Guide for using the Southland physiographic zones technical sheets

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1 Introduction

The Physiographics of Southland project was initiated by Environment Southland in 2014. The initial purpose of the project was to better understand variation in the hydrochemical and water quality evolution of freshwater across the Southland landscape.

The Physiographics of Southland Part 1 report (Rissmann *et. al.,* 2016) sought to understand the source of water in different physical environments and the processes it undergoes as it moves through the landscape. Analysis identified four key drivers of hydrochemistry and water quality variation in surface waters and shallow, soil influenced groundwater, which are (in no particular order):

- precipitation source;
- recharge mechanism and water source;
- combined soil and geological reduction potential, and;
- the combination of geomorphic setting and substrate (rock or biological sediment) composition.

Findings from this work were combined with other hydrological science to develop a classification system that groups land areas based on shared water quality risks. The classification system was developed specifically for the proposed Southland Water and Land Plan and comprises 9 classes (termed *physiographic zones*) and 8 sub-classes (termed *variants*) (Hughes *et al.,* 2016). The classification system provides a spatial framework for identifying appropriate mitigation strategies for agricultural activities in different parts of the Southland landscape intended to reduce land use impacts on water quality.

Technical sheets have been developed for individual physiographic zones to assist land managers in understanding water quality risks associated with each physiographic zone and variant.

1.1 Physiographic zone technical sheets

The physiographic zone technical sheets have been developed as a tool to assist land managers with identifying appropriate mitigations to avoid adverse effects on water quality resulting from agricultural land use. Each sheet provides detailed descriptions of environmental properties that make each physiographic zone distinctive and provide interpretations of water quality risk. The sheets are intended for users with some knowledge and understanding of environmental science.

The technical sheets describe the *dominant* physical, hydrological and geochemical characteristics of each physiographic zone. These characteristics have been identified at a regional-scale using geographic coverages of topography, climate, soils, geology and hydrological properties. The sheets also contain a binary (i.e. high or low) water quality risk assessment for four key contaminants: nitrogen, phosphorus, sediment and microbes.

While the actual environmental attributes at any point in the landscape may differ from the dominant characteristics identified for a given physiographic zone, it is important to note that:

- The characterisation in the technical sheets is limited by available information;
- The water quality risk assessment is based on natural (*inherent*) properties of the landscape (i.e. assesses the *potential* risk to water quality under intensive land use). Where the landscape has been modified by land management practices (e.g. soil compaction), water quality risk may differ from that identified in the sheets;
- Water quality risk is not characterised by any single factor (e.g. soil type). Rather it is the combination of a range of inherent environmental properties that result in distinct water quality risks. While finer-scale mapping of the environment may improve the accuracy and resolution of physiographic zone boundaries, such modification requires consideration of a range of characteristics; and,
- The number of physiographic zones identified reflects a trade-off between simplicity of application for policy purposes (i.e. where a smaller number of classes is desirable) and heterogeneity in environmental variables within each zone.

This guide attempts to explain the key concepts and terms used in the physiographic zone technical sheets. A description of how the classification system was developed can be found in the *Physiographics of Southland: Development and application of a classification system for managing land use effects on water quality in Southland* report (Hughes, *et al.,* 2016), and validation and testing results in the *Physiographic Zones for the Southland Region: Classification system validation and testing* report (Snelder, *et. al.,* 2016).

2 Classification system

At any point in the landscape, water quality reflects the nature and extent of interaction of the physical environment with water from its point of origin. These interactions may comprise a combination of hydrological processes that 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 environment, these processes are strongly influenced by environmental properties such as topography, climate, soil hydraulics and the biogeochemical properties of soils and aquifers.

Three key attenuation and dilution processes and five drainage pathways were identified as being key influences over water quality variability in Southland. These processes, and their influence over water quality are summarised in Table 1. Regional coverages of each of these were developed for Southland (described in Hughes *et al.,* 2016).

Table 1. Description of key processes influencing water quality outcomes.

Key dilution and attenuation processes	
Dilution	Dilution occurs where a large volume of recharge (or water flux) or dilute water (mixing) reduces the contaminant concentration in drainage waters (but does not reduce the overall load of contaminants conveyed to downstream receiving environments). In Southland, dilution is primarily associated with orographic enhancement of precipitation occurring in alpine and hill country areas.
Physical attenuation	Occurs when contaminants are physically removed or immobilised during passage through a porous media. Physical attenuation is primarily associated with drainage pathways that involve flow through the soil or geological matrix (deep drainage, lateral flow).
Reduction potential	Reduction potential describes the potential for oxidation-reduction (termed *redox*) reactions to occur. In natural waters 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. A common redox reaction is the conversion of nitrate to nitrogen gas (referred to as *denitrification*). This process is typically associated with poorly drained soils (where water moves slowly and contains low levels of oxygen) or geological materials which contain high concentrations of organic materials (e.g. peat and lignite). Under strongly reducing conditions, iron and manganese oxides dissolve increasing the solubility and mobility of phosphorus.
Drainage pathways	
Overland flow	Occurs where excess precipitation flows over the land surface in response to slope and gravity (also referred to as surface runoff). Overland flow may occur when precipitation occurs at a rate exceeding the infiltration capacity of the soil (infiltration excess overland flow) or when the soil is fully saturated (saturation excess overland flow).
Lateral drainage	Occurs 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	Occurs where soil water is intercepted and removed from the soil matrix via by mole-pipe or open drains.
Deep drainage	Occurs where water drains vertically through the soil matrix and vadose zone to underlying aquifers. 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 is abstracted for consumptive use).
Natural bypass flow	Occurs where water draining vertically through the soil profile preferentially infiltrates through cracks, fissures and macropores, effectively bypassing the soil matrix.

Dilution potential and reduction potential were identified as the key processes influencing water quality outcomes in Southland. 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).

Based on this distinction, initial development of the classification system utilised regional assessments of dilution and reduction potential developed from hydrological, geological and hydrochemical data assessments to define 12 possible classes for Southland. Each class represents a unique combination of these two factors, which is inferred to result in distinct water quality outcomes. Of the 12 potential classes defined, only 7 were present in Southland.

The seven classes were then evaluated using water quality and hydrochemical data. 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 two additional classes. The classes identified are summarised in Table 2.

Table 2. Identification of classes (including names).

<table>
<tr><td colspan="2"></td><th colspan="4">Dilution Potential</th></tr>
<tr><td colspan="2"></td><th>High Dilution Potential</th><th colspan="2">Low Dilution Potential</th><th>High Mixing Potential</th></tr>
<tr><th rowspan="4">Combined Reduction Potential</th><td>Low over Low</td><td>Class 1
Alpine</td><td>Class 3
Oxidising</td><td>Class 3a
Old Mataura</td><td>Class 7
Riverine</td></tr>
<tr><td>Elevated over Low</td><td>Class 2
Bedrock/Hill Country</td><td>Class 4
Gleyed</td><td>Class 4a
Central Plains</td><td>Not present in Southland</td></tr>
<tr><td>Low over Elevated</td><td>Not present in Southland</td><td colspan="2">Class 5
Lignite/Marine Terraces</td><td>Not present in Southland</td></tr>
<tr><td>Elevated over Elevated</td><td>Not present in Southland</td><td colspan="2">Class 6
Peat Wetlands</td><td>Not present in Southland</td></tr>
</table>

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

Delineation and characterisation of the classes (referred to as *physiographic zones*) involved an iterative process whereby a suite of mapping rules was developed based on the key controls over water quality in each zone. The physiographic zones were then mapped using regional coverages of *physically measurable* environmental properties i.e. soils, geology, topography and the surface drainage network which serve as a proxy for the water quality controls identified. The key features of the physiographic zones used to develop the mapping rules are summarised in Table 3.

Table 3. Key features of the Southland physiographic zones.

Physiographic Zone	Key Features
Alpine	• High elevation areas, which receive elevated precipitation (including seasonal snowpack accumulation), and contribute large volumes of runoff to the major river systems. • Soils and geology have a little influence over water quality (waters are very dilute). • Discharge occurs rapidly in response to individual precipitation events.
Bedrock/Hill Country	• Spatially extensive zone covering approximately 49% of Southland. • Occurs on prominent landforms (hills and sub-alpine areas), which receive elevated precipitation and contribute large volumes of runoff to lower elevation areas. • Discharge occurs rapidly in response to individual precipitation events due to overland flow on rolling to steep topography when soils are wet. • Soils overly bedrock or glacial till and exert a strong influence on the hydrochemistry and quality of water that infiltrates through the land surface (i.e. excluding overland flow).
Central Plains	• Distribution limited to areas of the Central Plains overlain by clay-rich soils, which shrink and swell with changing soil moisture. • Wet soils are prone to waterlogging so have a high density of artificial drainage to remove seasonal excess water. Contaminants (including nutrients, sediment and microbes) can be exported rapidly to surface waterways via mole-pip drainage. • Soils shrink and crack when dry allowing recharge to infiltrate rapidly from the land surface to underlying groundwater (termed *bypass* or *macropore* flow). This recharge effectively bypasses the soil matrix allowing elevated nitrate concentrations to reach groundwater.
Gleyed	• Fine-textured, imperfectly to poorly drained soils that exhibit redoximorphic features such as mottling and gleying. • Often found on older weathered alluvial terraces and along margins of smaller streams where fine-grained materials have accumulated. • Imperfect to poor profile drainage results in a high artificial drainage density in developed areas. This provides a pathway for export of contaminants (including nutrients, sediment and microbes) to surface waterways. • Significant attenuation of contaminants (including denitrification) occurs in deep drainage to groundwater.

Lignite/Marine Terraces	• Typically found on marine terraces along the south coast and in areas of Eastern Southland where lignite deposits occur near the land surface. • Aquifers contain carbonaceous sediments which exert a strong influence over hydrochemistry and water quality. • Groundwater are typically strongly reduced (i.e. low nitrate, elevated iron).
Old Mataura	• Distribution limited to older, weathered alluvial deposits in the mid-Mataura catchment. • Limited interaction with main-stem rivers. • Soils are well drained and overlie aquifers susceptible to nitrate accumulation.
Oxidising	• Primarily located on elevated alluvial terraces, which are overlain by moderately well to well drained soils. • Oxic soils and groundwater have a low reduction potential. • Limited interaction with main-stem rivers.
Peat Wetlands	• Located in areas of acidic, organic (peaty) soils with a high water table. • High reduction potential associated with organic carbon content in soils and saturated zone exerts a strong influence over hydrochemistry and water quality. • Significant denitrification in soil and aquifers (low nitrate, elevated iron). Elevated phosphorus solubility in groundwater and surface waters. • Extensive artificial drainage in developed areas increases potential for losses of nutrients, sediment and microbes to surface water.
Riverine	• Distributed along riparian margins of the mid to upper reaches of the main stem rivers. • Thin, well drained soils overlying permeable aquifers hydraulically connected to surface waters. • Local land surface recharge is diluted by large volumes of alpine runoff (contaminant concentrations in groundwater are generally moderated by dilution but significant loads may be exported to hydraulically connected surface waters).

2.1 Variants

Within individual physiographic zones, there is variation in soils, topography, geology and climate, which 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.

Variants occur within individual physiographic zones where the attenuation potential of the soil and saturated zones are reduced due to temporal hydrological variability. In areas of sloping land, temporal variability is commonly associated with overland flow or lateral flow occurring through more permeable soil layers, initiated in response to individual precipitation events. In lowland areas, artificial drains are extensively utilised to remove excess soil water to maintain agricultural productivity. These drainage pathways operate on an intermittent basis in response to variability in climate (e.g. precipitation and soil moisture), and can modify the extent to which contaminants are attenuated in the soil and saturated zones.

For example, in the Riverine zone, deep drainage represents the dominant drainage pathway for contaminant loss. 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 dominant 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 associated contaminant losses) to occur via overland flow at times when soils are wet. Thus, while deep drainage is the main contaminant pathway for the Riverine zone, in localised areas there is also 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 based on drainage pathway assessments where:

- The base assumption is that where deep drainage or natural bypass flow is the dominant contaminant pathway, water quality risk is increased in areas where drainage occurs via alternative pathways (i.e. artificial drainage and overland flow), which are associated with reduced reduction potential and/or physical attenuation;
- Where artificial drainage is the dominant contaminant pathway, water quality risk is 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.

Table 4 summarises the variants identified.

Table 4. Physiographic zone variants.

Physiographic zone	Primary contaminant pathway(s)	Overland Flow variant	Artificial Drainage variant
Alpine	Overland flow		
Bedrock/Hill Country	Deep drainage	✓	✓
Central Plains	Artificial drainage (wet soils) and natural bypass flow (dry soils)		
Gleyed	Artificial drainage	✓	
Lignite/Marine Terraces	Deep drainage	✓	✓
Old Mataura	Deep drainage		
Oxidising	Deep drainage	✓	✓
Peat Wetlands	Lateral drainage, deep drainage, artificial drainage (developed land only)		
Riverine	Deep drainage	✓	

3 Water quality risk assessment

As part of developing the classification system, a conceptual model was constructed to characterise how dilution, attenuation processes and drainage pathways combine to influence water quality. Figure 1 shows a simplified version of the model utilised. The model assesses attenuation and dilution processes in three physical zones, which reflect differing drainage pathways and water quality risk:

- **Surface zone** - influence the occurrence of overland flow (e.g. slope, soil drainage characteristics, rainfall rate and soil moisture) and its resulting influence on water quality in surface water receiving environments;
- **Soil zone** - determine the pathway followed by water moving through the soil zone (lateral drainage, artificial drainage, deep drainage and natural bypass flow) and the corresponding extent to which dilution and attenuation processes influence water quality along each pathway; and,
- **Saturated zone** - influence water quality in the groundwater receiving environment (i.e. as it moves between the base of the soil zone and the ultimate surface water receiving environment).

These three zones have been used as the core structure of the physiographic zone technical sheets and were used to assess water quality risks.

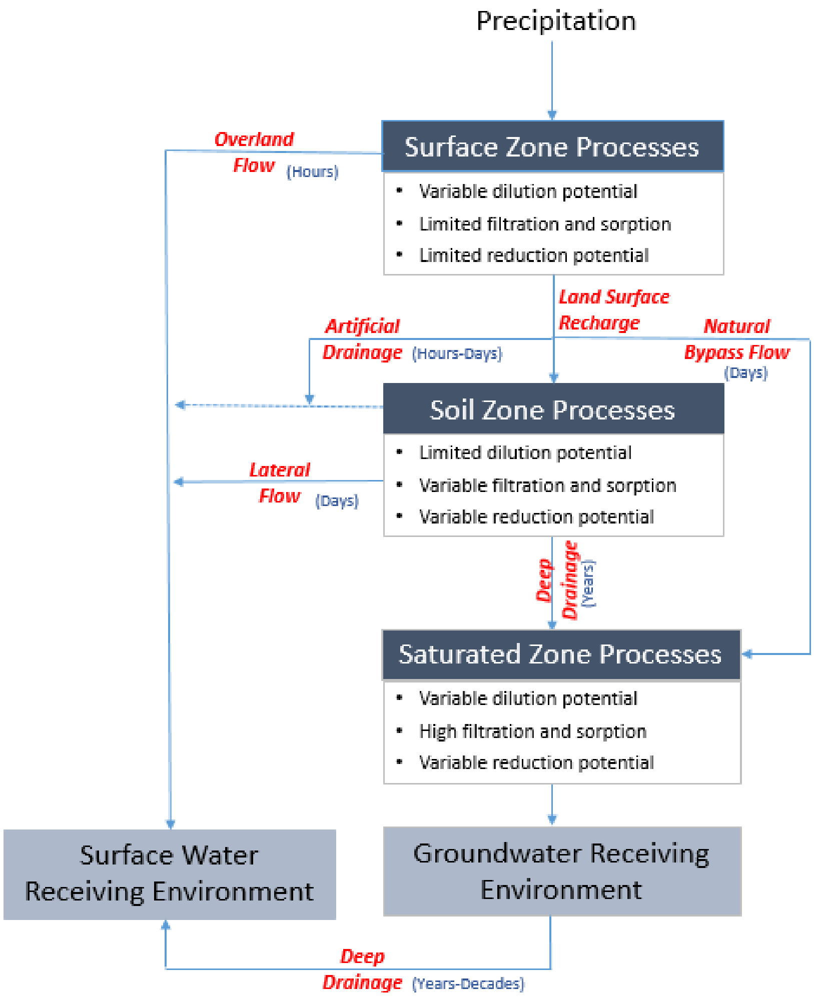

Figure 1. Simplified conceptual model used to assess water quality risk.

Assignment of water quality risk for nitrogen, phosphorus, sediment and microbial contamination for each physiographic zone and variant was undertaken using a binary risk category (i.e. either 'high' or 'low' risk) for policy purposes. Determination of water quality risk utilised assessments of dilution, attenuation potential and drainage pathways in accordance with the conceptual model illustrated in Figure 1.

The physiographic zone technical sheets document the environmental properties and processes that influence water quality risk, with the results summarised in Table 5.

Table 5. Water quality risks identified for physiographic zones and variants. N = nitrogen, P = phosphorus, S = sediment, M = microbial contaminants.

Physiographic Zone	Variant	Key pathways and contaminants			
		Overland flow	Artificial drainage	Lateral drainage	Deep drainage
Alpine		**N,P,S,M**			
Bedrock/Hill Country					
	Overland Flow	**N,P,S,M**			
	Artificial Drainage		**N,P,S,M**		
Central Plains			**N,P,S,M**		**N**
Gleyed			**N,P,S,M**		
	Overland Flow	**N,P,S,M**	**N,P,S,M**		
Lignite-Marine Terraces					
	Overland Flow	**N,P,S,M**			
	Artificial Drainage		**N,P,S,M**		
Old Mataura					**N**
Oxidising					**N**
	Overland Flow	**N,P,S,M**			**N**
	Artificial Drainage		**N,P,S,M**		**N**
Peat Wetlands			**N,P,S,M**	**P, M**	**P**
Riverine					**N**
	Overland Flow	**N,P,S,M**			**N**

4 Physiographic zone technical sheets

The physiographic zone technical sheets provide an overview of the *dominant physical, hydrological and chemical characteristics* that influence water quality outcomes in each physiographic zone. This section provides background to the data sources utilised, outlines the values (or range of values) assigned to categories used in the technical sheets and provides information to assist interpretation.

The scientific background and methodologies used to define the physiographic zones and associated water quality risks is provided in Rissmann, *et al.,* (2016) and Hughes, *et al.,* (2016). Additional information on the data sources used in the technical sheets, including maps and inter-zone comparisons, are provided in Appendix 1 and Appendix 2.

The physiographic zone technical sheets follow a standardised format comprising the following sections:

- **Overview:** summary of the key features and water quality risks associated with physiographic zone and variant;
- **Location:** description and map of the geographic distribution of the physiographic zone, including the main rivers and streams representative of that zone;
- **Variants and associations:** identifies any variants within a physiographic zone and describes other commonly associated physiographic zones;
- **Landscape characteristics:** describe the typical physical environment in which individual physiographic zones and variants are found, including the generalised spatial distribution, of topographical characteristics (slope and elevation), climate (precipitation and predominant airflows) and geology;
- **Surface zone characteristics:** describes properties that determine whether water flows through or over the land surface (overland flow potential), the surface water network and dilution potential;
- **Soil zone characteristics:** describes properties that determine the pathway water follows through the soil zone, the rate at which water moves, and soil properties that influence water quality including soil type, soil drainage, soil reduction potential, artificial drainage density and potential for lateral drainage;
- **Saturated zone characteristics:** describes properties that influence water quality in the unsaturated (vadose) zone and underlying groundwater receiving environment (i.e. as it moves between the base of the soil zone and the ultimate surface water receiving environment) including aquifer reduction potential and deep drainage potential; and,
- **Water quality implications:** describes the key water quality issues associated with land use, influences on surface water and groundwater quality, key hydrochemical features, contaminant pathways and mitigation objectives.

With each section, a suite of environmental properties describe each physiographic zone and enable inter-zone comparison. There is also a description of the particular properties that are characteristic of each zone (e.g. '*characteristics*'). These characteristic environmental properties collectively determine differences in potential water quality risks between the individual physiographic zones. All environmental properties used to describe the physiographic zones and variants are summarised in Table 6.

Table 6. Environmental properties used to characterise the physiographic zones and variants.

Properties used for inter-zone comparison	Additional properties used for characterisation
Elevation	Rock type and composition
Slope	Geomorphology
Geology	Land cover (vegetation)
Age	Degree of weathering
Annual rainfall	Proximity to main-stem rivers
Dilution potential	Stream flow hydrology
Drainage density	Surface water types
Stream order	Soil parent material
Overland flow	Soil base saturation
Soil type	Soil texture
Soil profile drainage	Soil series
Soil permeability	Soil depth
Soil anion storage capacity	Soil water holding capacity
Annual drainage season	Soil and aquifer organic matter content
Drainage seasonality	Waterlogging risk
Soil reduction potential	Soil moisture
Artificial drainage density	Groundwater hydrology
Lateral drainage potential	Aquifer type and composition
Water table depth	Groundwater discharge mechanisms
Aquifer permeability	Position in the landscape
Active groundwater storage	
Aquifer reduction potential	
Deep drainage potential	

The environmental variables used for inter-zone comparison are described in the following sections.

4.1 Environmental properties

4.1.1 Elevation

The elevation across each physiographic zone was calculated from the 8-metre digital elevation model (DEM) held by Environment Southland. Elevation was classified into 20 metre bins using ArcGIS, with the distribution used to characterise the range of elevations over which each zone and associated variants occur. Summary statistics for elevation in each zone and associated variants are provided in units of metres elevation relative to sea level (m RSL).

Elevation exerts a strong influence on precipitation volumes and marine aerosol loadings across Southland, with higher volumes of dilute precipitation occurring in higher elevation areas. Elevation is also linked to a range of other physical and hydrological characteristics that can influence water quality including drainage seasonality (due to seasonal snowpack accumulation at high altitude), vegetative growth, as well as soil physical and chemical characteristics.

4.1.2 Slope

Slope categories for individual physiographic zones were calculated from the 8m DEM held by Environment Southland. Calculated slopes were assigned to 1^{o} bins and classified according to the Land Resource Inventory classification system (Lynn *et al*., 2009) outlined in Table 7.

Table 7. Slope categories.

Slope angle (degrees)	Categories	Typical examples
0 - 3°	**Flat to gently undulating**	Flats, terraces
4 - 7°	**Undulating**	Terraces, fans
8 - 15°	**Rolling**	Downlands, fans
16 - 20°	**Strongly rolling**	Downlands, hill country
21 - 25°	**Moderately steep**	Hill country
26 - 35°	**Steep**	Hill country & steeplands
>35°	**Very steep**	Steeplands, cliffs

Slope exerts a significant influence on flow pathways, particularly in terms of the potential for overland flow and lateral drainage.

4.1.3 Geology

Geology was classified according to the *main_rock* attribute in the GNS Science QMap digital geological map coverage of Southland, which includes parts of the Wakatipu, Fiordland and Murihiku map sheets. The dominant subsurface geology for individual physiographic zones was calculated by intersecting the QMap coverage with the physiographic zone boundaries using ArcMap, and summing the area of individual polygons with the same *main_rock* attribute assigned following the simplified categories outlined in Table 8.

Table 8. Geology categories.

Categories	Description
Hard Rock	A wide range of lithologies which form basement rocks on the hills and ranges of Southland (e.g. amphibolites, dolerite, gneiss, granite, schist)
Volcanics	Various rock types of volcanic origin (e.g. lapilli tuff, tuff, volcanic)
Carbonate	Carbonate rocks (e.g. limestone)
Lignite Measure Sediments	Cenozoic sediments which overlie basement (e.g. mudstone, sandstone, siltstone)
Quaternary Sediment	Quaternary sedimentary deposits (e.g. gravel, peat, sand)

Additional geological detail is provided in the technical sheets using information in the QMap database. This includes rock types, geological composition and mineralogy, geological structures (such as faulting) and formation name.

Many chemical processes, such as denitrification, are influenced by the composition of geological substrates and mineralogical composition of soils and aquifers is often strongly reflected in hydrochemistry of soil and groundwaters. Geological composition can also influence the hydrological properties of the soil and/or saturated zone. Detailed analysis of geological composition and associated influences on regional hydrochemistry and water quality is provided in Technical Chapter 8 of the Physiographics of Southland Part 1 report (Rissmann, *et al.,* 2016).

4.1.4 Landform age

Landform age was characterised using the absolute maximum geological age defined in the regional QMap coverage following the categories outlined in Table 9. In QMap, the Quaternary period is subdivided into earlier (i.e. older) and later (i.e. younger) deposits. Sediments that comprise later Quaternary deposits are mapped using a "Q" notation. In the Southland, later Quaternary deposits are mainly represented by alluvial gravels and coastal deposits. Very few deposits have been age dated, with most age assignments based on geomorphic correlation with dated sequences, degree of weathering and preservation of landforms by "counting back" through glacial events (Turnball and Allibone, 2003).

The geological age classification derived from QMap was intersected with the physiographic zone coverage to identify the distribution of geological ages within each zone or variant.

Table 9. Geological age categories.

Categories	Description
Q1	~14 kya (Holocene deposits)
Q2 - Q4	
Q4 - Q6	
Q7 - Q9	
>Q10	
Pre-Quaternary	>1.8 mya

Land form age is correlated with soil pH and base saturation, both of which contribute to differentiation of hydrochemical characteristics between physiographic zones.

4.1.5 Average annual rainfall

Average annual rainfall was determined using coverage developed by NIWA based on an assessment of available rainfall data over the 1960 to 2010 period.

Average annual rainfall for individual physiographic zones and variants were calculated using ArcGIS. It is noted that average rainfall figures for individual physiographic zones that occur at higher elevations are often strongly influenced by the high rainfall occurring in the Fiordland area as well as orographic enhancement on hills and ranges elsewhere in the region.

The volume of precipitation occurring at any point significantly influences the recharge flux. Higher precipitation volumes increase the potential for the attenuation of contaminant losses by dilution both locally, and in downstream receiving environments. Precipitation volumes also influence temporal variability of specific flow pathways as drainage events generally only occur when soils are wet (deep drainage, artificial drainage, lateral drainage) or where precipitation occurs at a rate exceeding soil infiltration capacity (overland flow).

4.1.6 Dilution potential

Dilution refers to the process of decreasing the concentration of a solute (i.e. a chemical ion or molecule) in solution. Dilution refers to two separate, but closely related processes that influence water quality:

- The reduction in the concentration of a contaminant due to the recharge 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 water quality consideration for contaminant concentrations (e.g. suitability for potable water supply), it may have little influence over contaminant loading considerations (e.g. estuarine water quality).

Dilution has been assessed using the recharge mechanism hydrochemical driver defined in the Physiographics of Southland Part 1 report (Rissmann *et al.,* 2016). This metric characterises different recharge mechanisms in terms of their influence on regional hydrochemistry. It was reclassified to describe dilution potential in terms of the three generalised categories relevant for classification of water quality outlined in Table 9.

Table 10. Dilution potential categories.

Categories	Description
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, 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 mechanism.
High mixing potential	Areas that are recharged by a combination of lowland precipitation and runoff from distal sources (equivalent to the mixed recharge mechanisms described in Rissmann *et. al.,* 2016).

4.1.7 Drainage density

Drainage density is a measure of the length of stream network in each physiographic zone per unit area (based on the concept developed by Horton (1945)). It is an indicator of the residence time of water (i.e. the higher the drainage density, the lower the residence time as there is less distance to travel to a surface waterway) which influences the potential for contaminant transport to surface water.

Drainage density was calculated in ArcGIS using the NIWA River Environment Classification (REC, Version 3) coverage by summing the total length of stream reaches in each physiographic zone and dividing by the total land area. Drainage density for each physiographic zone was then ranked according to the categories outlined in Table 11.

Table 11. Drainage density categories.

Categories	Drainage Density Ratio
Very low	<5
Low	5 – 9.9
Moderate	10 – 19.9
High	20 – 29.9
Very high	≥30

Physiographic zones with a high drainage density tend to be drained by an extensive stream network, while surface waterways are relatively widely spaced in zones with a low drainage density. Drainage density is influenced by a range of physical characteristics including slope, geology, rainfall, vegetation and soil hydraulic properties. In terms of water quality, drainage density can be an important factor influencing the likelihood and rate (in terms of travel time) of drainage from the land surface to surface water.

4.1.8 Stream size

Stream size is a measure of the relative size (order) of surface waterways and provides an indication of the overall character of the stream network in each physiographic zone[1]. Stream order ratio is an indicator of typical stream size and dilution potential. It also gives a general indication of whether surface waterways originate locally (i.e. a high ratio of low order streams) or are more likely to transect multiple physiographic zone (i.e. a low ratio streams suggests surface waterways are predominantly larger rivers and streams)

Stream size was calculated from the NIWA River Environment Classification (REC, Version 3) (Snelder *et. al.,* 2004) coverage by summing the total length of individual stream reaches of various orders in each physiographic zone using ArcGIS, and calculating the ratio of 2nd and 3rd order stream length to the cumulative length of streams of 4th order and above. Each zone was then categorised according to the categories outlined in Table 12.

Table 12. Stream size categories.

Categories	Stream Size
Predominately small streams	>5
Mixed	2 - 5
Predominately large streams	<2

Surface waterways in physiographic zones with a high stream size tend to be dominated by a network of closely spaced smaller streams, while zones with a low stream size tend to be drained by larger rivers and streams with a sparse network of lower order tributaries. The potential for contaminant attenuation by dilution is frequently associated with stream size, with larger streams having a greater potential to attenuate elevated contaminant concentrations (although overall contaminant loads do not change).

4.1.9 Overland flow potential

Overland flow is a major pathway for the export of contaminants from the land surface to surface water. The period with the highest risk for overland flow in Southland is between May and September (McDowell *et al*., 2005) when soils are at or near saturation, and saturation excess overland flow can be initiated by individual rainfall events.

The potential for overland flow to occur at any point across the Southland landscape was categorised based on the assessment undertaken by Pearson (2015a). This assessment used the model described in McDowell *et al*., (2005) to characterise the potential for overland flow based on

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[1] Stream size as applied in this report is essentially a variant of *bifurcation ratio* which is used to characterise surface water drainage networks (e.g. Horton (1945), Shreve, (1966)).

soil categories (a combination of texture and slaking/dispersion index) and slope, expressed as a percentage of effective rainfall.

The potential for overland flow in each physiographic zone was assessed by intersecting the overland flow assessment with the physiographic zone coverage with the results ranked according to the categories outlined in Table 13.

Table 13. Overland flow categories.

Categories	Description
Very low	0 – 2.9% of effective rainfall
Low	3 – 4.9% of effective rainfall
Moderate	5 – 9.9% of effective rainfall
Moderately high	10 – 29.9% of effective rainfall
High	30 – 59.9% of effective rainfall
Very high	60 – 100% of effective rainfall

4.1.10 Soil order

To provide a regional soil map, the Topoclimate South (2001) soil survey coverage was combined with Wallace County (O'Byrne, 1986) and LRI (DSIR, 1968) soil surveys (in that order) to derive a regional coverage that extends across 90.7% of Southland. The unmapped areas are Stewart Island, large streams, and lakes, along with the major urban areas.

The LRI and Wallace County soil maps used the Genetic New Zealand Soil Classification (GNZC) (Taylor and Pohlen 1962) while the Topoclimate South survey used the more recent New Zealand Soil Classification (NZSC). The Topoclimate South user guide (Crops for Southland, 2003) notes:

> "*The NZSC replaced the NZ Genetic Classification (NZGC) in 1992. The latter had weaknesses that prevented it from coping well with the increasing understanding of New Zealand soils and the demands of our soil resource information systems. The main weakness was the lack of clearly defined classification criteria that could allow consistent allocation of soil types, and the inadequacy of the descriptive information that the classification could provide about the properties of a soil. The NZSC was developed from the NZGC, and there are enough similarities to allow relatively easy correlation between the two systems.*"

To standardise the soil classification system, the top classification levels of the two systems were correlated using the guide developed by Landcare Research (Hewitt, 1998), following the scheme outlined in Table 12 below. These assignments were then checked against the Topoclimate South soil survey where they overlapped to ensure consistent assignment. Un-mapped alpine areas were assigned to a NZSC Order of Podzol.

Table 14. Land Resource Inventory soil classification system correlation

Genetic NZSC (from LRI)	NZSC Order
Brown-grey earths	Semi-arid
Yellow-grey earths	Pallic
Yellow-grey to yellow-brown earths intergrade	Pallic
Lowland yellow-brown earths	Brown
Upland and high country yellow-brown earths	Brown
Lowland podzolised yellow-brown earths	Podzols
Upland and high country podzolised yellow-brown earths and podzols	Podzols
Yellow-brown sands	Brown
Rendzina and related soils	Melanic
Brown granular loams and clays	Melanic
Yellow brown loams	Brown
Organic soils	Organic
Gley soils	Gley
Gley recent soils	Gley
Saline recent soils	Gley
Recent soils	Recent
Alpine steepland soils	Podzols
Brown granular loams and clays to yellow-brown earths intergrade	Brown

Soil type is an indicator of the general hydrological and chemical properties of the soil. For example, Recent soils are typically thin, coarse-textured and highly permeable while Gley soils are generally fine-grained with imperfect to poor profile drainage and an elevated organic matter content.

4.1.11 Soil profile drainage

Soil profile drainage is an important physical property that describes the rate at which water will drain from a soil profile and is an overall indicator of likely soil drainage pathways. For example, deep drainage is more likely to occur under well drained soils, while artificial drainage and overland flow are more likely where soils are poorly to imperfectly drained. The Topoclimate South user guide describes profile drainage as follows:

> *"Profile drainage indicates how long a soil, or part of a soil, is saturated with water, and how quickly it can rid itself of excess water. Profile drainage is used to define land qualities such as aeration, structural compaction vulnerability, nutrient leaching vulnerability and waterlogging vulnerability. For example, in well-drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained"*

Soil profile drainage categories for Southland were derived from the soil profile drainage properties and classification utilised for the Topoclimate South soil survey. This data was combined with the internal drainage classification used for the Wallace Country soils map (O'Byrne, 1986). The two additional categories used in the Wallace County survey; "somewhat excessively drained" and "excessively drained" were reassigned to the "well drained" category in order standardise the classification system. No soil profile drainage information was available from the LRI soil survey, so a relatively large proportion of the region (approximately 37%) is not mapped..

Table 15 lists the soil profile drainage categories used for this assessment and associated soil drainage pathways.

Table 15. Soil profile drainage categories.

Categories	Estimated duration of limited aeration	Dominant soil drainage pathway(s)
Very poorly drained	Anaerobic for most of the year	Artificial drainage, overland flow
Poorly drained	Potentially anaerobic for 6-10 months in most of the upper 0.45 m layer, and commonly all year below 0.45m	Artificial drainage, overland flow
Imperfectly drained	Aeration limitations in upper 0.45 m for <6 months during winter, part spring and part autumn	Artificial drainage, overland flow, deep drainage
Moderately well drained	Adequate aeration all year except winter at depths usually below 0.45 m and generally below 0.9 m	Deep drainage
Well drained	Adequate aeration all year	Deep drainage

Soil profile drainage is an important hydraulic characteristic that influences drainage pathways, including deep drainage and overland flow.

4.1.12 Soil permeability

Soil permeability describes the rate at which water can flow through the soil matrix. Assessment of soil permeability was based on soil classifications in the Topoclimate South soil survey which utilised the New Zealand Soil Classification (NZSC) permeability categories outlined in Table 16.

Table 16. NZSC soil permeability categories.

Categories	Permeability (mm/hour)
Slow	<4
Moderate	4 to 71.9
Rapid	72 to >288

Typically, soil permeability is classified according to the slowest permeability horizon within the soil profile. However, given the influence of soil permeability on potential drainage pathways, for this project, soil permeability was classified according to the topsoil permeability (horizon A) over the subsoil permeability (horizons B, C and D). To generate a regional coverage, soil permeability information was obtained from Topoclimate South technical sheet profile descriptions (Crops for Southland, 2003) and a soil permeability category assigned to the topsoil and subsoil horizons following the categories outlined in Table 17. Where a subsoil had more than one permeability rate recorded, the permeability categories assigned were listed in order.

Table 17. Soil permeability categories.

Permeability (Topsoil over Subsoil)
Slow over slow
Moderate over slow
Moderate over slow, moderate
Moderate over slow, moderate, rapid
Moderate over moderate
Moderate over moderate, slow
Moderate over moderate, rapid
Moderate over rapid
Rapid over rapid

Many chemical processes such as denitrification, ion exchange and sorption are influenced by soil permeability, with longer residence times in slowly permeable soils providing an extended period for reactions to occur. For example, the extent of denitrification will be greater in a slowly permeable soil compared to a rapidly permeable soil with equivalent electron donor (organic carbon) content. Slow subsoil permeability also increases the potential for artificial drainage on flat to undulating agricultural land and lateral flow on sloping land.

4.1.13 Soil anion storage capacity

Anion storage capacity (ASC) is a measure used to describe the potential of a soil to immobilise phosphorus (P) and sulphur (S) compounds within the soil matrix. The term ASC has replaced the previously used concept of phosphate retention (PR), reflecting the fact that this property applies equally to phosphorus and sulphur. Variations in ASC between soil types are related to the relative abundance of specific iron and aluminium compounds present in clay minerals and are strongly influenced by the soil parent materials. For example, organic soils tend to exhibit low ASC while volcanic-derived soils may exhibit very high values.

ASC values for Southland soils were calculated based on P-retention values recorded on the available Topoclimate South soil profile point data. Data from all horizons were averaged from each profile point and combined to calculate an average base saturation for each soil type. This data was then classified using the categories outlined in Table 18 (based on the P-retention categories used by the Topoclimate South soil survey) to provide a representative category for each soil type.

Table 18. Soil anion storage capacity categories.

Categories	Anion Storage Capacity (%)
Very low	0 – 9.9
Low	10 – 29.9
Moderate	30 – 59.9
High	60 – 89.9
Very high	90 - 100

4.1.14 Soil reduction potential

Soil reduction potential reflects oxygen depletion and electron donor availability in the soil zone. Killick *et al*., (2014) established a quantitative assessment of soil denitrification potential (SDP) for Southland soils based on information available to describe gleying (indicating oxygen-depletion) and organic carbon content, for the area covered by the Topoclimate south soil survey.

The SDP coverage of Killick *et al*., (2014) was reclassified and extended to develop a regional coverage of soil reduction potential in Technical Chapter 6 of the Physiographics of Southland Part 1 report (Rissmann, *et al.,* 2016), using the categories outlined in Table 20. Representative categories for each physiographic zone and variant were calculated on a weighted area basis using ArcGIS.

Table 19. Soil reduction potential categories for Southland soils

Categories	Description
Low	Mostly Brown or Recent soils
Moderate	A mixture of soil types, mostly Brown, Gley or Perch-Gley Pallic
High	Mostly Gley, Perch-Gley Pallic and Organic soils

Denitrification is an important factor influencing the attenuation of nitrate in the soil zone. Where soil reduction potential is high (i.e. soils are ‘reducing’), denitrification can significantly reduce nitrate concentrations in infiltrating soil waters. Conversely, where soil reduction potential is low (i.e. soils are ‘oxidising’), limited attenuation of nitrate occurs within the soil zone. Therefore, virtually the entire mass of nitrate leached from the land surface is transmitted to the underlying saturated zone.

4.1.15 Artificial drainage density

Artificial drainage is used extensively in Southland to remove seasonal excess soil water to maintain agricultural productivity. Artificial drainage is typically most extensive in fine textured soils, where internal drainage is slow, or where a temporary water table exists in winter (Monaghan, 2014). Artificial drainage in Southland is typically characterised as mole-pipe drainage, also referred to as mole and tile drainage. Mole-pipe drainage typically comprises of an extensive fissure network, created by dragging a mole plough through the soil. The fissure network then drains into mole channels, which are linked to a connector pipes or tiles that ultimately discharge to a surface waterway.

Characterisation of the potential for artificial drainage was based on an assessment undertaken by Pearson (2015b). This assessment used drainage category and soil permeability to rank the potential likelihood of artificial drainage across Southland, taking into account soil type variants and mixed soil types identified in the Topoclimate South, Wallace County (O'Byrne, 1986) and LRI (DSIR, 1968) soil surveys. The assessment also used the Land Cover Database Version 4.1 (LCDB) to exclude non-agricultural land from the assessment.

The potential for artificial drainage in each physiographic zone was assessed by intersecting the modelled data with the physiographic zone coverage, with the results categorised as outlined in Table 21.

Table 20. Artificial drainage categories.

Categories	Typical Drainage Pattern
None (not agriculture)	No artificial drainage assumed as outside of area utilised for agricultural land use
Very low to none	Typically restricted to feeder drains from adjacent areas. Well drained soils with moderate to rapid permeability
Low	Contour drainage only. Moderately well to well drained soil with, moderate to slow permeability
Low (slope)	Soak holes. Moderately well to well drained soils with moderate to slow permeability
Moderate	Mix of contour and conventional drainage (slope dependant). Imperfect to moderately well drained soils, slow to rapid permeability
High	Mix of conventional and contour drainage (slope dependant). Poorly drained soils with slow to moderate permeability
Very high	Conventional. Very poor to poorly drained soils with slow permeability

Where artificial drainage is installed there is potential for contaminants to bypass the soil matrix thereby providing limited opportunity for contaminant attenuation by physical or chemical processes. Field trials in Southland (e.g. Monaghan, *et. al*., 2000, Monaghan, *et al.,* 2010) clearly demonstrate that artificial drainage systems can be conduits for the rapid movement of nutrients (nitrogen and phosphorus), sediment and faecal micro-organisms 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.

4.1.16 Lateral drainage potential

Where a soil and underlying unsaturated zone are uniformly permeable, infiltration from the land surface typically occurs vertically to the underlying saturated zone. However, where vertical drainage is impeded by layers of less permeable material, water may flow laterally within the soil zone.

Lateral flow (also termed 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. Lateral flow may also occur in flat-lying areas where a permeable soil overlies a slowly permeable, compact or cemented subsoil. In this case, water may accumulate above the slowly permeable horizon (forming a perched water table) and ultimately flow laterally through the soil to the surface (or artificial) drainage network or to areas where subsoil permeability is higher and vertical drainage can occur.

In the absence of a more comprehensive classification, areas with a significant potential for lateral flow to occur were identified 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.

Due to physical processes such as filtration and adsorption occurring within the soil profile, contaminant transport via lateral flow is typically limited to dissolved contaminants (e.g. nitrate) rather than particulate contaminants (e.g. sediment and faecal micro-organisms), although 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 but, due to limited residence time, is typically associated with limited denitrification.

4.1.17 Water table depth

Water table depth is an indicator of the residence time of water in the unsaturated zone and drainage pathways. Where the water table is very shallow, there is increased potential for ponding and associated overland flow, and use of artificial drainage to remove excess soil water.

Water table depth is derived from an assessment of static groundwater levels undertaken by Hughes (2013). This assessment compiled available static groundwater level information from Environment Southland monitoring, piezometric surveys and driller's logs, to produce a regional estimate of water table depth. The extent of the coverage is limited to the groundwater management zone boundaries defined in the Regional Water Plan for Southland (Environment Southland, 2010), due to the limited data available outside these areas to reliably characterise static groundwater levels.

Depth to groundwater for individual physiographic zones were calculated from the spatial groundwater depth coverage in ArcGIS and ranked according to the categories outlined in Table 22.

Table 21. Water table depth categories.

Categories	Depth to Water Table (metres below ground level)
Shallow	≤2
Moderate	2 – 4.99
Moderately Deep	5 – 9.99
Deep	≥10

4.1.18 Aquifer permeability

Aquifer permeability is a measure of the ability of water to flow through geological materials hosting a groundwater resource. Water can flow rapidly through aquifers exhibiting high permeability, while the rate of groundwater flow may be very slow through materials exhibiting low permeability.

Due to the nature of the alluvial deposits hosting the primary unconfined aquifers in Southland, aquifer permeability varies both spatially and with depth, reflecting factors such as sediment texture and the degree of weathering of the alluvial materials. However, at a sub-regional scale, the permeability of the Quaternary alluvium typically reflects a combination of geological age and the nature of depositional processes occurring during their deposition. For example, recent (Q1) alluvial deposits adjacent to the main stem rivers typically exhibit a coarse texture and high permeability, reflecting extensive reworking and winnowing of fine-grained materials during entrenchment of rivers since the last glaciation. In contrast, alluvial materials underlying elevated terrace remnants along the margins of the major river valleys (>Q6) tend to be older, highly weathered and exhibit lower permeability.

Aquifer permeability is expressed in terms of hydraulic conductivity, which is a measure of the volume of water that will flow through a unit area of an aquifer under a given hydraulic gradient. Aquifer permeability categories were assigned to individual physiographic zones according to the categories outlined in Table 23 based on expert opinion, informed by available aquifer test data and understanding of the regional hydrogeological setting.

Table 22. Aquifer permeability categories.

Categories	Description
Low	Typically less than 25 m/day. Most commonly associated with occurring in highly weathered and/or poorly sorted alluvial sediments or hosted in secondary permeability associated with jointing or fracturing in hard rocks.
Moderate	Typically in the order of 25 to 200 m/day with significant spatial and vertical variability. Most commonly associated with moderately well sorted and variable weathered alluvial sediments associated with Late Quaternary glacial periods when the major river systems deposited large volumes of sediment.
High	Typically more than 200 m/day. Most commonly associated with sediments reworked by paleo- or current day main-stem rivers and comprising coarse-grained sediments with little weathering.

Aquifer permeability is an indicator of ability of an aquifer system to dilute contaminants. In Southland, aquifers exhibiting high permeability typically have a large volume of water (termed *throughflow*) flowing through them so have significant capacity to dilute contaminant loads. Conversely, aquifers exhibiting low permeability typically exhibit slow throughflow and have a correspondingly lower capacity to dilute contaminant inputs.

4.1.19 Active groundwater storage

Active groundwater storage is a measure of the relative flux of groundwater flowing through an aquifer system over a given period, per unit area. It is an indicator of whether deep drainage is a significant flow pathway and groundwater is a significant receiving environment within a physiographic zone.

Active groundwater storage reflects several hydrogeological attributes of the hydrogeological environment including:

- **Hydraulic connection** - aquifers hydraulically connected to surface water typically exhibit a significantly greater recharge flux than those recharged by land surface recharge;
- **Soil drainage characteristics** - in aquifers primarily recharged by land surface recharge, the volume of recharge is influenced by the drainage characteristics of overlying soils. Where soils are well drained and highly permeable with a low water holding capacity, a significant proportion of seasonal excess soil moisture (i.e. rainfall minus evapotranspiration) typically drains to underlying groundwater. Where soils are poorly drained or sloping, a greater proportion of seasonal excess moisture is discharged via overland flow and/or artificial drainage, thereby reducing the volume of recharge per unit area to the underlying aquifer;
- **Aquifer hydraulic properties** - the permeability of the geological materials hosting the aquifer system and the hydraulic gradient determine the physical rate at which water moves through an aquifer system.

The rate and volume of groundwater flowing through an aquifer system contributes to the assimilative capacity of an aquifer due to dilution, as well as the residence time of water within the aquifer. This influences the time available for chemical interactions to occur between groundwater and the aquifer materials. In general, most aquifers exhibit a vertical gradient in the rate of groundwater flow, with shallow groundwater circulating more rapidly than deeper levels of the saturated zone. Active groundwater storage reflects the flux of water through upper levels of the aquifer system which are most likely to be influenced by recharge from overlying land use activities.

Active groundwater storage in individual physiographic zones were assigned to the categories in Table 24 based on expert opinion, informed by knowledge of the regional hydrogeological setting as well as assessment of temporal groundwater level variations and isotope and tracer data available to characterise mean groundwater residence time.

Table 23. Active groundwater storage categories

Categories	Description
Minor	Deep drainage to groundwater accounts for a relatively small proportion of the seasonal water surplus and recharge from surface water is typically minimal. Circulation of shallow groundwater typically occurs on a local scale at a relatively low rate
Moderate	Deep drainage to groundwater accounts for significant proportion of the seasonal water surplus and some recharge may occur from surface waters. Circulation of shallow groundwater typically occurs on a local scale but may occur relatively quickly
Extensive	Deep drainage to groundwater accounts for a significant proportion of the seasonal water surplus and is frequently augmented by recharge from surface water. Circulation of groundwater occurs rapidly at shallow depths

4.1.20 Aquifer reduction potential

Rissmann (2011) developed a regional assessment of aquifer denitrification potential using regional geological data. This assessment used the "main_rock" and "sub_rock" attributes in the digital QMap coverage to assign denitrification potential to individual geological units based on the sediment type and the likely presence of electron donors (organic carbon). This classification was further refined to develop an index of aquifer reduction potential in Technical Chapter 6 of the Physiographics of Southland Part 1 report (Rissmann, *et al.,* 2016), using the categories outlined in Table 25.

Table 24. Aquifer reduction potential categories.

Categories	Description
Low	Limited potential for denitrification to occur (nitrate can be elevated where intensive land use occurs). Low concentrations of redox sensitive species (Fe^{2+}, Mn^{2+} and NH_4-N)
Moderate	Mixed redox conditions with some potential for denitrification to occur (nitrate concentrations generally low to moderate). Concentrations of some redox sensitive species (Fe^{2+}, Mn^{2+} and NH_4-N) can be slightly to moderately elevated
High	Elevated potential for denitrification to occur (nitrate concentrations typically low). Concentrations of redox sensitive species (Fe^{2+}, Mn^{2+} and NH_4-N) often elevated

Aquifer reduction potential is a measure of the ability of the aquifer substrate materials to facilitate oxidation-reduction (redox) reactions. Aquifers with a high reduction potential (i.e. 'reducing' aquifer) exhibit extensive denitrification resulting in significant attenuation of nitrate concentrations infiltrating from the soil zone. Such aquifers are unlikely to exhibit elevated nitrate concentrations even if soil zone leaching rates are high but may exhibit elevated concentrations of redox sensitive species such as iron, manganese and ammonia. Conversely, aquifers with a low reduction potential exhibit limited denitrification and commonly have an elevated potential to accumulate elevated nitrate concentrations (and typically exhibit low concentrations of iron, manganese and ammonia).

4.1.21 Deep drainage potential

Deep drainage to groundwater occurs extensively across Southland and is generally the major source of recharge to aquifers located away from the main stem rivers. Chanut (2014) undertook an assessment of land surface (rainfall) recharge in Southland. While this assessment included an assessment of overland flow, it did not allow for the effects of artificial drainage which is significant in some areas of Southland.

The rainfall recharge assessment has therefore been modified to account for the potential effect of artificial drainage on the volume of deep drainage. This was undertaken using the assessment from Section 4.5.8, with the deep drainage categories according the criteria summarised in Table 26.

Table 25. Assessment of deep drainage in Southland

LSR (% rainfall)*		Artificial drainage	Deep drainage categories
<20%	or	Very high, high	Low
20 – 40%	or	Moderate	Moderate
>40%	and	Very low to none, low or low (slope)	High

*Calculated using land surface recharge (Chanut, 2014) as a percentage of annual rainfall (Section 4.3.3)

The resulting spatial distribution of deep drainage across Southland only covers 16% of Southland, hence an additional qualitative analysis of the potential magnitude of deep drainage was undertaken using soil moisture and groundwater hydrographs, sub-catchment water balances and an overall understanding of regional hydrogeology.

Analysis of groundwater hydrology to assess deep drainage was generally applied at a physiographic zone scale where deep drainage was unmapped, according to the criteria outlined in Table 27.

Table 26. Deep drainage categories.

Categories	Description
Low	Deep drainage to groundwater comprises a relatively minor component of the overall water balance, due to the prevalence of other drainage pathways (e.g. overland flow and artificial drainage)
Moderate	Deep drainage to groundwater is an important component of the overall water balance. However, the significance of deep drainage may vary temporally due to prevalence of other drainage pathways, particularly when soils are wet (often due to slow subsoil permeability)
High	Deep drainage to groundwater is a major component of the overall water balance, typically due to the prevalence of flay-lying, well drained soils

5 Limitations and assumptions

The classification system developed for the Physiographics of Southland project represents a simplified categorization of a complex natural environment. The physiographic zone technical sheets identify and characterise key inherent properties of the landscape that influence water quality risk within each physiographic zone. Key points to note include:

- The purpose of the characterisation was to describe *inherent* properties of the Southland landscape that have the greatest influence on water quality. Inherent properties are defined as referring to *'natural' properties of the landscape resulting from combinations of soil properties, climate, topography, geology and hydrology that are not affected by land use or land management practices, which influence water quality outcomes.* Where anthropogenic activities have significantly influenced hydrology (e.g. extensive mole-pipe drainage), this has also been included;
- Each physiographic zone represents a distinct combination of physical, hydrological and chemical characteristics. Potential water quality outcomes associated with an individual physiographic zone cannot be adequately characterised in terms of any single attribute;
- The technical sheets describe the *dominant* characteristics of each physiographic zone. It is however, acknowledged that there may be considerable variability in individual attributes within a given physiographic zones;
- The characterisation was standardised with the same attributes and assessment criteria used for all zones and variants. Physiographic zone characteristics reflect the dominant physical and chemical characteristics occurring across the whole zone. Physiographic zone variant characteristics reflect physical and chemical characteristics in areas where there is increased water quality risk when soils are wet;
- Only those properties which uniquely characterise the physiographic zones have been included. For instance, seasonal variability in rainfall is similar across most the zones and was therefore excluded from the characterisation; and,

- Some environmental properties used to characterise the physiographic zones were limited by data availability (e.g. water table depth only covers approximately 20% of the region) or a lack of suitable analysis methods (e.g. the amount of deep drainage occurring as bypass flow). Limitations in data coverage are documented in the user guide and notated in the technical sheets.

6 Mitigations and additional information

The technical sheets provide a summary of the mitigation aims for each physiographic zone and variant. More detailed information on mitigations are available on Environment Southland's website and in Monaghan (2016). Table 28 summarises the mitigation aims for the range of contaminant pathways.

Table 27. Mitigation aims for key contaminant pathways

Pathway	Mitigation Aims
All pathways (general)	- Capture nutrients, sediment and microbes in wetlands and sediment traps - Undertake good nutrient, riparian and effluent management
Overland flow	- Protect soil structure, particularly in gullies and near stream areas - Manage critical source areas - Reduce phosphorus use or loss
Artificial drainage	- Protect soil structure, particularly in gullies and near stream areas - Reduce phosphorus use or loss - Reduce the accumulation of surplus nitrogen in the soil, particularly over autumn and winter - Avoid preferential flow of effluent through drains - Capture contaminants at drainage outflows
Deep drainage (nitrogen)	- Reduce the accumulation of surplus nitrogen in the soil, particularly during autumn and winter
Lateral and deep drainage (phosphorus and microbes)	- Reduce phosphorus use or loss - Reduce transport of microbes

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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 of particulate or dissolved contaminants in a waterbody associated with removal of contaminants by physical (e.g. filtration) or biogeochemical (e.g. denitrification) processes.

Biogeochemical

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

Characteristics

Physical, hydrological and chemical properties (attributes) that distinguish a physiographic zone from other physiographic zones

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.

Drainage pathway

The specific pathway water flows through or over the landscape to the receiving environment.

Effective rainfall

In this report, effective rainfall refers to total rainfall minus surface runoff and evaporation.

Geomorphic age

Geomorphic age is a measure of the time elapsed since deposition for sedimentary deposits (rather than the age of the parent materials). Typically reported in thousands of years (Ka), or millions of years (Ma).

Hydrochemistry

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

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

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

Natural bypass 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 over the land surface after rainfall (or snow melt) of sufficient intensity to exceed soil infiltration capacity.

Physiographic zones
Land areas that contain distinct combinations of inherent properties that influence water quality outcomes.

Precipitation source
The origin of precipitation, in terms of altitude, distance from the coast and resulting marine aerosol concentrations.

Redox (Reduction–oxidation reaction)
Oxygen-reduction (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.

Reduction potential
The reduction setting describes the potential for redox reactions to occur.

Substrate composition
Substrate composition describes the mineralogical composition of materials forming soils or underlying geological deposits.

Water quality
A measure of the condition of water relative to ecological or human requirements.

Abbreviations

DEM	Digital elevation model.
LCDB	Land cover database
LRI	Land Resource Inventory
NIWA	National Institute of Water and Atmospheric Research
Q	Quaternary
REC	River Environment Classification
TAW	Total available water
VCSN	Virtual climate stations network