Waituna Catchment:
Physiographic Risk Assessment

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Land and Water Science Report 2018/02
July 2018

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Document Information
Land and Water Science Report No: 2018/02
Report Date: 31.07.2018
Project Number: 17018

Land and Water Science Reviewer: Abigail Lovett
Position: Project Manager and Senior Scientist
Review Date: 12.03.18

Living Water Reviewer: Nicki Atkinson
Organisation: Department of Conservation
Position: Freshwater Technical Advisor, Living Water South Island Manager
Review Date: 30.07.2018

Document Status: Final

Citation Advice
Pearson, L., Rissmann, C. and Lindsay, J. (2018). Waituna Catchment: Physiographic Risk Assessment. Land and Water Science Report 2018/02. Prepared for Living Water. 45p.

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 are spatially and temporally variable. The factors driving spatial and temporal variation include land use pressure and landscape attributes, within the soil and underlying geology. The factors driving temporal variation in water quality are mainly governed by climatic controls, both seasonal and event-driven. Living Water (a Fonterra and Department of Conservation partnership) commissioned a high-resolution physiographic assessment of the Waituna Lagoon Catchment, Southland, to support water quality and biodiversity investment decisions for the catchment. In this report, we produce outputs of the inherent risk to water quality associated with spatial variation in landscape properties specific to the Waituna Catchment. Temporal variation is incorporated through identifying the geographical location of the compartments supplying stream flow under different climatic conditions. A clear seasonal pattern exists in the Waituna Catchment with soil drainage starting in April (soil moisture >80% water-filled pores) and peaks in July. Surficial runoff is elevated during May to August with fewer runoff events in October to November.

The key outputs for this report are catchment scale maps of what we define as the 'inherent risk' for each of the main water quality parameters, nitrogen (N), phosphorus (P), sediment (S) and microbes (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 chemistry 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 Waituna Lagoon Catchment that form the basis for the development of numerical models to estimate variation in steady-state water quality outcomes. Specifically, models were produced that explain and accurately estimate spatial variation in steady-state Total Nitrogen (TN), nitrate and nitrite nitrogen (NNN), Total Kjeldahl Nitrogen (TKN, organic and ammoniacal nitrogen), Total Phosphorus (TP), Dissolved Reactive Phosphorus (DRP), Total Suspended Sediment (TSS), Volatile Suspended Sediment (VSS), Clarity, Turbidity and *E. coli*. (an indicator species for microbial contamination). Models and inherent risk maps can also be produced to estimate steady-state variation in other important indicators of water quality, e.g. Dissolved Oxygen (DO), pH, Potassium (K), Dissolved Organic Carbon (DOC) etc. For each of the inherent risk maps in the following report, we refer to the model outputs for each of the key water quality species and include the measure of performance and uncertainty.

Finally, the magnitude (scaling) of risk in the maps produced here are specific to the Waituna Lagoon 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 Lagoon Catchment.

1 Introduction

1.1 Overview

Living Water (a Fonterra and Department of Conservation partnership) commissioned a high-resolution physiographic assessment of the Waituna Lagoon 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 Lagoon 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 Lagoon Catchment in Southland, New Zealand. Shading shows areas of subcatchments including the area of direct contribution to Waituna Lagoon.

1.1.1 Supporting work

This report is based upon the high-resolution physiographic science for the Waituna Lagoon Catchment. There are two 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 Lagoon Catchment. The method for developing the high-resolution physiographic map and predictive model is reported.
- *Waituna Catchment: Temporal Variation* by Rissmann and Beyer (2018). This document assesses the temporal variation in water composition in the catchment providing flow and soil moisture thresholds of when surficial, soil and aquifers are contributing to stream flow.

1.1.2 Report Purpose and Structure

In this report, we provide a summary of key factors that control the loss and form of contaminants entering surface waterways (Section 2).

The following sections demonstrate how the high-resolution physiographic map was used to produce a risk assessment for the Waituna Lagoon Catchment for environmental contaminants, particularly nitrogen (N, Section 3), phosphorus (P, Section 4), sediment (S) and microbes (such as *E. coli*, M; Section 5). Temporal variation is incorporated in each section by identifying the geographical location of the compartments supplying stream flow under different climatic conditions (i.e., soil moisture conditions or stream flow). The physiographic model, developed in Rissmann et al (2018) is applied to estimate water quality for each subcatchment and the zone of direct contribution to Waituna Lagoon (Section 6).

2 Background Information

Depending on the setting and climatic events, 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 (MfE, 2014) for reduction to improve water quality in New Zealand.

The key controls over variability in water quality outcomes across the Waituna Lagoon 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.

2.1 Hydrological Pathways

All contaminants are transported by water; therefore the pathway water takes across or through the land surface influences the type and magnitude of contaminants transported to waterways. All water within the Waituna Lagoon 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 2.1; 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; Inamdar, 2011). Contaminants from land use are deposited at the land surface where concentrations of land use derived contaminants reach a maximum. 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; Rissmann and Beyer, 2018).

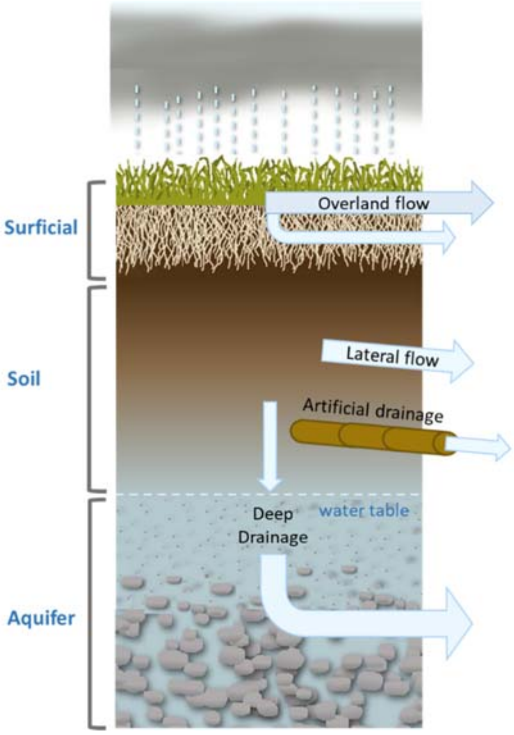

Figure 2.1: The hydrological flow pathways identified in Waituna catchment are overland flow, lateral flow, artificial drainage and deep drainage (Rissmann et al., 2018). Through hydrograph separation, the main sources of water supplying streams are identified as surficial (which includes the land surface and the upper 150 – 300 mm of soil), the soil zone (and 'C' horizon) which overlies the shallow aquifer(s). Arrows showing water direction are not to scale.

2.2 Temporal Variation

Surface water composition varies with flow, 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 (Figure 2.1). Rather, drainage from each compartment occurs in response to seasonal climatic cycles and lower frequency high-intensity precipitation events. The switching 'on' and 'off' of the compartments supplying stream results in temporal variation in water quality and composition across a 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 and transporting excess contaminants. When soils dry up in response to warmer weather and higher rates of evapotranspiration the flow of soil water decreases and/or stops.

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 2.1). 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 2.1: 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)

2.3 Inherent Risk

The characteristic attributes of the landscape define the inherent risk. Therefore, attributes such as soil drainage and carbon content become critical in assessing inherent risk for contaminant loss. Water moving through the soil into an aquifer by deep drainage or by overland flow are inherent risks. Artificial drainage, a modification to the drainage characteristics of the soil, is an extrinsic risk. However, as water moves through all three of these pathways at different times of the year, they can't be considered in isolation. Therefore, the risk is assessed by dominant and secondary pathways depending on the contaminant form.

2.4 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 where the underlying landscape attributes are different (e.g. different assemblages of soils, geology and hydrology).

Therefore, 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 2.2; 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 PGU 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.

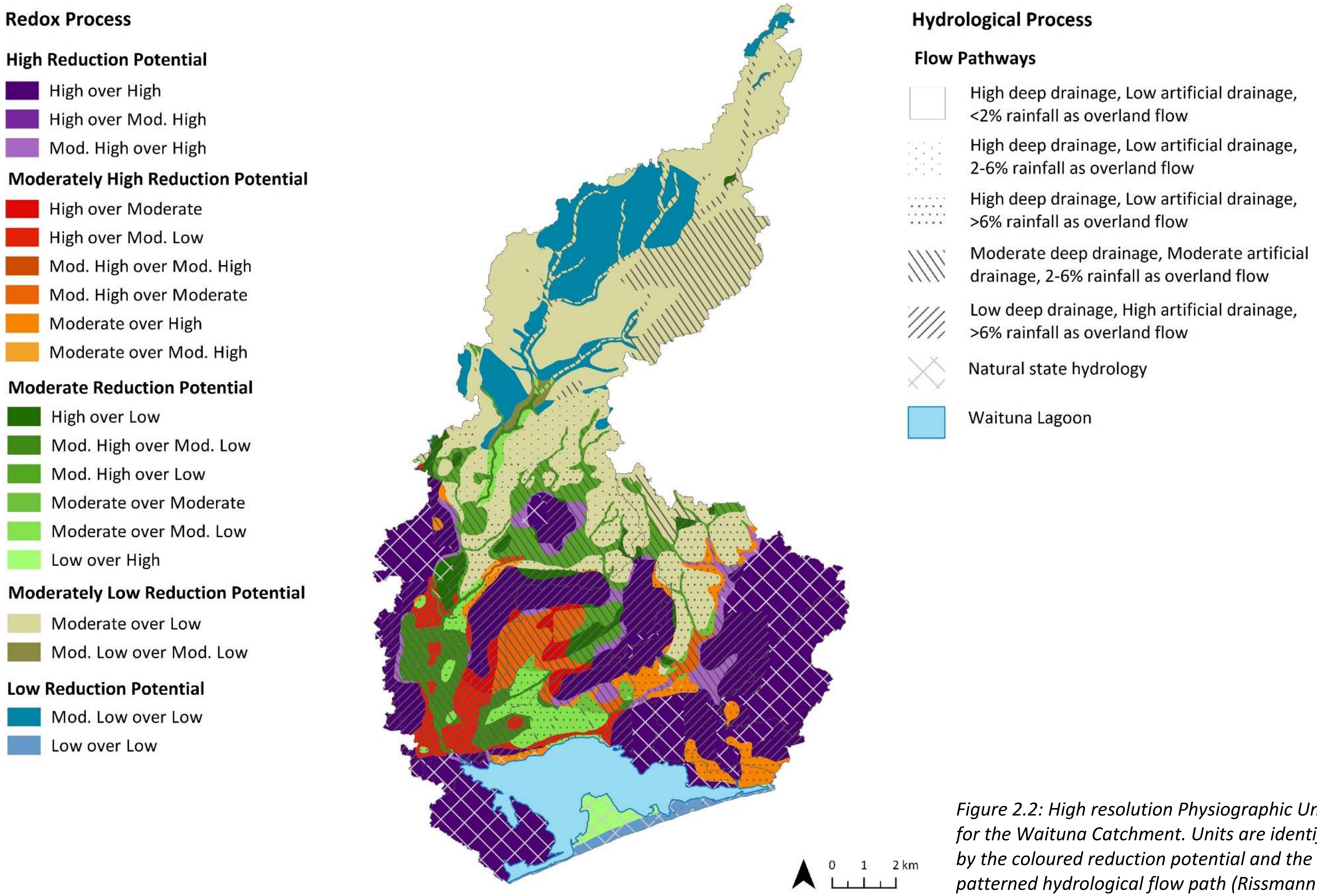

Figure 2.2: High resolution Physiographic Units for the Waituna Catchment. Units are identified by the coloured reduction potential and the patterned hydrological flow path (Rissmann et al., 2018).

2.5 Overview of Waituna Lagoon Catchment

2.5.1 Water Quality Monitoring Sites

There are 17 sites in the Waituna Lagoon Catchment with surface water monitoring data collected by Environment Southland (Table 2.2). Of the 17 sites, 5 are long-term monitoring sites, indicated in grey in Table 2.2. All available water quality monitoring data was selected between the years 2012 and 2016 for analysis. Median values were calculated for all analytes, except E.coli. Median values are used to remove the bias of high flow events in the data record. For *E. coli*, which is strongly correlated with high flow events, a subset of the data was selected for the year 2012 to remove climatic bias at sites with limited data and is reported as mean values. Figure 2.3 shows the location of the monitoring sites and capture areas which contribute to the monitoring point. Downstream monitoring points on the same river reach include the upper catchment area.

To aid in interpretation of water quality data presented in this report the following subsections provide a summary of the key factors controlling water quality including land use intensity, hydrological pathway, and the combined reduction potential of the soil and geological substrates.

Table 2.2: Surface water monitoring sites in Waituna Lagoon Catchment. The number of samples for the site is collected between the years 2012 and 2016 (inclusive). The main sites for each subcatchment are highlighted in grey.

Site No.	Site Name	Easting	Northing	No. of samples
	Waituna Creek			
1	Waituna Creek 1m upstream Rimu Seaward Downs Road	1266605	4851793	24
2	Waituna Creek 1m upstream Waituna Road	1261099	4847710	58
3	Waituna Creek NE tributary 10m upstream Waituna Creek Confluence	1261223	4845969	25
4	Waituna Creek SE trib 20m u/s Waituna Creek Confluence	1258355	4838917	22
5	Waituna Creek at Marshall Road	1258129	4838488	143
	Moffat Creek			
6*	Moffat Creek Sth branch 1.2km u/s Miller Road	1264016	4838470	13
7	Moffat Creek 20m u/s Hanson Road	1262043	4837367	14
8	Moffat Creek at Moffat Road	1260369	4836394	90
	Carran Creek			
9	Carran Creek west branch d/s Waituna Gorge Road	1265517	4841056	13
10	Carran Creek east branch u/s Waituna Gorge Road	1266646	4841244	13
11	Carran Creek 1km d/s Waituna Gorge Road	1267164	4840209	13
12	Carran Creek 3km u/s Waituna Lagoon Road	1268105	4839101	12
13	Carran Creek 800m u/s Waituna Lagoon Road	1267026	4837117	12
14*	Carran Creek drain 800m u/s Waituna Lagoon Road	1266988	4837201	13
15	Carran Creek at Waituna Lagoon Road	1266584	4836448	88
	Craws Creek			
16	Carran Creek tributary 1km u/s Waituna Lagoon Road	1267881	4836121	13
17	Carran Creek Trib at Waituna Lagoon Rd	1267080	4835836	45

*Sites excluded from the physiographic validation and testing dataset in Rissmann et al. (2018) due to strong land use signature.

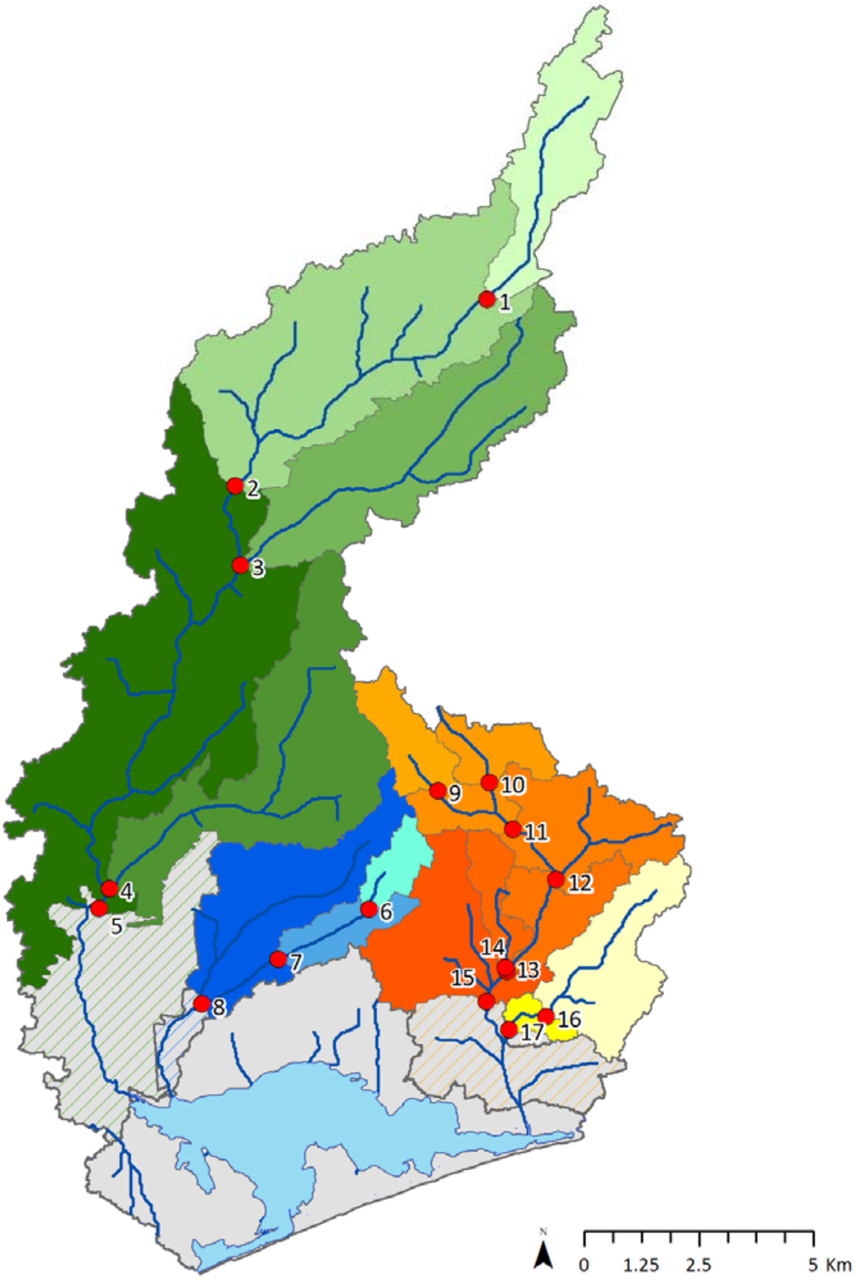

Figure 2.3: Surface water monitoring sites and capture zone within Waituna catchment. Waituna Creek catchment is represented in green, Moffat Creek catchment in blue, Carran Creek catchment in orange (includes Craws Creek) and Craws Creek catchment in yellow. Hatched areas show unmonitored areas within the subcatchments, coloured as identified above. The grey area is the unmonitored zone of direct contribution to Waituna Lagoon.

Rissmann et al. (2018) used this dataset to develop a physiographic model to predict water quality. The model is calibrated on the 5 long-term monitoring sites and can be used to estimate water quality at any point along a 3rd order or larger stream. It is possible that the model can estimate water quality for lower order streams, especially those with relatively large drainage areas, however, this has not been tested.

2.5.2 Land Use

The intensity of land use is an important factor controlling water quality. Waituna Lagoon Catchment has undergone significant catchment modification and land use/cover change, especially since the 1960s (Pearson and Couldrey, 2016). Along with land use change, the number of livestock within the catchment and wider Southland region has also intensified (Ledgard, 2013; Pearson and Couldrey, 2016). Figure 2.4 shows the actual and proportion areas of land use/cover for each monitoring site in Waituna Creek, including the unmonitored area of direct contribution to the lagoon.

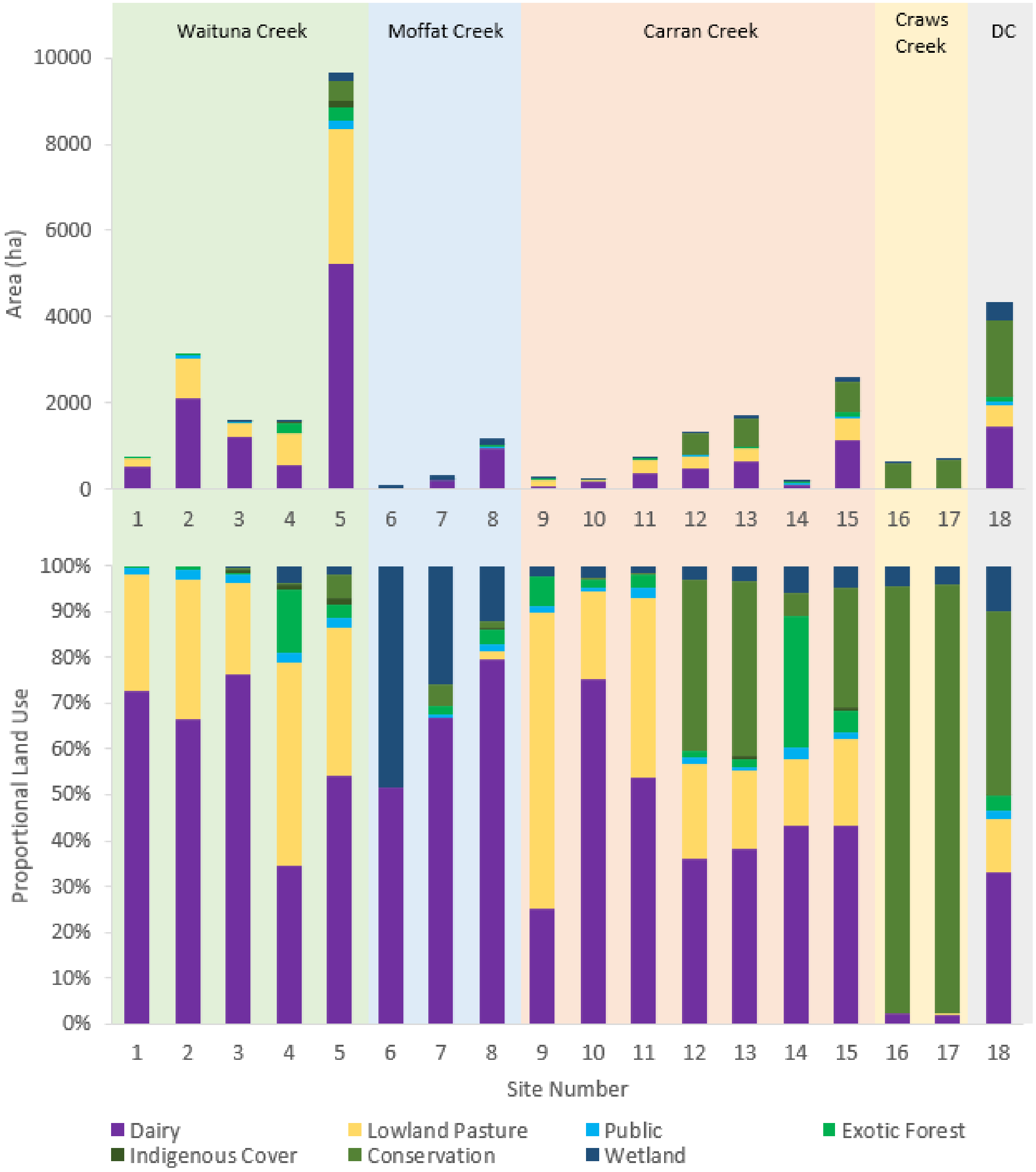

Figure 2.4: Land use/cover (ha) and proportional area (%) for each water quality monitoring site in Waituna Lagoon Catchment. Refer to Table 2.1 for site information. Site 18 is the unmonitored area of direct contribution (DC) to Waituna Lagoon. The figure is produced from an updated dataset following the method of Pearson and Couldrey (2016).

The high-resolution physiographic map and model for Waituna Catchment is independent of land use, with the exception of identifying natural state areas (Department of Conservation estate, and QEII covenants). As the physiographic model assumes a similar land intensity across the catchment, the ability of the model to accurately predict water quality is limited in areas where the land use is significantly different. For example, Site 14 in Carran Creek is sampled in a drain which was likely stagnant (very low DO) at times during the selected time period and is not a true representation of local hydrology for the capture zone associated with this catchment. This site was not included in the hypothesis testing and validation by Rissmann et al. (2018). Site 6 in Moffat Creek is also anomalous as the predominant land use in the capture area is the harvesting of peat, which has no agricultural inputs (i.e. fertilizer, animal wastes). Land cover data used to produce Figure 2.4 identifies this area as a wetland. Future iterations of the model could include a land use layer to overcome this limitation.

2.5.3 Hydrological Pathways

Water is the vehicle that transports land use derived contaminants from the land to water and the perennial hydrological network is the key distributor. Drainage from the northern portion of a catchment may be a key control over water composition and quality at its most distal sampling point.

In addition to the perennial stream network, finer grained variation in topography and soil hydrological properties determine the pathway water takes to the stream channel. Specifically, deep drainage or ‘vertical percolation’ of water through the soil to underlying aquifers; lateral drainage, where water mainly moves horizontally through the soil zone, commonly in association with subsurface artificial drains to an open drain or surface water body, and; overland flow that results in water running off across the land surface directly to open ditches or natural waterways.

The pathway water takes from the land to stream is a strong influence over the type of water quality outcomes (e.g. sediment vs. nitrate) as well as the magnitude of export. Specifically, it is widely recognised that the export of sediment, nutrients and microbes generally increases across the deep drainage > lateral > overland (or surficial) pathway continuum in intensively farmed catchments. Therefore, when attempting to understand the spatial variation in water quality within a distributed hydrological network it is important to recognise the source of water and the probable hydrological pathways water has taken to the stream channel.

Deep Drainage

Deep drainage occurs from the percolation of rainfall through the soil zone to underlying aquifers. Deep drainage tends to be highly effective at excluding microbes and sediment and variably effective at retaining P depending on substrate composition and the thickness of the unsaturated zone. Deep drainage to an aquifer, therefore, delivers primarily N and/or P depending on the composition of the soil and aquifer substrates. An assessment of deep drainage was undertaken for the Waituna Lagoon Catchment in Rissmann et al. (2018).

In the Waituna Lagoon Catchment, the areas with the highest likely deep drainage contribution occur in the north of the Waituna Creek catchment in areas with low artificial drainage density (Figure 1.4). Non-agricultural areas, with natural state hydrology, exist predominantly in Carran Creek catchment and the area of direct contribution to the lagoon. The internal drainage of these areas is low, as demonstrated by the accumulation of large areas of peat wetland. In contrast, areas of well-drained sandy soils close to the coast (e.g., Riverton soil) have a high contribution to deep drainage. However this area is unmonitored, therefore not depicted in Figure 1.4. Overall, the extent of well-drained soils in the catchment is very small.

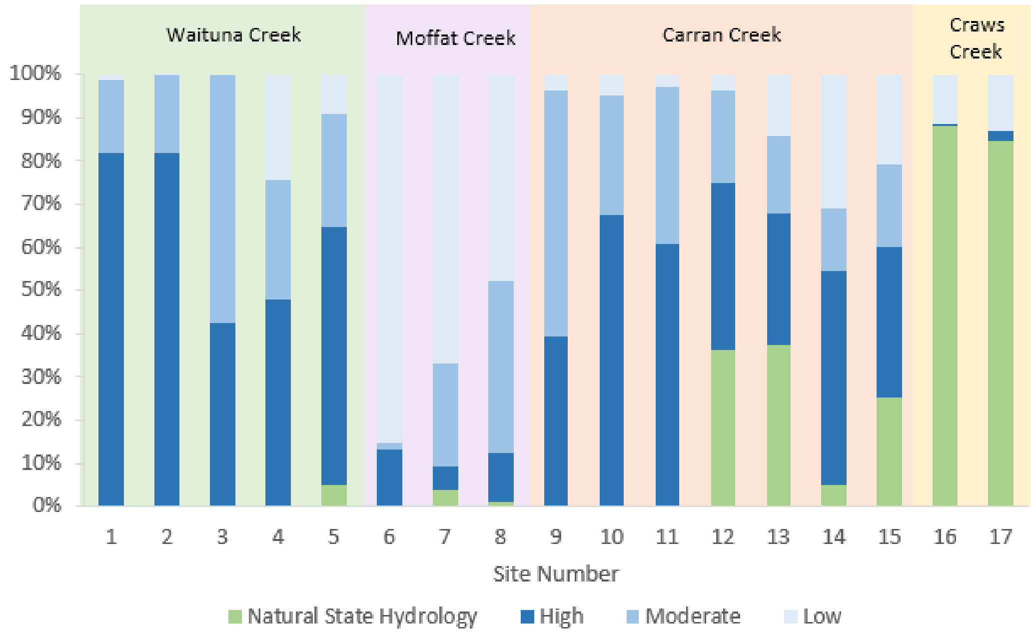

Figure 2.5: Proportional area of deep drainage for water quality monitoring sites in Waituna Lagoon Catchment.

Artificial Drainage

Subsurface drainage across Southland was estimated by Pearson (2015a) using the soil properties of permeability and drainage class, combined with land cover and topographical information to produce a framework to estimate drainage density for the Southland region. This classification was refined for Waituna in Rissmann et al. 2018.

Subsurface (tile) drains are typically installed in one of two arrangements in Southland, conventional and contour patterns (Pearson, 2015a). Conventional drainage is used in conjunction with open ditches when the land surface is a constant slope (minimal undulations) to lower the water table to a uniform depth. This type of drainage is typical in Organic (peat) soils and widespread through the south of the catchment. Contour drainage is used more commonly on undulating or sloping land, or where wetter areas of a paddock are present and drain into an open waterway (or ditch). The tiles/pipes are laid in hollows or swales and follow the natural contour of the landscape. The depth that the tiles are installed varies depending on the depth of the water table and the amount of fall necessary to drain the area. Tiles are typically found at 60 - 80 cm depth and between 20 - 100 m apart, and mole drains are typically ploughed at 45 cm depth and can be as close as 2 m apart (Houlbrooke and Monaghan, 2009). This drainage pattern is more common in the north of Waituna Lagoon Catchment in mineral soils.

In the Waituna Lagoon Catchment, the Waituna Creek subcatchment has the lowest density of artificial drainage, increasing down the stream reach as the proportion of poorly drained soils increases (Figure 2.5). Moffat Creek has the highest proportion of artificial drainage. Carran Creek is also extensively drained, however, there is also a large proportion of natural state wetland in this subcatchment.

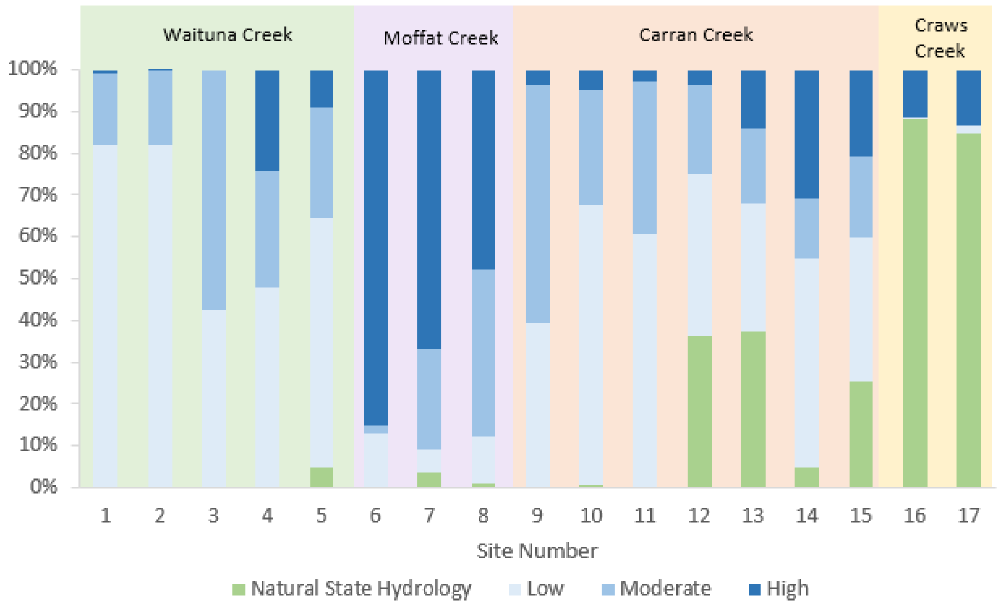

Figure 2.6: Proportional area of artificial drainage for water quality monitoring sites in the Waituna Lagoon Catchment.

Overland Flow (surficial runoff)

Overland flow risk was assessed by Pearson (2015b) by identifying areas where there is a higher likelihood of saturation excess overland flow occurring across the Southland region. Overland flow risk is increased in areas where soils have poor internal drainage and are structurally vulnerable to slaking and dispersion, or in areas where there is sufficient slope to generate runoff. It is expressed as a percentage of precipitation occurring as overland flow. In the Waituna Lagoon Catchment, the percentage of rainfall occurring as overland flow ranged from 2 to 12%. Rissmann et al. (2018) classified this risk as low for areas less than 2%, moderate for areas between 2-4% and high for areas greater than >6%.

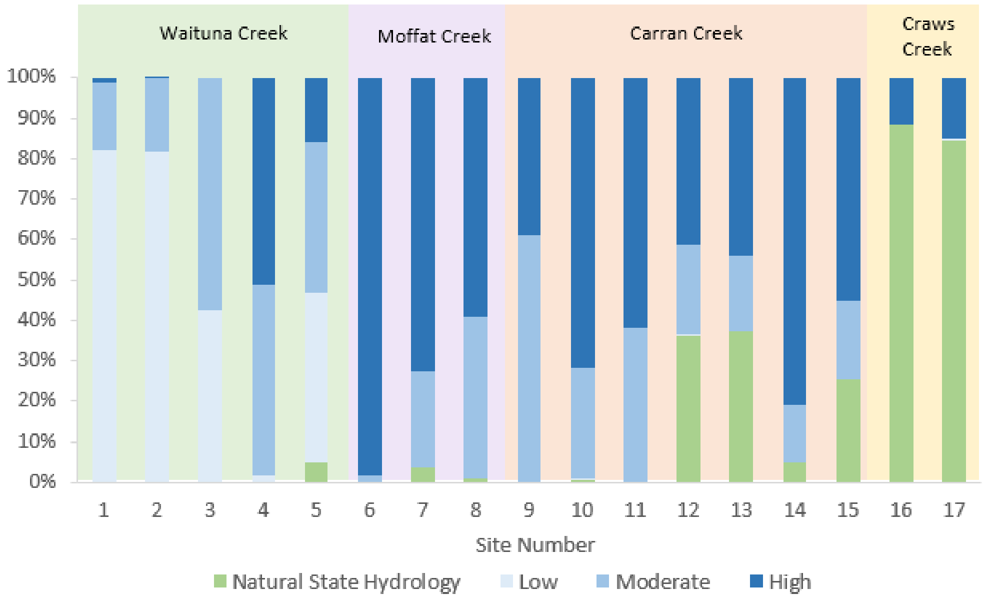

Figure 1.2: Proportional area of overland flow for water quality monitoring sites in Waituna catchment.

2.5.4 Reduction Potential

Redox is a biogeochemical process which occurs in soil and shallow groundwater that governs the concentration of the dissolved forms of nitrogen, oxygen, manganese, iron, sulphate, and heavy metals. Redox also indirectly controls the leachability and mobility of P species in soils, aquifers and subsequently surface waters. It is important to note that whilst redox processes influence the mobility and form of P, they do not result in the removal of P. In the majority of studies investigating the biogeochemical controls over water quality outcomes, redox is routinely identified as a major driver of variation in water quality outcomes and hydrochemical composition (McMahon and Chapelle, 2008; Rissmann, 2011; Rissmann et al., 2012).

In basic terms, redox state is characterised as the presence of oxygen (oxic) or absence (anoxic) of oxygen, however, it is more accurately described as reactions which involve the transfer of electrons from an electron donor to an electron receiver. The chemical species which loses the electron (increase in oxidation state) is oxidised, while the chemical species that gains the electron (decrease in oxidation state) is reduced. The key drivers of redox potential within the Waituna Lagoon Catchment are soil drainage class (soil zone redox) and the organic carbon content of shallow aquifers (Rissmann, 2011; Rissmann et al., 2012; Rissmann and Hodson, 2013; Rissmann et al., 2018). Typically, well-drained soils are characterised as oxidising and have a low reduction potential, while poorly drained soils are characterised as reducing and have a high reduction potential.

Denitrification is a redox reaction that deals specifically with the transformation of nitrogen, in which oxidised nitrogen (nitrate, NO_3^-) accepts an electron and is reduced to nitrous oxide (NO or N_2O) or nitrogen gas (N_2) and is removed from the water. Ammoniacal forms of nitrogen are also produced under reducing conditions in areas with high organic carbon content (Ponnamperuma, 1972; Moldan and Cerny, 1994; McMahon and Chapelle, 2008; Tratnyek et al., 2012).

Figure 2.7 shows Moffat Creek has the highest proportion of reducing soils and aquifer substrates in the Waituna Lagoon Catchment, with the upper monitoring site the most reducing. Carran Creek increases in reduction potential from the north to the south of the catchment. Waituna Creek has a predominantly low to moderately low reduction potential. The area captured by Site 4, which drains the Maher in Waituna Creek, has a higher reduction potential than other monitored areas within Waituna Creek subcatchment.

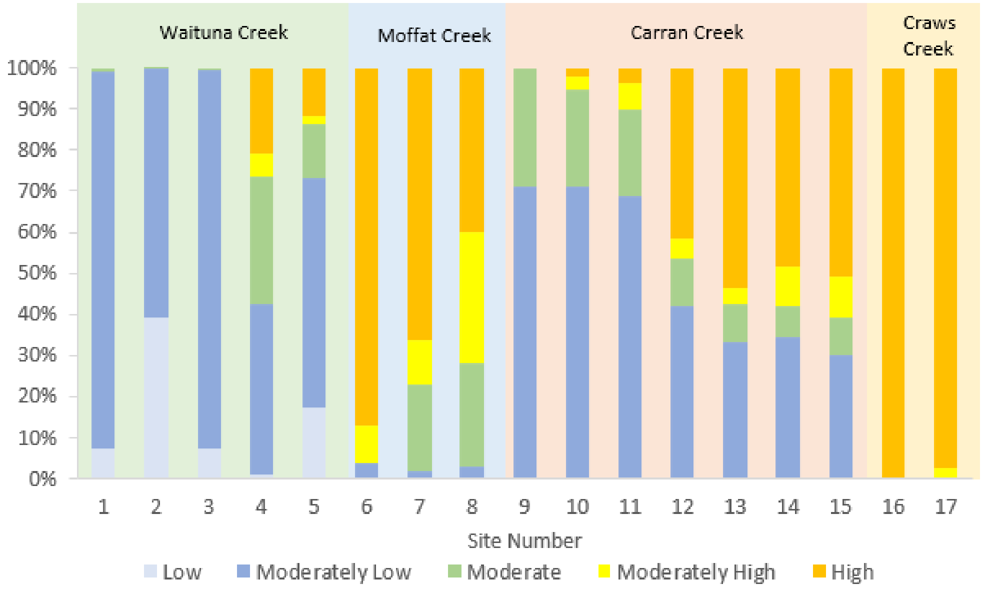

Figure 2.7: Proportional area of reduction potential for water quality monitoring sites in Waituna catchment.

3 Nitrogen

3.1 Introduction

Nitrogen is an essential nutrient for plant life. It occurs in three main forms in the environment, molecular, organic, and inorganic. Nitrogen in the environment is cycled (or transformed) from one form to another depending upon the environmental and biological conditions (Figure 3.1). In its molecular form, N is a gas (N_2) and makes up about 80% of the Earth's atmosphere. Organic nitrogen refers to the diverse array of nitrogen-containing organic molecules, ranging from simple amino acids through proteins and nucleic acids, to large and complex molecules, such as humic substances in soil and water. The organic and inorganic forms of N are the forms that are ecologically important. It is these compounds that are added as nutrients (i.e. fertilisers) to enhance plant growth. However, as they are highly soluble they can easily become environmental.

The main forms of inorganic nitrogen that occur are:

- **Nitrate** (NO_3^-) is the preferred form of nitrogen nutrition for most species of plants. Nitrate is highly soluble and is easily transported or leached through the soil if not assimilated by plants and microorganisms. Sources of nitrate include inorganic fertilizer, animal wastes including Farm Dairy Effluent (FDE), septic tanks and sewage systems. Nitrate also occurs as a result of nitrification of the ammonia in animal waste by bacteria in soil. It is toxic at high concentrations. Ultimately, the majority of nitrate is released via microbial mineralisation processes irrespective of the form of input.
- **Nitrite** (NO_2^-) is formed during the process of nitrification but its concentration is often low compared to other forms of inorganic nitrogen.
- **Ammoniacal nitrogen (NH_4^+/$NH3_{(g)}$)** is represented by ammonia (NH_3) and ammonium (NH_4^+). Which form dominates in water is dependent on pH, with ammonia concentrations increasing as pH increases. In most natural waters with pH values less ≤7.5 ammonium is the dominant form. Ammonium is less mobile that nitrate as it is strongly attracted to negatively charged clay minerals. Where it occurs, ammonia is highly toxic to fish and other aquatic organisms.

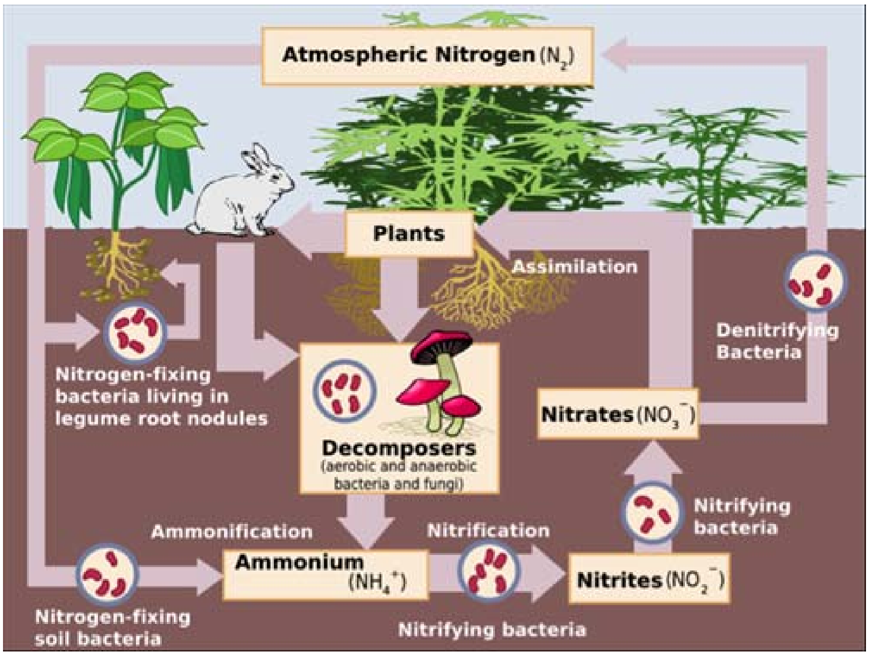

Figure 3.1: The nitrogen cycle (sourced from https://en.wikipedia.org/wiki/Nitrogen_cycle).

3.2 Water Quality Data

When a water sample is analysed for N, different techniques are applied to isolate the various forms (Figure 3.2). Total Nitrogen is typically analysed and reported as follows:

- Nitrate-Nitrite Nitrogen (NNN) = Nitrate + Nitrite
- Total Kjeldahl Nitrogen (TKN) = Total Organic Nitrogen + Total Ammoniacal ($NH_3 + NH_4^+$)
- Total Nitrogen (TN) = TKN + NNN

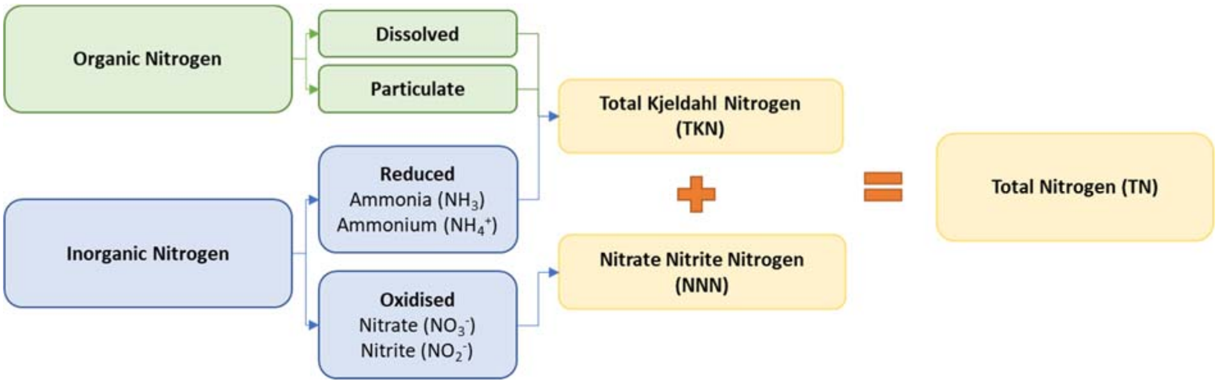

Figure 3.2: Analysis of the forms of nitrogen for water quality.

In the Waituna Lagoon Catchment, TN concentrations are highest in Waituna Creek, where nitrate is the dominant form (NNN), while TN concentrations are lowest in Craws Creek, where organic N dominates with lesser ammoniacal nitrogen (Figure 3.3, Table 3.1). As the proportion of poorly drained and Organic soils in a capture zone increases, the form of nitrogen changes from NNN dominated to TKN. Figure 3.4 demonstrates this relationship by comparing NNN concentration with the weighted average soil drainage class and soil carbon content. Nitrate increases as soils become increasingly more well drained and carbon content reduces. See Appendix for summary statistics (number of samples, mean, median, Coefficient of variation, minimum and maximum) of the dominant N forms for each monitoring site.

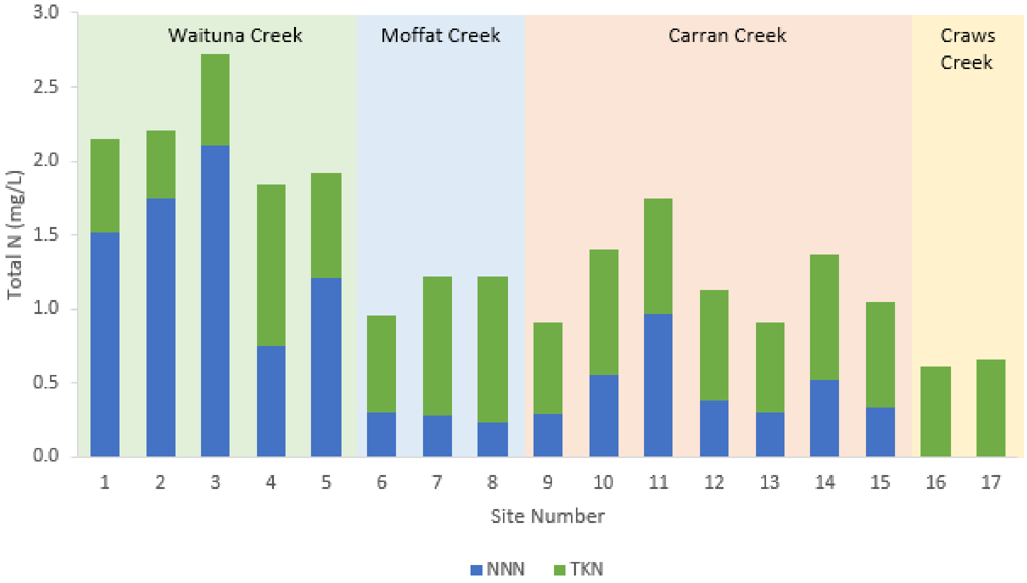

Figure 3.3: Nitrogen form contributing to median Total N concentration at monitoring sites in Waituna Lagoon Catchment.

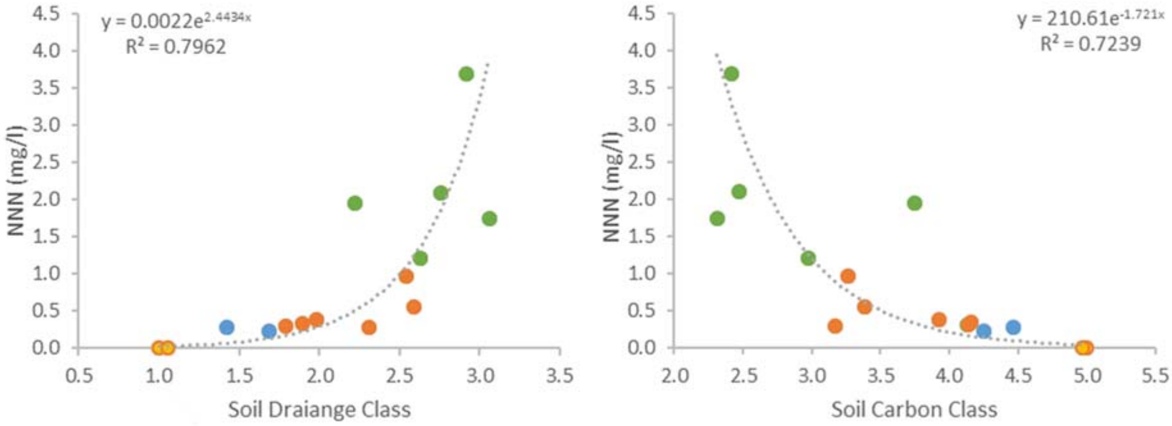

Figure 3.4: Median NNN concentration by weighted mean soil drainage and soil carbon content class for Waituna Lagoon Catchment surface water monitoring sites showing Waituna Creek (green), Moffat Creek (blue), Carran Creek (orange) and Craws Creek (yellow). A soil drainage class of 1 is very poorly drained, 2 poorly drained and 3 is imperfectly drained. A soil carbon class of 2 is 2-4 % C, 3 is 4-10% C, 4 is 10-20%, and 5 is >20% C.

Table 3.1: Median N forms (in mg/L) for Waituna Lagoon Catchment surface water monitoring sites.

No.	Site Name	NNN (NO_3^- + NO_2^-)	Nitrate (NO_3^-)	Nitrite (NO_2^-)	TKN (TAM + ON)	Total N
1	Waituna Creek 1m upstream Rimu Seaward Downs Road	1.52	0.53	0.013	0.63	2.65
2	Waituna Creek 1m upstream Waituna Road	1.75	1.71	0.014	0.46	2.50
3	Waituna Creek NE tributary 10m upstream Waituna Creek confluence	2.10	2.05	0.010	0.63	2.90
4	Waituna Creek SE tributary 20m u/s Waituna Creek confluence	0.75	0.44	0.009	1.09	1.88
5	Waituna Creek at Marshall Road	1.21	1.45	0.009	0.71	2.20
6	Moffat Creek Sth branch 1.2km u/s Miller Road	0.30	0.21	0.007	0.66	0.96
7	Moffat Creek 20m u/s Hanson Road	0.28	0.05	0.009	0.94	1.13
8	Moffat Creek at Moffat Road	0.23	0.19	0.008	0.99	1.32
9	Carran Creek west branch d/s Waituna Gorge Road	0.29	0.29	0.003	0.62	0.87
10	Carran Creek east branch u/s Waituna Gorge Road	0.56	0.45	0.016	0.84	1.49
11	Carran Creek 1km d/s Waituna Gorge Road	0.97	0.85	0.017	0.78	1.81
12	Carran Creek 3km u/s Waituna Lagoon Road	0.38	0.36	0.023	0.75	1.17
13	Carran Creek 800m u/s Waituna Lagoon Road	0.31	0.29	0.007	0.61	0.97
14	Carran Creek drain 800m u/s Waituna Lagoon Road	0.52	0.03	0.004	0.85	1.53
15	Carran Creek at Waituna Lagoon Road	0.34	0.29	0.005	0.71	1.09
16	Carran Creek tributary 1km u/s Waituna Lagoon Road	0.01	0.00	0.004	0.61	0.61
17	Carran Creek Trib at Waituna Lagoon Rd	0.01	0.01	0.007	0.65	0.70

3.3 Inherent Nitrogen Risk

3.3.1 Steady State

Nitrate (NNN) and Total N

In areas dominated by mineral soils, the dominant N form contributing to Total N is nitrate (Table 3.1). The inherent risk of nitrate to surface water and shallow groundwaters across the Waituna Lagoon Catchment is depicted in Figure 3.5. Areas of highest inherent NNN risk are associated with better-drained soils and shallow alluvial aquifers that occur across the northern portion of the catchment. These areas have the lowest densities of artificial drainage and occurrences of overland flow events. 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 Maher, a tributary of Waituna Creek. Areas of moderate to moderately-low risk mainly occur through the middle and southern portions of the catchment.

Due to the importance of reduction processes over NNN (and hence TN concentrations) areas with limited ability to remove NNN are associated with the highest export risk. Specifically, NNN concentrations from aquifer, soil and surficial runoff are 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 3.5. Areas of moderately high TN and NNN risk associated with imperfectly drained soils are more likely to have some subsurface artificial drainage, raising the risk of lateral soil zone export of NNN to stream.

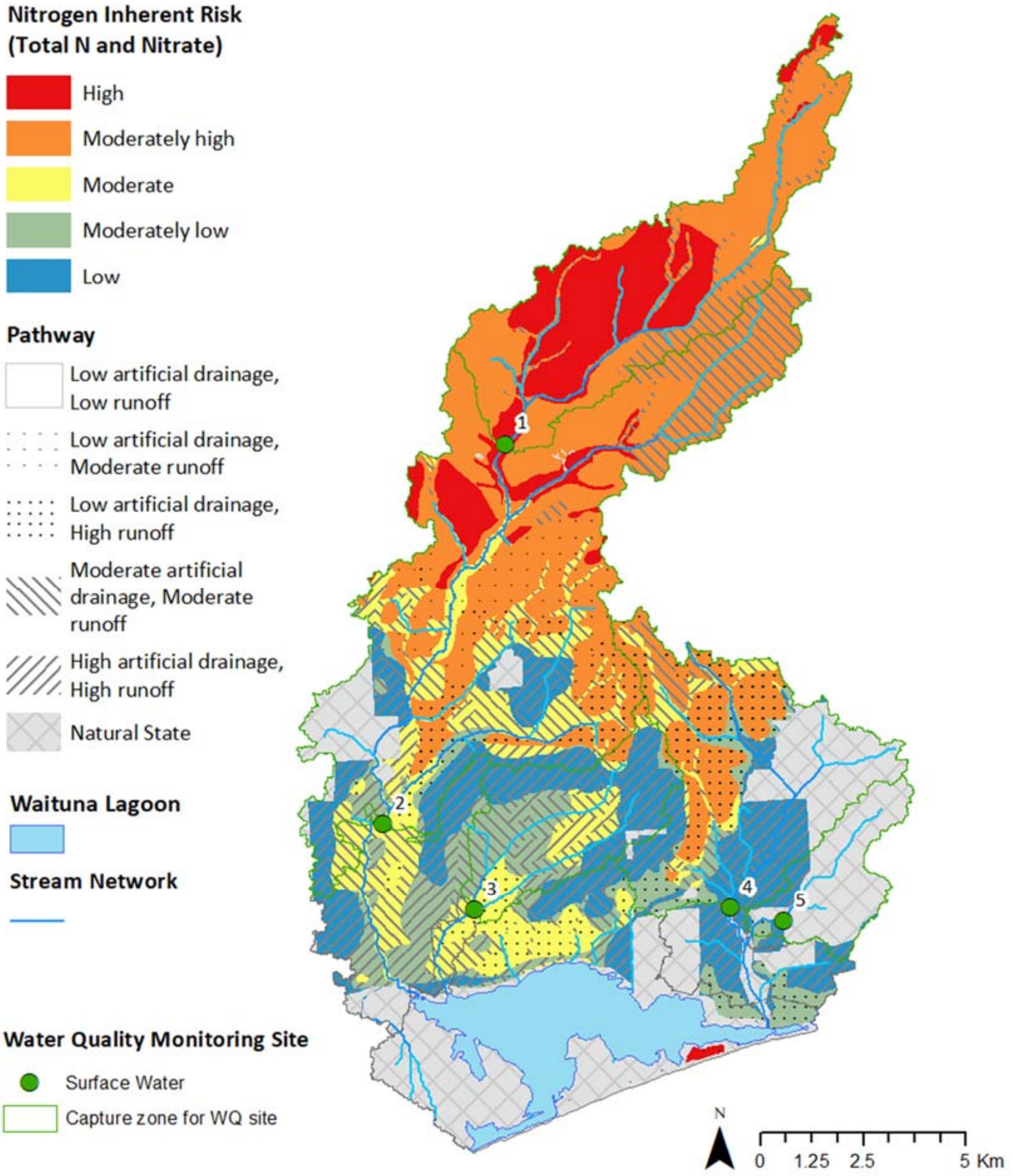

Figure 3.5: Inherent risk of nitrogen as NNN transported through the soil zone to the aquifer. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport. Numbers 1 – 5 identify key long-term monitoring sites within the catchment.

Organic and Ammoniacal (TKN)

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 (Land and Water Science, unpublished data). 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, 1.1 mg/L was associated with the ammoniacal nitrogen fraction and 1.9 mg/L occurred as NNN. As such, peak runoff events may supply significant pulses of organic and ammoniacal nitrogen to the stream network. It appears that this event was not large enough to result in significant soil drainage from the mineral soils in the northern proportion of the catchment, while the Organic soils in the Maher and further south in Waituna Creek subcatchment contributed to the increase in instream nitrogen.

Although TN and NNN 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 (Figure 3.3, Table 3.1). 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; (iii) a spatial correlation between soils susceptible to OLF and larger TKN concentrations. Accordingly, shallow lateral soil zone flow (mediated by mole-pipe drainage) and especially OLF are important pathways for organic and ammoniacal nitrogen delivery to streams. Accordingly, due to the importance of OLF in TKN mobilisation, the inherent risk of TKN is similar to that of Total Phosphorus (TP) and is depicted in Figure 3.6.

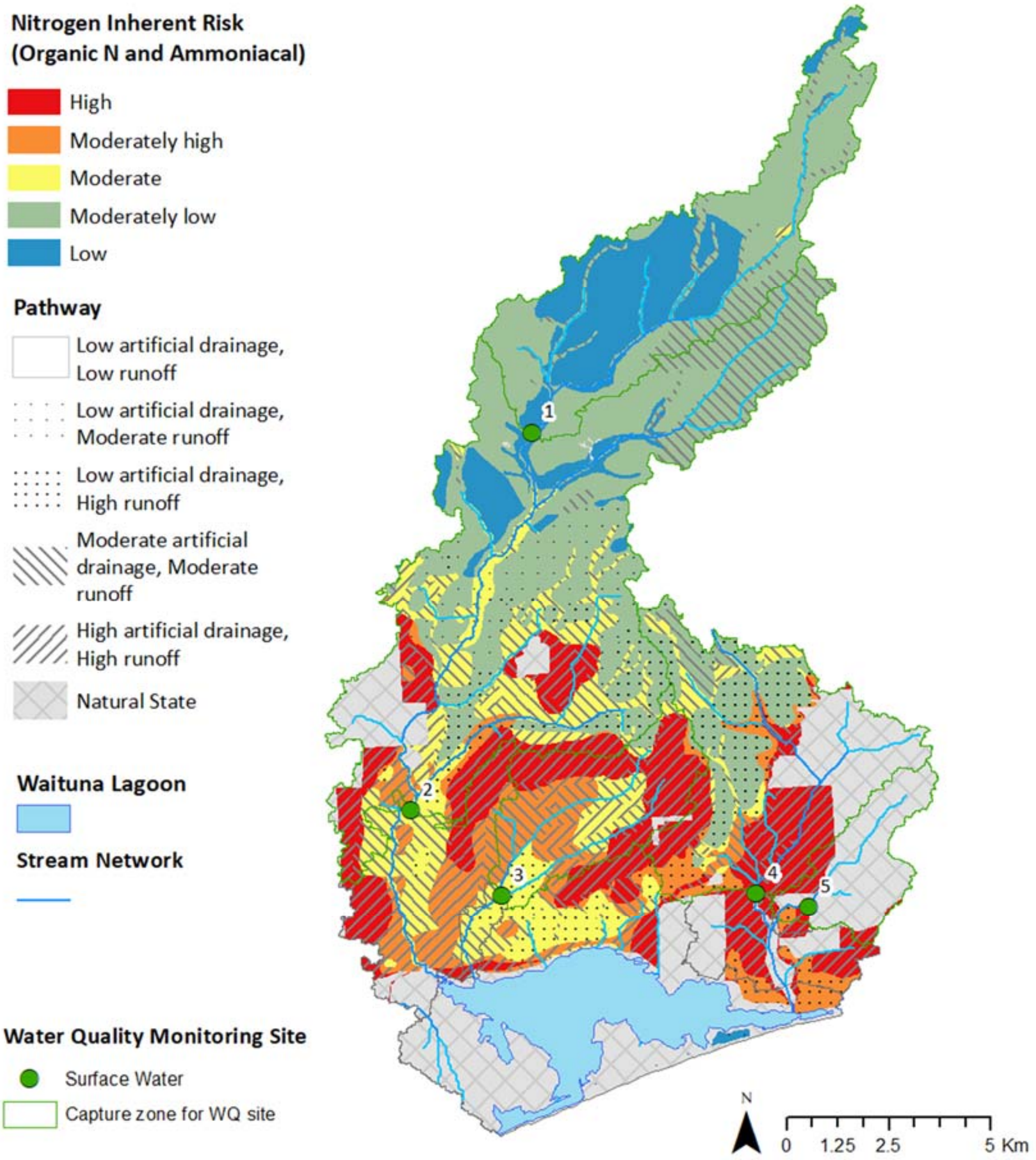

Figure 3.6: Inherent risk of nitrogen as TKN transported through the soil zone to the aquifer. The pathway shows the surficial risk by artificial drainage and overland flow. Natural state identifies source limited areas with minimal contaminants to transport. Numbers 1 – 5 identify key long-term monitoring sites within the catchment.

Due to a different set of controls, TKN behaves in the opposite manner to NNN, increasing as the proportion of reducing soils and aquifers and the %OLF from 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. 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 (Figure 3.6, Table 3.1). The north of the catchment and those areas of relatively well-drained soils have a low inherent risk for TKN.

In summary, TKN is the sum of ammoniacal and organic nitrogen forms and appears to be the dominant form of N supply to streams across the southern and south-eastern portion of the Waituna Catchment. Significantly, the export of organic nitrogen, as evidence in event sampling, is large relative to both ammoniacal and nitrate nitrogen making up ~76% of the TN load. Organic nitrogen if deposited as sediment within river beds or lagoon sediments may be mineralised *in situ* releasing ammonium and potentially nitrate to the overlying water column. If mineralisation is favoured under periods of peak water temperatures, e.g. summer months, then organic forms of nitrogen may be an important source of internal eutrophication associated with areas of accumulated sediment within the Waituna Lagoon and wide stream network. The recognition of organic nitrogen as the dominant nitrogen export/load from areas of intensively farmed wetland is an important observation, with nitrate nitrogen making up a small fraction of total exports from these areas. The role or organic nitrogen over internal eutrophication along with scholarly recognition of direct uptake of dissolved organic nitrogen by plant and algal species raises key questions as to the importance of organic nitrogen export for the Waituna Lagoon.

3.3.2 Temporal

Nitrate (and Total N)

The north of the catchment, and especially those high-risk areas transected by the stream network are key areas of NNN export to the stream network and ultimately Waituna Lagoon (Figure 3.5). Here, NNN export increases as soils wet up, exceed 80% water-filled pores, and peaks in response to surficial runoff during May-August, reflecting higher rates of soil profile flushing (Rissmann and Beyer, 2018). As the shallow alluvial aquifer is thin (c. 5 m) across this area, young oxidised groundwater is exhausted during periods of extended dry weather with deeper, more reduced groundwater associated with the shallow Gore Lignite Measures supplying the stream reaches across the northern portion of the catchment. Under this scenario, baseflow NNN and DO peaks and then declines in response to falling aquifer levels under periods of extended dry conditions (Rissmann et al., 2012; Rissmann and Hodson, 2013). However, NNN may be mobilised from this area during the summer months if the soil approaches saturation (≥85% at Lawson Rd soil moisture site) in response to a significant rainfall event (Land and Water Science, unpublished data).

Organic and Ammoniacal (TKN)

Under baseflow, peat and to varying degrees lignite aquifers within the Waituna Lagoon Catchment have naturally elevated ammoniacal and organic nitrogen (TKN) (Rissmann et al., 2012). However, there is little evidence for a significant ammoniacal nitrogen contribution to stream occurring as baseflow (Rissmann and Beyer, 2018). On the other hand, Dissolved Organic Nitrogen (DON) may be an important bioavailable nitrogen fraction associated with baseflow and soil water contributions to stream. Specifically, although the role of DON over instream eutrophication under baseflow conditions has not received a lot of attention there is growing evidence for significant bioavailability of this nitrogen species.

Analysis of temporal streamflow indicates a predominance of TKN export from developed land is associated with periods of soil saturation, mainly during the cooler months of the year, in conjunction with soils that are poorly drained or have a high organic composition. These soils also have a high and moderately high OLF risk. As noted above, OLF and associated TKN export can also occur during the drier months in response to high-intensity rainfall, although 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 TKN export from the northern portions of the catchment, where OLF risk is lowest.

4 Phosphorus

4.1 Introduction

Together with nitrogen, phosphorus (P) is an essential nutrient for life. Phosphorus is predominantly found as phosphate-based compounds (solid form) and is cycled through the lithosphere, hydrosphere, and biosphere. Unlike N, the atmosphere does not play a significant role in the cycling of P. In the environment, the weathering of rocks and minerals release P in a soluble form where it is taken up by plants, and subsequently transformed into organic compounds. Organic phosphate is P that has been incorporated into plant or animal tissue (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) with the soil particle (particulate). In natural waters, P usually occurs as both inorganic (including orthophosphates and polyphosphates) and organic forms (organically-bound phosphates).

4.2 Water Quality Data

When a water sample is analysed for P, different techniques are applied to isolate the various forms (Figure 4.1). Phosphorus in a water sample is typically analysed and reported as:

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

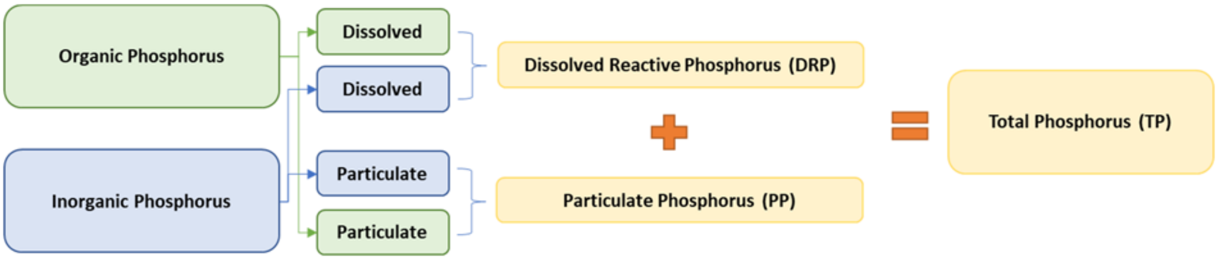

Figure 4.1: Analysis of phosphorus for water quality.

Particulate Phosphorus (PP) and Dissolved Reactive Phosphorus (DRP) export to streams is controlled by distinctly different processes. Within the developed areas of the Waituna Lagoon Catchment, PP makes up the largest fraction of P transported by overland flow via surficial runoff and to a lesser degree lateral soil zone flow (Rissmann et al., 2012; Rissmann and Hodson, 2013). Figure 4.2 and Table 4.1 shows all agriculturally dominated sites (Sites 1 - 15) are dominated by PP. Whereas, in the natural state peat wetland area of Craws Creek (Sites 16 and 17), Dissolved Reactive Phosphorus (DRP) is the dominant P fraction (Figure 4.2, Table 4.1). The sites with the highest TP concentrations are located on peat soils with agricultural land uses (i.e., Waituna Creek site 4, Moffat Creek sites 7 and 8, and Carran Creek sites 13 to 15, Figure 4.2). These sites have both a high PP and DRP form (see Appendix for summary statistics; number of samples, mean, median, coefficient of variation, minimum and maximum of the dominant P forms for each monitoring site).

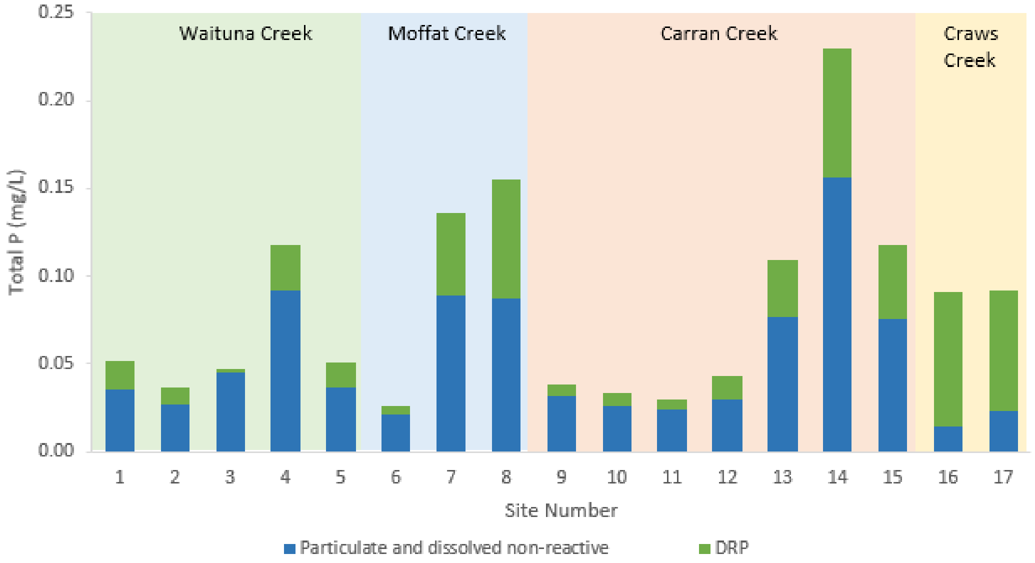

Figure 4.2: Phosphorus form contributing to median Total P concentration at monitoring sites in Waituna Lagoon Catchment.

The form of P associated with the different hydrological pathways P takes to leave the land is demonstrated in Figure 4.3. DRP is strongly controlled by the reduction potential of the soil and aquifer substrates, while PP is predominantly transported by overland flow with lesser artificial drainage components. This relationship is depicted using deep drainage as the non-dominant pathway in Figure 4.3. Sites with a low contribution to deep drainage, meaning more water moves surficially or laterally, have a higher concentration of PP.

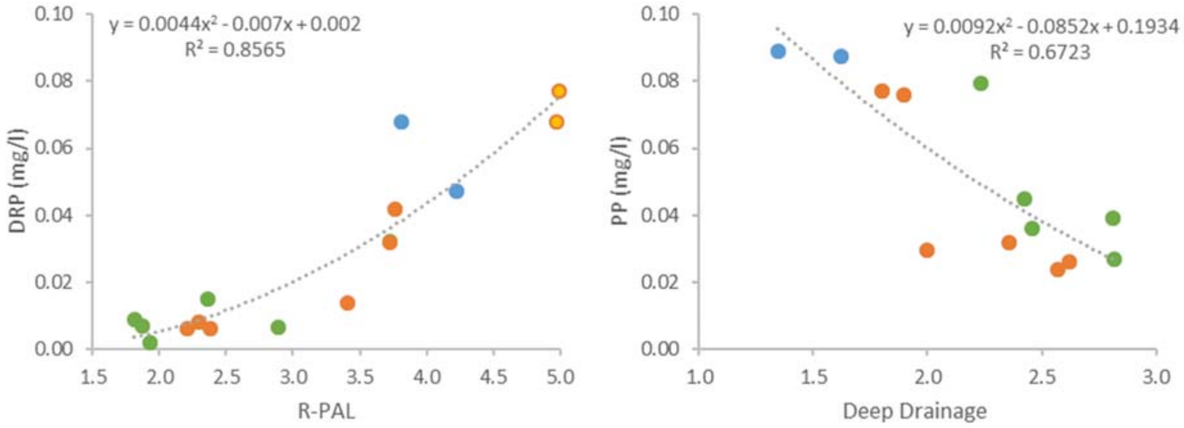

Figure 4.3: Relationship between DRP and reduction potential (R-PAL) (left), and PP and deep drainage (left) for Waituna Lagoon Catchment surface water monitoring sites showing Waituna Creek (green), Moffat Creek (blue), Carran Creek (orange) and Craws Creek (yellow). Reduction potential is ranked from 1 low to 5 high and Deep drainage is ranked from 1 low to 3 high in the Waituna Lagoon Catchment (Rissmann et al., 2018).

Table 4.1: Median P forms (in mg/L) for Waituna Lagoon Catchment surface water monitoring sites.

No.	Site Name	DRP	DOP	TDP	PP	Total P
1	Waituna Creek 1m upstream Rimu Seaward Downs Road	0.016	0.005	0.020	0.032	0.052
2	Waituna Creek 1m upstream Waituna Road	0.009	0.003	0.012	0.024	0.036
3	Waituna Creek NE tributary 10m upstream Waituna Creek confluence	0.002	0.003	0.008	0.039	0.047
4	Waituna Creek SE tributary 20m u/s Waituna Creek confluence	0.026	0.010	0.037	0.081	0.118
5	Waituna Creek at Marshall Road	0.015	0.003	0.021	0.030	0.051
6	Moffat Creek Sth branch 1.2km u/s Miller Road	0.005	0.008	0.013	0.013	0.026
7	Moffat Creek 20m u/s Hanson Road	0.047	0.012	0.060	0.076	0.136
8	Moffat Creek at Moffat Road	0.068	0.021	0.080	0.076	0.156
9	Carran Creek west branch d/s Waituna Gorge Road	0.006	0.006	0.014	0.024	0.038
10	Carran Creek east branch u/s Waituna Gorge Road	0.008	0.011	0.020	0.014	0.034
11	Carran Creek 1km d/s Waituna Gorge Road	0.006	0.011	0.016	0.014	0.030
12	Carran Creek 3km u/s Waituna Lagoon Road	0.014	0.010	0.022	0.022	0.044
13	Carran Creek 800m u/s Waituna Lagoon Road	0.032	0.010	0.042	0.067	0.109
14	Carran Creek drain 800m u/s Waituna Lagoon Road	0.074	0.003	0.070	0.160	0.230
15	Carran Creek at Waituna Lagoon Road	0.042	0.009	0.045	0.073	0.118
16	Carran Creek tributary 1km u/s Waituna Lagoon Road	0.077	0.009	0.095	0.000	0.091
17	Carran Creek Trib at Waituna Lagoon Rd	0.068	0.012	0.091	0.001	0.092

4.3 Inherent Risk

4.3.1 Steady State

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 Lagoon Catchment, the dominant form of P is Particulate Phosphorus (PP), associated with organic and inorganic sediment (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 (Table 3.1, Site 16 and 17). 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 source limitation.

In Figure 4.4 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 Lagoon 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, any area of moderate to high OLF risk across areas of developed land is 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.

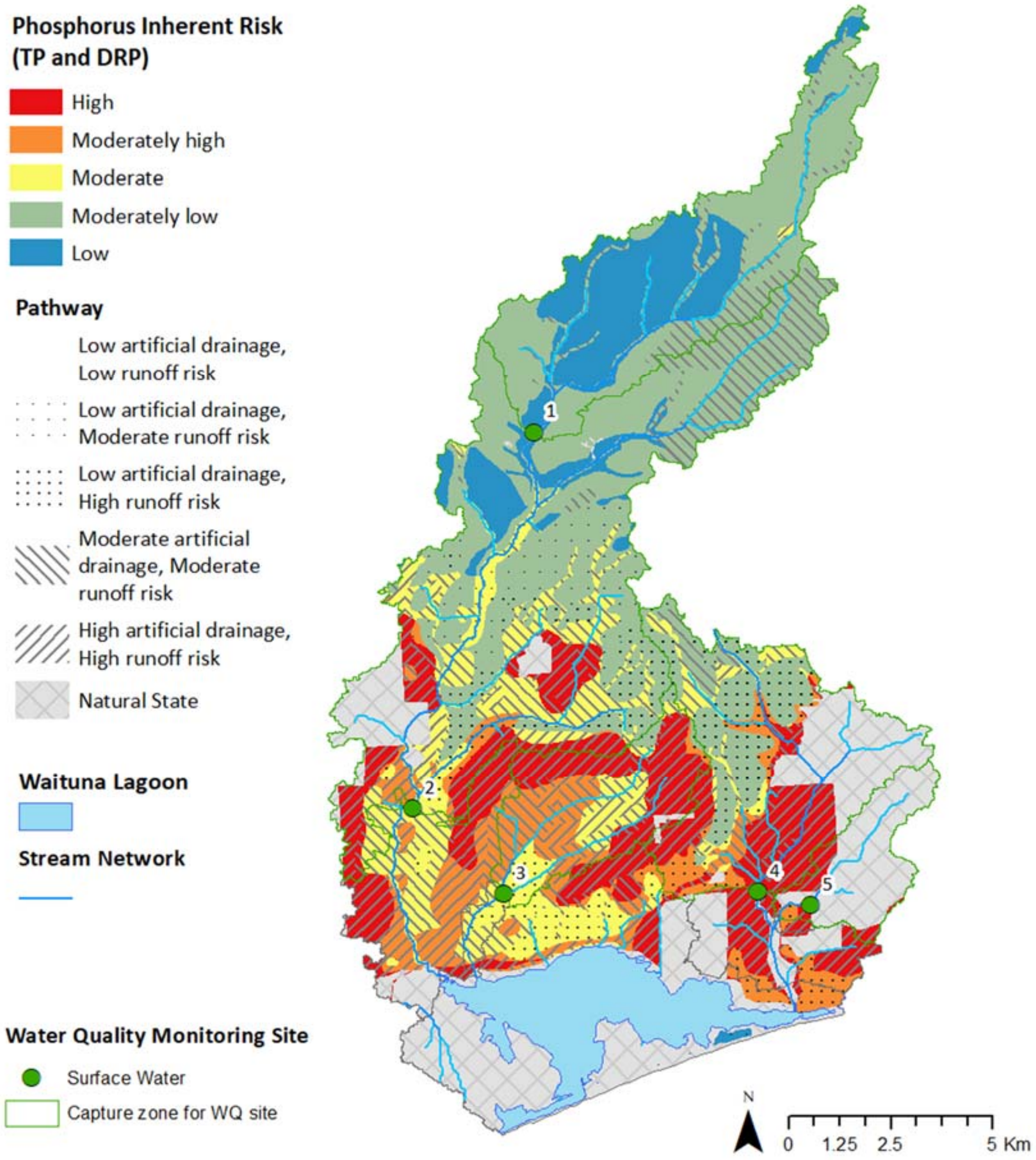

Figure 4.4: Inherent risk of (dissolved) phosphorus transported through the soil zone to the aquifer. The pathway shows the surficial risk of particulate P by artificial drainage and overland flow for sediment-bound P. Natural state identifies source limited areas with minimal contaminants to transport.

4.3.2 Temporal

Analysis of temporal stream flow indicates a predominance of TP export from developed land is associated with periods of soil saturation (May-August), mainly during the cooler months of the year, in conjunction with the wetland soil components that have high and moderately high OLF risk (Rissmann and Beyer, 2018). 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 of 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.

5 Sediment and Microbes

5.1 Introduction

Sediment is sometimes referred to as the ‘universal’ pollutant because it is invariably mobilised when vegetation or land is disturbed (Campbell et al. 2004). Sediment (S) refers to the suspended solid phase within a stream that is less than 0.2 mm in diameter; that is a heterogeneous mix of organic and inorganic constituents which may include organic carbon, clays (both poorly ordered and structured), silt and sand, attached bacteria, viruses and both organic and inorganic ions and molecules - including N and P species. Elevated sediment concentrations in rivers adversely affect ecosystem health by the process of infilling and shoaling and smothering biota. However, reduced clarity and light penetration, are probably of more ecological significance (Ryan, 1991; Davies-Colley et al. 2014). Dissolved organic carbon (DOC), leached from decaying plant material in soils, also affects light penetration in water. The greater the attenuation of light by suspended sediment and DOC, the lower the water clarity. While elevated suspended sediment has the greatest effect during flood events, the accumulation of sediment in the stream bed can also result in reduced clarity and elevated turbidity under baseflow conditions.

Sediment is analysed for both its total suspended sediment (organic and inorganic, TSS) and volatile components (organic, VSS). We consider Total Suspended Sediment (TSS) to be the best measure of suspended sediment. Other measures, such as absorbance, clarity (black disk) and turbidity (NTU) are measures of the optical properties of water that may be influenced by both dissolved and solid phase constituents. For example, clarity is generally lower in waters with a high dissolved organic carbon concentration and turbidity is influenced by the presence of ‘dissolved’ colloids that are smaller than the nominal 2 microns used to define TSS and SSC (Davies-Collies and Smith, 2001). Therefore, the relationship between turbidity, clarity, TSS and SSC is not always simple.

Microbial (M) 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. Sediment and microbes are deposited on and eroded from the soil surface and are therefore transported predominantly by overland flow (or surficial runoff). However, artificial drainage can also act as a conduit for S and M to surface water bodies.

5.2 Water Quality Data

5.2.1 Suspended Sediment

When a water sample is analysed for suspended sediment, different techniques are applied to isolate the various forms, inorganic (mineral) and volatile (organic matter). Sediment in a water sample is typically analysed and reported as:

- Total Suspended Sediment (TSS) = Inorganic + Volatile Forms (both <0.2 mm in diameter).
- Volatile Suspended Sediment (VSS)

In the Waituna Lagoon Catchment, Waituna Creek typically has the highest TSS concentration in the form of inorganic sediment, while VSS concentrations are highest in Moffat and Carran Creeks (Figure 5.1). As the proportion of poorly drained and Organic soils in a capture zone increases, the proportion of TSS that is volatile increases (see Appendix for summary statistics; number of samples, mean, median, coefficient of variation, minimum and maximum of the dominant S forms for each monitoring site).

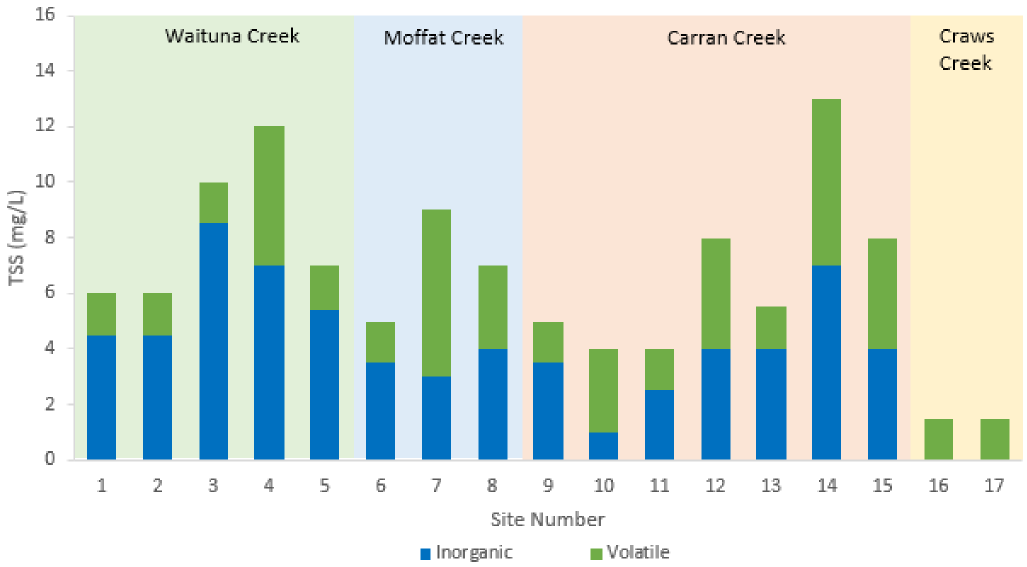

Figure 5.1: Sediment form contributing to median TSS concentration at monitoring sites in Waituna Lagoon Catchment. VSS is higher for subcatchments with a greater wetland component.

5.2.2 Microbes

Microbial contamination, assessed by the count of colony forming units of *E.coli,* is highest in the subcatchments with high-intensity land use and high surficial loss risk (Figure 5.2 and 5.3). Waituna Creek, which has a higher proportion of developed land than Carran Creek, has a lower *E.coli* count indicating the occurrence of overland flow events is significantly lower in the subcatchment. Craws Creek in predominantly natural state provides a good comparison for natural *E.coli* counts for a wetland system (Figure 5.2).

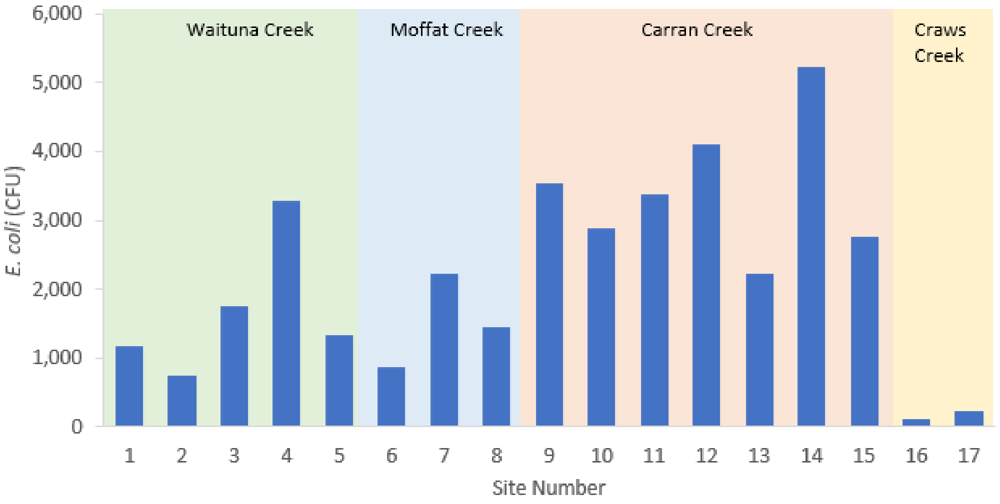

Figure 5.2: Mean E. coli count for the year 2012 at monitoring sites in Waituna Lagoon Catchment.

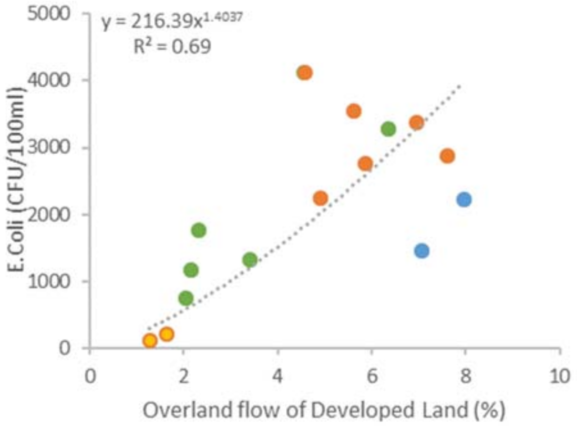

Figure 5.3: Relationship between E.coli and % overland flow of developed land for Waituna Lagoon Catchment surface water monitoring sites showing Waituna Creek (green), Moffat Creek (blue), Carran Creek (orange) and Craws Creek (yellow).

Table 5.1: Median sediment forms (in mg/L) and mean E.coli (CFU) for Waituna Lagoon Catchment surface water monitoring sites. Mean E.coli data is from 2012 only.

No.	Site Name	TSS	VSS	*E. Coli*
1	Waituna Creek 1m upstream Rimu Seaward Downs Road	6.0	1.5	1,179
2	Waituna Creek 1m upstream Waituna Road	6.0	1.5	742
3	Waituna Creek NE tributary 10m upstream Waituna Creek confluence	10.0	1.5	1,768
4	Waituna Creek SE tributary 20m u/s Waituna Creek confluence	12.0	5.0	3,279
5	Waituna Creek at Marshall Road	7.0	1.6	1,330
6	Moffat Creek Sth branch 1.2km u/s Miller Road	5.0	1.5	869
7	Moffat Creek 20m u/s Hanson Road	9.0	6.0	2,222
8	Moffat Creek at Moffat Road	7.0	3.0	1,450
9	Carran Creek west branch d/s Waituna Gorge Road	5.0	1.5	3,550
10	Carran Creek east branch u/s Waituna Gorge Road	4.0	3.0	2,879
11	Carran Creek 1km d/s Waituna Gorge Road	4.0	1.5	3,369
12	Carran Creek 3km u/s Waituna Lagoon Road	8.0	4.0	4,117
13	Carran Creek 800m u/s Waituna Lagoon Road	5.5	1.5	2,240
14	Carran Creek drain 800m u/s Waituna Lagoon Road	13.0	6.0	5,225
15	Carran Creek at Waituna Lagoon Road	8.0	4.0	2,758
16	Carran Creek tributary 1km u/s Waituna Lagoon Road	1.5	1.5	111
17	Carran Creek Trib at Waituna Lagoon Rd	1.5	1.5	223

5.3 Inherent Sediment and Microbial Risk

5.3.1 Steady State

Sediment as Total Suspended Sediment (TSS) concentration and *E. coli* are strongly positively correlated reflecting similar controls over export to stream. Figure 5.4 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 (Table 5.1).

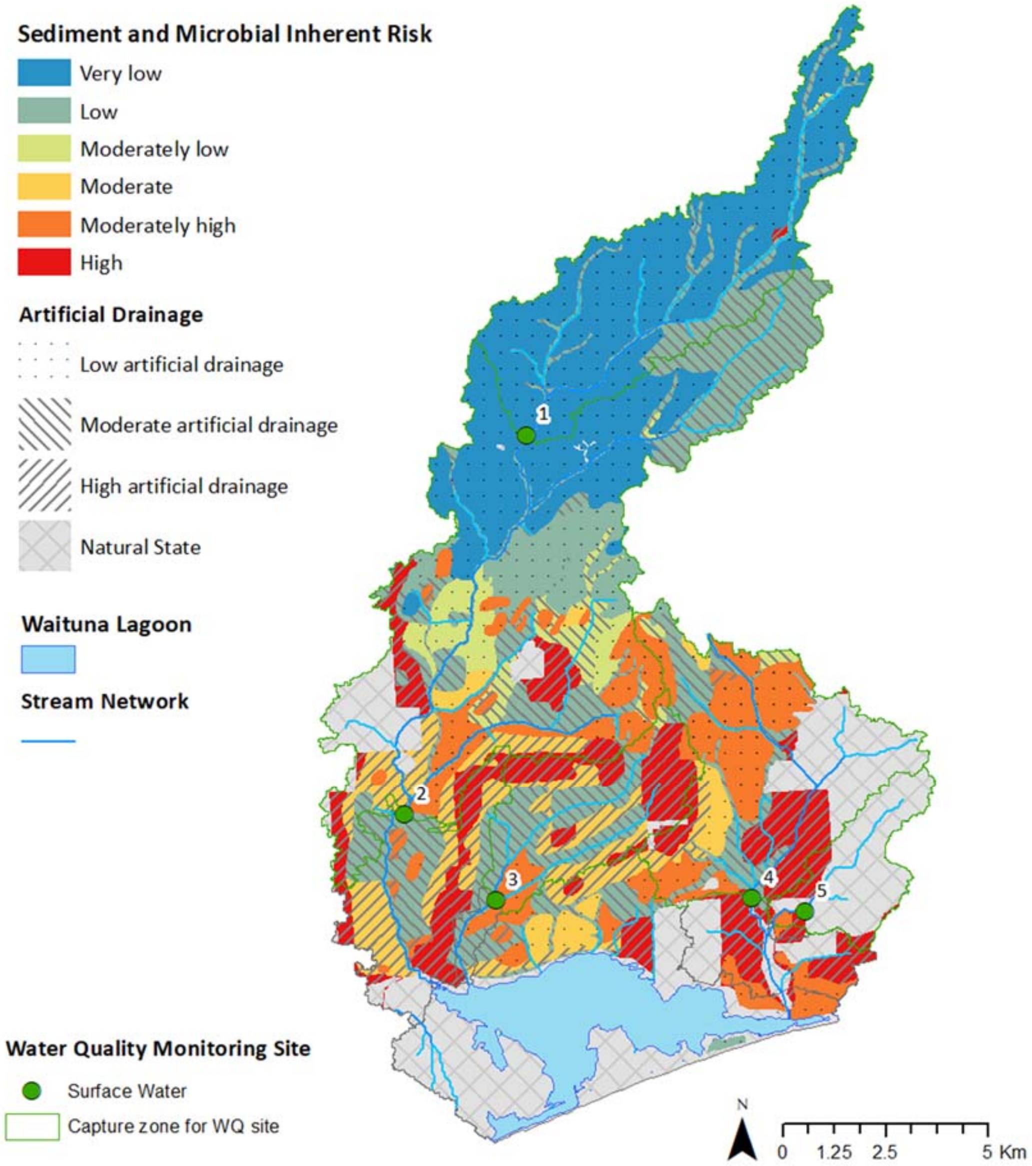

Figure 5.4: Inherent risk for sediment and microbial loss is by overland flow (surficial runoff). Risk of loss is increased by catchment modification through artificial drainage.

5.3.2 Temporal

Analysis of temporal stream flow 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 (Rissmann and Beyer, 2018). 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.

6 Waituna Catchment Physiographic Model

6.1 Introduction

The Waituna Catchment Physiographic Model consists of a number of numerical outputs in the form of simple equations that can be used to estimate the steady-state concentration of contaminants according to the physiographic assemblage within any given capture zone for a surface water site (Rissmann et al., 2018). Each model defines the relationship between the relevant process-attribute layer (PAL) and a key water quality measure (e.g. TN, TP, TSS etc). The numerical models developed here were calibrated against 5 sites with a sufficient time series data record to be considered most representative of the true water quality population (n = 1,399 including event flows). These sites account for 88% of the lagoon catchment area.

Models for TN, TP, TSS and *E. coli* were applied to the unmonitored areas and each sub-catchment in its entirety to provide an estimate of surface water contribution to Waituna Lagoon. It is also possible to produce models for estimating other ecologically important measures, such as dissolved oxygen, pH, alkalinity, temperature etc. This section summarises the outputs and limitations of the physiographic numerical modelling approach.

A comparison of model outputs for TN, TP, TSS and *E. coli* against data from all 17 surface water monitoring sites within the Waituna Catchment was also undertaken[1]. However, many of these sites are characterised by a limited data record (see Appendix). Evaluation of the data record against simulated flow shows poor representation and as such these sites and their associated data record are considered a poor basis for evaluating the performance of the model, especially for particle reactive species such as TKN, PP, sediment and *E. coli*. However, there is some value in contrasting the model outputs for these monitored sites in terms of provision of a potentially more representative measure.

6.2 Contribution from Unmonitored Areas and Subcatchments

The numerical models were applied to the unmonitored portion of the subcatchments within the zone of direct contribution to Waituna Lagoon, the whole subcatchment area and lagoon catchment area to provide an estimate of contribution from surface waters to Waituna Lagoon (Table 6.1). The concentration of TN and NNN concentrations decreased if the unmonitored area had a high proportion of organic soils, while TKN, TP and DRP typically increased. As applied to catchments with a significant natural state component, such as Carran Creek, the models show lower concentrations of TSS, TKN, TP, and *E. coli* but a small increase in TN and NNN. As OLF across developed areas of the catchment controls TSS, TKN, TP, and *E. coli,* concentrations decrease likely reflecting both source limitation and the unmodified hydrology of natural state area. Modelled values are consistent with expectations, with the variability in concentrations consistent with the inherent risk (see Sections 3 – 5).

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[1] Models for NNN, TKN, DRP, VSS, Turbidity, and Clarity were also produced in Rissmann et al., (2018), but for the sake of brevity are not shown.

Table 6.1: Prediction of water quality measures for Waituna Lagoon subcatchments, unmonitored areas and whole Lagoon Catchment. Water quality measures are reported as mg/l or ppm, and in CFU/100ml for E.coli. CS indicates the 5 long-term monitoring sites the model was calibrated against.

	Nitrogen			Phosphorus		Sediment			Microbes
	TN	NNN	TKN	TP	DRP	TSS	VSS	Turbidity	*E.coli*
Waituna Creek at Marshall Road (CS)	2.20	1.26	0.71	0.05	0.013	7.1	1.6	8.5	1,496
Waituna Creek unmonitored area	1.19	0.33	0.83	0.14	0.055	7.6	4.0	12.0	2,231
Waituna Creek Subcatchment Total	**2.07**	**1.08**	**0.73**	**0.06**	**0.016**	**7.4**	**1.8**	**8.2**	**1,849**
Moffat Creek at Moffat Road (CS)	1.20	0.34	0.93	0.16	0.068	7.0	3.0	8.8	1,450
Moffat Creek unmonitored area	1.77	0.74	0.75	0.09	0.027	8.1	3.4	10.4	2,756
Moffat Creek Subcatchment Total	**1.25**	**0.36**	**0.89**	**0.15**	**0.063**	**7.2**	**3.4**	**10.2**	**1,722**
Carran Creek at Waituna Lagoon Road (CS)	1.24	0.35	0.77	0.12	0.042	8.0	4.0	12.0	2,716
Carran Creek unmonitored	0.47	0.03	0.77	0.14	0.053	8.0	4.0	12.0	2,720
Carran Creek Tributary at Waituna Lagoon Rd (CS)	0.40	0.01	0.65	0.09	0.038	5.7	1.5	2.1	247
Craws Creek Subcatchment Total	0.41	0.01	0.69	0.09	0.039	5.9	1.5	4.9	328
Carran Creek Subcatchment Total	**1.59**	**0.59**	**0.74**	**0.08**	**0.025**	**7.9**	**2.7**	**9.0**	**2,556**
Direct Contribution unmonitored	1.09	0.28	0.74	0.08	0.030	6.8	1.5	8.7	1,212
Waituna Lagoon Catchment Total	**1.79**	**0.75**	**0.75**	**0.07**	**0.020**	**7.6**	**2.1**	**8.3**	**2,166**

6.3 Model Application to Monitored Areas

Here we apply the numerical models to all sites including those characterised by a limited or incomplete data record (i.e., <13 samples and as few as 7 repeat measures) in order to assess the representativeness of the water quality measures for these sites and if necessary provide a more representative estimate of steady-state concentrations. The model calibration sites are 2, 5, 8, 15 and 17. Validation and uncertainty analysis for the models was undertaken in Rissmann et al., (2018). The model performance parameters, including model-independent assessment of uncertainty, indicated a high level of confidence in the model outputs.

6.3.1 Nutrients (Total N and Total P)

Comparison of the modelled outputs for TN and TP with the median water chemistry for sites with limited water quality measures are comparable for the majority of the water quality monitoring sites (Figure 6.1 and 6.2). All sites where the model had poor performance, were upper catchment sites with small capture zone areas (< 300 ha) and a low number of time series water quality measures (i.e. < 13 samples). Evaluation of these sites reveals a poor representation across the simulated flow range indicating that the low number of samples has not adequately characterised the actual population (streamflow range). Therefore, it is plausible that model outputs may be a better predictor of long-term water quality than the measured data set. Another possible driver of differences between modelled and measured values are associated with small areas for which the land use intensity is lower than average. For example, Site 6 on Moffat Creek (174 ha) is largely associated with a low land use intensity, peat harvesting, with no livestock or associated fertiliser application in this area.

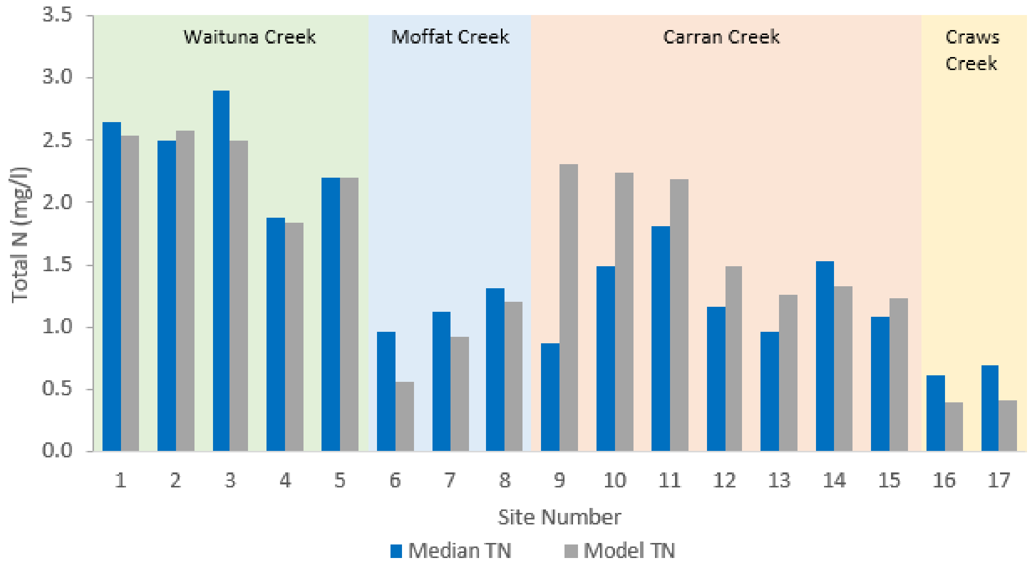

Figure 6.1: Measured median TN concentration vs modelled for all water quality monitoring sites. See Table 2.2 and Figure 2.3 for site information.

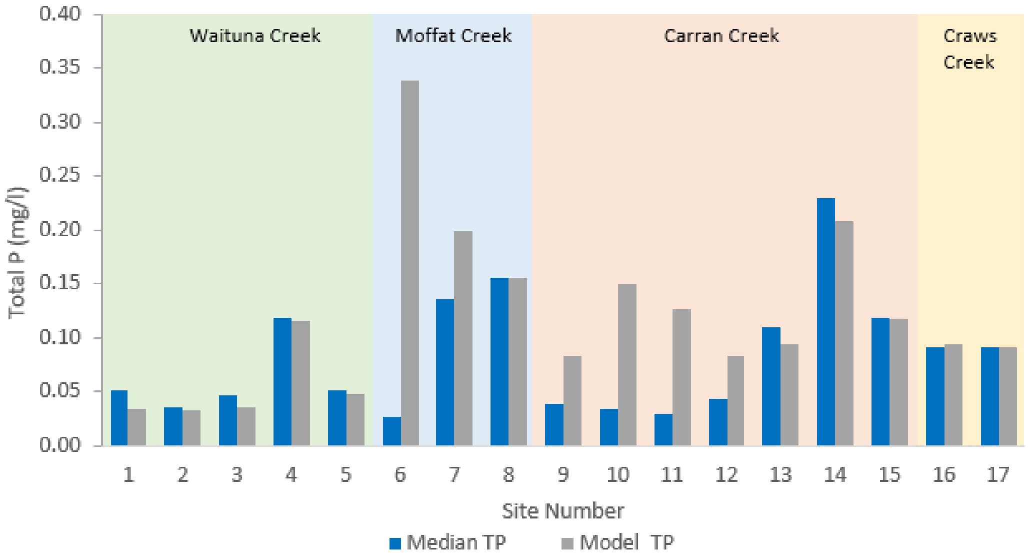

Figure 6.2: Measured median TP concentration vs modelled for all water quality monitoring sites. See Table 2.2 and Figure 2.3 for site information.

6.3.2 Sediment and Microbes

The comparison of the modelled outputs for TSS and *E. coli* with the median water chemistry for each site shows the model predictions are similar for the majority of the water quality monitoring sites, however not all sites were able to be modelled (Figure 6.3 and 6.4). For these analytes, the sites were significantly different from those used for model calibration. At the calibration sites (2, 5, 8, 15 and 17) the difference between measured and modelled outputs for TSS is between -0.01 and 4.52 mg/l. However, site 17 was not included in the calibration of this model, limiting the accuracy for predominantly natural state catchments. The difference between measured and modelled *E. coli* counts at calibration sites was -341 and 166.

The model underestimates TSS at sites 3, 4, 7 and 14 (Figure 6.3). Sites 3, 4, 7 and 14 all have a low number of samples and do not adequately characterised the actual flow population. Site 14 is an open ditch drain and was highlighted in Section 2 as being stagnant at times during the selected sampling period. This site also has the lowest number of repeat samples (n=7) and is not a true representation of local hydrology for the capture zone associated with this subcatchment. Modelled versus measured TSS, for both the Craws Creek sites, are overestimated. This was not unexpected given the TSS model did not include natural sate areas and assumes a high intensity of land use.

Relative to measured values, modelled *E. coli* is lower (Figure 6.4). These sites all have limited *E. coli* measures (as few as 7). Sites that were unable to be modelled were associated with small capture zones (<300 Ha) and/or had a high area of low-intensity land use (e.g., natural state). The authors consider that the *E. coli* model could be significantly improved with the addition of a land use pressure variable.

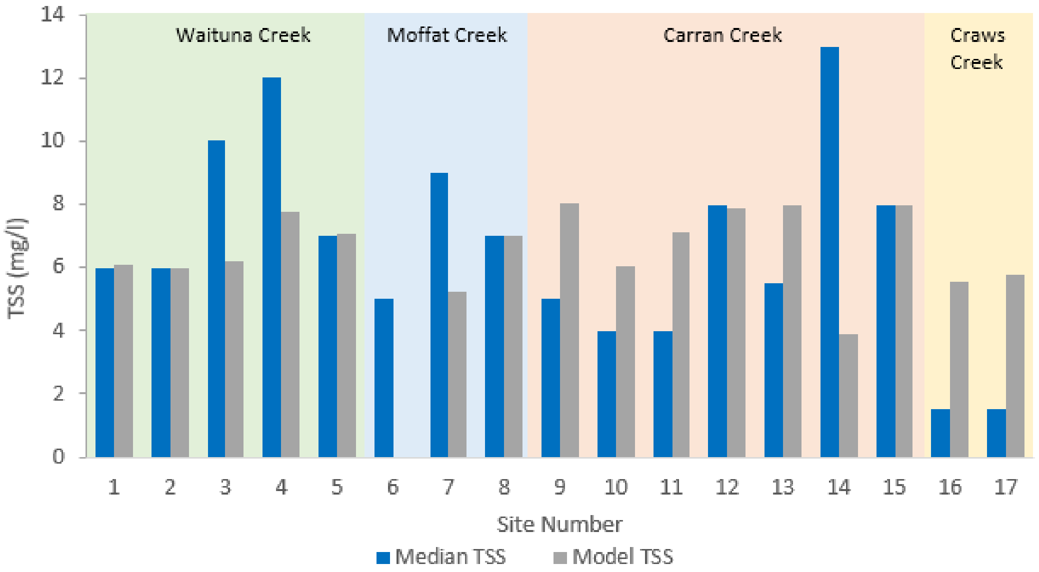

Figure 6.3: Measured median TSS concentration vs modelled for all water quality monitoring sites. Site 6 was unable to be modelled. Site 17 was not used in model calibration, therefore the TSS model is a poor indicator for natural state sites. See Table 2.2 and Figure 2.3 for site information.

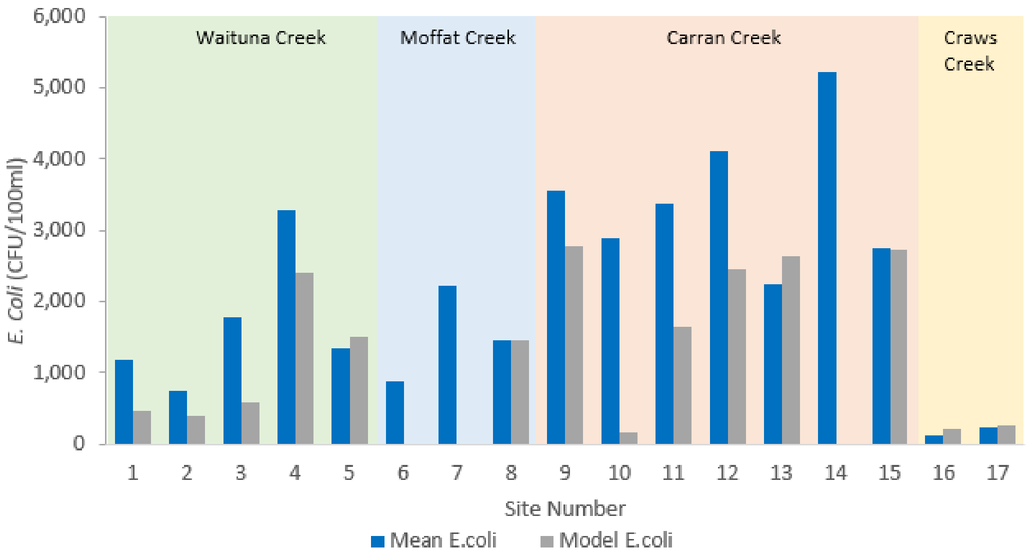

Figure 6 4: Measured mean E. coli concentration (2012) vs modelled for all water quality monitoring sites. Sites 6, 7, and 14 were unable to be modelled. See Table 2.2 and Figure 2.3 for site information.

6.4 Model Summary

The modelled estimates of key water quality measures performed well for most sites across the Waituna Lagoon Catchment. The model work particularly well for large capture zones with areas > 300 Ha and at the subcatchment level. However, model performance for *E. coli* and to a lesser degree TSS was limited for sites with capture zones < 300 Ha in area and/or where land use intensity was low (e.g., natural state areas). By including a land use factor in the assessment, the authors consider the accuracy of the model for low-intensity areas can be improved. The number of samples taken over the stream flow range and time of year was not representative for many sites, apart from the long-term monitoring sites (2, 5, 8, 15 and 17). Therefore, it is likely in some instances the model may be a better predictor of long-term water quality than the measured data set.

Models developed for mean values could be used in conjunction with flow data to provide an estimate of contaminant load for capture zones >300 Ha, subcatchments and the Waituna Lagoon.

7 Risk Summary

Maps of objective inherent risk were produced for N, P, S and M for the Waituna Lagoon Catchment. These maps depict spatially the controls over water quality outcomes. Coupled with the timing of contaminant export from each compartment (surficial, soil and aquifer), a powerful platform for guiding day-to-day farm management activities and prioritising efforts to minimise losses to waterways can be developed.

7.1 Water Source and Timing

Temporal analysis identifies the timing at which each of the 3-key compartments supplying streams switch on and off and the associated water quality signatures associated with each. Combining spatial and temporal controls provides a basis for highly targeted farm management. Hydrograph separation by water source shows a clear seasonal pattern in the Waituna Catchment with soil drainage starting in April and peaking in July (Figure 7.1) while surficial runoff is elevated during May to August with fewer runoff events occurring in October through November.

It is clear that surficial runoff events (OLF) associated with high soil moisture conditions (>85%) are the key contributor to contaminant loads to streams and ultimately the Waituna Lagoon. Not only is OLF occurrence and magnitude highest during this time, soil zone flushing is also at its maximum, driving the leaching of stored contaminants such as nitrate.

Overall, groundwater contributes little in terms of contaminant load to the streams in Waituna but is likely an important control over in-stream eutrophic response during the summer months (December – March). Unlike baseflow to streams, direct discharge of groundwater through the bed of the Waituna Lagoon may contribute a large, previously unaccounted load of P to the Waituna Lagoon, however, the magnitude of the contribution is at present poorly constrained (Guerin and Wourms, 2016; Rissmann et al., 2018).

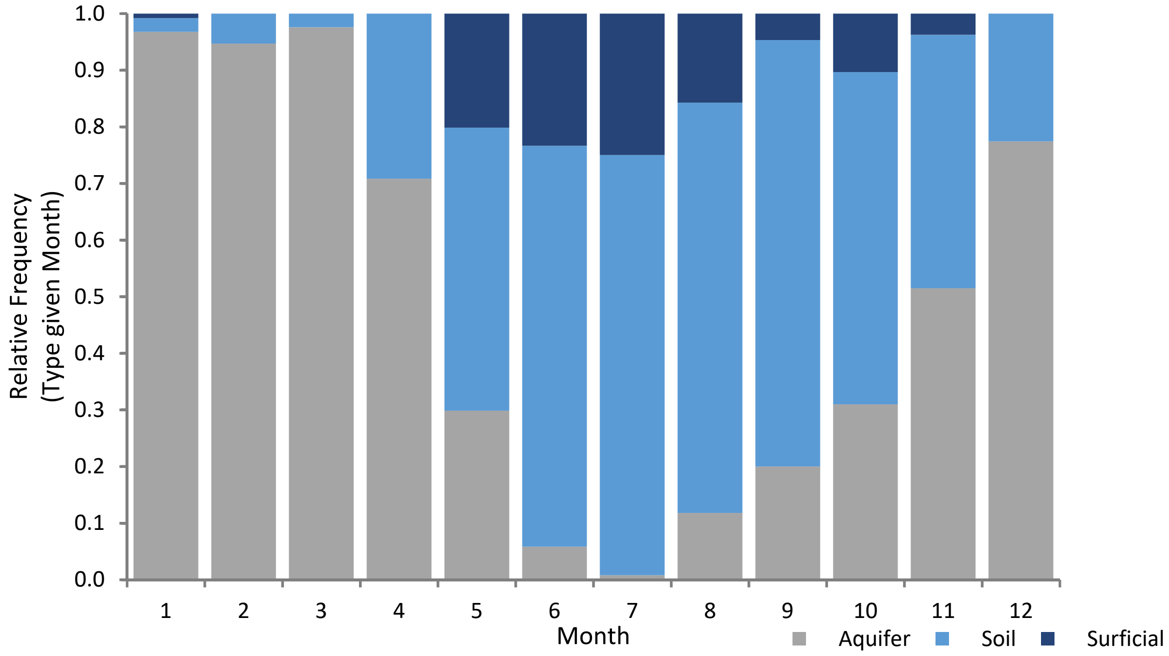

Figure 7.1: Frequency of dominant water source by month in the Waituna Catchment for the 2012 – 2016 time period (Figure from Rissmann and Beyer, 2018).

7.2 Water Quality Contaminants

In addition to land use, the spatial controls that govern variation in water quality contaminants and potential mitigations are summarised for each contaminant.

Total Nitrogen and Nitrate

- Spatial variation in TN is mainly controlled by the amount of NNN leaching.
- The majority of NNN (and hence TN) load to the Waituna Lagoon is sourced from well to imperfectly drained soils in the north of the catchment.
- Nitrate export to stream is greatest during late April – August in association with peak runoff conditions.
- If episodic NNN export during periods of peak runoff is an important control over eutrophication of streams and the Waituna Lagoon (?) then targeting NNN loss across high NNN risk areas in the north of the Waituna Creek Catchment is best managed by reducing nitrate in the soil zone prior to soil drainage events (late April – August). On-farm practices, such as the use of catch crops, and reductions in fertiliser and Farm Dairy Effluent (FDE) application to these areas are potential actions. Intensive wintering across these areas will increase the NNN available for export in the spring and perhaps the following autumn/winter.
- Experts with knowledge of the relative importance of NNN cycling during wintertime conditions may be able to better gauge its importance over the ecological health of the lagoon.

Organic and Ammoniacal Nitrogen

- Spatial variation in organic nitrogen and ammoniacal nitrogen (TKN) is the opposite to NNN.
- Although TKN makes up a smaller proportion of the TN load, episodic exports of high concentrations (> 11 mg/L) occur across the developed wetland parts of the catchment in response to surficial runoff (OLF).
- The bulk of TKN export occurs through May-August when soils are saturated soils (>85% water-filled pores). Additional export, via OLF, may occur in spring.
- Intensive wintering in high OLF risk areas is the largest contributor to TKN load. If wintering of livestock cannot be excluded from areas of high OLF risk, then strategic grazing practices in conjunction with peak runoff mitigations are considered the best mitigation tools (McDowell et al., 2012; Couldrey et al., in prep).
- Limiting stock numbers and strategic management during winter grazing in high-risk runoff areas, in conjunction with mitigations such as peak runoff control structures or equivalent (McDowell et al., 2012; Couldrey et al., in prep) could be used to reduce runoff and TKN loss.
- To our knowledge, the relative importance of particulate and dissolved organic nitrogen over internal eutrophication of streams and ultimately the Waituna Lagoon has not been studied, with a greater focus on TN export. On the basis of the large, albeit episodic, export of TKN from the developed wetland area of the Waituna Lagoon Catchment relevant experts are best placed to assess the role of TKN over in-stream and lagoon eutrophication.

Total and Particulate Phosphorus

- Spatial variation in TP is controlled by overland flow and the areas of highly reducing soils across developed areas of the catchment.
- The bulk of TP occurs as Particulate Phosphorus (PP) associated with surficial runoff predominantly occurring through May-August in response to saturated soils (>85% water-filled

pores). Additional export via OLF may occur in spring or when precipitation intensity exceeds the infiltration capacity of the soil. PP is not elevated in the natural state Craws Creek catchment (source limited).

- Intensive wintering of livestock in high-risk OLF areas is likely the largest contributor to PP load to streams. Limiting stock numbers and strategic management during winter grazing, in conjunction with mitigations such as peak runoff control structures or equivalent could be used to reduce runoff and PP loss (McDowell et al., 2012; Couldrey et al., in prep).
- In Waituna Lagoon, it is likely that PP is scavenged at the fresh-saltwater interface and that particulate P both in organic and inorganic forms is an important driver of internal eutrophication in the lagoon.

Dissolved Reactive Phosphorus

- Spatial variation in DRP is controlled by the proportion of reducing soils and aquifers. Specifically, DRP increases as the proportion of reducing soils and aquifers increase within the capture zone of a monitoring point or subcatchment, and in areas dominated by wetlands. DRP is naturally elevated in natural state peat wetland areas, but unlike developed areas, DRP does not increase significantly with flow.
- DRP is highly mobile in organic soils and aquifers and therefore more challenging to manage than PP.
- Managing for PP (derived from OLF in developed areas of the catchment) may be a more fruitful approach to reducing losses to stream and the lagoon as it makes up the bulk of the P exported.

Microbes (as indicated by *E.coli*)

- *E.coli* loss increases according to OLF risk associated with areas of developed land.
- *E.coli* is lowest in the north of Waituna Catchment where OLF risk is lowest and highest in areas of high OLF and artificial drainage in the south of the catchment.
- *E.coli* is source limited in natural state areas.

Suspended Sediment

- Spatial variation in suspended sediment (TSS/VSS) is controlled by OLF across developed areas of the catchment. The higher the occurrence of OLF, the greater the sediment flux is for developed areas.
- Sediment is source limited in natural state areas and is not elevated in the natural state tributary to Carran Creek (Craws Creek) catchment.
- The bulk of sediment export is associated with the inorganic particulate (i.e. mineral component) and is highly correlated with PP, TKN and *E. coli.*
- The majority of sediment loss occurs through May-August in response to saturated soils (>85% water-filled pores). Additional export via OLF may occur in spring or when precipitation intensity exceeds the infiltration capacity of the soil.
- Intensive wintering in high OLF risk areas is likely to be the largest contributor to sediment load. If wintering of livestock cannot be excluded from areas of high OLF risk, then strategic grazing practices, in conjunction with peak runoff mitigations are considered the best mitigation tools (McDowell et al., 2012; Couldrey et al., in prep).
- Managing for sediment will also reduce TKN, PP and microbial loss.

7.3 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

7.4 Conclusion

Environmental contaminants are most mobile at times when all compartments, surficial, soil zone and aquifers are actively discharging. We term this time peak runoff, which is the key driver of poor water quality outcomes across the Waituna Lagoon Catchment. Although peak runoff favours overland and surficial runoff, it is also a period of peak flushing of the soil zone (leaching), particularly NNN and in peat dominated areas DRP export. Combining maps of inherent risk with a knowledge of the timing of losses can be used to spatially and temporally prioritise resource management efforts. Experts with knowledge of the relative importance of NNN cycling during wintertime conditions may be able to better gauge its importance over the ecological health of the lagoon. Likewise, experts with knowledge of the relative importance of TKN, mainly as organic nitrogen, over internal cycling within the Waituna Lagoon may be able to better gauge its importance over lagoon ecological health. A considered assessment of the relative importance of these two different forms of nitrogen is important as they are associated with very different controls and are produced in different parts of the catchment.

This study focuses on the contribution of stream discharges to Waituna Lagoon; however, streams are not the only source of these contaminants. Although aquifer contributions to stream as base flow are small, direct groundwater discharges of P or organic and inorganic particulate forms of N to the Waituna Lagoon may constitute an important load. More work is required to constrain the magnitude of loads associated with direct groundwater discharge through the bed of the lagoon.

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Appendix: Water Quality Summary Statistics

Water quality data collected by Environment Southland between 2012 and 2016.

Site 1

Waituna Creek 1m upstream Rimu Seaward Downs Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	24	24	23	24	11	24	10	10
Mean	3.008	2.216	0.769	0.080	0.020	22.042	2.050	2461
Median	2.650	1.515	0.630	0.052	0.016	6.000	1.500	345
Coefficient of Variation	0.546	0.716	0.510	0.812	0.832	1.899	0.848	1.920
Minimum	1.080	0.143	0.380	0.020	0.002	1.500	1.500	60
Maximum	5.900	5.500	1.760	0.300	0.051	184.000	7.000	14000

Site 2

Waituna Creek 1m upstream Waituna Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	57	58	54	57	44	57	30	41
Mean	2.782	2.157	0.628	0.065	0.010	19.447	2.023	1183
Median	2.500	1.750	0.460	0.036	0.009	6.000	1.500	400
Coefficient of Variation	0.480	0.520	0.647	1.178	0.505	2.007	0.915	2.78
Minimum	1.160	0.890	0.220	0.012	0.002	1.100	0.300	90
Maximum	6.300	5.500	1.900	0.410	0.026	210.000	8.000	21000

Site 3

Waituna Creek NE tributary 10m upstream Waituna Creek confluence

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	25	25	24	25	12	25	11	11
Mean	3.912	2.931	0.988	0.118	0.005	35.040	4.091	2516
Median	2.900	2.100	0.625	0.047	0.002	10.000	1.500	270
Coefficient of Variation	0.485	0.487	0.836	1.339	1.274	1.517	1.713	1.902
Minimum	2.300	1.550	0.320	0.011	0.002	1.500	1.500	30
Maximum	9.100	6.400	3.700	0.590	0.025	190.000	25.000	14000

Site 4

Waituna Creek SE tributary 20m u/s Waituna Creek confluence

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	21	21	21	21	7	21	7	7
Mean	2.226	0.967	1.258	0.168	0.027	38.476	12.000	3279
Median	1.880	0.750	1.090	0.118	0.026	12.000	5.000	470
Coefficient of Variation	0.635	0.931	0.551	0.894	0.178	1.497	1.382	1.994
Minimum	0.570	0.035	0.530	0.062	0.020	6.000	1.500	140
Maximum	5.300	3.500	3.300	0.600	0.035	220.000	47.000	18000

Site 5

Waituna Creek at Marshall Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	130	131	116	129	102	120	77	69
Mean	2.383	1.474	0.894	0.086	0.016	19.473	3.988	1777
Median	2.200	1.210	0.710	0.051	0.015	7.000	1.600	350
Coefficient of Variation	0.498	0.585	0.642	1.107	0.333	1.926	1.681	3.108
Minimum	0.760	0.173	0.127	0.022	0.005	1.400	0.500	40
Maximum	6.500	4.800	2.900	0.580	0.028	250.000	49.000	42000

Site 6

Moffat Creek Sth branch 1.2km u/s Miller Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	1.291	0.489	0.800	0.066	0.009	6.385	3.577	1989
Median	0.960	0.300	0.660	0.026	0.005	5.000	1.500	70
Coefficient of Variation	0.623	1.206	0.416	1.468	0.901	0.982	0.682	2.206
Minimum	0.570	0.002	0.540	0.014	0.002	1.500	1.500	5
Maximum	3.200	1.740	1.500	0.370	0.028	19.000	8.000	14000

Site 7

Moffat Creek 20m u/s Hanson Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	1.642	0.461	1.180	0.170	0.065	12.000	6.154	9203
Median	1.130	0.280	0.940	0.136	0.047	9.000	6.000	260
Coefficient of Variation	0.656	1.192	0.536	0.484	0.531	0.860	0.793	2.741
Minimum	0.660	0.023	0.560	0.076	0.035	3.000	1.500	5
Maximum	3.900	1.830	2.400	0.340	0.150	39.000	18.000	92000

Site 8

Moffat Creek at Moffat Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	88	89	74	88	73	61	45	73
Mean	1.688	0.543	1.092	0.183	0.077	15.738	5.716	2382
Median	1.315	0.230	0.985	0.156	0.068	7.000	3.000	300
Coefficient of Variation	0.597	1.241	0.427	0.639	0.438	3.301	2.130	3.281
Minimum	0.690	0.004	0.152	0.088	0.002	1.500	1.500	10
Maximum	5.100	3.300	2.500	1.040	0.180	410.000	83.000	63000

Site 9

Carran Creek west branch d/s Waituna Gorge Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	1.406	0.579	0.833	0.053	0.011	17.192	5.038	7697
Median	0.870	0.290	0.620	0.038	0.006	5.000	1.500	170
Coefficient of Variation	0.801	1.228	0.555	0.898	1.000	2.093	1.222	2.132
Minimum	0.560	0.029	0.450	0.014	0.002	1.500	1.500	5
Maximum	3.800	2.300	1.900	0.154	0.039	134.000	23.000	51000

Site 10

Carran Creek east branch u/s Waituna Gorge Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	2.400	1.145	1.259	0.072	0.019	10.654	4.615	4897
Median	1.490	0.560	0.840	0.034	0.008	4.000	3.000	80
Coefficient of Variation	0.724	0.965	0.744	0.918	1.186	1.252	0.888	2.323
Minimum	0.790	0.082	0.430	0.016	0.002	1.500	1.500	5
Maximum	5.800	3.600	3.300	0.184	0.067	49.000	13.000	31000

Site 11

Carran Creek 1km d/s Waituna Gorge Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	2.230	1.175	1.057	0.061	0.012	11.654	4.308	7158
Median	1.810	0.970	0.780	0.030	0.006	4.000	1.500	270
Coefficient of Variation	0.633	0.754	0.547	1.073	1.135	1.848	1.317	2.182
Minimum	0.870	0.175	0.500	0.016	0.002	1.500	1.500	10
Maximum	5.300	3.300	2.100	0.200	0.044	79.000	19.000	48000

Site 12

Carran Creek 3km u/s Waituna Lagoon Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	12	12	12	12	12	12	12	12
Mean	1.421	0.519	0.910	0.085	0.015	18.583	6.625	6524
Median	1.170	0.380	0.745	0.044	0.014	8.000	4.000	295
Coefficient of Variation	0.536	0.696	0.536	1.027	0.333	1.164	1.112	2.125
Minimum	0.690	0.087	0.490	0.019	0.006	3.000	1.500	5
Maximum	3.400	1.260	2.200	0.290	0.021	68.000	22.000	39000

Site 13

Carran Creek 800m u/s Waituna Lagoon Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	12	12	12	12	12	12	12	12
Mean	1.182	0.440	0.739	0.117	0.037	8.083	3.583	3970
Median	0.965	0.305	0.605	0.109	0.032	5.500	1.500	190
Coefficient of Variation	0.554	0.725	0.498	0.449	0.286	0.756	0.921	2.128
Minimum	0.570	0.016	0.360	0.056	0.026	3.000	1.500	5
Maximum	2.700	1.040	1.670	0.230	0.056	23.000	10.000	23000

Site 14

Carran Creek drain 800m u/s Waituna Lagoon Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	7	7	7	7	7	7	7	7
Mean	1.489	0.583	0.906	0.277	0.074	17.571	7.857	5225
Median	1.530	0.520	0.850	0.230	0.074	13.000	6.000	70
Coefficient of Variation	0.396	0.836	0.322	0.498	0.563	0.761	0.848	2.514
Minimum	0.640	0.013	0.580	0.142	0.030	5.000	1.500	5
Maximum	2.400	1.120	1.420	0.520	0.153	37.000	17.000	35000

Site 15

Carran Creek at Waituna Lagoon Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	87	88	85	87	73	60	45	73
Mean	1.461	0.569	0.857	0.146	0.046	11.943	5.022	3038
Median	1.090	0.340	0.710	0.118	0.042	8.000	4.000	220
Coefficient of Variation	0.636	1.016	0.534	0.651	0.382	1.317	1.282	2.547
Minimum	0.560	0.004	0.102	0.056	0.011	1.500	1.500	5
Maximum	5.200	2.500	2.700	0.630	0.108	106.000	41.000	38000

Site 16

Carran Creek tributary 1km u/s Waituna Lagoon Road

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	13	13	13	13	13	13	13	13
Mean	0.622	0.008	0.614	0.106	0.092	2.038	2.154	221
Median	0.610	0.008	0.610	0.091	0.077	1.500	1.500	10
Coefficient of Variation	0.147	0.328	0.147	0.364	0.419	0.675	0.645	2.105
Minimum	0.470	0.005	0.460	0.056	0.044	1.500	1.500	5
Maximum	0.820	0.011	0.810	0.191	0.175	6.000	6.000	1400

Site 17

Carran Creek Trib at Waituna Lagoon Rd

	Total N (mg/l)	NNN (mg/l)	TKN (mg/l)	Total P (mg/l)	DRP (mg/l)	TSS (mg/l)	VSS (mg/l)	*E. Coli* (cfu)
Valid Cases	44	45	43	44	44	44	44	44
Mean	0.697	0.020	0.633	0.095	0.073	2.273	1.880	290
Median	0.700	0.010	0.650	0.092	0.068	1.500	1.500	20
Coefficient of Variation	0.170	1.189	0.268	0.294	0.375	0.732	0.437	2.985
Minimum	0.470	0.001	0.109	0.046	0.024	1.000	1.000	5
Maximum	1.090	0.100	1.080	0.167	0.133	10.000	5.000	5000