Constructed wetlands to reduce contaminant loss from pastoral farms

Key design guidelines and performance estimates.

The following summary is drawn from the NIWA guidelines provided in Tanner et al. (2020) and a companion review of available New Zealand and international performance data (Woodward et al. 2020).

Design guidelines

Flows of diffuse agricultural run-off are highly variable from day-to-day, season-to-season and year-to-year, and wetland treatment performance will vary according to the distribution, intensity and duration of rainfall and how this interacts with soils, slopes and vegetation across landscapes.

To function effectively, wetlands intercepting agricultural runoff and drainage flows normally need to comprise **between 1-5% of their contributing catchment** (i.e. 100 - 500 m2 of wetland per hectare). The performance of constructed wetlands depends to a large extent on the residence time of water within them, so larger relative wetland areas will show higher contaminant removal. Graphs of estimated long-term median annual performance in relation to relative wetland size, and expected range of variability, are provided for sediment, nitrogen and phosphorus. The basis for their derivation is detailed in the companion review (Woodward et al. 2020).

Contaminant removal performance is also 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).**

Constructed wetlands can either be constructed directly in an existing flow path (e.g. by modifying open drains to convert them into wetlands), or alongside the flow path (e.g. placed adjacent to a stream or river). **An off-line wetland provides additional benefits** as it can be engineered to accept the majority of flow during normal flow conditions, while allowing a larger proportion of the water to bypass the wetland during higher flow periods, passing along the existing stream channel. This approach provides more consistent flows to the wetland, allows partial fish passage along the existing stream channel, and minimises damage to the wetland during flood flows.

The three key components of constructed wetlands: **1) sedimentation ponds, 2) shallow vegetated and 3) deep open water zones**, need to be integrated into a treatment train.

Surface runoff tends to contain more particulate matter, whereas subsurface flows generally contain more dissolved nutrients (e.g. N and P). Larger particles will settle more quickly than smaller particles like fine silts and clays. Removal of dissolved contaminants usually requires chemical or biological processes like binding to minerals or organic matter, microbial transformation or uptake by plants. These processes take longer and are dependent on temperature, so performance will vary seasonally and for different climatic regions. They are also influenced by factors like pH, and oxygen and carbon availability.

Including a **sedimentation pond** as the first stage of a wetland complex helps capture the coarse sediment fractions. Accumulated sediment will need to be be mechanically removed from the sedimentation pond periodically. General principles for construction of a sedimentation pond are based on the MAF coarse sediment trap guidelines (Hudson 2002). Sizing of sedimentation ponds depends on peak flows that the pond is likely to experience during a storm event and is further detailed in Appendix A of the NIWA guidelines (Tanner et al. 2020).

Plants are very 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. It is recommended that **70% of the wetland is shallow water** (0.2-0.4 m deep) to support dense growths of emergent plants (e.g. sedges and bulrushes). The rich carbon supply from decomposing plant litter, and high surface area for growth of biofilms in these planted zones promotes nitrogen removal by conversion of nitrate to nitrogen gases (i.e. denitrification) which is supplemented by plant uptake during the growing season.

Having some **deep open water areas** (0.50-0.75 m) at the inlets and at intermediate stages within the wetland (~30% total coverage) can help settle sediment, slow the flow, and disperse it evenly through shallower, densely planted zones. These open water zones can provide habitat for waterfowl and increase wetland biodiversity. However, because feeding activities can disturb bottom sediments and generate faecal contamination, open water zones should not be located near the final outlet of the wetland.

Phosphorus can be removed in deposited sediments, by adsorption to sediments and organic matter, and through uptake by algae and plants. However, when the algae die or plant leaves fall and degrade in the wetland, a proportion can be released again. This means that as wetlands mature, net uptake of P by plants drops off and most of the P removal occurs through retention of particles. For this reason, it is important to **periodically remove the sediments** that accumulate in the deep water zones of the wetland, primarily in the sedimentation pond, to ensure P isn't remobilised during high flows or through decomposition and release of soluble P.

A well-functioning wetland will have:

- Low sediment accumulation rates in the main vegetated wetland
- Well-established, flourishing and evenly distributed wetland plants
- Evenly distributed flow, with no signs of channelization or short-circuiting
- Appropriate water levels for plant survival and treatment function
- Minimal invasion by weedy plants
- Well-maintained embankments and margins – negligible erosion/bank collapse, low incidence of weeds, fencing to exclude livestock.
- Outflow water is generally clear, with low odour.

Constructed wetland design basics

Size	1-5% of contributing catchment area - larger areas provide greater contaminant reduction
Wetland type	Surface-flow, also known as free-water surface constructed wetland
Shape	Elongated or multi-stage systems with inlet and outlet at opposite ends and overall length:width ratio 5:1-10:1 (minimum 3:1).
Wetland components	
Initial deep sedimentation pond (≥1.5 m depth).	Wherever there is potential for sediment transport into the wetland. Size according to expected peak flows, based on local rainfall intensity. Clean out accumulated sediment periodically to maintain at least half depth.
Shallow (average 0.3 m depth) densely vegetated zone.	~70% of wetland area, including the final 20% of wetland closest to the outlet.
Deep (>0.5 m) open water zones aligned transversely across the wetland.	~30% of wetland area including inlet dispersion zone and intermittently within the wetland, excluding the final 20% of the wetland area.
Planting	
Shallow zones	≥70% cover of native wetland sedges and bulrushes. Plant in spring, early summer at 3-4 plants/m2.
Embankments	Hardy riparian plants. Plant in winter, early spring at ~1-2 plants/m2
Protection	Control weeds mechanically or with an approved herbicide before planting. Protect new plantings from grazing by pukeko and Canada geese. Fence to exclude livestock.

Performance estimates

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. These estimates were further refined to generate conservative guidelines of long-term performance for appropriately designed, constructed, vegetated and maintained constructed wetlands.

These performance estimates are relevant to small-scale, edge-of-field and sub-catchment situations; discharge from streams of first-order or less, involving water-ways generally smaller than one metre wide and 30 cm deep at base-flow which receive flow from catchments no larger than about 50 ha in extent. They assume normal New Zealand pastoral farming conditions and management practices on flat to rolling landscapes only (average slopes of 15 degrees or less)[1], and to annual rainfall of 800-1600 mm. They do not apply to areas with highly permeable soils where groundwater is the dominant flow pathway[2]. Some additional limitations are noted below for specific contaminants and flow pathways.

Performance estimates for sediment

Figure 1 shows the expected long-term performance estimates for removal of suspended sediments by a constructed wetland built according to the above recommendations. The solid line defines the 'most likely' performance of well-constructed and maintained wetlands of different sizes. Wetlands occupying 1% and 5% of the catchment area should, typically remove between 50% and 90% respectively of the long-term sediment input. The shaded areas show the potential inter-annual and inter-site range of performance expected.

Sediments which might be transported in surface drains or overland flows (e.g. off raceways) will comprise a range of size fractions from fine clays, to sands to larger aggregates of soil and potentially clumps of dung. High intensity rain events will transport larger particles, while low intensity events will only 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.

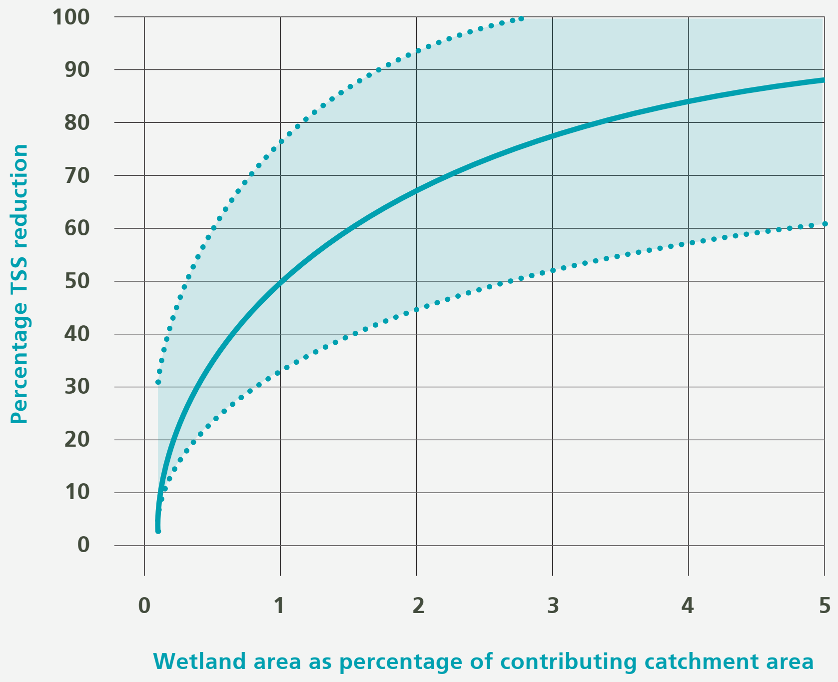

Figure 1: Long-term median annual performance expectations for reduction of Total Suspended Solids (TSS). Performance is for appropriately constructed wetlands receiving surface run-off and drainage from pastoral farmland in New Zealand. Not applicable to areas with clay soils (≥35% clay content) or catchment rainfall outside NZ norms as noted in the text. 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 generally decreases as temperature decreases. Different performance estimates are therefore provided for warmer (median annual air temperatures ≥12°C) and cooler regions (median annual air temperature 8 - 12°C) of New Zealand). Median annual temperatures for New Zealand (1981-2010) are provided in Tanner et al. (2020) for guidance.

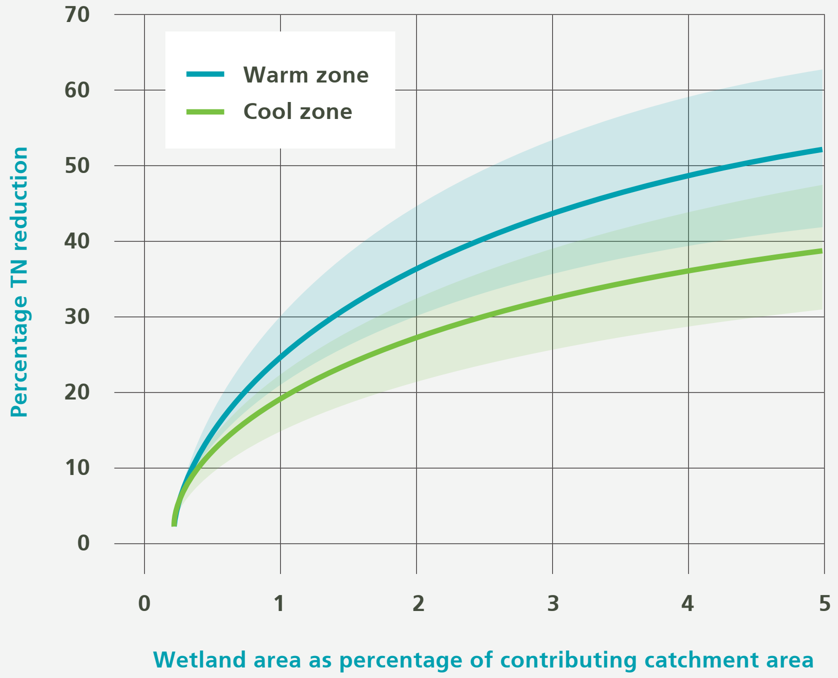

Figure 2: Long-term median annual Total Nitrogen (TN) reduction performance expectations. Performance is for appropriately constructed wetlands receiving surface run-off and drainage from pastoral farmland for warm (median annual temperature >12°C) and cool (median annual temperature 8-12°C) climatic zones in New Zealand and with catchment rainfall within NZ norms. 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 are applicable to constructed wetlands receiving surface run-off and drainage flows where P is predominantly associated with particulates only (sediments), and in catchments not dominated by clay soils (i.e. < 35% clay content). Phosphorus mobilised in subsurface drainage is mainly in dissolved forms and its removal is not covered by these guidelines. Some studies have shown the potential for dissolved P release from within a constructed wetland when P-rich agricultural soils are used as growth media for the wetland plants; therefore soils with low potential for P release should be selected for use in the wetland.

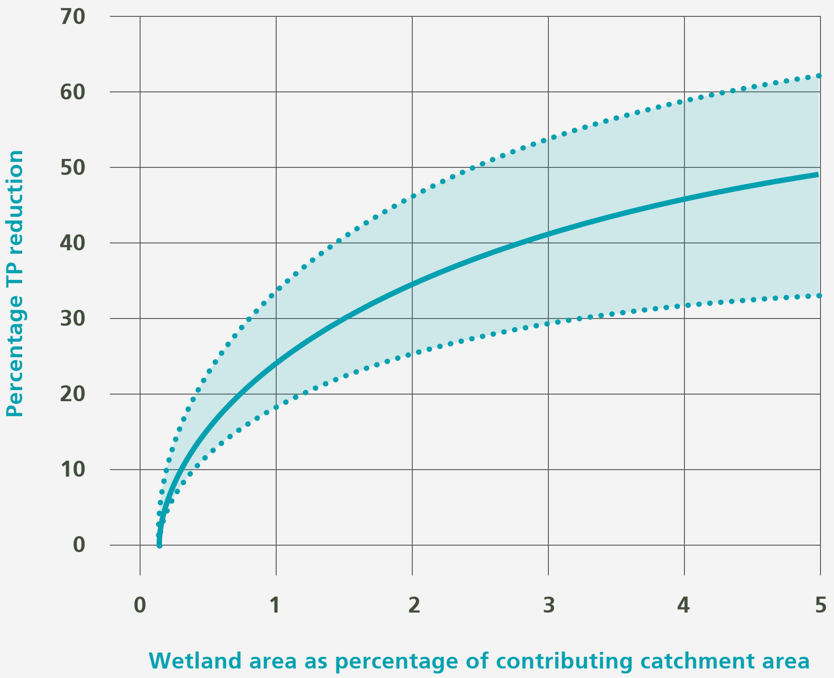

Figure 3: Long-term median annual Total Phosphorus (TP) reduction performance expectations. Performance is for appropriately constructed wetlands receiving surface run-off and drainage from pastoral farmland in New Zealand with catchment rainfall within NZ norms. Solid line shows expected median; shaded area shows inter-annual and inter-site range of performance expected. These predictions do not apply for constructed wetlands whose main source is subsurface drainage containing predominantly dissolved forms of phosphorus.

References:

Hudson, H.R. (2002) Development of an in-channel coarse sediment trap best management practice. Environmental Management Associates Limited, Report FRM500. Prepared for Ministry of Agriculture and Forestry.

Tanner, C.C., Sukias, J.P.S. and Woodward, B. (2020) Provisional guidelines for constructed wetland treatment of pastoral farm run-off. NIWA Client Report to DairyNZ, January 2020.

Woodward, B., Tanner, C.C., McKergow, L., Sukias, J.P.S. and Matheson, F.E. (2020) Diffuse-source agricultural sediment and nutrient attenuation by constructed wetlands: A systematic literature review to support development of guidelines. NIWA Client Report to DairyNZ, January 2020.