Waituna Catchment: Physiographic Stocktake

Lisa Pearson and Clint Rissmann

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Prepared by
Pearson, L., and Rissmann, C.

Land and Water Science Ltd.
www.landwaterscience.co.nz
61c Leet Street
Invercargill, 9810
New Zealand

Corresponding Author
Dr Lisa Pearson
Contact number: 03 214 3003
Email: lisa@landwatersci.net

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Story Map
The information contained in this report has been summarised in a web-based application. All maps have been provided over a base map of Southland, with main roads and land parcel boundaries to allow the user to easily locate areas of interest. Maps have an interactive component allowing the user to view maps at farm or catchment scale.

Access to the Story Map is through the following URL:
https://e3s.maps.arcgis.com/apps/MapJournal/index.html?appid=73571ecdd1e14f3eb3d07166952b897d

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Abstract

Water quality outcomes can vary spatially across the landscape, even when there are similar land use pressures. These differences are often the result of natural spatial variation in the landscape, which alters the composition of the water through coupled physical, chemical and biological processes. Living Water (a Fonterra and Department of Conservation partnership) commissioned a high-resolution physiographic assessment of the Waituna Catchment, Southland, to support water quality and biodiversity investment decisions for the catchment.

This document is intended to be a technical reference summarising the scientific reports produced for Living Water. The high-resolution physiographic science map from Rissmann et al. (2018) has been used to produce risk maps for the main environmental contaminants (N, P, S, M). To aid communication with the wider community and stakeholders, the physiographic map has been presented to show the landscape features across the Waituna Catchment (similar to Environment Southland's Physiographic Zones), whilst maintaining the high-resolution variation identified in Rissmann et al. (2018) and incorporating the temporal aspect from Rissmann and Beyer (2018). We have termed this map Fundamental Landscape Units (FLU).

The first part of this report is a reference guide for each Fundamental Landscape Unit. A section is provided which summaries the soil, geology, hydrology and risk of contaminant loss from the FLU. Therefore, there is repetition within the sections where soil, geology or hydrological pathways are similar. However, the combination of these attributes results in differing water quality outcomes and have been explained for each subunit in a water quality implication section.

The second part of this report is a stocktake by subcatchment, summarising the FLU areas, hydrological pathways and inherent risks.

1 Introduction

1.1 Overview

Living Water (a Fonterra and Department of Conservation partnership) commissioned a high-resolution physiographic assessment of the Waituna Catchment, Southland, to support water quality and biodiversity investment decisions for the catchment. Living Water recognise the main environmental issues for the Waituna catchment are: (i) a significant loss of wetland, freshwater ecosystems and lowland habitat; (ii) poor water quality caused by high levels of suspended sediment (S), nutrients (nitrogen (N) and phosphorus (P)), and microbial (M) contamination; and (iii) modified waterways, wetland and lagoon hydrology (Living Water, 2016).

The Waituna Catchment forms part of the Awarua-Waituna wetland complex and has been recognised under the Ramsar Convention as a wetland of international importance since 1976. The Awarua-Waituna Wetlands is one of the largest (3,556 ha) remaining wetland complexes in New Zealand. It is important for its biodiversity and cultural values. The Waituna catchment drains into the Waituna Lagoon, a brackish intermittently closed and open lagoon or lake (ICOLL), within the Waituna Wetland Scientific Reserve (Figure 1.1). The Waituna Lagoon is fed by Waituna, Moffat, and Carran Creeks. A tributary of Carran Creek, Craws Creek, is predominantly natural state and provides a good reference catchment for comparison with agriculturally land developed within a wetland setting.

Figure 1.1: Location of Waituna Catchment in Southland, New Zealand. Shading shows areas of subcatchments including the area of direct contribution to Waituna Lagoon.

1.1.1 Previous Work

This report summarises the physiographic science and associated risk assessment into a technical reference document for the Waituna Catchment. There are three supporting scientific documents that accompany this report:

- *Waituna Catchment: Technical Information and Physiographic Application* by Rissmann et al. (2018). This document details technical background information and summarises current research in Waituna Catchment. The method for developing the high-resolution physiographic map and predictive model is reported.
- *Waituna Catchment: Risk Assessment* by Pearson et al. (2018). This document shows how the high-resolution Waituna Catchment physiographic map was used to provide a risk assessment for the Waituna Catchment for the environmental contaminants particularly nitrogen (N), phosphorus (P), sediment (S) and microbes (such as *E. coli*, M). The physiographic model was applied to estimate water quality for each subcatchment and the zone of direct contribution to Waituna Lagoon.
- *Waituna Catchment: Temporal Variation* by Rissmann and Beyer (2018). This document assesses the temporal variation in water composition in the catchment.

1.1.2 Report Structure

This report is structured into 11 sections. This section introduces the project and summarises the learnings and outputs of the above scientific reports. Specifically, how the high-resolution physiographic science map from Rissmann et al. (2018) was used to produce risk maps for the main environmental contaminants (N, P, S, M). To aid communication with the wider community and stakeholders, the physiographic map has been presented to show the landscape features across the Waituna Catchment (similar to Environment Southland's Physiographic Zones), whilst maintaining the high-resolution variation identified in Rissmann et al. (2018) and incorporating the temporal aspect from Rissmann and Beyer (2018). We have termed this map Fundamental Landscape Units (FLU).

Sections 2 to 6 are intended to be a technical reference for the FLU characteristics. Each section summaries the soil, geology, hydrology and risk of contaminant loss from the FLU. Therefore, there is repetition within the sections where soil, geology or hydrological pathways are similar. However, the combination of these attributes results in differing water quality outcomes and have been explained for each subunit in a water quality implication section.

Sections 7 to 10 are a stocktake of each subcatchment, summarising the FLU, hydrological pathways and contaminant loss risk areas.

Section 11 summarises the inherent risk of contaminant loss for the Waituna Catchment.

It is important to note the outputs produced in this study are relative to Waituna Catchment only and cannot be extrapolated to other parts of Southland.

1.2 Physiographic Science

Water quality outcomes can vary spatially across the landscape, even when there are similar land use pressures. These differences are often the result of natural spatial variation in the landscape, which alters the composition of the water through coupled physical, chemical and biological processes. While poor water quality is unlikely to occur in the absence of intensive land use, similar intensities of land use don't always result in the same water quality issues if the underlying landscape attributes are different (e.g. different assemblages of soils, geology and hydrology).

The physiographic approach is an integrated or 'systems view', predicated upon the spatial coupling between landscape attributes and the key processes governing water quality outcomes in surface and shallow groundwater. For example, the relationship between soil drainage class (*attribute*), soil carbon (*attribute*), and reduction-oxidation (redox, *process*) can be used to predict soil denitrification potential. Unlike other mapping and classification approaches, the physiographic approach incorporates water quality, hydrochemical and/or hydrological response signals into a spatial format to identify, select, combine and classify those landscape gradients that drive variation in water quality outcomes.

Areas characterised by similar process-attribute classes for both hydrology and redox are defined as Physiographic Units (PGU) (Figure 1.2; Rissmann et al., 2018). Each PGU responds in a similar fashion at the process level to broadly equivalent land use pressures. Through classification of the catchment into PGUs Rissmann et al. (2018) demonstrated that: (i) physiographic mapping can be used to estimate the steady-state water composition of surface water and shallow unconfined groundwater with a high degree of confidence, and; (ii) process-attribute gradients and resultant PGUs are a powerful tool for informing and optimising efforts to improve water quality – matching efforts to the process level controls over water quality at the land parcel scale.

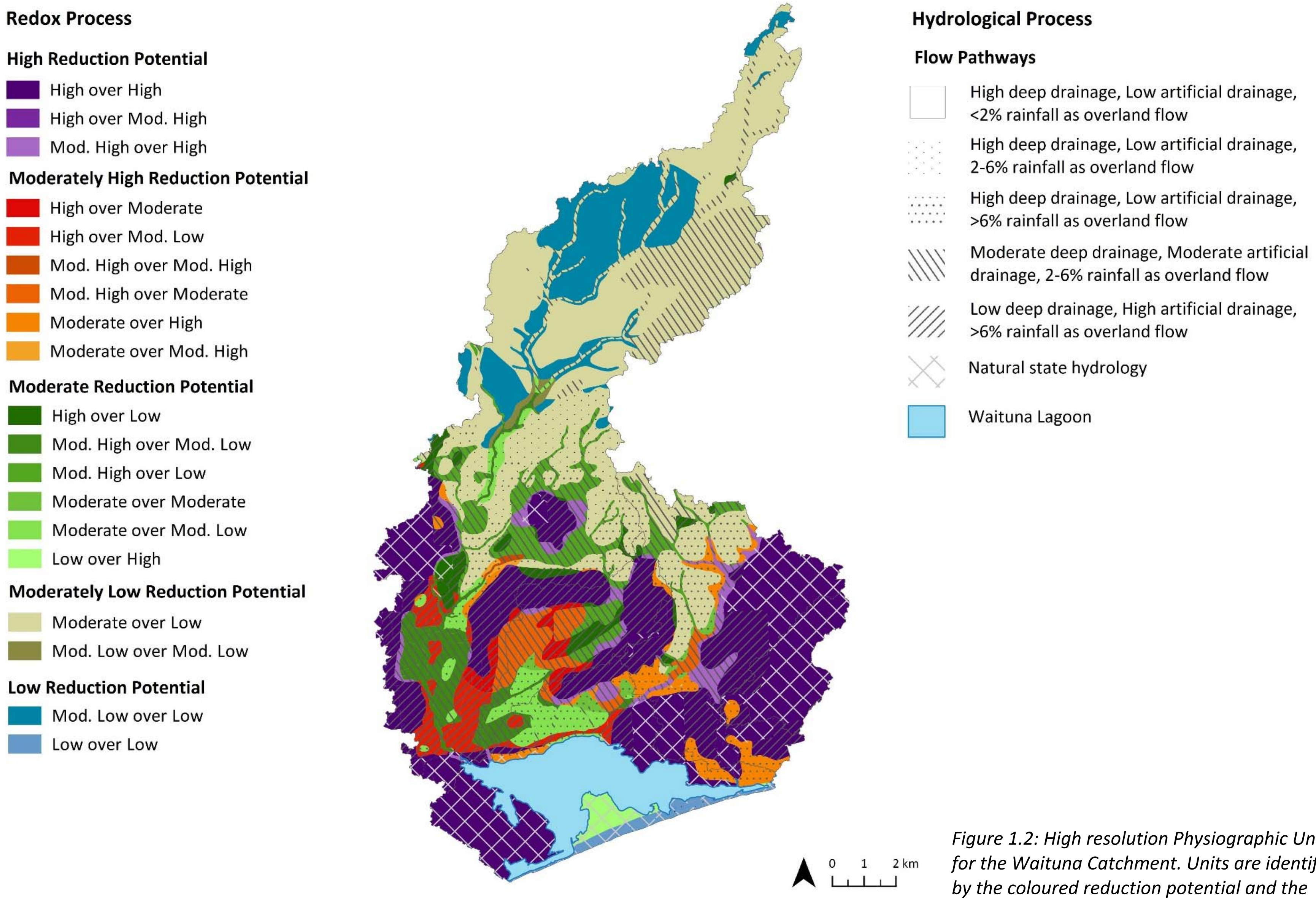

Figure 1.2: High resolution Physiographic Units for the Waituna Catchment. Units are identified by the coloured reduction potential and the patterned hydrological flow path (Rissmann et al., 2018).

1.3 Waituna Catchment Risk Assessment

In the wrong place, nutrients (nitrogen, N, and phosphorus, P) and sediment (S) can become environmental contaminants. Excessive nutrients can change the balance of nutrient cycling within a lake or waterway and can result in excessive algae or plant growth, depleted oxygen levels, fish deaths, and reduced recreational use of water resources. Sediment can also cause problems smothering aquatic habitats and transporting sediment-bound nutrients (particularly P), ammonium, and microbes. Microbial contaminants (such as *E. coli*, M) from animal waste can make water unsafe for drinking or recreational contact. These are the four contaminants are identified under the National Policy Statement for Freshwater Management (2014) for reduction to improve water quality in New Zealand.

The key controls over variability in water quality outcomes across the Waituna Catchment are associated with both natural and anthropogenic features. The inherent natural properties of a landscape are important as they are often responsible for a significant degree of variation in water composition and quality, both in space and in time. Inherent properties are defined as natural topography, geology, hydrology and soil composition and associated relationships with water and land use activities. Importantly, the character of these inherent properties of a catchment also determines the degree to which they require modification for land use. Modification of the inherent properties for land use is often restricted to the shallow surface of the earth, mainly vegetative clearance and modification of the drainage characteristics of the soil zone, as well as the sinuosity, length and depth of river channels and streams.

Most land use contaminants are concentrated at the or near the surface of the soil and decline in concentration with depth, reflecting the important and highly effective role of soil and aquifer materials in storing and variably attenuating contaminants. However, the mobility and persistence of a nutrient or contaminant varies according to the inherent properties of the soil and/or aquifer and the degree of modification of the hydrological setting for a given land use pressure. Therefore, it is important to recognise the different behaviour of land use derived contaminants between areas comprised of different assemblages of soil and geological materials.

The high-resolution physiographic map was used in Pearson et al. (2018) to develop a steady state risk assessment for the Waituna Catchment for nitrogen, phosphorus, sediment, and microbes. The risk assessment has been used in Sections 2 to 6 to show subunit variation in the Fundamental Landscape Units and in Sections 7 to 10 in the subcatchment stocktakes.

1.3.1 Hydrological Pathways

All contaminants are transported by water, therefore how water moves through or leaves the land surface controls how contaminants are transported. All water within the Waituna Catchment originates as precipitation within the catchment, which means there is no potential for dilution of contaminants from other water sources (e.g. Hill or High Country; Rissmann et al., 2018). The three main hydrological pathways that water takes to leave the land surface are deep drainage through the soil zone and into the underlying aquifer (groundwater), laterally through the soil zone (and artificial drainage network) into surface water, and surficially as overland flow (OLF, surficial runoff) (Figure 1.3; Pearson 2015 a and b, Rissmann et al., 2018).

Overland flow, transports water, solutes and particulates from the land surface (and upper 150 – 300 mm of the soil zone) to a surface water body (Winter et al., 1998; Inamar, 2011). Contaminants occurring at shallow levels generally have had insufficient time to migrate deeper into the soil zone where a range of beneficial process aid in the retention and variable attenuation of contaminants. For this reason, OLF commonly delivers the largest load of land use derived contaminants directly to stream (Smith and Monaghan, 2003; Goldsmith and Ryder, 2013; Orchiston et al., 2013; Curran

Cournane et al., 2011; McKergow et al, 2007). The period with the highest risk for OLF in Southland is between May and November (Smith and Monaghan, 2003; McDowell et al. 2005; Monaghan et al, 2016).

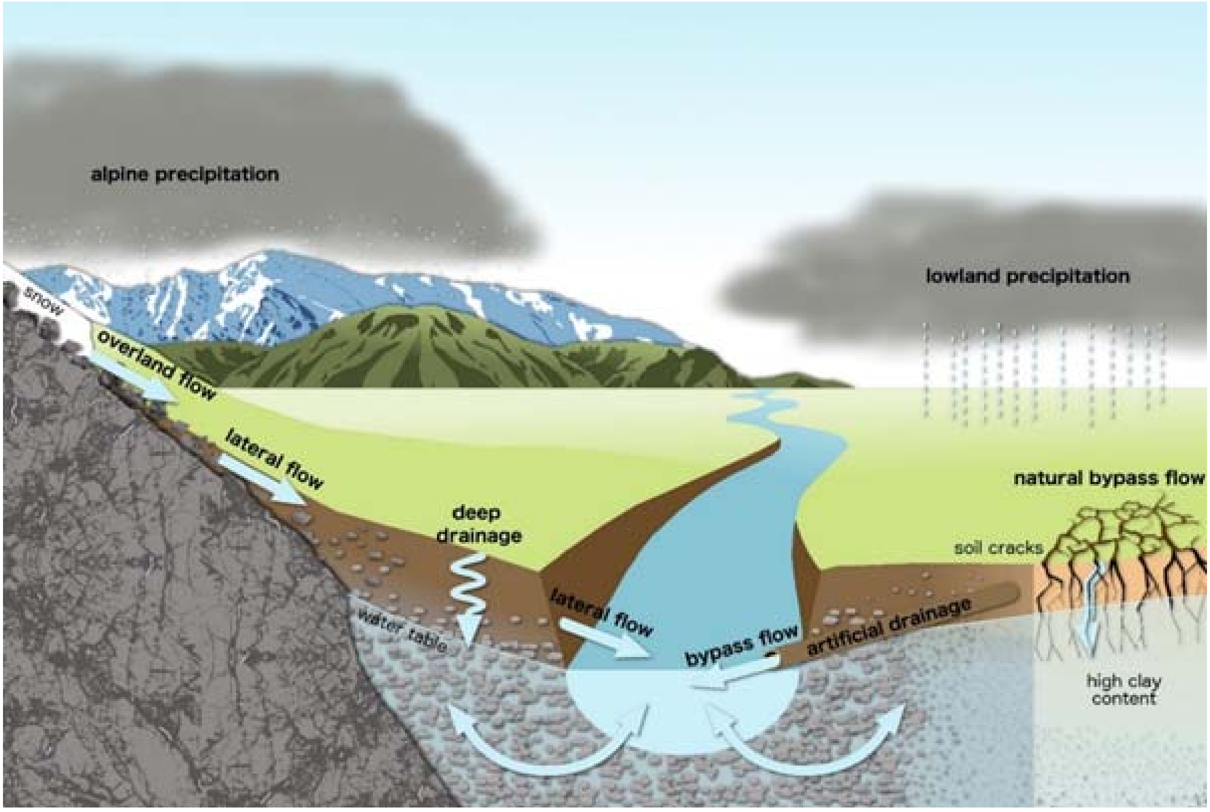

Figure 1.3: Summary of hydrological flow pathways identified in Southland during the 'Physiographics of Southland' Project.

1.3.2 Temporal Variation

Surface water composition varies with flow, therefore at any one time it can be a mix of shallow groundwater discharge, soil water and/or surficial runoff. Critically, of the three main compartments that contribute to flow, all three are seldom active at once. Rather, drainage from each compartment occurs in response to seasonal climatic cycles and lower frequency high-intensity precipitation events. This results in temporal variation in water quality across the catchment (Rissmann and Beyer, 2018). For example, soil drainage varies according to soil moisture status, increasing or decreasing in response to evapotranspiration and the magnitude of precipitation events. When soils are wet, tile drains are often flowing, contributing water to the stream network. When soils dry up in response to warmer weather and higher rates of evapotranspiration the flow of soil water decreases and/or stops. Nitrogen is therefore more mobile in the wetter months.

Rissmann and Beyer (2018) identified the flow and soil moisture thresholds of when surficial, soil and aquifers are contributing to stream flow at the four long-term water quality monitoring sites in the Waituna Catchment (Table 1.1). Soil moisture data is collected by Environment Southland at Lawson Road in Waituna Catchment. This data is available in real-time from: http://gis.es.govt.nz/index.aspx?app=soil-moisture

Table 1.1: Flow and soil moisture thresholds by dominant water source for 4 long-term monitoring sites in Waituna Catchment (95% confidence interval, Rissmann and Beyer, 2018).

	Aquifer	Soil	Surficial
Dominant Water Source by Flow (m^3/sec)			
Waituna Creek 1 m u/s Waituna Road	< 0.09	0.09 - 0.3	> 0.3
Waituna Creek at Marshall Road	< 0.60	0.6 - 1.2	> 5.0
Moffat Creek at Moffat Road	< 0.008	0.008 -0.3	> 0.3
Carran Creek at Waituna Lagoon Road	< 0.2	0.2 - 0.9	> 0.9
Dominant Water Source by Water Filled Pores (%) at Lawson Rd			
Waituna Creek 1 m u/s Waituna Road	< 78 (73 - 79)	82 (80 - 84)	> 83 (80 - 100)
Waituna Creek at Marshall Road	< 80 (77 - 80.5)	84 (82 - 85)	> 93 (87 - 100)
Moffat Creek at Moffat Road	< 78 (75 - 80)	82 (80 - 84)	> 86 (82 - 100)
Carran Creek at Waituna Lagoon Road	< 79 (77 - 82)	82 (81 - 85)	> 89 (83 - 100)

1.3.3 Environmental Contaminants

Nitrogen and phosphorus occur in several forms in the environment depending upon the environmental and biological conditions. The various forms range from non-reactive to highly reactive and can be either dissolved in water or as particulate material. To make improvements in water quality, knowing the form that is causing the ecological problem and the hydrological pathway it takes to enter the water body allows for targeted mitigation strategies to be implemented.

Nitrogen has three main forms, molecular (N_2 gas), organic (amino acids, proteins, nucleic acids, humic compounds), and inorganic (nitrate NO_3^-, nitrite NO_2^-, ammoniacal NH_3 and $NH4^+$). The organic and inorganic forms of N are the forms that are ecologically important. When a water sample is analysed for N, different techniques are applied to isolate the various forms. Total Nitrogen is typically analysed and reported as follows:

- Nitrate and Nitrite Nitrogen (NNN) = Nitrate + Nitrite
- Total Kjeldahl Nitrogen (TKN) = Total Organic Nitrogen + Total Ammoniacal (NH_3 + $NH4^+$)
- Total Nitrogen (TN) = TKN + NNN

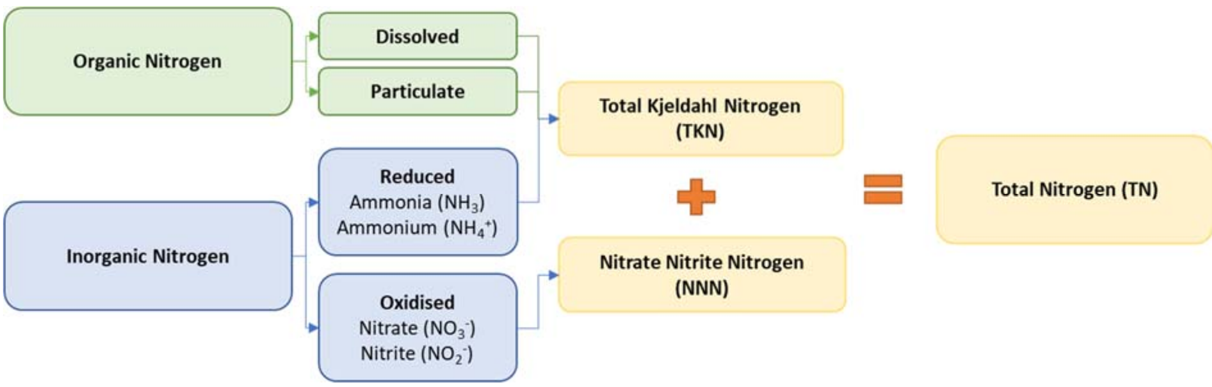

Figure 1.4: Analysis of nitrogen for water quality.

Phosphorus is found on land in rock and soil minerals. Weathering of rocks and minerals release P in a soluble form where it is taken up by plants, and subsequently transformed into organic compounds (e.g. seeds, leaves). In soil, phosphate is adsorbed by iron oxides, aluminium hydroxides, clay surfaces, and organic matter particles, and becomes incorporated (immobilised or fixed). In natural waters, P usually occurs as both inorganic (including orthophosphates and polyphosphates) and organic forms (organically-bound phosphates). Organic phosphate is P that has been incorporated into plant or animal tissue. Phosphorus in a water sample is typically analysed and reported as:

- Dissolved Reactive Phosphorus (DRP)
- Total Phosphorus (TP)

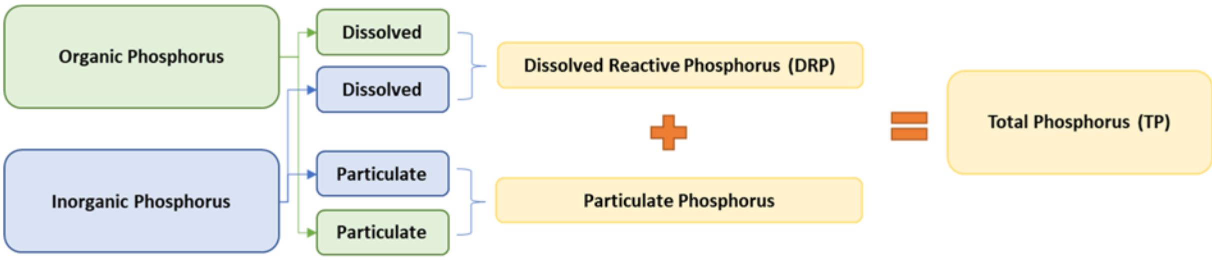

Figure 1.5: Analysis of phosphorus for water quality.

Sediment and microbes are eroded from or deposited on soil. Sediment is analysed for both its total suspended sediment (organic and inorganic, TSS) and volatile components (organic, VSS).

Microbial contamination is monitored using indicator species that are present in the faeces of warm-blooded mammals and birds. In freshwater the indicator species is Escherichia coli (*E. coli)* and is measured as a count under a microscope as Colony Forming Units (CFU) per 100ml.

1.3.4 Risk

The key outputs of this work are catchment scale maps of what we define as the 'inherent risk' for each of the main water quality parameters (i.e., N, P, S and M). We use the term inherent risk as unlike traditional risk maps, those presented here are generated from physiographic layers that reliably and accurately estimate spatial variation in the steady-state concentration of key water quality measures. The use of water to identify the relationship between landscape properties and water quality outcomes is a critical distinction when seeking to use maps of water quality risk for more effective resource management.

Each inherent risk map is based on the high-resolution physiographic layers produced for the catchment and which formed the basis for the development of numerical models to estimate variation in steady-state water quality outcomes for the catchment (Figure 1.2). Specifically, models were produced that explain and accurately estimate spatial variation in steady-state Total Nitrogen (TN), nitrate-nitrite nitrogen (NNN), Total Kjeldahl Nitrogen (TKN, organic and ammoniacal nitrogen), Total Phosphorus (TP), Dissolved Reactive Phosphorus (DRP), Total Suspended Sediment (TSS), Clarity, Turbidity and *E. coli* (Rissmann et al., 2018).

Finally, the magnitude (scaling) of risk in the maps produced here are specific to the Waituna Catchment. Meaning they provide a relative risk for the catchment and are not defined with respects to the broader Southland region. For example, there are larger areas of Southland with much greater nitrate leaching risk than those occurring within the Waituna Catchment.

Nitrogen

In the Waituna Catchment, total nitrogen is dominated by the soluble, highly reactive nitrate form. Therefore, Total N declines as the proportion of reducing conditions increases. The inherent risk of Total N and nitrate to surface water and shallow groundwaters across the Waituna Catchment is depicted in Figure 1.5. Areas of highest inherent TN and nitrate risk are associated with better-drained soils and shallow alluvial aquifers that occur across the northern portion of the catchment.

The lowest risk areas are associated with areas of peat soils overlying peat aquifers across the south of the catchment. Areas of moderately high risk occur across the north of the catchment but are also prominent within the headwaters of Carran Creek and the Marr, a tributary of Waituna Creek. Areas of moderate to moderately low to risk mainly occur through the middle and southern portions of the catchment.

Due to the importance of reduction processes over nitrate, and hence TN concentrations, areas with limited ability to remove nitrate are associated with the highest export risk. Specifically, nitrate concentration in baseflow supplying streams is highest across the north of the catchment, especially where the stream network transects areas of well-drained soils, as defined by the area of highest inherent risk (red) in Figure 1.5. Areas of moderately high TN and nitrate risk are more likely to have subsurface artificial drainage, raising the risk of lateral soil zone export of nitrate to stream.

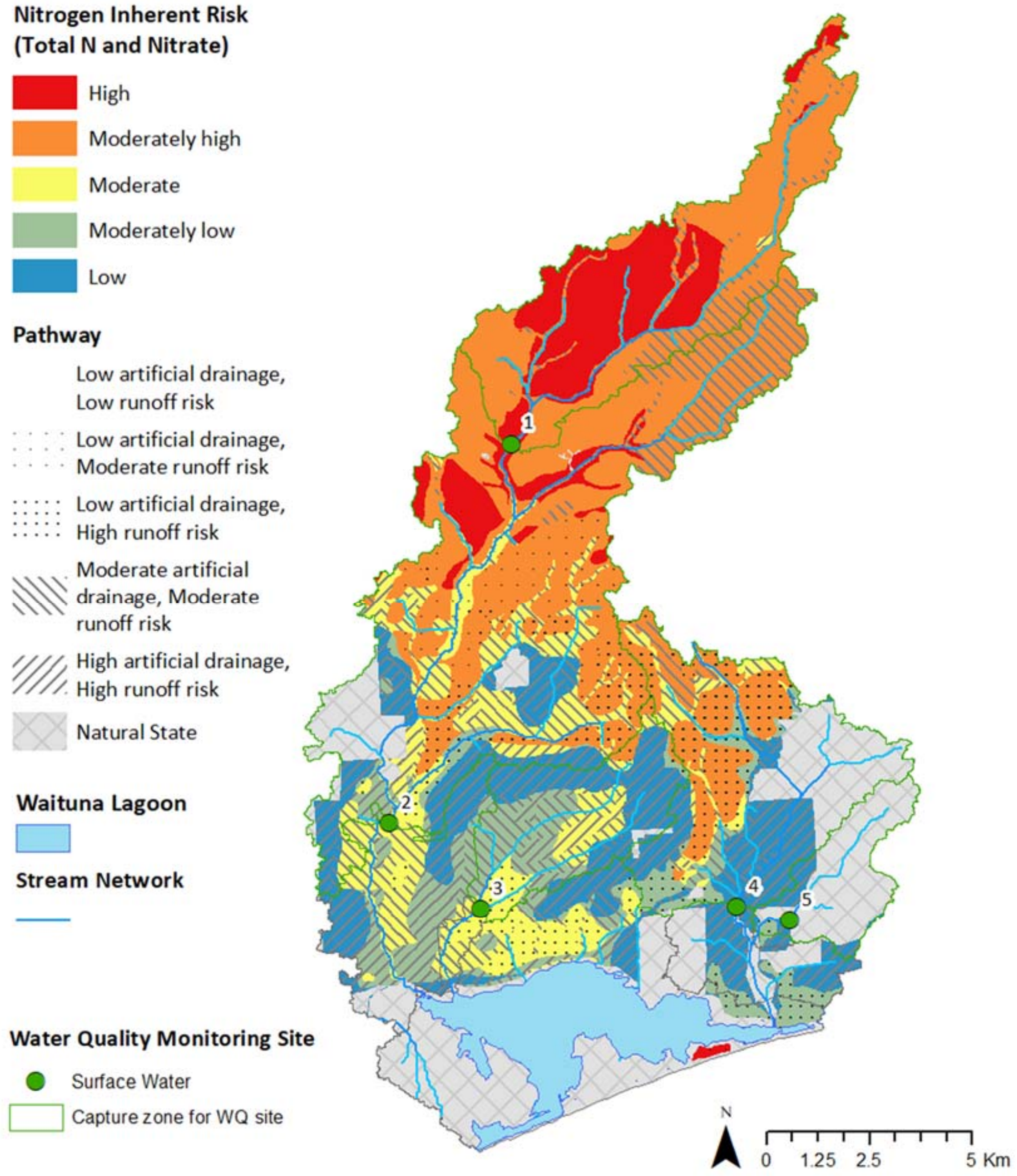

Figure 1.6: Inherent risk of nitrogen transported through the soil zone to the aquifer in Waituna Catchment.

Organic and ammoniacal (TKN) nitrogen is often a minor component of TN. However, it can be significant during periods of event flow across developed areas of the catchment (Rissmann et al., in prep). A recent sampling of an event flow following an extended period of drought conditions (2017/2018 summer) generated a TN concentration of 12.6 mg/L for Waituna Creek at Marshall Rd, of which 9.6 mg/L was associated with the organic nitrogen fraction and 1.1 mg/L was associated with the ammoniacal nitrogen fraction. As such, peak runoff events may supply significant pulses of organic and ammoniacal nitrogen to the stream network.

Importantly, although TN and nitrate concentrations decline as the proportion of soil and aquifer reduction potential increases across the catchment, the organic and ammoniacal forms of nitrogen (TKN) typically increase. This increase reflects several key processes (i) the production of ammoniacal and organic nitrogen in anaerobic soils (poorly drained); (ii) the concentration of ammonium and larger organic nitrogen molecules at or close to the soil surface, and; (iv) a spatial correlation between soils susceptible to OLF and larger TKN concentrations. Therefore, shallow lateral soil zone flow (mediated by mole-pipe drainage) and especially OLF are important pathways for organic and ammoniacal nitrogen delivery to streams.

Due to a different set of controls, TKN behaves in an opposite manner to nitrate increasing as the proportion of reducing soils and aquifers and the %OLF of developed land increases. By extension, subcatchments with different proportions of %OLF of developed land and reducing soils and aquifers exhibit different steady-state TKN concentrations. As nitrogen is source limited, consideration of land cover is also relevant to the supply of TKN to streams and ultimately the Waituna Lagoon. Therefore, the risk map for TKN is the same as that produced for phosphorus (Figure 1.6). Areas of red and to a lesser degree orange are associated with higher TKN losses. Red areas with the highest inherent risk for TKN are associated with areas of developed peat). The north of the catchment and those areas of relatively well-drained soils have a low inherent risk for TKN.

Phosphorus

The export of Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP) to streams is controlled by different processes. Within the larger developed area of the Waituna Catchment the dominant form of P is Particulate Phosphorus (PP), associated with organic and inorganic sediment (S) (Rissmann et al., 2012; Rissmann and Hodson, 2013). Whereas, in the natural state peat wetland areas of the catchment, Dissolved Reactive Phosphorus (DRP) is the dominant P fraction. Specifically, TP export (as PP) increases as the %OLF of developed land increases. The largest TP exports occur across developed land associated with the southern wetland portion of the catchment where the risk (frequency and magnitude) of OLF is highest. Contributions of TP are low for the northern portion of the catchment where %OLF risk is also low. Significantly, natural state areas exhibit source limitation with respects to PP. For DRP, redox plays an additional role over mobility and abundance, with increased yields from areas of reducing soils and aquifers. However, unlike TP, DRP is not source limited in natural state peat wetland areas where it is naturally elevated, although concentrations do not increase in response to flow reflecting negligible subaerial loading (Rissmann et al., in prep).

In Figure 1.6, the inherent risk of TP is depicted according to the pathway water takes across the landscape. For DRP both reducing soils and increasing %OLF of developed land are the key drivers of DRP export to stream. As identified in previous studies, developed peat wetland components of the Waituna catchment are considered the dominant source of P export to streams and ultimately the Waituna Lagoon (Rissmann et al., 2012; Rissmann and Hodson, 2013; McDowell and Monaghan, 2015). However, areas of moderate to high OLF risk across developed land are considered to have a high inherent risk in terms of P export. Across the north of the catchment, TP and DRP export to streams are significantly lower.

Analysis of temporal streamflow indicates a predominance of TP export from developed land is associated with periods of soil saturation, mainly during the cooler months of the year, in conjunction with the wetland soil components that have high and moderately high OLF risk. OLF and associated P export can also occur during the drier months in response to high-intensity rainfall, although the wetland portion of the catchment and areas of high and moderately high inherent risk are again the key areas governing export. There is little evidence from the time series record for significant runoff from the northern portions of the catchment, where OLF risk is lowest.

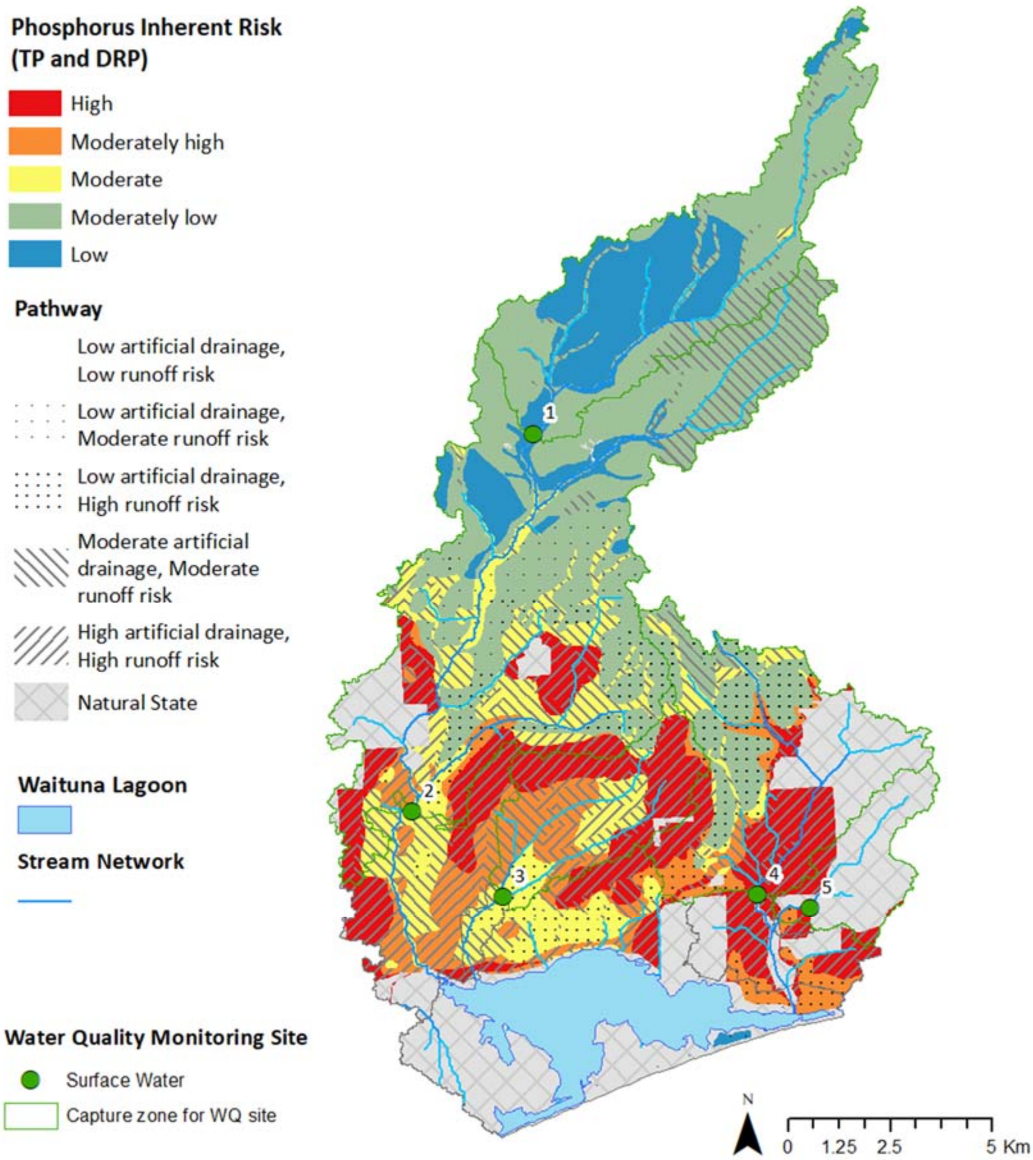

Figure 1.7: Inherent risk of phosphorus (and TKN) transported through the soil zone to the aquifer in Waituna Catchment.

Sediment and Microbes

Sediment, as Total Suspended Sediment (TSS) concentration, and microbes, as *E. coli,* are strongly positively correlated reflecting similar controls over export to stream. Figure 1.7 depicts the inherent risk of sediment and microbial export to streams and primarily reflects the role of % OLF in the mobilisation of sediment and faecal material to stream across the developed areas of the catchment. Specifically, *E. coli*, TSS and turbidity (NTU) increase as the % OLF of developed land increases. The largest sediment and microbial exports occur across developed land associated with the southern wetland portion of the catchment where the risk (frequency and magnitude) of OLF is highest. Contributions of sediment and TSS are low for the northern portion of the catchment where %OLF risk is also low. Significantly, natural state areas exhibit source limitation with negligible sediment and only minor *E. coli* export.

Analysis of temporal streamflow indicates a predominance of OLF associated with periods of soil saturation in conjunction with the wetland soil components that have high and moderately high OLF risk. OLF can also occur during the drier months in response to high-intensity rainfall, although the wetland portion of the catchment and areas of high and moderately high inherent risk are again the most responsive. There is little evidence from the time series record for significant runoff from the northern portions of the catchment, where OLF risk is lowest.

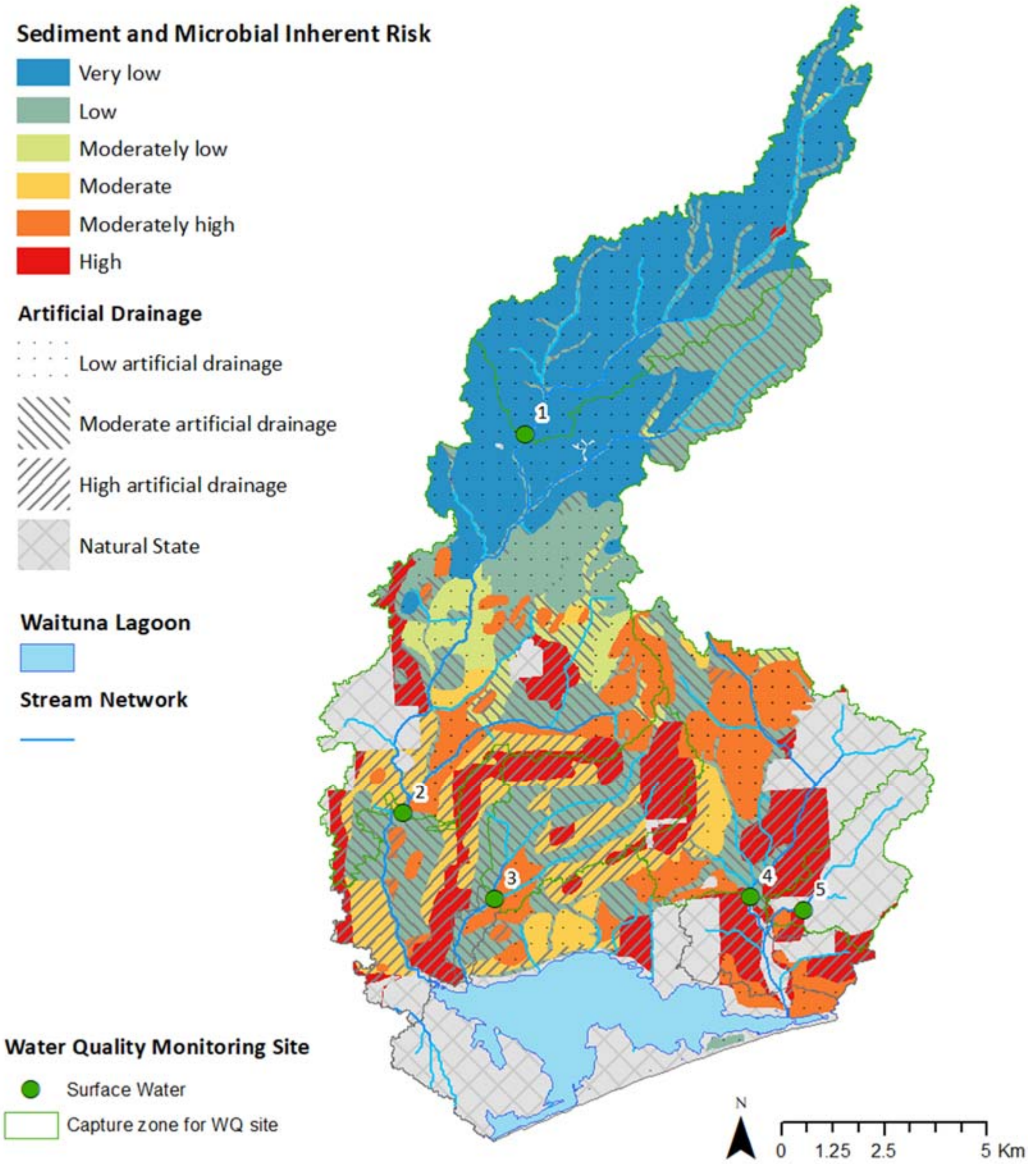

Figure 1.8: Inherent risk of sediment and microbes transported overland by surficial runoff.

1.4 Fundamental Landscape Units for the Waituna Catchment

To aid in communication with landholders and other stakeholders, the high-resolution physiographic assessment for the Waituna Catchment (Figure 1.2) has been grouped in a similar approach to Hughes et al. (2016) using key landscape features (Figure 1.9). A three-tier classification system has been applied to incorporate landscape variation and inherent risk for contaminant loss. We have termed these units Fundamental Landscape Units (FLU).

At the highest level, there are 5 Families, which identify prominent landscape features. These family groups are similar to Environment Southland's Physiographic Zones present in the catchment. The Families are divided into subunits which show variation in the soil and/or geological setting and result in varying reduction potentials of the surficial and underlying substrates. There are 16 subunits at this level. At the finest scale, the hydrological pathway is added to identify the risk of loss for contaminants and provide the highest resolution possible at the catchment scale. There are 31 siblings at this finest scale. The subunits classified by soil and geological reduction potential are typically ordered from most reducing to least within the family, with a preference for soil reduction potential over geology.

Sections 2 to 6 are intended to be a technical reference for the unit characteristics. Therefore, there is repetition within the FLU descriptions where soil, geology or hydrological pathways are similar. However, the combination of these attributes results in differing water quality outcomes and have been explained for each subunit in a water quality implication section. The FLUs identified for the Waituna catchment are:

- Section 2: Wetland Complex
- Section 3: Lignite
- Section 4: Marine Terrace
- Section 5: Reducing
- Section 6: Oxidising

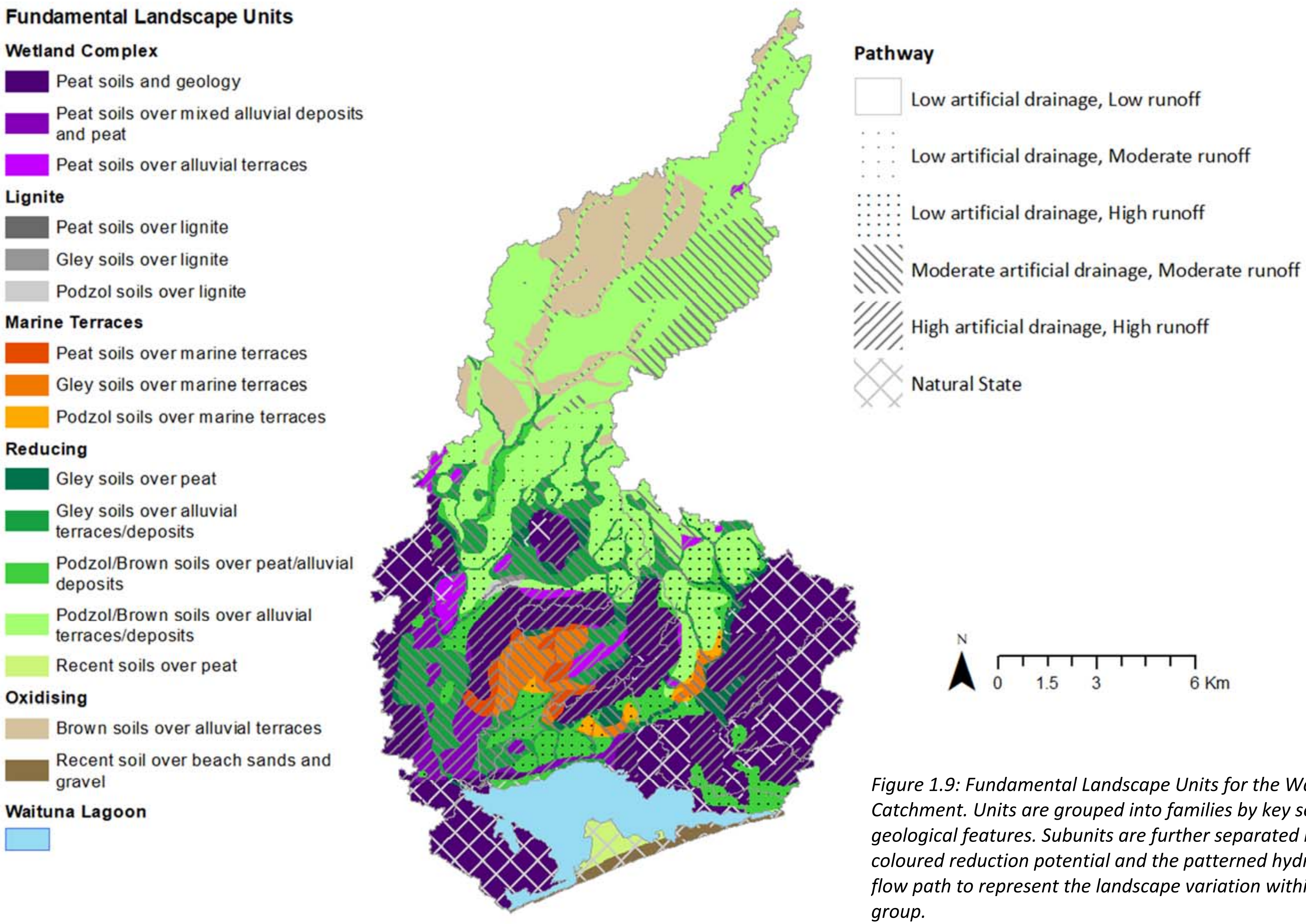

Figure 1.9: Fundamental Landscape Units for the Waituna Catchment. Units are grouped into families by key soil or geological features. Subunits are further separated by the coloured reduction potential and the patterned hydrological flow path to represent the landscape variation within a family group.

2 Wetland Complex Family

2.1 Family Overview

The Wetland Complex is characterised by soils with a high organic content over varying geological substrates. In the Waituna Catchment, the Wetland Complex is found in the south of the catchment in low-lying coastal areas across all sub-catchments (Figure 2.1). Natural state wetlands border the catchment in the west and east, which are part of a larger wetland complex, Awarua-Waituna. The Wetland Complex covers an area of 6,641.4 ha, which is 34.4% of the Waituna Catchment. Within the Wetland Complex family, there are 6 siblings with similar soils but varying geological substrates from peat to alluvial deposits that vary in terms of aquifer reduction potential (i.e., from high to low). Subunits are also defined by the hydrological pathway.

Key features

- Very poorly drained peat soils which are extremely acidic.
- Low P retention capacity in soil due to the limited mineral content. As subunits vary from peat to alluvial aquifer material P retention increases.
- High soil denitrification potential.
- Aquifer denitrification potential varies with underlying geology from high in peat to low in alluvial terraces.
- Extensive artificial drainage occurs through this unit in developed areas, resulting in reduced reduction potential.

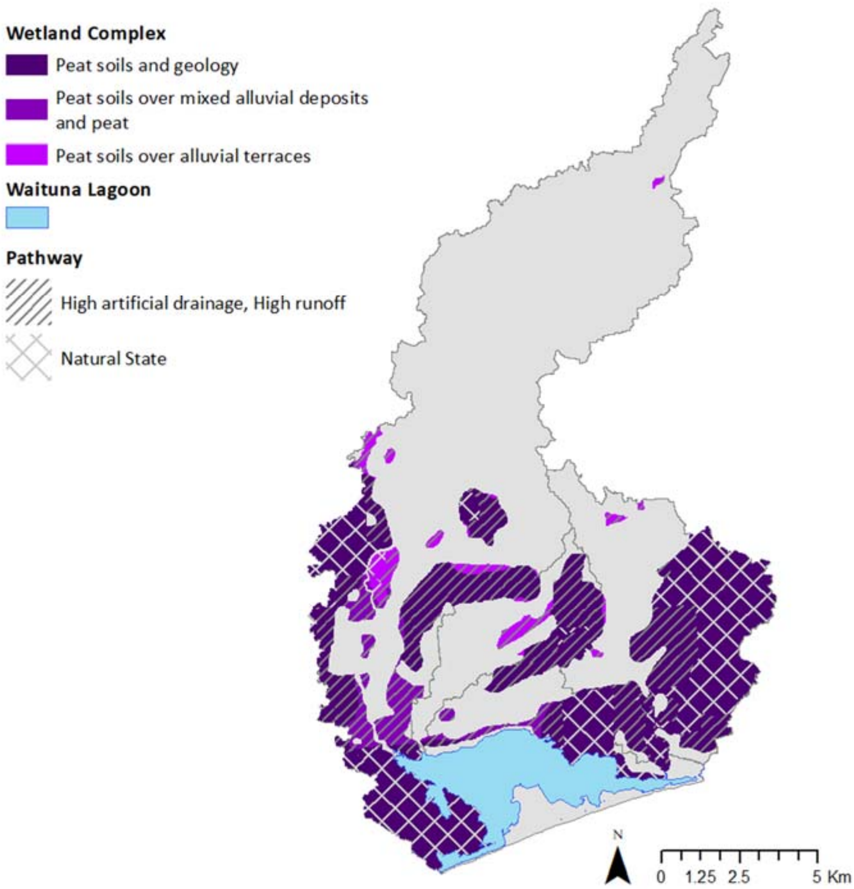

Figure 2.1: Extent of Wetland Complex Unit in Waituna Catchment.

2.2 Landscape Characteristics

2.2.1 Soils

Soils in this zone are classified by the New Zealand Soil Classification as Organic. Organic soils are formed in the partly decomposed remains of wetland plants forming peat. There is some mineral material present, but the soils are dominated by organic matter (50-90%). The soil series present in this unit are Otanomomo (Fibric Melanic Organic) and Invercargill (Mesic Acidic Organic), with minor Titipua (Orthic Peaty Gley) associated with the Invercargill soil series (Figure 2.2; Crops for Southland 2002). The peat of the Otanomomo soil shows weak to moderate decomposition of organic matter, while the Invercargill soils are moderate to strongly decomposed. See Reducing unit – Gley soil over peat for more information on the Titipua soil properties.

Near the land surface, the peat is typically loose and fibrous grading to denser, amorphous peat with depth. Organic soils are generally structureless with a low bulk density. They have very poor internal drainage which means they are prone to waterlogging, particularly where the water table is shallow (Crops for Southland, 2002). This also limits air movement through the soils resulting in very poor aeration and anoxic waters. The soils have a high reduction potential due to their high organic carbon content and high water table. This combination results in water that is strongly reducing.

Organic soils have a low P-retention making them susceptible to P-leaching. This occurs because of the low mineral content in the soils limiting the ability to sequester or sorb P out of solution and the strongly reducing conditions in the soil. Organic soils are extremely acidic which limits their versatility for agricultural use, without improved drainage and acidity (i.e. liming).

Figure 2.2: Otanomomo, Invercargill and Titipua typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

2.2.2 Hydrology

The hydrology of this unit is exclusively land surface recharge from local precipitation. There is limited potential for dilution of contaminant concentrations associated with this recharge mechanism.

Agriculturally developed areas are extensively drained due to the high potential for waterlogged soils within this zone. Artificial drainage is used to maintain a deeper water table as well as to facilitate more rapid drainage of excess soil water. This has augmented the stream network with open ditch drains and a dense subsurface drainage network in developed areas (Pearson, 2015a; Rissmann et al., 2018).

An important pathway for water movement is lateral drainage through the soil profile. Lateral flow occurs in soils where there is sufficient slope due to topography or mounding within the wetland. Water often drains laterally along the contact between soil horizons where the subsoil has a lower permeability than the horizon above. Where land is developed, lateral drainage is intersected by artificial drainage.

Overland flow and surface ponding occur when the water table becomes elevated above the ground level. The topography of the area will determine if precipitation will result in runoff. This unit has a relatively high potential for localised overland flow within the Waituna catchment due to the seasonally high water table. However, in developed areas this potential may not be fully realised due to the high density of artificial drainage.

Surface waters have a mixed redox state due to re-aeration with atmospheric oxygen and periodic rapid discharge via artificial drainage networks which reduce the time available for reduction to occur.

Groundwater levels are shallow and often occur at, or near, ground level. Seasonally groundwater levels are highest in spring following progressive recharge during winter and spring, and decline over summer and autumn as aquifer storage is progressively depleted by baseflow discharge to streams draining this unit. Groundwater from this unit discharges as baseflow streams (via artificial drains) or by throughflow into adjacent zones. The reduction potential of the aquifer varies within this family depending on the aquifer substrate from high in peat aquifers to low in alluvial aquifers.

2.3 Subunit Variation

The siblings within the Wetland Complex arise from the variation in aquifer geology and resultant reduction potential, and hydrological pathways:

- Peat soils and geology
    - Natural state hydrology
    - High artificial drainage and high runoff
- Peat soils over mixed alluvial deposits and peat
    - Natural state hydrology
    - High artificial drainage and high runoff
- Peat soils over alluvial terraces
    - Natural state hydrology
    - High artificial drainage and high runoff

2.3.1 Peat Soils and Geology

This subunit is the largest comprising 86.4% (5,737.1 ha) of the Wetland Complex and is associated with the peat bogs in the south of the Waituna catchment (Figure 2.1). Over half this unit is in conservation estate (54%) with natural state hydrology. The remainder of the unit is predominantly developed for pastoral farming with an extensive tile and open ditch drainage network. This results in two siblings:

- Peat soils and geology with natural state hydrology (3,102.2 ha)
- Peat soils and geology with high artificial drainage and high runoff (2,634.9 ha)

Geology

The underlying geology in this zone is identified as peat in swamps and peat mounds with incursions of sand and silt (QMAP; Turnbull and Allibone, 2003). The main geological material is peat with secondary sand and silt. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Reduction Potential

The reduction potential is high in soils, high in the underlying aquifer, and high overall.

2.3.2 Peat Soils over Mixed Alluvial Deposits and Peat

This subunit comprises 8% (533.5 ha) of the Wetland Complex and is located near Waituna Lagoon and along the south of Waituna Creek (Figure 2.1). The majority of this unit (98.4 %) is developed land which has significantly altered the natural hydrology through artificial drainage. The siblings within this subunit are:

- Peat soils over mixed alluvial deposits and peat with natural state hydrology (8.6 ha)
- Peat soils over mixed alluvial deposits and peat with high artificial drainage and high runoff (524.9 ha)

Geology

The underlying geology in this zone is identified as unconsolidated gravel, sand and peat in modern stream beds with minor overbank swamps (QMAP; Turnbull and Allibone, 2003). The main geological material is alluvial gravel with sand, silt, and peat. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Reduction Potential

The reduction potential is high in soils, moderately low in the underlying aquifer and moderately high overall.

2.3.3 Peat Soils over Alluvial Terraces

This subunit is the smallest comprising 5.6% (370.8 ha) of the Wetland Complex and is located around the main peat soils and geology subunit or in smaller more isolated wetland areas (Figure 2.1). The majority of this unit is developed land (87.3%) which has significantly altered the natural hydrology. The siblings within this subunit are:

- Peat soils over alluvial terraces with natural state hydrology (46.9 ha)
- Peat soils over alluvial terraces with high artificial drainage and high runoff (323.9 ha)

Geology

The underlying geology in this zone is identified as alluvial terraces. There are two terraces within the Waituna catchment. The geology of the older Kamahi Formation, located to the north of the catchment, is described as weathered sandy greywacke (quartz) in high terraces (stratigraphic age Q8-Q10) (QMAP; Turnbull and Allibone, 2003). The main geological material is alluvial gravel with sand, clay and silt.

Further south, the Waikiwi Terrace is reworked material from the Kamahi Formation (stratigraphic age Q6-Q8) (QMAP; Turnbull and Allibone, 2003). The geology is described as moderately weathered clay-rich sandy gravel in high terraces. The main geological material is alluvial gravel with silt, sand, and clay.

Reduction Potential

The reduction potential is high in soils, low in the underlying aquifer resulting in a moderate overall reduction potential.

2.4 Wetland Complex Water Quality Implications

Organic soils and peat aquifers have a high reduction potential. Groundwater is therefore strongly reducing and as a result is highly denitrifying. Water reaching the aquifer through deep drainage has a low inherent risk for nitrate (NO_3^-), but elevated ferrous iron (Fe^{2+}) and potentially ammoniacal nitrogen (NH_4^+) concentrations (naturally derived through ammonification of organic matter under reducing conditions). Surface waters often have a mixed redox state due to re-aeration with atmospheric oxygen and periodic rapid discharge via artificial drainage networks which reduce the time available for reduction to occur (Figure 2.3).

Aquifers in peat have a low phosphorus sorption capacity due to the organic composition of aquifer materials. Reducing conditions enhance phosphorus mobility in groundwater through the formation of microscopic phosphorus-colloids (Figure 2.3).

Overland flow and surface ponding occur when the water table becomes elevated above the ground level. The topography of the area will determine if precipitation will result in runoff that transports sediment (including sediment-bound phosphorus) and microbes to streams (Figure 2.3). The Wetland Complex unit has a moderate to high potential for localised overland flow within the Waituna Catchment due to the seasonally high water table. However, in developed areas this potential may not be fully realised due to the high density of artificial drainage.

The inherent water quality risk from the Wetland Complex unit is summarised in Table 2.1.

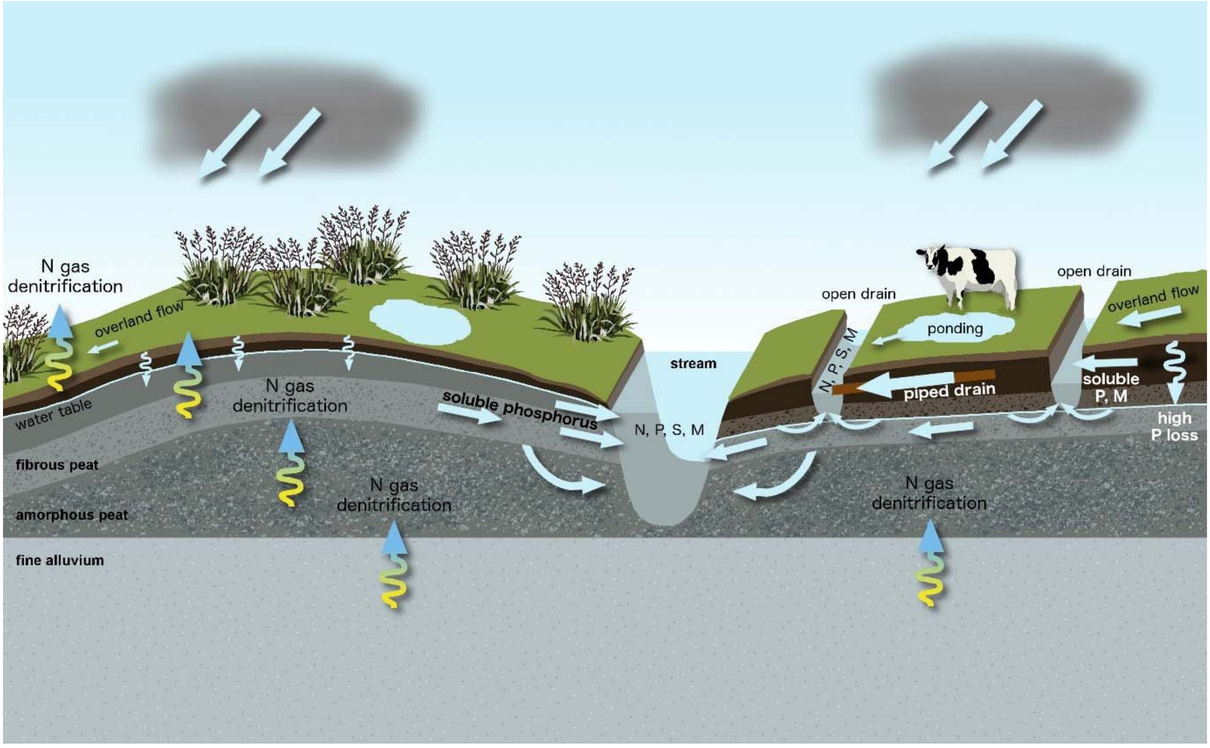

Figure 2.3: Contaminant pathways from the Wetland Complex.
Source: Physiographics of Southland, Peat Wetlands Technical Information Factsheet.

Table 2.1: Water quality risk from the Wetland Complex by sibling and flow pathway – deep drainage (DD), overland flow (OLF), subsurface artificial drainage (SAD). The risk is classified as very low (VL), low (L), moderately low (ML), moderate (M), moderately high (MH), high (H). Source limited (SL) identifies natural state areas with minimal contaminants to transport.

	Nitrogen			**Phosphorus**			**Sediment and Microbes**	
	DD	OLF	SAD	DD	OLF	SAD	OLF	SAD
Peat soils and geology								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
High artificial drainage and high runoff	L	H	H	H	H	H	M - H	H
Peat soils over mixed alluvial deposits and peat								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
High artificial drainage and high runoff	ML	H	H	MH	H	H	H	H
Peat soils over alluvial terraces								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
High artificial drainage and high runoff	M	H	H	M	H	H	M -H	H

3 Lignite Family

3.1 Family Overview

The Lignite Family is characterised by varying soil types over organic-rich sedimentary material (lignite). It is the smallest unit in the Waituna Catchment, with an extent of 45.8 ha (0.2%, Figure 3.1). The Lignite Unit is located in the south of Waituna Creek catchment only. There are 3 siblings with varying soils and hydrological pathways. The unit has been developed for pastoral farming.

Key features

- Underlying geology has a moderately high reduction potential (reducing).
- Soils are fine-textured with slow subsoil permeability.
- The redox state of groundwater varies according to the thickness of overlying alluvium.
- Surface water quality is influenced by groundwater quality (baseflow), overland flow and artificial drainage.

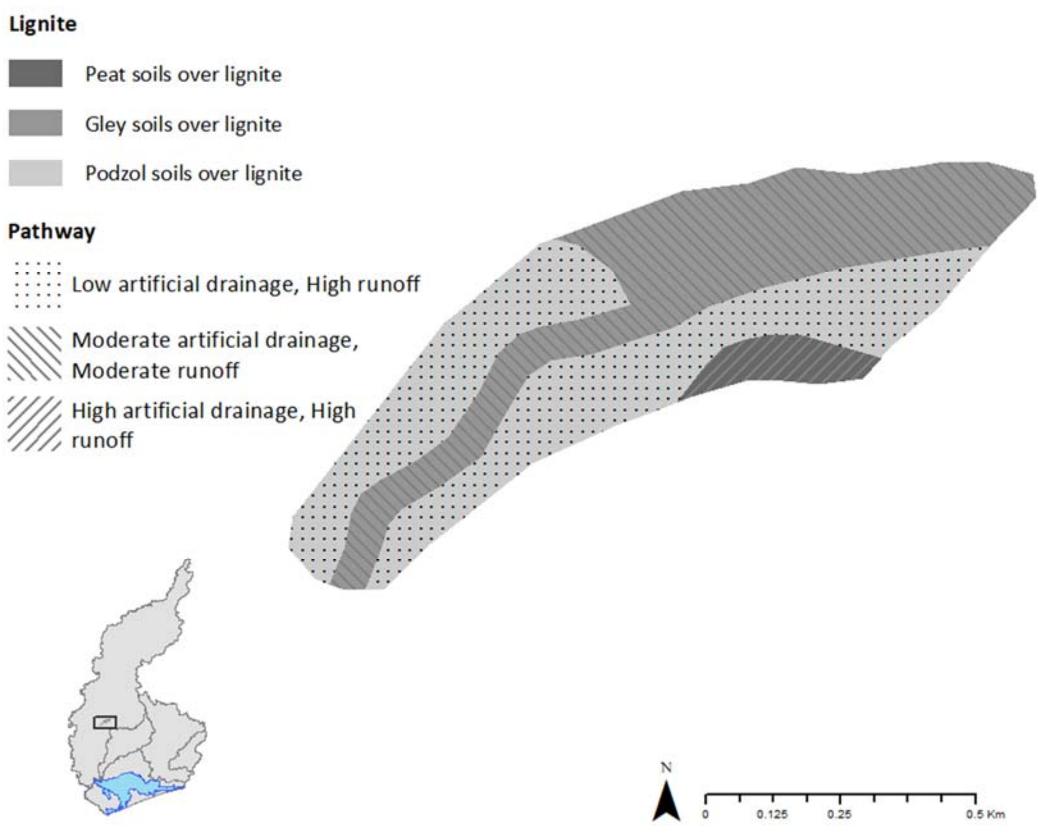

Figure 3.1: Extent of Lignite Unit in Waituna Catchment.

3.2 Landscape Characteristics

3.2.1 Geology

This unit is associated with the Gore Lignite Measures, a sandstone with lignite and carbonaceous mudstone (QMAP; Turnbull and Allibone, 2003). The main geological material is sandstone with lignite and claystone. The lignite measures need to be close to the land surface to be classified within the Lignite Unit. Lignite occurring at depth is not hydrologically connected to the surface water network and has little influence over water quality.

3.2.2 Hydrology

The hydrology of the catchment is exclusively land surface recharge by local precipitation. There is limited potential for dilution of contaminant concentrations associated with this recharge mechanism.

The hydrology of this unit has been modified for agricultural development. In flatter areas that are prone to seasonal waterlogging, natural drainage has been augmented by artificial drainage (Pearson 2015a; Rissmann et al., 2018). On undulating topography where the subsoil permeability is low, overland flow can be generated during sustained wet periods (Pearson 2015b; Rissmann et al., 2018).

Groundwater levels in the catchment are shallow and often occur at, or near, ground level. Seasonally groundwater levels are highest in spring following progressive recharge during winter and spring, and decline over summer and autumn as aquifer storage is progressively depleted by baseflow discharge to streams draining this zone. Groundwater from this unit discharges as baseflow streams (via artificial drains) or by throughflow into adjacent zones. The reduction potential of the aquifer is moderately high.

3.3 Subunit Variation

The sibling variation within the Lignite Family arises from the variation in soil types and hydrological pathways:

- Peat soils over lignite with high artificial drainage and runoff
- Gley soils over lignite with moderate artificial drainage and runoff
- Podzol soils over lignite with low artificial drainage and high runoff

3.3.1 Peat Soils over Lignite

This subunit is the smallest covering 5.3 % (2.4 ha) of the Lignite Family and is located on Organic soils in the South Waituna Creek catchment (Figure 3.1). The entire unit is developed land which has altered the natural hydrology through artificial drainage.

Soils

Soils in this zone are classified as Organic. Organic soils are formed in the partly decomposed remains of wetland plants forming peat. There is some mineral material present, but the soils are dominated by organic matter (50-90%). The soil series present in this unit is Invercargill (Mesic Acidic Organic), with minor Titipua (Orthic Peaty Gley) associated with the Invercargill soil series (Figure 3.2; Crops for Southland 2002). The peat of the Invercargill soils is moderate to strongly decomposed. See Reducing unit – Gley soil over peat for more information on the Titipua soil properties.

Near the land surface, the peat is typically loose and fibrous grading to denser, amorphous peat with depth. Organic soils are generally structureless with a low bulk density. They have very poor internal drainage which means they are prone to waterlogging, particularly where the water table is shallow (Crops for Southland, 2002). This also limits air movement through the soils resulting in very poor aeration and anoxic waters. The soils have a high reduction potential due to their high organic carbon content and high water table. This combination results in water that is strongly reducing.

Organic soils have a low P-retention making them susceptible to P-leaching. This occurs because of the low mineral content in the soils limiting the ability to sequester or sorb P out of solution and the strongly reducing conditions in the soil. Organic soils are extremely acidic which limits their versatility for agricultural use, without improved drainage and acidity (i.e. liming).

Figure 3.2: Invercargill and Titipua typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is high in soils, moderately high in the underlying aquifer, and moderately high overall.

3.3.2 Gley Soils over Lignite

This subunit covers 43.8 % (20.1 ha) of the Lignite Family and is located on Gley soils in the South Waituna Creek catchment (Figure 3.1). The entire unit is developed land which has altered the natural hydrology through artificial drainage.

Soil

Soils in this unit are classified as Gley. Gley soils, along with Organic, represent the original extent of wetlands prior to agricultural development. The soils are strongly affected by waterlogging, resulting in anoxic and reducing conditions producing soils with light grey subsoils, usually with reddish-brown mottles. The organic matter content in the topsoil is elevated reflecting their origin in historical wetlands. The soil series present in this unit are Titipua (Orthic Peaty Gley), Dacre (Recent, Acidic, Gley), and Tisbury (Orthic Acidic Gley) silt loams (Figure 3.3) with minor Invercargill. See Section 2 Wetland Complex for more information on the Invercargill soil properties.

These soils all have horizons with slow permeabilities (< 4mm/hr) and are poorly drained. Poor aeration occurs when the soils are wet, which may be for most of the year in the absence of artificial drainage. This results in subsoils that are acidic (pH < 5.5) and have a moderately high reducing potential. The redoximorphic features of mottling and gleying are indicative of reducing conditions. P-retention in these soils is moderate, minimising the risk of P-leaching.

Artificial drainage is used extensively in these soils to prevent waterlogging, which occurs due to the combination of flat topography and poor soil drainage (Crops for Southland, 2002; Pearson 2015a). Bypass flow via artificial drainage can reduce soil residence time reducing the potential for denitrification to occur. In soil types that have restricted drainage, lateral flow may occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

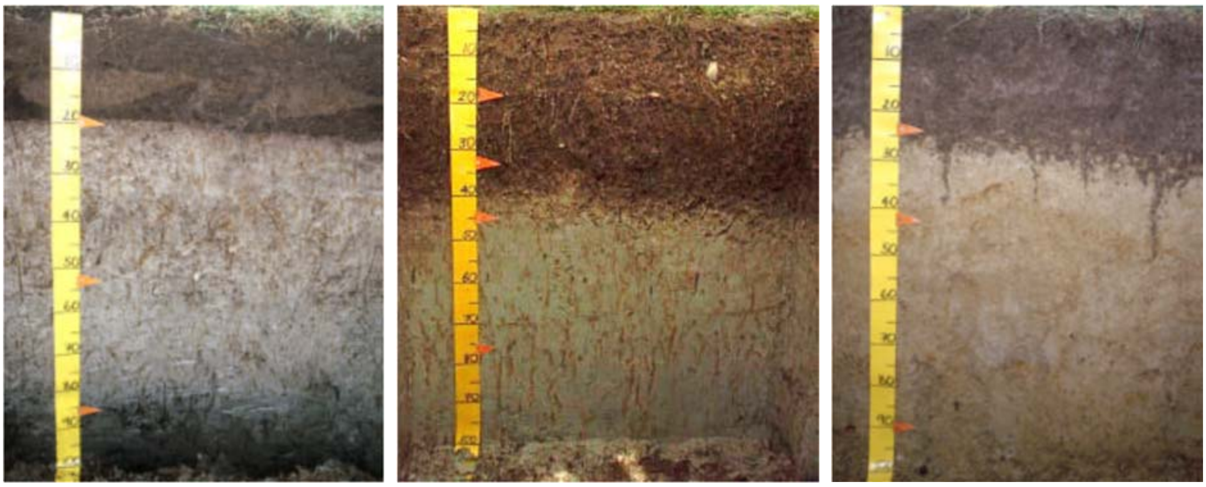

Figure 3.3: Titipua, Dacre, and Tisbury typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is moderately high in both soils and in the underlying aquifer.

3.3.3 Podzol Soils over Lignite

This subunit covers 50.9 % (23.3 ha) of the Lignite Family and is located on Podzol soils in the South Waituna Creek catchment (Figure 3.1). The entire unit is developed land which has altered the natural hydrology through artificial drainage.

Soil

The soil in this unit is classified as Podzol. Podzol soils are strongly acid soils that typically have a bleached horizon immediately beneath the topsoil. A key characteristic of these soil is an organic-rich A/O horizon as organic carbon is a critical feature of these soils. The soil series present in this unit is the Kapuka soil (Pan Fill Podzol) (Figure 3.4).

The Kapuka soil has a moderately developed structure and silt loam texture with gravels typically found between 45 and 90 cm depth. The soil is imperfectly drained, with slowly permeable subsoils that may cause short-term waterlogging after heavy rain. Subsurface mottling occurs in the clay-bound underlying gravels reflecting the slow permeability of this soil. The reduction potential of this soil is moderate, reflecting the seasonal waterlogging of the soil profile. The upper subsoil is characterised by the accumulation of complexes of iron and organic matter, indicative of podzolised soils. Crops for Southland (2002) reports the P-retention in the Kapuka soil as high, minimising the risk of P-leaching. However, P loss from soils undertaken by AgResearch for Waituna noted Podzols as having an elevated P leaching risk relative to other mineral soils (McDowell and Monaghan, 2015).

This occurs because the aluminium (Al) and iron (Fe) sesquioxides that sorb P are most unstable under reducing conditions and low pH.

Artificial drainage density is moderate to prevent waterlogging in wetter months (Pearson, 2015a). Bypass flow, via the artificial drainage network can reduce soil residence time reducing the potential for denitrification to occur. In soils with pans which restrict deep drainage, lateral flow can occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

Figure 3.4: Kapuka typical soil profile.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is moderate in soils, moderately high in the underlying aquifer and moderately high overall.

3.4 Lignite Family Water Quality Implications

Organic, Gley, and Podzol soils with their high organic carbon content and poor to imperfect drainage have a high to moderate reduction potential. The reduction potential of the soil decreases as the drainage and carbon content decreases. Groundwater is therefore strongly reducing under peat and becomes more oxidising and the ability to denitrify is reduced. Water reaching the aquifer through deep drainage has a low inherent risk for nitrate (NO_3^-), due to the moderately high reduction potential of the Gore Lignite Measures. However, the permeability of the underlying geology is lower than the overlying soils, favouring lateral flow along the contact of the sandstone. Surface waters often have a mixed redox state due to re-aeration with atmospheric oxygen and periodic rapid discharge via artificial drainage networks which reduce the time available for reduction to occur (Figure 3.5). Ferrous iron (Fe^{2+}) and ammoniacal nitrogen (NH_4^+) concentrations can also be naturally elevated (derived through ammonification of organic matter under reducing conditions).

Overland flow and surface ponding occur when the water table becomes elevated above the ground level. The topography of the area will determine if precipitation will result in runoff transporting sediment (including sediment-bound phosphorus) and microbes (Figure 3.5). The Lignite unit has the potential for localised overland flow due to the seasonally high water table. However, in developed areas this potential may not be realised due to the high density of artificial drainage.

The inherent water quality risk from the Lignite unit is summarised in Table 3.1.

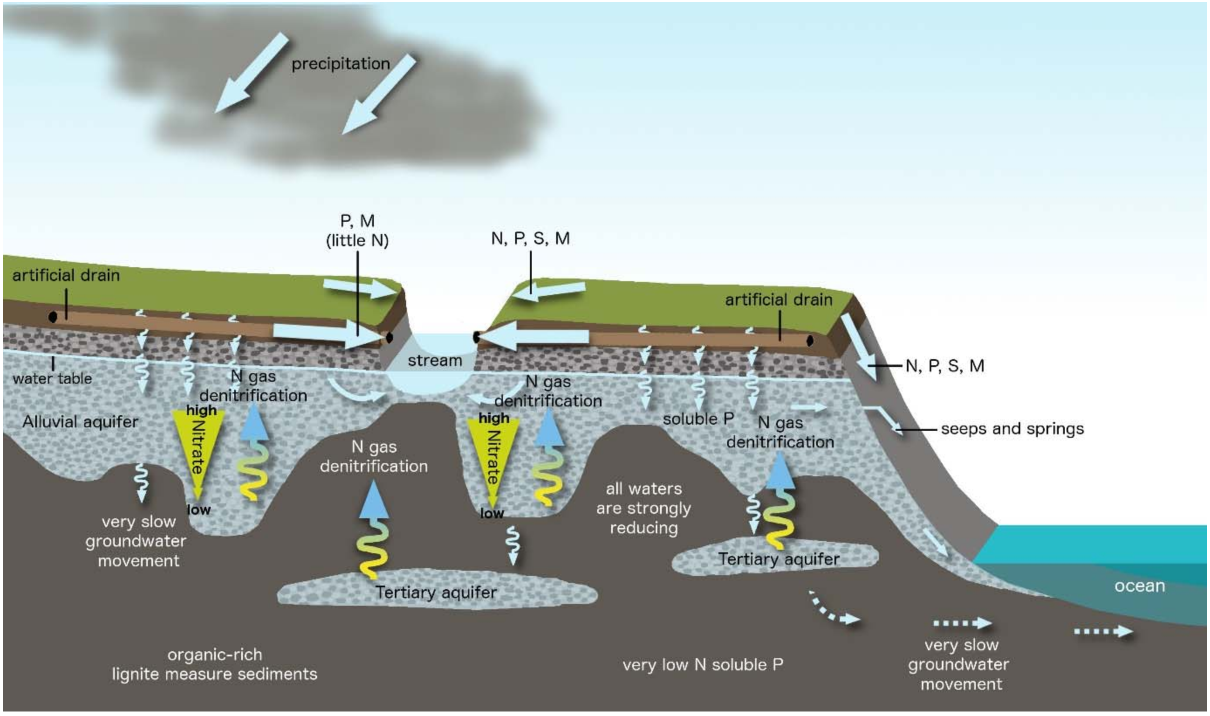

Figure 3.5: Contaminant pathways from the Lignite unit.
Source: Physiographics of Southland, Lignite/Marine Terraces Technical Information Factsheet.

Table 3.1: Water quality risk from the Lignite Family by sibling and flow pathway – deep drainage (DD), overland flow (OLF), subsurface artificial drainage (SAD). The risk is classified as very low (VL), low (L), moderately low (ML), moderate (M), moderately high (MH), high (H).

	Nitrogen			**Phosphorus**			**Sediment and Microbes**	
	DD	OLF	SAD	DD	OLF	SAD	OLF	SAD
Peat soils over lignite	L	H	H	H	H	H	M	M
Gley soils over lignite	ML	M	M	MH	M	M	L - ML	L - ML
Podzol soils over lignite	ML	H	L	MH	H	L	MH	MH

4 Marine Terrace Family

4.1 Family Overview

The Marine Terrace Family is characterised by poorly to imperfectly drained soils over organic-rich marine terrace sedimentary material. In the Waituna catchment, the Marine Terrace Unit is predominantly in the Moffat Creek catchment, with minor areas in Waituna Creek, Carran Creek, and the area of direct contribution to Waituna Lagoon (Figure 4.1). The Marine Terrace Unit covers a total area of 811.6 ha. Within this FLU family, there are 3 siblings with varying reduction potential from moderate to high. The unit has been developed for pastoral farming.

Key features

- Located where the underlying geology is moderately reducing.
- Soils are fine-textured with slow subsoil permeability.
- The redox state of groundwater varies according to the thickness of alluvium overlying organic-rich sediments.
- Surface water quality is influenced by groundwater quality (baseflow), overland flow and artificial drainage

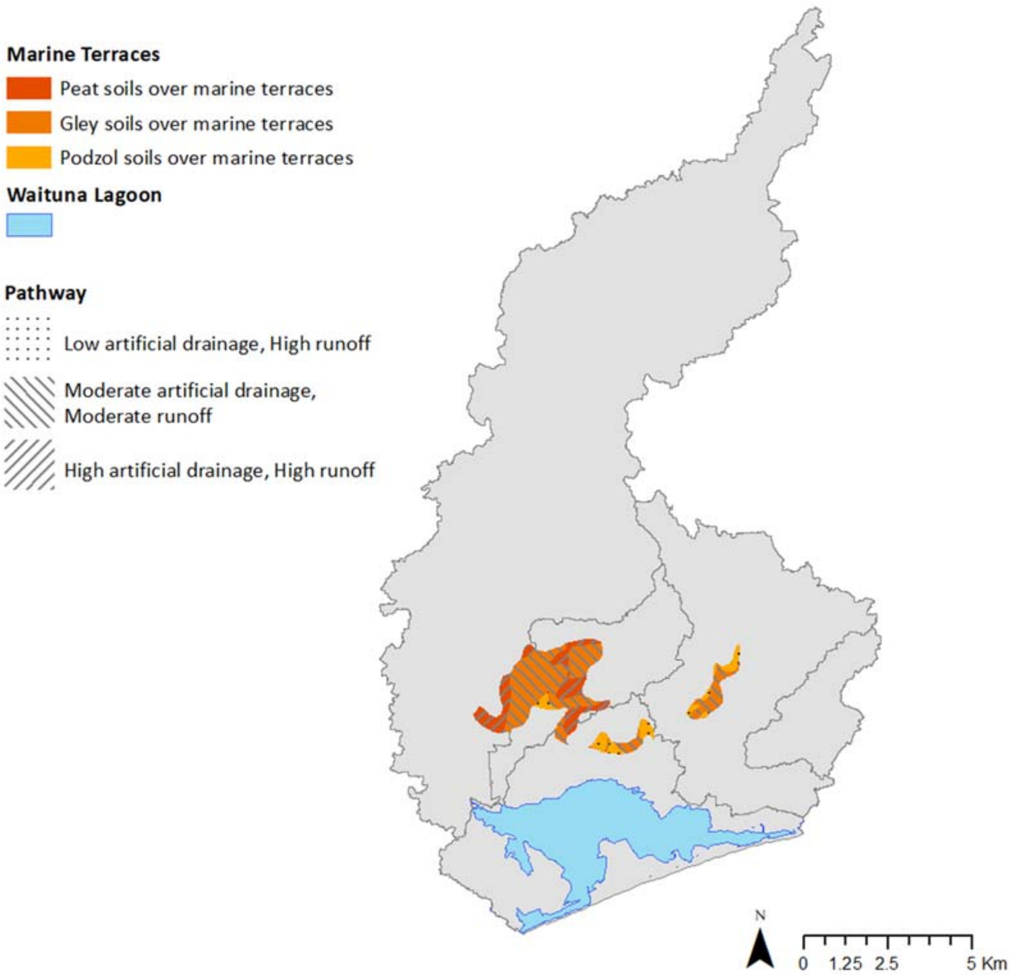

Figure 4.1: Extent of Lignite Unit in Waituna Catchment.

4.2 Landscape Characteristics

4.2.1 Geology

The underlying geology in this zone is identified as a marine terrace comprising of pebbly to boulder gravel, sand, and minor peat underlying marine benches behind old sea cliffs (QMAP; Turnbull and Allibone, 2003). The main geological material is gravel with secondary sand and peat. The zone occurs in areas that are late Quaternary aged (stratigraphic age is Q5).

The surficial alluvium is generally comprised of quartz-rich gravels in a highly weathered silty clay matrix. As a consequence, aquifers hosted in such sediments exhibit low to very low permeability and have a moderate reduction potential.

4.2.2 Hydrology

The hydrology of the catchment is exclusively land surface recharge from local precipitation. There is limited potential for dilution of contaminant concentrations associated with this recharge mechanism.

4.3 Subunit Variation

The sibling variation within the Marine Terrace arises from the variation in soil hydrological properties.

- Peat soils over marine terraces with high artificial drainage and runoff
- Gley soils over marine terraces with moderate artificial drainage and runoff
- Podzol soils over marine terraces with low artificial drainage and high runoff

4.3.1 Peat Soils over Marine Terraces

This subunit comprises 26.3% (213.8 ha) of the Marine Terrace Unit and is associated with the Wetland Complex predominantly in Moffat Creek catchment (Figure 4.1). The unit is developed which has significantly altered the natural hydrology through high density artificial drainage.

Soil

Soils in this zone are classified by the New Zealand Soil Classification as Organic. Organic soils are formed in the partly decomposed remains of wetland plants forming peat. There is some mineral material present, but the soils are dominated by organic matter (50-90%). The soil series present in this unit are Otanomomo (Fibric Melanic Organic) and Invercargill (Mesic Acidic Organic), with minor Titipua (Orthic Peaty Gley) associated with the Invercargill soil series (Figure 4.2; Crops for Southland 2002). The peat of the Otanomomo soil shows weak to moderate decomposition of organic matter, while the Invercargill soils are moderate to strongly decomposed. See Reducing unit – Gley soil over peat for more information on the Titipua soil properties.

Near the land surface, the peat is typically loose and fibrous grading to denser, amorphous peat with depth. Organic soils are generally structureless with a low bulk density. They have very poor internal drainage which means they are prone to waterlogging, particularly where the water table is shallow (Crops for Southland, 2002). This also limits air movement through the soils resulting in very poor aeration and anoxic waters. The soils have a high reduction potential due to their high organic carbon content and high water table. This combination results in water that is strongly reducing.

Organic soils have a low P-retention making them susceptible to P-leaching. This occurs because of the low mineral content in the soils limiting the ability to sequester or sorb P out of solution and the strongly reducing conditions in the soil. Organic soils are extremely acidic which limits their versatility for agricultural use, without improved drainage and acidity (i.e. liming).

Figure 4.2: Otanomomo, Invercargill and Titipua typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is high in soils, moderate in the underlying aquifer and moderately high overall.

4.3.2 Gley Soils over Marine Terraces

This is the largest sibling of the Marine Terrace family comprising 60.7% (493.3 ha). The unit is located predominantly in Moffit Creek catchment with minor areas in Carran Creek, South Waituna Creek and the area of direct contribution to Waituna Lagoon (Figure 4.1). The unit is developed which has significantly altered the natural hydrology through moderate density artificial drainage.

Soil

Soils in this unit are classified as Gley. Gley soils, along with Organic, represent the original extent of wetlands prior to agricultural development. The soils are strongly affected by waterlogging, resulting in anoxic and reducing conditions producing soils with light grey subsoils, usually with reddish-brown mottles. The organic matter content in the topsoil is elevated reflecting their origin in historical wetlands. The soil series present in this unit are Titipua (Orthic Peaty Gley), Dacre (Recent, Acidic, Gley), and Tisbury (Orthic Acidic Gley) silt loams (Figure 4.2).

These soils all have horizons with slow permeabilities (< 4mm/hr) and are poorly drained. Poor aeration occurs when the soils are wet, which may be for most of the year in the absence of artificial drainage. This results in subsoils that are acidic (pH < 5.5) and have a moderately high reducing potential. The redoximorphic features of mottling and gleying are indicative of reducing conditions. P-retention in these soils is moderate, minimising the risk of P-leaching.

Artificial drainage is used extensively in these soils to prevent waterlogging, which occurs due to the combination of flat topography and poor soil drainage (Crops for Southland, 2002; Pearson 2015a). Bypass flow via artificial drainage can reduce soil residence time reducing the potential for denitrification to occur. In soil types that have restricted drainage, lateral flow may occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

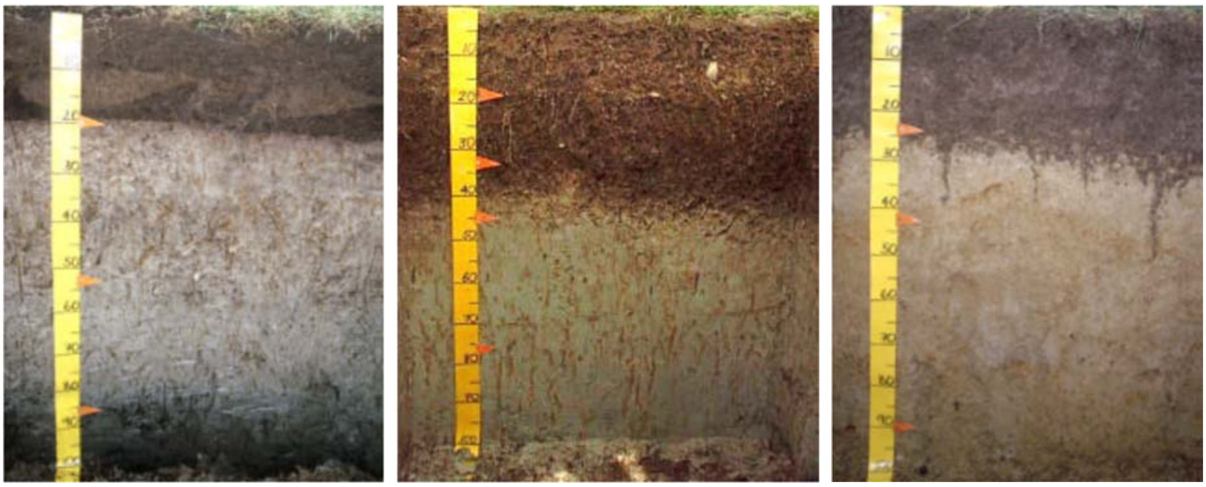

Figure 4.3: Titipua, Dacre, and Tisbury typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is moderately high in soils, moderate in the underlying aquifer.

4.3.3 Podzol Soils over Marine Terraces

This is the smallest sibling of the Marine Terrace family comprising 12.9% (105.1 ha) of the unit. The unit is located predominantly in the area of direct contribution to Waituna Lagoon and Carran Creek with minor occurrences in Moffit Creek catchment (Figure 4.1). The unit is developed which has significantly altered the natural hydrology through artificial drainage.

Soil

The soil in this unit is classified as Podzol. Podzol soils are strongly acid soils that typically have a bleached horizon immediately beneath the topsoil. A key characteristic of these soil is an organic-rich A/O horizon as organic carbon is a critical feature of these soils. The soil series present in this unit are Tiwai (Pan Humic Podzol) and Kapuka (Pan Fill Podzol), with minor Tisbury (Orthic Acidic Gley) soils (Figure 4.4). See Gley soils over Marine Terrace for soil properties of the Tisbury soil.

These Podzol soils have a moderately developed structure and loamy silt/silt loam textures with gravels typically found below 40 cm depth. The soils are imperfectly drained, with slowly permeable subsoils that may cause short-term waterlogging after heavy rain. Subsurface mottling occurs in the clay-bound underlying gravels reflecting the slow permeability of these soils and moderate reduction potential. The upper subsoils are characterised by the accumulation of complexes of iron and organic matter, indicative of podzolised soils. Crops for Southland (2002) reports the P-retention in Podzol soils as high, minimising the risk of P-leaching. However, P loss from soils undertaken by AgResearch for Waituna noted Podzols within the Waituna Lagoon Catchment as having an elevated

P leaching risk relative to other mineral soils (McDowell and Monaghan, 2015). This occurs because the aluminium (Al) and iron (Fe) sesquioxides that sorb P are most unstable under reducing conditions and low pH.

Artificial drainage density is moderate to prevent waterlogging in wetter months (Pearson, 2015a). Bypass flow, via the artificial drainage network can reduce soil residence time reducing the potential for denitrification to occur. In soils with pans which restrict deep drainage, lateral flow can occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

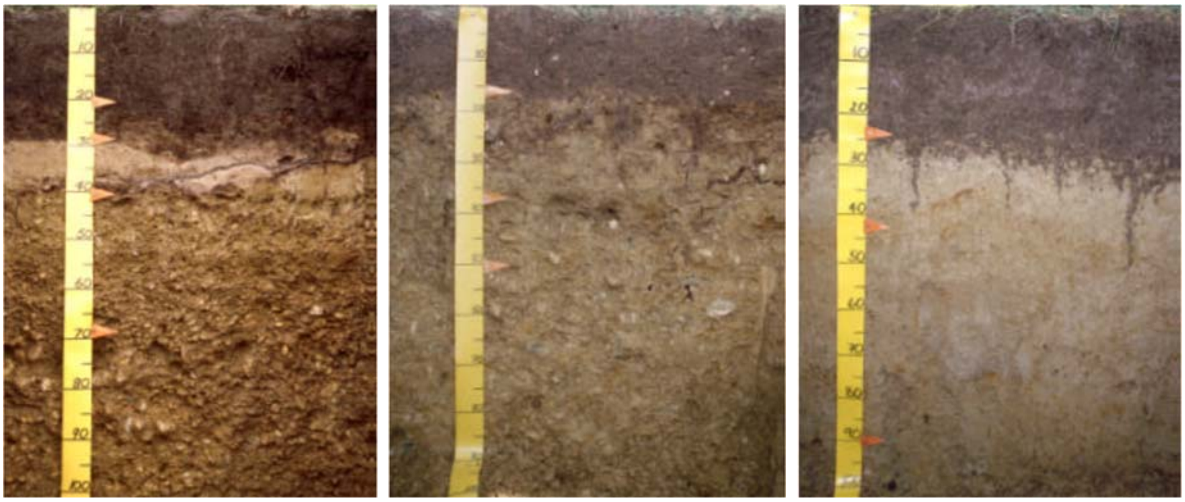

Figure 4.4: Tiwai, Kapuka and Tisbury typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Reduction Potential

The reduction potential is moderate in soils and moderate in the underlying aquifer.

4.4 Marine Terraces Family Water Quality Implications

Organic, Gley, and Podzol soils with their high organic carbon content and poor to imperfect drainage have a high to moderate reduction potential. The reduction potential of the soil decreases as the drainage and carbon content decreases. Groundwater is therefore strongly reducing under peat and becomes more oxidising and the ability to denitrify is reduced. Water reaching the aquifer through deep drainage has a low inherent risk for nitrate (NO_3^-), due to the moderate reduction potential of the Marine Terraces. However, the permeability of the underlying geology is slower than the overlying soils, favouring lateral flow along the contact of the terrace. Surface waters often have a mixed redox state indicative of the soil zone reduction potential due to periodic rapid discharge via artificial drainage networks which reduce the time available for reduction to occur (Figure 4.5). Ferrous iron (Fe^{2+}) and ammoniacal nitrogen (NH_4^+) concentrations can also be naturally elevated (derived through ammonification of organic matter under reducing conditions).

Overland flow and surface ponding occur when the water table becomes elevated above the ground level. The topography of the area will determine if precipitation will result in runoff transporting sediment (including sediment-bound phosphorus) and microbes (Figure 4.5). The Marine Terrace unit has the potential for localised overland flow due to the seasonally high water table. However, in developed areas this potential may not be realised due to the high density of artificial drainage.

The inherent water quality risk from the Marine Terrace unit is summarised in Table 4.1.

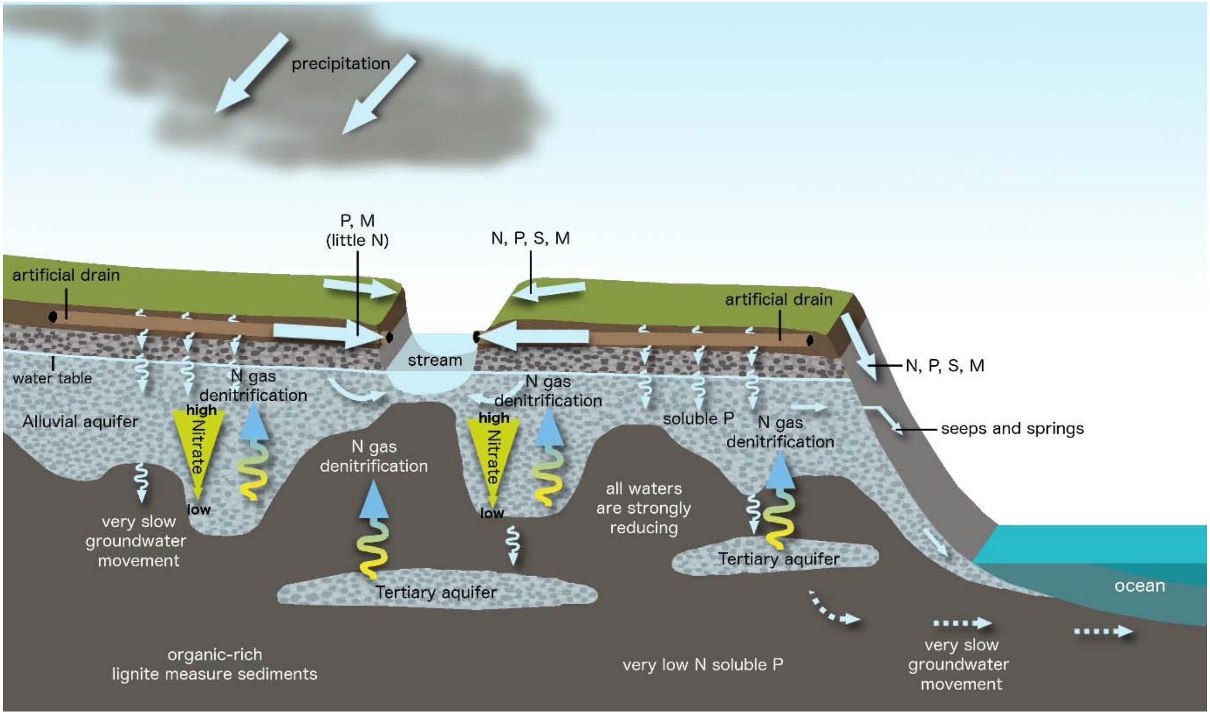

Figure 4.5: Contaminant pathways from the Marine Terrace Unit.
Source: Physiographics of Southland Lignite/Marine Terrace Technical Information Factsheet.

Table 4.1: Water quality risk from the Marine Terrace Family by sibling and flow pathway – deep drainage (DD), overland flow (OLF), subsurface artificial drainage (SAD). The risk is classified as very low (VL), low (L), moderately low (ML), moderate (M), moderately high (MH), high (H).

	Nitrogen			**Phosphorus**			**Sediment and Microbes**	
	DD	OLF	SAD	DD	OLF	SAD	OLF	SAD
Peat soils over marine terraces	ML	H	H	MH	H	H	M - H	M - H
Gley soils over marine terraces	ML	M	M	MH	M	M	L	L
Podzol soils over marine terraces	M	H	L	M	H	L	M-MH	M-MH

5 Reducing Family

5.1 Family Overview

The Reducing Family is the largest in the Waituna Catchment comprising an area of 9,903 ha (51.4%). It is characterised by poorly to imperfectly drained mineral soils with varying geological substrates from high to low reduction potential. In the Waituna catchment, the Reducing Unit is found across the whole catchment, with subunits becoming more reducing towards the south and Waituna Lagoon (Figure 5.1). Within this FLU family, there are 5 siblings with varying hydrological properties and varying reduction potential from high to moderately low. However, all units exhibit some evidence of reducing conditions in either the soil zone or underlying aquifer.

Key features

- Mineral soils are fine-textured and imperfectly to poorly drained.
- Soils exhibit redoximorphic features (e.g. mottling and gleying).
- Extensive use of artificial drains (mole-pipe) due to soils being prone to waterlogging.
- Deep drainage to groundwater occurs at a low rate through slowly permeable subsoils.

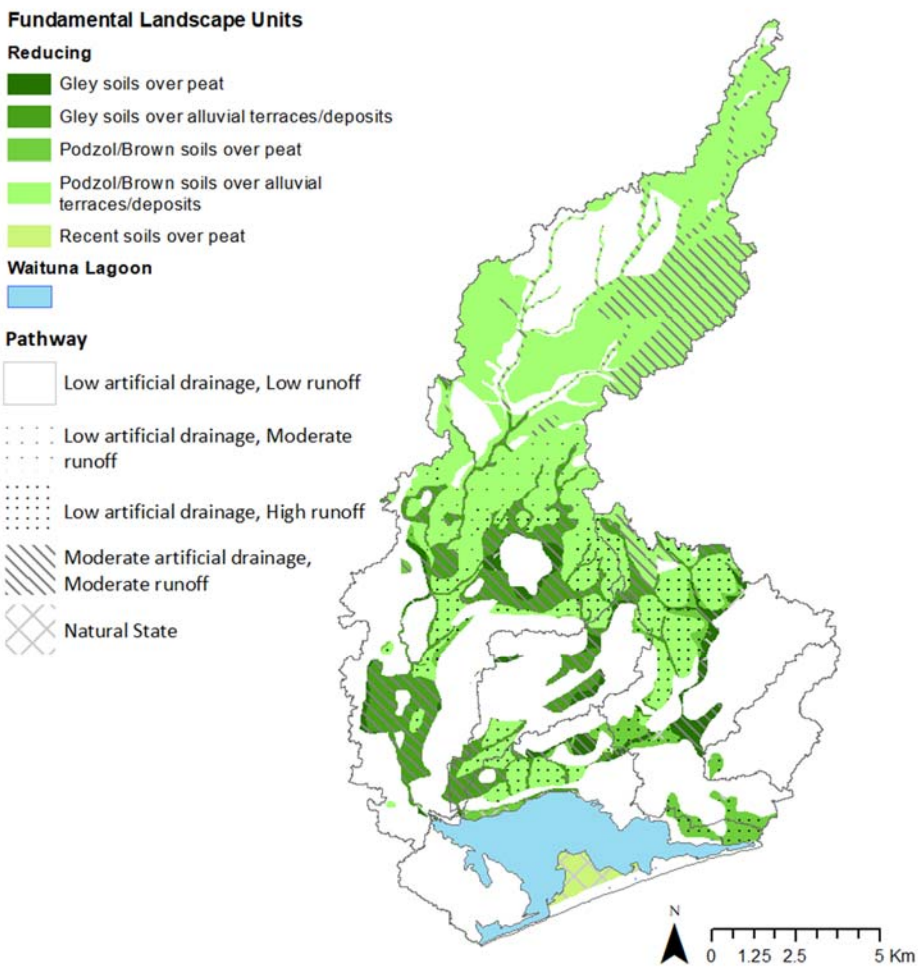

Figure 5.1: Extent of Reducing Unit in Waituna Catchment.

5.2 Landscape Characteristics

5.2.1 Hydrology

The hydrology of the catchment is exclusively land surface recharge from local precipitation. There is limited potential for dilution of contaminant concentrations associated with this recharge mechanism.

5.3 Subunit Variation

The siblings within the Reducing Family arise from the variation in soil, aquifer geology and resultant reduction potential, and hydrological pathways:

- Gley soils over peat
  - Natural state hydrology
  - Moderate artificial drainage and moderate runoff
- Gley soils over alluvial terraces/deposits
  - Natural state hydrology
  - Moderate artificial drainage and moderate runoff
- Podzol/Brown soils over peat
  - Natural state hydrology
  - Low artificial drainage and moderate runoff
  - Low artificial drainage and high runoff
  - Moderate artificial drainage and moderate runoff
- Podzol/Brown soils over alluvial terraces/deposits
  - Natural state hydrology
  - Low artificial drainage and low runoff
  - Low artificial drainage and moderate runoff
  - Low artificial drainage and high runoff
  - Moderate artificial drainage and moderate runoff
- Recent soils over peat
  - Natural state hydrology

5.3.1 Gley Soils over Peat

This subunit comprises 5.1% (507.5 ha) of the Reducing family. The unit is located in the south of the Waituna catchment and is closely associated with the Wetland Complex family (Figure 5.1 and 1.1). The unit is predominantly developed (89.2%) which has significantly altered the natural hydrology through artificial drainage. This results in two siblings:

- Gley soils over peat with natural state hydrology (54.7 ha)
- Gley soils over peat with moderate artificial drainage and moderate runoff (452.8 ha)

Soil

Soils in this unit are classified as Gley. Gley soils, along with Organic, represent the original extent of wetlands prior to agricultural development. The soils are strongly affected by waterlogging, resulting in anoxic and reducing conditions producing soils with light grey subsoils, usually with reddish-brown mottles. The organic matter content in the topsoil is elevated reflecting their association with historical wetlands. The soil series present in this unit are Titipua (Orthic Peaty Gley), Dacre (Recent, Acidic, Gley), Tisbury (Orthic Acidic Gley), and Jacobs (Recent Sandy Gley) silt loams (Figure 5.2). Minor areas of Invercargill soil series (Mesic Acidic Organic) may also be found in this zone. See Wetland Complex Peat soils and geology for more information on the soil properties.

These soils all have horizons with slow permeabilities (< 4mm/hr) and are poorly drained. Poor aeration occurs when the soils are wet, which may be for most of the year in the absence of artificial drainage. This results in subsoils that are acidic (pH < 5.5) and have a moderately high reducing potential. The redoximorphic features of mottling and gleying are indicative of reducing conditions. P-retention in these soils is moderate, minimising the risk of P-leaching.

Artificial drainage is used extensively in these soils to prevent waterlogging, which occurs due to the combination of low lying topography and poor soil drainage (Crops for Southland, 2002; Pearson 2015a). Bypass flow via artificial drainage can reduce soil residence time reducing the potential for denitrification to occur. In soil types that have restricted drainage, lateral flow may occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

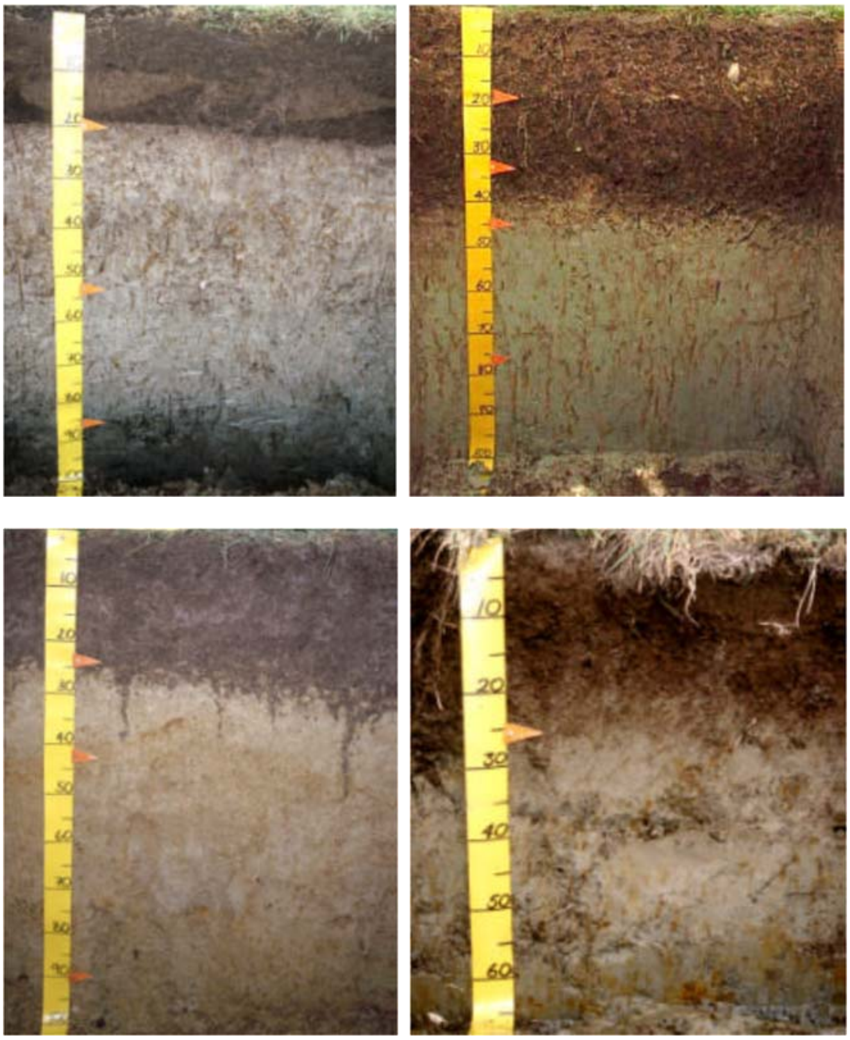

Figure 5.2: Titipua (top left), Dacre (top right), Tisbury (bottom left) and Jacobs (bottom right) typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this zone is identified as peat in swamps and peat mounds with incursions of sand and silt (QMAP; Turnbull and Allibone, 2003). The main geological material is peat with secondary sand and silt. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Aquifers in peat have a low phosphorus sorption capacity due to the organic composition of aquifer materials. Reducing conditions enhance phosphorus mobility in groundwater through the formation of microscopic organic-P complexes.

Reduction Potential

The reduction potential is moderately high in soils, high in the underlying aquifer, and high overall.

5.3.2 Gley Soils over Alluvial Terraces/Deposits

This subunit covers 18.3% (1,808.8 ha) of the Reducing family. The unit is located predominantly in the south of the Waituna catchment in Waituna Creek, Moffat Creek and the area of direct contribution to Waituna Lagoon (Figure 5.1). The unit is predominantly developed (99.1%) which has significantly altered the natural hydrology through artificial drainage. This results in two siblings:

- Gley soils over alluvial terraces/deposits with natural state hydrology (15.8 ha)
- Gley soils over alluvial terraces/deposits with moderate artificial drainage and moderate runoff risk (1792.9 ha)

Soil

The soil series present in this unit are Titipua (Orthic Peaty Gley), Dacre (Recent, Acidic, Gley), Tisbury (Orthic Acidic Gley), and Jacobs (Recent Sandy Gley) silt loams (Figure 5.2). See Section 5.3.1 Gley soils over peat unit above for more information.

Geology

The underlying geology in this zone is identified as either alluvial terraces or unconsolidated gravel (QMAP; Turnbull and Allibone, 2003). There are two terraces within the Waituna catchment. The geology of the older Kamahi Formation, located to the north of the catchment, is described as weathered sandy greywacke (quartz) in high terraces (stratigraphic age Q8-Q10). The main geological material is alluvial gravel with sand, clay and silt.

The Waikiwi Terrace, located south the Kahami Formation, is reworked material from the above unit (stratigraphic age Q6-Q8). The geology is described as moderately weathered clay-rich sandy gravel in high terraces. The main geological material is alluvial gravel with silt, sand, and clay.

South of the terraces, the underlying geology is identified as unconsolidated gravel, sand and peat in modern stream beds with minor overbank swamps. The main geological material is alluvial gravel with sand, silt, and minor peat. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Reduction Potential

The overall reduction potential is moderately high in soils and low (terraces) to moderately low (unconsolidated gravels) in the underlying aquifer. Overall the reduction potential of the unit is moderate.

5.3.3 Podzol/Brown Soils over Peat

This subunit covers 6% (601.7 ha) of the Reducing family. The unit is located in the south of the Waituna catchment and is closely associated with Reducing - Gley soils over peat, and the Wetland Complex family (Figure 5.1 and 1.1). A key feature of this unit is imperfectly drained soils and varied hydrological pathways. At times of the year when soils are not waterlogged, the hydrology and reduction potential of the soil zone is similar the Oxidising family. The unit is predominantly developed (91%) with low to moderate density of artificial drainage. This results in four siblings:

- Podzol/Brown soils over peat with natural state hydrology (53.4 ha)
- Podzol/Brown soils over peat with low artificial drainage and moderate runoff (10.6 ha)
- Podzol/Brown soils over peat with low artificial drainage and high runoff (509.4 ha)
- Podzol/Brown soils over peat with moderate artificial drainage and moderate runoff (28.3 ha)

Soil

Soils in this unit are classified as Podzol and Brown soils. Podzol soils are strongly acid soils that typically have a bleached horizon immediately beneath the topsoil. The soil series present in this unit are Tiwai (Pan Humic Podzol) and Kapuka (Pan Fill Podzol), with minor Tisbury (Orthic Acidic Gley) soils associated with the Tiwai soil series (Figure 5.3). See Gley soils over peat for soil properties of the Tisbury soil. Brown soils are aptly named due to their dark grey-brown topsoils and brown or yellow-brown subsoils formed by thin coatings of iron oxides weathered from the parent material. The soil series present in this unit are Mokatua (Orthic Mafic Brown) and Woodlands (Firm Mottled Brown) soils (Figure 5.4).

These soils all have loamy silt/silt loam textures, slowly permeable horizons (< 4mm/hr) and are imperfectly drained. Subsurface mottling occurs in the clay-bound underlying gravels reflecting the slow permeability of these soils and moderate reduction potential. Phosphorus retention in these soils is moderate to high, minimising the risk of P leaching. However, in areas with significant organic matter accumulation, P becomes more mobile and at risk of leaching. This occurs because the aluminium (Al) and iron (Fe) sesquioxides that sorb P are most unstable under reducing conditions and low pH.

Artificial drainage density is low to moderate in this unit to prevent short-term waterlogging in wetter months. Bypass flow, via the artificial drainage network can reduce soil residence time reducing the potential for denitrification to occur. In soils with pans which restrict deep drainage, lateral flow can occur along slowly permeable layers within the soil profile. However, the spatial extent of lateral flow is limited by the artificial drainage network.

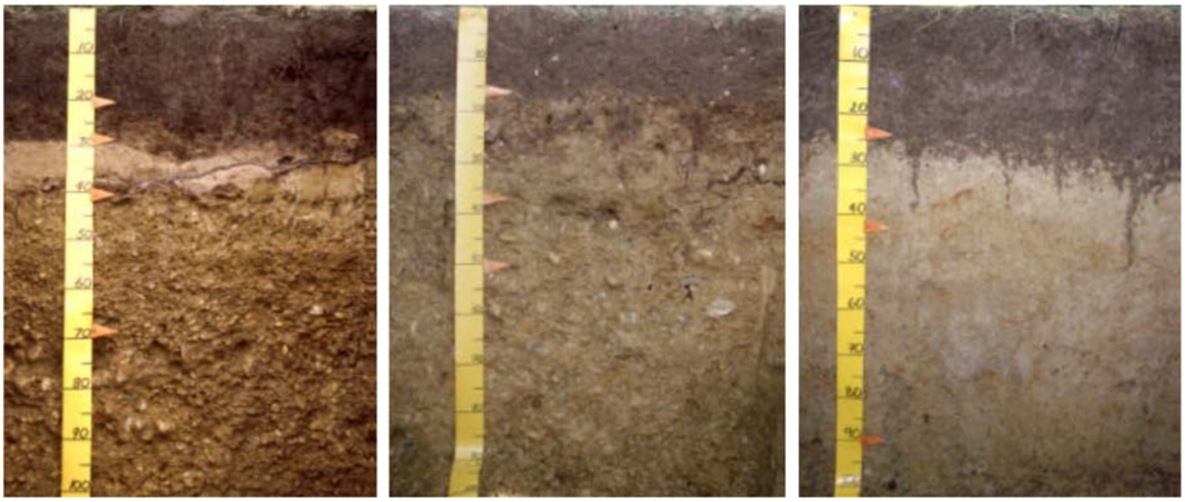

Figure 5.3: Tiwai, Kapuka and Tisbury typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Figure 5.4: Mokatua and Woodlands typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this zone is identified as peat in swamps and peat mounds with incursions of sand and silt (QMAP; Turnbull and Allibone, 2003). The main geological material is peat with secondary sand and silt. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Aquifers in this subunit have a high reduction potential. Groundwater is therefore strongly reducing resulting in elevated ferrous iron (Fe^{2+}) and ammoniacal nitrogen concentrations (naturally derived through ammonification of organic matter under reducing conditions).

Aquifers in peat have a low phosphorus sorption capacity due to the organic composition of aquifer materials. Reducing conditions enhance phosphorus mobility in groundwater through the formation of microscopic organic-P complexes.

Reduction Potential

The overall reduction potential is moderate in soils and high in the underlying aquifer.

5.3.4 Podzol/Brown Soils over Alluvial Terraces/Deposits

This subunit is the largest covering 68.8% (6,823 ha) of the Reducing family. Brown soils are predominantly found in the north of the Waituna catchment associated with the Kamahi Formation, while Podzol soils are found further south overlying the Waikiwi Terrace Formation (Figure 5.1). A key feature of this unit is imperfectly drained soils. At times of the year when soils are not waterlogged, the hydrology and reduction potential is similar to soils in the Oxidising family. The unit is predominantly developed (99.9%) which has significantly altered the natural hydrology through artificial drainage. This results in five siblings:

- Podzol/Brown soils over alluvial terraces/deposits with natural state hydrology (4.3 ha)
- Podzol/Brown soils over alluvial terraces/deposits with low artificial drainage and low runoff (2,429.2 ha)
- Podzol/Brown soils over alluvial terraces/deposits with low artificial drainage and moderate runoff (1,052.7 ha)
- Podzol/Brown soils over alluvial terraces/deposits with low artificial drainage and high runoff (1730.4 ha)
- Podzol/Brown soils over alluvial terraces/deposits with moderate artificial drainage and moderate runoff (1606.3 ha)

Soil

The Podzol soil series present in this unit are Tiwai (Pan Humic Podzol), Kapuka (Pan Fill Podzol), and Ashers (Pan Fill Podzol) (Figure 5.5), with minor Tisbury (Orthic Acidic Gley) soils associated with the Tiwai soil series. See Gley soils over alluvial terraces/deposits for soil properties of the Tisbury soil. The Brown soil series present in this unit are Mokatua (Orthic Mafic Brown) and Woodlands (Firm Mottled Brown) soils (Figure 5.4). See Section 5.3.3 Podzol/Brown soils over peat above for more information.

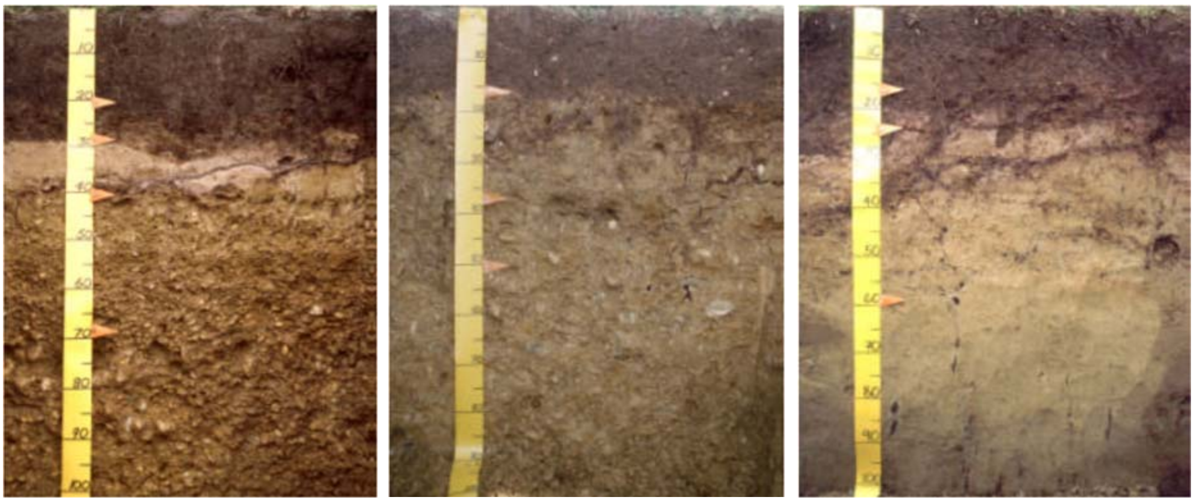

Figure 5.5: Tiwai, Kapuka, and Ashers typical soil profiles.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this zone is identified as either alluvial terraces or unconsolidated gravel (QMAP; Turnbull and Allibone, 2003). There are two terraces within the Waituna catchment. The geology of the older Kamahi Formation, located to the north of the catchment, is described as weathered sandy greywacke (quartz) in high terraces (stratigraphic age Q8-Q10). The main geological material is alluvial gravel with sand, clay and silt.

The Waikiwi Terrace, located south the Kahami Formation, is reworked material from the above unit (stratigraphic age Q6-Q8). The geology is described as moderately weathered clay-rich sandy gravel in high terraces. The main geological material is alluvial gravel with silt, sand, and clay.

South of the terraces, the underlying geology is identified as unconsolidated gravel, sand and peat in modern stream beds with minor overbank swamps. The main geological material is alluvial gravel with sand, silt, and minor peat. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Reduction Potential

The reduction potential is moderate in soils, and low (terraces) to moderately low (unconsolidated gravels) in the underlying aquifer. Overall the reduction potential of the unit is moderately low.

5.3.5 Recent Soils over Peat

This subunit is the smallest at 1.6 % (162.9 ha) of the Reducing Unit. It is located on oxidised Recent soils, between Waituna Lagoon and the southern coast overlying peat (Figure 5.1). All this unit is undeveloped conservation estate and has natural state hydrology.

Soil

Soils in this unit are classified as Recent. Recent soils are weakly developed, showing limited signs of soil-forming processes. The soil series present in this unit is a Riverton (Typic Sandy Recent) loamy sand (Figure 5.6). Riverton soils are formed into coastal dunes of wind-blown sand. These soils have sandy textures throughout resulting in well-drained soils with rapid permeability (> 72mm/hr). As a result, soils are well aerated and have a low reduction potential. Due to the limited amount of weathering, phosphorus retention in these soils is very low (<5%), increasing the risk of P leaching.

Figure 5.6: Riverton typical soil profile.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this unit is identified as peat in swamps and peat mounds with incursions of sand and silt (QMAP; Turnbull and Allibone, 2003). The main geological material is peat with secondary sand and silt. The zone occurs in areas that are recent in origin (stratigraphic age is Q1).

Reduction Potential

The overall reduction potential is low in soils and high in the underlying aquifer. Overall the reduction potential is moderate.

5.4 Water Quality Implications

The Reducing Family has the largest variation in water quality outcomes due to the variation in soil and geological properties. Organic, Gley, Podzol and Brown soils with moderate to high organic carbon content and poor to imperfect drainage result in a high to moderate reduction potential. Soils in this unit characteristically exhibit redoximorphic features, such as mottling and gleying, which indicate reducing conditions. The reduction potential of the soil decreases as the drainage and carbon content decreases. Therefore, the amount of denitrification that occurs is dependent on the residence time of water within the soil zone. If water bypasses the soil zone through the artificial drainage network or by overland flow, the reduction potential is greatly reduced. The areas with Podzol and Brown soils have the lowest reduction potential of this family and water quality implications from this unit will be similar to the Oxidising Family during the drier months of the year.

The groundwater varies from strongly reducing under peat and becomes more oxidising in alluvial gravels to most oxidising under alluvial terraces. Water reaching the aquifer through deep drainage has a lower inherent risk for nitrate (NO_3^-), due to the reduction potential of the soil, with the exception of the Recent Soils over Peat, where the reduction potential is higher in the underlying aquifer.

The occurrence of overland flow and artificial drainage increases as the soils become more poorly drained. The topography of the area will determine if precipitation will result in runoff transporting sediment (including sediment-bound phosphorus) and microbes (Figure 5.7). Artificial drains rapidly export excess soil water and contaminants to surface waterways, when soils are wet or in response to heavy or sustained precipitation. The Reducing unit has a moderate to high potential for localised overland flow due to the poor soil drainage and seasonally high water table. Drainage events tend to be episodic, occurring rapidly in response to precipitation events when soils are wet. As soils dry, the magnitude of rainfall required to initiate rapid drainage increases, especially in the imperfectly drained Brown and Podzol soils. The occurrence of overland flow is greatly reduced in developed areas where there is a moderate to high density of artificial drainage.

The inherent water quality risk from the Reducing Family is summarised in Table 5.1.

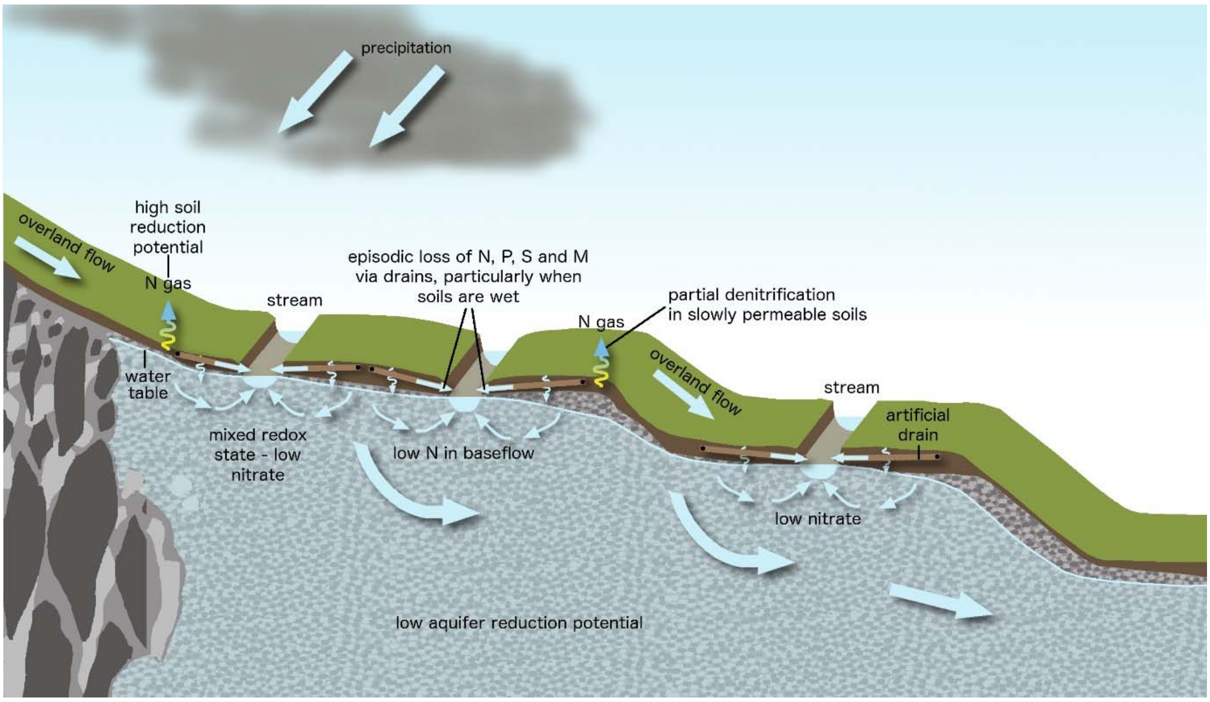

Figure 5.7: Contaminant pathways from the Reducing Unit.
Source: Physiographics of Southland, Gleyed Technical Information Factsheet.

Table 5. 1: Water quality risk from the Reducing Family by sibling and flow pathway – deep drainage (DD), overland flow (OLF), subsurface artificial drainage (SAD). The risk is classified as very low (VL), low (L), moderately low (ML), moderate (M), moderately high (MH), high (H). Source limited (SL) identifies natural state areas with minimal contaminants to transport.

	Nitrogen			Phosphorus			Sediment and Microbes	
	DD	OLF	SAD	DD	OLF	SAD	OLF	SAD
Gley soils over peat								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Moderate artificial drainage and moderate runoff	L	M	M	H	M	M	L-ML	M
Gley soils over alluvial terraces/deposits								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Moderate artificial drainage and moderate runoff	M	M	M	M	M	M	L-ML	M
Podzol/Brown soils over peat								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Low artificial drainage and moderate runoff	M	M	L	M	M	L	ML	L
Low artificial drainage and high runoff	M	H	L	M	H	L	M-MH	L
Moderate artificial drainage and moderate runoff	M	M	M	M	M	M	L	M

Podzol/Brown soils over alluvial terraces/deposits								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Low artificial drainage and low runoff	MH	L	L	ML	L	L	VL	L
Low artificial drainage and moderate runoff	M-MH	M	L	ML-M	M	L	L-ML	L
Low artificial drainage and high runoff	M-MH	H	L	ML-M	H	L	M-MH	L
Moderate artificial drainage and moderate runoff	MH	M	M	ML	M	M	L	M
Recent soils over peat								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-

6 Oxidising Family

6.1 Family Overview

The Oxidising Family is characterised by well-drained soils with varying geological substrates with low reduction potential. In the Waituna catchment, the Oxidising Unit is found predominantly in the north of the catchment, and along the coastal area of Waituna Lagoon where Recent soils have formed (Figure 6.1). The Oxidising Unit covers an area of 1,878 ha (9.7%) in the Waituna catchment. Within this FLU family, there are 5 siblings with varying reduction potential from moderately low to low and varying hydrological pathways.

Key features

- Located on unconsolidated alluvial gravels, older alluvial terraces, and recent beach sands close to Waituna Lagoon.
- Predominately well drained, fine to coarse-textured soils.
- Recharge occurs from local precipitation infiltrating through the soil matrix.
- Deep drainage to groundwater is the main contaminant pathway.
- Soils and aquifers have a moderately low to low denitrification potential.

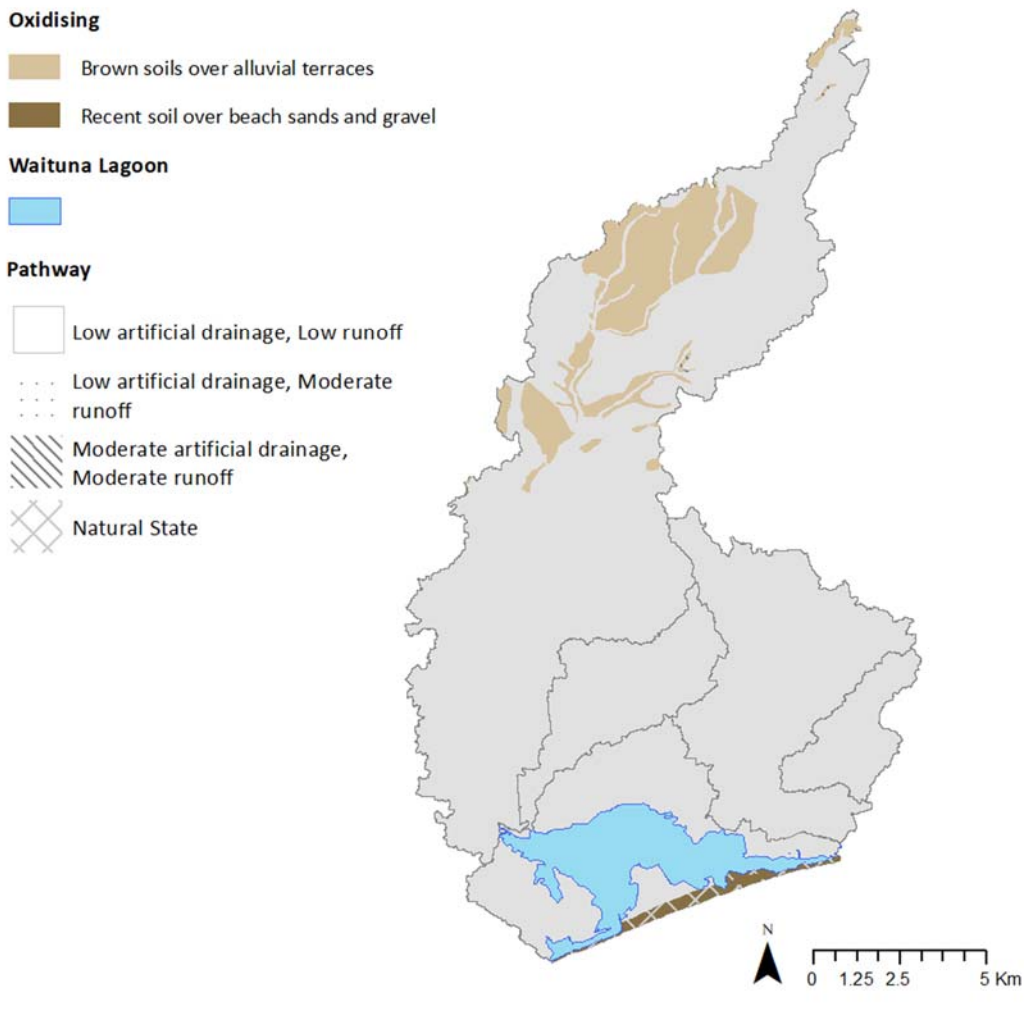

Figure 6.1: Extent of Reducing Unit in Waituna Catchment.

6.2 Landscape characteristics

6.2.1 Hydrology

The hydrology of the catchment is exclusively land surface recharge from local precipitation. There is limited potential for dilution of contaminant concentrations associated with this recharge mechanism.

Deep drainage to groundwater is the main drainage mechanism in this zone due to the predominantly flat-lying topography and well-drained soils. Deep drainage is typically seasonal. Where subsurface artificial drainage occurs, lateral soil zone transport is important. Most recharge occurs when soil moisture is at or near field capacity, generally between late autumn and spring. However, drainage to the water table or stream via mole-pipe drainage can occur at any time of the year in response to heavy or sustained precipitation.

Waituna Stream originates on higher elevation alluvial terraces from this unit. Surface waterways receive discharge via the artificial drainage network.

Aquifers within this zone have moderately low to low reduction potential due to their oxic redox state and low organic carbon content. As a result, there is low potential for denitrification to occur within the shallow alluvial aquifer system.

6.3 Sibling variation

The siblings within the Oxidising Family arises from the variation in soil, aquifer geology and reduction potential.

- Brown soils over alluvial terraces
  - Natural state hydrology
  - Low artificial drainage and low runoff
  - Moderate artificial drainage and moderate runoff
- Recent soil over beach sand and gravels
  - Natural state hydrology
  - Low artificial drainage and moderate runoff

6.3.1 Brown Soils over Alluvial Terraces

This subunit comprises 89.9% (1,687.7 ha) of the total Oxidising Family within the Waituna catchment. The unit can be found near Waituna Stream in the north of the catchment (Figure 6.1). The unit is predominantly developed (99.8%) which has altered the natural hydrology through artificial drainage. There are three siblings in this unit:

- Brown soils over alluvial terraces with natural state hydrology (2.1 ha)
- Brown soils over alluvial terraces with low artificial drainage and low runoff (1670.1 ha)
- Brown soils over alluvial terraces with moderate artificial drainage and moderate runoff (15.5 ha)

Soil

Soils in this unit are classified as Brown. Brown soils are aptly named due to their dark grey-brown topsoils and brown or yellow-brown subsoils formed by thin coatings of iron oxides weathered from the parent material. The soil series present in this unit are Waituna (Fluvial Typic Brown), Waikiwi (Orthic Typic Brown), and Woodlands (Firm Mottled Brown) (Figure 6.2).

These soils all have silt loam textures, slowly permeable horizons at depth (< 4mm/hr) and are well (Waituna, Waikiwi) to imperfectly drained (Woodlands). Due to their good internal drainage and relatively low organic carbon content, soils in this zone have moderately low to low reduction potential. The oxidising nature of these soils is primarily a feature of good drainage but also partly reflects the high proportion of loess parent materials, derived from siliceous/felsic rocks. Phosphorus retention in these soils is moderate to high minimising the risk of P leaching.

As soils in this zone are typically well-drained, artificial drainage densities are low to moderate depending on the extent of imperfectly drained Woodlands soil. Drainage is typically installed to improve the slow permeability of the soils.

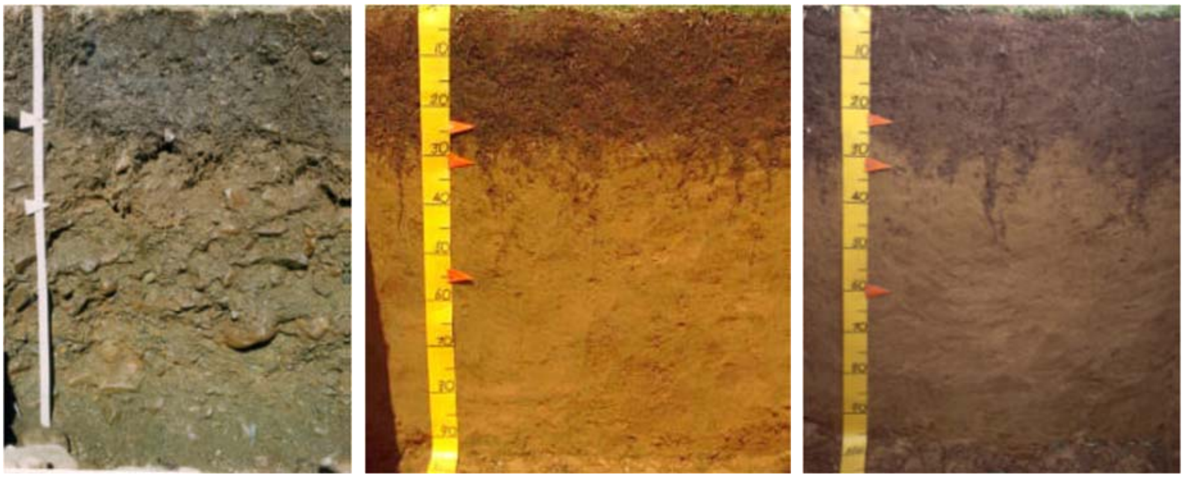

Figure 6.2: Typical Waituna, Waikiwi and Woodlands soil profiles.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this unit is identified as alluvial terraces associated with the Kamahi Formation (QMAP; Turnbull and Allibone, 2003). The geology of the Kamahi Formation, located to the north of the Waituna catchment, is described as weathered sandy greywacke (quartz) in high terraces (stratigraphic age Q8-Q10). The main geological material is alluvial gravel with sand, clay and silt.

Reduction Potential

The reduction potential is moderately low in soils, low in the underlying geology, and low overall.

6.3.2 Recent Soils over Beach Sands and Gravel

This subunit covers 10.1 % (190.4 ha) of the Oxidising Unit and is located on Recent soils between Waituna Lagoon and the Southern Coast (Figure 6.1). 90% of the unit is conservation area with natural state hydrology. There are two siblings in this unit:

- Brown soils over beach sands and gravel with natural state hydrology (171.5 ha)
- Brown soils over beach sands and gravel with low artificial drainage and moderate runoff (18.8 ha)

Soil

Soils in this unit are classified as Recent. Recent soils are weakly developed, showing limited signs of soil-forming processes. The soil series present in this unit is a Riverton (Typic Sandy Recent) loamy sand (Figure 6.3). Riverton soils are formed into coastal dunes of wind-blown sand. These soils have sandy textures throughout resulting in well-drained soils with rapid permeability (> 72mm/hr). As a result, soils are well aerated and have a low reduction potential. Due to the limited amount of weathering, phosphorus retention in these soils is very low (<5%), increasing the risk of P leaching under agricultural activities.

Figure 6.3: Riverton typical soil profile.
Source: Topoclimate South Soil Survey (2002).

Geology

The underlying geology in this unit is identified as Q1 sand and gravel in modern beaches, back-beach ridges and tidal platforms (QMAP; Turnbull and Allibone, 2003). The major geological material is sand with minor gravel.

Reduction Potential

The overall reduction potential is low in soils and low in the underlying aquifer.

6.4 Water Quality Implications

The largest factor controlling water quality from the Oxidising Family is the low reduction potential of soils and underlying aquifers. Deep drainage is the main contaminant pathway for this unit (Figure 6.4), which means artificial drainage densities and overland flow events are low. Nitrate concentrations can become elevated in groundwater due to the moderately low to low denitrification rates in the soil zone and underlying aquifers and the intensity of land use in this area. This area is likely supplying groundwater containing elevated nitrate concentrations to surface water streams.

Inversely, the better drained and fine textured mineral soils of the Oxidising Family equate to a low P risk due to good P-retention and low overland flow risk.

The inherent water quality risk from the Oxidising Family is summarised in Table 6.1.

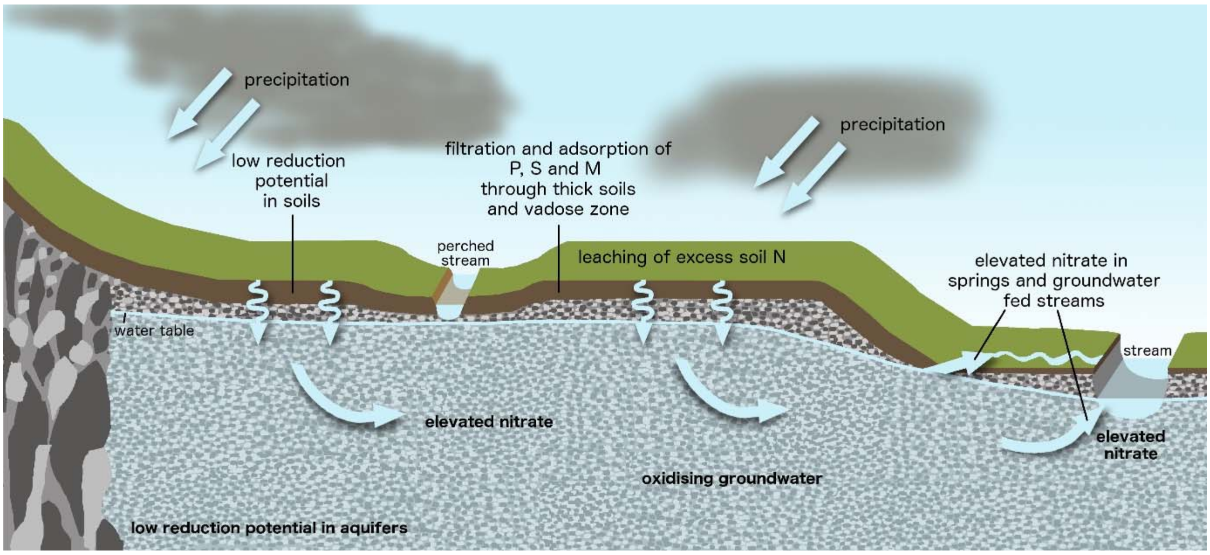

Figure 6.4: Contaminant pathways from the Oxidising Unit.
Source: Physiographics of Southland, Oxidising Technical Information Factsheet.

Table 6.1: Water quality risk from the Oxidising Family by sibling and flow pathway – deep drainage (DD), overland flow (OLF), subsurface artificial drainage (SAD). The risk is classified as very low (VL), low (L), moderately low (ML), moderate (M), moderately high (MH), high (H). Source limited (SL) identifies natural state areas with minimal contaminants to transport.

	Nitrogen			Phosphorus			Sediment and Microbes	
	DD	OLF	SAD	DD	OLF	SAD	OLF	SAD
Brown soils over alluvial terraces								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Low artificial drainage and low runoff	H	L	L	L	L	L	VL	L
Moderate artificial drainage and moderate runoff	H	M	M	L	M	M	ML	M
Recent soil over beach sands and gravel								
Natural state hydrology	VL-SL	VL-SL	-	VL-SL	VL-SL	-	VL-SL	-
Low artificial drainage and moderate runoff	H	M	L	L	M	L	L	L

7 Waituna Creek Stocktake

7.1 Fundamental Landscape Unit Stocktake

The Waituna Creek subcatchment comprises 58% (11,152 ha) of the Waituna Lagoon Catchment (Figure 4.1). All five of the FLU families are located within the Waituna Creek subcatchment (Table 4.1). The Reducing family covers the largest extent, at 64% of the upper to mid-catchment. In the south, the Wetland Complex family is more prominent. Unique to the Waituna Creek Catchment is the presence of the Oxidising unit Brown soils over alluvial terraces, and the Lignite Family, comprising 15.1% and 0.4% of the subcatchment area respectively. Lignite may be present elsewhere in the Waituna catchment at depth but is unlikely to be controlling the composition of shallow unconfined groundwater.

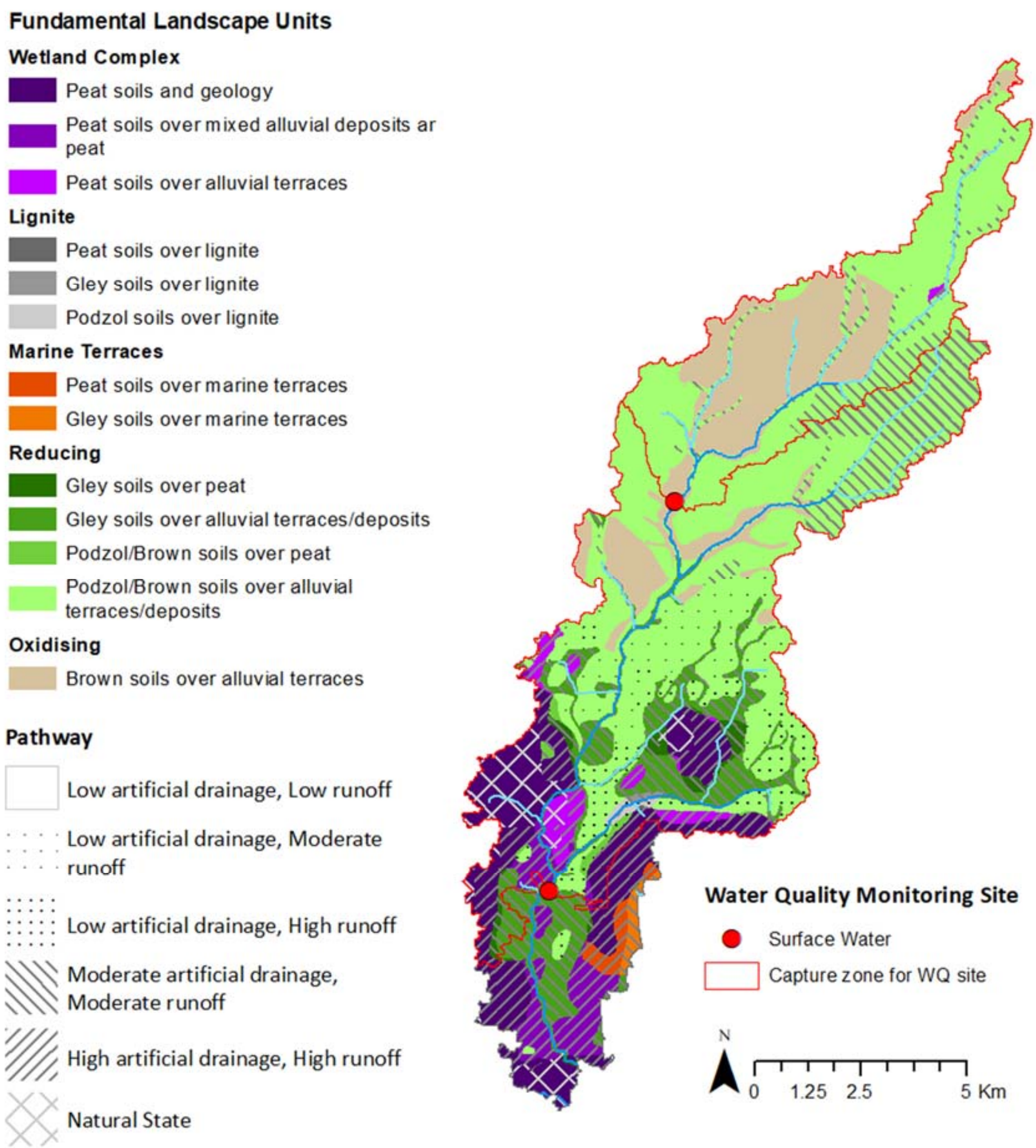

Figure 7.1: Fundamental Landscape Units of Waituna Creek Catchment. Water quality monitoring sites and capture areas are shown in red.

There are two long-term water quality sites monitored by Environment Southland on Waituna Creek, which were used to develop the physiographic model in Rissmann et al., 2018. These sites are used to provide a subcatchment stocktake, in addition to the catchment as a whole, and can be used to provide context to water quality analysis. The monitoring site 'Waituna Creek at 1 m upstream from Waituna Road' is located in the north of the catchment and covers an area of 3,138.7 ha (28%) of the subcatchment. 'Waituna Creek at Marshall Road is the lowest monitoring point on Waituna Creek, located further south. The Marshall Road monitoring site covers an area of 9,773.6 ha (87.6%) and includes the area monitored by the Waituna Road site. The capture zones of each water quality monitoring site are shown in red in Figure 4.1.

Table 7.1: Area of Fundamental Landscape Units for Waituna Creek by northern (1m upstream Waituna Road) and southern (Marshall Road) water quality monitoring sites, unmonitored area and total Waituna Creek catchment. The percentage for the siblings is the percentage of the subunit within the family for the monitoring sites. The percentage for Waituna Creek is calculated by the entire subcatchment area.

	Waituna Creek 1m upstream Waituna Road		**Waituna Creek at Marshall Road**		**Unmonitored Area**		**Waituna Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Wetland Complex								
Peat soils and geology			997.8	45.9	501.5	23.1	1499.3	13.4
High artificial drainage, high runoff			*587.6*	*27.0*	*379.9*	*17.5*	*967.5*	*8.7*
Natural state hydrology			*410.2*	*18.9*	*121.7*	*5.6*	*531.8*	*4.8*
Peat soils over alluvial terraces	8.4	0.4	245.1	11.3			245.1	2.2
High artificial drainage, high runoff	*8.4*	*0.4*	*198.2*	*9.1*			*198.2*	*1.8*
Natural state hydrology			*46.9*	*2.2*			*46.9*	*0.4*
Peat soils over mixed alluvial deposits and peat			95.9	4.4	333.4	15.3	429.3	3.8
High artificial drainage, high runoff			*90.7*	*4.2*	*333.4*	*15.3*	*424.1*	*3.8*
Natural state hydrology			*5.2*	*0.2*			*5.2*	*0.05*
Wetland Complex Family	**8.4**	**0.4**	**1338.8**	**61.6**	**834.9**	**38.4**	**2173.7**	**19.5**
Lignite								
Gley soils over lignite			20.1	43.8			20.1	0.2
Moderate artificial drainage, moderate runoff			*20.1*	*43.8*			*20.1*	*0.2*
Peat soils over lignite			2.4	5.3			2.4	0.02
High artificial drainage, high runoff			*2.4*	*5.3*			*2.4*	*0.02*
Podzol soils over lignite			23.3	50.9			23.3	0.2
Low artificial drainage, high runoff			*23.3*	*50.9*			*23.3*	*0.2*
Lignite Family			**45.8**	**100.0**			**45.8**	**0.4**
Marine Terraces								
Gley soils over marine terraces					58.0	39.8	58.0	0.5
Moderate artificial drainage, moderate runoff					*58.0*	*39.8*	*58.0*	*0.5*
Peat soils over marine terraces					87.7	60.2	87.7	0.8
High artificial drainage, high runoff					*87.7*	*60.2*	*87.7*	*0.8*
Marine Terraces Family					**145.8**	**100.0**	**145.8**	**1.3**
Oxidising								
Brown soils over alluvial terraces	1238.7	73.4	1687.7	100.0			1687.7	15.1
Low artificial drainage, low runoff	*1232.5*	*73.0*	*1670.1*	*99.0*			*1670.1*	*15.0*

Moderate artificial drainage, moderate runoff	*6.2*	*0.4*	*15.5*	*0.9*			*15.5*	*0.1*
Natural state hydrology		*0.0*	*2.1*	*0.1*			*2.1*	*0.02*
Oxidising Family	**1238.7**	**73.4**	**1687.7**	**100.0**			**1687.7**	**15.1**
Reducing								
Gley soils over alluvial terraces/deposits			902.6	12.7	366.9	5.2	1269.6	11.4
Moderate artificial drainage, moderate runoff			*899.5*	*12.7*	*365.0*	*5.1*	*1264.5*	*11.3*
Natural state hydrology			*3.1*	*0.04*	*1.9*	*0.03*	*5.0*	*0.05*
Gley soils over peat			145.2	2.0	11.7	0.2	157.0	1.4
Moderate artificial drainage, moderate runoff			*129.9*	*1.8*	*7.2*	*0.1*	*137.1*	*1.2*
Natural state hydrology			*15.3*	*0.2*	*4.5*	*0.1*	*19.8*	*0.2*
Podzol/Brown soils over alluvial terraces/deposits	1891.6	26.6	5597.5	78.8	25.5	0.4	5623.0	50.4
Low artificial drainage, low runoff	*1335.1*	*18.8*	*2427.4*	*34.2*			*2427.4*	*21.8*
Low artificial drainage, moderate runoff			*1040.2*	*14.6*			*1040.2*	*9.3*
Low artificial drainage, high runoff			*632.8*	*8.9*	*25.5*	*0.4*	*658.3*	*5.9*
Moderate artificial drainage, moderate runoff	*556.5*	*7.8*	*1492.9*	*21.0*			*1492.9*	*13.4*
Natural state hydrology			*4.3*	*0.1*			*4.3*	*0.0*
Podzol/Brown soils over peat			56.0	0.8			56.0	0.5
Low artificial drainage, moderate runoff			*10.6*	*0.1*			*10.6*	*0.1*
Low artificial drainage, high runoff			*34.5*	*0.5*			*34.5*	*0.3*
Moderate artificial drainage, moderate runoff			*10.9*	*0.2*			*10.9*	*0.1*
Reducing Family	**1891.6**	**26.6**	**6701.3**	**94.3**	**404.2**	**5.7**	**7105.5**	**63.7**
Waituna Creek Total	**3138.7**	**28.1**	**9773.6**	**87.6**	**1384.9**	**12.4**	**11158.4**	**100**

7.2 Hydrological Pathway

The hydrology of the Waituna Creek Catchment has been significantly modified through the development of agricultural land, with only a small proportion of the catchment remaining in natural state (5.5%, Table 7.2).

The north of the catchment has a relatively low density of artificial drainage and low runoff occurrence as soils in this area are relatively deep, silt loams derived from windblown loess. Artificial drainage is typically installed to improve the slow permeability of the soils. The dominant pathway for water to leave the land in this area is through the soil into alluvial aquifers. Artificial drainage is a secondary pathway, with tiles begin to flow when the soil moisture content exceeds the water holding capacity of the soil. The occurrence of overland flow in the north of the catchment is low as the soils are imperfect to well drained. At the northern water quality monitoring site at Waituna Road, 81.8% of the area is classified as low artificial drainage and runoff (Table 7.2).

The south of the catchment, closely associated with the Wetland Complex, drainage becomes poorer and the pathway water takes to leave the land becomes more lateral. The density of artificial drainage increases, as to the occurrence of overland flow events. The inherently shallow water table in this area drives this hydrological response. Deep drainage is minimal in wetland areas. A large proportion of this area is not within a monitoring site capture area (Table 7.2).

Table 7.2: Area and percentage of hydrological pathways for Waituna Creek by water quality monitoring sites, unmonitored area and total Waituna Creek catchment.

	1m upstream Waituna Road		Marshall Road		Unmonitored		Waituna Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Low artificial drainage, low runoff	2,567.6	81.8	4,097.5	41.9			4,097.5	36.7
Low artificial drainage, moderate runoff			1,050.7	10.8			1,050.7	9.4
Low artificial drainage, high runoff			690.5	7.1	25.5	1.8	716.0	6.4
Moderate artificial drainage, moderate runoff	562.7	17.9	2,568.8	26.3	430.2	31.1	2,999.1	26.9
High artificial drainage, high runoff	8.4	0.3	878.9	9.0	801.0	57.8	1,679.9	15.1
Natural state hydrology			483.7	5.0	128.1	9.2	611.8	5.5
Total	**3,138.7**	**100**	**9,770.2**	**100**	**1,384.9**	**100**	**11,155.1**	**100**

7.3 Water Quality Risk

Waituna Creek subcatchment has the largest proportional area of moderately high to high inherent nitrogen risk for soils and aquifers (Figure 7.2, Table 7.3). The area making the largest contribution of nitrogen to stream is associated with areas of well-drained soils that overly alluvial aquifers in the north of the catchment (see Oxidising Family). Areas of imperfectly drained Brown soils (and minor Podzols) across the north of the catchment are also known to generate nitrogen loss via mole-pipe drainage. The majority of nitrogen export from the north of the catchment occurs as nitrate. Given that nitrate makes up the bulk of Total N within the catchment, the largest TN contributions to the Waituna Lagoon come from the northern portion of the catchment. Accordingly, the Oxidising FLU is a key area when considering nitrate reductions to stream and ultimately the Waituna Lagoon. In terms of phosphorus, the better drained and fine textured mineral soils of the northern portion of the catchment equate to a low P risk due to good P-retention and low overland flow risk.

Towards the south, the wetland component of the Waituna Creek subcatchment includes the contribution from the Marr, a tributary of Waituna Creek, that drains a mix of Reducing and Wetland FLUs. As the Marr and the lower wetland reaches of Waituna Creek are characterised by a greater proportion of reducing soils and aquifers, nitrate export (and as such TN) is relatively low in contrast with the northern half of the catchment. However, organic and ammoniacal N contributions can be significant following periods of high-intensity rainfall and in particular following drought conditions. Although nitrate export is lower, contributions of sediment, P and E. coli increase in response to greater lateral soil drainage and more frequent and larger magnitude overland flow events (Figure 7.3 and 7.4; Table 7.4 and 7.5).

Notably, the composition of Waituna Creek waters at Marshall Rd vary according to the dominant source of water, northern or southern via the Marr. Temporal stream flow analysis indicates that the Marr and its catchment area is more responsive to rainfall events, as is consistent with the greater proportion of poorly drained soils and high water tables. The north of the catchment is less responsive to rainfall events due to greater soil water storage and better-drained soils. During the cooler months of the year the larger area and high soil water storage capacity of the northern portion of the catchment sustains higher flows, mainly associated with soil and aquifer drainage, with the reducing and wetland portion of the catchment producing more peaked flow at the Marshall Rd site. Volumetrically, groundwater is not a significant source of water when contrast with soil and overland flow.

Event flows are more frequent in the winter and spring months when soils are close to saturation and predominantly associated with those areas of Reducing and Wetland FLUs, with little evidence of surficial runoff from the northern portion of the catchment. Infiltration excess overland flow, usually during the drier and warmer months of the year, is less common and does not commonly elicit a significant flow response - although sampling indicates a large increase in soil zone contaminant contributions mainly from the reducing and wetland component of the catchment. Microbial contributions are also dominated by inputs from the southern portion of the catchment with the lowest mean E. coli concentrations outside of the natural state areas associated with the northern portion of the catchment.

In summary, the northern portion of the Waituna Creek subcatchment is a key source of nitrogen load to both the Waituna Creek and the Waituna Lagoon, mainly as nitrate-nitrogen sourced from areas of well to imperfectly drained mineral soils. The Oxidising FLUs are the key landscape units governing nitrate export to the shallow aquifer and stream. The Reducing and Wetland components of the catchment are important sources of organic and ammoniacal nitrogen, phosphorus, sediment and microbes to Waituna Creek, and ultimately the Waituna Lagoon. The Reducing and Wetland components of the catchment area are by far the most responsive units and as such are key drivers of surficial contaminant runoff to waterways.

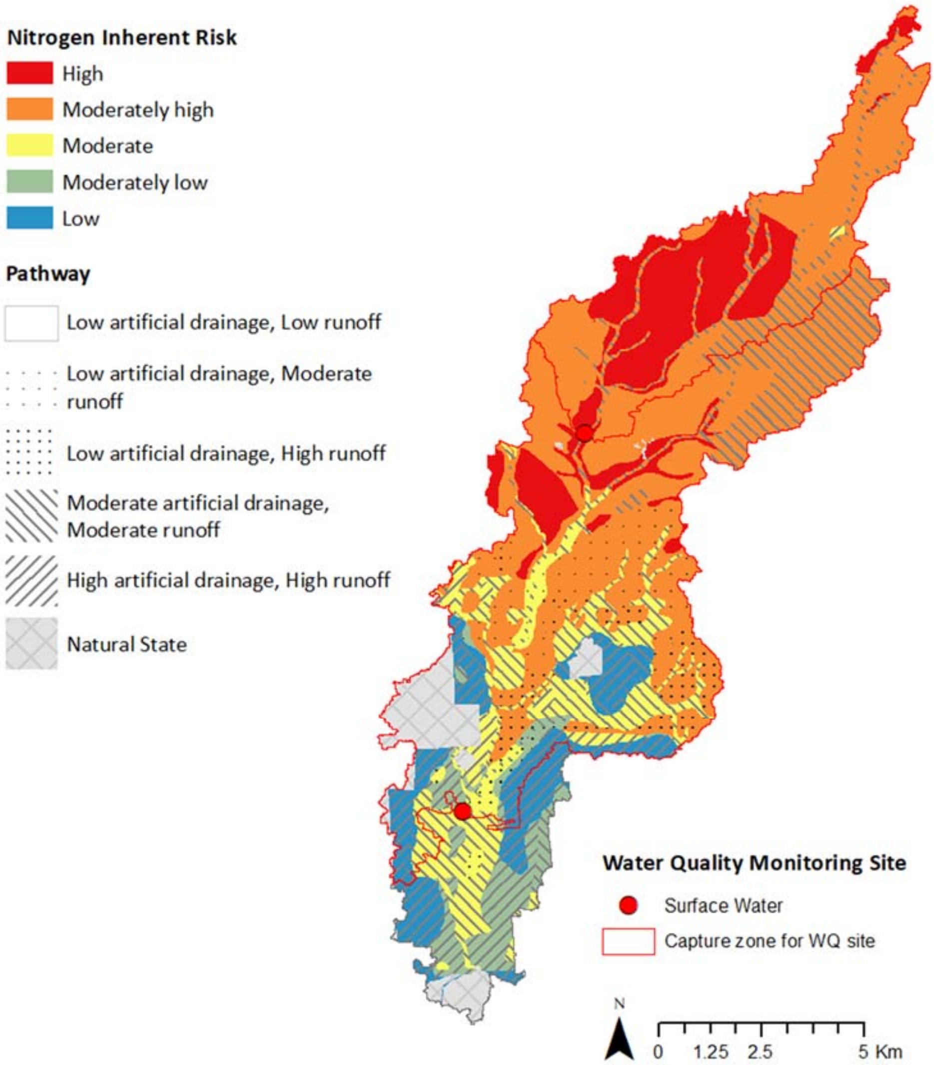

Figure 7.2: Inherent risk of nitrogen transported through the soil zone to the aquifer in Waituna Creek. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport.

Table 7.3: Nitrogen risk by loss through the soil zone to the aquifer in Waituna Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Waituna Creek is calculated by the entire subcatchment area.

	Waituna Creek 1m upstream Waituna Road		Waituna Creek at Marshall Road		Waituna Creek unmonitored		Waituna Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High								
Low artificial drainage, low runoff	1,232.5	73.0	1,670.1	99.0			1,670.1	15.0
Moderate artificial drainage, moderate runoff	6.2	0.4	15.5	0.9			15.5	0.1
Natural state hydrology			2.1	0.1			2.1	0.02
High Total	**1,238.7**	**73.4**	**1,687.7**	**100**			**1,687.7**	**15.1**
Moderately High								
Low artificial drainage, low runoff	1,335.1	24.5	2,427.4	44.5			2,427.4	21.8
Low artificial drainage, moderate runoff			963.8	17.7			963.8	8.6
Low artificial drainage, high runoff			564.3	10.4			564.3	5.1
Moderate artificial drainage, moderate runoff	556.5	10.2	1,489.6	27.3			1,489.6	13.3
Natural state hydrology			4.3	0.1			4.3	0.04
Moderately High Total	**1,891.6**	**34.7**	**5,449.3**	**100**			**5,449.3**	**48.8**
Moderate								
Low artificial drainage, moderate runoff			76.3	4.5			76.3	0.7
Low artificial drainage, high runoff			68.5	4.1	25.5	1.5	94.0	0.8
Moderate artificial drainage, moderate runoff			902.8	53.5	365.0	21.6	1,267.8	11.4
High artificial drainage, high runoff	8.4	0.5	198.2	11.7			198.2	1.8
Natural state hydrology			50.1	3.0	1.9	0.1	52.0	0.5
Moderate Total	**8.4**	**0.5**	**1,295.9**	**76.8**	**392.4**	**23.2**	**1,688.3**	**15.1**
Moderately Low								
Low artificial drainage, moderate runoff			10.6	1.6			10.6	0.1
Low artificial drainage, high runoff			57.8	8.6			57.8	0.5
Moderate artificial drainage, moderate runoff			31.0	4.6	58.0	8.6	89.0	0.8
High artificial drainage, high runoff			90.7	13.4	421.1	62.4	511.8	4.6
Natural state hydrology			5.2	0.8			5.2	0.05
Moderately Low Total			**195.2**	**29.0**	**479.2**	**71.0**	**674.4**	**6.0**
Low								
Moderate artificial drainage, moderate runoff			129.9	7.8	7.2	0.4	137.1	1.2
High artificial drainage, high runoff			590.1	35.6	379.9	22.9	969.9	8.7
Natural state hydrology			425.5	25.7	126.2	7.6	551.7	4.9
Low Total			**1,145.5**	**69.1**	**513.3**	**30.9**	**1,658.7**	**14.9**
Capture Area Total	**3,138.7**		**9,773.6**		**1,384.9**		**11,158.4**	**100**

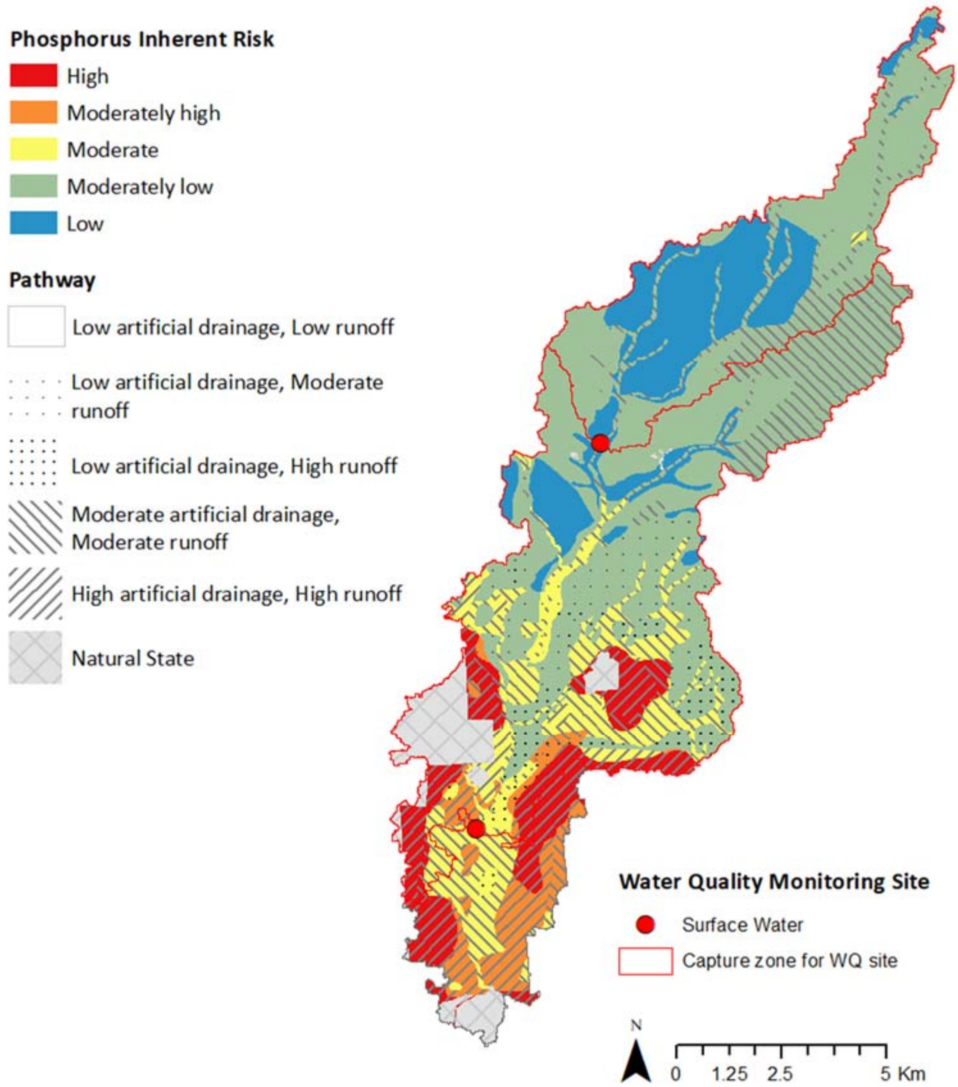

Figure 7.3: Inherent risk of (dissolved) phosphorus transported through the soil zone to the aquifer in Waituna Creek. The pathway shows the surficial risk by artificial drainage and overland flow for sediment-bound P. Natural state identifies source limited areas with minimal contaminants to transport.

Table 7.4: phosphorus risk by loss through the soil zone to the aquifer in Waituna Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Waituna Creek is calculated by the entire subcatchment area.

	Waituna Creek 1m upstream Waituna Road		**Waituna Creek at Marshall Road**		**Waituna Creek unmonitored**		**Waituna Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High								
Moderate artificial drainage, moderate runoff			129.9	7.8	7.2	0.4	137.1	1.2
High artificial drainage, high runoff			590.1	35.6	379.9	22.9	969.9	8.7
Natural state hydrology			425.5	25.7	126.2	7.6	551.7	4.9
High Total			**1,145.5**	**69.1**	**513.3**	**30.9**	**1,658.7**	**14.9**
Moderately High								
Low artificial drainage, moderate runoff			10.6	1.6			10.6	0.1
Low artificial drainage, high runoff			57.8	8.6			57.8	0.5
Moderate artificial drainage, moderate runoff			31.0	4.6	58.0	8.6	89.0	0.8
High artificial drainage, high runoff			90.7	13.4	421.1	62.4	511.8	4.6
Natural state hydrology			5.2	0.8			5.2	0.05
Moderately High Total			**195.2**	**29.0**	**479.2**	**71.0**	**674.4**	**6.0**
Moderate								
Low artificial drainage, moderate runoff			76.3	4.5			76.3	0.7
Low artificial drainage, high runoff			68.5	4.1	25.5	1.5	94.0	0.8
Moderate artificial drainage, moderate runoff			902.8	53.5	365.0	21.6	1,267.8	11.4
High artificial drainage, high runoff	8.4	0.5	198.2	11.7			198.2	1.8
Natural state hydrology			50.1	3.0	1.9	0.1	52.0	0.5
Moderate Total	**8.4**	**0.5**	**1,295.9**	**76.8**	**392.4**	**23.2**	**1,688.3**	**15.1**
Moderately Low								
Low artificial drainage, low runoff	1,335.1	24.5	2,427.4	44.5			2,427.4	21.8
Low artificial drainage, moderate runoff			963.8	17.7			963.8	8.6
Low artificial drainage, high runoff			564.3	10.4			564.3	5.1
Moderate artificial drainage, moderate runoff	556.5	10.2	1,489.6	27.3			1,489.6	13.3
Natural state hydrology			4.3	0.1			4.3	0.04
Moderately Low Total	**1,891.6**	**34.7**	**5,449.3**	**100**			**5,449.3**	**48.8**
Low								
Low artificial drainage, low runoff	1,232.5	73.0	1,670.1	99.0			1,670.1	15.0
Moderate artificial drainage, moderate runoff	6.2	0.4	15.5	0.9			15.5	0.1
Natural state hydrology			2.1	0.1			2.1	0.02
Low Total	**1,238.7**	**73.4**	**1,687.7**	**100**			**1,687.7**	**15.1**
Total	**3,138.7**	**28.1**	**9,773.6**	**87.6**	**1,384.9**	**12.4**	**11,158.4**	**100**

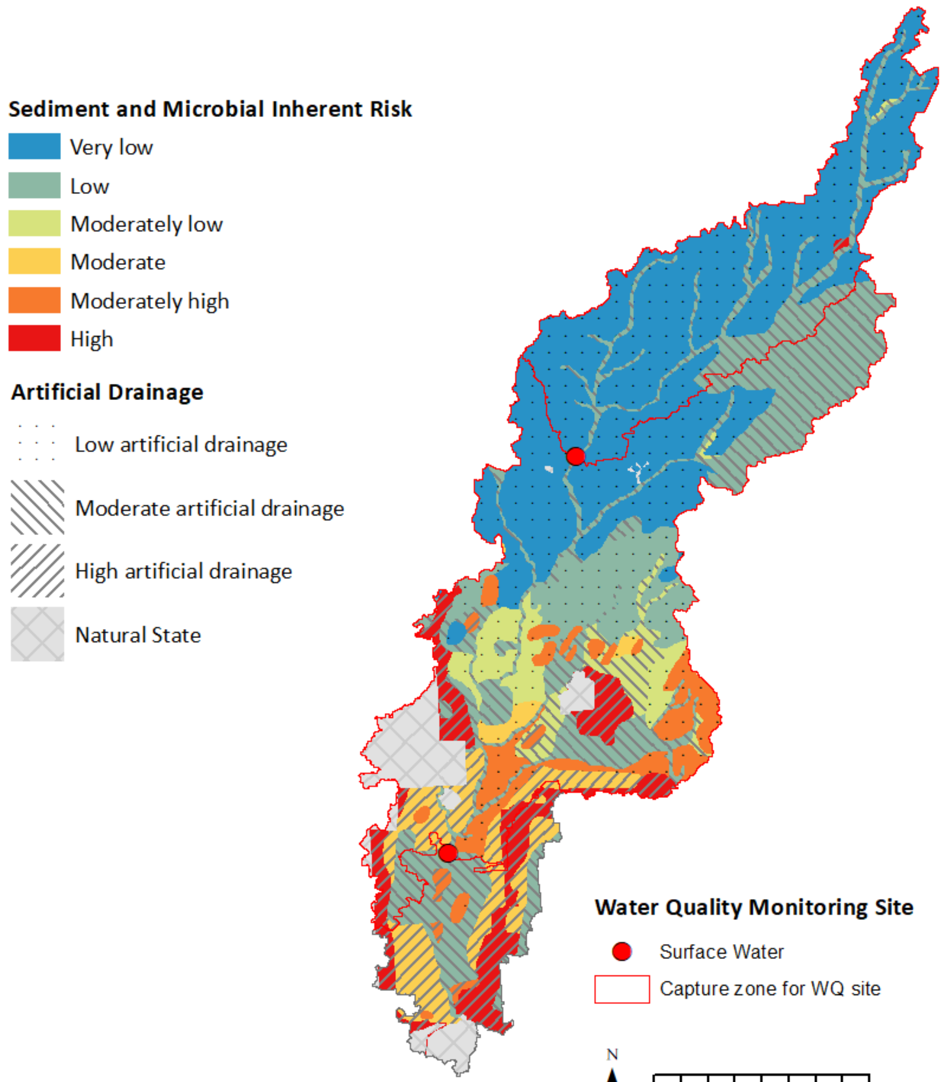

Figure 7.4: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff) in Waituna Creek. Risk of loss is increased by catchment modification through artificial drainage.

Table 7.5: Sediment and microbial risk by overland flow and artificial drainage for Waituna Creek. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Waituna Creek is calculated by the entire subcatchment area.

	Waituna Creek 1m upstream Waituna Road		Waituna Creek at Marshall Road		Waituna Creek unmonitored		Waituna Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High								
High artificial drainage, high runoff	8.4	0.6	474.8	35.3	353.9	26.3	828.7	7.4
Natural state hydrology			405.1	30.1	112.4	8.4	517.5	4.6
High Total	**8.4**	**0.6**	**879.9**	**65.4**	**466.4**	**34.6**	**1,346.2**	**12.1**
Moderately High								
Low artificial drainage, high runoff			606.3	84.1	25.5	3.5	631.8	5.7
High artificial drainage, high runoff			30.7	4.3	48.8	6.8	79.5	0.7
Natural state hydrology					9.2	1.3	9.2	0.1
Moderately High Total			**637.0**	**88.4**	**83.6**	**11.6**	**720.5**	**6.5**
Moderate								
Low artificial drainage, high runoff			84.3	9.2			84.3	0.8
High artificial drainage, high runoff			373.4	40.9	398.2	43.6	771.7	6.9
Natural state hydrology			57.2	6.3			57.2	0.5
Moderate Total			**514.9**	**56.4**	**398.2**	**43.6**	**913.1**	**8.2**
Moderately Low								
Low artificial drainage, moderate runoff			371.4	55.0			371.4	3.3
Moderate artificial drainage, moderate runoff	6.2	0.9	294.3	43.5			294.3	2.6
Natural state hydrology			10.1	1.5			10.1	0.1
Mod Low Total	**6.2**	**0.9**	**675.8**	**100.0**			**675.8**	**6.1**
Low								
Low artificial drainage, moderate runoff			679.3	20.0			679.3	6.1
Moderate artificial drainage, moderate runoff	556.5	16.4	2,274.6	66.9	430.2	12.7	2,704.8	24.2
Natural state hydrology			8.4	0.2	6.4	0.2	14.8	0.1
Low Total	**556.5**	**16.4**	**2,962.2**	**87.2**	**436.7**	**12.8**	**3,398.9**	**30.5**
Very Low								
Low artificial drainage, low runoff	2,567.6	23.0	4,097.5	36.7			4,097.5	36.7
Natural state hydrology			6.3	0.1			6.3	0.1
Very Low Total	**2,567.6**	**23.0**	**4,103.8**	**36.8**			**4,103.8**	**36.8**
Total	**3,138.7**	**28.1**	**9,773.6**	**87.6**	**1,384.9**	**23.0**	**11,158.4**	**100**

8 Moffat Creek Stocktake

8.1 Fundamental Landscape Unit Stocktake

The Moffat Creek subcatchment is the smallest of the three creeks contributing to Waituna Lagoon comprising 8% (1542.3 ha) of the catchment (Figure 8.1). There are three FLU families located within the Waituna Creek catchment, Wetland Complex, Marine Terraces and Reducing (Table 8.1). Wetland Complex covers the largest extent at 591 ha (38.3%). Moffat Creek has the largest proportion of the Marine Terrace Family (55.5% of the Family Unit) compared to the other subcatchments contributing to Waituna Lagoon.

There is one long-term water quality site monitored by Environment Southland in Moffat Creek, which was used to develop the physiographic model in Rissmann et al., 2018. The monitoring site 'Moffat Creek at Moffat Road' is located in the south of the catchment, capturing 91% of the catchment area. The capture zone for the water quality monitoring site is shown in red in Figure 8.1.

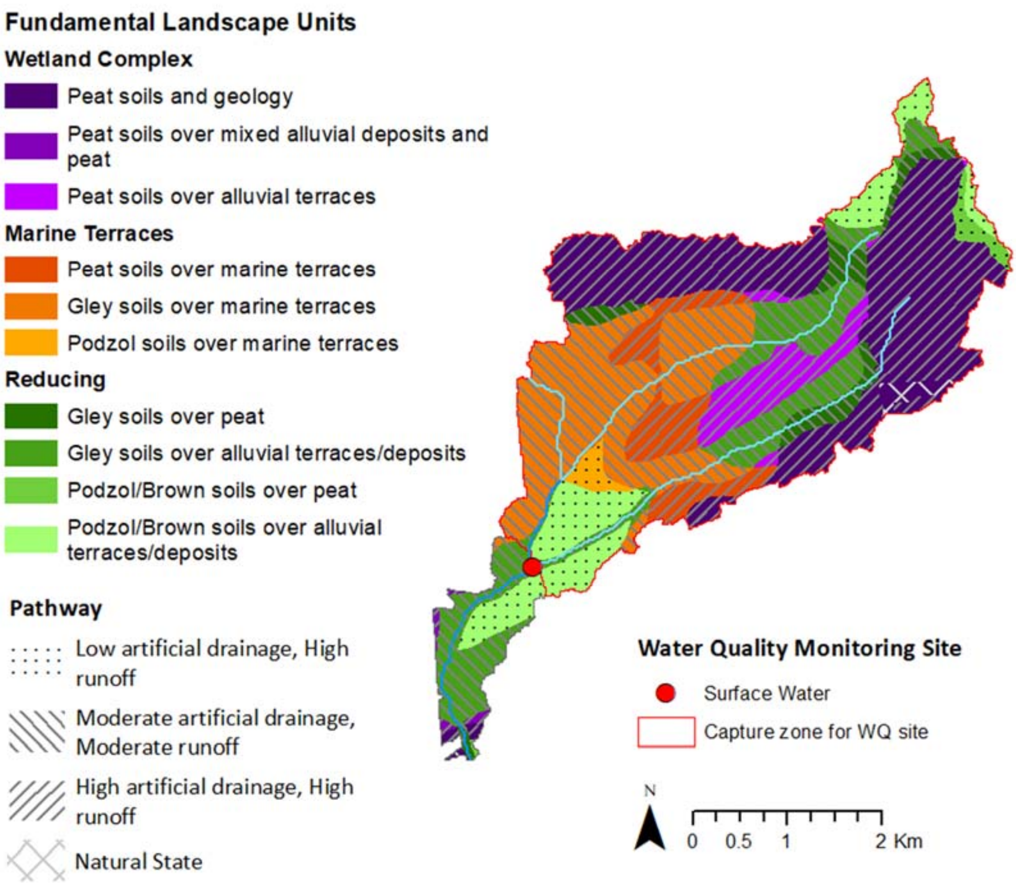

Figure 8.1: Fundamental Landscape Units of Moffat Creek Catchment. Water quality monitoring sites and capture areas are shown in red.

Table 8.1: Area of Fundamental Landscape Units for Moffat Creek by water quality monitoring site at Moffat Road, unmonitored area and total Moffat Creek catchment. The percentage for the siblings is the percentage of the subunit within the family for the monitoring sites. The percentage for Moffat Creek is calculated by the entire subcatchment area.

	Moffat Creek at Moffat Road		Moffat Creek unmonitored		Moffat Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Wetland Complex						
Peat soils and geology	493.3	83.4	5.7	1.0	499.0	32.3
High artificial drainage, high runoff	*478.4*	*80.9*	*4.8*	*0.8*	*483.2*	*31.3*
Natural state hydrology	*14.8*	*2.5*	*0.9*	*0.2*	*15.7*	*1.0*
Peat soils over alluvial terraces	85.8	14.5			85.8	5.6
High artificial drainage, high runoff	*85.8*	*14.5*			*85.8*	*5.6*
Peat soils over mixed alluvial deposits and peat			6.4	1.1	6.4	0.4
High artificial drainage, high runoff			*6.4*	*1.1*	*6.4*	*0.4*
Wetland Complex Family	**579.1**	**98.0**	**12.1**	**2.0**	**591.1**	**38.3**
Marine Terraces						
Gley soils over marine terraces	321.6	71.3	1.8	0.4	323.4	21.0
Moderate artificial drainage, moderate runoff	*321.6*	*71.3*	*1.8*	*0.4*	*323.4*	*21.0*
Peat soils over marine terraces	111.3	24.7			111.3	7.2
High artificial drainage, high runoff	*111.3*	*24.7*			*111.3*	*7.2*
Podzol soils over marine terraces	16.2	3.6			16.2	1.0
Low artificial drainage, high runoff	*16.2*	*3.6*			*16.2*	*1.0*
Marine Terraces Family	**449.1**	**99.6**	**1.8**	**0.4**	**450.9**	**29.2**
Reducing						
Gley soils over alluvial terraces/deposits	168.2	33.6	84.7	16.9	252.9	16.4
Moderate artificial drainage, moderate runoff	*168.2*	*33.6*	*84.7*	*16.9*	*252.9*	*16.4*
Gley soils over peat	70.0	14.0	3.1	0.6	73.1	4.7
Moderate artificial drainage, moderate runoff	*70.0*	*14.0*	*1.3*	*0.3*	*71.2*	*4.6*
Natural state hydrology		*0.0*	*1.8*	*0.4*	*1.8*	*0.1*
Podzol/Brown soils over alluvial terraces/deposits	126.1	25.2	31.8	6.3	157.8	10.2
Low artificial drainage, high runoff	*126.1*	*25.2*	*31.8*	*6.3*	*157.8*	*10.2*
Podzol/Brown soils over peat	16.3	3.3	0.6	0.1	16.9	1.1
Low artificial drainage, high runoff	*16.3*	*3.3*			*16.3*	*1.1*
Natural state hydrology			*0.6*	*0.1*	*0.6*	*0.04*
Reducing Family	**380.5**	76.0	**120.1**	24.0	**500.7**	**32.5**
Moffat Creek Total	**1408.7**	**91.3**	**134.0**	**8.7**	**1542.7**	**100**

8.2 Hydrological Pathway

Only a small proportion of the Moffat Creek Catchment remains in conservation estate with natural state hydrology (18.2 ha, 1.2%). While the remainder of the catchment is considered developed, Rissmann et al. (2018) noted the land use in the catchment, particularly the harvesting of peat, resulted in different water quality outcomes from other areas with similar FLU combinations. This is due to the lack of agricultural inputs (i.e. fertilizer, animal wastes) from this land use. The lack of animal wastes and fertiliser results within the peat cutting area equates to source limitation, which is reflected in better water quality. The actual density of artificial drainage in this area is likely to be lower than estimated, due to the non-pastoral farming land use.

The dominant pathway for water movement in the Moffat Creek subcatchment is lateral drainage through the soil profile which intersects the moderate to high-density artificial drainage network (Table 8.2). Lateral flow occurs due to the shallowness of the water table in the subcatchment and a general decline in the permeability of subsoil environments associated with pan formation and/or higher density amorphous peat.

Moffat Creek subcatchment also has a relatively high potential for localised overland flow due to the seasonally high water table. However, in developed areas this potential may not be fully realised due to the high density of artificial drainage.

Table 8.2: Area and percentage of hydrological pathways for Moffat Creek at the water quality monitoring site, unmonitored area and total Moffat Creek catchment.

	Moffat Creek at Moffat Road		**Moffat Creek unmonitored**		**Moffat Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Low artificial drainage, high runoff	158.5	11.3	31.8	23.7	190.3	12.3
Moderate artificial drainage, moderate runoff	559.8	39.7	87.7	65.5	647.5	42.0
High artificial drainage, high runoff	675.5	48.0	11.2	8.3	686.7	44.5
Natural state hydrology	14.8	1.1	3.3	2.5	18.2	1.2
Total	**1,408.7**	**100**	**134.0**	**100**	**1,542.7**	**100**

8.3 Water Quality Risk

Moffat Creek subcatchment is a relatively small short-run catchment dominated by poorly drained soils, high water table and low aquifer permeability (Figure 7.2, Table 7.3). Nitrate nitrogen export peaks early at a concentration of 2.5 mg/L and then declines as flow increases. Nitrate export is mainly associated with soil zone contributions from areas of Brown and Podzol soils and mediated by mole-pipe drainage. The bulk of N export is associated with the organic forms of nitrogen and a smaller ammoniacal nitrogen component. Organic forms of N increase with streamflow and the relationship is best defined by a simple power law function. The importance of organic N export reflects the dominance of poorly drained soils.

Phosphorus is elevated at low flows due to the abundance of strongly reducing aquifers containing high organic carbon contents, which favour the generation of highly mobile P-organic colloids. These colloids discharge to base flow and are associated with the Dissolved Reactive Phosphorus (DRP) fraction. As soil drainage increases and soil water contributions to stream increase, P export declines in response to relatively favourable conditions for P-retention. As flow increases beyond dominance by soil drainage P concentrations again increase in response to overland flow and the mobilisation of particulate phosphorus. Accordingly, the form and export of P to Moffat Creek varies according to the water source. Sediment and E. coli exhibit a generalised increase with flow reflecting greater mobilisation from the land surface, although sediment is still significantly elevated across the flow range.

In summary, water quality outcomes for the Moffat Creek subcatchment are dominated by the prevalence of poorly drained soils and reducing aquifers. Soil zone and surficial runoff mediated by overland flow are the most significant controls over water quality outcomes. Specifically, organic nitrogen, some ammoniacal nitrogen, particulate phosphorus and sediment yields and loads are associated with frequent peak runoff events, most of which occur during the cooler months of the year when soils approach saturation and water tables are at their highest.

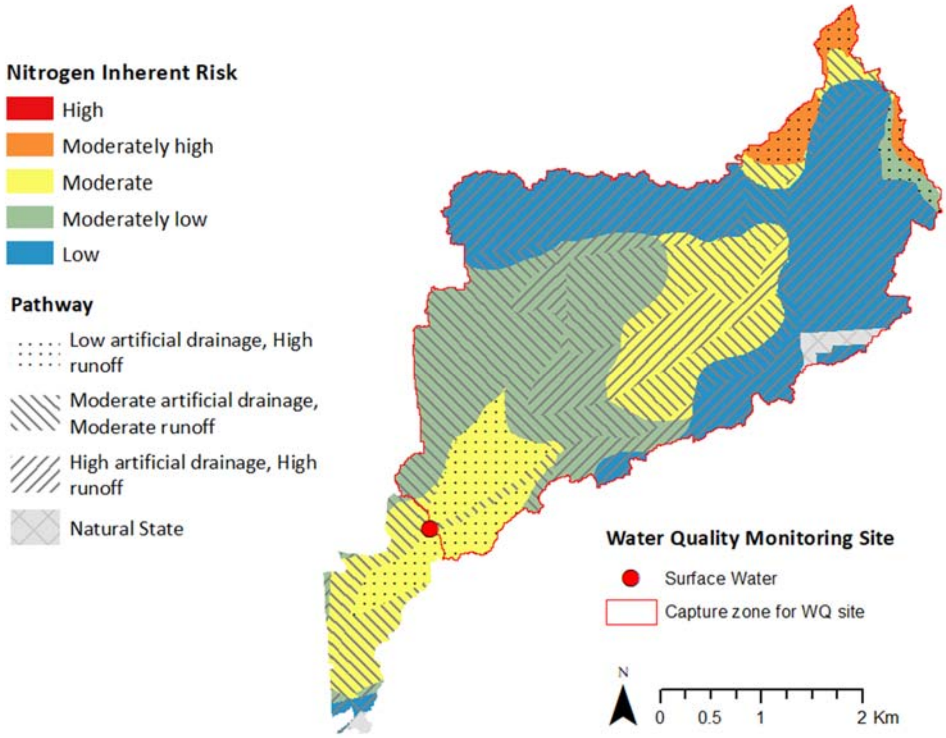

Figure 8.2: Inherent risk of nitrogen transported through the soil zone to the aquifer in Moffat Creek. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport.

Table 8.3: Nitrogen risk by loss through the soil zone to the aquifer in Moffat Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Moffat Creek is calculated by the entire subcatchment area.

	Moffat Creek at Moffat Road		Moffat Creek unmonitored		Moffat Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Mod. High						
Low artificial drainage, high runoff	45.6	100			45.6	3.0
Mod. High Total	**45.6**	**100**			**45.6**	**3.0**
Moderate						
Low artificial drainage, high runoff	96.6	20.7	31.8	6.8	128.4	8.3
Moderate artificial drainage, moderate runoff	168.2	36.0	84.7	18.1	252.9	16.4
High artificial drainage, high runoff	85.8	18.4			85.8	5.6
Moderate Total	**350.6**	**75.1**	**116.4**	**24.9**	**467.1**	**30.3**
Mod. Low						
Low artificial drainage, high runoff	16.3	3.6			16.3	1.1
Moderate artificial drainage, moderate runoff	321.6	70.2	1.8	0.4	323.4	21.0
High artificial drainage, high runoff	111.3	24.3	6.4	1.4	117.7	7.6
Natural state hydrology			0.6	0.1	0.6	0.04
Mod. Low Total	**449.2**	**98.1**	**8.7**	**1.9**	**458.0**	**29.7**
Low						
Moderate artificial drainage, moderate runoff	70.0	12.2	1.3	0.2	71.2	4.6
High artificial drainage, high runoff	478.4	83.6	4.8	0.8	483.2	31.3
Natural state hydrology	14.8	2.6	2.7	0.5	17.6	1.1
Low Total	**563.2**	**98.5**	**8.8**	**1.5**	**572.0**	**37.1**
Capture Area Total	**1,408.7**	**91.3**	**134.0**	**8.7**	**1,542.7**	**100**

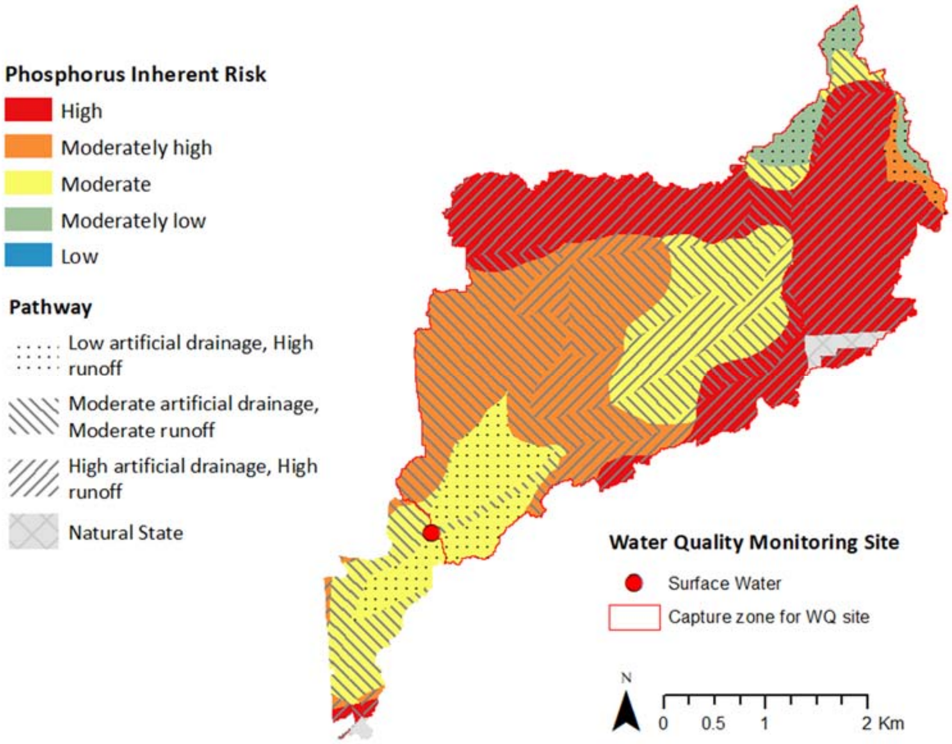

Figure 8.3: Inherent risk of (dissolved) phosphorus transported through the soil zone to the aquifer in Moffat Creek. The pathway shows the surficial risk by artificial drainage and overland flow for sediment-bound P. Natural state identifies source limited areas with minimal contaminants to transport.

Table 8.4: Phosphorus risk by loss through the soil zone to the aquifer for Moffat Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Moffat Creek is calculated by the entire subcatchment area.

	Moffat Creek at Moffat Road		**Moffat Creek unmonitored**		**Moffat Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High						
Moderate artificial drainage, moderate runoff	70.0	12.2	1.3	0.2	71.2	4.6
High artificial drainage, high runoff	478.4	83.6	4.8	0.8	483.2	31.3
Natural state hydrology	14.8	2.6	2.7	0.5	17.6	1.1
High Total	**563.2**	**98.5**	**8.8**	**1.5**	**572.0**	**37.1**
Mod. High						
Low artificial drainage, high runoff	16.3	3.6			16.3	1.1
Moderate artificial drainage, moderate runoff	321.6	70.2	1.8	0.4	323.4	21.0
High artificial drainage, high runoff	111.3	24.3	6.4	1.4	117.7	7.6
Natural state hydrology			0.6		0.6	0.04
Mod high Total	**449.2**	**98.1**	**8.7**	**1.9**	**458.0**	**29.7**
Moderate						
Low artificial drainage, high runoff	96.6	20.7	31.8	6.8	128.4	8.3
Moderate artificial drainage, moderate runoff	168.2	36.0	84.7	18.1	252.9	16.4
High artificial drainage, high runoff	85.8	18.4			85.8	5.6
Moderate total	**350.6**	**75.1**	**116.4**	**24.9**	**467.1**	**30.3**
Mod. Low						
Low artificial drainage, high runoff	45.6	100			45.6	3.0
Mod low total	45.6	100			45.6	3.0
Capture Area Total	**1,408.7**	**91.3**	**134.0**	**8.7**	**1,542.7**	**100**

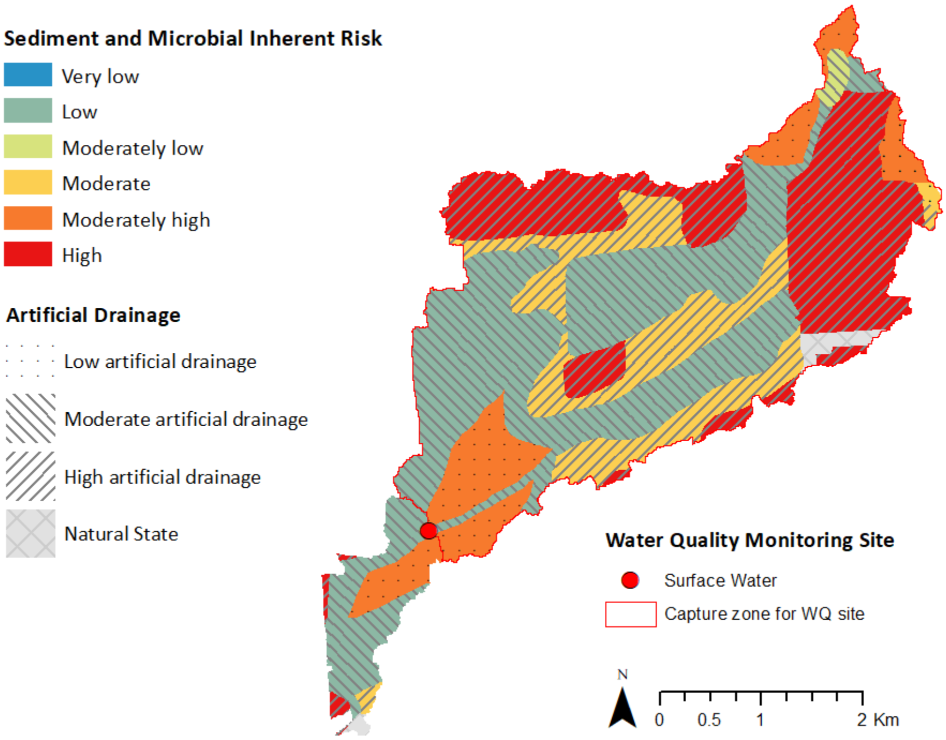

Figure 8.4: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff) for Moffat Creek. Risk of loss is increased by catchment modification through artificial drainage.

Table 8.5: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff) and artificial drainage in Moffat Creek.

	Moffat Creek at Moffat Road		**Moffat Creek unmonitored**		**Moffat Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High						
High artificial drainage, high runoff	418.3	94.9	6.9	1.6	425.2	27.6
Natural state hydrology	14.8	3.4	0.9	0.2	15.7	1.0
High Total	**433.1**	**98.2**	**7.8**	**1.8**	**440.9**	**28.6**
Moderately high						
Low artificial drainage, high runoff	154.6	83.0	31.8	17.0	186.4	12.1
Mod high total	**154.6**	**83.0**	**31.8**		**186.4**	**12.1**
Moderate						
Low artificial drainage, high runoff	3.9	1.5			3.9	0.3
High artificial drainage, high runoff	257.3	96.9	4.2	1.6	261.5	17.0
Moderate total	261.2	98.4	4.2	1.6	265.4	17.2
Moderately low						
Moderate artificial drainage, moderate runoff	11.5	100.0			11.5	0.7
Mod low total	**11.5**	**100.0**			**11.5**	**0.7**
Low						
Moderate artificial drainage, moderate runoff	548.3	85.9	87.7	5.7	636.1	41.2
Natural state hydrology			2.4	0.2	2.4	0.2
Low Total	**548.3**	**85.9**	**90.2**	**5.8**	**638.5**	**41.4**
Capture Area Total	**1,408.7**	**91.3**	**134.0**	**8.7**	**1,542.7**	**100**

9 Carran Creek Stocktake

9.1 Fundamental Landscape Unit Stocktake

The Carran Creek subcatchment comprises 22% (4,283.8 ha) of the Waituna Lagoon Catchment (Figure 9.1). There are three FLU families located within the Carran Creek catchment, Wetland Complex, Marine Terraces and Reducing (Table 9.1). Wetland Complex covers the largest extent at 2,629.6 ha (61.4%), of which 38% is in natural state conservation estate. The north of the catchment is largely classified within the Reducing Family.

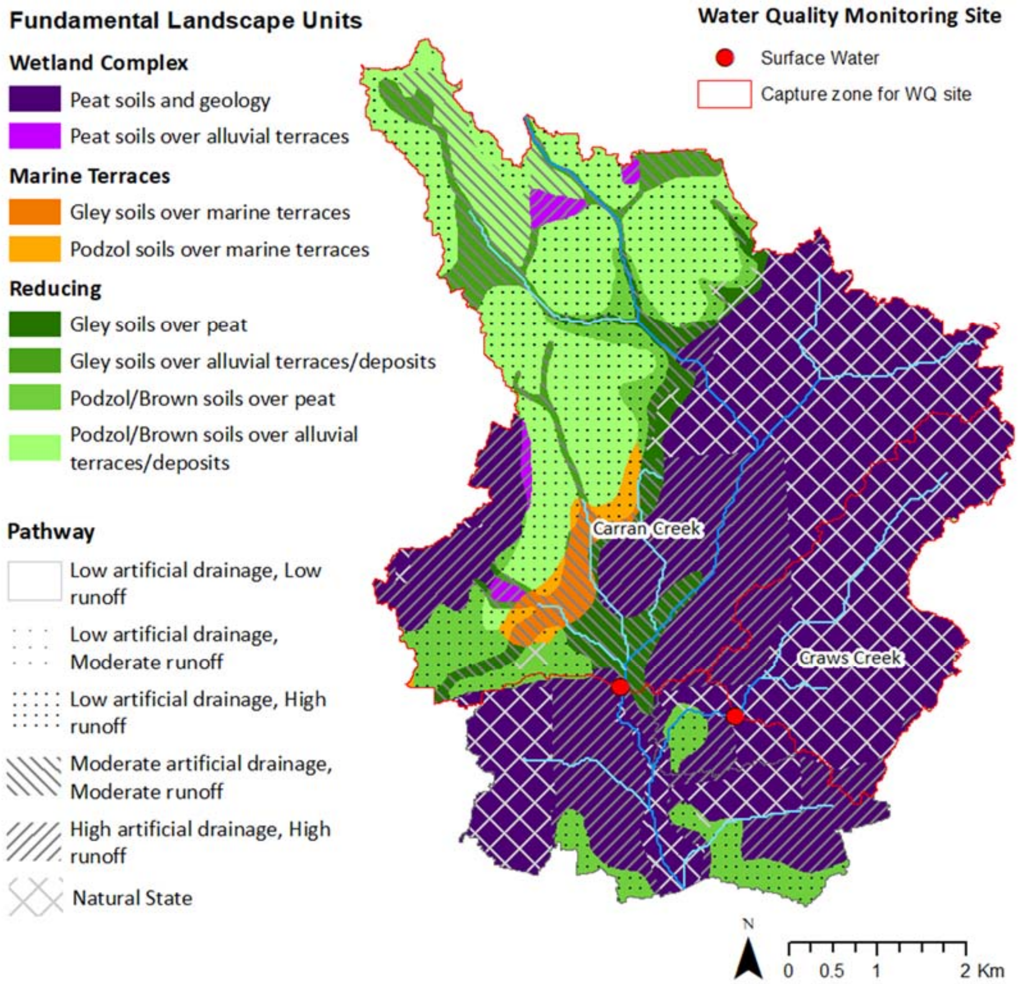

Figure 9.1: Fundamental Landscape Units of Carran Creek Catchment which includes Craws Creek. Water quality monitoring sites and capture areas are shown in red.

There are two long-term water quality sites monitored by Environment Southland on Carran Creek, which were used to develop the physiographic model in Rissmann et al., 2018. These sites are used to provide a subcatchment stocktake, in addition to the whole subcatchment and can be used to provide context to water quality analysis. The monitoring site 'Carran Creek at Waituna Lagoon Road' captures an area of 2,738.9 ha (63.9%) of the subcatchment. Craws Creek at Waituna Lagoon Road is a tributary to Carran Creek[1], capturing an area of 782 ha (18.3%). Craws Creek is

[1] Environment Southland site name 'Carran Creek Tributory at Waituna Lagoon Road'.

predominantly natural state and provides a good reference catchment for comparison with agriculturally land developed within a wetland setting. The capture zones of each water quality monitoring site are shown in red in Figure 9.1.

Table 9.1: Area of Fundamental Landscape Units for Carran Creek by water quality monitoring sites at Waituna Lagoon Road for Carran and Craws Creek, unmonitored areas and total Moffat Creek catchment. The percentage for the siblings is the percentage of the subunit within the family for the monitoring sites. The percentage for Carran Creek is calculated by the entire subcatchment area.

	Carran Creek at Waituna Lagoon Road		Carran Creek unmonitored		Craws Creek at Waituna Lagoon Rd		Craws Creek unmonitored		Carran Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Wetland Complex										
Peat soils and geology	1183.6	45.0	621.1	23.6	761.5	29.0	23.5	0.9	2589.7	60.5
High artificial drainage, high runoff	*530.6*	*20.2*	*311.2*	*11.8*	*103.3*	*3.9*	*17.9*	*0.7*	*963.1*	*22.5*
Natural state hydrology	*653.0*	*24.8*	*309.8*	*11.8*	*658.3*	*25.0*	*5.5*	*0.2*	*1626.6*	*38.0*
Peat soils over alluvial terraces	39.9	1.5							39.9	0.9
High artificial drainage, high runoff	*39.9*	*1.5*							*39.9*	*0.9*
Wetland Complex Family	**1223.5**	**46.5**	**621.1**	**23.6**	**761.5**	**29.0**	**23.5**	**0.9**	**2629.6**	**61.4**
Marine Terraces										
Gley soils over marine terraces	69.1	64.4							69.1	1.6
Moderate artificial drainage, moderate runoff	*69.1*	*64.4*							*69.1*	*1.6*
Podzol soils over marine terraces	38.2	35.6							38.2	0.9
Low artificial drainage, high runoff	*38.2*	*35.6*							*38.2*	*0.9*
Marine Terraces Family	**107.3**	**100.0**							**107.3**	**2.5**
Reducing										
Gley soils over alluvial terraces/deposits	164.4	10.6							164.4	3.8
Moderate artificial drainage, moderate runoff	*164.4*	*10.6*							*164.4*	*3.8*
Gley soils over peat	207.3	13.4	5.1	0.3					212.4	5.0
Moderate artificial drainage, moderate runoff	*178.7*	*11.5*	*5.1*	*0.3*					*183.8*	*4.3*
Natural state hydrology	*28.6*	*1.9*							*28.6*	*0.7*
Podzol/Brown soils over alluvial terraces/deposits	830.3	53.7			1.0	0.1			831.3	19.4
Low artificial drainage, low runoff	*0.8*	*0.0*			*1.0*	*0.1*			*1.8*	*0.04*
Low artificial drainage, moderate runoff	*12.6*	*0.8*							*12.6*	*0.3*
Low artificial drainage, high runoff	*703.5*	*45.5*							*703.5*	*16.4*
Moderate artificial drainage, moderate runoff	*113.4*	*7.3*							*113.4*	*2.6*
Podzol/Brown soils over peat	206.1	13.3	108.2	7.0	19.7	1.3	4.8	0.3	338.8	7.9

Low artificial drainage, high runoff	*194.6*	*12.6*	*104.4*	*6.7*	*16.3*	*1.1*	*4.8*	*0.3*	*320.1*	*7.5*
Natural state hydrology	*11.5*	*0.7*	*3.9*	*0.2*	*3.3*	*0.2*			*18.7*	*0.4*
Reducing Family	**1408.1**	**91.0**	**113.4**	**7.3**	**20.7**	**1.3**	**4.8**	**0.3**	**1547.0**	**36.1**
Carran Creek	**2738.9**	**63.9**	**734.4**	**17.1**	**782.3**	**18.3**	**28.3**	**0.7**	**4283.8**	**100**

9.2 Hydrological Pathway

Carran Creek subcatchment has the largest proportion of natural state land, with 39.1% (1,673.9 ha) in conservation estate (Table 9.2). This area is predominantly in the west of the catchment and includes the tributary of Craws Creek.

To the north in the Reducing Unit, deep drainage with secondary artificial drainage, are the dominant pathways. However, due to the imperfect to poor drainage of the soils, at wetter times of the year surficial runoff also occurs. This risk is increased as the topography becomes more undulating.

As the underlying geology transitions from alluvial terraces to marine terraces, peat and alluvial gravels, the aquifer thickness becomes less, resulting in more lateral drainage. Peat and poorly drained Gley soils become more prominent, which requires a denser artificial drainage network to maintain the water table for agricultural production. Due to the close proximity of the water table to the surface, overland flow occurrences are higher.

Table 9.2: Area and percentage of hydrological pathways for Carran Creek by water quality monitoring sites, unmonitored areas and total Carran Creek catchment.

	Carran Creek at Waituna Lagoon Road		**Carrans Creek unmonitored**		**Craws Creek at Waituna Lagoon Rd**		**Craws Creek unmonitored**		**Carran Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Low artificial drainage, low runoff	0.8	0.03	1.0	0.1					1.8	0.04
Low artificial drainage, moderate runoff	12.6	0.5							12.6	0.3
Low artificial drainage, high runoff	936.3	34.2	16.3	2.1	104.4	14.2	4.8	17.0	1,061.8	24.8
Moderate artificial drainage, moderate runoff	525.6	19.2			5.1	0.7			530.7	12.4
High artificial drainage, high runoff	570.5	20.8	103.3	13.2	311.2	42.4	17.9	63.5	1,003.0	23.4
Natural state hydrology	693.1	25.3	661.6	84.6	313.7	42.7	5.5	19.5	1,673.9	39.1
Total	2,738.9	100	782.3	100	734.4	100	28.3	100	4,283.8	100

9.3 Water Quality Risk

The Carran Creek subcatchment is characterised by a mix of inflows from natural state peat wetland and intensively farmed, Brown and Podzol soils that overly reducing aquifers of variable composition. Overall, ammoniacal and organic forms of nitrogen are relatively elevated across the flow range, albeit peaking under event flows. Elevated values under low to median streamflows likely reflect the naturally reducing soil and aquifer conditions associated with the large areas of peat wetland. In comparison, nitrate exhibits a stronger relationship to flow with low concentrations at baseflow that subsequently increase in response to soil water and surficial runoff. Given, little evidence for a significant N export with streamflow for the natural state Craws Creek subcatchment, peak flow organic, ammoniacal and nitrate are associated with the intensively farmed component of the catchment. Specifically, nitrate nitrogen export is associated with the areas of relatively well-drained mineral Brown/Podzol soils that constitute the headwaters of the Carran Creek subcatchment.

Like the organic and ammoniacal forms of nitrogen, DRP and TP are relatively elevated across the flow range, albeit peaking under event flows due to the naturally reducing soil and aquifer conditions associated with the large areas of peat wetland. Under event flows the DRP fraction of TP declines to as low as 4% with particulate phosphorus associated with surficial runoff dominating export. Sediment and E. coli concentrations are also strongly correlated with peak-runoff events and those developed areas of the catchment with a greater % rainfall occurring as overland flow. Once again, the magnitude of P, sediment or microbial export with streamflow for the natural state Craws Creek subcatchment is relatively minor, peak flow exports are mainly associated with the intensively farmed component of the catchment.

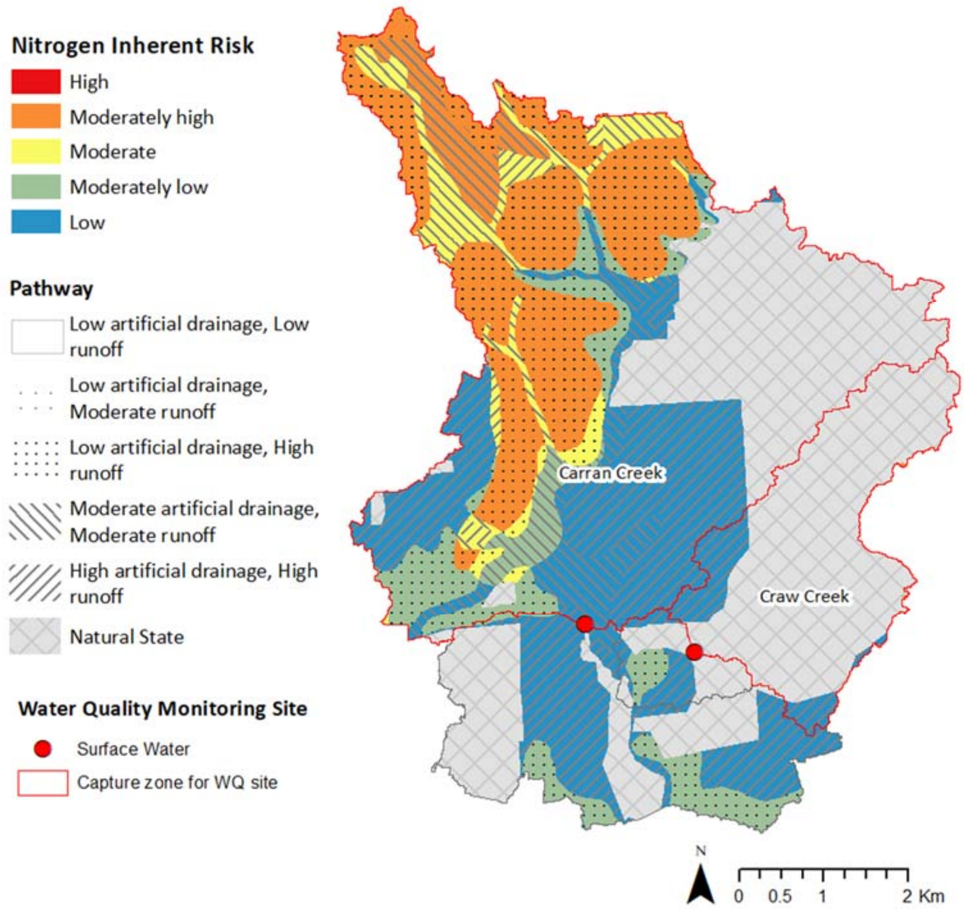

Figure 9.2: Inherent risk of nitrogen transported through the soil zone to the aquifer. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport.

Table 9.3: Nitrogen risk by loss through the soil zone to the aquifer in Carran Creek and Craws Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Carran Creek is calculated by the entire subcatchment area.

	Carran Creek at Waituna Lagoon Road		**Carran Creek unmonitored**		**Craws Creek at Waituna Lagoon Rd**		**Craws Creek unmonitored**		**Carran Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Mod. High										
Low artificial drainage, low runoff	0.8	0.1	1.0	0.1					1.8	0.04
Low artificial drainage, moderate runoff	12.6	1.5							12.6	0.3
Low artificial drainage, high runoff	703.5	84.6							703.5	16.4
Moderate artificial drainage, moderate runoff	113.4	13.6							113.4	2.6
Mod. High Total	**830.3**	**99.9**	**1.0**	**0.1**					**831.3**	**19.4**
Moderate										
Low artificial drainage, high runoff	38.2	15.8							38.2	0.9
Moderate artificial drainage, moderate runoff	164.4	67.8							164.4	3.8
High artificial drainage, high runoff	39.9	16.4							39.9	0.9
Moderate Total	**242.5**	**100**							**242.5**	**5.7**
Mod. Low										
Low artificial drainage, high runoff	194.6	47.7	16.3	4.0	104.4	25.6	4.8	1.2	320.1	7.5
Moderate artificial drainage, moderate runoff	69.1	16.9							69.1	1.6
Natural state hydrology	11.5	2.8	3.3	0.8	3.9	0.9			18.7	0.4
Mod. Low Total	**275.1**	**67.5**	**19.7**	**4.8**	**108.2**	**26.5**	**4.8**	**1.2**	**407.8**	**9.5**
Low										
Moderate artificial drainage, moderate runoff	178.7	6.4			5.1	0.2			183.8	4.3
High artificial drainage, high runoff	530.6	18.9	103.3	3.7	311.2	11.1	17.9	0.6	963.1	22.5
Natural state hydrology	681.6	24.3	658.3	23.5	309.8	11.1	5.5	0.2	1,655.2	38.6
Low Total	**1,390.9**	**49.6**	**761.5**	**27.2**	**626.2**	**22.3**	**23.5**	**0.8**	**2,802.1**	**65.4**
Capture Area Total	**2,738.9**	**63.9**	**782.3**	**18.3**	**734.4**	**17.1**	**28.3**	**0.7**	**4,283.8**	**100**

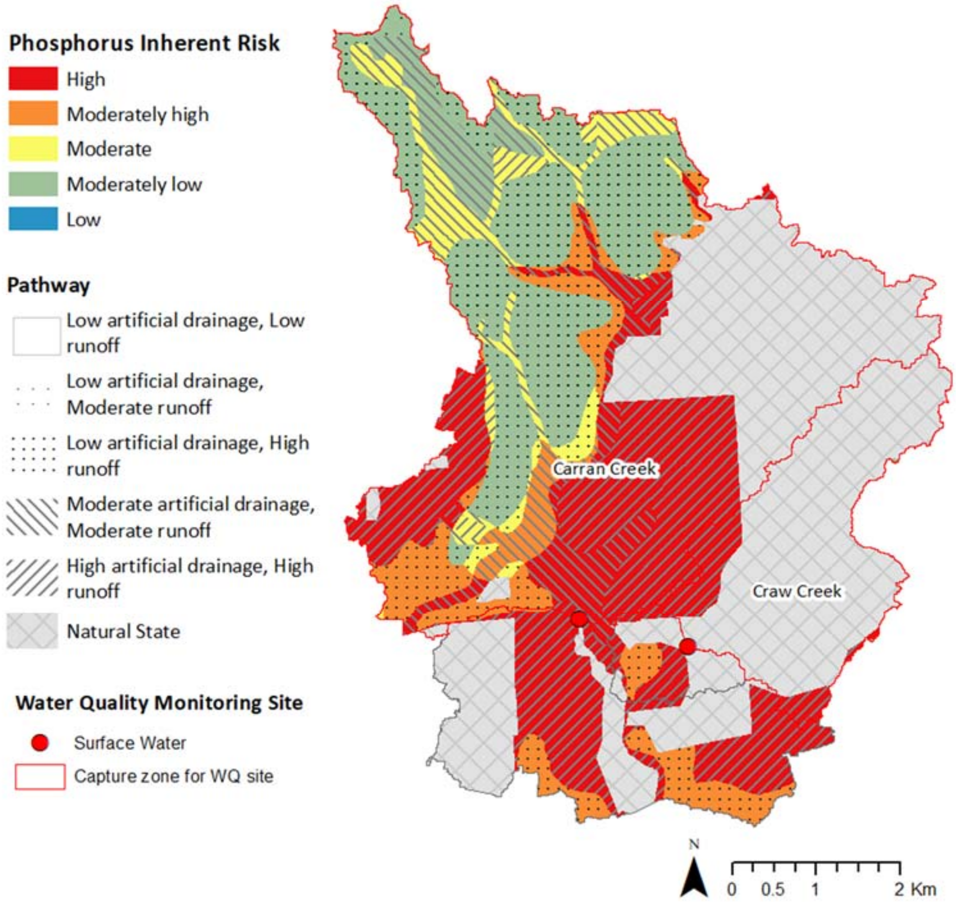

Figure 9.3: Inherent risk of (dissolved) phosphorus transported through the soil zone to the aquifer for Carran Creek Catchment. The pathway shows the surficial risk by artificial drainage and overland flow for sediment-bound P. Natural state identifies source limited areas with minimal contaminants to transport.

Table 9.4: Phosphorus risk by loss through the soil zone to the aquifer for Carran Creek. The hydrological pathway shows the surficial risk by artificial drainage and overland flow. The percentage is calculated for each inherent risk category for the monitoring sites. The percentage for Carran Creek is calculated by the entire subcatchment area.

	Carran Creek at Waituna Lagoon Road		**Carran Creek unmonitored**		**Craws Creek at Waituna Lagoon Rd**		**Craws Creek unmonitored**		**Carran Creek Subcatchment**	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High										
Moderate artificial drainage, moderate runoff	178.7	6.4			5.1	6.4			183.8	4.3
High artificial drainage, high runoff	530.6	18.9	103.3	3.7	311.2	18.9	17.9	0.6	963.1	22.5
Natural state hydrology	681.6	24.3	658.3	23.5	309.8	24.3	5.5	0.2	1,655.2	38.6
High Total	**1,390.9**	**49.6**	**761.5**	**27.2**	**626.2**	**49.6**	**23.5**	**0.8**	**2,802.1**	**65.4**
Mod. High										
Low artificial drainage, high runoff	194.6	47.7	16.3	4.0	104.4	47.7	4.8	1.2	320.1	7.5
Moderate artificial drainage, moderate runoff	69.1	16.9							69.1	1.6
Natural state hydrology	11.5	2.8	3.3	0.8	3.9	2.8			18.7	0.4
Mod high Total	**275.1**	**67.5**	**19.7**	**4.8**	**108.2**	**67.5**	**4.8**	**1.2**	**407.8**	**9.5**
Moderate										
Low artificial drainage, high runoff	38.2	15.8							38.2	0.9
Moderate artificial drainage, moderate runoff	164.4	67.8							164.4	3.8
High artificial drainage, high runoff	39.9	16.4							39.9	0.9
Moderate total	**242.5**	**100**							**242.5**	**5.7**
Mod. Low										
Low artificial drainage, low runoff	0.8	0.1							1.8	0.04
Low artificial drainage, moderate runoff	12.6	1.5							12.6	0.3
Low artificial drainage, high runoff	703.5	84.6							703.5	16.4
Moderate artificial drainage, moderate runoff	113.4	13.6							113.4	2.6
Mod low total	**830.3**	**99.9**							**831.3**	**19.4**
Capture Area Total	**2,738.9**	**63.9**	**782.3**	**18.3**	**734.4**	**63.9**	**28.3**	**0.7**	**4,283.8**	**100**

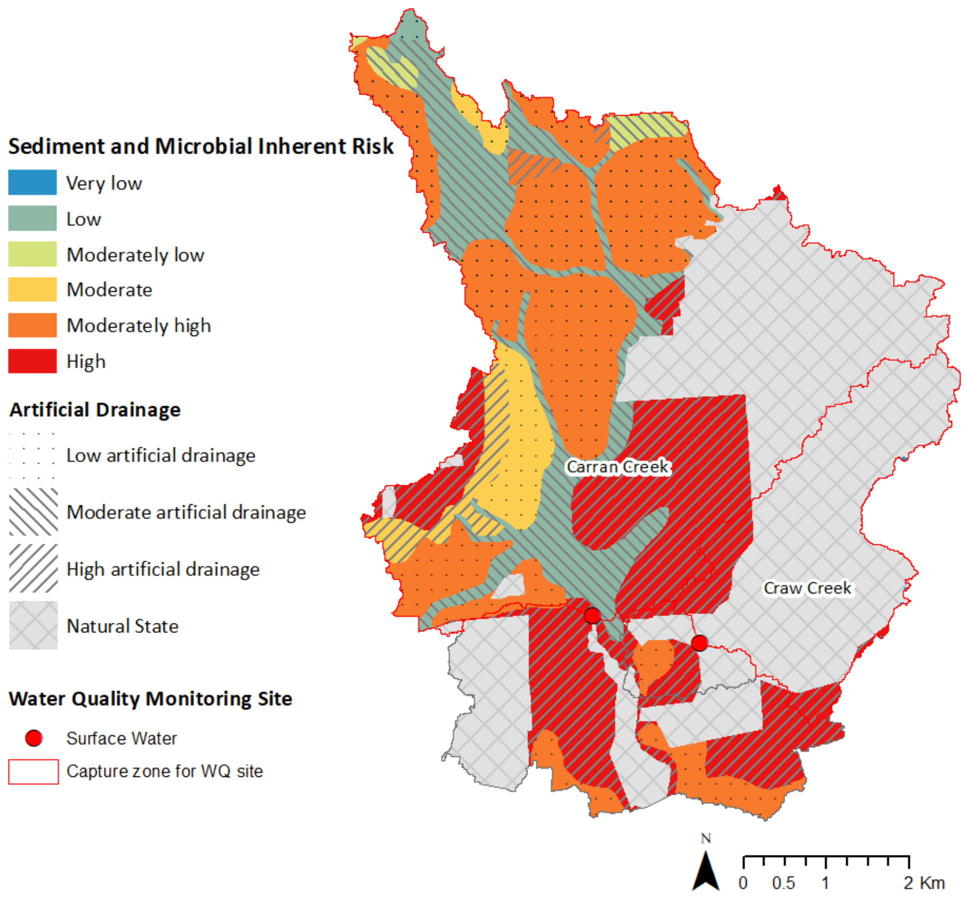

Figure 9.4: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff). Risk of loss is increased by catchment modification through artificial drainage.

Table 9.5: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff) and artificial drainage in Carran Creek.

	Carran Creek at Waituna Lagoon Road		Carran Creek unmonitored		Craws Creek at Waituna Lagoon Rd		Craws Creek unmonitored		Carran Creek Subcatchment	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
High										
High artificial drainage, high runoff	456.8	18.2	103.3	4.1	311.2	12.4	17.9	0.7	889.3	20.8
Natural state hydrology	653.0	26.0	658.3	26.2	309.8	12.3	5.5	0.2	1,626.6	38.0
High Total	**1,109.8**	**44.1**	**761.5**	**30.3**	**621.1**	**24.7**	**23.5**	**0.9**	**2,515.9**	**58.7**
Moderately High										
Low artificial drainage, high runoff	810.8	82.9	16.3	1.7	104.4	10.7	4.8	0.5	936.3	21.9
High artificial drainage, high runoff	23.3	2.4							23.3	0.5
Natural state hydrology	11.5	1.2	3.3	0.3	3.9	0.4			18.7	0.4
Moderately High Total	**845.6**	**86.4**	**19.7**	**2.0**	**108.2**	**11.1**	**4.8**	**0.5**	**978.3**	**22.8**
Moderate										
Low artificial drainage, high runoff	125.6	58.1							125.6	2.9
High artificial drainage, high runoff	90.4	41.9							90.4	2.1
Moderate Total	**216.0**	**100**							**216.0**	**5.0**
Moderately Low										
Low artificial drainage, moderate runoff	2.1	4.1							2.1	0.05
Moderate artificial drainage, moderate runoff	48.1	95.9							48.1	1.1
Moderately Low Total	**50.2**	**100**							**50.2**	**1.2**
Low										
Low artificial drainage, moderate runoff	10.5	2.0							10.5	0.2
Moderate artificial drainage, moderate runoff	477.5	91.5			5.1	1.0			482.6	11.3
Natural state hydrology	28.6	5.5							28.6	0.7
Low Total	**516.6**	**99.0**			**5.1**	**1.0**			**521.7**	**12.2**
Very Low										
Low artificial drainage, low runoff	0.8	42.4	1.0	57.6					1.8	0.04
Very Low Total	**0.8**	**42.4**	**1.0**	**57.6**					**1.8**	**0.04**
Capture Area Total	**2,738.9**	**63.9**	**782.3**	**18.3**	**734.4**	**17.1**	**28.3**	**0.7**	**4,283.8**	**100**

10 Direct Contribution Stocktake

10.1 Fundamental Landscape Unit Stocktake

The area of direct contribution to Waituna Lagoon comprises 11.9% (2,295.7 ha) of the Waituna Lagoon Catchment (Figure 10.1). There are four FLU families located within this direct contribution area, Wetland Complex, Marine Terraces, Reducing, and Oxidising (Table 10.1). Wetland Complex covers the largest extent at 1,247 ha (54.3%), of which 40.1% is in natural state conservation estate. The Reducing Family has the second largest extent, comprising 750.8 ha (32.7%). The zone of direct contribution is the only area where the Oxidising Recent soil over beach sands and gravel is found within the lagoon catchment.

This area of Waituna Catchment has no water quality monitoring sites. There are some small creeks which discharge directly to the lagoon in this area (Figure 10.1).

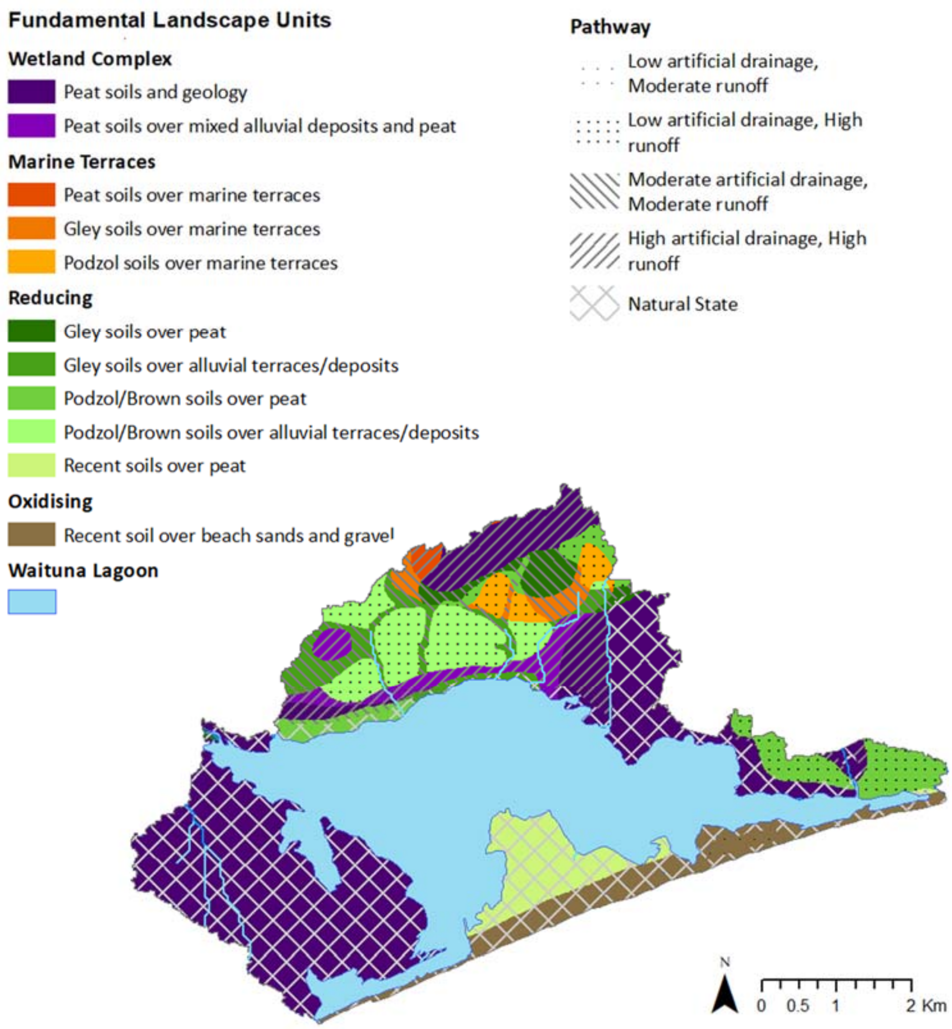

Figure 10.1: FLUs within the area of direct contribution to Waituna Lagoon.

Table 10.1: Area and percentage of Fundamental Landscape Units for the area of direct contribution to Waituna Lagoon.

	Direct Contribution (unmonitored)		
	(Ha)	Family (%)	Total (%)
Wetland Complex			
Peat soils and geology	1,149.1	92.2	50.1
High artificial drainage, high runoff	*221.1*	*17.7*	*9.6*
Natural state hydrology	*928.0*	*74.4*	*40.4*
Peat soils over mixed alluvial deposits and peat	97.8	7.8	4.3
High artificial drainage, high runoff	*94.4*	*7.6*	*4.1*
Natural state hydrology	*3.4*	*0.3*	*0.1*
Wetland Complex Family	**1,247.0**	**100**	**54.3**
Marine Terraces			
Gley soils over marine terraces	42.8	39.8	1.9
Moderate artificial drainage, moderate runoff	*42.8*	*39.8*	*1.9*
Peat soils over marine terraces	14.8	13.7	0.6
High artificial drainage, high runoff	*14.8*	*13.7*	*0.6*
Podzol soils over marine terraces	50.0	46.5	2.2
Low artificial drainage, high runoff	*50.0*	*46.5*	*2.2*
Marine Terrace Family	**107.6**	**100**	**4.7**
Reducing			
Gley soils over alluvial terraces/deposits	121.9	16.2	5.3
Moderate artificial drainage, moderate runoff	*111.1*	*14.8*	*4.8*
Natural state hydrology	*10.8*	*1.4*	*0.5*
Gley soils over peat	65.1	8.7	2.8
Moderate artificial drainage, moderate runoff	*60.6*	*8.1*	*2.6*
Natural state hydrology	*4.4*	*0.6*	*0.2*
Podzol/Brown soils over alluvial terraces/deposits	210.8	28.1	9.2
Low artificial drainage, high runoff	*210.8*	*28.1*	*9.2*
Recent soils over peat	162.9	21.7	7.1
Natural state hydrology	*162.9*	*21.7*	*7.1*
Podzol/Brown soils over peat	190.1	25.3	8.3
Low artificial drainage, high runoff	*138.6*	*18.5*	*6.0*
Moderate artificial drainage, moderate runoff	*17.4*	*2.3*	*0.8*
Natural state hydrology	*34.1*	*4.5*	*1.5*
Reducing Family	**750.8**	**100**	**32.7**
Oxidising			
Recent soil over beach sands and gravel	190.4	100	8.3
Low artificial drainage, moderate runoff	*18.8*	*9.9*	*0.8*
Natural state hydrology	*171.5*	*90.1*	*7.5*
Oxidising family	**190.4**	**100**	**8.3**
Total area	**2,295.7**		**100**

10.2 Hydrological Pathway

The zone of direct contribution to Waituna Lagoon is predominantly (57.3%) natural state hydrology (Table 10.2). Due to the shallowness of the water table in this area, the likely dominant hydrological pathway is through lateral flow to small creeks surrounding the lagoon.

In agriculturally developed areas, the dominant pathway for water movement is lateral drainage through the soil profile which intersects the moderate to high-density artificial drainage network (Table 10.2). Lateral flow occurs due to the shallowness of the water table in this zone and a general decline in the permeability of subsoil environments associated with pan formation and/or higher density amorphous peat.

The zone of direct discharge to Waituna Lagoon also has a relatively high potential for localised overland flow due to the seasonally high water table. However, in developed areas this potential may not be fully realised due to the high density of artificial drainage.

Table 10.2: Area and percentage of hydrological pathways for the area of direct contribution to Waituna Lagoon.

	Direct Contribution (unmonitored)	
	(Ha)	**(%)**
Low artificial drainage, moderate runoff	18.8	0.8
Low artificial drainage, high runoff	399.4	17.4
Moderate artificial drainage, moderate runoff	231.9	10.1
High artificial drainage, high runoff	330.3	14.4
Natural state hydrology	1,315.3	57.3
Total	2,295.7	100

10.3 Water Quality Risk

Recent work on the role the area of direct contribution has over water quality in the Waituna Lagoon raises the potential of a significant direct groundwater contribution to the lagoon (Rissmann et al., 2012; Guerin and Wourms, 2016). Specifically, there is evidence for a significant shallow groundwater contribution directly to the western beachfront of the lagoon (Rissmann et al., 2012; Guerin and Wourms, 2016, Rissmann et al., 2018). Here, the opening of the lagoon for drainage results in a rapid drop in groundwater level and discharge to the lagoon. These shallow groundwaters show high concentrations of P with tentative and uncertain estimates of a direct P load that may be as large as that associated with the entire surface water network load. It is significant to note that wintering on virgin peat soils within the area of direct contribution was associated with extreme P leaching rates (Monaghan and McDowell,2015). Towards the east and Carran Creek the connection between shallow aquifers and the lagoon is limited. However, overland flow risk is also elevated along the fringes of the lagoon with a moderately high to high inherent risk of direct nitrogen, phosphorus, sediment and microbial export to the lagoon where the land is developed. Refinement of the contribution made from the area of direct contribution to the lagoon nutrient load requires an evaluation of water flux from successive opening and closing events and sampling of local groundwaters from bores around the lagoon. Repeat measures of concentrations from inflows associated with the many small streams would further aid in refining the contribution from this important area directly to the lagoon.

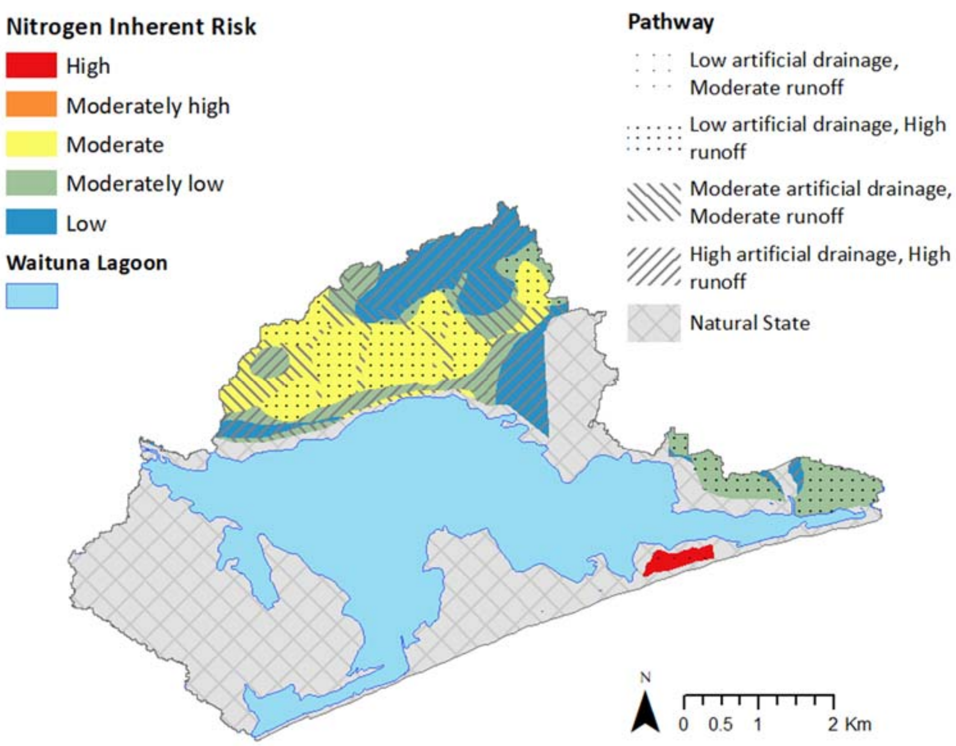

Figure 10.2: Inherent risk of nitrogen transported through the soil zone to the aquifer in the area of direct contribution to Waituna Lagoon. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport.

Table 10.3: Area and percentage of nitrogen risk for the area of direct contribution to Waituna Lagoon.

	Direct Contribution (unmonitored)		
	(Ha)	Unit (%)	Total (%)
High			
Low artificial drainage, moderate runoff	18.8	9.9	0.8
Natural state hydrology	171.5	90.1	7.5
High Total	**190.4**	**100**	**8.3**
Moderate			
Low artificial drainage, high runoff	260.8	47.4	11.4
Moderate artificial drainage, moderate runoff	115.6	21.0	5.0
Natural state hydrology	173.7	31.6	7.6
Moderate Total	**550.1**	**100**	**24.0**
Mod. Low			
Low artificial drainage, high runoff	138.6	40.6	6.0
Moderate artificial drainage, moderate runoff	55.7	16.3	2.4
High artificial drainage, high runoff	109.2	32.0	4.8
Natural state hydrology	37.5	11.0	1.6
Mod. Low Total	**341.0**	**100**	**14.9**
Low			
Moderate artificial drainage, moderate runoff	60.6	2.6	2.6
High artificial drainage, high runoff	221.1	9.6	9.6
Natural state hydrology	932.4	40.6	40.6
Low Total	**1,214.2**	**52.9**	**52.9**
Capture Area Total	**2,295.7**	**100**	**100**

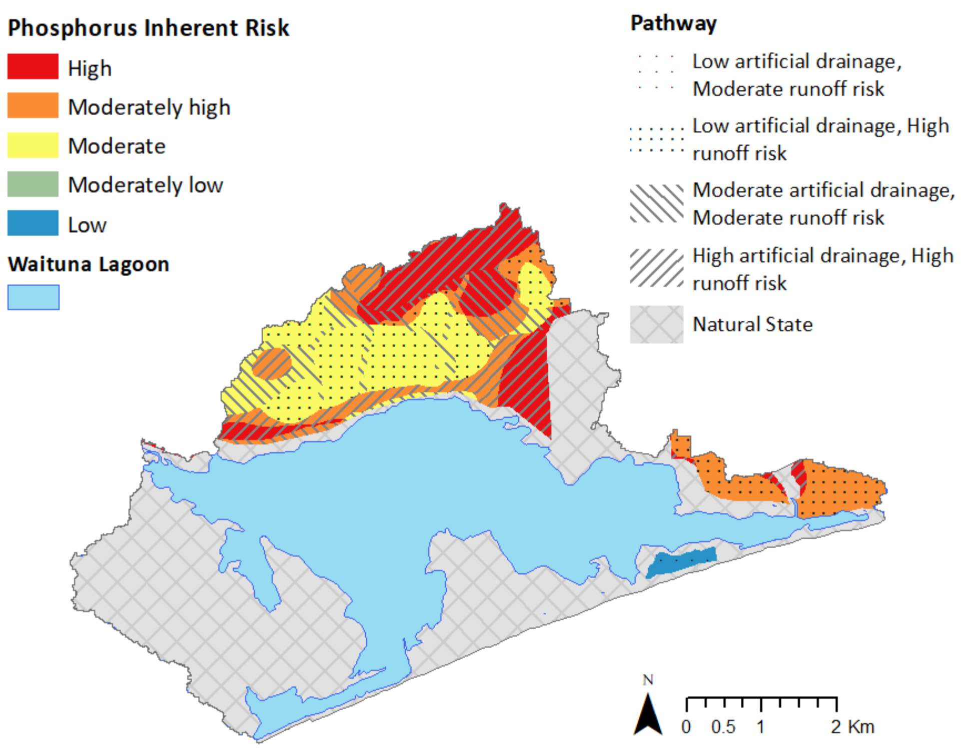

Figure 10.3: Inherent risk of (dissolved) phosphorus transported through the soil zone to the aquifer. The pathway shows the surficial risk by artificial drainage and overland flow for sediment-bound P. Natural state identifies source limited areas with minimal contaminants to transport.

Table 10.4: Area and percentage of phosphorus risk for the area of direct contribution to Waituna Lagoon.

	Direct Contribution (unmonitored)		
	(Ha)	Unit (%)	Total (%)
High			
Moderate artificial drainage, moderate runoff	60.6	5.0	2.6
High artificial drainage, high runoff	221.1	18.2	9.6
Natural state hydrology	932.4	76.8	40.6
High Total	**1,214.2**	**100**	**52.9**
Mod. High			
Low artificial drainage, high runoff	138.6	40.6	6.0
Moderate artificial drainage, moderate runoff	55.7	16.3	2.4
High artificial drainage, high runoff	109.2	32.0	4.8
Natural state hydrology	37.5	11.0	1.6
Mod high Total	**341.0**	**100**	**14.9**
Moderate			
Low artificial drainage, high runoff	260.8	47.4	11.4
Moderate artificial drainage, moderate runoff	115.6	21.0	5.0
Natural state hydrology	173.7	31.6	7.6
Moderate total	**550.1**	**100**	**24.0**
Low			
Low artificial drainage, moderate runoff	18.8	0.8	0.8
Natural state hydrology	171.5	7.5	7.5
Low total	**190.4**	**8.3**	**8.3**
Capture Area Total	**2,295.7**	**100**	**100**

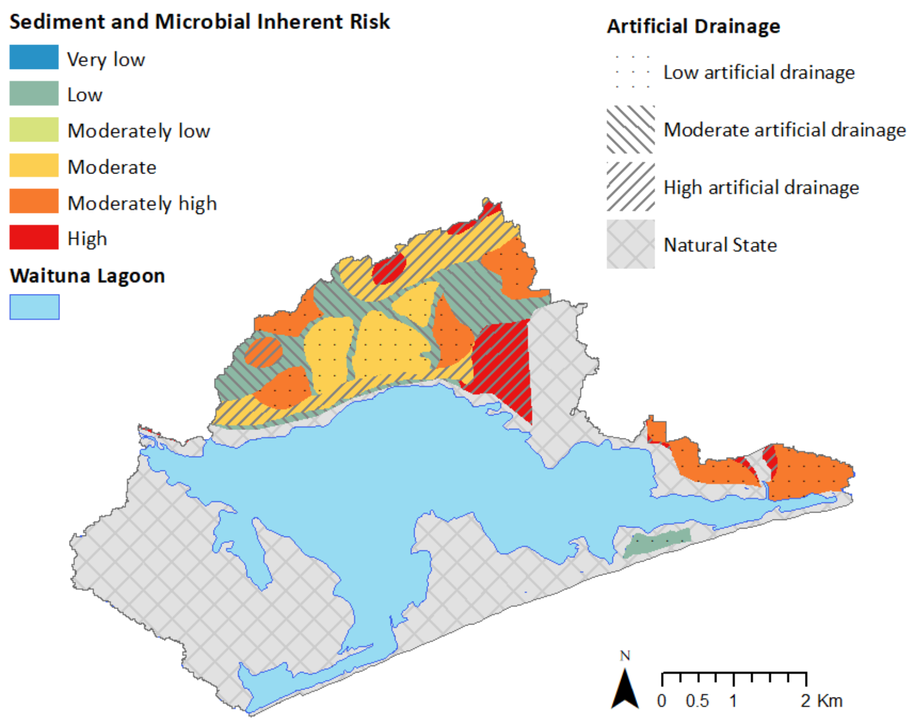

Figure 10.4: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff). Risk of loss is increased by catchment modification through artificial drainage.

Table 10.5: Area and percentage of sediment and microbial risk for the area of direct contribution to Waituna Lagoon.

	Direct Contribution (unmonitored)		
	(Ha)	Unit (%)	Total (%)
High			
High artificial drainage, high runoff	123.9	11.7	5.4
Natural state hydrology	930.7	88.3	40.5
High Total	**1,054.6**	**100**	**45.9**
Moderately High			
Low artificial drainage, high runoff	247.3	91.7	10.8
High artificial drainage, high runoff	17.5	6.5	0.8
Natural state hydrology	5.0	1.8	0.2
Moderately High Total	**269.9**	**100**	**11.8**
Moderate			
Low artificial drainage, high runoff	152.1	44.6	6.6
High artificial drainage, high runoff	188.9	55.4	8.2
Moderate Total	**340.9**	**100**	**14.9**
Low			
Low artificial drainage, moderate runoff	18.8	4.1	0.8
Moderate artificial drainage, moderate runoff	231.9	50.2	10.1
Natural state hydrology	210.8	45.7	9.2
Low Total	**461.6**	**100**	**20.1**
Very Low			
Natural state hydrology	168.7	100	7.3
Very Low Total	**168.7**	**100**	**7.3**
Capture Area Total	**2,295.7**	**100**	**100**

11 Summary

This section compares and contrasts the different inherent risks of each subcatchment within the broader Waituna Lagoon Catchment for each of the dominant hydrological pathways. This assessment contrasts the difference between subcatchments as a percentage, as well as the difference in terms of relative areas, to aid in the prioritisation of catchment investments by Living Water.

11.1 Deep Drainage

Deep drainage is the pathway by which the dissolved forms of nutrients is predominantly transported. This section has been summarised by N and P as the transport risk for each contaminant is inversely related.

11.1.1 Nitrogen (Nitrate and TN)

Waituna Creek catchment is the subcatchment with the highest nitrate, and hence TN risk, with >70% of the subcatchment associated with a moderately high to high risk (Figure 11.1, Table 11.1). Proportionately, the Carran Creek subcatchment, especially its headwater area, has the second largest area of moderate nitrate risk within the catchment followed by the Moffat Creek subcatchment. Nitrate, and hence TN risk, is lowest for the Craws Creek subcatchment due to both a large area of natural state peat wetland and reducing soils and aquifers. The actual risk by hectare, shown in Figure 11.2 also shows Waituna Creek to have the largest area of high N loss, followed by Carran Creek.

The important role of the northern portion of the catchment over TN and nitrate export to Waituna Lagoon has long been recognised (Waituna Lagoon Technical Group, 2013; Rissmann et al., 2012). Any efforts to reduce TN and nitrate export to the Waituna Lagoon should focus on the areas of highest inherent N risk associated with better drained soils occurring across the northern portion of the catchment.

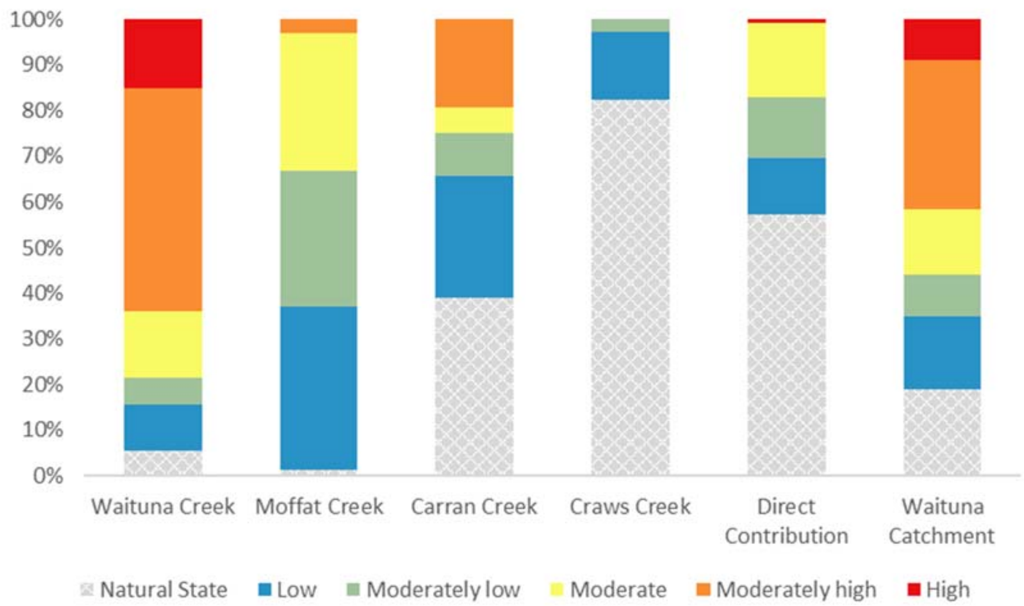

Figure 11.1: Proportional N risk by subcatchment and total Waituna Catchment.

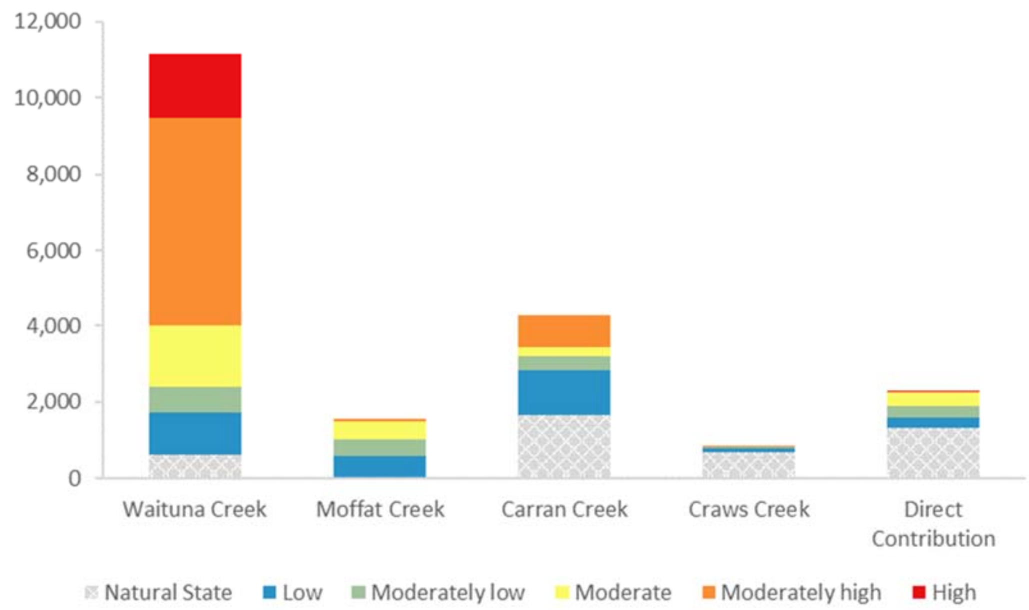

Figure 11.2: Actual nitrogen risk by subcatchment.

Table 11.1: Area (ha) of inherent nitrogen risk.

	Waituna Creek	Moffat Creek	Carran Creek	Craws Creek	Direct Contribution	Waituna Catchment
High	1,685.6	-	-	-	18.8	1,704.4
Moderately high	5,445.1	45.6	831.3	1.0	-	6,322.0
Moderate	1,636.3	467.1	242.5	-	376.4	2,722.3
Moderately low	669.2	457.4	389.2	21.1	303.5	1,819.2
Low	1,107.1	554.5	1,146.9	121.2	281.7	3,090.2
Natural State	615.2	18.2	1,673.9	667.1	1,315.3	3,622.5
Total area	11,158.4	1,542.7	4,283.8	810.5	2,295.7	19,280.6

11.1.2 Phosphorus (DRP) and TKN

The Moffat Creek subcatchment has the highest proportionate DRP risk, with >70% of the subcatchment associated with a moderately high to high-risk category (Figure 11.3, Table 11.2). Proportionately, the Carran Creek subcatchment, especially across its lowest reaches, and the area of developed land associated with the zone of direct contribution both exhibiting a relatively high proportional DRP risk. Overall, the proportional DRP risk is lowest for the Waituna Creek subcatchment. By actual area, both Waituna Creek and Carran Creek, have twice as much land area within the high-risk area than Moffat Creek (Figure 11.4).

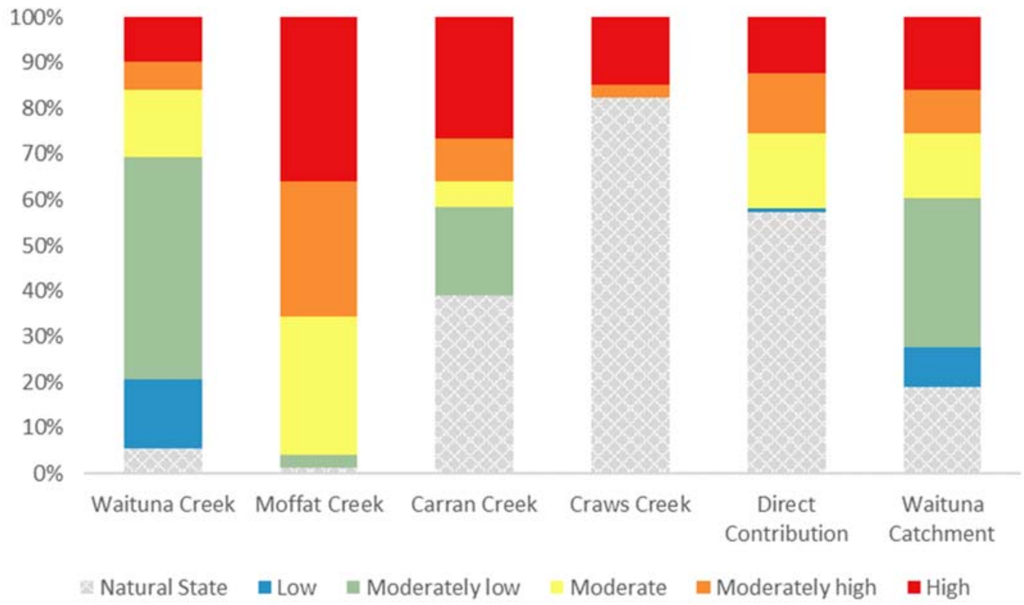

Figure 11.3: Proportional P risk by subcatchment and total Waituna Catchment.

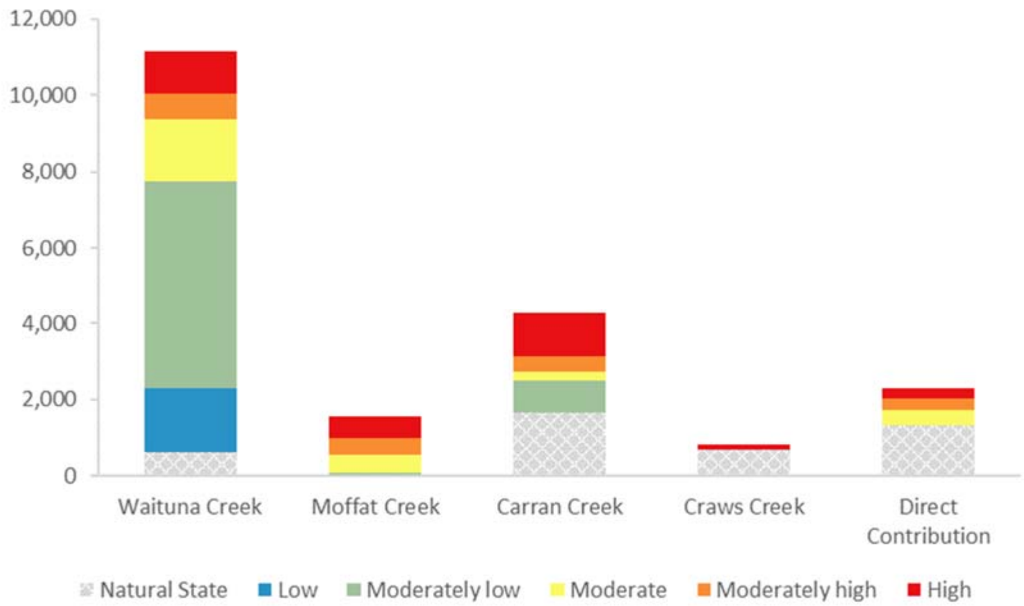

Figure 11.4: Actual phosphorus risk by subcatchment.

Table 11.2: Area (ha) of DRP risk.

	Waituna Creek	Moffat Creek	Carran Creek	Craws Creek	Direct Contribution	Waituna Catchment
High	1,107.1	554.5	1,146.9	121.2	281.7	3,090.2
Moderately high	669.2	457.4	389.2	21.1	303.5	1,819.2
Moderate	1,636.3	467.1	242.5	-	376.4	2,722.3
Moderately low	5,445.1	45.6	831.3	1.0	-	6,322.0
Low	1,685.6	-	-	-	18.8	1,704.4
Natural State	615.2	18.2	1,673.9	667.1	1,315.3	3,622.5
Total area	11,158.4	1,542.7	4,283.8	810.5	2,295.7	19,280.6

11.2 Overland Flow (Particulate P, Sediment, Microbes, and TKN)

Sediment and microbes are predominantly transported by overland flow. The organic and ammoniacal forms of nitrogen (TKN) and Particulate Phosphorus (PP) are primarily exported by overland flow (OLF). However, soil reduction potential also influences the inherent risk of both of these contaminants.

Proportionately, the Moffat Creek subcatchment has the greatest area of high risk followed by the Carran Creek subcatchment (Figure 11.5, Table 11.3). Relative to the area of developed land the Craws Creek subcatchment has a large proportionate area of high risk to TKN and TP export. Overall, the Waituna Creek subcatchment has the lowest proportional area of moderately high to high risk to TKN and TP export.

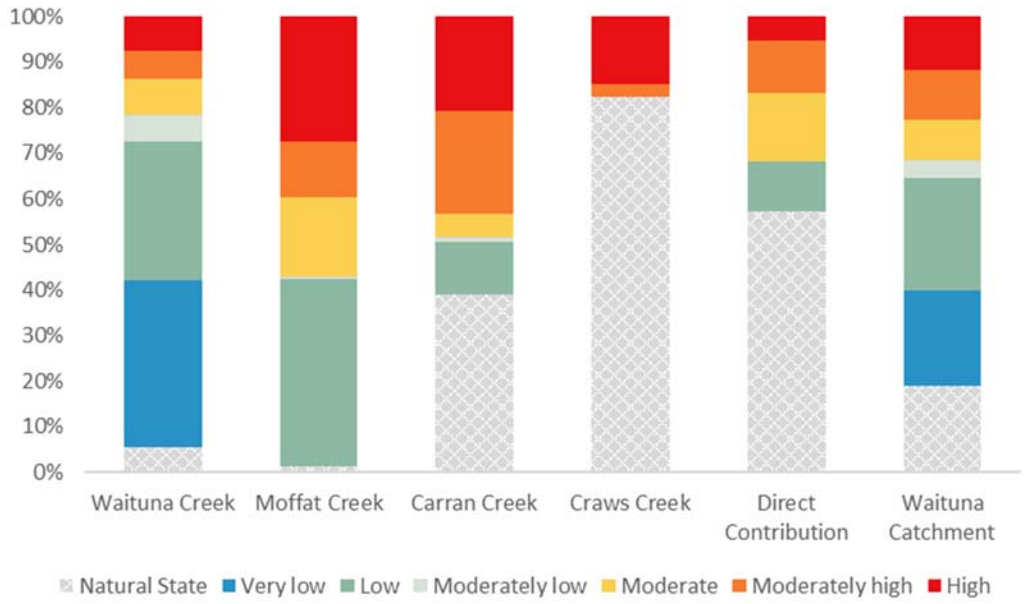

Figure 11.5: Proportional risk of overland flow by subcatchment and total Waituna Catchment.

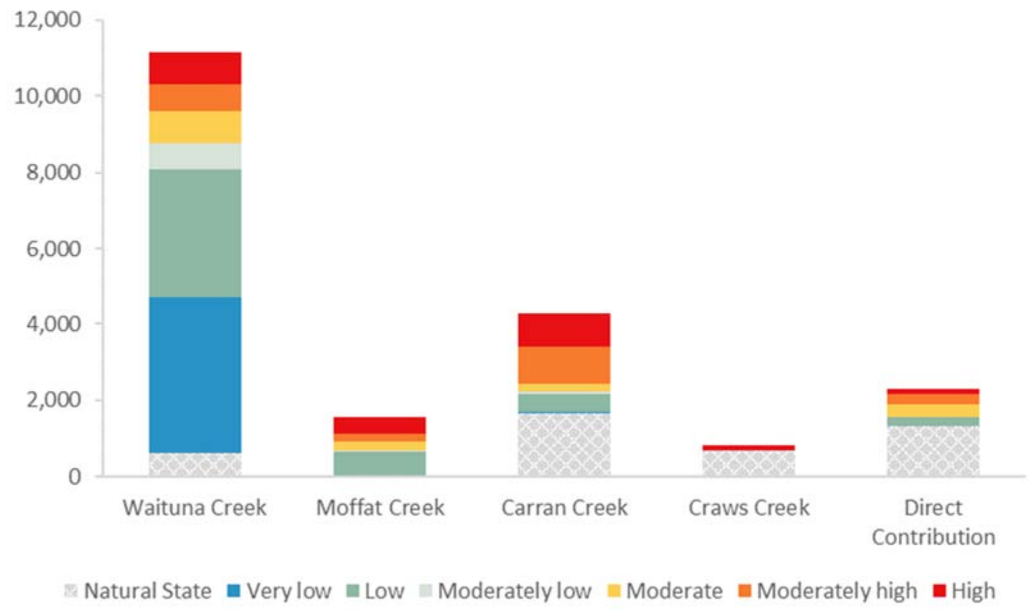

Figure 11.6: Actual overland flow risk by subcatchment.

Table 11.3: Contaminant loss risk through overland flow by catchment area (ha).

	Waituna Creek	Moffat Creek	Carran Creek	Craws Creek	Direct Contribution	Waituna Catchment
High	828.7	425.2	889.3	121.2	123.9	2,267.1
Moderately high	711.3	186.4	959.6	21.1	264.9	2,122.2
Moderate	855.9	265.4	216.0	-	340.9	1,678.2
Moderately low	665.7	11.5	50.2	-	-	727.3
Low	3,384.1	636.1	493.1	-	250.7	4,764.0
Very low	4,097.5	-	1.8	1.0	-	4,099.3
Natural State	615.2	18.2	1,673.9	667.1	1,315.3	3,622.5
	11,158.4	1,542.7	4,283.8	810.5	2,295.7	19,280.6

11.3 Artificial Drainage (all contaminants)

Artificial drainage accelerates the discharge of water from the catchment, therefore any contaminant can be transported through this pathway. However, artificial drainage is only active when soils have a high moisture content or in areas where the water table is shallow (associated with peat soils). The time that artificial drainage is active is lower in the northern part of the catchment compared to the south. Southern areas of Waituna Creek Catchment, with moderate to high drainage densities can respond rapidly to precipitation events, while the same magnitude event in the north of the catchment may be insufficient to activate this pathway. Proportionally Moffat Creek has the highest density of artificial drainage, followed by Carran Creek (Figure 11.7, Table 11.4). By catchment area, Waituna Creek has the largest area of high-density drainage (Figure 11.8).

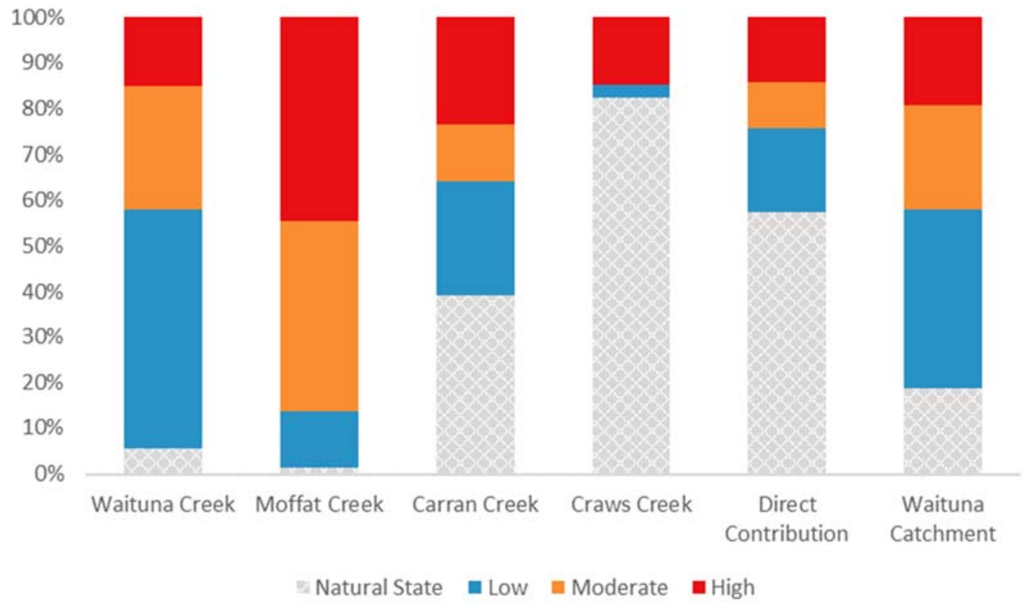

Figure 11.7: Proportional risk of artificial drainage by subcatchment and total Waituna Catchment.

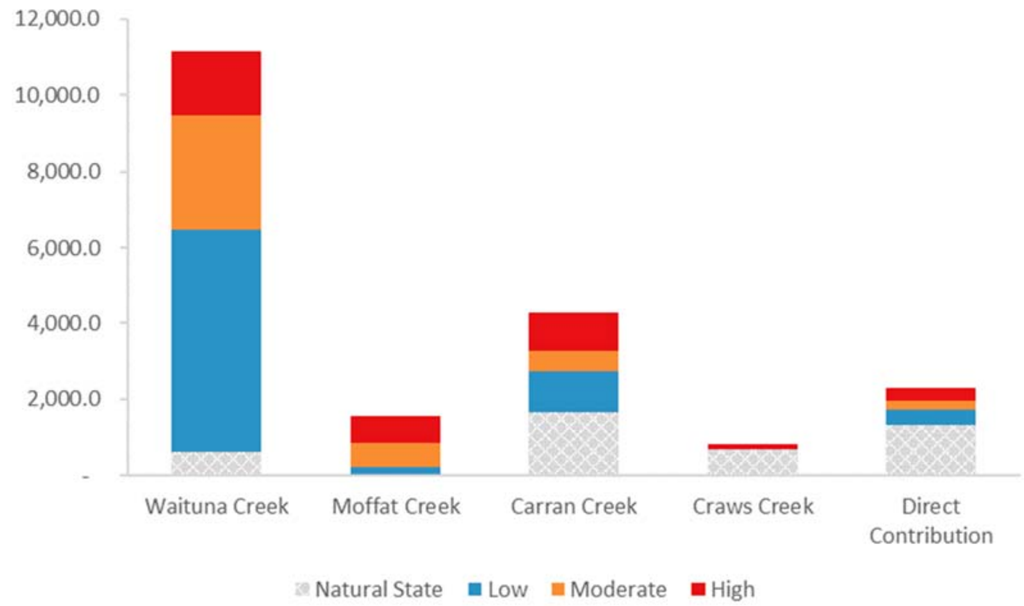

Figure 11.8: Actual artificial drainage risk by subcatchment.

Table 11.4: Contaminant loss risk through artificial drainage by catchment area (ha).

	Waituna Creek	Moffat Creek	Carran Creek	Craws Creek	Direct Contribution	Waituna Catchment
Low artificial drainage	5,864.3	190.3	1,076.2	22.2	418.2	7,549.0
Moderate artificial drainage	2,999.1	647.5	530.7	-	231.9	4,409.2
High artificial drainage	1,679.9	686.7	1,003.0	121.2	330.3	3,699.9
Natural state hydrology	615.2	18.2	1,673.9	667.1	1,315.3	3,622.5
Total area	11,158.4	1,542.7	4,283.8	810.5	2,295.7	19,280.6

11.4 Story Map

The information contained in this report has been summarised in a web-based application, ESRI Story Maps. The figures contained in this report have been provided over a base map of Southland, with main roads and land parcel boundaries to allow the user to easily locate and interrogate areas of interest. Maps have an interactive component allowing the user to view maps at farm or catchment scale.

Access to the Story Map is through the following URL: https://e3s.maps.arcgis.com/apps/MapJournal/index.html?appid=73571ecdd1e14f3eb3d07166952b897d

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