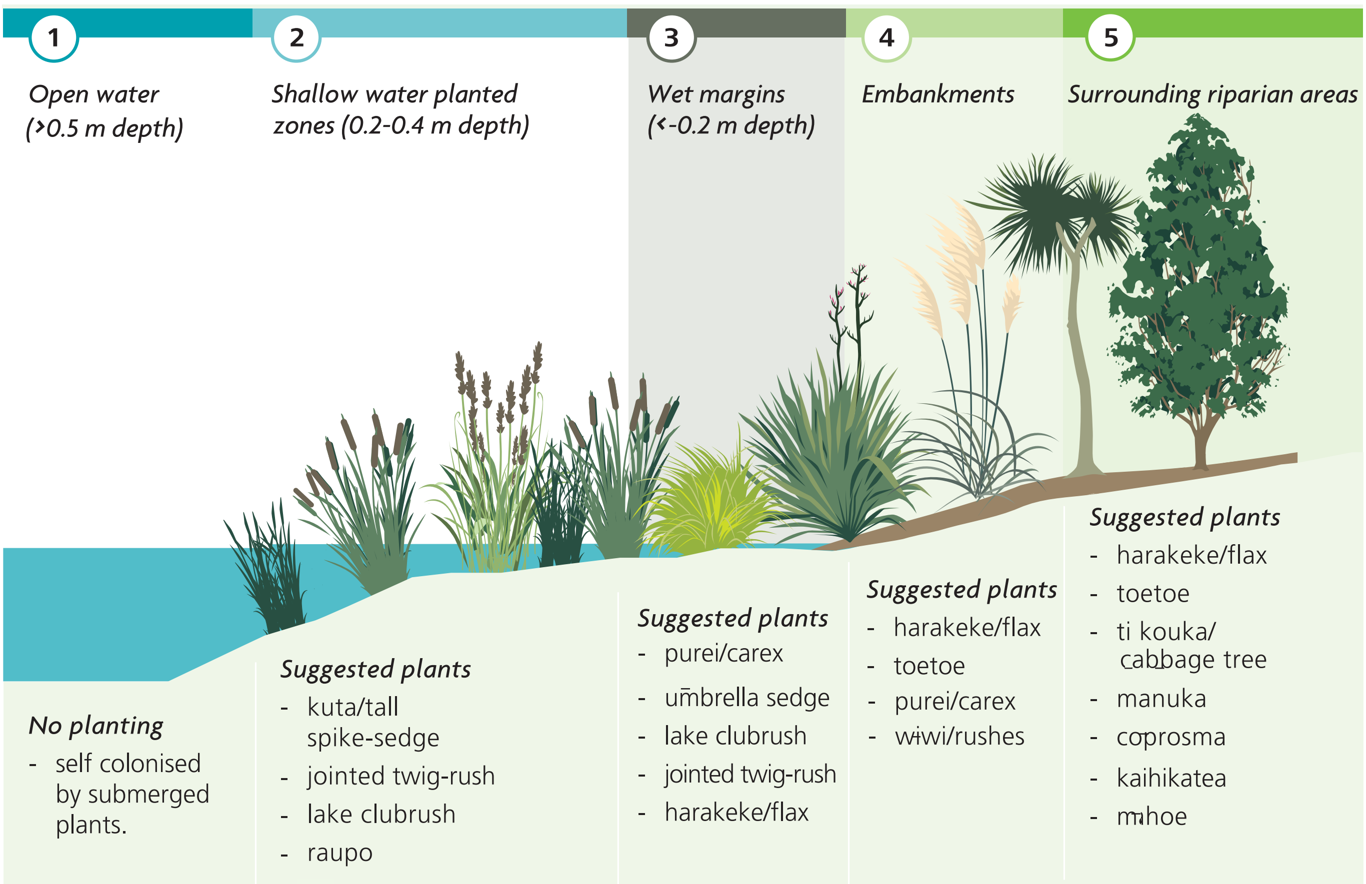


Figure 17. Planting zones and typical plant species.

6. Wetland vegetation

Plants are important in the overall functioning of wetlands, particularly through their support for microbial processes, for example by providing carbon-rich organic matter, and helping disperse flows within wetlands. Plants also promote the settling and filtration of suspended solids and take up nutrients for their growth and oxygenate water and sediments which supports aquatic life.

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, contribute organic matter (carbon) and promote biodiversity (**Figure 17**).

It is recommended that at least 70% of the wetland is shallow water (0.2-0.4m deep) to support dense growths of emergent plants (e.g., sedges and bulrushes). Deep unvegetated open water areas (>0.5m depth) are recommended at the inlet to disperse the flow uniformly through the shallower, densely planted zones.

Plant selection

A range of plant species suitable for treatment wetlands is shown in **Figures 18** and **19**. Native species are preferable. Plant selection should consider the following:

- What grows naturally in shallow water wetlands in the region.
- Likely exposure to frost (some species die back when exposed to frost).
- Hydrological conditions, i.e., whether the wetland is likely to be permanently wet or have periods or sections likely to dry out over summer.
- Range of water depths.

An example of plant selection and their relative contribution in a 0.5ha constructed wetland in the Waikato is show in **Table 2**.

More detailed planting advice is provided in Tanner (2021).

Table 2: Example of plant selection for a constructed wetland in the Waikato. Note: Relative quantities of plants needed for wet margins, embankments and riparian zones will vary with wetland shape and size. A range of additional species will also colonise naturally over time.

Species	Common names	Percentage of constructed wetland area (approx)	Number of plants/ sq m†	No. of plants/ ha constructed wetland
Within the constructed wetland				
Deep open water	No planting	**30%**	0	0
Shallow water (0.2-0.4 m depth)		**60%**		
Schoenoplectus tabernaemontani	kapungawha, lake club-rush	25%	3	7500
Machaerina articulata	mokuāūtoto, joined twig-rush	20%	3	6000
Eleocharis sphacelata (deeper water)	kuta, tall spike-rush	15%	2	3000
Wet margins (0-0.2m depth)		**10%**		
Carex secta (shallow edge)	pūrei/makura, carex	4%	1	400
Cyperus ustulatus	toetoe upokotangata, giant umbrella sedge	4%	2	800
Bolboschoenus fluviatilis	riwaka, marsh clubrush	2%	3	600
Surrounding the constructed wetland				
Embankments*		**6%***		
Phormium tenax	harakeke, flax	4%*	1	400
Carex secta	purei/makura, carex	2%*	1	200
Astroderia toetoe	toetoe	2%*	1	200
Riparian margins*		**12%***		
Phormium tenax	harakeke, flax	10%*	1	1000
Cordyline australis	tī kōuka, cabbage tree	2%*	1	200

* Additional to wetland area at standard water level. † Based on well grown PB1-grade (~600ml pot) plants

Typha orientalis

raupō, bulrush
(planting depth 0-40cm)

Machaerina articulata

mokuāūtoto, jointed twig-bush, baumea
(planting depth 0-40cm)

Eleocharis sphacelata

kuta, tall spike-rush, spike-sedge
(planting depth 20-60cm)

Schoenoplectus tabernaemontani

kāpūngāwhā, kūwāwā, lake club-rush
planting depth 0-40cm

Figure 18. Key native plants in the shallow vegetated zone.

Bolboschoenus fluviatilis and B. medianus, purua grass, kukuraho, ririwaka, river bulrush, marsh clubrush

Carex secta, pūrei, makura

C. germinata, C. lessoniana and C. virgata, rautahi, carex

Austroderia richardii, A. fulvida, A. toetoe, toetoe

(New Zealand native species only, not to be confused with introduced pampas grasses)

Cordyline australis, tī kōuka, cabbage tree

Cyperus ustulatus, toetoe upokotangata, giant umbrella sedge

Phormium tenax, harakeke, New Zealand flax

Avoid invasive introduced species such as *Glyceria maxima,* reed sweetgrass

Figure 19. Plant selection for the wet margins and embankments.

Plant placement and establishment

Planting densities for most wetland species should be between 2 and 4 plants per square metre, or at a spacing of between 0.5m and 0.7m apart. Larger plants such as *Carex secta* and raupō can be planted slightly further apart (approximately 1m). Best establishment and subsequent spread are usually achieved using nursery stock grown from locally eco-sourced seed. Plants with well-developed roots and rhizomes grown up in 0.5-1.8L pots (PB1-3) are recommended. Larger plants are less risky, especially if planting late in the growing season.

Most wetland species, especially those that grow in the permanently wet zones, are best planted in clumps or bands of the same species across the full width of the wetland channel. This is to prevent plant losses due to competition between species and also to encourage vegetative regeneration from the rhizomes of wetland species that can reproduce this way.

Wetland plant establishment should 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, such as pūkeko and Canada geese.

Although most of the wetland species used for treatment wetlands are able to thrive in open water (tolerances range from water depths of 0.2 to 0.5m) seedlings grown in a nursery will not survive being planted directly into open water. Successful establishment of plants into new wetlands requires an ability to control the wetland water level for the first 2 to 3 months following planting. Seedlings are best planted into damp but not waterlogged substrate and then the wetland water level lifted gradually over several weeks to allow the plants to acclimatise.

For shallow flooded zones, planting needs to occur soon after earthworks are completed. Most wetland plants do not grow much during winter and for many species the above-ground portions die back over this period. Ideally planting should take place in spring or early summer (September–December) to promote rapid establishment and to enable growth of a tall dense cover that can outcompete weeds. However, planting at this time is often difficult in practice, where ground conditions remain too wet for construction.

Planting later 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 smaller plants later in the season, or when the availability of supplementary water cannot be guaranteed, is not recommended. Instead, it is better to wait until the following spring to undertake planting.

During establishment, the water level should be maintained at 10-15cm above the wetland soil surface, once plants are established and have acclimatised. Plants can be initially planted into dry topsoil provided enough water can be supplied to cover the topsoil immediately after planting. If inflow to the wetland is insufficient during the initial establishment period, supplementary water may be necessary to avoid desiccation of young plants.

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 like a snorkel, conveying oxygen to the submerged portions of the growing plant. As the plants grow, the water level can gradually be raised. Pre-planting weed and pest control is important – this gets much harder once the wetland is flooded.

Once properly established (generally after two growth seasons), tall-growing wetland species should be sufficiently resilient to water level fluctuations, predation by wildfowl and other stressors.

7. Wetland costing

Construction cost can vary substantially depending on the site characteristics. The main costs are earthworks (cut and fill) to form the wetland channel, plant purchase and planting, and fencing.

Indicative construction and establishment costs per hectare for a treatment wetland are summarised in **Table 3**. Approximate costings are also provided for range of case studies below. This costing assumes that all work is undertaken by professional contractors charging at commercial rates. It also assumes a favourable site (low permeability substrate, no woody vegetation to clear, relatively level ground surface, contours favourable to wetland construction without excessive earthworks, sufficiently deep topsoil that can be re-laid on the excavated wetland base, a simple wetland shape that does not require extra fencing, and the assumption that cattle but not sheep need to be fenced out. This costing also assumes that no resource consent is necessary to construct a wetland but it is important to note that in some regions, a consent may be required, and will carry a cost.

Table 3: Indicative cost per hectare (2020) to establish a new treatment wetland if all work is undertaken by contractors at commercial rates.

Cost item	Indicative cost	$/ha (excl GST)	Notes/Explanation
Site survey and wetland design	Lump sum	$3,000 - $7,000	Survey of wetland site and design, including positioning of inlet and outlet structures, treatment basins and estimate of excavation works.
Earthworks	$6.25/m^2 of wetland surface area for initial site clearance. $15/m^3 for excavation.	$110,000 - $130,000	Includes excavation and re-laying of topsoil to form wetland base for planting, and construction of a suitable weir and outlet structure at downstream end. Excludes provision for fish passage structures.
Fencing	$5 - $10 /linear metre (plus gate)	$1,000 - $5,000	Two or four-wire electric fence on 2 or 4 sides of wetland; assumes optimised wetland shape to minimise fence length.
Plant purchase	$1.80 - $5 /plant	$25,000 - $60,000	2.04 plants per square metre (0.7 m spacings) within the wetland area to be flooded; all plants purchased from commercial nurseries.
Planting	$2 - $3/plant	$28,000 - $43,000	Assumes planting is done by commercial planters.
Replacement planting (blanking)	$1.80 - $5/plant	$2,500 - $5,000	5% mortality assumed; includes plant purchase and planting.
Project /construction management	$1.00/m^2 of wetland	$10,000	Earthworks and planting supervision.
Resource consent	Variable.	Variable.	Dependent on regional council.
Maintenance/weed control	Lump sum	$2,000 - $4000	Per annum. Assumes bi-yearly clean-out of sedimentation pond.
Total construction cost/ ha		175,000 - $260,000	Assumes all work is done by professional contractors at commercial rates. Excludes resource consent costs.

Opportunities to reduce cost

The costs of constructed wetlands can be reduced in a number of ways. Excavation costs can be minimised by locating wetlands in natural depressions that may already exist as natural drainage channels or represent historical wetland areas that have been drained and are not subject to protection as natural wetlands under current legislation. In this situation less earth will need to be moved to create a wetland if part of a natural channel already exists.

The greatest potential to reduce wetland costs lies with planting. Planting costs can be reduced on-farm by using staff, community groups and family to do the planting. Initial supervision and instruction by a professional with wetland planting experience is necessary but otherwise planting can be carried out by people with minimal experience.

Some wetland plant species suitable for wetland margins and riparian zones, especially rushes i.e. *Juncus* may already be present in grazed seepage wetlands or wet farm depressions that don't need excavation. Simply removing grazing pressure while controlling any weed species may be sufficient to enable those remnant plant populations to thrive and expand across the wetland area naturally. Sourcing plants from other parts of the farm can also be considered although it is generally recommended to use high quality plants sourced from nurseries for newly constructed systems, to ensure successful plant establishment. Note that species such as rushes, which grow in wet pastures will generally not survive in water depths >100mm for more than a few weeks.

8. Maintenance

A well-established wetland will have only minor maintenance requirements (**Table 4**), provided that wetland plants establish rapidly and the potential for invasive weed species to enter the wetland and become a nuisance is minimised. Common "weeds" in wetlands include pasture species such as Yorkshire fog (*Holcus lanatus*), mercer grass (*Paspalum distichum*) and wetland weeds such as reed sweetgrass (*Glyceria maxima*). Manual removal or chemical control should be done before the weeds become well established. Herbicides used should only be formulations that are permitted for use in or near waterways. Although both glyphosate and diquat are permitted by the EPA, local regional council rules may also apply and should also be checked before using herbicides. A number of other herbicides can be used with care around wetlands and under dry conditions providing there is low risk of water contamination.

Once wetland vegetation has established, wetland maintenance involves periodic checking of inlets and outlets, and clearance of any blockages; checking structural integrity of any embankments, dams and high-level overflows; weed management around the wetland; and maintenance of gates and fences.

Removal of accumulated sediments from the sedimentation trap/pond will be necessary periodically. The frequency of sediment removal is highly dependent upon the size of the sedimentation pond and the quantity of incoming sediment. Sediment removal should be undertaken when the pond is about half full so it keeps working optimally and does not resuspend sediment during stormflows.

Table 4: Requirements during and after wetland establishment.

Fortnightly action list for first three months	
Plants	Visual inspection of plant health and damage by pūkeko or other birds/animals. Check water level and adjust as appropriate (particularly during dry periods or periods of low inflow). Control weeds in wetlands and surrounds by hand-weeding, careful herbicide application, and/or temporary water level increases.
Inlet	Visually check for adequate inflow and 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 to maintain unrestricted flow and optimal water level.
Embankments	Inspect for weeds, erosion, and damage by pūkeko, rabbits or other birds/animals.
Seasonal action list once established	
Plants	Visual inspection of plant health, weed and pest problems, take remedial action as necessary.
Inlet	Visually check for adequate 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 quantity (is it normal based on recent rainfall levels?).
Embankments	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 but avoid damage to any native plantings.
Sedimentation pond(s)	Check accumulation of sediment. If the pond is more than 1/2 full of sediment, it requires emptying.

9. Constructing effective wetlands to reduce contaminant loss from dairy farms: case study examples from Northland to Southland

The following case studies, located throughout New Zealand, provide examples of constructed wetlands that have been developed to improve water quality and provide wetland habitat. They encompass a range of wetland designs, contaminant reduction performance, and construction costs.

Case Study 1: Titoki

Location:	Maungatapere, Northland	
River catchment:	Mangakahia	
Year constructed:	2000	
Wetland configuration:	On-line two-celled constructed wetland	
Treatment area:	900m^2 (1.6% of catchment)	
Wetland catchment area:	5.65ha, irrigated dairy pasture	
Scope:	The farm is a 1000-cow, 300ha dairy farm. The wetland receives subsurface tile drainage from pastures irrigated with dairy shed wastewater as well as dam water during dry spells. Monitoring in the first 3 years showed a high annual drainage yield of ~ 800mm/yr with annual nitrogen losses 72-109kg/ha. The first cell is deeper, up to 1.3m, with open water areas. The second cell is shallower (0.2-0.4m) and fully vegetated with a mix of native sedges.	
Additional information:	Use of fertile agricultural topsoils in the wetland resulted in dissolved P release relative to low inflowing concentrations from tile drainage. Monitored for 3 annual periods (2001-4) by NIWA.	
Approximate cost*:	$ (Farmers undertook construction and planting themselves)	
Wetland Performance:**	Nitrogen - 18-38% reduction	Phosphorus – variable with overall small-moderate increase
	Sediment – not monitored	Faecal indicator bacteria – small increases during normal flows, but large reduction (>99.99%) recorded during 5 days of accidental inflow from burst effluent irrigation pipe
*** $ < $20,000 $$ $20,000-$80,000 $$$ > $80,000; $$$$> $200,000** ****Average annual proportion of contaminants removed relative to receiving load**		

Two-stage constructed wetland soon after construction and planting (top) and one year later when plants have established (bottom). Arrows show inflow of subsurface tile drainage and its passage through the wetland, finally discharging to the stream behind.

Case study 2: Whangamaire

Location:	Taupiri, Waikato
River catchment:	Tributary of the Mangawara Stream, Waikato
Year constructed:	2019
Wetland configuration:	Four 0.3m deep cells in series, each planted with a single species of wetland plant. The inflow is diverted from a nearby surface drain with excess flows able to pass down the existing drain.
Treatment area:	0.27ha (0.6% of catchment)
Wetland catchment area:	43ha
Scope:	This wetland is situated on the Walker farm and is placed in an area of native trees and shrubs which had previously been retired from grazing. The system was designed as a New Zealand interpretation of the Integrated Constructed Wetland concept developed in Ireland and the UK. The wetland cells are irregularly shaped and sized to fit within previously planted native trees, which resulted in a natural appearance. The design and construction were jointly managed by Manaaki Whenua Landcare Research and NIWA as a demonstration site. Scientific assessment of performance was undertaken over a one-year period. Funding was provided by the Ministry for the Environment's Community Environment Fund, with contributions from landowners, Manaaki Whenua Landcare Research and NIWA.
Additional information:	Initial establishment of plants in two wetland cell was poor. This allowed some growth of algae and floating macrophytes in the open water areas. These areas have now been successfully replanted.
Approximate cost*:	$$
Wetland performance:**	Low intensity monitoring soon after wetland establishment showed phosphorus reduction was >50%. Apparent nitrogen removal was minimal, likely due to minimal build-up of leaf litter, associated with the early stage of development of this wetland and is expected to improve with time.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**	

The serpentine path of the wetland excavated into a boggy area previously planted with harakeke/flax and native trees is shown soon after planting (left) and from the opposite end once wetland vegetation was fully established (right).

Case Study 3: Toenepi

Location:	Kiwitahi, Matamata-Piako, Waikato	
River catchment:	Toenepi Stream, Piako River catchment	
Year constructed:	2000	
Wetland configuration:	In-line two celled, shallow (0.3m deep) elongated wetland cells in series.	
Treatment area:	260m^2 (1.1% of catchment)	
Wetland catchment area:	2.6ha	
Scope:	The wetland is situated on a 130 ha dairy farm. It receives subsurface tile drainage water and is vegetated primarily with raupō (*Typha orientalis*), with harakeke/flax plantings on the embankments. The wetland was designed by NIWA primarily to evaluate nitrate removal performance.	
Additional information:	The first and most studied agricultural constructed wetland in New Zealand, with 6 years of performance monitoring by NIWA (2001-6, 2010/11). Use of fertile agricultural topsoils in the wetland resulted in dissolved P release relative to low inflowing concentrations from tile drainage.	
Approximate cost*:	$$	
Wetland performance:**	Nitrogen - 30% reduction.	Phosphorus – variable with overall small-moderate increase.
	Sediment - not measured.	Faecal indicator bacteria - overall small-moderate increase.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**		
****Average annual proportion of contaminants removed relative to receiving load**		

Two-celled linear wetland soon after construction (left) and once plantings established (right). Flows from subsurface tile drains enter in the foreground and exit at the far end to a open farm drain. The wetland was built along the edge of the paddock so it was out of the way of farming operations and easy to fence off.

Case Study 4: Owl Farm

Location:	St Peters School Farm, Cambridge, Waikato	
River catchment:	Waikato	
Year constructed:	2016	
Wetland configuration:	In-line multi-celled, linear configuration	
Treatment area:	0.34ha (4.5% of catchment)	
Wetland catchment area:	7.6ha, predominantly dairy	
Scope:	A 160ha, 400 dairy cow demonstration farm, joint venture between St Peter's School and Lincoln University. The wetland receives approximately equal inputs of diffuse groundwater and tile drained groundwater and is vegetated with a mix of native sedges, with self-established raupō in patches. It was designed and constructed by Opus Consultants, with funding for construction from the Waikato River Authority and Waikato Regional Council, and in-kind support from The Livestock Improvement Corporation, PGG Wrightson Seeds, DairyNZ, Ballance Agri-nutrients, Fonterra Farm Source, Lincoln Agritech and Westpac Bank.	
Additional information:	Extensive riparian planting and fencing around the wetland. Monitored for 4 years (2008-12) by NIWA. Wetland visited and performance reported as part of focus days for farmers and rural professionals and at open-days for the public. The school uses the area as part of its education programme.	
Approximate cost*:	$$	
Wetland performance:**	Nitrogen - 50% reduction.	Phosphorus - 15% reduction.
	Sediment - 45% reduction.	Faecal indicator bacteria - increase due to resident wildlife in wetland.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**		
****Average annual proportion of contaminants removed relative to receiving load**		

Wetland receiving tile drainage and shallow groundwater seepage in the foreground before flowing though a series of cells to a surface drain leading to the Waikato River just over the hill.

Case Study 5: Baldwins

Location:	Lichfield, South Waikato	
River catchment:	Ngutuwera Stream, Pokaiwhenua/Karapiro catchment	
Year constructed:	2015	
Wetland configuration:	On-line multi-celled with initial sediment pond and seven wide, shallow (0.3 to 0.5m deep) interconnected basins.	
Treatment area:	0.642ha (1.2% of catchment). Total area of 1.1 ha including final cell of wetland (not monitored) and riparian plantings.	
Wetland catchment area:	52ha	
Scope:	Design, construction and scientific assessment of a 0.5ha constructed wetland on a 267ha dairy farm. Part of a 5-year research project to provide greater knowledge on wetland design, performance, and practicality to Waikato dairy farmers. Led by DairyNZ and undertaken in partnership with Baldwin Family Trust, the Waikato River Authority, Opus International Consultants (Hamilton), Waikato Regional Council, Hill Laboratories, and NIWA. Project included extensive monitoring of water flows and contaminant concentrations to determine wetland performance over several seasons. Protection, restoration, and scientific monitoring of three adjacent shallow groundwater seepage wetlands was also undertaken.	
Additional information:		
Approximate cost*:	$$$	
Wetland performance:**	Nitrogen - 60% reduction	Phosphorus - 20% reduction
	Sediment - 70% reduction	Faecal indicator bacteria - 80% reduction
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K** ****Average annual proportion of contaminants removed relative to receiving load for 0.642 ha proportion of wetland area monitored**		

Site before (left) and after (right) wetland construction in a low-lying valley. A sedimentation pond at the far inlet end is an important component sustaining the longer-term operation of this wetland. Arrows indicate direction of water movement through the wetland.

Case Study 6: Okaro

Location:	Lake Okaro, Te Arawa Lakes, Rotorua, Bay of Plenty	
River catchment:	Small un-named stream - the main surface inflow to Lake Okaro	
Year constructed:	2006/2007	
Wetland configuration:	Two-celled off-line constructed wetland	
Treatment area:	2.3ha (0.7% of catchment)	
Wetland catchment area:	359ha. Predominantly dairy, with beef and sheep grazing in headwaters.	
Scope:	The Birchall family provided 2ha of their farm and the Rotorua Lakes Council 0.3ha of lake-side reserve land for construction of the wetland. The wetland receives surface waters from a channelised stream. The stream is diverted into the wetland via a timber weir, which allows for bypassing of excess stormflows via the old stream channel. Earthen bunds are used to create a long serpentine path through the wetland. Construction and planting of the wetland was managed by NIWA and Opus Consultants, with funding from the Bay of Plenty Regional Council, as part of the Te Arawa Restoration Program. The wetland was planted throughout with a mix of native sedges, and the riparian zones with native plants such as harakeke/flax and toetoe, tī kōuka/cabbage tree and mānuka.	
Additional information:	The performance of the wetland was monitored for 3 years (2008-10) by NIWA with funding from BoPRC and the Pastoral 21 consortium. The catchment is rolling to steep with Rotomahana mud soils. A detainment bund has been recently constructed in the upper catchment to buffer stormflows and associated export of sediment and particulate phosphorus.	
Approximate cost*:	$$$$	
Wetland performance:**	Nitrogen – 12-41% reduction (77-80% of nitrate-N)	Phosphorus – 12-60% reduction
	Sediment – 71-88% reduction	Faecal indicator bacteria – 89-96% reduction
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K** ****Average annual proportion of contaminants removed relative to receiving load**		

Well established wetland at Okaro receiving diverted stream-flows showing native wetland and riparian plantings. Note the farmers house situated alongside the wetland.

Case study 7: Awatuna

Location:	Awatuna, South Taranaki
River catchment:	Unnamed tributary of Oeo Stream, Taranaki
Year constructed:	2019
Wetland configuration:	In-line, multi-celled, with an initial 1.5m deep sediment pond followed by three elongated, shallow (0.3-0.6m deep), densely vegetated cells in series. No high flow bypass constructed, since the wetland is in-line and occupies a widened section of an agricultural drainage ditch, with predominant inflows from subsurface drainage. The system has been planted with a mix of native sedges.
Treatment area:	0.44ha (2.2% of catchment)
Wetland catchment area:	18ha predominantly dairy
Scope:	Taranaki Regional Council, NIWA, and the Cram family initiated the construction of this wetland as a regional demonstration site in 2019. The Cram family agreed to retiring some marginally productive pasture, fencing the wetland, and maintaining long-term weed control in the wetland. Scientific assessment of nutrient, sediment, and *E. coli* load reductions have been initiated as part of a 4-year NIWA-led, MPI-funded Sustainable Land Management and Climate Change Freshwater Mitigation Fund Project, with in-kind funding from Taranaki Regional Council's Wetland Consent Fund and support from DairyNZ and Beef + Lamb NZ.
Additional information:	Taranaki Regional Council conducts a semi-annual biodiversity survey of the flora and fauna in the constructed wetland. The landowners maintain rat and stoat traps around the wetland for mammalian pest control.
Approximate cost*:	$$
Wetland performance:**	Monitoring in progress.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**	


Newly constructed and planted wetland (left) showing direction of flow through initial deep sedimentation pond and subsequent two shallow elongated cells. Plant cover after one year shown on the right.

Case study 8: Ashley Clinton

Location:	Southern Hawke's Bay
River catchment:	Unnamed tributary of Avoca Stream, Tukipo subcatchment of the Tukituki River
Year constructed:	2021
Wetland configuration:	Off-line, five interconnected cells, with initial sedimentation pond (>1.5m deep). Shallow planted zone 0.3-0.6m deep occupying 50-60% of wetland, with deep open-water zones at the inlets and outlets of each cell to disperse inflows and re-collect outflows before passage to the next cell. A high flow bypass channel routes storm flows around the wetland to the main waterway downstream of the wetland outlet. The final cell was left primarily as a shallow, densely planted zone 0.3m deep.
Treatment area:	1.6 ha (0.9% of catchment)
Wetland catchment area:	180ha dry-stock farm
Scope:	Design and construction funded by Hawke's Bay Regional Council and Fonterra in partnership with NIWA. The White family agreed to retiring some marginally productive pasture where the wetland was built, fencing the wetland and adjoining native forest patch, and maintaining long-term weed control in the wetland. Scientific assessment of nutrient, sediment, and *E. coli* load reductions have been initiated as part of a 4-year NIWA-led, MPI-funded Sustainable Land Management and Climate Change Freshwater Mitigation Fund Project, with in-kind funding from HBRC and support from DairyNZ and Beef + Lamb NZ.
Additional information:	The wetland location was identified by NZ Landcare Trust through a regional constructed wetland scoping initiative supported by Hawke's Bay Regional Council. A 7.5ha patch of remnant native forest (predominantly totara) is located adjacent to the wetland and will be fenced and placed under QEII Trust protection. A wetland of this size is expected to provide habitat for bittern, and the adjacent large trees in the forest patch might be suitable for bat roosts. At the request of the landowner, several of the open water areas were built large enough to be attractive for duck hunting.
Approximate cost*:	$$$
Wetland performance:**	Monitoring in progress.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**	

Establishing wetland plantings after six months growth. Arrows show flow path through the wetland cells. Flow enters in the top right from a stream that flows through the patch of native forest and from upwelling shallow groundwater. The dotted line shows high- level flow bypass channel.

Case study 9: Kaiwaiwai

Location:	Kaiwaiwai Dairies Ltd, Southern Wairarapa	
River catchment:	Otukura Stream/Lake Wairarapa	
Year constructed:	2014	
Wetland configuration:	Off-line, multi-celled: an area of wet pasture land (0.75ha) converted to wetland with a surface area of approximately 0.5ha and an average water depth of 0.3m. Comprising three multi-hairpin cells (6m wide) connected in series, providing a serpentine flow path.	
Treatment area:	~0.5ha	
Wetland catchment area	Unknown. Estimated at approximately 630ha, but wetland only receives a portion of total flow.	
Scope:	A wetland planted with native species was constructed at Kaiwaiwai Dairies Ltd (405ha dairy farm) on an area of wet pasture land adjacent to a remnant stand of kahikatea and tōtara trees. Water from a perennial drain (est. normal flow ~60L/s) is diverted through the wetland at a constant flow rate of 14L/s. The area is fenced to exclude livestock. Aquatic planting includes raupō (*Typha orientalis*), Lake clubrush (*Schoenoplectus tabernaemontani*) and a cutty grass (*Carex geminata*). Project led by Groundtruth Ltd, and administered by Sustainable Wairarapa, with shared funding from the Ministry of Primary Industry, DairyNZ, NIWA, Greater Wellington and Landcorp. In 2016 Sustainable Wairarapa were awarded a Sustainable Farming Fund project to continue monitoring to measure effectiveness of the wetland. This included monthly monitoring of water flows and contaminant concentrations to determine seasonal wetland performance.	
Additional information:	This wetland differs in its design from that recommended in the present guide. Its objectives were to improve water quality and biodiversity. The highly serpentine design with multiple bunds was employed to minimise double handling of excavated earth when constructing the wetland, and to provide a high proportion of land-water edge habitat for wildlife. It provides a very long path length, but around a third of the area is taken up by embankments reducing the effective treatment area.	
Approximate cost*:	$$	
Wetland performance:**	Total Nitrogen: 38% removal Nitrate: 56% removal	Total Phosphorus: 21% export Dissolved Reactive Phosphorus: 24% export
	Total suspended solids: 6% reduction	Faecal indicator bacteria – not analysed
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K** ***Average annual proportion of contaminants removed relative to receiving load (computed from monthly load removal rates)**		

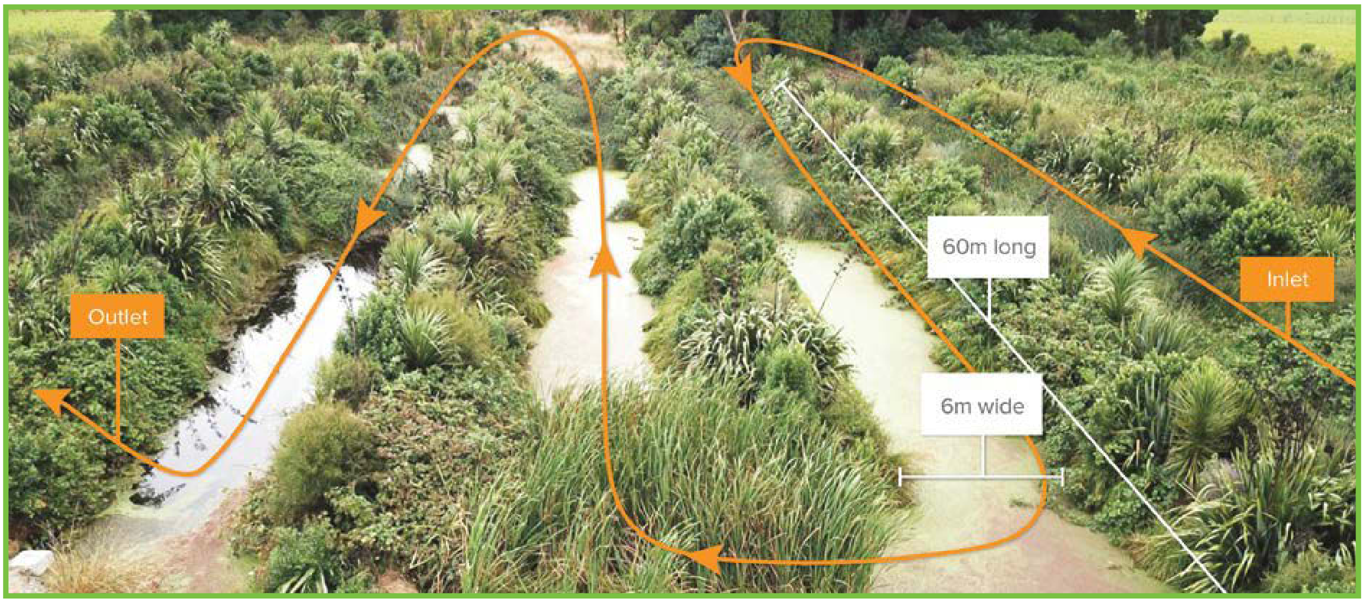


Photo shows serpentine flow-path though one section of the wetland. Shallower water depths would likely provide improved plant establishment and cover. Graphic courtesy of John-Paul Pratt (Groundtruth Ltd) and Neville Fisher (Kaiwaiwai Dairies).

Case study 10: Fish Creek

Location:	Takaka, Golden Bay
River catchment:	Unnamed tributary of Fish Creek, Golden Bay
Year constructed:	2020
Wetland configuration:	In-line, four interconnected cells, with initial sedimentation pond (>1.5m deep). Shallow planted zone 0.3-0.6m deep occupies 70% of wetland with deep open-water zones at the inlets and outlets of each cell to disperse inflows (except for the final cell). An in-line high-flow bypass armoured with boulders and cobble is constructed between each cell to convey high storm flows through the wetland, since the catchment has very clayey soils and is subject to frequent periods of heavy rainfall (>2000mm annual rainfall). The system has been planted with a mix of native sedges.
Treatment area:	0.3ha (1% of catchment)
Wetland catchment area:	30ha predominantly dairy
Scope:	Design and construction funded by Tasman District Council (TDC) in partnership with NIWA. The Page family provided the land in an unproductive gully and agreed to fence the wetland and maintain long-term weed control. Scientific assessment of nutrient, sediment, and *E. coli* load reductions have been initiated as part of a 4-year NIWA-led, MPI-funded Sustainable Land Management and Climate Change Freshwater Mitigation Fund Project, with in-kind funding from TDC and support from DairyNZ and Beef + Lamb.
Additional information:	Focus on solar disinfection of faecal microbes to protect water quality of Waikoropūpū Springs during storm-flows, so wetland has ~40% deep, open water areas.
Approximate cost*:	$$$
Wetland performance:**	Low intensity monitoring soon after wetland establishment showed phosphorus reduction was >50%. Apparent nitrogen removal was minimal, likely due to minimal build-up of leaf litter, associated with the early stage of development of this wetland and is expected to improve with time.
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K**	

Stepped series of wetland cells constructed in a natural gully viewed from the inlet (left) and outlet (right) ends. Wetland plantings are still establishing.

Case study 11: Warnock's

Location:	Warnock's Farm	
River catchment:	Waituna Lagoon, Southland	
Year constructed:	2015	
Wetland configuration:	In-line, open water constructed wetland positioned down-stream of a pre-existing duckpond	
Treatment area:	0.22ha. wetland (0.65% of catchment) below 0.42ha pond (total system 1.9% of catchment)	
Wetland catchment area:	34ha	
Scope:	Open wetland intercepting flow from a permanently flowing first-order stream on a 424ha dairy run-off farm in Waituna catchment, Southland. Built in 2015 based on guidance from NIWA, DairyNZ and Environment Southland, and planted with native emergent plants (tall spike rush/kuta, (*Eleocharis sphacelata*). Wetland intercepts discharge from a pre-existing duckpond. Performance monitored monthly (10 samples collected at 5 locations through treatment system, over years 2017, 2018). Parameters monitored: nitrate, total-N, ammonium, DRP, total-P, TSS, turbidity, DO, electrical conductivity, *E. coli*, temperature, turbidity, water clarity & flow. Nitrate comprised ~30% of total-N load. Median concentration 0.62mg NO^3-N/L). Average concentration 1.08 mg NO^3-N/L. Flows ranged <2 to 70L/s (median 2 L/s); HLR in wetland ranged 29-10^3 m/yr (median 29m/yr).	
Additional design features:	Duckpond up-stream of wetland which functions as a sediment pond. Two experimental filter beds, one filled with limestone and the other with oyster shells, were constructed to further reduce phosphorus concentrations in the outflow. The additional P reduction measured was marginal.	
Approximate cost*:	$$ (excluding filter beds).	
Wetland performance:**	**Nitrogen :** Nitrate-N: Duckpond = 28% reduction. Wetland = 32% reduction. Collectively = 51% reduction. Total-N: Duckpond = 28% increase due to groundwater inflows. Wetland = 42% reduction. Collectively = 26% reduction.	**Phosphorus :** Dissolved reactive phosphorus (DRP): Duckpond = 33% reduction Wetland = 89% reduction Collectively = 92% reduction Total phosphorus: Duckpond = 44% reduction Wetland = 71% reduction
	Sediment (total suspended solids): Duckpond = 90% reduction TSS loads into wetland too low to detect change	*E. coli*: Duckpond = 73% reduction Wetland = 81% reduction Collectively = 95% reduction
*** $ < $20K $$ $20-$80K; $$$ $80-200K; $$$$> $200K **Average annual proportion of contaminants removed relative to receiving load**		

Wetland viewed from the inlet showing emergent beds of kuta and island in the background. Greater plant coverage particularly on the margins would improve the performance of this wetland.

10. References:

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11. Further resources

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12. Useful Websites

Department of Conservation: https://www.doc.govt.nz/nature/habitats/wetlands/ ; https://www.wetlandtrust.org.nz/

Fish and Game New Zealand: https://fishandgame.org.nz/environment/protecting-nz-game-bird-habitats/wetlands/

New Zealand Landcare Trust: https://www.landcare.org.nz/

New Zealand National Wetland Trust: https://www.wetlandtrust.org.nz/

New Zealand Fish Passage Guidelines: https://niwa.co.nz/freshwater-and-estuaries/research-projects/new-zealand-fish-passage-guidelines

Appendix 1: Construction timeline

	Planning Period	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Plan wetland - identify appropriate site, delineate catchment, determine appropriate wetland size and associated contaminant reductions, determine appropriate design configuration, get quotes for construction and planting.	■															
Check regulations with local Council. Discuss proposed design. Supply required information and apply for consent if required.	■															
Determine construction requirements and book contractor/machinery hire and any engineering oversight required.	■															
Pre-order plants.		■	■													
Construct wetland.				■												
Plant embankments.*					■	■	■									
Plant wetland.					■	■	■									
Control weeds, pre- and post-planting and manage pests. Irrigate plants if required.							■	■	■		■		■		■	
Check and maintain wetland inlets and outlets (water levels), embankments, sedimentation pond							■	■	■		■		■		■	

* Planting is optimal in spring and early summer, but construction generally has to occur in summer, requiring planting in late summer and early autumn, or in the following spring.

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