# Physiographics of Southland:

## Development and application of a classification system for managing land use effects on water quality in Southland

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### Technical Report

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# Synopsis

A classification system for managing water quality risk has been developed for the Southland region for use in Environment Southland's proposed Southland Water and Land Plan. For the purpose of this report, water quality risk is associated with four main contaminants: nitrogen, phosphorus, sediment and microbes. The classification system comprises 9 physiographic zones (or classes) and 8 variants (or sub-classes). Each zone describes areas with similar characteristics that determine water quality risk.

Water quality risk for each physiographic zone and variant was identified using assessments of their drainage pathways, and the potential for attenuation or dilution processes to occur along each pathway. This water quality risk assessment was then used to identify appropriate mitigation measures to reduce the effects of land use on water quality to support implementation of the proposed Southland Water and Land Plan. Understanding differences between zones allows for targeted land use and management strategies to be developed to reduce impacts on water quality.

# Executive Summary

Environment Southland has established a classification system that groups land areas based on water quality risk. The classification system was developed as a spatial framework for the proposed Southland Water and Land Plan (Environment Southland, 2016) to assist with managing land use effects on freshwater quality.

The classification system comprises 9 classes (referred to as *physiographic zones*) and 8 sub-classes (referred to as *variants*). Each physiographic zone represents combinations of biogeochemical and hydrological controls that result in distinct water quality risks. Variants represent areas within each zone where there is increased risk to water quality when soils are wet.

Classification of physiographic zones and variants was based on a conceptual model that assesses the potential for transport, dilution potential and attenuation processes associated with four main contaminants: nitrogen, phosphorus, sediment and microbes. These processes occur within three physical spaces; the surface zone, soil zone and saturated zones (summarised in Figure 1).

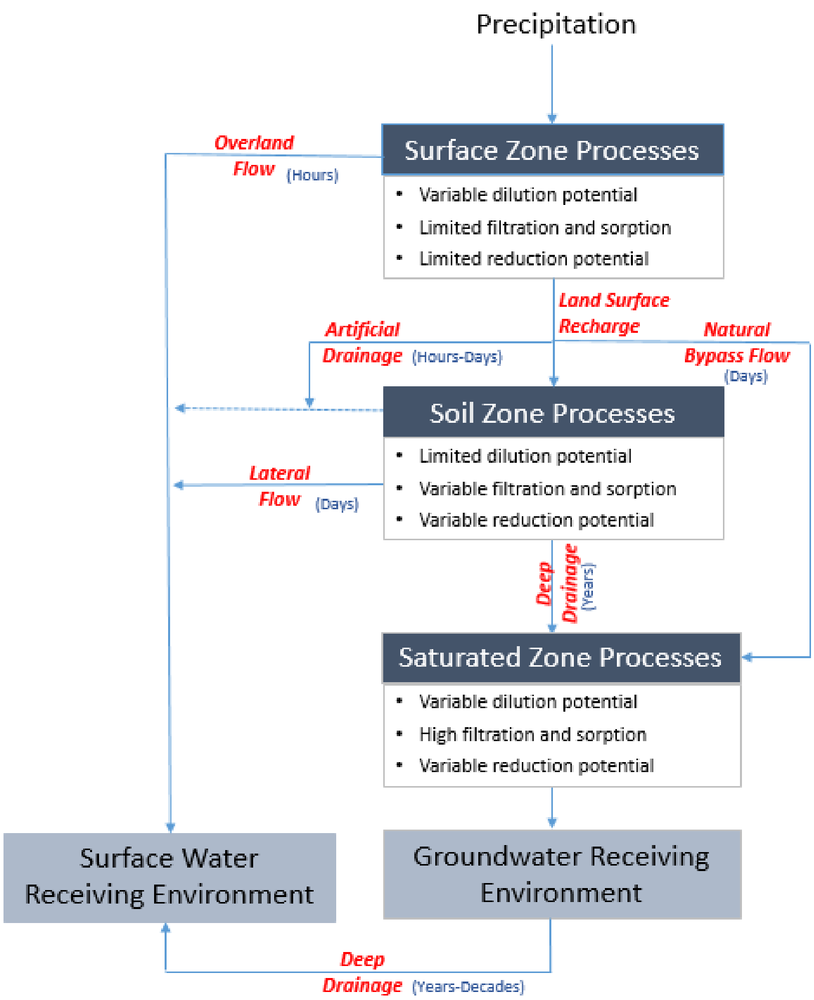


***Figure 1:*** ***Simplified conceptual model used to develop a classification system for water quality risk.***

We found that the movement and impact of contaminants on water quality are influenced by the following key processes in Southland:

- **Dilution potential:** Large volumes of recharge flux such as alpine runoff, can decrease the concentration of contaminants. Note that while dilution may influence the concentration of contaminants, it does not alter the total loading to the receiving environment.
- **Reduction potential:** The reduction potential of soils and aquifer materials has a major influence on the concentration and load of soluble nitrate and dissolved phosphorus.
- **Filtration and sorption:** Filtration and sorption are key processes in the attenuation of water quality variables within soil and aquifer materials and therefore affect water quality.
- **Drainage pathways:** The pathway water travels during drainage from the land surface to a receiving environment is an important component of quantifying water quality risk. Five major drainage pathways were considered for this project:
    - *Overland flow:* where excess precipitation flows across the land surface in response to slope and gravity (also referred to as surface runoff).
    - *Lateral flow:* where soil water moves laterally through the soil matrix.
    - *Artificial drainage:* where soil water is removed from the soil matrix via an artificial drain.
    - *Deep drainage:* where water drains vertically through the soil matrix and unsaturated zone to the underlying aquifer. Deep drainage also includes water movement through the aquifer system to receiving environments, such as rivers, streams, lakes or the coastal environment.
    - *Natural bypass flow:* similar to deep drainage except water drains preferentially through cracks, fissures and macropores in the soil profile, effectively bypassing the soil matrix.

Initial development of the classification system utilised the dilution potential and reduction potential assessments to delineate areas of Southland into the following seven preliminary physiographic zones: Alpine, Bedrock/Hill Country, Gleyed, Lignite/Marine Terraces, Oxidising, Peat Wetlands and Riverine. The variability of observed water quality and hydrochemical data within each of the seven zones was then assessed. The variation was identified to be sufficiently large in two classes to warrant subdividing them into two additional classes denoted as the Old Mataura and Central Plains physiographic zones.

Subsequent spatial delineation (mapping) of the physiographic zones was based on a suite of mapping rules. Once the physiographic zones were delineated, they were intersected with spatial coverages describing a range of environmental variables (e.g. climate, soils, geology, hydrology) to enable identification of the *dominant characteristics* of each physiographic zone. The key features of the physiographic zones are summarised in Table 1.

*Table 1: Key features of the Southland physiographic zones.*

| Physiographic zone | Key features |
|---|---|
| Alpine | ➢ High elevation areas where soils and geology have a little influence over hydrochemistry and water quality<br>➢ Waters are very dilute |
| Bedrock/Hill Country | ➢ Prominent landforms where soils overly bedrock or glacial till<br>➢ Soils exert a strong influence over hydrochemistry and water quality on water infiltrating through the land surface (i.e. excluding overland flow) |
| Central Plains | ➢ Clay-rich soils that shrink and swell with changing soil moisture resulting in bi-modal drainage (i.e. deep drainage when soils are dry and artificial drainage when soils are wet)<br>➢ Reducing soils overlie oxidising groundwater |
| Gleyed | ➢ Poorly drained soils that exhibit redoximorphic features such as mottling and gleying |
| Lignite/Marine Terraces | ➢ Aquifers contain carbonaceous sediments that can exert a strong influence over hydrochemistry and water quality |
| Old Mataura | ➢ Highly weathered soils and geology on elevated terraces<br>➢ Soils are well drained and overlie oxidising groundwaters |
| Oxidising | ➢ Oxic soils and groundwater<br>➢ Groundwater is hosted in alluvial deposits<br>➢ Little to no interaction with main-stem rivers |
| Peat Wetlands | ➢ Acidic, peaty soils with a high water table<br>➢ High organic carbon content in soils exerts a strong influence over hydrochemistry and water quality |
| Riverine | ➢ Rivers and adjacent groundwater are recharged by large volumes of pristine alpine waters |

It is noted that the classification system is based on a relatively coarse subdivision of a continuously variable natural system. Consequently, there can be appreciable variability in hydrochemistry, water quality and associated physical and hydrological characteristics within each zone.

Variants define areas within individual physiographic zones where drainage pathways result in additional water quality risks. The drainage paths identified by variants operate on an intermittent basis, generally when soils are wet (i.e. at field capacity), and potentially reduce contaminant attenuation. Variants were delineated using assessments of overland flow potential and artificial drainage density.

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# 1 Introduction

Southland is New Zealand's second largest region, occupying 12.5% of the total land area of New Zealand (approximately 3.2 million hectares (ha)). The region extends from Awarua Point (Tasman Sea) on the west coast to Brothers Point (Pacific Ocean) on the east coast. The region also includes Stewart Island, which lies to the south of Foveaux Strait.

Southland is characterised by its diverse geological landscapes, climate and soils. The climate is heavily influenced by topography and prevailing westerly airflows, with spatial and temporal variation in precipitation and temperature making it one of the most diverse climatic regions in New Zealand. The range of soils present is also diverse, reflecting climate history and the varied geology of the region.

Public conservation land makes up 53% of Southland's land area, most of which occurs in two national parks: Fiordland National Park and Rakiura National Park (Stewart Island). Most of the remaining land (76%) is occupied by pastoral agriculture which has undergone extensive intensification and expansion over the last 150 years (Ledgard, 2013).

Deforestation, extensive land drainage and intensification of land use have impacted on Southland's freshwater resources. During human occupation in Southland, the single biggest land cover change has been the loss of indigenous forest, shrubland and wetlands and subsequent replacement by agricultural farming systems. This change has disproportionately affected lowland ecosystems with both wetlands and forests occupying less than 10% of their original extent in these environments (Ledgard, 2013). A consequence of this land use change has been extensive alteration to the region's hydrology resulting from widespread vegetation clearance, channel straightening and artificial drainage in developed areas (Poole, 1990).

## 1.1 Managing Southland's freshwater resources

Southland has a primary production economy and is dependent on both the quantity and quality of water available in the region. As a regional council, Environment Southland is responsible for managing the natural and physical resources of Southland, including air, land, water and the coast. A key responsibility is the management of Southland's water resources, in terms of both quality and quantity.

All regional councils in New Zealand must implement the Government's National Policy Statement for Freshwater Management, 2014 (NPS-FM) (New Zealand Government, 2014). The NPS-FM directs regional councils to set objectives for the quantity and quality of their freshwater resources, and to define actions, including limits to achieve these objectives. These objectives should safeguard freshwater's life-supporting capacity, ecosystem processes and indigenous species, provide for the health of people who come into contact with water through recreational activities and maintain or improve the overall quality of water within a region.

To meet its statutory obligations, Environment Southland has established the *Water and Land 2020 & Beyond* (WAL2020) project, which aims to manage Southland's freshwater resources (including rivers, lakes, wetlands and groundwater). This project is in partnership with Ngai Tahu ki Murihiku and will ultimately help the Southland community achieve its goals for the region's water.

The WAL2020 project incorporates Environment Southland's response to the NPS-FM and includes a range of measures to manage water quality, including promoting good on-farm practices and development of the proposed Southland Water and Land Plan, which brings together and updates existing policies and rules. Eventually, the WAL2020 project will set catchment limits for water quality (discharges) and quantity (abstraction).

This report is just one part of the considerable scientific, economic, social and cultural work and research underway in Southland to better inform decision making processes associated with the WAL2020 project.

### 1.1.1 Key water quality variables

Water quality is a measure of the condition of water relative to ecological or human requirements. While the hydrochemical characteristics of water reflect the relative concentrations of a wide range of chemical and isotopic constituents, water quality is defined in terms of selected parameters that influence the life supporting capacity, uses and values associated with a particular water resource.

The WAL2020 project identifies four main contaminants of concern for freshwater quality:

- **Nitrogen** and **Phosphorus** are essential nutrients required for all life, including plant and animal growth. However, high concentrations of nutrients in a waterbody can result in excessive (eutrophic) abundance (biomass) and toxicity to living organisms (e.g. nitrate and ammonia). Eutrophic levels of aquatic plant biomass (algae blooms and macrophytes) alter water quality, changing acidity and dissolved oxygen concentrations, and in some circumstances, some types of algae can be toxic to humans and animals. Eutrophication can therefore affect ecosystem health and reduce the recreational and aesthetic value of waterbodies and impact on the economic use of water (for example by blocking water intakes). In addition to their role in eutrophication, nitrate and ammonia are toxic to aquatic organisms, livestock and humans at high concentrations.
- **Sediment** either suspended in water or deposited on the bed of streams, rivers, lakes and estuaries can affect the health, recreational, cultural and aesthetic values of an ecosystem. Fine suspended sediments change two key optical characteristics of water: visual clarity and light penetration. Visual clarity affects the distance that humans and animals can see through water, and mainly affects predatory species such as eels, that prey using sight. Sunlight penetration into water is needed for aquatic plants to photosynthesise, therefore their growth is impaired when light penetration is decreased. When sediment loss is excessive, sediment can also damage in-stream ecosystems via smothering and/or habitat modification. Deposited fine sediment on the beds of rivers, lakes and estuaries can severely degrade benthic habitat and may result in burial and suffocation of benthic organisms (due to increased oxygen demand and reduced oxygen exchange). Fine sediment can also damage the gills and delicate body parts of invertebrates and native fish. Sediment can also be a major source of phosphorous, as phosphorous binds to the surface of soil particles carried to water.

- **Micro-organisms** (or pathogens) can have a detrimental effect on human and animal health, particularly when ingested. The main sources of pathogens in fresh water in New Zealand are human sewage and animal manure (PCE, 2012).

## 1.2 Water quality issues in Southland

Contaminants affecting water quality in Southland have changed over time in terms of impact and source. For example, sediment from land clearance and development was once the main cause of degraded water quality. Discharges of industrial effluents, community wastewater and dairy farm effluents into water were also once important contributors to degraded water quality in Southland (Hodson, 2014).

Greater regulatory control of the quality of point source discharges came with the enactment of the Resource Management Act (RMA) 1991. Post implementation of the RMA, the impact of point source discharges in Southland has greatly reduced, largely due to both stronger regulatory processes under the RMA and improvements in technologies involved in the treatment and disposal of discharges. For example, many industrial, community and agricultural wastewater and effluents are now discharged to land rather than surface water (Hodson, 2014).

Up to the 1950s, agricultural land use was generally of low intensity, and diffuse discharges of sediment, nutrients and bacterial loadings were of lesser importance than point source discharges. However, today, diffuse discharges are the primary driver of degraded water quality in Southland (Hodson, 2014). A combination of increased agricultural productivity and positive market conditions have resulted in extensive land use change and intensification.

Intensification of land use has primarily occurred in the lowland plains and inland basins of Southland and is placing more and different pressures on water quality in Southland (Ledgard, 2013). The conversion of land to dairying and dairy support grazing is linked to increasing nitrogen, phosphorus, sediment and faecal contamination of water (Environment Southland and Te Ao Marama Inc. 2011; Snelder *et al.,* 2014; Moreau and Hodson, 2015). Higher intensity land use and greater use of mole-pipe drainage has also increased potential contaminant loss to surface waters due to the by-passing of attenuation associated with deeper soil filtration and riparian zones (Monaghan *et al.,* 2016).

Ongoing analysis of water quality in Southland demonstrates the spatial extent and magnitude of reduced water quality. Nitrate concentrations and loadings to surface and groundwaters have increased across the region (Environment Southland and Te Ao Marama Inc. 2011; Snelder *et al.,* 2014; Moreau and Hodson, 2015). In catchments with higher proportions of intensive land use, many waterways show elevated levels of nitrate, phosphorus, *E. coli*, and sediment (Monaghan *et al.,* 2007).

Monitoring data show that at a regional level, water quality is generally declining in developed areas and that there is spatial and temporal variation in water quality across the region (Environment Southland and Te Ao Marama Inc., 2011; Rissmann, 2012; Snelder *et al*., 2014; Moreau and Hodson, 2015). To date, factors influencing this variation have not been well characterised.

### 1.2.1 Understanding water quality and variability

Water quality is variable in both space and time. This variability may reflect differences in land use type or intensity, and can occur in response to differences in environmental variables including geology, soils, topography, climate, hydrology and biology.

Environment Southland's monitoring programmes have been collecting an extensive suite of hydrochemical, water quality and water quantity measurements over the last 20 years. This includes water quality samples and measurements that enable characterisation of the rate, volume and source of water moving through the region's soils, rivers, streams, aquifers and lakes. These data, combined with information on regional topography, soil and geology, form the basis of the *Physiographics of Southland* project.

## 1.3 Physiographics of Southland project

The Physiographics of Southland project was developed to better understand variation in the hydrochemical and water quality evolution of freshwater across the Southland landscape. By understanding where water comes from and the processes it undergoes as it moves through the drainage network, we can better estimate the risk to water quality associated with different contaminants and identify the most effective management actions to improve water quality outcomes.

The Physiographics of Southland project comprises several streams of work, which reflects the scale and complexity of the project. As illustrated in Figure 2, these work streams include ongoing scientific investigations to better understand the processes influencing spatial and temporal variations in water quality in Southland, as well as development of specific applications for policy purposes.

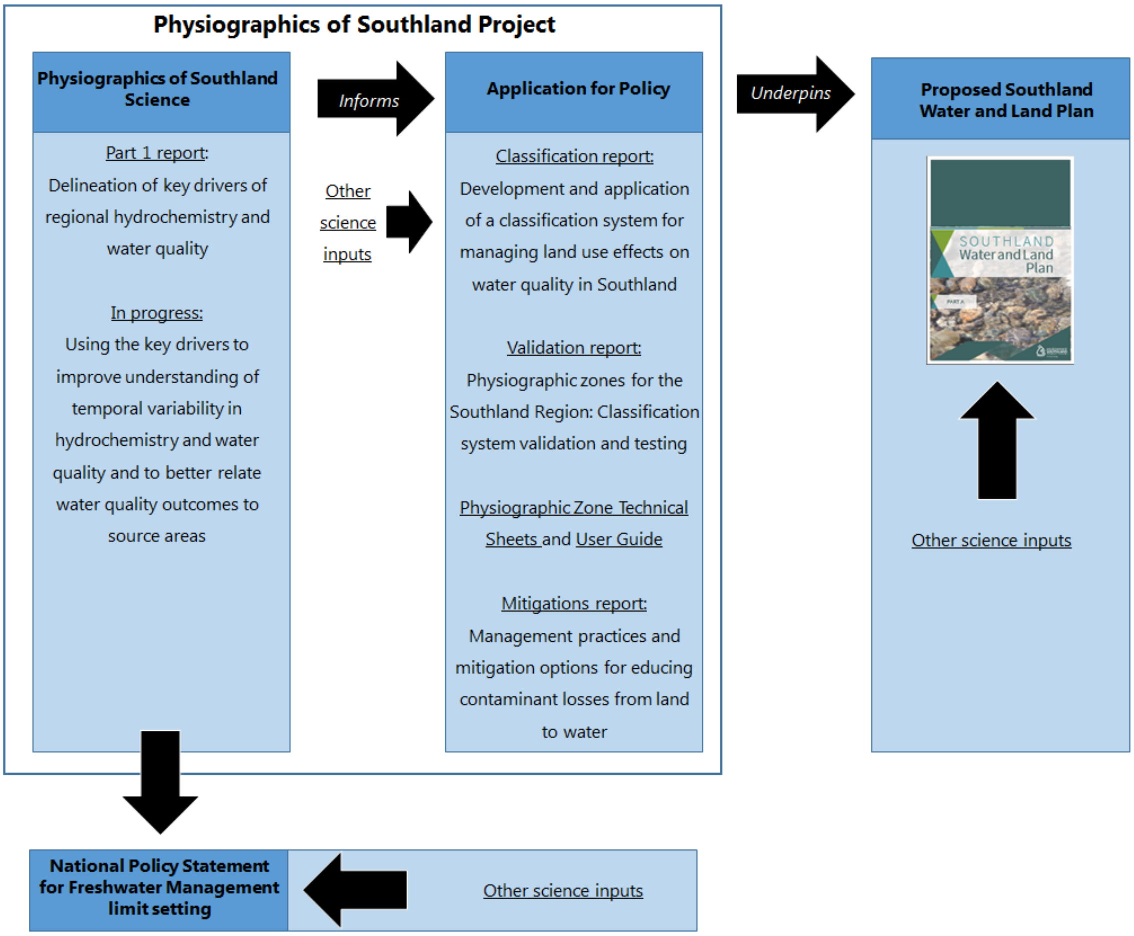


***Figure 2: Schematic overview of the components of the Physiographics of Southland Project.***

In summary, the Physiographics of Southland project comprises:

- *Physiographics of Southland Part 1: Delineation of key drivers of regional hydrochemistry and water quality* report (Rissmann, *et. al.,* 2016) (referred to as Physiographics of Southland Part 1 report)**.** This report details how hydrochemistry and water quality variation in surface waters and shallow, soil influenced groundwater reflect four key drivers (excluding land use): (i) precipitation source, (ii) recharge mechanisms and water source, (iii) combined soil and geology reduction potential, and (iv) the combination of geomorphic setting and substrate (rock or biological) composition). These driver layers are being incorporated into a wider suite of science packages which will support the limit setting process required by the NPS-FM.
- *Physiographics of Southland: Development and application of a classification system for managing land use effects on water quality in Southland* (Hughes, *et. al.,* 2016). Application of the Physiographics of Southland Part 1 report in combination with other hydrological science was used to develop a land classification system that delineates the region into 9 physiographic zones and 8 variants according to their water quality risk. This classification system was developed specifically for the proposed Southland Water and Land Plan (Environment Southland, 2016), with the concepts and processes undertaken summarised in this report. The classification system developed has been validated and tested in the

*Physiographic Zones for the Southland Region: Classification system validation and testing* report (Snelder, *et. al.,* 2016)[1].

- *Management practices and mitigation options for reducing contaminant losses from land to water* (Monaghan, 2016). Using the classification system developed in Hughes *et. al* (2016), this report identifies and documents a range of good agricultural management practices and mitigation measures that are relevant to managing water quality in Southland;

- *Physiographic zone technical sheets* (Environment Southland, *in prep.*). An overview of the key characteristics of each physiographic zone, their implications for water quality outcomes and appropriate mitigations aims to avoid adverse water quality outcomes. A companion *Guide for using the Southland physiographic zone technical sheets* has been produced to explain terms, categories and data used in the technical sheets.

## 1.4 Purpose and scope of this report

The primary aim of this this report was to develop a classification system that explains how similar land use activities result in spatially variable water quality outcomes in Southland. The classification system differentiates land areas based on water quality risk (specifically nitrogen, phosphorus, sediment and microbes) and comprises of 9 classes (or physiographic zones) and 8 sub-classes (or physiographic zone variants).

It is intended that the classification system described in this report, in conjunction with other outputs from the Physiographics of Southland project, will provide land managers and decisions makers with a spatial framework to assist with managing the effects of land use activities on water quality in Southland.

Figure 3 provides a summary of process used to develop the classification system described in this report. The chapters in this report follow the actual process undertaken.

[1] Note that the Physiographics of Southland Part 1 report (Rissmann *et al.,* 2016) has its validation and testing results incorporated as part of the report.

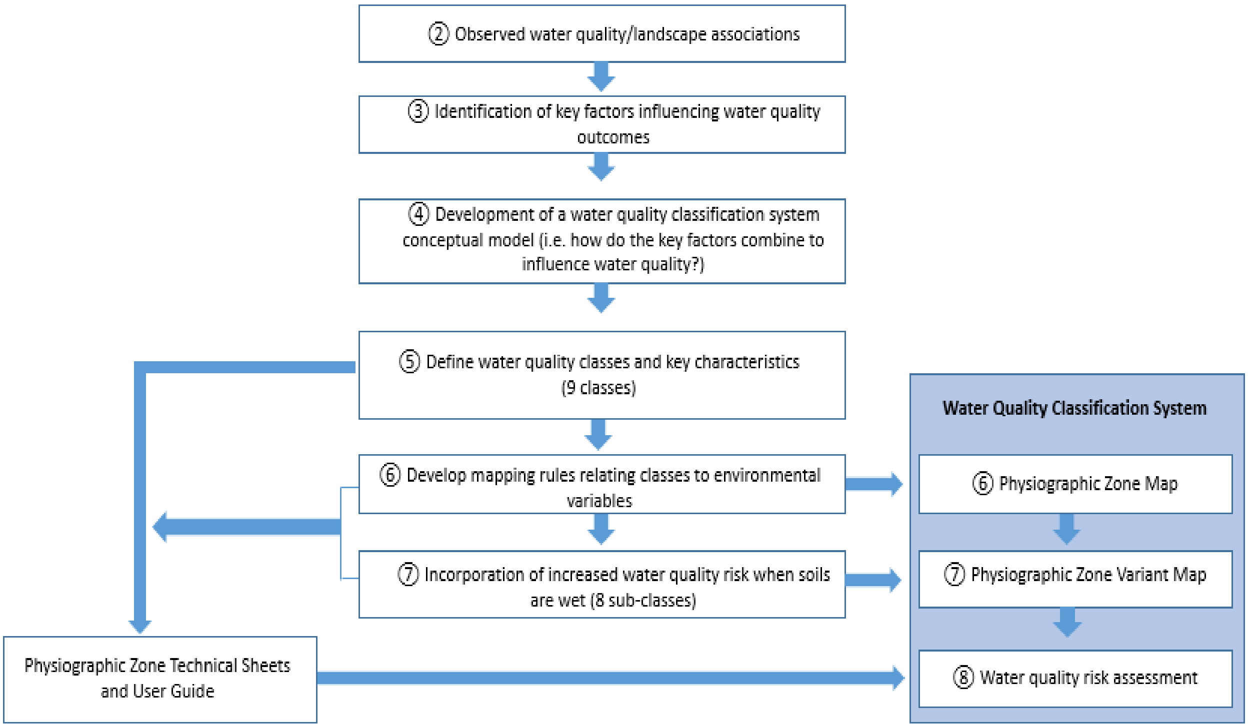


***Figure 3:*** ***Schematic overview of the process undertaken to develop a classification system for Southland. The circled numbers denote the associated sections in this report.***

# 2 Spatial variability in regional water quality

Over the past 20 years, Environment Southland has collected an extensive range of environmental monitoring data as part of its State of the Environment (SoE) monitoring programme and for various technical investigations. This extensive dataset has been analysed to increase understanding of spatial and temporal variability in freshwater quality and quantity within Southland.

In recent years, improved understanding of factors influencing spatial and temporal patterns in water quality across Southland has resulted from the inclusion of additional variables, such as stable isotopes, to the traditional water quality analytical suite. There has also been a concerted effort to fill gaps in the coverage of hydrochemical and water quality data across the region. This information was supplemented by expansion of data collection to include precipitation, soil chemical data and soil water samples, as well as sampling aimed at describing the chemical characteristics of potential contaminant sources. This data set has been used to characterise regional hydrochemistry (e.g. Rissmann, 2011, Rissmann *et al.*, 2012, Killick *et al.,* 2015, Daughney *et al.*, 2015).

Analysis of Southland's water quality over time indicates an overall decrease in the quality of surface and groundwaters in many parts of the region, which has been associated with an ongoing increase in the intensity of land use since the mid-1990s (e.g. Environment Southland and Te Ao Marama Inc. 2010, 2011, NIWA 2011, Snelder *et al.*, 2014; Moreau and Hodson, 2015). As knowledge of regional hydrology and water quality has increased over time, consistent patterns have been identified in spatial and temporal water quality variations. These patterns suggest that the magnitude, extent and timing of effects on water quality associated with land use activities vary in different environmental settings across the Southland landscape.

Consistent patterns observed in water quality data indicate that the water quality risk associated with land use activities varies spatially depending on the biophysical and hydrological characteristics of the location in which an activity occurs and the drainage pathways for that area. For example, significant attenuation of nitrate may occur in water infiltrating through a poorly drained, organic-rich soil, while limited attenuation may occur in drainage infiltrating through coarse, well drained soils or flowing laterally across the land surface (i.e. overland flow). In contrast, the occurrence of particulate contaminants (sediment and microbes) is significantly influenced by land management practices with the greatest potential to occur where overland flow or artificial drainage provide direct pathways for discharge of these contaminants to surface water receiving environments.

Table 2 summarises general relationships observed between physical setting, hydrological characteristics and hydrochemistry identified across Southland from analysis of spatial and temporal variations in monitoring data. These relationships reflect the diverse range of climatic, topographical and geological environments present in Southland.

***Table 2: Generalised landscape and hydrochemical relationships observed across Southland.***

| Observed hydrochemistry and hydrology | Physical setting / geographic area |
|---|---|
| ▪ Large volumes of runoff containing low concentrations of dissolved ions<br>▪ Significant event-driven discharge to main stem rivers in response to precipitation | ▪ High altitude (alpine and sub-alpine) areas receiving elevated rainfall |
| ▪ Low to moderate groundwater nitrate concentrations and slightly elevated dissolved manganese and iron in both groundwater and surface water<br>▪ Episodic losses of nutrients, sediment and microbes to surface water (often associated with artificial drainage) during periods of elevated soil moisture (generally late autumn to winter)<br>▪ Dense network of lower order streams that drain groundwater from shallow unconfined aquifers | ▪ Flat-lying to gently rolling terraces overlain with poorly drained soils |
| ▪ Event driven losses of nutrients, sediment and microbes to surface water | ▪ Poorly drained soils along the base of hillslopes |
| ▪ Relatively dilute surface waters generally containing low nitrate, slightly elevated iron (particularly during low flows) and elevated dissolved organic carbon<br>▪ Event driven discharge to surface waters, increasing in frequency when soils are wet<br>▪ Limited groundwater resource | ▪ Mid to low altitude hill country areas |
| ▪ Oxic groundwater exhibiting low to moderate dissolved ion concentrations containing elevated nitrate (in places) and low | ▪ Flat-lying, elevated, alluvial terraces with well drained |

| Observed hydrochemistry and hydrology | Physical setting / geographic area |
|---|---|
| sulphate concentrations<br>▪ Majority of recharge derived from local precipitation with little or no hydraulic connection with main stem rivers<br>▪ Limited surface water drainage (typically only occurring in response to high precipitation and/or extended periods of elevated soil moisture) | soils |
| ▪ Oxic groundwater containing relatively low concentrations of dissolved ions (low electrical conductivity) even proximal to intensive land use<br>▪ Spring-fed streams that drain groundwater from surrounding riparian aquifers<br>▪ Significant interaction between river and streams and hydraulically connected aquifers<br>▪ Nutrient (particularly nitrogen) concentrations in surface water during low flow periods significantly influenced by nutrient concentrations in hydraulically connected aquifers<br>▪ Significant dilution of contaminant inputs from local land surface recharge (low concentrations of dissolved ions and nutrients in groundwater, increasing with distance from main stem rivers) | ▪ Alluvial floodplains along the margins of the major rivers |
| ▪ Groundwater containing low nitrate, elevated Fe and dissolved reactive phosphorus<br>▪ Elevated phosphorus and microbes in surface waters<br>▪ Episodic losses of phosphorus, sediment and microbes when soils are wet<br>▪ Surface waters becoming increasingly reduced during low flows | ▪ Developed and natural wetland areas |
| ▪ Significantly elevated carbonate alkalinity, total hardness, calcium, manganese, electrical conductivity and pH | ▪ Extensive artificial drainage development |
| ▪ Highly reduced (often anoxic) groundwater containing low nitrate, elevated iron and manganese | ▪ Carbonate geology (often with evidence of karst development) |
| ▪ Well drained soils with limited surface drainage<br>▪ Elevated potassium, sulphate and nitrate concentrations in groundwater<br>▪ Streams often perched or exhibiting limited hydraulic connection to surface water | ▪ Bores screened in or near lignite measure sediments (typically in Eastern Southland) |

Given the statutory requirement for Environment Southland to manage water quality to meet nominated water quality objectives (e.g. NPS-FM and the proposed Southland Water and Land Plan), the observed relationships between environmental variables and water quality outcomes provided a basis for more extensive analysis to better characterise the key environmental variables that govern regional patterns in freshwater hydrochemistry and water quality. This work provided a basis for development of the Physiographics of Southland project.

The following section describes how the relationships identified in Table 2 have been incorporated into regional-scale assessments of key processes influencing water quality outcomes.

# 3 Key processes influencing water quality outcomes

Water quality at any point in the landscape reflects the nature and extent of its interactions with the physical environment between its point of origin and the receiving environment. These interactions reflect a combination of hydrological processes which control the pathway water follows over or through the land surface, as well as physical and biogeochemical processes that influence the concentrations and mobility of dissolved ions and particulates. In the natural[2] environment, these processes are strongly influenced by environmental variables such as topography, climate, soil hydraulics and the biogeochemical properties of soils and aquifers. The following section provides an overview of the key processes that influence water quality outcomes.

## 3.1 Dilution potential

Dilution is the process of decreasing the concentration of a solute such as a chemical ion or molecule, in solution. Dilution potential refers to the potential for dilution to occur in a given environmental setting.

In the context of this report, dilution potential incorporates two separate, but closely related, processes that influence water quality:

- the reduction in the concentration of a contaminant due to the flux of water moving through a flow pathway or receiving environment; and,
- the rate and extent to which a contaminant is mixed with the water contained in a receiving environment.

It is important to note that while dilution may alter the concentration of a contaminant, it does not alter the total loading of that contaminant to the receiving environment. Thus, while dilution is an important consideration in receiving environments where water quality is defined in terms of contaminant concentrations (e.g. suitability for potable water supply), it may have little impact where water quality considerations relate to overall contaminant loadings (e.g. estuarine water quality).

### 3.1.1 Recharge flux

Recharge flux refers to the rate and volume of water entering a given water body. Recharge flux has a major influence on contaminant concentrations and therefore water quality. Receiving environments with a high recharge flux have a greater capacity to dilute contaminant inputs, and

[2] In this context the term 'natural' refers to those features of the environment that are not made or caused by human activities.

consequently exhibit lower contaminant concentrations for a given contaminant input that environments with a low recharge flux.

Precipitation is the main source of recharge flux in Southland and therefore has a major influence over of the dilution potential of water in different receiving environments. However, precipitation is highly variable across the region due to both prevailing weather patterns and topography.

Weather patterns over southern New Zealand are characterised by westerly airflows and the general eastward progression of associated weather systems. Interaction between the prevailing weather conditions and the mountainous terrain results in considerable rainfall variability across Southland. The mountains of Fiordland form a partial barrier to the prevailing westerly airflow and consequently receive extremely high rainfall totals. To the east, the topography of Southland is relatively complex with large mountain ranges separated by basins, river valleys and alluvial plains. This topography results not only in orographic enhancement of rainfall on hills and ranges, but significant spill-over and rain-shadow effects in inland basins.

Figure 4 shows a plot of average annual rainfall across Southland. The figure shows annual rainfall varies from over 5,000 mm/year (up to 10,000 mm/year in places) across a large portion of the Fiordland Mountains to less than 800 mm/year in inland basins of the mid and upper Mataura River catchment. The figure highlights the large volumes of precipitation falling in the Fiordland Mountains with a significant rain shadow to the east. However, even in eastern areas, where mean annual rainfall is substantially lower, rainfall is observed to increase with elevation across the hills and ranges of inland Southland.

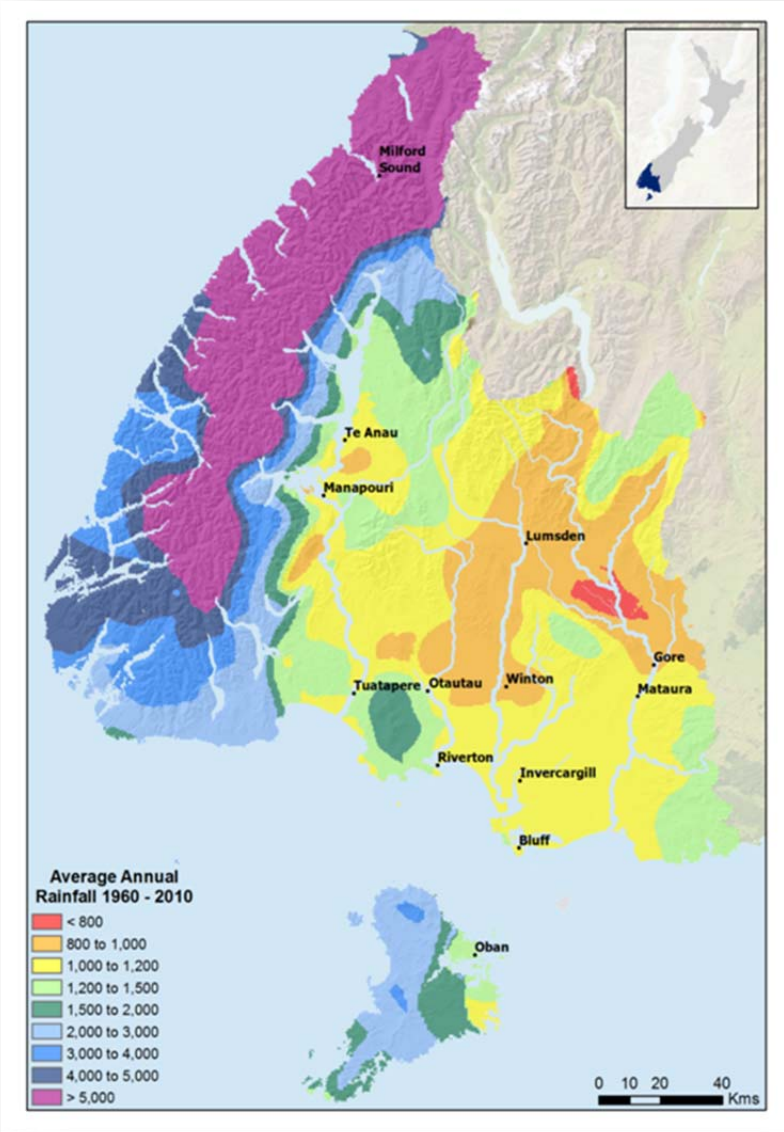


***Figure 4:*** ***Average annual rainfall (in mm) for the 1960 to 2010 period.***

The spatial variation in annual rainfall results in appreciable differences in the recharge flux across Southland. Overall, recharge flux is very high in the Fiordland Mountains and increases with elevation on the hills and ranges of inland Southland, compared to lowland areas.

Rivers and streams sourced from recharge occurring in alpine and hill country areas (such as in the mid to upper reaches of the main stem rivers) have significant capacity to dilute contaminant inputs. While developed land in such areas can still be a significant source of contaminant loads to downstream receiving environments, contaminant concentrations are generally low reflecting elevated dilution potential associated with the high recharge flux.

In contrast, lowland areas of Southland typically receive lower volumes of precipitation and experience higher evapotranspiration rates than hill country and alpine areas. In such areas land surface recharge is generally the dominant drainage pathway with limited recharge from distal sources. Such areas generally have a low dilution potential.

### 3.1.2 Mixing

Recharge can be local or distal (from a source far away). 'Mixing' refers to the ratios of water derived from local and distal sources.

#### 3.1.2.1 Surface water

Streams and rivers often carry water recharge from more than one source. Relatively pristine dilute alpine runoff will mix with water derived locally from land surface recharge. Mixing can vary both spatially along the length of a river, and temporally with different seasons, and has a significant impact on water quality.

Due to a large recharge flux, rivers and streams draining alpine and sub-alpine headwaters carry significant volumes of dilute runoff. This provides a critical ecosystem service associated with the dilution of contaminant inputs derived from lower elevation, developed areas.

Electrical conductivity can be used as a measure of recharge source and mixing. Alpine recharge is dilute and has relatively low electrical conductivity. In contrast, land surface recharge is concentrated and has high electrical conductivity. Rivers sourced from alpine and sub-alpine areas typically exhibit low electrical conductivity in their headwaters which progressively increases downstream. This reflects the increased contribution of recharge from developed land to lower stream and river reaches.

Figure 5 shows a longitudinal profile of catchment yield (mean flow per unit catchment area) and electrical conductivity in the Mataura River catchment. The figure shows headwater areas (Parawa, Keowns Rd) generate significant volumes of relatively dilute runoff. Electrical conductivity values then progressively increase downstream, reflecting the greater volumetric contribution of runoff from developed lowland areas, which receive lower recharge flux and which consequently exhibit higher electrical conductivity values.

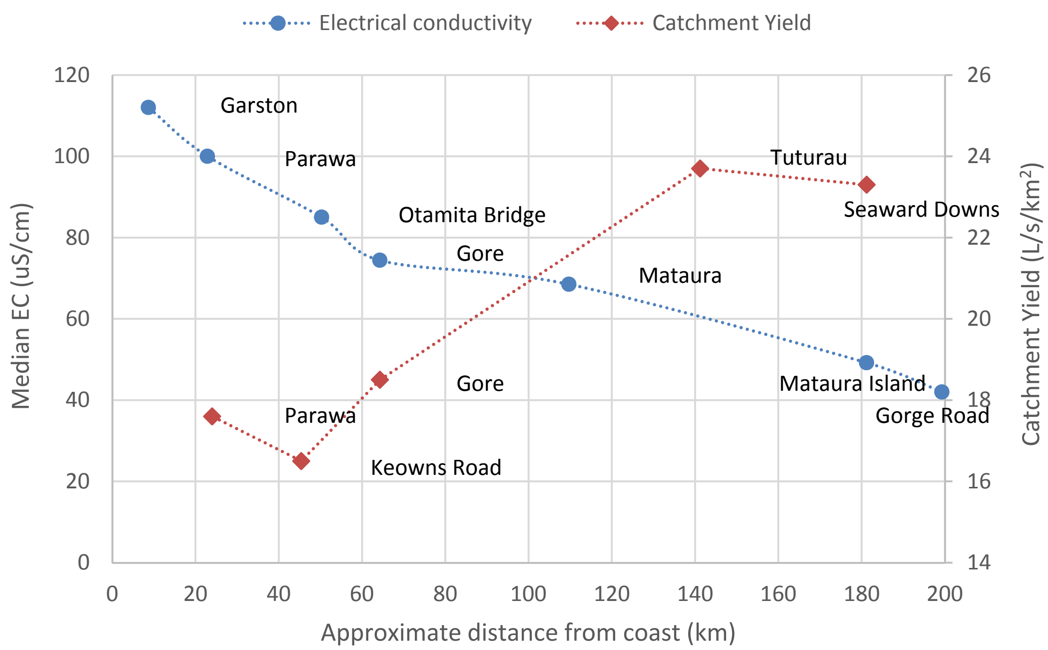


***Figure 5: Median electrical conductivity (EC) and catchment yield in the Mataura River system.***

The influence of dilution on water quality in Southland also varies temporally in response to varying runoff from differing parts of the main river catchments. For example, Figure 6 shows a plot of mean monthly electrical conductivity measured in the Mataura River at Gore and discharge in the Waikaia River at Piano Flat[3] and the Waimea Stream at Mandeville[4].

The data indicate that electrical conductivity values vary inversely with the proportion of total discharge derived from headwater (alpine) catchments with a peak in electrical conductivity values during the winter months. This reflects an increased proportion of discharge derived from land surface recharge across the mid reaches of the catchment and decreased alpine river recharge (due to snowpack accumulation). During the spring and early summer, electrical conductivity values decline as increased alpine river recharge provides greater dilution for contaminants originating from the middle reaches of the catchment.

[3] Representative of discharge from headwater catchments to this section of the Mataura River.

[4] Representative of streams draining the middle reaches of the Mataura catchment.

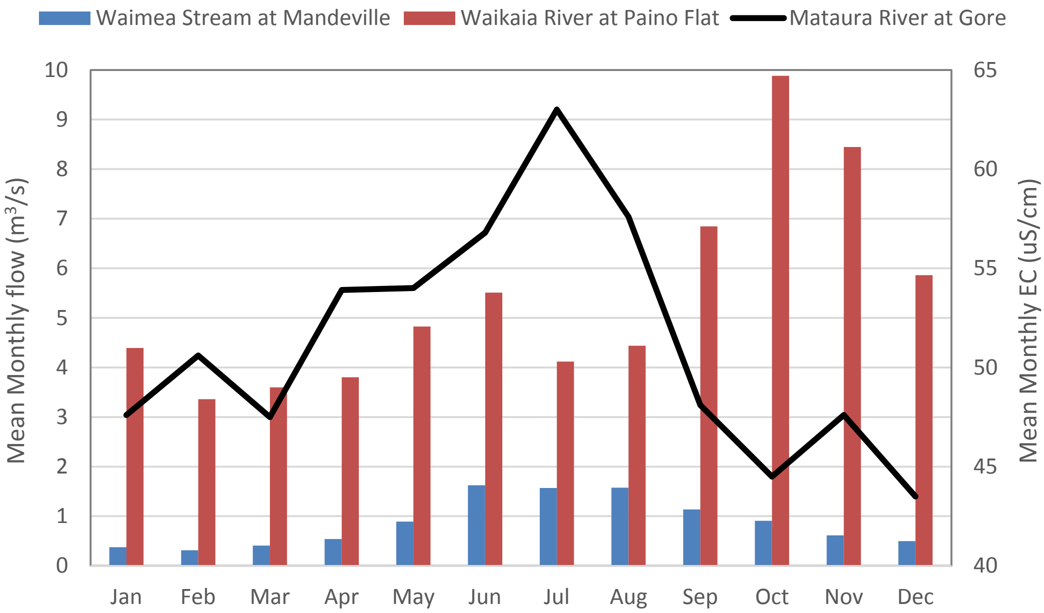


***Figure 6:*** ***Mean monthly electrical conductivity (EC) in the Mataura River at Gore and mean monthly flow in the Waikaia River at Piano Flat and the Waimea Stream at Mandeville.***

#### 3.1.2.2 Groundwater

Mixing of water from local and distal recharge sources can also occur in groundwater. Water moving through an aquifer may represent a distal recharge source, which mixes with localised land surface recharge.

The hydrogeological characteristics of alluvial materials exert a significant influence on the mixing potential of groundwater. In older, more highly weathered geological deposits where the permeability of aquifer materials is low, limited mixing of local recharge may occur with groundwater flowing through the aquifer from more distal recharge sources enabling elevated contaminant concentrations in soil drainage waters to accumulate in the aquifer (at least on a localised or sub-aquifer scale). In contrast, where aquifer permeability is higher, more rapid groundwater throughflow increases the rate of mixing between local and distal recharge reducing the potential for localised accumulation of elevated contaminant concentrations.

### 3.1.3 Dilution potential

Spatial variations in water quality are significantly influenced by dilution. Dilution potential describes the potential for contaminant concentrations to be reduced due to recharge flux or mixing in a given waterbody.

Three categories of dilution potential have been assessed for Southland:

- **High to moderate recharge flux** - areas that receive elevated volumes of precipitation (as rainfall or snow) due to orographic enhancement, in places augmented by runoff from adjacent hill country and alpine areas (equivalent to the alpine river recharge, bedrock river recharge (alpine) and bedrock river recharge (hill) recharge mechanisms described in Rissmann *et. al.,* 2016). Overland flow is typically the dominant drainage mechanism;

- **Low recharge flux** - areas where recharge is primarily restricted to lowland precipitation, and which receive limited recharge from distal sources (equivalent to the land surface recharge (matrix flow) and land surface recharge (bypass flow) recharge mechanisms described in Rissmann *et. al.,* 2016). Land surface recharge is typically the dominant drainage pathway; and,
- **High mixing potential** - areas that are recharged by a combination of lowland precipitation and runoff from distal sources (equivalent to the mixed recharge mechanism described in Rissmann *et. al.,* 2016).

Figure 7 identifies broad-scale dilution potential in Southland based on the above categories. These are consistent with the recharge mechanism hydrochemical driver defined in the Physiographics of Southland Part 1 report (Rissmann *et al*., 2016).

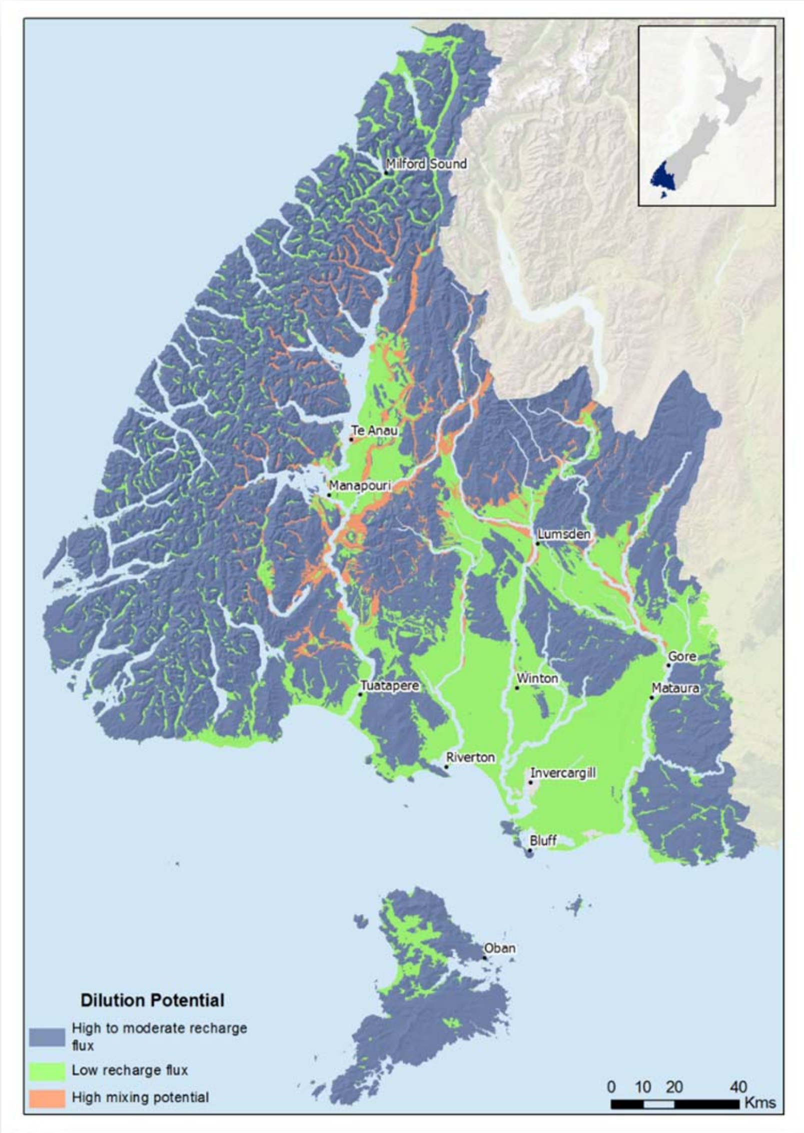


***Figure 7: Assessment of dilution potential.***

## 3.2 Reduction potential

Reduction potential is a measure of the tendency for oxidation-reduction reactions (shortened to *redox*) to occur, whereby a chemical species acquires electrons and is thereby reduced.

Redox reactions are chemical processes that involve the transfer of electrons between two chemical species. In water and soils, redox reactions are largely driven (catalysed) by bacteria, which gain energy by facilitating the transfer of electrons (usually from organic matter) to an electron acceptor. This process results in the breakdown of organic matter into its constituent elements (carbon, oxygen, nitrogen, phosphorus and some minor trace elements), the conversion of the electron acceptor to a more reduced form (e.g. conversion of ferrous iron ($Fe^{3+}$) to ferric iron ($Fe^{2+}$)), and a net energy release for the micro-organism.

Of available electron acceptors, oxygen releases the greatest energy to micro-organisms so is consumed preferentially. However, if dissolved oxygen concentrations decline (e.g. in water that is isolated from the atmosphere), the decay of organic matter continues through a succession of reactions sequentially involving nitrate, manganese, iron, sulphate and finally carbon dioxide. These reactions involve the conversion of these dissolved species into their reduced form (e.g. conversion of nitrate to nitrite and finally, nitrogen gas).

Redox can exert a significant influence on the concentrations of selected ions in solution where land surface recharge is the dominant recharge mechanism. In this environment, the reduction potential of soils and underlying saturated zone influences the degree to which concentrations of redox sensitive species (e.g. nitrate, iron and manganese) may change as water flows from its recharge source to the ultimate receiving environment.

### 3.2.1 Denitrification

Denitrification is a redox reaction that refers exclusively to the removal of oxidised forms of nitrogen (TON) from nutrient cycling due to conversion to either nitrous oxides or $N_2$ gas.

Where soils or aquifer materials have a high reduction potential, the concentrations and/or load of nitrate may be significantly attenuated by denitrification. The redox state of soil and groundwater (and hence denitrification potential and phosphate solubility) reflects the physical and chemical characteristics of the soil and aquifer substrates through which the water has passed since recharge.

The reduction potential of a soil can be characterised in term of its overall drainage characteristics (Killick *et al*., 2014). Typically, well drained soils are characterised as oxidising, while poorly drained soils are reducing. Thus, limited denitrification will occur in soil water passing through an oxidising soil, while significant denitrification may occur in reducing soils, depending on the retention time of the water within the soil matrix.

In aquifers, groundwater reduction potential (and associated denitrification) is strongly influenced by the presence or absence of significant volumes of organic material. Aquifers hosted in materials containing a significant proportion of lignite, peat or other organic materials have an elevated organic carbon content and tend to be strongly reducing whereas alluvial aquifers low in organic carbon are oxidising (Rissmann, 2012).

Denitrification has an influence on water quality in different physical environments. As illustrated in Figure 8, water draining through oxic soils into oxic aquifers tends to remain oxic with limited denitrification occurring (i.e. nitrate concentrations remain close to that of recharge waters, allowing for any dilution which may occur). In contrast, extensive denitrification may occur in water infiltrating through poorly drained soils into aquifers with high organic carbon content. In many parts of the Southland landscape (particularly those with imperfectly drained soils) soil waters are only partially reduced, due to limited retention time within the soil matrix. Water passing through such soils tend to exhibit a mixed redox signature, with nitrate concentrations moderated from those in occurring recharge waters, and concentrations of other redox sensitive species (e.g. manganese and iron) slightly elevated.

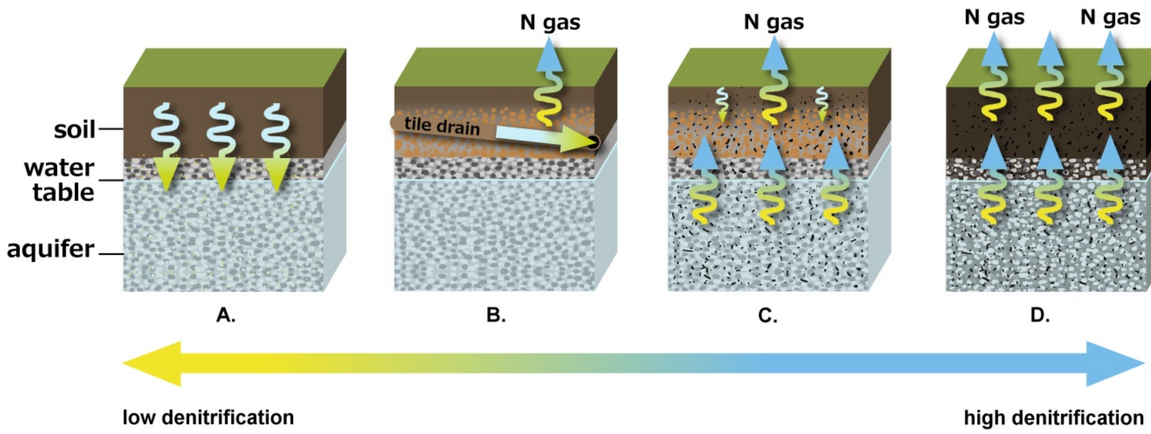


***Figure 8:*** ***Denitrification continuum associated with differences in soil drainage and subsurface geology: (a) low denitrification occurring in oxic soil and groundwaters; (b) some denitrification occurring in poorly drained soils (as evident by mole-pipe drainage); (c) some denitrification where soil and groundwaters exhibit a mixed redox state and (d) significant denitrification occurring in soil and groundwater where waters are anoxic.***

Denitrification tends to be limited in surface water due to the diffusion and mixing of atmospheric oxygen. However, where soil drainage or baseflow make a significant contribution to surface water discharge, the nutrient content may be strongly influenced by denitrification occurring within the soil zone (in the case of lateral flow and artificial drainage) or underlying aquifers (in the case of baseflow).

As an example of the potential influence of redox setting on surface water quality, Figure 9 compares median seasonal nitrate concentrations in three developed catchments in lowland Southland with differing redox characteristics. The figure shows median nitrate concentrations exhibit an appreciable increase from Carran Creek (reducing soils and groundwater) to Waituna Creek (reducing soils and mixed groundwater redox) and Waikiwi Stream (oxic soils and groundwater). Given land use is relatively similar across the three catchments, the observed differences in both the magnitude and seasonal variation in nitrate concentrations is inferred to, at least in part[5], reflect the extent of denitrification occurring in environmental settings with differing reduction potential.

[5] In-stream uptake of nitrate by aquatic plants can also significantly influence nitrate concentrations in surface waters.

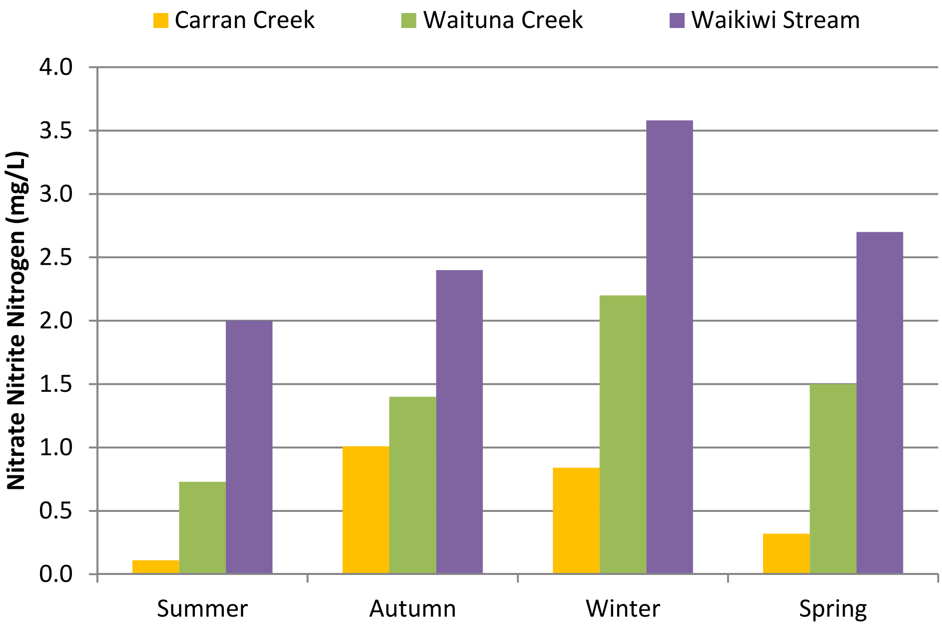


***Figure 9:*** ***Seasonal variation in median nitrate concentration in the Waikiwi Stream (oxic soils over oxic aquifers), Waituna Creek (reducing soils over mixed redox aquifers) and Carran Creek (reducing soils over reducing aquifers).***

It is noted that nitrate concentrations in Carran Creek are very low in summer reflecting the increased contribution of reduced (or anoxic) groundwater to baseflow in summer. The oxic baseflow in Waikiwi Stream results in elevated nitrate concentrations during this period and reflects the limited denitrification occurring via deep drainage in this catchment. All three sites show consistent seasonal variation in nitrate, with highest concentrations recorded during the winter and spring. However, the larger seasonal variations observed in Carran Creek and Waituna Creek are inferred to reflect the transition from reduced baseflow during summer and autumn to other drainage pathways (overland flow and artificial drainage) during the winter and spring, which are associated with less denitrification.

Figure 10 and Figure 11 illustrate the effect of temporal variations in redox status on nitrate concentrations in Waituna Creek. Figure 10 illustrates a decline in nitrate concentrations observed during low flows, which is attributed to a greater contribution of reduced baseflow to stream discharge. This variation is observed in the transition from more oxidised soil waters [$O_2$] associated with quickflow at mid to high flows, to increasingly reduced [$O_2$-Mn(IV) and $O_2$-Fe(III)/$SO_4$] waters during baseflow conditions[6] shown in Figure 11.

[6] It is noted only a sub-set of samples from this site have an analyte suite suitable for calculation of redox category.

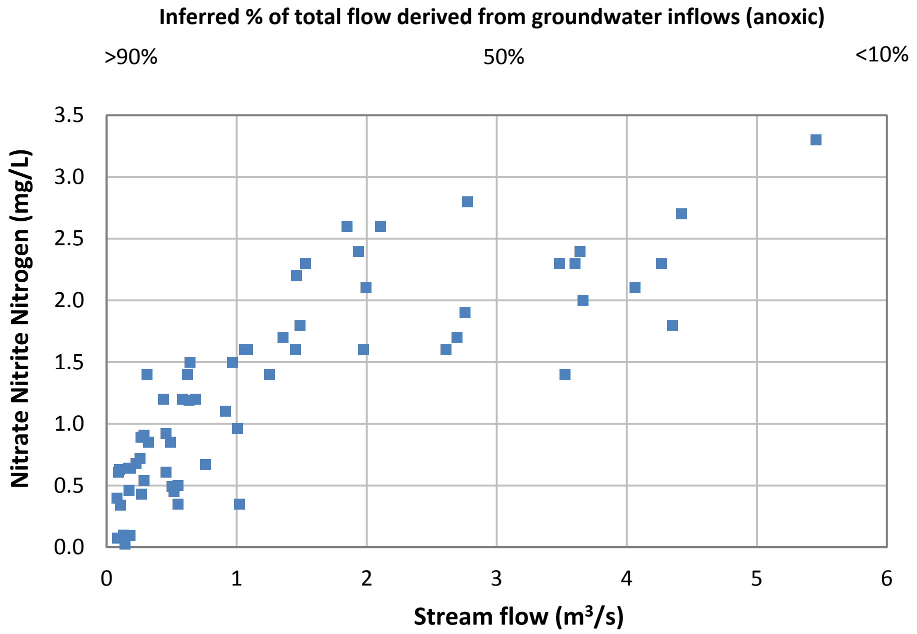


***Figure 10: Variation in nitrate concentration with flow in Waituna Creek at Marshall Road.***

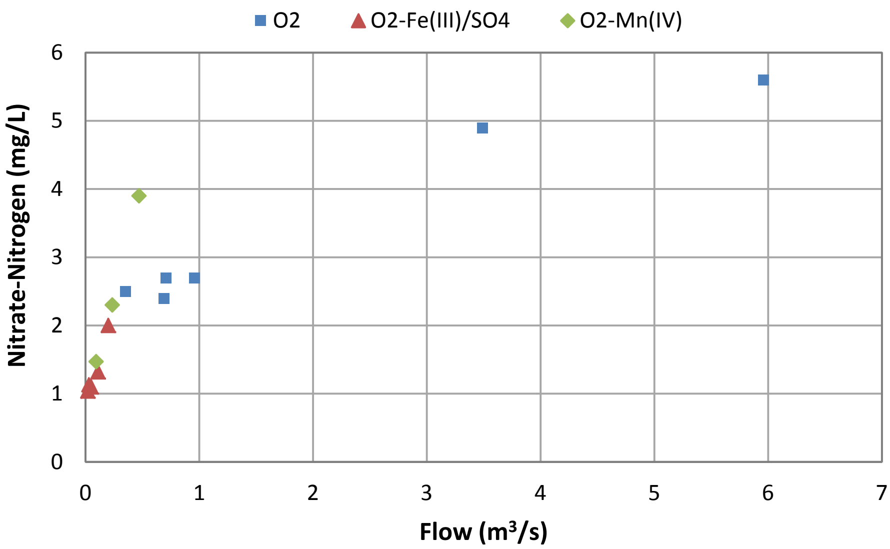


***Figure 11: Variation in nitrate concentration with redox category in Waituna Creek 1 metre upstream of Waituna Road and flow in Waituna Creek at Marshall Road.***

### 3.2.2 Phosphorus solubility and mobility

Phosphorus is also influenced by the reduction potential of soil and aquifer materials, which in turn affects water quality. In its dissolved reactive form, phosphorus tends to be more soluble and mobile under reducing conditions (Rissmann, *et al.,* 2012). In contrast, under oxic conditions, dissolved reactive phosphorus (DRP) is able to sorb onto mineral surfaces and becomes much less mobile.

Dissolved reactive phosphorus (DRP) can be rapidly removed from solution via chemical sorption onto iron (Fe) and manganese (Mn) oxides. Under oxic conditions, Fe and Mn oxides exist as poorly structured minerals containing large surface areas that have a strong affinity for DRP. As water evolves beyond nitrate ($NO_3$) reducing conditions, Mn and Fe oxides dissolve as bacteria use each as a terminal electron acceptor. As Mn and Fe are dissolved, any DRP that has been sorbed onto these minerals is released back into solution. For systems that reach Fe or sulphate ($SO_4$) reducing conditions, only minor concentrations of Fe and Mn oxides remain. Under these strongly reduced conditions, any introduced DRP tends to remain in solution.

Organic soils typically have low Fe and Mn oxide content, which makes them less effective at removing phosphate from solution. Organic soils also tend to have reducing conditions due to the abundance of organic carbon supplied by peat and poor drainage characteristics. Consequently, these soils are more prone to phosphate losses than other soil types.

As an example of the potential influence of redox setting on surface water quality, Figure 12 compares median seasonal dissolved reactive phosphorus (DRP) concentrations in three developed catchments in lowland Southland that exhibit differing redox characteristics. The figure shows median DRP concentrations exhibit an appreciable decrease from Carran Creek (reducing soils and groundwater) to Waituna Creek (reducing soils and mixed groundwater redox) and Waikiwi Stream (oxic soils and groundwater). Given land use is relatively similar across the three catchments, the observed differences in both the magnitude and seasonal variation in DRP concentrations is inferred to, at least in part[7], reflect the extent of phosphorus solubility occurring in environmental settings with differing reduction potential.

[7] In-stream uptake by aquatic plants can also significantly influence dissolved phosphorus concentrations in surface waters.

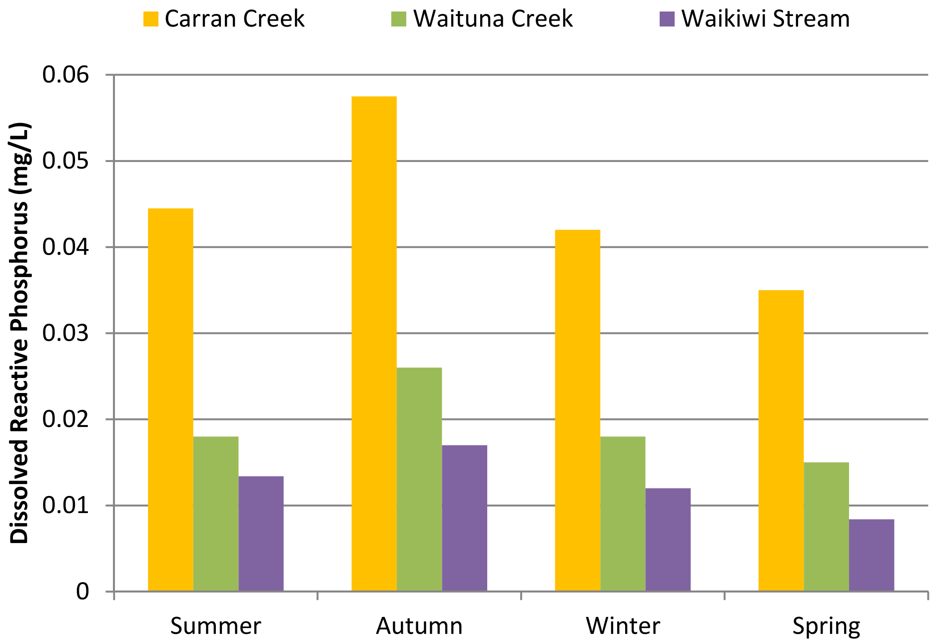


***Figure 12:*** ***Seasonal variation in median dissolved reactive phosphorus concentration in Carran Creek (reducing soils over reducing aquifers), Waituna Creek (reducing soils over mixed redox aquifers) and the Waikiwi Stream (oxic soils over oxic aquifers).***

### 3.2.3 Combined reduction potential

Combined reduction potential refers to the combination of soil and aquifer reduction potential into a single index expressed as soil over aquifer reduction potential.

Figure 13 shows a plot of the combined reduction potential across Southland. The figure shows extensive areas of elevated soil reduction potential across hill country and lowland areas (including coastal organic soils) with low soil reduction potential mainly limited to older elevated alluvial terraces and young alluvium on active floodplains. Elevated groundwater reduction potential is mainly limited to shallow lignite in Eastern Southland and peat wetlands along the south coast.

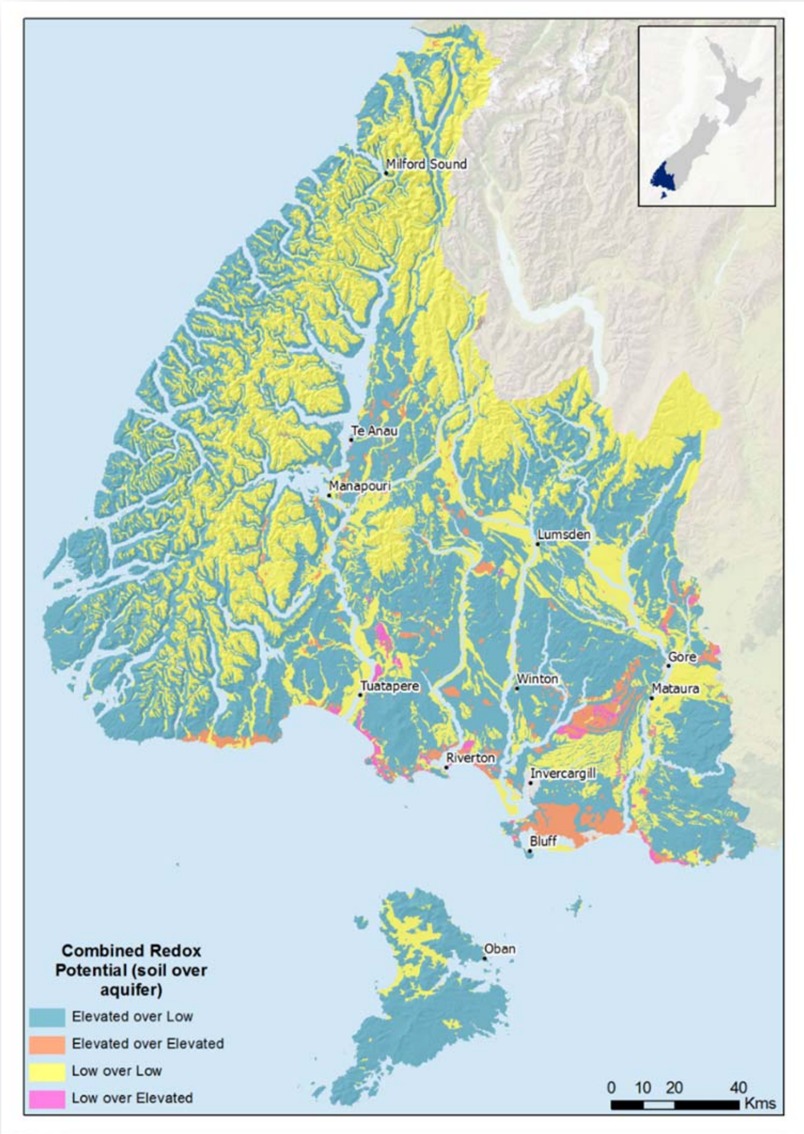


***Figure 13: Combined (soil over aquifer) reduction potential in Southland***

## 3.3 Filtration and sorption

Physical processes, including filtration and sorption[8], affect the movement of particulates, suspended solids and microbial contaminants through the environment and consequently exert a significant influence on water quality. Chemical processes such as flocculation, colloid neutralisation, complexation and chemisorption also play an important role in regulating the movement of particulates.

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[8] The term sorption includes both adsorption (accumulation of a substance at the surface of a solid or liquid) and absorption (incorporation of a substance in one state into another of a different state e.g. a liquid being adsorbed by a solid). Desorption is the reverse process of sorption.

### 3.3.1 Filtration

Filtration occurs when particulates such as sediment or bacteria are physically removed from water moving over the land surface or through underlying geological materials. Due to the variation in pore spaces between individual grains comprising a rock or soil material, particulates become trapped in smaller pore spaces, effectively retaining them within the geological material.

Grain size distribution exerts a significant influence on filtration, with particulates rapidly removed from water infiltrating through fine-grained materials such as clay, silt, or sand. Particulates may be transported greater distances through coarser-grained materials such as gravel, which have large, open pores. However, even in coarse-grained materials there is typically sufficient variability in pore spaces to remove most particulates within a short distance of their point of origin[9].

Filtration may also remove some particulate materials transported by overland flow if the velocity of the water is significantly reduced as water flows through dense materials such as riparian vegetation.

### 3.3.2 Sorption

Sorption takes place when particulates in solution bind to the surface of the soil or aquifer materials. This process results from electrostatic attraction between particles in solution and surrounding geological materials. Many rock or soil particles carry a surface electrical charge (resulting from processes such as isomorphous replacement, broken bonds or lattice defects), which may be satisfied by adsorbing a charged ion or particle from solution.

Many compounds that have limited solubility in water have a strong tendency to sorb to soil or aquifer media, thus being removed from solution and becoming immobilised. Clay minerals tend to be particularly strong adsorbers, due to a high surface area per unit volume and significant surficial electrical charges at the surface.

Sorption has a variable influence on nutrient concentrations in water. While nitrate has a low tendency to sorb, phosphate has a higher propensity to sorb. Sorption of phosphate is often strongly influenced by redox conditions. Under reducing conditions aquifer grains can become coated with iron oxides which have a strong tendency to sorb (or co-precipitate) phosphate from solution.

### 3.3.3 Regional assessment of filtration and sorption

Filtration and sorption depend on the physical and chemical characteristics of soil and aquifer materials including grain size distribution and composition (including the occurrence of clay minerals, organic carbon). These processes exert a significant influence on the movement of suspended sediment and microbial contaminants through the environment. Drainage pathways that involve infiltration of water through the soil or aquifer matrix result in the removal of most particulate contaminants (including microbial contaminants) between the source and receiving environment.

[9] The removal rate is dependent on the size of the particles relative to the size of the pore space.

Depending on the physical environment, these processes may also attenuate particulates transported via other pathways (e.g. overland flow and artificial drainage) to varying extents.

No specific assessment of the potential for physical attenuation of particulate contaminants has been undertaken for Southland. However, significant attenuation of microbes and nutrients are well documented (e.g. Šimůnek, *et. al.,* 2006; Pang *et. al.,* 2008; Wall *et. al*., 2008) in a wide range of soil and aquifer media.

For the purposes of this report it has therefore been assumed that filtration, sorption and associated biogeochemical processes will significantly attenuate particulate contaminant concentrations where water flows through a soil or geological material except under strongly reducing, acidic conditions where phosphorus mobilisation may increase.

## 3.4 Drainage pathways

When precipitation intercepts the land surface, it may follow several different drainage pathways through or over the underlying rock and soil materials. The specific pathway taken is dependent on a complex interaction of a range of factors that characterise the topography and hydraulic properties of the soil materials and underlying geology. For example, precipitation in steep mountainous terrain may flow rapidly over bare rock to a nearby river or stream, infiltrate into shallow soil or colluvial deposits (e.g. scree or talus) or slowly percolate to great depths along fractures within the underlying rock mass.

Water quality is significantly influenced by physical and hydrogeochemical processes occurring along different drainage pathways. Seasonal or episodic variations in water quality often directly result from temporal variation in the drainage pathway water follows through the environment.

Characterising a landscape based on drainage pathways is an important consideration for identifying factors that influence spatial and temporal water quality variation in Southland. With respect to contaminant transport, five major drainage pathways were considered (Figure 14):

- **Overland flow**: where excess precipitation flows laterally over the land surface in response to slope and gravity (also referred to as surface runoff). Overland flow occurs when precipitation falls at a rate higher than the infiltration capacity of the soil (infiltration excess overland flow) or when the soil is fully saturated (saturation excess overland flow);
- **Lateral flow**: where soil water moves laterally through the soil matrix, usually along the upper surface of a low permeability layer within the soil profile (e.g. within a permeable topsoil overlying a slowly permeable subsoil);
- **Artificial drainage**: where soil water is intercepted and removed from the soil matrix via by mole-pipe or open drain;
- **Deep drainage**: where water drains vertically through the soil matrix and vadose zone to the underlying aquifer. Once it reaches the groundwater table, water moves through an aquifer system before discharging to its receiving environment in rivers, streams lakes or the coastal environment (or being abstracted); and

- **Natural bypass flow**: similar to deep drainage except water drains preferentially through cracks, fissures and macropores in the soil profile, effectively bypassing the soil matrix.

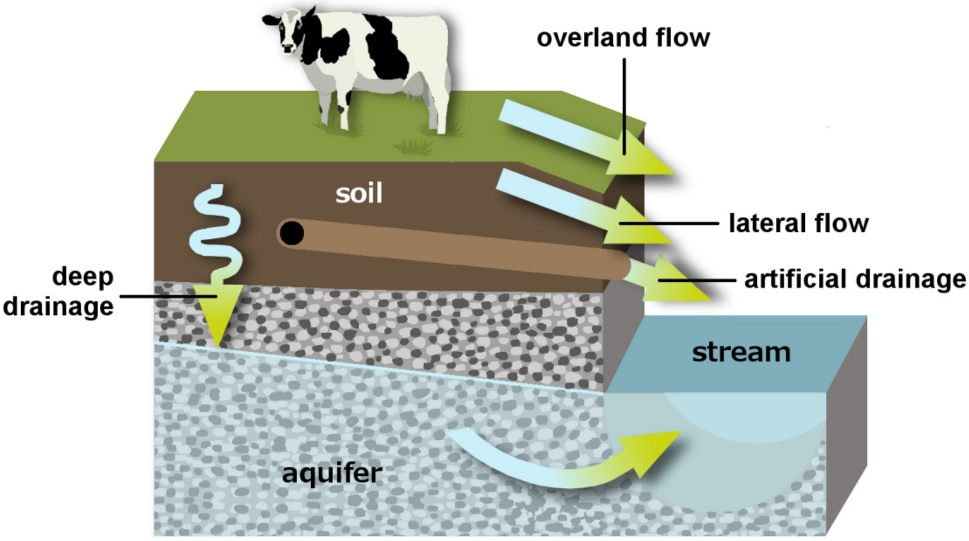



***Figure 14: Schematic illustration of the major drainage pathways***

Regional assessments were undertaken for each drainage pathway in order to better understand spatial drainage patterns in Southland. Detailed descriptions of each drainage pathway and an overview of regional assessments for each are outlined below.

### 3.4.1 Overland flow

Overland flow refers to water that moves over the land surface under the influence of gravity. Overland flow may occur as the result of two separate processes:

- **Infiltration excess** (or Hortonian) overland flow occurs when the rate of precipitation exceeds the infiltration rate of the soil; or
- **Saturation excess** overland flow occurs when the soil profile becomes fully saturated and the rate of infiltration into the soil profile is limited by the vertical hydraulic conductivity of the soil materials.

In both situations, illustrated in Figure 15, excess precipitation collects on the land surface and flows laterally following the topographic gradient. Where the land surface has minimal topographic gradient, this process may result in surface ponding.

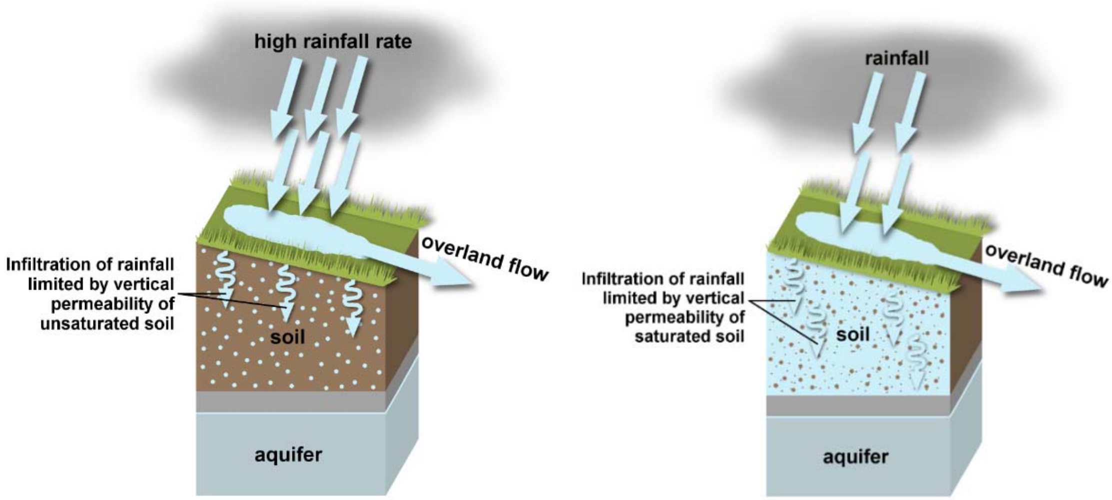



***Figure 15: Conceptual diagram of infiltration excess (left) and saturation excess overland flow (right).***

The conditions and interactions that determine the timing and rate at which overland flow occurs are complex and include factors such as slope, slope length, soil type, soil depth, porosity, soil cover, soil infiltration characteristics (permeability, structure, surface sealing, hydrophobicity, compacted layers, slaking, dispersion), hydraulic characteristics such as surface roughness and depressional storage, antecedent soil moisture conditions, precipitation intensity (depth per unit time) and event duration. Vegetative cover may also affect the generation of overland flow due to its influence on soil water balances and slope characteristics (such as roughness).

Overland flow generally occurs with sufficient energy to mobilise and entrain particulate contaminants including sediment, attached phosphorus and microbes, in addition to organic matter and soluble contaminants, including organic nitrogen. In certain situations, overland flow may also result in soil erosion, which can increase sediment and phosphorus loadings to receiving waters. As it occurs on a short timescale (typically hours), overland flow also limits the potential for attenuation of contaminants by physical or biogeochemical processes, such as sorption and redox.

#### 3.4.1.1 Regional assessment of overland flow

Overland flow has the potential to significantly impact Southland's water quality. Therefore, an important component of this project was to include an assessment of where overland flow is likely to occur across the region.

Pearson (2015a) utilised the methodology developed by McDowell *et al.,* (2005) to develop a regional-scale assessment of overland flow for Southland. This assessment used two factors (soil texture and slaking/dispersion) to calculate a hydrologic class for each individual soil polygon recorded in the combined Topoclimate South (2001), O'Byrne (1986) and Land Resource Inventory (LRI) (DSIR, 1968) soil survey data sets. The hydrological class assigned to each soil unit was then multiplied by a slope factor (derived from analysis of the regional digital elevation model) to calculate an index of overland flow, expressed as a percentage of effective annual rainfall[10].

The resulting overland flow assessment is illustrated in Figure 16. The highest potential for overland flow in Southland occurs on very steep, weakly developed shallow soils in alpine areas of Fiordland, which comprise large areas of sparsely vegetated, exposed rock or bare ground. The areas of lowest overland flow potential are the intensively farmed, flat-lying areas of lowland Southland (around Invercargill, Woodlands and Tussock Creek), parts of the plains north of the Hokonui Hills (Riversdale and Wendonside) and Te Anau basin. In southern Southland, areas with lowest overland flow potential are typically dominated by deeply developed (>1 m), well drained brown soils formed on loess parent materials or gravelly substrates. In northern Southland and the Te Anau basin, soils with the lowest overland flow potential are typically shallow, gravelly, well drained brown or recent soils.

[10] Effective rainfall refers to total rainfall minus evapotranspiration.

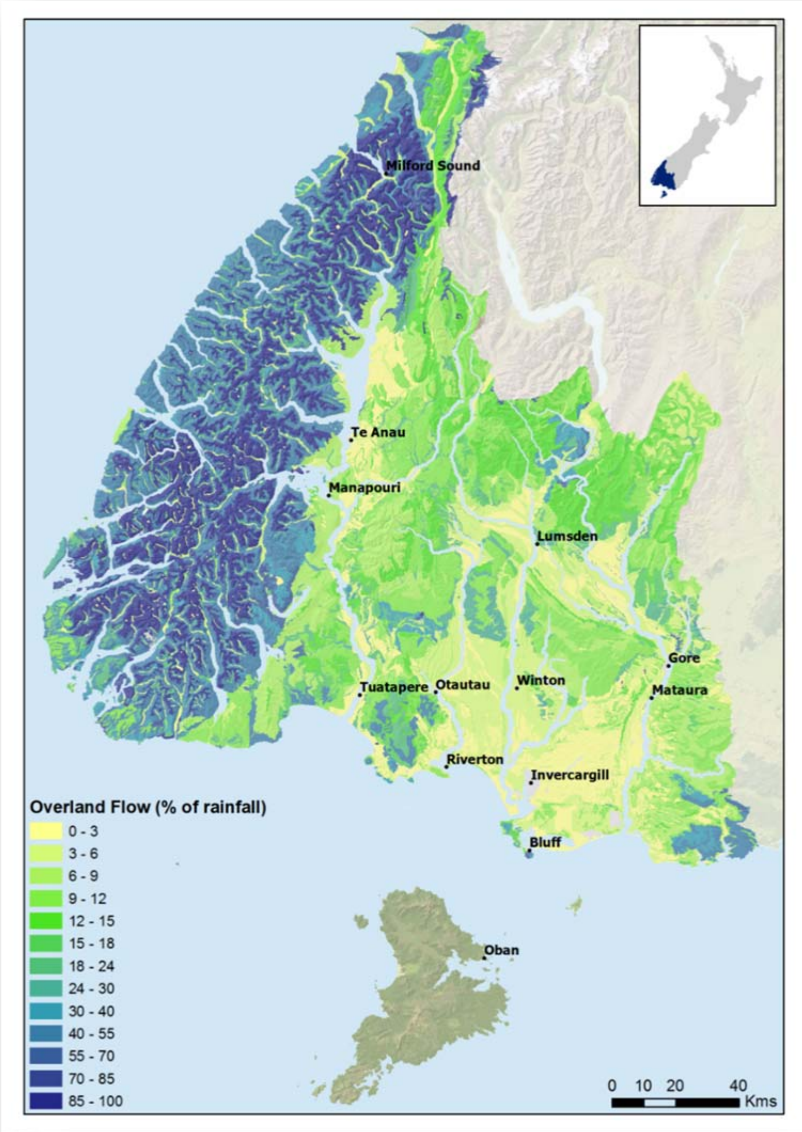



***Figure 16:*** ***Index of overland flow potential in Southland expressed as a percentage of effective annual rainfall.***

[Source: Pearson, 2015a]

### 3.4.2 Lateral drainage

Lateral drainage occurs where vertical drainage is impeded by layers of less permeable material, resulting in water flowing laterally within the soil zone. Lateral flow (or interflow) can be a significant drainage pathway in sloping land where subsoil permeability is low or where a thin permeable soil overlies low permeability bedrock materials (Figure 17). Lateral flow may also occur in flat-lying areas where a permeable soil overlies slowly permeable, compact or cemented subsoil. In this situation, water may accumulate above the slowly permeable horizon forming a perched water table. Water ultimately flows laterally through the soil to the surface or artificial drainage network, or to areas where subsoil permeability is higher and vertical drainage can occur.

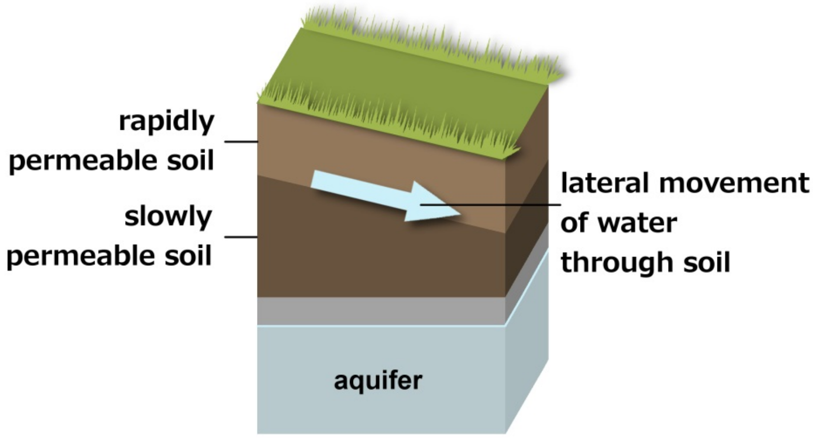



***Figure 17: Schematic illustration of lateral flow within the soil profile due to slow subsoil permeability.***

In areas with a dense surface drainage network, lateral flow may comprise a significant component of surface water flow, particularly in hill country and alpine catchments where underlying bedrock materials have limited permeability.

#### 3.4.2.1 Regional assessment of lateral drainage

In the absence of an existing classification, areas with an elevated potential for lateral flow were identified for this study on the following basis:

- hill country and alpine areas where thin sloping soils overlie slowly permeable bedrock; and,
- soils in lowland areas identified as having moderate to highly permeable topsoil overlying a slowly permeable subsoil, which were also assessed as having very low to low artificial drainage (see Section 3.4.3)

Figure 18 shows the areas identified as having an elevated potential for lateral flow.

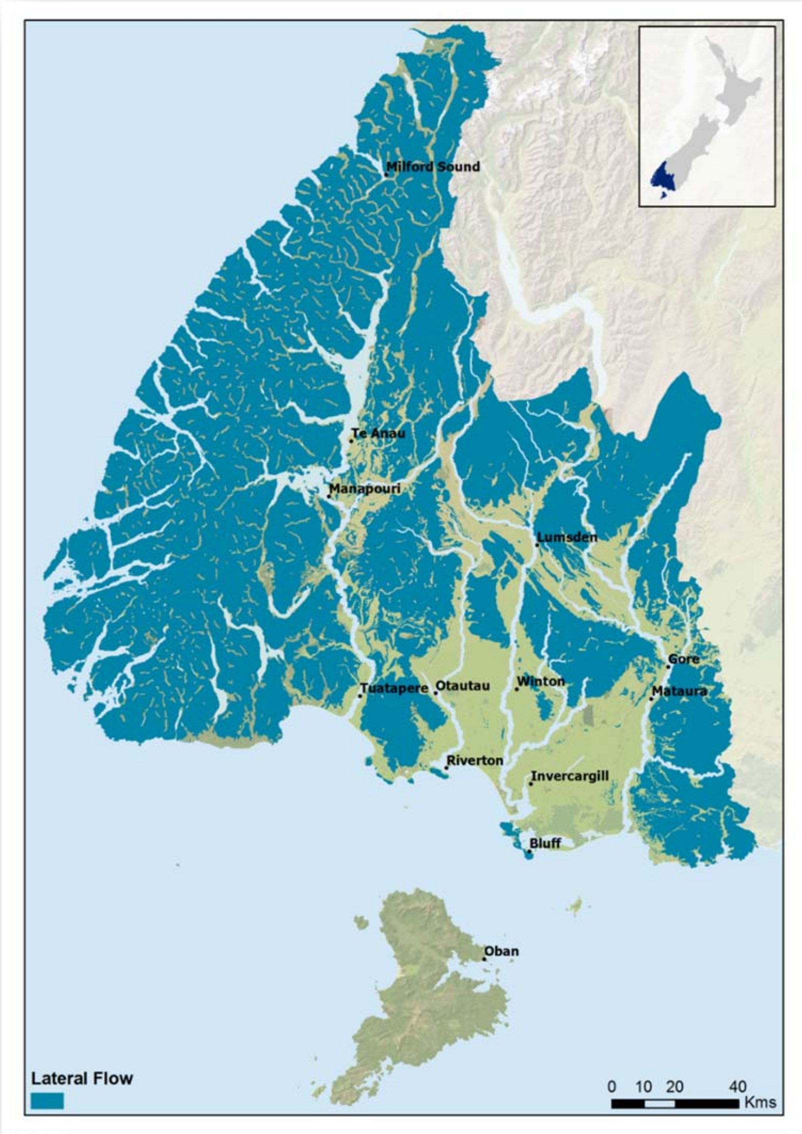



***Figure 18: Areas identified as having an elevated potential for lateral flow.***

### 3.4.3 Artificial drainage

Artificial drainage is installed to remove excess soil water to maintain agricultural productivity. It is commonly found in fine textured soils, where vertical drainage is limited by slow subsoil permeability, resulting in the formation of a temporary perched water table during the winter months. Such drainage is typically undertaken in Southland using mole-pipe drainage systems.

Moling is a process by which a channel is formed through the soil using a mole plough. This process causes the soil to heave slightly, forming a network of cracks that provide pathways for water to move rapidly through the soil into the mole channel. Mole channels are generally formed at right angles to collector pipe drains (clay tile or Novaflow), which provide an outlet for water from the moles. The preferential movement of drainage water from the land surface and topsoil layer through cracks to the mole drains transforms both perched soil water and some surface runoff flow into accelerated subsurface drainage (Monaghan, 2014).

Mole-pipe drainage is widespread in Southland's fragic pallic soils, such as Pukemutu and Waikoikoi silt loams, which contain impermeable or slowly-permeable subsoil layers (Crops for Southland, 2002). Mole-pipe drains benefit agricultural production as topsoil strength returns sooner after heavy rain, creating more safe grazing days and the topsoil is returned to an aerobic state faster, thereby improving plant growth and soil health (Monaghan and Smith, 2004). Open drains are also extensively utilised in maintaining organic soils where soils are not sufficiently compact or fine-textured for mole ploughing to be effective in creating cracks or fissures through the soil structure.

In areas where there is insufficient fall for mole-pipe drains to operate efficiently, soak holes are also used to prevent surface ponding. Typically, a soak hole is excavated to a depth past the impeding soil horizon and backfilled with a gravel substrate to allow for rapid drainage of water from the land surface and soil zone. This type of drainage system is sometimes used in Southland on flat land, where soils are well drained but slowly permeable (e.g. Edendale). Artificial drainage is also commonly used to drain seeps and springs as well as ephemeral or first order streams.

Figure 19 shows a schematic diagram of mole-tile and open channel drainage systems commonly utilised in Southland.

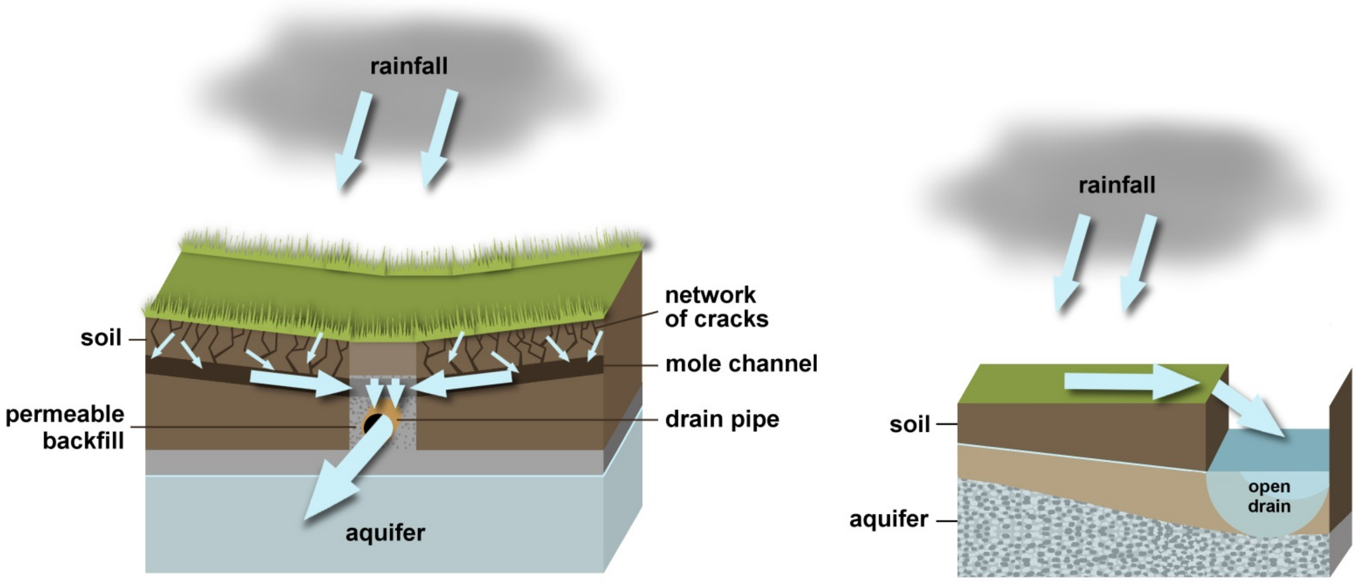



***Figure 19:*** ***Schematic illustration of artificial drainage types in Southland: mole-pipe (left) and open drain (right).***

#### 3.4.3.1 Regional assessment of artificial drainage

Assessment of the potential for artificial drainage in Southland was undertaken by Pearson (2015b). Due to the limited availability of data to quantify the physical location of artificial drainage, this assessment utilised drainage class and soil permeability attributes, to rank the probable density of artificial drainage across the Southland landscape, considering soil type variants and mixed soil types identified in the Topoclimate South, Wallace County and LRI soil surveys. Where soil polygons contained multiple soil types, permeability and drainage classes were assigned based on the proportion of each soil type. The assessment also used the Land Cover Database Version 4.1 (LCDB) to identify non-agricultural land.

By intersecting soil permeability and drainage class, thirteen categories were identified (Table 3). These categories were then further refined to five classes representing the likely density of artificial drainage in these areas. Soils with a slope greater than 7 degrees (rolling) were assigned to a separate classification of 'low (slope)' drainage density, regardless of permeability and drainage class of the soil. Figure 20 shows the resulting assessment of probable artificial drainage density for Southland.

***Table 3: Classification of probable artificial drainage density in Southland***
[Source: Pearson 2015b]

| Probable artificial drainage density | Drainage pattern | Soil permeability | Drainage class |
|---|---|---|---|
| **Very High** | Conventional | Slow | Very poor |
| **High** | Mix of conventional and contour (slope dependant) | Slow<br>Moderate<br>Rapid | Poor<br>Poor<br>Poor |
| **Moderate** | Mix of conventional and contour (slope dependant) | Slow<br>Moderate<br>Rapid<br>Slow | Imperfect<br>Imperfect<br>Imperfect<br>Moderately Well |
| **Low** | Contour and soak hole (flat) | Moderate<br>Slow | Moderately Well<br>Well |
| **Low (Slope)** | | Any (>7$^{o}$ slope) | Any (>7$^{o}$ slope) |
| **Very low to none** | Typically feeder drains from other areas | Rapid<br>Moderate | Well<br>Well |

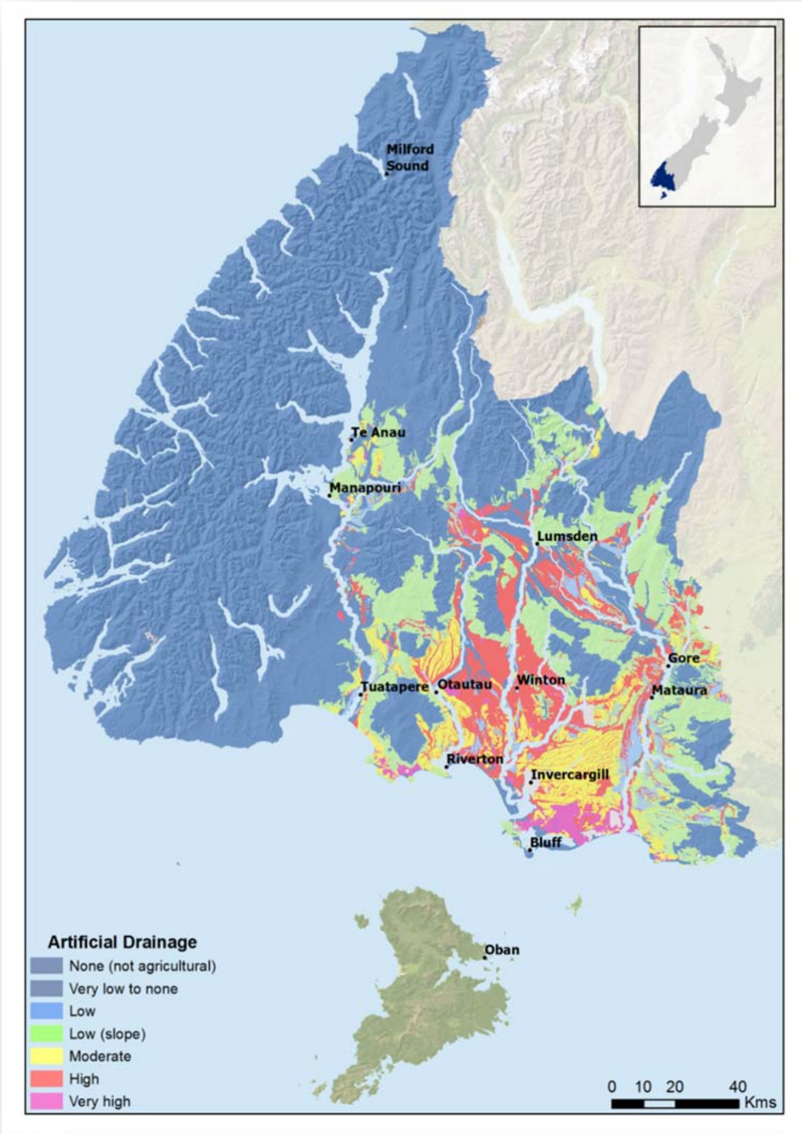



***Figure 20: Assessment of probable artificial drainage density in Southland.***

[Source: Pearson, 2015b]

### 3.4.4 Deep drainage

In the context of this report, deep drainage refers to water draining vertically from the land surface into the underlying saturated zone and discharging to surface water receiving environments. Lateral (and vertical) movement of water through aquifer systems (termed *throughflow)* is also therefore a major component of deep drainage.

Water infiltrating from the land surface to the underlying soil is retained in the soil matrix by capillary forces. Vertical drainage is only initiated when the soil moisture content increases to a point where additional water cannot be retained (termed *field capacity*). The rate and volume of deep drainage reflects the balance between precipitation and evapotranspiration and is strongly influenced by the hydraulic properties of the soil materials, which includes water holding capacity and saturated hydraulic conductivity.

Most deep drainage occurs via infiltration through the soil matrix (termed *matrix flow)* as illustrated in Figure 21. Matrix flow occurs at a rate controlled by the saturated hydraulic conductivity of the soil materials. This form of drainage is generally associated with what is called '*piston flow'* whereby soil water is sequentially displaced downwards though the soil profile. Soil waters infiltrating via piston flow may have a relatively long residence time (years), depending on the thickness of the unsaturated zone and the rate of recharge. Circulation of groundwater through the saturated zone typically occurs over an extended timescale (years to centuries).

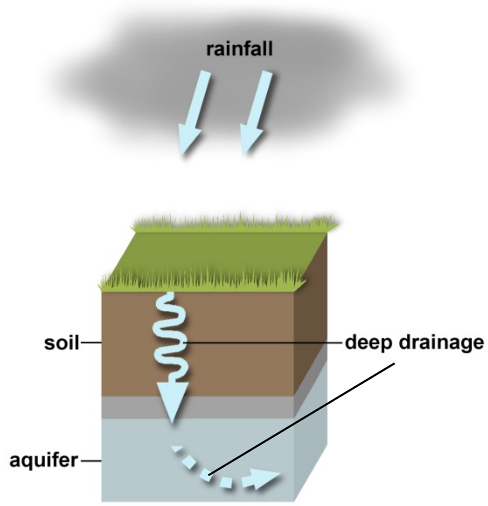



***Figure 21: Schematic illustration of deep drainage occurring as matrix flow.***

Once it has transited the unsaturated zone, circulation of groundwater through the underlying saturated zone typically occurs over an extended timescale. As illustrated on Figure 22, significant variation in the length and travel time of groundwater flow pathways occurs both spatially and with depth in most aquifer systems. Groundwater may move rapidly though the upper parts of the saturated zone on a timescale of days to months, while it may take centuries for groundwater to move from the recharge source to its ultimate discharge point.

Spatial and depth variations in the residence time of groundwater along different flow pathways may exert a significant influence on hydrochemistry and water quality due to the time available for geochemical reactions between groundwater and the host aquifer materials to occur.

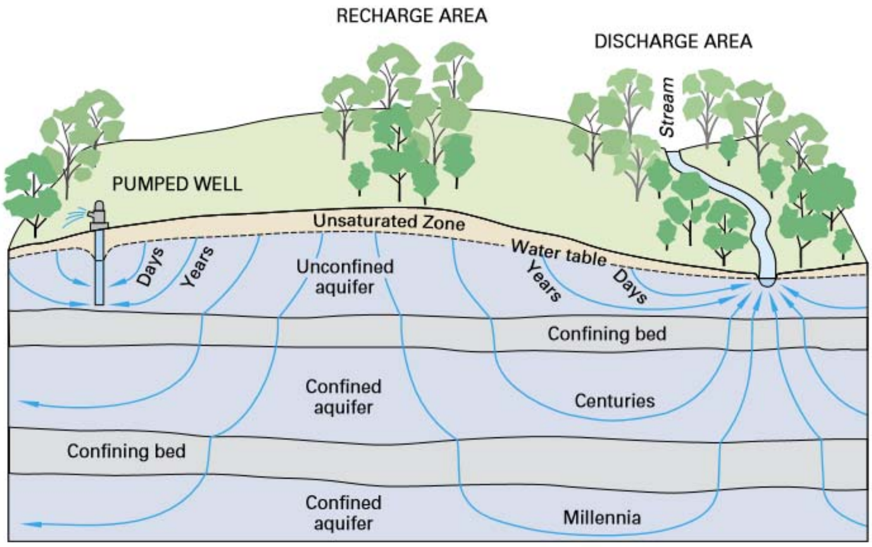



***Figure 22: Schematic illustration of variation in the length and travel time of groundwater flow pathways spatially and with depth.***

[Source: USGS, 1998]

### *3.4.4.1 Regional assessment of deep drainage*

Deep drainage has the potential to significantly impact Southland's water quality. Therefore, an important component of this project was to include an assessment of where deep drainage is likely to occur across the region.

Chanut (2014) undertook a model-based assessment of land surface (rainfall) recharge in Southland utilising the soil moisture water balance methodology developed by Rushton e*t al.* (2006). This assessment simulated deep drainage for approximately 2,800 individual polygons across Southland, each representing a unique combination of soil and climate (rainfall and evapotranspiration), using a 30-year climate record.

Results of this assessment are illustrated in Figure 23 and show that in the areas modelled, calculated mean annual rainfall recharge in Southland range from less than 200 mm across drier parts of the Waimea Plains, to more than 500 mm along the south coast. It is noted that the spatial extent of the modelled area was limited to the Topoclimate soil map coverage which comprised approximately 16 percent of the total land area of Southland.

Wlison *et.al* 2014 described validation of the Rushton soil moisture model in Southland. Results indicated calculated annual recharge volumes were within +/- 25% of recharge volumes estimated from measured groundwater level response.

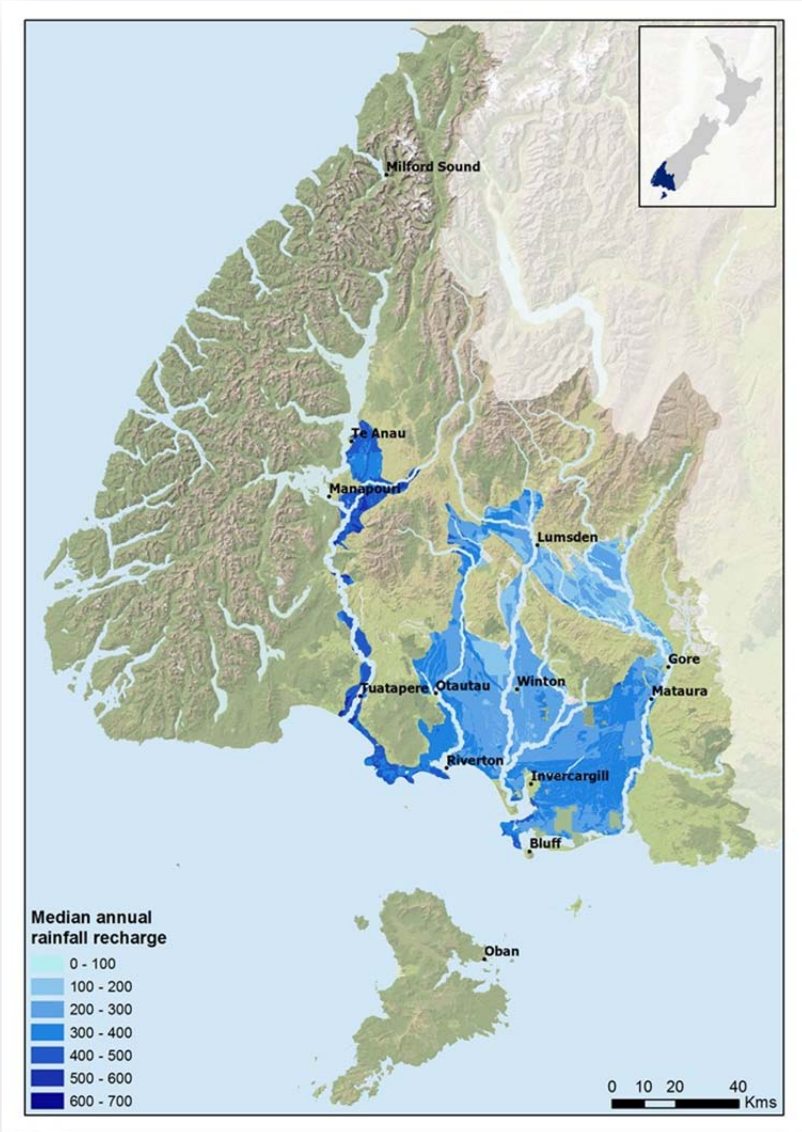



***Figure 23: Median annual rainfall recharge (mm) in Southland***

[Source: Chanut, 2014]

While the assessment of rainfall recharge undertaken by Chanut (2014) included consideration of potential overland flow, it did not allow for the effects of lateral flow or artificial drainage, which are potentially significant components of the water balance in many areas of Southland. For application in this project the rainfall recharge assessment was modified to account for the potential effect of artificial drainage on the volume of deep drainage. This was undertaken using the assessment from Section 3.4.3 Artificial drainage, with the deep drainage classes categorised using the criteria summarised in Table 4. Figure 24 shows the resulting spatial distribution of deep drainage across Southland.

*Table 4: Assessment of deep drainage in Southland for this study*

| Land surface recharge (% rainfall) | | Artificial drainage | Deep drainage class |
|---|---|---|---|
| <20% | or | Very high, high | Low |
| 20 – 40% | or | Moderate | Moderate |
| >40% | and | Very low to none, low or low (slope) | High |

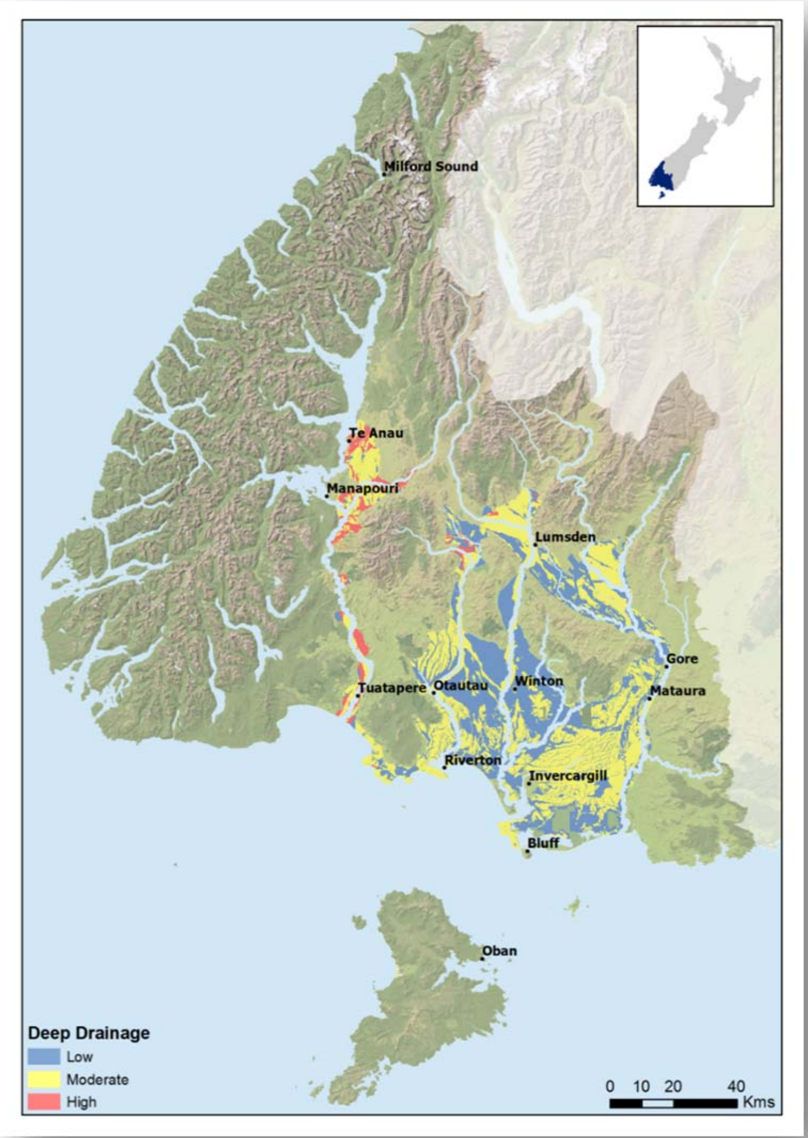



***Figure 24: Assessment of potential for deep drainage in Southland.***

Due to the restricted spatial coverage of Chanut (2014), additional qualitative analysis of the potential magnitude of deep drainage was undertaken for unmapped areas using soil moisture monitoring data, groundwater hydrographs, sub-catchment water balances and an overall understanding of regional hydrogeology. For areas where land surface recharge was unmapped, analysis of groundwater hydrology to assess deep drainage was undertaken at a physiographic zone scale, according to the following criteria:

- *Low:* areas where deep drainage comprises a relatively minor component of the overall water balance, due to the prevalence of other drainage pathways (such as overland flow and artificial drainage), for example in rolling hill country and steep alpine areas;
- *Moderate*: areas where deep drainage is an important component of the overall water balance. However, the magnitude of deep drainage may vary temporally due to prevalence of other drainage pathways, particularly when soils are wet (often due to slow subsoil permeability), for example in areas with flat to undulating land with gley or podzol soils; and,
- *High:* Deep drainage to groundwater is a major component of the overall water balance, typically due to the prevalence of flat-lying, well drained soils, for example in flat to undulating areas underlain by Quaternary sediments.

### 3.4.5 Natural bypass flow

Natural bypass (macropore) flow is a form of deep drainage that occurs via cracks or discontinuities (e.g. formed from plant roots or earthworm casts) within the soil matrix. It is particularly prevalent in soils containing a high percentage of clay minerals that exhibit shrink/swell behavior. Depending on the geometry of the macropore structures, drainage may be initiated before soil moisture content reaches field capacity.

Natural bypass flow typically occurs at a higher rate than matrix flow, resulting in shorter soil water residence times with a consequent reduction in the influence of soil zone hydrochemical processes on infiltrating soil water. Natural bypass flow can exhibit temporal variability where soil hydraulic properties are influenced by soil moisture status (e.g. where flow occurs via soil macropores associated with cracking are shrink/swell behavior).

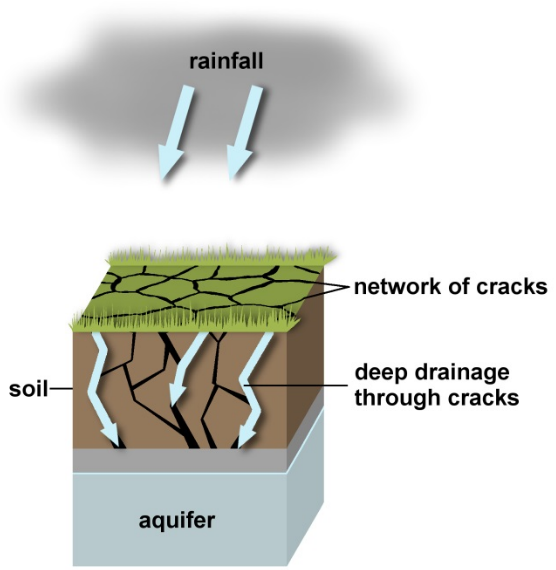



***Figure 25: Schematic illustration of deep drainage occurring as natural bypass flow.***

#### 3.4.5.1 Regional assessment of natural bypass flow

The method used for assessing natural bypass flow potential in Southland is described in the Physiographics of Southland Part 1 report, Technical Chapter 2 (section TC2.3) (Rissmann *et. al.,* 2016).

In summary, the assessment of bypass flow from S-map (Webb *et. al*., 2010) was modified using a subsurface drainage density assessment (Pearson, 2015b) along with field observations (Greenwood, 1999) and monitoring data from Heddon Bush. The resulting assessment, shown in Figure 26, shows the areas identified as being highly vulnerable to deep soil cracking and bypass flow. In these areas, recharge flowing through soil macropores may transit the soil zone sufficiently quickly to limit the extent of denitrification associated with the reducing soil matrix and may increase the potential for transmission of particulates through the soil zone.

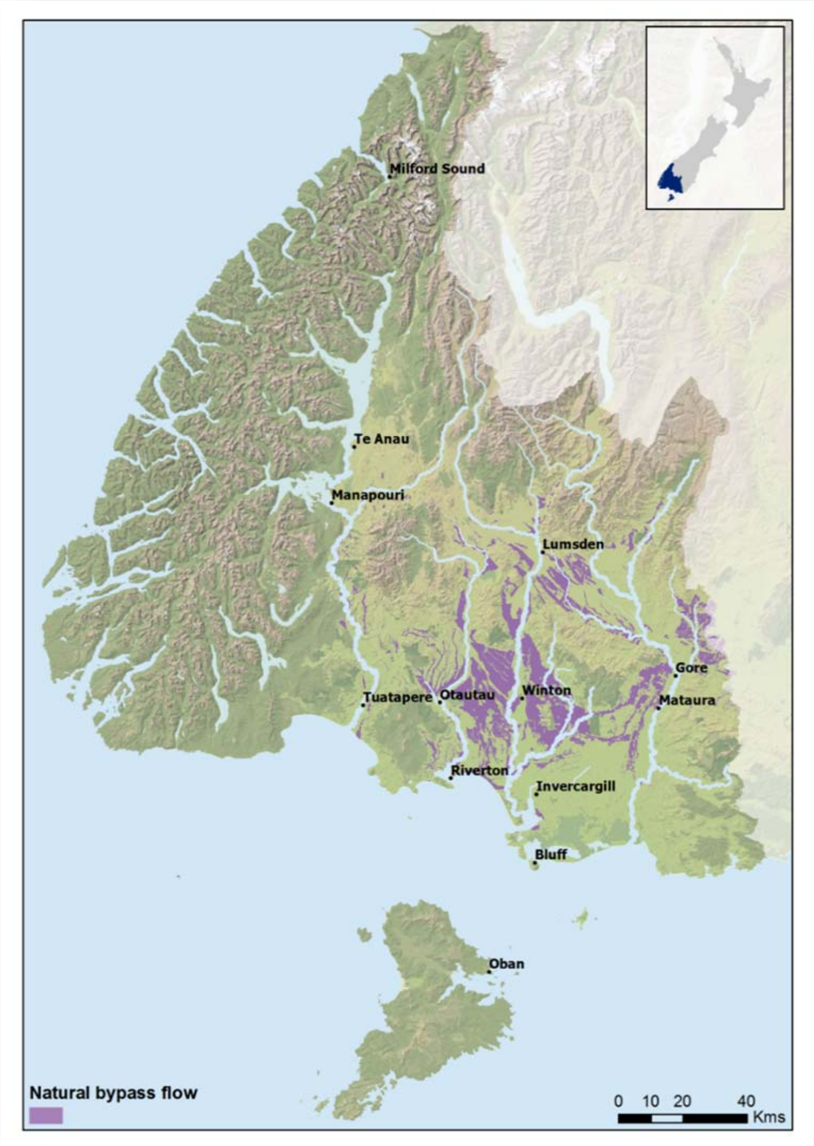



***Figure 26: Potential for natural bypass flow in Southland.***

[Source: Physiographics of Southland Part 1 report, (Technical Chapter 2)]

# 4 Classification system conceptual model

Land use and land management often have a strong influence over temporal variations in water quality. Given land use and land management are highly variable in both space and time, they were excluded as considerations when developing the classification system. Rather, classes have been derived using inherent environmental variables[11] that control water quality outcomes.

The main implication of this approach is that the classification system is not intended to *predict* water quality. Rather, the purpose is to describe *potential* water quality outcomes that may, or may not, be realised depending on land use and land management practises.

Water quality is influenced by land use and land management activities, and therefore monitoring data cannot be used as a means of deriving a classification system independent of land use. The use of water quality data in developing the classification system was limited to testing and validation (i.e. visual assessments of whether water quality outcomes were consistent with expectations in areas where land use intensity is high). Instead, the classification was developed using a combination of inherent environmental variables as described in Section 3, and hydrochemical data not influenced by land use, such as. water facies and conservative isotope tracers.

This section describes the conceptual model used to develop a classification system for managing water quality risk in Southland. The purpose of the model is to integrate attenuation and dilution processes (summarised in Table 5) with drainage pathways so that land areas can be grouped into classes (physiographic zones) that represent distinct water quality risks.

***Table 5: Summary of the potential influence dilution and attenuation processes have on water quality outcomes.***

| **Dilution** | **Attenuation** | |
|---|---|---|
| | **Reduction potential** | **Filtration and sorption** |
| - Reduces contaminant concentrations but does not influence contaminant loads. | - Decreases concentrations of nitrate ($NO_3$) through denitrification but can increase dissolved phosphorus concentrations under certain conditions (i.e. where there are few Fe and Mn oxides).<br>- Microbes and sediment are unaffected by reduction potential. | - Decrease concentrations of microbes, sediment and particulate phosphorus.<br>- Nitrogen is generally not affected by filtration and sorption. |

## 4.1 Physical zones

From the point of origin to its receiving environment, the quality of water changes due to interaction with a range of physical and biogeochemical drivers. The extent to which these interactions occur depends on the drainage pathway water follows through the environment. As outlined in Section

[11] Inherent environmental variables are defined as referring to *'natural' properties resulting from particular combinations of soil properties, climate, topography, geology and hydrology which are not affected by land use or land management practices which influence water quality outcomes* (adapted from Greenwood, 2001).

1.1.1, considerations of water quality outcomes in this report are based around four key variables: nitrogen (N), phosphorus (P), sediment (S) and microbes (M).

A conceptual model was developed to describe how the key processes described in Section 3 combine to influence water quality outcomes. Contaminants may be transported through three physical zones; the surface, soil, and saturated zones, along differing drainage pathways. At any location, water quality risk reflects the dilution and attenuation and dilution potential occurring along drainage pathways. The processes associated with each physical zone are described below.

### 4.1.1 Surface zone

The surface includes processes that influence the occurrence of overland flow, such as slope, soil structural vulnerability, soil drainage characteristics, precipitation rate and soil moisture.

Overland flow has limited physical attenuation or reduction potential. However, dilution may occur depending on the environmental setting.

### 4.1.2 Soil zone

The soil zone includes process that determine the:

- drainage pathway through the soil zone, such as lateral drainage, artificial drainage, deep drainage and natural bypass flow; and,
- extent to which dilution and attenuation processes influence water quality.

Where artificial drainage occurs, there is potential for contaminants to bypass the soil matrix, providing limited opportunity for contaminant attenuation by physical or biogeochemical processes.

Field trials in Southland (e.g. Monaghan, *et. al.*, 2005, Monaghan, *et al.,* 2016) demonstrate that artificial drainage systems can be conduits for the rapid movement of nutrients (nitrogen and phosphorus), sediment and microbes from agricultural land to surface water. Such contaminant transport tends to be episodic, and is strongly influenced by temporal variability in soil moisture and precipitation. The reduction potential for artificial drainage typically increases with a greater proportion of water is derived from matrix flow rather than bypass flow, but in general artificial drainage has limited dilution potential.

Water quality in receiving environments (surface waterways) often reflects the transport limited nature of contaminant movement. Contaminant concentrations often exhibit order of magnitude increases during peak discharge.

Contaminant transport via lateral flow is typically limited to dissolved contaminants such as nitrate, rather than particulate contaminants such as sediment and microbes. This is due to physical processes (e.g. filtration and sorption) occurring within the soil profile. In situations where drainage pathways are short and/or soil materials are highly permeable, some transport of particulates may occur. Overall, lateral flow provides significantly more physical attenuation of particulate contaminants than overland flow and artificial drainage, with reduction potential dependent on residence time.

### 4.1.3 Saturated zone

The saturated zone includes processes that influence water quality in the groundwater receiving environment. Factors such as filtration, sorption and redox influence water quality as it moves from the base of the soil zone, through an aquifer system and ultimately to a surface water receiving environment.

Deep drainage and natural bypass flow are generally characterised by significant physical attenuation, variable reduction potential (depending on the soil and/or saturated zone properties) and variable dilution (mixing) capacity.

Physical infiltration of water through the soil matrix results in extensive filtration and sorption of particulate contaminants, particularly sediment and microbes. The relatively slow rate of flow through the soil and underlying saturated zone also provides time for biogeochemical processes such as ion exchange and redox reactions. This influences the concentrations of dissolved nutrients to a much greater extent than water moving via other drainage pathways.

## 4.2 Water quality risk

Figure 27 shows a schematic representation of the three physical zones, the drainage pathways and consequent effects on water quality resulting from potential attenuation and dilution processes occurring along each pathway. This conceptual framework forms the basis for determining water quality risk for individual physiographic zones and variants outlined in Section 9.

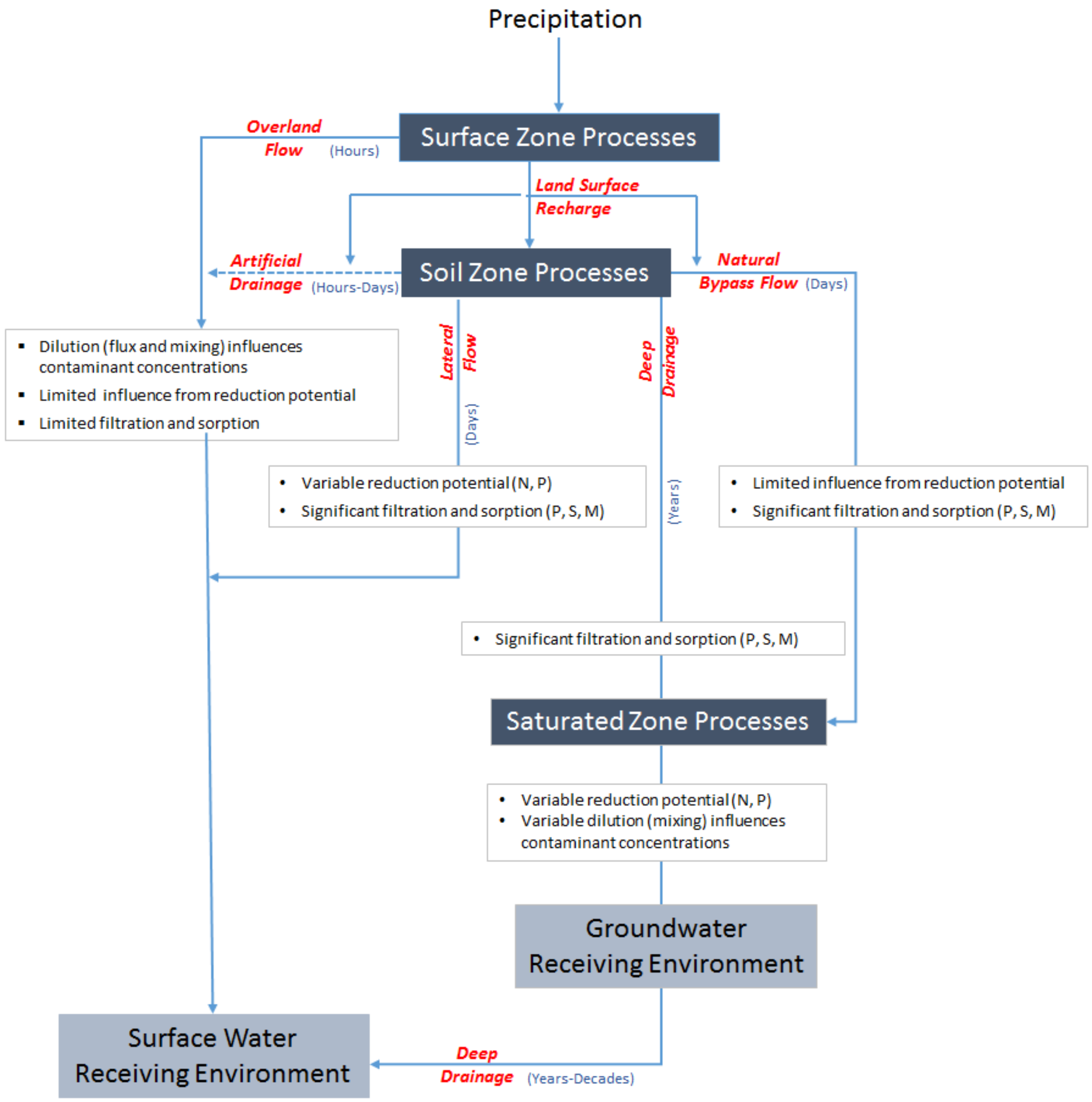



***Figure 27: Schematic representation of how key processes influence water quality outcomes.***

Implicit in the conceptual model is the premise the primary drainage pathway may not represent the main contaminant transport pathway. For example, while deep drainage to groundwater may represent an important drainage pathway for the water balance in a particular area, physical attenuation of contaminants and reduction (denitrification) in the soil zone may reduce its significance as a contaminant pathway. Thus, contaminant pathways are determined using a combined assessment of dilution and attenuation potential, and drainage pathways.

The drainage pathways that transport contaminants to primary receiving environments influence temporal variability in water quality outcomes. Some pathways, such as overland flow, occur rapidly in response to precipitation events, while other pathways, such as deep drainage, occur on a seasonal basis. Table 6 outlines the influence of drainage pathways on water quality.

***Table 6:*** ***Summary of inherent influences on water quality outcomes for different drainage pathways. Contaminants and water quality variables considered are nitrogen (N), phosphorus (P), sediment (S) and microbes (M).***

| Drainage pathways | Occurrence | Variables that influence water quality | Processes that influence water quality | Receiving environment | Effect on water quality |
|---|---|---|---|---|---|
| **Overland Flow** | Event driven<br>*(drainage occurs in response to precipitation events)* | Surface Zone<br>- Slope<br>- Soil drainage characteristics<br>- Soil moisture<br>- Precipitation rate | - Dilution | Surface Water | - Contaminants transported rapidly to surface water receiving environment (hours)<br>- Little or no denitrification (N), nitrogen mainly occurs in the organic form<br>- Some attenuation of particulate contaminants (P, S, M) by filtration (e.g. riparian vegetation)<br>- Significant dilution of dissolved and particulate contaminants by precipitation |
| **Artificial Drainage** | Episodic<br>*(drainage occurs in response to precipitation but magnitude and frequency influenced by soil moisture)* | Surface Zone<br>- Slope<br>- Soil drainage characteristics<br>- Soil moisture<br>Soil Zone<br>- Soil moisture<br>- Soil drainage characteristics<br>- Residence time<br>- Hydrochemical influences (ion exchange) | - Reduction potential<br>- Filtration and sorption | Surface Water | - Contaminants exported rapidly to surface water receiving environment (hours/days)<br>- Limited denitrification in peak discharge due to short soil residence time<br>- Attenuation of particulate contaminants influenced by type (open vs mole-tile) and construction of drainage system<br>- May provide some attenuation but generally not during peak flows<br>- Reduction potential (denitrification) has greater influence on N concentrations in water derived from matrix flow (typically during flow recession after precipitation) |
| **Lateral Flow** | Episodic<br>*(drainage occurs in response to precipitation but magnitude and frequency influenced by soil moisture)* | Surface Zone<br>- Slope<br>- Soil drainage characteristics<br>- Soil moisture<br>Soil Zone<br>- Soil moisture<br>- Soil drainage characteristics | - Reduction potential<br>- Filtration and sorption | Surface Water (and groundwater) | - Contaminant export to surface water receiving environment (or groundwater in some areas) occurs relatively rapidly (days/weeks)<br>- Significant attenuation of particulate contaminants (P, S, M) by physical processes (e.g. filtration, sorption) in the soil zone<br>- Reduction potential influenced by residence time within |

| Drainage pathways | Occurrence | Variables that influence water quality | Processes that influence water quality | Receiving environment | Effect on water quality |
|---|---|---|---|---|---|
| | | - Residence time<br>- Hydrochemical influences (ion exchange) | | | soil matrix<br>- Similar attenuation characteristics to deep drainage except for limited attenuation of P and M in fibrous peat soils |
| **Bypass Flow (Natural)** | Seasonal<br>*(drainage reflects seasonal soil moisture variation)* | Surface Zone<br>- Geological parent material<br>- Soil moisture<br>Soil Zone<br>- Soil moisture<br>- Soil drainage characteristics<br>- Hydrochemical influences (ion exchange)<br>Saturated Zone<br>- Mineralogical characteristics<br>- Hydrological characteristics | - Reduction potential<br>- Filtration and sorption | Groundwater and Surface Water | - Contaminant export to the groundwater receiving environment occurs over relatively rapidly (days/weeks)<br>- Attenuation of a significant proportion of particulate contaminants (P, S, M) by physical processes (e.g. filtration, sorption) during macropore infiltration<br>- Limited reduction potential due to short residence time in soil zone |
| **Deep Drainage** | Seasonal<br>*(drainage reflects seasonal soil moisture variation)* | Surface Zone<br>- Slope<br>- Soil drainage characteristics<br>Soil Zone<br>- Soil moisture<br>- Hydrochemical influences (ion exchange)<br>Saturated Zone<br>- Mineralogical characteristics<br>- Hydrological characteristics | - Reduction potential<br>- Filtration and sorption | Groundwater and Surface Water | - Contaminant export to groundwater receiving environment at a slow rate (months/years). Discharge to surface water receiving environment occurs over very long timescale (decades/centauries)<br>- Significant attenuation of particulate contaminants (P, S, M) by physical processes (e.g. filtration sorption) in the soil zone<br>- Variable denitrification depending on redox status, pH and other hydrochemical processes in the soil zone and underlying groundwater receiving environment<br>- Contaminant concentrations in groundwater receiving environment influenced by dispersion (mixing) which reflects hydraulic properties of the geological materials |

# 5 Assumptions and limitations

This section describes the key assumptions and limitations associated developing a classification system that represents a simplified description of a complex natural environment.

## 5.1 Context limitations

This classification system was developed primarily for the proposed Southland Water and Land Plan, as a means of better understanding how similar land uses can result in different water quality outcomes across the region, and to assist with the development of spatially targeted mitigations to reduce water quality impacts from land use.

The classification system comprises physiographic zones (or classes), which group land areas based on their attenuation and dilution potential, and physiographic zone variants (or sub-classes) that identify areas where variability in drainage pathways may reduce attenuation potential.

The physiographic zones represent a simple classification system, with a minimum number of zones dictated by the needs of a policy framework to be pragmatic and practical. Therefore, it’s important to note that within the physiographic zones, there is considerable heterogeneity.

## 5.2 Classification system limitations

The classification system described in this report represents a simplified description of a complex natural environment. Thus, the classification system is based on grouping land areas with similar combinations of *inherent* environmental variables that control spatial variability in water quality outcomes across Southland.

The classification system comprises land areas grouped on the basis of water quality risk. Individual classes may contain a range of physical settings that share the same water quality risk.

### 5.2.1 Inclusions and exclusions

The classification system has not been developed to *predict* water quality outcomes as these are significantly influenced by land use and values.

This project does not incorporate freshwater values (including Māori values) and water quality has not been considered against standards, guidelines, limits and targets. Hydrochemistry and water quality characteristics have been assessed relative to other areas (or zones) within Southland.

Although mapped for convenience, the physiographic zones do not characterise surface waterways that drain multiple physiographic zones. The exception to this is the Riverine zone, which is the primary receiving environment for most water draining Southland.

Limited analysis has been undertaken on how the physiographic zones interact with each other, and the implications of the physiographic zones at a catchment scale. This work will be undertaken in more detail as part of the next phase of this project, and as part of limit setting required by the NPS-FM.

### 5.2.2 Data limitations

Delineation of the classification framework was based on developing mapping rules, which were designed to be as simple as possible, reproducible, and based on data sets that represent physically measurable (as opposed to modelled or inferred) attributes.

The accuracy and resolution of the classification system and characterisations are dependent on the source data used. Generally, the scale of the data used is appropriate at a regional to sub-regional scale. There may be spatial variability at a finer scale (i.e. <1:50,000) which is outside the resolution of currently available data sets.

# 6 Development and characterisation of classes

## 6.1 Development of classes (physiographic zones)

At a regional-scale, dilution and reduction processes are identified as primary controls on regional hydrochemistry and water quality in terms of median (dissolved) nutrient concentrations. Temporal variations in drainage pathways and associated attenuation processes that increase water quality risk have been incorporated as sub-classes within the classification system (physiographic zone variants), and are described in Section **Error! Reference source not found.**.

- Based on this distinction, initial development of classification system utilised the dilution potential and reduction potential assessments outlined in Section 3 to define 12 potential classes for Southland. These classes are shown in

Table 7. Each class represents a unique combination of these two factors, which is expected to result in distinct water quality outcomes. Of the 12 potential classes identified, the respective dilution potential and reduction potential assessments (shown in Figure 7 and Figure 13) indicated only 7 of the potential classes identified were present in Southland.

- As outlined in

Table 7, each class is inferred to represent a different physical setting within Southland, which can be characterised by a unique combination of dilution potential and soil/aquifer reduction potential as follows:

- Class 1 – low reduction potential (soil and aquifer) and high dilution potential
- Class 2 – elevated soil reduction potential and high dilution potential
- Class 3 – low reduction potential (soil and aquifer) and low dilution potential
- Class 4 – elevated soil reduction potential and low dilution potential
- Class 5 – elevated aquifer reduction potential and low dilution potential
- Class 6 – elevated reduction potential (soil and aquifer) and low dilution potential
- Class 7 – low reduction potential (soil and aquifer) and high mixing potential

***Table 7: Preliminary identification of classes.***

| | | **Dilution Potential** | | |
|---|---|---|---|---|
| | | High Dilution Potential | Low Dilution Potential | High Mixing Potential |
| **Combined Reduction Potential** | Low over Low | **Class 1** (Low redox/high dilution) | **Class 3** (Low redox/low dilution) | **Class 7** (Low redox/high mixing potential) |
| | Elevated over Low | **Class 2** (Elevated soil redox/high dilution) | **Class 4** (Elevated soil redox/ low dilution) | Not present in Southland |
| | Low over Elevated | Not present in Southland | **Class 5** (Elevated aquifer redox/low dilution) | Not present in Southland |

| | | | | |
|---|---|---|---|---|
| | Elevated over Elevated | Not present in Southland | **Class 6** (Elevated soil and aquifer redox/low dilution) | Not present in Southland |

- The seven classes defined in

Table 7 were then assessed using water quality and hydrochemical data (e.g. water types and isotopes). This process assessed the variability of observed water quality and hydrochemistry within the seven classes. The variation was identified to be sufficiently large in two classes to warrant subdividing them into a further two classes:

- **Class 3a** – observations of low combined (soil and groundwater) reduction potential and low dilution potential where major ion and nutrient concentrations in groundwater differ from those observed across the wider Class 3. Class 3a is typically associated with the highest groundwater nitrate concentrations observed across Southland;
- **Class 4a** – elevated soil reduction potential and low dilution potential where oxic groundwater containing elevated nitrate concentrations differs from that observed across the wider Class 4.

It is noted that the number of classes adopted reflects a trade-off between simplicity of application for policy purposes (i.e. where a smaller number of classes is desirable) and heterogeneity in hydrochemistry and water quality within each class. Overall, it is considered the nine classes illustrated in

Table 8 appropriately represent spatial variations in relative water quality outcomes for the purposes of managing land use effects on freshwater resources.

*Table 8: Final identification of classes (including names).*

| | | Dilution Potential | | | |
|---|---|---|---|---|---|
| | | High Dilution Potential | Low Dilution Potential | | High Mixing Potential |
| Combined Reduction Potential | Low over Low | Class 1 ***Alpine*** | Class 3 ***Oxidising*** | Class 3a ***Old Mataura*** | Class 7 ***Riverine*** |
| | Elevated over Low | Class 2 ***Bedrock/Hill Country*** | Class 4 ***Gleyed*** | Class 4a ***Central Plains*** | Not present in Southland |
| | Low over Elevated | Not present in Southland | Class 5 ***Lignite/Marine Terraces*** | | Not present in Southland |
| | Elevated over Elevated | Not present in Southland | Class 6 ***Peat Wetlands*** | | Not present in Southland |

## 6.2 Characterisation of classes (physiographic zones)

The following section outlines the dominant physical, hydrochemical and water quality characteristics of each physiographic zone based a combination of knowledge gained during the mapping process as well as intersection of the physiographic zone map with spatial coverages describing a range of environmental variables.

### 6.2.1 Class 1: Alpine physiographic zone

The Alpine physiographic zone represents areas where dilution potential is very high (recharge flux is high due to orographic enhancement of precipitation) and reduction potential is low (i.e. soils and geology provide little attenuation of dissolved nutrients).

The Alpine physiographic zone includes areas with the following key characteristics:

- *Topographic features:*
  High elevation (>800 m asl), rolling to very steep topography.
- *Dilution potential:*
  High recharge flux of dilute precipitation reflecting orographic enhancement at high elevation and rainout of marine aerosol load (especially with increased distance from the coast)[12]. Runoff to surface water is initiated in response to individual precipitation events on sloping topography. Temporal variability in runoff via main stem rivers reflects seasonal snowpack accumulation during winter and subsequent melt during spring.

[12] Equivalent to the *alpine river recharge* domain described in Technical Chapter TC-2 in the Physiographics of Southland Part 1 report (Rissmann *et al.,* 2016).

- *Soil and geological characteristics:*
  Coarse, weathered (well flushed) colluvium and slope debris with limited soil accumulation overlying slowly permeable, unreactive bedrock.
- *Reduction potential:*
  Low reduction potential in the soil zone reflecting low soil organic carbon associated with limited vegetative growth. Water draining through the soil matrix is almost exclusively oxic with concentrations of dissolved organic carbon being very low, and manganese and iron below detection limits. Basement rocks forming the underlying geology are primarily of igneous or metamorphic origin so also contain limited organic carbon.
- *Hydrological characteristics:*
  Rapid discharge via overland flow to surface drainage network in response to individual rainfall events. Low baseflow reflecting limited groundwater resource.

#### *6.2.1.1 Characterisation*

Topography is the key landscape feature of the Alpine zone influencing water quality.

**Recharge**

As noted in Section 3.1, precipitation (including seasonal snowpack accumulation) increases significantly in the Fiordland Mountains and with altitude across the hills and ranges of inland Southland. The high recharge flux (>5,000 mm/year across much of Fiordland and exceeding 1,500 mm/year elsewhere) significantly increases the dilution potential associated with runoff from these areas.

The Alpine zone is a source of large volumes of dilute recharge to downstream receiving environments. This is due to a combination of orographic enhancement of precipitation, rainout of marine aerosol loads at lower elevations and rapid overland flow generation on steep topography.

Concentrations of dissolved ions and nutrients in runoff from the Alpine zone are typically the lowest observed in Southland. Waters are almost exclusively oxic and typical water facies (Ca-Cl and Ca-$HCO_3$) reflect dilute snowmelt and/or precipitation percolating through talus, scree and weathered soils with low base saturation.

**Hydrology**

Flow in streams draining the Alpine zone increase rapidly in response to individual precipitation events before receding relatively quickly to stable baseflow conditions. Runoff from alpine catchments may be initiated in response to relatively small precipitation events due to the steep topography, limited soil development and sparse vegetative cover.

Groundwater comprises a very minor component of the water balance, being hosted within fractures and secondary porosity within the rock mass.

At high elevations and during the colder months, a significant proportion of precipitation in the Alpine zone falls as snow. This accumulates and is ultimately released as snowmelt as temperatures warm during spring. This pattern is evident in the hydrographs of alpine-fed rivers. As illustrated in

Figure 28, discharge in the Waikaia River at Piano Flat (draining an alpine catchment) is relatively low due to snowpack accumulation in winter (June to August) and peaks during the spring thaw (September and October). In contrast, discharge in the Waimea Steam at Mandeville exhibits a broad peak from May to August reflecting seasonal runoff from a low elevation catchment on the Waimea Plains.

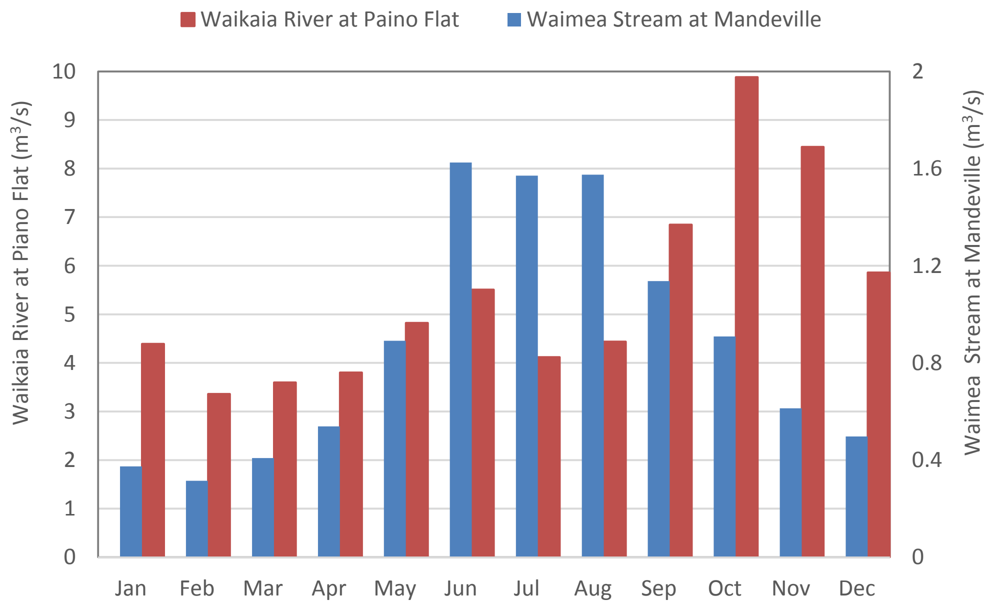



***Figure 28: Mean monthly flow for the Waikaia River at Piano Flat and the Waimea Stream at Mandeville.***

**Water quality**

The snowpack accumulation/melt cycle that characterises the Alpine zone hydrograph also influences water quality data in rivers and streams draining the Alpine zone and downstream receiving environments in the Riverine zone.

Figure 29 shows the influence of temporal variations in discharge on nutrient concentrations in the Mataura River system. The figure shows that nitrate concentrations increase during winter when baseflow from alpine headwaters is low and the proportion of flow derived from catchments draining mid to low altitude developed areas is greatest. However, during spring nitrate concentrations fall to a minimum as the proportion of flow derived from alpine headwaters increases. This variation is likely to reflect dilution of nutrient inputs to the river system by large volumes of pristine discharge derived from alpine headwaters during the spring combined with seasonal variations in nutrient uptake by macrophyte and periphyton species (which is at a minimum during the winter months) and limited intensive land use in alpine areas.

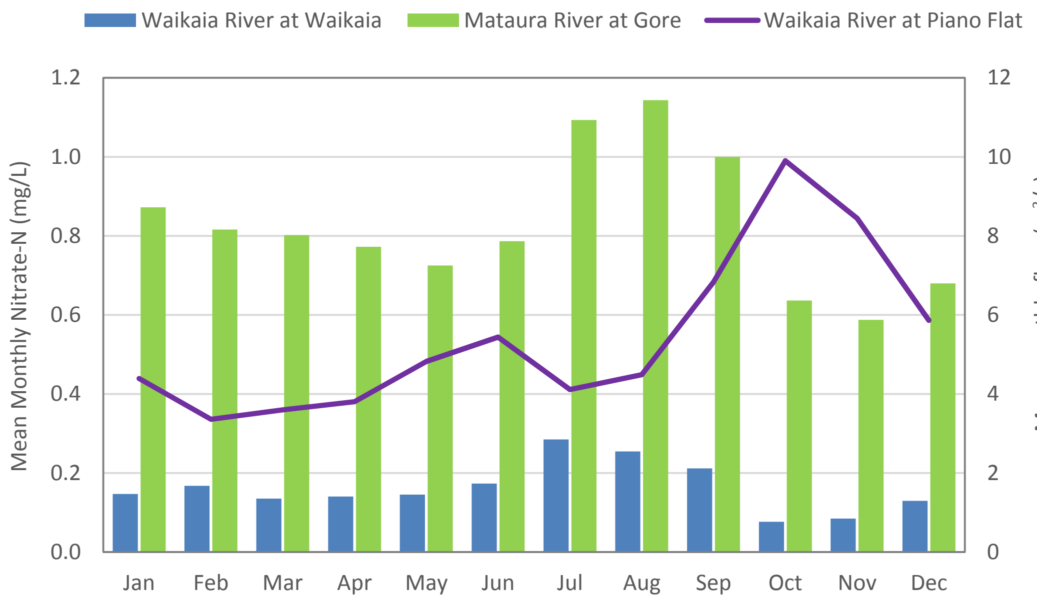



***Figure 29:*** ***Mean monthly nitrate (bars) in the Waikaia River at Waikaia and Mataura River at Gore and mean monthly flow (line) in the Waikaia River at Piano Flat.***

**Altitude**

Altitude also exerts a significant influence on soils and geology in the Alpine zone. Much of this zone consists of bare rock and rock debris, such as scree or talus with soil development limited by rapid erosion, particularly on steeper slopes. Overall, soils in the Alpine zone are characterised as thin, coarse textured and highly permeable with low organic carbon (due to the limited vegetation present above the bushline) and low base saturation due to significant flushing associated with high precipitation. Subsurface geology largely consists of hard rocks of igneous or metamorphic origin, which are slowly permeability and exhibit limited hydrochemical reactivity.

**Drainage pathways**

Overland flow is a major drainage pathway in the Alpine zone, reflecting the steep topography, high precipitation and slowly permeable subsurface geology. Combined with the low reduction potential, rapid runoff via overland flow reduces the potential for attenuation of dissolved or particulate contaminants in this zone. However, effects on water quality are significantly reduced due to the low intensity of land use in the Alpine zone.

**Summary**

The Alpine physiographic zone is characterised by steep topography receiving high volumes of dilute precipitation where soils and underlying geology exert limited influence on water quality. Due to climatic, topographic and regulatory constraints (e.g. the zone encompasses a significant proportion of Fiordland National Park), limited intensification of land use has occurred in the Alpine zone. Thus, the high potential for dissolved and particulate contaminants to be mobilised via quickflow from steep topography is seldom realised (although the potential for generation of suspended sediment can be significantly influenced by landcover and/or erosion).

### 6.2.2 Class 2: Bedrock / Hill Country physiographic zone

The Bedrock/Hill Country zone is geographically the largest physiographic zone in Southland and plays an important role in supplying significant volumes of relatively dilute runoff to lowland areas. However, due to topography and elevated precipitation, this zone has an elevated potential for losses of dissolved and particulate contaminants resulting from land use activities.

The Bedrock/Hill Country physiographic zone represents areas where the dilution potential is high (i.e. precipitation is elevated due to orographic enhancement on elevated topography) and soils exhibit an elevated reduction potential. The zone includes areas with the following key characteristics:

- *Topographic features:*
  Undulating to steep land on prominent landforms up to 800 m asl elevation (hills and sub-alpine areas).
- *Dilution potential:*
  High dilution potential reflecting elevated volumes of dilute precipitation associated with orographic precipitation enhancement[13] and, in places, runoff from adjacent alpine areas[14]
- *Soil and geological characteristics:*
  Typically, coarse-grained (stony silt loam and sandy loam) soils overlying bedrock or glacial till.
- *Reduction potential:*
  High reduction potential within the soil zone, reflecting elevated soil organic carbon associated with historical vegetative cover (e.g. scrub, forest or tussock communities).
- *Hydrological characteristics:*
  Elevated potential for overland flow due to sloping topography and orographic enhancement of rainfall. Runoff tends to be seasonal with the magnitude and frequency of discharge increasing when soils are wet. Baseflow tends to be very low due to the limited groundwater resource.

#### *6.2.2.1 Characterisation*

The key landscape influences on water quality in the Bedrock/Hill Country zone are the thin accumulations of reducing soils and colluvial deposits overlying low permeability bedrock or till. These areas are generally associated with:

- Undulating to steep topography, generally above 200 m asl elevation, but below the bush line (which nominally occurs at 800 m asl);
- Orographic enhancement of precipitation (typically greater than 1,200 mm/year), with some areas also receiving runoff from adjacent, higher altitude, alpine areas. Large volumes of

[13] Equivalent to the Bedrock 1 river recharge domain described in Technical Chapter TC-2 in the Physiographics of Southland Part 1 report (Rissmann *et al.,* 2016).

[14] Equivalent to the Bedrock 2 river recharge domain described in Technical Chapter TC-2 in the Physiographics of Southland Part 1 report (Rissmann *et al.,* 2016).

precipitation in this zone mean drainage water typically contains low concentrations of dissolved ions and nutrients, which provides dilute recharge to downstream receiving environments; and,

- High organic carbon content within the soil zone reflecting historical shrub, forest or tussock cover. Soils in this zone have high reduction potential, which is reflected in elevated dissolved manganese and iron concentrations in both groundwater and surface waters. Low sodium and elevated calcium and magnesium concentrations in surface and groundwaters reflect the low base saturation of soils in this zone.

**Drainage pathways**
Overland flow and lateral drainage are the dominant drainage pathways in this zone, due to the undulating to steep topography and limited permeability of the underlying geology. Runoff generation varies seasonally, with the magnitude and frequency of runoff increasing when soils are wet. Subsurface geology in the Bedrock/Hill country zone typically comprises slowly permeable bedrock or till which hosts a limited groundwater resource.

Figure 30 illustrates the overall seasonal flow variation in representative Bedrock/Hill Country catchments. Note that the overall seasonal trend in runoff tracks with soil moisture. The highest flows occur during winter when precipitation totals are typically lowest but soil moisture is elevated for extended periods. Note also the comparatively low baseflow during summer, which is approximately 30% of the seasonal maximum. This reflects the limited groundwater storage in basement rocks and overlying colluvial materials.

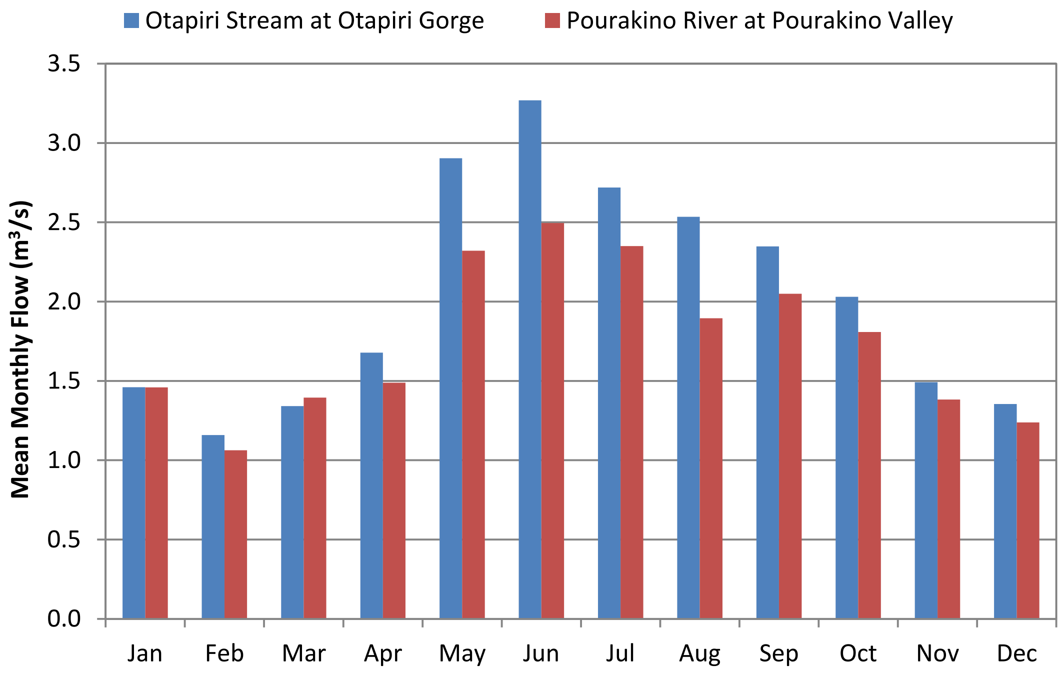



***Figure 30: Mean monthly flow for the Otapiri Stream and Pourakino River.***

Overland flow is the dominant drainage pathway in this physiographic zone due to the relatively steep topography. As illustrated in Figure 31, surface water drainage from the Bedrock/Hill Country zone is typically event-driven, with discharge occurring rapidly in response to significant precipitation events, then receding quickly to stable baseflow conditions.

When soils are dry during summer, runoff is initiated only in response to larger and/or more intense precipitation events. However, as soil moisture levels increase during autumn and winter runoff occurs on a frequent basis due to both infiltration and saturation excess overland flows, initiated in response to smaller and more frequent precipitation events on wetter soils.

Lateral flow through soil and colluvial materials is also likely to be a significant drainage pathway in the Bedrock/Hill Country zone due to the combination of topography, soil hydraulics (i.e. moderately permeable topsoil overlying slowly permeable subsoil) and the slow permeability of the underlying geology. This drainage pathway is reflected in the extended stable flow recession observed following individual precipitation events.

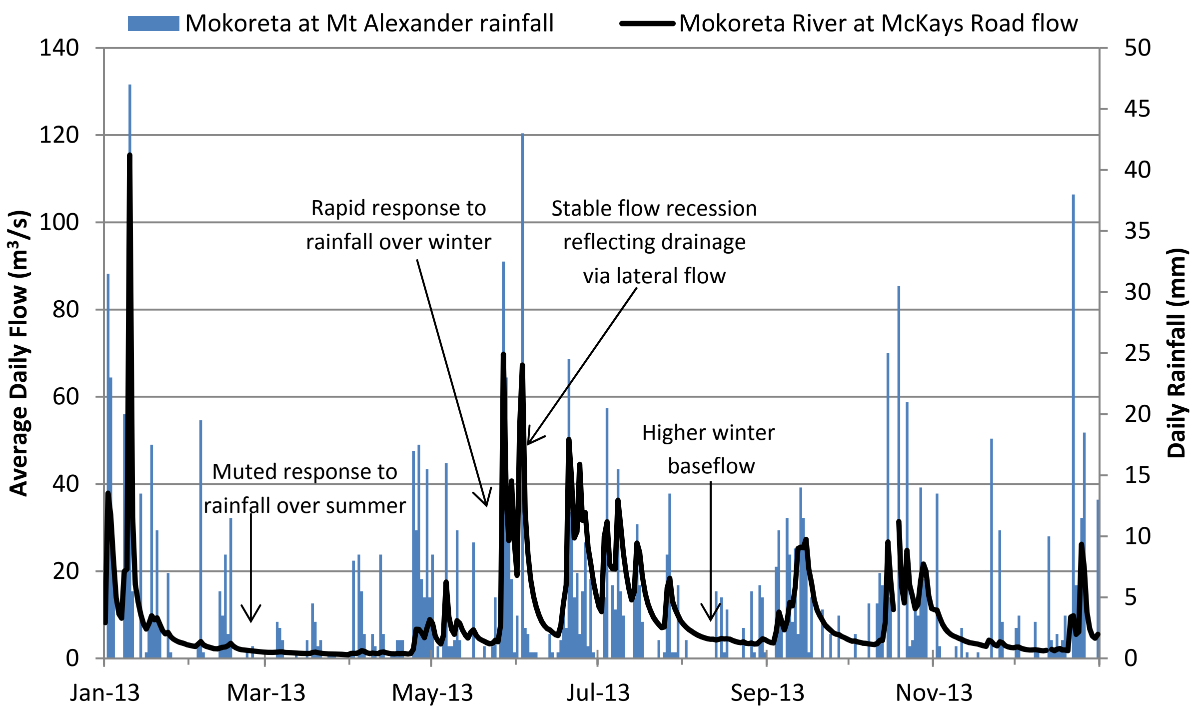



***Figure 31: Mokoreta River at McKays Road hydrograph and rainfall at Mt Alexander, 2013.***

**Water quality**

Soils in the Bedrock/Hill country physiographic zone have elevated reduction potential. Therefore, surface waters also exhibit temporal variations in redox status associated with the dominant drainage pathway. As illustrated in Figure 32, concentrations of redox sensitive species such as iron, increase during periods of mid to low flows. This reflects changes in the relative volume of waters derived from oxic quickflow and more reduced waters associated with soil zone drainage (lateral flow and baseflow).

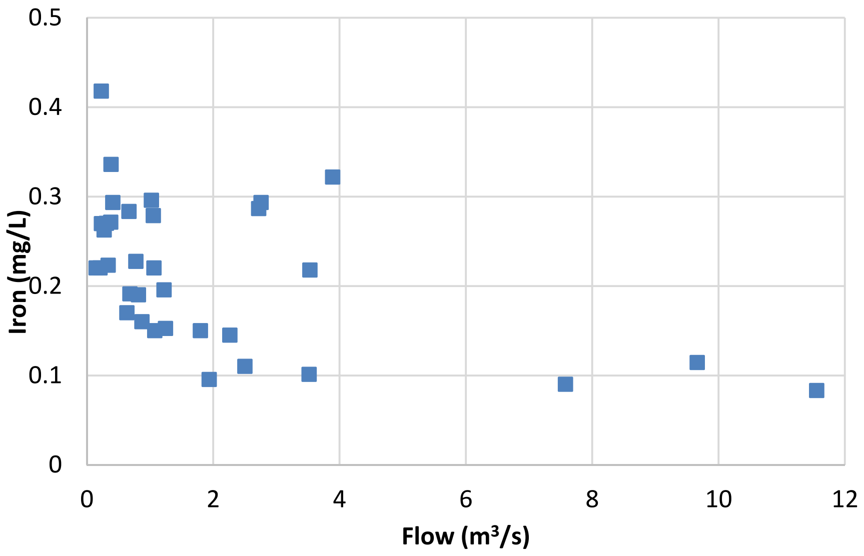



***Figure 32:*** ***Variation in dissolved iron concentrations with flow in the Otapiri Stream at Otapiri Gorge.***

Temporal variations in dissolved nutrient concentrations in surface waters draining the Bedrock/Hill Country zone reflect a combination of variable redox status and dilution. As illustrated in Figure 33, lowest nitrate concentrations occur under baseflow conditions reflecting the greater contribution of reduced soil and groundwater to cumulative discharge, and increase as the proportion of oxic quickflow increases. Conversely, during periods of high flows, nitrate concentrations decline[15] reflecting increased dilution associated with large volumes of overland flow occurring in response to significant precipitation events (possibly combined with some depletion of nitrogen sources).

Although the rate of change in nitrate concentrations varies between monitoring sites (reflecting differences in catchment topography, landcover and hydrology), a consistent pattern is observed across the Bedrock/Hill Country zone with highest nitrate concentrations observed during mid-range flows.

[15] Although cumulative loads may still increase.

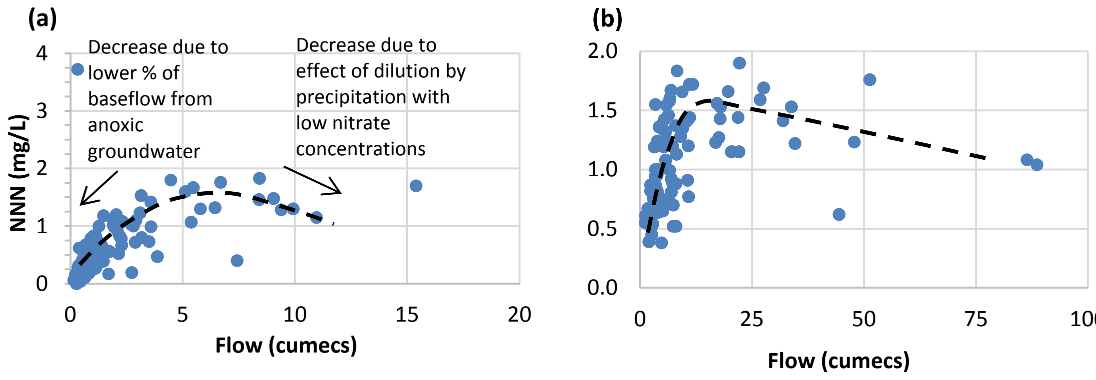



***Figure 33:*** ***Scatter-plots of nitrate nitrite nitrogen (NNN) and flow data from the (a) Mokoreta River at Wyndham and (b) Otapiri Stream at Otapiri Gorge (with indicative trend line).***

**Summary**

The Bedrock/Hill Country zone is characterised by undulating to steep topography in sub-alpine areas of Southland, which receive elevated volumes of dilute precipitation. Soils and associated colluvial materials are typically thin and overlie low permeability bedrock and till deposits, which host a limited groundwater resource. The influence of elevated soil reduction potential is reflected in elevated iron and low nitrate concentrations in surface and groundwater.

### 6.2.3 Class 3: Oxidising physiographic zone

The Oxidising physiographic zone represents areas where the dilution potential is low (i.e. the recharge mechanism is land surface recharge) and reduction potential is low (i.e. soils and aquifers are oxic).

The Oxidising physiographic zone includes areas which exhibit the following key characteristics:

- *Topographic features:*
  Flat to undulating land on elevated alluvial terraces along the margins of the active floodplains associated with the major river systems.
- *Dilution potential:*
  Low dilution potential reflecting the low recharge flux associated with local land surface recharge.
- *Soil and geological characteristics:*
  Predominantly fine-grained moderately well to well drained Brown soils derived from felsic parent materials overlying alluvial deposits.
- *Reduction potential:*
  Low reduction potential in soils and groundwater. Some dilution potential (mixing) associated with the typically moderate to high permeability of alluvial aquifer systems.
- *Hydrological characteristics:*

Extensive groundwater resource hosted in moderate to highly permeable alluvial aquifers. Many surface waterways are perched above the underlying water table. Springs and spring-fed streams commonly occur along terrace risers which mark the lateral extent of this zone.

#### *6.2.3.1 Characterisation*

The Oxidising zone is relatively disseminated and heterogeneous, occurring in three main landscape settings:

- flat to undulating land with fine textured soils;
- undulating land with lower subsoil permeability; and,
- undulating to rolling areas that have slow subsoil permeability.

These areas share common water quality influences including a low dilution potential (land surface recharge with limited distal recharge input) and low reduction potential in soils and underlying groundwater. Water facies vary between Na-Cl and Ca-$HCO_3$ types. Na-Cl waters typically occur in coastal locations, reflecting marine aerosol deposition while Ca-$HCO_3$ waters are associated with inland soils of higher base saturation where marine aerosol loads are lower.

The water types observed in the Oxidising zone are consistent with localised land surface recharge interacting with base rich soils. Oxic waters, low total dissolved solids and low dissolved organic carbon concentrations reflect the predominance of both loessial soils (felsic silt mainly occurring as quartz grains with a thin coating of iron oxides) and low organic carbon content in the soil, unsaturated and saturated zones. Elevated potassium, nitrate and sulphate concentrations reflect the dominance of soil zone recharge and the generally young age of geomorphic surfaces (as opposed to older, more highly weathered alluvium).

**Hydrology**

Unlike the Old Mataura zone (Class 3a), permanent surface waterways are a feature of the Oxidising physiographic zone. Although many streams traversing this zone have flow originating from headwaters in adjacent physiographic zones, streams that are incised sufficiently to intercept groundwater maintain a steady rate of base flow, even during prolonged dry periods. Where streams are perched above the underlying groundwater table, such as the Oteramika Stream on the Edendale Terrace or Murray Creek near Castlerock, stream flow approaches zero during dry periods.

Water table depth in the Oxidising zone varies from less than 5 metres below ground under lower alluvial terrace areas to as much as 10 to 20 metres below ground under higher terraces in the Lintley, Sandstone, Edendale, Mabel Bush, Woodlaw and Lower Waiau areas. Areas with deeper water tables tend to occur where terrace remnants are demarcated from adjacent younger alluvial terraces by well-defined terrace risers.

Temporal groundwater level variations also exhibit a degree of variability across this physiographic zone. As illustrated in Figure 34, groundwater levels under higher terrace areas such as Edendale typically exhibit a relatively regular sinusoidal seasonal variation of up to 1.5 metres, with levels peaking in spring (September-November) and reaching a minimum in late autumn (April-May). The limited response to individual recharge events reflects the moderating effect of the thick, moderately to poorly drained soil profile and relatively thick unsaturated zone. The hydrograph also shows significant inter-annual variability reflecting the accumulation or dissipation of aquifer storage following long-term variations in rainfall.

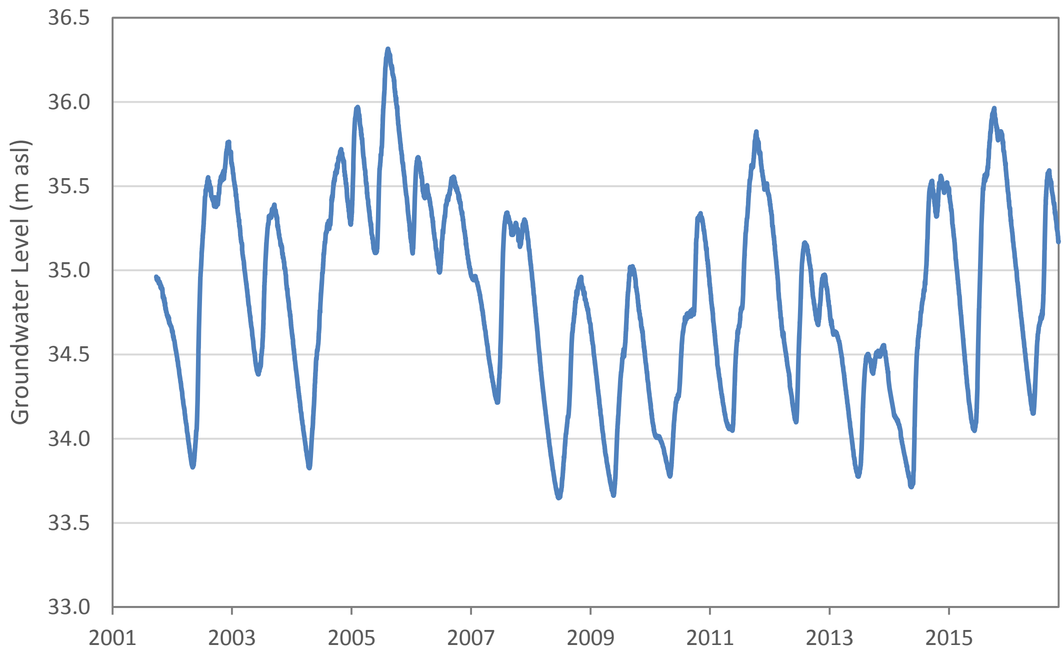



***Figure 34: Groundwater levels in the Edendale Aquifer at Hilda Road, 2002-2007.***

**Water quality**

Groundwater, springs and seeps within the Oxidising zone exhibit some of the highest nitrate concentrations within Southland. The susceptibility to accumulation of oxidisable nitrogen reflects the very low reduction potential of soils and aquifers, and the limited dilution potential associated with land surface recharge.

**Summary**

The Oxidising physiographic zone occurs across a range of landscape settings that share common attributes associated with low dilution potential and a low reduction potential in both the soil and saturated zones. Such areas are characterised by an extensive groundwater resource, which typically exhibits water types consistent with localised land surface recharge interacting with base rich soils. Many surface waterways traversing this zone are perched above the local water table and only receive discharge where overland flow occurs when soils are wet on sloping land or where artificial drainage is used to remove seasonal soil water surplus on soils which have slow subsoil permeability.

### 6.2.4 Class 3a: Old Mataura physiographic zone

The Old Mataura physiographic zone represents areas where the dilution potential is low (i.e. the recharge mechanism is land surface recharge) and soils and aquifers exhibit low reduction potential.

The Old Mataura physiographic zone identifies areas with the following key characteristics:

- *Topographic features:*
  Flat to gently undulating land on elevated terraces in the mid-Mataura catchment with very few surface waterways.

- *Dilution potential:*
  Low dilution potential reflecting the low recharge flux associated with land surface recharge and low mixing potential in the saturated zone.
- *Soil and geological characteristics:*
  Highly weathered soil and alluvial deposits reflecting their generally older age when compared to surrounding sediments.
- *Reduction potential:*
  Low reduction potential in soils and groundwater.
- *Hydrological characteristics:*
  Limited permanent surface water features due to well flat topography and well drained soils. Spatially extensive groundwater resource hosted in low to moderate permeability alluvium.

#### *6.2.4.1 Characterisation*

The key landscape features of the Old Mataura zone that influence water quality are the highly weathered soils and geology associated with mid-Quaternary alluvial deposits of the Shotover and Luggate formations. These areas occur as elevated alluvial terraces in the middle reaches of the Mataura River catchment.

The Old Mataura zone comprises remnants of older alluvial terraces and terrace gravels along the margins of the Mataura River valley. These deposits comprise weathered greywacke-schist alluvium in a silty, sandy matrix (QMap, 2002). Due to their age (Q6 to Q10) these alluvial materials are highly weathered and are typically mantled by well drained Brown soils formed in felsic loess deposits.

**Recharge**
Land surface recharge is the dominant recharge mechanism, with little or no recharge occurring from distal sources (i.e. such areas exhibit limited hydraulic connectivity with the main river systems).

The combination of flay-lying topography and moderately to well drained soils results in soil moisture infiltration and groundwater throughflow dominating the water balance of this zone. There are few permanent surface waterways, with overland flow largely restricted to small ephemeral streams, which carry discharge originating from laterally connected higher elevation areas during significant precipitation events.

Water facies comprise a mix of Na-Cl, Ca-$HCO_3$ and Ca-Cl types, which reflect land surface recharge occurring through highly weathered soils and unsaturated zone materials of low base saturation. The water types observed in this zone are consistent with land surface recharge occurring through highly weathered geology. Low alkalinity values reflect the relatively acidic groundwater pH due to limited pH buffering in the unsaturated zone.

**Groundwater**

Groundwater in the Old Mataura zone is typically strongly oxic with low dissolved organic carbon concentrations. This results from infiltration through geological materials, which have experienced millions of pore volume replacements by meteoric waters, resulting in the exhaustion of bulk of electron donors within the regolith materials. Due to the relatively inert, oxic nature of the soils and underlying alluvial materials in the Old Mataura zone recharge passing through the soil profile to underlying groundwater is not significantly altered in composition from that of recharge waters.

There is limited attenuation of nitrate loadings originating in land surface recharge due to the oxidised state of soils and groundwater. The dilution potential within the saturated zone is further limited by the low limited mixing potential in groundwater hosted in low to moderate permeability alluvial materials.

Sulphate concentrations are very low despite there being no evidence for strongly reducing conditions. This characteristic of waters in the Old Mataura zone is interpreted to represent preferential removal of sulphate by aluminium and iron oxides (oxy hydroxides) within the soil and unsaturated zone, supported by the number of old, weathered soils having high to very high subsoil sulphate.

**Differences between the Old Mataura and Oxidising zones (Class 3a and Class 3)**

Groundwater quality in the Old Mataura zone is appreciably different from that observed in the Oxidising zone, in terms of both major ions and nutrients. This is despite both zones having similar recharge mechanisms and redox setting, as illustrated in Figure 35. For example, the median groundwater nitrate concentration of 10.3 mg/L in the Old Mataura zone is appreciably higher than those observed in the Oxidising zone (and all other zones).

Difference in groundwater quality is attributed to the combination of two main factors. The first being, highly weathered soils exhibiting low base saturation and organic carbon, which limits ion exchange and denitrification in the soil zone in the Old Mataura zone. The second is the limited assimilative capacity in the soil zone and lower mixing potential in the saturated zone. The low rates of denitrification and mixing are reflected in the occurrence of multiple nitrate 'hotspots' across this zone.

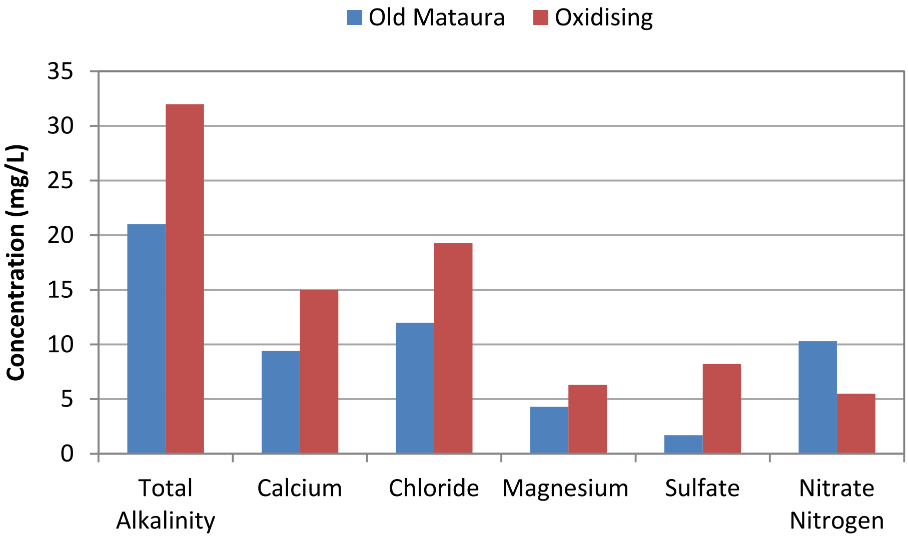



***Figure 35: Median groundwater major ion, alkalinity and nitrate concentrations in the Old Mataura and Oxidising zones.***

It is noted that landforms in the Old Mataura zone are also associated with longer modelled unsaturated lags times of between 3 to 10 years (up to 30 years across parts of the Wendonside terrace) compared to most Southland (Wilson *et al.*, 2014). The longer lag times calculated for the Old Mataura zone reflect the deep groundwater table across much of this zone and the high clay content of the weathered alluvium. Similarly, the rate of groundwater throughflow in the saturated zone is limited by the low to moderate transmissivity of the weathered alluvial materials. The result is that water quality in receiving environments (groundwater and hydraulically connected surface waters in adjacent physiographic zones) associated with the Old Mataura zone is likely to respond slowly to changes in the intensity of overlying land use in this zone.

**Summary**

The Old Mataura physiographic zone is characterised by strongly oxic groundwaters frequently exhibiting elevated groundwater nitrate and low sulphate concentrations. These characteristics reflect the low dilution and reduction potential associated with older elevated alluvial terraces in the mid-Mataura catchment, combined with the moderate to low assimilative capacity of the underlying saturated zone. Due to flat topography and well drained soils, little surface water runoff occurs from this zone with most drainage occurring as groundwater throughflow to hydraulically connected surface waterways in adjacent physiographic zones.

### 6.2.5 Class 4: Gleyed physiographic zone

The Gleyed physiographic zone represents areas where the dilution potential is low (i.e. land surface recharge is the dominant recharge mechanism), and reduction potential in soils is moderate to high (i.e. elevated denitrification potential) but the potential for bypass flow is low to moderate.

The Gleyed physiographic zone identifies areas with the following key characteristics:

- *Topography:*
  Flat to gently undulating topography with a dense network of lower order streams.

- *Dilution potential:*
  Low dilution potential reflecting the limited recharge flux associated with land surface recharge and little or no inputs from distal recharge sources.
- *Soil and geological characteristics:*
  Fine-textured, organic-rich, imperfectly to poorly drained soils that exhibit redoximorphic features (e.g. mottling), reflecting elevated soil reduction potential overlying moderate to slowly permeable alluvial deposits.
- *Reduction potential:*
  Elevated reduction potential in the soil zone to poor internal drainage. Low reduction potential in the saturated zone.
- *Hydrological characteristics:*
  Extensive artificial drainage network on flat-lying agricultural land. Spatially extensive groundwater resource hosted in low to moderate permeable alluvial deposits.

#### *6.2.5.1 Characterisation*

Water quality in the Gleyed zone is significantly influenced by soil hydraulic properties. Soils in this zone are typically fine-textured, organic-rich and occur across areas of flat to undulating alluvial terraces that are elevated above main-stem rivers and major tributaries. Soils are imperfectly to poorly drained, which is reflected in their characteristic redoximorphic features, such as mottling and gleying[16]. The poor internal drainage of soils in this zone means that artificial (mole-tile) drains are extensively used to remove seasonal excess soil water.

**Water quality**
The poorly to imperfectly drained soils of the Gleyed zone are associated with an elevated reduction potential, as they also have an elevated soil organic carbon content. This results in appreciable denitrification in soil moisture infiltrating through the slowly permeable soil matrix and is illustrated by the occurrence of redoximorphic features evident in soils throughout this zone.

Groundwaters in the Gleyed zone typically exhibit a mixed redox state, with moderate to low nitrate concentrations reflecting the influence of denitrification occurring within the soil zone. As a consequence, the groundwater nitrate load from this zone to hydraulically connected surface water bodies (i.e. lowland streams) is generally low.

Although soils contain enough organic carbon to allow denitrification to occur, the amount of denitrification that occurs is controlled by residence time within the soil. Shorter residence time associated with large recharge events may result in episodic losses of nitrate, particularly via artificial drainage, if there is insufficient time for denitrification to occur. Due to the ubiquity of subsurface drainage across this zone, the proportion of recharge water occurring as deep drainage to groundwater is relatively low, with a greater proportion exiting the soil zone laterally as bypass flow (mediated by artificial drains) or overland flow. In this setting, nutrients may accumulate within

[16] Except for those included in the Central Plains zone.

the upper 60 cm of soil until a significant recharge event. For example, during heavy precipitation, surplus or poorly bound contaminants are transported laterally via the artificial drainage network to surface water bodies. Such systems are said to be *transport limited* with surface water nutrient concentrations exhibiting episodic. There can be order of magnitude variation during large recharge events.

**Drainage pathways**

The poor internal drainage of soils in the Gleyed zone also results in significant lateral movement of water through the soil zone. This typically occurs via an extensive artificial drainage network in developed areas to the surface drainage network, particularly during the late autumn and winter months. Thus, the artificial drainage network provides a pathway for the rapid export of nutrients, suspended sediment and microbes to surface water receiving environments.

The transport limited nature of contaminant export from the Gleyed zone is illustrated in Figure 36 which shows measured nitrate losses from the Southland Demonstration Farm at Wallacetown. This study showed most nitrate leaching loss occurred during and immediately following episodic precipitation events when soils were wet and farm drains were discharging to surface waterways. During flow recession (as artificial drainage flows reduce), the rate of nitrate export declined significantly indicating tile drainage was the major pathway for nitrate export from this zone.

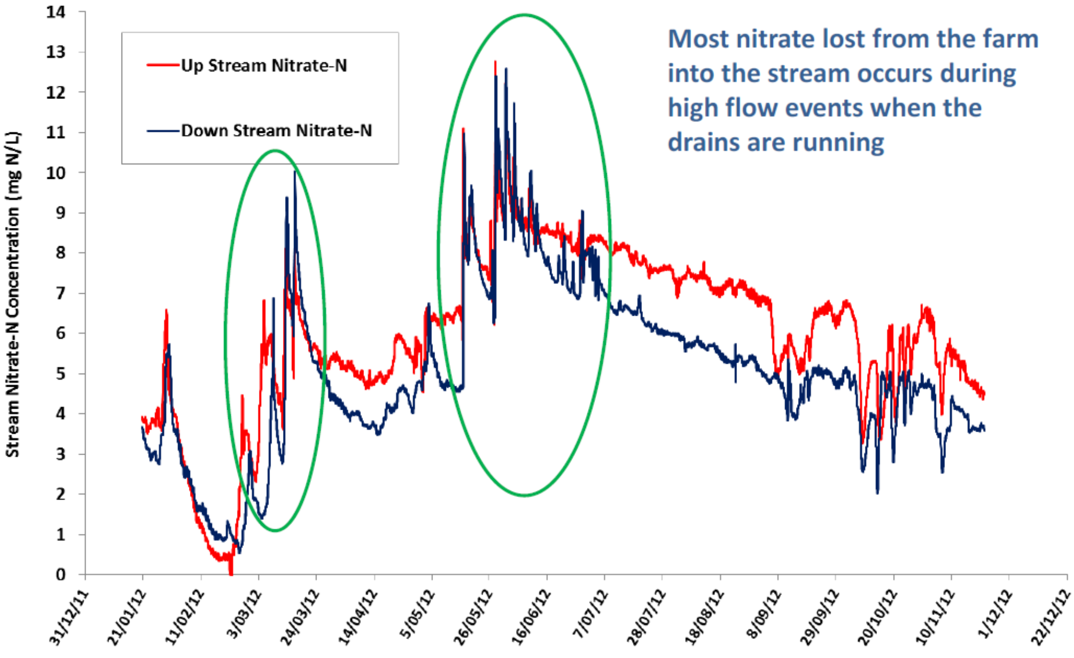



***Figure 36:*** ***Upstream and downstream nitrate concentrations showing periods of nitrate leaching loss from a Wallacetown monitoring farm (in the Gleyed zone). The decrease in nitrate concentrations at the downstream site are attributed to dilution from groundwater discharge into the stream.***

[Extract from Cameron *et. al*., 2014]

**Summary**

The Gleyed zone is characterised by imperfectly to poorly drained soils that exhibit an elevated reduction potential, illustrated by the presence of redoximorphic features (e.g. mottling) in the soil profile. Due to elevated soil reduction potential, deep drainage to groundwater is typically characterised by a mixed redox status (e.g. elevated iron, manganese, ammoniacal-N and low nitrate). Artificial drainage is extensively utilised to remove seasonal excess soil water to enable agricultural development. This provides a pathway for the rapid export of contaminants to surface water, particularly when soils are wet.

### 6.2.6 Class 4a: Central Plains physiographic zone

The Central Plains physiographic zone represents areas where water quality is strongly influenced by soil hydraulic properties.

The Central Plains physiographic zone includes areas with the following key characteristics:

- *Topography:*
  Flat to gently undulating topography with a dense network of lower order streams.
- *Dilution potential:*
  Low dilution potential reflecting the low recharge flux associated with land surface recharge and limited inputs from distal recharge sources.
- *Soil and geological characteristics:*
  Fine grained, clay-rich soils derived from mafic and ultra-mafic parent materials that exhibit shrink-swell behaviour, which results in bi-modal drainage characteristics. When wet, soils are poorly drained and prone to waterlogging requiring extensive artificial drainage. However, as soil moisture falls, shrinkage of clay minerals (e.g. smectite) in the soil matrix results in extensive cracking, which forms extensive macropore structures. This allows for rapid infiltration through the soil profile to the underlying saturated zone.
- *Reduction potential:*
  Elevated reduction potential in soils with low reduction potential in underlying alluvial aquifers. However, the extent of denitrification occurring within the soil zone is limited by rapid infiltration via macropore structures which effectively bypasses the soil matrix.
- *Hydrological characteristics:*
  Drainage pathways vary temporally between bypass flow to groundwater when soil are dry and artificial drainage when soils are wet. Sustained baseflow discharge to surface waterways during summer and autumn reflecting drainage of shallow groundwater.

#### *6.2.6.1 Characterisation*

The key landscape feature influencing water quality in the Central Plains zone is inferred to be the Gley and Pallic soils which cover most this zone. These soils exhibit temporal variations in soil hydraulic properties, which alter both the dominant drainage pathway and associated attenuation of dissolved and particulate contaminants on a seasonal basis.

**Bi-modal drainage**

Most of this zone occupies flat to gently undulating terraces comprising of recent alluvial deposits associated with a historical course of the Aparima River. Soils are deep, clay-rich and poorly drained with elevated soil reduction potential (Killick *et al.*, 2015). When wet, these soils are prone to waterlogging and require an extensive artificial drainage network to maintain agricultural productivity. However, as soil moisture declines, extensive macropore structures develop allowing deep drainage to bypass the soil matrix to the underlying saturated zone. This bi-modal drainage significantly reduces the attenuation of contaminants within the soil zone when soils are dry (particularly in terms of denitrification) and increases the potential for export of contaminants to surface water via the artificial drainage network when soils are wet.

**Water quality**

The Central Plains zone is characterised by oxidised surface and groundwaters with elevated electrical conductivity, alkalinity and nitrate concentrations. Water facies are mainly calcium-bicarbonate (Ca-$HCO_3$), reflecting base rich soils formed in mafic parent materials. Relative to groundwater, surface waters exhibit elevated manganese, iron and lower dissolved inorganic nitrogen concentrations, indicative of greater soil zone denitrification. Surface waters also reflect a greater soil zone contribution compared to groundwater, with surface waters having higher concentrations of potassium and sulphate and lower concentrations of silica. The weaker soil zone signature in groundwater is inferred to reflect macropore flow bypassing the soil matrix through fissures and fractures.

**Differences between the Central Plains and Gleyed zones (Class 4a and Class 4)**

The Central Plains zone comprises similar combined reduction potential (i.e. elevated over low reduction potential) to the Gleyed zone. However, groundwater quality data from the Central Plains zone indicate concentrations of redox-sensitive species in groundwater indicative of strongly oxic waters (elevated nitrate, low iron and manganese).

Figure 37 shows cumulative frequency plots of chloride, magnesium and nitrate from the Central Plains and Gleyed zones. The data show that while major ion concentrations are broadly similar in both zones, appreciable differences are observed in concentrations of redox-sensitive species, particularly nitrate. Given the similar recharge mechanism (land surface recharge) and reduction potential (reducing soils over oxic aquifers) in both zones, the observed differences in groundwater quality are attributed to soil hydrology.

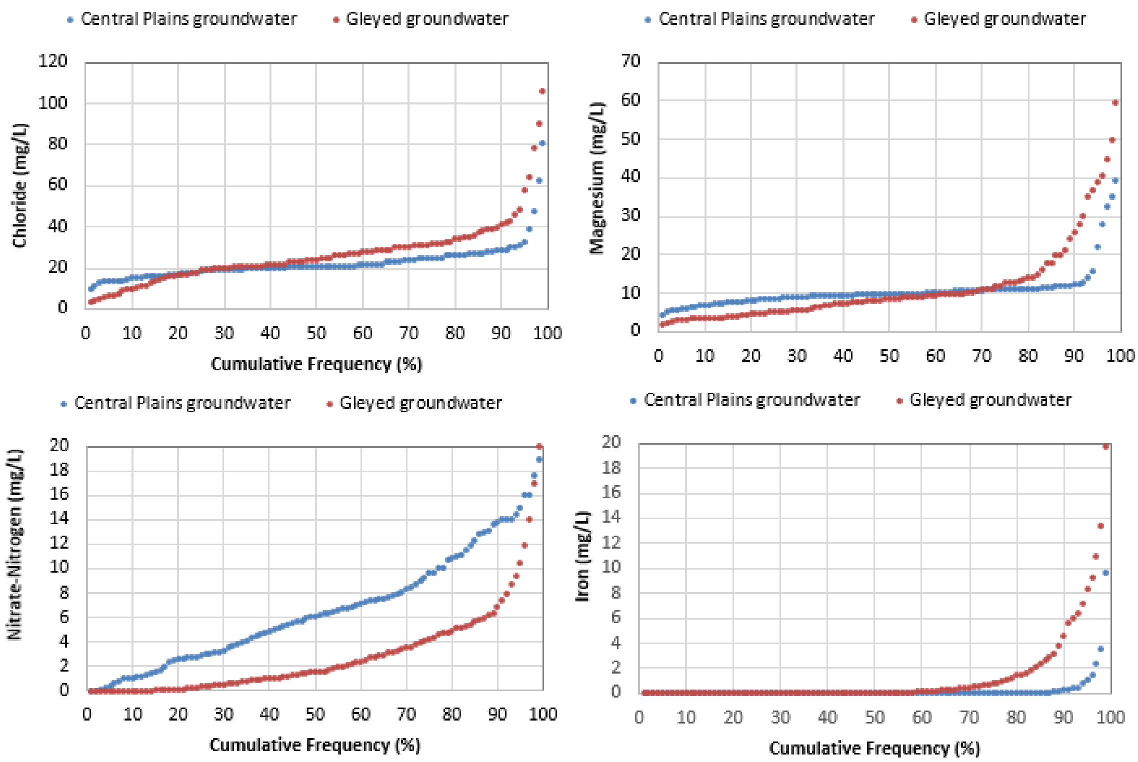



***Figure 37: Cumulative frequency plots of chloride, magnesium, nitrate-nitrogen and iron in groundwater from the Central Plains and Gleyed zones.***

In the Central Plains area, the magnitude and extent of bypass (macropore flow) through the soil zone appears to be appreciably larger than in other areas exhibiting similar soil types[17]. The more extensive occurrence of macropore flow in the Central Plains area is attributed to the provenance of soil materials in the Central Plains area being sourced from the tuffaceous greywacke and volcanic rocks of the Takitimu Mountains. These parent materials contain a high proportion of ferromagnesium minerals, which weather to form clay minerals, such as smectites. The resultant clay minerals are prone to shrink/swell behavior, which increases the potential for vertical bypass (or macropore) flow when soils are dry.

**Drainage pathways**

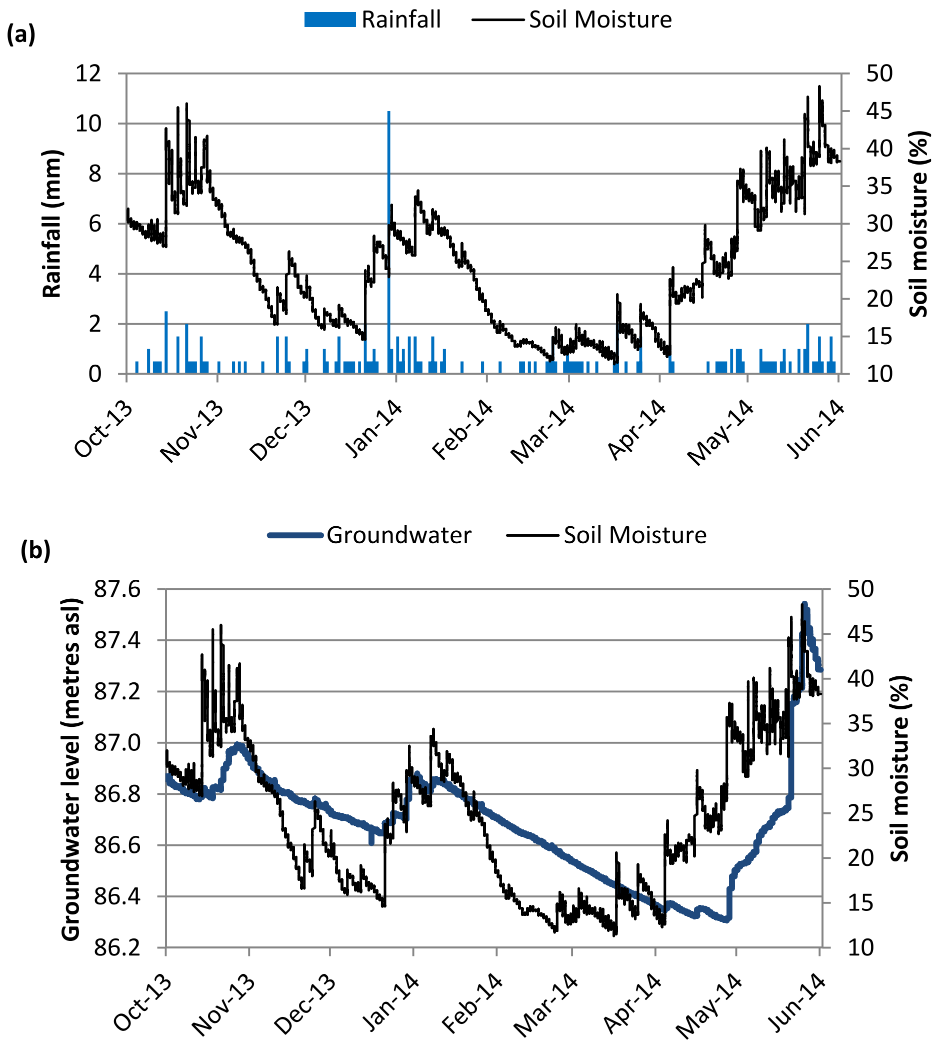
Vertical bypass flow occurs as a result of preferential drainage through the soil profile via discontinuities (e.g. cracks or fissures with large open pore spaces) in the soil matrix. These macropore structures form pathways for rapid infiltration of recharge that avoids passage through a large proportion of the soil matrix. Consequently, soil moisture drainage within these soils varies according to soil moisture status.

During the summer and autumn when soil moisture is low, clay minerals shrink opening macropore structures (e.g. cracks and fissures) within the soil matrix enabling rapid (vertical) infiltration of

[17] Refer to Technical Chapter 2 in the Physiographics of Southland Part 1 report (Rissmann, *et al.,* 2016).

recharge through the soil profile. During the late autumn, as soil moisture increases, clay minerals rehydrate, expanding to close the macropores and the soils revert to being poorly drained.

The shrink-swell behaviour of soils in the Central Plains area is also reflected in hydrology data shown in Figure 38. This plot shows that when soil moisture levels are low, significant rainfall events result in recharge to groundwater with little to no corresponding response in surface water flows. This indicates most recharge drains rapidly through the soil profile with limited discharge occurring directly to the surface water network. Conversely, during the winter months when soil moisture is high, surface water flows respond rapidly to rainfall events reflecting drainage via an extensive artificial drainage network. During this latter period groundwater levels typically only respond to large recharge events due to the slowly permeably nature of the subsoil when wet.



(c)

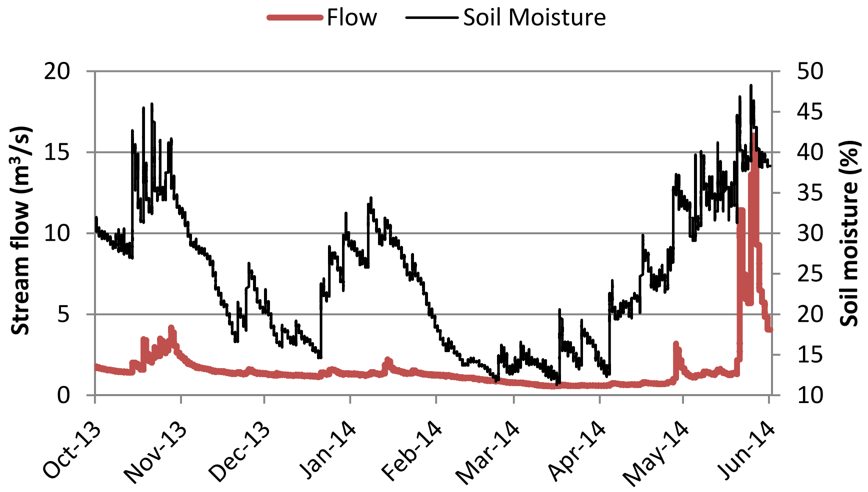



***Figure 38:*** ***Soil moisture monitoring from Heddon Bush and (a) rainfall at Heddon Bush (b) Waimatuku Aquifer groundwater level (bore E44/0330) and (c) Waimatuku Stream at Waimatuku Township Road stream flow, October 2013 – June 2014.***

Water quality in the Central Plains is strongly influenced by the bi-modal drainage characteristics of the soils in this physiographic zone. When soils are dry, rapid infiltration of water through the soil profile via macropores provides a pathway for the transfer of contaminants from the land surface to underlying groundwater which bypasses the fine-grained, reducing soil matrix. As soils become saturated, clay minerals rehydrate and macropore structures close, and the soils revert to being slowly permeable. Under these conditions, deep drainage of reduced groundwater continues via the reducing soil matrix, albeit at a much slower rate than that occurring via macropore flow. The dominant drainage pathway then transitions to lateral soil zone transport (e.g. artificial subsurface drainage), which transfers contaminants directly to the surface drainage network.

The occurrence of vertical bypass flow when soils are dry is reflected in the elevated and temporally variable nitrate concentrations observed in the shallow unconfined aquifer. Figure 39 shows a plot of nitrate concentrations and electrical conductivity in a shallow well near Drummond (E44/0093). The well exhibits appreciable seasonality, with highest nitrate concentrations (and electrical conductivity) typically observed during autumn, coinciding with the period when macropore flow is most likely to occur. The magnitude and regularity of seasonal groundwater quality variations in the Central Plains zone are the most pronounced observed in Southland groundwater.

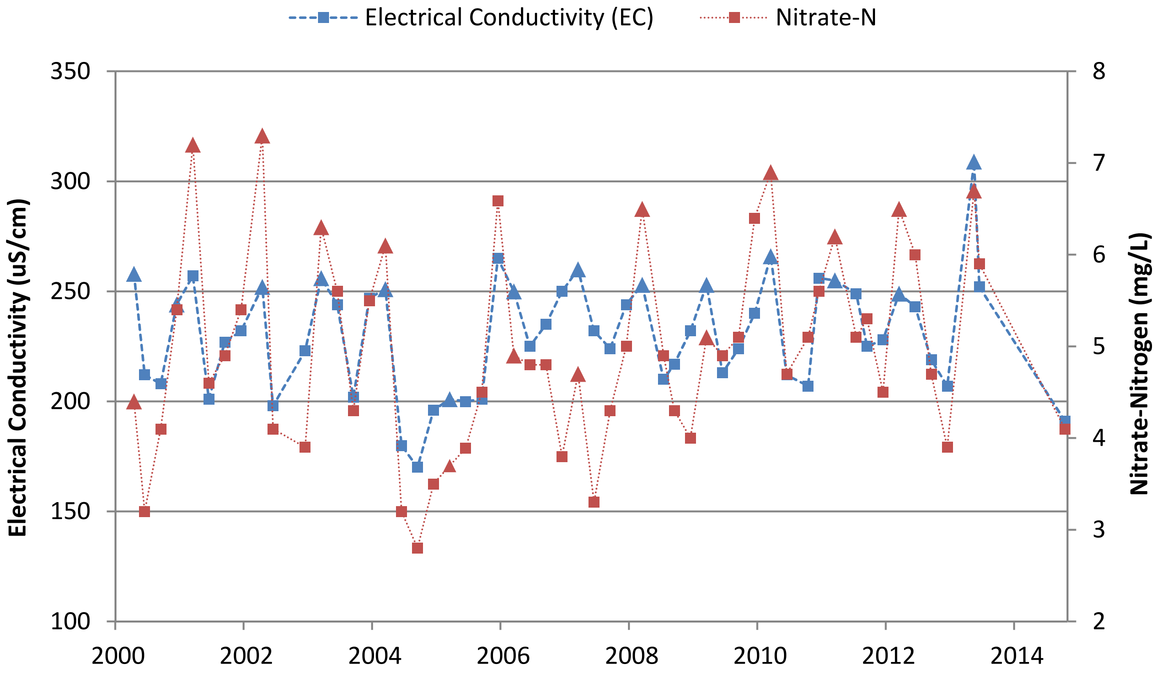



***Figure 39: Temporal variation in electrical conductivity and nitrate in Central Plains groundwater (E44/009). Note: triangles denote samples collected during autumn (March-May).***

The occurrence of elevated *E.coli* concentrations in surface waters in the Central Plains zone is interpreted to reflect rapid lateral discharge to surface waters via mole-tile drains. This is exacerbated by macropore flow when soils are dry, which provides a direct conduit for export of contaminants applied to the land surface via the artificial drainage network.

**Summary**

Water quality in the Central Plains zone is significantly influenced by the bi-modal nature of soil drainage. While the extent and influence of artificial drainage is consistent with the soil drainage classification, evidence supporting the widespread occurrence of bypass (macropore) flow is more circumstantial and inferred based on:

- Observed hydrochemical and water quality observations (e.g. high nitrate concentrations underlying reducing soils, greater soil zone signature in surface waters) compared to other areas exhibiting similar dilution and reduction potential;
- Observed temporal variations in groundwater levels and stream flows consistent with temporal variations in recharge/discharge mechanisms; and,
- Anecdotal reports of extensive soil cracking.

### 6.2.7 Class 5: Lignite / Marine Terraces physiographic zone

The Lignite/Marine Terraces physiographic zone represents areas where the dilution potential is low (i.e. land surface recharge is the dominant recharge mechanism) and the reduction potential in the saturated zone is high.

The Lignite/Marine Terraces physiographic zone includes areas with the following key characteristics:

- *Topography:*
  Flat to rolling topography drained by a network of lower order streams.
- *Dilution potential:*
  Low dilution potential reflecting the low recharge flux associated with and limited inputs from distal recharge sources.
- *Soil and geological characteristics:*
  Variable soil types typically overlying thin alluvial deposits that either contain significant quantities of organic material (marine terraces), or overlie organic-rich sediments (coal, lignite or carbonaceous mudstone) at shallow depths (~<15 m below ground level).
- *Reduction potential:*
  Varying reduction potential in soils overlying aquifers exhibiting an elevated reduction potential. A redox gradient is often observed with depth transitioning from shallow oxic conditions to strongly reducing (anoxic) near organic-rich sediments.
- *Hydrological characteristics:*
  Groundwater system with limited saturated thickness hosted in Quaternary alluvium. Spatially variable potential for overland flow and artificial drainage, reflecting differences in topography and soil drainage characteristics.

#### *6.2.7.1 Characterisation*

The key landscape feature that influences water quality in the Lignite/Marine Terraces zone is the presence of significant quantities of organic carbon in the subsurface geology. This commonly occurs in Tertiary sediments containing coal or lignite but also includes marine terraces, which contain significant quantities of organic materials. The redox status of surface and ground- waters is mostly mixed with strongly reducing (anoxic) conditions typically observed in groundwater near carbonaceous sediments.

Water facies in this zone are predominantly Na-Cl in coastal areas (reflecting marine aerosol deposition) and Ca-$HCO_3$ in inland areas (due to elevated alkalinity associated with soil and saturated zone processes).

**Water quality**

The key feature of the Lignite/Marine Terraces zone is the presence of strongly reducing conditions in the saturated zone due to the presence of sediments containing elevated levels of organic carbon. In areas where organic-rich sediments are overlain by alluvium (e.g. across much of Eastern Southland) a strong redox gradient is observed with depth, with groundwater transitioning from oxic near the water table to anoxic (e.g. containing low concentrations of dissolved oxygen, nitrate and sulphate, elevated concentrations of iron, manganese and, in places, hydrogen sulphide) near underlying organic-rich sediments.

Where waters are reduced (mixed to anoxic redox status), dissolved iron, manganese and ammoniacal nitrogen can be elevated while nitrate concentrations are low. However, the redox status of soil waters and shallow groundwater may vary temporally reflecting seasonal inputs of (oxic) land surface recharge.

Based on observed groundwater redox and nutrient concentrations, it is considered that even where oxic conditions exist at shallow depths locally, sufficient vertical mixing will occur in the saturated zone where organic-rich sediments occur at shallow depths (within ~15m on the land surface) for a mixed to reducing redox equilibrium to be established in sub-regional groundwater flow.

For example, Figure 40 shows groundwater quality results for event sampling conducted during June 2011 in the Waituna Stream catchment. Results clearly illustrate the effect of an individual recharge event on the concentrations of redox-sensitive species in shallow groundwater in the Lignite/Marine Terraces zone. The data indicate a rapid increase in oxidisable species (NNN and $SO_4$) with simultaneous decrease reduced species ($Mn^{2+}$ and $Fe^{2+}$), reflecting the infiltration of oxic soil water recharge into the upper levels of the underlying mixed redox state saturated zone following a significant recharge event. Over the subsequent period, concentrations of dissolved ions equilibrate toward concentrations observed prior to the recharge event, reflecting mixing and dispersion of the oxic recharge in the saturated zone and re-establishment of stable (mixed) redox conditions in the saturated zone.

**Surface water**

In surface waters, while dissolved nutrient concentrations may be elevated in quickflow (reflecting runoff via overland flow or artificial drainage), nitrate concentrations are low during baseflow. This reflects the reduced nature of groundwater across in the Lignite/Marine Terraces zone. Similarly, exports of sediment and microbes to surface waters may occur where overland flow or lateral soil zone transport (via artificial drainage) are the main drainage pathways, particularly when soils are wet.

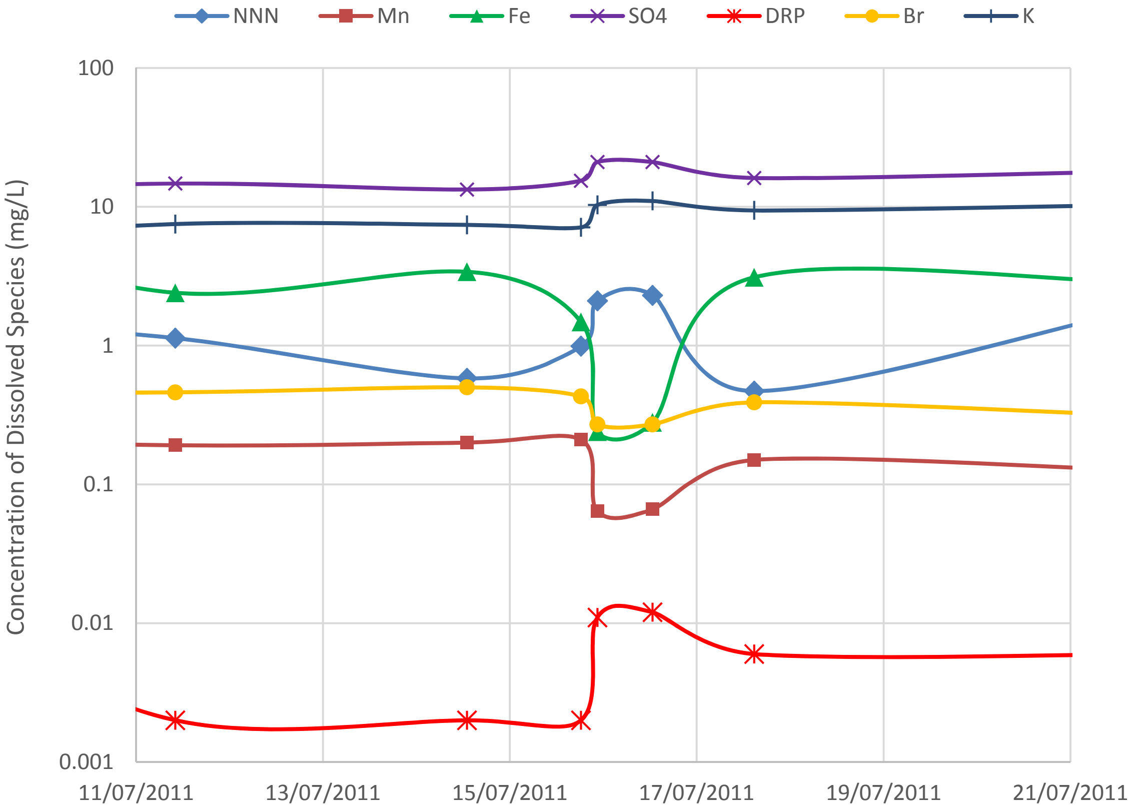



***Figure 40:*** ***Influence of a soil zone recharge event on groundwater quality in the Lignite/Marine Terraces zone. The dashed box depicts the period a storm event that caused a spike in soil moisture levels (>50 mm of rainfall in 24 hours).***

[Source: Rissmann *et al*., 2012]

**Summary**

The Lignite/Marine Terraces zone is characterised by a strong redox gradient in the saturated zone, with strongly reducing (anoxic) conditions generally occurring at shallow depths. Due to mixing, sub-regional groundwater flow typically exhibits mixed to strongly reducing redox characteristics (elevated iron, ammoniacal nitrogen and low nitrate). Variable soil drainage and topography, results in contaminants being exported to surface waters via overland flow or artificial drainage in some areas. However, baseflow typically exhibits a mixed redox status reflecting inputs of reduced groundwater.

### 6.2.8 Class 6: Peat Wetlands physiographic zone

The Peat Wetlands physiographic zone represents areas where the dilution potential is low (i.e. the recharge mechanism is land surface recharge) and both soils and aquifers have a high reduction potential.

The Peat Wetlands zone includes areas with the following key characteristics:

- *Topography:*
  The Peat Wetlands zone mostly occurs in flat-lying coastal locations but also includes isolated wetland remnants (including raised peat bogs) across a range of elevations in inland areas.
- *Dilution potential:*
  Dilution potential is low, reflecting the low recharge flux associated with local land surface recharge and limited inputs from distal sources.
- *Soil and geological characteristics:*
  Organic soils with a high organic content in subsurface geology, which often comprise of fine-grained sediments.
- *Reduction potential:*
  High reduction potential in soils and groundwater. Low P retention in soils and high P mobility in both surface and groundwater. Nitrogen tends to be present as ammonia ($NH_4$) with little or no nitrate ($NO_3$).
- *Hydrological characteristics:*
  Very high water table, which sits near or above the land surface. Extensive artificial drainage in developed areas, including open drains.

#### *6.2.8.1 Characterisation*

The key environmental feature of the Peat Wetlands zone is the high organic carbon content in soils and underlying geology. This exerts a strong influence over hydrochemical and water quality characteristics. Waters in this zone are typically acidic and strongly reducing (anoxic).

The Peat Wetlands zone occurs in existing remnant wetland areas and in former wetland areas that have been developed. Such areas are typically flat and occupy lower-lying parts of the landscape, although some remnant wetland areas form mounded areas, which rise about the surrounding topography.

Due to a combination of their low-lying position in the landscape and the slow permeability of underlying silt and amorphous peat sediments, areas of the Peat Wetlands zone typically exhibit a water table (perched in some places) close to, or at times above, the land surface.

**Recharge**

Recharge to the Peat Wetlands zone is derived exclusively from land surface recharge. Discharge varies seasonally, reflecting the poor internal drainage and very high total available water (TAW) in organic soils. Where organic soils are agriculturally developed, artificial drainage exerts a major influence over local hydrology, intercepting lateral drainage through near-surface fibrous peat deposits and groundwater where the water table occurs close to ground level. In some wetland systems the water table can become elevated above ground level (either seasonally or on a permanent basis), also contributing to overland flow.

**Water quality**

The peat wetlands zone is characterised by strongly reducing (generally anoxic) waters which are acidic due to the high organic acid content in peat sediments, low pH buffering capacity and low alkalinity in surface waters.

Groundwater is strongly reducing resulting in elevated ferrous iron (Fe2+) and ammoniacal nitrogen concentrations (naturally derived through ammonification of organic matter under reducing conditions) in groundwater. Surface waters tend to exhibit a mixed redox state, reflecting the mixing of atmospheric O2 with reduced groundwater and soil water inflows.

Water quality associated with this zone tends to exhibit low dissolved oxidisable nitrogen (nitrate) and high phosphorus concentrations, reflecting the dominant control of organic carbon over redox evolution and the low abundance of Fe and Mn oxides. Soils have negligible mineral content for phosphorus retention and phosphorus is mobilised under reducing conditions due to the formation of vivanite and Mn phosphate-type colloids and the inhibition of oxidation of reduced particulate assemblages due to the presence of organic ligands, reduced sulphur compounds and low pH (Rissmann *et al.,* 2012, 2013).

Dissolved reactive phosphorus (DRP) is elevated in surface waters in this zone due to poor anion storage capacity (ASC) in peat soils in areas where land use is developed. During high flow events, phosphorus concentrations increase markedly in surface waters in catchments with intensive land use (i.e. transport limited) but remain largely unchanged in undeveloped peat wetland catchments (i.e. source limited). DRP concentrations are generally not as elevated in groundwater compared to surface water due to a degree of regulation by iron-oxides.

Decomposition of organic matter releases organic anions that can compete with phosphorus for adsorption sites within the soil profile. Mineralisation of organic material releases soil organic phosphorus. Concentrations of Al and Fe tend to be low in organic soils resulting in poor sorption of added phosphorus (e.g. through agricultural activity). Thus, phosphorus loss is a major water quality issue for this zone. Figure 41 illustrates the general relationship observed between lower anion storage capacity (ASC) in organic soils and the increased potential for mobilisation of phosphorus.

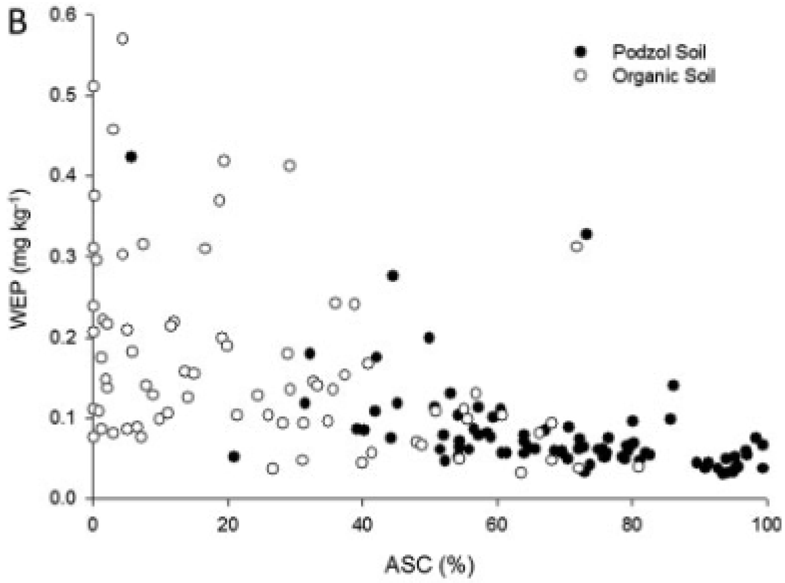



***Figure 41:*** ***Plot of water-extractable phosphorus (WEP) concentration against anion storage capacity (ASC) for organic and podzol soils.***

[Extract from Simmons *et al.*, 2014]

Figure 42 shows that Moffat Creek, which drains the Peat Wetlands zone, exhibits appreciably higher mean DRP concentrations than other lowland streams in Southland. It is noted that Moffat Creek exhibits highest mean DRP concentrations during summer (January and February) while other streams peak during winter (May to July) when soils are wettest. This is interpreted to reflect the influence of phosphorus-enriched groundwater augmenting stream DRP concentrations via baseflow discharge in the Peat Wetlands zone compared to inputs associated with seasonal transport pathways (overland flow and artificial drainage) in other physiographic zones.

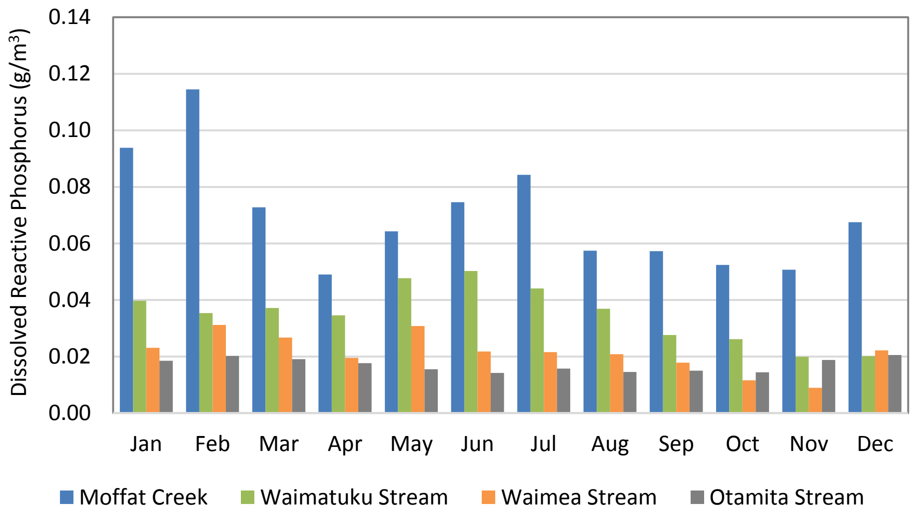



***Figure 42:*** ***Mean monthly DRP concentrations in the Peat Wetlands zone (Moffat Creek) and other lowland Southland streams.***

Due to the very high soil and aquifer denitrification rates, the loss and build-up of oxidisable nitrogen (nitrate) is not of major concern for water quality in the Peat Wetlands zone.

*E.coli* concentrations can become elevated where the Peat Wetlands zone is artificially drained and intensive land use occurs, with elevated microbial indicator concentrations observed in many surface waterways. Export of microbial contaminants to surface waters in the Peat Wetlands zone is inferred to reflect low microbial removal rates due to the high intrinsic permeability and low effective porosity of shallow fibrous peat soils, however the exact mechanism for this form of contaminant loss is not well characterised.

**Summary**

The Peat Wetlands zone represents areas that have a low dilution potential and exhibit an elevated reduction potential in both the soil and saturated zones. Due to the elevated reduction potential, nitrate concentrations are very low while concentrations of iron, ammonia and sometimes manganese can be elevated in both groundwater and surface waters. Concentrations of dissolved phosphorus are also elevated in both groundwater and surface water, reflecting the low anion storage capacity (ASC) of organic soils and the influence of reducing conditions on Fe and Mn oxides. Microbial contaminants can also be elevated in surface waters in developed areas of this zone due to extensive artificial drainage, combined with low removal rates in shallow organic soils.

### 6.2.9 Class 7: Riverine physiographic zone

The Riverine physiographic zone represents areas where the dilution potential is high (i.e. recharge is derived from a combination of alpine river runoff and local land surface recharge) and the reduction potential is low (i.e. oxic soils and aquifers).

The Riverine physiographic zone includes areas with the following key characteristics:

- *Topographical features:*
  Located along the active floodplains of main-stem rivers and large tributaries with headwaters in the Alpine zone (>800m asl).
- *Dilution potential:*
  High mixing potential due to large volumes of dilute recharge from alpine rivers, which mixes with and dilutes local land surface recharge.
- *Soil and geological characteristics:*
  Thin, coarse soils in places incorporating overbank silt deposits accumulated on recent alluvial floodplains overlying coarse-grained highly permeable alluvium.
- *Reduction potential:*
  Low reduction potential in soils and groundwater.
- *Hydrological characteristics:*
  Significant hydraulic connection between main stem rivers and adjacent riparian aquifers. High rates of groundwater throughflow in shallow unconfined aquifers. Groundwater discharge often occurs via spring-fed streams.

#### *6.2.9.1 Characterisation*

The key landscape feature of the Riverine zone that influences water quality is the hydraulic connection to runoff from the Alpine zone. Waters in this zone are strongly influenced by mixing of local land surface recharge and distal recharge from alpine headwaters.

The Riverine zone includes the main stem rivers downstream of their alpine headwaters and hydraulically connected alluvial aquifers along their riparian margins. These areas are typically characterised as comprising the active floodplains of the major river systems where recent soils overlie coarse-grained alluvial deposits which host aquifers exhibiting a high degree of hydraulic connection to surface water.

As alpine sourced rivers and streams debouch onto inland basins and lowland plains, they interact with adjacent alluvial aquifers with flow being gained or lost depending on the local hydrogeological setting. Where flow is lost from the stream or river to surrounding aquifers it acts to dilute contaminant inputs associated with local land surface recharge. Where aquifers or local catchments discharge to alpine sourced streams and rivers, the pristine composition of alpine river water progressively changes downstream in response to additions of mid to low altitude land surface recharge.

**Recharge**

The Riverine zone is characterised by mixed-altitude recharge waters, which reflect a large input of dilute alpine-derived water and a smaller contribution of concentrated mid to low altitude land surface recharge. Spatial variations in electrical conductivity (EC) and nitrate concentrations indicate a relatively small proportion of much more highly concentrated land surface recharge can significantly increase the dissolved solute load in surface waters. While concentrations of water quality variables are typically low in the Riverine zone, loads of dissolved contaminants can be high due to the large volumes of groundwater throughflow occurring in highly permeable alluvial aquifers.

Figure 43 shows an example of the significant hydraulic interaction that occurs between main-stem rivers and adjacent aquifer systems in the Riverine zone.

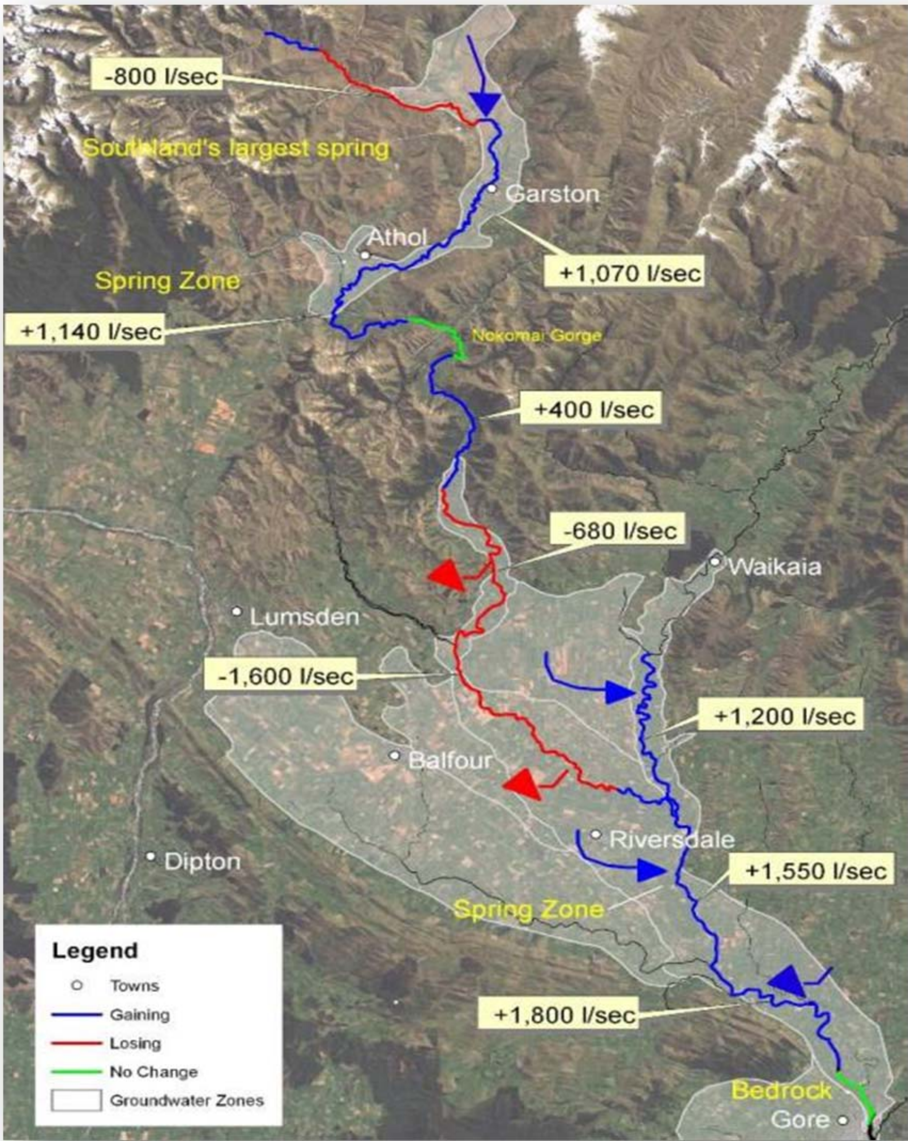



***Figure 43: Net flow gains and losses in the Mataura and Waikaia Rivers (with tributary inputs accounted for) under low flow conditions.***[18]

[Source: Wilson, 2008]

**Surface water**

A key factor influencing water quality in the Riverine zone is the dilution of local land surface recharge by large volumes of dilute runoff from alpine areas. Typically, surface water quality associated with the Riverine zone is best near alpine headwaters and declines down-stream as the proportion of land surface recharge increases. Groundwater quality generally varies spatially, reflecting the higher contribution of alpine river recharge to groundwater (and hence greater

[18] Based on the Mataura River at Gore flow being 13.5 $m^3/s$. For context, the 7-day mean annual low flow at this site is 17.57 $m^3/s$ and mean flow is 65.14 $m^3/s$.

dilution of land surface recharge) along the riparian margins of hydraulically connected rivers and streams compared to areas further removed from river channels.

Surface water quality in the Riverine zone may also vary temporally, reflecting the differing contribution of discharge from headwater areas and baseflow derived from local groundwater. For example, Figure 44 shows nitrate concentrations in the Irthing Stream at Ellis Road. While the number of samples collected at higher flows is limited, the data indicate a clear increase in maximum nitrate concentrations at low flows. This variation is inferred to reflect the greater relative contribution of baseflow from oxidised groundwater from the Five Rivers area, which discharges water with higher nitrate concentrations into the stream. During high flows, the greater proportion of quickflow (overland flow and lateral drainage) from pristine alpine headwater catchments results in low nitrate concentrations.

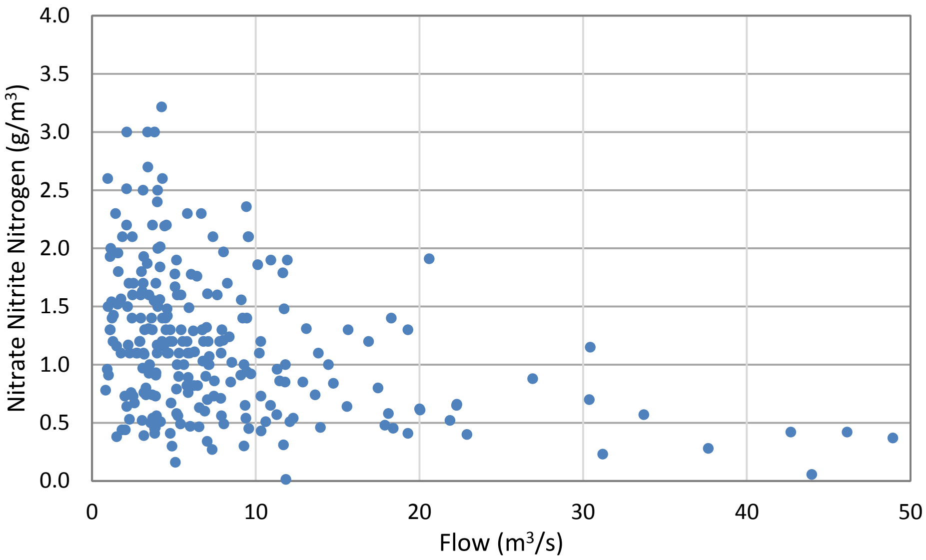



***Figure 44: Relationship between flow and nitrate for the Irthing Stream at Ellis Road. The highest nitrate concentrations occur during low (baseflow) conditions. At high flows, nitrate concentrations are diluted by alpine-runoff.***

**Groundwater**

Silt, sand and minor clay within the gravel matrix traps sediment, filters out particulate and microbial contaminants and assists in the sorption and retention of phosphorus prior to infiltration to the underlying aquifer. Groundwater within this zone shows little evidence of *E.coli* contamination or elevated phosphorus, yet comparatively, nitrate and electrical conductivity are elevated. Therefore, it is the leaching of soil zone nitrate to underlying aquifers and ultimately the nutrient load via baseflow to main stem rivers which is the primary water quality issue for the Riverine zone.

**Summary**

The Riverine zone includes areas along the riparian margins of the major rivers and streams. Water quality in this zone is significantly influenced by the mixing of large volumes of dilute runoff from alpine headwaters with local rainfall recharge.

# 7 Delineation of classes (physiographic zones)

Classes were delineated and mapped using environmental variables, which were used as a proxy for the key processes influencing water quality. This allowed for the delineation and spatial mapping of classes regardless of whether water quality and/or hydrochemistry data were available for any given location. Hence, all areas of the Southland region were able to be assigned to one of the nine classes as defined in section 6.

## 7.1 Delineation process

Delineation of the physiographic zones involved the following steps:

- identification of the key controls on water quality in each physiographic zone;
- identification of inherent environmental variables, which serve as a proxy for the identified water quality controls;
- preliminary mapping of the physiographic zones using the identified inherent environmental variables;
- refinement of mapping rules by comparing the mapped extent of each zone with available hydrochemical and water quality data to ensure the spatial coverage was consistent (to the extent practicable) with known and inferred landscape/water quality relationships.

Once delineation of the physiographic zones was completed, the spatial coverage was intersected with a range of environmental variables (e.g. climate, soils, geology, hydrology) to enable identification of the *dominant characteristics* of each physiographic zone.

As previously noted, the classification is a simplification of a complex, continuously variable natural system. Consequently, there can be appreciable variability in hydrochemistry, water quality and associated physical and hydrological characteristics within each physiographic zone. The dominant (i.e. most geographically widespread or frequently occurring) environmental variables form the basis of the characterisation outlined in Section 7.3.

### 7.1.1 Key water quality characteristics

The following provides a summary of the key water quality characteristics and linkages to inherent environmental variables and hydrological characteristics for each physiographic zone[19] established from the initial delineation process:

**Alpine**

The key water quality characteristics of the Alpine zone are the large volumes of dilute, oxic waters which originate from alpine areas which have a high recharge flux (due to orographic enhancement

[19] In this section the Physiographic zones have been placed in alphabetical order, rather than in class order (as in section 6).

of precipitation) and limited soil cover. Due to the high precipitation volumes/intensity and sloping topography, overland flow is the dominant drainage pathway.

**Bedrock/Hill Country**

The key water quality characteristics of the Bedrock/Hill Country zone are the relatively dilute, slightly reduced waters that originate from mid elevation areas, which have an elevated recharge flux (due to orographic enhancement of precipitation). Soil cover is typically well developed and typically has elevated reduction potential. Soils have high organic carbon content associated with historical vegetative cover below the nominal bushline. Overland flow is a significant drainage pathway, due to the rolling to steep topography, particularly when soils are wet. Subsurface geology generally comprises slowly permeable bedrock or till which limits the extent of the groundwater resources.

**Central Plains**

This zone shares the low recharge potential and elevated soil reduction potential characteristics of the Gleyed zone. However, both surface and groundwater quality are appreciably different in the Central Plains zone due to bi-modal drainage associated with the shrink/swell characteristics of soils derived from mafic and ultra-mafic parent materials.

**Gleyed**

Key water quality characteristics of the Gleyed zone are the low dilution potential associated with land surface recharge and an elevated reduction potential in the soil zone due to imperfect to poor soil drainage characteristics. These soil hydraulic characteristics are reflected in redoximorphic features (e.g. mottling) in the soil zone and typically result in appreciable denitrification within the soil zone. However, the poor soil drainage also increases the potential for contaminant losses via artificial drainage on agricultural land when soils are wet.

**Lignite/Marine Terraces**

Key water quality characteristics in this zone are the low dilution potential and elevated reduction potential in the saturated zone associated with the near surface occurrence of organic carbon rich sediments (lignite measures and marine deposits). The hydrochemical characteristics of these sediments significantly influences groundwater quality and baseflow discharge in streams draining this zone.

**Old Mataura**

The Old Mataura zone is characterised by a low dilution and redox potential in both the soil and saturated zone. These characteristics reflect the landscape setting and geological history of higher alluvial terraces in the middle reaches of the Mataura catchment. Due to the well-drained, flat-lying nature of these features, deep drainage to groundwater is the dominant drainage pathway.

**Oxidising**

The low dilution potential associated with land surface recharge and the low reduction potential in soils and groundwater are the key water quality features in this zone. Deep drainage to groundwater is a significant drainage pathway however variations in topography and soil drainage properties increase the potential for overland flow and artificial drainage in some areas.

**Peat Wetlands**

This zone is defined by a low dilution potential and an elevated reduction potential in both soils and aquifers associated with remnant or historical peat wetland areas. Artificial drainage is commonly a major drainage pathway in developed areas.

**Riverine**

Key influences on water quality in the Riverine zone are the low reduction potential in soils and aquifers and the high potential for mixing (dilution) of local land surface recharge.

Table 9 summarises how these key water quality influences relate to inherent environmental variables for the individual physiographic zones.

*Table 9: Key water quality influences and associated inherent environmental variables for individual physiographic zones*

| Physiographic Zone | Key water quality influences | Associated inherent environmental variables | Defining landscape feature(s) | Data source for mapping |
|---|---|---|---|---|
| **Alpine** | ➢ High dilution potential<br>➢ Low reduction potential | *High Altitude*<br>➢ High precipitation<br>➢ Seasonal snowpack accumulation<br>➢ Low organic carbon in soils and geology | Elevation (>800m) | Digital elevation model (DEM) |
| **Bedrock/Hill Country** | ➢ Elevated soil reduction potential<br>➢ Elevated dilution potential | *Geology (near surface basement rock)*<br>➢ Elevated precipitation<br>➢ Elevated soil organic carbon<br>➢ Limited groundwater resource | Rolling to steep topography with thin soil and/or colluvium overlying bedrock or glacial till (i.e. low permeability sediments) | Qmap (geology) |
| **Central Plains** | ➢ Low reduction potential<br>➢ Low dilution potential | *Soils with a high potential for bypass flow*<br>➢ Soils with mafic parent materials exhibiting shrink/sell characteristics (i.e. extensive cracking when dry) | Soils exhibiting natural bypass flow characteristics | Combined soils layer (CSL), Qmap (geology) |
| **Gleyed** | ➢ Low (soil and aquifer) reduction potential<br>➢ Low dilution potential<br>➢ Highly weathered geology | *Reducing Soils*<br>➢ Soils exhibiting poor internal drainage and/or redoximorphic features | Imperfectly to Poorly drained soils exhibiting redoximorphic features | CSL (soils) |
| **Lignite/Marine Terrace** | ➢ Elevated soil reduction potential<br>➢ Low dilution potential | *Carbon-rich subsurface geology*<br>➢ Near surface carbon-rich lignite measure or marine-derived sediments | Elevated organic carbon in subsurface geology | Qmap (geology), Wells database (bore logs) |
| **Old Mataura** | ➢ Elevated soil reduction potential | *Oxic Soils and Geology* | Highly weathered soils and geology | Qmap (geology) |

| | | | | |
|---|---|---|---|---|
| | ➢ Low dilution potential<br>➢ Bypass flow through soil zone | ➢ Well drained soils<br>➢ Elevated terraces set back from main stem rivers (low dilution potential) | associated with the Shotover and Luggate Formations | |
| **Oxidising** | ➢ Elevated groundwater reduction potential<br>➢ Low dilution potential | *Oxic Soils and Geology*<br>➢ Well drained soils<br>➢ Elevated terraces set back from main stem rivers (low dilution potential) | Moderately well to Well drained soils overlying alluvial deposits | CSL (soils), Qmap (geology) |
| **Peat Wetlands** | ➢ Elevated soil and groundwater reduction potential<br>➢ Low dilution potential | *Strongly Reducing Soils and Geology*<br>➢ Organic-rich soils<br>➢ Remnant wetlands | Organic soils and geology | Qmap (geology), CSL (soils) |
| **Riverine** | ➢ Low reduction potential<br>➢ High mixing potential | *Hydraulic connection to alpine sourced rivers and streams*<br>➢ Recent fluvial soils and alluvium<br>➢ Proximal to rivers and streams draining alpine headwaters | Hydraulic connection to alpine rivers and recent fluvial soils | River environment classification (REC), CSL (soils) |

## 7.2 Mapping rules

A series of mapping rules were developed to assign all locations in the region to a class. The rules were developed with the following criteria:

- mapping rules should be as simple as possible;
- physiographic zones should be defined using data sets that provide regionally consistent coverages of measurable (as opposed to modelled or inferred) variables; and,
- delineation of the physiographic zones should be replicable.

The approach enabled a spatial framework to be developed that identifies areas where similar water quality outcomes can be expected to occur. The accuracy and resolution of the physiographic zone map (or the boundaries of each physiographic zone) is limited by the source datasets used for mapping. The datasets (illustrated in Figure 45) identified as suitable were:

- A combined **soil** layer (CSL) comprising three separate soil surveys: the 2001 Topoclimate South (TCS) soil survey (1:50,000 scale) and associated technical sheets (Crops for Southland, 2002), the 1986 Wallace County soil survey (1:50,000 scale) and the 1968 Land Resource Inventory (LRI) soil survey (1:50,000 and 1:63,360 scale). Soil maps were assembled according to the following hierarchy Topoclimate > Wallace County > LRI reflecting the age and level of detail available from the respective surveys;
- A seamless **geology** coverage derived from the QMap (GNS Science) geological coverage including portions of the Fiordland, Murihiku, Dunedin and Wakatipu 1:250,000 scale geological maps;
- The Environment Southland **Wells database** which contains more than 2,700 bore logs for the region;
- A **Digital Elevation Model** (DEM) (8 metre pixel resolution) held by Environment Southland;
- The **surface water network** coverage defined in the River Environment Classification (REC) version 3 (NIWA); and,
- The Environment Southland **water quality database** comprising upwards of 17,000 groundwater and surface water quality samples sites distributed across the region. These data were used to support the delineation process.

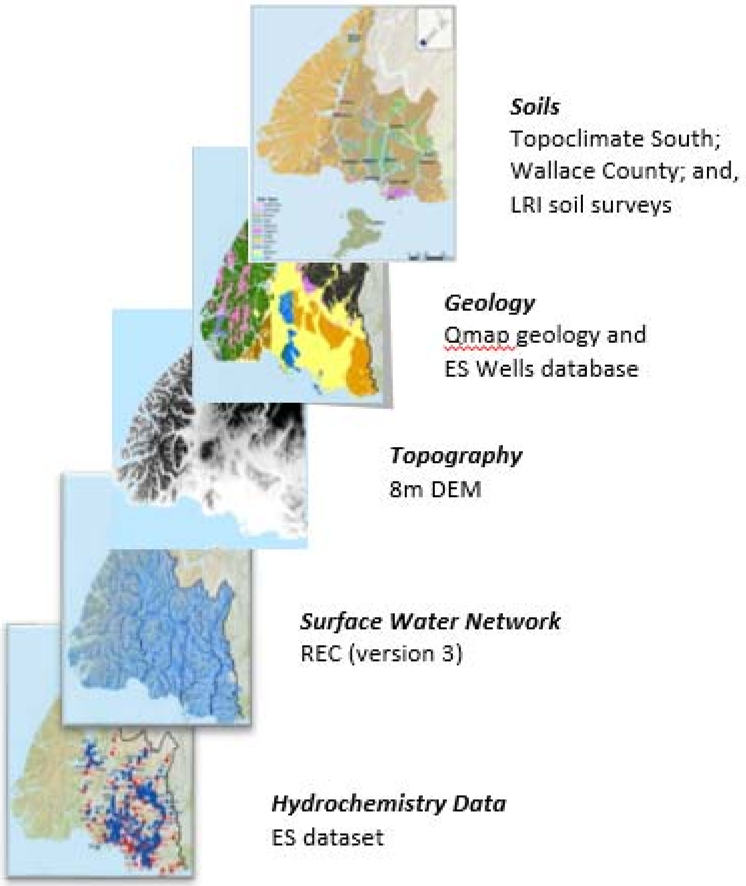



***Figure 45: Source layers used to map the physiographic zones.***

The physiographic zones were mapped using datasets that describe topography, hydrology, geology and soil properties at every point across the Southland landscape. These environmental variables were selected because they directly influence the dilution and attenuation processes identified in Sections 3.1 to 3.3. The relationship between the environmental variables used to delineate the physiographic zone map and dilution and attenuation potential are summarised in Table 10.

***Table 10: Relationship between the environmental variables used for mapping and water quality risk***

| | | Environmental variables (datasets used) | | | | |
|---|---|---|---|---|---|---|
| | | **Soils (combined layer)** | **Geology (Q-map)** | **Wells database** | **Digital elevation model** | **River environment classification** |
| **Dilution** | **Water flux and mixing** | Soils have little influence over dilution potential | Geology has little influence over dilution potential | | Slope and elevation correlate to precipitation volume | Stream network determines whether there is a hydraulic connection to alpine runoff, providing for dilution and mixing |
| **Attenuation** | **Reduction potential** | Soil drainage properties determine reduction potential in the soil zone | Where geological materials contain abundant organic carbon, reduction potential is elevated | | Slope and elevation have limited influence over reduction potential | The stream network has little influence over reduction potential |
| | **Filtration and sorption** | Soil texture and drainage properties determine filtration and sorption rates | Filtration and sorption occurs in almost all geological settings | | Slope and elevation have limited influence over filtration and sorption processes | The stream network has little influence over filtration and sorption processes |

The mapping rules used to delineate the physiographic zones were developed iteratively, with each iteration visually inspected against Environment Southland's water quality and hydrochemistry monitoring data. This process enabled the relationship between inherent environmental variables and water quality outcomes to be tested to be tested against the conceptualisation (Section 6.2), with cognitive learning incorporated into the mapping process.

It is noted that while no specific field investigations were undertaken to 'ground truth' the physiographic zones map, the datasets used were selected based on their origin, existing use for land management in Southland and for having suitable accuracy for regional-scale mapping. Most data sources utilised (e.g. soil and geological maps) have been field verified during their development to ensure their accuracy at the scale identified in their metadata.

Once preliminary mapping rules had been developed, they were reviewed by a group comprising:

- Environment Southland staff (including Land Sustainability Officers, Hazard Management, Environmental Scientists and experienced Senior Consent Officers);
- Consultants (including hydrogeologists, water quality specialists and soil scientists all with considerable experience and familiarity with Southland); and,
- Crown Research Institute Scientists (including AgResearch and GNS Science).

The objective of this review was to ensure the mapping rules, and corresponding spatial framework (i.e. the physiographic zone map) were consistent with the underlying conceptual model.

The mapping process included intersecting individual source layers with the physiographic zones to ensure delineation of the physiographic zones was faithful to the mapping criteria. This process assisted development of the ArcGIS definition queries listed in Appendix 2 and, in some cases, proved a useful means to identify discrepancies in the source data.

### 7.2.1 Sequential mapping

The final set of mapping rules in sequential order is outlined in Table 11. A sequential order to mapping the physiographic zones ensures land areas are assigned to the correct physiographic zone. Different arrangements of the sequence of mapping rules were considered, with the final mapping order being based on:

- the very high precipitation volumes associated with the Alpine zone is expected to overwhelm any other potential attenuation processes, hence it is the first zone to mapped;
- strongly reducing conditions in peat wetland areas results in highly distinct water quality and hydrochemistry, overwhelming the characteristics all remaining zones. Hence, the Peat Wetlands zone was the second to be mapped;
- the Lignite/Marine Terraces zone contains relatively homogenous geology comprising of sediments with high organic carbon (i.e. lignite, coal, marine terraces). It’s distinctiveness and high groundwater reduction potential resulted in this zone being mapped fourth;
- the Riverine zone and parts of the Bedrock/Hill Country zone receive alpine-sourced water, which dilutes water quality concentrations. The Riverine zone was mapped prior to the Bedrock/Hill Country zone because it is the receiving environment for all other physiographic zones. The Bedrock/Country zone was mapped after the Lignite/Marine Terraces zone because it has lower groundwater reduction potential;
- the Old Mataura zone has greater susceptibility to developing elevated nitrate levels due to its lower dilution (mixing) potential, hence this zone was mapped prior to the Oxidising zone, which shares similar attenuation processes;
- the Central Plains and Gleyed zones share similar soil descriptions; however, hydrology, hydrochemistry and water quality data identified a different drainage pathway in the Central Plains zone. Because it is anomalous, the Central Plains zone was mapped prior to the Gleyed zone; and,
- the Oxidising zone is heterogeneous and is found in a range of physical settings. As a result, this zone was mapped last.

Figure 46 shows the distribution of the physiographic zones across the entire Southland region including national parks (such as Fiordland and Rakiura National Parks) and other natural state areas (such as Department of Conservation reserves). Details of the ArcGIS definition queries utilised to generate the final map are listed in Appendix 2, with finer scale maps provided in Appendix 3.

*Table 11: Physiographic zone mapping rules*

| Physiographic zone | Mapping order | Mapping rule 1 | Mapping rule 2 |
|---|---|---|---|
| **Alpine** | 1 | DEM = Elevation > 800 m asl | |
| **Peat Wetlands** | 2 | Qmap – Main_Rock = "Peat" OR CSL = Order or Group = "Organic" | |
| **Lignite/Marine Terraces** | 3 | Qmap – Main_Rock or Sub_Rocks = any description of coal lignite or carbonaceous lithology OR = Map Unit = any description of marine terrace formation. Including areas in Eastern Southland delineated using bore logs stored on ES Wells database | |
| **Riverine** | 4 | CSL - NZSC Order, Group, series or class = Recent or Fluvial or similar description (i.e. "River Complex", "river"). | AND hydrologically connected to an alpine source (> 800 m asl, DEM, REC). |
| **Bedrock/Hill Country** | 5 | QMap – Main_Rock does NOT equal alluvium/colluvium, sand silt, gravel, peat, loess, or water. Till or moraine are included within the bedrock classification. | |
| **Old Mataura** | 6 | QMap - Strat Unit = Luggate; Shotover fmns; McI tce4 (Q6 - Q8 surface or eroded equivalent) within the Mid Mataura Catchment | AND CSL = Soils without redoximorphic signatures as defined by the oxidising layer. |
| **Central Plains** | 7 | QMap - Unit Code = Q2al within Central Plains area (defined by query specifying individual polygons). Not including Q2 alluvium associated with Q4 in the Hillend area. | AND CSL - Series = Gleyed soils with inferred mafic origin (Braxton, Makarewa, McLeish, Caroline. Also Pukemutu soils). |
| **Gleyed** | 8 | CSL - NZSC Order, Group or Subgroup = All Gley soils and all soils with redoximorphic features including (any description of mottling at group or subgroup level). Includes podzols and soils with "severe waterlogging" as specified in the CSL. | |
| **Oxidising** | 9 | CSL – All soils not classified as part of the Gleyed zone. | |

QMap = NZ Geology Map (GNS Science)
CSL = Combined Soil Layer (i.e. Topoclimate > Wallace County > LRI)
DEM = Digital Elevation Model
REC = River Environment Classification

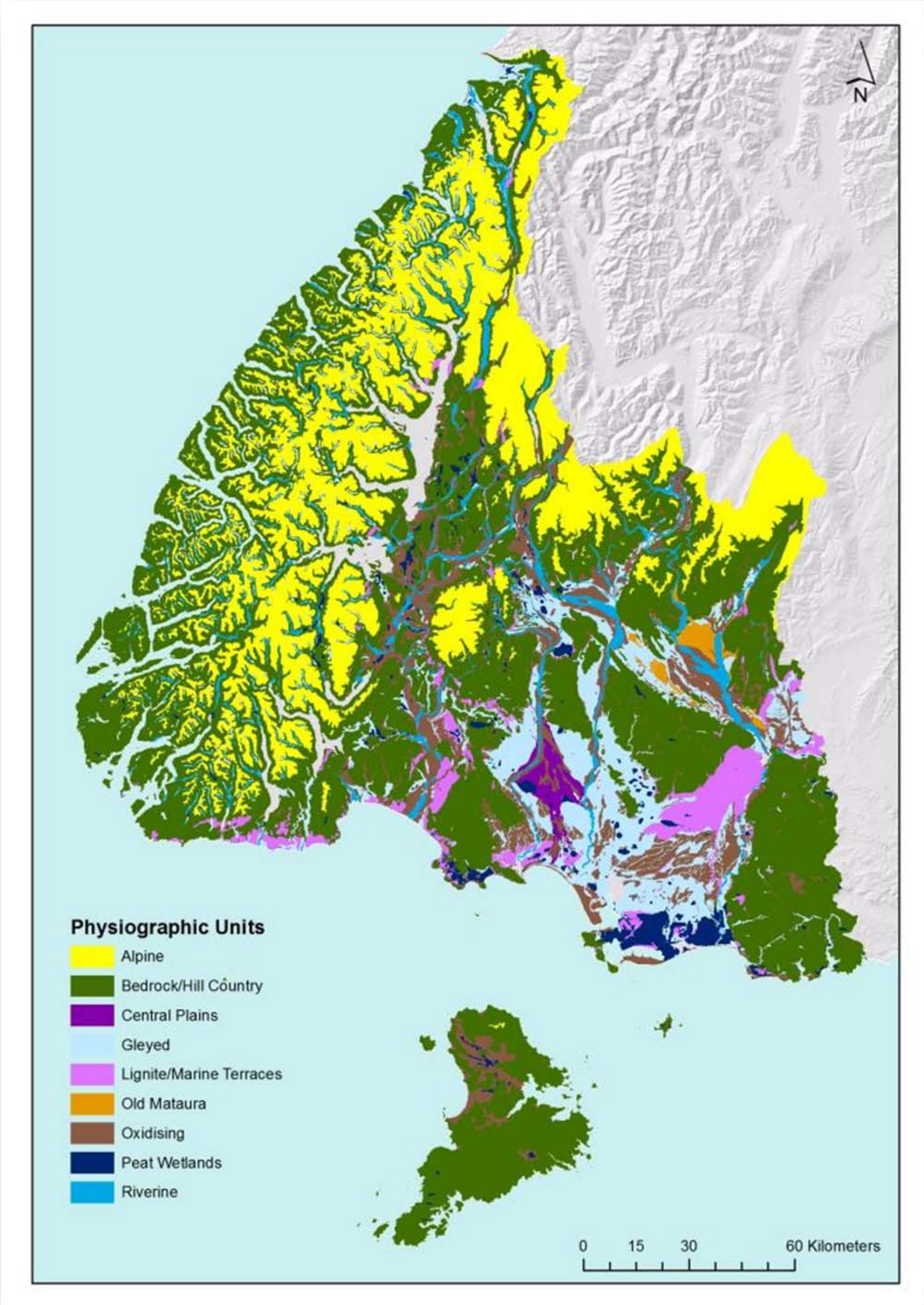



***Figure 46: Map of the physiographic zones of Southland.***

### 7.2.2 Refining the physiographic zone map

A physiographic zone map was publicly released in July 2015 via Environment Southland's Beacon website. The public was offered an opportunity to provide feedback on the map as part of Environment Southland's broader process for seeking feedback on a draft plan change.

Refinements to the mapping criteria resulted in changes to the mapped extent of some individual physiographic zones in the current version published May 2016 (shown in Figure 46). Overall, changes made to mapped areas between the respective map versions are relatively minor in extent and include:

- reclassification of areas with QMap geological descriptions (Main_Rock and Sub_Rock attributes) containing reference to coal, lignite or carbonaceous lithology with slopes exceeding $7^{o}$ from the Bedrock/Hill Country zone to the Lignite/Marine Terraces zone;
- addition of areas in Eastern Southland (Waimumu, Croydon, Pebbly Hills) where East Southland Group (Gore Lignite Measure) sediments occur at shallow depths (<15 m bgl) to the Lignite/Marine Terraces zone (based on geological information derived from the Environment Southland Wells database and available groundwater quality data);
- inclusion of Podzol soils in forested areas (mainly Fiordland) in the Gley zone;
- reclassification of Pallic soils overlying weathered alluvium in the mid-Mataura catchment from the Old Mataura zone to the Gleyed zone; and,
- amendments to the mapped area of the Riverine zone in Western Southland.

Additional details of the changes made to the mapping criteria and resulting amendments to physiographic zone areas between the respective map versions are provided in Appendix 1. It is noted that the mapping rules described in Sections 6.2.1 to 6.2.9 refer to the current map version (released May 2016).

## 7.3 Preliminary testing of the classes

The physiographic zones map was cross-checked with available water quality data to ensure general consistency with the characterisation of water quality risk described in Section 6.2. As an example, groundwater nitrate concentrations in the physiographic zones associated with elevated soil or geological (saturated zone) reduction potential were compared to those characterised as having oxic soils and geology, along with other redox-sensitive parameters less like to be influenced by land use, such as iron and manganese.

Similarly, median *E.coli* concentrations in surfaces waters draining physiographic zones or variants with a high artificial drainage density were compared to those where deep drainage was identified as a dominant drainage pathway. Within the constraints of the available data, these comparisons indicated that the physiographic zones represented distinct combinations of water quality risks consistent with the characterisation described in Section 6.2. Validation of the classification system is addressed further in the *Physiographic Zones for the Southland Region: Classification system validation and testing* report (Snelder *et al.,* 2016).

Analysis of available water quality data within each physiographic zone shows the proposed classes strongly reflect the key water quality controls. Figure 47 shows a box and whiskers plot of surface water electrical conductivity values the across the physiographic zones[20]. The figure shows clear differences in measured electrical conductivity values between individual zones, which are consistent with inferred effects associated with dilution potential. Similarly, as illustrated in Figure 48, groundwater nitrate concentrations show clear differences between individual classes consistent with the reduction potential associated with the individual classes. These figures illustrate that the rationale used to develop the classification system is broadly consistent with observed spatial differences in water quality across Southland.

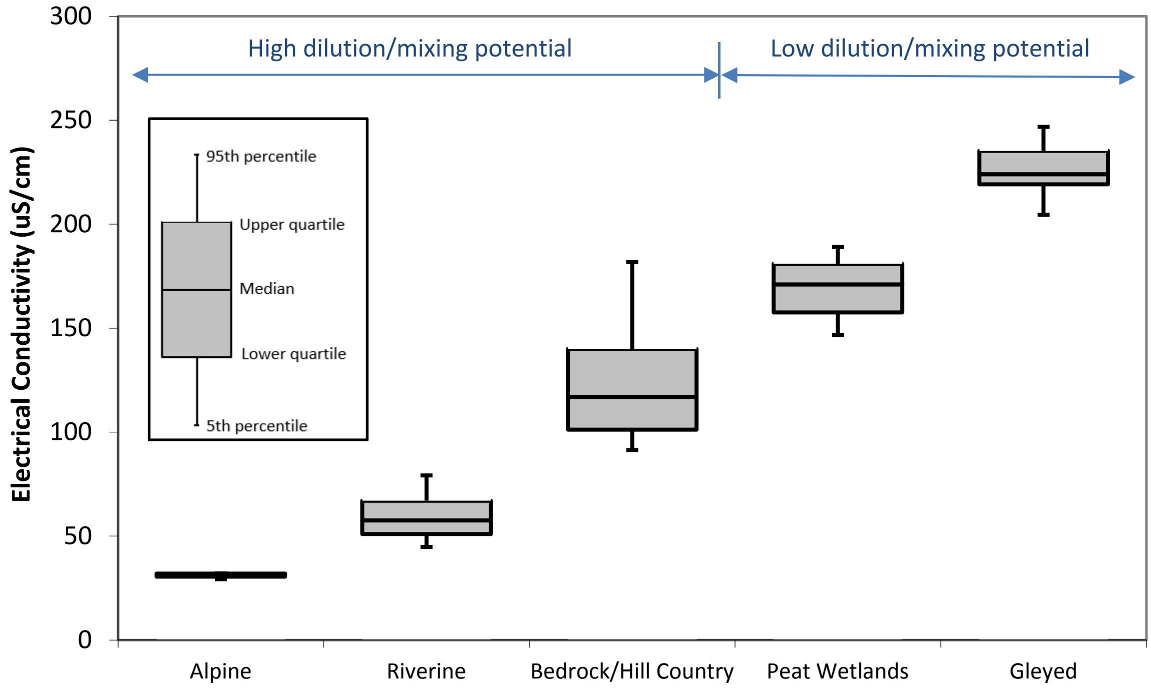



***Figure 47:*** ***Box and whisker plot of surface water site median electrical conductivity (EC) values for individual classes. Note: too few data were available for the Lignite/Marine Terraces, Oxidising and Old Mataura zones.***

[20] Electrical conductivity is a measure of the total concentration of dissolved ions in solution, it is assumed to be a suitable proxy for dilution potential.

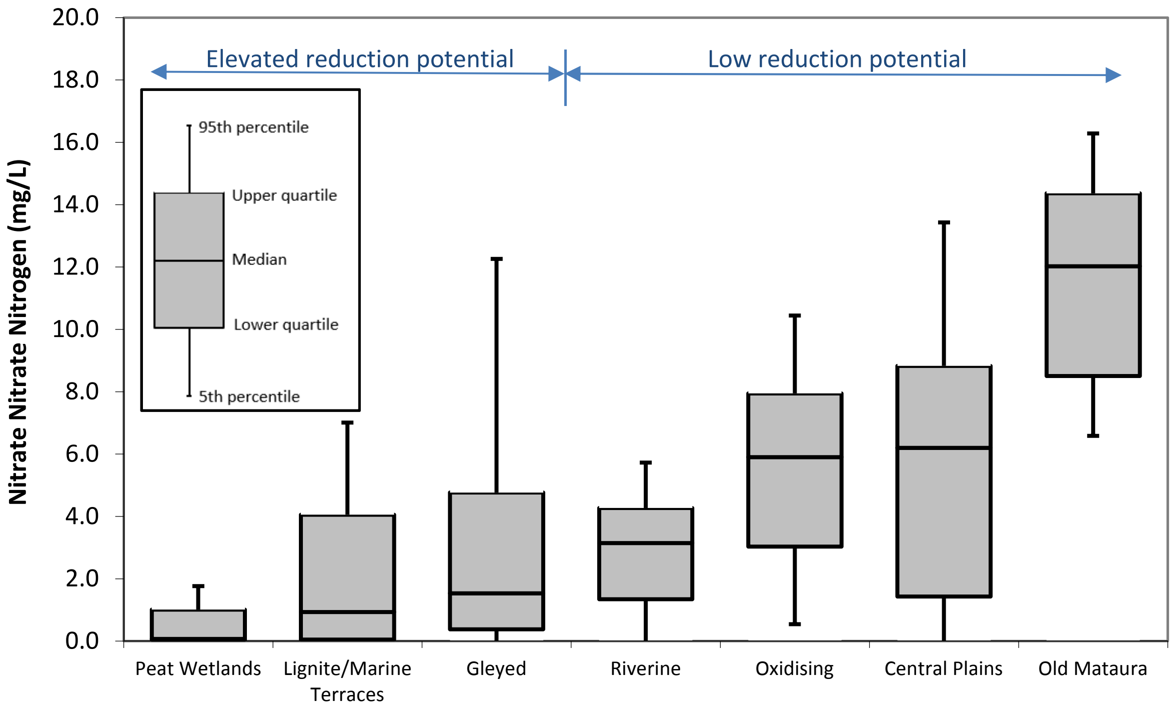



***Figure 48:*** ***Box and whisker plot of groundwater site median nitrate concentrations for individual classes. Note: too few data were available for the Alpine and Bedrock/Hill Country zones.***

# 8 Delineation of sub-classes (variants)

Within individual physiographic zones, there is variation in soils, topography, geology and climate. This variation results in increases water quality risk in some areas due to discharge via alternate drainage pathways when soils are wet. These areas are identified as *variants* and have been included in the classification system as sub-classes.

For example, in the Riverine zone, deep drainage represents the dominant drainage pathway and mode of contaminant transport. Due to filtration and sorption of contaminants in the soil and saturated zone, nitrate loss via deep drainage through soils and aquifers with a low reduction potential represents the primary water quality risk across the entire zone. However, at some locations within this zone, a combination of imperfectly drained soils and sloping topography increases the potential for drainage and contaminant losses to occur via overland flow when soils are wet. Thus, while deep drainage is the main contaminant pathway for the Riverine zone, in localised areas there is additional water quality risk associated with overland flow to surface water receiving environments. Such areas have been identified as an Overland Flow variant within the Riverine zone.

A simple hierarchical approach was used to distinguish the spatial extent of physiographic zone variants using the drainage pathways described in Section 3.4. Variants were assigned using the water quality classification conceptual model (Table 6), whereby:

- the base assumption is that where deep drainage or natural bypass flow is the dominant contaminant pathway, water quality risk can be temporally elevated in areas where there is an increased potential for artificial drainage or overland flow (i.e. pathways which are associated with reduced reduction potential and/or physical attenuation;
- where artificial drainage is the dominant contaminant pathway, water quality risk can be temporally elevated in areas where there is an increased potential for overland flow;
- where overland flow is the dominant contaminant pathway, drainage via alternative pathways (e.g. deep drainage, artificial drainage or lateral flow) does not significantly modify water quality risk so no variants are assigned; and,
- where lateral flow is the dominant contaminant pathway, there is generally also an elevated potential for overland flow. As overland flow is associated with higher water quality risks (due to the greater potential for mobilisation of contaminants), no variants are associated with lateral drainage.

The hierarchical process used to differentiate drainage pathways for the physiographic zones and variants is summarised in Table 12.

***Table 12:*** ***Key drainage pathways inferred for the physiographic zones and variants. Physiographic zone drainage pathways are identified by bold red text and variant pathways by blue italics.***

| Physiographic Zones | Overland flow | Artificial drainage | Lateral drainage | Deep drainage | Natural bypass flow |
|---|---|---|---|---|---|
| | *Drainage is event-driven or episodic. Surface water is the primary receiving environment.* | | | *Drainage is seasonal. Groundwater is the primary receiving environment.* | |
| **Alpine** | **Extensive due to slope, thin soils and high precipitation** | Minor | Extensive - attenuation reduces contaminant risk | Minor | Minor |
| **Bedrock/Hill Country** | *Occurs on rolling to steep topography* | *Occurs in developed areas prone to waterlogging (generally along the base of sloping topography)* | Extensive due to low permeability of subsoil and/or underlying geology – attenuation reduces contaminant risk | **Localised to fine-textured soils overlie more permeable aquifers** | Minor |
| **Central Plains** | Minor | **Extensive due to soils prone to waterlogging when wet** | Minor | Minor | **Extensive due to shrink/swell behaviour of soils** |

| | | | | | |
|---|---|---|---|---|---|
| **Gleyed** | *Localised to poorly or imperfectly drained soils on sloping land* | **Extensive due to waterlogging associated with poorly to imperfectly drained soils** | Minor | Minor | Minor |
| **Lignite/Marine Terraces** | *Localised to poorly drained soils on sloping land* | *Localised to developed areas with soils prone to waterlogging* | Minor | **Extensive due to soil and aquifer drainage properties** | Minor |
| **Old Mataura** | Minor | Minor | Minor | **Extensive due to flat topography and moderately well to well drained soils** | Minor |
| **Oxidising** | *Localised to areas where imperfectly drained soils occur on sloping land* | *Localised to developed areas with slow subsoil permeability* | Minor | **Extensive due to soil and aquifer drainage properties** | Minor |
| **Peat Wetlands** | Minor | **Occurs where land is developed to remove excess soil water** | **Occurs in fibrous peat** | **Extensive due to high (near surface) water table** | Minor |
| **Riverine** | *Localised to areas where moderately well drained soils occur on sloping land* | Minor | Minor | **Extensive due to soil and aquifer drainage properties on flat topography** | Minor |

## 8.1 Delineation process for variants

Physiographic zone variants were delineated using regional coverages of overland flow potential and artificial drainage density developed by Pearson (2015a and 2015b).

Section 3.4.1 describes the methodology used to derive a regional assessment of overland flow potential. An arbitrary threshold value of 6% of effective rainfall was used to identify areas having an elevated potential for overland flow to occur. This threshold was used as it excluded most flat-lying agricultural land across Southland, while encompassing most undulating to rolling land with moderate or poor soil drainage characteristics.

Section 3.4.3 describes the methodology used to derive a regional assessment of artificial drainage density. Areas with an elevated potential for artificial drainage were delineated based on the extent of the moderate to very high artificial drainage density classifications.

Areas that were identified as having elevated risk of both overland flow and artificial drainage were reclassified based on topography and soil type. Generally, polygons encompassing undulating to steep topography with imperfectly to poorly drained soils were assigned as having elevated overland flow potential while similar soil types on flat to undulating topography were assigned as having an elevated artificial drainage risk. Where larger polygons covered a range of slopes, they were reclassified and/or split to ensure consistency with the dominant topography or landscape position. Larger polygons were also manually checked to ensure the slope assigned represented a weighting consistent with local topographical features.

Following reclassification, the overland flow and artificial drainage coverages were intersected with the physiographic zones, and variants assigned to those zones where areas of elevated overland flow or artificial drainage risk represent either a significant spatial area (more than 20,000 hectares) or comprised a significant percentage of the total physiographic zone area (more than 15%). Based on these criteria:

- Artificial drainage variants were assigned to the Bedrock/Hill Country, Lignite/Marine Terraces and Oxidising physiographic zones; and,
- Overland flow variants were identified in the Bedrock/Hill Country, Gleyed, Lignite/Marine Terraces, Oxidising and Riverine zones.

As an example, of the application of variants, while deep drainage is identified as the primary drainage pathway influencing water quality risk across the Oxidising zone, flat-lying areas of this zone with slowly permeable subsoil have an elevated potential for artificial drainage to remove seasonal excess soil water (i.e. the Oxidising Artificial Drainage variant), while undulating to rolling areas commonly have an elevated potential for overland flow (i.e. the Oxidising Overland Flow variant). The delineation of variants allows the water quality risk in the Oxidising zone primarily associated with deep drainage to be differentiated from areas where can be temporally modified due to the water quality risks associated with other drainage pathways.

It is noted that no variants were assigned to the Alpine, Central Plains, Old Mataura and Peat Wetlands physiographic zones as the drainage pathways are relatively uniform across the entire zone regardless of temporal soil moisture variability.

In the case of the Bedrock/Hill Country zone, the most extensive contaminant pathway is overland flow with an elevated overland flow potential identified for 86% of the total zone area. However, because the aim of the risk assessment is to inform identification of appropriate land management mitigations for management of water quality, the hierarchy outlined in the preceding section was used to determine variants. Thus, although only identified as a minor drainage pathway at a zone-scale, due to its differing land management mitigations across a relatively extensive area (approximately 184,000 Ha), deep drainage was adopted as the primary contaminant pathway for the Bedrock/Hill Country zone, with areas exhibiting elevated potential for overland flow or artificial drainage delineated as variants (cumulatively totalling approximately 88% of the total zone area).

Figure 49 illustrates shows the geographic distribution of variants and their spatial extent (Appendix 3 contains more detailed maps).

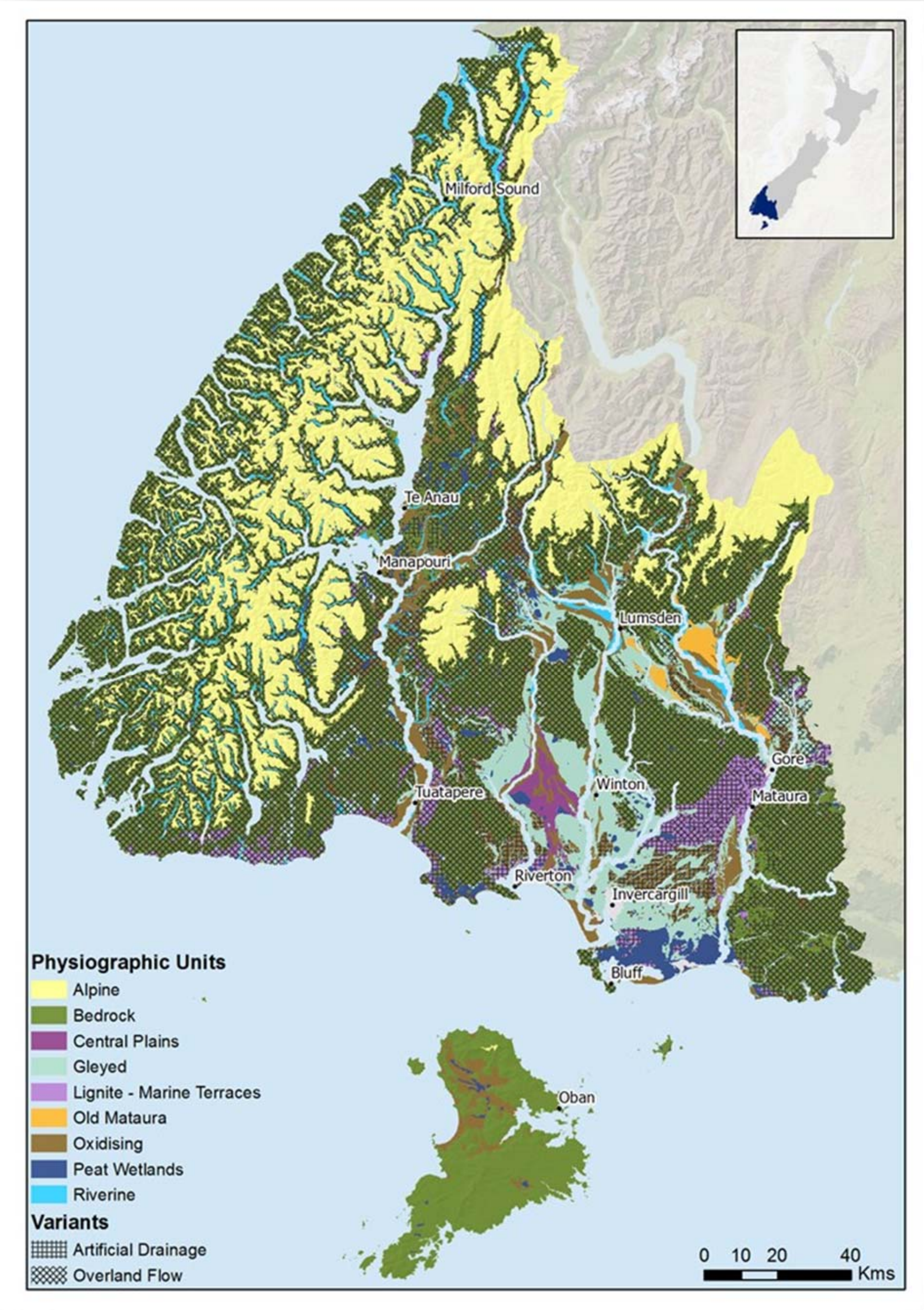



***Figure 49: Map of the physiographic zone variants.***

# 9 Water quality risk

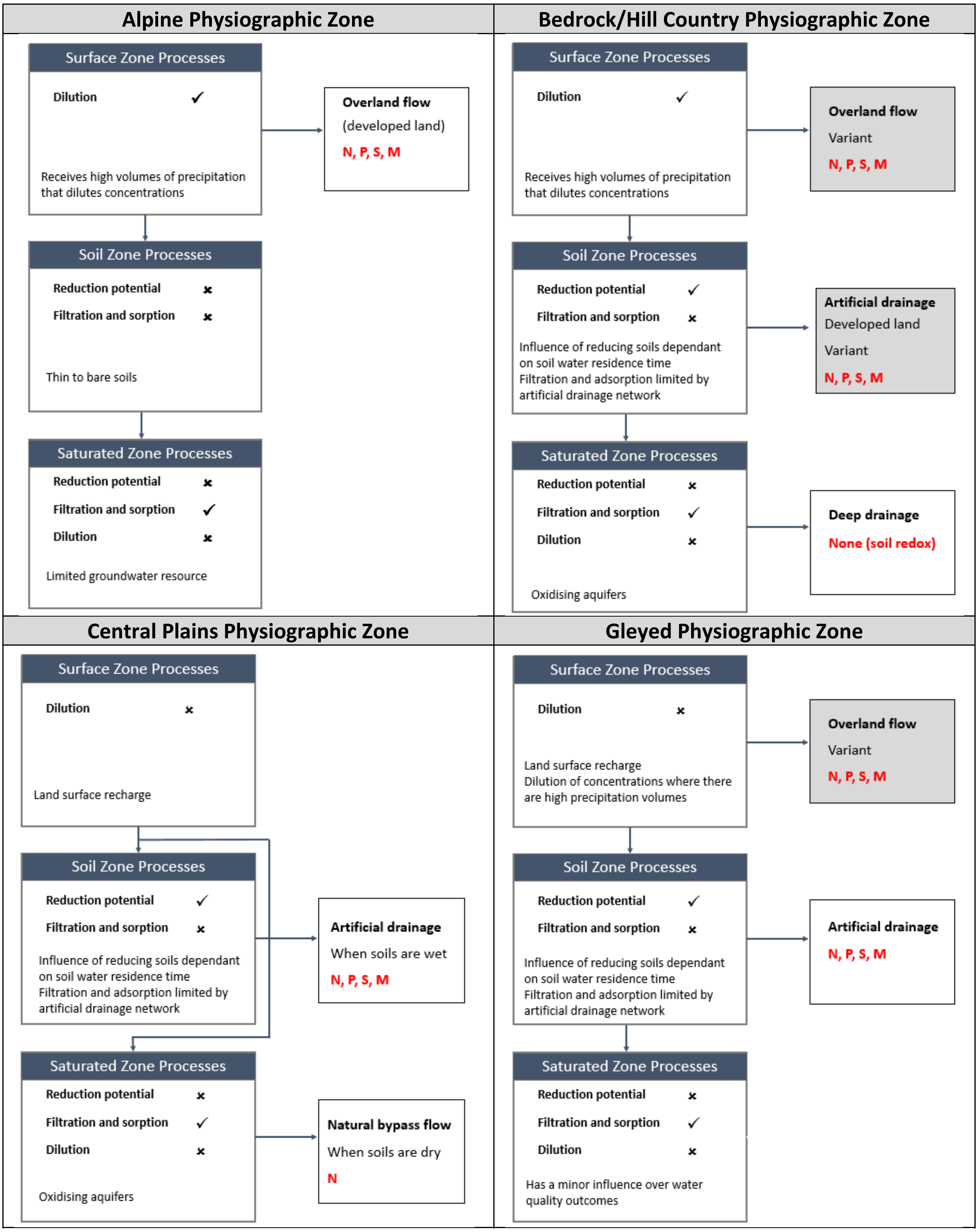
Assignment of water quality risk for nitrogen, phosphorus, sediment and microbial contamination utilised an assessment of the potential for attenuation or dilution processes to occur along different drainage pathways occurring within each physiographic zone and variant. A simple binary risk category of either ‘high’ or ‘low’ risk was used, for policy purposes. The resulting water quality risk assessment is summarised in Figure 50.

Under certain conditions (e.g. extreme precipitation), overland flow can occur at virtually any point in the region. While this creates a potential pathway for contaminant export, water quality risk was assessed using ‘typical’ climate conditions, as outlined in Section 4.

Assessment of water quality risk involved intersecting the spatial coverage of the physiographic zones and variants with the assessments of dilution potential, reduction potential, filtration and sorption and drainage pathways described in Section 3. This process allowed the dominant contaminant pathways and associated water quality risks to be identified, as illustrated in Table 13.

The contaminant transport pathways assigned to each physiographic zone do not always reflect the contribution of individual drainage pathways to the overall zone water balance. Rather, they identify pathways that have the greatest potential to be associated with contaminant losses. For example, although lateral drainage may be an important drainage pathway in the Bedrock/Hill Country zone, physical attenuation and denitrification associated with soils in this zone reduce its significance as a contaminant transport pathway.

*Figure 50: Summary of water quality risk for each physiographic zone (class) and variant (sub-class) using the classification system conceptual model. Water quality risk for the variants are in shaded boxes. Contaminants of concern for each zone and variant are in red.*




Lignite/Marine Terraces Physiographic Zone
Surface Zone Processes
Dilution ×
Land surface recharge
Dilution of concentrations where there are high precipitation volumes
Overland flow
Variant
N, P, S, M
Soil Zone Processes
Reduction potential ×
Filtration and sorption ×
Oxidising soils
Filtration and adsorption limited by artificial drainage network
Artificial drainage
Variant
N, P, S, M
Saturated Zone Processes
Reduction potential ✓
Filtration and sorption ✓
Dilution ×
Reducing aquifers due to high organic carbon content
Deep drainage
None (aquifer redox)
Old Mataura Physiographic Zone
Surface Zone Processes
Dilution ×
Land surface recharge
Soil Zone Processes
Reduction potential ×
Filtration and sorption ✓
Oxidising (well-drained) soils
Saturated Zone Processes
Reduction potential ×
Filtration and sorption ✓
Dilution ×
Oxidising aquifers
Low groundwater mixing rates
Deep drainage
N
Oxidising Physiographic Zone
Surface Zone Processes
Dilution ×
Land surface recharge
Dilution of concentrations where there are high precipitation volumes
Overland flow
Variant
N, P, S, M
Soil Zone Processes
Reduction potential ×
Filtration and sorption ✓
Oxidising (well-drained) soils
Filtration and sorption limited by artificial drainage network
Artificial drainage
Variant
N, P, S, M
Saturated Zone Processes
Reduction potential ×
Filtration and sorption ✓
Dilution ×
Oxidising aquifers
Deep drainage
N
Peat Wetlands Physiographic Zone
Surface Zone Processes
Dilution ×
Land surface recharge
Soil Zone Processes
Reduction potential ✓
Filtration and sorption ×
Strongly reducing, acidic soils with low P-retention
Fibrous peat has limited filtration and adsorption ability
Artificial drainage
(developed land)
N, P, S, M
Lateral drainage
P, M
Saturated Zone Processes
Reduction potential ✓
Filtration and sorption ✓
Dilution ×
Strongly reducing aquifers
Deep drainage
P

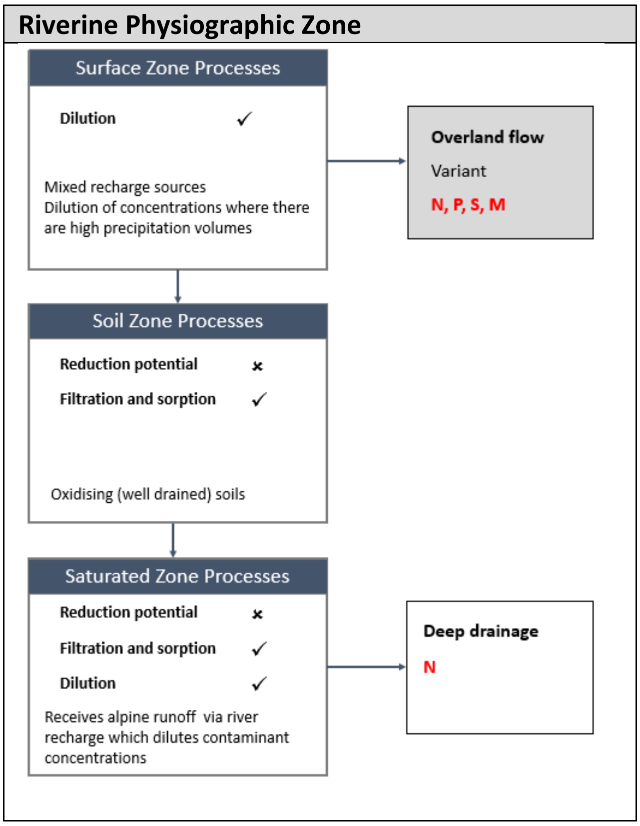

Riverine Physiographic Zone
Surface Zone Processes
Dilution ✓
Mixed recharge sources
Dilution of concentrations where there are high precipitation volumes
Overland flow
Variant
N, P, S, M
Soil Zone Processes
Reduction potential ×
Filtration and sorption ✓
Oxidising (well drained) soils
Saturated Zone Processes
Reduction potential ×
Filtration and sorption ✓
Dilution ✓
Receives alpine runoff via river recharge which dilutes contaminant concentrations
Deep drainage
N

***Table 13: Summary of key processes influencing water quality risk for the classification system. Contaminants considered are nitrogen (N), phosphorus (P), sediment (S) and microbes (M).***

| Physiographic zone and variant | Dilution | Reduction potential | Filtration and sorption | Contaminant pathway(s) | Contaminants |
|---|---|---|---|---|---|
| **Alpine** | - Receives high volumes of precipitation that dilutes concentrations | - Low in soils and aquifers | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |
| **Bedrock/Hill Country** | - Receives high volumes of precipitation that dilutes concentrations | - High in soils (N) and low in aquifers | - Removes virtually all particulate and microbial contaminants (P, S, M) | - Deep drainage | - None (due to attenuation in the soil zone) |
| *Overland flow variant* | - Receives high volumes of precipitation that dilutes concentrations | - High in soils depending on drainage residence time and low in aquifers | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |
| *Artificial drainage variant* | - Receives high volumes of precipitation that dilutes concentrations | | - Limited filtration, sorption occurring in water moving through the soil matrix | - Artificial drainage (where land is developed) | - N, P, S, M |
| **Central Plains** | - Limited dilution potential | - High in soils depending on drainage residence time and low in aquifers | - Limited filtration, sorption occurring in water moving through the soil matrix | - Artificial drainage<br>- Natural bypass flow | - N, P, S, M |
| **Gleyed** | - Limited dilution potential | - High in soils depending on drainage residence time and low in aquifers | - Limited filtration, sorption occurring in water moving through the soil matrix | - Artificial drainage | - N, P, S, M |
| *Overland flow variant* | - Dilution of contaminant concentrations may occur where there are higher precipitation volumes | | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |
| **Lignite/Marine Terraces** | - Limited dilution potential | - Low to moderate in soils and high in aquifers (N) | - Removes virtually all particulate and microbial contaminants (P, S, M) | - Deep drainage | - None (due to attenuation in the saturated zone) |
| *Overland flow variant* | - Dilution of contaminant concentrations may occur where there are higher precipitation volumes | - High in soils depending on drainage residence time and low in aquifers | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |
| *Artificial drainage variant* | | | - Limited filtration, sorption occurring in water moving through the soil matrix | - Artificial drainage | - N, P, S, M |

| Physiographic zone and variant | Dilution | Reduction potential | Filtration and sorption | Contaminant pathway(s) | Contaminants |
|---|---|---|---|---|---|
| **Old Mataura** | - Limited dilution potential | - Low in soils and aquifers | - Removes virtually all particulate and microbial contaminants (P, S, M) | - Deep drainage | - N |
| **Oxidising** | - Limited dilution potential<br>- Higher mixing (dispersion) potential relative to the Old Mataura zone | - Low in soils and aquifers | - Removes virtually all particulate and microbial contaminants (P, S, M) | - Deep drainage | - N |
| *Overland flow variant* | - Dilution of contaminant concentrations may occur where there are higher precipitation volumes | | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |
| *Artificial drainage variant* | | | - Limited filtration, sorption occurring in water moving through the soil matrix | - Artificial drainage | - N, P, S, M |
| **Peat Wetlands** | - Limited dilution potential | - High in soils and aquifers (N) | - Limited filtration, sorption occurring in water moving through the soil matrix (S) | - Lateral flow through the soil matrix where shallow fibrous peat overlies finer-grained lower permeability sediments<br>- Artificial drainage in developed areas<br>- Deep drainage | - P, M |
| **Riverine** | - Receives high volumes of alpine runoff that dilutes concentrations | - Low in soils and aquifers | - Removes virtually all particulate and microbial contaminants (P, S, M) | - Deep drainage | - N |
| *Overland flow variant* | | | - Little opportunity for filtration and sorption to occur | - Overland flow | - N, P, S, M |

The classification system was developed for the proposed Southland Water and Land Plan (Environment Southland, 2016) as a tool for improving the effects of land use on water quality outcomes within the region. To support policy development, a simple binary risk category (i.e. 'high' or 'low' risk) was evaluated for each physiographic zone and variant using the assessment summarised in **Error! Reference source not found.**Table 13. The resulting water quality risk table shown in Table 14, is included in the proposed Southland Water and Land Plan.

***Table 14: Water quality risk assessment for nitrogen (N), phosphorus (P), sediment (S) and microbes (M). Note that the water quality risk associated with variants are in addition the risk assigned to the relevant physiographic zone.***

| **Physiographic Zone** | **Variant** | ***Key contaminant pathways and contaminants*** | | | | ***Water Quality Risk*** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Overland flow** | **Artificial drainage** | **Lateral drainage** | **Deep drainage** | **Nitrogen** | **Phosphorus** | **Sediment** | **Microbes** |
| **Alpine** | | N,P,S,M | | | | High | High | High | High |
| **Bedrock/Hill Country** | | | | | N | Low* | Low | Low | Low |
| | Overland Flow | N,P,S,M | | | | High | High | High | High |
| | Artificial Drainage | | N,P,S,M | | | High | High | High | High |
| **Central Plains** | | | N,P,S,M | | N | High | High | High | High |
| **Gleyed** | | | N,P,S,M | | | High | High | High | High |
| | Overland Flow | N,P,S,M | | | | High | High | High | High |
| **Lignite-Marine Terraces** | | | | | N | Low* | Low | Low | Low |
| | Overland Flow | N,P,S,M | | | | High | High | High | High |
| | Artificial Drainage | | N,P,S,M | | | High | High | High | High |
| **Old Mataura** | | | | | N | High | Low | Low | Low |
| **Oxidising** | | | | | N | High | Low | Low | Low |
| | Overland Flow | N,P,S,M | | | N | High | High | High | High |
| | Artificial Drainage | | N,P,S,M | | N | High | High | High | High |
| **Peat Wetlands** | | | N,P,S,M | P, M | P | High | High | High | High |
| **Riverine** | | | | | N | High | Low | Low | Low |
| | Overland Flow | N,P,S,M | | | N | High | High | High | High |

*Low risk due to high reduction potential (i.e. denitrification likely to occur)

Mitigation measures that may reduce the effects of land use on water quality were developed for the physiographic zones and variants. These are documented in the *Management practices and mitigation options for reducing contaminant losses from land to water* report (Monaghan, 2016).

A summary of the mitigation aims associated with different contaminant pathways is provided in Table 15. Specific mitigation measures for improving nutrient and effluent management, capturing or attenuating nutrients, targeting critical sources of contaminant losses and reducing the accumulation of surplus nutrients in the soils (particularly nitrogen during autumn and winter), are included in Monaghan (2016) along with fact sheets developed by Environment Southland[21].

***Table 15: Mitigation aims associated with contaminant pathways***

| Contaminant pathway | Contaminants | Mitigation aims |
|---|---|---|
| Good practices that apply everywhere | | ➢ Capture sediment and microbes in wetlands and sediment traps<br>➢ Nutrient management<br>➢ Riparian management<br>➢ Effluent management |
| Overland flow | N, P, S, M | ➢ Protect soil structure, particularly in gullies and near-stream areas<br>➢ Manage critical source areas<br>➢ Reduce P use or loss |
| Artificial drainage | N, P, S, M | ➢ Protect soil structure, particularly in gullies and near stream areas<br>➢ Reduce P use or loss<br>➢ Reduce the accumulation of surplus N in soils particularly during autumn and winter<br>➢ Avoid preferential flow of effluent through drains<br>➢ Capture contaminants at drainage outflows |
| Lateral drainage | P, M | ➢ Ensure soil P fertility matches expected production levels<br>➢ Capture contaminants leaving the property via seepage zones |
| Deep drainage | N | ➢ Reduce the accumulation of surplus N in soils particularly during autumn and winter<br>➢ In some settings, permeable reactive barriers may reduce N loss<br>➢ Biosimulation (enhanced denitrification) may facilitate attenuation of N |
| Deep drainage and lateral drainage | P, M | ➢ Reduce P use or loss<br>➢ Reduce transport of microbes |

[21] www.es.govt.nz/document-library/factsheets/Pages/Good-management-practice.aspx

# Abbreviations

| | |
|---|---|
| **Al** | Aluminium |
| **asl** | above sea level |
| **CSL** | Combined soil layer |
| **DEM** | Digital Elevation Model |
| **DRP** | Dissolved reactive phosphorus |
| **EC** | Electrical conductivity |
| ***E.coli*** | *Escherichia coli* |
| **Fe** | Iron |
| **Ha** | Hectares |
| **LCDB** | Land Cover Database |
| **LRI** | Land Resource Inventory |
| **m** | Metres |
| **mm** | Millimetres |
| **Mn** | Manganese |
| **N** | Nitrogen |
| **$NO_3$** | Nitrate |
| **NPS-FM** | National Policy Statement for Freshwater Management, 2014 |
| **M** | Microbes |
| **P** | Phosphorus |
| **$PO_4$** | Phosphate |
| **QMap** | New Zealand Geological Map |
| **S** | Sediment |
| **SoE** | State of the Environment |
| **$SO_4$** | Sulphate |
| **SS** | Suspended sediment |
| **RMA** | Resource Management Act, 1991 |
| **WAL2020** | Water and Land 2020 & Beyond |

# Glossary

**Artificial drainage**
Engineered structures forming a network of subsurface and/or surface drainage channels designed to remove excess water from the land surface and/or soil matrix.

**Attenuation**
A reduction in the concentration and/or load of particulate or dissolved contaminants as it moves through or over the environment, associated with removal of contaminants by physical (e.g. filtration) or biogeochemical (e.g. denitrification) processes.

**Baseflow**
The portion of flow in a surface waterway derived from the inflow of groundwater. The proportion of total discharge derived from baseflow increases during periods of low rainfall.

**Biogeochemical**
Chemical, physical, geological and biological processes and reactions that govern the composition of the natural waters.

**Contaminant pathway**
The route followed by a specific contaminant from its point of origin to a downstream receiving environment.

**Deep drainage**
Movement of water from the land surface through the underlying unsaturated and saturated zone.

**Denitrification**
Microbially facilitated process of nitrate reduction (performed by a large group of heterotrophic facultative anaerobic bacteria) that ultimately produces molecular nitrogen ($N_2$) through a series of intermediate gaseous nitrogen oxide products. Denitrification forms part of the biological nitrogen cycle.

**Dilution**
The process of decreasing the concentration of a solute (i.e. a particular chemical ion or molecule) in solution.

**Drainage pathway**
The specific path water flows over (surface) or through (subsurface) land to a surface water receiving environment.

**Field capacity**
The moisture content of a soil where the addition of further water will result in saturation or vertical drainage of water from the soil.

**Hydrochemistry**
A measure of the chemical composition of water, which results from chemical, physical and biological processes occurring in the surrounding environment.

**Isotopes**

Isotopes are different forms of a specific chemical element that exhibit identical chemical properties but which contain differing numbers of neutrons in the atomic nucleus (and hence exhibit differing atomic weights). Stable isotopes of a particular element may occur in differing ratios in different physical (e.g. pressure, temperature) or chemical environments and can be used to identify the origin of chemical compounds with different isotopic ratios.

**Land surface recharge**

Water originating from percolation of local precipitation through the soil profile to the underlying saturated zone.

**Lateral flow (or interflow)**

Water flowing laterally through the soil zone due to impeded vertical drainage.

**Matrix flow**

Movement of water via pore spaces in the soil matrix.

**Natural bypass (macropore) flow**

Vertical drainage through the soil zone via cracks or discontinuities (e.g. plant roots or earthworm casts) within the soil matrix. This form of drainage is particularly prevalent in soils containing a high percentage of clay minerals that exhibit shrink/swell behavior.

**Overland flow**

Overland flow is water that flows horizontally across the land surface after rainfall (or snow melt) of sufficient intensity to exceed soil infiltration capacity.

**Oxic**

A process or environment in which oxygen is involved or present.

**Physiographic zones**

Physiographic zones represent the spatial extent of individual classes in the proposed water quality classification. Physiographic zones represent areas with consistent, similar inherent environmental variables, where comparable (long-term median) water quality outcomes are likely to occur.

**Piston flow**

Uniform migration of water through the soil matrix with limited mixing, which results in water in consecutive layers being successively displaced downwards.

**Quickflow**

The component of rainfall that moves rapidly to the surface drainage network via overland flow or shallow subsurface flow. Quickflow is reflected in the rapid increase in discharge following rainfall.

**Redox (reduction–oxidation reaction)**

Redox reactions are biogeochemical processes that involve the transfer of electrons between two chemical species. In natural waters and soils, redox reactions are largely driven (catalysed) by bacteria, which gain energy by facilitating the transfer of electrons from organic matter to an electron acceptor. This process results in the breakdown of organic matter into its constituent elements (carbon, oxygen, nitrogen, phosphorus and some minor trace elements), the consumption of the electron acceptor, and a net energy release for the micro-organism.

**Redoximorphic**
Redoximorphic features are colour patterns (e.g. mottles) in a soil formed by the oxidisation/reduction of iron and/or manganese and associated removal, translocation or accrual of these elements in the soil matrix.

**Reduction potential**
Reduction potential describes the potential for redox reactions to occur. Although this could be considered a nutrient source control, for the purposes of this report reduction potential has been treated as an attenuation process.

**Saturated zone**
The volume of a geological material below the water table where pore spaces or voids between individual rock or soil particles are filled with water.

**Soil zone**
The zone of biologically active and altered geological material that extends across the land surface extending downward to the mineral rock material (parent material) from which the soil has developed.

**Sorption**
Refers to both adsorption, which is the accumulation of a substance at the surface of a solid or liquid, and absorption, which is the incorporation of a substance in one state into another of a different state such as a liquid being adsorbed by a solid. Desorption is the reverse process of sorption.

**Surface zone**
Areas on or above the land surface, across which water may move in response to precipitation. Characteristics of the surface zone reflect topography (slope) and vegetative cover as well as the physical and hydraulic properties of the rock or soil materials at the land surface.

**Throughflow**
Lateral and horizontal movement of groundwater through geological materials comprising the saturated zone (aquifer).

**Variants**
Localised areas within individual physiographic zones where temporal variations in contaminant pathways modify water quality risk from that occurring across the wider zone.

**Water quality**
A measure of the condition of water relative to ecological or human requirements. In this report, the key water quality variables of concern are nitrogen, phosphorus, sediment and microbes.

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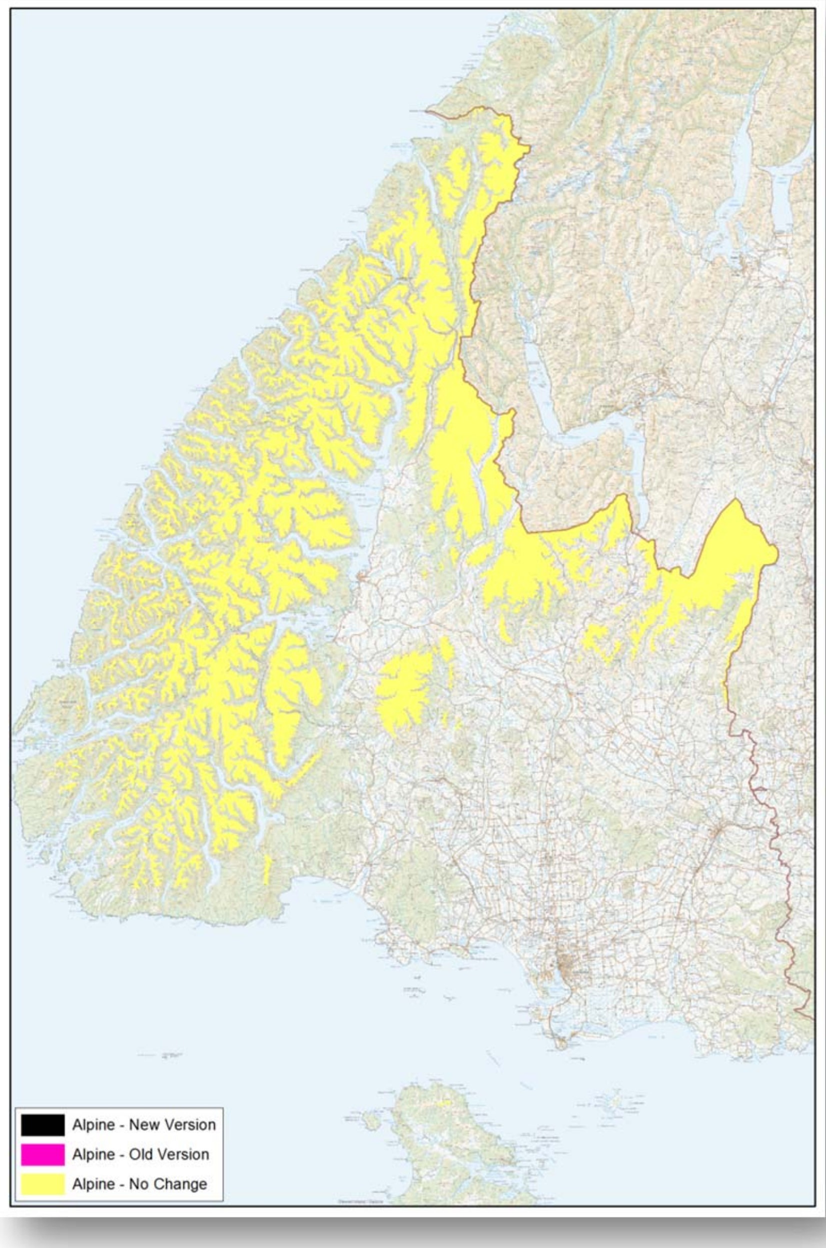
# Appendices

## Appendix 1 – Amendments to physiographic zone map

The following section provides details and rationale for changes to the physiographic zone map between that published with the WAL2020 Discussion Document (Version 1.0) and May 2016 (Version 2.0)

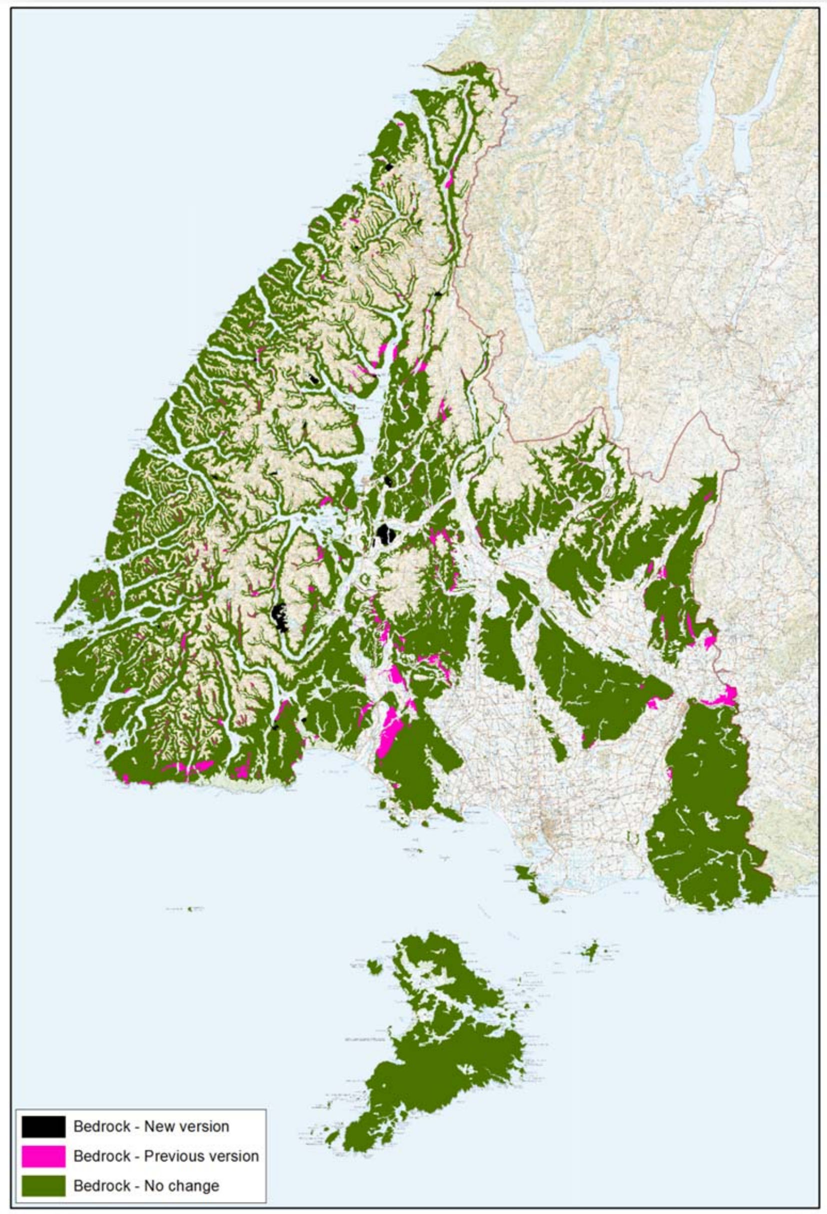
**Alpine**

No change to original mapped extent.



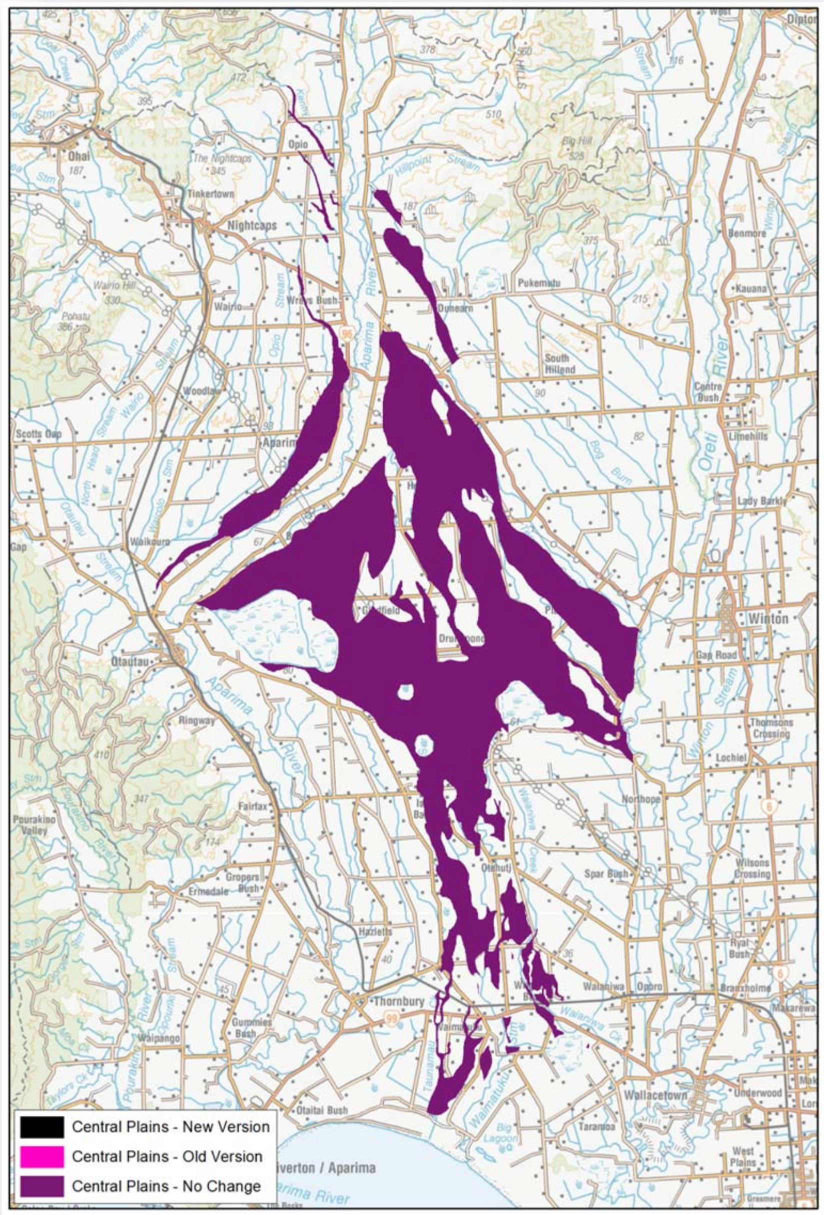
**Bedrock/Hill Country**

Changes to the Bedrock/Hill Country zone primarily reflect the reclassification of areas where QMap (MAIN_ROCK or SUB_ROCK) attributes contain reference to coal, lignite or carbonaceous lithology and slope exceeds 7$^{o}$ (calculated from the DEM) to the Lignite/Marine Terraces zone.



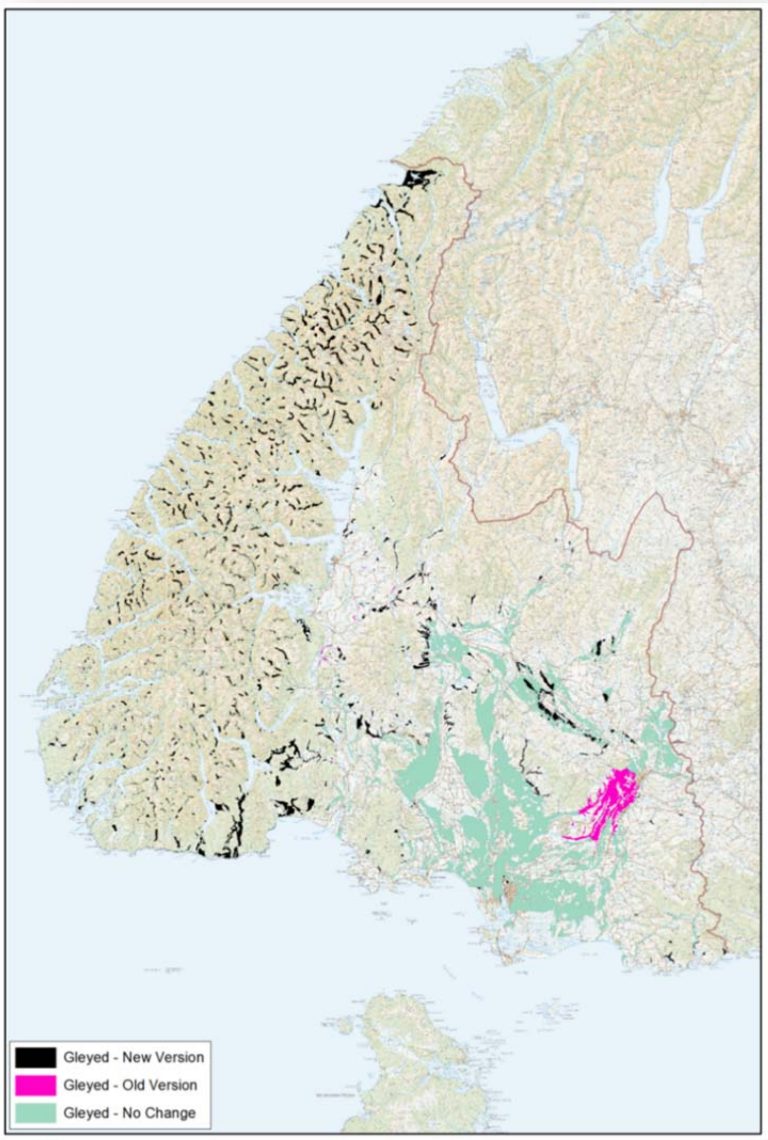
**Central Plains**

No change to the original mapped extent



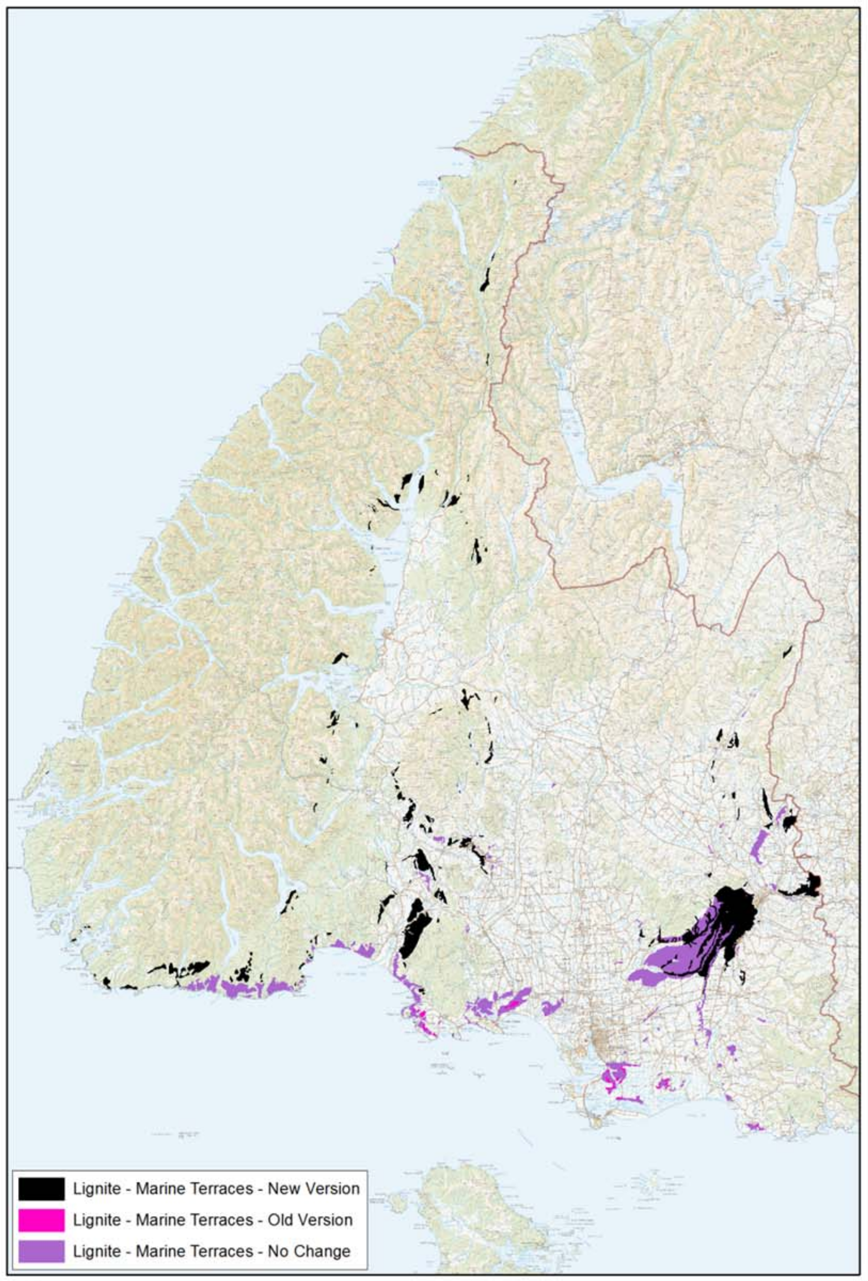
**Gleyed**

- Reclassification of portions of the Gleyed zone in the Waimumu/Croydon/Pebbly Hills areas to the Lignite/Marine Terraces zone based on the presence of East Southland Group sediments within 15m of the land surface (indicative of high redox potential in the saturated zone) and low groundwater nitrate concentrations (typically <2 mg/L);
- Inclusion of Pallic Soils overlying alluvial terraces comprising Luggate and Shotover Formations in the mid-Mataura catchments in the Gleyed zone (formerly mapped as part of the Old Mataura zone). This change reflects the imperfect to poor internal drainage of these soils (and associated denitrification potential) which are more like those of the Gley zone rather than the well-drained, oxic soils found elsewhere in the Old Mataura zone.
- Reclassification of Podzol soils in the LRI soil coverage (mainly in forested areas of Fiordland) from the Oxidising zone to reflect their relatively poor internal drainage.



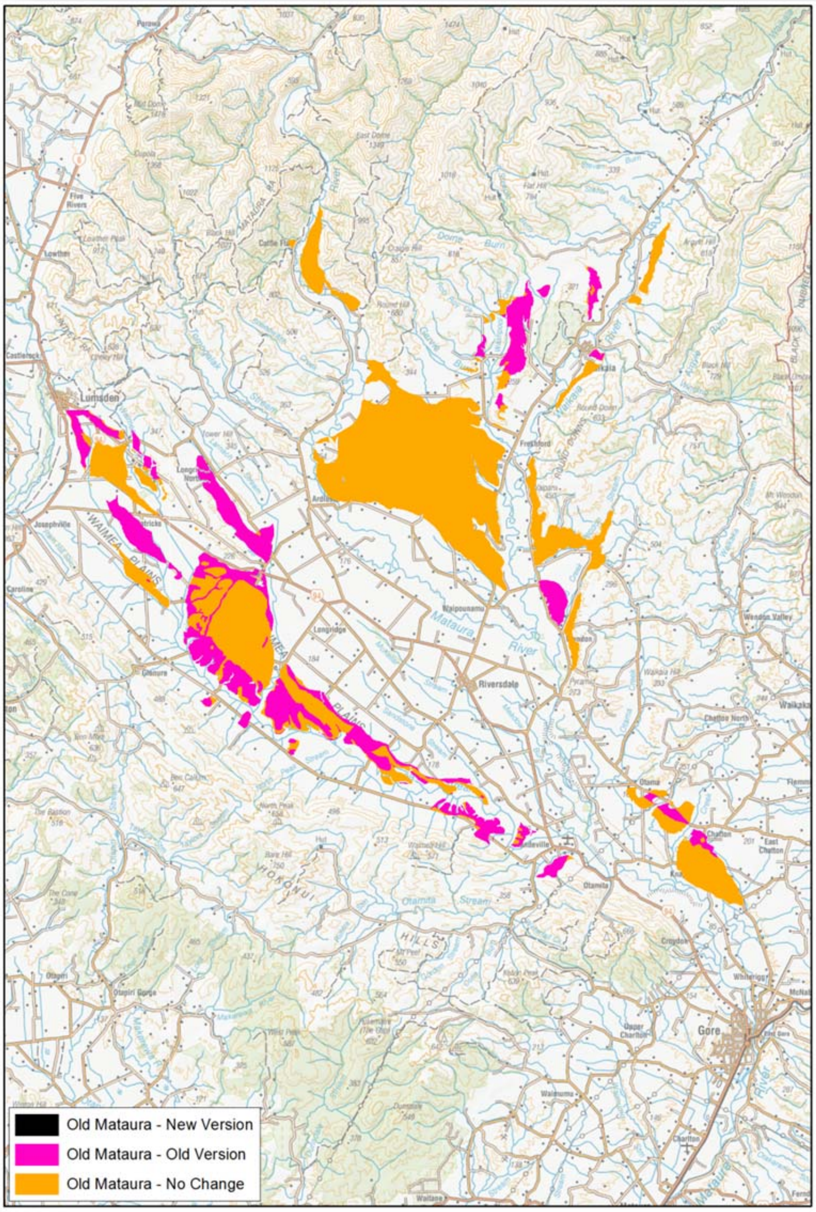
**Lignite/Marine Terraces**

- Areas of the Bedrock/Hill Country zone (previously the Bedrock/Hill Country variant) containing reference to coal, lignite or carbonaceous geology (QMap MAIN_ROCK or SUB_ROCK attribute) with slopes exceeding 7$^{o}$ reclassified to the Lignite/Marine Terraces zone;
- Portions of the Gleyed zone in the Waimumu/Croydon/Pebbly Hills areas were reclassified in the Lignite/Marine Terraces zone based on the presence of East Southland Group sediments within 15m of the land surface (indicative of high redox potential in the saturated zone). This change was made based on geological logs held on the Environment Southland Wells database and cross checked against available water quality data to confirm high redox potential in the saturated zone (i.e. indicated by low to very low nitrate).



**Old Mataura**

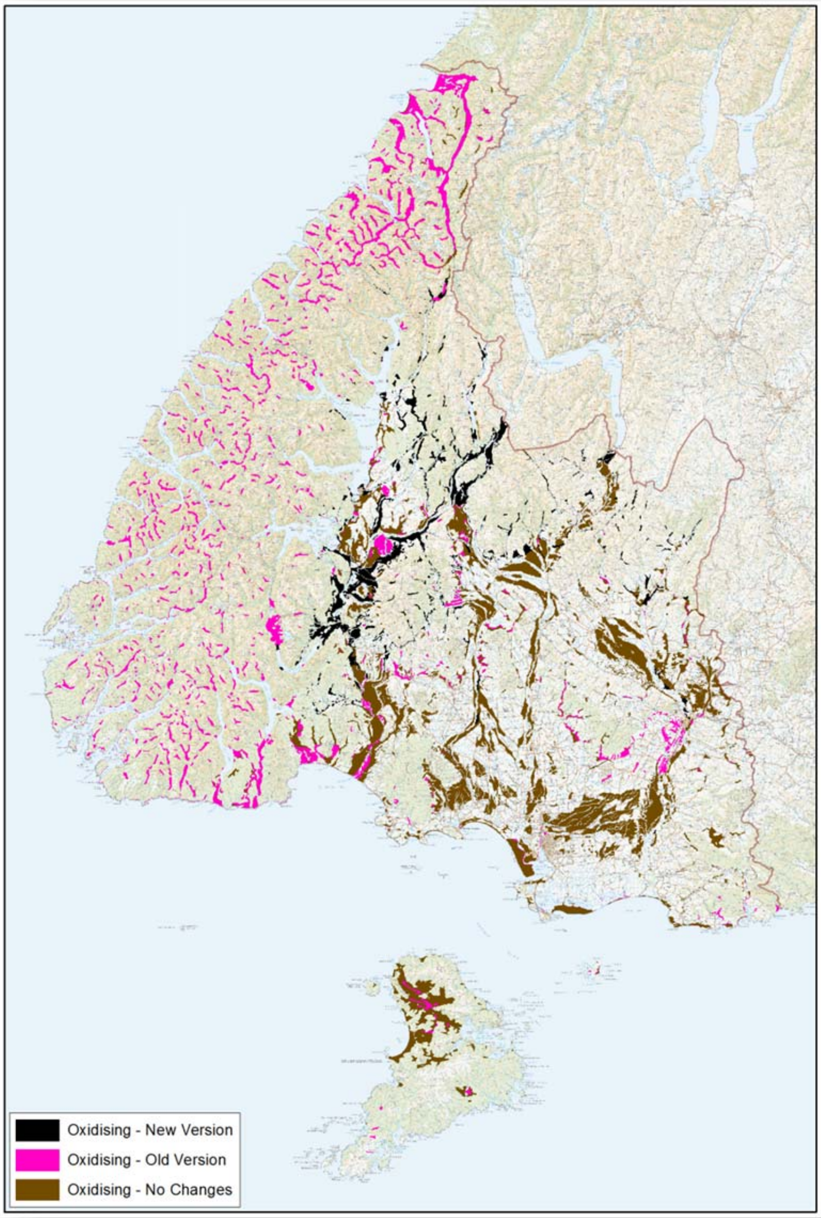
- Areas of Pallic soils included in the Old Mataura zone reclassified to the Gleyed zone, which better reflects the imperfect to poor internal drainage of these soils (and associated denitrification potential) compared to the moderately well to well drained, oxic soils found elsewhere in the Old Mataura zone.



**Oxidising**

- Areas of Podzol soils in forested parts of Fiordland were classified to the Gleyed zone to better reflect the poor internal drainage of these soils;

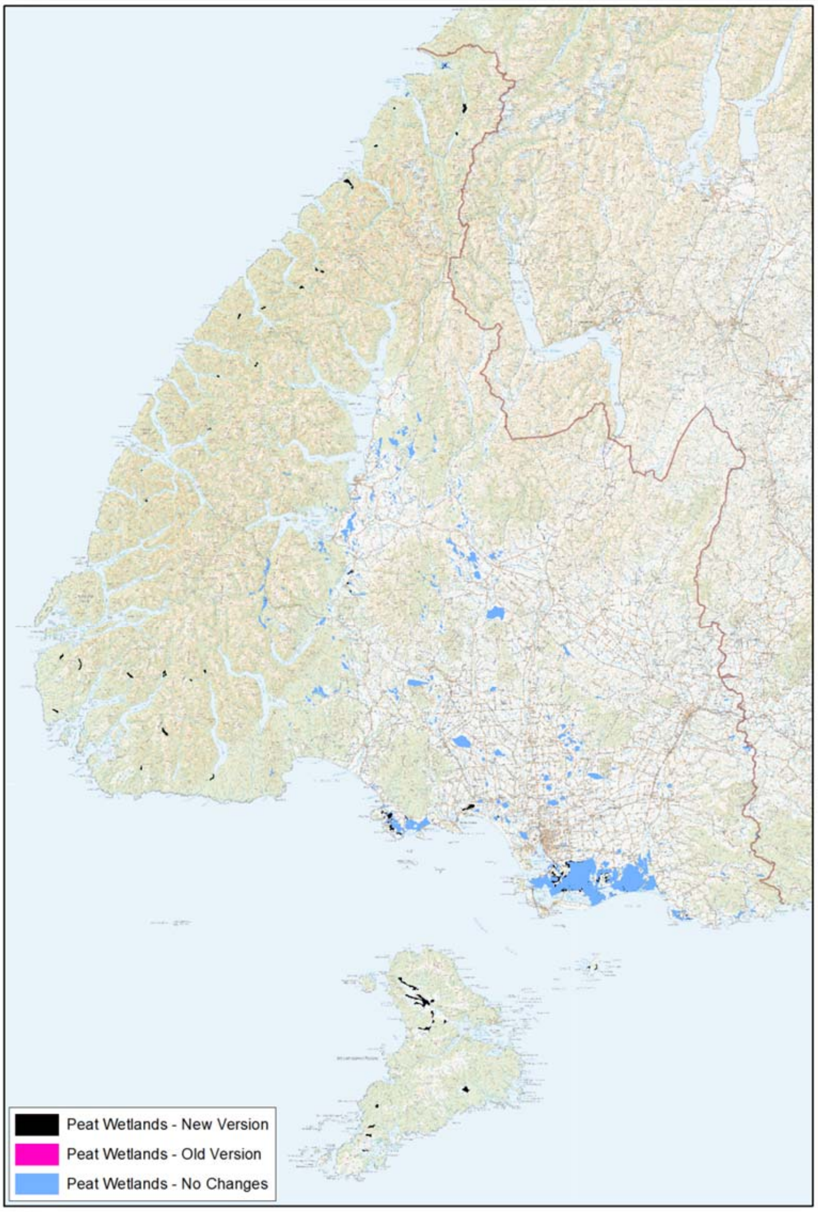
- Reclassification of areas of coarse-textured, moderately well to well drained soils (primarily in Western Southland) from the Riverine zone to the Oxidising zone to better reflect areas where there is limited potential for hydraulic connection to an alpine-source river or stream.



**Peat Wetlands**

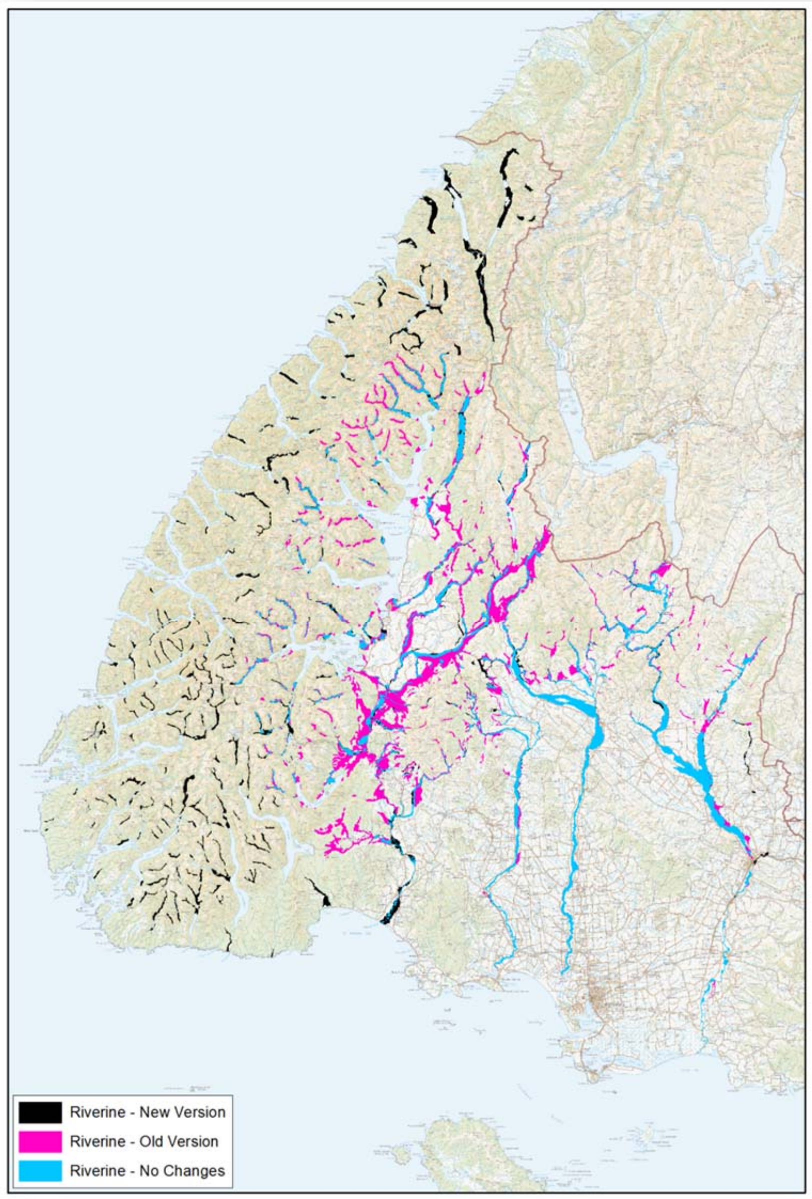
The Peat Wetlands zone was updated to incorporate the combined soil layer (CSL), which included the Topoclimate, Wallace County and LRI soil surveys. This enabled the Peat Wetlands in Western Southland and Fiordland to be mapped based on soil types rather than geological units as previously used.

- Areas of the Bedrock/Hill Country zone in Western Southland and Fiordland reclassified to the Peat Wetlands zone based on the presence of organic soils.



**Riverine**

- The Riverine zone was updated to incorporate the combined soil layer (CSL), which included the Topoclimate, Wallace County and LRI soil surveys. This enabled the Riverine zone in Western Southland and Fiordland to be mapped based on soil types and landform rather than geological units as previously used;
- Areas of elevated alluvial terraces overlain by well drained soils in the Waiau catchment were reclassified to the Oxidising zone to reflect limited hydraulic connection with alpine-sourced waters;
- Sections of the Bedrock/Hill Country zone in the Fiordland area were reclassified to the Riverine to reflect areas of recent alluvium overlain by fluvial soils in hydraulic connection with major rivers



# Appendix 2 – Definition queries for physiographic zone map

**Alpine**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| All areas > or equal to 800m using resampled 8m DEM | 1 | |

**Bedrock/Hill Country**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| Areas where QMap geology (MAIN_ROCK) geology is mapped as bedrock or till rather than alluvial sediments (i.e. does not equal gravel, loess, mud, peat, sand, silt or water) | 5 | MAIN_ROCK <> 'gravel' AND MAIN_ROCK <> 'loess' AND MAIN_ROCK <> 'mud' AND MAIN_ROCK <> 'peat' AND MAIN_ROCK <> 'sand' AND MAIN_ROCK <> 'silt' AND CODE <> 'water' |

**Central Plains**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| ▪ Q2 alluvium (QMAP) with inferred mafic parent material in the central plains area overlain by clay rich soils (Topoclimate) also of mafic origin that demonstrate shrink/swell characteristics leading to development of a soil bypass drainage pathway in summer.<br>▪ Not including areas of Q2al in the Oreti floodplain or Hillend area due to differing parent materials in these areas. | 7 | ("GEOL_U_P_" = 2590 OR "GEOL_U_P_" = 2526) AND ("SERIES" = 'Braxton' OR "SERIES" = 'McLeish' OR "SERIES" = 'Makarewa' OR "SERIES" = 'Caroline' OR "SERIES" = 'Pukemutu') |

**Gleyed**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| Soils included in NZSC Soil Order Gley or Podzol or which exhibit redoximorphic features (e.g. ‘mottling’) or which are classified as having a severe waterlogging risk (Topoclimate South) | 8 | Soils_ExcelToTable2_NZSC_Group = 'Perch-gley' OR Soils_ExcelToTable2_NZSC_Subgroup = 'Argillic-mottled' OR Soils_ExcelToTable2_NZSC_Subgroup = 'Mottled' OR Soils_ExcelToTable2_Type = 'Gley soils' OR Soils_ExcelToTable2_Type = 'Saline gley soils' OR NZSC_ORDER = 'Gley' OR NZSC_ORDER_1 = 'Gley' OR NZSC_GROUP = 'Perch-gley' OR NZSC_SUBGR = 'Mottled-acidic' OR NZSC_SUBGR = 'Mottled' OR NZSC_SUBGR = 'Mottled-Melanic' OR NZSC_SUBGR = 'Mottled-pallic' OR NZSC_SUBGR = 'Mottled-pedal' OR NZSC_SUBGR = 'Mottled-placic' OR NZSC_SUBGR = 'Mottled - Weathered' OR WATERLOGGI = 'severe' OR WATERLOGGI = 'severe' OR NZSC_ORDER = 'Podzols' OR NZSC_ORDER_1 = 'Podzol' |

**Lignite/Marine Terraces**

| Mapping Rule Summary | | ArcGIS Definition Query |
|---|---|---|
| ▪ Areas where QMap geology description includes reference to coal, lignite or carbonaceous lithology<br>▪ Areas in Eastern Southland where bore logs recorded on ES Wells database indicate present of East Southland Group within 15m of land surface | 3 | MAIN_ROCK = 'coal' OR MAIN_ROCK = 'shale' OR SUB_ROCKS = 'breccia, coal measures' OR SUB_ROCKS = 'breccia, sandstone, coal' OR SUB_ROCKS = 'claystone, coal, sandstone, conglomerate, carbonaceous shale, ironstone' OR SUB_ROCKS = 'claystone, shellbeds, lignite' OR SUB_ROCKS = 'coal seams' OR SUB_ROCKS = 'coal, conglomerate, mudstone' OR SUB_ROCKS = 'coal, sandstone' OR SUB_ROCKS = 'coal, siltstone, limestone' OR SUB_ROCKS = 'conglomerate, carbonaceous sandstone, coal seams' OR SUB_ROCKS = 'conglomerate, coal measures' OR SUB_ROCKS = 'conglomerate, coal seams' OR SUB_ROCKS = 'conglomerate, limestone, tuff, coal' OR SUB_ROCKS = 'conglomerate, mudstone, coal' OR SUB_ROCKS = 'conglomerate, mudstone, coal seams' OR SUB_ROCKS = 'conglomerate, mudstone, coal, breccia' OR SUB_ROCKS = 'conglomerate, sandstone, coal' OR SUB_ROCKS = 'gravel, silt, clay, lignite, oil shale' OR SUB_ROCKS = 'lignite' OR SUB_ROCKS = 'lignite, claystone, mudstone, conglomerate' OR SUB_ROCKS = 'lignite, conglomerate' OR SUB_ROCKS = 'lignite, mudstone' OR SUB_ROCKS = 'lignite, mudstone, limestone, greensand' OR SUB_ROCKS = 'lignite, sandstone' OR SUB_ROCKS = 'lignite, sandstone, conglomerate, |

| | | |
|---|---|---|
| | | clay' OR SUB_ROCKS = 'mud, gravel, peat, lignite, tephra, pumice' OR SUB_ROCKS = 'mudstone, coal' OR SUB_ROCKS = 'mudstone, coal seams' OR SUB_ROCKS = 'mudstone, coal, basalt, tuff, breccia' OR SUB_ROCKS = 'mudstone, coal, conglomerate' OR SUB_ROCKS = 'mudstone, coal, conglomerate, claystone' OR SUB_ROCKS = 'mudstone, coal, oil shale' OR SUB_ROCKS = 'mudstone, coal, shale, conglomerate' OR SUB_ROCKS = 'mudstone, conglomerate, carbonaceous shale' OR SUB_ROCKS = 'mudstone, conglomerate, carbonaceous shale, tuff' OR SUB_ROCKS = 'mudstone, conglomerate, coal, siltstone' OR SUB_ROCKS = 'mudstone, conglomerate, lignite' OR SUB_ROCKS = 'mudstone, lignite' OR SUB_ROCKS = 'mudstone, lignite, tephra' OR SUB_ROCKS = 'mudstone, shale, coal' OR SUB_ROCKS = 'mudstone, siltstone, conglomerate, coal' OR SUB_ROCKS = 'sand, gravel, peat, lignite' OR SUB_ROCKS = 'sand, lignite' OR SUB_ROCKS = 'sand, silt, clay, lignite' OR SUB_ROCKS = 'sandstone, claystone, coal' OR SUB_ROCKS = 'sandstone, conglomerate, coal' OR SUB_ROCKS = 'sandstone, lignite' OR SUB_ROCKS = 'sandstone, lignite, conglomerate, shellbeds' OR SUB_ROCKS = 'sandstone, limestone, coal seams' OR SUB_ROCKS = 'sandstone, mudstone, coal' OR SUB_ROCKS = 'sandstone, mudstone, coal seams' OR SUB_ROCKS = 'sandstone, mudstone, conglomerate, coal' OR SUB_ROCKS = 'sandstone, mudstone, lignite' OR SUB_ROCKS = 'sandstone, mudstone, limestone, coal' OR SUB_ROCKS = 'sandstone, mudstone, siltstone, coal seams' OR SUB_ROCKS = 'sandstone, mudstone, tephra, silt, lignite' OR SUB_ROCKS = 'sandstone, siltstone, mudstone, coal seams' OR SUB_ROCKS = 'sandstone, siltstone, mudstone, limestone, silt, lignite' OR SUB_ROCKS = 'shale' OR SUB_ROCKS = 'shale, coal seams' OR SUB_ROCKS = 'shale, limestone' OR SUB_ROCKS = 'silt, sand, gravel, lignite, pumice' OR SUB_ROCKS = 'siltstone, conglomerate, coal' OR SUB_ROCKS = 'siltstone, limestone, conglomerate, coal seams' OR SUB_ROCKS = 'siltstone, sandstone, coal, conglomerate'<br>**Plus (Southland Qmap)**<br>"MAP_UNIT" = 'marine bench' OR "MAP_UNIT" = 'marine terrace' OR "MAP_UNIT" = 'marine terrace deposit' OR "MAP_UNIT" = 'marine terrace gravel' OR "MAP_UNIT" = 'marine terraces'<br>**Plus (area from ES wells database)**<br>Area contained within LMT_extension.shp |

**Old Mataura**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| ▪ Alluvial terraces in the mid-Mataura catchment associated with the Shotover and Luggate Formations<br>▪ Excludes soils exhibiting redoximorphic features overlying Shotover and Luggate Formations | 6 | ("STRAT_UNIT" = 'Luggate Shotover fmns McI tce4' OR "STRAT_UNIT" = 'Luggate; Shotover fmns; McI tce4' OR "STRAT_UNIT" = 'Luggate Shotover fmns McI tce4' OR "STRAT_UNIT" = 'Luggate Shotover fmns McI tce4' OR "GEOL_U_P_" = 702 OR "GEOL_U_P_" = 733 OR "GEOL_U_P_" = 2569) |

**Oxidising**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| ▪ Includes all soils (except Gley and Podzol soils) not included in other physiographic zones | 9 | NOT (Soils_ExcelToTable2_NZSC_Group = 'Perch-gley' OR Soils_ExcelToTable2_NZSC_Subgroup = 'Argillic-mottled' OR Soils_ExcelToTable2_NZSC_Subgroup = 'Mottled' OR Soils_ExcelToTable2_Type = 'Gley soils' OR Soils_ExcelToTable2_Type = 'Saline gley soils' OR NZSC_ORDER = 'Gley' OR NZSC_ORDER_1 = 'Gley' OR NZSC_GROUP = 'Perch-gley' OR NZSC_SUBGR = 'Mottled-acidic' OR NZSC_SUBGR = 'Mottled' OR NZSC_SUBGR = 'Mottled-Melanic' OR NZSC_SUBGR = 'Mottled-pallic' OR NZSC_SUBGR = 'Mottled-pedal' OR NZSC_SUBGR = 'Mottled-placic' OR NZSC_SUBGR = 'Mottled - Weathered' OR WATERLOGGI = 'severe' OR WATERLOGGI = 'severe' OR NZSC_ORDER = 'Podzols' OR NZSC_ORDER_1 = 'Podzol') |

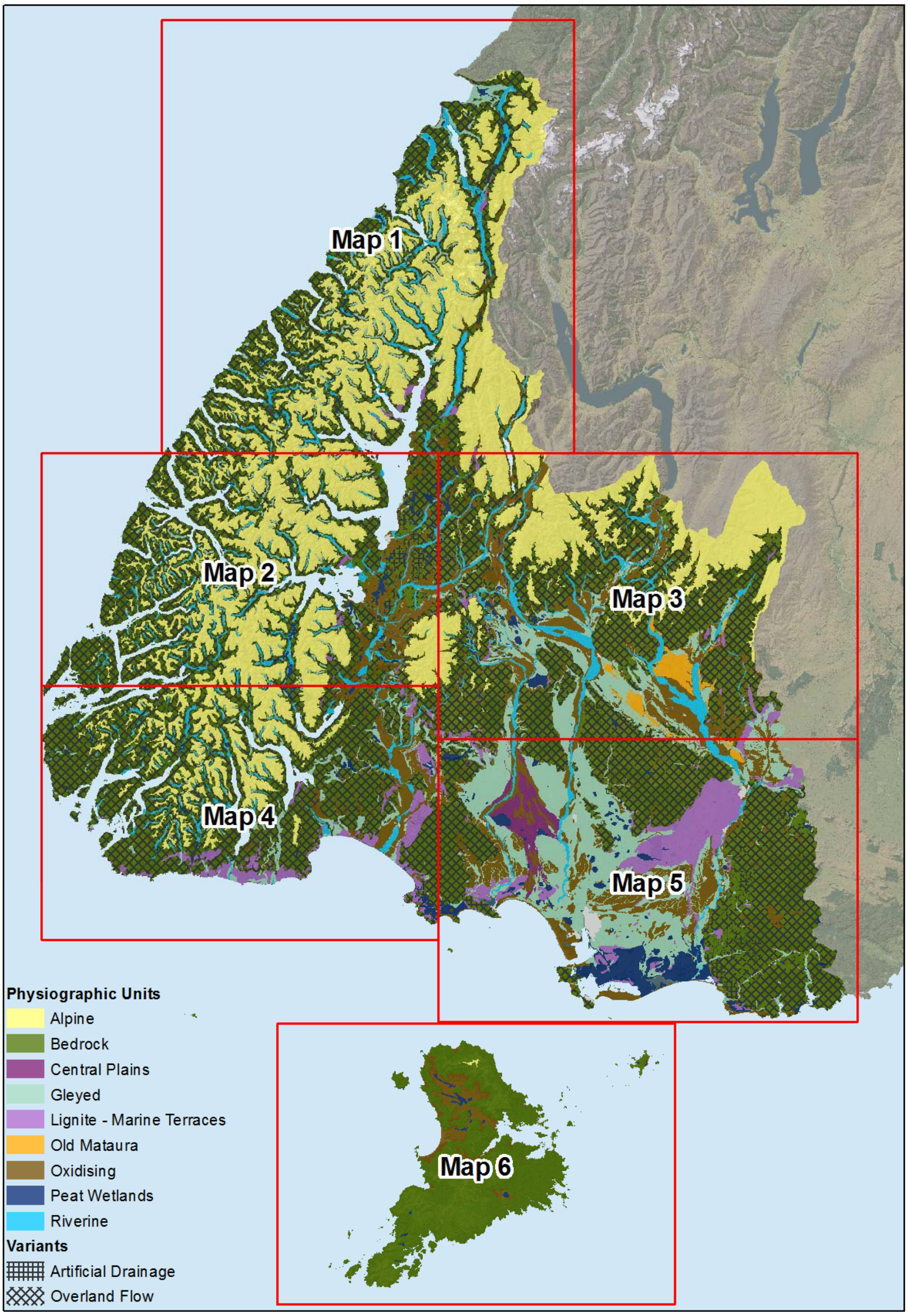
**Peat Wetlands**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| Existing wetland areas | 2 | Soils_ExcelToTable2_NZSC_Group = 'Organic' OR NZSC_ORDER = 'Organic' OR NZSC_ORDER_1 = 'Organic'<br>MAIN_ROCK = 'peat' |

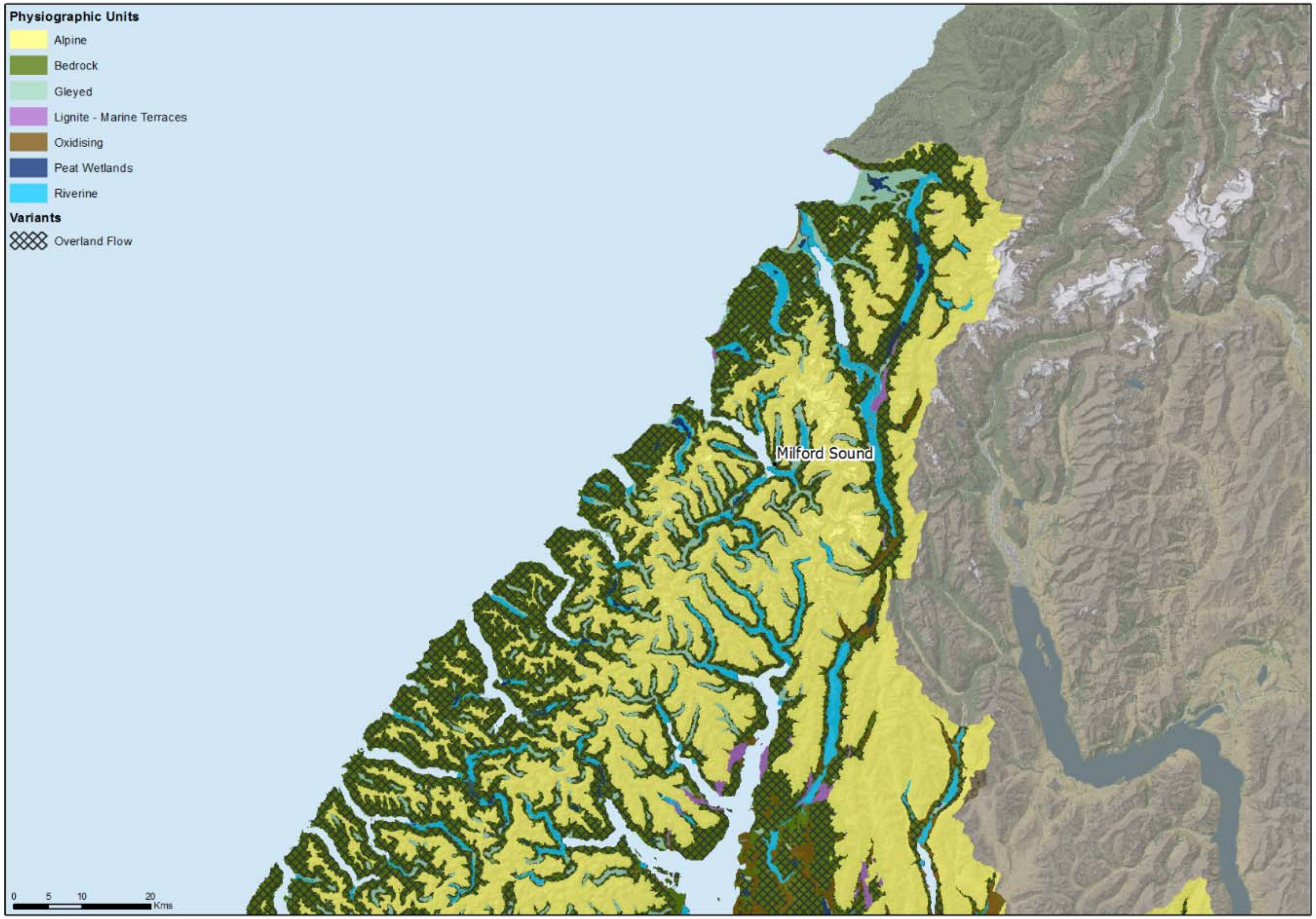
**Riverine**

| Mapping Rule Summary | Mapping Hierarchy | ArcGIS Definition Query |
|---|---|---|
| Areas of recent fluvial soils/geology which are hydraulically connected to alpine-derived rivers or streams (headwaters originating >800 m asl) | 2 | Soils_ExcelToTable2_NZSC_Group = 'Fluvial' OR Soils_ExcelToTable2_NZSC_Group = 'Recent' OR Soils_ExcelToTable2_Type = 'Recent soils' OR SERIES = 'rive' OR NZSC_ORDER = 'Recent' OR LUC = 'rive' OR SERIES_1 = 'River' OR SERIES_1 = 'River Complex' OR VARIANT_1 = 'recent alluvial depo' OR NZSC_ORDER_1 = 'Recent' OR NZSC_GROUP = 'Fluvial' OR NZSC_GROUP = 'Recent'<br>**Minus**<br>Any areas that are not hydraulically connected to an alpine source stream or river (REC stream network originating >800 m asl) (reclassified as Oxidising) |

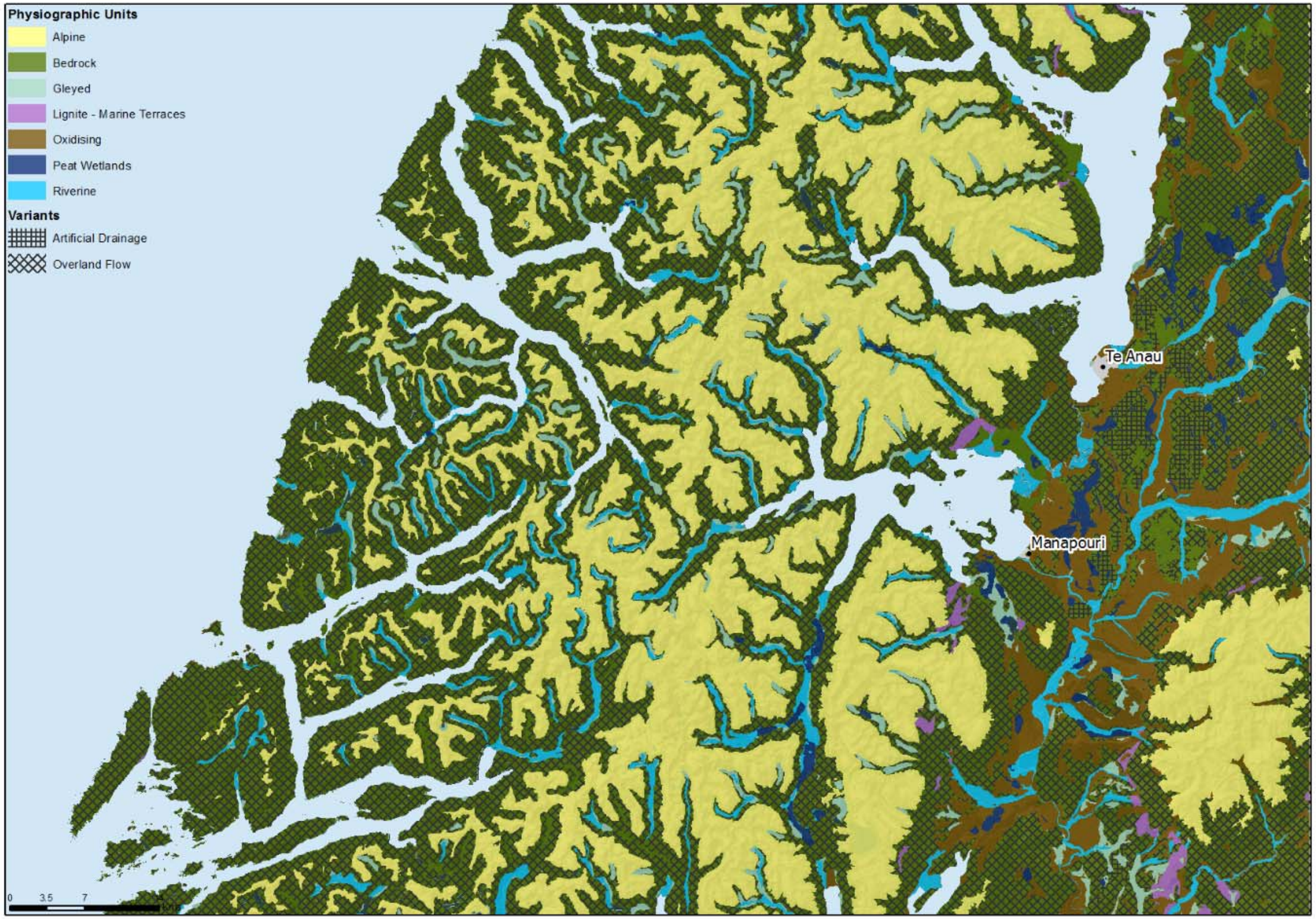
## Appendix 3 – Maps of the physiographic zones and variants



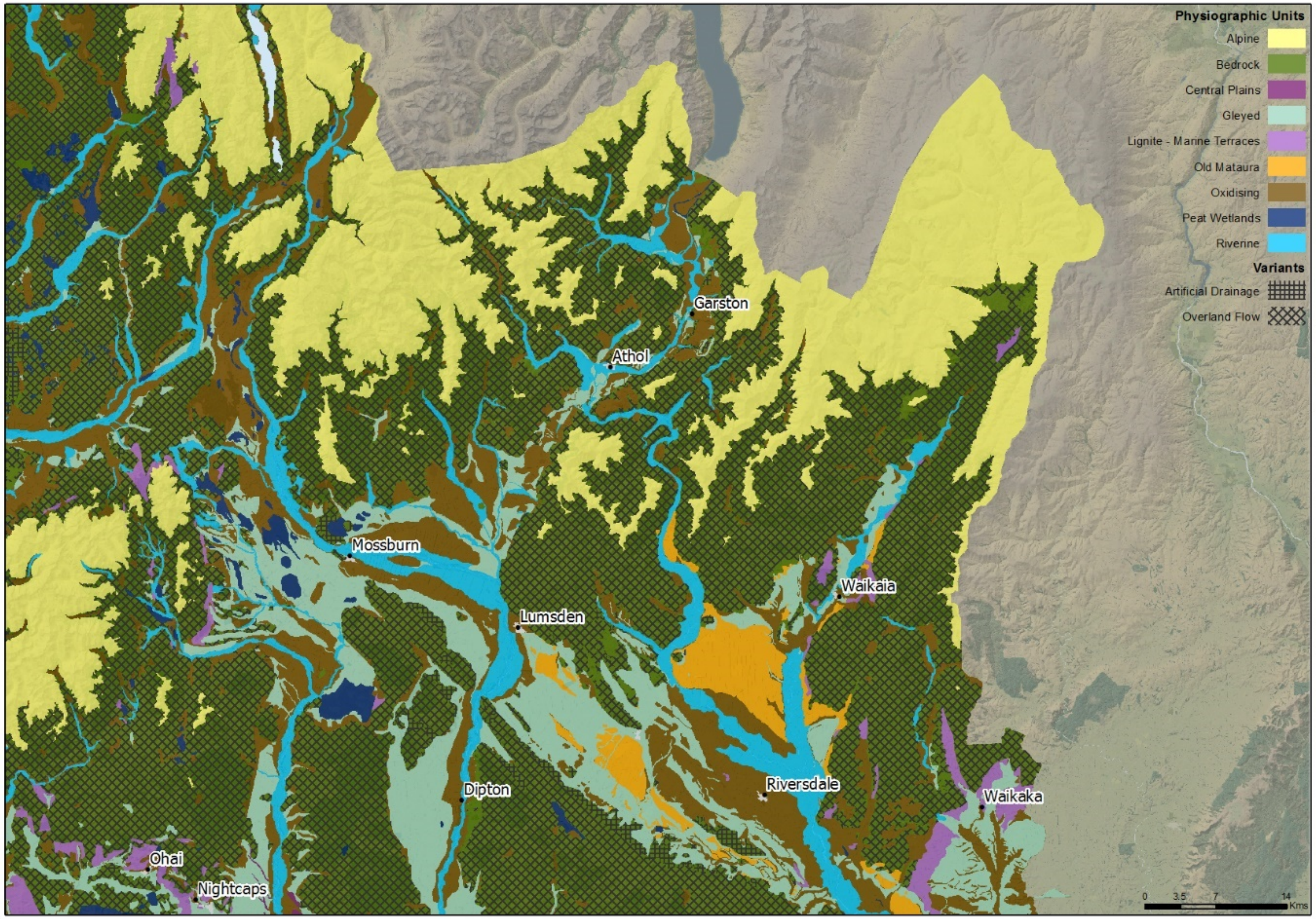
**Map 1:**


Physiographic Units
Alpine
Bedrock
Gleyed
Lignite - Marine Terraces
Oxidising
Peat Wetlands
Riverine
Variants
Overland Flow
Milford Sound
0
5
10
20
Kms

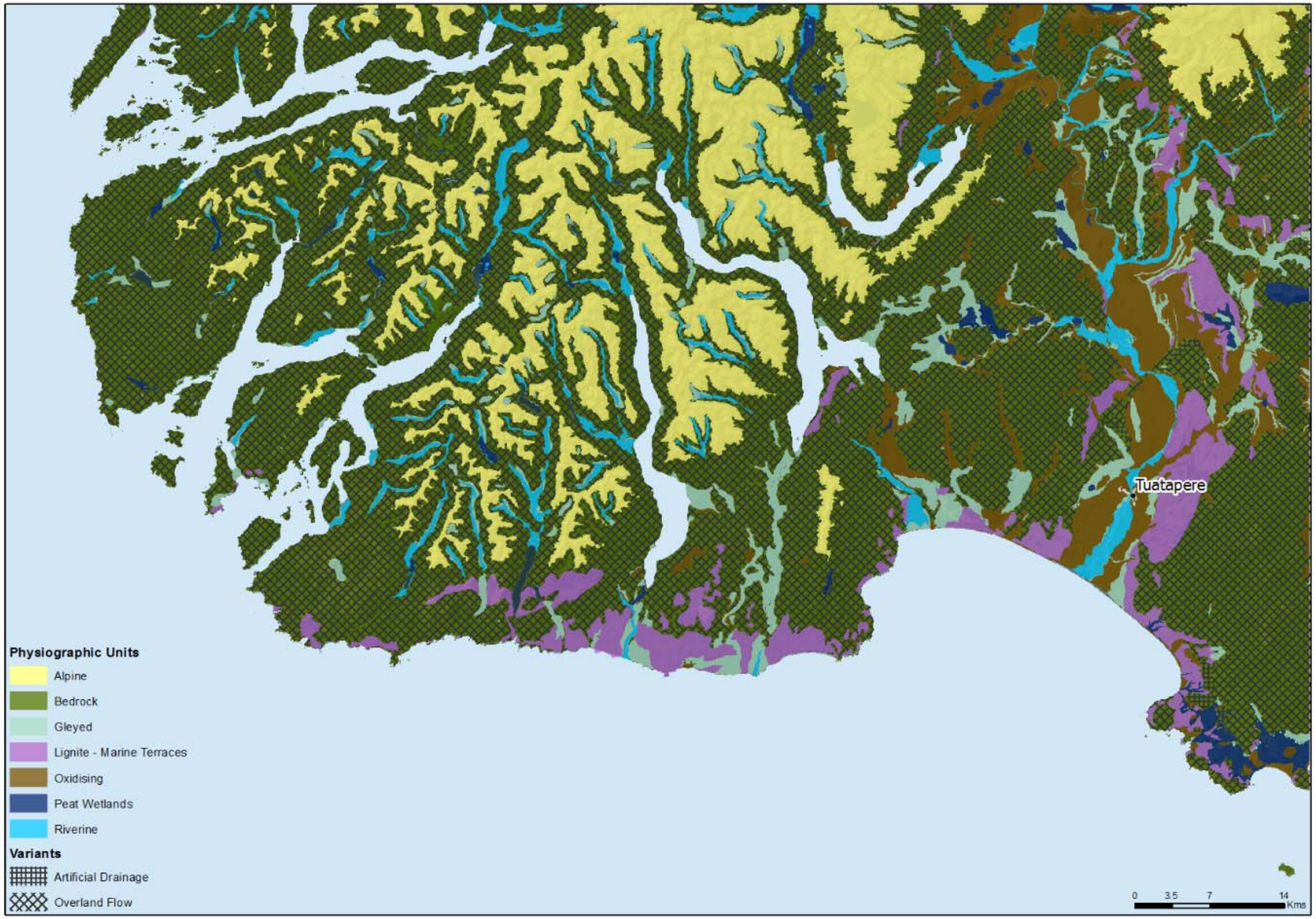
**Map 2:**


Physiographic Units
Alpine
Bedrock
Gleyed
Lignite - Marine Terraces
Oxidising
Peat Wetlands
Riverine
Variants
Artificial Drainage
Overland Flow
Te Anau
Manapouri
0
3.5
7

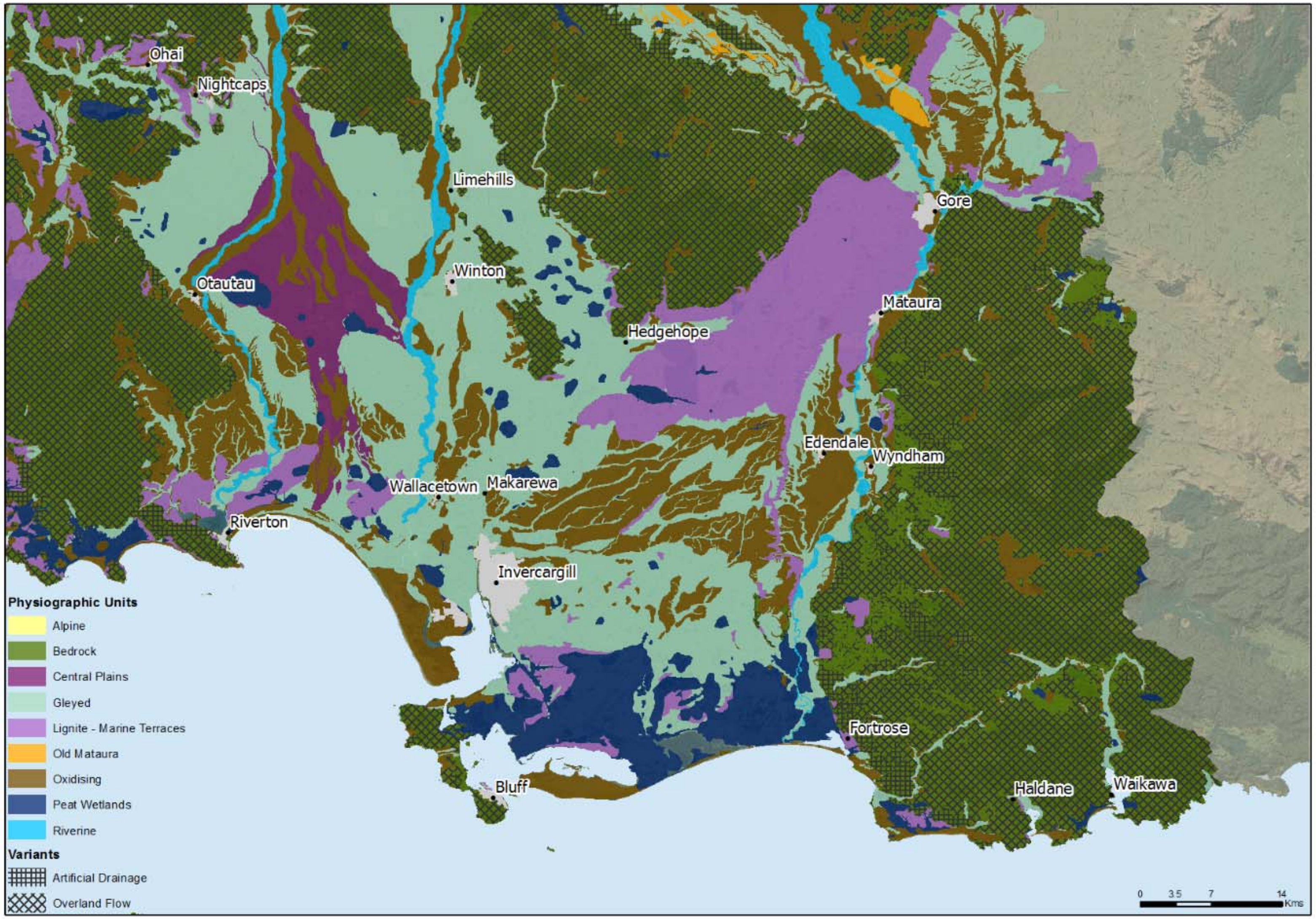
**Map 3:**


Physiographic Units
Alpine
Bedrock
Central Plains
Gleyed
Lignite - Marine Terraces
Old Mataura
Oxidising
Peat Wetlands
Riverine
Variants
Artificial Drainage
Overland Flow
Garston
Athol
Mossburn
Waikaia
Lumsden
Dipton
Riversdale
Waikaka
Ohai
Nightcaps
0 3.5 7 14 Kms

**Map 4:**

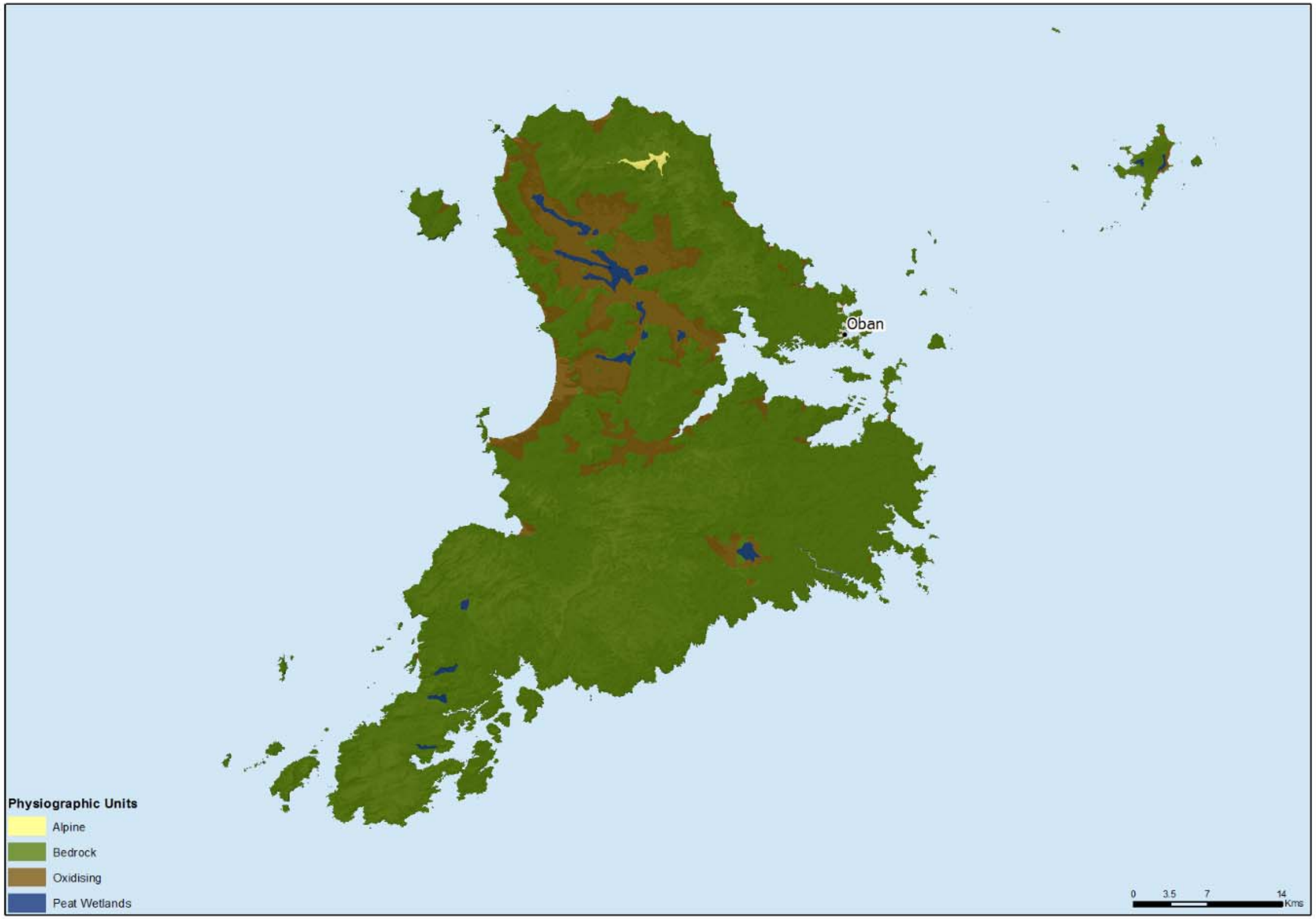

Tuatapere
Physiographic Units
Alpine
Bedrock
Gleyed
Lignite - Marine Terraces
Oxidising
Peat Wetlands
Riverine
Variants
Artificial Drainage
Overland Flow
0 3.5 7 14
Kms

**Map 5:**



Ohai
Nightcaps
Limehills
Gore
Winton
Otautau
Mataura
Hedgehope
Edendale
Wyndham
Wallacetown
Makarewa
Riverton
Invercargill
Fortrose
Bluff
Haldane
Waikawa
Physiographic Units
Alpine
Bedrock
Central Plains
Gleyed
Lignite - Marine Terraces
Old Mataura
Oxidising
Peat Wetlands
Riverine
Variants
Artificial Drainage
Overland Flow
0 3.5 7 14 Kms

**Map 6:**


Oban
Physiographic Units
Alpine
Bedrock
Oxidising
Peat Wetlands
0 3.5 7 14
Kms