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Water Management REPORT

WHAKAMANA TE WAITUNA: Contaminant Load Reduction Plan

PREPARED FOR
Whakamana Te Waituna Trust

RD18020

Jan 2020

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EXECUTIVE SUMMARY

The overall purpose of this catchment-scale project was to find a pathway to reduce contaminant impacts on Waituna Lagoon and its catchment to ensure that the ecological health of the lagoon and catchment are improved while also ensuring that the wellbeing of the Waituna community is sustained.

Specific objectives of the catchment contaminant project were:

1. Design and model a catchment intervention plan that:
    - Re-designs the drainage network to include catchment wide infrastructure which reduces contaminants to water, enhances biodiversity and meets community and cultural expectations.
    - Illustrates what farm management practice changes and technologies could do to reduce contaminants to water, enhance biodiversity and meet community and cultural expectations.
2. Propose a series of contaminant targets, which range from easily achievable to aspirational, based on the load reductions modelled during the development of the catchment intervention plan.

Contaminant load reduction strategies were devised by combining a number of different types of mitigation options: On-farm mitigations, constructed wetlands and retiring selected areas of land from agricultural use and restoring its natural land-cover. The effectiveness of each was assessed in terms of the modelled reduction in Nitrogen load to the lagoon, relative to estimates of the current load.

There are multiple strategies for reducing N load to the lagoon by at least 50%. Each strategy involves On-Farm mitigations and the construction of at least one large wetland on the Waituna Creek.

As expected, increasing investment in wetlands and land retirement reduces the degree (and cost) of On-Farm mitigation required to achieve a 50% reduction in the N load to the lagoon. Without these investments a high level of On-Farm mitigations is required. This has a significant impact on dairy farms, in particular, reducing their cash operating surplus by 30%. This is likely to seriously threaten their financial viability - depending on farm debt levels.

If the N load target is reduced to 60%, or less, of the current N load it is possible to meet this by constructing only one wetland on Waituna Creek but the On-Farm mitigations would need to be at a Medium level. It would be preferable for this wetland to be near the bottom of the catchment because this would treat virtually all of the surface water flow out of Waituna Creek and it's wetland area can be a higher percentage of the catchment area draining to the wetland than is the case for a mid-catchment wetland (for the same dam height).

All of the strategies analysed that reduce N load to 60%, or less, of the current N load involve the construction of at least one large wetland. All these strategies are therefore expected to significantly reduce the sediment load to the lagoon, providing they are well designed, constructed and maintained.

Achieving the objectives of contaminant load reduction is expected to require the construction of both of the wetlands included in the scenario analysis, the retirement of a significant area of land around Waituna Lagoon and the implementation of a modest level of on-farm mitigations.

It is recommended that any plan involving two large constructed wetlands be staged. Staging enables modifications to be made to the plan partway through its implementation if performance monitoring of the first stage reveals ways to improve the plan.

It is recommended that drain and waterway management be re-designed to minimise the risk of sediment inputs to flowing waterways, with the overall aim of avoiding the need for mechanical clearing of sediment and macrophytes from waterways. This will require:

1. Re-constructing drain cross-sections to avoid or minimise the risk of soil loss to waterways due to bank instability.
2. Re-constructing the cross-sections of the larger creeks and streams, ideally to achieve a 2-stage cross-section to reduce contaminant loads while providing sufficient capacity to safely route flood flows to the lagoon.
3. Riparian planting with native species selected to shade the waterway where-ever possible and so minimise macrophyte growth.
4. Switch to using herbicides to remove macrophytes, assuming the current trials are successful and that the necessary approvals can be obtained.

It is recommended that re-shaping the stream banks and associated riparian planting be used as a means of creating wildlife corridors that connect up remnant wetlands and native bush areas, where practical, and connect these areas with the lagoon. In other words, use the drainage network to achieve biodiversity objectives as well has hydrological and agricultural objectives.

1 INTRODUCTION

1.1 Background

The Waituna Lagoon is one of the premier examples of a coastal lagoon wetland complex environment in New Zealand. Traditionally it was an important source of mahinga kai such as tuna and kai moana for the tangata whenua – hence the area holds significant cultural and spiritual values for Te Runanga o Ngāi Tahu and Te Rūnanga o Awarua. A Statutory Acknowledgement under the Ngāi Tahu Claims Settlement Act 1998 formally recognised this connection.

These values are also shared by fisherman, hunters, naturalists and local landowners - such that following the 1975 UNESCO Ramsar Convention, Waituna became New Zealand's first designated Ramsar site in 1976 (Tanner et al., 2013).

The introduction of European farming practices resulted in changes to the landscape such as clearance of wetlands, drainage enhancement and fertiliser inputs. These changes have progressively increased inputs of suspended sediments and nutrients into the lagoon

Over the past 25 years, conversion to dairy farming has seen a significant population growth in the area compared to other areas of Southland that have limited dairy farming, with dairy cattle farming and dairy product manufacturing now being the two biggest employers in the region. It is estimated that there are some 560,000 cows in the Southland area (2.69 cows / ha) producing 1120 kg/ Milk solids/ ha (National Average 1070 kg/ Milk solids/ ha) (LIC, 2017, Taylor et al., 2015).

The confluence of the conversion to dairy farming and the cumulative effects of historical agricultural and land management practices is understood to have led to the deterioration of the Waituna Lagoon. Consequently, the water quality of the lagoon has declined to the extent that it is at risk of having a regime shift from an oligotrophic to a eutrophic state (McDowell et al., 2013).

A number of agencies have been involved in proactively increasing the monitoring of water quality in the lake and the surrounding catchment since 2001, and in changing land management practices to improve water quality. These initiatives lead to the formation of the Waituna Partners' Group, a governance group made up of Environment Southland, Department of Conservation, Te Rūnanga o Awarua, Te Rūnanga Ngāi Tahu and the Southland District Council, to provide strategic direction to the management of the Waituna Catchment.

The partners formed the Whakamana te Waituna Charitable Trust in February 2018 to establish and manage the Whakamana te Waituna programme (WtW, 2018), alongside other programmes, the aim of which is to enhance social, cultural, economic and environmental resilience throughout the Waituna Catchment, as well as the resilience of the lagoon itself. It also aims to improve access to the lagoon.

Its objectives for achieving these aims include:

1. The development of a landward buffer around the lagoon.
2. The re-establishment and strengthening of manawhenua role as kaitiaki, while building mataraunga Maori and community capacity.
3. The design, adoption and implementation of a catchment-wide contaminant load reduction programme to increase the resilience of ecosystems in and around the lagoon and its tributaries.
4. Maintaining or improving the economic resilience of the farming community.

1.2 Project Purpose

The overall purpose of the catchment-scale, mountains-to-the-sea approach of this project was to find a pathway to reduce contaminant impacts on the Waituna Catchment and lagoon, and so contribute to objective 3 above.

Specific objectives of the catchment contaminant project were:

- Design and model a catchment intervention plan that:
  - Re-designs the drainage network to include catchment wide infrastructure which reduces contaminants to water, enhances biodiversity and meets community and cultural expectations.
  - Illustrates what farm management practice changes and technologies could do to reduce contaminants to water, enhance biodiversity and meet community and cultural expectations.
- Propose a series of contaminant targets, which range from easily achievable to aspirational, based on the load reductions modelled during the development of the catchment intervention plan.

This summary report describes the proposed catchment intervention plan, placing it in the context of the recommended contaminant load reduction targets, and makes recommendations on how to monitor against these targets.

1.3 Acknowledgements

A considerable amount of science and research has been conducted in the Waituna Catchment over the past fifteen years. The outputs from this prior work have provided the foundations for the catchment intervention plan proposed in this report. In many respects this project simply integrates and applies these outputs to develop a plan for reducing the contaminant load on the Waituna Catchment.

The authors of this report acknowledge and thank those who have developed scientific understanding of the catchment to its current level.

2 SETTING

2.1 Location

The Waituna Lagoon (Waituna) is a coastal lagoon and wetland complex situated on the northern margins of Toetoes Bay, nominally located at -46.5647° South 168.5896° East; approximately 24 km south east of Invercargill (pop. 54,800) and 60 km south of Gore (pop. 12,450). Covering an area of some 3,500 ha, it represents 18% of the larger (20,000 ha) Awarua Waituna Wetland catchment.

Figure 1: Location of Waituna Lagoon

2.2 Cultural Context

Manawhenua / Manamoana – Ngāi Tahu Whānui is the iwi (Māori tribe) who holds manawhenua over a large proportion of Te Waipounamu / the South Island. The modern iwi originates from three main tribal strands: Waitaha, Ngāti Mamoe and Ngāi Tahu. Through intermarriage, warfare and alliances, these tribal groups migrated, settled, occupied, amalgamated and established manawhenua over their tribal area prior to European arrival. Specific hapū, or sub-tribes, established control over distinct areas of the island and have maintained their mana over these territories to this day.

Te Rūnanga o Ngāi Tahu is the mandated iwi authority established by Ngāi Tahu Whānui under Section 6 of the Te Runanga o Ngai Tahu Act 1996 to protect the beneficial interests of all members of Ngāi Tahu Whānui, including the beneficial interests of the Papatipu Rūnanga and its members. Te Rūnanga o Ngāi Tahu is governed by elected representatives from each of the 18 Papatipu Rūnanga and has an administrative office as well as several commercial companies.

Four Papatipu Rūnanga are located within Murihiku – Oraka Aparima, Waihōpai, Awarua and Hokonui.

Te Rūnanga o Awarua has the primary interest in the Waituna catchment and its wider landscape. Their takiwā (territory), as described in the Te Tangi a Tauira: The Cry of the People, centres on Awarua and extends to the coasts and estuaries adjoining Waihōpai sharing an interest in the lakes and mountains between Whakatipu-Waitai and Tawhititarere with other Murihiku Rūnanga and those located from Waihemo southwards. Te Rau Aroha Marae is situated in Bluff, with the wharenui named Tahupōtiki.

Te Ao Mārama Incorporated was established in 1996 in response to Resource Management Act requirements for consultation with Māori. This organisation represents Murihiku tangata whenua for resource management purposes and is made up of representatives of the four Murihiku rūnanga.

The information provided in this memo, on cultural context and values, provides an overview of publicly available information. Te Rūnanga o Awarua and Te Rūnanga o Ngāi Tahu are part of the Waituna Partners Group that governs the Whakamana te Waituna programme. Te Ao Marama is working with the Partners Group to undertake a cultural values report as part of the overall programme, this is likely to be completed in early 2019 and should be referred to for further and more detailed information.

Place Names (refer to Figure 2 on next page)

<u>Waituna Lagoon</u> - Waipārera is the traditional Māori name for Waituna Lagoon - described as a large, brackish, coastal lagoon that is drained through a managed opening to Toetoes Bay, east of Awarua (Bluff) on the Murihiku (Southland) coastline. The name Waipārera refers to the pārera (grey duck).

<u>Waituna Creek</u> - Waituna Creek flows in a southerly direction into the lagoon, incorrectly known as Waituna, on the Murihiku (Southland). Wai meaning water, and tuna is a general term for eels of various species including the long and short fin eels.

<u>Kā-puna-wai</u> - Known as the eastern end where the lagoon breaks out to sea.

Wāhi Tapu, Wāhi Taonga

<u>Ngā Ara Tawhito</u> – Branching off from an important ara tawhito (traditional travel route) west of the Mataura River, a travel route was known to follow the Waiharakeke (Flax Stream) and Mimihau Streams, south down the length of the Mataura River where it meets the sea. Crossing the mouth of the Mataura River, the route followed the sea-coast along Waituna Lagoon and culminated at the bluff of Awarua Bay.

<u>Area of Statutory Acknowledgements</u> – Under Schedule 73 of the Ngāi Tahu Claims Settlement Act 1998, Waituna Wetland is identified as an area of statutory acknowledgement; this acknowledges Ngāi Tahu ki Murihiku / Te Rūnanga o Ngāi Tahu's cultural, spiritual, historic and traditional association to Waituna, as summarised below.

Sites of Significance

<u>Urupā</u> - Particular sections of the wetland were known to be used for waiwhakaheketūpāpāku (water burial). Urupā and wāhi tapu are the resting places of Ngāi Tahu tūpuna and, as such, are the focus for whānau traditions. These places hold the memories, traditions, victories and defeats of Ngāi Tahu tūpuna (ancestors) and are frequently protected and information about burial sites will, in some circumstances, be withheld.

<u>Mauri</u> - Mauri is a critical element of the spiritual relationship of Ngāi Tahu whānui with the area. The mauri of Waituna represents the essence that binds the physical and spiritual elements of all things together, generating and upholding all life. All elements of the natural environment possess a life force and all forms of life are related.

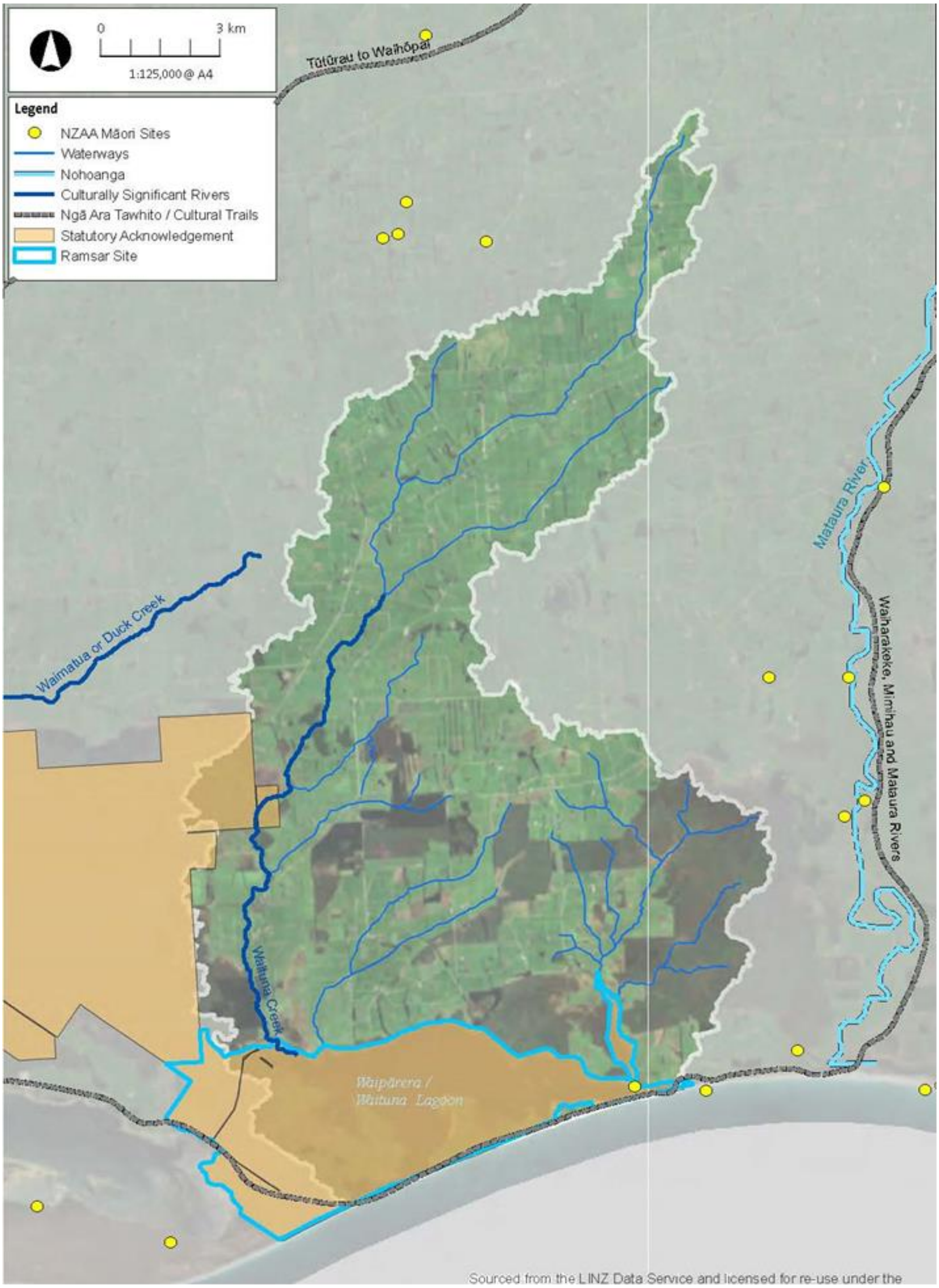

Figure 2: Areas of Cultural Significance (from Boffa Miskell, 2019)

Mahinga Kai - Traditionally, ancestors had considerable knowledge of whakapapa (genealogy), traditional trails, tauranga waka (canoe landing sites), places for gathering kai (food) and ways in which to use the resources of Waituna in an appropriate and sustainable way. The relationship of Māori with the lake, and their dependence on it as a means for survival, remains valuable and important to Ngāi Tahu today. Intermittently open to the sea, Waituna wetland was a major food basket utilised by nohoanga (permanent settlements) located amongst the wetlands of Waituna and further afield, for its wide variety of mahinga kai. The diversity of wildlife associated with Waituna includes several breeds of ducks, white heron, gulls, spoonbill, kōtuku, oyster-catchers, dotterels, terns and fernbirds. The wetlands are an important kōhanga (spawning) ground for a number of indigenous fish species; giant and banded kōkopu, varieties of flatfish, tuna (eels), kanakana (lamprey), inaka (whitebait), waikākahi (freshwater mussel) and waikōura (freshwater crayfish) were known to be harvested. Harakeke, raupō, mānuka, tōtara and its bark, and pingao were also regularly harvested. Paru or black mud was collected as a product for making dyes.

Nohoanga – In close proximity to Waituna Lagoon, the Mataura River is recognised as an important nohoanga. The Mataura River flows south-east from the Eyre Mountains east of Te Ana-au. It passes through the township of Mataura before entering Te Moana-nui-a-Kiwa (Pacific Ocean) at Toetoes Bay, on the Murihiku (Southland) coast. The Mataura was a significant kāinga mahinga kai (food-gathering place) for local Kāi Tahu, and was tribally renowned for its abundance of kanakana. Kanakana are normally caught when climbing natural waterfalls, such as Te Au-nui-pihapiha-kanakana (Mataura Falls) which was a renowned spot for gathering kanakana. The Mataura was an important ara tawhito that provides direct access from Murihiku to Whakatipu Waimāori (Lake Wakatipu).

Recorded Archaeological Sites – As a result of the history of use and occupation of the area, there are wāhi tapu and wāhi taonga located along the shore line of Waituna Lagoon, and west across to the Mataura River. Recorded NZAA sites F47/9, F47/6 and F47/4 report findings of ovens and an adze; these finds support the value of Waituna Lagoon and the shoreline as a place of settlement by Ngāi Tahu. It should be noted that the absence of data for any area should not be taken to mean that it contains no archaeological sites as there may be any number of undiscovered or unrecorded sites in any given area.

2.3 Ecological context

The Waituna catchment forms part of the Awarua-Waituna wetland complex, one of the largest remaining wetland complexes in New Zealand. Awarua-Waituna Wetlands is recognised under the Ramsar Convention as a wetland of international importance.

Waituna Lagoon is classed as a brackish, intermittently closed and open lagoon or lake (ICOLL) with a gravel barrier bar, which is periodically (mechanically) opened to maintain water levels below a specified water depth. The lagoon was once surrounded by extensive peat bog wetland (approx. area of 20,000 ha, from Fortrose Estuary to New River Estuary). Widespread drainage for agriculture (intensive sheep, beef and dairying) activities has substantially reduced the area of wetlands in the Waituna catchment (Figure 3).

The lagoon has high biodiversity and cultural values, supporting many species of conservation interest.

Waituna Lagoon has diverse habitats that support many species of waterfowl, migratory birds and coastal birds, and freshwater, estuarine and marine fish species. Waituna catchment supports a high diversity of freshwater fishes, including giant and banded kokopu and inanga, common, giant and redfin bullies, longfin and shortfin eels, black flounder and brown trout. The catchment is recognised as a national stronghold for giant kokopu (see Figure 4).

The preservation and enhancement of the macrophyte (aquatic plant) *Ruppia* (of which two species occur in Waituna Lagoon, *R. polycarpa* and *R. megacarpa*) is a key interest for the management of Waituna Lagoon. *Ruppia* is considered an indicator of lagoon health. These macrophytes play an important role in the uptake of nutrients from the water column, and in binding suspended sediments with their roots.

Waituna Lagoon was a macrophyte-dominated, oligotrophic system, with clear waters and dense beds of *Ruppia* and other macrophytes. Long-term monitoring has shown that *Ruppia* populations have been significantly affected by timing and duration of opening of the lagoon. When the lagoon is open during summer months, *Ruppia* beds are impacted / lost through desiccation, disturbance from wave action, lowered water levels, and increased salinity (esp. during prolonged lagoon openings).

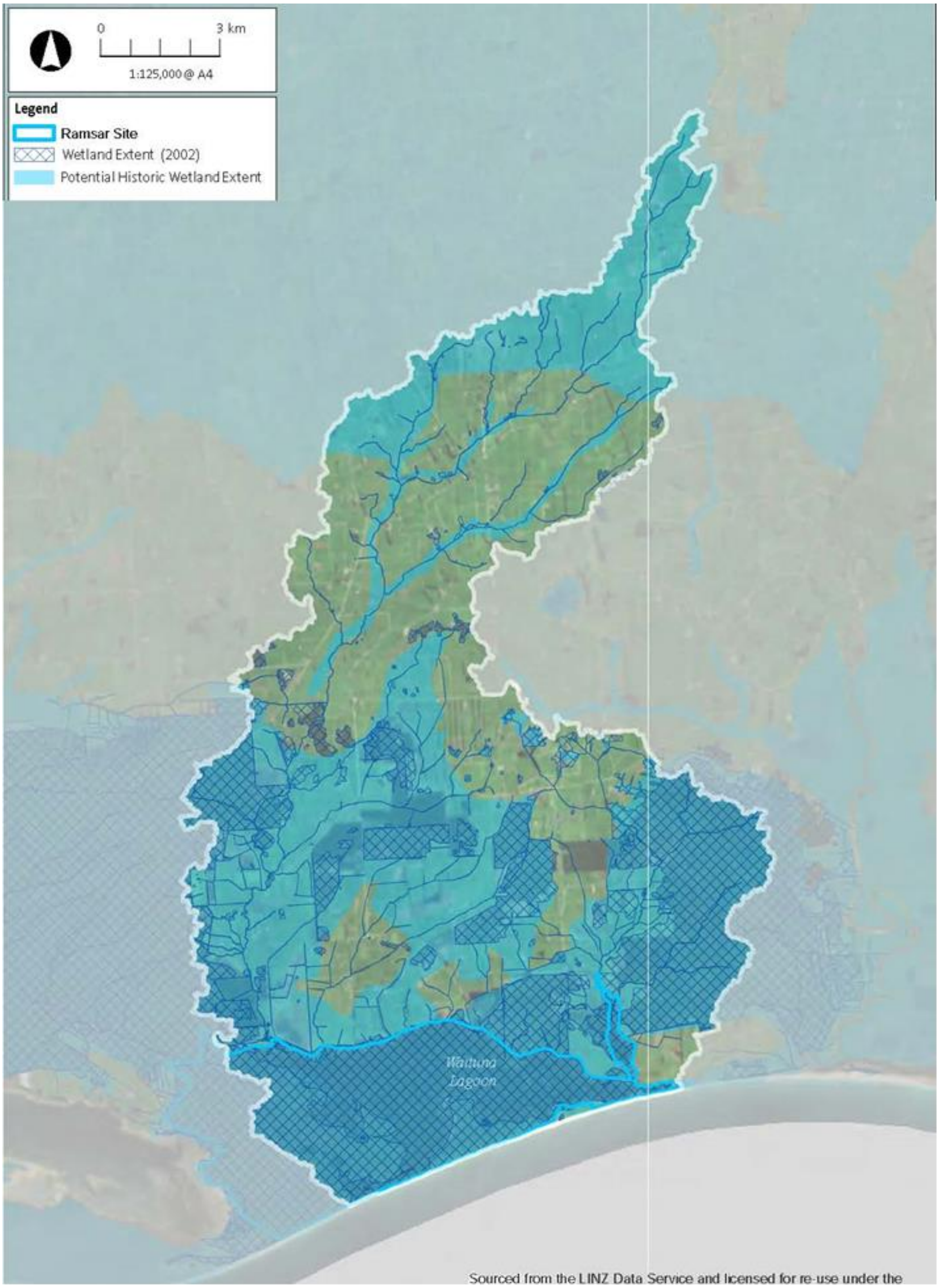

Figure 3: Change in wetland extent (from Boffa Miskell, 2019)

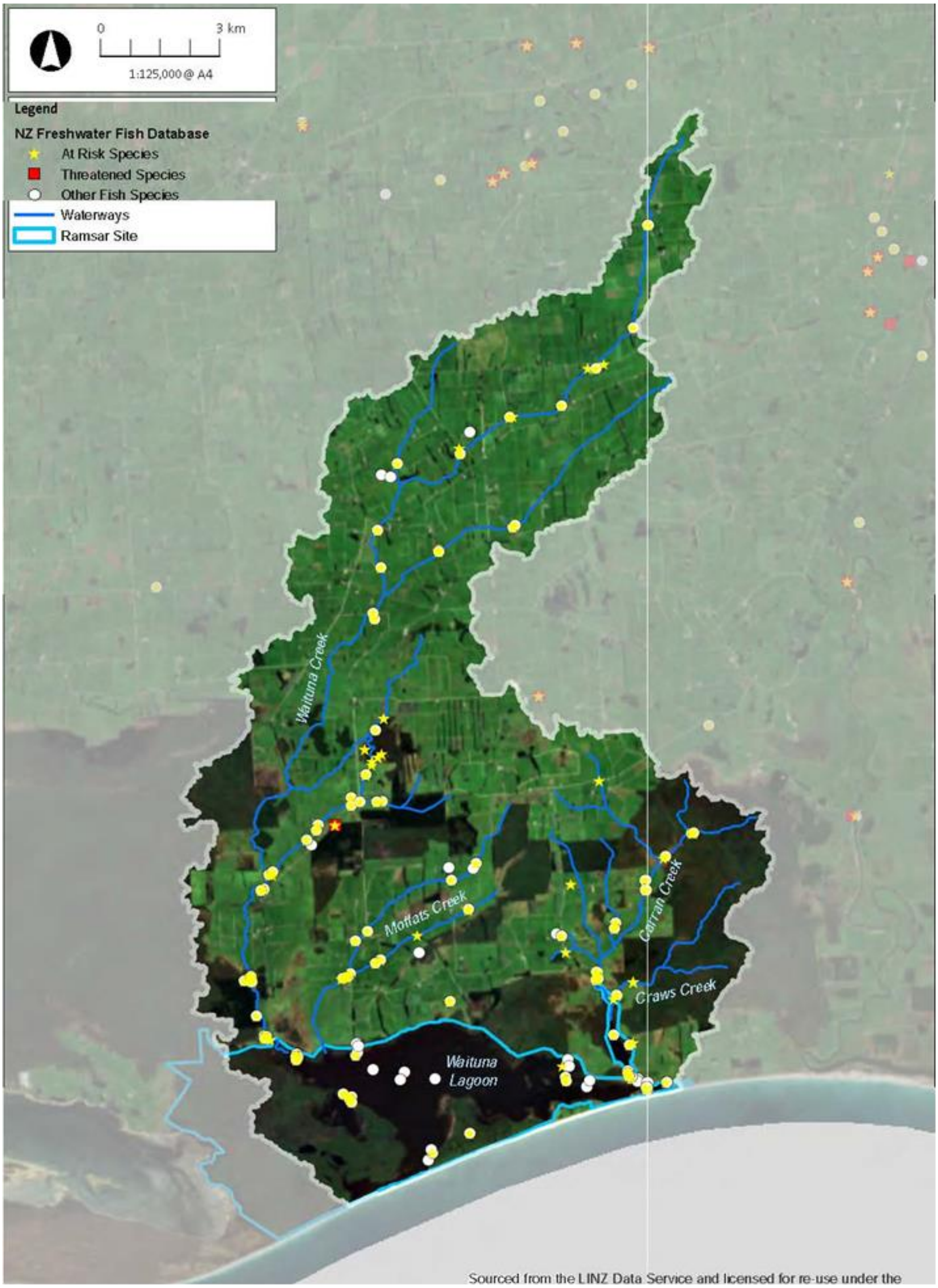

Figure 4: Freshwater Fish Distribution (from Boffa Miskell, 2019)

By 2018, Waituna Lagoon had deteriorated to a mesotrophic state (LAWA, 2019) (based on the Trophic Level Index), with degraded water quality and high levels of sediment and nutrients entering the lagoon from the surrounding farmland. This degraded water quality is exacerbated by the lagoon being intermittently closed for extended periods and, therefore, its limited ability to flush the water column or contaminants deposited within lagoon sediments. The lagoon is considered to be vulnerable to the collapse of aquatic plants and shifting to an algal-dominated state (Environment Southland, 2013).

Opening of the lagoon was, traditionally, aimed to minimise flooding in the surrounding farmland. The management of the lagoon level today is designed to manage *Ruppia* (and other macrophyte) beds as well as maintain the proper functioning of the drainage network, which is a balancing act between the need to flush the lagoon of sediments and nutrients (i.e. to address degraded water quality) and to maintain sufficient water levels and low salinity within the lagoon to sustain *Ruppia* spp.

The eutrophic state of Waituna Lagoon has raised concern over the potential for the lagoon to switch (or flip) from a macrophyte-dominated to algal-dominated state, where submerged macrophytes would no longer be present.

2.4 Climate

Invercargill has a temperate oceanic climate (Cfb according to the Köppen-Geiger system) with a yearly mean temperature is 9.8°C and 1,112 millimetres of rainfall annually (Macara, 2013).

Summary climate data is presented in Figure 5 and Figure 6 below.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	14.2	14.3	12.6	10.5	8	5.5	5.1	6.3	8.4	10.1	11.3	13.1
Min. Temperature (°C)	9.7	9.5	7.9	5.9	3.7	1.5	0.8	1.8	3.7	5.6	6.8	8.6
Max. Temperature (°C)	18.8	19.1	17.4	15.1	12.3	9.6	9.4	10.9	13.1	14.7	15.9	17.7
Avg. Temperature (°F)	57.6	57.7	54.7	50.9	46.4	41.9	41.2	43.3	47.1	50.2	52.3	55.6
Min. Temperature (°F)	49.5	49.1	46.2	42.6	38.7	34.7	33.4	35.2	38.7	42.1	44.2	47.5
Max. Temperature (°F)	65.8	66.4	63.3	59.2	54.1	49.3	48.9	51.6	55.6	58.5	60.6	63.9
Precipitation / Rainfall (mm)	100	79	91	103	110	102	78	64	76	88	88	87

Figure 5: Summary of climatic data for Invercargill

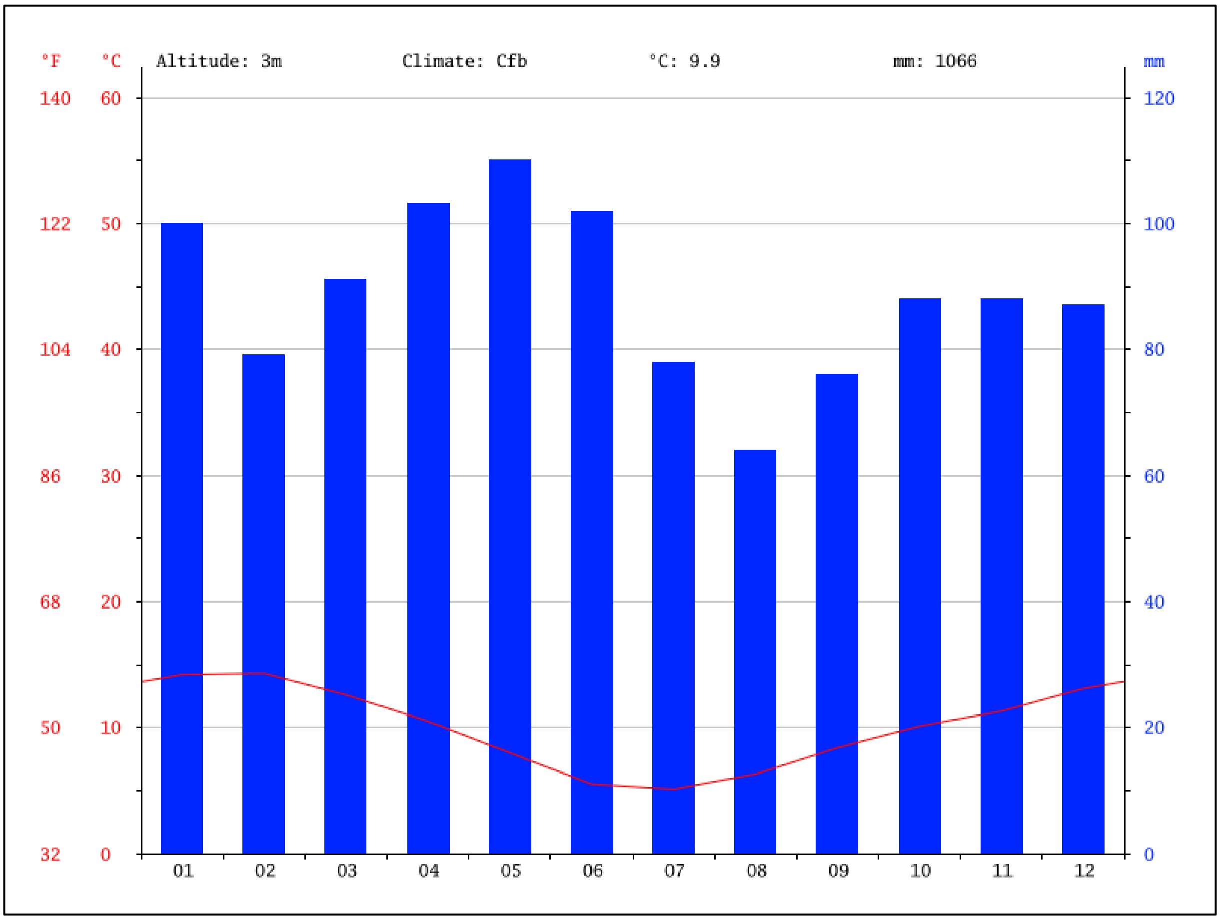

Figure 6: Histogram of climatic data for Invercargill

2.5 Geology

The geology of the area consists of Early to Late Quaternary alluvial and swamp sediment that overlie Oligocene to Pliocene sedimentary rock (Figure 8). The hills around Bluff are formed of mafic to ultramafic igneous rock of Permian age (Turnbull and Allibone, 2003).

Waituna Lagoon is situated on a quartz gravel outwash plain of Late Quaternary to Holocene age underlain by a thick sequence of fine-grained sediments of the Tertiary East Southland Group, which in turn overlie the Mesozoic basement rocks of the Murihiku and Brook Street Terranes (Figure 7) (Rissmann et al., 2012)

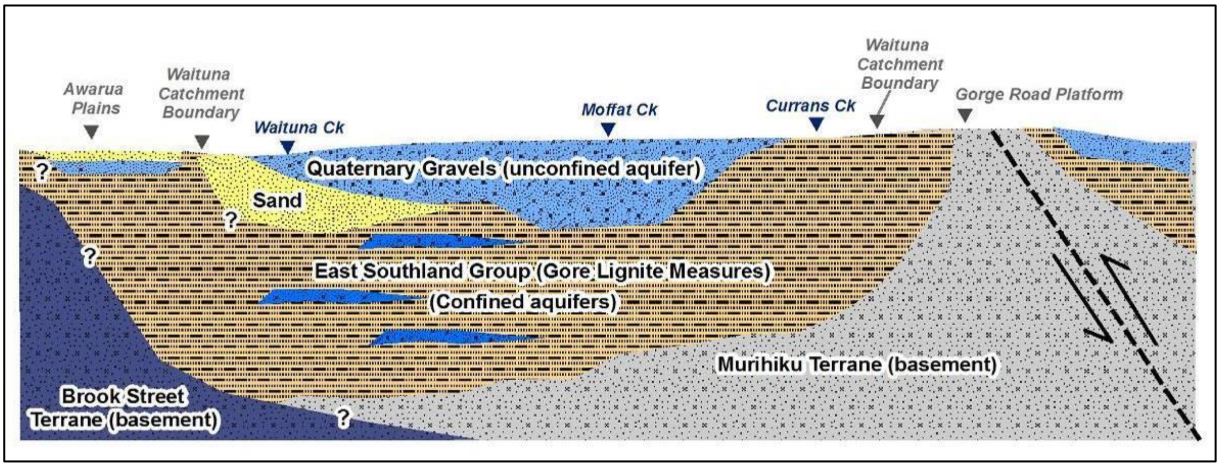

Figure 7: Schematic hydrogeological cross-section of the Waituna catchment

The area became a wetland some 7,880 - 7,560 years ago in response to sea-level rise, and has had standing water in it for the last 7,600 - 7,000 years. Waituna Lagoon was larger than at present, and connected to Awarua Bay to the west (Cosgrove, 2011)

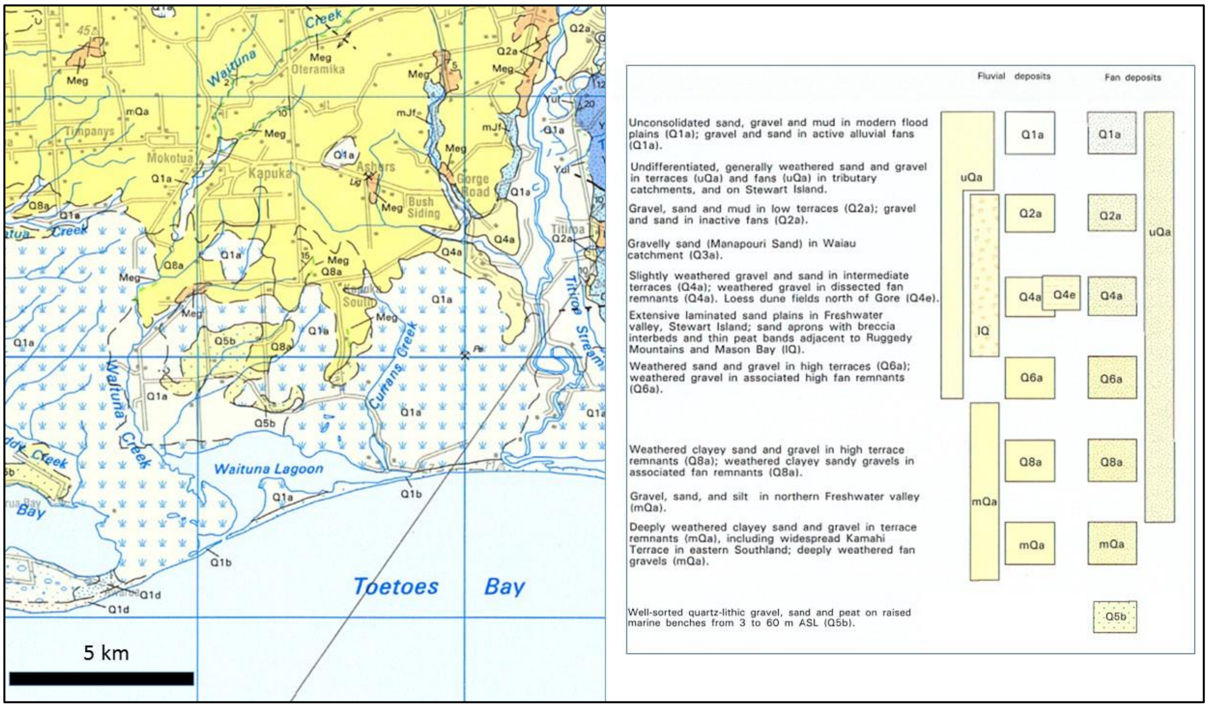

Figure 8: Excerpt of the Murihiku geological map showing the Waituna Lagoon

2.6 Geomorphology

Relief throughout the catchment is gently undulating to flat with elevation ranging from about 65 m metres above sea level in the upper catchment to sea level at the lagoon over a linear distance of 27.5 km. Within this range, there are some clear topographic features, which are manifest as distinct breaks in slope on an otherwise subdued terrain as shown in Figure 9 (Rekker and Wilson, 2016).

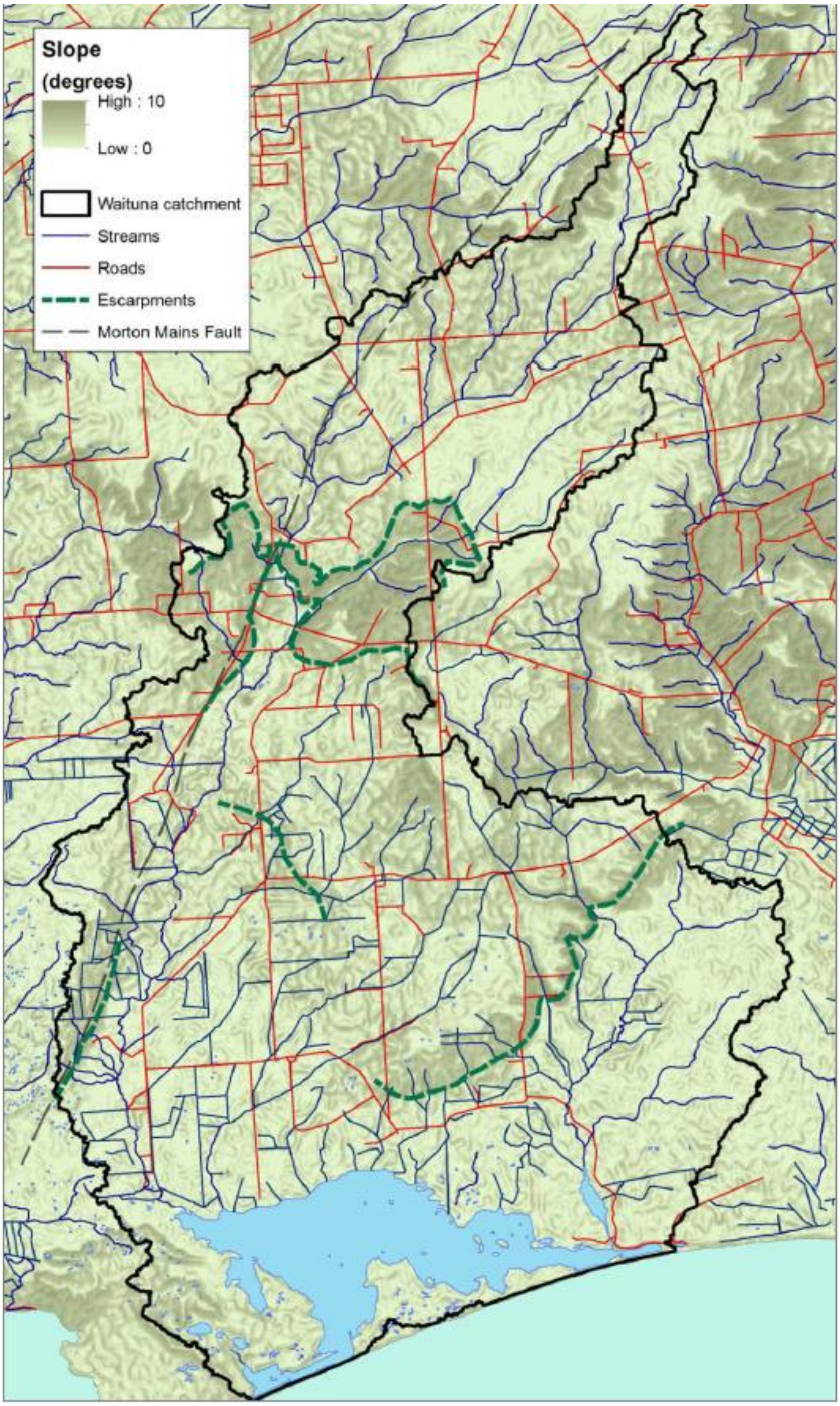

Figure 9: Map of topographic slope with surface features

2.7 Hydrology

The introduction of European farming practices in the 19th century resulted in the swampy lower parts of the Waituna catchment being drained for agriculture, thereby improving the plant growth and load capacity of the soil[1].

Waituna Lagoon forms at the confluence of several small creeks that receive water from extensive artificial drainage networks associated with agricultural production. Figure 10 presents the largest creeks at outflow into Waituna Lagoon, namely:

- Waituna Creek (catchment area 12,600 ha);
- Carran Creek (catchment area 5,700 ha);
- Moffat Creek (catchment area 1,700 ha); and,
- Craws Creek (catchment area 788 ha)

Figure 10: Waituna Lagoon, wider catchment and sub-catchments.

[1] i.e. the capacity of the soil to support the loads applied to the ground, such as vehicles.

As presented in Figure 5, average monthly rainfall is distributed evenly throughout the year, hence variation in surplus rainfall (i.e. drainage water) is driven by variation in evaporation rates. Most of the drainage into the lagoon therefore takes place during winter (April to August) (Muirhead, 2013).

The Waituna catchment is considered a closed catchment as the calculated discharge into Waituna Lagoon can be reconciled against mass balance within a confining topographical catchment boundary. The extensive artificial drainage within this closed catchment makes the catchment 'highly connected' to the lagoon (Rekker and Wilson, 2016). Consequently, the current baselines for sediment and nutrient loads to the lagoon are considered higher than would be expected from the catchment prior to development for farming.

Historically these waterways fed into the lagoon, which increased in depth until it overtopped the gravel barrier beach, breaching it and emptying the lagoon. This natural regime would have involved the lagoon rising as much as 4 m above sea level before emptying. The first artificial breach of the barrier beach was made in 1908, in an effort to improve the fishing in the lagoon.(Thompson and Ryder, 2003).

Average inflows and incident rainfall into the lagoon is presented in Table 1

Table 1: Annual freshwater inflows and calculated mean flow

Inflow	Annual Flow (000 m^3/ yr)	Percentage	Mean Flow m^3/ s
Waituna Creek	50,888	42%	1.61
Moffat Creek	10,310	8%	0.33
Carran Creek	12,839	11%	0.41
Craws Creek (Carran Creek tributary)	4,076	3%	0.13
Groundwater	43,822	36%	1.39
Total	121,935	100%	

(Rekker and Wilson, 2016, Tuckey, 2015).

2.8 Hydrogeology

Groundwater in the Waituna Catchment occurs throughout the Quaternary gravels and underlying Gore Lignite Measure sediments and is controlled by the geomorphological catchment boundary (refer to section 2.7) and surface waterways, particularly Waituna Creek, and to a lesser extent Carran Creek.

Figure 11 presents piezometric groundwater contours compiled by Environment Southland in 2012 that indicate that static water levels vary from > 60 m below the surface in the upper catchment to < 1 m near the lagoon (Rekker and Wilson, 2016).

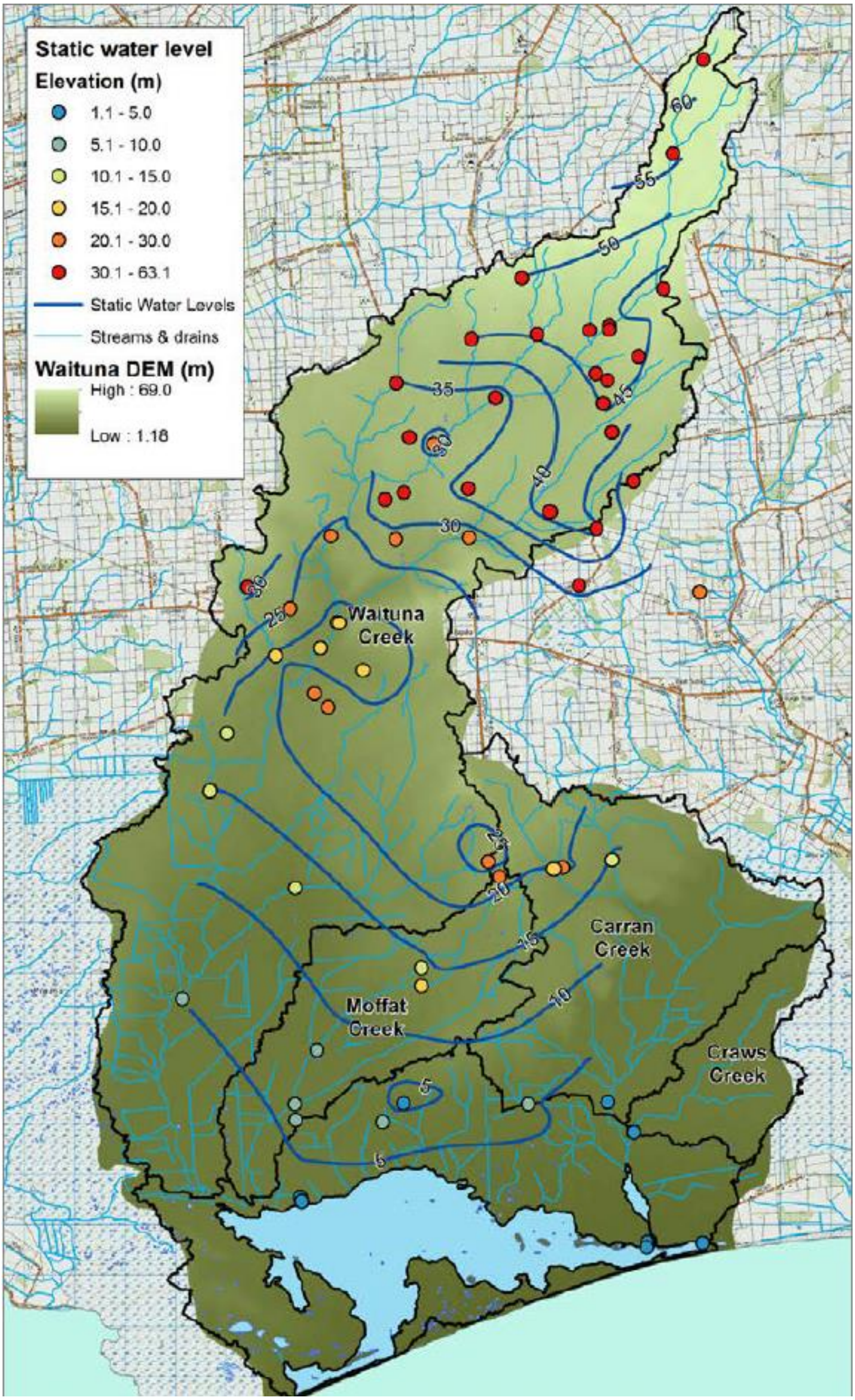

Figure 11: Static water levels from a survey carried out by Environment Southland in 2012 (Rekker and Wilson, 2016)

2.9 Soils

Due to the extensive artificial drainage networks associated with farming and agriculture, the land within the catchment is considered to be highly 'connected' to the lagoon, with variable drainage rates into Waituna Lagoon being a function of soil type and geomorphology (refer to section 2.6). The catchment is characterised by three zones:

- The **northern areas or upper part** of the catchment (north of Mokotua/Kapuka), is characterised by thick, stoneless, mineral-brown soils (types:Woodlands, Mokotua, and minor Tisbury) that are generally imperfectly drained[2]. The area also hosts Waikiwi typic firm brown soils, the only soil types in the catchment which are considered to be well-drained. This suggests that they are more prone to nutrient loss through drainage, and are more likely to drain to groundwater rather than near-surface routing to tile drains. Accordingly, nitrate accumulation vulnerability in underlying shallow, oxic groundwater is largely associated with Waikiwi soils in the Waituna catchment. Groundwater appears to have a residence time of about 120 days and shows evidence of impact from intensive land use (Rekker and Wilson, 2016). Whilst the soil morphology and extended residence times plays a role in removing soil contaminants associated with intensive farming, Muirhead (2013) notes that the area has artificial drainage networks (such as Mole and Pipe drains) which enables water (and entrained nutrients and sediments) to be re-directed away from groundwater recharge to Waituna Creek and then to the lagoon itself.
- The **central or mid regions** of the catchment have catena soils whereby reworked Brown Soils (associated with higher sea levels approximately 70,000–100,000 years ago) develop to Gley soils proximal to waterways and low lying boggy areas. Intensive sub-surface drainage of these soils results in relatively rapid movement of excess soil water and entrained contaminants to surface waterways, such that resident times are estimated to be less than two weeks. The Mokotua Discharge Zone (Rekker and Wilson, 2016) is located within the mid-region and is understood to be responsible for oxic, high nitrate water that originates from upgradient Waikiwi soils being discharged from groundwater or drainage networks into Waituna Creek and tributaries. (Rekker and Wilson, 2016).
- The **southern or lower region** of the catchment (i.e. the Moffat and Carran Creek catchments) is characterised by poorly drained Organic, Podzol and Gley soils (including the sub-category of Peat soils) with rapid recharge (< 5 days). Subsequently groundwater in the southern region is oxygen-poor/ iron-rich groundwater due to the abundance of wetland peat deposits, and to a lesser extent, lignite measures, with lateral flow of low nitrate water into the open drains as well as direct ground water seepage into the lagoon (Muirhead, 2013; Environment Southland, 2013). Leaching of phosphorous to groundwater is higher in this region than upper and mid regions because of the low phosphorous retention capacity of Organic soils. Consequently the loss of phosphorous per unit catchment area is higher from Moffat and Carran Catchments than from Waituna Catchment (Muirhead, 2013).

2.10 Land Use

The Waituna area was a source of mahinga kai for the Ngāi Tahu for centuries prior to the settlement of the area by Scottish pastoral farmers (Beattie, 1979, cited in Cosgrove, 2011). Sheep, beef grazing, and cropping became the predominant agricultural activities in the 20th century and the lagoon was first opened to the sea in 1951 (Environment Southland, 2015; Taylor et al., 2015).

Today, land use within the catchment includes arable, forestry, sheep, beef and dairy; with some areas of native vegetation remaining (predominantly in wetland areas in the southeast of the catchment and bordering the lagoon).

[2] These soils are also found in subordinate quantities in the other parts of the catchment; hence the total quantities of the soils are 35% Brown Soils, 32% Organic Soils, 20% Gley Soils, and 13% Pan Podzols

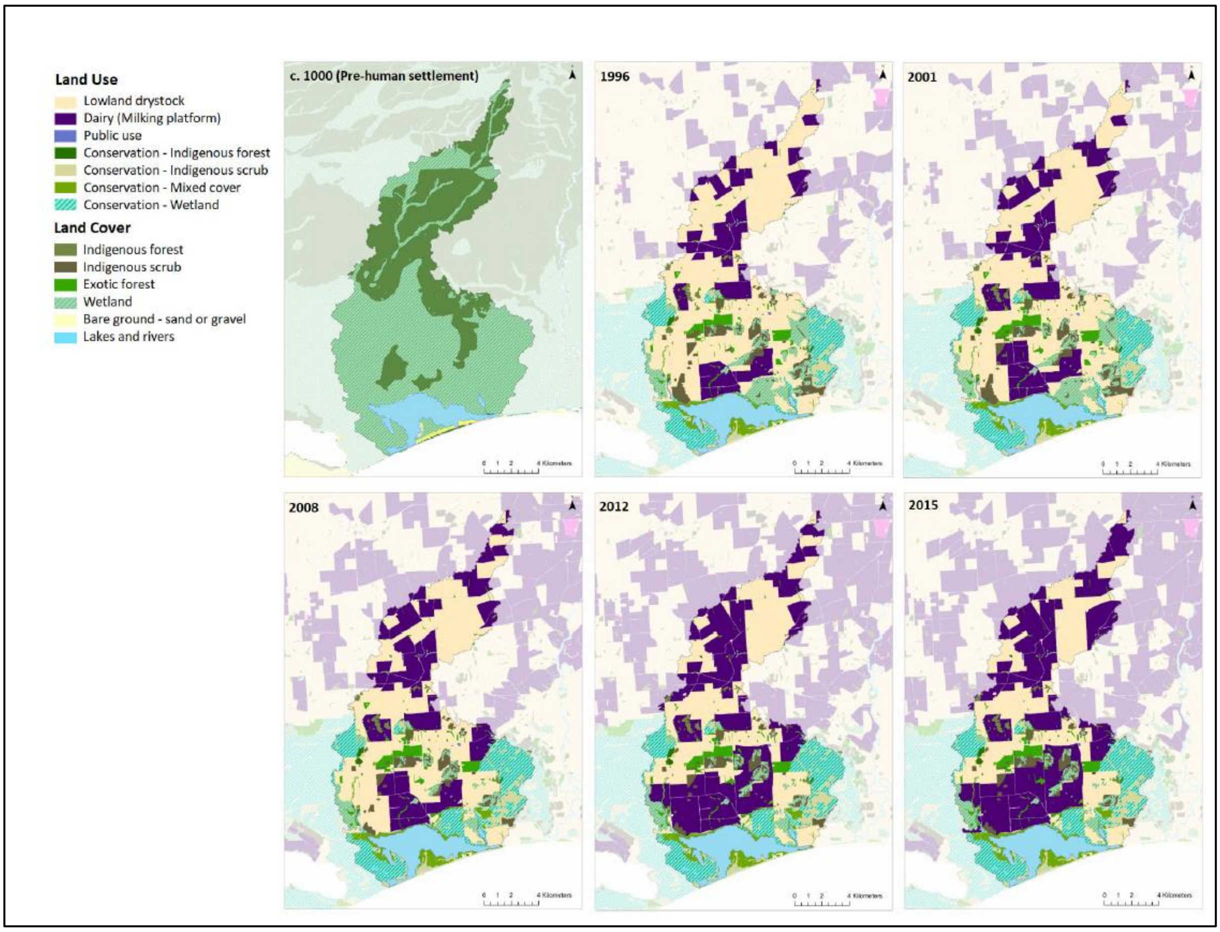

Figure 12: Land use and land cover change in the Waituna catchment from a natural state (Rissmann et al., 2018)

In recent years, conversion to dairy farming has seen a significant population growth in the area, with dairy cattle farming and dairy product manufacturing now being the two biggest employers. It is estimated that there are some 560,000 cows in the Southland area (2.69 cows / ha) producing 1120 kg/ Milk solids/ ha (National Average 1070 kg/ Milk solids/ ha) (LIC, 2017, Taylor et al., 2015).

2.11 Drainage

Catchment drainage is provided by the aforementioned creeks and an extensive agricultural drainage network consisting of drainage ditches and mole and tile drains. Gradual accumulation of sediment and the growth of aquatic plants in drains ultimately leads to impeded flow.

Some 70km of drainage ditches and creeks in the Waituna Creek catchment are maintained by Environment Southland to:

- Reduce the risk of flooding and associated soil erosion; and,
- Prevent soil saturation and thus maintain soil quality and productivity.

This work is funded by a targeted rate. Local input into Council's management of the Waituna Creek Drainage District is provided by the Waituna Liaison Committee. The Committee and Council discuss the state of the drainage network every year, and use landowner feedback as well, to decide if and where any maintenance work needs to be done. Drain clearing may occur anywhere from a 3 to 5 to 10 year cycle, depending on need.

Drain maintenance in Moffat Creek and Carran Creek Catchments is undertaken by farmers and private contractors.

Drain maintenance is undertaken via the use of excavator or digger buckets or rakes to physically remove the weeds and sediment that have accumulated over time thereby reducing the hydrological efficiency. Additionally, private contractors undertake tile drain clearing via water blasting.

The excavated sediment is dumped on the adjacent riverbank or fringes of the paddock, thereby changing the shape of the drain (and thus its hydrology) as well as altering the morphology and lithology of the banks.

Figure 13: Digger clearing Carran Creek 2012 (Hicks, 2012)

The use of a rake has the advantage that it grabs and removes the vegetation and only any attached sediment (rather than scooping it and adjacent material up in a bucket) (Hicks, 2012). This process:

- reduces the possibility of aquatic life becoming entrained in the clearing process,
- has less disturbance to the water column as predominantly solid material is removed,
- but is less effective at removing sediment, and indeed may leave loose sediment in the drain channel that could become mobilised during the next elevated flow event.

3 CONTAMINANT MOBILISATION AND TRANSPORT

3.1 Contaminant mobilisation on-farm

The sources of nutrient losses in the Waituna catchment were investigated by using Overseer (Version 6.3.1) nutrient modelling for a matrix of six representative pastoral farm types in the Waituna catchment by the four main soil types.

To identify sources of nutrient losses in the catchment and evaluate the effectiveness of different mitigation practices, Overseer nutrient modelling was conducted using a matrix of six representative farm types by the four main soil order types in the Waituna catchment. The combinations that were modelled are shown in **Table 2**.

Table 2: Land use and soil combinations used for Overseer modelling

	Brown	Podzol	Organic	Gley
Dairy platform (no feed pad) – 3 cows/ha, System 3	✓			
Dairy platform (feed pad) – 3 cows/ha, System 3	✓			
Dairy platform (no feed pad) – 2.7 cows/ha, System 2		✓	✓	✓
Dairy platform (feed pad) – 2.7 cows/ha, System 2		✓	✓	✓
Drystock - Dairy support	✓	✓	✓	✓
Drystock - Sheep and beef	✓	✓	✓	✓

Typical to the Waituna catchment, all farms were modelled using a flat topography (0-7 degrees slope) and a consistent climate using the long-term average NIWA climate data at the intersection of Gorge Road-Invercargill Highway and Kapuka Road. The average rainfall was 1,150 mm with a low seasonal variation. The climate data used is shown in **Table 3**.

Table 3: Climate data used for Overseer modelling

Mean annual rainfall (mm/yr)	1150
Mean annual temperature	10.2
Annual PET (mm/yr)	790

Base Overseer files were created for each farm model, to estimate the current nutrient losses from different farm types in the Waituna catchment. The farm management information used for the Overseer modelling was based on a range of industry sources:

- Beef & Lamb New Zealand Sheep and Beef Survey Class 7: South Island Intensive Finishing Farms (3-year average- 2015-16; 2016-17; 2017-18 provisional)
- MPI Farm Monitoring Report 2012: Southland/ South Otago Intensive Sheep and Beef
- DairyNZ Economic Survey (2016-17, 2015-16) – financial data of 29 average owner-operated dairy platforms in Southland
- MPI Farm Monitoring Report 2012: Southland Dairy – financial data from 25 dairy farms in Southland
- New Zealand Dairy Statistics (2017-18, 2016-16, 2015-16) – KPIs the of average Southland dairy herd.

- Situation and Outlook for Primary Industries: March 2019 (MPI, 2019) – average product prices
- The Southland Economic Project: Agriculture and Forestry. (Moran et al., 2017) - Overseer modelling and farm financial information for 14 dairy farms and 15 sheep and beef farms in the Mataura FMU.
- Science Summary and Overseer Analysis of the Waituna Catchment (Muirhead, 2013) - farm inputs for Overseer models of 3 dairy platforms and 3 drystock farms in the Waituna.

The key inputs and assumptions of the representative farms were verified through conversations with industry representatives (Fonterra) and five individual farmers in the Waituna catchment, based on their experience and knowledge of farm systems in the catchment.

The representative farm files were consistent with the provisions of the draft Southland Water and Land Plan; however, the dairy support model will require a resource consent as the area of forage crop is greater than 15% of the farm area, and the number of cattle grazing forage crop exceeds 120. Overseer also assumes farms operate at Good Management Practice, so the farms were set up consistent with the assumption that the farm is operating at Good Management Practice. For example, if fertiliser is applied, Overseer assumes that the stated rate is applied evenly across the application area, and it is not applied in waterways. Similarly, the model assumes that stock are excluded from all waterways and streams.

All files were created based on the current Overseer model (Version 6.1.3) and Best Practice Data Input Standards. The nutrient losses were reported using the farms total area (i.e. the farms nutrient losses divided by the total area to give a per hectare rate).

3.1.1 Dairy farm

The representative dairy farm is a 220 effective ha seasonal milking platform. The top of the Waituna catchment on Brown soils has higher pasture production than the wetter peat soils, therefore stock and production were changed accordingly:

Table 4: Key performance indicators for the dairy model

	Brown soil	Other soils[3]
Pasture production (tDM/ha/yr)	16	15
Stocking rate	3.0	2.8
Milk production	390 / cow; 1,152 / ha	410 / cow; 1,150 / ha
Imported supplements	System 2: 430 kg DM /cow; 8% of diet	System 3: 800 kg DM/cow; 15% of diet

Due to lower pasture production and more susceptibility to pugging, the other soils had a lower stocking rate. These soil types also had more imported supplements, to compensate for loss in pasture production. Due to the lower stocking rate and more imported supplements, per cow milk production was slightly higher. The imported supplements consist of mostly pasture silage with a small amount of palm kernel extract (PKE).

The dairy herd are wintered off-farm for 10 weeks and all replacement heifers are grazed off-farm. A small area of fodderbeet (about 5 ha, 20 tDM/ha) is used to transition the cows for winter.

The pasture block receives about 170 kgN/ha, through split dressings from August to April. Maintenance phosphorus fertiliser is applied in November (350 kg/ha superphosphate). No supplements are grown on farm.

The effluent system is a holding pond; liquid effluent is applied regularly at a low rate (less than 12mm). This is consistent with all Fonterra dairy farms in the Waituna catchment. The effluent area is 42% of the effective area for the 'no feed pad' model, and 52% of the effective area with the feed pad. Solids are separated before entering the holding pond and applied to the non-effluent block during October and March.

For each soil type, there was a non-feed pad and feed pad option modelled. For the feed pad model, the stock uses the feed pad for two to three hours per day during the season. All supplements are fed

[3] Organic, Podzol and Gley soil

out on the feed pad; due to the higher utilisation rate the amount of imported supplement required is slightly lower. The liquid effluent is added to the farm dairy effluent pond, while manure is scraped from the pad and applied to the non-effluent block in October and March.

Stock are excluded from all waterways. Further Overseer modelling inputs for the dairy model can be found in the Appendices.

3.1.2 Dairy support farm

The representative dairy support farm is a 130 ha operation; the effective area (120 ha) consists of 90 ha of pasture and 30 ha of kale crop. The farm supports the grazing needs of all heifer replacements and winters half the average Southland dairy herd. A total of 150 weaned heifer calves arrive on the property in December and remain there until the end of June in their second winter. In addition, 300 cows are wintered for 10 weeks.

There are two cuts of baleage during November and early summer; 400 tDM is exported off-farm (back to the milking platform) and 150 tDM is fed out on farm, mostly to the cows grazing kale. No supplements are imported.

The kale crop (14 tDM/ha) is sown in November (conventional cultivation). Cropmaster DAP (250 kg/ha) is incorporated at sowing and there are two side dressings of urea (100 kg/ha each). The kale is grazed in-situ by stock over winter.

The main pasture block receives a total of 135 kgN/ha, through split dressings from August to April. Maintenance phosphorus fertiliser is applied in November (200 kg/ha Superphosphate). There are no off-paddocks structures, as only a couple of farmers have these for dairy support in the Waituna catchment.

Further Overseer modelling inputs for the dairy support model can be found in Irving and Ford (2019).

3.1.3 Sheep & Beef farm

The sheep and beef model is a 235 ha intensive finishing unit; the effective area (225 ha) consists of 210 ha pasture and 15 ha swede forage crop.

The farm has a total of 2,334 stock units (10.4 SU/ha). Typical to intensive finishing units, the total stock unit ratio was 1,757 (92%) sheep and 163 (8%) cattle finishing. This sheep dominated farm reflects farmers having adapted to their environment by running small light stock relative to cattle. Note there is no dairy support in this model as there are only a couple of sheep and beef farmers in the Waituna catchment with a dairy grazing enterprise[4].

The sheep enterprise had about 1750 Romney ewes, with a lambing percentage of 142%. The lambs are finished and sold prime from late December to the end of March, with a carcass weight of 21 kilograms. All hoggets were grazed on farm. A small number (30) weaner dairy-beef cross steers were purchased in March and retained until sold to the works at the end of April (at 275 kg carcass weight) in the following year.

There was one cut of baleage in November on the baleage block when there was surplus pasture; the 285 bales made were out on farm mostly during autumn and winter. No supplements were imported. The swede crop (14 tDM/ha) was sown in November (conventional cultivation), and is grazed in-situ by the stock over winter.

The main pasture block had a Superphosphate application in November (200 kg/ha). The silage block had an application of Cropmaster 20 in October (175 kg/ha), to promote grass growth prior to harvest. No nitrogen fertiliser was applied to pasture, as per conversations with the sheep farmers in Waituna.

There are no off-paddock structures, such as feed pads, on the sheep and beef model.

[4] Refer to Irving and Ford (2019) for the representative dairy support model for the Waituna model

3.1.4 Key results

- Land use had a significant impact on nitrogen loss from farms (see Figure 14). For example, on the Brown soil the dairy systems lost 36% more nitrogen to water relative to the dairy support farm, and over 2.5 times more nitrogen than the sheep and beef farm. Dependent on soil type, average annual nitrogen losses in the base farm models were 26 to 46 kg for dairy, 25 to 34 kg for dairy support and 13 to 18 kg for the sheep and beef farm.
- Soil type was a significant driver of contaminant losses (see below graph), as nitrogen losses decreased in the order of Brown > Gley > Podzol > Organic (within the same land use). In particular, Brown soil had significantly higher nitrogen losses due it its relatively higher drainage. Conversely, Brown soil had the lowest phosphorus loss, while Podzol and Organic soil had the highest phosphorus loss. This highlights that there is no 'ideal' soil for stock wintering, as a particular soil is likely to be susceptible to either nitrogen (leaching) or phosphorus (runoff) losses.
- Winter forage crop contributed to a disproportionally large proportion of each farm's total nitrogen losses, as found in other modelling studies (Chrystal et al., 2012). For example, swedes represented only 6% of the total sheep and beef farm area, yet contributed to 41% of the farm's total nitrogen losses. Wintering livestock by break-feeding on forage crops is a common practice in Southland, as pasture growth during winter is minimal, when soil temperatures are cold.

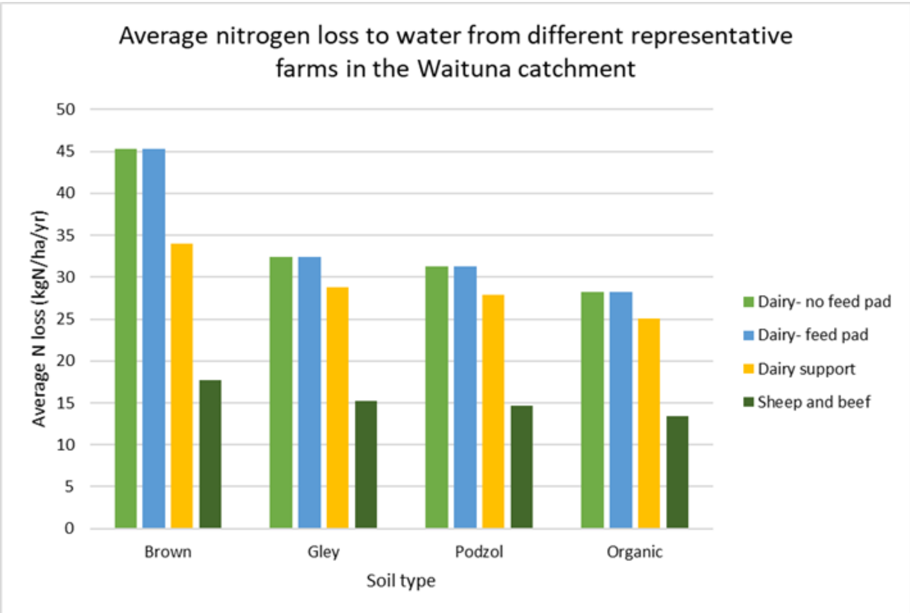

Figure 14: Average modelled nitrogen loss to water for representative farms in Waituna Catchment.

3.2 Contaminant mobilisation in the drainage network

Stream water quality decreases markedly during drain clearing, with the highest total Suspended Sediment and phosphorus values being recorded during these periods.

During this maintenance period, the Suspended Sediment inputs can be elevated considerably – for example, routine clearing of the main channel of Waituna Creek in 2012 saw a 25 fold increase in Suspended Sediment loads from 22 mg/ l to 550 mg/ l. This process also liberates sediment-bound water quality contaminants such as phosphorus, organic compounds and metals (McDowell et al., 2013, Hicks, 2012). Notably, there is little change in NO_3-N concentrations in the water column (Hicks, 2012).

Sediment characterisation and identification – or 'fingerprinting' – is a well-established method for identifying the source of Suspended Sediment and has been widely used to develop BMP's to address sediment transport issues.

A study undertaken by AgResearch in 2012 sought to identify the source of the Suspended Sediment material by reconciling upstream soil samples with the Suspended Sediment material.

The aim of this study was to

> *"…test whether the sediment fingerprinting technique may be a useful tool in determining likely sources of sediment within an intensively farmed lowland catchment. More specifically, the study aimed to derive the probability of a match between suspended solids samples taken at four stream sites in the Waituna catchment and potentially contributing sources."* (McDowell et al., 2013)

Suspended Sediment samples were collected along the Carran, Moffat and Waituna Creeks in the northern and southern zones of the catchment between April and July 2012. All samples underwent a nitric acid - hydrogen peroxide digestion with the digest being analysed for full-suite multi element & Rare Earth Element (REE) compounds via Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES). The results were compared to the results obtained from soil, subsoil and stream bank samples taken further up the catchment.

The study concluded that

- Suspended Sediment concentrations in general paralleled flow regimes, land use, and edaphic factors (e.g. soil and climate) for all three creeks;
- Waituna Creek was the major source of Suspended Sediment into Waituna Lagoon, contributing 64% in the upper catchment and 94% in the lower catchment;
- The Suspended Sediment in the upper catchment of Waituna Creek had contributions of topsoils and bank sediment, but was predominantly bank sediment in the lower areas of the catchment.
- Sources of sediment could not be distinguished for Carran Creek and Moffat Creek sites.

As noted in an earlier Section, drain clearing is a significant factor in mobilising sediments. The outcomes of typical drain clearing processes are:

- Changes in channel shape such as widening, deepening or the removal of gravel bars can affect the hydraulic properties of the drain.
- Increased turbidity up to 1,500 m downstream resulting in reduced visual water clarity and light penetration that in turn affects plant and aquatic life.
- Increase in water temperature due to the removal of shading plants – which may lead to the increased potential for eutrophication.
- A threefold increase in Ammoniacal Nitrogen (NH_4-N) and phosphorous concentrations in stream water.
- Reduced bio diversity and biomass due to the disruption of habitat.
- Increased bank erosion due to the removal of plants growing on stream banks.

3.3 Contaminant Transport Pathways

3.3.1 Surficial Migration

Sediment migration has several effects on water quality, acting as both a pollutant and a transport pathway for nutrients. Sediments affect visual water clarity and light penetration that in turn affects plant and aquatic life. Additionally, nutrients such as P, organic compounds and pathogens (e.g. faecal matter, fertilizers etc.) adsorb to the sediment grains and are thus transported via surface flow paths to low lying areas such as riverbanks where retention can cause large quantities of P to accumulate (Hicks, 2012).

In comparison, Nitrogen (sourced from fertiliser and/ or animal urine) is highly soluble and thus migrates largely through the sub-surface environment.

Table 5 presents the sediment and nutrient yields estimated for the sub-catchments of the Waituna Lagoon (Tanner et al., 2013)

Table 5: Estimated TSS, TP and TN yields for the sub-catchments of the Waituna Lagoon

Sub catchment	TSS (kg/ha/yr)	TP (kg/ha/yr)	TN (kg/ha/yr)
Waituna Creek	95.7	0.6	17.7
Carran Creek	67.2	0.8	8.6
Moffat Creek	70.7	1.2	12.6

3.3.2 Groundwater Migration

The Equilibrium Phosphorus Concentration (EPC) is a parameter often used to ascertain if sediments are a sink or a source of phosphorus to flowing water. If the EPC is approximately equal to the dissolved P in the water, then the sediments and water column are in equilibrium. If the EPC is less than the dissolved water concentration, then the sediments are acting as a sink and absorbing P. If the converse is true, then the sediments are acting as a source by desorbing P.

Notably, the concentrations of P in the reduced groundwater's of the lower catchment (Figure 15) are up to 50 times higher than in the oxidised redox state groundwater's in the north (Rissmann et al., 2012).

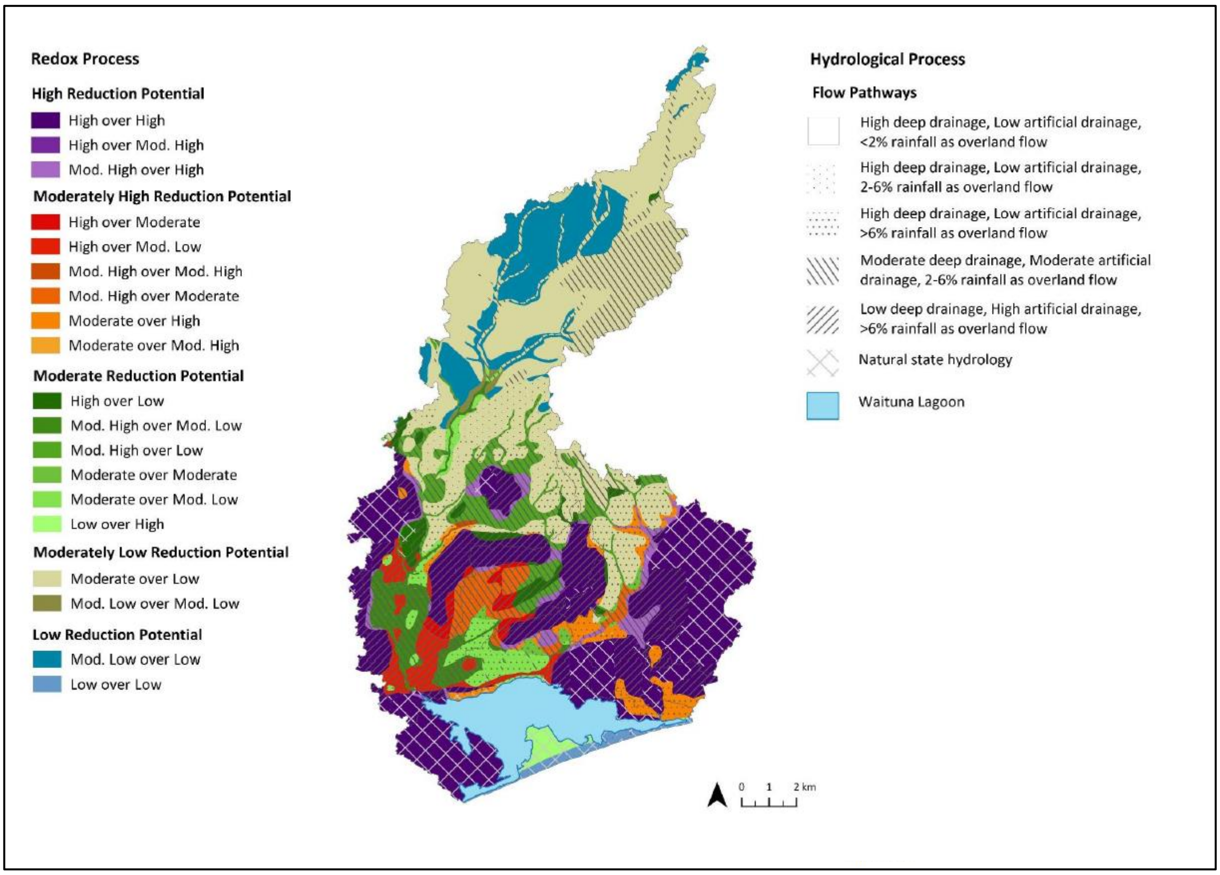

Figure 15: Redox potential associated with different physiographic units for the Waituna Catchment (Pearson and Rissmann, 2018)

The elevated P within these groundwater's likely reflects both the leakiness of P from organic soils (i.e. EPC > dissolved P in the water column), indicating naturally higher solubility and mobility of phosphate under reducing conditions and a potentially significant phosphate input from the underlying lignite measure aquifers (Rissmann et al., 2012).

Although there is some evidence for anthropogenic phosphate contamination of southern groundwater's due to diffuse soil leaching and localised septic inputs, further work is required to ascertain the magnitude of anthropogenic sources in this sector of the catchment. Rissmann et al. (2012) estimates that groundwater contributes

- 28 to 48 tonnes p.a. of TN to Waituna Lagoon, of which approximately 30 to 40% is derived from base flow in the MIZ.
- 1,434 to 2,389 kg/year of TP of which around 40 to 60% is sourced from direct groundwater seepage into the lagoon.

Rekker and Wilson (2016) noted:

> *"The Waituna catchment displays strong elements of temporal dynamism in its nutrient transfer mechanisms due to moderately retentive soil, thin unsaturated zone and winter-spring flushing of groundwater into creek base-flow."*

From this position Rekker and Wilson (2016), proposed the following mechanisms for increased nitrate migration during higher flow rates:

5. **Groundwater pathway**: Rainfall is being infiltrated to groundwater beneath well-drained soils, thereby increasing the instream nitrate concentration by an increase in nitrate-enriched base-flow. Rissmann et al. (2012) determined that groundwater plays a minor, albeit important role, in the transport of nutrient loads into the Waituna Lagoon. When compared to the estimated surface-water nutrient loadings, groundwater inputs may contribute approximately 11% to 18% of the cumulative TN and 10% to 15% of the cumulative TP loadings to Waituna Creek.
6. **Refused recharge:** Soil moisture exceeds field capacity, but either high water table or low hydraulic conductivity in limiting horizons in the soil/sub-soil opposes infiltration to the shallow aquifer and the excess diverts into the creek network by lateral drainage.
7. **Artificial drainage pathway:** Nitrate in poorly-drained soils is being flushed via tile drains into the main stream channels in response to rainfall events.

A reconciliation of mean surface water Nitrate+Nitrite Nitrogen and groundwater Nitrate – Nitrogen concentrations with nitrate concentration levels in proximal soils revealed that in the Mokotua area, NO_3-Nitrogen concentrations exceed 2 mg/l beneath or down-gradient of Waikiwi soils as shown in Figure 16.

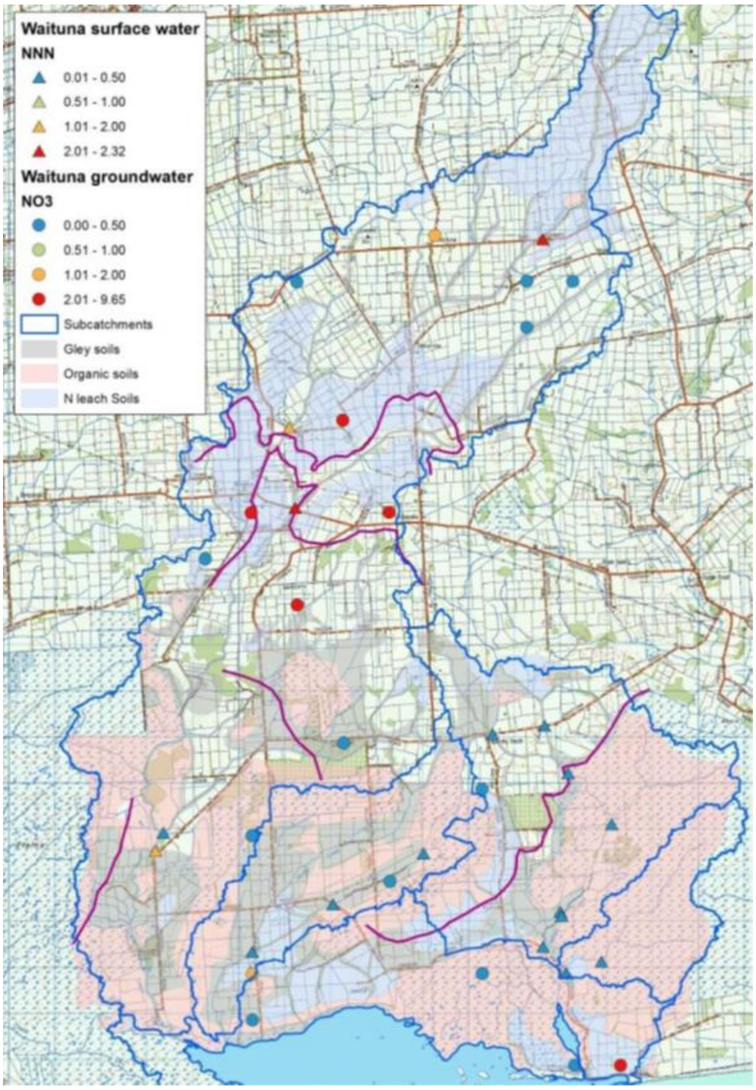

Figure 16: Map of soil type with aquifer nitrate results (Rekker and Wilson, 2016).

4 WAITUNA LAGOON HEALTH

Waituna Lagoon and the surrounding area was designated a Ramsar Site in 1976 in recognition of its high biological diversity and that it supports a number of rare and endangered species. It is a wetland of international importance.

New Zealand's obligations under the Ramsar Convention require that the Waituna Lagoon be managed to preserve habitats important for sustaining its endemic species.

The health of the Waituna Lagoon ecosystem has been the subject of much monitoring and analysis over the past fifteen years. This work has been comprehensively reported by a number of authors, from Thompson and Ryder (2003) to Environment Southland (2013) to Schallenberg et al (2017).

This work has reported that:

- Sustaining the submerged area covered by the macrophyte *Ruppia* is critical to sustaining the biodiversity of Waituna Lagoon (Hamilton et al, 2012).
- Annual monitoring over the period 2009 – 2013 "indicates a decline in lagoon condition and *Ruppia* biomass and cover" (Environment Southland, 2013).
- The macrophyte community is susceptible to multiple stressors, including the altered hydrological regime, increased nutrient loading, reduced water clarity and increased salinity at key stages in *Ruppia's* growth cycle (Environment Southland, 2013).
- Nutrient concentrations in the lagoon have increased and the sedimentation rate has increased markedly (Environment Southland, 2013).

The Waituna Lagoon is now in a highly disturbed ecological state: there is a high risk of it shifting to an algal-dominated eutrophic state from its previously stable native macrophyte dominated oligotrophic state (Robertson et al, 2011). If the lagoon undergoes a regime change to a eutrophic state it is likely that the abundance of mahinga kai and other indicator species will reduce substantially and perhaps cease to provide the habitats needed to sustain its populations of rare and endangered species.

Lagoon water quality fails to meet national bottom lines for total nitrogen and E-coli water quality attributes specified in the NPS-FM's National Objectives Framework (Hodson et al, 2017).

A Lagoon Technical Group comprising experts in coastal lagoon/lake ecology and water quality was convened in 2011 by Environment Southland and partners to develop recommendations aimed at improving the ecological condition of the lagoon to reduce the risk of a regime shift occurring.

They recommended that the lagoon and its catchment be actively managed to achieve and sustain an average annual coverage of the permanently wetted area, by *Ruppia* and other native macrophytes, of between 30% and 60% (Environment Southland, 2013).

To achieve this they recommend (among other things) the following:

- Reducing the total nitrogen input to the lagoon to less than 125 tonnes/year (i.e. about half the current load).
- Reducing the total phosphorous input to the lagoon to less than 7.7 tonnes/year (i.e. about half the current load).
- Limiting lagoon openings to the sea for water level control and sediment flushing to the May to July period (inclusive) or to a maximum height of 2.5m.
- Improving water clarity so that the photosynthetically active radiation that reaches the lagoon bed is at least 10% of the level at the lagoon surface.

These measures are expected to stabilise the lagoon in a moderately disturbed ecological state and significantly reduce the risk of it flipping to a eutrophic state. They are also expected to result in water quality national bottom lines for ICOLL's being surpassed.

These recommendations are derived from the results of three independent lines of enquiry (Schallenberg et al, 2017):

1. A literature review to identify nitrogen load thresholds above which macrophyte communities have collapsed in similar lagoon or lake systems.
2. Independent expert assessment of local data and that from 57 Australian coastal lagoons and lake.
3. A computer modelling study that simulated the ecological outcomes of various nutrient loading rates.

The close similarity in the nitrogen load threshold provided by each of these studies (Schallenberg et al, 2017) confers greater confidence in the robustness of the nitrogen load limit than that derived from either of these studies on their own.

Phosphorous load thresholds derived by these studies were more variable. Consequently the Lagoon Technical Group recommended taking the precautionary step of reducing the total phosphorous load by the same percentage as for total nitrogen. It is understood that increasing the phosphorous to nitrogen concentration ratio (by reducing the nitrogen concentration) increases the risk of toxic algae blooms. Reducing phosphorous load by the same percentage as for the nitrogen load seeks to avoid increasing this risk.

Computer simulation of lagoon dynamics is the only practical way to develop a quantitative relationship between sediment load into the lagoon and lagoon water clarity, and thus set a sediment load limit to achieve the water clarity recommendation stated above. Water clarity varies through time in response to variations in a number of parameters, including lagoon water depth, flow through the lagoon, wind velocity and direction, macrophyte bed cover, sediment inflow from the creeks and lagoon bed sediment properties. To our knowledge, comprehensive computer simulation based analyses of this type have not been undertaken for the Waituna Lagoon.

Lack of quantitative information has therefore precluded setting a specific percentage reduction target for the total suspended sediment load reaching the lagoon. However a significant reduction in this load is required if the rate of sediment accumulation in the lagoon is to be materially reduced. A significant reduction is also expected to be required in order to achieve the recommended phosphorous load reduction and photosynthetically active radiation levels at the lagoon bed.

5 THE CONTAMINANT LOAD REDUCTION CHALLENGE

The Whakamana te Waituna programme aims to enhance social, cultural, economic and environmental resilience throughout the Waituna Catchment, as well as the resilience of the lagoon itself. It also aims to improve access to the lagoon.

Its objectives for achieving these aims include:

1. The development of a landward buffer around the lagoon.
2. The re-establishment and strengthening of manawhenua role as kaitiaki, while building mataraunga Maori and community capacity.
3. The design, adoption and implementation of a catchment-wide contaminant load reduction programme to increase the resilience of ecosystems in and around the lagoon and its tributaries.
4. Maintaining or improving the economic resilience of the farming community.

Reducing the input of the principal contaminants (N, P, and sediment) to the degree needed to stabilise the lagoon in a moderately disturbed ecological state will require changes in land-use or land-use intensity and how land and waterways (including land drainage systems both on- and off-farm) are managed throughout the Waituna Catchment.

Analyses of a wide range of contaminant loss reduction options available to farmers (DairyNZ 2015, Muirhead 2013) indicates that taking the measures required to reduce N losses to water by more than about 30% would put the financial viability of farms throughout the Waituna Catchment at serious risk (conflicting with objective 4 above). The reduction recommended for achieving a resilient lagoon is 50% (Environment Southland, 2013).

Analysis of the cost and N reduction efficacy of in-farm-scale wetlands in the Waituna Creek catchment indicate that even if wetlands were constructed on all the sites identified (both on- and off-farm) in Tanner et al (2013), the reduction in N load would fall well short of the reduction required.

These analyses suggest that to achieve both an economically resilient farming community AND a resilient though moderately disturbed lagoon, it is likely to be necessary to implement each of the following:

- Retire strategic areas of land within the catchment.
- Reduce contaminant losses to water from the remaining farms in a manner and to a degree that protects their financial viability.
- Construct substantial wetlands to trap and reduce contaminants.

The challenge is determining where to implement each of these actions, to what degree, and at what cost, in order to meet the objectives listed above.

Collectively purchasing the land buffering Waituna Lagoon and ‘retiring’ it would enable land-cover to return, over time, to indigenous species and remove the need to drain it. This would enable the contaminant load from this area to be reduced to pre-development levels, provide affected landowners with viable exit options, meet objective 1 and create opportunity for objective 2 to be met.

Waituna Creek contributes about 75% of the annual Total N load received by the Waituna Lagoon, and about 65% of the Total P load. Areas directly discharging to the lagoon and via Carran Creek are other important sources (van den Roovaart et al, 2014).

This is broadly consistent with the N and P risk assessment shown in Figures 17, 18 and 19 below, from Pearson and Rissmann (2018).

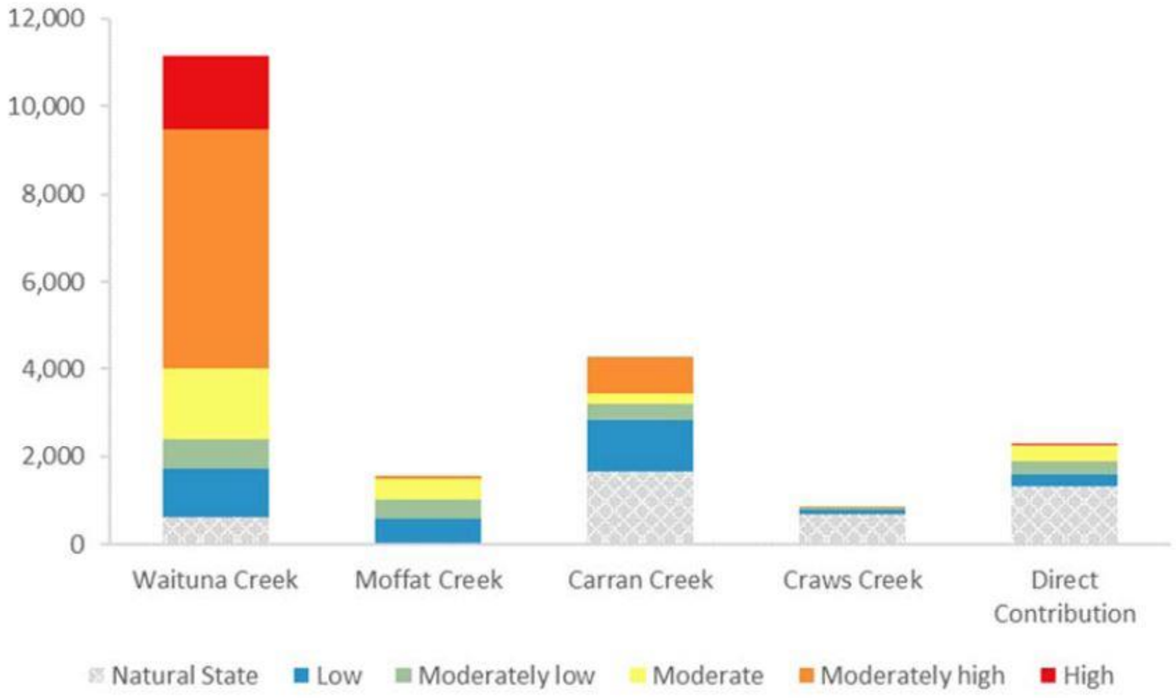

Figure 17: Assessed N loss risk – area (ha) of each risk category by catchment (Pearson and Rissmann, 2018)

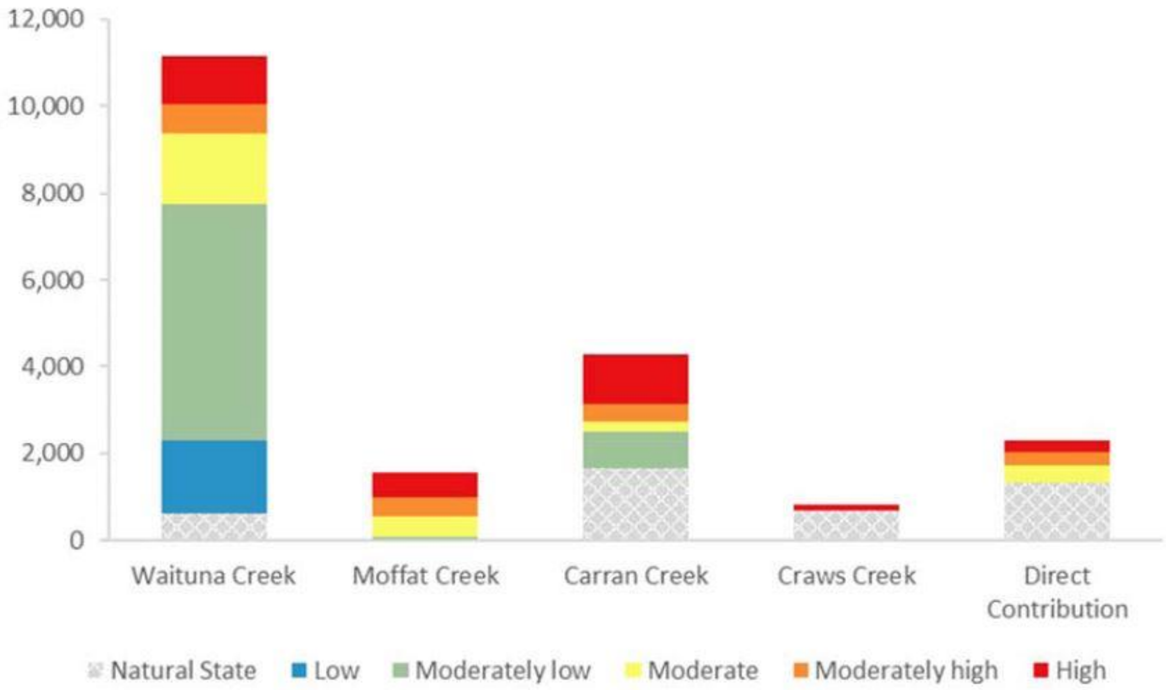

Figure 18: Assessed DRP loss risk – area (ha) of each risk category by catchment (Pearson and Rissmann, 2018)

Measures taken to reduce the N and P load received by Waituna Lagoon must focus on the Waituna Creek catchment, if reductions as significant as those recommended are to be achieved.

The area of High plus Moderately High risk of DRP loss are very similar in each of Waituna, Moffat and Carran Creeks. Measures taken to reduce the DRP loss should apply across all three catchments.

Sediment finger-printing suggests that the main source of the sediment load from Waituna Creek is the banks of streams and drainage channels – either by stream-bank collapse or by mechanical cleaning. Strategies for minimising sediment delivery from this catchment should be built around measures that reduce the incidence of stream-bank collapse and modification of drain clearing practices (McDowell et al, 2013).

Measures to reduce erosion of the soil surface and interrupt the transport of soil particles to streams and drainage channels should focus on Carran Creek and Waituna Creek catchments, based on Pearson and Rissmann's (2018) surface run-off risk assessment (Figure 19) and assuming areas with High plus Moderately High risk are the critical areas. Measures taken to reduce sediment loss from soil surfaces, for example fencing and planting of riparian margins, will generally have the co-benefit of reducing E.coli inputs to drains and creeks.

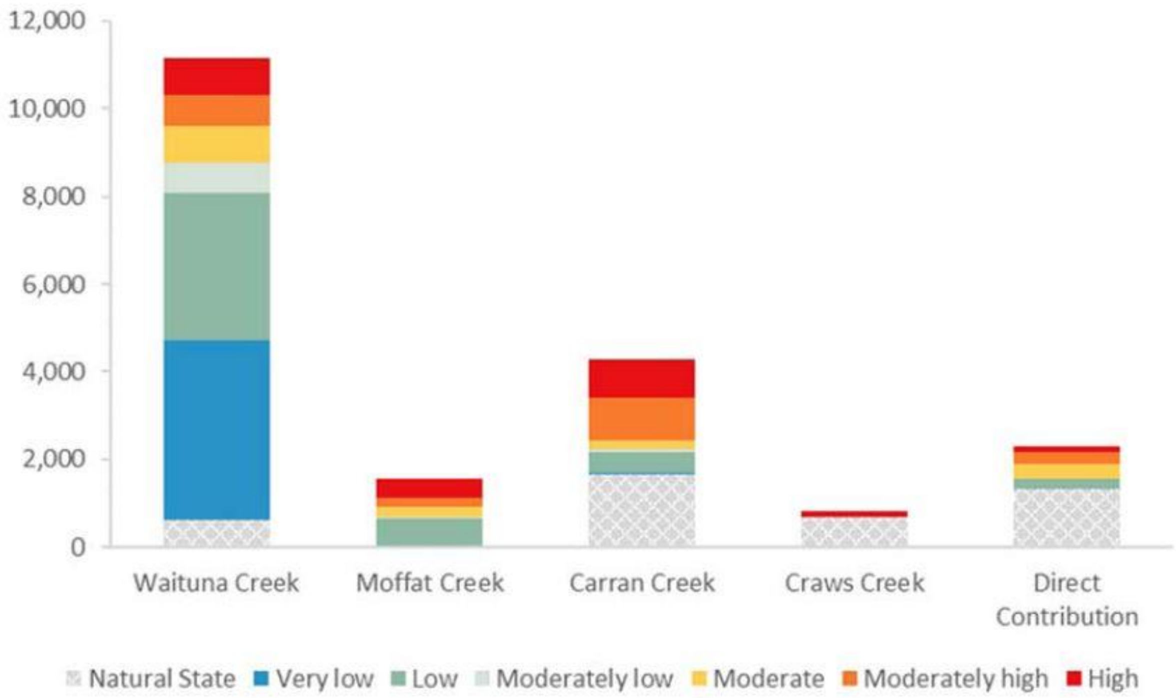

Figure 19: Assessed runoff risk – area (ha) of each risk category by catchment (Pearson and Rissmann, 2018)

6 CONTAMINANT LOSS AND TRANSPORT REDUCTION OPTIONS

There are a wide range of specific measures for reducing contaminant loads in agricultural catchments. Options relevant to the Waituna Catchment are described in this Section, assessed for suitability in Section 7 and the estimated efficacy of implementing various combinations of selected measures in the Waituna Catchment is reported in Section 8.

6.1 On-Farm practices

To investigate the potential to mitigate nutrient losses, a series of cumulative mitigation bundles were applied to each of the farm and soil type combinations. Financial models were also created to align with each base Overseer model and mitigation scenario based on Southland regional averages, to evaluate the impact of the mitigation measures on farm profitability. These results were used to construct nitrogen abatement curves for each land use; to define the financial cost of achieving a given level of nitrogen mitigation.

There has been extensive research in New Zealand (Menneer et al. (2004), Monaghan et al. (2007), de Klein et al. (2010), Vibart et al. (2015) and Howarth and Journeaux (2016) regarding mitigation options to reduce the mobilisation of contaminants due to farming activities and their transport to water bodies. Individual contaminants have different sources and transport pathways; therefore no single mitigation can effectively decrease the losses of all contaminants at the same time, but some can have multiple benefits.

Mitigation of nitrogen leaching typically focuses on three main options:

- Reducing nitrogen inputs (i.e. de-intensification)
- More efficient utilisation of nitrogen within the farm system
- Capturing or re-using nitrogen before it enters waterbodies.

In comparison, mitigation of sediment, phosphorus and E. coli contaminants generally focuses on critical source areas (hotspots), such as winter forage crops; gateways and laneways; effluent discharge areas; and ensuring sufficient buffers between waterways and farm activities to filter contaminant runoff.

The mitigations chosen were based on empirical research, a literature review and modelling experience, according to the following criteria:

- The mitigation is cost-effective,
- The mitigation is able to be incorporated into the farm system in a practical manner, with the farmer having a similar level of skill
- The mitigation is recognised by the current Overseer model[5]

The mitigation bundles for each relevant land use are described below.

Wetlands were not modelled as a mitigation, as the Overseer wetland model is currently under review, therefore the Overseer Input Standards recommend that users ignore using wetland model if it is not a significant feature on the farm. The mitigation modelling also did not include the retiring of land. It stopped at this point because the land would be retired from production.

Although the mitigation modelling reported nitrogen and phosphorus loss, the mitigations primarily focused on nitrogen. This is because there is less certainty about the use of Overseer in regards to phosphorus, as critical source areas (such as swales and gullies) which contribute to a high proportion of phosphorus losses are unable to be specifically modelled in Overseer. While Overseer modelling can estimate average phosphorus losses from a farm, the reality is that losses are not spatially uniform across the property. Mitigations for sediment and microbes were also not included as Overseer does not model these contaminants.

5 There are a number of alternative forage species that field trials indicate have the potential to lower farm N loss to water, albeit such impacts are not well captured in the current Overseer model

6.1.1 Mitigation scenarios

The following mitigation bundles were applied in cumulative steps to the relevant base model:

6.1.1.1 Dairy – Low Bundle

Both models (non-feed pad and feed pad):

- Reduce autumn fertiliser applications by 50% - reduce milksolid production and lower producing cows in autumn to compensate for loss in pasture production.
- Reduce fertiliser applications on effluent area – taking the effluent nitrogen content into account[6]
- Apply maintenance phosphorus fertiliser using low water-soluble fertiliser, i.e. the use of reactive phosphorus rock – ensuring same amount of phosphorus and sulphur applied

Feed pad model:

- Increase the duration that cows are on the feed pad by one hour per day (to three hours on Brown soil; four hours on other soils)

6.1.1.2 Dairy – Medium Bundle

Both models (non-feed pad and feed pad):

- Reduce stocking rate by 10% and increase per animal milk production by 5%
- Dry off cows a week early
- Reduce replacement rate from 23 to 21%
- Apply effluent solids on crop area (while continuing to apply solids to the non-effluent block)
- Reduce spring nitrogen fertiliser applications by 50% - increase imported silage to compensate for loss in pasture production

6.1.1.3 Dairy – High Bundle

Both models (non-feed pad and feed pad):

- Use an uncovered wintering pad to implement a restricted grazing strategy as follows:
  - All dairy cows on the pad from March to May and in August (after cows calved) for 12 hours per day. It is not used during June and July due to cows already being wintered off farm.
  - Pad surface is concrete with bark covering. It is lined and effluent is captured.
  - Manure is removed by scraping and are spread on the non-effluent block in October, following uncovered storage.
  - Liquid effluent is managed by the FDE system
  - Concrete feeding apron is used.
- Fodderbeet crop is lifted (rather than grazed in-situ) and fed on the feed pad

The results of the mitigation modelling are illustrated by the following abatement curve for nitrogen loss to water (Figure 20).

[6] Assuming about half of effluent nitrogen is plant readily available

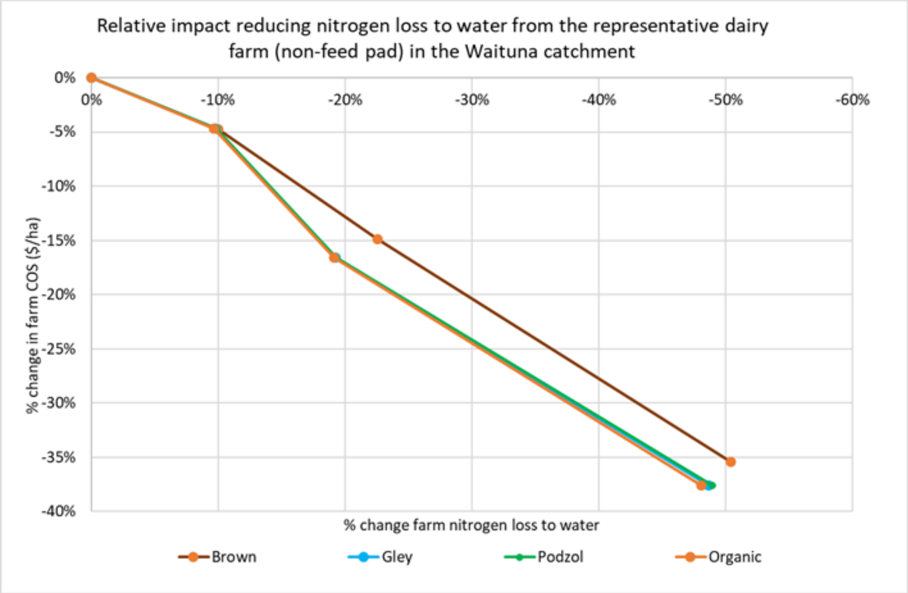

Figure 20: Abatement curve for nitrogen loss to water for representative Waituna dairy farm

6.1.1.4 Dairy Support – Low Bundle

- Reduce autumn nitrogen fertiliser by 50% (from 18 to 9 kgN/ha in April), reduce silage made and exported to the dairy platform to compensate for loss in pasture
- Direct drill kale (instead of conventional cultivation)
- Apply maintenance phosphorus fertiliser using low water-soluble fertiliser, i.e. the use of reactive phosphorus rock – ensuring same amount of phosphorus and sulphur applied

6.1.1.5 Dairy Support – Medium Bundle

- Remove all autumn fertiliser (9 kgN/ha in April) - reduce silage made and exported to the dairy platform by a further 18 tDM to compensate for loss in pasture
- Reduce all other urea fertiliser by 10% - reduce heifer numbers by 20 (to 130 total heifers) to compensate for loss in pasture

6.1.1.6 Dairy Support – High Bundle

- Reduced kale area (used for wintering cows) by 25%
    - Reduce wintered cows by 25%. Silage made to feed these cows is exported to the milking platform instead.
    - Increase in pasture area (due to decrease in kale area), increase heifer numbers to consume additional pasture.

The results of the mitigation modelling for dairy support are shown in Figure 21.

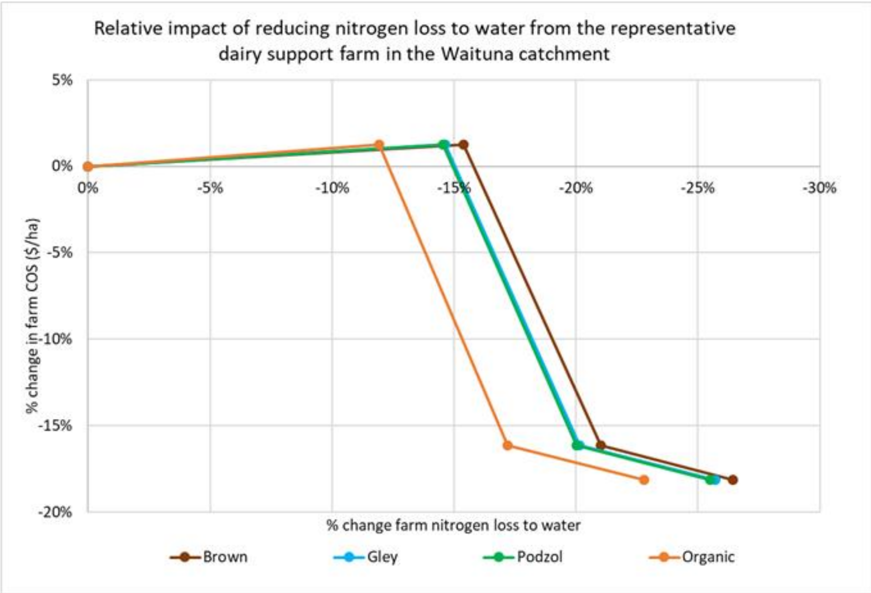

Figure 21: Abatement curve for nitrogen loss to water for the representative Waituna dairy support farm

Drystock farms have limited use of external inputs in their production systems, such as nitrogen fertiliser to pasture and imported supplements, and stocking rates are generally within the carrying capacity of the land (Moran et al., 2017). Generally, their livestock are wintered on-farm and off-paddock structures are rare. As a result, there are only a few mitigations available for modelling.

This particular representative sheep and beef model had no nitrogen fertiliser applications, excluding the fertiliser applied to the baleage block, which was essential for baleage production. It also had no feed pads. Due to only one soil type being represented in each model, there was no ability to shift heavier stock from grazing vulnerable soils. In the initial scoping, the impact of changing the crop grown from swedes to fodderbeet was investigated, to decrease crop area (as fodderbeet is a higher yielding and lower protein crop). However, the interim modelling showed this actually increased nitrogen losses, so this mitigation was removed.

The following mitigation bundles were applied in cumulative steps to the sheep and beef farm:

6.1.1.7 Sheep and Beef – Low Bundle

- Exclude all cattle from streams[7]
- Apply maintenance phosphorus fertiliser using low water-soluble fertiliser[8], i.e. the use of reactive phosphorus rock – ensuring same amount of phosphorus and sulphur applied
- Direct drill swedes (instead of conventional cultivation)

6.1.1.8 Sheep and Beef – Medium Bundle

- Reduce swede crop area by a third (from 15 to 10ha) - increase baleage production by 70 tDM, to feed to stock over winter to account for loss in dry matter from swede crop.

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[7] Overseer only considers the effects of the exclusion of cattle from steams and stream banks; no account is available for other stock types such as sheep

[8] Two sheep farmers contacted in the Waituna catchment have been using RPR for several years, rather than conventional P fertiliser, as it has a slower release and improvements in soil microbiology have been observed

6.1.1.9 Sheep and Beef – High Bundle

- Reduce breeding ewe numbers by 5%
- Increase the lambing percentage from 141 to 145%
- Increase weight gain of lambs and sell them earlier at the same target live-weight of 41 kg (21 kg carcass weight)

Month sold (at end)	% Base file	% High Bundle file
December	8	32
January	17	32
February	25	32
March	50	4

- Increase weight gain of steers and sell two months early at greater live-weight

	% Base file	% High Bundle file
Month sold (at end)	April	February
Sale live weight (kg)	525	550

The results of the mitigation modelling are illustrated by the following figure.

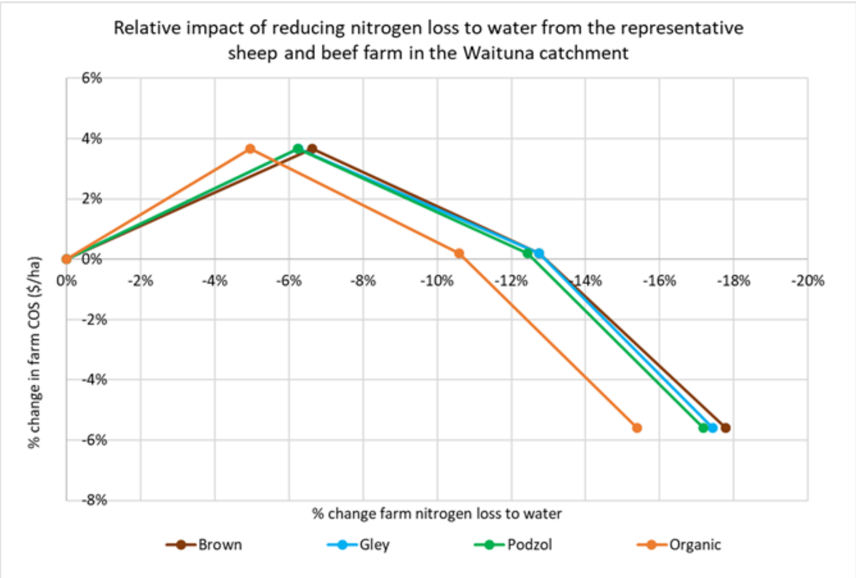

Figure 22: Abatement curve for nitrogen loss to water for the representative Waituna sheep and beef farm

6.1.2 Key findings from on-farm mitigation modelling

- Effective nitrogen mitigations in the drystock Overseer models included adopting minimal tillage (removing conventional cultivation) of forage crops, removing or reducing autumn fertiliser, small reductions in stocking rates, reducing winter crop areas and improving animal performance (weight gains and lambing percentages).
- In the dairy model, reductions in nitrogen leaching were achieved by reducing autumn and spring nitrogen fertiliser applications, ensuring nitrogen applications to dairy effluent blocks take effluent nutrients into account, drying cows off a week early, removing cull cows earlier, reducing the

stocking rate by 10% while increasing per cow milk production by 5%, reducing replacement rates and finally implementing a standoff pad.

- The mitigation curves are shown below. Across all land uses, the percentage reduction in nitrogen leaching was larger than the percentage reduction in farm profitability.
- The drystock farms had less capacity to reduce nitrogen losses than the dairy platform. For example, implementation of the high mitigation bundles reduced nitrogen losses by almost 50% on the dairy models, 17 to 26% on the dairy support models and 15 to 18% on the sheep and beef models. This was also identified in a recent study of 95 farms across the wider Southland region (Moran et al., 2017). It is suggested that the drystock farms have less ability to reduce losses as they have lowest nitrogen losses to start with (so mitigations have little effect) and they have limited inputs (nitrogen fertiliser and supplementary feed) and therefore have fewer mitigation options.
- Relative to the nitrogen reductions, phosphorus reductions were reduced marginally following implementation of all mitigations (7-11% reduction for dairy, 5-10 % dairy support and 3-9% sheep and beef). However, the mitigations primarily focused on nitrogen. This is because there is less certainty about the use of Overseer in regards to phosphorus, as critical source areas (such as swales and gullies) which contribute to a high proportion of phosphorus losses are unable to be specifically modelled in Overseer. The majority of farm practices which mitigate phosphorus losses are unable to be modelled in the current version of Overseer.
- In terms of farm financials, the low mitigation bundle slightly improved profitability on both drystock models, largely due to the reduction in fertiliser expenses. However, profitability declined in the medium and high mitigation bundles, largely due to reductions in stock numbers.
- In the dairy model, the low and medium mitigation bundles caused farm profitability to reduce by about 5 and about 15% respectively. The implementation of a standoff pad in the high mitigation bundle caused farm profit to reduce significantly to 35 to 39% due to the operating expenses associated with this structure and nitrogen losses to also reduce significantly to 45 to 49%. However, it is important to recognise that the capital cost of the standoff pad is not included. Off-paddock structures have significant capital costs, thus high financial returns are required in order to meet debt repayments. For example, a cost benefit analysis conducted by Newman and Journeaux (2015) found there is conflict between the profitability of winter barn systems and their ability to reduce nitrogen losses, as farmers will often intensify to justify the cost of the structure.

It is important to note the limitations and assumptions used in this Overseer and financial analysis. In particular, there were only four Overseer models to represent average land use in the Waituna catchment and farm financials were based on long-term averages. The use of representative farms inevitably reduces the complexity that exists. In reality, there is no such thing as an average farm; every farm is unique. Further, farm financials are sensitive to prices such as milk payout, lamb schedule and supplementary feed. As a result, farmers may not identify with these representative farms as the same as their own, but rather based on the modelling they will be able to get a feel for the effectiveness and impacts of different mitigations on their farms.

Finally, it is important to recognise that the effectiveness of mitigations will by highly variable, based on the farm they are applied on; there is no 'one size fits all' approach to mitigating contaminant losses.

6.2 Drain maintenance practices

In response to the adverse outcomes of typical drain clearing processes, the Waikato Regional Council (WRC) has developed a Best Management Practices (BMP) document for drain maintenance[9]. These practices include (after Hicks (2012), Goldsmith et al. (2013)and Gibbs (2007)):

- Fencing buffer zones between farms and waterways with grassed or vegetated areas to act as bio and mechanical filters as well as excluding stock from water ways
- Retaining existing non-invasive riparian plants and planting similar plants where they are absent
- Bridging stream crossings
- Managing stocking rates to reduce soil compaction and erosion

[9] GIBBS, M. 2007. Best Practice Environmental Guidelines - Land Drainage. Hamilton: Waikato Regional Council

- Plant and/ or maintain tall shady trees to reduce water temperatures- thus reducing macrophyte growth
- Drain areas with riffles, pools or sensitive areas should not be disturbed
- Mechanical removal of macrophytes:
  - One section of the drain should be cleared at a time to reduce the impact and so that downstream plants can act as filters for the suspended sediment
  - Only clear areas that require maintenance, with a focus on removing channel bed rather than channel bank material
  - Use a rake where possible so fish and other aquatic life can escape back into the drain
  - After excavated material has been spread away from the waterways it should be seeded or planted
- Removal of macrophytes by using herbicides:
  - Establish the technical feasibility of using herbicides to clear waterways of macrophytes.
  - Obtain all necessary permits to use herbicides to clear waterways of macrophytes.
- Where technically feasible and legally permissible, the use of herbicides is preferable to mechanical removal of macrophytes from the perspective of minimising sediment mobilisation.

6.3 Temporary sediment filter fences

Sediment filter fences are designed to limit the flow of sediment from construction sites. They are temporary barriers constructed from geotextile cloth and posts (eg waratahs), often in combination with hay bales.

Depending on the size and shape of the drain, the sediment filter can be made of small hay bales or big round bales (see Figure 23). The bales are placed into position prior to clearing upstream sections of channels and left in position until the sediment has settled out of the water upstream of the bales. Often more than one set of hay bales is used – this is a low-cost way of enhancing their effectiveness. The upstream/downstream contrasting water samples shown in Figure 23 show the result of passing drain water through three successive hay bale filters.

Figure 23: Temporary hay bale and geofabric sediment filters and upstream / downstream water samples

6.4 Open-channel design changes

The shape of a drains cross-section has a significant effect on the risk of sediment mobilisation and transport. Steep batters increase the risk of banks slumping during wet weather, in particular. It is also more difficult to maintain good protective cover by vegetation if the batters are very steep. Unfortunately there is a tendency for the batters to become steeper over time, as a consequence of mechanically clearing drains.

Reducing the batter slope is a practical method for reducing the risk of sediment mobilisation in constructed drains. Slope stability analysis should guide the selection of batter slope. In the absence of this analysis, a batter slope of 1V:2H should be considered. The benefits of reduced risk of sediment transport need to be weighed up alongside the cost of lost productive land.

Two-stage channels are artificially created flood plains within open-channels such as creeks and (typically) large-capacity constructed drains. They are designed to provide a channel within a channel. Normally the flow is wholly contained in the smaller channel. High flows spill out into the "flood plain" contained within the larger channel, as shown in the following figure. This reduces the erosive power of high flows and provides opportunity for sediments entrained in the flow to be trapped by the vegetated "flood plain".

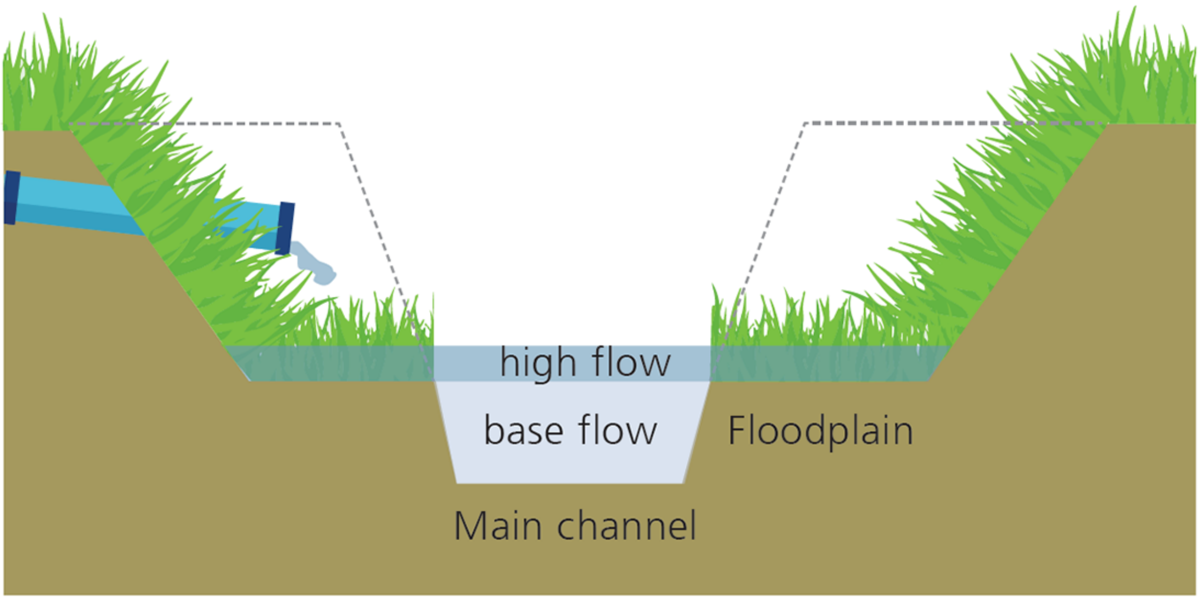

Figure 24: Two-stage channel, from Febria and Harding (2018)

Two-stage channels have been shown to increase flood capacity and reduce sediment and nutrient transport. Although they are used extensively in North America, their performance in New Zealand has only recently begun to be investigated (Febria and Harding, 2018).

6.5 Peak Runoff Control (PRC) structures

As noted previously, transportation of sediments with adsorbed nutrients can be a significant component of the total N and P load. This transportation is achieved via runoff and drainage water into the lagoon. McDowell and Woodward (2012) note that

"Drainage of agricultural fields generally decreases surface runoff and soil water content by allowing excess water to flow away from the field. However, drainage, as opposed to surface runoff, can transport

a greater proportion of nitrogen and phosphorus in dissolved (filterable), and immediately available forms".

From this position, Peak Runoff Control (PRC) structures were presented as an option to Environment Southland in 2012 to reduce flow rates and induce sedimentation and denitrification.

Unlike traditional controlled drainage systems where water is maintained in a "pseudo" wetland area for long periods of time (e.g. 80 days), a PRC structure generally only retains water for 1-5 days during periods of high flow, thereby allowing ponding and sedimentation to occur.

PRC's work by retaining runoff in a network of ditches using a set of control pipes that regulate flow, which decreases the load of suspended solids and suspended solids-bound nutrients (total nitrogen and phosphorus) via sedimentation. These ditches can then be cleared of sediment or rehabilitated once full.

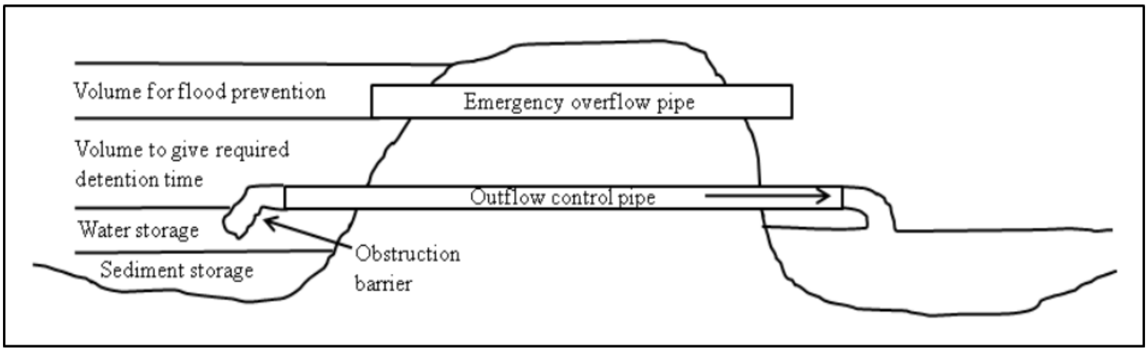

Figure 25: Generic schematic section of a peak runoff control structure

As shown in Figure 25, PRC's are relatively simple and thus have low construction costs, although a filter or obstruction barrier and routine maintenance would be required to ensure that the drainage pipes do not become blocked with debris.

The effectiveness of PRC structures for enhancing water protection depends on:

- how well a structure accounts for catchment topography (e.g. slope);
- the volume of runoff to be retained;
- the rate of the runoff; and,
- the detention capacity of the drained network behind the structure.

A well-designed PRC structure will have a good balance and control of flow velocities and water detention time. It will control runoff without overflowing or using the emergency outflow pipe during most peak runoff events. It will also provide increased settling conditions of SS and prevent erosion or resuspension of bed sediments by keeping the water flow velocity low without affecting drainage conditions

In a peatland forest near Pihiipudas in central Finland, found that PRC's (Hökkä et al., 2011, Marttila et al., 2010)

- Decreased runoff peaks by 10–73%
- Reduced suspended solids load by 86%
- Reduced the storm flow load of nitrogen by 65% and phosphorus by 67%.

6.6 Controlled Drainage

Controlled drainage structures aim to manage the water table at a level that is optimised for the desired land-cover or for maximising de-nitrification. If the desired land-cover is wetland species then both objectives are potentially achievable simultaneously. The depth from the land-surface to the water table is adjusted to provide suitable ground conditions when needed for cultivation, plant growth and harvest/grazing, and to enhance contaminant reduction at other times. A schematic of structures used within artificial drainage systems to control water table depth is shown in the following figure.

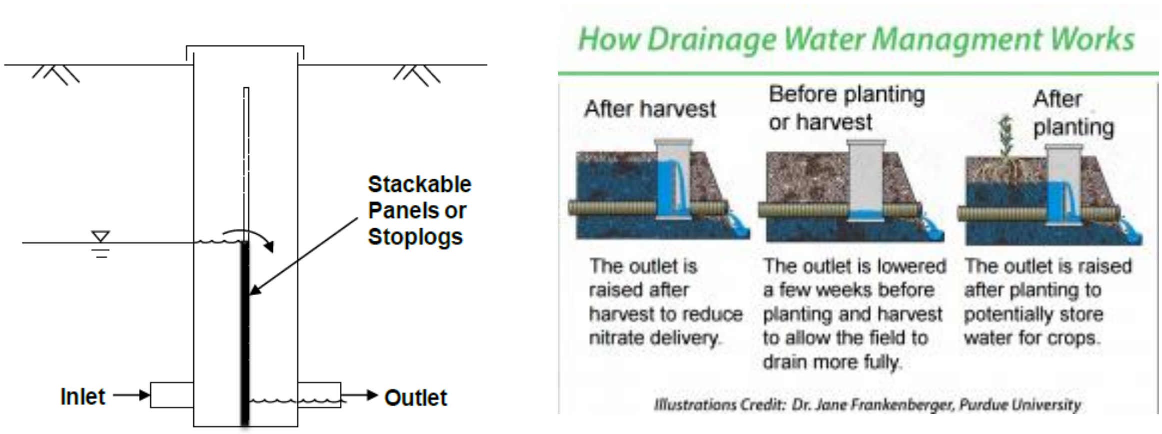

Figure 26: Schematic of how controlled drainage (or drainage water management) works

A summary of the benefits and caveats (around suitability to the Waituna Catchment) associated with traditional controlled drainage systems are given in Table 6 (McDowell and Woodward, 2012)

Table 6: Summary of the potential effects and suitability of controlled drainage in the Waituna Catchment.

Effect	Caveat	Suitability in the Waituna Catchment
Less flow through open channel drainage network	1. Potential for greater frequency of surface runoff and localised flooding. 2. Less flow through drainage network may decrease flushing within drains and increase the residence time of nutrients in the lagoon if not balanced by nutrient poor seepage into the lagoon via groundwater.	Less flow through drainage network may decrease flushing within drains and increase the residence time of nutrients in the Lagoon if not balanced by nutrient poor seepage into the lagoon via groundwater.
Decreased nitrogen loss	1. There is potential for the pathway of nitrate loss to be driven from the surface drainage network into groundwater. 2. Losses only decreased where drainage was decreased and denitrification potential was maximised.	Greatest potential for decreasing nitrate is in the Brown soils of the upper catchment as opposed to the lower catchment where denitrification is naturally high and the likelihood of decreasing drainage volumes less.
Decreased phosphorus loss	1. Increased dissolved P losses result, which could increase periphyton growth. Unless this is balanced by decreased particulate phosphorus losses it could result in a net increase in P load. 2. High water table increases the risk of coming into contact with P-rich topsoil.	Greater dispersion and erosion potential of soils in lower half of catchment imply greater potential to decrease P losses compared to upper catchment, but has to be balanced by the risk of losses via greater surface runoff/flooding.
Decreased sediment loss	1. Dependant on soil type – e.g. Podzol and Gley soils more erosion prone than Brown soils. 2. Effect greatest where sedimentation potential enhanced i.e. flat topography (low flows) and deep water column.	Although net decrease in sediment loss potential is greater in the lower than upper catchment (soil type and topography), there is a greater risk of surface runoff and pasture damage.
Improved forage yield	1. Only likely for deep rooted species 2. Maintaining high water table for the benefit of drought relief of pasture or better establishment of forage crops increases likelihood of interaction with P-rich topsoil.	Improved forage yields and profitability are unlikely considering the cost of installation and maintenance of a controlled drainage system. Further work is required to access the cost-benefit of a controlled drainage system.

6.7 Constructed Wetlands

The use of biological filters via constructed wetlands is an established water management strategy that has been shown to reduce P concentrations by 10% – 50% and N 26% to 77%

These reductions are achieved via the interaction of contaminant water cycling through a wetland ecosystem where microbial plant communities and sediment or root-bed substrates bacterial communities, metabolize, degrade, and remove contaminants from the flowing water. (Sakadevan and Bavor, 1999, White, 2013)

In 2013, NIWA was engaged to identify the most appropriate locations and types of constructed wetlands that could be implemented in the Waituna catchment to intercept nutrients and sediments.

NIWA investigated the potential for some 30 different constructed wetland options at 14 different sites across the Waituna catchment ranging in size from 50 ha to < 600 m^2 (0.06 ha) (Figure 27)

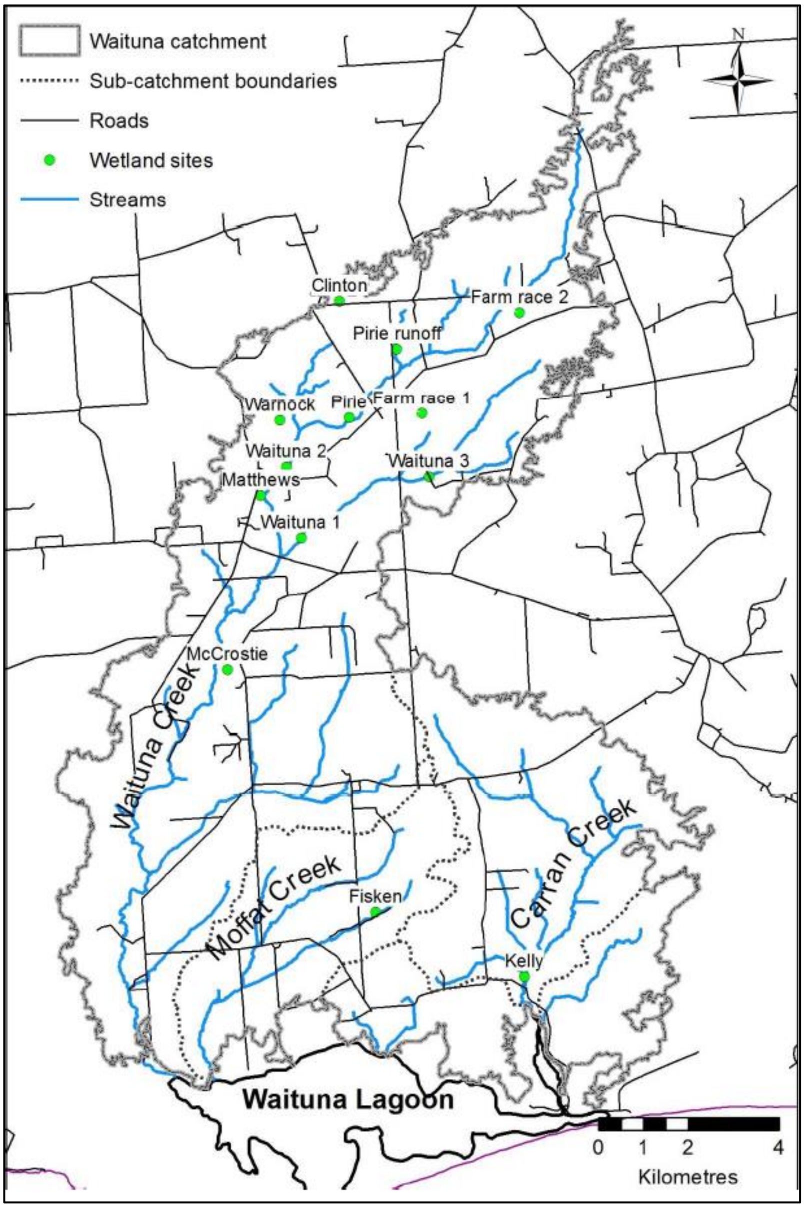

Figure 27: Locations of potential constructed wetland sites (from NIWA 2013).

They considered that the re-creation of wetlands in lower parts of the catchment (such as the Moffat Creek Catchment) would necessitate large-scale excavation for wetland construction because of the low topographic gradient.

NIWA concluded that the upper catchment areas of the Waituna Creek catchment offered the greatest range of potentially viable opportunities for wetland construction because it has the highest yield of TSS and TN.

The low topographic gradient in the lower part of the Waituna Creek catchment suggested the possibility of creating a wetland near the bottom of the catchment by constructing a low dam. A high resolution digital terrain model based on LiDAR topographic mapping was used to identify potential dam sites. This investigation revealed a site suitable (topographically) for creating a wetland of up to 200 hectares in the lower Waituna Creek Catchment by constructing a low dam (see Section 8.1.3).

6.7.1 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 channelization 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. 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.
- To reduce annual TN and TP loads by 50%, wetlands may need to occupy ~ 5% of the contributing catchment (Tanner et al., 2013), depending on their performance.

6.7.2 Construction & Maintenance costs

There is limited experience with construction of wetlands for contaminant attenuation in agricultural landscapes in New Zealand and a paucity of associated financial information. Depending on the situation and configuration, the costs can vary significantly. Some generalisations are presented below (from Tanner et al., 2013):

Large-scale wetlands

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. The estimated costs presented below are based on the design and construction costs for the Lake Okaro wetland in the Bay of Plenty.

Main stream channels wetland construction costs = \$460,415 x wetland area$^{0.69}$

Fully excavated wetlands

Alternatively, 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. Based on a similar project at the Bog Burn wetland in Southland, and estimated cost is provided below.

Fully-excavated wetland construction costs = \$196,560 x area$^{0.69}$

Partially-excavated wetland

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. For preliminary comparison, the costs of partially-excavated wetlands have been assumed to be approximately half the cost of fully excavated

Partially-excavated wetland construction costs =\$98,280 x area$^{0.69}$

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.

6.8 Bio Reactors

Bio filtration as a water pollution management strategy was first introduced in England in 1893. The process involves using a bio-reactor to capture and biologically degrade pollutants. Common uses include processing wastewater, capturing harmful chemicals or silt from surface runoff, and microbiotic oxidation of contaminants in air (Chaudhary et al., 2003).

Two bio-reactor trials were conducted in the Waituna Creek Catchment between November 2015 and April 2017, one in the upper and one in the lower catchment.

A nitrogen N filter consisting of a 100 m^3 lined woodchip bioreactor which receives subsurface drainage under gravity from an approximately 9 ha sloping, cropped catchment. The process entailed water passing slowly through a wood chip filter bed whereby naturally occurring denitrifying bacteria, convert nitrate in the water to nitrogen gas. The bacteria use carbon from the wood chip as a food source and nitrate in the water as part of their respiration process (Figure 28) (Hudson et al., 2018).

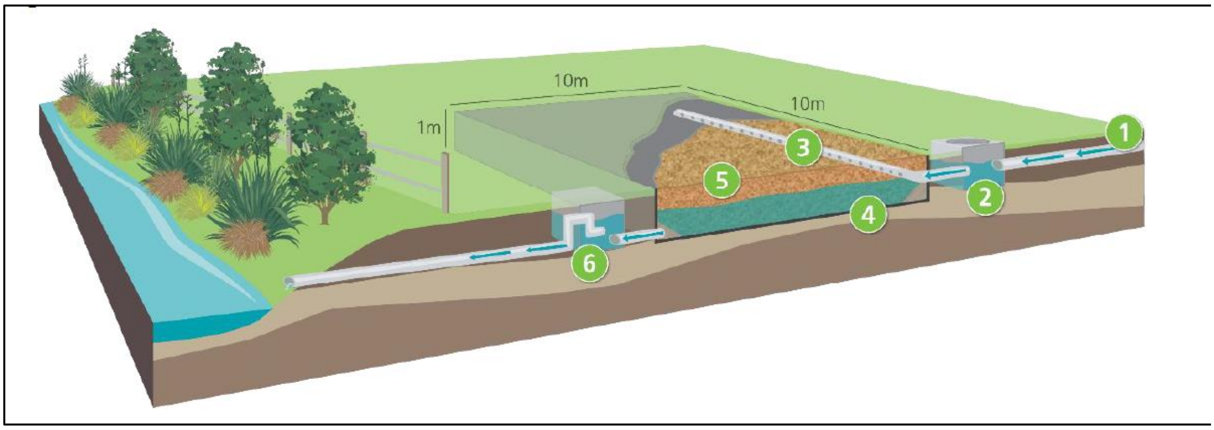

Figure 28: Schematic diagram of the woodchip bio-reactor near Oteramika

1) inflow from two tile drains;	2) inlet flow measurement structure;
3) inlet flow distribution manifold;	4) water level bed (700 mm deep)
5) woodchip filter bed;	6) outlet flow measurement structure.

The site chosen for the trial of a woodchip filter was determined using several criteria including:

- adequate grade (allowing for a gravity-fed system),
- a reasonably defined catchment source area, soils and lithology that made the farming system susceptible to N loss through the root zone,
- and existence of tile drainage that could be intercepted and directed to a filter bed

A smaller above ground P filter in the lower catchment consisting of a 1 m^3 bin containing Aqual-P[10] was also used with input from subsurface tile drain derived from approximately 1,000 m^2 of pasture (Tanner et al., 2017).

The results of the respective filtration processes are presented in Table 7.

Table 7: Results of the N and P bio filtration study.

Variable	Input	Output	Change
Nitrogen Filter			
Flow Rate (l/ s)	0.10 – 10	-	-
Median $NO_3 – N$ (µg/l)	2190	421	80% reduction
Sediment load (g/ day)	47.1	2.9	94% reduction
Phosphorus Filter			
Flow Rate (l/ hr)	165	-	
P Input (µg/l)	195	43	78% reduction
Dissolved Reactive Phosphorus	88	4.5	95% reduction

Efficacy of the woodchip treatment filter is strongly dependent on hydraulic retention time, and to a lesser extent temperature, with N removal efficacy improving with temperature increase. Treatment efficacy varies seasonally. Environment Southland has ongoing trials that will provide more information on the performance of woodchip bio-reactors.

[10] Aqual-P is a Modified zeolite-based powdered recyclable granule, used to combat nutrient-based algal bloom in waterways developed by Blue Pacific Minerals NZ.

7 CONTAMINANT REDUCTION OPTIONS ASSESSMENT

No single contaminant load reduction option described in Section 6 is likely to be feasible, on its own, because of the need to achieve multiple objectives, particularly maintaining the financial resilience of the community as well as increasing the resilience of the Waituna Lagoon. Our approach therefore involved developing potential load reduction strategies comprising multiple options for subsequent analysis (see Section 8 for this).

To reduce the number of contaminant load reduction options to those which are the more likely to be part of an effective load reduction strategy we assessed each option in terms of Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) factors, and the Strengths, Weaknesses, Opportunities and Threats (SWOT) of each in the Waituna Catchment context. This is a commonly used approach for developing strategic plans.

Tables 8 and 9 present the PESTLE and SWOT assessments respectively. It indicates that there is no one option or practice which will meet all of the objectives. However, by combining options into an overall integrated contaminant reduction strategy the objectives can potentially be met.

The controlled drainage option was dropped after the PESTLE assessment because of uncertainty around its ability to achieve an overall net reduction in N and P load to the lagoon. It therefore does not appear in the SWOT assessment.

Table 8: PESTLE analysis of contaminant load reduction options.

	Political	Economic	Society	Technology	Legal	Environmental
On-Farm Mitigations	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Achievement of desired N load reductions by this method alone likely to make farms uneconomic.	Farmers seen to be reducing the environmental impact of farming.	Known methods and technologies employed.	Likely to involve new consents or changes to existing consents.	Can achieve the desired N load reductions.
Retirement of Land from Farming and restoration of native flora and fauna	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Achievement of desired N load reductions by this method alone unlikely to be affordable. Best used in conjunction with other measures.	Reduces the number of farming families in the catchment. Potentially offset by employment opportunities related to new use of the land retired.	Known methods and technologies.	Uses familiar methods for property sale and purchase. Potential for a protracted sale process.	Reduces contaminant loads to natural state loads, over time. Enables restoration of native flora and fauna. Contributes to restoration of kaitiakitanga.
Drain Clearing Practice Changes	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Low cost changes to current practices.	Changes probably go unnoticed by the wider community.	Uses existing technologies better.	Practice changes could be part of permitted activity rules.	Reduces environmental impact of the drain clearing operation.
Temporary Sediment Filter Fences	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Low cost.	Changes probably go unnoticed by the wider community.	Established practice in some areas.	Could be part of permitted activity rules.	Precedence to reduce sediment loads by 85%.
Open-channel design changes (re-battering or 2-stage channels)	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Cost of changing channel cross-section potentially offset by reduced drain clearing costs. Reduces effective farmed area.	Could be included as part of a Farm Environment Plan, alongside fencing of waterways and riparian planting.	Known methods and technologies employed.	Requires consent to modify the bed of an open-channel water course.	Reduces the risk of sediment becoming entrained in streamflow. When used in conjunction with well-designed riparian planting, expected to reduce need for drain clearing.
Peak Run-off Control Structures	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Comparatively low cost option. Ongoing maintenance requirement.	Could be included as part of a Farm Environmental Plan.	Low tech solution Requires some degree of earthworks and engineering construction.	Likely to require consent to construct. If on crown land, applications/concessions to change land use may be required.	Precedence to reduce • runoff by 10–73% • TSS load by 86% • TN by 65%

						• TP by 67%.
Controlled Drainage	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Comparatively low cost option. Ongoing maintenance requirement.	Changes probably go unnoticed by the wider community.	Low tech solution Requires some degree of earthworks and engineering construction.	Likely to require consent to dam waterway.	Uncertain mix of positive and negative outcomes in relation to nutrient loads.
Wetland Construction	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Moderate to high costs to establish depending on area and design Ongoing maintenance and running costs.	Wetlands could be used to develop eco-tourism for the larger Waituna catchment.	Low tech solution Requires some degree of earthworks and engineering construction, as well as agricultural / horticultural inputs.	If on crown land, applications/concessions to use land may be required May require the relinquishment / requisition of farming leases. Likely to require consent from ES if damming of waterway required, and for diversion, taking and discharge of water.	Reduction of • TP by 10-50% • TN by 26- 77% Develops environmental habitats, as well as mahinga kai.
Bio Reactors	Meets Whakamana te Waituna programme objective to reduce contaminant load.	Moderate costs to establish Ongoing maintenance and running costs.	Could be included as part of a Farm Environmental Plan.	Low tech solution Requires some degree of earthworks and engineering construction.	Likely to require consent application for installation and discharge of water.	Precedence to reduce • NO_3 – N by 80% • P by 80% • TSS load by 95%.

Table 9: SWOT analysis of contaminant load reduction options

Strategy	Strengths	Weakness	Opportunity	Threats
On-Farm Mitigations	Based on established methods Overseer analyses shows that desired N load reduction is achievable.	Relies on every land owner implementing mitigation options, or equivalent, in perpetuity.	To achieve desired N load reduction. To derive better financial returns from agriculture through sustainability branding, once lagoon health is improved.	Reliance on On-Farm mitigations alone to achieve desired level of load reductions likely to put many farms out of business and de-populate the catchment.
Retirement of Land from Farming and restoration of native flora and fauna	Achieves a permanent reduction in contaminant losses to natural-state levels over time. Multiple co-benefits (i.e. beyond contaminant loss reduction).	Usually a reluctant seller situation. Reaching agreement on purchase price often protracted.	To contribute significantly to reducing contaminant loads to the lagoon. Creates opportunity to restore native flora and fauna on a larger scale. Creates opportunity to restore kaitiakiatanga. Creates opportunity for increased recreation and tourism.	Regional Council or Government may not feel able to justify the purchase price to their constituents.
Drain Maintenance Practices	Many of the Good Practices are the same as those in On-Farm mitigations. Changes in clearing practices are low tech and readily applied.	Relies on multiple contractors to implement correctly in perpetuity. Not likely to achieve a major reduction in sediment transport on its own.	Incremental reduction in sediment mobilisation and transport. Reduce impact on fauna.	If it were the only option taken, would be perceived to be tokenism.
Temporary Sediment Filter Fences	Proven effectiveness. Low cost, low tech. Only a temporary barrier to fish passage. Applicable throughout the constructed drainage network.	Relies on multiple contractors to implement correctly in perpetuity. Not suitable for larger permanently flowing streams.	To achieve a significant reduction in sediment load in the Waituna Creek catchment, in particular.	Incorrect installation could result in poor performance and the method becoming discredited.
Open-channel design changes (re-battering or 2-stage channels)	Proven effectiveness in reducing risk of sediment loss to waterways. Low tech.	Farmers may balk at the reduction in effective farm area.	Potential to reduce TSS load significantly. Opportunity to reduce draining clearing frequency if riparian planting designed to shade waterway as well as stabilise banks.	Requires good slope stability analysis and design. A risk of failure if treated as a simple job – "just have to flatten the banks off a bit".
Peak Run-off Structures	Demonstrated precedence. Low cost, low tech. Only retains runoff water for short period of time – thus not enabling / limiting point source seepage.	Potential disruption to productive area. Restricted scale. Requires engineering works. Generally prevents fish passage.	Decrease runoff peaks by 10–73%. Reduce TSS load by 86%. Reduced the storm flow loads of • TN by 65% • TP by 67%.	Localised concentration of nutrients. Change to drainage regime with detrimental outcomes such as increased erosion.

Wetland Construction	Provides cultural, environmental, and potentially economic benefit to the community.	Hydrology and hydraulics are crucial to wetland treatment performance and sustainable functioning. Potentially large areas required (1 to 5% of the catchment they intercept). Expensive capital costs.	Reduction of • TP by 10% – 50% • TN by 26% to 77%. Develop areas for mahinga kai. Development of alternative income streams via eco-tourism.	If not designed and managed / maintained property, could become habitat for weeds and feral pests.
Bio Reactors	Established practice and technology around the world. Could be incorporated into constructed wetland.	Requires engineering inputs for design and operation. Only been done as a trial in Southland.	Reduction of • $NO_3 – N$ by 80% • P by 80% • DRP by 95% • TSS by 95%.	If engineering inputs are inadequate (e.g. input flow rate) then the system may become a concentrated point source of pollution.

8 EFFICACY OF SELECTED CONTAMINANT REDUCTION STRATEGIES

The strategies developed for analysis have been guided by the following:

1. If the desired N load reduction (50%) were to be achieved solely through On-Farm mitigations it would almost certainly put a lot of farmers out of business because of the large reduction in cash operating surplus.
2. A few large wetlands that treat all of the flow in Waituna Creek, at one or more locations, developed and maintained as catchment infrastructure (like stop-banks for flood protection), is more likely to succeed in perpetuity than relying on lots of individuals to develop and maintain their own wetlands. This is not to discourage the latter from occurring – it's simply a pragmatic approach to achieving and sustaining the degree of contaminant load reduction desired, as quickly as possible.
3. Taking a relatively small proportion of the catchment out of farming through land purchase and retirement or wetland construction reduces the burden on the remaining farms to reduce their contaminant losses.
4. Trapping sediment in a few well-engineered and maintained structures is going to be simpler to operate in perpetuity than the very many in-drain structures required to achieve the same degree of sediment trapping.

8.1 Selected integrated contaminant reduction strategies

8.1.1 Changes in land management (i.e. on-farm mitigations)

Three levels of on-farm mitigations were modelled, in addition to current practice: high, medium and low. The effects on farm cash operating surplus of each mitigation option was estimated, as well as estimating the effects on N and P losses to water – see Section 6.1. The results populated a look-up table. Key assumptions about the farm systems and a description of the mitigation bundles may be found in Irving and Ford (2019).

The effects of land management change scenarios on the average annual received N and P loads (i.e. the loads passing the water quality monitoring or flowing into the lagoon) were modelled by calculating the new N and P source loads under the changed land management (i.e. with mitigations) and multiplying the source load by the relevant attenuation factor. This result was then compared to the N and P load received under the current situation to establish the degree of contaminant load reduction.

The effect of land management changes on the average annual farm cash operating surplus was calculated using the lookup table to find the cash operating surplus for the land-use and level of mitigation applied for each source area polygon, aggregating this up to give the total cash operating surplus from the Upper Waituna Creek, Lower Waituna Creek, Moffat Creek and Carran Creek, and comparing this to the total cash operating surplus under the current situation.

8.1.2 Changes in Land-Use

The land-use change assumed in the scenario analyses is the conversion of selected dairy and sheep and beef farms to conservation land – i.e. restoring wetlands and native flora. It was assumed that the cash operating surplus from these areas would become zero and that contaminant losses from them would revert to natural levels.

The areas assumed to be retired from farming in the scenarios analysed are identified as the colour shaded areas in Figure 29. Retirement and restoration of indigenous flora on these areas would, in conjunction with the existing undeveloped areas, create a significant naturalised buffer around Waituna Lagoon.

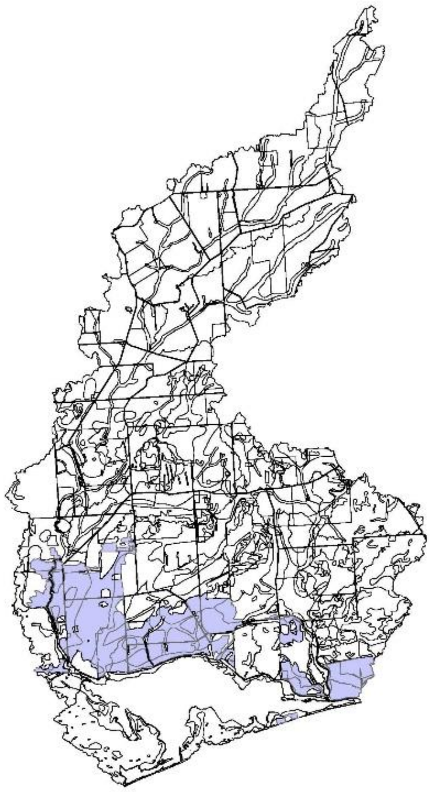

Figure 29: Areas of farmland assumed to be retired in some of the integrated contaminant reduction strategies.

8.1.3 Changes within the drainage network.

Significant changes to the cross-section of Waituna Creek to reduce the risk of soil loss to the stream have already been made. This flattening of the batters and associated riparian planting to stabilise the banks and shade the stream can be expected to significantly reduce the risk of sediment deposition in the stream. It is strongly recommended that this re-shaping and riparian planting work continue. It is a very practical approach to keeping the soil on-farm, where it belongs. Over time it should reduce the cost of maintaining the drainage network. Reducing the supply of suspended sediment in this way will also prolong the life of any structures built on-stream to reduce contaminant loads to the lagoon.

Sediment transport through the channel network will still occur, if only because soil that has already been deposited in the streambed (through banks slumping, for example) will gradually move through the drainage network. Reducing this sediment load is understood to be necessary if the resilience of Waituna Lagoon is to be increased.

Our review of the efficacy of other potential modifications to the drainage network lead us to focus on simple measures for trapping sediment mobilised during high flow events and drain clearing, and on constructed wetlands for N and P load reduction.

Our initial thinking was to construct sediment trap / peak flow control structures (see Figure 30) at strategic locations within the drainage network, at an estimated cost of about $33,000 each.

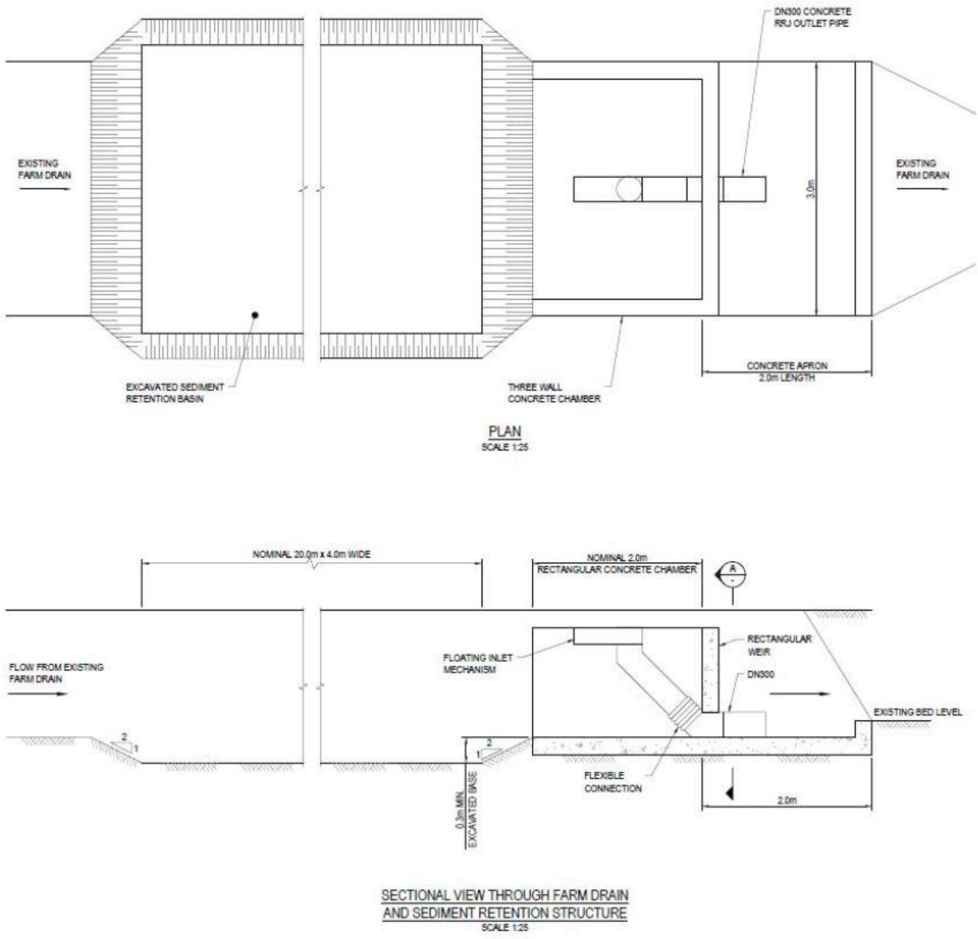

Figure 30: Schematic of Peak Run-off Control / Sediment Retention structure for farm drains

However it is very difficult to build practical fish passage elements into these structures. Our recommendation is to use temporary sediment filters constructed from hay bales and geotextile fabric inserted downstream of drain clearing operations (see Section 6.4). These can be lifted out using the digger a day or two after drain clearing has been completed and so avoid fish passage issues, apart from during the clearing operation. Recent experience with these in the drainage network in Kaikoura district has shown them to be very effective.

Reviewing the wide range of constructed wetland options considered to-date lead us to the conclusion that the most cost effective option is to construct one or two large wetlands to “treat” the flow at key locations in the Waituna Creek catchment, this being the largest conduit for the movement of N and P to the lagoon. The estimated capital cost of each constructed wetland(s) envisaged is about $5 million each. The breakdown of this is:

Mid-catchment wetland

Wetland construction (including dam)	$3,375,000
Fish pass	$250,000
Design	$375,000
Land purchase	$1,000,000

Lower catchment wetland

Wetland construction (including dam)	$4,375,000
Fish pass	$250,000
Design	$375,000
Land purchase (covered by land retirement cost)	-

The capital cost was annualised using an interest rate of 7.5% and a payment term of 25 years. Annual maintenance costs of $30,000 were assumed.

Scenario analysis has assumed large wetlands would be constructed to treat the flow in the Waituna Creek at two locations: lower Waituna Creek (between 100ha and 200ha in area) and mid catchment (~50ha in area). Four wetland configurations have been analysed: None, Lower only, Mid only, Both lower and mid. This provides wetland to catchment area ratios of up to ~2.5%. Indicative locations and extent of these wetlands are shown in Figures 31, 32 and 33.

A wide range of N, P and sediment load reduction factors have been reported for constructed wetlands. The NIWA report on constructed wetland options for the Waituna catchment suggests load reductions for N, P and suspended solids of 12%, 13% and 68% respectively whereas Waidler et al (2011) suggest load reductions of 55% (N), 68% (P) and 86% (suspended solids).

The scenario modelling has assumed N load reductions of 30% (mid-catchment wetland) and 40% (lower catchment wetland) and P load reductions of 20% and 26% respectively.

A bark nugget permeable reactive barrier (i.e. bio-reactor, see Section 6.8) could be built into the wetland to ensure achievement of the N load reductions required. Such permeable reactive barriers are a well-established method for removing N from water via denitrification. Preliminary analysis indicates that it is practical to have all the stream flow up to the median flowrate (potentially higher) to pass through the barrier. At higher flows a proportion of the flow would pass over the barrier and thus not be treated to the same extent. The need for this should be assessed during the wetland detailed design process.

The inflow to the wetland would first pass through a sediment deposition forebay to localise sediment accumulation for subsequent removal, if this is found to be desirable, and to minimise sediment accumulation in the permeable reactive barrier (if built) and around the outlet control structure.

The outlet structure for the wetland would be designed so that the wetland provides some flood detention storage and therefore capacity to reduce peak flows downstream.

With the combination of existing in-channel works, temporary sediment filters, sediment trap in the wetland forebay, and the peak flow reduction function of the wetland(s), it is reasonable to assume the sediment load from the Waituna Creek catchment can be reduced by at least 70%. The component of the TP load adsorbed to sediment particles can be assumed to be reduced to the same degree.

8.2 Efficacy assessment method

The catchment contaminant model used to assess the effects of contaminant reduction measures is a straightforward mass balance model.

Each subcatchment is divided into source area polygons based on soil type, land-use and contaminant capture zone. GIS coverages developed in earlier work by Rissmann et al (2018) were intersected using ArcGIS to produce polygons within which the soil, land-use and capture zone are the same.

Average annual nitrogen and phosphorous losses to water from each combination of land-use and soil type were estimated for farms using Overseer. Farm data for this was sourced from Fonterra and prior Waituna projects. Four farm types were modelled: dairy (2.7 cows/ha, system 2), dairy (3 cows/ha, system 3), dairy support, and sheep and beef. For land uses mapped as conservation and forestry, nitrogen and phosphorous losses to water were sourced from prior NZ studies.

Nitrogen and phosphorous loads from each source area were aggregated for each capture zone to obtain the total average annual source load for the capture zone.

The estimated average annual received load at the main water quality monitoring sites has been estimated previously by Diffuse Sources and NIWA (2012), for example.

Attenuation factors for N and P applicable to source loads in the Upper Waituna Creek, Lower Waituna Creek, Moffat Creek and Carran Creek were calculated as the ratio of the received load at the relevant water quality monitoring points to the source load from the capture zones for those monitoring points. Attenuation factors for nitrogen were calculated to be between 0.48 and 0.54. Phosphorous attenuation factors were between 0.0 and 0.1.

The received load, for example the load passing a water quality monitoring point, was thus estimated to be the total source load from all land within the capture zone for that monitoring point multiplied by the relevant attenuation factor. Changing land management from the current state changes the modelled source load and therefore the modelled load passing the monitoring point. If this load is then passed through an in-channel contaminant reduction structure, such as a wetland, the input load is reduced by a load reduction factor for that structure. The resulting output load is passed on as an input to the downstream elements of the drainage network load modelling.

This analysis has focussed on N and P because there is no realistic method for modelling sediment mobilisation throughout the catchment, particularly from the bed of streams and drains, and the transport of suspended sediment to the lagoon.

For each option for reducing N and P load through making structural changes within the drainage and stream network, the ability of such options to also trap sediment was checked. Wherever possible, options that have significant suspended sediment load reduction performance, as well as good N and P load reduction performance, should be chosen.

8.3 Trade-offs between the options

There are obvious trade-offs between On-Farm mitigations and Land Retirement or Constructed Wetlands. The greater the proportion of the desired load reduction that's achieved through On-Farm mitigations, the smaller the land area required for retirement or wetlands to achieve the balance of the desired load reduction.

Multiple combinations of On-Farm mitigation level, number of large wetlands and the extent of land retirement were analysed to gain information on these trade-offs.

8.4 Expected contaminant load reduction and cost outcomes

The outcomes expected from each scenario were evaluated in terms of the percent reduction in N and P load, and costs.

The cost of the on-farm mitigations is expressed as the reduction in the average annual Cash Operating Surplus (COS). The capital cost of land purchased for retirement and the capital cost of the large wetlands have been annualise by assuming all the capital is borrowed at 7.5% interest and repaid over a 25 year period.

<u>Note that it is not correct to add these three cost categories together to arrive at an overall cost.</u>

No assumptions have been made concerning who pays for the land and wetlands. These assumptions or decisions would need to be made before the full financial effects on any of the potential funding partners of any of the strategies analysed can be determined.

The results of each scenario analysis are presented in Table 10. The degree of contaminant load reduction and the reduction in COS are for the Waituna Catchment as a whole. The reduction in COS has been split into two parts: reduction due to applying mitigations to ongoing farm businesses and reduction due to retiring farmed areas. The former gives a sense of the financial effect on the remaining farm businesses. The effect on the cash operating surplus generated within the whole catchment is given by the sum of the two COS numbers.

Scenarios have been grouped in terms of the degree of N load reduction achieved in order to identify the range of scenarios that meet a given load reduction target. This is shown in Table 11. This provides a sense of the trade-offs between the level of On-Farm mitigation and Land Retirement or Wetland construction. As expected, there are multiple ways (scenarios) to achieve a given degree of N load reduction. Factoring in the need to reduce suspended sediment load favours strategies involving constructed wetlands, supported by use of temporary sediment filter fences, over strategies involving High on-farm mitigation because the former is more effective at trapping sediment.

Table 10: Assessed performance of contaminant reduction scenarios

Scenario	On-Farm Mitigation	Drainage Network Modifications	Retirement of Farmed Areas near Lagoon	N Load	P Load (from Farms only)	Reduction in Cash Operating Surplus (COS) due to Mitigations	Reduction in COS due to Retirement	Annualised cost of wetland	Annualised cost of land purchase
	(Level)			(kg or % of current)	(kg or % of current)	($)	($)	($)	($)
Current	None	None	None	216.3	9.5	$ -	$ -	$ -	$ -
1	Low	None	None	90%	98%	$ 1,002,963	$ -	$ -	$ -
2	Medium			81%	90%	$ 3,510,370	$ -	$ -	$ -
3	High			57%	90%	$ 8,274,443	$ -	$ -	$ -
4	None	1 Constructed Wetland, Mid-Waituna Ck	None	84%	100%	$ -	$ -	$ 479,000	$ -
5	Low			76%	97%	$ 1,002,963	$ -	$ 479,000	$ -
6	Medium			68%	90%	$ 3,510,370	$ -	$ 479,000	$ -
7	High			48%	90%	$ 8,274,443	$ -	$ 479,000	$ -
8	None	2 Constructed Wetlands, Mid and Lower Waituna Ck	None	66%	87%	$ -	$ -	$ 958,000	$ -
9	Low			59%	85%	$ 1,002,963	$ -	$ 958,000	$ -
10	Medium			53%	78%	$ 3,510,370	$ -	$ 958,000	$ -
11	High			38%	78%	$ 8,274,443	$ -	$ 958,000	$ -
12	None	None	Dairy & SheepBeef farms near lagoon retired	88%	83%	$ -	$ 3,761,110	$ -	$ 3,867,000
13	Low			80%	81%	$ 752,220	$ 3,761,110	$ -	$ 3,867,000
14	Medium			71%	74%	$ 3,008,888	$ 3,761,110	$ -	$ 3,867,000
15	High			51%	74%	$ 7,020,739	$ 3,761,110	$ -	$ 3,867,000
16	None	1 Constructed Wetland, Mid-Waituna Ck	Dairy & SheepBeef farms near lagoon retired	72%	82%	$ -	$ 3,761,110	$ 479,000	$ 3,867,000
17	Low			65%	80%	$ 752,220	$ 3,761,110	$ 479,000	$ 3,867,000
18	Medium			58%	74%	$ 3,008,888	$ 3,761,110	$ 479,000	$ 3,867,000
19	High			41%	74%	$ 7,020,739	$ 3,761,110	$ 479,000	$ 3,867,000
20	None	2 Constructed Wetlands, Mid and Lower Waituna Ck	Dairy & SheepBeef farms near lagoon retired	55%	71%	$ -	$ 3,761,110	$ 958,000	$ 3,867,000
21	Low			50%	69%	$ 752,220	$ 3,761,110	$ 958,000	$ 3,867,000
22	Medium			45%	64%	$ 3,008,888	$ 3,761,110	$ 958,000	$ 3,867,000
23	High			32%	64%	$ 7,020,739	$ 3,761,110	$ 958,000	$ 3,867,000

Table 11: Scenarios grouped by N load reduction category and their associated costs

Aim	Scenarios (Annualised costs)														
													Low or No Mitigation		
N load is 50% of Current, or less	7	11	19	21	22	23									
Farm Mitigations - COS reduction	$ 8,274,442	$8,274,442	$ 7,020,739	$ 752,220	$ 3,008,888	$ 7,020,739							Medium Mitigation		
Wetland	$ 479,000	$ 958,000	$ 479,000	$ 958,000	$ 958,000	$ 958,000									
Retirement - land purchase	$ -	$ -	$ 3,867,000	$ 3,867,000	$ 3,867,000	$ 3,867,000							High Mitigation		
Retirement - COS reduction	$ -	$ -	$ 3,761,110	$ 3,761,110	$ 3,761,110	$ 3,761,110									
N load is 55% of Current, or less							10	15	20						
Farm Mitigations - COS reduction	As above						$ 3,510,369	$ 7,020,739	$ -						
Wetland							$ 958,000	$ -	$ 958,000						
Retirement - land purchase							$ -	$ 3,867,000	$3,867,000						
Retirement - COS reduction							$ -	$ 3,761,110	$3,761,110						
N load is 60% of Current, or less										3	9	18			
Farm Mitigations - COS reduction	As above									$8,274,442	$1,002,963	$3,008,888			
Wetland										$ -	$ 958,000	$ 479,000			
Retirement - land purchase										$ -	$ -	$3,867,000			
Retirement - COS reduction										$ -	$ -	$3,761,110			
N load is 65% of Current, or less													17		
Farm Mitigations - COS reduction	As above												$ 752,220		
Wetland													$ 479,000		
Retirement - land purchase													$3,867,000		
Retirement - COS reduction													$3,761,110		
N load is 70% of Current, or less														6	8
Farm Mitigations - COS reduction	As above													$3,510,370	$ -
Wetland														$ 479,000	$958,000
Retirement - land purchase														$ -	$ -
Retirement - COS reduction														$ -	$ -

8.5 Expected biodiversity and recreational outcomes

Increasing areas of indigenous planting throughout the catchment, reducing nutrient and erosion sources and contributions to waterways and the lagoon, has the potential to provide positive outcomes for biodiversity. It will be important to pursue opportunities to maintain and enhance the existing high ecological values within the catchment. Ensuring fish passage is protected and enhanced throughout the catchment is important to realise the full potential benefits of improved water quality and hydrological management regimens.

In terrestrial areas, both active planting of appropriate native vegetation communities and allowing natural regeneration processes will increase habitat opportunities. Valuable lowland terrestrial and wetland habitats including regionally rare associations such as kahikatea forest should be encouraged as part of a long-term successional strategy.

Appropriate plant and animal pest management will be critical to ensure exotic species do not outcompete native species. In some areas, land-management practices may include cut and carry harvesting of biomass, mahinga kai gathering or occasional grazing and may be desirable to reduce weed infestation. There are a variety of options that should be investigated once the preferred contaminant load reduction solution is found.

Where marginal land and riparian buffers along watercourse are retired, as part of nutrient management strategies, there will be opportunities for improvement of aquatic habitat. A key component for this will be ensuring best practise drainage management, such as minimising physical disturbance through mechanical clearances and establishing ecologically-sensitive plantings in the riparian margins planting to increase shading for temperature moderation and suppression of aquatic weed growth, and provision of terrestrial and aquatic fauna.

The large-scale retirement scenarios offer the most significant opportunity for long-term biodiversity gains with potential for development of core habitat zones for key indigenous terrestrial and aquatic plant and animal species.

A full assessment of the biodiversity and recreational outcomes is not achievable until the final proposed contaminant reduction options are fully developed.

A conceptual plan (Figure 34), illustrates how this could be integrated with recreational and tourism opportunities via regional pathways linking between lagoon access points and wildlife watching platforms. Mahinga kai harvesting and alternate land-uses production systems within the retired lands could be the basis for local economic development and ecotourism ventures that support ongoing biodiversity initiatives.

The cost and time to achieve change at this scale may be prohibitive, but even a scaled back scheme with a reduced lagoon buffer could offer some biodiversity and recreational benefits, particularly with improved connectivity to existing habitat patches in the wider landscape via riparian buffers.

The proposed constructed wetlands also offer potential biodiversity benefits if designed to provide a variety of habitat types with a diverse species mix. However, there may be a need to balance treatment efficiency with biodiversity and recreational outcomes when designing constructed wetlands.

Careful consideration of ensuring fish passage is maintained along the catchment with any new structures will be essential, to ensure both appropriate legislative and ecological outcomes.

Figure 35 illustrates how the wetland could be designed to provide recreational and ecotourism opportunities with a network of trails, wildlife viewing hides and potential for a visitor information and accommodation centre.

8.6 Planning Assessment

The Proposed Southland Water and Land Regional Plan (PWALP) controls activities such as the taking and damming of water, activities in and on the beds of waterbodies, discharges to land and water and activities in and in proximity to wetlands. The Southland District Plan (SDP) controls land use activities such as earthworks, the removal of indigenous vegetation, and the erection of structure and buildings outside of waterbodies. There is some overlap between regional and district plans, as both may address activities in riparian margins.

Appendix B provides results from a statutory assessment of the proposed mitigation options and their associated activities. This assessment was very high level as no specific details of the options is known at this time. However, it is considered that many of the options proposed are likely to require resource consent under the PWALP. Activities that require structures or buildings on land, earthworks and the removal of vegetation may also require consent under the SDP. Table 12 sets out a summary of the options, associated activities and most stringent activity status likely to apply to an activity, if the permitted activity standards are not met.

Table 12: Summary of the options, associated activities and most stringent activity status likely to apply, if the permitted activity standards are not met. Provided by Boffa Miskell Ltd.

Option	Activity	Most stringent activity status
On-Farm Mitigations	**Regional Plan**	
	Farming.	Discretionary.
	The discharge of nitrogen, phosphorus, sediment or microbial contaminants onto or into land.	Non-Complying.
	The use of land for the construction, maintenance and use of a new agricultural effluent storage facility, and any incidental discharge of agricultural effluent.	Discretionary.
	The discharge of agricultural effluent or water containing agricultural effluent onto or into land in circumstances where contaminants may enter water.	Discretionary.
	The use of land for a feed pad/lot.	Discretionary.
	The discharge of solid animal waste (excluding any discharge directly from an animal to land), sludge or vegetative material containing animal excrement or vegetative material into or onto land, or into or onto land in circumstances where a contaminant may enter water.	Discretionary.
	The discharge of fertiliser onto or into land in circumstances where contaminants may enter water.	Non-Complying.
	District Plan	
	Feedpads.	Restricted Discretionary.
Changes in Land Use	**Regional Plan**	
	Only controls land use conversion to farming. Consents may be required for works that involve discharges, earthworks and removal of vegetation.	Unknown.
	District	
	Consents may be required for works that involve buildings and/or structures, earthworks and removal of vegetation.	Unknown.
	Regional Plan	

Drain Clearing/ Maintenance Practice Changes	The removal of aquatic weeds and plants and sediment from any modified watercourse[11] for the purpose of maintaining or restoring drainage outfall, and any associated bed disturbance and discharge resulting from carrying out the activity.	Discretionary.
	The introduction or planting of any plant, or part of any plant, in the bed or margins of a lake, river, modified watercourse or wetland.	Discretionary.
	The excavation or disturbance of the bed of a lake, river or modified watercourse for the purpose of realigning, widening or deepening any channel within the bed.	Discretionary.
	The placement, erection or reconstruction of any bridge in, on or over the bed of a lake, river, modified watercourse or wetland and any associated bed disturbance and discharge resulting from the carrying out of the activity.	Discretionary.
	The removal of aquatic weeds and plants and sediment from any modified watercourse for the purpose of maintaining or restoring drainage outfall, and any associated bed disturbance and discharge resulting from carrying out the activity.	Discretionary.
	The clearance of subsurface drainage systems.	Not managed by the Plan.
	District Plan	
	Earthworks within a Riparian Margin.	Restricted Discretionary.
Peak Run-Off Control Structures	**Regional Plan**	
	Discharge from subsurface drainage systems.	Discretionary.
	District Plan	
	Earthworks.	Discretionary.
Temporary Sediment Filter Fences	**Regional Plan**	
	The construction, excavation, modification or maintenance of an on-farm sediment trap in, on, under or over the bed of any intermittent or ephemeral river and any associated bed disturbance, removal of aquatic weeds and plants and associated discharge.	Discretionary.
Wetland Construction	**Regional Plan**	
	The taking and diversion of surface water.	Non-Complying.
	Discharge of water.	Discretionary.
	Dam in, on or over the bed of a lake, river, modified watercourse.	Discretionary.
	The use of land within a wetland for the purposes of maintaining or enhancing the wetland.	Discretionary.
Bio Reactors/ Filters	**Regional Plan**	
	Discharge of water.	Discretionary.
	District Plan	
	Land use consent may be required for a building/structure.	Discretionary.
	Earthworks.	Discretionary.

In completing the planning assessment, Boffa Miskell considered a draft version of this report and determined that the report was not proposing any options / activities that are not already addressed by the PWALP and SDP. In other words, there is nothing radical or unexpected that would require the Regional Council to undertake plan changes to introduce new rules to give effect to the Whakamana te Waituna Contaminant Load Reduction Plan.

However, a more detailed planning assessment would be required once a project / activity is fully proposed and it may be that potential non-compliances can be designed out or reduced in scale.

[11] A water carrying channel that was existing in some form prior to land development but has been modified or straightened for drainage or other purposes and excludes ephemeral rivers.

That said, it is strongly suggested that the Regional Council's planning team are consulted during the early stages of designing any works to ensure any specific concerns can be addressed, with relative ease.

It is also noted that future works may be affected by the Proposed National Policy Statement for Freshwater Management (NPS-FM), the Proposed National Environmental Standards for Freshwater (NES-FW) and the National Policy Statement for Highly Productive land (NPS-HPL). The NPS-FM will require the Regional Council to identify values, outcomes and limits for FMUs or individual waterbodies. As such, the work being done as part of this project will assist the Council in meeting its responsibilities under the NPS-FM.

The NES-FW is a key document as it seeks to manage activities in and in the vicinity of wetlands. It will be important to consider if it's necessary to define any wetlands constructed to reduce the volume of nutrients entering Waituna Lagoon as 'constructed wetlands'. Otherwise, future maintenance and enhancements could be 'caught' by the proposed provisions in the NES-FW and be subject to stringent standards.

To give effect to the NPS-HPL, the Regional Council will need to identify highly valued productive land in its region. This is unlikely to affect the Waituna catchment unless the Regional Council finds the water quality issues to be a limiting factor in enabling primary production.

8.7 Summary of key findings

There are multiple strategies for reducing N load to the lagoon by at least 50%. Each strategy involves On-Farm mitigations and the construction of at least one large wetland on the Waituna Creek.

As expected, increasing investment in wetlands and land retirement reduces to the Low or Medium level the On-Farm mitigation required to achieve a 50% reduction in the N load to the lagoon. Without these investments the High level of On-Farm mitigations is required. This has a significant impact on dairy farms, in particular, reducing their cash operating surplus by 30%. This is likely to seriously threaten their financial viability - depending on farm debt levels.

If the N load target is reduced to a 60% load reduction, it is possible to meet this by constructing only one wetland on Waituna Creek but the On-Farm mitigations would need to be at the Medium level. It would be preferable for this wetland to be the lower wetland because this would treat virtually all of the surface water flow out of Waituna Creek and it's wetland area can be a higher percentage of the catchment area draining to the wetland than is the case for the mid-catchment wetland (for the same dam height).

All of the strategies analysed that reduce N load to 60%, or less, of the estimated 2012 N load involve the construction of at least one large wetland. All these strategies are therefore expected to significantly reduce the sediment load to the lagoon, providing they are well designed, constructed and maintained.

9 A CONTAMINANT REDUCTION PLAN FOR WAITUNA CATCHMENT

The following plan has been formulated to achieve the following objectives:

1. Reduce contaminant load to the Waituna Lagoon by at least 50%.
2. Maintain the financial viability of the farming community.
3. Establish a significant naturalised buffer area around the lagoon.
4. Increase mahinga kai and biodiversity in and around the lagoon.

Achieving the above objectives is expected to require the construction of both of the wetlands included in the scenario analysis.

It is recommended that any plan involving two large constructed wetlands be staged. Staging enables modifications to be made to the plan partway through its implementation if performance monitoring of the first stage reveals ways to improve the plan. Changes in technology, for example, may create on-farm mitigations that would be more effective than building a second wetland. Measurement of the actual performance of the first wetland may dictate changes be made to the specifications of the second wetland.

It is recommended that drain and waterway management be re-designed to minimise the risk of sediment inputs to flowing waterways, with the overall aim of avoiding the need for mechanical clearing of sediment and macrophytes from waterways. This will require:

5. Re-constructing drain cross-sections to avoid or minimise the risk of soil loss to waterways due to bank instability.
6. Re-constructing the cross-sections of the larger creeks and streams, ideally to achieve a 2-stage cross-section to reduce contaminant loads while providing sufficient capacity to safely route flood flows to the lagoon.
7. Riparian planting with native species selected to shade the waterway where-ever possible and so minimise macrophyte growth.
8. Switch to using herbicides to remove macrophytes, assuming the current trials are successful and that the necessary approvals can be obtained.

It is recommended that re-shaping the stream banks and associated riparian planting be used as a means of creating wildlife corridors that connect up remnant wetlands and native bush areas, where practical, and connect these areas with the lagoon. In other words, use the drainage network to achieve biodiversity objectives as well has hydrological and agricultural objectives.

The main elements of this plan are:

Stage 1.

a. Prevent further increases in N and P losses to water from farmed land.

b. Re-construct the banks of the main creeks and drains to increase the stability of their banks and reduce the mobilisation of sediment through bank collapse. Establish wide, fenced, riparian margins planted out with native vegetation that shade waterways where practical. Switch to herbicide removal of macrophytes.

c. Complete the implementation of farming sector industry good management practices, including fencing of waterways and riparian planting.

d. Require the use of temporary sediment filter fences downstream of stream reaches being mechanically cleared of weed and sediment and/or undergoing channel reshaping.

e. Purchase farms and begin the process of restoring native flora and fauna to create a significant naturalised buffer around the lagoon.

f. Gain commitment to implement, by an agreed date, the Low-level On-Farm mitigations on all remaining farms within the lagoon catchment and begin the implementation.

g. Construct a large wetland on the lower reaches of Waituna Creek.

h. Establish a water flow and water quality monitoring site between the outlet of the constructed wetland and the lagoon. Use the data from this with data from the existing monitoring sites to monitor wetland treatment performance and to verify that the actions taken are having the expected effect on the contaminant load to the lagoon.

i. Construct a peak run-off control structure in the lower reaches in each of Moffat and Carran Creeks, providing fish passage can be maintained. Monitor their performance.

Stage 2.

j. When sufficient monitoring data has been collected to provide a reasonable understanding of how much the contaminant load has been decreased, assess how much further the load needs to be reduced and determine whether it's best to achieve this by increasing the On-Farm mitigation level to Medium or construct the mid-catchment wetland on the Waituna Creek, or both.

If construction of the mid-catchment wetland is required in the Waituna Creek catchment:

k. Purchase land for the second wetland.

l. Construct the wetland.

If further on-farm mitigations are required:

m. Gain commitment to implement, by an agreed date, the Medium-level On-Farm mitigations (or equivalent) on all remaining farms within the catchment and begin the implementation.

If the sediment load to the lagoon needs to be reduced further and the reduction can be achieved by using additional peak run-off control structures in Moffat and Carran Creeks, construct the required extras, providing that fish passage is maintained.

It is recommended that assessment of the effectiveness of mitigation measures be based on continuous monitoring of nitrate concentration, turbidity and flow rate. Monthly water quality samples will also need to be taken, supplemented by sampling during high flow events, in order to develop relationships between turbidity, TSS and TP. Expert advice should be sought before selecting the type, make and model of turbidity sensor to deploy due to variability in the performance of these sensors.

The dams required to form the constructed wetlands recommended above will be significant structures in terms of the volume of water contained. Investigation, design, construction and operation of the wetlands must therefore be in accordance with the New Zealand Dam Safety Guidelines. The following excerpts from these guidelines broadly outline the scope of the required investigations phase.

Dam safety planning for new projects starts with the assessment of potential effects, their likelihoods of occurrence and how to design for them to a standard society will accept via the RMA process. It is important to assess the hazards and risks which apply during construction of the dam as well as during the long term in-service condition. The RMA enables conditions to be set on the design of building structures and therefore dams. The RMA governs with respect to land and water use and the Building Act governs construction and subsequent use. In the RMA consent process the applicant needs to demonstrate that the design, construction and operation practices for the dam will address hazards that have the potential to impact on the environment. Hazards may be natural hazards such as earthquakes or floods, construction hazards such as poor materials, or operational hazards such as sudden changes in river flow. Typical design, construction and operation issues that need to be addressed in consent application documents include:

- *The site topography and how the dam will fit into or modify the topography.*
- *The regional and local geology which greatly influences structural safety, water retention and reservoir slope integrity.*

- *The proposed construction materials and dam arrangements to ensure safety during construction and operation.*
- *The flood risks at the dam and how floods are managed and passed through the structure during construction and operation.*
- *The seismic risks and earthquake loads which the dam, with its stored contents, and the reservoir shoreline may experience.*
- *The surveillance, maintenance and operational procedures to ensure safe operation of the dam.*
- *Strategies for the management of other risks such as wind, slope stability upstream of the reservoir, and human error in design, construction, and operation of the project.*
- *The downstream effects of a potential dam failure and strategies for emergency management should the integrity of the dam be in doubt.*

All investigations and data assembly for the design must be to a level which is appropriate to the complexity of the dam site, the contemplated dam design, and the commercial value of the dam.

Most investigation programmes are completed in a series of separate stages with the following objectives:

1. *A pre-feasibility investigation – to identify possible dam sites and dam types, and obtain sufficient information for the planning of a feasibility investigation.*
2. *A feasibility investigation – to identify a preferred dam site and dam type, confirm the technical feasibility of the preferred solution, and estimate the cost of project development.*
3. *A design investigation – to address any outstanding issues raised in the feasibility investigation, and any additional questions that are raised during the detailed design and construction of the dam or rehabilitation works.*

It is essential that these investigations are carried out by an appropriately qualified Chartered Engineer.

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Appendix A: Abbreviations

ASC	Anion Storage Capacity
BMP	Beneficial Management Practices
CCP	Catchment Contamination Project
CTG	Catchment Technical Group
Cumec	Cubic Meter per Second (m3/s) = 1,000 litres per second
ELF	Engineered Land Form
EPC	Equilibrium Phosphorus Concentration
ES	Environment Southland
Gl	Giga Litre (1,000,000,000 Litres)
ha	10,000 square meters (2.471 acres)
ICM	Integrated Catchment Management
ICP-OES	Inductively Coupled Plasma - Optical Emission Spectrometry
kl	Kilo Litre (1,000 Litres or 1m3)
l	Litre: a metric unit of capacity equal to 1,000 cm^3 (0.264 gallons)
MfE	Ministry for the Environment
Mg	milligrams
MIZ	Mokotua Infiltration Zone
NIWA	National Institute of Water & Atmospheric Research Ltd
NO3	Nitrate
NO3-N	Nitrate – Nitrogen
NH_4-N	Ammoniacal Nitrogen
P	Phosphorus
p.a.	per annum (for each year)
PFS	Pre-Feasibility Study
pH	a numeric scale used to specify the acidity or alkalinity of an aqueous solution
PP	Particulate Phosphorus
PRC	Peak Runoff Control
PSU	Practical Salinity Unit
QBL	Quadruple Bottom Line
SS	Suspended Sediment
TN	Total Nitrogen

TP	Total Phosphorus
UNESCO	United Nations Educational, Scientific and Cultural Organization

Appendix B: Planning Assessment of Mitigation Scenarios

Planning matters considered, provided by Boffa Miskell Ltd.

Option	Activities involved (simplified)	District/Regional Plan Matter	Activity	Consents required
On-Farm Mitigations	• Reduce fertiliser applications. • Use low water-soluble fertiliser. • Increase the time that cows are on the feed pad. • Use uncovered wintering pad. • Effluent is stored before being applied to land.	Regional.	Farming.	Given scale and number of cows, a dairy platform is likely to require consent as a **Restricted Discretionary Activity** or **Discretionary Activity**. There are also rules that manage cultivation particularly in proximity to waterbodies, above an altitude of 800m and on a slope greater than 20 degrees.
			The discharge of nitrogen, phosphorus, sediment or microbial contaminants onto or into land in circumstances that may result in a contaminant entering water.	**Permitted** if the land use activity associated with the discharge is authorised and after reasonable mixing it does not give rise to any identified effects on receiving waters. Otherwise the discharge is **Non-Complying**.
			The use of land for the construction, maintenance and use of a new agricultural effluent storage facility, and any incidental discharge of agricultural effluent directly onto or into land from that facility which is within the normal operating parameters of a leak detection system or the pond drop test criteria.	**Permitted Activity** if certain conditions are met. Otherwise consent is required.

			The discharge of agricultural effluent or water containing agricultural effluent onto or into land in circumstances where contaminants may enter water.	**Permitted Activity** from a dairy shed servicing a maximum of 20 cows or 100 of any other animals. Otherwise the discharge of effluent is likely to be a **Restricted Discretionary** or **Discretionary Activity**.
			The use of land for a feed pad/lot.	**Permitted Activity** provided certain conditions including that it does not accommodate more than 120 adult cattle. Otherwise consent is required as a **Discretionary Activity**.
			The discharge of solid animal waste (excluding any discharge directly from an animal to land), sludge or vegetative material containing animal excrement or vegetative material, including from a high intensity farming process, feed pad/lot or wintering barn or industrial or trade process, into or onto land, or into or onto land in circumstances where a contaminant may enter water.	**Permitted Activity** provided certain conditions are met including that the maximum loading rate of nitrogen onto any land area does not exceed 150 kilograms of nitrogen per hectare per year; and the material is not discharged onto the same area of land more frequently than once every two months. Otherwise consent is required as a **Discretionary Activity**.
			The discharge of fertiliser onto or into land in circumstances where contaminants may enter water.	**Permitted Activity** provided certain conditions are met, generally relating to setbacks from waterbodies. Otherwise consent is required as a **Non-Complying** Activity.
		District.	Feedpads.	**Permitted Activity** provided that they are set back at least 200 metres from an existing dwelling, consented dwelling or building platform in separate ownership.

				Otherwise consent is required as a **Restricted Discretionary Activity**. Consent may also be required to remove indigenous vegetation depending on the extent of the clearance.
Changes in Land Use	Conversion of selected dairy and sheep and beef farms to conservation land – i.e. restoring wetlands and native flora.	Regional.	Only controls land use conversion to farming. Consents may be required for works that involve discharges, earthworks and removal of vegetation.	**Unknown.**
		District	Consents may be required for works to erect structures and/or buildings, earthworks and removal of vegetation.	**Unknown.**
Drain Clearing/Maintenance Practice Changes	• Fencing buffer zones between farms and waterways with grassed or vegetated areas to act as bio and mechanical filters as well as excluding stock from water ways. • Retaining existing non-invasive riparian plants and planting similar plants where they are absent. • Bridging stream crossings.	Regional.	The removal of aquatic weeds and plants and sediment from any modified watercourse for the purpose of maintaining or restoring drainage outfall, and any associated bed disturbance and discharge resulting from carrying out the activity.	**Permitted Activity** if certain conditions are met. Otherwise consent is required as a **Discretionary Activity**.
			The introduction or planting of any plant, or part of any plant, in the bed or margins of a lake, river, modified watercourse or wetland.	**Permitted Activity** provided certain conditions are met including not planting pest species and the activity being in accordance with a Farm Environmental Management Plan or for the purposes of soil conservation or

	• Managing stocking rates to reduce soil compaction and erosion. • Plant and/ or maintain tall shady trees to reduce water temperatures- thus reducing macrophyte growth. • Drain areas with riffles, pools or sensitive areas should not be disturbed. • One section of the drain should be cleared at a time to reduce the impact and so that downstream plants can act as filters for the suspended sediment. • Only clear areas that require maintenance, with a focus on removing channel bed rather than channel bank material. • Use a rake where possible so fish and other aquatic life can escape back into the drain.			river control, or for enhancing biodiversity, or for enhancing mahinga kai or taonga species. Otherwise consent is required as **Discretionary Activity**.
			The excavation or disturbance of the bed of a lake, river or modified watercourse for the purpose of realigning, widening or deepening any channel within the bed.	**Discretionary Activity**.
			The placement, erection or reconstruction of any bridge in, on or over the bed of a lake, river, modified watercourse or wetland and any associated bed disturbance and discharge resulting from the carrying out of the activity.	**Permitted Activity** provided certain conditions are met including having no support structures in the bed. Also need to provide for fish passage. Otherwise consent is required as a **Restricted Discretionary** or a **Discretionary Activity**.
			The removal of aquatic weeds and plants and sediment from any modified watercourse for the purpose of maintaining or restoring drainage outfall, and any associated bed disturbance and discharge resulting from carrying out the activity.	**Permitted Activity** provided certain conditions are met. Otherwise consent is required as a **Discretionary Activity**.
			The clearance of subsurface drainage systems is not managed by the plan.	**N/A**
		District.	Earthworks within a Riparian Margin.	**Permitted Activity** provided certain conditions are met. Otherwise consent is required as a **Restricted Discretionary**.

	• Cleared areas should be seeded or planted after excavated material has been spread away from the waterways.			
Peak Run-Off Control Structures	Retaining runoff in a network of ditches using a set of control pipes that regulate flow, which decreases the load of suspended solids and suspended solids-bound nutrients (total nitrogen and phosphorus) via sedimentation. These ditches can then be cleared of sediment or rehabilitated once full.	Regional.	Discharge from subsurface drainage systems.	**Permitted Activity** if certain conditions are met including effects on water quality, flooding and the locations of drain outlets are mapped. Otherwise consent is required as a **Discretionary Activity**.
		District.	Earthworks in any 12-month period, do not exceed, the disturbance of more than 1,000m³ (volume) of land per property and (i) is greater than 20 metres from a waterbody that do not alter the existing ground level by more than 5 metres in depth or 2 metres in height; (ii) is within 20 metres of a waterbody that do not alter the existing ground level by more than 2 metres in depth or height.	**Permitted Activity** if conditions are met. Otherwise consent is required as a **Restricted Discretionary** or a **Discretionary Activity**.
Temporary Sediment Filter Fences	They are temporary barriers constructed from geotextile cloth and posts (e.g. waratahs), often in combination with hay bales.		The construction, excavation, modification or maintenance of an on-farm sediment trap in, on, under or over the bed of any intermittent or ephemeral river and any associated bed disturbance, removal of aquatic weeds and plants and associated discharge.	**Permitted Activity** if assessed as an on-farm sediment trap and certain conditions are met. Whilst some general matters have to be met, this does not include providing for fish passage or avoiding certain months of the year. Consent is required as a **Discretionary Activity** if: - the conditions are not met, or

				- the activity is not deemed to be an 'on-farm' trap. Fish passage could be considered when determining a consent for a discretionary activity.
Wetland Construction	• Sediment deposition forebay. • Damming of water. • Diversion/taking of water. • Discharge of water.	Regional.	The taking and diversion of surface water.	May be a **Permitted Activity**, especially if the water is returned to its original course. Otherwise consent is required, the status of which depends on the conditions that are not met.
			Discharge of water.	Likely to be a **Discretionary Activity**.
			Dam in, on or over the bed of a lake, river, modified watercourse.	**Discretionary Activity** if the discharge would not be to the original bed.
			The use of land within a wetland for the purposes of maintaining or enhancing the wetland.	Permitted Activity provided that: • there is no destruction or removal of any indigenous vegetation from any natural wetland; and • there is no reduction in the size of the wetland; and • there is no flooding or ponding caused on any land owned or occupied by another person; and • there is no establishment of pest plant species. Otherwise consent is required as a **Discretionary Activity**.
Bio Reactors/Filters	Bio-reactor to capture and biologically degrade pollutants	Regional.	Discharge of water.	Likely to be a **Discretionary Activity**.
		District	Land use consent may be required for a building/structure.	Likely to be a **Discretionary Activity**.
			Earthworks in any 12-month period, do not exceed, the disturbance of	**Permitted Activity** if conditions are met.

			more than 1,000m^3 (volume) of land per property and (i) is greater than 20 metres from a waterbody that do not alter the existing ground level by more than 5 metres in depth or 2 metres in height; (ii) is within 20 metres of a waterbody that do not alter the existing ground level by more than 2 metres in depth or height.	Otherwise consent is required as a **Restricted Discretionary** or a **Discretionary Activity**.