BEFORE THE ENVIRONMENT COURT
I MUA I TE KOOTI TAIAO O AOTEAROA

UNDER	the Resource Management 1991
IN THE MATTER	of of appeals under Clause 14 of the First Schedule of the Act
BETWEEN	**TRANSPOWER NEW ZEALAND LIMITED** (ENV-2018-CHC-26)
	FONTERRA CO-OPERATIVE GROUP (ENV-2018-CHC-27)
	HORTICULTURE NEW ZEALAND (ENV-2018-CHC-28)
	ARATIATIA LIVESTOCK LIMITED (ENV-2018-CHC-29)
	WILKINS FARMING CO (ENV-2018-CHC-30)

(Continued next page)

STATEMENT OF EVIDENCE OF EWEN RODWAY ON BEHALF OF THE SOUTHLAND REGIONAL COUNCIL

14 December 2018

Judicial Officer: Judge Borthwick and Judge Hassan

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(ENV-2018-CHC-31)

DAIRYNZ LIMITED
(ENV-2018-CHC-32)

H W RICHARDSON GROUP
(ENV-2018-CHC-33)

BEEF + LAMB NEW ZEALAND
(ENV-2018-CHC-34 & 35)

DIRECTOR-GENERAL OF CONSERVATION
(ENV-2018-CHC-36)

SOUTHLAND FISH AND GAME COUNCIL
(ENV-2018-CHC-37)

MERIDIAN ENERGY LIMITED Act 1991
(ENV-2018-CHC-38)

ALLIANCE GROUP LIMITED
(ENV-2018-CHC-39)

FEDERATED FARMERS OF NEW ZEALAND
(ENV-2018-CHC-40)

HERITAGE NEW ZEALAND POUHERE TAONGA
(ENV-2018-CHC-41)

STONEY CREEK STATION LIMITED
(ENV-2018-CHC-42)

THE TERRACES LIMITED
(ENV-2018-CHC-43)

CAMPBELL'S BLOCK LIMITED
(ENV-2018-CHC-44)

ROBERT GRANT
(ENV-2018-CHC-45)

SOUTHWOOD EXPORT LIMITED, SOUTHLAND PLANTATION FOREST COMPANY OF NZ, SOUTHWOOD EXPORT LIMITED
(ENV-2018-CHC-46)

TE RUNANGA O NGAI TAHU, HOKONUI RUNAKA, WAIHOPAI RUNAKA, TE RUNANGA O AWARUA & TE RUNANGA O ORAKA APARIMA
(ENV-2018-CHC-47)

PETER CHARTRES
(ENV-2018-CHC-48)

RAYONIER NEW ZEALAND LIMITED
(ENV-2018-CHC-49)

ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NEW ZEALAND
(ENV-2018-CHC-50)

Appellants

AND **SOUTHLAND REGIONAL COUNCIL**

Respondent

Introduction

1 My full name is Ewen Maurice Rodway.

2 I am an Environmental Scientist – Chemistry and Groundwater at the Southland Regional Council (**Council**).

3 I have worked as an Environmental Scientist – Chemistry and Groundwater since September of 2014. Prior to this I worked for 1 year as an Environmental Technical Officer – Groundwater for the Council. Prior to this I worked for 1 year as a Hydrogeologist for Klohn Crippen Berger in Brisbane, Australia.

4 I hold a Bachelor of Science with majoring in Geology and a Master of Science in Geology and Geochemistry from the University of Otago. I hold a certificate in Advanced Sustainable Nutrient Management from Massey University. I have 6 years of experience working in the field of water contamination and resource management.

5 My work for the Council includes technical input to the proposed Southland Water and Land Plan (**pSWLP**) development process, running the Southland Regional State of Environment ground water quality monitoring program, as well as reporting on this program to Council (and community).

6 My involvement in pSWLP to date has included technical input to the Southland Water and Land Plan development process, particularly with regard to groundwater quality, physiographic zones, and supporting technical information for the development of land use and nutrient management rules.

7 I have been asked by the Council to prepare evidence for these proceedings.

Code of Conduct

8 I confirm that I have read the Code of Conduct for expert witnesses as contained in the Environment Court Practice Note 2014. I have complied with the Code of Conduct when preparing my written statement of evidence, and will do so when I give oral evidence.

9 The data, information, facts and assumptions I have considered in forming my opinions are set out in my evidence. The reasons for the opinions expressed are also set out in my evidence.

10 Other than where I state I am relying on the evidence of another person, my evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Scope

11 I have been asked by the Council to provide evidence on two matters. The first is in relation to the state of the environment in Southland, specifically relating to groundwater quality. My evidence addresses:

(a) Background description of groundwater in Southland;

(b) Groundwater quality State of the Environment and monitoring

(c) Groundwater quality state and trend for nitrogen, phosphorus and microbial contamination.

(d) The risk that groundwater contamination poses to surface water environments.

12 The second matter I address is in relation to the Physiographic Zones. My evidence addresses:

(a) Descriptions of the water quality risks associated with each Physiographic Zone and the water quality risk assessment carried out for each zone.

(b) A summary of water quality issues in Southland as context for recognising the requirement to address high contaminant loss activities.

(c) A description of the contaminant loss associated with two high loss activities (dairy farming and winter grazing), that are widespread in Southland.

(d) The relative regional scale contribution of these dairy farming and winter grazing to contaminant loss in Southland.

(e) Dairy farming and winter grazing specific assessment of which Physiographic Zones pose the highest risk to water quality in Southland.

13 In preparing this evidence, I have read and considered a number of documents, which are referenced throughout my evidence, and a complete list of references is set out in **Appendix A** at the end of my evidence.

Executive Summary

Groundwater

14 Data and reports[1] published from the Council's SoE monitoring network data sets show several consistent themes:

(a) Anthropogenic contamination of groundwater is widespread in Southland. In particular, nitrogen and faecal contamination are of primary concern, both from a human and ecosystem health perspective.

(b) Although most monitored groundwater is suitable for drinking with respect to nitrogen, 19 of the 159 bores or wells (approximately 12%) regularly monitored between 2012 and 2016 recorded NNN concentrations in excess of the drinking water standards. Note, this analysis includes compliance monitoring bores so could be assumed to be more representative of high risk areas (high intensity agricultural land use).

(c) For the 17 year period 2000 to 2016, increasing trends in groundwater NNN have been determined at 15 of the 23 (65%) regional SoE monitoring sites with sufficient data for analysis. Decreases in concentration were detected at 3 of 23 sites monitored by the Council and 1 of 6 sites monitored by GNS[2], with trend direction at the remainder of sites being unable to be determined with confidence[3].

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[1] Including: Environment Southland (2000); Environment Southland and Te Ao Marama Incorporated (2010); Liquid Earth (2010); Moreau and Hodson (2015); Snelder et al. (2014); Daughney et al. (2015); and Hodson et al (2017).

[2] The Institute of Geological and Nuclear Sciences Limited (or "GNS Science").

[3] Hodson et al. (2017).

(d) Monitoring and modelling shows that approximately 50% (by area) of managed aquifers have NNN concentrations higher than 1.0 mg/L[4]. This indicates that one fifth of the region's groundwaters may pose a risk to ecosystem health in streams, particularly those with a high proportion of groundwater sourced baseflow and during periods of low flow[5].

(e) In 2015, 80 of 296 (approximately 27%) of groundwater monitoring sites sampled for faecal contamination had median *E. coli* values in excess of drinking water standards[6].

Physiographic zones

15 The Physiographic Zones underpin an array of management approaches outlined in the pSWLP. The nine Physiographic Zones are:

(a) Alpine

(b) Bedrock/Hill Country

(c) Central Plains

(d) Gleyed

(e) Lignite – Marine Terraces

(f) Old Mataura

(g) Oxidising

(h) Peat Wetlands

(i) Riverine

16 The Physiographic Zones differ in the way sediment, microbes (e.g. *E. coli*) and nutrients (nitrogen and phosphorus) are attenuated and transported over and through the soil, aquifers (areas of groundwater) and into rivers and streams.

17 Four main transport pathways have been identified via which contaminants travel to groundwater and surface water. These are:

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[4] Rissmann (2012).

[5] Snelder et al. (2014) and Ministry for the Environment (2017).

[6] Daughney et al. (2015).

(a) Overland flow (where excess precipitation flows across the land surface in response to slope and gravity (also referred to as surface runoff) this commonly flows directly and rapidly to watercourses, streams or rivers).

(b) Artificial drainage (where soil water moves through open tile, plastic and mole pipe drains toward surface water features).

(c) Deep drainage (vertical movement of contaminants down through the soil zone as either matric flow or natural bypass flow to underlying groundwater and includes water movement through the aquifer system to receiving environments, such as rivers, streams, lakes or the coastal environment).

(d) Lateral drainage (movement of contaminants laterally through the soil zone toward surface water features).

18 Water quality risk is also influenced by key contaminant attenuation processes, which also differ between the Physiographic Zones.

Background description of Groundwater in Southland

19 Groundwater is an extremely valuable resource for the Southland Region. Groundwater forms an integral part of the hydrological cycle and has a significant influence on aquatic ecosystems in riverine and wetland habitats. Groundwater is extensively used for domestic, municipal, industrial and farm water supplies. In addition, the assimilative capacity[7] of the region's groundwater systems plays an important role in the treatment of point and non-point source contaminant sources[8]. In other words, groundwater systems provide an important ecosystem service whereby they remove or dilute anthropogenic contaminants through a multitude of processes.

20 The majority of the aquifer systems in Southland's alluvial gravels are shallow, unconfined, and receive a significant proportion of water recharge from land surface infiltration. As a consequence, groundwater in these aquifers is susceptible to the activities occurring

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[7] 'Assimilative capacity' here refers to the ability of an aquifer or groundwater system to attenuate contaminants, whether that be via dilution, chemical transformation, filtration or adsorption.

[8] Liquid Earth (2010).

on the land surface and in particular water soluble contaminants associated with those uses.

21 Southland has a mosaic of unconfined, shallow groundwater aquifers that exchange groundwater to surface water relatively quickly. Approximately 40-60% of all of the water in Southland streams is groundwater from these aquifers[9]. However, it is highly variable across the region, with lowland streams having a much higher proportion of groundwater than alpine streams.

22 The mostly shallow groundwater table, relatively thin aquifer host geologies, and high hydraulic connection to surface waters means that groundwater within unconfined aquifers with hydraulic connection to surface waters is generally young, with an average residence time or age of less than 10 years[10]. Elsewhere in New Zealand, aquifers are often much deeper and can be up to several thousand years in age (e.g. Canterbury and large areas of the Waikato). Notable exceptions in Southland are small areas within the Te Anau Basin and a few lowland aquifers hosted by thicker and older alluvial formations.

23 The importance of groundwater quality to ecosystem health is internationally recognised[11], and is increasingly recognised in Southland where groundwater and surface waters are often highly connected[12]. Groundwater can transport significant amounts of nitrogen and phosphorus that can have eutrophication[13] effects in surface water environments such as streams, rivers, wetlands, estuaries, lagoons and the coastal environment[14].

24 Groundwater systems are ecosystems themselves containing abundant microbial communities as well as aquatic invertebrates known as stygofauna. Stygofaunal communities can include crustaceans, snails, worms, mites, and beetles. The health of these

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[9] Liquid Earth (2012).

[10] Daughney et al. (2015).

[11] Griebler and Avramov (2015).

[12] Rissmann et al. (2012).

[13] Eutrophication is the process whereby a water body becomes enriched with nutrients (most commonly nitrogen and phosphorus) resulting in excessive proliferation of plants and algae. This can have many subsequent detrimental effects on the existing ecosystem.

[14] Rissmann et al. (2012); Moreau et al. (2018); Snelder et al. (2014).

ecosystems and the ecosystem services they provide (such as water purification) can be compromised depending on the state of the system[15].

25 The region has a limited extent of potable (or drinkable) groundwater, compared with other regions. This is because its fluvio-glacial[16] gravels form only a thin veneer over poorly permeable basement rocks. Groundwater within basement or tertiary age rock tends to be poorly potable and needs treatment before use. Groundwater quality in the Southland Region is influenced by a range of factors including: the physical and chemical interactions water has with differing soil and geological materials; the nature and source of aquifer recharge; and the overall rate of groundwater circulation within an aquifer system.

26 Groundwater is used as a source of human drinking water by a number of population centres in Southland, as well as by individual households in addition to rain water supplies. Compromised drinking water quality can result in negative human health outcomes as have well as subsequent negative social and economic impacts.

27 Groundwater human health related issues in Southland are generally related to the presence of either microbial (as indicated by *E.coli*[17]) or nitrogen contamination. Elevated *E.coli* levels are mainly related to poor well-head construction and point source contamination (e.g. leaking sewage tanks or stock access to well heads)[18]. Widespread nitrogen contamination is primarily related to non-point, diffuse sources from agricultural land uses[19].

Notes on terminology

28 Within my evidence the term “nutrients” includes the plant available forms of nitrogen and phosphorus. In my evidence I have endeavoured to use the same terminology that is used by Mr Hodson in his evidence. For completeness, I have set out the relevant terminology below.

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[15] Fenwick et al. (2018).

[16] Gravel deposits derived from river or glacial activity.

[17] Escherichia coli (*E. coli*) levels are used as an indicator of the risk posed to human health.

[18] Daughney et al. (2015) and Snelder et al. (2014).

[19] Snelder et al. (2014).

29 Nitrogen can be present in an aquatic environment in a variety of forms and oxidation states. Both the oxidised and reduced inorganic nitrogen species (being Nitrite (NO_2^-), Nitrate (NO_3^-), ammonium (NH_4^+), ammonia (NH_3)), and organic nitrogen fractions (being dissolved organic nitrogen (**DON**), and particulate organic nitrogen (**PON**)) are commonly found in all freshwater, estuarine and coastal waters. Nitrate, nitrite, ammonium and DON are directly available for plant uptake, supporting production in both the algal and higher plant communities.

30 Hereafter the form of nitrogen referred to in my evidence is Nitrate Nitrite Nitrogen (**NNN**). NNN is the concentration of nitrogen that is present in the form of Nitrite (NO_2^-) and Nitrate (NO_3^-). This may be referred to in other documents as Total Oxidised Nitrogen (**TON**).

31 NNN is the measure of nitrate the Council has historically tested and recorded in surface and ground water environments and is used to assess against nitrate guidelines and standards. This is appropriate as it provides the longest duration of consistent record for trend analysis and nitrite concentrations are a very small proportion of NNN in most surface and ground water environments.

32 The form of phosphorus referred to in my evidence is dissolved reactive phosphorus (**DRP**). DRP is the form of phosphorus immediately available to support algae and plant growth.

Groundwater - State of Environment monitoring and background

33 The Council operates a State of the Environment (**SoE**) groundwater quality monitoring programme within the region. The regional-scale monitoring programme has been designed to assess indicators of water quality in terms of both current state and long-term trends.

34 Monitoring water quality state and trend involves measuring the physical and chemical properties of water such as temperature, dissolved oxygen, pH, major and trace ion concentrations, nutrient concentrations, and micro-organism (*E.coli*) concentrations at a quarterly frequency (every 3 months).

35 The main anthropogenic groundwater contaminants[20] of concern to freshwater ecosystem health and human health are nitrogen, disease causing micro-organisms (microbial contamination), and in some places phosphorus. Some background on these contaminants is given below.

Nitrogen

36 Nitrogen is a common anthropogenic contaminant in Southland groundwater. In groundwater, as described above, nitrogen is present in ground and surface water in several different forms. Nitrogen is most commonly present as the oxidised form nitrate (NO_3^-). As described above, NNN is the concentration of nitrogen that is present in the form of Nitrite (NO_2^-) and Nitrate (NO_3^-). NNN concentrations above approximately 1 mg/L are primarily anthropogenic in origin. Concentrations above 3.5 mg/L are considered indicative of moderate to high anthropogenic impacts[21].

37 Diffuse pollution (non-point sources) from agriculture (animal excretion and fertiliser application) is the primary driver for widespread elevated NNN concentrations in Southland groundwater. Discharge from point sources such as septic tanks and landfills also contribute to localised contamination[22].

38 Groundwater contamination is variable across the region, primarily due to the distribution of intensive agriculture and the inherent susceptibility of the shallow groundwater to NNN contamination. This susceptibility is primarily dependant on natural landscape features such as the soil and aquifer chemical, physical and hydrologic properties.[23] The New Zealand Drinking Water Standard for nitrogen is 11.3 mg/L nitrogen in the form of nitrate[24] and this limit can be

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[20] Anthropogenic contaminants refers to those contaminants originating from humans and/or their activities.

[21] Daughney and Reeves (2005); Morgenstern and Daughney (2012); and Rissmann et al. (2011, 2012).

[22] Liquid Earth (2010).

[23] These effects are described and discussed extensively in Rissmann et al. (2016) and Hughes et al. (2016).

[24] Ministry of Health (2008) and WHO (2003).

exceeded in Southland groundwater in areas of high anthropogenic use[25].

39 NNN can be removed from groundwater for drinking purposes via treatment. However, this process is expensive and in some cases impractical.

40 Groundwater contributes a high proportion of baseflow[26] to surface waters in the Southland region. This baseflow can carry significant loads of plant nutrients (particularly nitrogen) to the surface water systems and contribute to eutrophication of waterways. There are no specific standards for what groundwater nitrogen or phosphorus concentrations should be to protect surface water ecosystems because these would have to account for the uncharacterised attenuation processes that occur in aquifers and during discharge to the surface water environment.

Microbial Contamination

41 Contamination of groundwater by micro-organisms is of particular concern in regard to drinking water quality and human health. The Council measures concentrations of *E. coli* in groundwater as an indicator organism for faecal contamination and gives an indication of the risk to human health. Faecal contamination is generally rapidly attenuated in soil and groundwater systems[27] and hence is commonly associated with point source inputs rather than widespread diffuse sources. Point sources often include bores or wells with poor head protection, leaky or malfunctioning septic systems, offal pits or landfills, and stock access to well heads[28]. Some soils with particularly open soil structure such as vertisols[29] may be susceptible to bypass flow or direct transport of faecal material with drainage water to shallow groundwater[30].

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[25] Rissmann (2012) and Hodson et al. (2017).

[26] Baseflow is the portion of stream or river flow derived from delayed pathways such as drainage from soils, aquifers, and swamps. These sources provide sustained stream flow between precipitation events.

[27] Toze (2004) and references within.

[28] Daughney et al. (2015) and Liquid Earth (2010).

[29] Vertisols are soils with high expansive clay content that expand in wet conditions and contract to form vertical cracks or flow paths in dry conditions.

[30] Rissmann et al. (2016) and Hughes et al. (2016).

42 The New Zealand Drinking Water Standard requires that *E. coli* is not detected and therefore any detection within the sample is a breach of the Standard[31]. The most common detection limit for the analysis is 1 colony-forming unit (CFU).

Phosphorus

43 Phosphorus is a groundwater contaminant of concern in some areas of Southland. Particularly in areas where soils and aquifer chemical, physical and hydrological properties result in a high susceptibility of phosphorus loss from land use activities. For example, soil and aquifer materials with high organic carbon content (such as peat) are prone to phosphorus mobilisation and loss[32]. Phosphorus contamination does not generally pose a risk to human health and does not have a maximum allowable value in the New Zealand drinking water standards. However, the discharge of groundwater carrying phosphorus to surface waterbodies can contribute to eutrophication in lakes, lagoons, streams and rivers[33].

Groundwater quality state and trends in Southland

44 In this part of my evidence I address groundwater quality state and trends in Southland, as follows:

(a) Summary of state and trends for groundwater quality;

(b) Nitrogen state, risks to surface waterbodies, and trend;

(c) Microbes state; and

(d) Phosphorus state and trend.

Summary of state and trends for groundwater quality

45 Data and reports[34] published from the Council's SoE monitoring network data sets show several consistent themes:

(a) Anthropogenic contamination of groundwater is widespread in Southland. In particular, nitrogen and faecal contamination are

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[31] Ministry of Health (2008).

[32] Rissmann et al. (2016); Hughes et al. (2016); and McDowell & Monaghan (2015).

[33] McDowell et al. (2009).

[34] Including: Environment Southland (2000); Environment Southland and Te Ao Marama Incorporated (2010); Liquid Earth (2010); Moreau and Hodson (2015); Snelder et al. (2014); Daughney et al. (2015); and Hodson et al (2017).

of primary concern, both from a human and ecosystem health perspective.

(b) Although most monitored groundwater is suitable for drinking with respect to nitrogen, 19 of the 159 bores or wells (approximately 12%) regularly monitored between 2012 and 2016 recorded NNN concentrations in excess of the drinking water standards. Note, this analysis includes compliance monitoring bores so could be assumed to be more representative of high risk areas (high intensity agricultural land use).

(c) For the 17 year period 2000 to 2016, increasing trends in groundwater NNN have been determined at 15 of the 23 (65%) regional SoE monitoring sites with sufficient data for analysis. Decreases in concentration were detected at 3 of 23 sites monitored by the Council and 1 of 6 sites monitored by GNS[35], with trend direction at the remainder of sites being unable to be determined with confidence[36].

(d) Monitoring and modelling shows that approximately 50% (by area) of managed aquifers have NNN concentrations higher than 1.0 mg/L[37]. This indicates that one fifth of the region's groundwaters may pose a risk to ecosystem health in streams, particularly those with a high proportion of groundwater sourced baseflow and during periods of low flow[38].

(e) In 2015, 80 of 296 (approximately 27%) of groundwater monitoring sites sampled for faecal contamination had median *E. coli* values in excess of drinking water standards[39].

Nitrogen (state)

46 The New Zealand Drinking Water Standard sets the maximum allowable value (**MAV**) at 11.3 mg/L of nitrogen in the form of nitrate[40]. Monitoring indicates that most of Southland's groundwaters

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[35] The Institute of Geological and Nuclear Sciences Limited (or "GNS Science").

[36] Hodson et al. (2017).

[37] Rissmann (2012).

[38] Snelder et al. (2014) and Ministry for the Environment (2017).

[39] Daughney et al. (2015).

[40] Ministry of Health (2008) and WHO (2003).

have NNN concentrations below this limit and are therefore fit for human consumption with respect to this contaminant[41].

47 19 of the 159 bores or wells (approximately 12%) regularly monitored between 2012 and 2016 recorded NNN concentrations in excess of Drinking Water Standards (see Figure 1)[42]. These primarily occur in parts of the: Waimea Plains; Edendale; Lower Mataura; Knapdale; Central Plains; Makarewa; Waihopai; Lower Oreti; Castle Rock; Five Rivers; Awarua; Waimatuku; Lower Aparima; Te Waewae; Blackmount; Longridge; Croydon; Riversdale; Upper Aparima; Wendonside aquifer systems. Note, this analysis includes compliance monitoring bores so could be assumed to be more representative of high risk areas (high intensity agricultural land use).

48 As discussed earlier, NNN concentrations above 1 mg/L are generally of anthropogenic origin. It is predicted that NNN concentrations exceed 1 mg/L in approximately 50% or 265,000 ha of the managed groundwater zones (see Figure 2)[43]. Similarly, approximately 62% of all sites ever monitored by Environment Southland (n = 1894) have recorded NNN concentrations above 1 mg/L[44]. This reflects the high sensitivity of the majority of Southland aquifers to losses associated with intensive land use as identified in several groundwater quality risk assessments.[45]

49 Figure 3 below shows the extent of groundwater modelled NNN concentrations relative to 8.5 mg/L or 75% of the drinking water standard[46]. This highlights the estimated of extent of highly contaminated groundwater or ‘hotspots’[47] within Southland. The pSWLP groundwater management zones are shown for reference.

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[41] Rissmann (2012) and Daughney et al. (2015).

[42] Hodson et al. (2017).

[43] Rissmann (2012) – 50% refers to area not volume.

[44] Data held in the Environment Southland database, available upon request.

[45] Wilson and Hughes (2007); Rissmann (2011); and Hughes et al. (2016).

[46] Rissmann (2012).

[47] A groundwater NNN hotspot refers to a localised area of groundwater where NNN concentrations are significantly elevated above background or even exceed the drinking water standards.

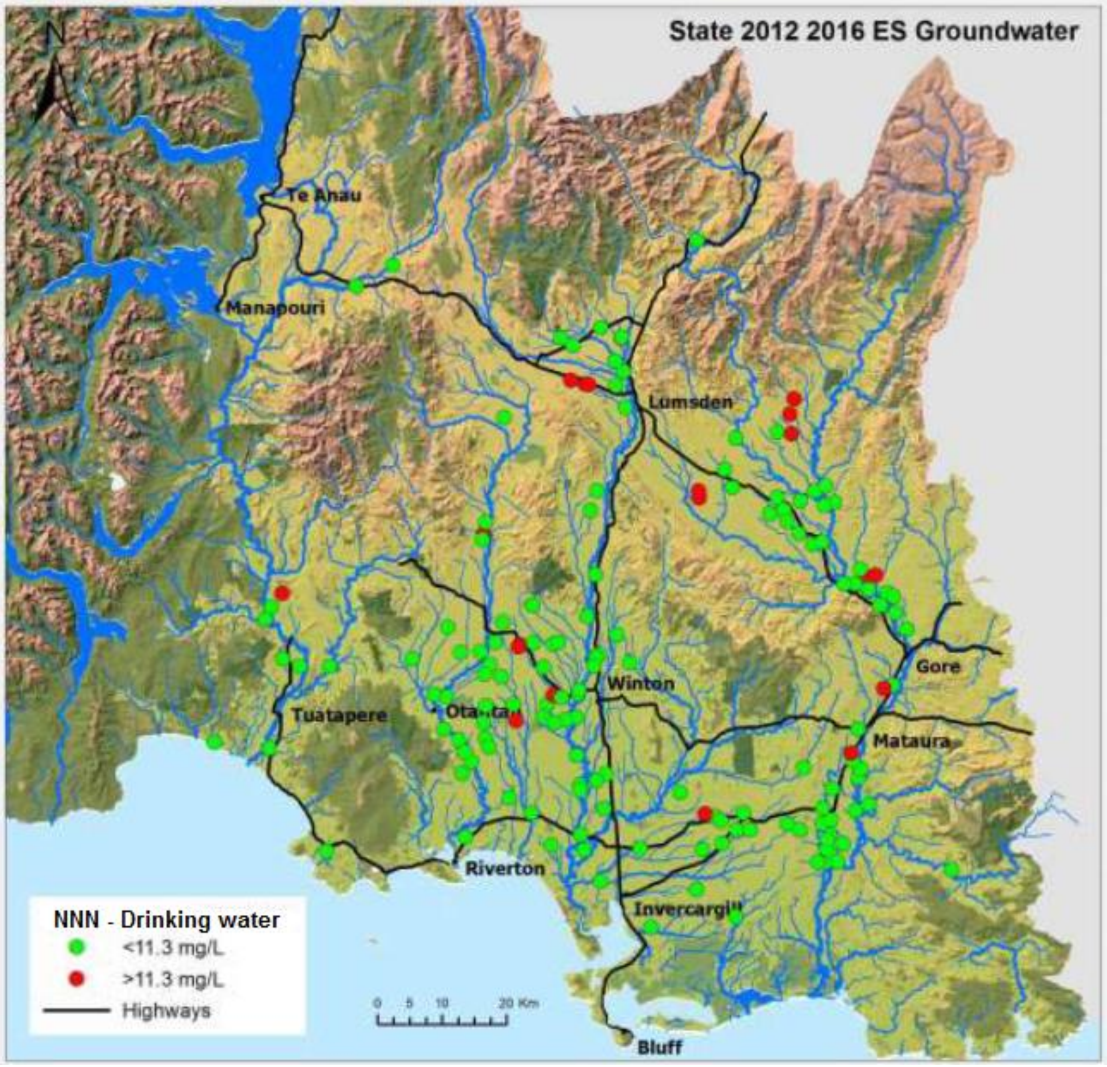

Figure 1: Environment Southland groundwater quality state for NNN in drinking water (2012-2016) (modified from Hodson et al., 2017).

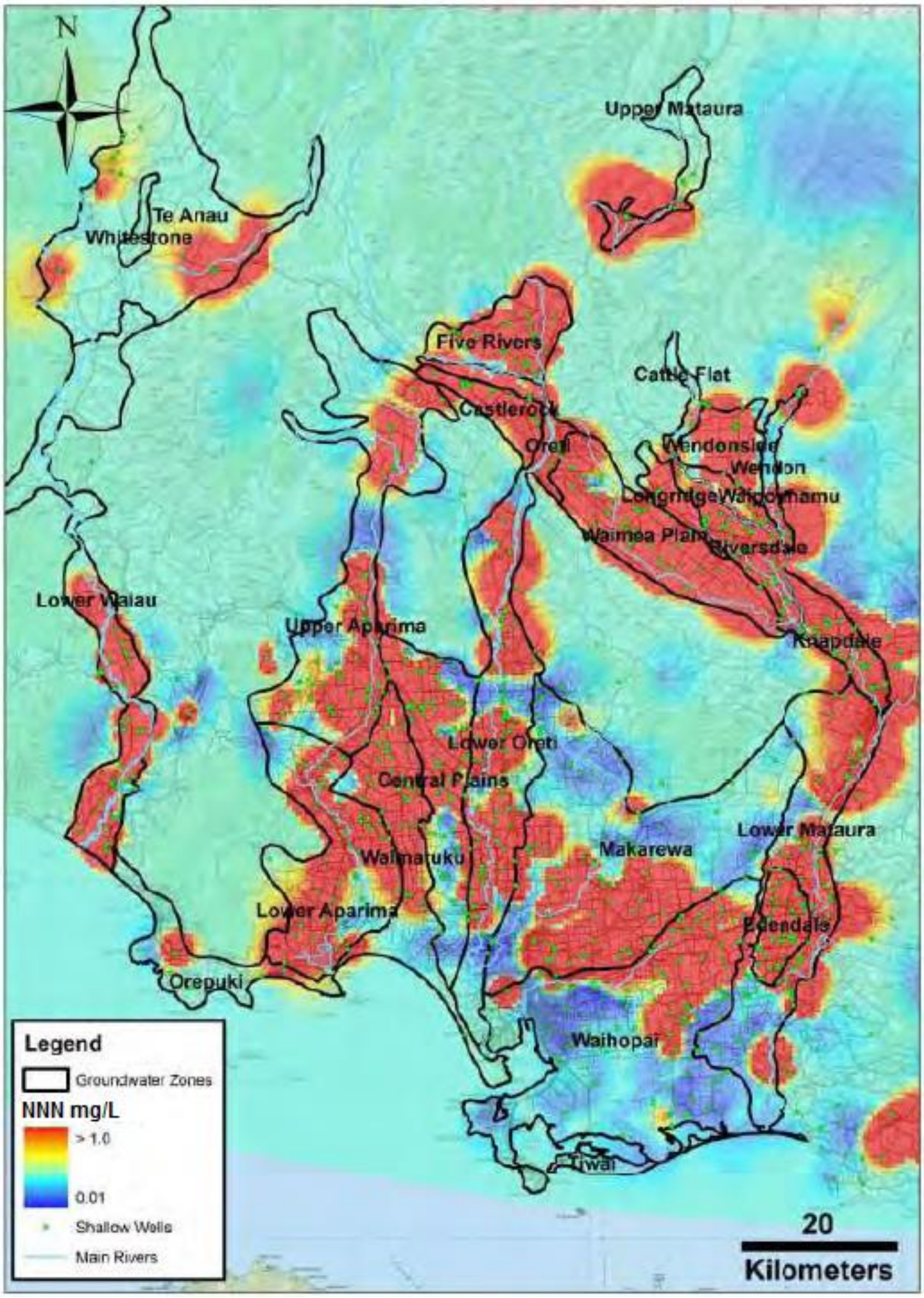

Figure 2: Extent of NNN concentrations in excess of the modern day background threshold of 1 mg/L (modified from Rissmann 2012). (Note the groundwater management zone boundaries represent those of the Regional Water Plan).

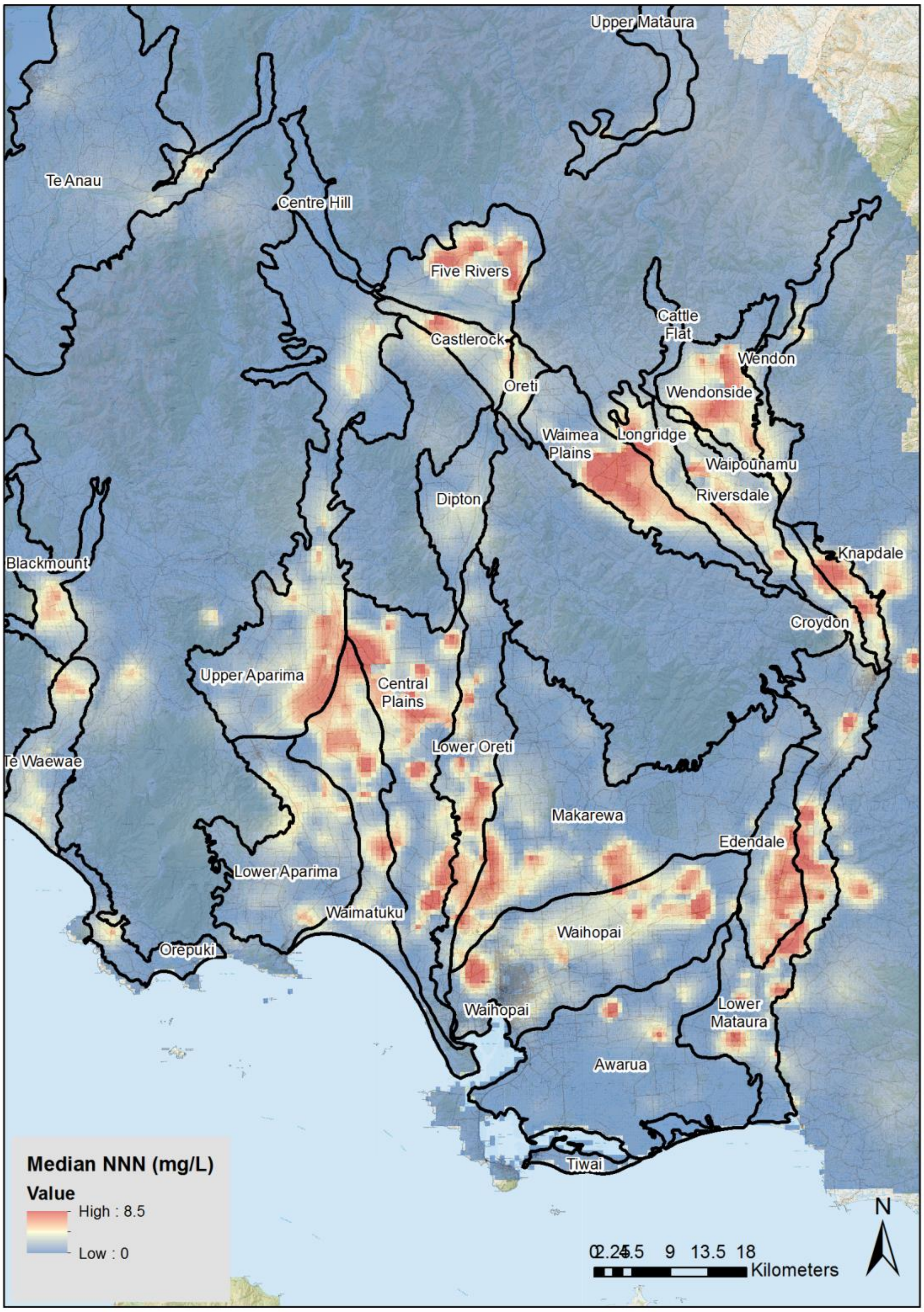

Figure 3: Extent of NNN concentrations relative to 75% of the maximum allowable value for drinking water (11.3 mg/L). Shaded red areas indicate modelled concentrations that are ≥8.5 mg/L.

50 It is my opinion that there is widespread NNN contamination in Southland groundwater that poses a risk to surface water ecosystem health and in some places exceeds the New Zealand standards for drinking water. Further intensification of land use without increased mitigation of nitrogen loss would be expected to result in an expansion of elevated NNN concentrations, or NNN ‘hotspots’ within the managed groundwater zones[48].

Nitrogen - the risk to surface water environments

51 The majority of Southland rivers and streams derive between 40% to 60% of their flow from groundwater[49]. The percentage of flow from groundwater increases during low flow conditions, when streams and rivers are almost entirely derived from groundwater. In particular, riparian aquifers have a high degree of connectivity between surface and groundwater, and terrace aquifers commonly discharge to surface water bodies such as streams and rivers.

52 The high connectivity between regional surface water and groundwater means that contaminants in groundwater can significantly contribute to the contaminant levels of Southland’s rivers, lakes and estuaries[50].

53 The groundwater contaminant of most concern is NNN. This is because of its potential eutrophication effects on surface water. Phosphorus and microbes are more readily attenuated in groundwater systems and are therefore of less concern particularly in the oxidised groundwater systems that are most hydraulically connected to surface waters in Southland.

54 The pSWLP does not specify nitrogen thresholds in groundwater with regards to ecosystem health, but Objective 8 requires aquifers that meet the Drinking Water Standards and any freshwater objectives (established under the Freshwater Management Unit process) for connected waterbodies to be maintained. Research suggests that to avoid toxic growth effects on stream species, annual median NNN should not exceed 1.0 mg/L in surface waters[51]. The trigger value[52]

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[48] Rissmann et al. (2016) and Hughes et al. (2016).

[49] Rissmann et al. (2012) and Liquid Earth (2010).

[50] Snelder et al. (2014).

[51] Snelder et al. (2014) and Ministry for the Environment (2017).

for NNN in lowland rivers is 0.444 mg/L, indicating that concentrations in excess of this may be having adverse effects on ecosystems. (particularly eutrophication) and investigation should be undertaken. As described above, it is predicted that NNN concentrations exceed 1 mg/L in approximately 50% or 265,000 ha of the managed groundwater zones (Figure 2)[53]. Similarly, approximately 62% of all sites with data available to Environment Southland (n = 1894) have recorded NNN concentrations above 1 mg/L[54].

55 It is important to note that due to mixing, dilution and chemical attenuation processes concentrations in groundwater are likely to be higher than those realised in the receiving surface water. For example groundwater with high NNN concentrations will likely undergo attenuation though the forms of denitrification and dilution prior to, and during discharge to any surface water body. This means the resulting NNN concentrations in the surface water body may be considerably lower than those observed in groundwater.

56 However, conservatively, the elevation of NNN concentrations does indicate that approximately half of the region's groundwater may pose a risk to ecosystem health in regional streams, particularly those with a high proportion of high base flow and during periods of low flow.

57 In demonstration of this, groundwater NNN concentrations can be compared to the NPS-FM National Objectives Framework (**NOF**) surface water toxicity objectives[55]. These are not numerical objectives for groundwater and this assessment is presented for comparative purposes only (Figure 4).

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[52] Trigger values as defined in ANZECC (2000) are used to assess risk of adverse effects due to contaminants.

[53] Rissmann (2012) – 50% refers to area not volume.

[54] Data held in the Environment Southland database, available upon request.

[55] Ministry for the Environment (2017).

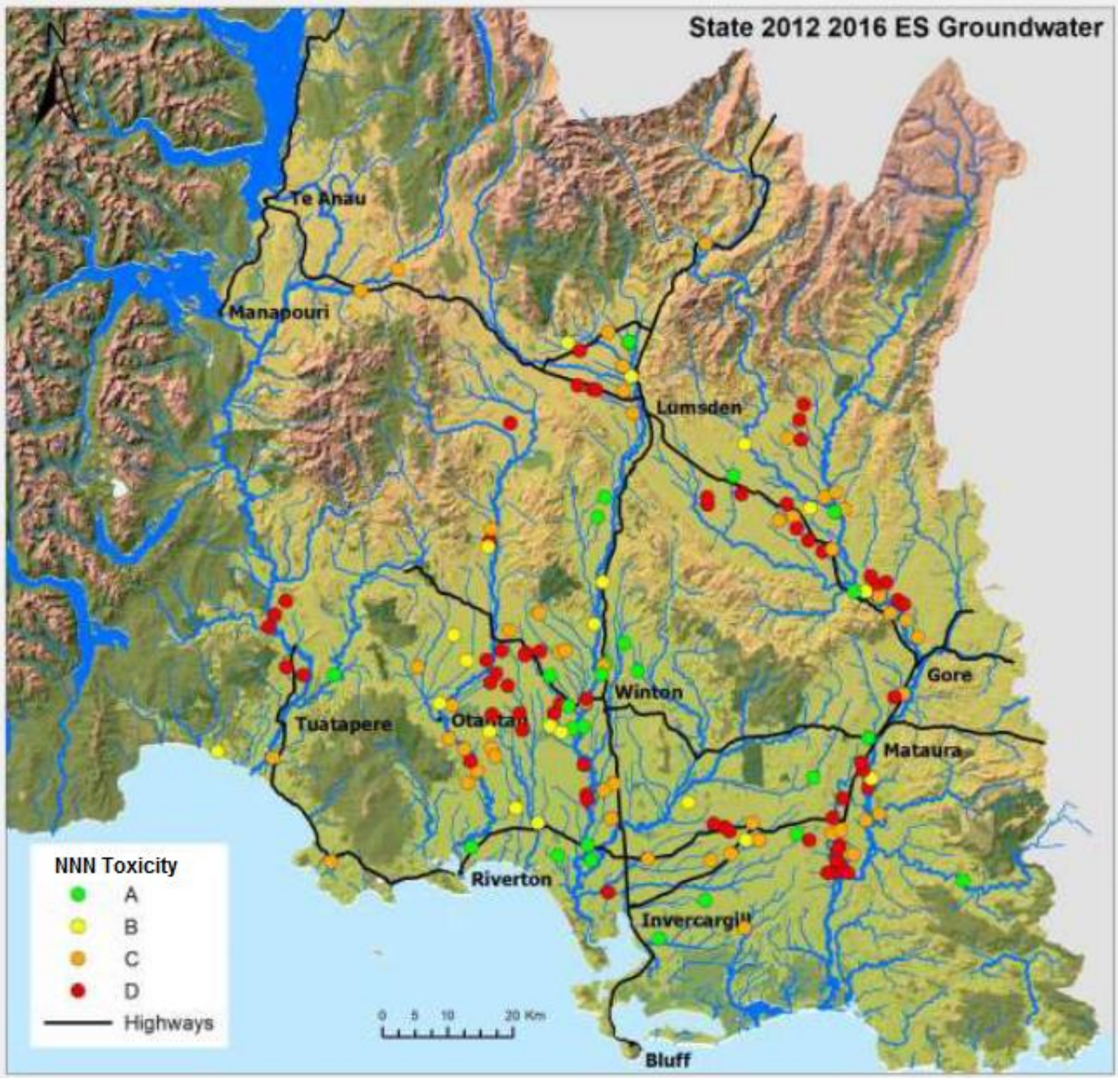

Figure 4 Groundwater quality state for NO_3-N surface water toxicity (2012-2016) (from Hodson et al., 2017).

58 Again, it is important to consider that the level of risk presented in Figure 4 may not be fully realised due to attenuation processes, prior to and during the discharge of groundwater to any given surface water body.

59 In demonstration of the risk to surface water Table 1 (below) displays the median NNN concentrations for the Edendale, Waimea Plain and Waimatuku aquifers and correspondingly the streams they provide recharge to. These streams have some of the highest surface water NNN concentrations in the region.

Table 1: NNN concentrations in three highly impacted aquifers and the respective streams discharging from those aquifer systems.

Aquifer	Aquifer median NNN mg/L[56]	Stream receiving aquifer discharge	Stream median NNN mg/L[57]	Stream maximum NNN mg/L[58]
Edendale	4.9	Oteramika	1.6	4.6
Waimea Plain	6.1	Waimea	2.8	5.4
		Longridge	3.45	7.8
Waimatuku	5.7	Waimatuku	3.35	7.4

60 Table 1 presents only four examples where aquifer and stream NNN concentrations are correspondingly elevated. There is no analysis available that assesses and correlates groundwater NNN and stream NNN concentrations for the entire region. However, Figures 2, 3 and 4 demonstrate the regional scale of this risk.

61 Moreau et al. (2018) provide another example of the measured impact of groundwater inflow on instream NNN concentrations. As the Waimea stream flows past a groundwater nitrogen hotspot at Balfour[59], in stream NNN concentrations were measured to increase from 1.41 mg/L to 3.30 mg/L. This is inferred to be a result of inflow from groundwater sourced tributaries with NNN concentrations ranging from 8.7 mg/L to 14.1 mg/L. If an increase in NNN concentration were characterised by annual median measurements this would equate to a change in attribute state from the B to C band under the NOF[60].

62 Please refer to the evidence of Mr Hodson for the assessment of stream NNN concentrations in Southland.

Nitrogen (trend)

63 For the 17 year period from 2000 to 2016, increasing trends in groundwater NNN have been determined at 15 of the 23 (65%) regional SoE monitoring sites with sufficient data for analysis (Figure

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[56] Liquid Earth (2010).

[57] Hodson et al. (2017).

[58] Hodson et al. (2017).

[59] Rissmann (2012).

[60] Ministry for the Environment (2017).

5)[61]. Decreases in NNN concentration were detected at 3 of 23 sites monitored by the Council, and 1 of 6 sites monitored by GNS. Trend direction at the remainder of sites was unable to be determined with confidence[62].

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[61] Minimum data requirements for trend analysis were that data is available for more than 90% of sampling dates within the respective time period, so 4 samples per year per parameter for groundwater (applied for ES and GNS data) that imputed values account for less than 15 % of the observations. As described in Hodson et al. (2017). These criteria meant that compliance monitoring data were not analysed.

[62] Hodson et al. (2017).

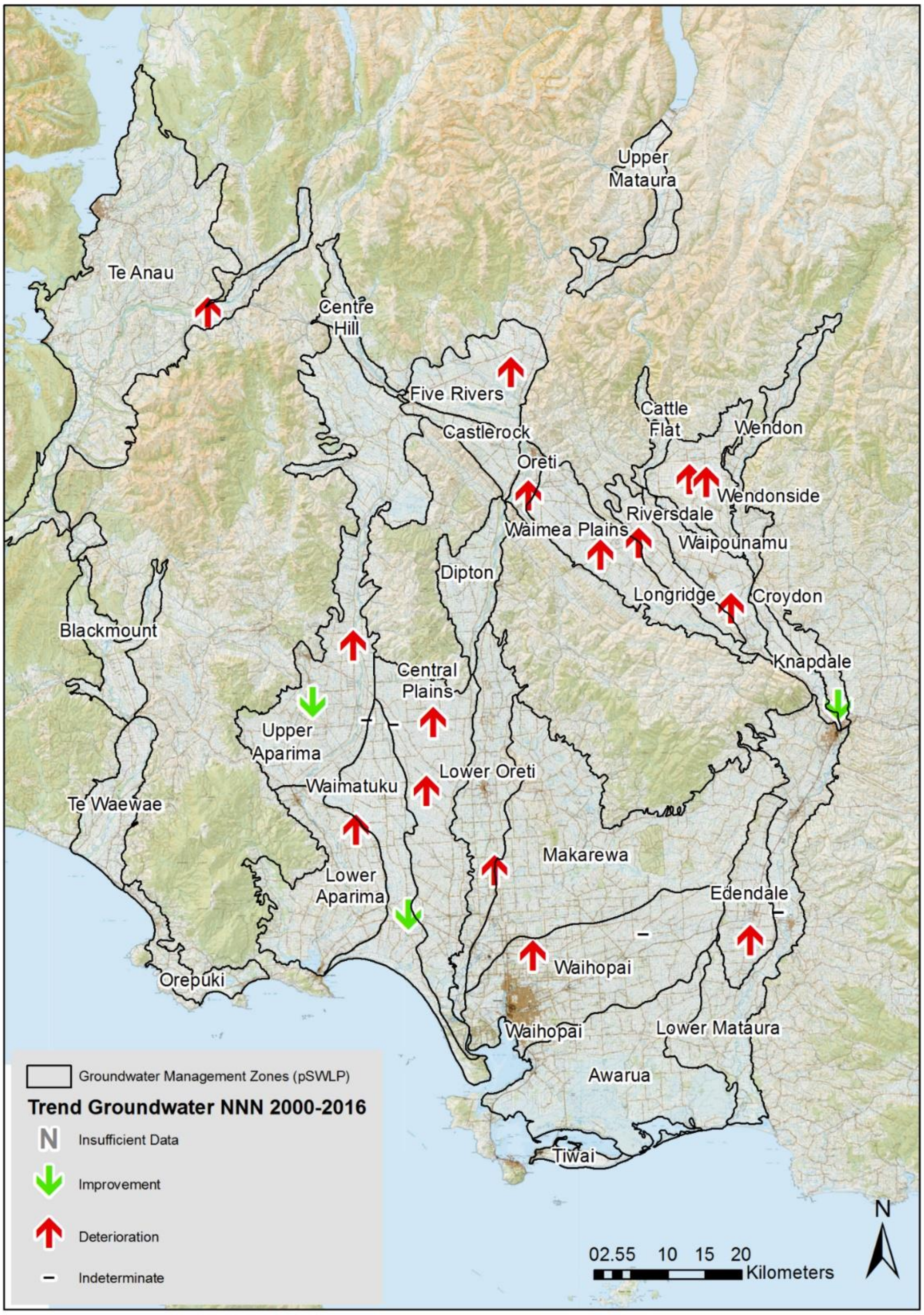

Figure 5: Southland groundwater quality trend between 2000 and 2016 for NNN (modified from Hodson et al., 2017). The pSWLP groundwater management zones are shown for reference.

64 For the 10 year period from 2007 to 2016, increases in NNN concentration were detected at 10 of 25 monitored by the Council, and 1 of 6 sites monitored by GNS. Decreases in NNN concentration were detected at 6 of 25 sites monitored by Environment Southland and 1 of 6 sites monitored by GNS. Trend direction at the balance of sites was unable to be determined with confidence[63].

65 For the 5 year period from 2012 to 2016, increases in NNN concentration were detected at 5 of 25 sites operated by Environment Southland. Decreases NNN concentration were detected at 6 of 25 monitored by the Council and 2 of 6 sites monitored by GNS. Trend direction at the balance of sites was unable to be determined with confidence[64].

66 The longer 17 year time period is considered to provide a more robust trend assessment than the more recent 2012-2016 time period. The 2000-2016 analysis utilises considerably more samples and assesses a longer time period that is more relevant to groundwater given the potential lag times and processes involved.

67 It is my opinion that there have been widespread, and meaningful increases in NNN concentration in Southland groundwater since 2000, as displayed in the 2000 to 2016 trend assessment. Furthermore, the apparent improvement (i.e., less deteriorating sites and more improving sites) depicted in the 2012-2016 trend assessment should be considered with caution, as for the majority of sites (56%), a trend direction was not able to be determined with confidence. There are six sites in which measured NNN concentrations have decreased in the 2012-2016 period. The reasons for these decreases are unclear, but may be related to changes in land use practices or changes in climate, groundwater recharge, and or hydraulic properties associated with the site.

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[63] Hodson et al. (2017).

[64] Hodson et al. (2017).

Phosphorus (state)

68 There are no recent assessments of phosphorus state in Southland groundwater. This is primarily due to a lack of an appropriate comparative framework to assess against.

Phosphorus (trend)

69 For DRP, 9 of 19 sites with sufficient data for analysis have a decreasing trend in concentration (Figure 6). Three sites have an increasing trend in concentration. For the remaining seven sites, the trend direction is unable to be confidently determined[65].

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[65] Hodson et al. (2017).

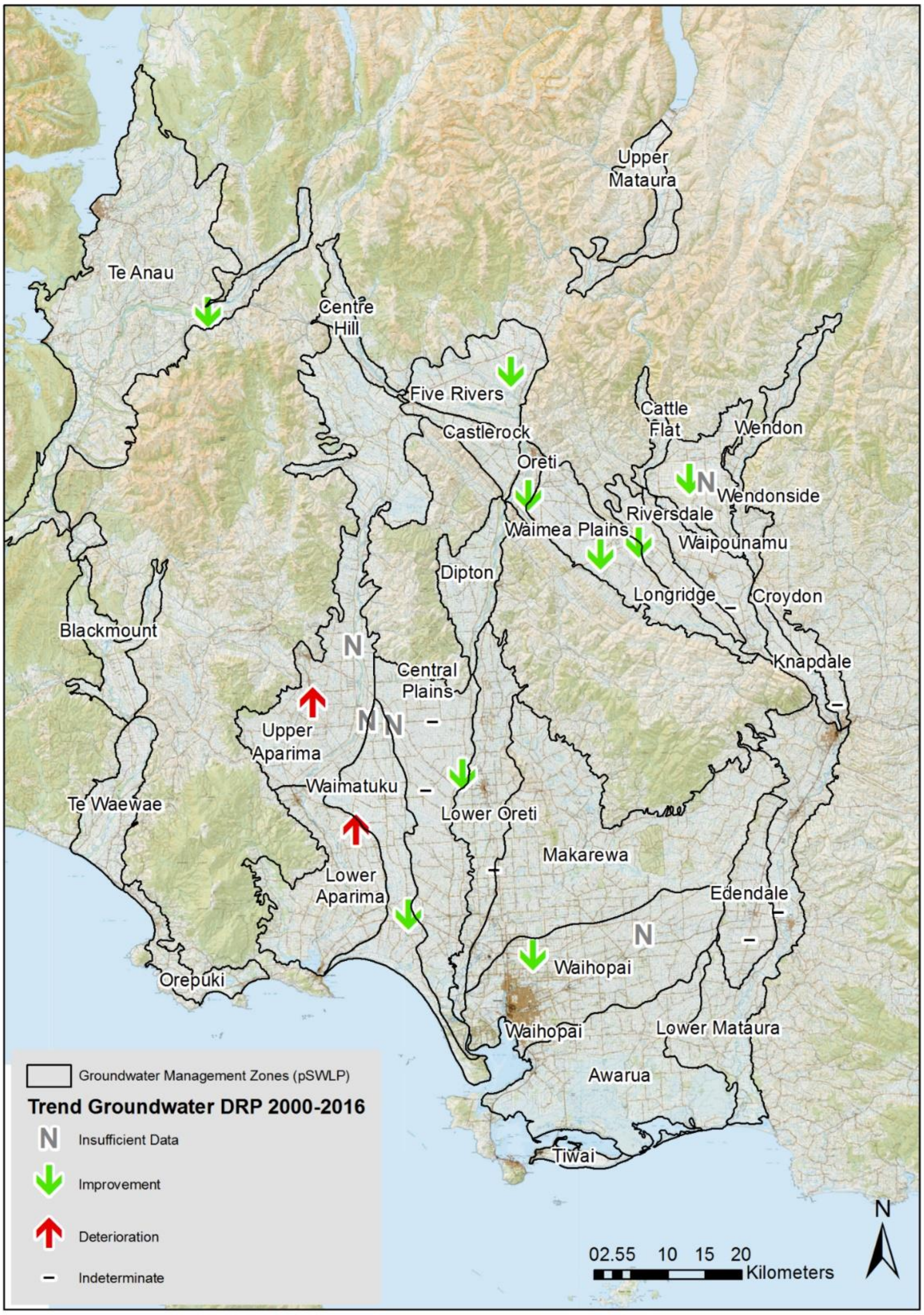

Figure 6: Southland groundwater quality trend between 2000 and 2016 for DRP (modified from Hodson et al., 2017). The pSWLP groundwater management zones are shown for reference.

Microbial contamination (state)

70 The Drinking Water Standards for New Zealand specify that *E.coli* should not be present in water to be used for human consumption. Monitoring shows that the number of reported instances of *E. coli* in Southland wells increased between 2001 and 2010 (Figure 7). However, the proportion of affected wells has decreased. This is probably due to improved well-head construction and well protection. In 2010, 23% of the groundwater bores showed the presence of *E. coli*[66].

71 A 2015 assessment using all available data found median *E. coli* values were elevated above the New Zealand Drinking Water Standard threshold (> 1 cfu/100mL) at 80 of 296 groundwater sites in Southland, where median values could be determined[67]. This indicates that approximately 27% of regional groundwater sites showed the presence of indicator bacteria *E. coli*, and were therefore unsuitable to be used for drinking water without treatment.

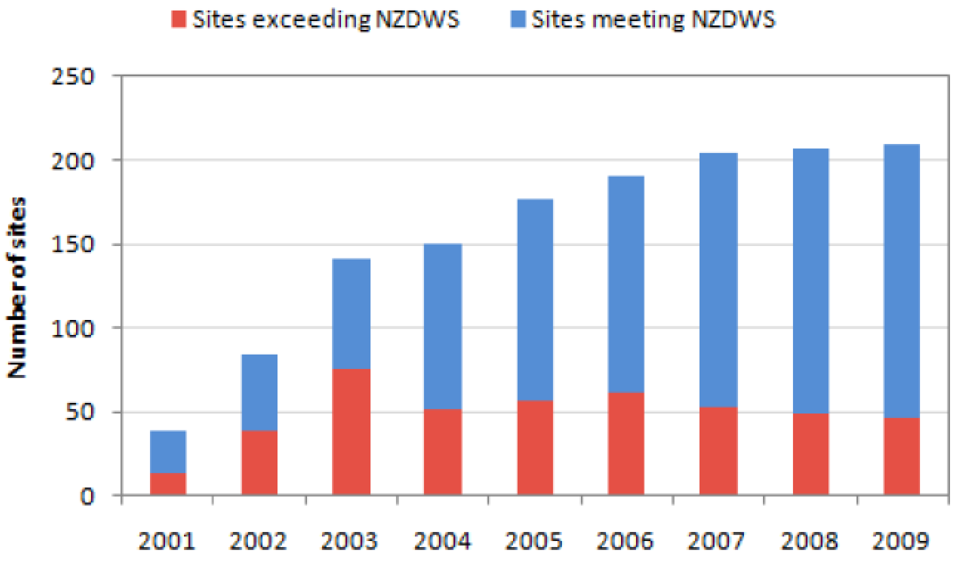

Figure 7: Proportion of monitoring bores showing presence of *E. coli* (Liquid Earth, 2010).

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[66] Liquid Earth (2010).

[67] Daughney et al. (2015).

Physiographic Zones

72 In this part of my evidence I discuss the Physiographic Zones. In particular, I address:

(a) Descriptions of the water quality risks associated with each Physiographic Zone and the water quality risk assessment carried out for each zone.

(b) A summary of water quality issues in Southland as context for recognising the requirement to address high contaminant loss activities.

(c) A description of the contaminant loss associated with two high loss activities (dairy farming and winter grazing) that are widespread in Southland.

(d) The relative regional scale contribution of these dairy farming and winter grazing to contaminant loss in Southland.

(e) Dairy farming and winter grazing specific assessment of which Physiographic Zones pose the highest risk to water quality in Southland.

73 The background to the development of Physiographic Zones in the pSWLP and the limitations and potential uses of the Physiographic Zones is addressed by Dr Snelder in his evidence.

Description of the water quality risks associated with each Physiographic Zone

74 The Southland Physiographic Zones project was carried out by the Council to better understand the regional variation in the chemical composition of water and water quality risks associated with different landscapes[68]. By understanding where water comes from and the processes it undergoes as it moves through drainage networks, we can better understand the reasons for different water quality outcomes across Southland and inform management of water quality risks[69] in a more efficient way.

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[68] Hughes et al. (2016).

[69] Water quality risk specifically refers to the risk that sediment, microbes (e.g. *E. coli*) and nutrient contamination pose to freshwater ecosystem and human health.

75 The Physiographic Zones underpin an array of management approaches outlined in the pSWLP. Scientists have divided Southland into nine Physiographic Zones.[70] Each zone represents areas of the landscape with a common influence over water quality.

76 The Physiographic Zones differ in the way sediment, microbes (e.g. *E. coli*) and nutrients (nitrogen and phosphorus) are attenuated and transported over and through the soil, aquifers (areas of groundwater) and into rivers and streams. The nine Physiographic Zones are:

(a) Alpine

(b) Bedrock/Hill Country

(c) Central Plains

(d) Gleyed

(e) Lignite – Marine Terraces

(f) Old Mataura

(g) Oxidising

(h) Peat Wetlands

(i) Riverine

77 Four main transport pathways have been identified via which contaminants travel to groundwater and surface water. These are:

(a) Overland flow (where excess precipitation flows across the land surface in response to slope and gravity (also referred to as surface runoff) this commonly flows directly and rapidly to watercourses, streams or rivers).

(b) Artificial drainage (where soil water moves through open tile, plastic and mole pipe drains toward surface water features).

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[70] See evidence of Dr Snelder for further detail.

(d) Deep drainage (vertical movement of contaminants down through the soil zone as either matric flow or natural bypass flow to underlying groundwater and includes water movement through the aquifer system to receiving environments, such as rivers, streams, lakes or the coastal environment).

(e) Lateral drainage (movement of contaminants laterally through the soil zone toward surface water features).

78 The key contaminant transport pathways are different for each Physiographic Zone. For example, in the Old Mataura Zone, deep drainage is the key transport pathway, compared to the Alpine Zone where overland flow is the key transport pathway. Different pathways have differing associated contaminant risk. For some zones, there are areas within the zone that have an increased water quality risk when soils are wet (i.e. after extended periods of rain), and these are called variants. There are two types of variants:

(a) overland flow or "(o) variant"

(b) artificial drainage or "(a) variant"

79 For example, deep drainage of nitrogen is the typical contaminant transport pathway in the Oxidising Zone. However, in some parts of the Zone, when soils are wet additional transport pathways occur, such as overland flow on sloping land. These areas are within the (o) variant of the Oxidising Zone.

80 The Physiographic Zones with variants are listed below:

(a) Bedrock/Hill Country – (o) and (a) variants;

(b) Gleyed – (o) variant;

(c) Lignite/Marine Terraces – (o) and (a) variants;

(d) Oxidising – (o) and (a) variants;

(e) Riverine – (o) variant.

81 The transport pathways for each of the Physiographic Zones and their variants are presented in the Table below. Note that pathways may exist in each Zone however only the key pathways are shown.

Table 2: Key transport pathways for each of the Physiographic Zones and their variants.

Physiographic Zone	**Key transport pathways (✓)**		
	Overland Flow	**Deep drainage (leaching to groundwater)**	**Artificial Drainage**
Alpine	✓	-	-
Bedrock/Hill Country	✓(o)	-	✓(a)
Central Plains	-	✓	✓
Gleyed	✓(o)	-	✓
Lignite-Marine Terraces	✓(o)	-	✓(a)
Old Mataura	-	✓	-
Oxidising	✓(o)	✓	✓(a)
Peat Wetlands	-	✓	✓
Riverine	✓(o)	✓	-

82 As well as the key transport pathways described above, water quality risk (as defined above) is influenced by the following key contaminant attenuation[71] processes in Southland:

(a) Dilution potential: Large volumes of recharge water such as alpine runoff, can decrease the concentration of contaminants. Note that while dilution may influence the concentration of

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[71] In this context, attenuation refers to a variety of physical, chemical, or biological processes that reduce the amount (i.e. mass, toxicity, mobility, volume, or concentration) of contaminants in soil or water.

contaminants, it does not alter the total loading of contaminants to the receiving environment.

(b) Reduction potential[72]: The reduction potential of soils and aquifer materials has a major influence on the concentration and load of soluble nitrogen and dissolved phosphorus.

(c) Filtration and sorption[73]: Filtration and sorption are key processes in the attenuation of sediment, microbes and phosphorus within soil and aquifer materials.

83 Further descriptions of each Physiographic Zone and associated key contaminant transport pathways and attenuation process are presented below and summarised in Table 3.

Alpine

84 The Alpine Physiographic Zone includes all land above 800 metres elevation and is mainly located in northern and western parts of Southland. This zone is characterised by steep slopes with thin soils or bare bedrock. Its high elevation results in large volumes of snowfall and rainfall, which provides large volumes of pristine water to downstream Physiographic Zones. The primary contaminant transport pathway is overland flow due to steep slopes and the bedrock nature of the zone. Filtration, adsorption and reduction potentials are low. Dilution potential is high. Contaminant loss is limited due to low intensity of land use.

Central Plains

85 The Central Plains Physiographic Zone extends across flat to gently undulating terraces in the lower reaches of the Aparima and Oreti Catchments in Central Southland. Clay-rich soils in this zone exhibit shrink-swell characteristics, which means they become waterlogged and swell when wet and shrink and create open macropore

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[72] Reduction potential is a measure of the tendency for oxidation-reduction reactions to occur, whereby a chemical species acquires electrons and is thereby reduced. A common reduction reaction is the multi-step transformation of nitrate to nitrogen gas (denitrification).

[73] 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). Filtration occurs when particulates such as sediment or bacteria are physically removed from water moving over the land surface or through underlying soil or geological materials.

structures[74] or cracks when dry. When soils are wet, contaminants move quickly through artificial drainage networks to surface waterways. When soils are dry, cracks or macropore structures allow water and contaminants to rapidly drain down through the soil to groundwater, bypassing the attenuation properties of the soil matrix. Ground and surface waters within the Central Plains Zone show significant deterioration. The median groundwater NNN concentration within the unit is approximately 6.1 mg/L, this is second only to the Old Mataura Zone (approximately 12 mg/L)[75].

Gleyed

86 The Gleyed Physiographic Zone extends across flat to gently undulating land across the plains of both northern and southern Southland. This Zone is characterised by imperfectly to poorly drained soils that exhibit redoximorphic features[76] such as mottling and gleying. Soils in this Zone have some denitrification[77] ability, which reduces build-up of soil nitrogen. However, artificial drains (mole-pipe) are extensively used in this Zone due to soils being prone to waterlogging. The extensive network of artificial drainage rapidly transports contaminants to surface water, particularly during heavy rain. These drains bypass much of the filtration, adsorption and reduction potential of the soil. The Zone also has an overland flow or (o) variant, which means that in parts of the Zone, overland flow is also a key transport pathway for contaminants when soils are wet.

Bedrock/Hill Country

87 The Bedrock/Hill Country Physiographic Zone is the largest in the Southland Region, covering half the mapped area (approximately 1.6 million hectares). It is characterised by prominent landforms below 800 metres elevation where soils overlie bedrock or glacial till. This

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[74] Macropore structures are open spaces that allow free drainage via gravity. These pore structures are generally greater than ~0.08mm in diameter.

[75] Hughes et al. (2016).

[76] Soil features that are indicative of reduction and oxidation (redox) reactions occurring within the soil profile. 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.

[77] Denitrification is a naturally occurring reduction process whereby nitrate is ultimately converted to nitrogen gas.

zone has high rainfall due to higher elevations, which results in a dense network of streams that comprise the headwaters of many lowland streams. This zone contains an overland flow or (o) variant, as well as an artificial drainage or (a) variant, which means that in some parts of the zone, overland flow is a key transport pathway, and in some parts artificial drainage is the key contaminant transport pathway. This means that streams in developed areas of these variants are at risk of receiving contaminants from surface runoff and artificial drainage. These variants comprise the majority of the zone area.

Lignite/Marine Terraces

88 The Lignite/Marine Terraces Physiographic Zone is distributed along Southland's south coast, and in areas of eastern and western Southland where the underlying geology has elevated organic carbon (such as lignite or coal). Small areas of the Zone are inferred to have deep drainage as the dominant pathway, however, the potential for nitrogen contamination in aquifers is limited by high denitrification potential. Like Bedrock/Hill Country, this Zone contains an overland flow or (o) variant, as well as an artificial drainage or (a) variant and these comprise most of the Zone area.

Old Mataura

89 The Old Mataura Physiographic Zone is located on the older, high terraces in the Mataura catchment. Soils and aquifers in this Zone have a high risk of nitrogen leaching and contamination due to low denitrification potential. The combination of flat land and well drained soils can result in high rates of nitrogen leaching (deep drainage) to underlying groundwater. Groundwater in this zone discharges into springs, streams and aquifers in lower parts of the Mataura catchment, adding to their cumulative nutrient inputs. The median groundwater NNN concentration within the unit is approximately 12.0 mg/L, the highest of any Physiographic Zone[78].

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[78] Hughes et al. (2016).

Oxidising

90 The Oxidising Physiographic Zone is located on intermediate terraces along the margins of major river systems. Soils and aquifers in this zone have a high risk of nitrogen leaching and contamination due to low denitrification potential. The combination of flat land and well drained soils can result in high rates of nitrogen leaching (deep drainage) to underlying groundwater. Like Bedrock/Hill Country and Lignite-Marine Terraces, this zone contains an overland flow or (o) variant, as well as an artificial drainage or (a) variant. The median groundwater nitrate-N concentration within the unit is approximately 6 mg/L, the third highest of any Physiographic Zone[79].

Peat Wetlands

91 The Peat Wetlands Physiographic Zone is characterised by high organic carbon content in soils and underlying geology, which exerts a strong influence over water quality. Soils in the zone are poorly drained, peaty and acidic. This Zone is also characterized by an elevated water table requiring extensive artificial drainage where land is developed. There is low risk of nitrogen leaching and contamination in soils and aquifers due to high denitrification potential. However, limited mineral content and acidic conditions can result in elevated concentrations of soluble phosphorus in both soil water and groundwater. Median groundwater phosphorus concentrations for areas of Peat Wetland across the southern portion of the Waituna catchment are 50 times higher than those of the northern half of the catchment[80].

Riverine

92 The Riverine Physiographic Zone occurs along the margins of Southland's major river systems. This Zone is characterised by dilution and flushing from large volumes of pristine water from alpine headwaters that is carried down major river systems to the coast. River water in this Zone also contains soil water and groundwater drainage from adjacent land. Within the Zone, water drains quickly through shallow, stony, well drained soils to underlying aquifers that

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[79] Hughes et al. (2016).

[80] Rissmann et al. (2012).

are highly hydraulically connected to rivers. Because this Zone has large volumes of water flowing through it, there is little risk of nitrogen contamination resulting in high concentrations in groundwater. However, nitrogen loss from leaching (deep drainage) through aquifers can contribute significant nitrogen loads to downstream environments. This Zone has an overland flow or (o) variant that includes areas of sloping land.

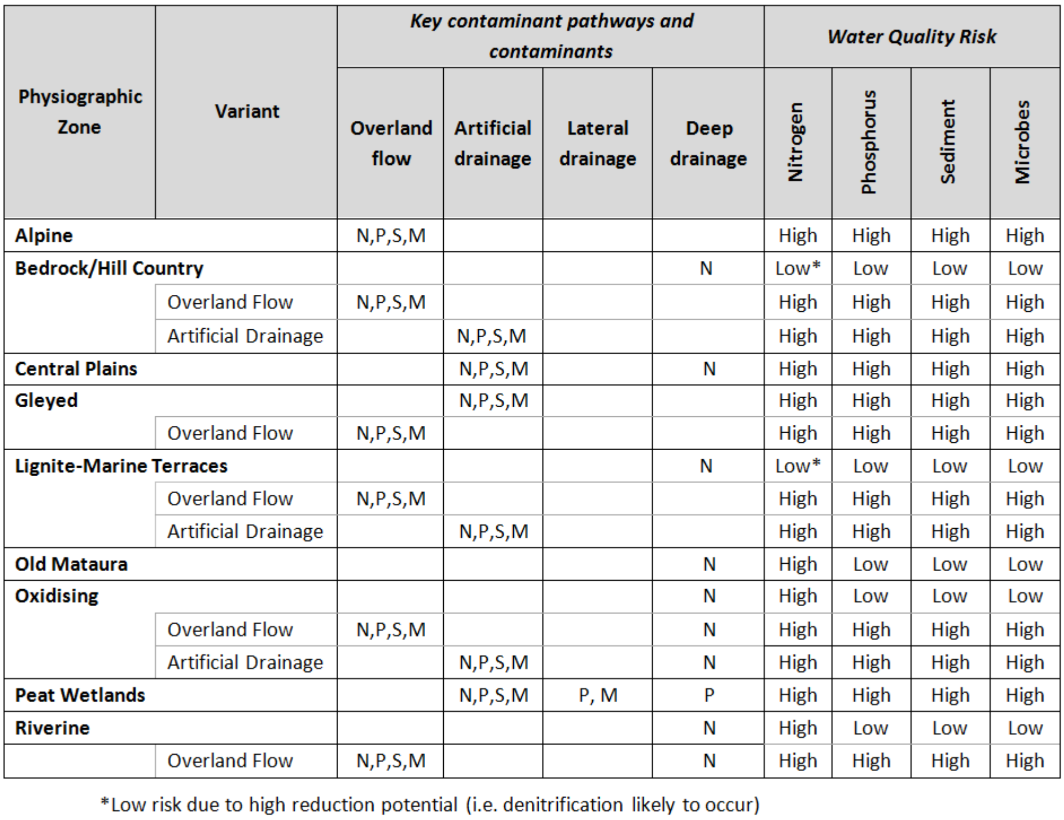
Table 3: ***Summary of key processes influencing water quality risk for each Physiographic Zone. Contaminants considered are nitrogen (N), phosphorus (P), sediment (S) and microbes (M)*** **(from Hughes et al., 2016)*.***

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 - 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	- Dilution of contaminant concentrations may	- High in soils depending on drainage residence time	- Little opportunity for filtration and sorption to occur	- Overland flow	- N, P, S, M

Physiographic zone and variant	Dilution	Reduction potential	Filtration and sorption	Contaminant pathway(s)	Contaminants
variant	occur where there are higher precipitation volumes	and low in aquifers			
Artificial drainage variant			- Limited filtration, sorption occurring in water moving through the soil matrix	- Artificial drainage	- N, P, S, M
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 - 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 - Artificial drainage in developed areas - 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

93 Utilising the above information, a binary risk classification was generated specifically for the pSWLP. This is presented below in Table 4.

Table 4: 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 (from Hughes et al., 2016).



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)

A summary of water quality issues in Southland

94 Water quality state and trends in relation to groundwater and surface water (including rivers, streams, lakes and estuaries) provides important context for recognising the requirement to address high contaminant loss activities.

95 A summary of the water quality state and trends for groundwater is set out in my evidence above.

96 Water quality trends in rivers and streams is addressed in the evidence of Mr Hodson and water quality in lakes and estuaries in addressed in the evidence of Mr Ward.

Contaminant losses associated with dairy farming and winter grazing

Dairy farming

97 In the Southland Region, diffuse nitrogen losses from dairy farms are estimated to be more than double those from intensive sheep and beef pasture farm systems[81]. Comparison is made only to sheep and beef systems as this is the other dominant agricultural land use in Southland. These estimates are from measured and modelled (Overseer) sources. Moran et al. (2017) reports that of 41 Southland case study farms modelled in Overseer version 6.2.1, the mean nitrogen loss for dairy farms was 38 kg N/ha/yr compared to 15 kg N/ha/yr for sheep and beef farms (36 Southland case study farms) (Figure 8).

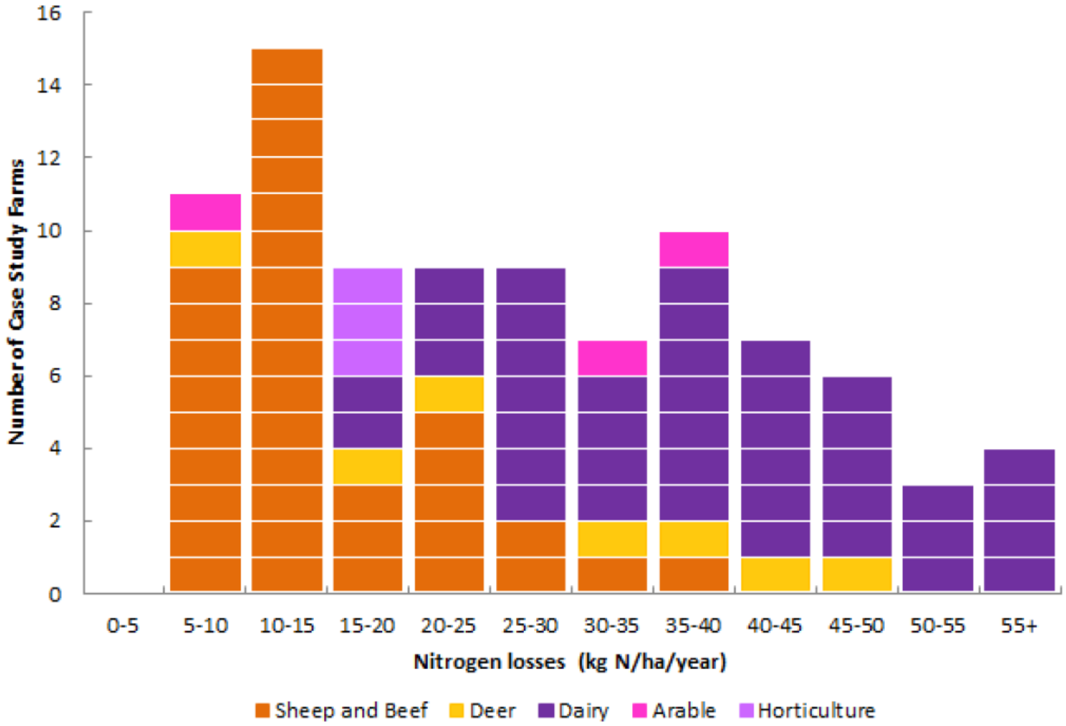


Figure 8: Baseline nitrogen losses for all case study farms modelled as part of the Southland Economics Project (from Moran et al., 2017). Each coloured block represents a case study farm.

98 Nitrogen losses to the environment occur primarily as soluble nitrate (NO_3^-) in drainage water either via leaching below the root zone (deep drainage), by lateral or overland flow, or by artificial drainage through installed drain networks. Losses also occur to the

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[81] Ledgard (2014) and refs. within and Moran et al. (2017).

atmosphere as either nitrous oxide (N_2O) or nitrogen (N_2) gas via denitrification or as ammonia gas (NH_3) via volatilisation of ammonium (NH_4^+).

99 An animal urine patch is a hotspot for NO_3^- leaching and N_2O emissions. This is because the N concentration in a urine patch (700 - 1400 kg N ha-1) is in excess of plant demand for growth[82]. Plants take up, on average, 300 kg N ha-1 yr-1[83]. It is widely reported that approximately 90% of nitrate leached originates from animal urine deposition[84].

100 Phosphorus losses from dairy farms are estimated to be approximately 30% greater than those from intensive sheep and beef farm systems[85]. Moran et al. (2017) reports that of 41 Southland case study farms modelled in Overseer 6.2.1, the mean phosphorus loss for dairy farms was 0.9 kg P/ha/yr compared to 0.7 kg P/ha/yr for sheep and beef farms (36 Southland case study farms). However, phosphorus losses vary considerably with land type and form.

101 Suspended sediment losses from dairy farms are estimated to be comparable or slightly greater than those from intensive sheep and beef farm systems[86].

102 Very few studies have quantified or compared *E.coli* losses from different agricultural land use types. Studies have however shown that microbial loadings to land are greatest when stocking rates of dairy cattle are highest and associated with farming systems such as wintering pads, block-grazed pasture and feed pads[87].

Winter grazing (any stock type)

103 In-situ grazing of forage crops over the months of May to August has been shown to make a disproportionately large contribution to nutrient losses from the total farm system[88]. This is primarily due to

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[82] Haynes & Williams (1993) and Eckard (2006).

[83] McLaren and Cameron (1996) and Moir et al. (2010) & refs within.

[84] Ledgard et al. (1999) and Di & Cameron (2002).

[85] Ledgard (2014) and refs. within.

[86] Ledgard (2014) and refs. within.

[87] Wilcock (2006) and Moriarty (2013).

[88] De Klein et al. (2010); Monaghan et al. (2013); McDowell & Monaghan (2015); McDowell & Stevens (2008); McDowell & Houlbrooke (2008); Shepherd et al. (2012); and Smith et al. (2012).

large stores of mineral nitrogen in the soil after pasture cultivation and crop establishment, the deposition of large amounts of excreta nitrogen from a high density of grazing stock, and a low uptake of nitrogen by plants during the winter period[89]. Proportions of nitrogen and phosphorus lost, and the mechanism of loss, is dependent on the land form and type.

104 Nitrogen losses from grazed winter forage crop land are estimated to be approximately 85% greater than losses from grazed dairy pasture. The range reported in Ledgard (2014) is 39 to 114 kg N/ha/yr. The magnitude of loss can be very variable dependant on land form, stock, and crop type.

105 Phosphorus losses from grazed winter forage crop land (all stock types) are estimated to be approximately 50% greater than losses from grazed dairy pasture[90]. The magnitude of loss can be very variable dependant on land form, stock, and crop type.

106 Suspended sediment losses from dairy winter grazing land are estimated to be approximately 550% greater than those from dairy pasture grazing, 330 kg/ha/yr compared to 60 kg/ha/yr respectively[91]. The magnitude of loss can be very variable dependant on management methods, land form, stock, and crop type.

The relative regional scale contribution of these activities to contaminant loss in Southland

107 Using land use maps developed following the methods of Pearson (2015) and Pearson and Couldrey (2018), areas of dairy grazing (milking platform only) and winter forage crop grazing (all stock types) can be estimated for the year 2017. In 2017, there was an estimated 236,892 Ha of dairy grazing land and 56,824 Ha of winter forage crop[92]. Figure 9 below shows the approximate proportions of these and other land uses by area within agricultural land in Southland in 2017.

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[89] Monaghan (2012).

[90] Ledgard (2014) and refs. within

[91] Ledgard (2014) and refs. within

[92] North et al., 2018.

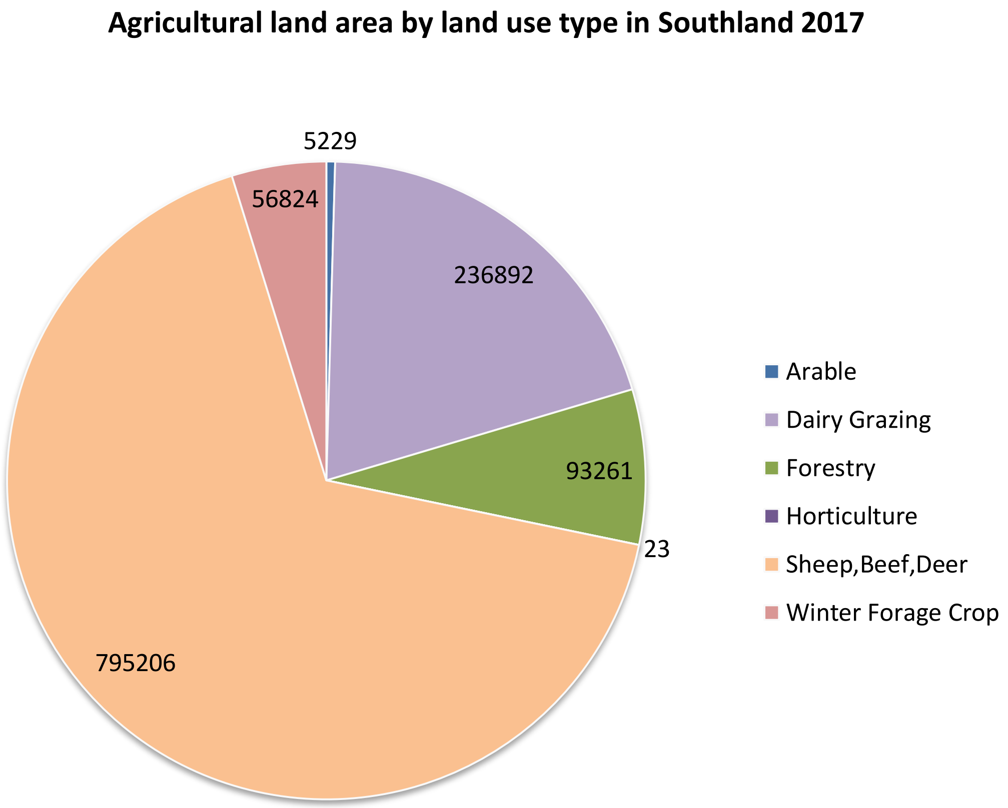

Figure 9: Estimated agricultural land area by land use type in Southland 2017. Labels shown are in hectares.

108 Using loss estimates described above and from other sources,[93] estimates of the relative proportion that each land use contributes to the total nitrogen and phosphorus loss for the Southland region can be made. Note the loss estimates used in this analysis do make approximations for land type, farm intensity and intensification over time. The loss estimates are shown below for nitrogen and phosphorus in Figure 10 and Figure 11 respectively. Please note, these estimates do not include point sources, are generalised, and for indicative purposes only. These estimates also do not account for any attenuation beyond the root zone so are in no way indicative of actual loads to receiving environments.

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[93] Ledgard (2014) and refs. within & NZIER (2013).

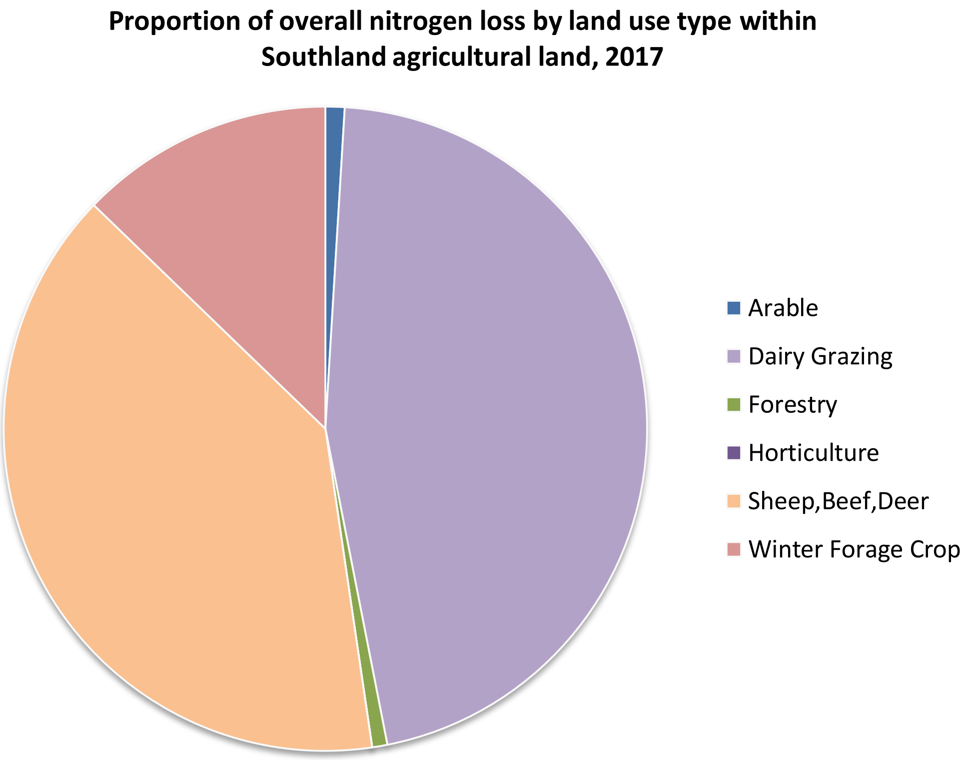

Figure 10: Estimated proportion of overall nitrogen loss by land use type within Southland agricultural land, 2017.

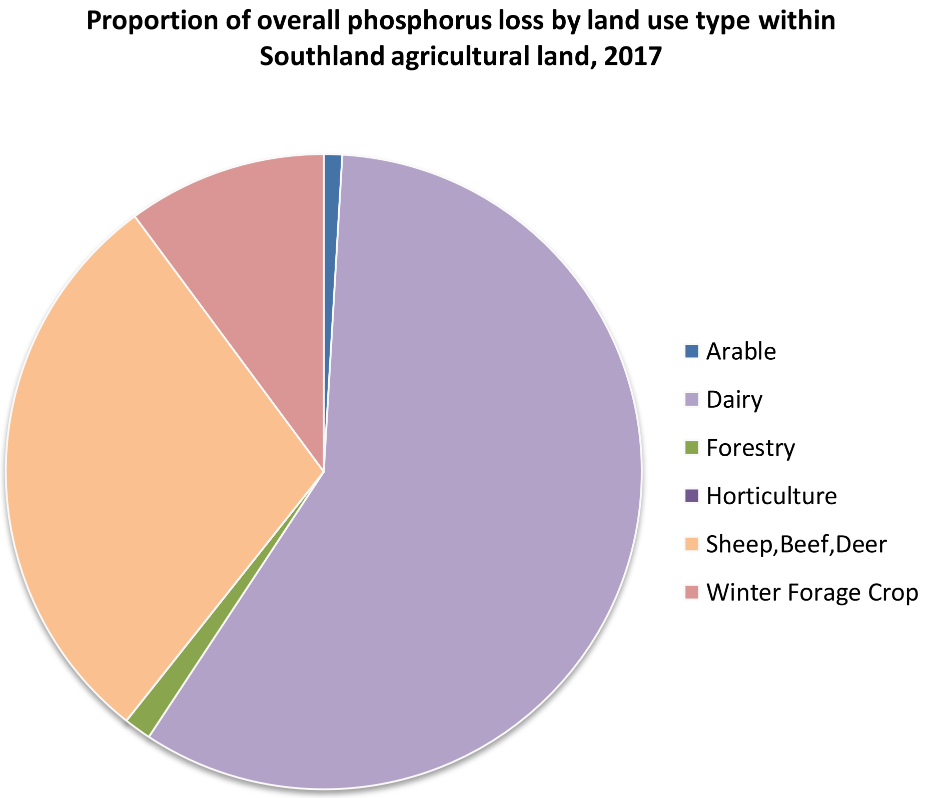

Figure 11: Estimated proportion of overall phosphorus loss by land use type within Southland agricultural land, 2017.

109 Figure 10 and Figure 11 highlight that although dairy farming and winter forage grazing make up only approximately one quarter of land use in Southland, these activities are responsible for a disproportionately large amount of the overall nitrogen and phosphorus loss. While sheep, beef and deer land does contribute a significant proportion of nitrogen and phosphorus loss, it occupies approximately two thirds of the overall agricultural land use.

110 Similar assessments cannot be made for *E. coli* or sediment as there is insufficient information available.

Dairy farming and winter grazing specific assessment of which Physiographic Zones pose the highest risk to water quality in Southland

111 Adverse environmental effects of dairy farming and winter grazing are exacerbated when they occur on parts of the landscape that are susceptible to contaminant loss. This is especially true if the mode of that contaminant loss is problematic to mitigate.

112 A method to assess the difference in risk posed by these activities within the different Physiographic Zones is by focussing on the key contaminant loss pathways for each Zone and the potential for these losses to be reduced through good management practice. Monaghan (2016) and McDowell et al. (2013) describe the good management practices and farm actions available to address contaminant loss via these pathways. These reports describe the actions taken as well as the effectiveness and relative cost of the mitigations. A table of broad options for addressing each contaminant loss pathway is presented below in Table 5.

Table 5: Contaminant loss pathways with a broad overview of associated available options to reduce contaminant losses.

Contaminant loss pathway	Options to reduce contaminant loss[94]	Assessment of actions available to reduce contaminant losses
Overland Flow	• Protect soil structure, particularly in gullies and near stream areas • Manage critical source areas • Provide physical interception of water • Reduce contaminant inputs	Relatively more options
Lateral Flow	• Reduce contaminant inputs to land • Minor opportunities to intercept flow by wetlands or artificial structures	Few options
Artificial Drainage	• Reduce contaminant inputs to land • Minor opportunities to intercept flow by wetlands or artificial structures	Few options
Deep Drainage	• Reduce contaminant inputs to land	Few options

113 Each Physiographic Zone can then be classed, based on its key contaminant pathways and options available to reduce contaminant losses (Table 6).

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[94] Only broad examples are shown, for a full description of options please refer to the good management fact sheets provided at www.es.govt.nz as well as Monaghan (2016) and McDowell et al. (2013).

Table 6: Key contaminant pathways with associated Physiographic Zones and an assessment of actions available to reduce contaminant losses. Note that physiographic zones are in no particular order within the key contaminant pathway classes.

Key Contaminant Pathway[95]	Physiographic Zone[96]	Actions available to reduce contaminant losses[97]
Deep Drainage	Old Mataura	Few options
	Peat Wetlands	
	Central Plains	
	Riverine	
	Riverine (o)	
	Oxidising	
	Oxidising (o)	
	Oxidising (a)	
Lateral Flow	Peat Wetlands	Few options
Artificial Drainage	Gleyed	Few options
	Central Plains	
	Peat Wetlands	
	Oxidising (a)	
	Bedrock/Hill Country (a)	
	Lignite/Marine Terraces (a)	
Overland Flow	Bedrock/Hill Country (o)	Relatively more options
	Lignite/Marine Terraces (o)	
	Gleyed (o)	
	Oxidising (o)	
	Riverine (o)	
	Alpine	

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[95] The key contaminant pathway accounts for the key transport pathways and the potential for attenuation as described in the water quality risk framework above. For example the Bedrock/Hill Country and Lignite/Marine Terraces Zones are not shown under deep drainage even though this is a key water transport pathway. This is because of the potential for attenuation in these zones.

[96] Note Zones are listed under each of their relevant key contaminant pathways so can be listed multiple times.

[97] For a full description of options please refer to the good management fact sheets provided at www.es.govt.nz as well as Monaghan (2016) and McDowell et al. (2013).

114 One assessment of water quality risk posed by each of the Zones would be to assume that the Zones with key contaminant pathways with relatively less actions available to reduce contaminant losses pose a greater risk.

DATED this 14th day of December 2018

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Ewen Rodway

Appendix A

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