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Regional Scale Stratification of Southland's Water Quality – Guidance for Water and Land Management

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EXECUTIVE SUMMARY

Southland Regional Council (SRC) has developed a long-term project (*Water and Land 2020 & Beyond*; WAL2020) for water and land management in the Southland region. The project responds to increasing pressure on water quantity and water quality deterioration within the region (particularly the four major contaminants: nitrogen, phosphorus, microbes and sediment). The strategy incorporates SRC's response to the National Policy Statement – Freshwater Management 2012 (NPS-FM), which requires SRC to set limits and establish methods to avoid over-allocation. WAL2020 proposes that limit setting processes be collaborative and that catchments with the most significant land and water management issues be prioritised first. To arrest ongoing declines in water quality and 'hold the line' until limits have been set, WAL2020 has also recommended shorter-term actions, including the adoption of good management practices, to 'hold the line' (i.e. prevent further water quality deterioration) and making a start towards meeting community goals in degraded areas. Council therefore needs to identify the most significant land and water management issues in the region to provide a basis for prioritising shorter-term actions and limit setting processes.

This report details the development of the Water and Land Management Stratification (WLMS). The purpose of the WLMS is to identify the highest priority areas for actions to address specific land and water management issues and, conversely, areas where land and water management risks are low. The WLMS has been developed by:

1. Defining a set of regional water quality criteria that are consistent with objectives set out in the Regional Water Plan (RWP) and the Regional Coastal Plan (RCP).
2. Describing the current state of freshwater receiving environments (including streams and rivers, groundwater and estuaries) in the Southland region based primarily on state of environment monitoring (SoE) data.
3. Assessing where there are 'issues' (i.e. water quality objectives are not being met) based on the comparison of the current state with the regional water quality criteria.
4. Estimating contaminant contribution rates from areas upstream of issues.
5. Stratifying the region based on the combination of the issues and the estimated contaminant contribution rate.

Water quality criteria were used to test if the current state of rivers and streams, groundwater and estuaries would allow RWP and RCP objectives to be met. Where possible, the criteria were taken from the plans. However, it was necessary to adjust some of the criteria and to include additional criteria that are relevant and consistent with the objectives of the plans. These changed and added criteria represent expert opinion, and have not been formally adopted by SRC.

Statistical models were used to extend the SoE monitoring data into spatially comprehensive predictions of water quality, condition measures and contaminant loads. Model performance was sufficient to describe regional patterns accurately, and allowed the analysis to 'fill in the gaps'. However, the predictions are uncertain at small scales, and should not be relied on to evaluate conditions at specific sites.

This study found that diffuse (non-point) sources from agricultural land are the most significant contribution to nutrient contamination at the regional scale. Point sources (discharges from factories and sewage treatment plants) accounted for <10% of the estimated total nitrogen (TN) loads at affected SoE sites, with most being <5% and <25% of the estimated total phosphorus (TP) loads. However, point source loads constitute significantly larger proportions of the load of contaminants at some locations (close to the discharge point) and also at specific times (e.g. during low flow periods).

The assessment indicated that water quality objectives are not met in some locations in Southland. This conclusion was reached based on both the observed site data and the model predictions. It was found that periphyton (i.e. slime) breaches the criteria in the main stem of the Mataura River and many lowland tributaries of other rivers. Indices measuring invertebrate community health did not comply with the criteria in most lowland streams. There were high levels of non-compliance with criteria for water clarity in rivers. Nitrate concentrations in some lowland streams exceeded the nominated criteria for ecosystem health. A small number of lowland streams exceeded the nominated ‘secondary’ contact criteria (i.e. contact with the water but not full immersion) for microbial contaminants. The nominated groundwater nitrate concentration criteria for the protection of ecosystem health is exceeded in some parts of the region.

Based on criteria that were applied to condition grades for sedimentation and nutrient enrichment, water quality objectives are not met in four estuaries (New River Estuary, Waimatuku Estuary, Jacobs River Estuary and Waiau River Estuary). Condition grades were poor for both sedimentation and nutrient enrichment for the New River Estuary and Jacobs River Estuary (i.e. the Oreti and Aparima catchments, respectively), whereas the Waimatuku Estuary and the Waiau River Estuary had poor grades for only sedimentation and nutrient enrichment, respectively.

TN and nitrate concentrations in streams and rivers were found to be increasing in those locations where nitrogen concentrations are already high. This study did not find regional patterns of trends for most other water quality variables. Given that many of the water quality issues are associated with nutrients in general, or specifically nitrogen, the nitrogen trends are a relevant concern. Although only three estuaries (New River Estuary, Waimatuku Estuary and Jacobs River Estuary) had a poor condition grade for nutrient enrichment, a further three had a grade of fair (Waimatuku Estuary, Waikawa Estuary and Haldane Estuary). Given the increasing nitrogen trends, these estuaries are at risk of not meeting the RCP objectives.

The water and land management strata subdivide the region on the basis of two factors: the number of downstream issues (locations where criteria are not met), and estimated source loads of contaminants. The source loads were defined for current (2012) and the estimated maximum potential loads so that stratifications were defined to represent current and potential future land use. The stratifications can be made more or less complicated by subdividing the two defining factors (number of issues and source loads) into more or fewer categories. The study provided two options for stratifying the region at differing levels of detail. The first option defines nine strata by subdividing each factor into three categories. The second option defines four strata by subdividing each factor into two categories. We also defined a four stratum subdivision for which the source load factor represents the change in contaminant source loads associated with potential intensification of land use.

The stratifications indicate that the areas making large contributions to locations with several water quality issues are tributaries of the Aparima, the Waimatuku catchment, much of the Makarewa catchment, lowland areas of the Oreti catchment, and parts of the Waimea basin. These locations could be considered priority areas for addressing existing water quality issues. Much of the Waiau River and Mataura River catchments are in strata that represent either low source loads and low issues, or high source loads and low issues. In the case of the Mataura River catchment, this arises in part because the estuary (Toetoes Harbour) has a very good condition grade for nutrient enrichment. In the case of the Waiau River catchment, the estuary has a poor condition grade for nutrient enrichment, but complies with many of the riverine criteria such as those for invertebrate community health, slime and nitrate concentrations.

The WLMS provides a starting point for prioritisation of effort for management of water quality issues within the region. For example, areas that may have the highest priority for improving water quality could be those with high contaminant source loads and receiving environments with water quality issues. Low priority areas are those with low source loads and few downstream issues, provided that the potential to increase loads in future is low. The current study also defined a stratification that evaluated the potential change in contaminant source loads. This evaluation identifies areas where there are currently many downstream issues, and where there is also potential for significant increase in source loads due to land use intensification.

The current project has not considered what the responses should be. It is recommended that formulation of appropriate responses needs to include additional technical considerations, such as contaminant migration pathways and contaminant mitigation measures, as well as a wider range of community values, including social, cultural and economic values.

1 INTRODUCTION

1.1 Purpose

Southland Regional Council (SRC) has a long term-project for the management of water and land in the Southland region called *Water and Land 2020 & Beyond* (WAL2020). The project responds to the water quality deterioration and increasing pressure on water quantity that is currently being experienced in parts of the region. Among the significant environmental issues are: (i) nitrate contamination of groundwater; (ii) breaches of nitrate toxicity criteria in surface waters; (iii) breaches of guidelines for periphyton and toxic algae in streams and rivers; and (iv) eutrophication and sedimentation of shallow coastal lakes and estuaries. The project is also SRC's response to recent government policies, particularly the National Policy Statement – Freshwater Management 2012 (NPS-FM).

The NPS-FM requires that regional councils establish objectives, set limits and establish methods (including rules) to avoid over-allocation. In particular, the NPS-FM recognises the need to manage land, water and coastal environments in an integrated way, and to establish limits to effectively manage the cumulative effects of land use on water quality.

WAL2020 recognises that limits will impact on a wide range of community values, including social, cultural, economic and environmental. It proposes using a collaborative process to establish limits for quality and quantity on a catchment-by-catchment basis. WAL2020 recognises that catchment limit setting will require long timeframes and considerable resources, and that processes will need to be prioritised in catchments with the most significant land and water management issues. To arrest on-going declines in water quality, WAL2020 has recommended shorter-term actions, including the adoption of good management practices and other measures, to 'hold the line' (i.e. prevent further water quality deterioration). The short-term actions will be spatially targeted to locations where there is evidence that objectives set out in the Regional Water Plan for Southland 2010 (RWP) are not being met. Council therefore needs to identify the most significant land and water management issues in the region and, where water quality objectives are not being met, characterise the causal mechanisms to provide a basis for prioritising shorter-term actions and limit setting processes.

The purpose of this report is to describe the scientific basis for the prioritising the water and land management issues in the Southland region. To assist with this, we developed the Water and Land Management Stratification (WLMS). The purpose of the WLMS is to identify the highest priority areas for actions to address specific land and water management issues and, conversely, areas where land and water management risks are low. The WLMS subdivides the Southland region based on the current status of receiving environments with respect to RWP objectives, and the relative contribution of contaminant source areas in the upstream catchment. The WLMS is intended to be used to identify the highest priority areas for actions to address specific land and water management issues and, conversely, areas where water and land management risks are low.

1.2 Structure of This Report

Section 2 sets out the general approach to defining the WLMS, including the key principles, the relevant regional policy frameworks, the methodology for assessing the current state of water quality in the region, and how the land areas and contaminant loads contributing to these issues have been evaluated.

Section 3 presents the sources of data that were used in this analysis, and describes spatial modelling that was undertaken to extend this data to represent the water quality state for the whole region.

Section 4 describes the criteria that are used to assess whether or not water quality is in an acceptable state. These criteria apply to physical and chemical water quality measures and to condition measures (biological variables, including periphyton biomass and macro-invertebrate indices).

Section 5 describes the state of regional water quality, and compares the current water quality state against the criteria outlined in Section 4. Water quality issues are identified where the current state does not comply with the defined criteria.

Section 6 presents an assessment that identifies the catchments that are upstream of locations with water quality issues and sources of contaminants that contribute to the identified water quality issues.

Section 7 describes how the region has been subdivided into water and land strata based on two factors: the water quality state, and the estimated contaminant contribution rate from the land surface. Two examples of the WLMS are presented.

Section 8 draws some conclusions from the study, including a broad overview of the water quality issues in the Southland region and some considerations for how the WLMS may be interpreted, and recommended next steps.

2 APPROACH

2.1 Key principles

Broadly the WLMS has been defined by:

1. Defining a set of regional water quality criteria.
2. Describing the current state of freshwater receiving environments (including streams and rivers, groundwater and estuaries) in the Southland region based on water quality and condition measures.
3. Assessing where there are ‘issues’ (i.e. water quality objectives are not being met) in the region based on the comparison of the current state with the regional water quality criteria.
4. Identifying the contaminant sources that are contributing to the issues.

5. Subdividing the region into strata based on the combination of the issues and the contaminant sources.

Three key principles have been used in the development of the WLMS. First, the WLMS is based on existing data and reports, including state of environment (SoE) data and reports, as well as other relevant investigations. This report summarises this information in order to broadly describe water quality and contaminant loads in the Southland region. For rivers, some new analysis of SoE data has been conducted to provide a broader picture of river water quality and contaminant loads across the entire region, rather than just at specific monitoring sites.

The second principle is that actions under WAL2020 need to be justified by sound analysis and demonstration of the connection between issues and their causes. The WLMS must therefore identify areas that make high contributions of contaminants (particularly the four major contaminants: nitrogen, phosphorus, microbes and sediment) to receiving environments that have water quality issues. At the same time, regional scale responses to current water quality issues must not be overly complicated, and need to be tractable from a management perspective. The specificity of the management actions will be determined, in part, by how finely the region is subdivided into water and land management strata. Finer scale subdivision of the region into more strata (i.e. greater resolution) could allow more specific actions to be derived, but would also increase the overall complexity of the approach. In addition, at some point, justification of finer subdivision will not be supported by the available scientific information. Thus, the degree to which the region is sub-divided into strata and the complexity of the underlying analysis represents a combination of scientific information and pragmatic considerations concerning the complexity of the classification.

The third key principle of the WAL2020 is the recognition of *ki uta ki tai* (mountain to sea). From a scientific perspective, this principle is consistent with the recognition of the connected nature of land and water within catchments and receiving environments. These connections mean that the impacts of land and water use generally occur at locations downstream from where the activities take place. Therefore, the management of impacts of land and water use need to be based on an understanding of the sources of impacts (for example, the sources of contaminants), the flow paths along which these contaminants migrate and ultimately accumulate down the catchment, and the downstream receiving environments where the effects occur (rivers, lakes, estuaries and aquifers).

2.2 Regional Water Quality Objectives and Criteria

2.2.1 Policy Frameworks

The primary policy frameworks for management of freshwater in the Southland region are the RWP and the Regional Coastal Plan (RCP). The values and objectives in the RWP and RCP provide the basis for identifying ‘issues’ (i.e. where water quality objectives are not being met).

Water quality outcomes described in the RWP that are relevant to the classification are both long and short term. The long-term outcome is relevant beyond the 10-year life of the Plan:

- *The water quality of all surface water bodies in the region will be suitable for contact recreation, trout and native fish (including all life stages the water body naturally contains habitat for), stock drinking water and Ngāi Tahu cultural values, including mahinga kai.*

The RWP defines short-term outcomes as indicators of progress toward the long-term outcome that are expected to be achieved within the 10-year life of the Plan, as follows:

- *There will be no reduction of water quality in the Southland region beyond the zone of reasonable mixing for discharges;*
- *Water quality will be maintained in Natural State Waters;*
- *The water quality of surface water bodies will be maintained and enhanced so that it is suitable for bathing in popular bathing sites, trout and native fish, stock drinking water and Ngāi Tahu cultural values, including mahinga kai;*
- *An improvement in the water quality and in particular a minimum 10 percent reduction in levels of microbiological contaminants, nitrate and phosphorous and a 10 percent improvement in water clarity will be achieved in hill, lowland and spring-fed surface water bodies over 10 years from the Plan becoming operative (January 2010);*
- *Discharges to water bodies will not result in levels of toxic substances that harm humans, domestic animals including stock or aquatic life;*
- *Wherever practicable, and where effects are less adverse, discharges will be to land rather than to water;*
- *The significant adverse effects of discharging during low flows are avoided;*
- *The number of surface water bodies with riparian vegetation that assists in maintaining and enhancing water quality, bank and channel stability is significantly increased;*
- *Stormwater discharges will meet water quality standards and current ANZECC sediment guidelines by 2010;*
- *Freshwater quality does not have an adverse effect of coastal water quality;*
- *New dairy farming is undertaken in accordance with good practice and has no more than minor adverse effects on the environment, and does not result in a significant risk to water quality in the region;*
- *As a minimum, there is no net reduction in the integrity and diversity of aquatic and riverine ecosystems, including fish and wildlife habitat. Restoration of degraded habitats and creation of new habitats can offset losses;*
- *Groundwater (excluding aquifers where ambient water quality naturally exceeds guidelines) is suitable for human consumption without the need for treatment;*

- *Groundwater contribution to surface water bodies does not have any adverse effect on surface water quality, aquatic life or recreational values.*

Water quality objectives of the RCP that are relevant to the classification are as follows:

> *7.2.2.1 – Water quality is maintained in coastal waters that are currently suitable for:*
> *i contact recreation;*
> *ii the growth of shellfish that is safe for human consumption;*
> *iii the health and vitality of aquatic ecosystems; and,*
> *iv a fishery that is safe for human consumption when harvested.*
>
> *7.2.2.2 – By the year 2020, the quality of contaminated water is improved so that it can be used for activities i to iv above.*
>
> *7.2.2.3 – By the year 2005, the coastal waters in Halfmoon Bay, Stewart Island are suitable for activities i to iv above.*
>
> *7.2.2.4 – The quality of water that is in its natural state is maintained.*

2.2.2 Spatial Variation in Objectives

A key feature of the RWP is the recognition of spatial variation in community values and objectives across the region. This variation is reflected in a framework of non-contiguous areas (patches) that recur across the region that are referred to as “management units” in the RWP. Management units are groups of surface water receiving environments that that have similar environmental characteristics and, therefore, similar environmental and resource use values and sensitivity to human activity or management actions. The management units have different objectives and, therefore, criteria for some water quality variables and condition measures.

The RWP divides the region’s surface water bodies into 13 management units based largely on the National River Environment Classification (REC) framework, which was field tested and adapted to suit the Southland region. The REC is based on the principle that the characteristics of rivers and streams are largely determined by the characteristics of their catchments, and the RWP extends this to include the characteristics of lakes and wetlands. The REC assumes that the climate and topography, which are together referred to as the “source of flow”, are the dominant cause of differences in these characteristics. The RWP management units reflect differences in source of flow and are defined as: lowland (hard bed); lowland (soft bed); hill; mountain; lake-fed; spring-fed; lowland/coastal lakes and wetlands; hill lakes and wetlands; and mountain lakes and wetlands. In addition to the management units based on the REC, the RWP defines a natural state management unit. The natural state management unit includes all surface water bodies within the region’s two national parks (Fiordland and Rakiura) and areas of public conservation land where anthropogenic impacts are very low.

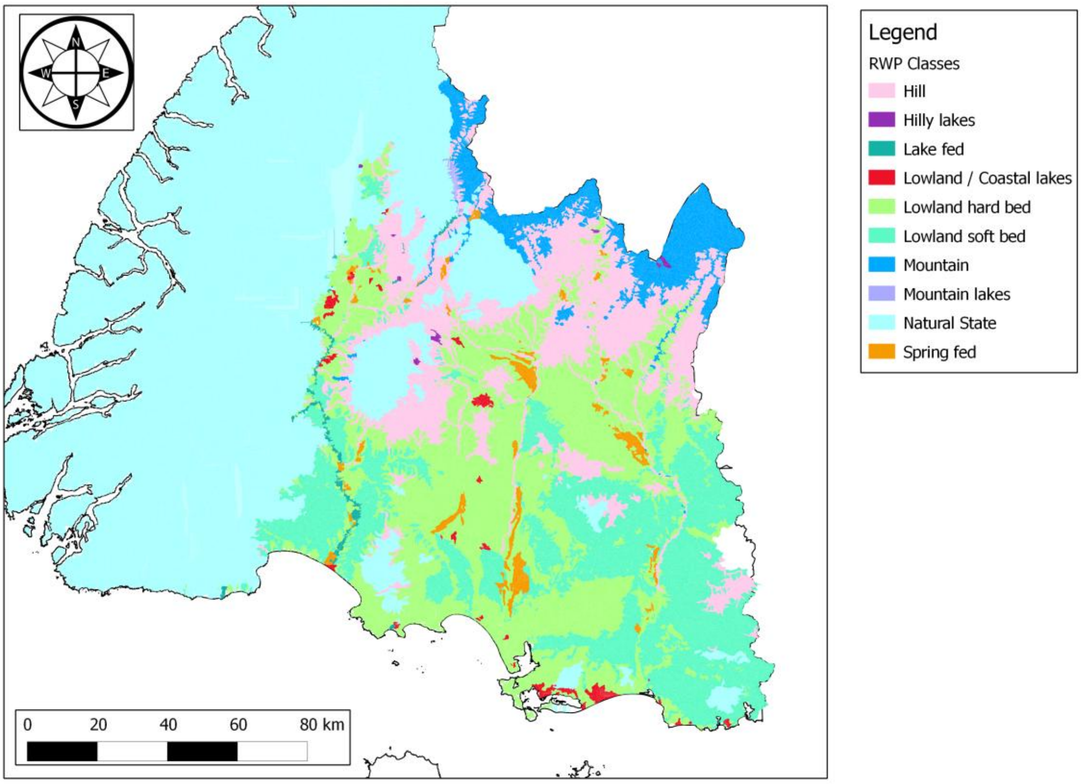

Figure 1: Management units defined by the RWP for rivers and lakes of the Southland region.

Recent work undertaken by SRC has identified three types of estuaries in the region: shallow Intermittently Closed Open Lakes and Lagoons (ICOLLs), shallow tidal lagoons, and shallow tidal river estuaries. These types are based on differences in the hydrodynamic properties of the estuaries that lead to differences in the mixing and flushing regimes and the types of habitat they support. These types discriminate differences in the sensitivity of the estuaries to contaminant inputs.

2.2.3 Criteria

Water quality criteria were used to test if the current state would allow RWP objectives to be met. At locations where current state complies with the criteria it is assumed that, as long as all other aspects of the environment are adequate, the objectives are likely to be met. Where possible, the criteria used in this analysis have been RWP standards. However, we made adjustments to some of these standards (periphyton – see Section 4.1.1) and included additional criteria in order to better represent the objectives of the RWP. These adjustments and additional criteria are nominal (i.e. have been nominated based on our expert opinion rather than defined by a regional policy process). This introduces subjectivity into the assessment because some of the criteria have not been formally adopted by the SRC. However, their inclusion allows relevant contaminants and condition measures to have influence in the stratification. We point out that there are additional subjective steps in defining the stratification (see Section 8). Because of this, the final results are likely to be reasonably insensitive to the exact values of the criteria.

The water quality criteria used in this analysis can be broadly categorised as pertaining to either water quality variables or condition indicators. Water quality variables are generally the concentration of contaminants (e.g. nitrate) for which the criteria is a specified concentration, beyond which there is an unacceptable risk that regional objectives will not be met. Condition indicators are measures of environmental or ecological state that reflect the effects of contaminants. Condition indicators are used because the effects of contaminants on the health of Southland's freshwater receiving environments is determined by multiple variables, including the combination of individual contaminants as well as natural factors such as flows and flushing regimes. Disentangling the effects of contaminants and determining criteria for each is complex, and the scientific tools to do so are often lacking. Therefore, the effects of contaminants are often monitored by measuring the symptoms using condition indicators. Examples of condition indicators for which targets have been specified are slime (periphyton biomass) in rivers and algae in estuaries.

The RWP standards include standards that are specific to three Mataura management units, which recognise the Mataura River Conservation Order. The standards for these management units are inconsistent with those for the remainder of the region; therefore, in this analysis, we have extended the more general RWP standards to the Mataura catchment. Another deviation from the RWP criteria reflects the additional data that has been collected in the 10 years since the RWP became operative. Some of the RWP standards are clearly too stringent when compared to data describing the current state in some relatively pristine environments, and have been altered accordingly (see Section 5.2 for details).

Relevant criteria have been proposed in the National Objectives Framework (NOF) that forms part of the amendment to the NPS-FW, which is currently under consideration (MfE, 2013a). These criteria include nitrate toxicity to protect ecosystem health for surface water, *E coli* for human health (secondary contact), and condition measures for estuaries. The NOF criteria will become mandatory considerations in future water management decision-making if the NOF is adopted as it currently stands; as such, these criteria have been included in our analysis (see Section 4.1 for details).

Since the early 2000's, SRC has had an estuary monitoring programme that has monitored a range of condition measures, including measures of sedimentation, toxicity, nutrient enrichment, and habitat quality. Sedimentation and nutrient enrichment are specifically relevant to water quality, and condition measures related to these have been reported against criteria in SoE and other reports (e.g. Cawthron, 2006; Stevens & Robertson. 2012). These criteria have been used to evaluate water quality issues for estuaries (see Section 4.2 for details).

2.3 Assessment of the State of Water Quality

For this analysis, SoE data were used to assess the state of water quality in the Southland region. The analysis has focussed on three types of aquatic environments: rivers and streams (Figure 2), estuaries (Figure 3), and groundwater (Figure 4). These types of environments are widely distributed throughout the region, and their upstream catchments comprise much of the developed land in Southland. Assessment of these environment types in Southland is therefore regional in scope. Lakes have been excluded from this analysis, as there are relatively few large lakes within the developed land of Southland, and their contributing catchment areas generally comprise only small portions of the developed area.

SoE data from individual sites on rivers and in groundwater may be considered to represent broader areas. We used spatial modelling to extend these SoE data to all the river and groundwater systems in the region. Spatially explicit predictions, which were mapped, allowed us to examine patterns in regional water quality across the various contaminants of interest. Data pertaining to 10 Southland estuaries have been used to represent only the individual estuaries (i.e. no spatial modelling was undertaken for estuaries).

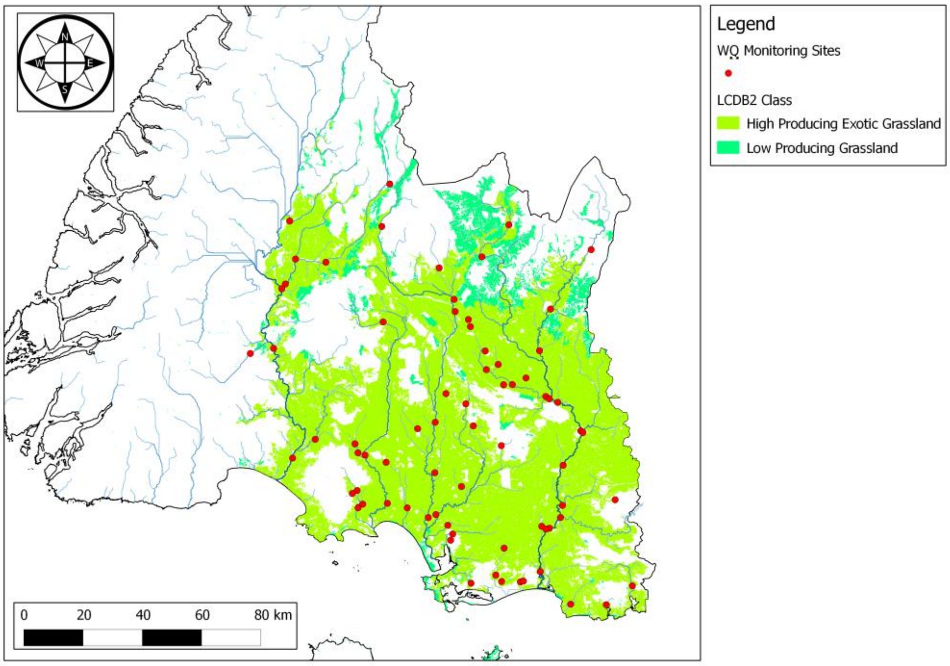

Figure 2: SoE sites on rivers and streams in the Southland region. The areas classified by the LCDB2 as high and low producing grassland (pasture) and main river systems are also shown.

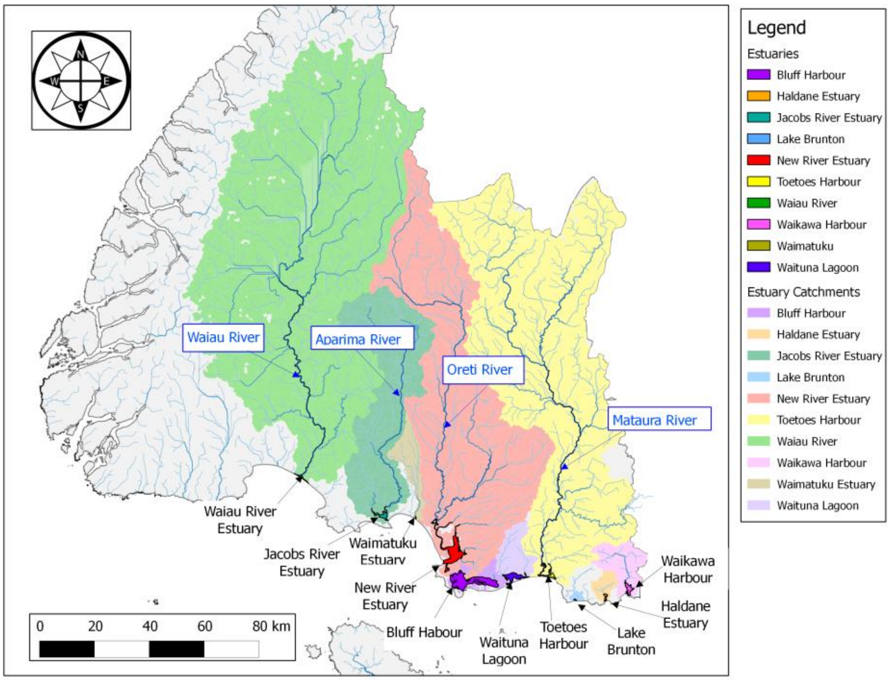

Figure 3: Location of the 10 estuaries and their catchments included in this study.

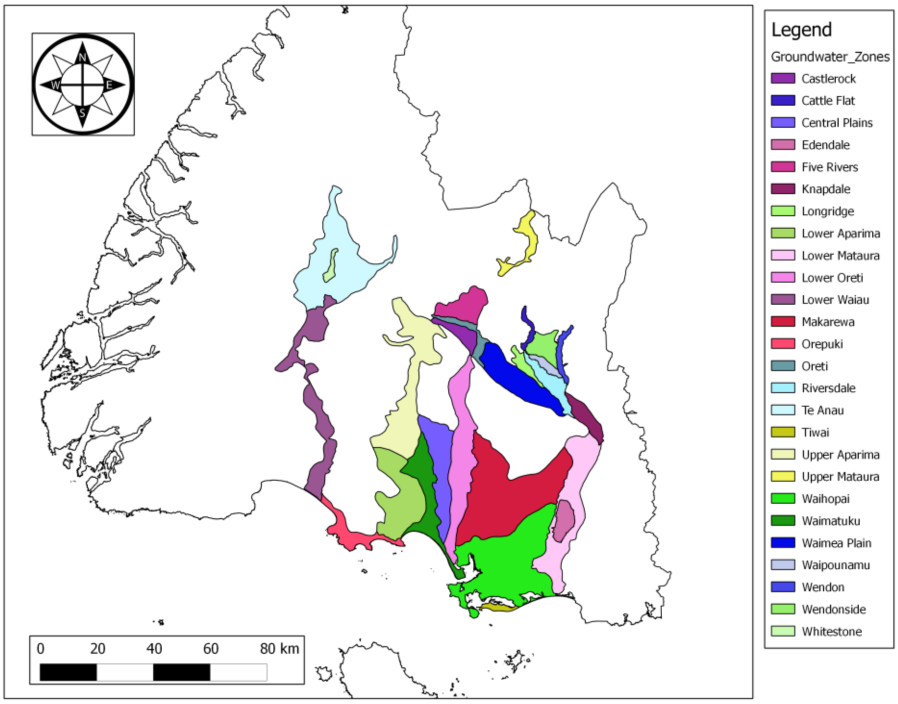

Figure 4: Location of the groundwater zones considered in the analysis of regional groundwater water quality.

We used Principle Components Analysis[1] (PCA) to examine the relationship among the water quality variables for rivers. In particular, PCA was used to determine

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[1] PCA is a mathematical procedure that converts a set of observations of several variables into a set of values of linearly uncorrelated variables called 'principal components'. The components are defined so that the first principal component accounts for as much of the variability in the data as possible, and each succeeding

whether there are regional differences in the contaminants of most concern (e.g. whether some locations have high nitrogen and low phosphorus, and vice versa).

To broadly characterise river water quality at the regional scale, a classification of river water quality in Southland was defined, using Hierarchical Cluster Analysis[2] (HCA). Because HCA is a purely data-driven approach, the grouping of locations is made without any assumptions about the environmental setting or land use history. Details of the procedures used to produce the classification are appended in Appendix B. As well as providing a basis for broadly characterising river water quality at the regional scale, the water quality classification was used as a basis for evaluating water quality trends across the region.

We identified areas where water quality objectives are not being met in the region based on the comparison of the current state, derived from the SoE data, with the regional water quality criteria. For estuaries, the assessment was performed for each individual estuary. For rivers and streams and groundwater, we identified the areas where water quality objectives are not being met in two ways: (i) by comparing the water quality variables and condition indicators for each monitoring site with the relevant criteria, and (ii) by comparing the predicted water quality variables and condition indicators at all points in the region with the relevant criteria. The second approach produces a map of where water quality objectives are not being met across the region.

Finally, trends calculated for SoE sites throughout Southland provided by DairyNZ (Mike Scarsbrook, *pers comm*) were examined. The trend results were not used in the definition of the water quality management zones, but a simple analysis was included to provide additional context and examination of the water quality issues in the region.

2.4 Identifying Contaminant Sources

We used regional estimates of contaminant loads to identify areas and activities contributing contaminants, including source 'hotspots' (areas that appear to be making particularly large contributions of contaminants). Two sources of information were used to estimate the loads of contaminants from land across the region: (i) the observed loads (calculated from flows and concentrations at the SoE sites – see Appendix A for details), and (ii) estimated leaching of total nitrogen and total phosphorus made by AgResearch and NZIER as part of an economic evaluation of farm mitigation measures (NZIER, 2013). We also considered significant point source contributions across the region, which include discharges from factories and sewage treatment plants.

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component in turn has the highest variance possible under the constraint that it be orthogonal to (i.e. uncorrelated with) the preceding components.

[2] HCA works by quantifying the degree of similarity of multiple water quality variables between different locations. HCA unambiguously assigns different locations to distinct 'clusters' or classes, which are organised hierarchically. The hierarchical organisation of classes defines groups of rivers in a logical progression from a small number of groups (a coarse discrimination of differences in water quality) to a large number of groups (fine discrimination of differences in water quality). More details of the classification procedure are contained in Appendix B.

3 DATA

3.1 River Water Quality Variables

River water quality was characterised in this study by eight water quality variables (Table 1). Monthly measurements of these variables were obtained for 73 SoE sites located in the Southland region, and were filtered as described by McDowell *et al.* (2012). Observations of the eight water quality variables for the 5-year time period from 2007 to 2011 (inclusive) were retained for the analysis.

Table 1: The eight water quality variables included in this study.

Variable type	Variable name	Description	Unit
Physical	CLAR	Black disc visibility	m
	SS	Total suspended solids	mg/m^3
Nutrients	NH_4-N	Ammoniacal nitrogen	mg/m^3
	NO_x -N	Oxidised nitrogen	mg/m^3
	TN	Total nitrogen	mg/m^3
	DRP	Dissolved reactive phosphorus	mg/m^3
	TP	Total phosphorus	mg/m^3
Bacteria indicator	*E coli*	*Escherichia coli*	n/100 mL
	FC	*Faecal coliforms*	n/100mL

The data for the 73 sites was extended to represent the river and stream water quality for the whole region using spatial modelling of water quality approach of Unwin *et al.* (2010). The rivers and streams of Southland were represented by a digital river network that was obtained from the River Environment Classification (REC) (Snelder & Biggs, 2002). The REC represents the drainage path map for the country, derived from a Digital Elevation Model (DEM). The network has a spatial resolution of 50 m and comprises ~570,000 unique river segments defined by upstream and downstream confluences with tributaries, with a mean segment length of 740 m. Each segment is associated with its upstream catchment, also derived from the DEM. The REC represents the Southland region with 65,000 segments and associated sub-catchments.

We used Random Forest regression modelling to model water quality characteristics as a function of predictor variables. The predictor variables were obtained from the REC, and were largely catchment average values of environmental variables such as rainfall, temperature, slope, geological characteristics and land cover. These variables had previously been derived by combining the network with a Geographic Information System (GIS) database describing the climate, topography, geology, land cover and hydrology of New Zealand. Additional predictors for each segment were derived from models (e.g. mean flow estimates) (Woods *et al.*, 2006).

Random Forest models were fitted to the median concentrations of the observations of the water quality variables (Table 1), the median clarity for observations when flows were less than the median, and the 95th percentile of nitrate concentrations. Independent predictions of the site values were compared to the observations at all sites in Southland to evaluate the performance of each model and to confirm it represented the pattern of each variable across the Southland region (see Appendix A). More details of these models are included in Appendix A, and are contained in the cited references.

3.2 Contaminant Loads

3.2.1 Source Loads

We define 'source loads' to be the total annual mass of contaminant generated at the source (e.g. from a point source or from land under a specific land use). The major point source loads for nutrients (TN and TP) in the Southland region are described by Palliser and Elliott (2013). These loads were used to evaluate the contribution of point sources to source loads regionally.

A recent study of the economic impact of mitigation of water quality impacts by agriculture in Southland (NZIER, 2013) provides estimates of the source loads of total nitrogen (TN) and total phosphorus (TP) from agriculture and forestry in the region. The NZIER study identified the location of all farms within the region, and then categorised them based on four factors:

- Enterprise type (Dairy, Sheep & Beef, or Forestry)
- Land Use Capability (LUC) class (1-2, 3-4, and 5+)
- Drainage type (poorly or well drained)
- Land use intensity level (high, medium or low)

Estimates of total annual loads of TN and TP lost from each farm (kilogrammes/hectare/year) were made by AgResearch using OVERSEER simulations of representative farm types that were based on all potential combinations of the four factors. Each farm's estimates took account of specific physiographic conditions, including the LUC class and drainage class. Estimates were derived for each farm for alternative enterprise types and different management practices. Estimates of the current (2012) source loads were made for all farms, as well as an estimated maximum load that could be generated from each farm under the most intensive land use. Based on these simulations, estimates of TN and TP losses were assigned to each farm in the region. We note that losses of nitrogen from wintering-off (i.e. the grazing of dairy cows off the dairy platform during winter) was not accounted for in the TN figures. This results in relatively small underestimates of the total TN load (NZIER, 2013).

The estimated loads of TN and TP from each farm and the location of the farm centroid were used to calculate:

1. Accumulated source loads throughout the river network for 2012;
2. A source load map for 2012; and
3. A maximum potential source load map

To calculate the accumulated source loads throughout the network, we first allocated each individual farm load to the nearest REC segment. The farm loads were then accumulated down the river network (i.e. the total farm load from all upstream farms was calculated at all points in the REC network for which there were upstream farms). This method ignores that many farms span several REC subcatchments, and also implicitly assumes that groundwater flow paths follow surface water catchments. The loss of spatial detail that occurs as a result produces errors in the load estimates for small catchments; however, they have little influence on load estimates for larger catchments or the regional pattern of source loads.

Maps that expressed the spatial variation in farm source loads across the region were derived from the NZIER (2013) data. These maps provided the basis for identifying the areas contributing contaminants (described later in Section 6.2). The maps were defined by spatial interpolation (kriging) of the individual farm load estimates, located at the farm centroids, across all farms within Southland. The maps express the variation in annual loads of TN and TP over the region on a per hectare basis.

The maximum potential source loads were based on OVERSEER simulations provided by NZIER (2013). Maximum leaching is dependent on a farm's physiography, intensity and enterprise type. Because physiography is fixed for each farm, the outputs from the OVERSEER simulations could be used to identify the maximum possible leaching rates for each farm based on the different combinations of the other two factors (i.e. enterprise type and intensity). The highest leaching rates for LUC 1-2 and 3-4 sites were always high intensity dairy farming. For LUC 5+ the maximum rates occurred under high intensity sheep & beef farming because NZIER assumed dairy farming would not occur on these LUC types.

3.2.2 Realised Loads Estimated from SoE Data

We refer to loads of contaminants at specific sites on streams and rivers as 'realised loads'. The realised load reflects two processes. First, there is an accumulation of multiple sources of contaminants from diffuse and point sources down the catchments of rivers and streams. Second, there is generally a reduction in load that occurs between the source and points downstream due to attenuation (losses due to sedimentation, de-nitrification and die-off of microbes) and potentially due to groundwater lags (delays due to long travel times for dissolved contaminants, particularly nitrate). The realised loads were calculated from the SoE data based on the observed concentrations and flows (see Appendix A for details). We note that these load estimates are uncertain because they are based on monthly samples, which means that concentrations are not observed for the majority of the time.

We extended the observed (i.e. realised) annual loads of eight contaminants (DRP, NH_4N, NO_3N, SS, TN, TP, *E coli*, and FC) in three steps. Firstly, the estimated annual loads at SoE sites were expressed as specific loads with units of kilogrammes/hectare/year or number/hectare/year for *E coli* and FC. At the second step, we fitted models of each contaminant using the same predictors and Random Forest models that were used to model the water quality (concentration) data. Finally, we used the fitted models to make predictions of loads (kg/ha/yr) for all segments in the Southland region for all the contaminants. We produced maps showing the distribution of predicted values across the network segments.

3.3 River Condition Indicators

3.3.1 Periphyton

Nutrient species (oxidised nitrogen, total nitrogen, ammoniacal nitrogen, dissolved reactive phosphorus, and total phosphorus) stimulate the growth of plants, including algae, which can be either suspended in the water column or attached to substrates. Nutrient contamination results from point and non-point source discharges, and is strongly associated with agricultural land use. A key indicator of the ecological health of rivers is the abundance of algae growing on the bed. Algae growing on the bed of rivers are known as periphyton, and are a primary source of food for invertebrate insects, which in turn are food for fish and birds.

The growth of periphyton is determined primarily by light, temperature and the concentration of nitrogen and phosphorus. Periphyton is periodically removed by high flows, and its abundance is also controlled to a degree by grazing invertebrates, die-off and sloughing. If nutrient concentrations exceed certain values, growth rates can be high, and periphyton can become abundant. High or ‘nuisance’ levels of periphyton abundance can smother habitat, alter invertebrate communities, and produce adverse fluctuations in dissolved oxygen and pH. High abundance can also cause changes to water colour, odour and the general physical nature of the river bed, which has resultant detrimental effects on aesthetics and human uses of a river (MfE, 2000). Not all rivers have suitable physical conditions for the growth of conspicuous periphyton. In particular, soft-bottomed (i.e. muddy) lowland streams are often not a suitable habitat for periphyton.

Invertebrate and periphyton surveys have been conducted at approximately 70 sites per year since 2007. This monitoring was started in 1996, with more sites added over time such that about 70 sites (on average) have been surveyed annually since 2007. Periphyton samples are analysed for chlorophyll *a* and Ash Free Dry Weight (AFDW), and assessed according to standard procedures. Periphyton has been generally sampled once annually during summer, when river flows have been low and stable, so that abundance is likely to be highest. However, periphyton has also been sampled at many sites at other times of the year (see Appendix D for details).

3.3.2 Macro-invertebrates

Macro-invertebrates are invertebrate animals that live on the bed of rivers. The composition of the invertebrate community is used to measure the ecological health of waters, and expresses the long-term effect of water and habitat quality at a site. Invertebrate organisms are long-lived and, consequently, the community composition reflects the historic flux of contaminants and habitat quality at a site. Therefore, invertebrates need not be sampled as frequently as water quality variables, and annual samples taken during summer provide a good indication of the ecological health of waters.

Invertebrates are sampled annually during summer to assess habitat stress at low flows and high temperatures. Annual sampling may miss seasonal land use impacts such as the peak production from dairy farming that occurs during spring and is subject to bias from atypical conditions (e.g. higher than usual rainfall and river flow). However, annual sampling is generally considered to be suitable (Stark & Maxted, 2007).

3.3.3 Groundwater

The groundwater resource of Southland has been classified into 29 zones on the basis of hydrogeological properties and hydrological response (Rissmann, 2011; 2012). The 29 designated groundwater zones of the region fall into four ‘aquifer types’: riparian aquifers, terrace aquifers, lowland aquifers, and fractured rock aquifers. Each aquifer type exhibits physical, geological and hydraulic characteristics, which may exert a significant influence on water quality.

Groundwater is extensively used for domestic, stock and municipal water supplies throughout the Southland region. Groundwater is also extensively used for industrial and farm (particularly dairy shed) supply, which also require water of potable quality. In this study, we have used a kriged surface of median nitrate concentrations from 799 wells to estimate regional groundwater nitrate concentrations (Rissmann, 2011; 2012).

3.4 Estuaries

3.4.1 Condition Measures

The estuary monitoring programme operated by SRC uses the National Estuary Monitoring Protocol (NEMP) (Robertson *et al.*, 2002) to monitor the condition of the 10 estuaries that were included in this study (Figure 3). Several categories of condition measures are designed to measure stressors (primarily sedimentation and eutrophication) and responses (primarily habitat quality and ecological responses). Because this analysis was focussed on water quality, condition measures belonging to the sedimentation and nutrient enrichment stressor categories were used to assess estuary water quality (Table 2).

Table 2: Estuary condition measures used to assess estuary water quality.

Stressor category	Condition measures
Sedimentation	Area of soft mud change over time Sedimentation rate
Nutrient enrichment	Macroalgae cover extent Sediment nutrients Depth of sediment oxygen

The condition measures shown in Table 2 have been assessed for seven estuaries included in this analysis. The frequency of monitoring and time since the last measurements were made is variable between estuaries (see http://www.es.govt.nz/environment/coast/estuaries/estuarine-reports/). For reporting purposes, the condition measures have been expressed as a descriptive condition rating on a four-point scale (very good, good, fair and poor). These ratings have been developed over time, based on a comparison of the estuaries and their condition in relation to each indicator. There is currently no comprehensive description of how the ratings are derived, and there is limited scientific knowledge concerning the implications of particular values of the condition measures included in the NEMP.

3.4.2 Contaminant Loads

We used the realised load models (Section 3.2.2) to estimate the load of total nitrogen and suspended sediment entering the 10 Southland estuaries that were included in this analysis (Figure 3). All rivers and streams that were tributaries to each estuary were identified using a GIS. The load for each estuary was then estimated by summing each of the sediment and nitrogen loads across the contributing tributaries.

4 WATER QUALITY CRITERIA

4.1 Rivers

4.1.1 Periphyton

Periphyton abundance at a site tends to be highly variable in time. Low values are most often observed with occasional high values. Very high values may not be observed for several years, but then occur when particular conditions, generally prolonged low flows and high temperatures, allow the accrual of high abundance. Thus, the criterion for periphyton abundance is based on the expected (or mean) of the maximum annual values of chlorophyll *a*. This is consistent with the proposed NOF periphyton attribute (MfE, 2013a), and means that the criteria should not be exceeded in the average year. Short time series of periphyton observations may under-represent the highest values that are possible at a site, and the extremes of the observations (e.g. the frequency that values exceed 200 mg/m^2) are unlikely to be a good basis for prediction at other locations. Therefore, the raw periphyton data collected by SRC were used to develop a predictive model of maximum annual periphyton abundance (chlorophyll *a*), and these predictions compared with the periphyton thresholds. The details of the model are described in Appendix D.

Criteria for periphyton abundance are specifically included in the RWP, in terms of chlorophyll *a*, for each RWP management unit (Figure 1 and Table 3). The RWP also provides abundance criteria for periphyton as Ash Free Dry Mass (AFDM). In this study, the AFDM criteria was not used due to difficulties in modelling this variable.

Some modifications were made to the standards for periphyton biomass defined by the RWP. Very stringent standards (50 mg chlorophyll *a*/m^2) were defined by the RWP for the “Mountain” and “Lake” management units and standards of 120 mg chlorophyll *a*/m^2 for “Lowland (hard bed),” and “Hill” management units. These RWP standards are exceeded in a number of locations that may be regarded as pristine environments (i.e. the standards are stricter than natural conditions). In addition, the RWP standards are specified for different types of periphyton (filamentous and diatom mats). However, the monitoring carried out by SRC has not measured the biomass of the two periphyton types separately. We therefore adopted criteria that relaxed the RWP standards upward to account for their conservative nature and to reflect the total periphyton biomass (Table 3). These adjustments were based on periphyton criteria proposed in amendments to the NPS for Freshwater Management (MfE, 2013a) and our expert judgement. The modified criteria have not been formally adopted by the SRC.

Table 3: Periphyton biomass criteria (chlorophyll a) by RWP management units. These criteria apply to the estimated mean annual maximum biomass.

RWP management unit	mg chl *a* /m^2 (RWP)	mg chl *a* /m^2 (adopted)
Natural State	NA	120
Lowland (Hard bed)	120	200
Hill	120	200
Lakes	50	200
Mountains	50	120
Lowland (Soft bed)	NA	200
Spring Fed	50	200

4.1.2 Macro-invertebrate Community

The invertebrate data were expressed as macro-invertebrate community (MCI) scores, which are widely used for environmental monitoring in New Zealand (Stark & Maxted, 2007). The MCI score is a tolerance metric, which was designed to reflect water quality, where site scores potentially range from >150 (high water quality) to as low as 20 (very poor water quality) (Stark & Maxted, 2007). We used a national model to predict median MCI scores for Southland rivers (Clapcott *et al.,* 2013). Tests showed that the national model fitted the observed median MCI scores in Southland wells (see Appendix C). The criteria for MCI scores that are defined by the RWP vary by management unit (Figure 1), as shown in Table 4.

Table 4: MCI score criteria by RWP management units. These criteria are applied to the median annual value.

RWP management unit	MCI score criteria
Natural State	NA
Lowland (Hard bed)	90
Hill	100
Lakes	90
Mountains	120
Lowland (Soft bed)	80
Spring Fed	90

4.1.3 Nitrate Toxicity

Nitrate is a toxicant that can adversely affect both ecosystems and human health. Criteria for protection of ecosystem health are based on both the long-term average exposure and the seasonal maximum exposure to nitrate (Hickey, 2013). The two criteria are respectively applied to the median and 95th percentile concentrations of nitrate at a site. The RWP does not define criteria for nitrate, but nitrate toxicity criteria for freshwaters are proposed in the NOF (MfE, 2013a). The NOF introduces a banded system of criteria for water quality. These bands represent the degree of impact in terms of the proportion of test species that are affected at the given concentrations. The A-band represents less than 1% of test species being affected, and the D-band represents more than 20% of test species being affected.

The NOF proposes that the D-band is below the national bottom line, and higher bands (C, B and A) represent three successively better water quality states that communities can choose, depending on aspirations and a balancing of other values. However, an important requirement of both the NPS and the RWP is to maintain, or improve, water quality. This requirement precludes setting water quality criteria that would degrade the current state. Regard was given to this in nominating criteria for nitrate toxicity, and the B-band was nominated; this band is protective of 95% of test species, because the majority of sites in the region lie in this or the A-band (see Section 5.2 for details). The long-term and seasonal maximum criteria were applied to the median and 95th percentiles, respectively; the worst band between the two was adopted to determine an overall nitrate toxicity band for a site (Table 5). Thus, objectives are not met when median concentrations of nitrate are greater than 2.4 g/m^3, or 95th percentile concentrations are greater than 3.5 g/m^3 (Table 5).

Table 5: Nitrate toxicity bands proposed by the NOF.

Band	**Proportion of test species protected**	**Long term average exposure NO_3N g/m^3**	**Seasonal maximum NO_3N g/m^3**
A	99%	<1.0	<1.5
B	95%	<2.4	<3.5
C	80%	<6.9	<9.8
D	>80%	>6.9	>9.8

4.1.4 Water Clarity

Low visual clarity has ecosystem effects, including the attenuation of light in the water column and changes in animal behaviour (MfE, 1994). Water clarity also has implications for contact recreation due to its effect on human visibility through water (MfE, 1994). Visual water clarity is also associated with suspended solids that have the potential for smothering the beds of rivers and downstream water bodies. Visual clarity is measured as the sighting range of a black disc, and is monitored on a monthly basis at SoE sites in Southland.

The criteria for visual clarity are the standards defined by the RWP (Figure 1 and Table 6). The criteria are applied to the median value of measurements of clarity taken when flows are less than the median flow. This is because clarity is naturally low during high flows (floods), but should be high during normal to low flows.

Table 6: River water clarity criteria by RWP management units.

RWP management unit	**Clarity (m)**
Natural State	3
Lowland (Hard bed)	1.6
Hill	1.6
Lakes	3
Mountains	3
Lowland (Soft bed)	1.3
Spring Fed	3

4.1.5 Faecal Coliforms and *Escherichia Coli*

Faecal coliforms (FC) and *Escherichia coli (E coli)* indicate the presence of human or animal faeces and the associated risk of infectious disease from waterborne pathogens for both humans (via contact recreation and drinking water) and for livestock (via drinking water). The criteria for FC is the RWP standard of <1,000/100 ml, which is applied uniformly over all management units.

The RWP does not define criteria for *E coli*, but we used criteria proposed in the NOF (MfE, 2013a), which follow the same banded system as for nitrate toxicity. The NOF criteria are linked to the infection risk associated with secondary contact (non-immersion). This is consistent with the RWP objective that all surface water bodies in the region will be suitable for contact recreation, but is not as stringent as requirements for primary contact (swimming).

As regards were given to the requirement of the NPS to maintain or improve water quality, the study nominated the B-band (which is associated with a 1% infection risk) for *E coli* because the majority of sites in the region lie in this, or the A-band (see Section 5.2 for details). Thus, objectives are not met when median concentrations of *E coli* are greater than 540 *E coli*/100 ml (Table 7).

Table 7: E coli criteria. These criteria are applied to the median concentration of E coli measured at a site and across all RWP management units.

Band	**Infection risk**	**Criteria (*E coli*/100 ml)**
A	<0.1%	<260
B	0.1-1%	<540
C	1-5%	<1000
D	>5%	>1000

4.2 Estuaries

4.2.1 Nutrient Loads

The loads of nutrients including TN and TP are key attributes that determine ecosystem health in estuaries. Marine environments are generally limited by nitrogen because sea water has a relatively high concentration of phosphorus. Thus, the load of nitrogen largely determines the trophic state of estuaries; high N loading (particularly of inorganic N) can lead to potential estuarine concentrations that will maximise growth of phytoplankton and nuisance macro-algae (i.e. numerous forms of leafy or branching marine algae). This in turn results in detrimental environmental impacts within the estuary, including oxygen depletion, sulphide accumulation, smothering and habitat modification. The load of TP is more often important in estuaries that are intermittently closed (these are referred to as Intermittently Closed and Open Lakes and Lagoons [ICOLLs]).

There has been some effort to specify loading rate criteria for nitrogen and phosphorus in Southland's estuaries (e.g. Wriggle Coastal Management, 2012). The Wriggle Coastal Management loading rates specify a single threshold above which the estuary is considered to be unacceptably impacted by nutrients. The nutrient loading rates are specified as areal loading rates (i.e. loads per unit surface area of the estuary). These loading rates differ by estuary type to account for differences in hydrodynamic conditions. Hydrodynamic conditions are important because this affects the rate of flushing, and therefore residence time of water in estuaries, which affects the potential uptake of nutrients by plants. There are three estuary types defined for the Southland region: Tidal River Estuaries, Tidal Lagoons, and ICOLLs. Tidal River Estuaries export most of their nutrients to the sea, hence the loading bands nominated for them are relatively high. Tidal Lagoons (mudflat-dominated with large intertidal areas) are unlikely to be light-limited for much of the year because they are shallow. They have large amounts of suitable substrate for macro-algal growth; however, short residence times may limit algal growth. Therefore, the loading rates for Tidal Lagoons are intermediate to the level of the other estuary types. ICOLLs, which are open very infrequently, represent the extreme of eutrophic sensitivity, because of high residence times and poor flushing; hence, they have the lowest loading rate thresholds. The classification of estuaries into three types only crudely accounts for differences in hydrodynamic conditions, and there are likely to be significant differences in flushing and residence times within the individual types.

The Wriggle Coastal Management (2012) loading rates were considered as part of a regional analysis of the economic impacts of the NOF in Southland (MfE, 2013b). The results of this analysis indicated that the total nitrogen load criteria are probably conservative (Snelder & Fraser, 2013). Loading rates are a relevant consideration, but the science may not yet be at a point where robust criteria can be defined. The study therefore used condition measures as a basis for its assessment, and attempted to link an index that summarised the condition of the estuaries with the estimated nitrogen loading rate.

4.2.2 Condition Measures

Overall condition grades were developed for each of the two estuary stressor categories (sedimentation and nutrient enrichment) for the monitored estuaries based on each estuary's most recent assessment. The overall grades for each estuary were based on each stressor's condition measures, and were derived by assigning a numeric value from one to four to the descriptive ratings from poor to very good. These numeric values were then added for each condition measure and divided by the number of condition measures to obtain an overall condition grade for each stressor that can take a value from 1 to 4. Threshold values were nominated for these overall condition grades to convert them to a descriptive rating, as follows:

- >3 very good
- >2.5 good $\leq$ 3
- >2 fair $\leq$ 2.5
- $\leq$2 poor

Finally, an overall condition grade of fair or better (i.e. greater than 2) was adopted as the criteria in the analysis. Thus all estuaries with overall condition grades (in either or both stressor category) of less than 2 were considered unlikely to meet RWP objectives.

4.3 Groundwater

Nitrate-nitrogen is a significant contaminant of groundwater, because it has both ecosystem and human health effects. The national standard for drinking water is 11.3 g NO_3N/m^3. However, groundwater should also be protective of the ecological health of surface water that it discharges into. During periods of low flow, most surface waters are derived from groundwater. This means that nitrate concentrations in groundwater should be such that the seasonal maximum criteria for surface water is met during low flow conditions. The study adopted the C-band seasonal maximum criteria for surface water (Table 5) as the criteria for groundwater, on the basis that mixing and uptake of emerging groundwater is likely to mean that surface water concentrations would likely meet the B-band (Table 5). It is acknowledged that there is inadequate science to better justify this criteria, and that it has not been formally adopted by the SRC. Thus, objectives are not met when median groundwater nitrate concentrations exceed 9.8 NO_3N g/m^3 (Table 5).

5 ASSESSMENT OF WATER QUALITY STATE

5.1 Analysis of River SoE Data

5.1.1 Water Quality Models

Independent predictions made of the observed values of the water quality variables at the SoE sites (i.e. predictions made when the site was excluded from the fitting data) indicated that random forest models for the contaminants NH_4N, NO_3N, TN, TP and for Clarity were strongly related to the observations. Nash-Sutcliffe Efficiencies[3] (NSE) for these models ranged between 0.49 and 0.83, indicating good performance (see Appendix A). The models for DRP, *E coli* and FC performed less well with NSE values ranging from 0.25 to 0.44. The DRP data, in particular, were strongly influenced by values that were below the detection limit, with the median values at several sites being at the detection limit. This reduced the potential performance of the models for these variables. The model for SS performed poorly with an NSE value of 0.22. In addition, the model uncertainties, as defined by the root mean square deviation (RMSD) (see Appendix A) were small, relative to regional variation in most of the modelled variables. This indicated that the models describe regional patterns accurately, and allowed the analysis to 'fill in the gaps'. However, the uncertainties indicate that the predictions should not be relied on to evaluate conditions at specific sites.

The mapped patterns for the nine water quality variables indicated that there are strong regional patterns in water quality that are consistent between the variables (Figure 5). Concentrations of all contaminants were low in the west and north of the region, and increased in the pastoral areas on the inland basins. In general, concentrations of all contaminants increased down the catchment and as a function of the proportion of pastoral land cover. The highest concentrations and lowest clarity were predicted for the small streams and rivers rising on the Southland Plains. These patterns are consistent with pastoral land use being the dominant cause of water quality issues.

The similarity in the regional patterns indicates that the variables are highly correlated, and that, at the regional scale, there is little localisation in the contaminants of most concern. Suspended solids had the largest deviation from the regional pattern of water quality, with proportionally larger concentrations of SS predicted in the northwest of the region than the other contaminants. This reflects the stronger association between SS and physiography (topography and geology) than the other contaminants, which are more closely associated with land use.

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[3] The Nash-Sutcliffe efficiency is a measure of the performance of a model that indicates how closely a plot of observed versus predicted values lies to the 1:1 line (i.e. how close to perfect coincidence the two sets of values are) (Nash & Sutcliffe, 1970). NSE values can range from one (a perfect fit) to negative infinity. Values larger than zero indicate that the model has some predictive capability, and the closer the NSE value is to one, the more accurate the model is. Values less than zero suggest that the data is better predicted by the mean of the observations than the proposed model.

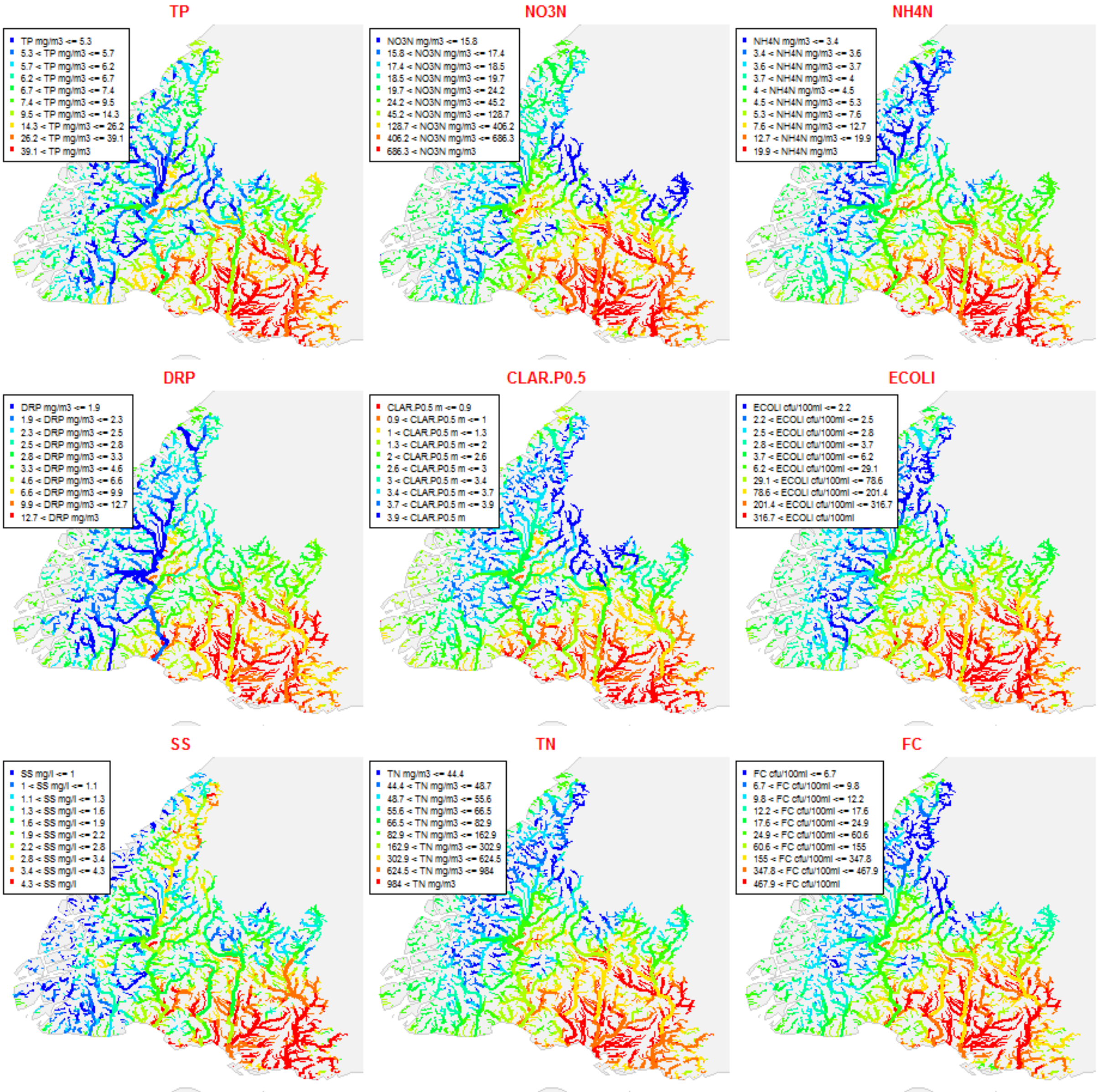

Figure 5: Predicted patterns in the median value of the eight water quality variables (see Table 1 for the variable names).

5.1.2 Water Quality Classification

A classification of water quality in Southland was defined using hierarchical cluster analysis (HCA) (Figure 6). Table 8 provides a summary of the median water quality predictions within each class. At the 6-class level, the pattern was dominated by classes 1 and 2, which represented the high water quality areas of the region draining land primarily in Fiordland and mountainous areas of the region. Classes 3, 4, 5 and 6 represent a gradient of decreasing water quality; note the summary in Table 8 indicates that the concentration of all contaminants increases along this gradient and clarity decreases. The mapped classification indicates the classes with the poorest water quality represent: the streams and rivers rising on the Southland plains and inland basins (Class 6); pastoral hill country (Class 5); and the main stems of hill-fed rivers whose catchments have some agricultural development (Class 4). These patterns are similar to the management units that are used in the Southland RWP (Figure 1).

Table 8: General characterisation of the water quality classification at the 6-class level (by water quality varaiable). The values are the median values of the predicted median concentrations for all segments in each class.

Class	TN (mg/m^3)	TP (mg/m^3)	DRP (mg/m^3)	FC (cfu/100 ml)	NH4N (mg/m^3)	NO3N (mg/m^3)	Clarity (m)	ECOLI (cfu/100 ml)	SS (g/m^3)
1	47	7	2	7	4	18	3.8	2	1722
2	62	6	3	12	4	21	3.0	3	1005
3	88	8	5	24	5	28	1.9	5	1011
4	234	16	7	75	8	42	1.0	40	2197
5	547	24	10	319	12	280	1.0	170	3240
6	1219	39	13	454	21	916	0.9	312	3885

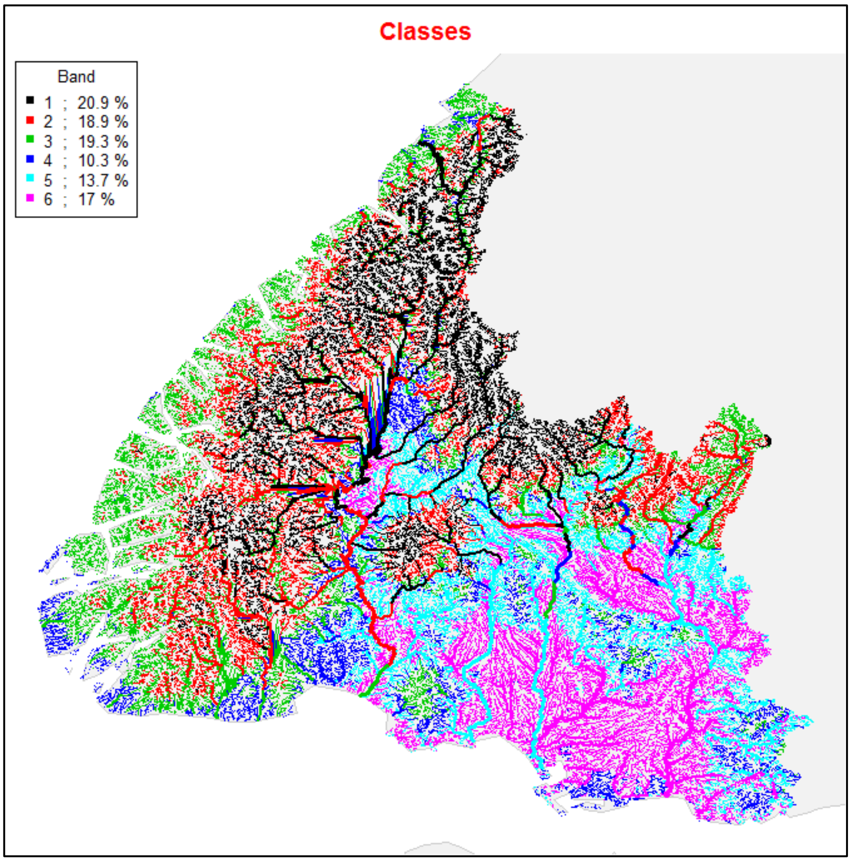

Figure 6: Map of the HCA classification of existing water quality in Southland at the 6-class level.

5.1.3 Regional Differences in Contaminants

A PCA was used to examine the regional differences in the contaminants of most concern. PCA analyses were performed on (i) the median values of the nine observed water quality variables at the 73 SoE sites (of which only 66 monitored all 9 variables), and (ii) on the predicted water quality variables for all segments. PCA is sensitive to the relative scaling and distributions of the original variables. We performed the PCA on the correlation matrix, which effectively re-scales the variables to have the same mean and standard deviation.

The first, second and third components of the PCA performed on the data for the 66 SoE sites explained 51%, 14% and 13% (respectively) of the total variation in the water quality data. A biplot of the PCA indicates that the first axis was strongly associated with increasing concentrations of all contaminants (with the exception of clarity) (Figure 7). The relatively high variation explained on the first axis indicates that all variables are highly correlated and that, across the SoE sites, there is only modest localisation in the contaminants of most concern.

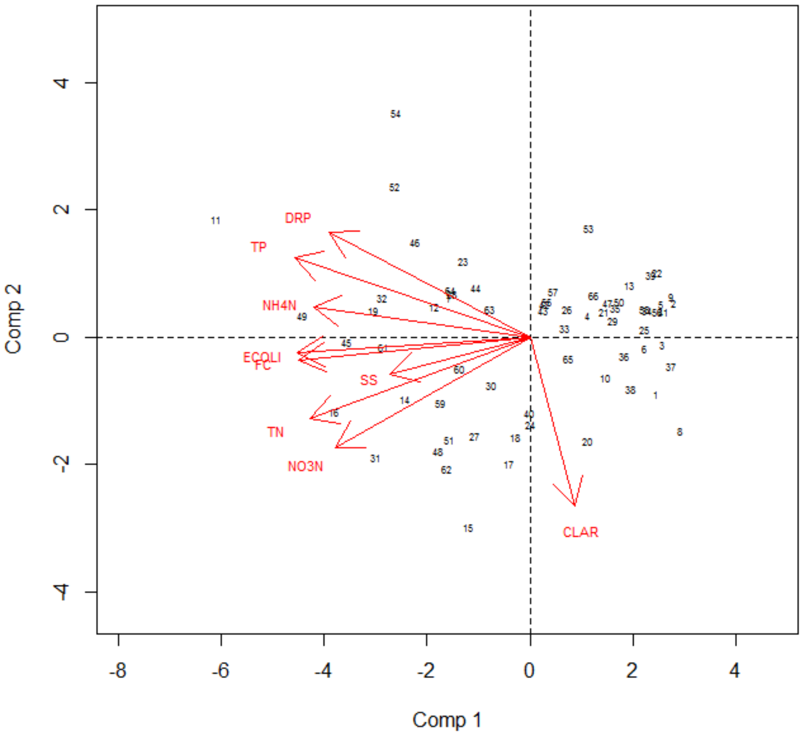

Figure 7: Biplot of the PCA performed on the median values for eight water quality variables measured at the 73 SoE sites. The first and second components explained 51% and 14% (respectively) of the total variation.

The first, second and third components of the PCA performed on the predicted water quality data for all network segments in Southland explained 82%, 7% and 4% (respectively) of the total variation in the water quality data. A biplot of the PCA indicates that the first axis was strongly associated with increasing concentrations of all contaminants and decreasing clarity (Figure 8); this is consistent with the relationship observed for the SoE monitoring sites. The high proportion of variation explained on the first axis indicates that all variables are highly correlated and that, across the region, there is only modest localisation in the contaminants of most concern. Differences in the spatial patterns of the water quality variables are shown on the maps in Figure 5.

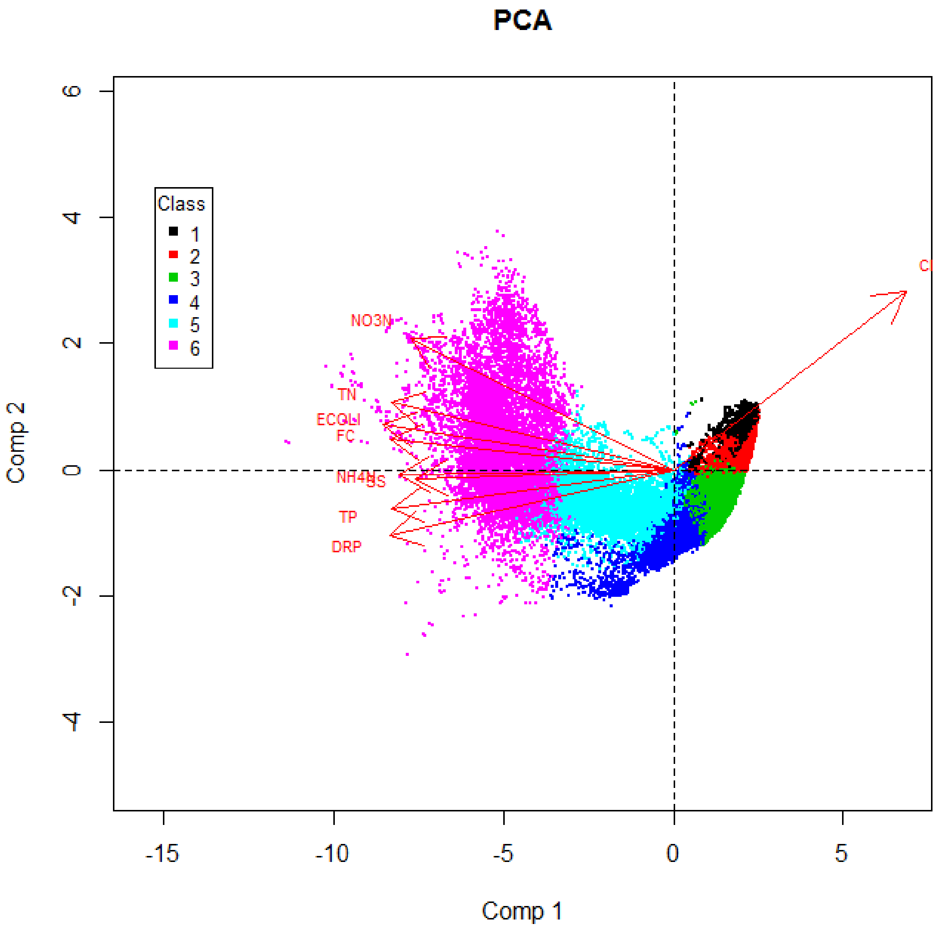

Figure 8: Biplot of the PCA performed on the predicted median concentration of eight water quality data variables for all network segments in Southland. The first and second components explained 82% and 7% (respectively) of the total variation. Each segment is represented on the plot as a dot coloured by its class membership of the water quality classification at the 6 class level.

5.1.4 Regional Trends in River Water Quality

Trends were calculated for the 73 SoE sites by DiaryNZ (Mike Scarsbrook, *pers comm.*) using the Seasonal Kendall Sen Slope Estimator (SKSSE) (Sen, 1968). This analysis was performed on the raw data (i.e. there was no adjustment of the data to account for covariates such as is often performed, particularly for flow). Monthly observations for the period July 2002 to June 2012 were included for all sites, except those that had less than five years of data (less than 60 samples). The SKSE values were divided by the median concentrations to convert them to Relative Seasonal Kendal Sen Slope Estimator (RSKSSE). This allows the comparison of trend strength between sites by expressing the trend as the change per year relative to the median value at each site (Ballantine *et al.*, 2010).

To characterise regional patterns in water quality trends, the trend slope estimates were grouped into classes, and the data presented on box and whisker plots. The SoE sites were assigned to classes at the 6-class level of the water quality classification derived from the HCA analysis (Figure 6). This resulted in variable numbers of sites in each class (Figure 9). For example, there were 26 sites in Class 6 and only 3 in Class 2. There are therefore differences in the strength of evidence for overall (within-class) trends between classes.

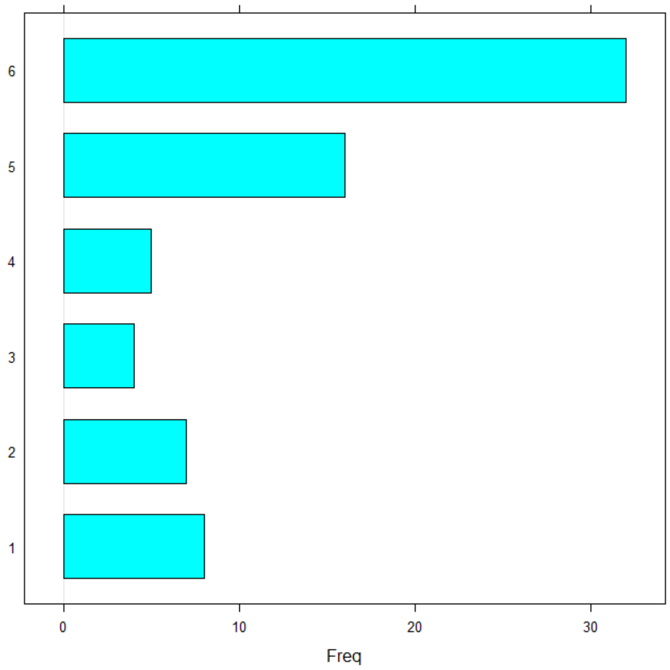

Figure 9: Number of SoE sites in each class at the 6-class level of the water quality classification.

In Figure 10, box and whisker plots of RSKSE indicated that more than 50% of the sites in all classes, except class 1, had increasing trends in TN, and all classes, except 1 and 4, had increasing trends in oxidised nitrogen (NO_3N) (i.e. the black dot representing the class median RSKSE values are greater than zero). The median class trends for TP and DRP were less than or equal to zero for all classes (i.e. improving water quality). The median within class trends for *E coli* showed increases for classes 4, 5 and 6. There are formal tests of trends within classes, but because this analysis was simply to provide contextual information, these have not been applied in this study.

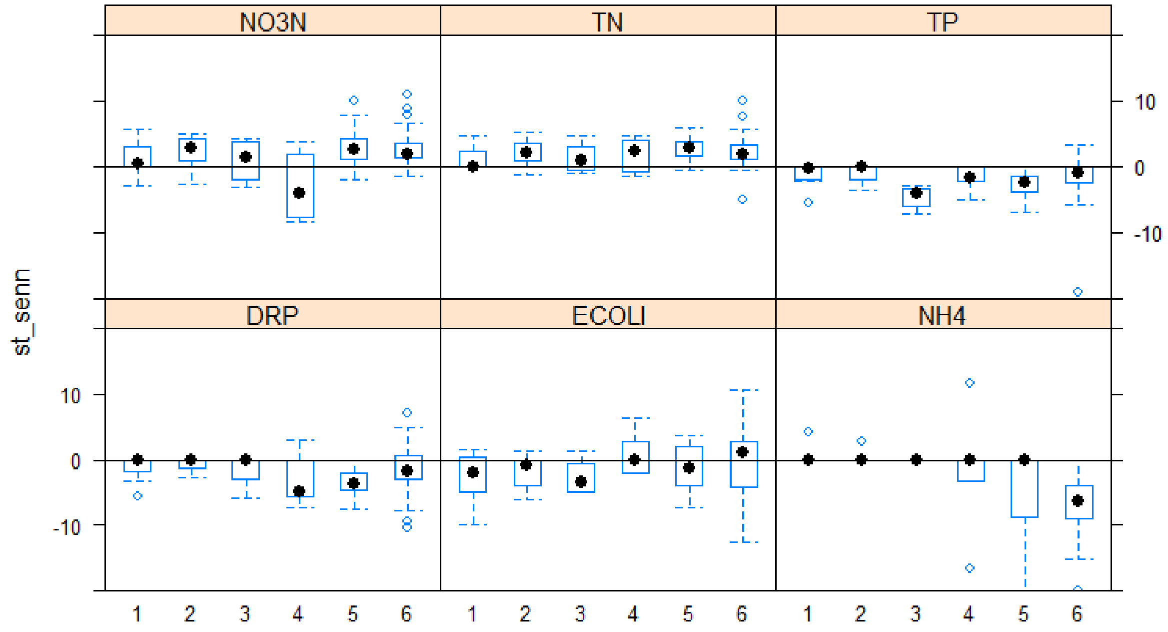

Figure 10: RSKSE grouped by water quality class at the 6-class level. The horizontal line indicates RSKSE values of zero (no trend). Class medians (black dots) above or below this line indicated that more than 50% of the sites in the class have either increasing or decreasing trends.

5.2 Identification of Issues for Rivers

5.2.1 Periphyton

Exceedance of the periphyton biomass criteria (Table 3) at the monitoring sites are shown in Table 9. Predictions of periphyton biomass in Southland are shown in Figure 11 (left hand plot). The proportion of monitoring sites that had ever exceeded the biomass criteria, or for which the observed mean annual maximum chlorophyll *a* exceeded the criteria, was much larger than the proportion of the network that was predicted to exceed the chlorophyll *a* criteria (Table 9). This suggests that the periphyton sampling sites tend to be located on rivers with high periphyton (i.e. the pool of sites are not representative of the region as a whole).

The predicted values were compared to the criteria shown in Table 3 to produce a map showing where there are issues (Figure 11: right hand plot). The main stem of the Matuara River in its lower reaches was generally non-complying. Periphyton biomass objectives were also not met in some tributaries of the Aparima, Oreti, Waimatuku and Makarewa rivers.

Table 9: Exceedance of the periphyton biomass criteria (chlorophyll a) predicted for the network and observed at the monitoring sites grouped by management units.

RWP management unit	Number of sites	Sites not complying based on observed MAM (%)	Sites that have ever exceeded threshold (%)	Network not complying (%)

Natural State	4	0.0	25.0	0.0
Mountains	1	0.0	100.0	0.7
Lakes	5	0.0	0.0	0.0
Hill	16	6.3	6.3	0.9
Spring Fed	2	0.0	0.0	4.6
Lowland (Hard bed)	16	37.5	50.0	2.9
Lowland (Soft bed)	14	28.6	21.4	0.0

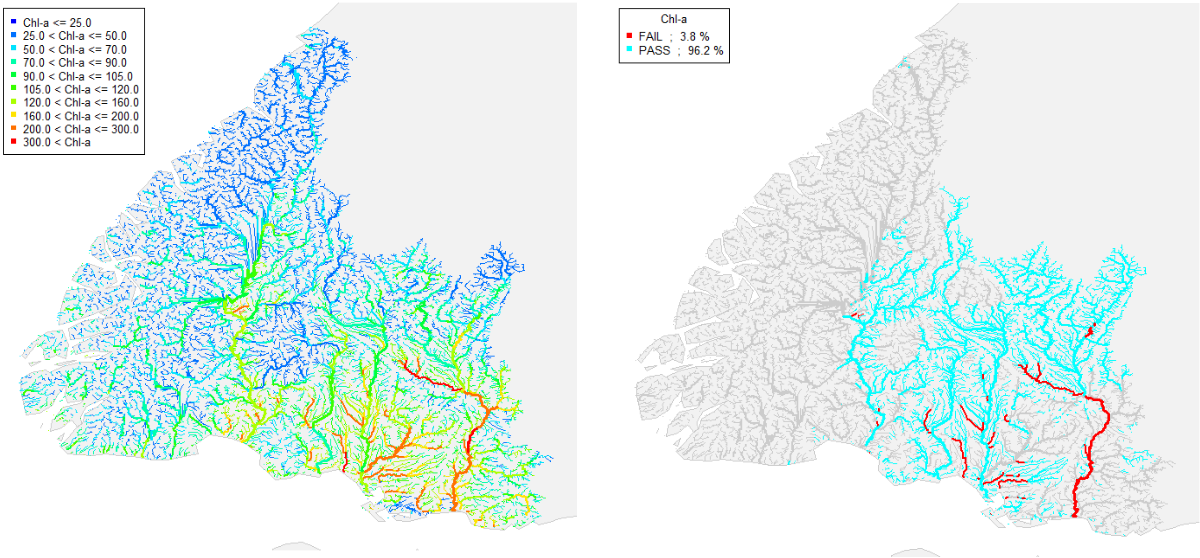

Figure 11: Predictions of periphyton biomass (chlorophyll a) in Southland (left panel) and identification of issues (right panel). Segments are coloured in the right panel according to whether they pass ('objective met': blue) or fail ('objective not met': red) the criteria.

5.2.2 Macro-invertebrate Community

Exceedances of the MCI score criteria (Table 4) at SoE sites are shown in Table 10. Predictions of MCI scores in Southland are shown in Figure 12 (left hand plot). There was reasonable agreement between the proportion of non-complying sites and the proportion of non-complying network segments (Table 10). The predicted values were compared to the criteria shown in Table 4 to produce a map showing where objectives are met (Figure 12: right hand plot). Lowland Hard (LH) class had a high level of non-compliance with the criteria of 90 (Table 10). There was also a high level of non-compliance in NS and M management units, which are largely unaffected by human activities, indicating the RWP standards (120) may be too conservative.

Table 10: *Exceedance of the MCI score criteria predicted for the network and observed at the monitoring sites grouped by management units.*

RWP management unit	Number of sites	Sites not complying (%)	Network not complying (%)
Natural State	6	50.0	0.0
Mountains	1	0.0	75.7
Lakes	5	0.0	10.6
Hill	21	4.8	4.3
Spring Fed	4	75.0	64.8
Lowland (Hard bed)	22	40.9	43.9
Lowland (Soft bed)	19	10.5	4.2

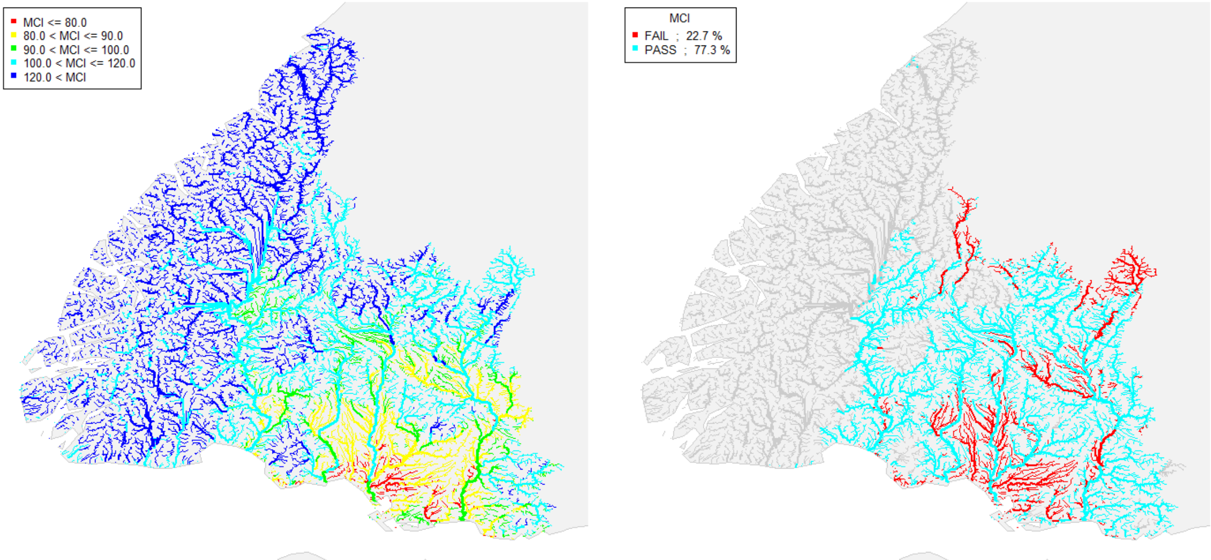

Figure 12: *Predictions of MCI scores in Southland (left panel) and identification of issues (right panel). Segments are coloured in the right panel according to whether they pass ('objective met': blue) or fail ('objective not met': red) the criteria.*

5.2.3 Clarity

Exceedance of the clarity criteria (Table 6) at the SoE sites are shown in Table 11. Predictions of clarity in Southland are shown in Figure 13 (left hand plot). There was reasonable agreement between the proportion of non-complying sites and proportion of non-complying network segments (Table 11). The predicted values were compared to the criteria shown in Table 4 to produce a map showing where objectives are met (Figure 13: right hand plot). The Lowland Hard (LH) and Lowland Soft (LS) classes had high levels of non-compliance with the threshold of 1.6 m and 1.3 m, respectively (Table 11). There was also a high level of non-compliance in NS and M management units, which are largely unaffected by human activities, suggesting the RWP standards (3 m) may be too conservative.

Table 11: Exceedance of the clarity criteria predicted for the network and observed at the monitoring sites grouped by management units.

RWP management unit	Number of sites	Sites not complying (%)	Network not complying (%)
Natural State	1	100.0	50.4
Mountains	1	0.0	43.1
Lakes	3	66.7	94.7
Hill	16	6.3	33.6
Spring Fed	NA	NA	98.1
Lowland (Hard bed)	29	79.3	99.6
Lowland (Soft bed)	16	87.5	97.9

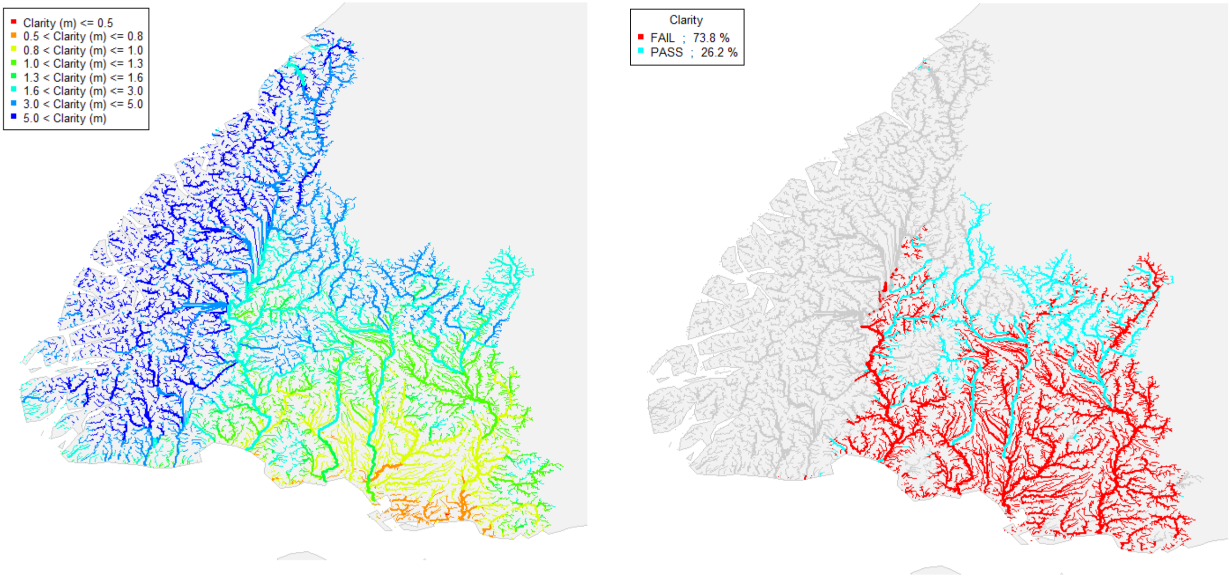

Figure 13: Predictions of river and stream water clarity at flows less than the median in Southland and identification of clarity issues (left panel) and compliance with the relevant thresholds (right panel). Segments are coloured in the right panel according to whether they pass (‘objective met’: blue) or fail (‘objective not met’: red) the criteria.

5.2.4 Nitrate Toxicity

Exceedance of the nitrate toxicity criteria (Table 5) at the monitoring sites are shown in Table 12. Predictions of the median and 95th percentile nitrate concentrations in Southland are shown in (Figure 14: left hand plots; and Figure 15). There was reasonable agreement between the proportion of non-complying sites and the proportion of non-complying network segments (Table 12). The predicted values were compared to the criteria shown in Table 5 to produce a map showing where objectives are met (Figure 14: right hand plot). Of the observed sites, 26% of LH and 12% of LS management units were in the C-band, and 3% of LH in the D-band. For the predicted nitrate concentrations, 13%, 1% and 41% of network segments in the LH, LS, and S management units (respectively) were predicted to be in the C-band.

Table 12: Proportion of the network (predicted) and monitoring sites (observed) in nitrate toxicity bands (A to D) grouped by management units. The grading represents the combination of the long and short term (median and 95th percentile) with the band assigned being the most constraining.

RWP management unit	**Network A**	**Network B**	**Network C**	**Site A**	**Site B**	**Site C**	**Site D**
Natural State	100	0	0	100	0	0	0
Mountains	100	0	0	100	0	0	0
Lakes	91	9	0	100	0	0	0
Hill	100	0	0	94	6	0	0
Spring Fed	14	45	41	NA	NA	NA	NA
Lowland (Hard bed)	44	43	13	32	39	26	3
Lowland (Soft bed)	59	41	1	38	50	13	0

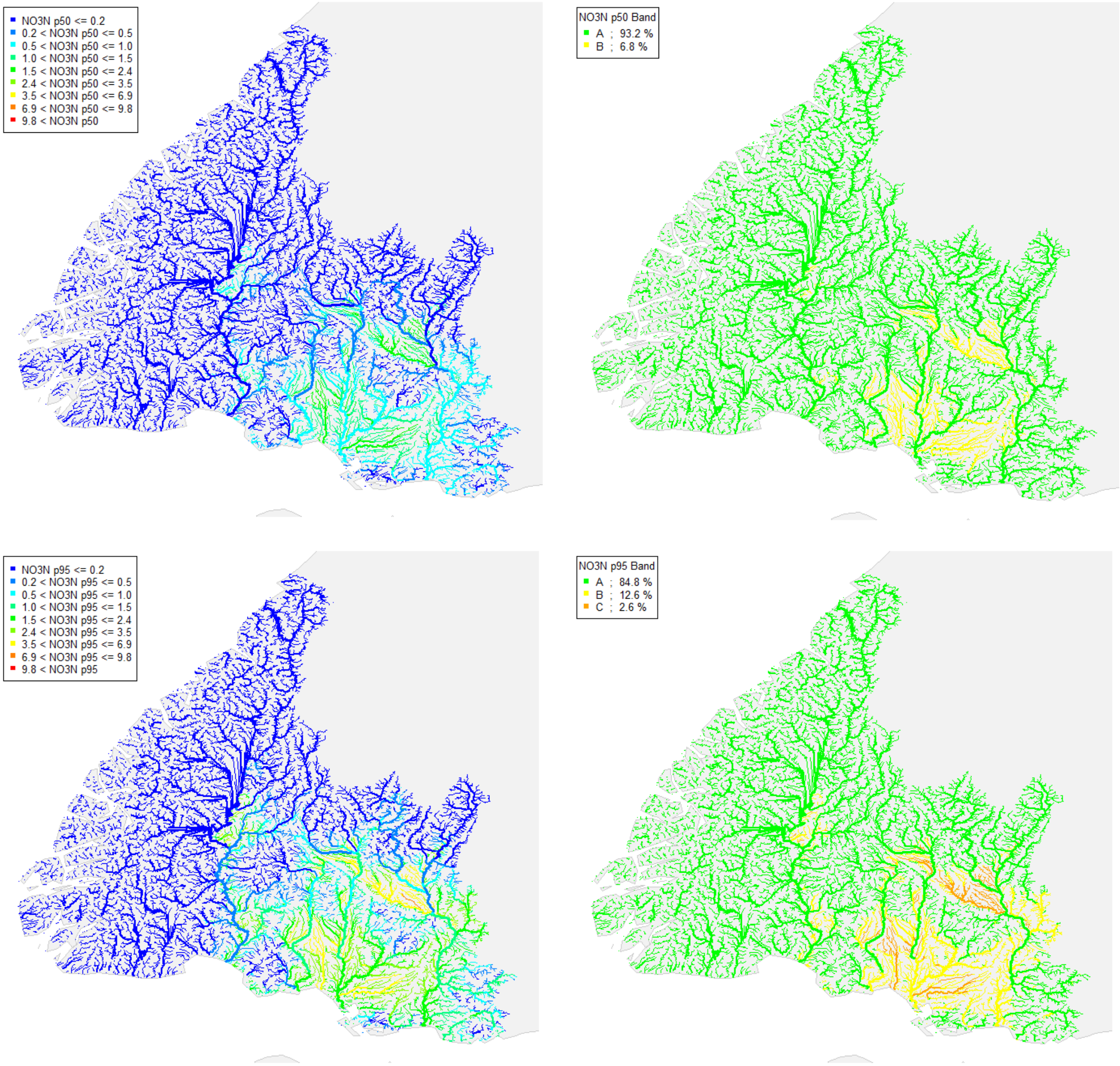

Figure 14: Predictions of nitrate concentrations in Southland, and identification of nitrate toxicity issues (left panel) and compliance with the relevant thresholds (right panel). Segments are coloured in the right panel according to their NOF quality band.

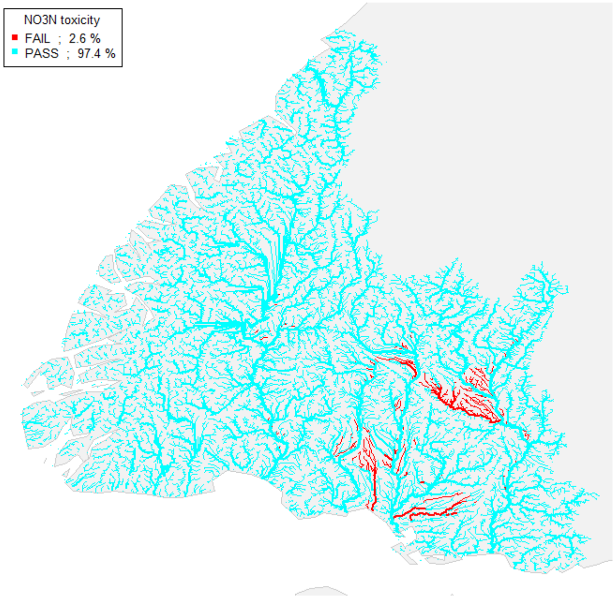

Figure 15: Predictions of nitrate concentrations in Southland. Segments are coloured according to whether they pass ('objective met': blue) or fail ('objective not met': red) the criteria.

5.2.5 E Coli

Exceedance of the *E coli* criteria (Table 7) at the monitoring sites are shown in Table 13. Predictions of the median concentrations of *E coli* in Southland are shown in (Figure 16: left hand plot). There was good agreement between the proportion of non-complying sites and the proportion of non-complying network segments (Table 13). The predicted values were compared to the criteria shown in Table 7 to produce a map showing where objectives are met (Figure 16: right hand plot; and Figure 17). Of the observed sites, 16% of LH and 13% of LS management units were in the C-band, and 13% of LS were in the D-band. For the predicted *E coli* concentrations, only 1% of network segments in the S management unit was predicted to be in the C-band.

Table 13: Proportion of the network (predicted) and monitoring sites (observed) in secondary contact bands (A to D) based on E coli concentrations grouped by management units.

RWP management unit	Network A	Network B	Network C	Site A	Site B	Site C	Site D
Natural State	100	0	0	100	0	0	0
Mountains	100	0	0	100	0	0	0
Lakes	95	5	0	100	0	0	0
Hill	99	1	0	89	6	0	6
Spring Fed	28	71	1	NA	NA	NA	NA
Lowland (Hard bed)	48	52	0	19	58	16	6
Lowland (Soft bed)	41	59	0	6	69	13	13

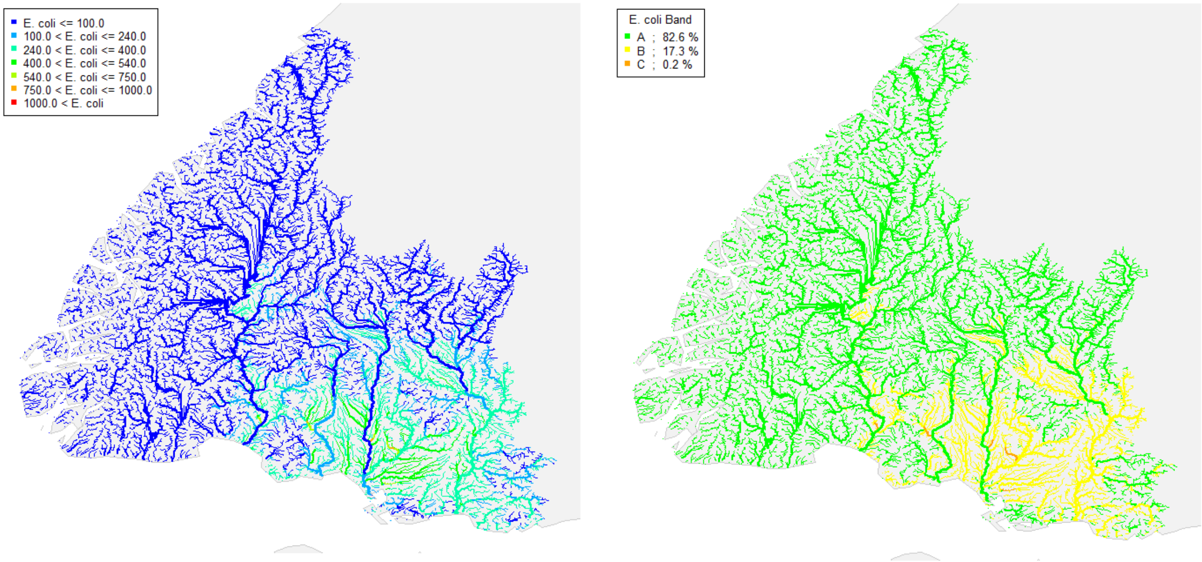

Figure 16: Predictions of E coli concentrations in Southland and identification of E coli issues (left panel) and compliance with the relevant thresholds (right panel). Segments are coloured in the right panel according to their NOF quality band.

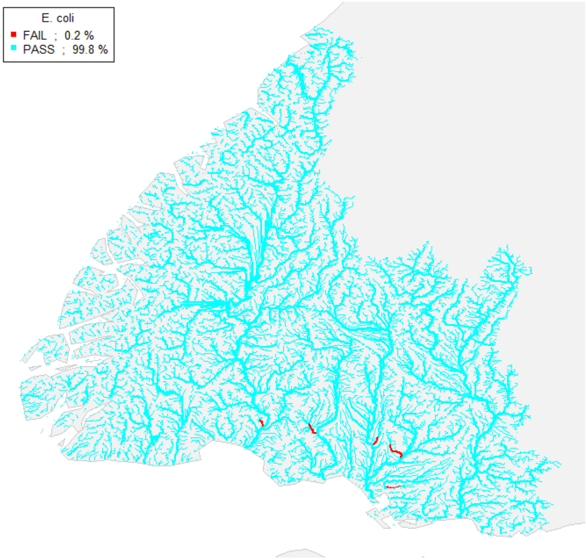

Figure 17: Predictions of E.coli concentrations in Southland and identification of secondary contact issues. Segments are coloured according to whether they pass ('objective met': blue) or fail ('objective not met': red) the criteria

5.2.6 Faecal Coliform

Exceedances of the FC criteria (1000/100 mL) at the monitoring sites are shown in Table 14. Predictions of the median concentrations of FCs in Southland are shown in (Figure 18: left hand plot). There was poor agreement between the proportion of non-complying sites and the proportion of non-complying network segments (Table 14). The predicted values were compared to the criteria to produce a map showing where objectives are met (Figure 16: right hand plot). The predicted values suggested that there were very few locations where the FC criteria were not being met.

Table 14: Exceedance of the FC criteria predicted for the network and observed at the monitoring sites grouped by management units.

RWP management unit	Number of sites	Sites not complying (%)	Network not complying (%)
Natural State	2	0.0	0.0
Mountains	1	0.0	0.0
Lakes	3	0.0	0.0
Hill	16	6.3	0.0
Spring Fed	NA	NA	0.0
Lowland (Hard bed)	29	6.9	0.1
Lowland (Soft bed)	16	12.5	0.1

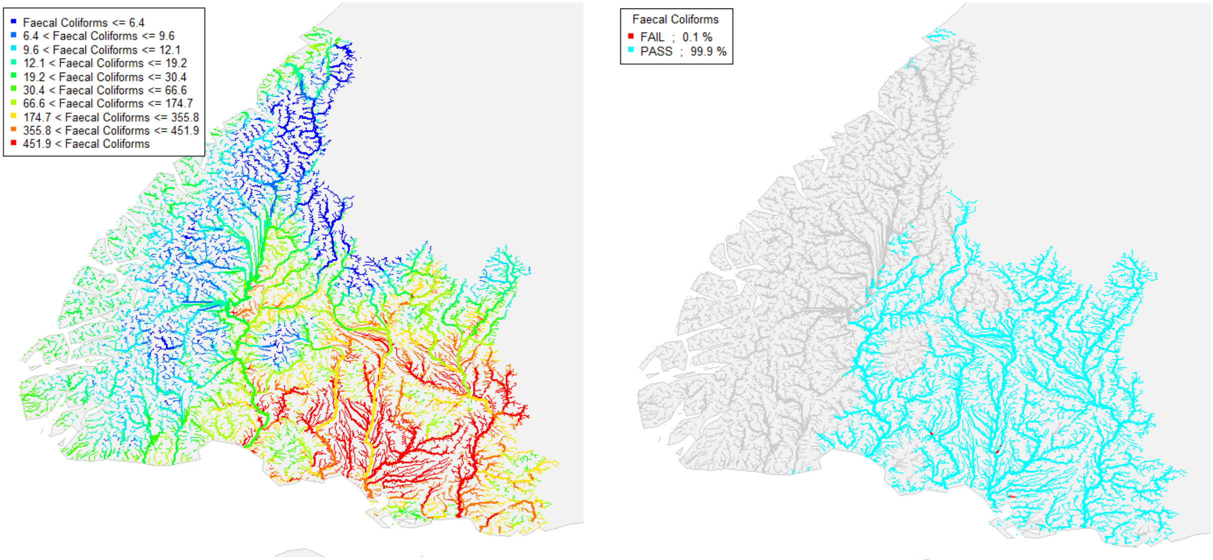

Figure 18: Predictions of FC concentrations (number/100 ml) in Southland (left panel) and identification of issues (right panel). Segments are coloured in the right panel according to whether they pass ('objective met': blue) or fail ('objective not met': red) the criteria.

5.3 Identification of Issues for Groundwater

Exceedance of the groundwater nitrate concentration criteria (9.8 NO_3N g/m^3; Table 5) at the 799 monitoring sites are shown in Table 15. Predictions of the median groundwater nitrate concentration criteria in Southland's aquifers are shown in (Figure 19). This figure is a kriged surface through the 799 observations points, with additional points used to constrain the surface within physical boundaries of the aquifer system (Rissmann, 2012). Areas coloured red to purple are those which exceed the nitrate concentration criteria. The observed values and predicted values suggest that the nitrate criteria are not met in some parts of the region.

Table 15: Exceedance of the groundwater nitrate criteria observed at the monitoring sites grouped by groundwater zones.

Groundwater zone	**Number of non-compliant wells**	**Number of wells**
Castlerock	3	9
Cattle Flat	0	1
Central Plains	8	59
Edendale	3	35
Five Rivers	1	27
Knapdale	3	28
Longridge	2	5
Lower Aparima	0	45
Lower Mataura	3	64
Lower Oreti	2	56
Lower Waiau	2	37
Makarewa	3	58
Orepuki	0	4
Oreti	0	8
Riversdale	0	42
Te Anau	0	11
Upper Aparima	0	48
Upper Mataura	0	12
Waihopai	3	83
Waimatuku	1	27
Waimea Plain	14	52
Waipounamu	0	5
Wendon	0	8
Wendonside	3	19
UNDEFINED	0	56
Total	**51**	**799**

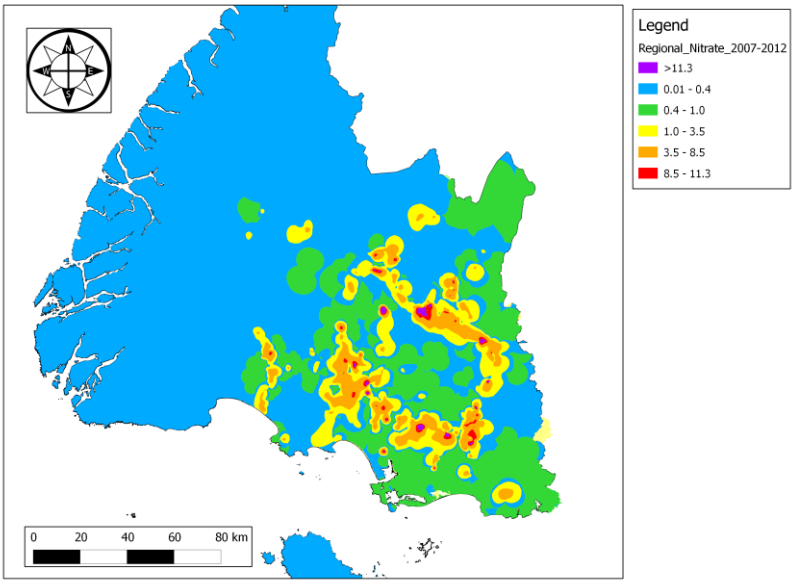

Figure 19: Predictions of groundwater nitrate concentrations in Southland (from Rissmann, 2012). The nominated nitrate criterion of 9.8 NO_3N g/m^3 is exceeded in areas that are shaded red and purple.

5.4 Identification of Issues for Estuaries

5.4.1 Condition Measures

Table 16 shows the results of the most recent assessment of condition measures for seven Southland estuaries, and the condition grades for sedimentation and nutrient enrichment that were calculated from the individual condition measures. Based on the condition grades, water quality objectives are not met (condition grades were less than 2) in four estuaries (New River Estuary, Waimatuku Estuary, Jacobs River Estuary, and Waiau River Estuary). The New River Estuary and Jacobs River Estuary had poor condition grades (below 2) for both sedimentation and nutrient enrichment, whereas the Waimatuku Estuary and Waiau River Estuary had poor grades for only sedimentation and nutrient enrichment, respectively.

The condition grades for the Waikawa Estuary, Haldane Estuary and Toetoes Harbour were more than 2, indicating that objectives are met in these estuaries. The two Shallow ICOLL estuaries (Lake Brunton and Waituna Lagoon) are not represented in the condition measures because these are monitored using protocols that are different to the NEMP (Robertson *et al.*, 2002). In addition, Bluff Harbour is not included because the most recent monitoring of this estuary predated the development of NEMP and, therefore, the available information is inconsistent with the other estuaries.

Table 16: Condition of Southland estuaries with respect to two water quality stressor categories: sedimentation and nutrient enrichment. The cells in the table are coloured based on a qualitative assessment of each condition measure according to a scale of very good (green), good (yellow), fair (orange), and poor (red). These descriptive ratings are assigned values from 1 (poor) to 4 (very good). The overall condition grade is the average of the condition measures within each stressor category.

Water quality stressor	Sedimentation		Nutrient enrichment			Overall condition grade	
Condition measure	Area of soft mud	Sedimentation rate	Nuisance macroalgae extent/or macrophyte	Sediment nutrient concentration	Depth of sediment oxygen	Sedimentation	Nutrient enrichment
New River Estuary	1	1	1	1	1	**1.0**	**1.0**
Jacobs River Estuary	1	2	1	2	1	**1.5**	**1.3**
Waimatuku Estuary	1	2	3	2	1	**1.5**	2.0
Waiau River Estuary	4			1	2	2.0	**1.5**
Waikawa Estuary	1	4	3	3	1	2.5	2.3
Haldane Estuary		4		3	2	4.0	2.5
ToetoesHarbour			3	4	3		3.3

Condition measure rating

4	Very good condition
3	Good condition
2	Moderate/fair condition
1	Poor condition

Overall condition grade

>3	Very good condition
2.6-3.0	Good condition
2.0 - 2.5	Moderate/fair condition
<2	Poor condition

5.4.2 Estuary Nutrient and Sediment Loads

The estimated annual TN and suspended sediment loading rates, types and surface areas for 10 Southland estuaries are shown in Table 17. TN and suspended sediment loads were estimated using models derived from the river SoE data (see Appendix A).

The relationship between the overall condition grade for nutrient enrichment (Table 16) and the loading rate for TN (expressed as an annual load per km^2) is shown in Figure 20**Error! Reference source not found.**. There is an expected negative relationship between the nutrient condition grade and the TN loading rate (Figure 20**Error! Reference source not found.**). The relationship also indicates that shallow tidal lagoons are more sensitive to the loading rate than the shallow tidal rivers (shallow tidal lagoons with similar overall nutrient condition grades to shallow tidal rivers have loading rates that are approximately an order of magnitude less; Figure 20**Error! Reference source not found.**). Although there are few estuaries included in this analysis, and therefore there is insufficient statistical power to be conclusive, the data is consistent with the use of the nutrient enrichment condition measures as indicators of the stress to the estuaries due to nutrient loading. The analysis also supports the expectation that the sensitivity of estuaries to nutrient loading rates depends on the estuary type and the associated differences in the estuary flushing rate.

The relationship between the condition grade for sedimentation (Table 16) and the estimated loading rate for suspended sediment (expressed as an annual load per km^2) is shown in Figure 21**Error! Reference source not found.**. These data do not show an expected relationship between the sedimentation condition grade and the annual suspended sediment load. This may be because the fate of sediments in estuaries (e.g. the extent to which they are trapped or flushed from the estuary) is complex and not well represented by the simple estuary types. In addition, the suspended load model performed poorly compared to the total nitrogen load model (see Table 19 in Appendix A) and, therefore, the sediment load may be poorly estimated.

Table 17: Estuary type, estimated TN and SS loads, and surface area for 10 Southland estuaries. See Figure 3 for the location of the estuaries.

Estuary	Estuary type	Annual load TN (t/yr)	Annual load SS (t/yr)	Estuary area (km^2)
Bluff Harbour	Shallow tidal lagoon	28	332	54.6
Haldane Estuary	Shallow tidal lagoon	25	870	1.9
Jacobs River Estuary	Shallow tidal lagoon	1288	20473	6.7
Lake Brunton	Shallow ICOLL	14	123	0.3
New River Estuary	Shallow tidal lagoon	3736	51803	39.8
Toetoes Harbour	Shallow tidal river estuary	4433	121797	4.7
Waiau River Estuary	Shallow tidal river estuary	1840	864971	0.8
Waikawa Estuary	Shallow tidal lagoon	181	5790	6.4
Waimatuku Estuary	Shallow tidal river estuary	284	1172	0.2
Waituna Lagoon	Shallow ICOLL	222	2317	13.6

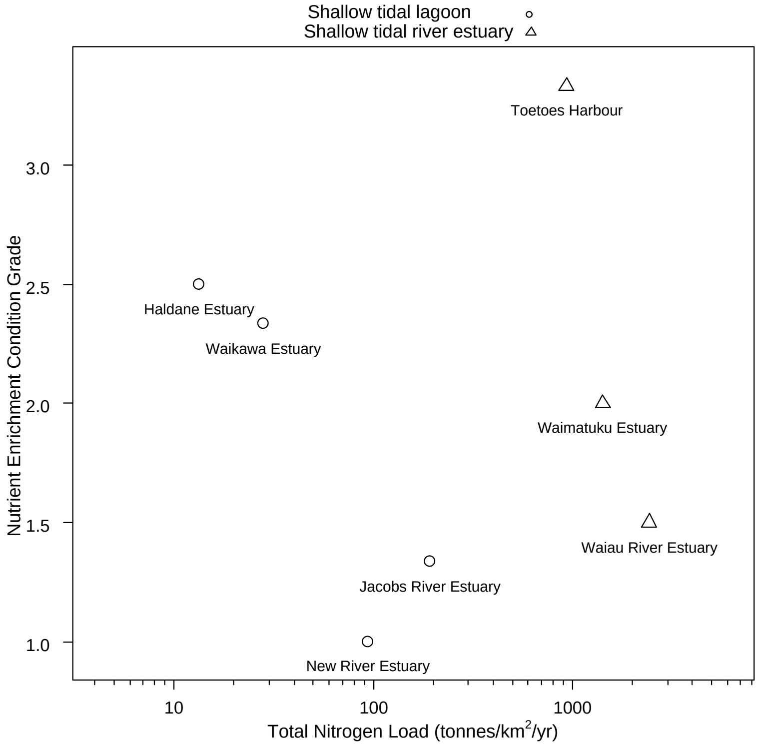

Figure 20: Relationship between condition grade for nutrient enrichment and the estimated loading rate for TN. TN loads were estimated using a model derived from the river SoE data (see Appendix A).

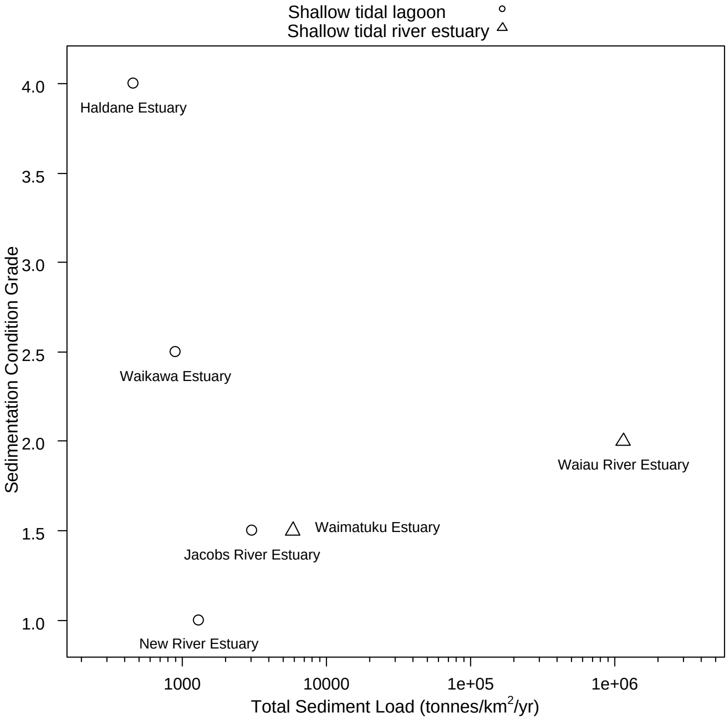

Figure 21: Relationship between condition grade for sedimentation and the estimated loading rate for sediment. Suspended sediment loads were estimated using a model derived from the river SoE data (see Appendix A).

6 ASSESSMENT OF CONTAMINANT SOURCES

6.1 Farm Source Loads

Farm source loads predicted by NZIER (2013) varied considerably depending on enterprise type (i.e. sheep & beef or dairy farms), and by LUC and drainage classes (Figure 22 and Figure 23). The dominant control on TN and TP leaching rates was enterprise type, with dairying having higher leaching rates than sheep & beef. Further differences in TN leaching rates were equally attributable to variation in LUC and drainage classes. The next most important factor determining TP leaching rates was drainage type, with higher rates for poorly drained soils. Note that the zero leaching rates shown for dairying under LUC class C is because the NZIER analysis assumed that dairy farming is not viable on this LUC class.

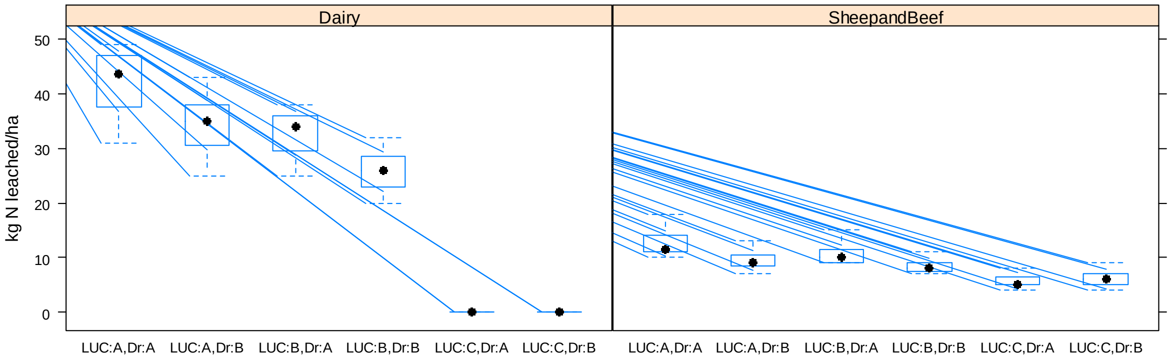

Figure 22: Box and whisker plot of farm TN leaching rates (kg/ha/yr). Differences in leaching rates predicted by NZIER (2013) are attributable to variation in enterprise type, LUC class (A = LUC 1 and 2, B = LUC 3 and 4, C = LUC 5 and above) and drainage class (A = Well drained, B = Poorly drained).

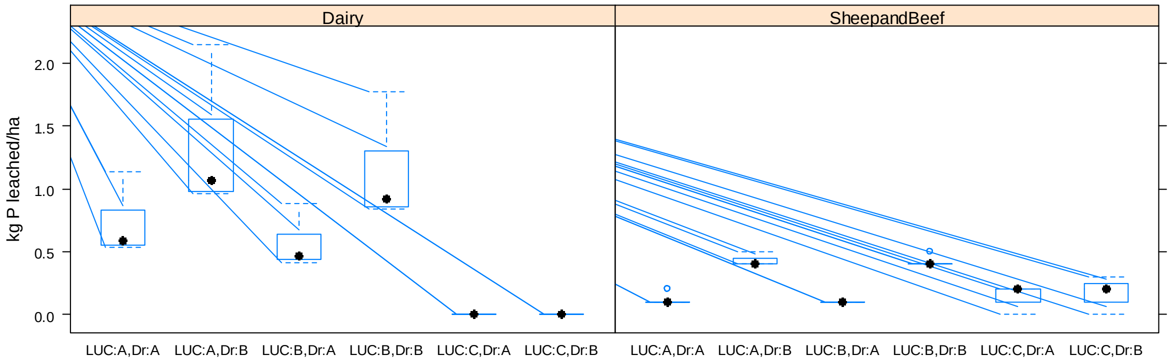

Figure 23: Box and whisker plot of farm TP leaching rates (kg/ha/yr). Differences in leaching rates predicted by NZIER (2013) are attributable to variation in enterprise type, LUC class (A = LUC 1 and 2, B = LUC 3 and 4, C = LUC 5 and above) and drainage class (A = Well drained, B = Poorly drained).

6.2 Regional Patterns in Farm Source Loads

The estimated farm leaching rates (NZIER, 2013) were accumulated down the river network and expressed as a specific load (load per unit of upstream catchment area: kg/ha/yr) (Figure 24 and Figure 25). Specific annual source loads were highest in small streams and rivers whose catchments are wholly located on intensively farmed areas of the Southland plains. Specific annual source loads were lowest in the main stems of large rivers draining catchments with little or no farming activity (Figure 24 and Figure 25).

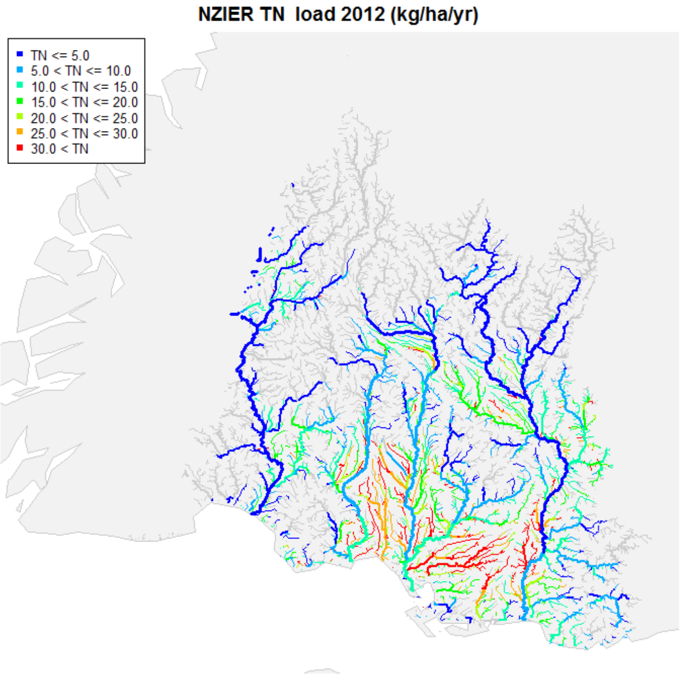

Figure 24: Estimated farm TN source loads under current (2012) land use accumulated down the river network. Loads estimated by NZIER (2013) were expressed as annual loads per unit area (kg/ha/yr) and accumulated down the network.

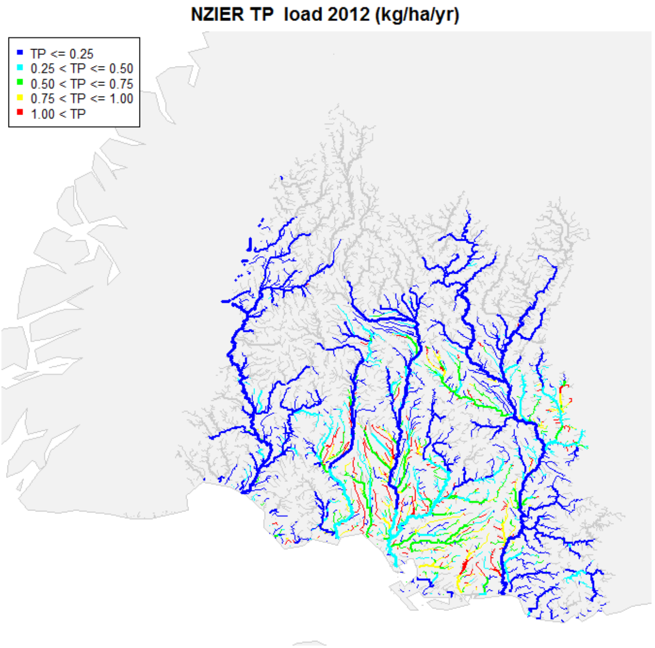

Figure 25: Estimated farm TP source loads under current (2012) land use accumulated down the river network. Loads estimated by NZIER (2013) were expressed as annual loads per unit area (kg/ha/yr) and accumulated down the network.

The krigged farm loads are shown as maps of the variation in source loads for 2012 (Figure 26). The estimated maximum potential source loads derived based on physiographic constraints (described earlier in Section 3.2.1) are shown in Figure 27. The maps indicate that source loads are currently highest in intensively farmed areas of the lower Southland plains (Figure 26).

The maximum potential loads are highest in the areas that currently have the highest loads, but large increases in source loads are possible over much of the region (Figure 27). The maximum loads disregard other factors that constrain agricultural development, such as water availability, and therefore this map represents a ‘worst case’ land use scenario and associated source load.

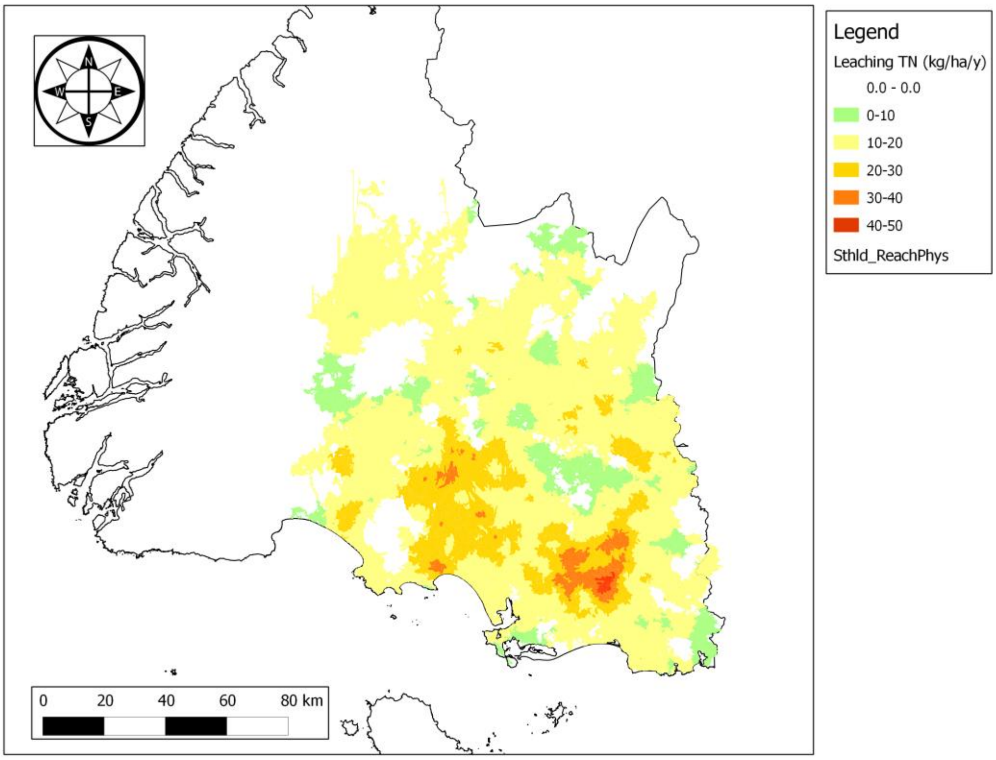

Figure 26: Annual TN source load under current (2012) land use. This map was based on data from NZIER (2013). Loads are expressed as annual loads per unit area (kg/ha/yr).

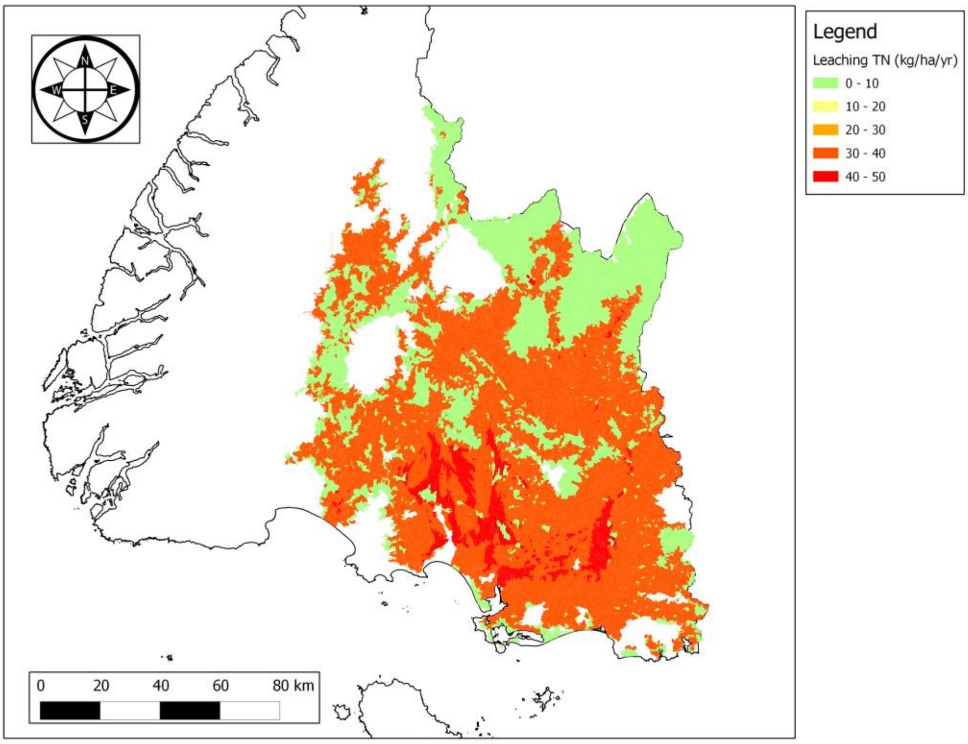

Figure 27: Maximum potential annual TN source load. This map is based on the on the land use and enterprise types with the highest contaminant loads that were assumed to occur for each farm given its physiography by NZIER (2013). Loads are expressed as annual loads per unit area (kg/ha/yr).

6.3 Regional Patterns in Realised Loads

Independent predictions of specific realised loads observed at the SoE sites (i.e. predictions made when the site was excluded from the fitting data) indicated good model performance for the contaminants NH_4N, NO_3N and TN (NSE of 0.5 or higher). The remaining models (TP, DRP, SS, *E coli* and FC) performed less well, with NSE values between 0.19 and 0.25. Poor performance for the TP and DRP models is likely partly due to the relatively large number of sampling occasions when concentrations were below the detection limit.

The mapped predictions of specific realised loads estimated from the SoE data (Figure 28 and Figure 29) were broadly consistent with the modelled water quality concentrations (Figure 5). Specific realised loads for all contaminants were highest in small streams and rivers whose catchments are wholly located on intensively farmed areas of the Southland plains, and were lowest in the main stems of large rivers draining catchments with little or no farming activity.

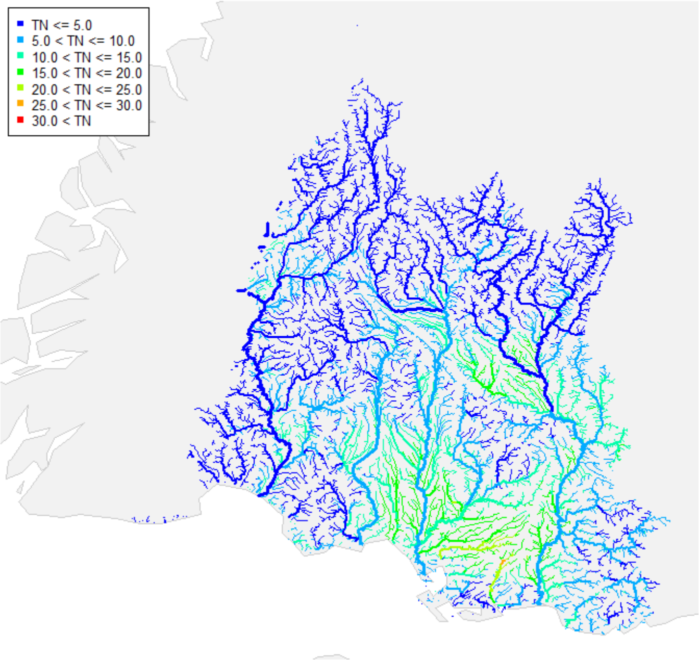

Figure 28: The predicted realised TN load at all points in the river network. The realised loads were estimated from the SoE data and spatial model, and expressed as annual loads per unit area (kg/ha/yr).

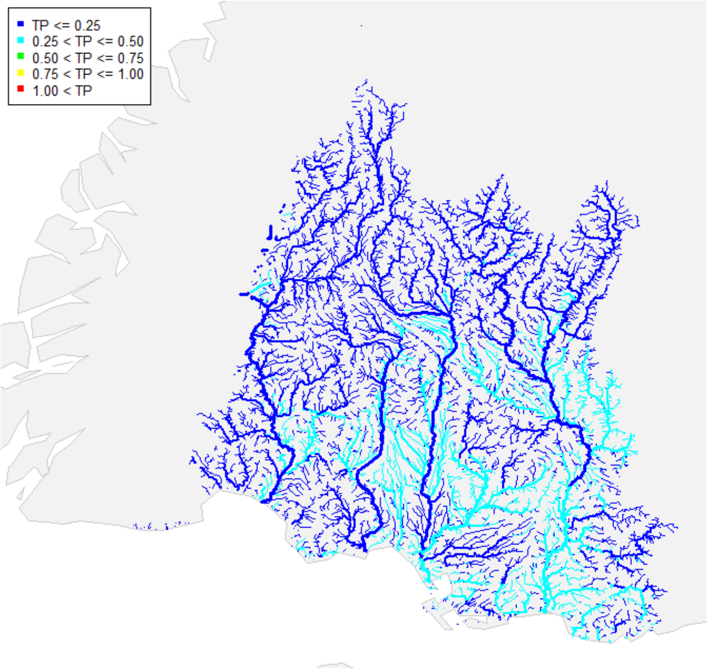

Figure 29: The predicted realised TP load at all points in the river network. The realised loads were estimated from the SoE data and spatial model, and expressed as annual loads per unit area (kg/ha/yr).

A PCA was used to examine the regional patterns in the realised specific loads estimated for the SoE sites. The PCA analysis was performed on the realised specific loads for all variables for the 62 SoE sites where all variables had been monitored. The distributions of the realised specific loads for the SoE sites were approximately normal for all variables, and the PCA was performed on the correlation matrix derived from the loads.

The first, second and third components of the PCA performed explained 53%, 19% and 13% (respectively) of the total variation in the specific loads data. A biplot of the PCA indicates that the first axis was strongly associated with increasing loads of all contaminants, with the exception of SS (Figure 30). The relatively high variation explained on the first axis indicates that loads for all variables are highly correlated and that, across the SoE sites, there is only modest localisation in the contaminants of most concern.

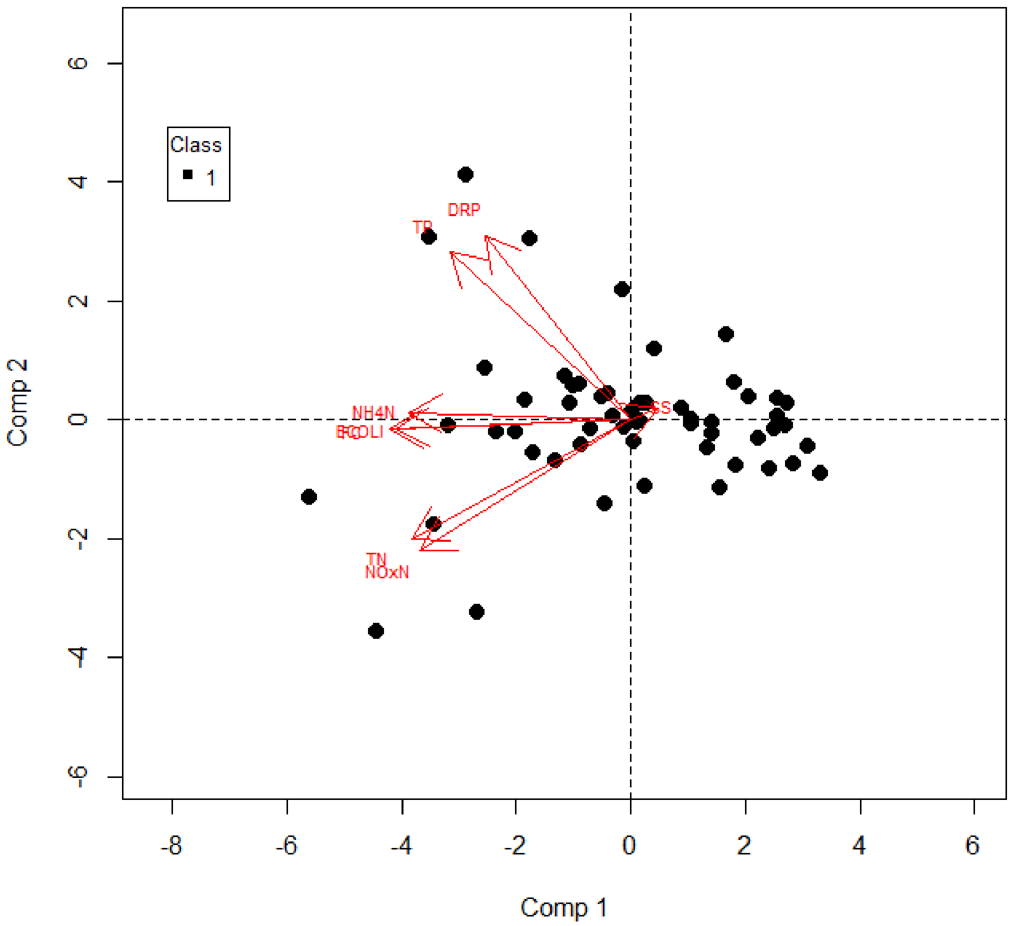

Figure 30: Biplot of the PCA performed on the specific realised load data. The PCA was performed on specific load estimates for six water quality variables measured at 62 SoE sites. The first and second components explained 53% and 19% of the total variation, respectively.

6.4 Regional Point Source Loads

Some of the SoE monitoring sites used to develop the realised load models are downstream of the significant contaminant point sources identified by Palliser and Elliot (2013) (Figure 31). Further details about these point source loads are provided in Appendix E. To evaluate the relative contribution of point sources to the total realised load, the contribution to loads from all upstream point sources at each of the SoE monitoring site was calculated and compared to the model predictions (from Section 6.3). In total, only 10 of the 73 SoE sites are located downstream from at least one point source discharge. All TN point source loads at SoE sites comprised less than 10% of the modelled realised TN load, with most being <5% (Figure 32). This level of contribution is within the error of the TN regional load model (see Appendix A). All TP point source loads were less than 25% of the modelled realised TP load (Figure 33). This contribution is also less than the error on the regional TP realised load model (see Appendix A). Hence, the realised load models are unlikely to be unduly affected by point source contributions. In addition, the analysis indicates that point sources make a relatively small contribution to nutrient annual loads regionally. However, the relative contribution from point source loads can be much higher close to the point source and in small tributaries; this is demonstrated in Appendix E. Also, the nutrient contribution from point sources during low flows can be significant.

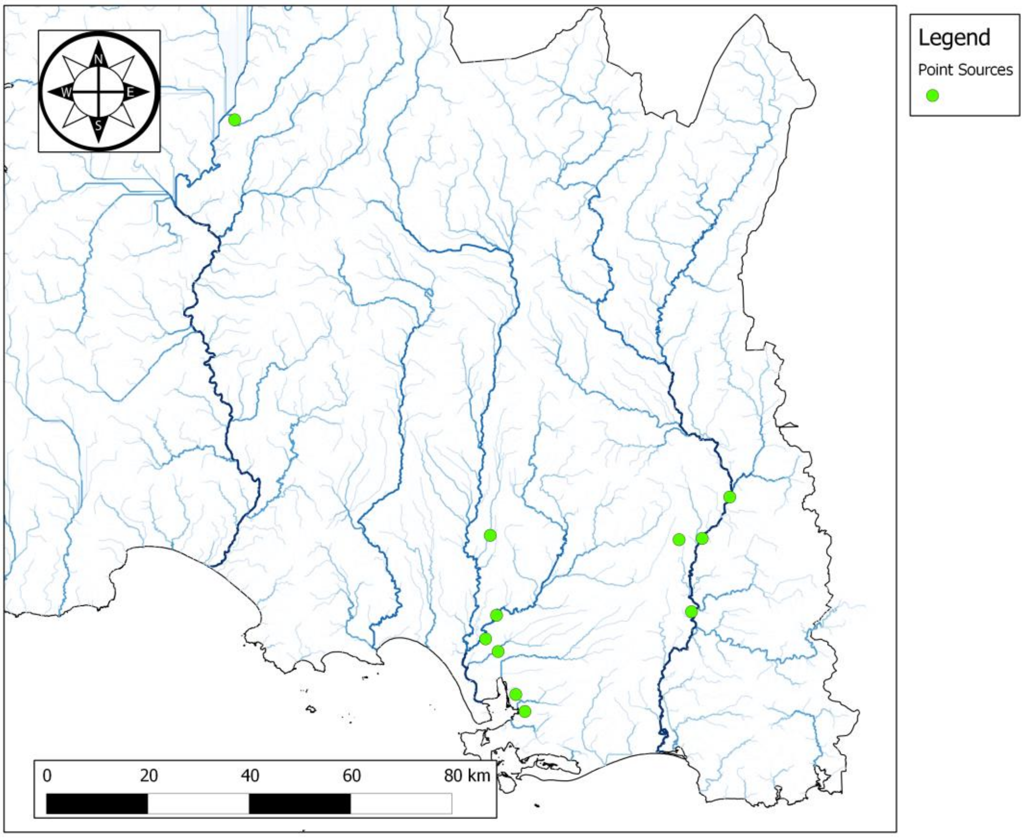

Figure 31: Location of major point source loads in the Southland region.

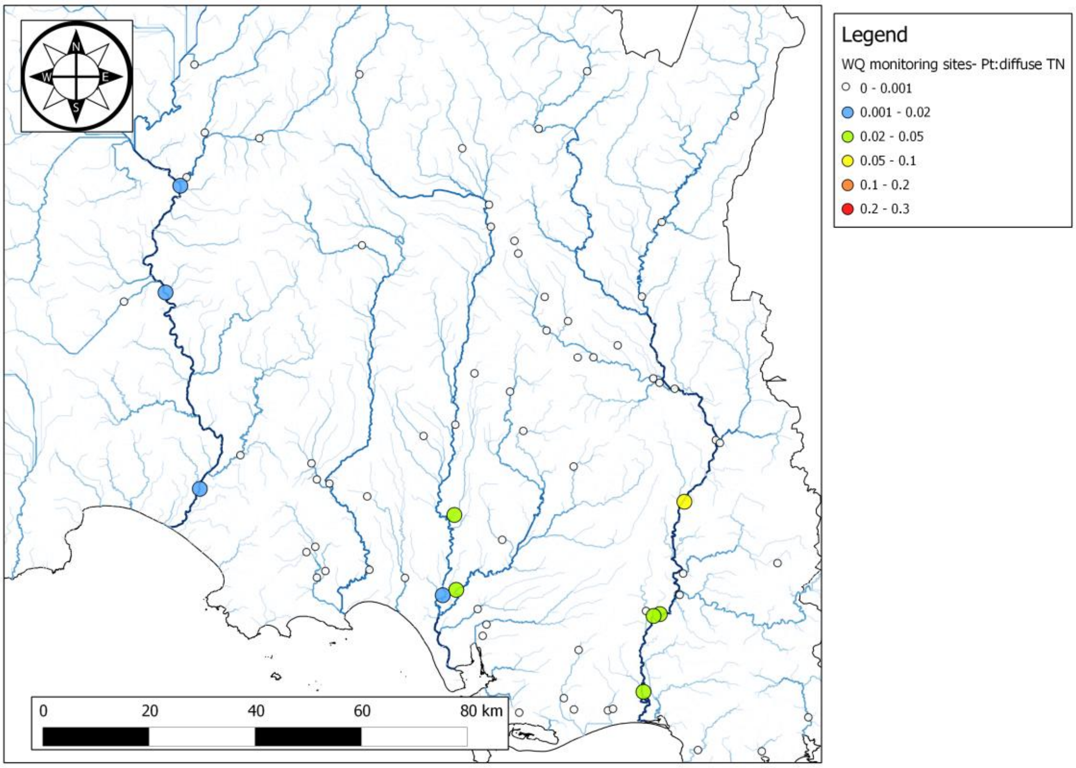

Figure 32: Ratio of TN point source loads to modelled TN realised loads at the SoE monitoring locations in Southland.

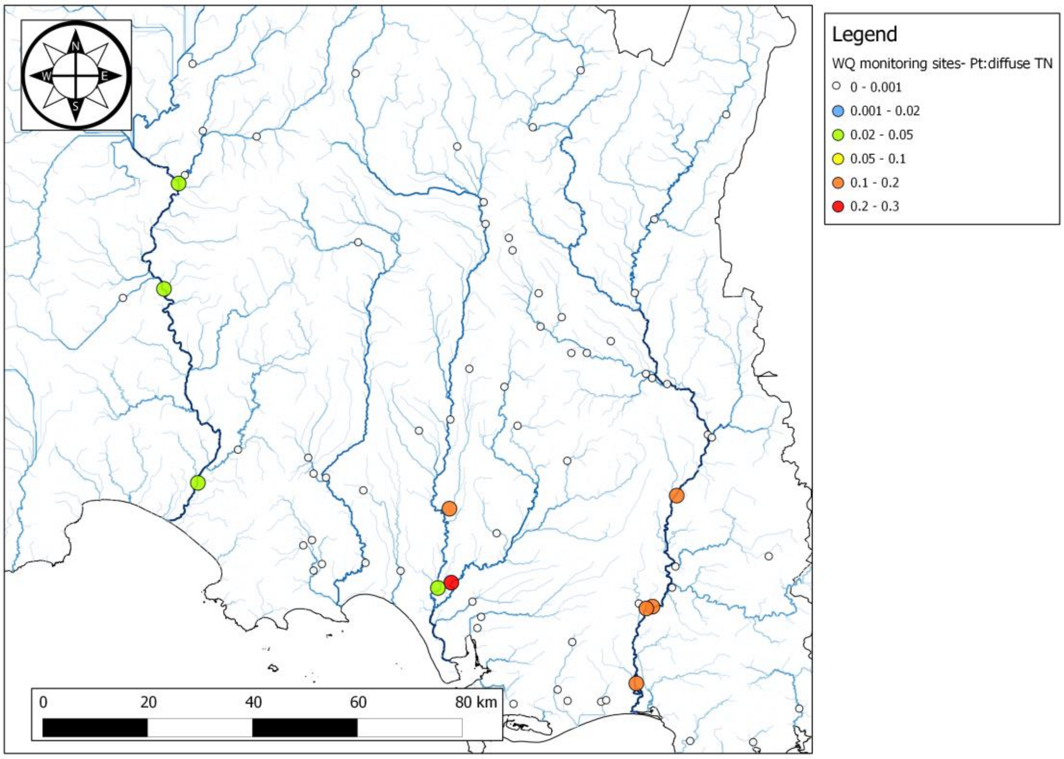

Figure 33: Ratio of TP point source loads to modelled TP realised loads at the SoE monitoring locations in Southland.

6.5 Comparison of Source and Realised Loads

The current (2012) source loads of TN and TP (Figure 24 and Figure 25) were compared with the modelled realised loads for each segment of the river network (Figure 28 and Figure 29). There were large differences in the relationships between source and realised loads for TN and TP (Figure 34). The source and realised loads of TN consistently increased together; however, source and realised loads were less well related for TP.

At values of TN below 5 kg/ha/yr, the realised loads were generally larger than the source loads. This is an expected outcome because the source load estimates do not include natural background loads from non-pastoral areas, which are likely to be dominant when the agricultural contribution is low. At realised load values above approximately 12 kg/ha/yr, the source load was consistently larger than the realised load (Figure 34). This is also an expected result because attenuation processes, such as denitrification and sedimentation, generally reduce loads between their source and downstream points.

Reasons for the poor relationship between source and realised loads for TP are not clear. This may be partly due to the poor performance of the TP realised load model. In addition, phosphorus is generally considered to be transported by surface runoff during rainfall, and a large component of the annual load is therefore likely to be associated with high flows. Because the water quality samples associated with the SoE sites are collected on a monthly basis, high flows are not well represented. This means that realised TP loads are likely to be underestimated, which is consistent with the poor relationship for TP shown in Figure 34.

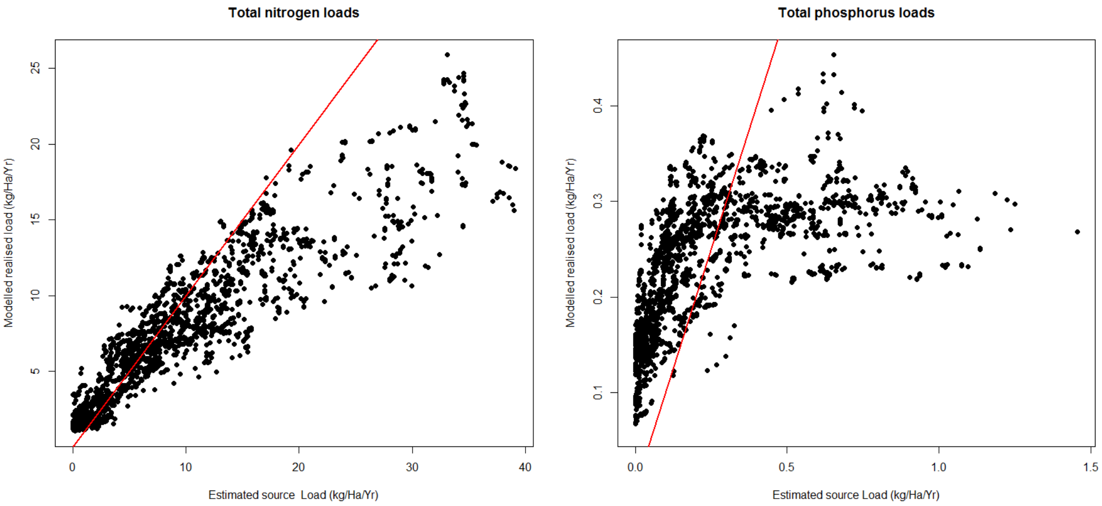

Figure 34: Comparison of the source specific loads of TN and TP estimated by NZIER with the modelled realised loads for each segment of the river network.

6.6 Categorisation of the Drainage Network Based on Downstream Issues

Categorisations of the river drainage network in Southland were developed to identify all areas that drain to locations where the water quality criteria are not met. For each water quality criteria, each segment of the network was categorised based on whether the criteria was breached in any segment in the downstream direction. Category values were assigned as either ‘issue downstream’ or ‘no issue downstream’. Thus, when these categories were mapped onto the river network, the catchment areas that potentially contribute to issues were identified.

6.6.1 Periphyton

The categorisation of the river drainage network on the basis of downstream periphyton issues identified the entire Mataura River catchment due to exceedances of the criteria in the lower main stem. In addition, catchments of lowland tributaries of the Aparima, Oreti, Waimatuku and Makarewa rivers were identified, but not their main stems or upper catchments (Figure 35).

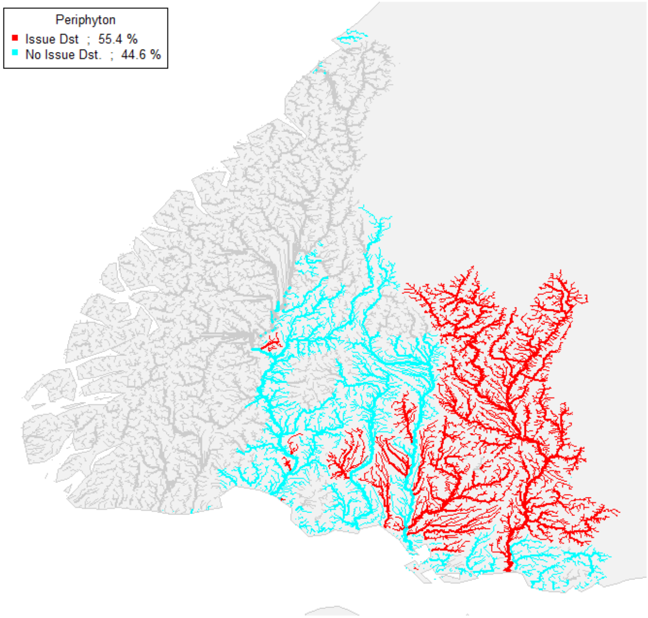

Figure 35: Southland river drainage network categorised by compliance with the periphyton criterion downstream.

6.6.2 Macro-invertebrate Community

The categorisation of the river drainage network on the basis of downstream MCI issues identified the entire Mataura River catchment due to exceedances in the lower main stem. In addition, lowland tributaries of the other major rivers were identified, but not their main stems or upper catchments (Figure 36). The catchments of rivers belonging to the mountain RWP management unit were also identified. These exceedences are related to the conservative MCI standards in the RWP for this management unit.

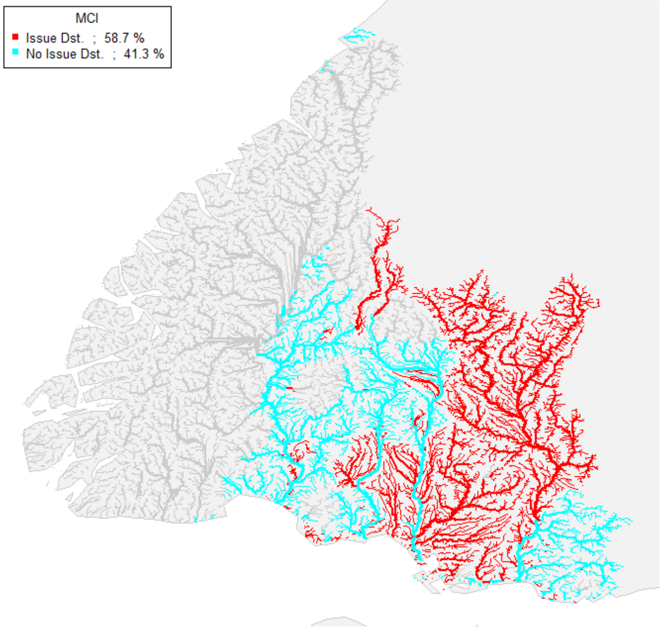

Figure 36: Southland river drainage network categorised by the compliance with the MCI criterion downstream.

6.6.3 Clarity

The categorisation of the river drainage network on the basis of downstream water clarity issues discriminated the entire network (Figure 37).

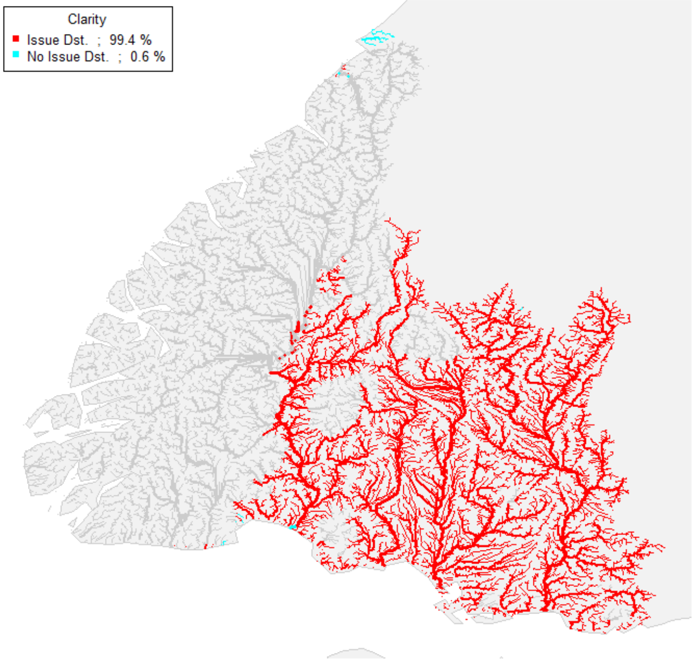

Figure 37: Southland river drainage network categorised by the compliance with the clarity criterion downstream.

6.6.4 Nitrate Toxicity

The categorisation of the river drainage network on the basis of downstream nitrate toxicity issues (Figure 15) discriminated a large portion of the Waimea basin, the Waimatuku catchment, and some lowland areas that drain to the Oreti River (Figure 38).

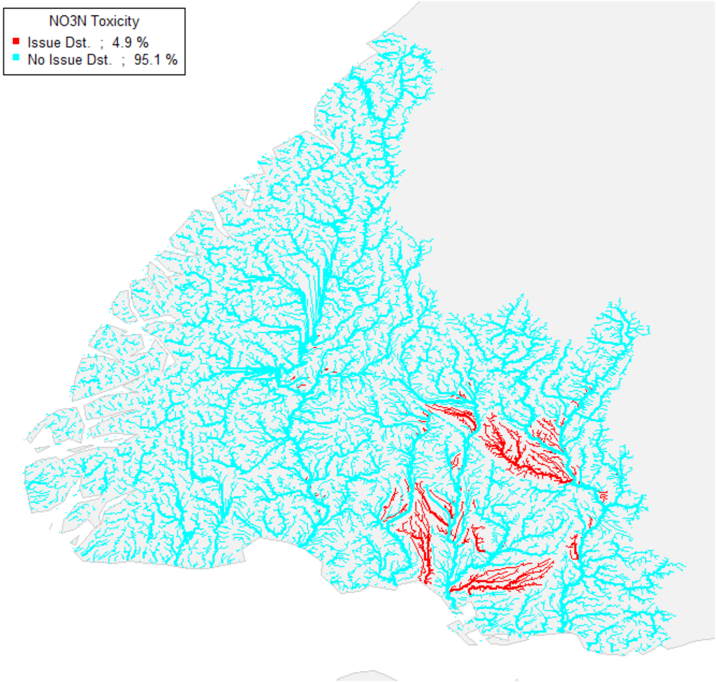

Figure 38: Southland river drainage network categorised by the compliance with the nitrate toxicity criterion downstream.

6.6.5 E Coli

The categorisation of the rivers drainage network on the basis of downstream *E coli* issues discriminated some small catchments, notably the Otautau stream catchment and a lowland tributary of the Oreti that flows through Winton (Figure 39).

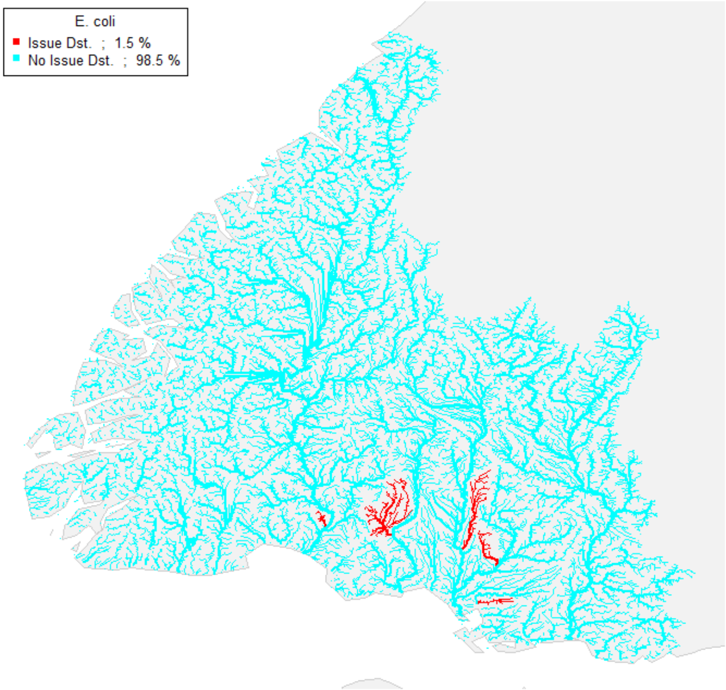

Figure 39: Southland river drainage network categorised by the compliance with E coli criterion downstream.

6.6.6 Faecal Coliform

The categorisation of the river drainage network on the basis of downstream FC issues discriminated the catchments of small lowland tributaries (the same as for *E coli*) as non-complying (Figure 40).

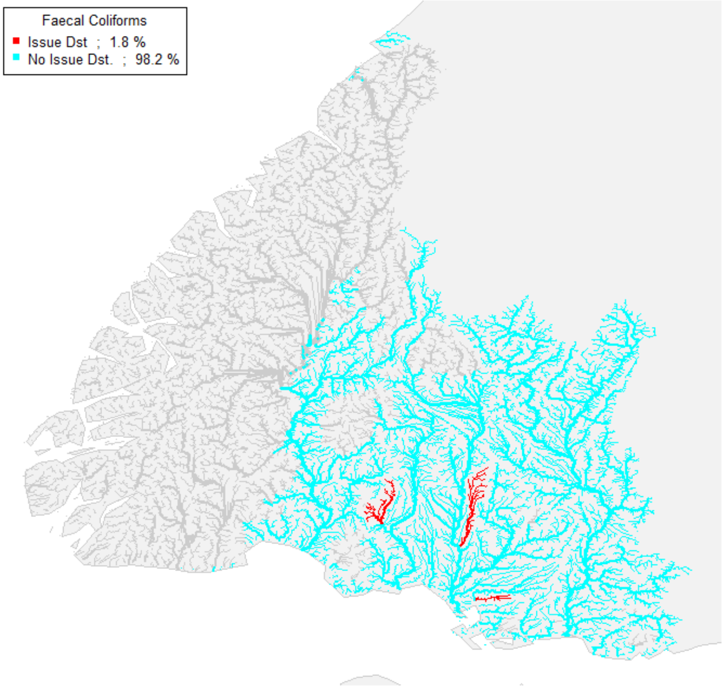

Figure 40: Southland river drainage network categorised by the compliance with FC criterion downstream.

6.6.7 Groundwater Nitrate Concentrations

A different approach was used to for identifying areas contributing to groundwater issues. We assumed that groundwater issues would be predominantly derived from the land surface recharge of the aquifers shown in Figure 4. We therefore identified the contributing area to an issue to be the upstream surface flow path, as far as the flow path remained within the body of the aquifer.

The categorisation identified the inland basins, middle Matuara, upper Aparima and Oreti rivers, and lowland tributaries of the Makarewa as contributing to groundwater nitrate issues (Figure 41).

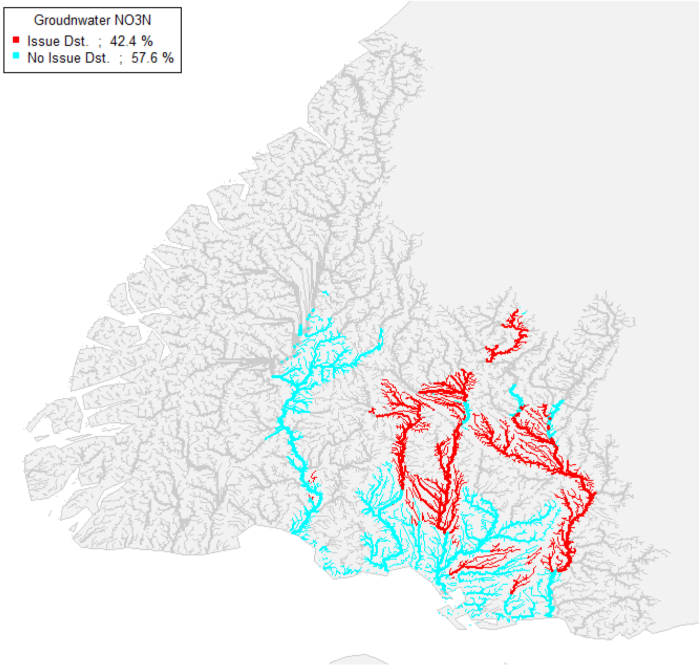

Figure 41: Southland river drainage network categorised by the compliance with groundwater nitrate criterion downstream.

6.6.8 Estuary Condition Measures

The categorisation of the river drainage network on the basis of contributions to estuary issues identified the catchments of four of the ten estuaries (Figure 42 and Figure 43). The catchments of the Jacobs River and New River Estuary contributed to both nutrient and sediment issues, whereas the catchments of the Waiau and Waimatuku estuaries contributed to only nutrient or sediment issues, respectively.

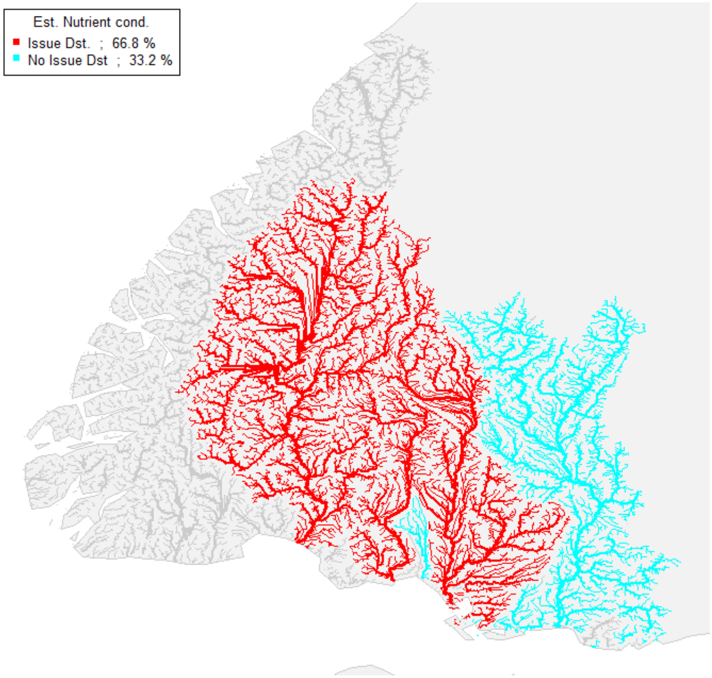

Figure 42: Southland river drainage network categorised by the compliance with estuary nutrient condition criterion.

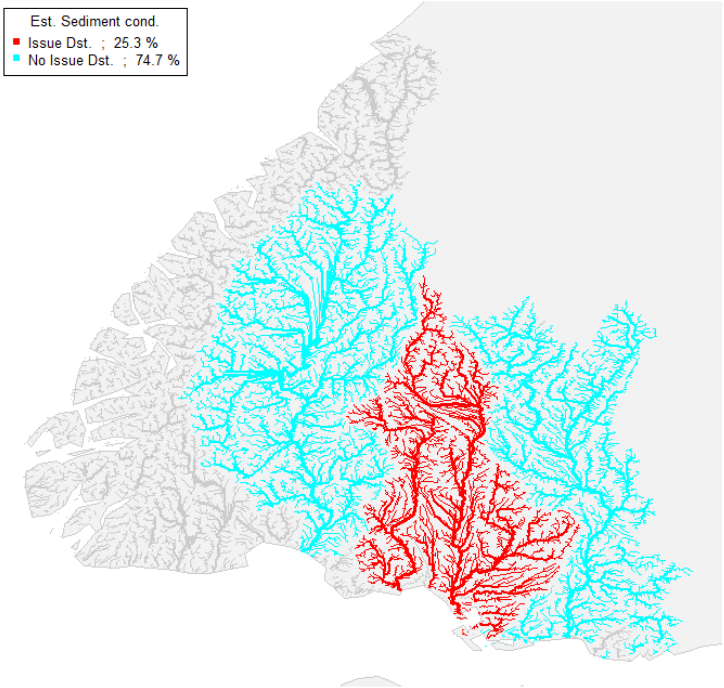

Figure 43: Southland river drainage network categorised by the compliance with estuary sediment condition criterion.

6.7 Overall Categorisation of the Drainage Network Based on All Downstream Issues

An overall categorisation of the river drainage network was defined based on a summation of all downstream issues (Figure 44). The areas with the most issues were tributaries of the Aparima, the Waimatuku catchment, much of the Makarewa catchment, lowland areas of the Oreti catchment, and the much of the Waimea basin.

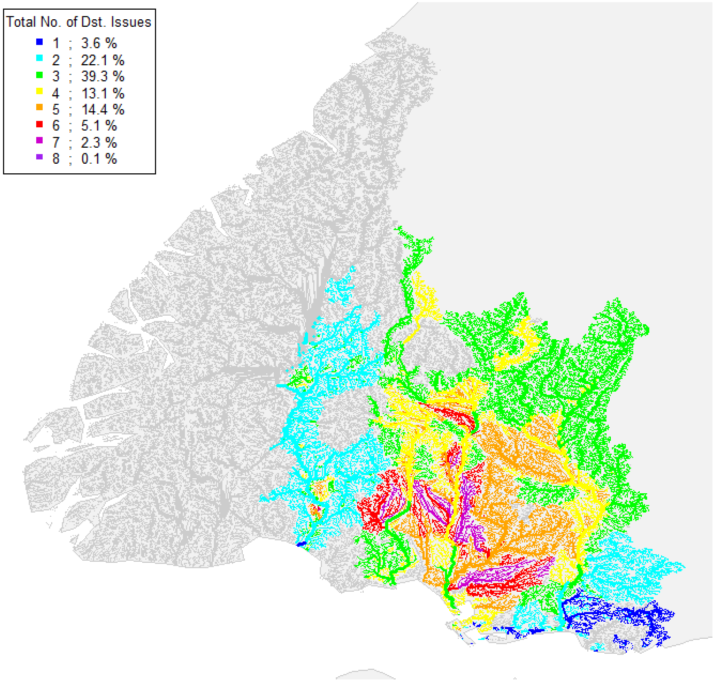

Figure 44: Southland river drainage network categorised by the overall issues. The categories represent the total number of downstream issues, and are based on a summation of the individual issues described above for rivers, groundwater and estuaries. Network segments with no downstream issues are shown in grey.

7 DEFINITION OF WATER AND LAND MANAGEMENT STRATIFICATION

The final step of the analysis defined the Water and Land Management Stratification (WLMS). Water and land management strata subdivide the Southland region on the basis of two factors: (i) categorisation of the river drainage network are based on the overall issues (Figure 44), and (ii) maps used are of estimated source load of TN for 2012 and the estimated maximum potential source load of TN (Figure 26 and Figure 27). The strata are defined by all possible combinations of the factor categories (e.g. Figure 45).

7.1 Assumptions

The stratification incorporates some key assumptions and subjective judgements. Firstly, we used the estimated source load of TN for 2012 and the estimated maximum potential source load of TN based on the NZIER (2013) data (Figure 26 and Figure 27) to identify the degree to which areas are contributing to all issues (i.e. including those not related to nitrogen such as the *E coli* and FC criteria). We consider that this assumption is reasonable at the regional scale because our analyses showed that water quality variables and loads of contaminants are strongly correlated (Figure 8 and Figure 30). These findings indicate that, at the regional scale, there is only modest localisation in the contaminants of most concern. Thus, the simplifying assumption that contributions of contaminants can be treated in terms of a single variable, rather than dealing separately with the individual variables (e.g. *E coli,* TN), is reasonable. In addition, the estimated source loads of TN are strongly related to physiographic factors (LUC categories and drainage), as well as enterprise type and intensity. These factors are broadly related to the generation of all of the contaminants of concern and control the potential for production of the contaminants on a unit area basis.

The second set of key assumptions and judgements is related to the weighting of the issues. Different weighting of the individual issues would alter the overall issues definition (Figure 44), and may be considered justifiable. For example, issues associated with the estuary criteria could be given a higher weighting on the basis that water quality impacts in these environments are more difficult to reverse than in rivers. The weightings could also be changed, for example, to put greater weight on criteria related to human health objectives rather than to ecosystem health objectives. Our analysis has not explicitly weighted the individual issues (all issues are given equal weighting by default), but has been constructed so that weightings could be applied.

The third set of judgements involves the manner in which we developed a stratification of the region. This involved combining the two factors (overall categorisation of issues (Figure 44) and the estimated source loads of TN [Figure 26 and Figure 27]). To achieve this, we subdivided the ranges of the two factors into a number of categories, with the number of categories and the thresholds that define these being subjectively determined. To demonstrate the subjectivity at this step, we have provided two separate versions of the WLMS.

7.2 Nine Stratum WLMS

The first option for the WLMS subdivides the region into nine strata. These strata are defined by subdividing the overall issues into three categories (A, B and C) based on thresholds of ≤2, >2 to ≤4, and >4. In addition, the estimated source load of TN was categorised into three categories (A, B and C) based on loads of ≤20 kg/ha/yr, >20 to ≤40 kg/ha/yr, and >40 kg/ha/yr. These were then combined to produce nine strata (Figure 45). The resulting water quality management strata were defined and mapped for the current (2012) estimated source loads and the maximum potential loads (Figure 46 and Figure 47).

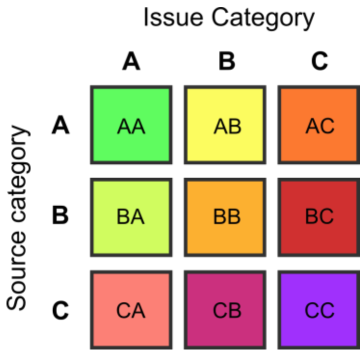

Figure 45: Schematic diagram showing how the Southland region was subdivided into nine water and land management strata. The strata are defined by the combination of specific TN source load and the number of downstream issues.

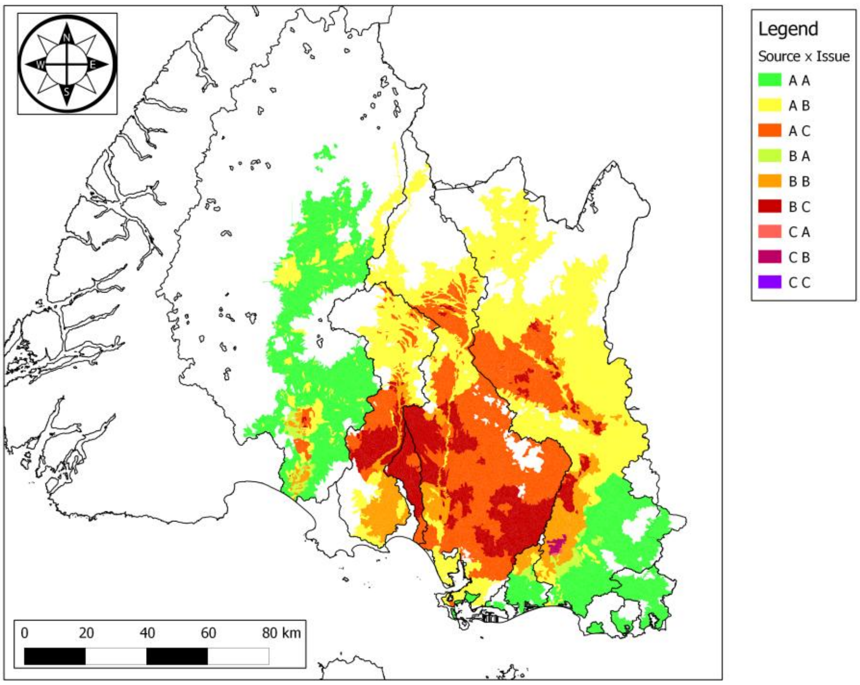

Figure 46: Stratification of the region into nine water and land management strata. This stratification reflects contaminant source loads estimated for current (2012) land use.

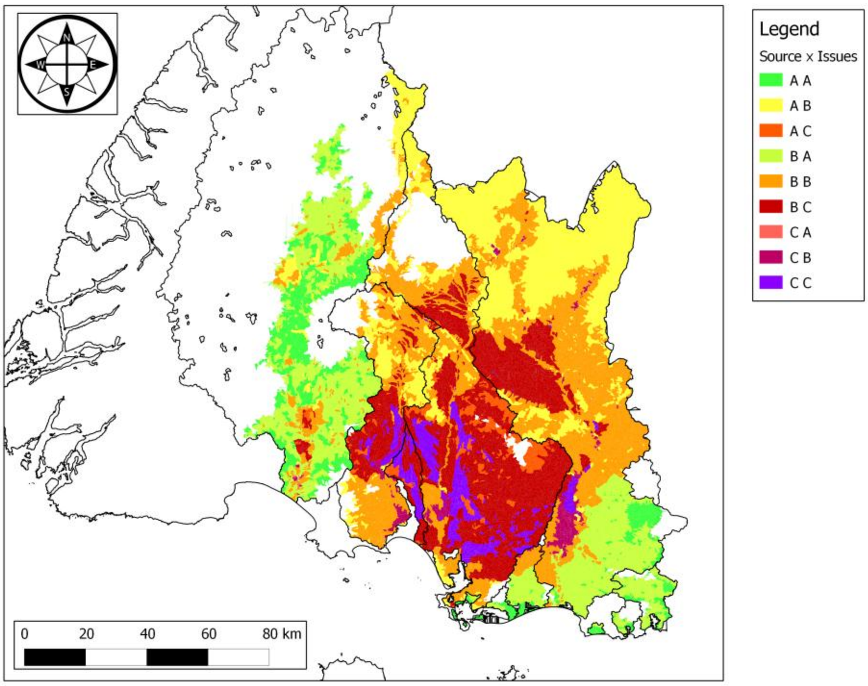

Figure 47: Stratification of the region into nine water and land management strata. This stratification reflects the estimated maximum contaminant source TN loads based on the physiographic constraints and most intensive land use assumed by the NZIER (2013) study.

7.3 Four Stratum WLMS

Four water and land management strata were defined by subdividing the overall categorisation of the river drainage network into two categories (A and B) based on a threshold of ≤4 issues. In addition, the estimated source load of TN was categorised into two categories (A and B) based on a load of ≤20 kg/ha/yr. These were then combined to produce four strata. The resulting water and land management strata were defined and mapped for the current (2012) estimated source loads and the maximum potential loads (Figure 49 and Figure 50).

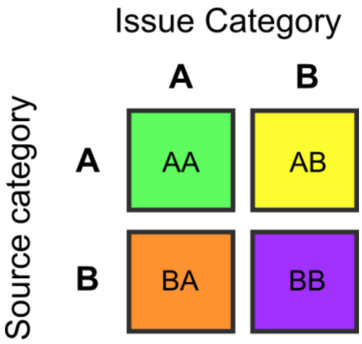

Figure 48: Schematic diagram showing how the Southland region was subdivided into four strata. The strata are defined by the combination of specific source load from the NZIER data and the number of issues within each catchment.

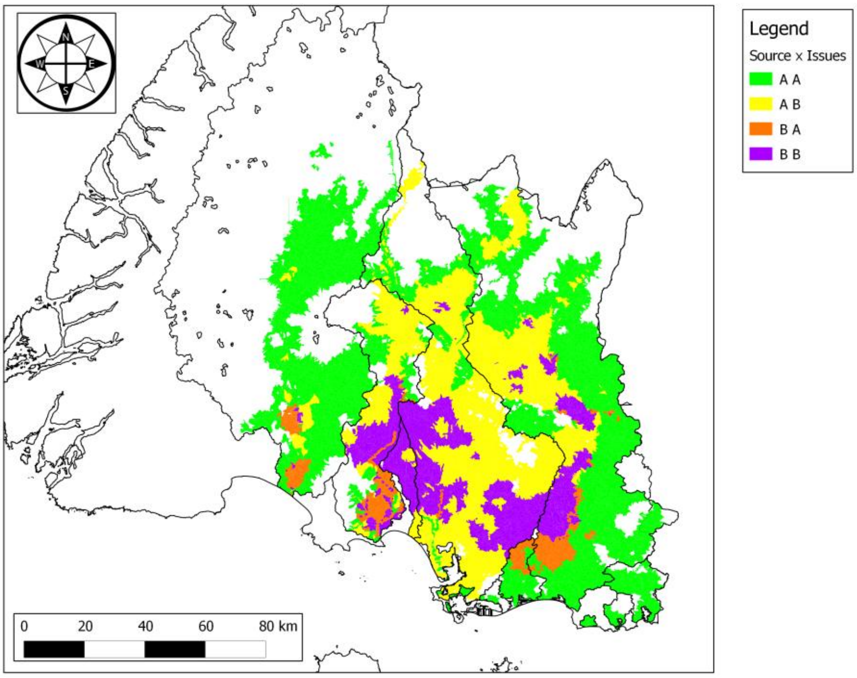

Figure 49: Subdivision of the region into four water and land management strata. This stratification reflects contaminant source loads estimated for current (2012) land use.

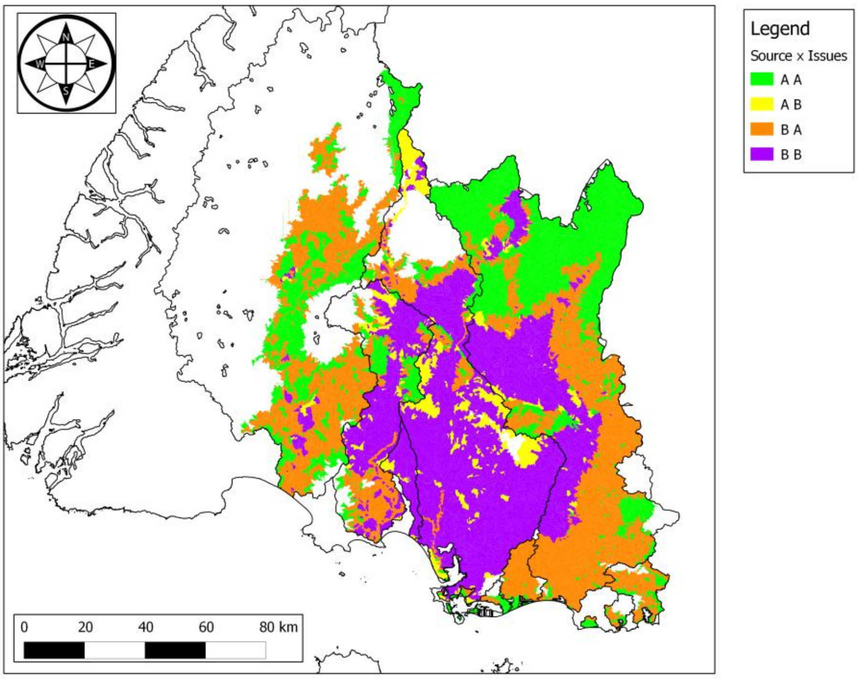

Figure 50: Subdivision of the region into four water and land management strata. This stratification reflects the estimated maximum contaminant source loads based on the physiographic constraints and most intensive land use assumed by the NZIER (2013) study.

The stratifications indicate that the areas making the large contributions to locations with the many issues (i.e. strata CC [Figure 46] and strata BB [Figure 49]) are tributaries of the Aparima, the Waimatuku catchment, much of the Makarewa catchment, lowland areas of the Oreti catchment, and parts of the Waimea basin. Much of the Waiau River and Mataura River catchments are in strata that represent either low source loads and low issues, or high source loads and low issues. In the case of the Mataura River catchment, this arises at part because the estuary (Toetoes Harbour) has a very good condition grade for nutrient enrichment. In the case of the Waiau River catchment, the estuary has a poor condition grade for nutrient enrichment, but the catchment complies with many other criteria (e.g. periphyton [Figure 11], MCI [Figure 12] and nitrate [Figure 14]).

7.4 WLMS Representing Potential Land Use Changes

We defined a stratification of the region that represents the interaction between issue and potential (future) land use changes. We subdivided the region into four strata in a similar manner to above, but rather than using the current source loads, we used the potential change in source load. Potential change in source load was defined by subtracting the estimated TN source load under current (2012) land use (Figure 26) from the maximum potential annual TN source load (Figure 27). The estimated change in source load of TN was categorised into two categories (A and B) based on a change in load of ≤15 kg/ha/yr. This was then combined with the two category issues stratification to produce a subdivision of the region in four strata (Figure 51).

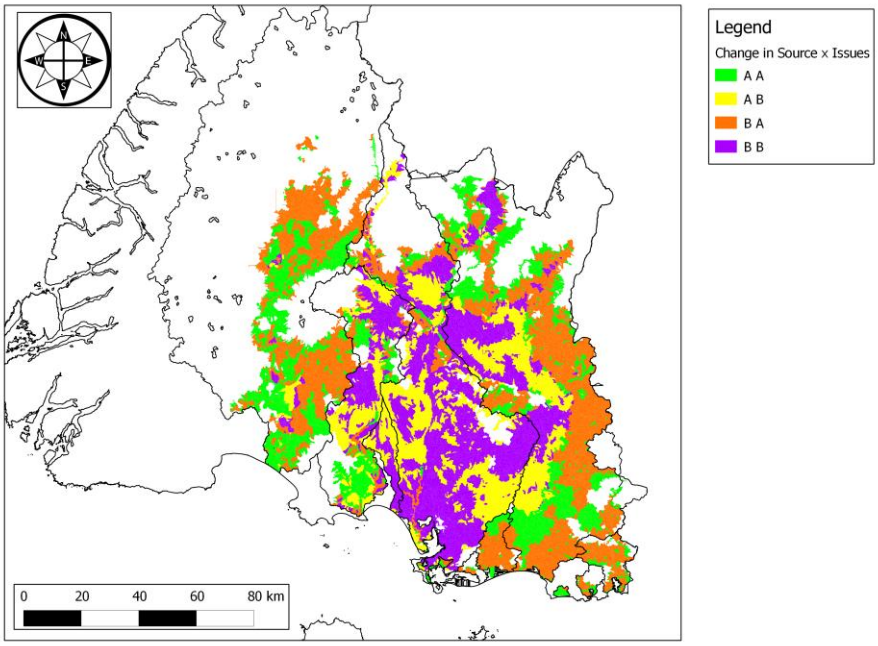

Figure 51: Stratification of the region to demonstrate future development risk.

The purple strata shown on Figure 51 are areas where there are currently many downstream issues and where there is also potential for significant increase in source loads. This includes large areas of the Oreti River (New River Estuary) catchment of the upper portions of the Mataura River (Toetoes Harbour) catchment. These areas could be considered to be at risk of increasing the severity of existing issues. The yellow strata are areas with many downstream issues, but current source loads are close to the maximum potential loads (i.e. loads would not increase greatly in future). The orange strata are areas with few downstream issues where source loads could increase significantly. This includes large areas of the Waiau River catchment and eastern areas of the Mataura River catchment. These areas could be considered to be at risk of increasing the number of downstream issues. Areas in green currently have few issues and where source loads are unlikely to increase; hence they could be considered to be low risk.

8 CONCLUSIONS

8.1 Water Quality Issues in the Southland Region

In this study we have undertaken a high resolution regional scale analyses of the state of water quality in the Southland region. The analysis has made extensive use of modelling to extend point observations of water quality, condition measures, and contaminant loads into spatially comprehensive estimates (maps). Modelling has enabled the analysis to 'fill in the gaps' and to compare the current state with criteria for all locations. We have detailed the performances of the models, and consider that these generally indicate that they capture regional patterns accurately even though there is uncertainty at the site scale.

We found that diffuse (non-point) sources from agricultural land are the most significant contribution to annual nutrient loads at the regional scale. In total, only 10 of the 73 SoE sites are located downstream from significant point source discharges. Point sources accounted for less than 10% of the estimated realised annual TN load at SoE sites comprised, with most being <5% (Figure 32). Point source loads were less than 25% of the modelled realised annual TP load (Figure 33). Point source loads may constitute significantly larger proportions of the load of contaminants at some locations (close to the discharge point) and also at specific times (e.g. during low flow periods).

The results of the assessment indicate that water quality objectives are not being met in some locations in Southland. We found this conclusion would be reached for analysis of current state regardless of whether the analysis was based on the observed site data and/or on the modelled data. We found that periphyton breaches the criteria in the main stem of the Mataura and other lowland tributaries. MCI criteria are exceeded in lowland tributaries and also in the natural state and mountain management units. We consider that the non-compliance in the natural state and mountain management units indicates that the RWP thresholds are too conservative. There are high levels of non-compliance with clarity criteria. Again, we consider that the non-compliance with clarity criteria in the natural state and mountain management units indicates that the RWP thresholds for clarity are too conservative. Nitrate concentrations in some lowland streams exceeded the B-band criteria nominated for ecosystem health. We found that only a small number of lowland locations exceeded the nominated B-band for *E coli*, and very few locations exceeded the FC criteria. We note these criteria are protective of secondary contact and stock drinking water, respectively, and are significantly higher than indicator bacteria levels for primary contact (i.e. swimming).

The nominated groundwater nitrate concentration criteria of 9.8 NO_3N g/m^3 for the protection of ecosystem health is exceeded in isolated parts of the region. There are also isolated locations (hotspots) that exceed the human drinking water standard.

Water quality objectives are not met in four estuaries (New River Estuary, Waimatuku Estuary, Jacobs River Estuary, and Waiau River Estuary) based on criteria that were applied to condition grades for sedimentation and nutrient enrichment. Condition grades were poor for both sedimentation and nutrient enrichment for the New River Estuary and Jacobs River Estuary (i.e. the Oreti and Aparima catchments, respectively), whereas the Waimatuku Estuary and Waiau River Estuary had poor grades for only sedimentation and nutrient enrichment, respectively. We also found that condition grades for nutrient enrichment in individual estuaries decreased with the estimated specific annual loading rate (load per unit surface area of estuary) for total nitrogen; however, there was insufficient data to establish statistical significance. This suggests that there is a link between the relative nutrient loading rate and the condition measures. A similar analysis of condition grades for sediment enrichment showed a less convincing relationship with the estimated specific annual loading rate for total sediment.

Our derivation of the water and land management strata did not use information about trends. However, we did find that total nitrogen and nitrate concentrations in streams and rivers were increasing in those locations where water quality is currently poor. We did not find consistent trends for most other water quality variables. Given that many of the water quality issues (i.e. non-compliance with water quality criteria) are associated with nutrients in general or specifically nitrate, the trends in nitrogen are a relevant concern. We note that although only three estuaries (New River Estuary, Waimatuku Estuary, and Jacobs River Estuary) had a poor condition grade for nutrient enrichment, a further three had a grade of fair (Waimatuku Estuary, Waikawa Estuary, and Haldane Estuary). Given the increasing nitrogen trends, these estuaries could therefore be considered at risk.

8.2 Definition of the Water and Land Management Stratification

In this study we used available data to produce options for a Water and Land Management Stratification (WLMS) for the Southland region. The strata subdivide the region on the basis of two factors: the number of issues and estimated source loads of contaminants. Source loads were defined for current (2012) and the estimated maximum potential loads so that zones can be used to evaluate both existing and potential future issues and their management. The strata are defined by all possible combinations of the factor categories. The combination of the two factors means the strata account for the connection between issues and their causes. We have provided three options for sub-dividing the region into strata at differing levels of detail.

8.3 Interpretation of Water and Land Management Stratification and Next Steps

The subdivision of the region into strata is subjective in that the outcome reflects our choice of method to combine the issues, and also the thresholds used to categorise both sources and issues. Nevertheless, for the two alternative stratifications presented within this analysis, the dominant patterns were consistent. This suggests that the final strata are not particularly sensitive to the subjective elements of the WLMS.

The WLMS provides a basis for prioritisation of effort for management of water quality issues within the region. For example, areas that can be targeted for improving water quality are those with high contaminant source loads and receiving environments with water quality issues. For the intermediate strata (e.g. BA and AB, 6), the policy responses may differ. The BA strata has high source loads, but few downstream issues; suggesting that risks are low and that the management response would reflect this. For the AB strata, there are many downstream issues and source loads are low. This suggests that actions to limit loads (e.g. relating to land use change or intensification) might be appropriate. The stratification based on the potential change in contaminant source loads (Figure 51) also suggests where priorities are highest. For example, this stratification identifies areas where there are currently many downstream issues and where there is also potential for significant increase in source loads due to land use intensification.

The WLMS provides the WAL2020 project with a stratification of the region that can be used for prioritising management actions. However, the current project has not considered what the responses should be. We recommend that development of appropriate responses needs to include additional technical considerations such as contaminant migration pathways and contaminant mitigation measures, as well as a wider range of wide range of community values, including social, cultural, and economic values.

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Appendix A: Water quality and contaminant load modelling

Modelling methods

We related the water quality variables and contaminant loads to the environmental variables using random forests (RF), a type of non-parametric regression model (Breiman, 2001). RF models have the advantage of being free from distributional assumptions and automatically fitting non-linear relationships and high-order interactions between variables. Although RF models cannot be described parametrically, the relationships between predictors and the response can be described (see below).

Potential predictors for the RF models were selected from data derived for a GIS representation of New Zealand's river network derived as part of the River Environment Classification (REC) (Snelder & Biggs, 2002). Predictors comprised variables used to derive the REC (Snelder & Biggs 2002); variables representing catchment land cover derived from Version 2 of the New Zealand Land Cover Database (LCDB2) (MFE, 2004); variables developed as part of Freshwater Environments of New Zealand classification (FWENZ) (Wild *et al.*, 2005), and estimated mean flow (Woods *et al.*, 2006) and predictions of hydrological indices (Snelder & Booker, 2012).

An RF model comprises an ensemble of individual classification and regression trees (CART) (Breiman *et al.*, 1984). In a regression context, CART partitions observations into groups that minimise the unexplained variance of the response; in this case, the mean grain size, based on a series of binary rules (splits) constructed from the predictor variables (Breiman *et al.*, 1984). Although CART models flexibly accommodate complex relationships between predictors and response, they have the limitation of not searching for optimal tree structures and being sensitive to small changes in input data (Hastie *et al.*, 2001). These limitations can be reduced by RF models, which comprise an ensemble of trees (a forest) from which a final prediction is based on averaging results over all trees (Breiman, 2001).

RF models retain the desirable features of CART. However, they increase prediction accuracy by introducing random variation by growing each tree with a bootstrap sample of the training data, and only using a small random sample of the predictors to define the split at each node. Independent predictions (i.e. independent of the model-fitting procedure) for each tree are then made for the observations that were excluded from the bootstrap sample (the out-of-bag [OOB] samples). These predictions are aggregated over all trees, and the error (the OOB error) provides an estimate of the generalisation error (i.e. the predictive accuracy of the model for cases that are independent of the model-fitting procedure [Breiman, 2001]). We evaluated the model performance by comparing the OOB predictions with the corresponding observations, and quantified the correspondence using Nash-Sutcliffe Efficiencies (NSE). NSE is a measure of the performance of a model that indicates how closely a plot of observed versus predicted values lies to the 1:1 line (i.e. how close to perfect coincidence the two sets of values are [Nash & Sutcliffe, 1970]).

Water quality models

Further details of RF models and the performance of the national models of the water quality variables are provided in Unwin *et al.* (2010). This report also provides information on the relationships between the individual predictors and the response variables.

Independent predictions (i.e. the OOB predictions) of the water quality variables confirmed that the national model represented the pattern in the Southland region (Figure 52). NSE for the models ranged from 0.24 to more than 0.80 or more, indicating fair to excellent performance. Model error was correspondingly low, and none of the models had significant bias (i.e. intercepts were not statistically different to zero).

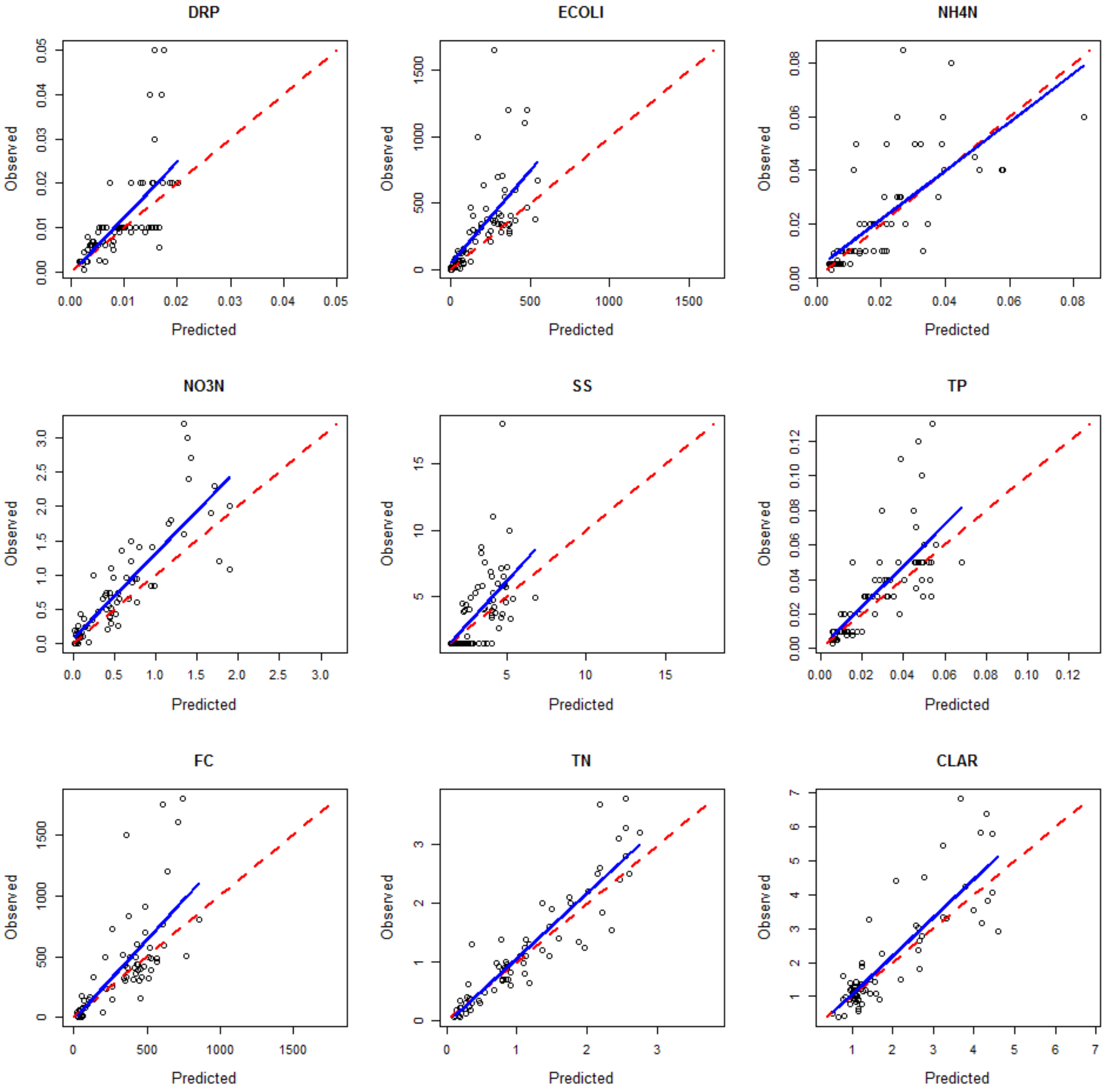

Figure 52: Performance of the national water quality models for the 73 SoE sites in Southland. The plots show the observed median site values against the fitted values from the relevant models (with the exception of Clarity, which is the median of observations taken below the median flow).

Table 18: Details of the performance of regional contaminant load models for the SoE sites in Southland. Where n *is the number of sites used to fit the model,* NSE *is Nash-Sutcliffe Efficiency,* RMSD *is root mean square deviation,* bias *measures the average tendency of the predicted values to be larger or smaller than the observed, and the* P values *refer to a test of whether the line of best fit is significantly different to the 1:1 line.*

	n	NSE	RMSD	Bias	P value (slope)	P value (intercept)
DRP	73	0.35	0.008	0.002	0.156	0.882

ECOLI	73	0.25	273.64	121.187	0.034	0.396
NH4N	73	0.52	0.014	0.002	0.361	0.133
NO3N	73	0.61	0.464	0.21	0.012	0.236
SS	67	0.22	2.574	0.687	0.224	0.684
TP	73	0.49	0.02	0.006	0.153	0.889
FC	67	0.44	303.57	85.642	0.057	0.815
TN	73	0.83	0.381	0.071	0.047	0.507
CLAR	66	0.71	0.849	0.178	0.128	0.713

Contaminant load models

Loads were estimated at SoE sites in the Southland region from the observed concentration and flow data for each sampling occasion. Two methods of load calculation were used (for details, see Defew *et al.*, 2013). The first was an interpolation method that assumes that the concentration of the contaminant of a water sample is representative of the conditions in the river for the period between two observations. The second method was an extrapolation technique that defines the relationship between concentration and flow, and then applies this to a flow duration curve (FDC). We used the second method to estimate loads when the log-log (base 10) relationship between concentration and flow explained more than 50% of the variation in the observed concentrations. It was considered unlikely that the concentration and flow data represented high flows. We therefore used independent estimates of hydrology (mean flow and FDC for the respective methods) to reduce the reliance on the observed flows. The relevant equations for the two methods are as follows:

$$Load = K\,\frac{\sum_{i=1}^{n}(C_iQ_i)}{\sum_{i=1}^{n}Q_i}\widehat{Q_r} \qquad \text{Method 1}$$

$$Load = K\left(\sum_{i=1}^{n}C_cQ_c\right) \qquad \text{Method 2}$$

Where, C_i and Q_i are the concentrations and flows on the individual sample occasions, $\widehat{Q_r}$ is the estimated mean flow at the site based on Woods *et al.* (2007), C_c is the concentration estimated from a log-log (base 10) regression of concentration versus flow, and Q_c is the estimated flow in 1% increments from a FDC based on Booker and Snelder (2011). The constants K were used to convert the loads to tonnes per year, and this was then expressed as tonnes per hectare per year by dividing the load by the catchment area. We note that a correction was applied to the estimates calculated using Method 2 to account for bias associated with log-log regression models (Defew et al. 2013).

Independent predictions made to the observation sites (i.e. predictions made when the site was excluded from the fitting data) indicated that random forest contaminant load models for NH4N, NOxN, TN, ECOLI, and FC were strongly related to the observations (NSE of 70% or higher; Figure 53; Table 19). The TP model performed less well (NSE of 36%), and the models for DRP and SS performed very poorly.

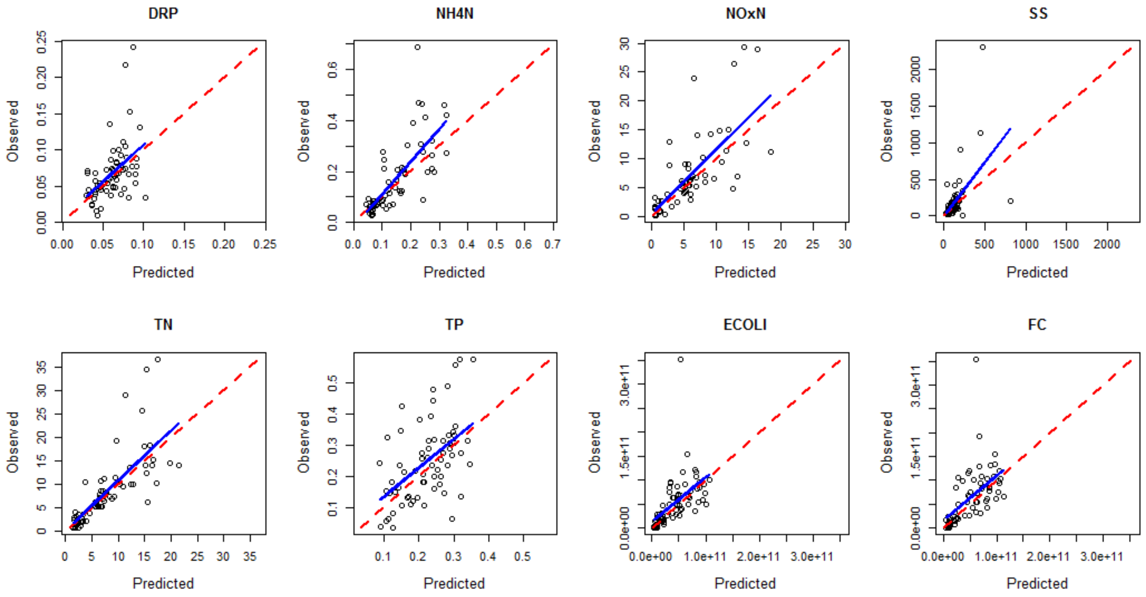

Figure 53: Performance of the regional contaminant load models for the SoE sites in Southland. The plots show the observed loads against the independent predictions from the relevant models.

Table 19: Details of the regional contaminant load models for the SoE sites in Southland. Where n *is the number of sites used to fit the model,* NSE *is Nash-Sutcliffe Efficiency,* RMSD *is root mean square deviation,* bias *measures the average tendency of the predicted values to be larger or smaller than the observed, and the* P values *refer to a test of whether the line of best fit is significantly different to the 1:1 line.*

	n	NSE	RMSD	Bias	P value (slope)	P value (intercept)
DRP	65	0.19	0.0	0.0	0.9	0.7
NH4N	66	0.53	0.1	0.0	0.0	0.4
NOxN	65	0.52	4.6	1.1	0.4	0.6
SS	66	0.22	282.4	60.2	0.1	0.9
TN	66	0.56	5.0	0.7	0.6	0.9
TP	66	0.23	0.1	0.0	0.7	0.4
ECOLI	67	0.25	4.5E+10	9.9E+09	0.7	0.2
FC	62	0.25	5.0E+10	1.3E+10	0.8	0.2

Appendix B: Multivariate water quality and classification

There are two strategies that can be employed to define classifications from data at a limited number of sites and to then extrapolate the classification to all locations across the region of interest (in this case, the segments that represent the river network in Southland). The strategies differ in terms to the order in which HCA and statistical modelling are employed. A classification of the SoE sites with observation data can be made first, and then the class membership of all segments can be predicted using a statistical model; this is a ‘classify then predict’ strategy. The alternative strategy is ‘predict then classify’. This uses the SoE site data to predict the water quality variables for all segments, and to then use HCA to cluster the segments into classes. Previous work has shown that a predict-then-classify strategy is more likely to produce a good classification, primarily because it reduces the bias that is inherent in the spatial distribution of the observation data (e.g. Snelder *et al.*, 2012, 2010; Snelder & Booker, 2012). It has been shown the spatial distribution of SoE sites in Southland (NIWA, 2010) that the 73 SoE sites over-represent some river types (e.g. rivers with catchments characterised as lowland pasture) and under-represented others. This is an expected outcome because SoE networks are often concentrated in locations where there is significant human pressure, and are not necessarily aiming to be a representative sample of the region. However, classification of the region’s water quality based on a cluster analysis of the 73 SoE sites is likely to be biased (i.e. pessimistic in terms of regional water quality). We therefore used the predict-then-classify strategy by applying HCA to the water quality predictions made for all network segments using the Random Forest models.

Other choices that must be made when applying HCA concern the measure of similarity, the transformation and weighting of variables, and the linkage method used by the clustering procedure. These are essentially subjective choices that have to be made, and the outcomes are sensitive to these (Snelder *et al.*, 2010).

Another issue is that of correlation between the variables that are used to define the classification. Correlation is undesirable in the context of multivariate classification, because dimensions that correspond with the correlated variables will be emphasised at the expense of uncorrelated variables (Snelder & Booker, 2012; Snelder *et al.*, 2009). We reduced the dimensionality of the water quality data by using the scores from the PCA for the network segments on each of the first three principle components. We performed the HCA on the unscaled principle components, which weights the dimensions according to the variation they explain. We note that rescaling the principle components to all have the same scale treats all dimensions as having equal weight (Snelder *et al.*, 2010; Snelder & Booker, 2012).

Appendix C: Macro-invertebrate model

We used an existing national model that predicted site median MCI scores as a function of catchment and segment characteristics (Clapcott *et al.*, 2013). The model fitting data set MCI samples from 1033 sites distributed across all regions of New Zealand and collected during the five-year period from 2007 to 2011. The dataset included 80 biological modelling sites distributed throughout Southland.

The national model was fitted using an RF model and predictors that were associated with the REC and that were common to the water quality and contaminant load models, including the New Zealand Land Cover Database (LCDB2) (MfE, 2004), variables developed as part of Freshwater Environments of New Zealand classification (FWENZ) (Wild *et al.*, 2005), and estimated mean flow (Woods *et al.*, 2006) and predictions of hydrological indices (Snelder & Booker, 2012).

Independent predictions (i.e. the OOB predictions) of median MCI made to the individual biological monitoring sites in Southland confirmed that the national model represented the regional pattern (Table 20).The Nash-Sutcliffe Efficiency (NSE) for the model was 0.74, indicating excellent performance. Model error was correspondingly low, and bias was insignificant (i.e. intercepts were not statistically different to zero).

Table 20: Details of the median MCI model for the biological monitoring sites in Southland. Where n *is the number of sites used to fit the model,* NSE *is Nash-Sutcliffe Efficiency,* RMSD *is root mean square deviation,* bias *measures the average tendency of the predicted values to be larger or smaller than the observed, and the* P values *refer to a test of whether the line of best fit is significantly different to the 1:1 line.*

	n	**NSE**	**RMSD**	**Bias**	**P value (slope)**	**P value (intercept)**
MCI	80	0.74	8.3	0.6	0.5	0.6

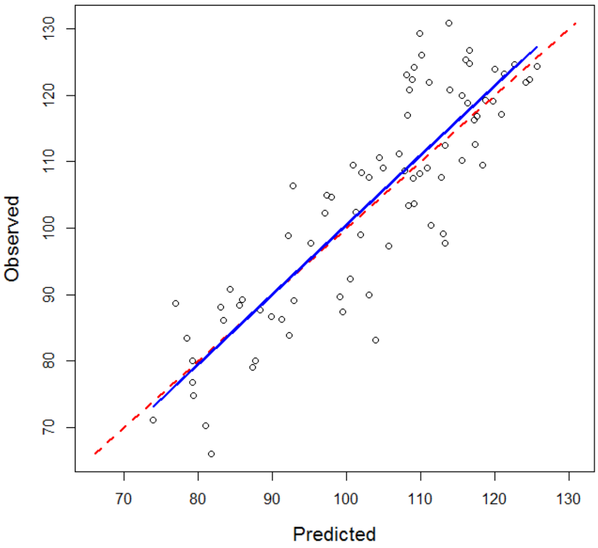

Figure 54: Performance of the national MCI model for the 80 MCI biological monitoring sites in Southland.

Appendix D: Periphyton model

Estimating the exceedance of chlorophyll *a* thresholds

Periphyton abundance at a site tends to be highly variable in time. Low values are most often observed with occasional high values. Very high values may not be observed for several years but then occur when particular conditions (generally prolonged low flows and high temperatures) allow the accrual of high abundance. Thus, short-time series of periphyton observations may under-represent the highest values that are possible at a site, and the extremes of the observations (e.g. the frequency that values exceed 200 mg/m^2) are unlikely to be a good basis prediction at other locations.

Periphyton surveys have been conducted at approximately 70 sites per year since 2007. This monitoring was started in 1996, with more sites added over time, such that about 70 sites (on average) have been surveyed annually since 2007. Periphyton samples (collected following Stark and Maxted 2007) are analysed for chlorophyll *a* and Ash Free Dry Mass (AFDM), and assessed according to standard procedures. Periphyton were sampled one to three times annually, most often during summer, when pressures of temperature and algae growth are likely to be highest, and river flows are low and stable. The low sampling frequency means that the maximum periphyton abundance is unlikely to be well represented by these data. Because the criterion for periphyton is based on maximum values, the raw data are not suitable for testing if the criterion is met. However, we used the periphyton data to develop a predictive model of maximum periphyton biomass.

Snelder *et al.* (2013) showed that, at most sites, periphyton cover is approximately exponentially distributed. The exponential distribution has the mean as its only parameter. This means that if the exponential distribution is also a reasonable approximation for abundance observed as chlorophyll *a* (in Snelder *et al.*, abundance was represented by cover), then the frequency that relatively extreme values are exceeded may be estimated from the mean of observations based on the quantile function:

$$Abundance = -\ln(Pr) \times \mu$$

where Pr($0 \leq Pr < 1$) is the probability that abundance is exceeded given the mean ($\mu > 0$). If the mean is derived from monthly observations, the quantile function can be used to estimate the expected value of the abundance exceeded for not more than 1 month per year by setting probability to 1/12 (i.e. 8%).

We tested whether this assumption is reasonable for chlorophyll *a* using the available data. First, we computed the overall mean chlorophyll *a*, and the value exceeded for 8% of the records for each site. We assumed that the means were reasonable approximations of the mean monthly chlorophyll *a* for the Southland sites. We then predicted the value exceeded for 8% of the time, using the estimated mean and the quantile function. There were strong relationships between the observed and estimated chlorophyll *a* exceeded for 8% of the time, indicating that the exponential distribution assumption was reasonable.

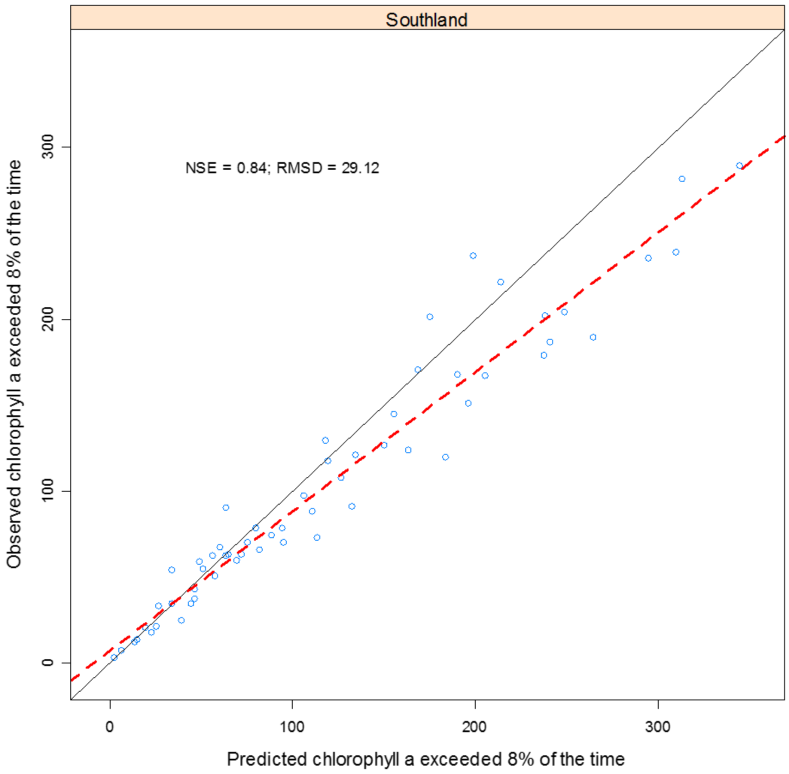

Figure 55: Relationship between the observed and predicted chlorophyll a exceeded for 8% of the time. The predictions were made using the estimated mean and the quantile function for the exponential distribution. Nash-Sutcliffe Efficiency (NSE) is a measure of the performance of a model that indicates the agreement between observed and predicted (Nash & Sutcliffe, 1970). NSE values can range from 1 (a perfect fit) to negative infinity, and values over 0.8 suggest excellent performance. Root mean square deviation (RMSD) indicates the mean prediction error as chlorophyll a (mg/m^2).

Modelling spatial distribution of exceedance of the chlorophyll *a*

We used regression models to predict the mean site chlorophyll *a* as a function of predictors that were available for all segments of the REC network. This enabled us to then predict mean chlorophyll *a* for all segments of the REC network and to predict the chlorophyll *a* concentration exceeded for not more than 1 month per year.

A relevant set of potential explanatory variables for the regression models was selected based on a conceptual model and that represented periphyton abundance as a consequence of counteracting processes of biomass accrual and loss (Biggs, 1996). The explanatory variables included site water quality, flow regime, temperature, solar radiation, and substrate (an index describing sediment grain size). All the explanatory variables were produced for all segments of the REC network using national models in a variety of previous studies. The conceptual model and explanatory variables are discussed more fully in Snelder *et al.* (2013).

Predictions of current (i.e. existing conditions) for clarity (black disc visibility), ammoniacal nitrogen, nitrate nitrogen, total nitrogen (TN), dissolved reactive phosphorus (DRP), and total phosphorus (TP) was derived from the water quality models (see Appendix A). Predictions for ammoniacal nitrogen and nitrate nitrogen were added to estimate dissolved inorganic nitrogen (DIN). The proportion of bed covered by several substrate size classes was represented by single substrate index, as described by Jowett and Richardson (1990). Predictions of this index were derived using a national model developed as part of species distribution modelling (Leathwick *et al.*, 2011). Predictions of summer temperature were made based on a model fitted to observations of the 95% percentile water temperature at NRWQN sites (Snelder *et al.*, 2013). Predictions for hydrological indices, which describe aspects of the flow regime, were obtained for each site from predictions made by Snelder and Booke (2012). The frequency of floods was represented by the number of events per year that exceeded a multiple (n) times, the long-term median flow (FREn) where n = 2, 3, and 4. The frequency of changes of flows was represented by hydrological reversals (Reversals). Sites with frequent reversals have many hydrograph peaks. Rates of increase of flow were represented by the number of days on which flow was less than that of the previous day (nNeg). Sites with steep rising limbs have large values of nNeg. The mean annual 7-day low flow divided by the mean flow was used to represent the low flow magnitude (LowFlow). The general variability of flows was represented by the coefficient of variation of the daily flows (CV_Flows). This index discriminates sites that have stable flow regimes (sustained flows) from sites with long periods of low flows, which tend to be located on the eastern coasts of both islands.

We fitted additive linear regression model to the square root transformed mean chlorophyll *a* observed at the monitoring sites, using forwards and backwards stepwise regression in the same manner as Snelder *et al.* (2013). The linear regression model for the Southland region explained 52% of the variation of mean (square root transformed) chlorophyll *a*. The fitted responses of chlorophyll *a* to the predictor variables were largely consistent with the conceptual model (plots not included). For example, chlorophyll *a* decreased with increasing FRE3, and increased with increasing T95 and most nutrients (Table 21).

The fitted model was used to predict mean chlorophyll *a* for all segments in the Southland region. We predicted mean periphyton for all segments of the REC network in the Southland region, and then calculated the chlorophyll *a* exceeded for not more than 1 month per year using the quantile function and adding the estimated bias (37 mg/m^2). We mapped these predictions and calculated the proportion of REC network segments for which the values were in excess of the thresholds (e.g. 200 mg/m^2). The predictions indicated that chlorophyll *a* exceeded 200 mg/m^2 once and twice per year at 1% and 0.1% of segments in the region, respectively (Figure 56).

Table 21: Coefficients for the additive linear regression model of Southland region mean chlorophyll a.

	Coefficient	**Standard error**	**t-value**	**Pr(>|t|)**
Intercept	-14.87	7.55	-1.97	0.054
Substrate	1.95	0.75	2.60	0.012
T95	1.45	0.39	3.71	0.001
PAR	0.00	0.00	-1.39	0.171
$\log_{10}(\mathrm{DIN})$	5.44	2.82	1.93	0.059
$\log_{10}(\mathrm{TN})$	-12.07	4.37	-2.76	0.008
$\log_{10}(\mathrm{TP})$	5.89	1.87	3.14	0.003
FRE3	-0.23	0.14	-1.64	0.108

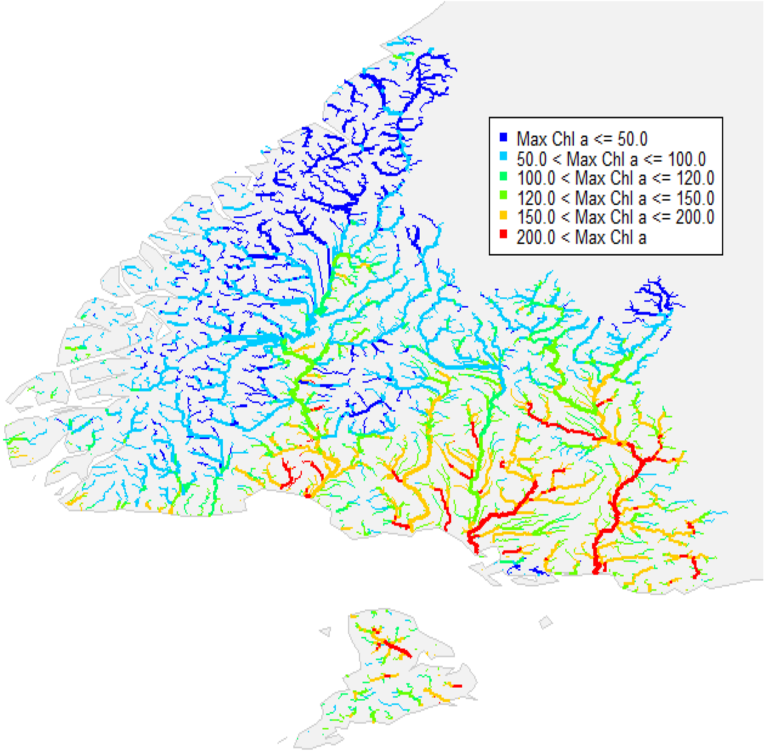

Figure 56: Predicted chlorophyll a exceeded on average for 1 month per year for the Southland region.

Appendix E: Point source loads

The table below provides a summary of the loads from the 11 major contaminant sources in the Southland region (from Palliser & Elliot, 2013).

Name	**Type**	**NZReach**	**TN load (t/yr)**	**TP load (t/yr)**	***E coli* load (number/yr)**
Fonterra[a]	Dairy factory (Edendale)	15057604	3.0	0.2	
Winton	Sewage/Wastewater Treatment Plant	15052712	4.4	1.1	6.43×10^{12}
Gore	Sewage/Wastewater Treatment Plant	15050094	11.0	2.7	4.16×10^{14}
ICC WWTP Clifton	Sewage/Wastewater Treatment Plant	15060656	231.1	34.7	1.88×10^{14}
SDC Te Anau STP	Sewage/Wastewater Treatment Plant	15020633	4.3	2.4	
Alliance: Makarewa	Meat Works	15057697	67.0	8.1	6.82×10^{12}
Alliance: Lorneville	Meat Works	15058785	448.1	48.8	4.38×10^{13}
Alliance: Mataura	Meat Works	15053089	164.7[b]	14.8	1.01×10^{16}
Prime Range Meats	Meat Works	15059270	6.1	0.1	
Ballance: Awarua	Fertiliser Plant	15061198	6.1[c]	0.1[d]	
Ballance: Awarua	Fertiliser Plant	15061198	6.1[c]	0.1[d]	

Notes:

[a] Only stormwater is discharged to the waterway (wastewater goes to land).
[b] Just TKN.
[c] Just NH4-N + NH3-N.
[d] Just DRP.

The locations of the point source are shown in Figure 31. We propagated the point source loads down the stream network to determine the additional load contributions from all point sources at all locations within Southland REC network. We then compared these point source contributions to the modelled loads (as described in Section 6.4). The following figures demonstrate the spatial distribution of the ratios of the point source load to the modelled load. Values greater than one (shown in orange) demonstrate locations where the point source load is greater than the modelled diffuse load. In most cases, the relative contributions from the point source loads are <20% of the modelled loads, although there are some locations near point source loads in small tributaries where the point source contributions are significantly larger than the predicted diffuse loads.

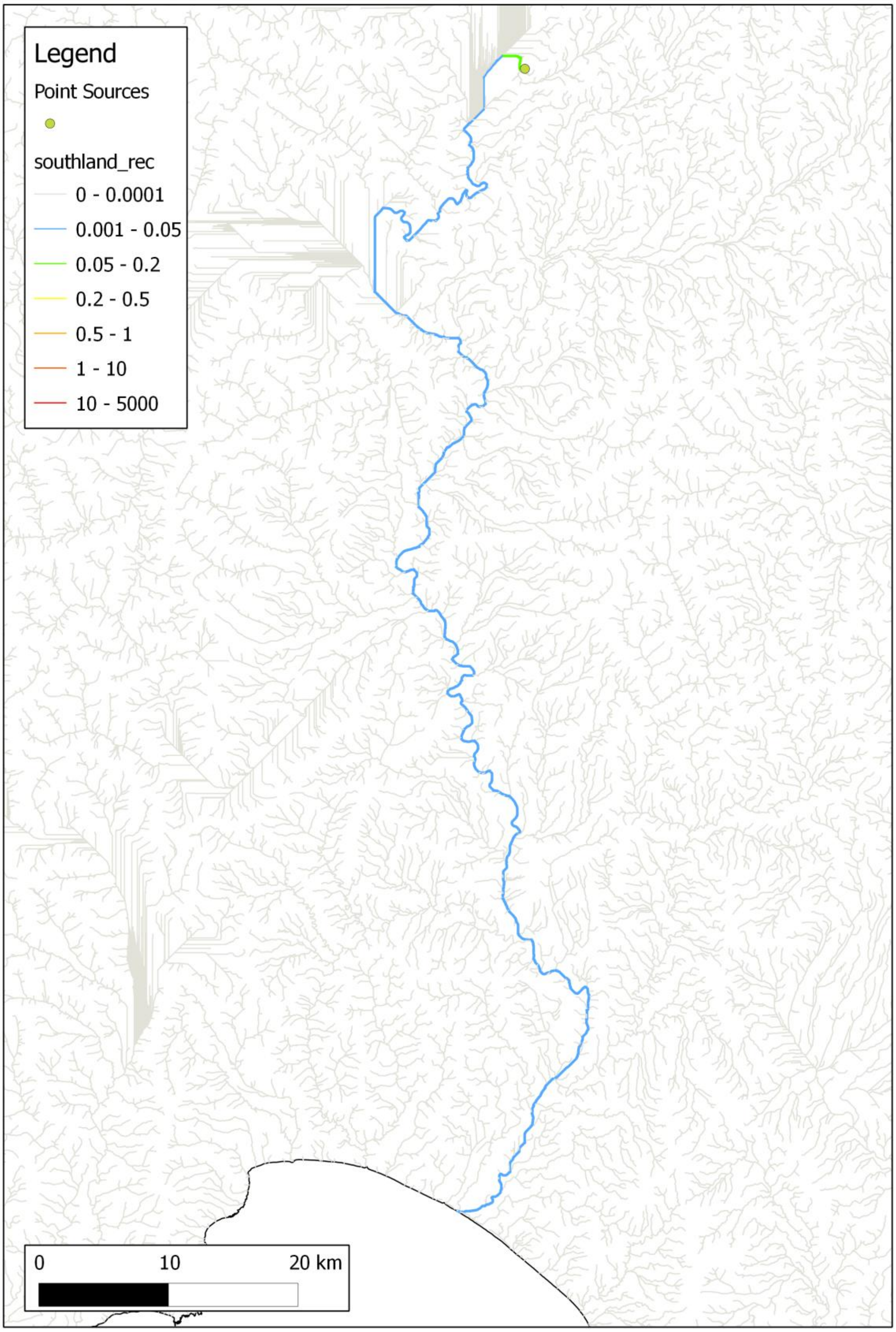

Figure 57: Map of the ratio between the point source TN load and the modelled TN load for the Waiau River.

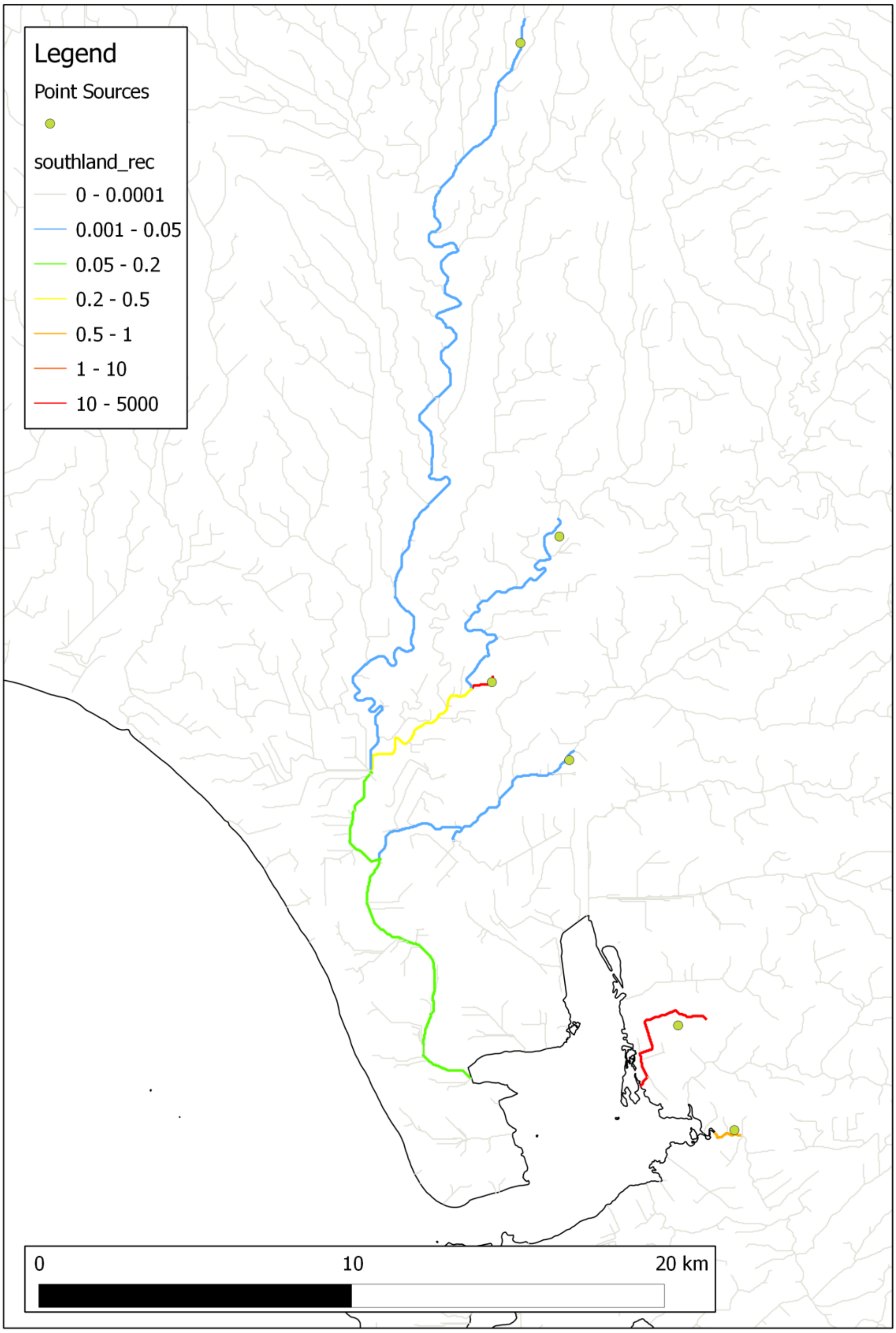

Figure 58: Map of the ratio between the point source TN load and the modelled TN load for the Oreti River.

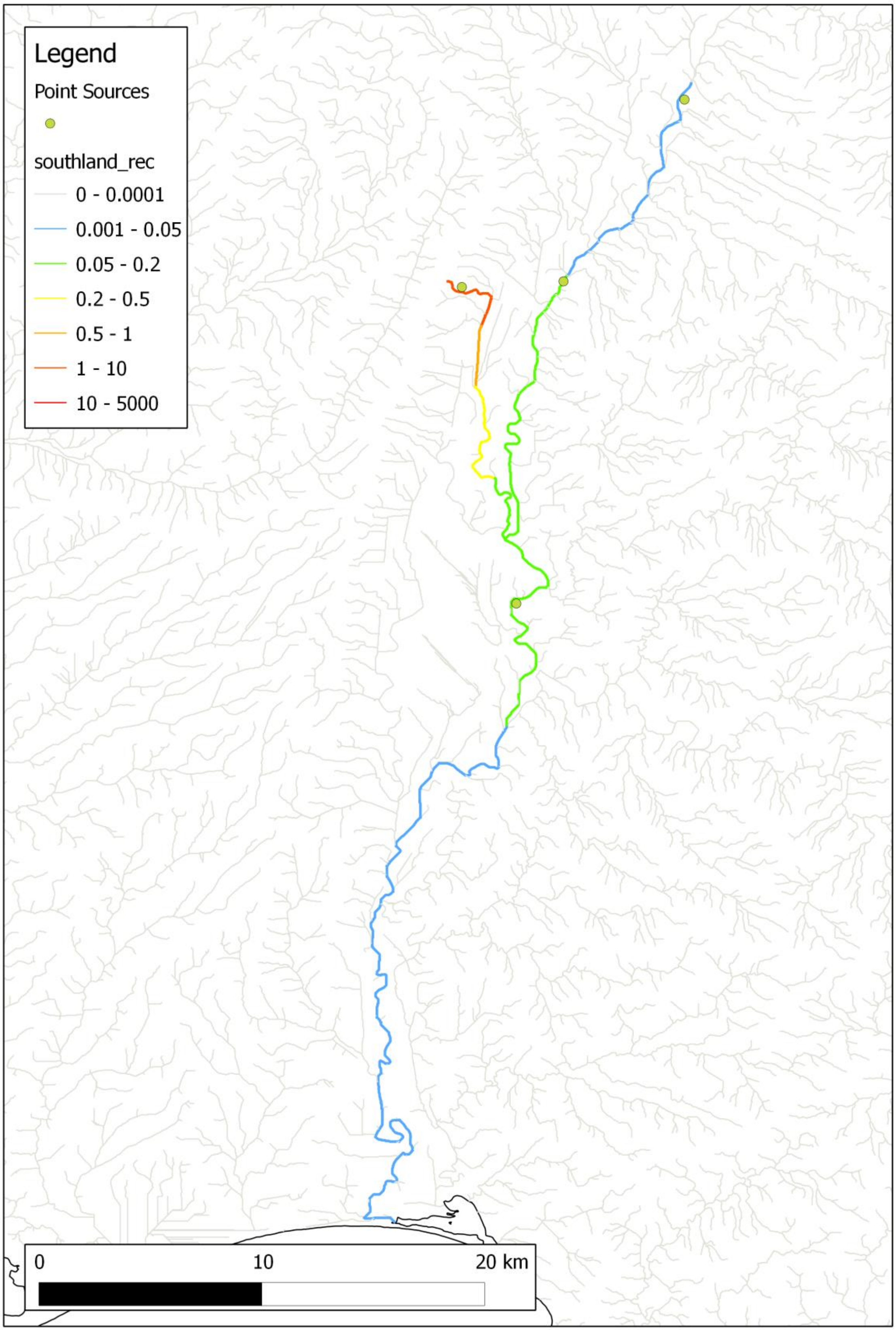

Figure 59: Map of the ratio between the point source TN load and the modelled TN load for the Mataura River.

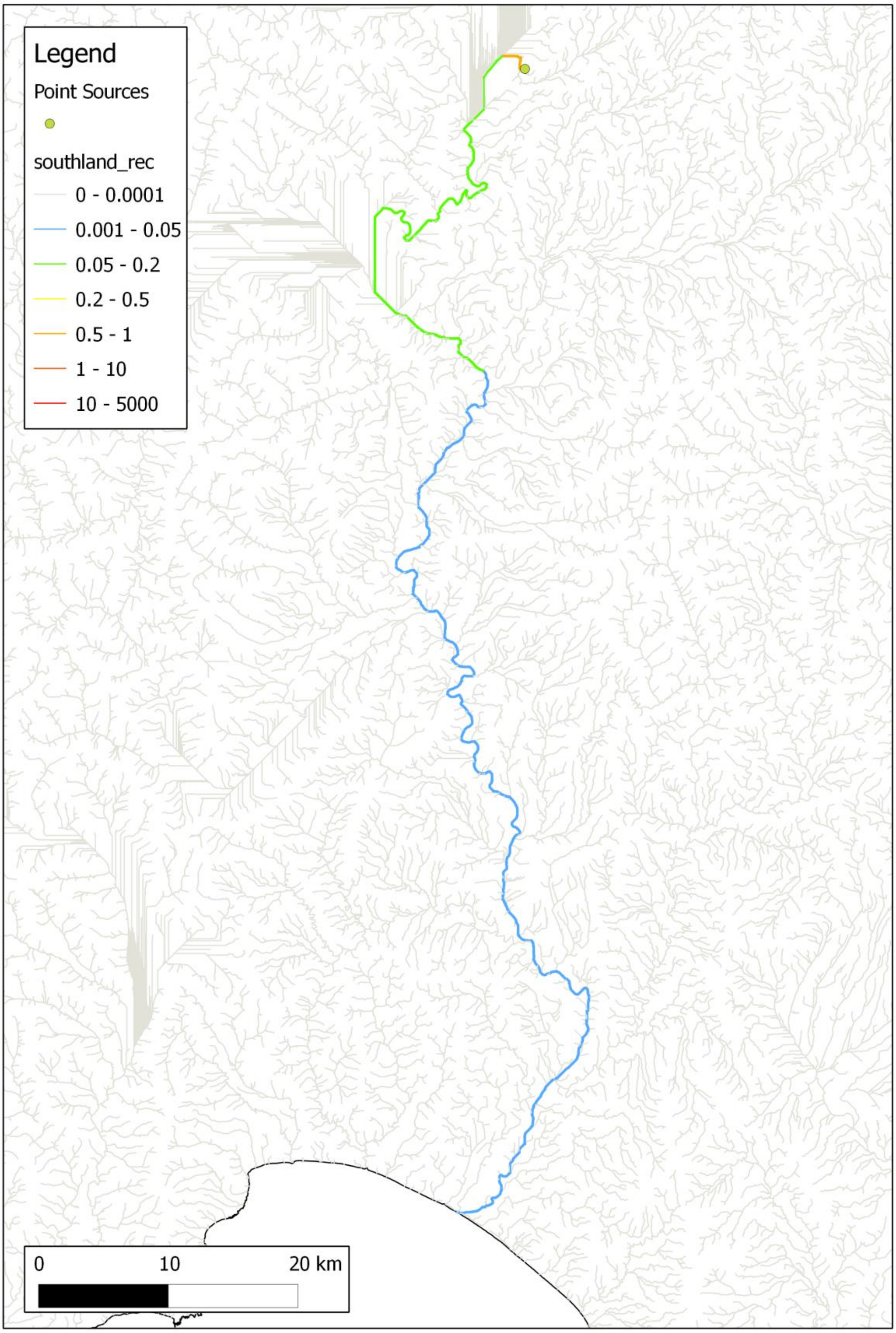

Figure 60: Map of the ratio between the point source TP load and the modelled TP load for the Waiau River.

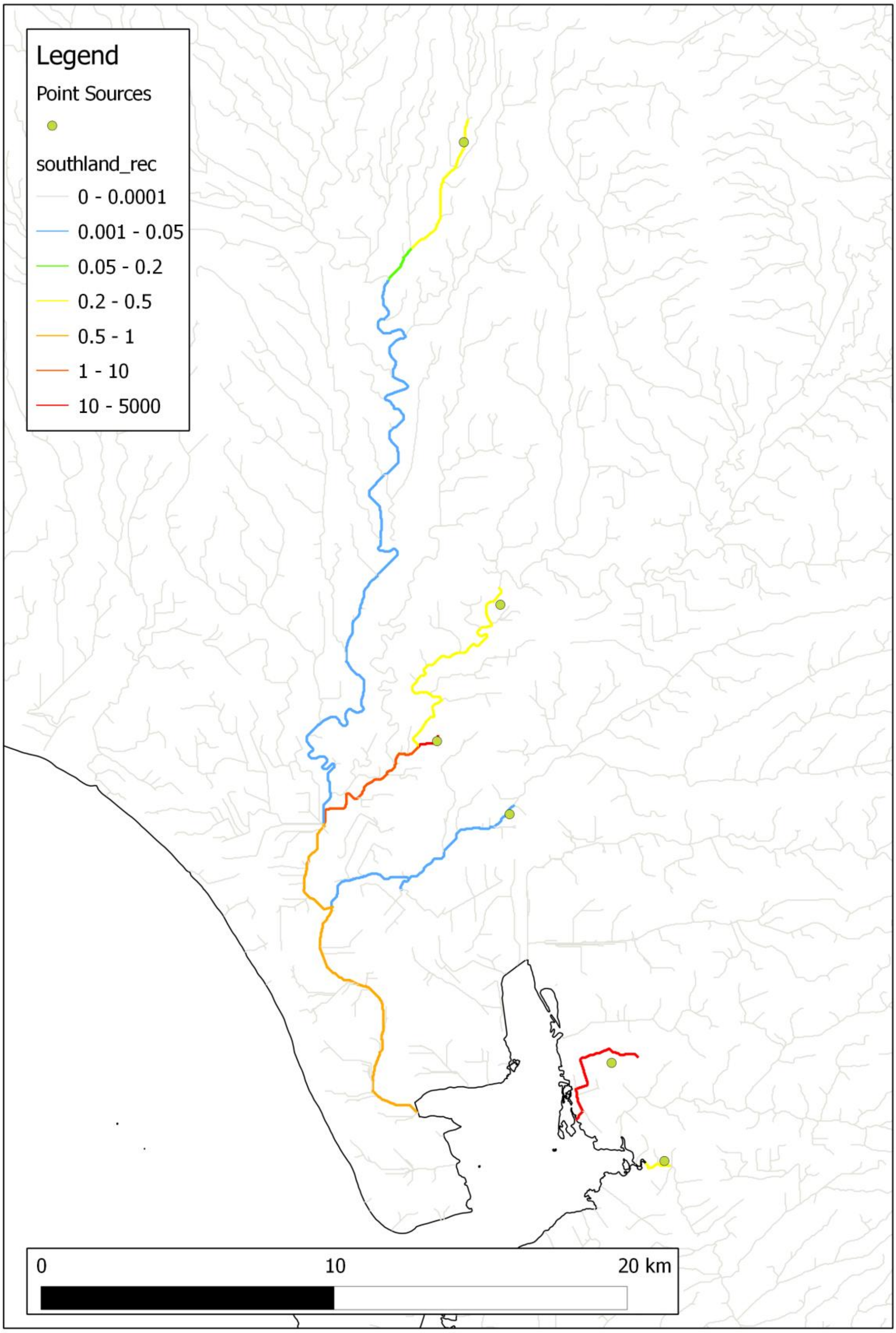

Figure 61: Map of the ratio between the point source TP load and the modelled TP load for the Oreti River.

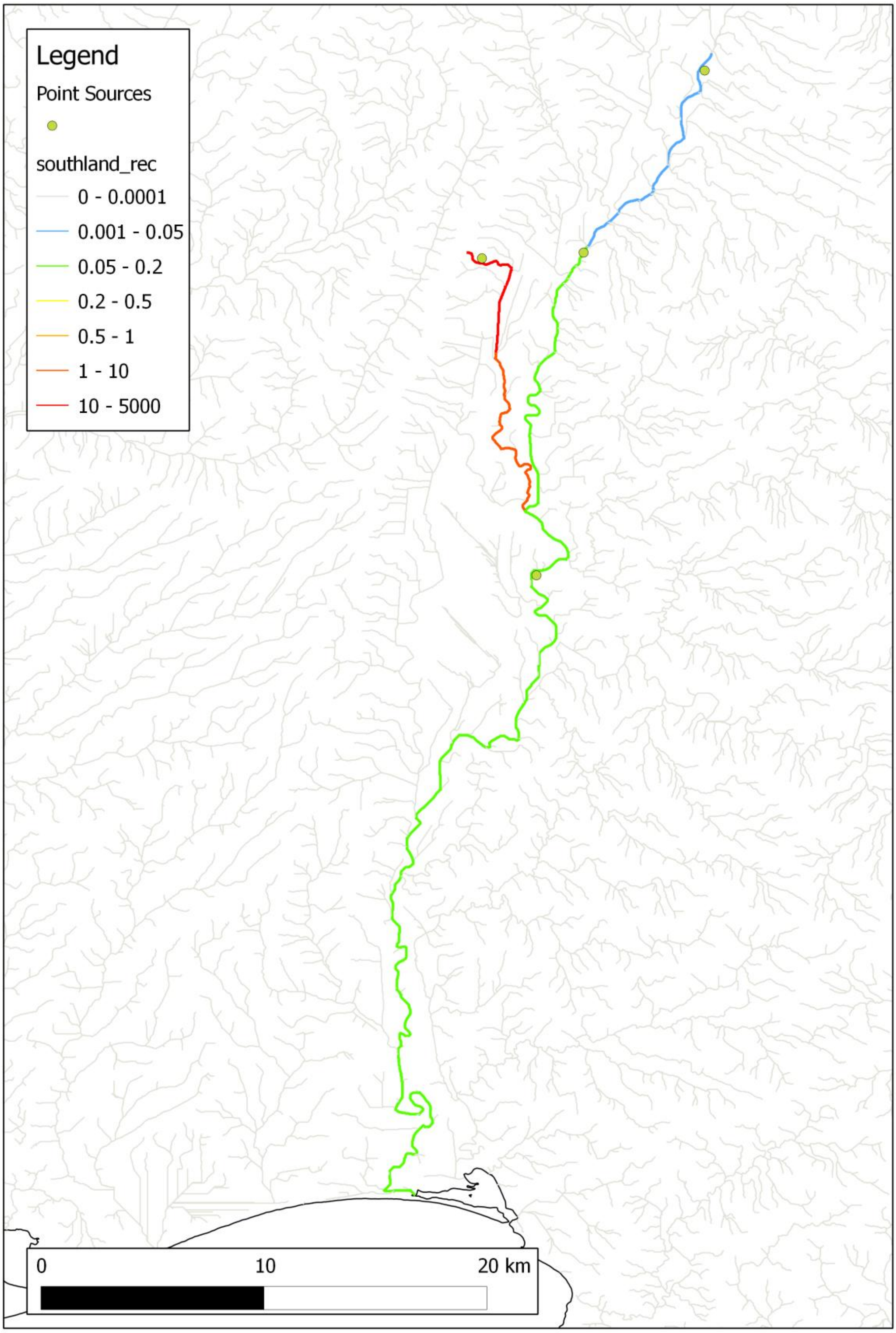

Figure 62: Map of the ratio between the point source TP load and the modelled TP load for the Matura River.