Assessment of potential constructed wetland sites within the Waituna Catchment

Prepared for Environment Southland and DairyNZ

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Executive summary

- NIWA was contracted by Environment Southland and DairyNZ to:
  - undertake an analysis exercise to identify the most appropriate locations and types of constructed wetlands that could be implemented in the Waituna catchment to intercept nutrients and sediments, and
  - provide cost estimates using a common measurement unit, and recommendations on wetland locations, size, and type to optimise environmental improvement for the funding available.
- Thirty different constructed wetland options at 14 different sites were investigated across the Waituna catchment.
- The Waituna Creek catchment has the highest yield of TSS and TN, and offers the greatest range of potentially viable opportunities for wetland construction, ranging from large main-channel wetlands in the centre of the catchment approaching 50 ha down to small wetlands in the contributing catchment of 600 m^2.
- Opportunities were less common at the bottom of the catchment where the low gradient would necessitate large-scale excavation for wetland construction and there was high potential to impact on water tables and drainage efficiency in adjacent areas.
- Constructed wetlands occupying 0.5% or less of the contributing catchment could substantially reduce annual TSS loads. To reduce annual TN and TP loads by 30% more than 2% and ~2.5%, respectively, of the catchment would need to be converted to wetland. To reduce annual TN and TP loads by 50%, wetlands would need to occupy ~ 5% of the contributing catchment.
- Estimated wetland construction costs for the sites investigated ranged from ~$2K to $3.35M depending on size and site characteristics. Annualised costs per kg of contaminant were calculated to provide a common unit to compare the cost benefit of different options.
- Different wetland sites and options were ranked for each contaminant and across all three priority contaminants. Because of diminishing returns per unit area as wetland size increases, smaller wetlands removing a small fraction of the load will generally show the lowest cost per kilogram of contaminant removed. This means that prioritisation of sites needs to be done in relation to an agreed wetland contaminant removal target.
- Other factors will also need to be considered in prioritising sites for demonstration purposes, including: practical feasibility, total construction costs relative to available funds, land value, representativeness, accessibility, and land-owner amenability and cooperation.

1 Introduction

Waituna Lagoon, the focal point of the internationally recognised Awarua wetland complex on the Southern Coast of the South Island, became New Zealand's first designated Ramsar site in 1976. It is considered to be one of the best remaining examples of a natural coastal lagoon in New Zealand and is highly valued by Ngai Tahu, fisherman, hunters, naturalists and local landowners.

Increasing agricultural development and intensification in the Waituna catchment has been implicated in the declining water quality and environmental health of the lagoon. Environmental monitoring shows that since 1995 nutrient levels in the lagoon and the streams that flow into it have increased significantly and substantial sediment accumulation has occurred within the lagoon (Environment Southland 2012). Of particular recent concern are elevated levels of phytoplankton and benthic slime algae, persistent sediment anoxia and declining abundance of the macrophyte beds (*Ruppia* spp.) which stabilise the bottom sediments. These changes suggest the lagoon is at risk of "flipping" from a clear water macrophyte-dominated state to a turbid algal-dominated state. Environment Southland, which is part of a multi-agency response to improve the health of the lagoon, is therefore looking at management actions to reduce sediment and nutrient inputs to the lagoon.

2 Study Brief

NIWA was contracted by Environment Southland (ES) and DairyNZ to:

- Undertake an analysis exercise to identify the most appropriate locations and types of constructed wetlands that could be implemented in the Waituna catchment to intercept nutrients and sediments.
- Provide cost estimates using a common measurement unit, and recommendations on wetland locations, size, and type to optimise environmental improvement for the funding available.

3 Waituna Catchment

The Waituna Lagoon is located on the south coast of the South Island, approximately 25 kilometres southeast of Invercargill. The Waituna Catchment comprises three subcatchments drained by the Waituna (~104 km^2), Moffat (~17 km^2) and Carran (~29 km^2) Creeks (Figure 3-1). The main channels of these streams have been substantially straightened and deepened, and are maintained primarily as drainage channels with regular mechanical clearance. An extensive network of farm drains (both open and sub-surface) make up the broader drainage network. This network transports water, sediment, nutrients and other material from the land within the catchment to the lagoon. A lesser quantity of groundwater also enters the lagoon via subsurface pathways (estimated to be <10% of inflow). This may also transport dissolved forms of nutrients into the lagoon.

The brown soils found in the upper Waituna Creek catchment are intensively drained to promote pasture productivity and enable grazing by dairy cattle . This area of the catchment has gently rolling relief that reaches a maximum of ~70m above mean sea level (MSL). In contrast the southern part of the Waituna Creek catchment and the adjacent Moffat and Carran Creeks are dominated by poorly drained organic soils and the relief is principally flat to gently rolling.

By New Zealand standards, specific yields of both sediment and nutrients appear to be low (Table 3-1). This may be in part due to regular water quality sampling missing high-flow events that transport proportionally large loads of contaminants. Monitoring of drain clearing suggests that this also results in mobilisation of large pulses of sediment and nutrients in the catchment . Waituna Creek shows the highest yields of Total Suspended Solids (TSS) and Total Nitrogen (TN), and Moffat Creek the highest yield of Total Phosphorus (TP). ES data for drain flows in the Waituna Creek shows concentrations of TSS, TP, Nitrate-N and TN to be markedly higher than in the main channel. This suggests that the Waituna Creek catchment and in particular drain flows should be specifically targeted to maximise TSS and TN load reductions to the lagoon. TP removal should be targeted in the Moffat and Carran Creek catchments and indrain-flows to the Waituna Creek.(Ballantine and Hughes 2012).

Table 3-1: Specific and sediment and nutrient yields estimated for the subcatchments of the Waituna Lagoon. Data derived from Diffuse Sources (2012).

Subcatchment	TSS (kg/ha/yr)	TP (kg/ha/yr)	TN (kg/ha/yr)
Waituna Creek (Marshall Road)	95.7	0.6	17.7
Carran Creek (Waituna Lagoon Road)	67.2	0.8	8.6
Moffat Creek (Moffat Road)	70.7	1.2	12.6

Figure 3-1: Map of the Awarua Plains, Southland showing the location of the Waituna Lagoon and the three main subcatchments. (Source, Environment Southland).

4 Constructed wetland primer

4.1 Wetland treatment of agricultural run-off

The ability of wetlands to remove sediments and nutrients from agricultural runoff is now well established (Jordan, Whigham et al. 2003; Mitsch, Day et al. 2005; Crumpton, Kovacic et al. 2008; Tanner and Sukias 2011; Díaz, O′Geen et al. 2012). Interception of diffuse agricultural run-off using constructed and restored wetlands can complement on-farm source control measures to reduce sediment and nutrient losses from agricultural landscapes and buffer impacts on receiving waters. Surface-flow (or free-water surface) constructed wetlands are the most relevant type applied for interception and treatment of agricultural run-off because of their simplicity and robustness under highly variable flow conditions. Essentially comprising shallow impoundments or channels planted with emergent wetland plants (Figure 4-1), surface-flow wetlands are the easiest and cheapest type of constructed wetland to construct.

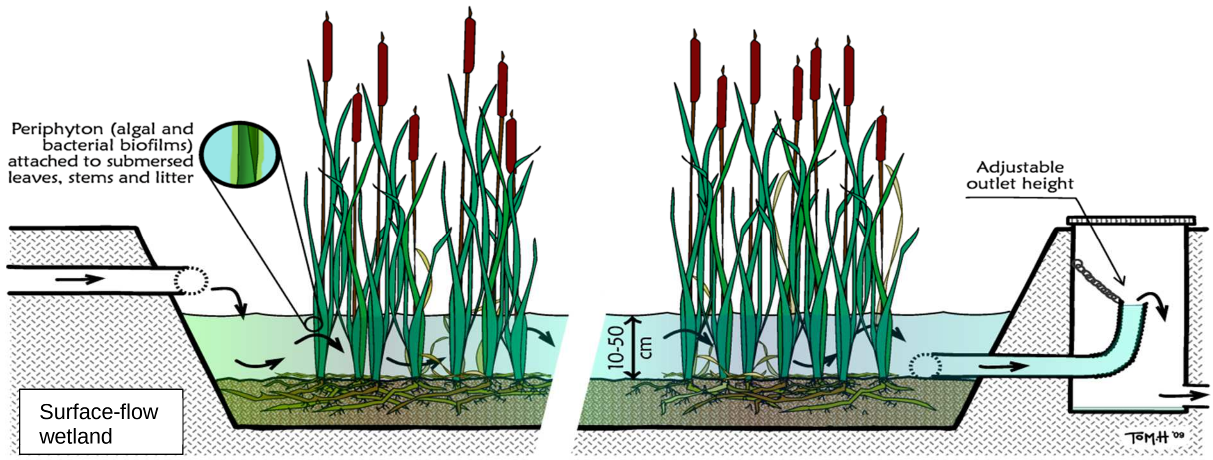


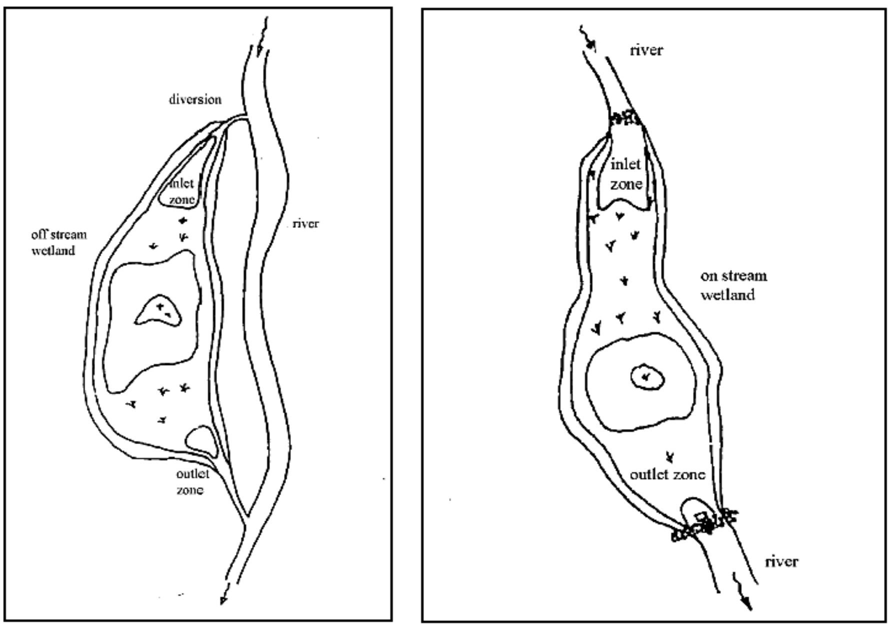
Figure 4-1: Typical cross section of a surface-flow constructed wetland. The wetland may also include deeper open-water zones. A range of alternative inlet and outlet structures are possible to disperse flows and maintain desired water levels (illustration by Tom Headley).

Surface-flow wetlands such as these can provide effective nitrate-N removal via microbial denitrification supplemented by plant uptake and accretion in sediments. Generally the larger the wetland the better the treatment achieved, but with diminishing returns. Nitrate removal performance is temperature sensitive, and will generally be poorer during winter than summer. Nitrate removal via denitrification is promoted by close contact with organic sediments and wetland plants that provide anoxic conditions and organic matter (decomposing plant litter) for denitrifying microbes. Such conditions may also be created or supplemented through the addition of organic amendments such as cereal straws or wood chips/sawdust.

Wetlands can generally provide good removal of particulate-associated phosphorus, but only low level removal of dissolved P. Particulate P removal occurs predominantly by settling, which is promoted in quiescent conditions such as occur in deep water and in areas within vegetated zones. Soluble P removal occurs via reversible soil sorption (which eventually becomes saturated) and uptake by bacterial biofilms, algae and macrophytes. Cycling through growth, death and decomposition returns much of the biotic uptake, but an important residual contributes to long-term accretion of P in newly formed sediments and soils (Reddy, Kadlec et al. 1999). P removal may also be promoted by the use of P-sorbing media, including iron and calcium-rich materials (Ballantine and Tanner 2010), but such materials generally have a finite life, after which they must be replaced.

Previous studies in New Zealand (McKergow, Tanner et al. 2007; Tanner, Sukias et al. 2010) and around the world (Mitsch and Grosslink 2007; Kadlec and Wallace 2009) have identified the need for wetland areas of 1-5% of the contributing catchment to provide reasonable levels of nutrient attenuation in humid-climate agricultural landscapes. Depending on the specific attributes of suspended solids, smaller wetland areas in the range of 0.1-1% of contributing catchment can often achieve satisfactory suspended sediment removal.

From a practical point of view, optimal wetland treatment conditions for both N and P removal are created through provision of wetland areas, depths and length to width ratios that provide sufficient wetland assimilative area, efficient hydraulic characteristics and conditions suitable for establishment of dense growths of desirable vegetation. For systems constructed to treat stream flows, provision must also be made for management of storm and low flows, siltation, and fish passage. Wetlands built off-stream (Figure 4-2) have significant advantages in this respect, because the original stream channel remains intact and can be used to convey a proportion of flood flows. However, off-stream wetlands are not always practically achievable, requiring provision for routing of flood-flows around (or through an armoured floodway within) the wetland. Wetlands receiving flood flows may require more frequent maintenance and specific rehabilitation after large flood events.



A: off-stream wetland　　　b: on stream wetland

Figure 4-2: Comparison of (a) off-stream (in parallel) and (b) on-stream (in-channel) treatment wetlands. (Bendoricchio, Cin et al. 2000).

4.1.1 General principles for wetland design

- Hydrology and hydraulics are crucial to wetland treatment performance and sustainable functioning. Flow must be dispersed across the wetland cross-section, minimising short-circuiting and preferential flow which markedly reduce performance. Provision must also be made to protect the wetland from extreme flood flows (e.g., via diversion) which could cause scouring and/or sedimentation resulting in channelisation and damage to vegetation.
- Wetland area should be sufficient to receive and sustainably process the contaminant loads. This will generally require wetlands comprising 1-5% of the catchment they intercept.
- The water depths over the majority of the wetland should be 0.2-0.5 m with up to one third of the area in deeper zones (0.4 to 1 m). This will promote good growth of emergent wetland plants under sustained inundation. Open water zones will generally provide poorer nitrate removal performance per unit area than vegetated zones.
- Deeper, open-water zones are useful in the inlet zones of wetlands for removal and retention of coarse sediment loads and dispersal of flow, will generally provide poorer nitrate removal performance per unit area than vegetated zones. Provision should be made for periodic mechanical removal of accumulated sediment from influent zones. Open water areas in the wetland can also improve flow dispersion and can enhance wildlife habitat values, although this may compromise performance in terms of water quality and microbiological safety.

4.2 Wetland Vegetation

A variety of wetland plant species are suitable for constructed wetlands in Southland (Peters and Clarkson 2010; Tanner, Sukias et al. 2010). Where nitrate-N removal is a priority, species such as Raupo (*Typha orientalis*) are valuable due to their high production of readily degradable leaf material which provides an organic matter source to fuel microbial denitrification (conversion of nitrate into nitrogen gases). Other hardy tall-growing sedges such as purei/makura (*Carex* spp.) and rushes (*Juncus* spp.) can be planted in shallow zones, and kuta (tall spikerush, *Eleocharis sphacelata*) can be planted in deeper zones. A wide variety of water-tolerant species including harakeke (Phormium tenax), red tussock (*Chionochloa rubra*) and toitoi (*Cortaderia richardii)* are suitable for the edges and embankments around wetlands, where they help to stabilise banks and enhance amenity and biodiversity values.

4.3 Potential wetland locations and construction approaches

Two different broad types of wetland locations have been evaluated in this report:

1. large-scale on-stream wetland in main stream channels, and
2. smaller wetlands within the contributing catchment, that either:
   A. utilise or supplement existing farm ponds or gravel pits, or
   B. intercept natural flow channels (swales and gullies) and subsurface drains. In this region subsurface drains are often laid in natural drainage channels, so wetlands in these situations will therefore intercept both subsurface drainage and surface runoff.

Existing gravel pits and duck ponds do not result in further loss of productive land or in substantial (extra) construction costs. However, although they are likely to be reasonably effective in trapping sediment and associated particulate-P, such open water ponds are likely to be relatively ineffective for removal of dissolved forms of N and P. Addition of wetlands to these existing ponds so that through-flowing water passes through shallow vegetated zones could substantially increase their nutrient removal potential.

The most straightforward approach to create wetlands where they do not presently exist is their retirement (from grazing) and the disconnection of any exiting subsurface drains, so that all the water from the contributing catchment is intercepted by the wetland. A major limitation of this approach is that such wetlands will effectively raise the local groundwater level and thereby compromise drainage efficiency in upslope and surrounding areas.

To maintain drainage function compatible with agricultural use, partial or full excavation will generally be required at the wetland site to ensure that the land immediately upslope and surrounding the wetland is still able to drain effectively. On low gradient land substantial excavation is likely to be required to avoid constraints on drainage of upstream and surrounding farmland (Figure 4-3). As the gradient increases and natural swales and gullies constrain the lateral extent of inundation, there is greater potential for use of dams and bunds to impound flows (Figure 4-4). Partial excavation is still likely required at the upstream end to avoid constraints on drainage in the land above. Figure 4-5 provides an example where an existing farm race causeway is modified to impound flows behind it. At such sites, subsurface drains are likely to be present that currently prevent water from ponding behind the farm race. The disconnection of these drains and provision of an outflow structure would be required to form a detainment pond or wetland. The outflow structure could be designed to either temporarily detain flows (primarily to settle suspended solids), or to retain a more permanent wetland. Detention bunds (corresponding to initial of these options) have been tested in the Bay of Plenty and have been found to effectively trap sediment and particulate phosphorus mobilised in surface runoff events (Clarke, Paterson et al. 2013), but would have negligible effect on dissolved nutrients. Such systems have not been further addressed in this assessment.

Excavation of a pond at the upstream end of constructed wetlands is recommended to trap coarse sediment deposits (that would otherwise gradually fill in the wetland) where they can be mechanically removed periodically. This can also provide habitat for waterfowl and associated recreational activities.

Where surface and subsurface drains flow directly into stream channels, creation of riparian wetlands on the floodplain alongside the stream channel may be appropriate. Figure 4-6 shows a range of riparian wetland configurations. To maximise their function and hydraulic efficiency, drainage channels should be routed to flow into one end of such wetlands and exit via the other. Channel straightening and realignment activities often create poorly drained patches in old channel cut-offs and meanders which prove difficult to properly drain. These recalcitrant patches of lower-productivity land can provide good sites for wetland construction with less impact on farm profitability.

Wetland construction on main stream channels will require special consideration to deal with floods and address issues such as fish passage. Only in-stream options have been considered in the present study, but off-stream wetland options could also be considered. Off-channel wetlands would generally only intercept a proportion of the flow, and so receive and remove less contaminant, however they may have advantages in terms of issues like fish passage. In-stream wetlands would need to be built to withstand major floods, and would likely require high flow diversion channels to maintain flow passage and reduce associated damage to the wetlands. Ideal situations occur where there are constrictions in valleys (to anchor dams and reduce their size and cost) and where land surrounding the flood plain rises relatively steeply to delimit the wetland margins. Larger-scale options really need detailed geotechnical and engineering investigations to determine their feasibility and assess associated risks.

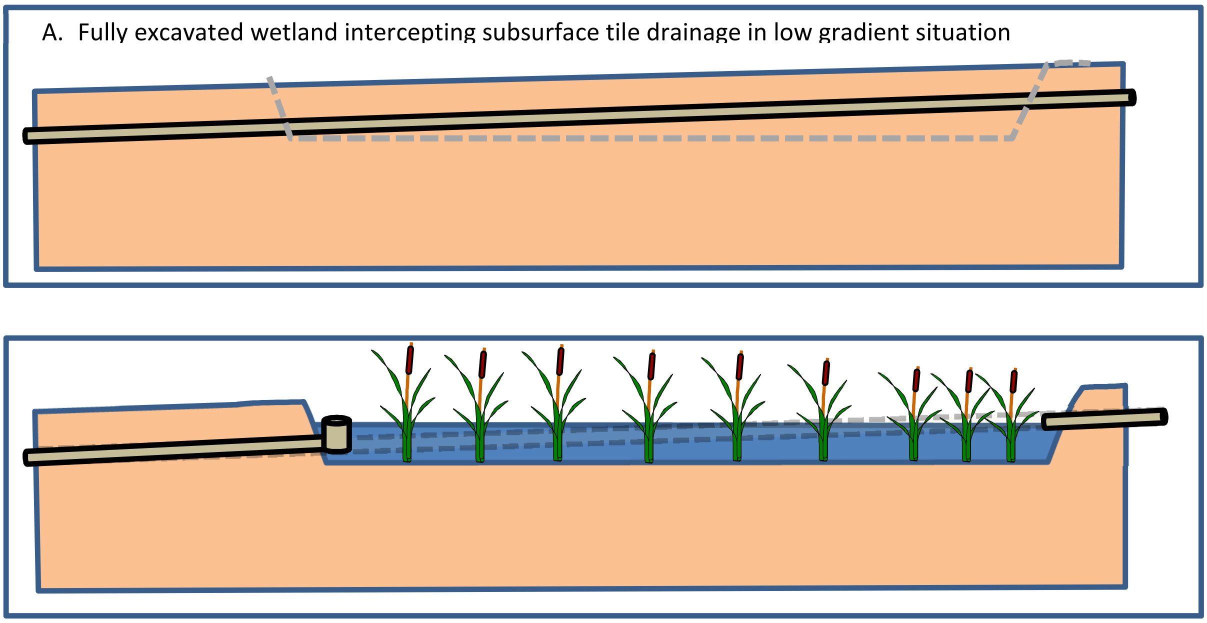


Figure 4-3: Illustration of wetland creation in low gradient, tile-drained situations. Note that to maintain the functioning of the upstream land areas the wetland needs to be excavated to below the upstream drain depth.

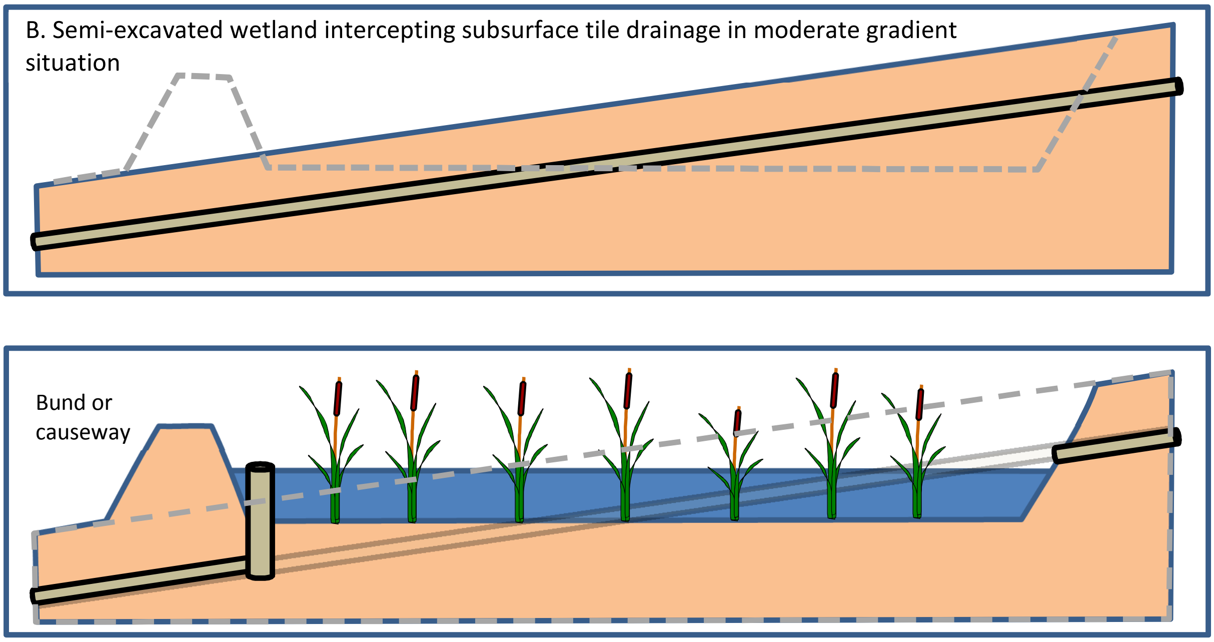


Figure 4-4: Illustration of wetland creation in moderate gradient, tile-drained situations. Note that in this case only partial excavation is required to maintain the functioning of upstream land areas.

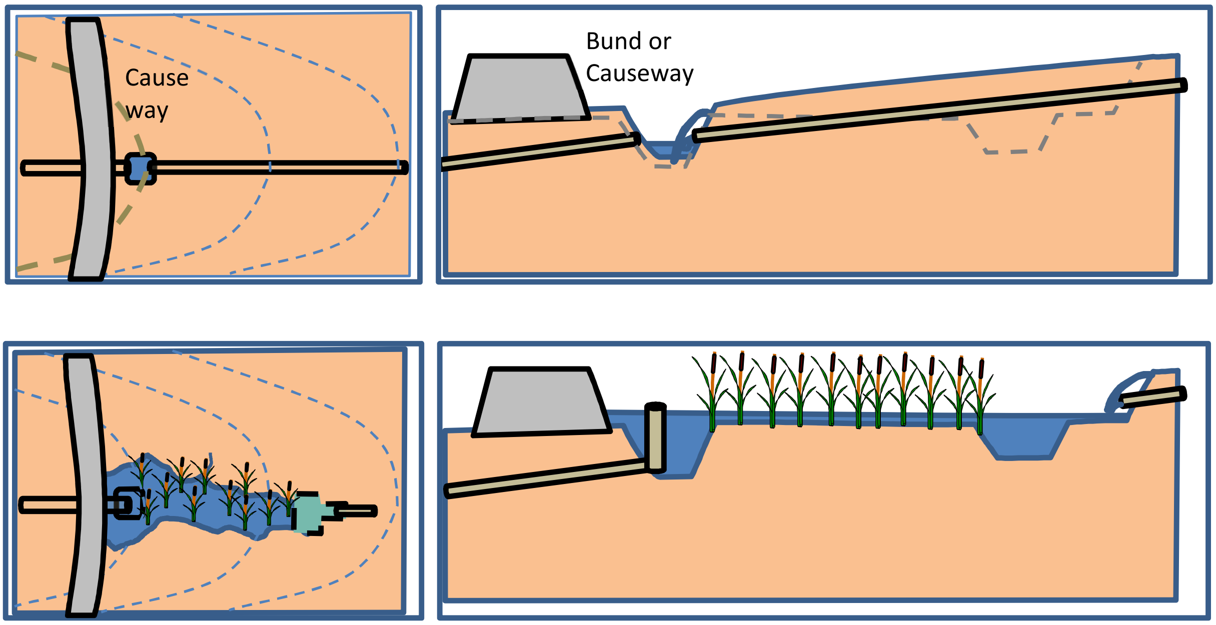


Figure 4-5: Example of semi-excavated wetland created upstream of an existing farm race causeway. Note that this will also capture surface run-off.

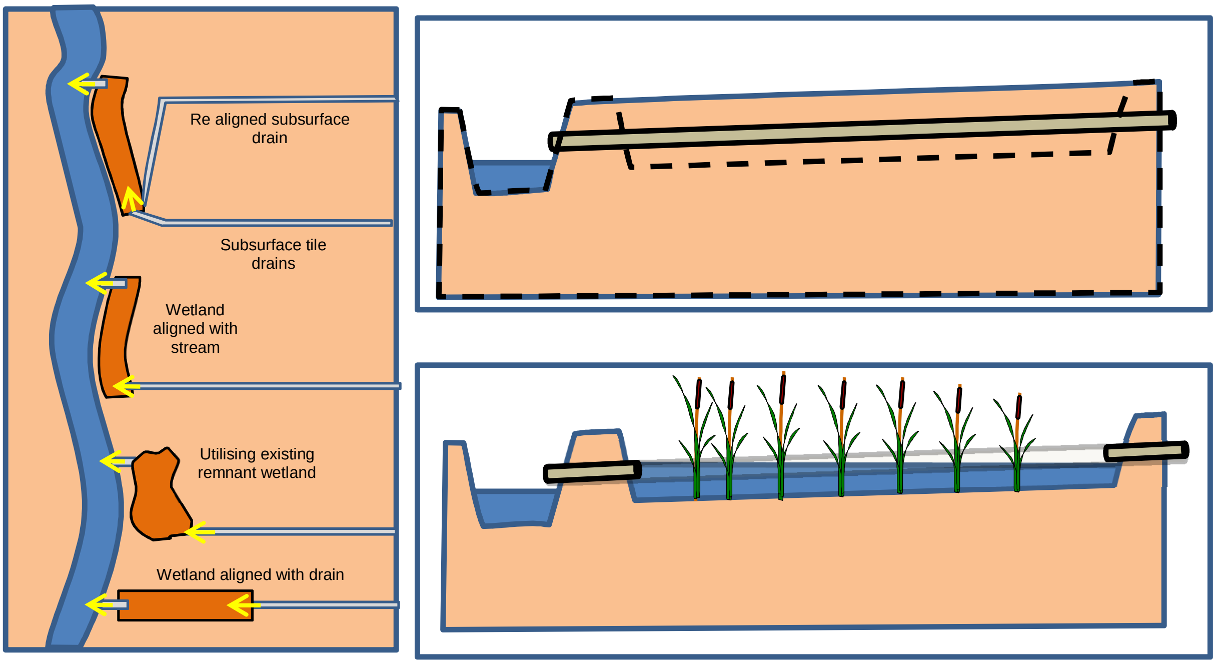


Figure 4-6: Examples of riparian wetlands constructed at the end of subsurface drains before they enter streams and surface drains. Note that depending on the depth of the steam channel or drain these may also capture flood-flows.

5 Methods and materials

Fourteen sites were selected for evaluation which included a site visit followed by a desktop evaluation of wetland area and extent, predicted attenuation performance, construction and maintenance costs and Net Present Value analysis. A range of additional sites in the lower part of the catchment and adjacent to the lagoon were also visited.

5.1 Site selection

Potential locations for wetlands have been assessed at a range of scales within the catchment; ranging from small on-farm wetlands targeting tile-drain flows to larger wetlands on tributaries and stream channels. The location of the sites we consider in this report are shown in Figure 5-1.

Environment Southland did an initial screening and identified properties within the Waituna catchment that either had potential for wetland construction, or were representative of constituent parts of the catchment. These were visited by NIWA and ES staff during early May 2013. Discussions were held with landowners during many of these visits regarding dominant flow paths of runoff (including subsurface drainage), associated nutrient and sediment losses and potential sites for interception and attenuation using constructed wetlands. Other sites within the catchment were observed from the roadside or sought out during our reconnaissance of the catchment (where access was agreed by the landowner or public access was allowed).

In addition, a desktop exercise, using satellite imagery and high resolution LiDAR[1] topographical data provided by ES, was used to identify other potential constructed wetland sites within the catchment. These sites have not been visited by NIWA staff.

[1] LiDAR (lightradar; also often referred to as Light Detection and Ranging) is an optical remote-sensing technique that uses laser light to densely sample the surface of the earth, producing highly accurate topographical measurements.

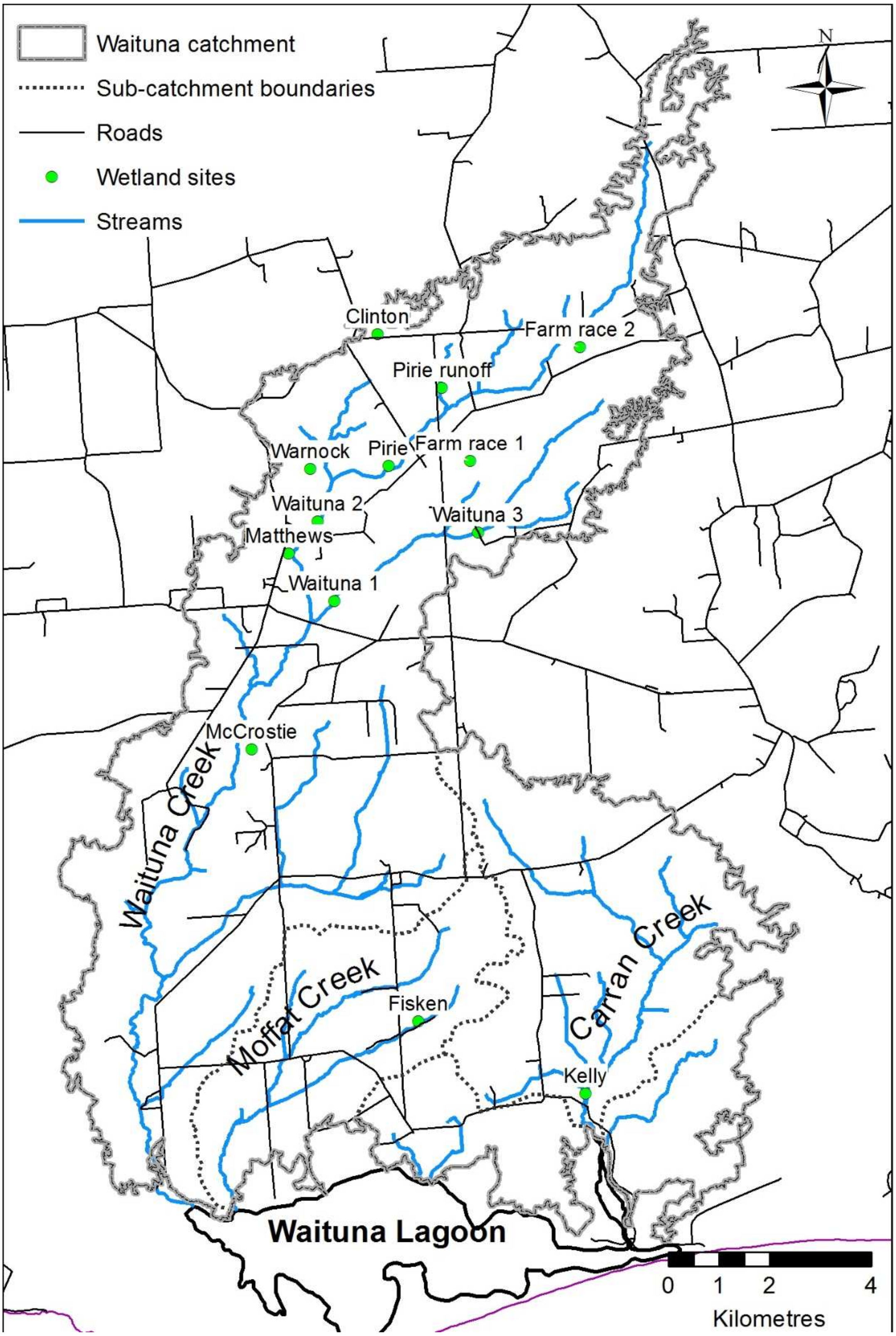


Figure 5-1: Waituna Catchment and locations of potential constructed wetland sites considered in this report.

5.2 Wetland and catchment extents

Assessment of wetland performance requires data on wetland areas, and flows and contaminant loads from the contributing catchment area. The availability of LiDAR data for the whole Waituna Catchment enabled detailed site specific data to be obtained, including modelling the extent of different depth wetlands at each site. ArcGIS 10 was used to define wetland extents by delineating the areas upstream of each selected site that were a known height above the wetland outflow site elevation. For example, at the McCrostie farm site, the floodplain elevation at the proposed wetland site outflow was 15.7 m above mean sea level (AMSL), therefore the wetland surface for the 1 m scenario included all the land above the outflow site that had an elevation between 15.7 m and 16.7 m AMSL. A range of wetland size scenarios have been modelled for most sites. For each wetland scenario, the height (e.g., 0.5 m, 1 m, etc.,) refers to the height of the water immediately behind the dam or impoundment. The actual depth of water within the wetland will vary depending on location, with it getting shallower with increasing distance upslope. ArcGIS 10 was also used to create a flow accumulation surface of the entire catchment. This enabled the catchment areas draining into each proposed wetland site to be accurately determined.

5.3 Water quality and hydrology

To determine the attenuation potential of each of wetland site, water quality and hydrological data was also required. Water quality data was available from a number of locations throughout the Waituna Catchment. There are five State of the Environment (SoE) sites within the catchment (Waituna@Marshall Road, Waituna@Mokotua, Carran Creek@Waituna Lagoon Rd, Carran Creek Tributary@Waituna Lagoon Rd and Moffat Creek@Moffat Creek Rd) where monthly water quality data has been collected since at least 2001. Further monthly water quality data was available from another 14 sites which were sampled between December 2011 and November 2012 as part of the Waituna Surface Water Quality Study. Because of the longer record available from the SOE sites, the SoE records have been used in preference to the shorter longitudinal study. For those wetland sites where there is no large stream channel inflow, data obtained from ES sampling of subsurface drains within and around the Waituna catchment was used.

Reliable long-term flow data from sites within the Waituna Catchment is patchy. However, good relationships exist between the flow record from Waihopai River@Kennington and Waituna@Marshall Road, Carran Creek@Waituna Lagoon Rd and Moffat Creek@Moffat Creek Rd, which were employed in recent assessments of catchment loads for Waituna Lagoon (Williamson, Hughes et al. 2012). This provided good interpolated records for these three sites back to at least 1995. Mean daily flows for each potential wetland site were determined for each season by calculating an area specific discharge for each sub-catchment gauging site then multiplying this value by the contributing area of each wetland site. For example, the area specific mean daily winter discharge for the Waituna@Marshall Road site was 21.65 m^3/ha/day (202,520 m^3/day ÷ 9,353 ha) and the contributing area to the McCrostie farm site was 6,048 ha, therefore the mean daily winter discharge for the McCrostie site was estimated as 130,936 m^3/day (6048 ha x 21.65 m^3/ha/day).

5.4 Treatment performance

For this preliminary assessment surface-flow wetland treatment performance was predicted for mean seasonal flows and contaminant concentrations using a three tanks-in-series derivation of the *P-k-C** first-order kinetic modelling approach proposed by Wallace and Kadlec (2009). This model is represented by the following equation:

$$\frac{C_o}{C_i} = \left(1 + \frac{k}{Pq}\right)^{-P}$$

where:

C_i	=	inlet concentration (g m^{-3})
C_o	=	outlet concentration (g m^{-3})
k	=	temperature dependant first order removal rate constant (m y^{-1})
P	=	hydraulic efficiency parameter
q	=	hydraulic loading (m y^{-1})

Seasonal removal performance was assessed for each contaminant of interest using long-term mean flows and concentrations derived from the most relevant nearby monitoring site (see Section 5.3). Annual performance of the wetlands was calculated by summing the predicted seasonal mass reductions for each contaminant and comparing this to the summed seasonal mass loadings. Total Suspended Solids (TSS) and Total Phosphorus (TP) removal were assessed for each season using the median removal rate constants reported for surface-flow wetlands by Wallace and Kadlec (2009).

The modelling approach for nitrogen accounted for net mineralisation of organic-N, nitrification of ammonium-N and denitrification of nitrate-N, with Total Nitrogen (TN) removal calculated as the net removal of its constituent forms. As wetland nitrogen removal is sensitive to temperature, mean seasonal water temperatures recorded for the Waituna Creek were used in addition to seasonal flows and N concentrations to calculate seasonal performance. For nitrate-N removal, mean *k* rates and modified Arrhenius temperature coefficients were derived from a comprehensive recent review of available international (Kadlec 2012) and New Zealand data for wetlands treating nitrate-rich, non-wastewater waters (Tanner and Sukias 2011). For other forms of N median removal rate constants and modified Arrhenius temperature coefficients reported for surface-flow wetlands by Wallace and Kadlec (2009) were applied.

It should be noted that different wetland systems show a range of performance depending on their specific flow and loading regime, design, age, vegetation type and cover, and local climate and site conditions (Kadlec 2012; Tanner and Kadlec 2013). We expect that with good design and construction, and appropriate vegetation establishment that these model predictions should provide a realistic estimate of average treatment performance. However given the potential level of investment in wetland mitigation envisaged in the region and the importance of the outcomes, further monitoring and assessment of demonstration systems under local conditions is recommended to verify performance attributes and help refine the modelling tools available.

5.5 Construction costs

There is limited experience with construction of constructed wetlands for contaminant attenuation in agricultural landscapes in New Zealand and a paucity of associated financial information. Our investigation of the potential sites has also of necessity been only cursory without the benefit of detailed geotechnical information which could prove some sites considered require specialised construction techniques or may not be practically feasible. Our estimates of wetland construction costs should therefore only be considered as preliminary “rough-order” estimates.

Costs of wetland construction will vary significantly depending on specific site factors, with relative costs tending to reduce with increasing wetland size (Kadlec and Wallace 2009). For the purposes of this preliminary assessment, the costs for constructing surface-flow wetlands in the Waituna Catchment have been estimated based on the approach proposed by Kadlec and Wallace (2009).

Large-scale wetlands constructed on the main stream channels are expected to be structurally more complex and expensive to design and construct than smaller on-farm wetlands intercepting contributing catchment flows. Cost estimates for large-scale wetlands include professional engineering design and supervision, full construction costs, provision of fencing and access gates and planting with appropriate wetland plants. The construction costs for the large-scale main channel wetlands have been calculated based on the design and construction costs for the Lake Okaro wetland in the Bay of Plenty (Tanner, Caldwell et al. 2007), adjusted for general inflation since 2005 using the New Zealand Reserve Bank on-line inflation calculator. The 2.3 ha Lake Okaro wetland cost $684,000 to design and construct in 2005, which translates to a current cost of $460,415 per ha (1st quarter of 2013). This was scaled according to the cost versus wetland area relationship derived for 84 surface-flow wetlands by Kadlec and Wallace (2009), to give the relationship:

*Main stream channel wetland costs = $460,415 x wetland area*$^{0.69}$

The construction costs of smaller-scale wetlands in contributing catchments are based on cost estimates made by an experienced local agricultural engineer, John Scandrett (Dairy Green Ltd). These estimates for fully excavated surface-flow wetlands treating subsurface tile drainage made in mid-2006 were based on his experience supervising construction of the Bog Burn wetland in Southland (Tanner and Sukias 2011). They were adjusted to equivalent first quarter 2013 values using the New Zealand Reserve Bank on-line inflation calculator, and include professional engineering supervision, full construction costs, provision of fencing and access gates and planting with appropriate wetland plants.

Fully excavated contributing catchment wetlands up to 1 ha in size were assumed to cost $196,560 per ha. Beyond this size their costs were scaled according to the cost verses wetland area relationship derived by Kadlec and Wallace (2009), that is:

Fully-excavated contributing catchment wetland construction = $196,560 *x area*$^{0.69}$

Such fully excavated wetlands are assumed to involve conversion of essentially flat land into a wetland by excavation, and construction of earthen embankments and inflow and outflow control structures.

There are also situations where existing landscape features such as valleys, gullies and depressions can be used to facilitate lower cost wetland construction. In this case the wetland is largely retained within existing landscape features and we have assumed only partial excavation will be required (see Section 4.1.1). For preliminary comparison, the costs of partially-excavated wetlands have been assumed to be approximately half the cost of fully-excavated wetlands. Fully excavated wetlands up to 1 ha in size were assumed to cost $ 98,280 per ha. Beyond this size their construction costs were scaled according to the cost versus wetland area relationship derived by Kadlec and Wallace (2009), that is:

*Partially-excavated contributing catchment wetland construction cost =$*98,280 *x area*$^{0.69}$

These relationships between wetland area and construction costs for the three different wetland types are illustrated in Figure 5-2 and Figure 5-3.

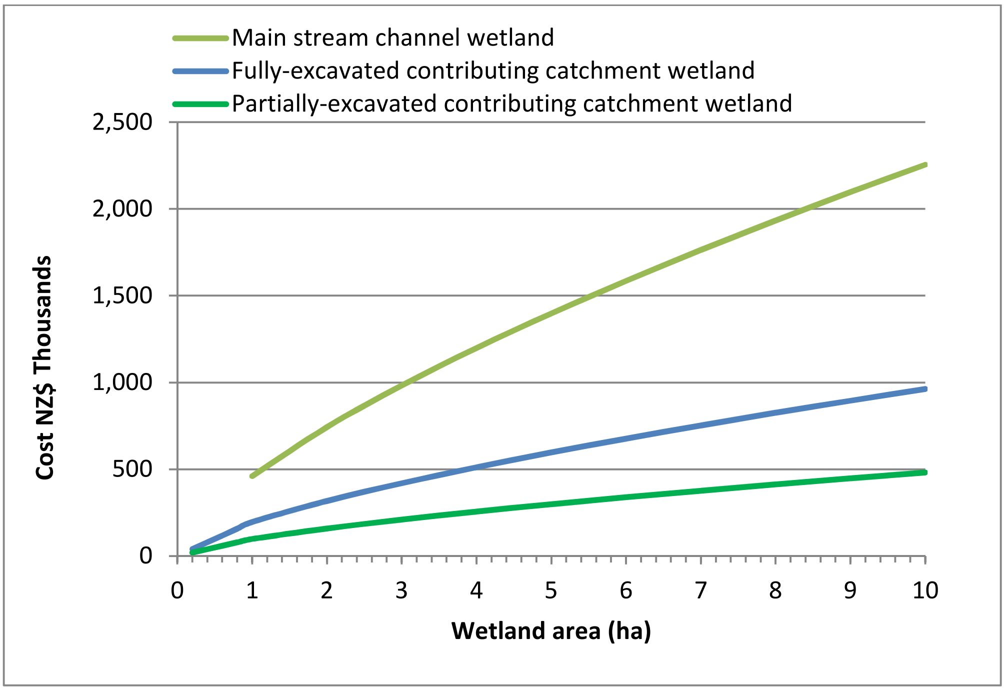


Figure 5-2: Construction cost estimates for different sizes and types of constructed wetlands.

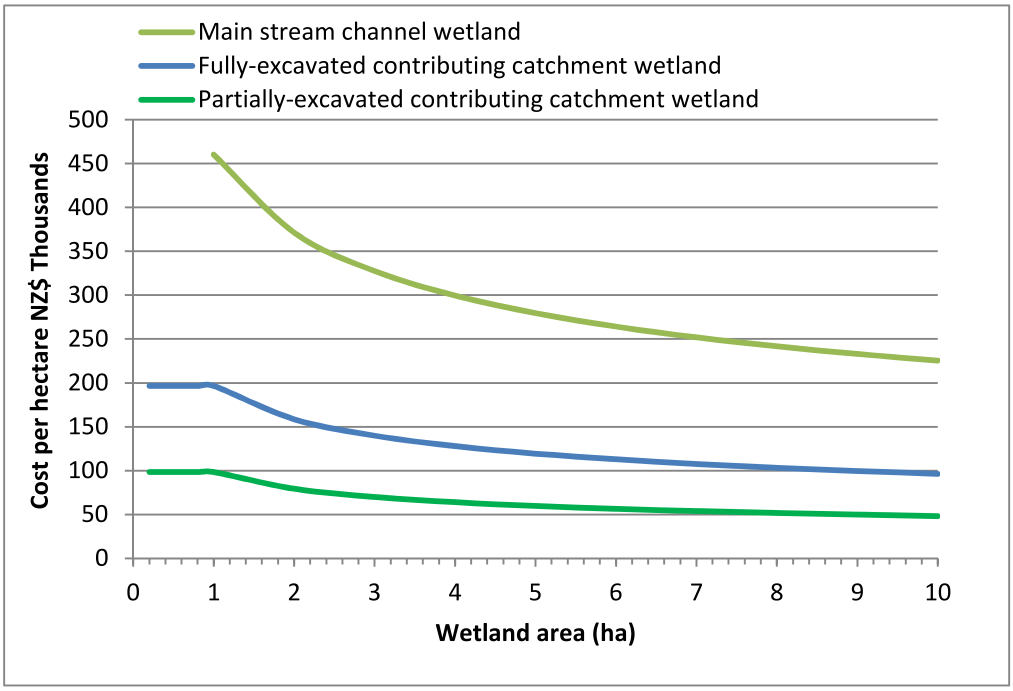


Figure 5-3: Construction cost estimates per hectare for different sizes and types of constructed wetlands.

5.6 Maintenance costs

Wetland maintenance (once wetland vegetation has established) 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. The annual costs to undertake this has been estimated at $300 per ha. The cost is assumed to scale according to the cost verses wetland area relationship derived by Kadlec and Wallace (2009) (Figure 5-4).

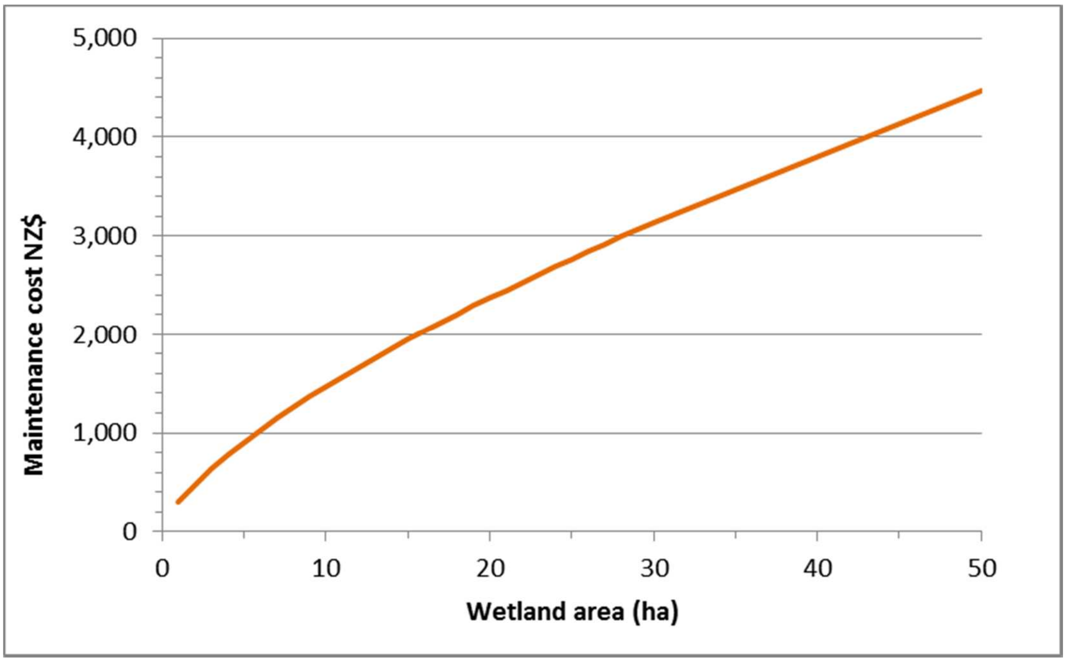


Figure 5-4: Estimated annual maintenance costs for constructed wetlands.

5.7 Annualised costs

Net present value analysis was used to derive an annualised cost for the use of constructed wetlands which accounted for estimated construction costs, the cost of capital (8% per year assumed long-term) over an estimated lifetime of 25 years, annual wetland maintenance costs less associated tax benefits, and the loss of potential income from the land occupied by the wetland. Loss of income from prime farm land was estimated based on the average dairy farm net profit per ha before tax for Southland calculated from the last 8 years of available data (2004/5-2011/12; MPI Statistics 2012). Where ever possible preferential use of lower productivity land was targeted for construction of wetlands. The lost income from this land, generally only suitable for rough grazing, was assumed to be 20% of the average income from prime land. These costs were then expressed per kg of each contaminant removed for each wetland option.

No allowances were made for potential positive economic gains from wetland construction; for example via increased land value, enhanced aesthetic, recreational and biodiversity values, or maintenance of farm productivity under regulatory environmental limits.

6 Constructed wetland sites

In this section the location and characteristics of each of the sites investigated in the Waituna catchment are outlined, and the specifications of the different constructed wetland options and their contributing catchments are detailed.

6.1 Existing pond sites

6.1.1 Warnock pond

The Warnock farm pond is contained by a small earth dam located in the northern part of the Waituna Creek catchment (Figure 5-1). The pond was constructed for duck hunting and has been extended in size in the last few years (Figure 6-1). The pond currently occupies ~0.42 ha and has a contributing area of almost 34 ha (Table 6-1). Based on analysis of LiDAR data the pond is unlikely to exceed 3 metres deep and is probably much shallower for most of its extent. The pond is bounded by some willow trees in the older section. A fence has recently been erected to exclude stock from its margins and some native shrub planting has occurred within this fenced area (Figure 6-2).

Three areas for supplementary constructed wetlands above and below the existing pond are evaluated (Figure 6-3, Table 6-1). Together these areas of low-productivity swampy ground would comprise ~2.2% of the contributing catchment, substantially increasing the nutrient removal potential of the existing pond area.

Table 6-1: Warnock duck pond location, proposed supplementary wetlands and contributing area data.

Site	Easting	Northing	Catchment area (ha)	Wetland area (ha)	Wetland as % of catchment area
Warnock duck pond	2170945	5411081	33.8	0.42	1.2
Warnock upper	2170800	5411051	29.5	0.36	1.2
Warnock lower1	2171085	5411071	36.1	0.24	0.67
Warnock lower2	2170910	5411061	43.1	0.10	0.23

Figure 6-1: Google Earth derived satellite image of the Warnock farm duck pond. Blue area indicates the approximate current extent of the pond. The pond has been extended since the satellite image was captured.

Figure 6-2: Warnock duck pond and surrounds.

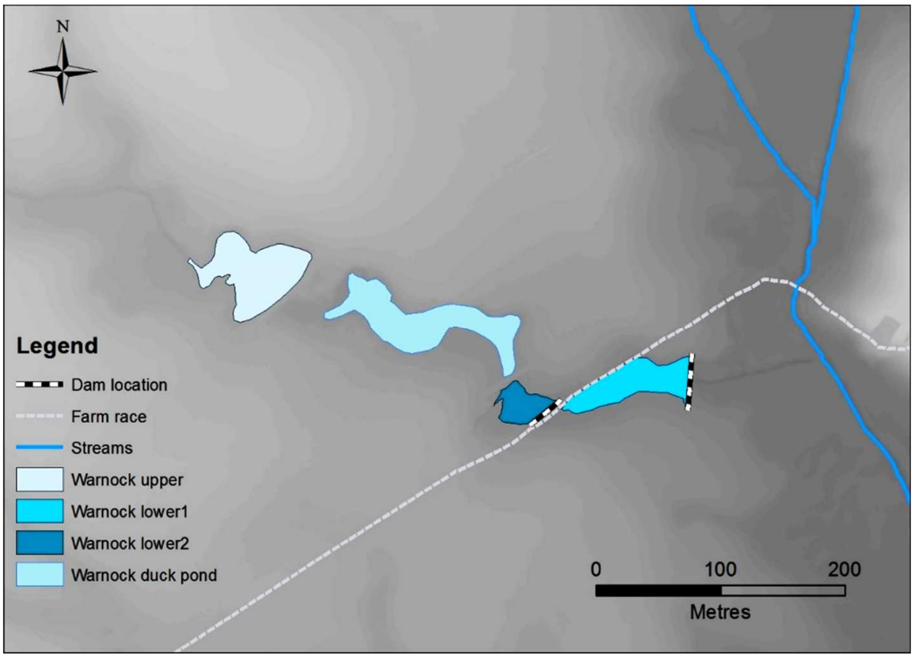


Figure 6-3: LIDAR image of Warnock Duck Pond and the modelled supplementary wetlands. Note both the upper and lower wetlands are considered together for modelling purposes.

6.1.2 Matthews pond

The Matthews farm pond is located in the northern part of the Waituna Creek catchment (Figure 5-1). Although not confirmed during a road-side viewing, the Matthews farm pond is likely to be contained by a small earth dam. There is a maimai located on the pond edge, which suggested that this pond was constructed for duck hunting. The pond currently occupies ~0.20 ha and has a contributing area of ~2 ha (Table 6-2). The pond depth in unknown but, unless major excavation has taken place, is unlikely to be deeper than ~2 metres. The pond is bounded by some large trees and the paddock which it is situated does not appear to be extensively grazed, with sedge and weed species being widespread (Figure 6-5). The large relative extent of Mathew's Pond (9.6% of catchment) and small contributing catchment area suggests additional wetland treatment is unlikely to provide significant benefits and so this site has been excluded from further analysis.

Table 6-2: Matthews duck pond location and contributing area data.

Easting	Northing	Catchment area (ha)	Wetland area (ha)	Pond as % of catchment area
2170504	5409364	2.0	0.20	9.6

Figure 6-4: Google Earth derived satellite image of the Matthews farm duck pond. Blue area indicates the approximate current extent of the pond.

Figure 6-5: Matthews farm duck pond.

6.1.3 Fisken gravel pit

The Fisken farm gravel pit is located in the upper part of a tributary of the Moffat Creek (Figure 5-1). The small gravel pit (~200 m^2) on the Fisken farm was excavated to use the gravel in the construction of farm races on this recently converted dairy farm. The gravel pit is located near the confluence of a farm drain and the main channel of Moffat Creek. On the recommendation of ES staff, the main drain was diverted through the gravel pit. Water enters the gravel pit on the north-western corner and exits near the south-eastern corner (Figure 6-7). Assuming any subsurface drains follow the contour of the land, the LiDAR data indicates the gravel pit has a catchment area of ~14 ha (Table 6-3).

Table 6-3: Fisken gravel pit location and contributing area data.

Easting	Northing	Catchment area (ha)	Wetland area (ha)	Wetland as % of catchment area
1263331	4838060	14.2	0.02	0.2

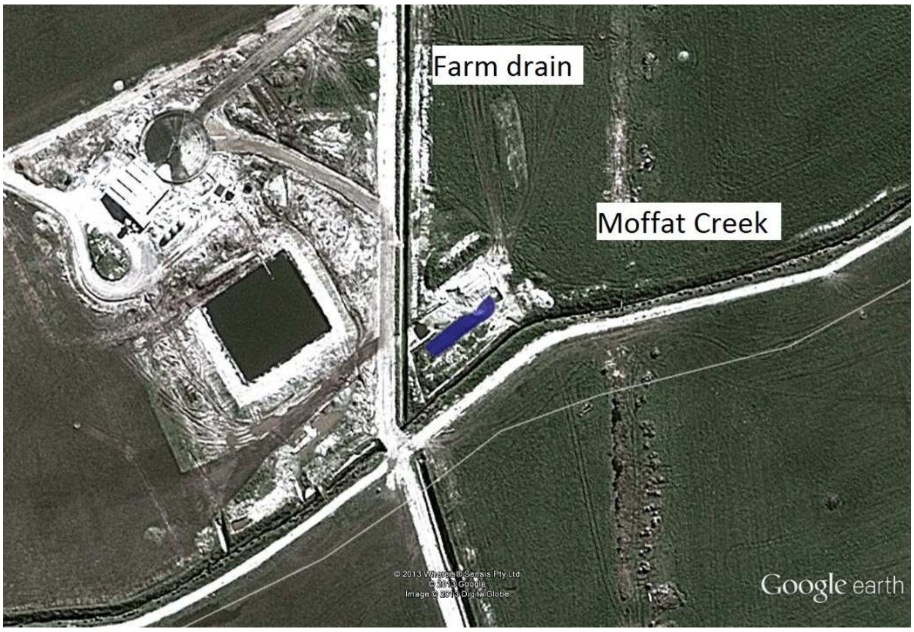


Figure 6-6: Google Earth derived satellite image of the Fisken farm gravel pit. Blue area indicates the approximate current extent of the pit.

Figure 6-7: Fisken farm gravel pit.

6.2 Other sites with potential

6.2.1 Pirie farm

The Pirie farm is located in the northern part of the Waituna Creek catchment (Figure 5-1). Five sites of various scales were identified on this farm (and an associated runoff property) were identified as potential constructed wetland sites (Table 6-4).

Table 6-4: Pirie farm wetland site location and contributing area data.

Site	Easting	Northing	Channel depth (m)	Depth at dam (m)	Dam width (m)	Catchment area (ha)	wetland area (ha)	Wetland as % of catchment area
Stream channel								
Pirie (0.5m)	1262494	4848783	3	0.5	7.2	2163	1.3	0.1
Pirie (1m)	1262494	4848783	3	1	7.4	2163	3.6	0.2
Pirie (3m)	1262494	4848783	3	3	155	2163	16.4	0.8
Contributing catchment								
Site A	1262647	4848984	-	-	-	25.1	1.2	4.6
Site B	1262611	4848767	-	-	-	4.6	0.6	12.0
Site C	1262420	4848803	-	-	-	9.4	0.3	3.0
Runoff property								
Impoundment 1	1263784	4850531	1.5	0.5	7	-	0.034	-
Impoundment 2	1263798	4850565	1.5	0.5	9	-	0.037	-
Impoundment 3	1263779	4850598	1.5	0.5	31	-	0.092	-
Total	-	-	-	-	-	204.6	0.163	0.1

Waituna Creek channel site

The main stream channel at this site was identified as a possible location for a large scale wetland. This site was identified as a potential wetland site due to a constriction in the river floodplain (enhanced by a farm race; Figure 6-8) and the presence of relatively extensive floodplain area upstream of the constriction. At this location three different wetland depths have been modelled (0.5 m, 1 m and 3 m; Figure 6-9). These wetland depths refers to the depth of the water on the floodplain directly behind a dam structure. As any dam structure would also need to impound the channel, the dam structure would need to be a minimum of 3.5 m high (3 metres deep channel plus 0.5 metre on floodplain) for the width of channel at this site (in the case of the 0.5 m scenario). The total dam width would need to be at least 7.2 metres wide for the 0.5 m scenario and ranging over 155 m for the 3 m scenario (Table 6-4). The wetland size as a percentage of catchment area would range from 0.1 % for the 0.5 m scenario to 0.8% for the 3 m scenario.

Figure 6-8: Pirie farm channel site. The farm bridge crossing is the approximate location of the suggested impoundment site.

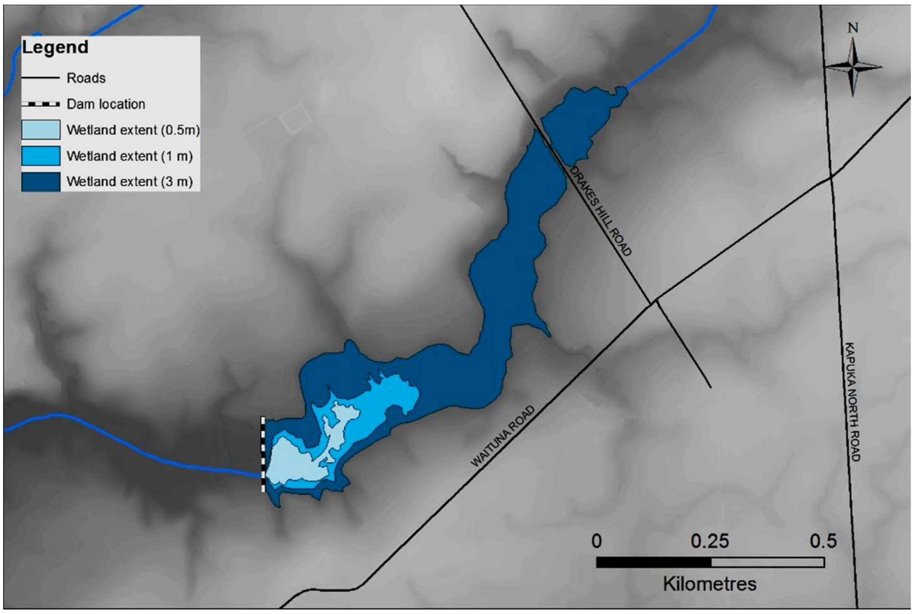


Figure 6-9: Pirie farm stream channel site and three modelled wetland extents. Wetland extents are based on the depth of water above the present floodplain level at the selected dam site. Note that the channel is ~three metres deep at the suggested dam site (current farm bridge location).

Contributing catchment sites

There are numerous sites on the Pirie property where much smaller scale wetlands intercepting surface and subsurface drains are also possible in the contributing catchment. These most commonly occur in natural swales and gullies and on floodplains. Three sites (Sites A, B and C), each with different characteristics were identified and will be described here (Figure 6-10). Site A is a naturally poorly drained area adjacent to the true right bank of the Waituna Creek. The area is poorly drained despite the presence of subsurface drains. This low lying area appears to be an area of low productivity that is occupied by many weed species (including gorse) (Figure 6-11). Site A has an area of 1.2 ha and a catchment area of ~25 ha. The detailed drainage lines on Figure 6-10 illustrate the approximate areas that drain into each of the contributing catchment sites, including Site A.

Site B is located across the stream from Site A, adjacent to the true left bank of the Waituna Creek. Site B is mainly pasture, although patches are also present. When the site was observed on 6 May 2013 most of it was saturated (Figure 6-12). Site B has an area of 0.6 ha and a catchment area of ~4.6 ha (Table 6-4).

At Site C there is currently no evidence of impaired drainage. This is likely to be because the subsurface drains are working effectively in this location. Site C has been included as example of a site where the size of the wetland can be designed to suit the size of its catchment area. Previous constructed wetland research has identified that wetlands that are ~2.5% of their catchment area can be very effective sediment and nutrient attenuation tools (McKergow, Tanner et al. 2007). For Site C, the catchment area is 9.4 ha, therefore we know that that a wetland of ~0.3 ha in area at this site would be an effective size.

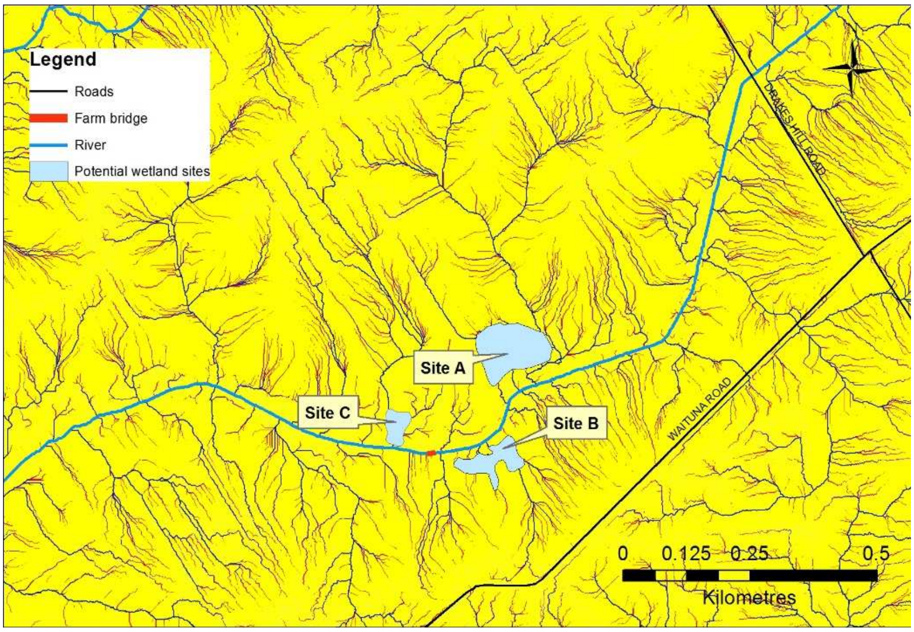


Figure 6-10: Pirie farm potential contributing catchment wetland locations and extents. The detailed drainage network (obtained from LiDAR data) illustrates the approximate areas that drain into the wetland sites.

Figure 6-11: Pirie farm contributing catchment wetland site A.

Figure 6-12: Pirie farm contributing catchment wetland site B.

Pirie runoff property stepped wetland

Another approach that is possible within steeper areas is the design of a multi-impoundment or stepped wetland approach. On the Pirie runoff property a small tributary of the Waituna Creek was identified as a potential location (Figure 6-13). Three wetland surfaces were modelled by backing up water to a height of 0.5 m above the channel height (Figure 6-14). The combined area of the three wetlands is ~0.16 ha and the total catchment area is ~205 ha. Such an approach would require a total of ~50 m of dam width (at least 0.5m high) and would result in a total wetland area equal to ~ 0.1% of its catchment area (Table 6-4).

Figure 6-13: Pirie runoff property stream channel site.

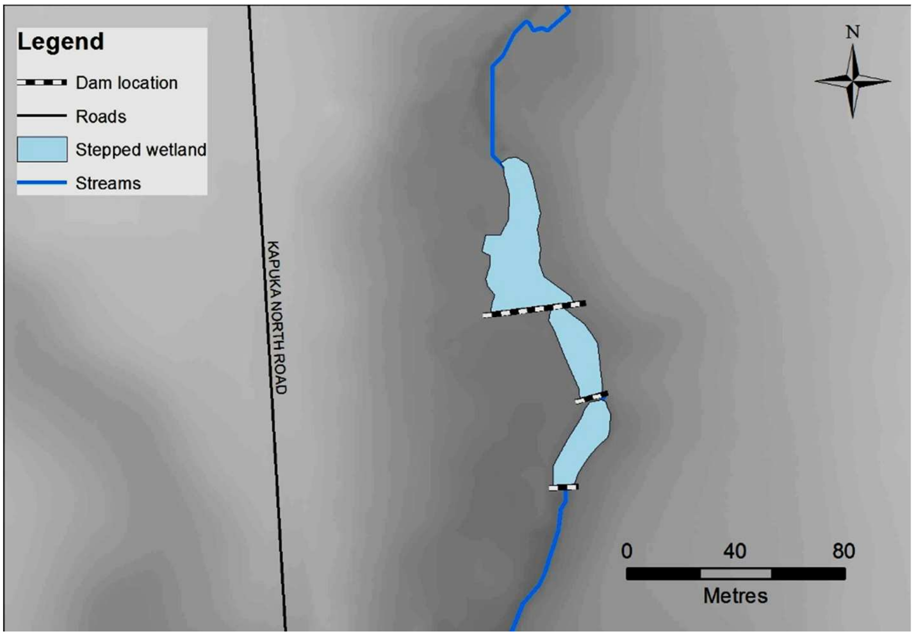


Figure 6-14: Stepped wetlands at Pirie runoff property stream channel site. This figure illustrates a stepped wetland approach with three individual impoundment structures being required.

6.2.2 Kelly farm

The Kelly farm is located in the lower reaches of the Carran Creek catchment, only a short distance upstream from Environment Southland's Carran Creek SoE monitoring site (Figure 6-16Figure 6-16: Google Earth derived satellite image of the potential wetland site on the Kelly farm.). This site was identified by the farm owner (Owen Kelly) as an area that was often saturated and therefore of limited use for productive grazing (Figure 6-15). The approximate size of the area identified by Owen Kelly is 2.1 ha and it has an upstream catchment area of 2842 ha (Figure 6-16; Table 6-5). A wetland of this size would only comprise ~ 0.1% of its catchment area.

Table 6-5: Kelly farm potential wetland site location and contributing area data.

Easting	Northing	Catchment area (ha)	Wetland area (ha)	Wetland as % of catchment area
2176334	5398774	2842	2.1	0.1

Figure 6-15: Kelly farm potential wetland site (during flooding). The picture was taken looking approximately north. The creek runs adjacent to the line of trees visible on the right side of the picture (Photo: Katrina Robertson, Environment Southland)

Figure 6-16: Google Earth derived satellite image of the potential wetland site on the Kelly farm. Blue area indicates the approximate wetland extent.

6.2.3 Clinton farm

The Clinton farm is located in the northern part of the Waituna Creek catchment (Figure 5-1). During the May 2013 site visits, the farm owners showed us an area immediately upstream of a road bund where, despite extensive subsurface drain construction, drainage is poor (Figure 6-17). Three scenarios were modelled at this site (Table 6-6; Figure 6-18). The first scenario is the retirement of a small area of land (0.6 ha; approximately the current area of poor drained area). A wetland of this size would be equal to ~ 0.5% of its catchment area. The second scenario raises the water level 0.5 m above the current road culvert, this would create a wetland ~3 ha in area (~2.6% of its catchment area). The third raises the water level to 1 m above the current road culvert, this would create a wetland ~4.4 ha in area (~3.8% of its catchment area). Detailed investigation would be required at this site to ensure that use of the road causeway did not pose structural or flooding risks for the roadway.

Table 6-6: Clinton farm wetland site location and contributing area data.

Extent	Easting	Northing	Contributing area (ha)	Wetland area (ha)	Wetland as % of catchment area
Clinton (poorly drained area)	2172263	5413741	117.0	0.6	0.5
Clinton (0.5m)	2172263	5413741	117.0	3.0	2.6
Clinton (1m)	2172263	5413741	117.0	4.4	3.8

Figure 6-17: Clinton farm potential wetland site.

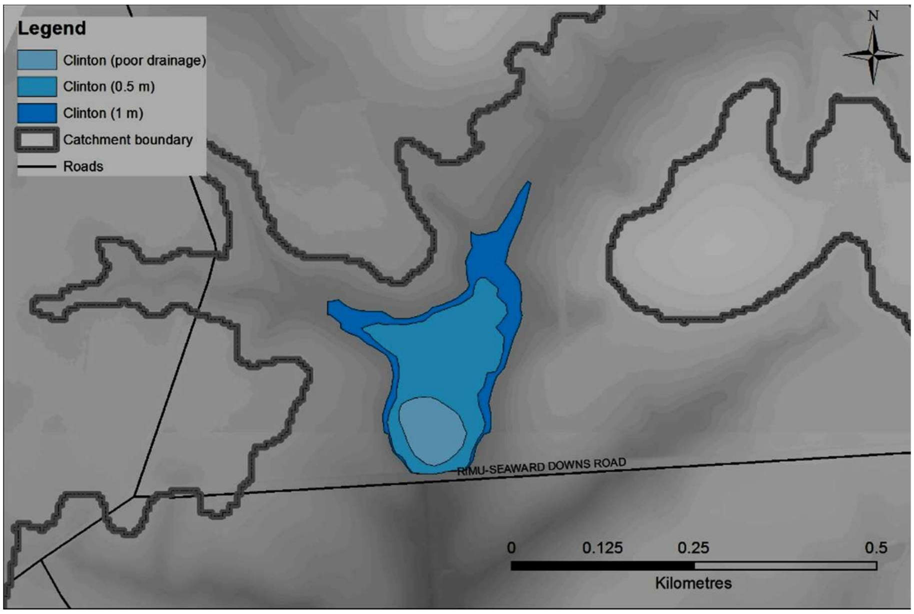


Figure 6-18: Clinton farm and two modelled wetland extents. Wetland extents are based on the depth of water above the current drainage culvert position that flows through the road bund.

6.2.4 McCrostie farm

The McCrostie farm is located in the middle reaches of the Waituna Creek (Figure 5-1). As with the Pirie farm, this farm was specifically visited and assessed for its potential to locate a wetland on it. The main stream channel was identified as a potential site for a large wetland treating flows from the upper catchment (Figure 6-19). The channel is deeply incised at this location (~ 5 metres deep), but an expansive floodplain with the steeply rising adjacent land, suggested that a large-scale wetland may be possible at this site. Accordingly, three different wetland depths were modelled (0.5 m, 1 m and 2 m; Figure 6-20). As with the Pirie farm sites, these wetland depths refers to the depth of the water on the floodplain directly behind a dam structure. As any dam structure would also need to impound the channel, the dam structure would need to be a minimum of 5.5 m high (5 metres deep channel plus 0.5 metre on floodplain) for the width of channel at this site (in the case of the 0.5 m scenario). The total dam width would need to be at least 148 m wide for the 0.5 m scenario and ranging over 333 m for the 2 m scenario (Table 6-7). The wetland size as a percentage of catchment area would range from 0.2 % for the 0.5 m scenario to 0.8% for the 2 m scenario.

Table 6-7: McCrostie farm wetland site location and contributing area data.

Site	Easting	Northing	Channel depth (m)	Depth at dam (m)	Dam width (m)	Catchment area (ha)	wetland area (ha)	Wetland as % of catchment area
McCrostie (0.5m)	1262494	4848783	5	0.5	148	6048	12.9	0.2
McCrostie (1m)	1262494	4848783	5	1	177	6048	20.1	0.3
McCrostie (2m)	1262494	4848783	5	2	333	6048	48.5	0.8

Figure 6-19: McCrostie farm stream channel site.

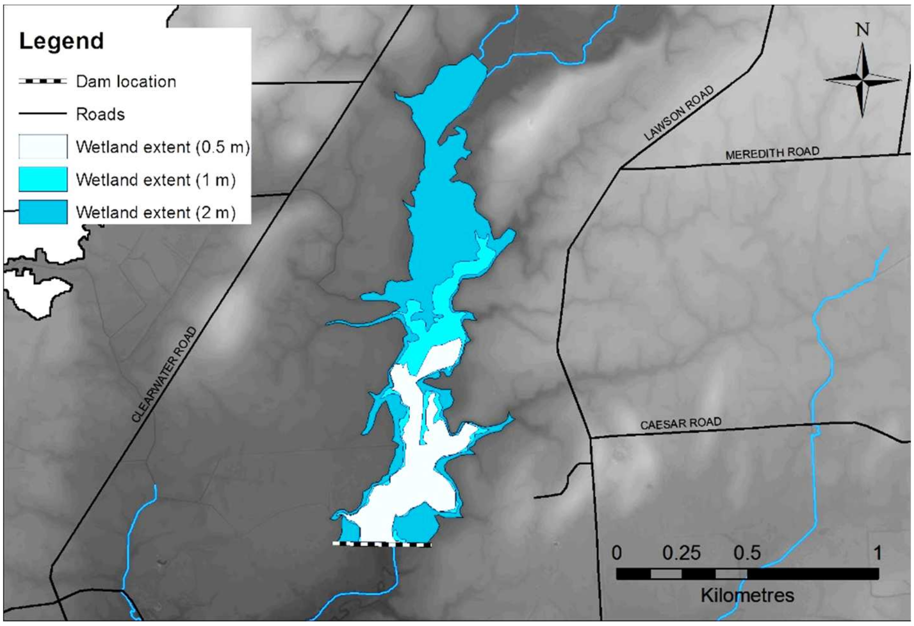


Figure 6-20: McCrostie farm stream channel site and three possible wetland extents. Wetland extents are based on the depth of water above the present floodplain level at the selected impoundment site. Note that the channel is ~five metres deep at the suggested impoundment site.

6.2.5 Other large-scale Waituna Creek wetland sites

To provide some further assessment of the feasibility of large-scale wetlands in the Waituna Catchment, other main channel sites were also investigated. Because the establishment of large impoundments would be costly, channel sites that are located within natural or artificial constrictions (where smaller impoundments may be required) could be the most cost-effective sites to locate impoundment structures. Three such sites were identified from the LiDAR data (Waituna1, Waituna2 and Waituna3; Figure 5-1). All three sites are located in the upper Waituna catchment area and all use elevated road causeways as a partial impoundment. For each site three different water level scenarios were modelled (0.5 m, 1 m and 3 m). At the Waituna1 site (Figure 6-21) the total dam width would need to be at least ~22 m wide for the 0.5 m scenario and ranging over 236 m for the 3 m scenario (Table 6-8). The wetland size as a percentage of catchment area would range from 0.3 % for the 0.5 m scenario to 1.8% for the 3 m scenario. At the Waituna2 site (Figure 6-22) the total dam width would need to be at least ~71 m wide for the 0.5 m scenario and ranging over 283 m for the 3 m scenario. The wetland size as a percentage of catchment area would range from 0.5 % for the 0.5 m scenario to 2.1% for the 3 m scenario. At the Waituna3 site (Figure 6-23) the total dam width would need to be at least ~51 m wide for the 0.5 m scenario and ranging over 205 m for the 3 m scenario. The wetland size as a percentage of catchment area would range from 0.4 % for the 0.5 m scenario to 2.0% for the 3 m scenario.

Table 6-8: Other Waituna Creek wetland site locations and contributing area data.

Site	Easting	Northing	Channel depth (m)	Depth at dam (m)	Dam width (m)	Catchment area (ha)	wetland area (ha)	Wetland as % of catchment area
Waituna1 (0.5m)	1261673	4846345	2.4	0.5	21.6	1559	4.7	0.3
Waituna1 (1m)	1261673	4846345	2.4	1	27	1559	8.4	0.5
Waituna1 (3m)	1261673	4846345	2.4	3	236	1559	28.8	1.8
Waituna2 (0.5m)	1261353	4847918	3	0.5	71	3036	14.2	0.5
Waituna2 (1m)	1261353	4847918	3	1	90	3036	21.2	0.7
Waituna2 (3m)	1261353	4847918	3	3	283	3036	63.2	2.1
Waituna3 (0.5m)	1264504	4847699	2.5	0.5	51	787	2.8	0.4
Waituna3 (1m)	1264504	4847699	2.5	1	95	787	4.2	0.5
Waituna3 (3m)	1264504	4847699	2.5	3	205	787	16.0	2.0

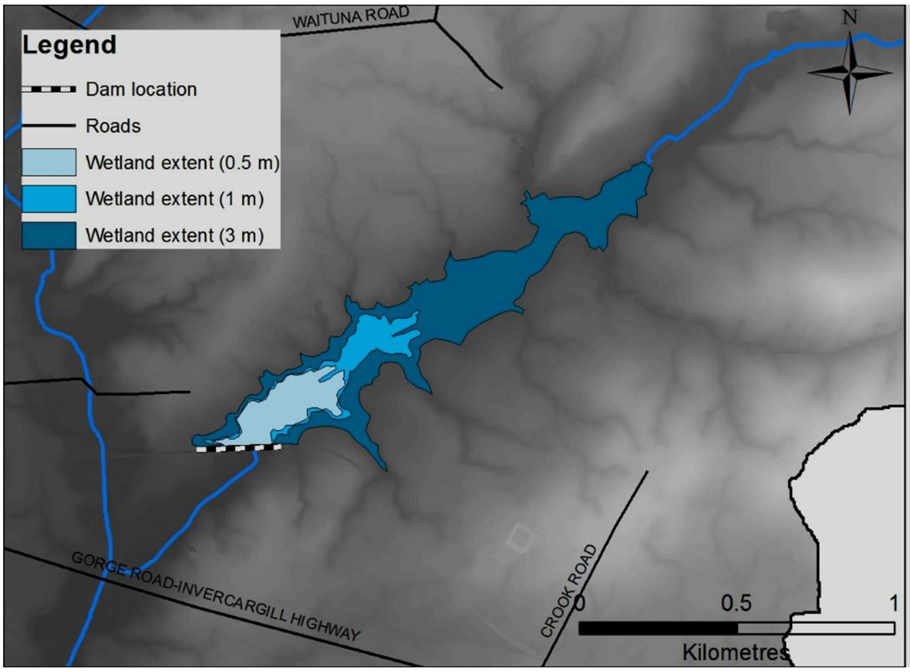


Figure 6-21: Waituna Creek channel site 1 and three possible wetland extents. Wetland extents are based on the depth of water above the present floodplain level at the selected impoundment site. Note that the channel is ~2.4 metres deep at the suggested impoundment site.

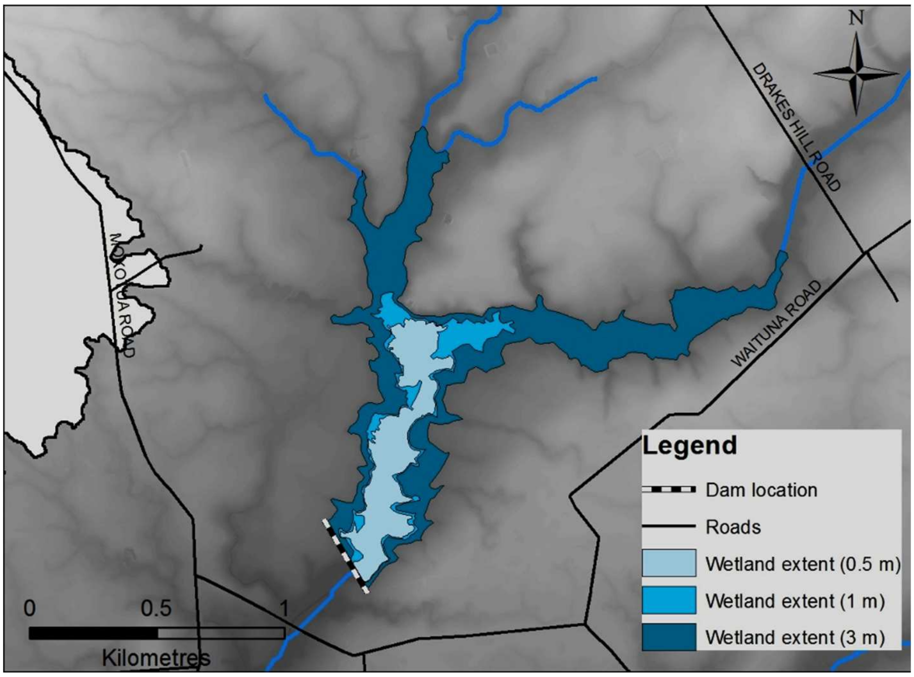


Figure 6-22: Waituna Creek channel site 2 and three possible wetland extents. Wetland extents are based on the depth of water above the present floodplain level at the selected impoundment site. Note that the channel is ~3 metres deep at the suggested impoundment site.

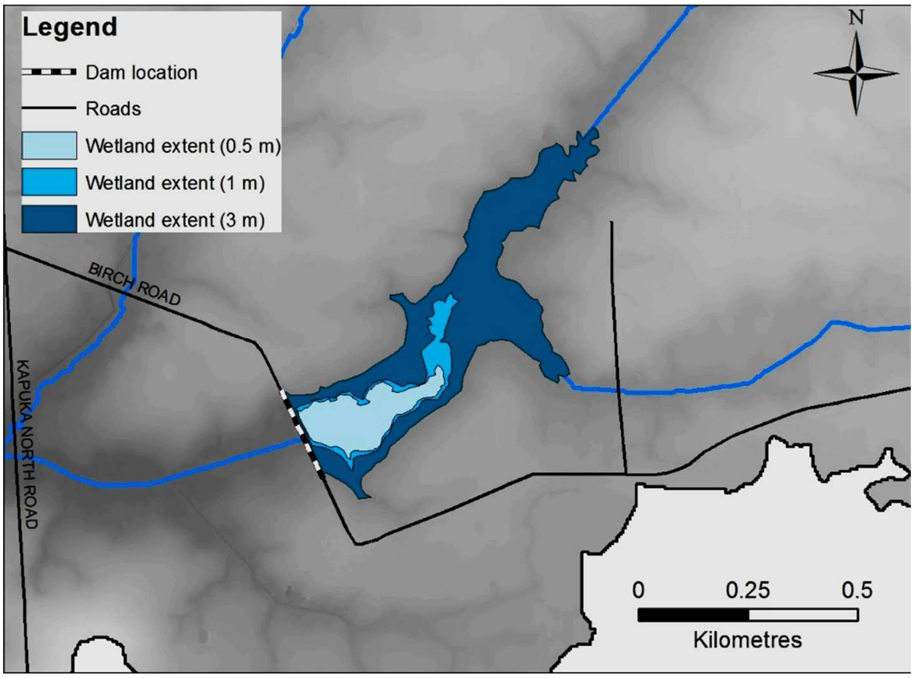


Figure 6-23: Waituna Creek channel site 3 and three possible wetland extents. Wetland extents are based on the depth of water above the present floodplain level at the selected impoundment site. Note that the channel is ~2.5 metres deep at the suggested impoundment site.

6.2.6 Farm race causeway sites

A suitable farm-race wetland site was observed on the Clinton property (Figure 6-24). The Clinton farm race site is, however, outside of the Waituna catchment therefore no LiDAR data was available to model wetland extent. Two other sites were, however, located by examining satellite imagery and the LiDAR data. Both sites are located in the northern Waituna Creek catchment area (Figure 5-1). For Site 1 three different water level scenarios were modelled (0.2 m, 0.5 m and 1 m; Figure 6-25). At Site1 the farm race level would need to be raised over more than17 m of its length for the 0.2 m scenario and over 45 m of its length for the 1 m scenario (Table 6-9). The wetland size as a percentage of catchment area would range from 2.9 % for the 0.2 m scenario to 7.8% for the 1 m scenario.

For Site 2 two different water level scenarios were modelled (0.5 m and 0.7 m; Figure 6-26). For the 0.5 m scenario the current farm race level would sufficient to impound all the water, but at least 33 metres of farm race would need to be raised for the 0.7 m scenario (Table 6-9). The wetland size as a percentage of catchment area would range from 2.6 % for the 0.5 m scenario to 20.8% for the 0.7 m scenario.

Figure 6-24: Farm race bund on the Clinton farm. This location is outside of the Waituna Catchment but is included as a good visual example of a potential farm race site.

Table 6-9: Farm race site location and contributing area data.

Site	Easting	Northing	Depth at dam (m)	Dam width (m)	Catchment area (ha)	wetland area (ha)	Wetland as % of catchment area
Farm race 1 (0.2m)	2174083	5411184	0.2	17	16.7	0.48	2.9
Farm race 1 (0.5m)	2174083	5411184	0.5	26	16.7	0.72	4.3
Farm race 1 (1m)	2174083	5411184	1	45	16.7	1.31	7.8
Farm race 2 (0.5m)	2176258	5413458	0.5	0	2.3	0.06	2.6
Farm race 2 (0.7m)	2176258	5413458	0.7	33	2.3	0.48	20.8

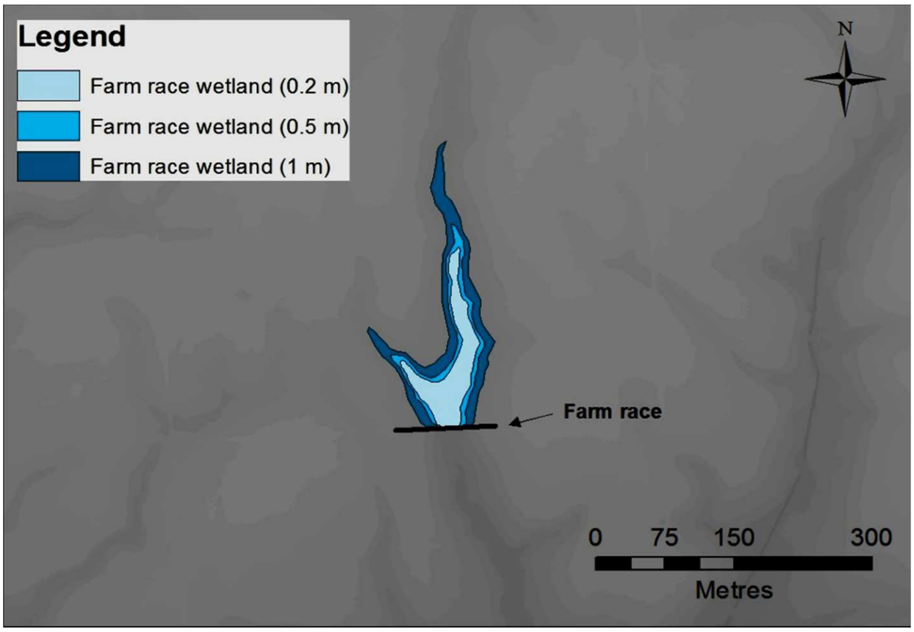


Figure 6-25: Farm race site 1 and three possible wetland extents. Wetland extents are based on the depth of water above the base of the current farm race bund.

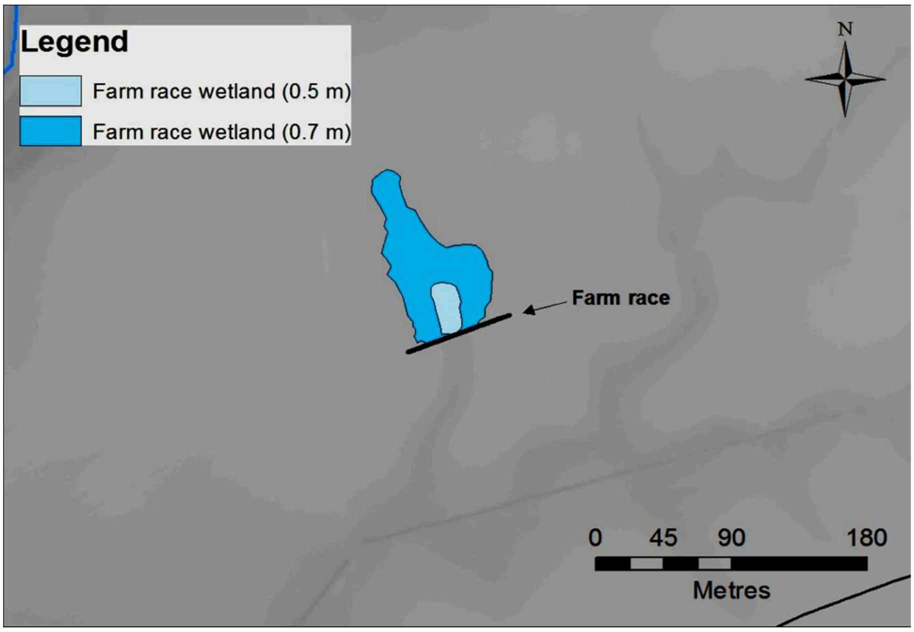


Figure 6-26: Farm race site 2 and three possible wetland extents. Wetland extents are based on the depth of water above the base of the current farm race bund.

7 Modelled contaminant attenuation

7.1 General performance attributes

Modelled removal of suspended solids and nutrients by constructed wetlands depends primarily on influent concentrations and inflow rates, temperature (N only), and the area of the wetland (Kadlec and Wallace 2009). Based on long-term mean seasonal run-off yield and nutrient concentrations recorded for the Waituna Creek catchment (and assuming standardised wetland conditions in terms of vegetation, depth, shape and hydraulic efficiency), Figure 7-1 shows how the percentage removal of Nitrate-N will vary as the wetland area (as a percentage of contributing catchment) increases. The percentage of nitrate-N removal achieved can be seen to be considerably higher in summer when flows are lower (so hydraulic residence times in the wetland will be longer) and higher temperatures stimulate higher rates of microbial denitrification in the wetland.

As the relative size of wetlands increase there are gradually reducing returns (i.e., a doubling of wetland size does not result in a doubling of treatment performance). This means that it is always easiest (and cheapest) to remove the first 1% of a contaminant, and each additional 1% removed will require a larger wetland area than the previous one. Wetlands treating higher contaminant concentrations and more consistent flows will also tend to perform best in terms of load removed per unit area (Tanner and Kadlec 2013). The reasons behind these performance responses and implications for wetland treatment efficiency are further elaborated in Kadlec and Wallace (2009) and Kadlec (2012).

Figure 7-2 shows the equivalent relationship for TP. In this case rates of removal do not vary substantially with temperature and the predominant effect is due to differences in influent flow rates and concentrations between seasons. However for both TN and TP, the higher flows and concentrations during winter mean that the loading rates to the wetland (g of contaminant per m^2 per day) are markedly higher. This means that despite lower apparent efficiency (% removal), the quantity of contaminant removed by the wetland during winter will actually be higher than during summer.

To take account of these seasonal differences in loading and performance we have modelled wetland performance for each season (based on average seasonal flows and concentrations) and then summed these to estimate annual performance in terms of the load or quantity of contaminants removed. To give an overall indication of expected performance of the different wetland options investigated in this assessment, the modelled annual performance for Nitrate-N and TN percentage load reduction has been plotted for each wetland according to its relative size in Figure 7-3. The data has been re-plotted in Figure 7-4 to identify the sites involved. Because many of the wetlands investigated were clustered below 1% of catchment area and would not otherwise be easily distinguished from each other, a log scale has been used on the horizontal axis.

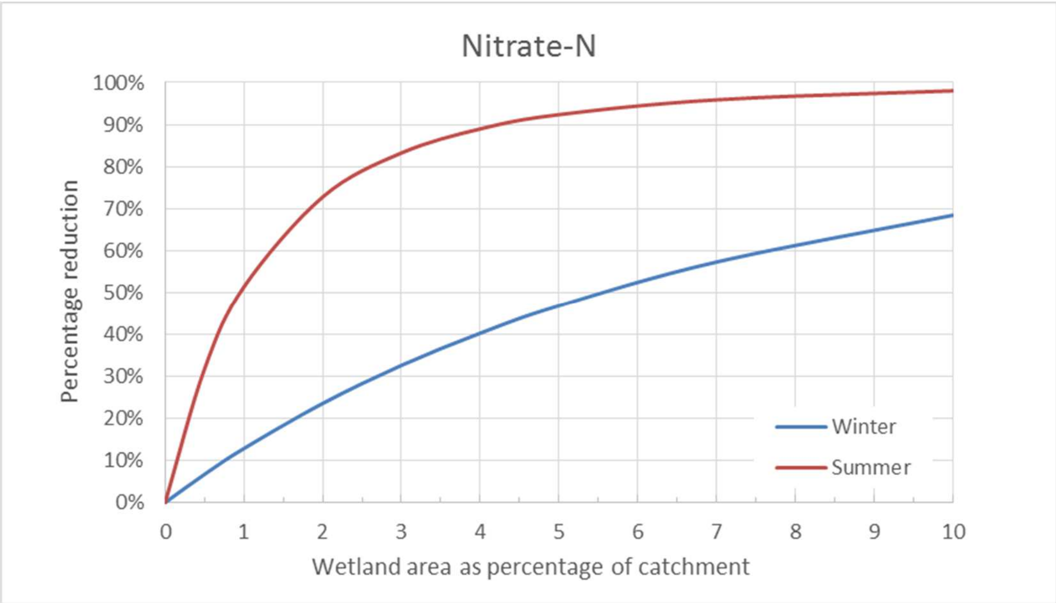


Figure 7-1: Generalised percent nitrate removal as a percentage of catchment as constructed wetland. Summer and winter extremes shown.

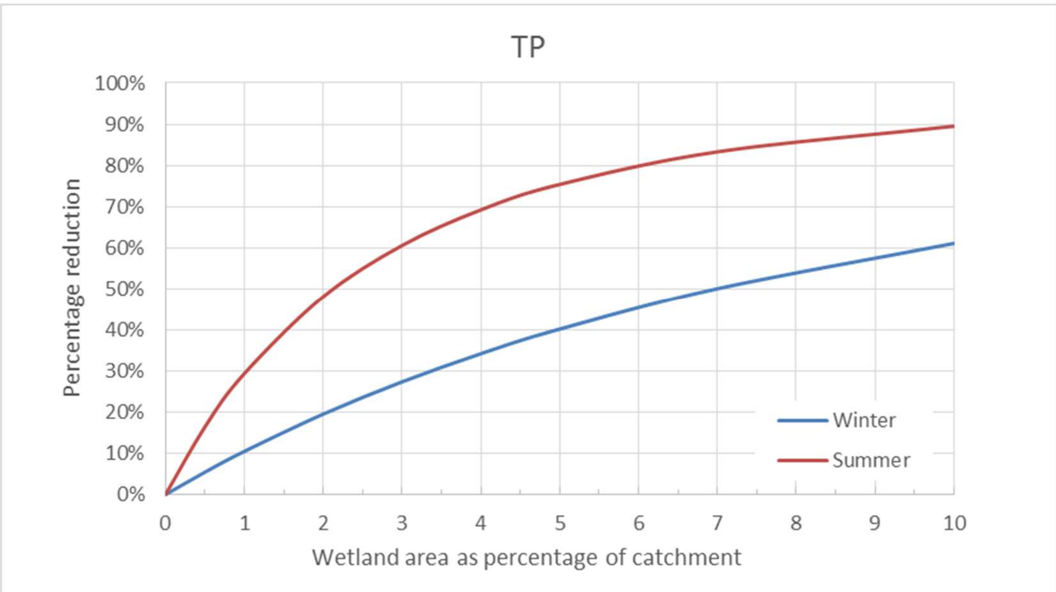


Figure 7-2: Generalised percent TP removal as a percentage of catchment as constructed wetland.

It can be seen that percentage nitrate-N removal (which comprises around half to two thirds of TN) is removed at a slightly higher rate than TN, and that annual treatment performance shows a clear relationship to relative wetland area across a wide range of actual wetland sizes. The modelling predicts that constructed wetlands would need to occupy more than 2% of the catchment to reduce annual TN loads by 30% and occupy 5% or more of the catchment to reduce annual TN loads by 50%.

Figure 7-5 and Figure 7-6 show equivalent annual percentage removal for TSS and TP. Removal of a large proportion of TSS can be achieved in relatively small wetland areas comprising 0.5% or less of the contributing catchment. Larger wetlands do not show much further improvement in removal due to autochthonous production of organic TSS in the wetland itself, which we assume results in an irreducible background load. The removal rates estimated have been restricted in many cases by the relatively low mean concentrations of TSS that have been applied in our modelling based on measured concentrations in the main Waituna Catchment creeks. Elevated TSS levels that occur during storm-flows and following drain clearance (Ballantine and Hughes 2012) are also likely to be substantially reduced by wetlands, so the modelled TSS removal rates are likely to be conservative estimates.

Annual percent TP reduction follows a similar performance relationship to that shown by TN. The modelling predicts that constructed wetlands would need to occupy around 2.5% of the catchment to reduce annual TP loads by 30% and occupy around 5% of the catchment to reduce annual TP loads by 50%.

7.2 Relative removal of different contaminants

Table 7-1 summarises the annual treatment performance predicted for each contaminant for each of the different wetland options. This shows that the quantity and efficiency of suspended solids removal is substantially higher than for nutrients, and the quantity of TN removal is substantially greater than for TP. However, the percentage reduction of both TP and TN is predicted to be roughly similar. The differences in loads removed for the different contaminants primarily reflect differences in relative concentrations and loads exported from the catchment. Suspended sediments are readily removed though simple physical settling processes in relatively small wetland areas, while removal of dissolved forms of nutrients requires relatively larger wetland areas.

Wetland nutrient removal in terms of kg removed per hectare of wetland is expected to be highest for wetlands treating drain flows, which typically show higher influent concentrations than the main stream channels.

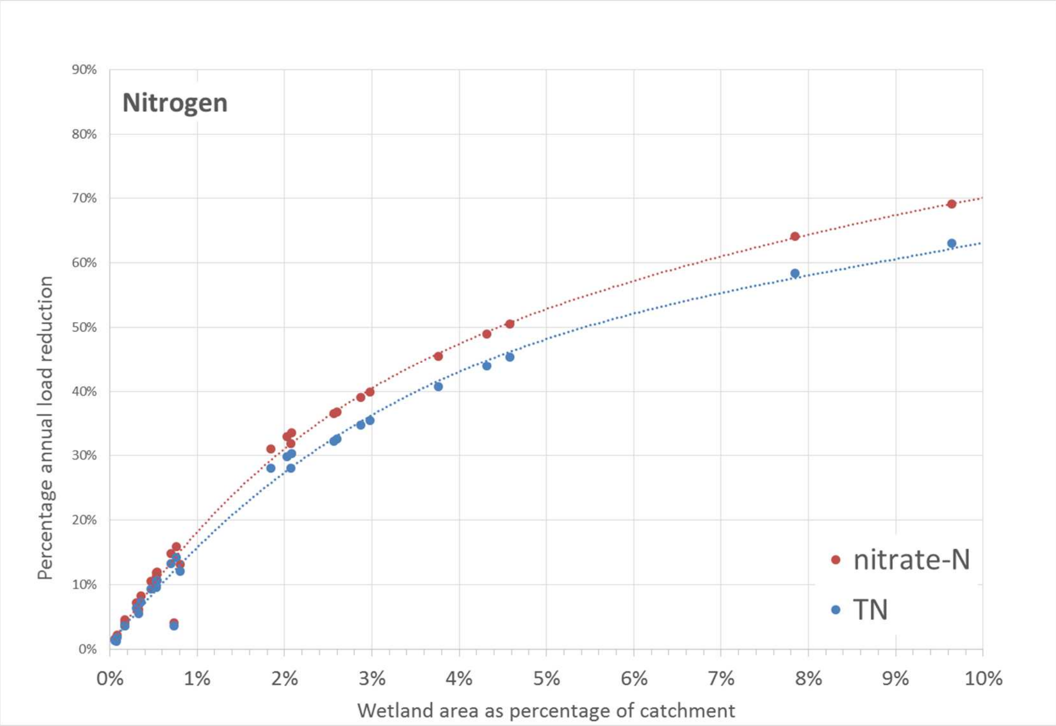


Figure 7-3: Predicted annual percent nitrate-N and TN removal as a percentage of catchment for the constructed wetland options investigated. Wetland options > 10% of catchment area excluded.

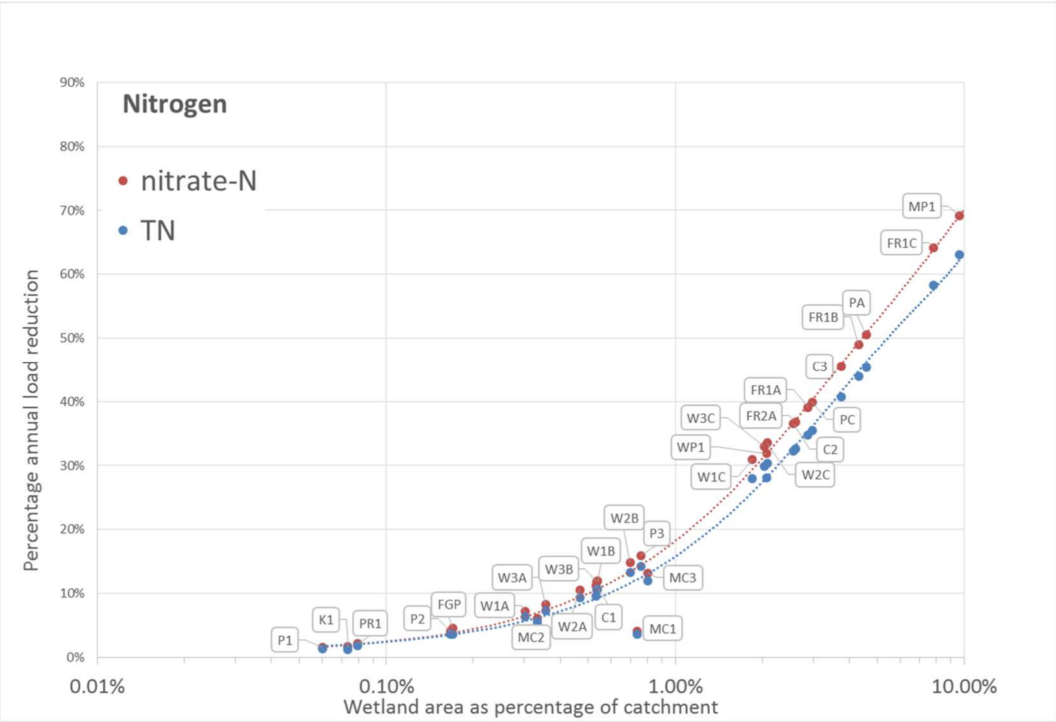


Figure 7-4: Predicted wetland nitrate-N and TN removal performance identifying specific wetland options. The position of sites on the nitrate-N line are equivalent to the point on the TN line directly below each marker. Note log scale on x-axis.

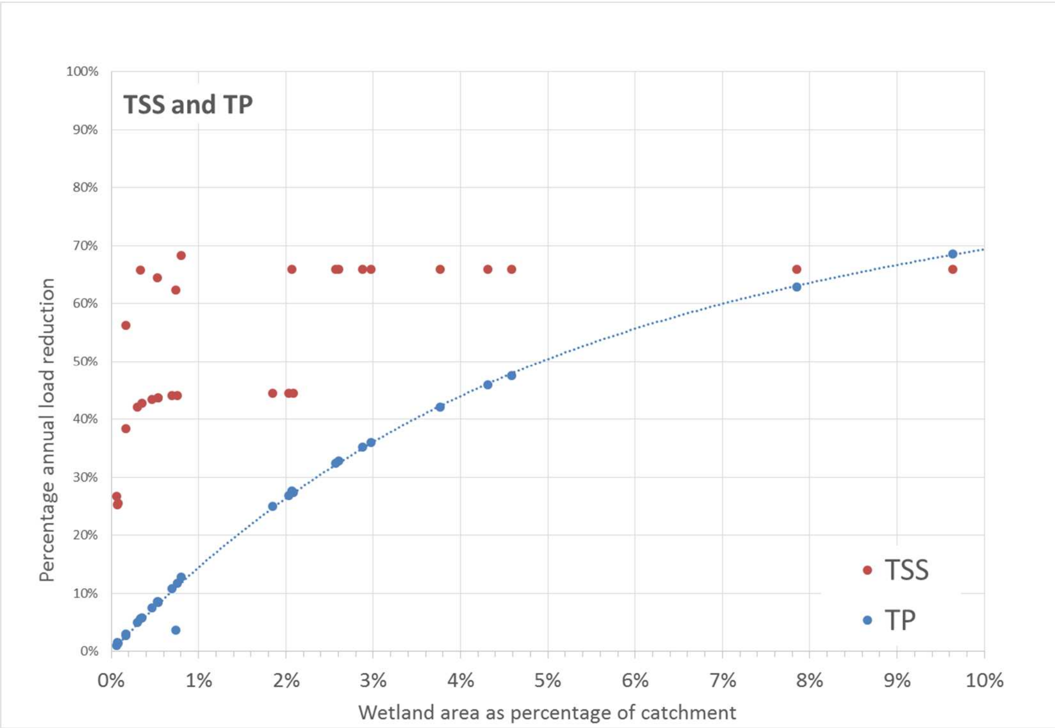


Figure 7-5: Predicted annual percent TSS and TP removal as a percentage of catchment for the constructed wetland options investigated. Wetland options > 10% of catchment area excluded.

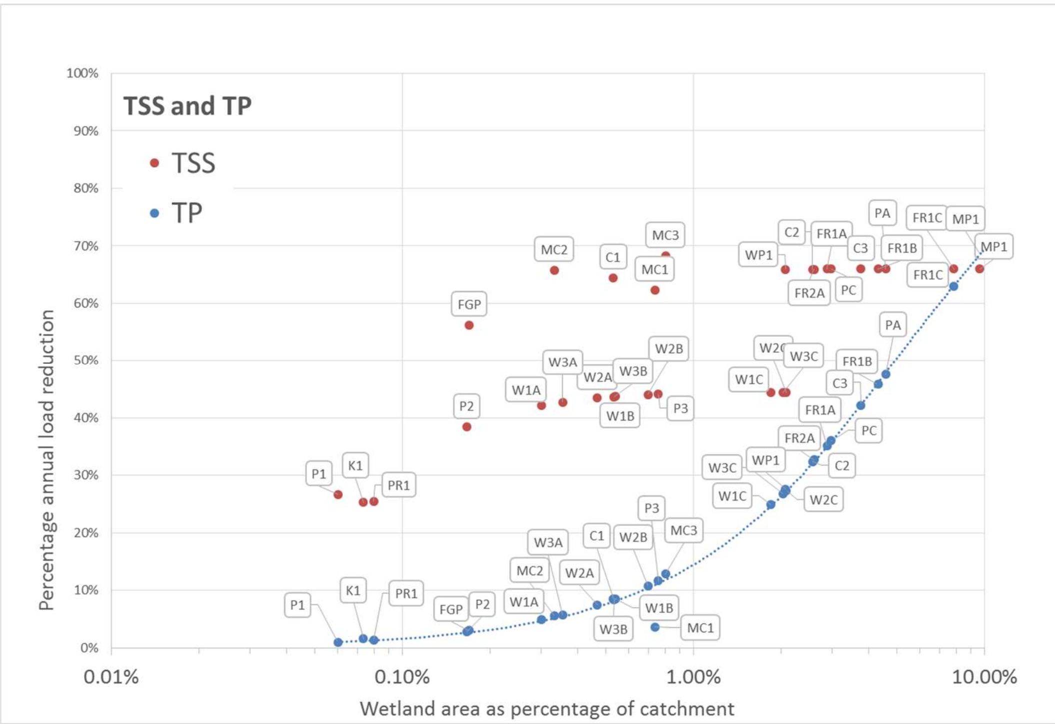


Figure 7-6: Predicted wetland TP removal performance identifying specific wetland options. Sites are identified for both TSS and TP. Note log scale on x-axis.

Table 7-1: Predicted annual loading and treatment performance. Note areal wetland in-loads and reductions for TP expressed as g/m²/yr, other contaminants as kg/m²/yr)

Site	Code	Wetland as % of catch-ment area	TSS				TP[1]				TN			
			In load (kg/m²/yr)	Load reduced (kg/m²/yr)	% load reduced	Load reduced (kg/wetland/yr)	In load (g/m²/yr)	Load reduced (g/m²/yr)	% load reduced	Load reduced (kg/wetland/yr)	In load (kg/m²/yr)	Load reduced (kg/m²/yr)	% load reduced	Load reduced (kg/wetland/yr)
McCrostie (0.5m)	MC1	0.80%	3.90	2.43	62%	313,756	20.62	0.76	4%	98	0.816	0.029	4%	3,801
McCrostie (1m)	MC2	0.06%	2.50	1.65	66%	330,862	13.24	0.75	6%	150	0.524	0.029	5%	5,767
McCrostie (2m)	MC3	0.17%	1.04	0.71	68%	343,449	5.49	0.70	13%	342	0.217	0.026	12%	12,661
Pirie (0.5m)	P1	0.76%	7.79	2.08	27%	27,048	28.31	0.29	1%	4	2.525	0.034	1%	442
Pirie (1m)	P2	0.30%	2.81	1.08	38%	38,912	10.22	0.28	3%	10	0.912	0.033	4%	1,187
Pirie (3m)	P3	0.54%	0.62	0.27	44%	44,687	2.24	0.26	12%	43	0.200	0.028	14%	4,664
Waituna1 (0.5m)	W1A	1.85%	1.55	0.65	42%	30,752	5.64	0.28	5%	13	0.503	0.032	6%	1,494
Waituna1 (1m)	W1B	0.47%	0.87	0.38	44%	31,922	3.16	0.27	9%	23	0.282	0.030	11%	2,515
Waituna1 (3m)	W1C	0.70%	0.25	0.11	44%	32,432	0.92	0.23	25%	66	0.082	0.023	28%	6,629
Waituna2 (0.5m)	W2A	2.08%	1.00	0.44	43%	61,800	3.64	0.27	7%	39	0.324	0.030	9%	4,326
Waituna2 (1m)	W2B	0.36%	0.67	0.30	44%	62,628	2.44	0.26	11%	56	0.217	0.029	13%	6,112
Waituna2 (3m)	W2C	0.53%	0.23	0.10	44%	63,175	0.82	0.22	27%	142	0.073	0.022	30%	14,006
Waituna3 (0.5m)	W3A	2.03%	1.32	0.56	43%	15,759	4.79	0.28	6%	8	0.427	0.031	7%	878
Waituna3 (1m)	W3B	2.88%	0.88	0.38	44%	16,116	3.19	0.27	8%	11	0.284	0.030	11%	1,259
Waituna3 (3m)	W3C	4.31%	0.23	0.10	44%	16,383	0.84	0.23	27%	36	0.075	0.022	30%	3,570
Farm race 1 (0.2m)	FR1A	0.80%	0.27	0.18	66%	842	1.10	0.39	35%	2	0.063	0.022	35%	105
Farm race 1 (0.5m)	FR1B	0.06%	0.18	0.12	66%	842	0.73	0.34	46%	2	0.042	0.019	44%	133

[1] Note TP areal mass loading and removal expressed as g/m²/yr, compared to TSS and TN as kg/m²/yr (i.e., 1000-fold higher).

Site	Code	Wetland as % of catch-ment area	TSS				TP[1]				TN			
			In load (kg/m^2/yr)	Load reduced (kg/m^2/yr)	% load reduced	Load reduced (kg/wetland/yr)	In load (g/m^2/yr)	Load reduced (g/m^2/yr)	% load reduced	Load reduced (kg/wetland/yr)	In load (kg/m^2/yr)	Load reduced (kg/m^2/yr)	% load reduced	Load reduced (kg/wetland/yr)
Farm race 1 (1m)	FR1C	7.85%	0.10	0.06	66%	842	0.40	0.25	63%	1.9	0.023	0.014	58%	177
Farm race 2 (0.5m)	FR2A	2.60%	0.29	0.19	66%	116	1.22	0.40	33%	2.4	0.070	0.023	33%	14
Farm race 2 (0.7m)	FR2B	20.78%	0.04	0.02	66%	117	0.15	0.13	85%	3.3	0.009	0.007	78%	33
Pirie Site A	PA	4.58%	0.17	0.11	66%	1,267	0.69	0.33	48%	0.2	0.040	0.018	45%	207
Pirie Site B	PB	11.99%	0.06	0.04	66%	232	0.26	0.20	74%	0.6	0.015	0.010	68%	57
Pirie Site C	PC	2.98%	0.26	0.17	66%	475	1.06	0.38	36%	3.8	0.061	0.022	35%	61
Pirie runoff (3 stepped wetlands)	PR1	0.08%	5.28	1.35	26%	2,198	20.84	0.28	1%	0.5	1.995	0.036	2%	59
Kelly	K1	0.07%	4.59	1.16	25%	24,295	68.17	1.07	2%	1.1	0.954	0.011	1%	240
Fisken gravel pit	FGP	0.17%	4.16	2.34	56%	562	16.74	0.51	3%	8.3	1.023	0.037	4%	9
Clinton (poorly drained area)	C1	0.53%	1.44	0.93	64%	5,768	5.98	0.51	9%	22.3	0.343	0.033	10%	204
Clinton (0.5m)	C2	2.57%	0.30	0.20	66%	5,900	1.24	0.40	32%	0.1	0.071	0.023	32%	687
Clinton (1m)	C3	3.76%	0.20	0.13	66%	5,902	0.84	0.35	42%	3.2	0.048	0.020	41%	866
Warnock pond	WP1	7.85%	0.37	0.24	66%	1,705	1.53	0.42	28%	12.0	0.088	0.025	28%	172

[1] Note TP areal mass loading and removal expressed as g/m^2/yr, compared to TSS and TN as kg/m^2/yr (i.e., 1000-fold higher).

8 Costs and benefits

8.1 Cost estimates

The relative costs estimated for removal per kg of contaminants primarily reflect differences in mass loads of the different contaminants lost from the catchment and secondarily the relative efficiency with which they can be removed by wetlands (Table 8-1). Costs per kg for TP removal are thus much higher than for TN, which in turn are much higher than for TSS removal.

The costs for different wetlands are also influenced by the costs expected to be incurred in constructing wetlands at the specific site and the productive potential of the land they occupy. Constructed wetlands on low productivity land are likely to have less impact on farm profitability than those constructed on high productivity land. Wetlands constructed within the contributing catchment are also expected to be simpler and cheaper to build than wetlands constructed in main stream channels, but as the size of wetlands increase their costs per unit area will tend to reduce. Although the costs are calculated individually for each contaminant, in reality all contaminants would be removed concurrently, and are so are essentially cross-subsidised by each other. Further cost issues are discussed in the following sub-section (8.2).

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Table 8-1: Wetland type and cost indices.

Site	Code	Wetland area (ha)	Construction cost	Annualised cost	Annual cost $ per kg pollutant removed				Productive value of land	Construction type[1]
					TSS	TP	Nitrate-N	TN		
McCrostie (0.5m)	MC1	12.90	$2,688,168	$126,784	0.40	1294.01	47.72	33.35	High	Main channel
McCrostie (1m)	MC2	20.10	$3,650,520	$175,675	0.53	1168.91	43.83	30.46	High	Main channel
McCrostie (2m)	MC3	48.50	$6,703,649	$338,328	0.99	990.42	39.19	26.72	High	Main channel
Pirie (0.5m)	P1	1.30	$551,786	$24,195	0.89	6476.29	61.82	54.77	High	Main channel
Pirie (1m)	P2	3.60	$1,114,290	$50,183	1.29	4922.20	47.83	42.28	High	Main channel
Pirie (3m)	P3	16.40	$3,172,428	$151,219	3.38	3520.24	37.07	32.42	High	Main channel
Waituna1 (0.5m)	W1A	4.7	$1,339,359	$60,825	1.98	4654.21	46.19	40.71	High	Main channel
Waituna1 (1m)	W1B	8.4	$1,999,411	$92,678	2.90	4094.68	41.99	36.85	High	Main channel
Waituna1 (3m)	W1C	28.78	$4,676,513	$229,162	7.07	3463.06	40.03	34.57	High	Main channel
Waituna2 (0.5m)	W2A	14.2	$2,872,291	$136,033	2.20	3522.30	35.79	31.45	High	Main channel
Waituna2 (1m)	W2B	21.2	$3,787,226	$182,725	2.92	3265.46	34.15	29.89	High	Main channel
Waituna2 (3m)	W2C	63.2	$8,047,190	$412,893	6.54	2917.11	34.20	29.48	High	Main channel
Waituna3 (0.5m)	W3A	2.80	$936,890	$41,886	2.66	5419.02	54.20	47.73	High	Main channel
Waituna3 (1m)	W3B	4.20	$1,239,343	$56,081	3.48	4952.01	50.75	44.54	High	Main channel
Waituna3 (3m)	W3C	15.97	$3,114,798	$148,293	9.05	4121.78	48.17	41.54	High	Main channel
Farm race1 (0.2m)	FR1A	0.48	$1,344,084	$2,719	3.23	1461.41	32.10	25.81	High	Contributing/partial
Farm race1 (0.5m)	FR1B	0.72	$1,825,260	$4,047	4.80	1667.80	38.17	30.36	High	Contributing/partial
Farm race1 (1m)	FR1C	1.31	$3,351,824	$6,875	8.16	2065.92	49.47	38.84	High	Contributing/partial
Farm race2 (0.5m)	FR2A	0.06	$275,893	$360	3.10	1505.11	32.69	26.37	High	Contributing/partial
Farm race2 (0.7m)	FR2B	0.48	$557,145	$2,719	23.32	4346.69	107.94	83.26	High	Contributing/partial
Pirie Site A	PA	1.15	$108,230	$4,972	3.92	1314.17	30.24	24.02	Low	Contributing/partial

Site	Code	Wetland area (ha)	Construction cost	Annualised cost	Cost per kg pollutants removed				Productive value of land	Construction type[1]
					TSS	TP	Nitrate-N	TN	High/Low	
Pirie Site B	PB	0.55	$54,054	$2,510	10.84	2328.43	56.92	44.35	Low	Contributing/partial
Pirie Site C	PC	0.28	$999,706	$1,605	3.38	1494.56	32.95	26.47	High	Contributing/partial
Pirie runoff (3 stepped wetlands)	PR1	0.163	$131,692	$5,398	2.46	11891.68	97.78	91.26	Low	Main channel
Kelly	K1	2.09	$326,886	$14,142	0.58	632.80	95.02	58.88	Low	Contributing/full
Fisken gravel pit	FGP	0.024	$2,359	$124	0.22	1013.24	15.05	13.80	Low	Contributing/minimal
Clinton (poorly drained area)	C1	0.62	$60,934	$2,821	0.49	888.45	16.49	13.83	Low	Contributing/partial
Clinton (0.5m)	C2	3	$468,445	$13,101	2.22	1090.13	23.64	19.08	High	Contributing/partial
Clinton (1m)	C3	4.4	$619,671	$17,732	3.00	1135.75	25.65	20.48	High	Contributing/partial
Warnock pond	WP1	0.7	$68,796	$3,176	1.86	1072.57	22.70	18.43	Low	Contributing/partial

1. Main channel and contributing refer to location , and partial and full refer to extent of excavation expected. See Section 5.5 for further information.

8.2 Wetland ranking and prioritisation

8.2.1 Ranking cost-effectiveness in terms of a primary contaminant

Because each of the contaminants show substantially different costs per kg to remove, direct comparison across the spectrum of contaminants of interest is difficult. To visualise the relative cost/benefit of the different CW options, all options were plotted for each contaminant, comparing cost per kg removed verses percent of catchment occupied. This is illustrated for TN in Table 8-2 [Results for other contaminants are available in the Appendices (Figure A-1 to Figure A-8)]. Specific sites are identified in Figure 8-2 for the subset of wetlands occupying <5% of catchment with lowest relative costs per kg of TN removed. This subset of options is ranked in Table 8-1 based on cost per kg of TN removed (from lowest to highest), and provides information on the associated removal of the other contaminants. This allows comparison and sequential selection of options with greatest cost-benefit in terms of a primary contaminant of concern.

In most instances the smallest wetland at a given site will have the lowest cost per kg of contaminant removed and will be the higher-ranked option, however there are some exceptions. For example, if a larger-sized wetland option at a site still ranks above other comparable sites, we have selected the larger CW, despite it being more expensive per kg of contaminant removed.

We have also cumulatively summed the total construction costs of the selected wetlands. Thus, depending on total funds available (and priority pollutant chosen), the funder can simply move down the list until arriving at the maximum available funding available (up to a maximum of ~$5M). At this point, the funder may choose to substitute a higher cost CW for a number of lower cost ones to allow extra sites to be constructed. Tables showing ranking for each of the contaminants considered in this report are presented in Appendix B as this may assist Environment Southland in exploring alternative prioritisations.

8.2.2 Ranking cost-effectiveness across multiple contaminants

Simultaneous reductions of TSS, TP and TN have all been identified as necessary for protection of Waituna Lagoon. The wetland options are compared and ranked in Table 8-3 by considering all contaminants of equal importance. This identifies 4 sites (MC3, FGP, C1,WP1) in which removal of all three contaminants is in the top third in terms of cost effectiveness, followed by a further 4 sites with removal in the top third of cost-effectiveness for two contaminants and the middle third for the other contaminant (all of which are size variants of one the top ranked options). It is interesting to note that both large main channel and smaller contributing catchment wetlands can show high cost-effectiveness depending on the situation.

The lower peat-dominated parts of the catchment drained via the Moffat and Carran Creeks are characterised by relatively high P losses but low net nitrogen losses (presumably due to denitrification during passage through the organic soils) so at these sites the cost per kg of TN removal is relatively high, while the cost per kg of TSS and TP removal is relatively low. This illustrates one of the potential issues that can arise when multiple contaminants are considered equally across a catchment.

Table 8-2: Ranking of constructed wetlands based on their relative cost for removal of TN. Construction costs and net annual removal of other priority pollutants are presented along with cumulative construction costs.

Site	Code	% of catchment	Wetland area (ha)	TN $ kg-1	Construction cost	Cumulative cost	Annual TSS removal kg	Annual TP removal kg	Annual TN removal kg	Annual Nitrate-N removal kg
Fiskin gravel pit	FGP	0.2%	0.024	**$ 13.80**	$ 2,359	$ 2,359	562	0.1	9	8
Clinton (1m)	C3	3.8%	4.4	**$ 20.48**	$ 273,179	$ 275,538	5902	3.2	866	691
Warnock pond	WP1	2.1%	0.7	**$ 22.84**	$ 68,796	$ 344,334	1705	3.0	172	140
Pirie Site A	PA	4.6%	1.15	**$ 24.02**	$ 108,230	$ 452,564	1267	3.8	207	164
Farm race 1 (0.2m)	FR1A	2.9%	0.48	**$ 25.81**	$ 47,174	$ 499,738	842	1.9	105	85
Farm race 2 (0.5m)	FR2A	2.6%	0.06	**$ 26.37**	$ 5,897	$ 505,635	116	0.2	14	11
Pirie Site C	PC	3.0%	0.28	**$ 26.47**	$ 27,518	$ 533,153	475	1.1	61	49
McCrostie (2m)	MC3	0.8%	48.5	**$ 26.72**	$ 3,351,824	$ 3,884,977	343449	342	12661	8633
Waituna2 (3m)	W2C	2.1%	63.2	**$ 29.48**	$ 4,023,595	$ 7,908,572	63175	142	14006	12074
Pirie (3m)	P3	0.8%	16.4	**$ 32.42**	$ 1,586,214	$ 9,494,786	44687	43	4664	4079
Waituna1 (3m)	W1C	1.9%	28.78	**$ 34.57**	$ 2,338,256	$ 11,833,042	32432	66	6629	5725
Waituna3 (3m)	W3C	2.0%	15.97	**$ 41.54**	$ 1,557,399	$ 13,390,441	16383	36	3570	3078
Pirie Site B	PB	12.0%	0.55	**$ 44.35**	$ 54,054	$ 13,444,495	232	1.1	57	44
Kelly	K1	0.1%	2.09	**$ 58.88**	$ 163,443	$ 13,607,938	24295	22	240	149
Pirie runoff (3 stepped wetlands)	PR1	0.1%	0.163	**$ 91.34**	$ 65,846	$ 13,673,784	2198	0.5	59	55

Table 8-3: Traffic light ranking of sites based on relative removal costs for all three priority contaminants. Green (score of 3) signifies that cost of removal for the wetland proposed at this site is in the lowest third, amber (score of 2) the mid third, and red (score of 1) the highest third of those being considered. The scores (1-3; for lowest to highest cost effectiveness) are then averaged across the 3 contaminants and sites correspondingly ranked.

Wetland	Code	TSS	TP	TN	Average score	Rank
McCrostie (0.5m)	MC1	Green	Green	Amber	2.67	5
McCrostie (1m)	MC2	Green	Green	Amber	2.67	5
McCrostie (2m)	MC3	Green	Green	Green	3.00	1
Pirie (0.5m)	P1	Green	Red	Red	1.67	15
Pirie (1m)	P2	Green	Red	Red	1.67	15
Pirie (3m)	P3	Green	Amber	Amber	1.67	15
Waituna1 (0.5m)	W1A	Green	Red	Red	1.67	15
Waituna1 (1m)	W1B	Amber	Red	Amber	1.67	15
Waituna1 (3m)	W1C	Red	Amber	Amber	1.67	15
Waituna2 (0.5m)	W2A	Amber	Red	Amber	1.67	15
Waituna2 (1m)	W2B	Amber	Amber	Amber	2.00	13
Waituna2 (3m)	W2C	Red	Amber	Amber	1.67	15
Waituna3 (0.5m)	W3A	Amber	Red	Red	1.33	25
Waituna3 (1m)	W3B	Red	Red	Red	1.00	28
Waituna3 (3m)	W3C	Red	Red	Red	1.00	28
Farm race 1 (0.2m)	FR1A	Amber	Amber	Green	2.33	9
Farm race 1 (0.5m)	FR1B	Red	Amber	Amber	1.67	15
Farm race 1 (1m)	FR1C	Red	Amber	Amber	1.67	15
Farm race 2 (0.5m)	FR2A	Amber	Amber	Green	2.33	9
Farm race 2 (0.7m)	FR2B	Red	Red	Red	1.00	28
Pirie Site A	PA	Red	Green	Green	2.33	9
Pirie Site B	PB	Red	Amber	Red	1.33	25
Pirie Site C	PC	Red	Amber	Green	2.00	13
Pirie runoff (3 stepped wetlands)	PR1	Amber	Red	Red	1.33	25
Kelly	K1	Green	Green	Red	2.33	9
Fisken gravel pit	FGP	Green	Green	Green	3.00	1
Clinton (poorly drained area)	C1	Green	Green	Green	3.00	1
Clinton (0.5m)	C2	Amber	Green	Green	2.67	5
Clinton (1m)	C3	Amber	Green	Green	2.67	5
Warnock pond wetlands	WP1	Green	Green	Green	3.00	1

9 Summary

Thirty different constructed wetland options at 14 different sites were investigated across the Waituna catchment. The Waituna Creek has the highest yield of TSS and TN, and offers the greatest range of potentially viable opportunities for wetland construction, ranging from large main-channel wetlands in the centre of the catchment approaching 50 ha down to small wetlands in the contributing catchment of 600 m^2. Opportunities were less common at the bottom of the catchment where the low gradient would necessitate large-scale excavation for wetland construction and there was high potential to impact on water tables and drainage efficiency in adjacent areas.

Predicted TSS reductions ranged from 0.02-2.4 kg/m^2 of wetland per year (25 to 68% load reduction), TP reductions from 0.13-1.1 g/m^2 of wetland per year (1-85% load reduction), and TN from 0.007-0.036 kg/m^2 of wetland per year (1-78% load reduction). The modelling predicts that constructed wetlands occupying 0.5% or less of the contributing catchment can substantially reduce TSS loads. Wetland areas comprising more than 2% of the catchment would be required to reduce annual TN loads by 30% and ~2.5% of the catchment to reduce annual TP loads by 30%. To reduce annual TN and TP loads by ~50%, constructed wetlands would need to occupy ~ 5% or more of the contributing catchment.

Estimated wetland construction costs for the sites investigated ranged from ~$2K to $8M. Annualised costs per kg of contaminant were calculated to provide a common unit to compare the cost benefit of different options. Minimum annualised costs per kg of contaminant removed were $0.22 for TSS, $632.80 for TP, and $13.80 for TN, reflecting their relative loads, the efficiency of wetland treatment, the relative costs of construction at different sites and the potential lost production from the land. Different wetland sites and options were ranked for each contaminant and also across all three priority contaminants.

Because of diminishing returns per unit area as wetland size increases, smaller wetlands removing a small fraction of the load will generally show the lowest cost per kilogram of contaminant removed. This means that prioritisation of sites really needs to be done in relation to an agreed contaminant removal target.

Other factors will also need to be considered in prioritising sites of highest priority for demonstration purposes including: practical feasibility, total construction costs relative to available funds, land value, representativeness, accessibility, and land-owner amenability and cooperation.

Although all efforts have been made within the scope of this assessment to provide the best information possible, it should be noted that there are uncertainties in both the cost and performance estimates provided and our site investigations have necessarily been preliminary in nature. Monitoring of financial costs for construction, operation and management, in addition to water quality performance of proposed demonstration systems will significantly improve our capacity to evaluate the real costs and benefits of constructed wetlands for attenuation of diffuse pollutant loads from intensive livestock farming.

10 Acknowledgements

This study was jointly funded by Environment Southland and DairyNZ. ES provided LIDAR elevation data, and comprehensive flow and water quality data collected within the Waituna Catchment. ES staff Andy Hicks, Roger Hodson and Clint Rissmann provided detailed local knowledge of the catchment and water quality issues facing the Waituna Lagoon. Katrina Robertson provided background on farming practices and organised a tour of key sites around the catchment and meetings with land owners. We are particularly grateful to the farmers who provided access to their farms and information on farm and drainage management, discussed potential wetland construction options, and shared their wealth of local knowledge which greatly assisted our understanding of the Waituna Catchment. Rachael Hayton, Financial Analyst at NIWA, developed the Net Present Value model used to calculate the annualised cost of wetlands over their operational lifetime.

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Appendix A Costs per kg of contaminant removed

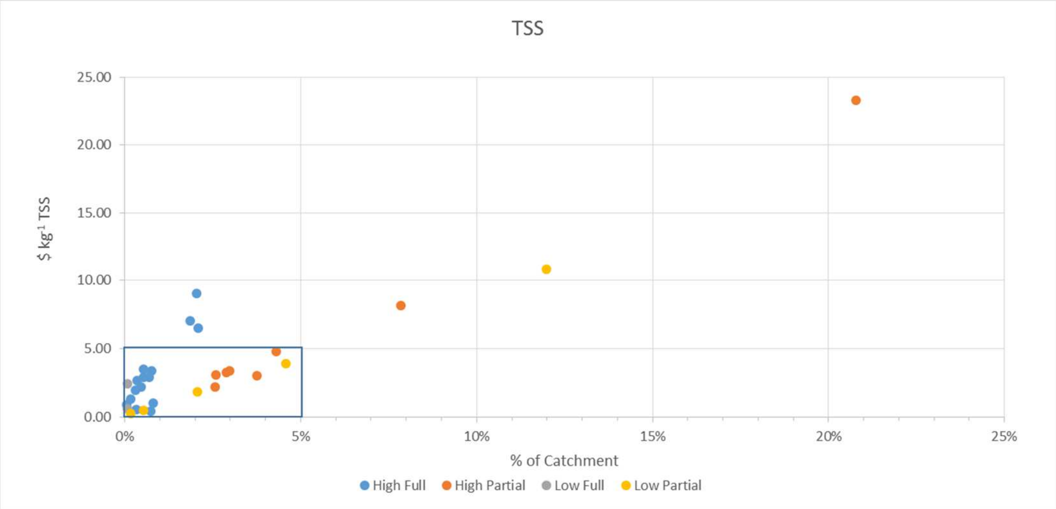

Figure A-1: Cost per kg of TSS removed vs. percent of catchment. All sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

Figure A-2: Cost per kg of TSS removed vs. percent of catchment (<5%). Codes refer to specific subset of wetland sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

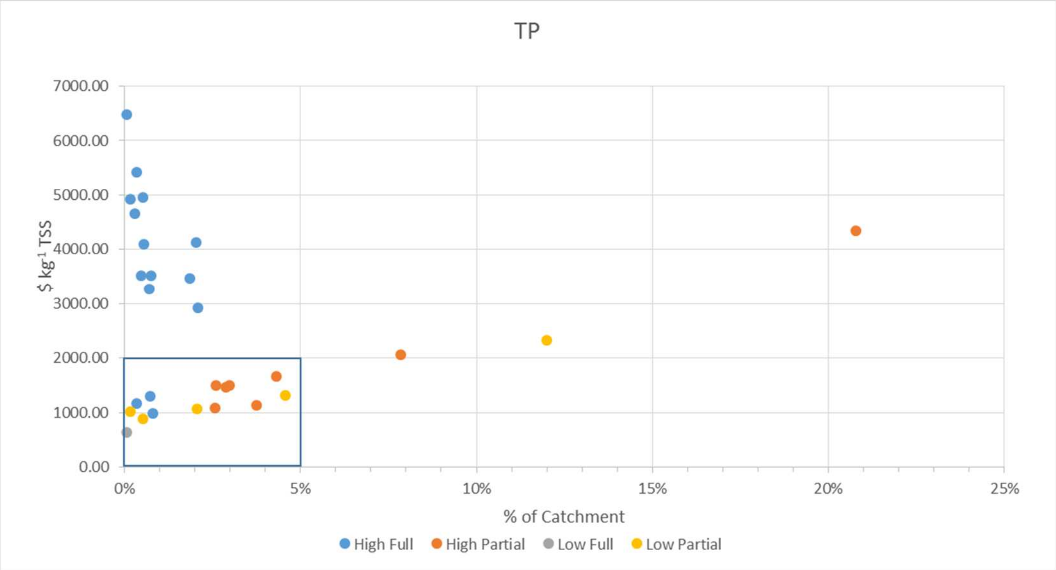

Figure A-3: Cost per kg of TP removed vs. percent of catchment. All sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

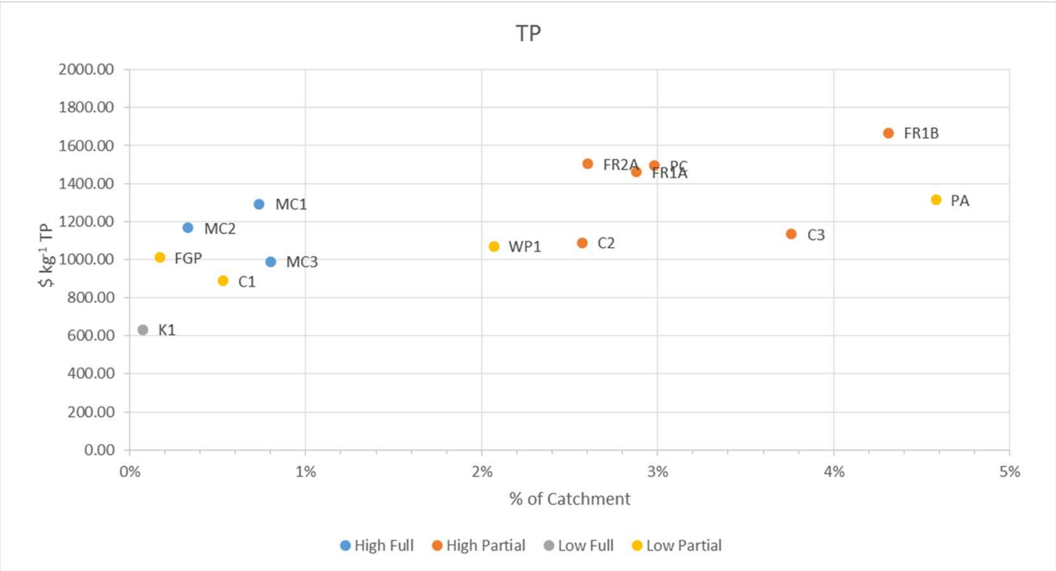

Figure A-4: Cost per kg of TP removed vs. percent of catchment (>5%). Codes refer to specific subset of wetland sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

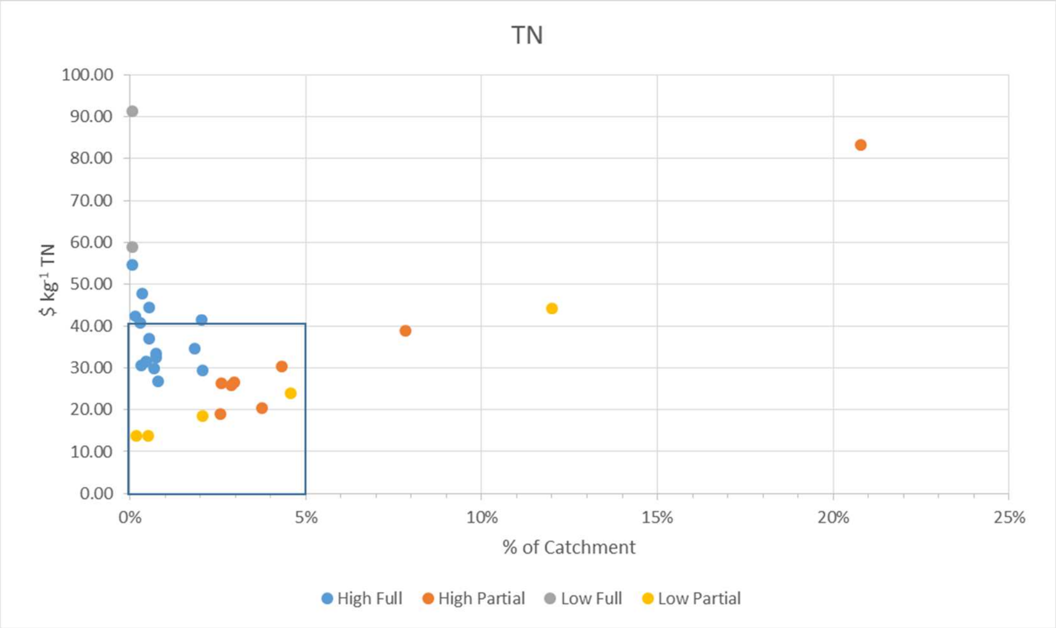

Figure A-5: Cost per kg of TN removed vs. percent of catchment. All sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

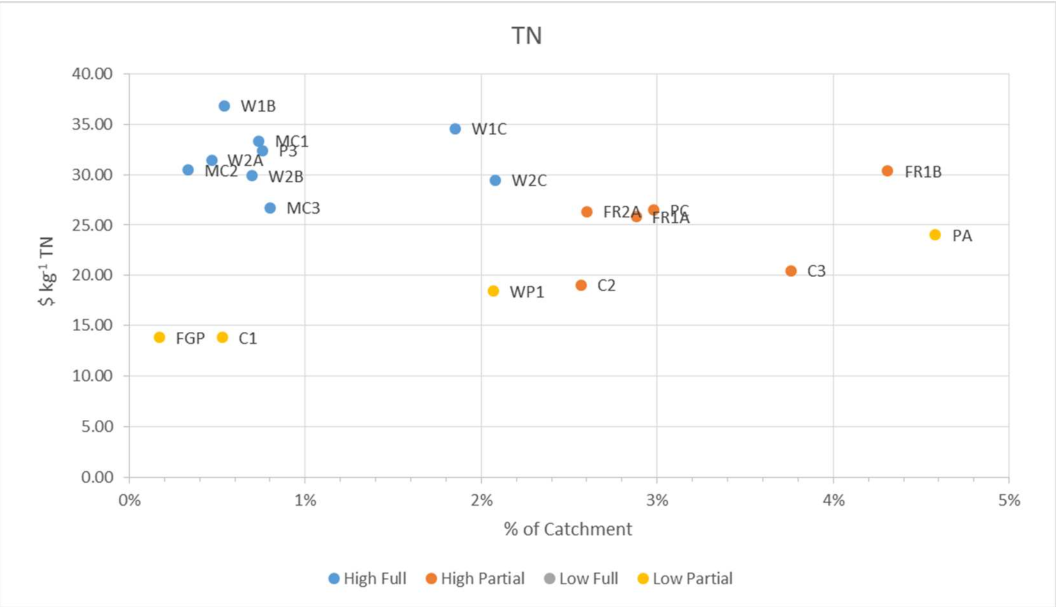

Figure A-6: Cost per kg of TN removed vs. percent of catchment (<5%). Codes refer to specific subset of wetland sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

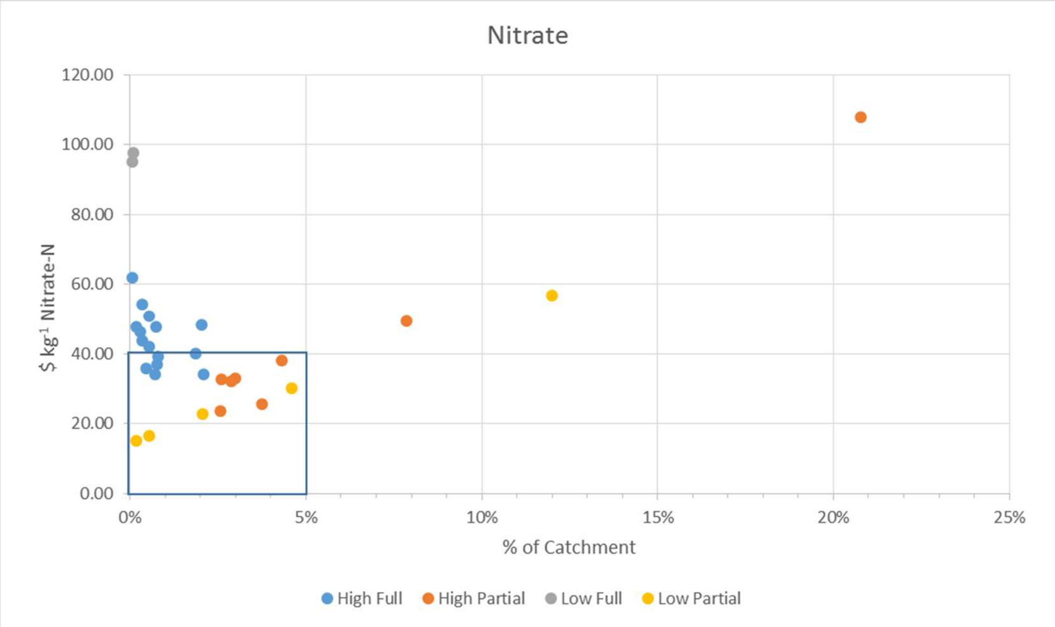

Figure A-7: Cost per kg of Nitrate-N removed vs. percent of catchment. All sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

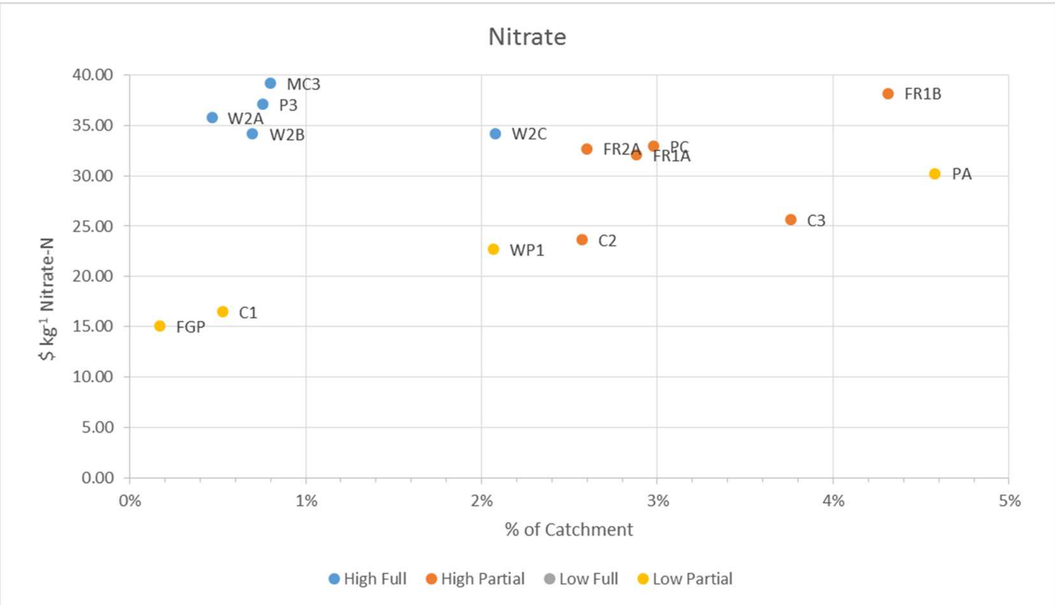

Figure A-8: Cost per kg of Nitrate-N removed vs. percent of catchment (<5%). Codes refer to specific wetland sites. High/Low refers to economic productivity of land; Full/Partial to degree of excavation required to create wetland.

Appendix B Wetland cost-benefit ranked for each contaminant

Preferred options are highlighted in green. Where a lower ranked (on \$ kg^{-1}) may be a preferred option due to a larger size, this is highlighted in gold. Cumulative costs for successive options are calculate up to ~\$5M.

Table B-1: CW ranking based on TSS costs.

Site	Designation	Construction cost	Annualised cost	% of catchment	Wetland area (ha)	TSS \$ kg^{-1}	Cumulative cost
Fiskin gravel pit	FGP	\$ 2,359	124	0.17%	0.024	\$ 0.22	\$2,359
McCrostie (0.5m)	MC1	\$1,344,084	17505	0.74%	12.9	\$ 0.40	\$1,346,443
Clinton (poorly drained area)	C1	\$ 60,934	2821	0.53%	0.62	\$ 0.49	
McCrostie (1m)	MC2	\$1,825,260	27276	0.33%	20.1	\$ 0.53	\$1,825,260
Kelly	K1	\$ 163,443	2836	0.07%	2.09	\$ 0.58	\$1,988,703
Pirie (0.5m)	P1	\$ 275,893	1764	0.06%	1.3	\$ 0.89	
McCrostie (2m)	MC3	\$3,351,824	65815	0.80%	48.5	\$ 0.99	
Pirie (1m)	P2	\$ 557,145	4885	0.17%	3.6	\$ 1.29	\$2,545,848
Waituna1 (0.5m)	W1A	\$ 669,679	6378	0.30%	4.7	\$ 1.98	\$3,215,527
Waituna2 (0.5m)	W2A	\$1,436,145	19269	0.47%	14.2	\$ 2.20	\$4,651,672
Clinton (0.5m)	C2	\$ 209,739	13101	2.57%	3.0	\$ 2.22	\$4,861,411
Warnock pond	WP1	\$ 68,796	3176	2.07%	0.7	\$ 2.31	\$4,930,207
Pirie runoff (3 stepped wetlands)	PR1	\$ 65,846	221	0.08%	0.163	\$ 2.46	\$4,996,053
Waituna3 (0.5m)	W3A	\$ 468,445	3800	0.36%	2.8	\$ 2.66	
Waituna1 (1m)	W1B	\$ 999,706	11399	0.54%	8.4	\$ 2.90	
Waituna2 (1m)	W2B	\$1,893,613	28768	0.70%	21.2	\$ 2.92	
Clinton (1m)	C3	\$ 273,179	17732	3.76%	4.4	\$ 3.00	
Farm race 2 (0.5m)	FR2A	\$ 5,897	360	2.60%	0.06	\$ 3.10	
Farm race 1 (0.2m)	FR1A	\$ 47,174	2719	2.88%	0.48	\$ 3.23	
Pirie (3m)	P3	\$1,586,214	22255	0.76%	16.4	\$ 3.38	
Pirie Site C	PC	\$ 27,518	1605	2.98%	0.28	\$ 3.38	
Waituna3 (1m)	W3B	\$ 619,671	5699	0.53%	4.2	\$ 3.48	
Pirie Site A	PA	\$ 108,230	4972	4.58%	1.15	\$ 3.92	
Farm race 1 (0.5m)	FR1B	\$ 70,762	4047	4.31%	0.72	\$ 4.80	
Waituna2 (3m)	W2C	\$4,023,595	85762	2.08%	63.2	\$ 6.54	
Waituna1 (3m)	W1C	\$2,338,256	39054	1.85%	28.78	\$ 7.07	
Farm race 1 (1m)	FR1C	\$ 118,408	6875	7.85%	1.31	\$ 8.16	
Waituna3 (3m)	W3C	\$1,557,399	21671	2.03%	15.97	\$ 9.05	

Table B-2: CW ranking based on TP costs.

Site	Designation	Construction cost	Annualised cost	% of catchment	Wetland area (ha)	TP $ kg^{-1}	Cumulative cost
Kelly	K1	$ 163,443	$ 2,836.00	0%	2.09	632.8	$ 163,443
Clinton (poorly drained area)	C1	$ 60,934	$ 2,821.00	1%	0.62	888.45	
McCrostie (2m)	MC3	$ 3,351,824	$ 65,815.00	1%	48.5	990.42	$ 3,351,824
Fiskin gravel pit	FGP	$ 2,359	$ 124.00	0%	0.024	1013.24	$ 3,354,183
Clinton (0.5m)	C2	$ 209,739	$ 13,101.00	3%	3.0	1090.13	
Clinton (1m)	C3	$ 273,179	$ 17,732.00	4%	4.4	1135.75	$ 3,627,362
McCrostie (1m)	MC2	$ 1,825,260	$ 27,276.00	0%	20.1	1168.91	
McCrostie (0.5m)	MC1	$ 1,344,084	$ 17,505.00	1%	12.9	1294.01	
Pirie Site A	PA	$ 108,230	$ 4,972.00	5%	1.15	1314.17	$ 3,735,592
Warnock pond	WP1	$ 68,796	$ 3,176.00	2%	0.7	1329.17712	$ 3,804,388
Farm race 1 (0.2m)	FR1A	$ 47,174	$ 2,719.00	3%	0.48	1461.41	$ 3,851,562
Pirie Site C	PC	$ 27,518	$ 1,605.00	3%	0.28	1494.56	$ 3,879,080
Farm race 2 (0.5m)	FR2A	$ 5,897	$ 360.00	3%	0.06	1505.11	$ 3,884,977
Farm race 1 (0.5m)	FR1B	$ 70,762	$ 4,047.00	4%	0.72	1667.8	
Farm race 1 (1m)	FR1C	$ 118,408	$ 6,875.00	8%	1.31	2065.92	
Pirie Site B	PB	$ 54,054	$ 2,510.00	12%	0.55	2328.43	$ 3,939,031
Waituna2 (3m)	W2C	$ 4,023,595	$ 85,762.00	2%	63.2	2917.11	
Waituna2 (1m)	W2B	$ 1,893,613	$ 28,768.00	1%	21.2	3265.46	
Waituna1 (3m)	W1C	$ 2,338,256	$ 39,054.00	2%	28.78	3463.06	
Pirie (3m)	P3	$ 1,586,214	$ 22,255.00	1%	16.4	3520.24	
Waituna2 (0.5m)	W2A	$ 1,436,145	$ 19,269.00	0%	14.2	3522.3	
Waituna1 (1m)	W1B	$ 999,706	$ 11,399.00	1%	8.4	4094.68	
Waituna3 (3m)	W3C	$ 1,557,399	$ 21,671.00	2%	15.97	4121.78	
Farm race 2 (0.7m)	FR2B	$ 47,174	$ 2,719.00	21%	0.48	4346.69	
Waituna1 (0.5m)	W1A	$ 669,679	$ 6,378.00	0%	4.7	4654.21	
Pirie (1m)	P2	$ 557,145	$ 4,885.00	0%	3.6	4922.2	
Waituna3 (1m)	W3B	$ 619,671	$ 5,699.00	1%	4.2	4952.01	
Waituna3 (0.5m)	W3A	$ 468,445	$ 3,800.00	0%	2.8	5419.02	

Table B-3: CW ranking based on TN costs.

Site	Designation	Construction cost	Annualised cost	% of catchment	Wetland area (ha)	TN $ kg^{-1}	Cumulative cost
Fiskin gravel pit	FGP	$ 2,359	$ 124.00	0%	0.024	$ 13.80	$ 2,359
Clinton (0.5m)	C2	$ 209,739	$ 13,101.00	3%	3	$ 19.08	
Clinton (1m)	C3	$ 273,179	$ 17,732.00	4%	4.4	$ 20.48	$ 275,538
Warnock pond	WP1	$ 68,796	$ 3,176.00	2%	0.7	$ 22.84	$ 344,334
Pirie Site A	PA	$ 108,230	$ 4,972.00	5%	1.15	$ 24.02	$ 452,564
Farm race 1 (0.2m)	FR1A	$ 47,174	$ 2,719.00	3%	0.48	$ 25.81	$ 499,738
Farm race 2 (0.5m)	FR2A	$ 5,897	$ 360.00	3%	0.06	$ 26.37	$ 505,635
Pirie Site C	PC	$ 27,518	$ 1,605.00	3%	0.28	$ 26.47	$ 533,153
McCrostie (2m)	MC3	$ 3,351,824	$ 65,815.00	1%	48.5	$ 26.72	$ 3,884,977
Waituna2 (3m)	W2C	$ 4,023,595	$ 85,762.00	2%	63.2	$ 29.48	
Waituna2 (1m)	W2B	$ 1,893,613	$ 28,768.00	1%	21.2	$ 29.89	
Farm race 1 (0.5m)	FR1B	$ 70,762	$ 4,047.00	4%	0.72	$ 30.36	
McCrostie (1m)	MC2	$ 1,825,260	$ 27,276.00	0%	20.1	$ 30.46	
Waituna2 (0.5m)	W2A	$ 1,436,145	$ 19,269.00	0%	14.2	$ 31.45	
Pirie (3m)	P3	$ 1,586,214	$ 22,255.00	1%	16.4	$ 32.42	
McCrostie (0.5m)	MC1	$ 1,344,084	$ 17,505.00	1%	12.9	$ 33.35	
Waituna1 (3m)	W1C	$ 2,338,256	$ 39,054.00	2%	28.78	$ 34.57	
Waituna1 (1m)	W1B	$ 999,706	$ 11,399.00	1%	8.4	$ 36.85	
Farm race 1 (1m)	FR1C	$ 118,408	$ 6,875.00	8%	1.31	$ 38.84	
Waituna1 (0.5m)	W1A	$ 669,679	$ 6,378.00	0%	4.7	$ 40.71	
Waituna3 (3m)	W3C	$ 1,557,399	$ 21,671.00	2%	15.97	$ 41.54	
Pirie (1m)	P2	$ 557,145	$ 4,885.00	0%	3.6	$ 42.28	
Pirie Site B	PB	$ 54,054	$ 2,510.00	12%	0.55	$ 44.35	
Waituna3 (1m)	W3B	$ 619,671	$ 5,699.00	1%	4.2	$ 44.54	
Waituna3 (0.5m)	W3A	$ 468,445	$ 3,800.00	0%	2.8	$ 47.73	
Pirie (0.5m)	P1	$ 275,893	$ 1,764.00	0%	1.3	$ 54.77	
Kelly	K1	$ 163,443	$ 2,836.00	0%	2.09	$ 58.88	
Farm race 2 (0.7m)	FR2B	$ 47,174	$ 2,719.00	21%	0.48	$ 83.26	
Pirie runoff (3 stepped wetlands)	PR1	$ 65,846	$ 221.00	0%	0.163	$ 91.34	
Clinton (poorly drained area)	C1	$ 60,934	$ 2,821.00	1%	0.62	$ 13.83	