Assessment of Nutrient Load Reductions to Achieve Freshwater Objectives in the Rivers, Lakes and Estuaries of Southland Including Uncertainties

To inform the Southland Regional Forum process

November 2021

Prepared by:

Ton Snelder

For any information regarding this report please contact:

Ton Snelder

Phone: 027 575 8888

Email: ton@lwp.nz

LWP Ltd

PO Box 70

Lyttelton 8092

LWP Client Report Number:	2021-04
Report Date:	November 2021

Quality Assurance Statement

Version	Reviewed By	
Final	Ned Norton	

Table of Contents

Figures

Tables

Executive Summary

This report describes nutrient (nitrogen and phosphorus) load reductions predicted to achieve options for freshwater objectives (FWO) in rivers, lakes and estuaries in Southland. The analysis does not consider how the nutrient load reductions would be achieved and only aims to inform the Southland Regional Forum Process about the magnitude of the load reductions needed for each option, how these vary across the region, and the uncertainty inherent in this assessment.

The study assesses nutrient load reductions required to achieve two different sets of options for FWOs developed by Environment Southland and the Te Ao Marama Inc (TAMI) board (defined below), as well as a set of FWOs that are consistent with the National Objectives Framework (NOF) national bottom lines. In addition, this study assesses nutrient load reductions pertaining to two options for nutrient criteria to achieve river periphyton objectives, which are referred to as the 20% and 30% spatial exceedance criteria. The two spatial exceedance criteria can be understood as different levels of risk that adopted nutrient criteria will fail to achieve the required periphyton outcomes; the 30% criterion accepts a higher level of this risk than the 20% criterion. The study includes an assessment of the uncertainties associated with the various input models describing current nutrient loads and concentrations.

The study area includes all of Southland except the Fiordland and Islands Freshwater Management Unit (FMU). The underlying analysis utilised several models that are based on regional river water quality monitoring data. These models are used to estimate concentrations and loads of nutrients in the rivers, lakes and estuaries across the study area. The concentrations and loads were combined with criteria associated with FWOs. Calculations were made of the amounts by which current loads would need to be reduced to allow the FWOs to be achieved (i.e., the load reduction required).

The options for FWOs are defined in terms of a band (A, B or C) for all river, lake and estuary receiving environments in the study area. Two sets of FWO options for rivers, lakes and estuaries were nominated and are referred to as the Hauora option and the Proposed Southland Water and Land Plan water quality standards (pSWLP option). The Hauora option was based on hauora principles as reported in Bartlett et al., (2020) and represents the minimum state necessary to support hauora for the nutrient-related ecosystem health attributes assessed in this report (i.e., river periphyton, lake and estuary phytoplankton and estuary macroalgae). The pSWLP option represents the possible minimum FWOs based on water quality standards in the pSWLP as reported in detail in Norton and Wilson (2019). In December 2020, the Southland Regional Council and the Te Ao Marama Inc (TAMI) board approved in principle the minimum level of hauora as the draft FWOs for the region. The FWOs will remain draft until they are set through a plan process.

The assessment combined the two sets of FWOs with the two choices of spatial exceedance criteria for defining nutrient criteria to achieve river periphyton objectives. Collectively the combination of the FWO options (Hauora and pSWLP) and the two sets of periphyton criteria (20% and 30% spatial exceedance criteria) are referred to as settings.

The load reductions required were assessed for all individual river segment, lake and estuary receiving environments in the study area. The results for the individual receiving environments were aggregated to report on individual 'reporting catchments', the catchments of eight individual estuaries, and the whole study area. The results for the whole study area are the most succinct and broad summaries of the load reductions required and are shown in Table A below. The study also identified the 'limiting environment'; i.e., whether it is an estuary, lake or river that has the most sensitive FWO and has therefore driven the load reduction required in each catchment.

The study estimated the uncertainties associated with all assessments of the reductions in TN and TP loads required to achieve nominated FWOs for rivers, lakes and estuaries. Uncertainty is unavoidable because the analyses are based on models that are simplifications of reality and because the models are informed by limited data. The uncertainties associated with two key components of the analyses: the estimated nutrient concentrations and loads were quantified and were combined in a Monte Carlo analyses. The Monte Carlo analyses simulated 100 'realisations' of the load reduction calculations, which were used to define the probability distributions of all estimates. The probability distribution describes the range over which the true values of the load reductions are expected to lie. The best estimate of the load reduction is the mean value of the distribution, and the extreme lower and upper values were represented by the 5th and 95th percentiles of the distribution (i.e., these are the limits of the 90% confidence interval).

Table A. The load reductions required for TN and TP for the study area for the Hauora and pSWLP FWOs and the 20% and 30% spatial exceedance criteria settings. The last line is the load reductions required for the national bottom line attribute states and the 20% spatial exceedance. The load reductions are expressed as proportions of the current load and the values shown in parentheses are the 5th and 95th confidence limits for the reported values (i.e., the range is the 90% confidence interval).

Setting	TN reduction (%)	TP reduction (%)
Hauora – using 20%	70 (61-78)	70 (62-77)
Hauora – using 30%	64 (55-72)	24 (14-38)
pSWLP – using 20%	66 (58-74)	69 (59-77)
pSWLP – using 30%	60 (49-70)	26 (15-44)
NBL (C/D) – using 20%	47 (33 – 61)	21 (13 -33)

The study also assessed load reductions required to achieve FWOs specified by the NOF bottom lines for rivers and lakes, and proposed minimum acceptable state for estuaries (i.e., generally the C/D band threshold in the NOF except for nitrate toxicity in which case it is the B/C band threshold). The regional TN load reduction required to achieve the bottom lines for the study area was 47% (90% confidence interval 33% to 61%) and the regional TP load reduction required was 21% (90% confidence interval 13% to 33%). Note that more detailed results for this analysis are not provided in this report. The FWOs associated with the Hauora and pSWLP options evaluated by this study are therefore more restrictive compared to NOF bottom lines.

It is unlikely that the uncertainties associated with the assessments made by this study can be significantly reduced in the short to medium term (i.e., in less than 5 to 10 years). This is because, among other factors, the modelling is dependent on the collection of long-term water quality and ecosystem health data and reducing uncertainty would require data for considerably more sites than were available for the present study.

There are also uncertainties associated with the nutrient criteria used in this study for lakes, rivers and estuaries. These criteria represent the best assessment of the nutrient concentration or load that will achieve the FWO. The relevant FWOs are maximum plant biomass in the associated receiving environment: phytoplankton in lakes and some estuaries, macroalgae in some estuaries and periphyton in rivers. The uncertainties associated with these criteria mean that some locations may develop biomass greater than specified by the FWO despite having nutrient concentrations that are no higher than the criteria. The uncertainties also mean that some locations may be less susceptible to developing high biomass meaning that the criteria are unnecessarily restrictive in these locations. This study has used the most up to date and appropriate criteria that are currently available. The assessment of uncertainty did not incorporate the uncertainties associated with the nutrient criteria. Rather, it has been assumed that the exceedance of a criteria represents an unacceptably high risk that the FWO will not be achieved and that the appropriate management response is to reduce the current nutrient level (i.e., the nutrient load reduction).

This report can help inform the process for deciding on limits to resource use, by providing an assessment of the approximate magnitude of nutrient load reductions needed to achieve several options for FWOs, with a quantified level of confidence and risk associated with each option. However, this report does not consider what kinds of limits on resource might be used to achieve any load reductions, how such limits might be implemented, over what timeframes and with what implications for other values. The NPS-FM requires regional councils to have regard to these and other things when making decisions on setting limits. This report shows that these decisions will ultimately need to be made in the face of uncertainty.

1 Introduction

This report describes an assessment of nutrient (nitrogen and phosphorus) load reductions required to achieve freshwater objectives (FWOs) in the rivers, lakes and estuaries of Southland Murihiku. The purpose is to inform the Southland Regional Forum and plan change process, which is considering how FWO can be achieved in the Southland Region.

The study assesses nutrient load reductions required to achieve two different sets of FWOs and attribute states that are consistent with the National Objectives Framework (NOF) national bottom lines. In addition, this study assesses nutrient load reductions pertaining to two options for nutrient criteria to achieve river periphyton objectives, which are referred to as the 20% and 30% spatial exceedance criteria. The two spatial exceedance criteria can be understood as different levels of risk that adopted nutrient criteria will fail to achieve the required periphyton outcomes with the 30% criterion accepting a higher level of this risk than the 20% criterion. The study includes an assessment of the uncertainties associated with the various input models describing current nutrient loads and concentrations.

The analysis described in this report does not consider how the nutrient load reductions would be achieved; this will be the subject of subsequent studies. The current report therefore only aims to inform the Forum Process about the magnitude of the required load reductions and how these vary across the region and to establish a framework for future scenario testing of methods.

The analysis methodology is based on two previous national-scale studies of nitrogen load reduction requirements (MFE, 2019; Snelder *et al.*, 2020). The MFE (2019) study concerned evaluating the impact of the periphyton attribute of the National Policy Statement – Freshwater (NPS-FM; NZ Government, 2017) and the proposed addition of a dissolved inorganic nitrogen (DIN) attribute. The national-scale study evaluated the total nitrogen (TN) load reductions required across New Zealand to allow rivers to achieve the NPS-FM bottom-lines associated with the periphyton attribute and the additional proposed DIN requirement. The Snelder *et al.* (2020) study evaluated the total nitrogen (TN) load reductions required across New Zealand to allow rivers, lakes and estuaries to achieve the NPS-FM bottom lines for rivers and lakes, and nominated equivalent objectives for estuaries. This methodology has been applied to the Southland region and refined using regional data.

The documentation associated with the MFE (2019) and Snelder *et al.* (2020) studies contain detailed description of the methodology that was used by the study described in this report. However, the current analysis involved some modifications to methods used by the earlier studies to represent the Southland region in greater detail, to add phosphorus to the analysis and to represent a range of options for FWOs in contrast to just the bottom lines assessed in the earlier studies. To keep the current report simple, the methods are described only in broad terms and the reader is referred to MFE (2019), Snelder *et al.* (2020) and other reports for the details of the methodology. The exceptions to this are descriptions of details of the method where these pertain to modifications made for the current study.

2 Methods

2.1 Overview

This study's methodology is based on a spatial framework that represents the drainage network (i.e., streams and rivers) and its' associated catchments and the connected freshwater (river and lakes) and coastal (estuary) receiving environments of the study area. This study used the same spatial datasets as Snelder (2020), MFE (2019) and Snelder *et al.* (2020) to represent the drainage network, lakes and estuaries.

Conceptually, nutrient (nitrogen and phosphorus) loads derive from the upstream catchments and are transported to the receiving environments by the drainage network (Figure 1). Models are used to predict the current concentrations and loads of nutrients at each segment of the drainage network, each of which also represents a river receiving environment. The nutrient loads predicted for the drainage network are used to estimate the nutrient loads delivered to lake and estuary receiving environments.

The criteria to achieve FWOs in river, lake and estuary receiving environments are primarily defined in terms of nutrient concentrations. For accounting purposes, the analysis converts the concentration criteria into an equivalent annual load that is called the maximum allowable load (MAL; i.e., the load that will allow the FWO to be achieved). The compliance of rivers, lakes and estuaries with the concentration criteria is assessed by comparison to current concentrations or the associated loads. Receiving environments with concentrations or loads that are less than or greater than the criteria or MAL are compliant or non-compliant, respectively. The current annual load of TN and TP are compared to the MAL and where the current load is higher, the difference is the local excess load (i.e., the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO).

The load reduction required at any point in the drainage network is the minimum load reduction that ensures the current load at that and all upstream receiving environments do not exceed the MAL. The load reduction required differs from the local excess load in that it considers the excess load of all upstream receiving environments. Thus, a point in the network may have a local excess load of zero but, if it is situated downstream of receiving environments that have local excess loads, it will have a load reduction required that reflects a reconciliation of those upstream local excess loads.

The final step identifies critical point catchments, their load reduction required and their limiting environment (i.e., whether it is an estuary, lake or river criterion that is most restrictive at the critical point and has therefore driven the reduction required in that catchment). This begins by identifying critical points in each sea-draining catchment in the study area. A critical point is defined as a receiving environment for which the local excess load, expressed as a yield (i.e., mass per catchment area, kg ha^{-1} yr^{-1}), is not exceeded by any upstream receiving environment. The catchment upstream of the critical point is a critical point catchment and has a load reduction required status, which is the load reduction required at the critical point. The critical point catchment status can be expressed as a percentage of current TN and TP load or as a reduction in yield (kg ha^{-1} yr^{-1}). The status indicates the spatially averaged reduction rate that would be required over the entire area of the critical point catchment to reduce the load to the MAL (i.e., to allow the FWO to be achieved) for all receiving environments within the catchment. The limiting environment of the critical point catchment indicates whether status is determined by a load reduction requirement for an estuary, river or lake. Sea-draining catchments can have one critical point (the most downstream receiving environment) or multiple critical points, which include the most downstream receiving environment and other sub-catchments.

The process of identifying the critical points is as follows. The terminal segment of every sea-draining catchment (the river mouth or estuary) is defined as a critical point and the local excess load at that point is noted as a yield (i.e., mass per upstream catchment area) and is defined as the catchment status. From the terminal segment, the local excess load (expressed as yields) at successive upstream receiving environment are obtained. Note that successive receiving environments may be river segments or lakes. At each receiving environment, the local excess load is compared with the local excess load for the downstream critical point. If the local excess load at the receiving environment is greater than that of the downstream critical point, the receiving environment is defined as a critical point and the status for the catchment upstream of this point is the local excess load of this receiving environment. If the local excess load at the receiving environment is less than that of the downstream critical point, the catchment load reduction required, and critical point and catchment status are unchanged. The process continues upstream to the catchment headwaters. More details of the process of defining critical points and catchments are provided by Snelder *et al.* (2020)[1].

The catchment status can be expressed in both absolute terms and as a percentage of the current load. The absolute load reduction required is expressed in this report as a mass per year (t yr^{-1}) and as a yield (mass per area per year; kg ha^{-1} yr^{-1}). The yield has special relevance to agricultural land use because it has the same units as nutrient loss rate estimates that are commonly estimated using nutrient budgeting models such as OVERSEER. It should be kept in mind that the absolute load reduction values that are reported for critical point catchments are averages over the catchment. If the catchment includes areas of non-productive land, the required average load reduction from productive land would need to be higher than the reported value because reductions cannot be achieved in non-productive areas. The percentage load reduction required provides an indication of the reduction from the current situation. The same caveat regarding the interpretation of these values where there is non-productive land applies as for absolute values.

[1] Snelder et al. (2020) based the identification of critical points on excess loads, which were expressed as the ratio of the current load to the maximum allowable load.

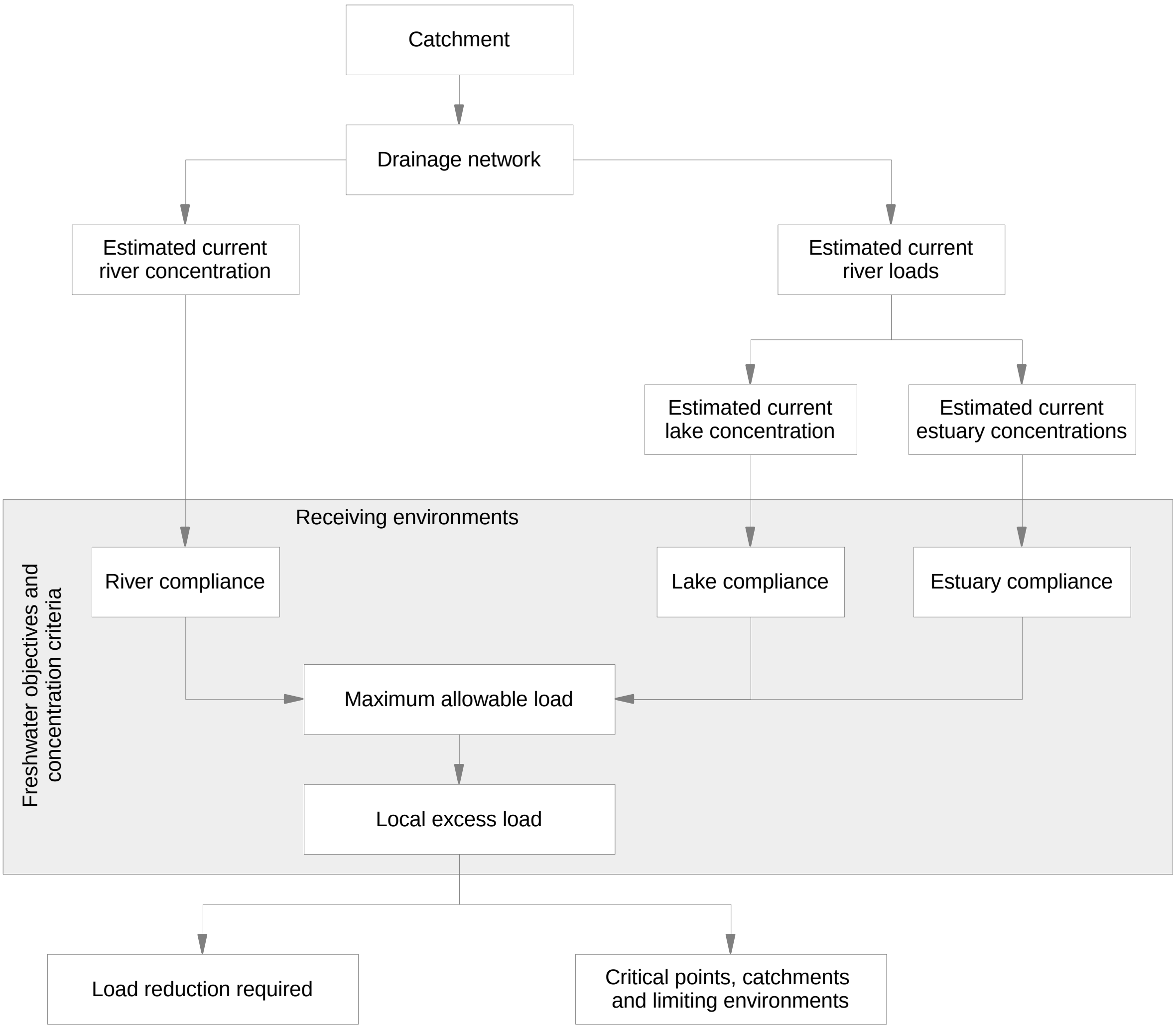

Figure 1. Schematic diagram of the assessment of nutrient load reductions required to achieve freshwater objectives.

The following sections describe the various components of the analysis shown in Figure 1 in more detail.

2.2 Spatial framework

The study area comprised the Southland region excluding Fiordland and Offshore Islands (Figure 2). The drainage network and river receiving environments were represented by the GIS-based digital drainage network, which underlies the River Environment Classification (REC; Snelder and Biggs, 2002). The digital network was derived from 1:50,000 scale contour maps and represented the rivers within the study area as 44,000 segments bounded by upstream and downstream confluences, each of which is associated with a sub-catchment (Figure 2). The terminal segments of the river network (i.e., the most downstream points in each drainage network that discharges to the ocean) were identified.

Lakes were represented in the spatial framework by the lakes layer of the Freshwater Environments of New Zealand GIS database (FENZ; Leathwick *et al.*, 2010). The FENZ lake polygons were intersected with the river network and the river segments that terminate at lakes were identified. Of the c. 1,000 lakes with surface area greater than 1 hectare in the Southland region, there were 121 within the study area for which inflow segments in the drainage network could be defined (Figure 2). The remaining lakes had catchment areas that were too small to be represented by the drainage network and were not included in the analysis.

The spatial framework included eight estuaries in the study area (Figure 2). Estuaries were represented by the national classification of coastal hydrosystems (Hume *et al.*, 2016). Two additional estuaries were added to the coastal hydrosystems layer: Te Waewae Lagoon and the Waimatuku Estuary. The drainage network segments that terminated at these estuaries were identified by intersecting estuary polygons from a GIS layer of 421 New Zealand estuaries with the river network.

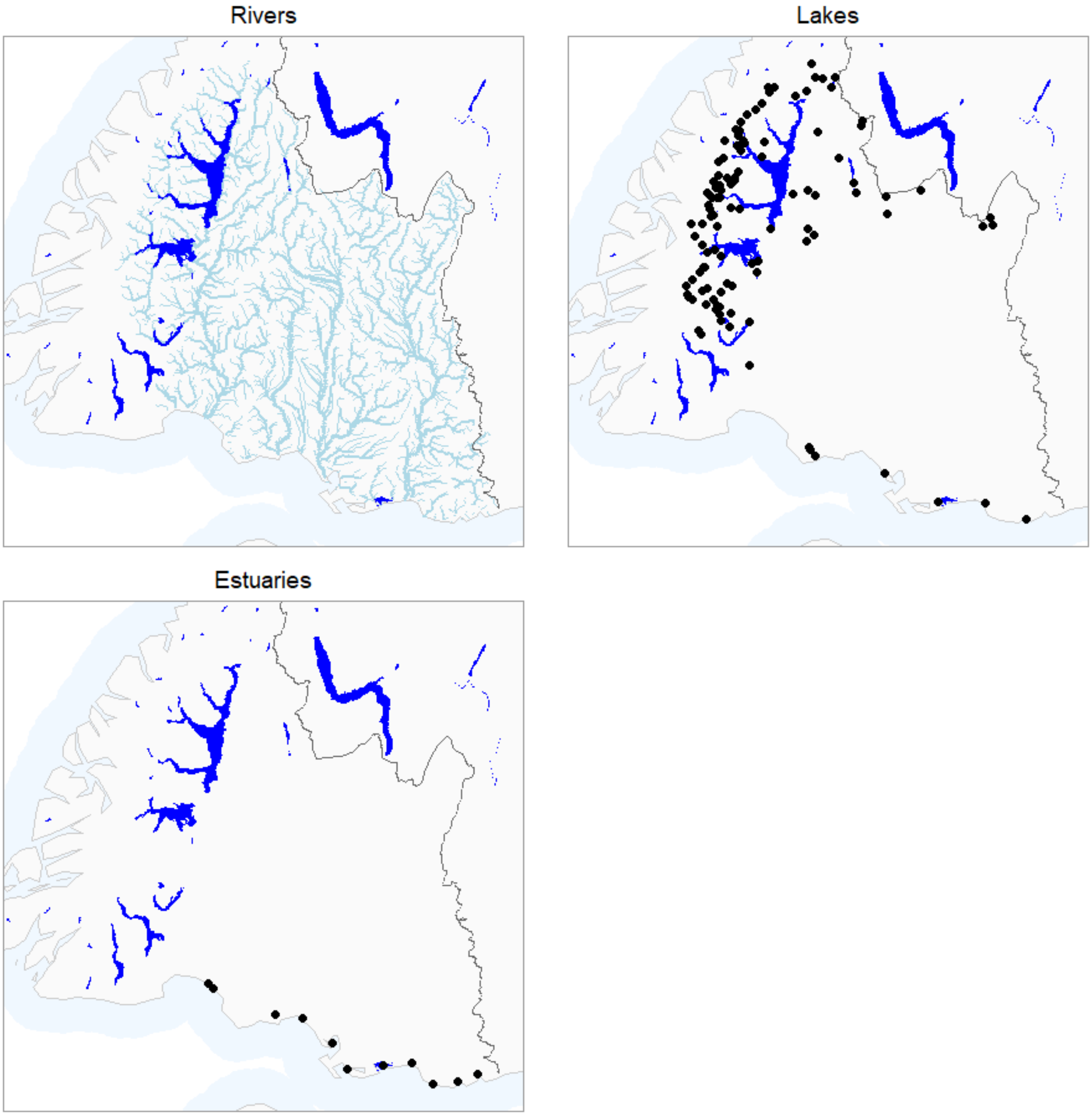

Figure 2. Components of the spatial framework.

The results of the analyses carried out in this study can be reported at any spatial scale from individual receiving environments (i.e., river segments, lakes and estuaries; Figure 2) to the whole study area. Maps indicating the local excess loads were produced as yields by dividing by the upstream catchment area (kg ha^{-1} yr^{-1}) and maps of critical point catchment status were produced as yields and as proportions of the current load (%). Summaries of the load reductions required as mass per year (t yr^{-1}) were produced for the study area, reporting catchments (Figure 3) and the catchments of estuaries and brackish lakes (see Section 2.9.1 for details). These summaries were evaluated by summing the load reductions required over all terminal segments (i.e., network of segments intersecting the coastline) of the summary area.

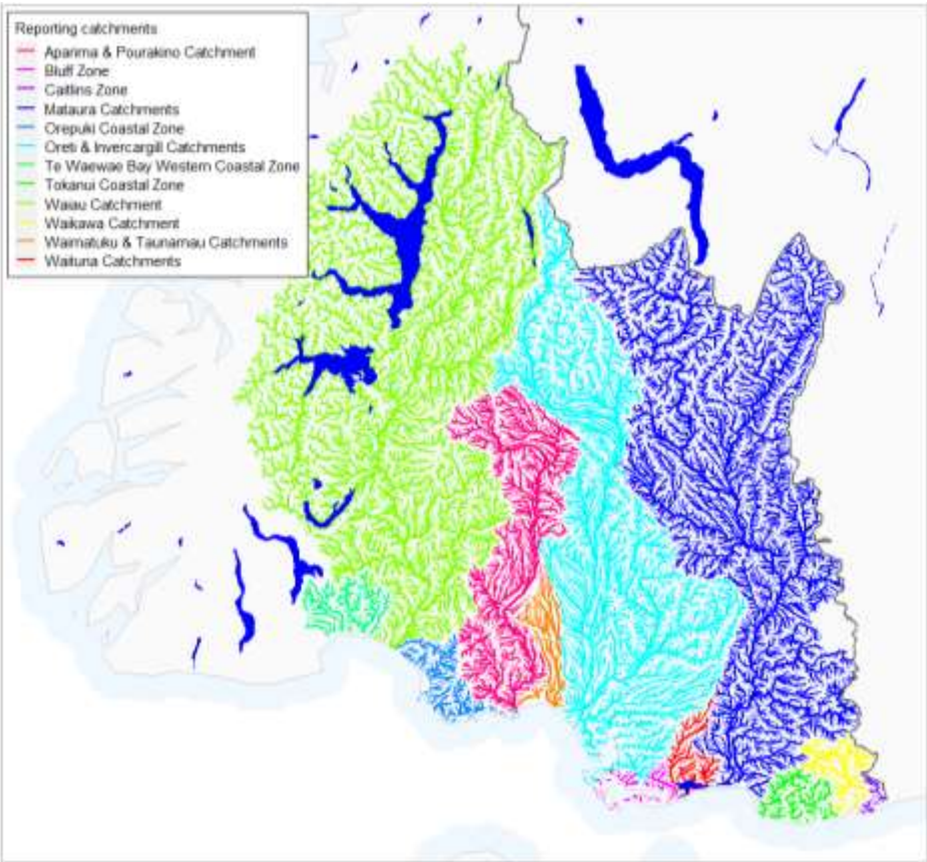

Figure 3. Reporting catchments used for summarising the results of the analyses.

2.3 Estimated current river nutrient concentrations

Estimates of the current median concentrations of the nutrients: total nitrogen (TN), nitrate-nitrogen (NO3N), dissolved reactive phosphorus (DRP) and total phosphorus (TP), were made for all segments of the drainage network using river water quality monitoring data and statistical regression modelling. In addition, estimates of the median soluble proportion of TN (NO3N in TN) and the median soluble proportion of TP (DRP in TP) were made for all segments of the drainage network. Because the site median values of NO3N in TN and DRP in TP represent proportions, they ranged between zero and one.

The statistical regression modelling approach was identical to several similar national and regional studies (e.g., Whitehead, 2018) and the studies on which the current analysis was based (MFE, 2019; Snelder *et al.*, 2020). For each water quality variable, a type of regression model called a random forest (RF) was fitted to the observed monitoring site median values. The regression model predictor variables describe various aspects of each site's catchment including the climate, geology and land cover. In addition, this study included five predictors that quantified the density of pastoral livestock in 2017 to indicate land use intensity. These predictors were based on publicly available information describing the density of pastoral livestock (https://statisticsnz.shinyapps.io/livestock_numbers/). These predictors improve the discrimination of catchment land use intensity compared to previous studies that have only had access to descriptions of the proportion of catchment occupied by different land cover categories (e.g., Whitehead, 2018). The densities of four livestock types (dairy, beef, sheep and deer) in each catchment were standardised using 'stock unit (SU) equivalents', which is a commonly used measure of metabolic demand by New Zealand's livestock (Parker, 1998). These five predictors express land use intensity as the total stock units and the stock units by each of the four livestock types divided by catchment area (i.e., SU ha^{-1}).

The RF models were fitted to site median values of TN, TP, NO3N, DRP, NO3N in TN and DRP in TP calculated from the monitoring site data pertaining to only the Southland region because predictions of concentrations at Southland sites using national-scale models were found to be slightly biased. The values NO3N in TN and DRP in TP for each site were derived in two steps. First, for each observation date, the complement of the total minus the soluble component divided by the total (i.e., $1-\left[\frac{(TN-NO3N)}{TN}\right]$ and $1-\left[\frac{(TP-DRP)}{TP}\right]$ was calculated. Second, NO3N in TN and DRP in TP for each site was calculated as the site medians of the preceding values.

A total of 58 river water quality monitoring sites were used to fit the models for all nutrients (Figure 4). These sites had monthly observations of all four nutrients for the five year period 2013 to 2017 from which the median values were calculated. Three sites were removed from the regional data set (Waiau River at Sunnyside, Waiau River at Tuatapere and Monowai below Gates) because the flow regimes at these sites are modified by the diversion of the majority of flow to Doubtful/Patea Sound by the Manapōuri Power Scheme (Waiau River sites) and the Monowai Power Station.

Prior to fitting the models, the site median values were transformed to increase the normality of their distributions. Note that although RF models make no assumptions about data distributions, normalising the response variable improves model performance (Snelder *et al.,* 2018). The distributions of the site median concentration values for TN, TP, NO3N and DRP were $\log_{10}$ transformed. A logit transformation was applied to the values to increase the normality of the distributions. A logit transformation is defined as:

$$logit = log\left(\frac{x}{1-x}\right) \qquad \text{Equation 1}$$

where x are the site NO3N in TN and DRP in TP values. The logit transformed values range between $-\infty$ and $+\infty$.

The fitted RF models were combined with a database of predictor variables for every network segment in the region and used to predict current median concentrations of TN, TP, NO3N, DRP, and the values of NO3N in TN and DRP in TP for all segments. Because the modelled variables were $\log_{10}$ or logit transformed prior to model fitting, the raw model predictions were in the $\log_{10}$ or logit space. The raw model predictions for TN, TP, NO3N and DRP were back transformed to the original units (i.e., mg m^{-3}) by raising them to the power of 10 and correcting for re-transformation bias as described by Whitehead (2018). The raw predictions for NO3N in TN and DRP in TP values were back transformed to proportions (i.e., values in the 0 to 1 range) using the inverse logit transformation:

$$Proportion = \frac{e^x}{1+e^x} \qquad \text{Equation 2}$$

where x represents the raw prediction (in logit space) from the model.

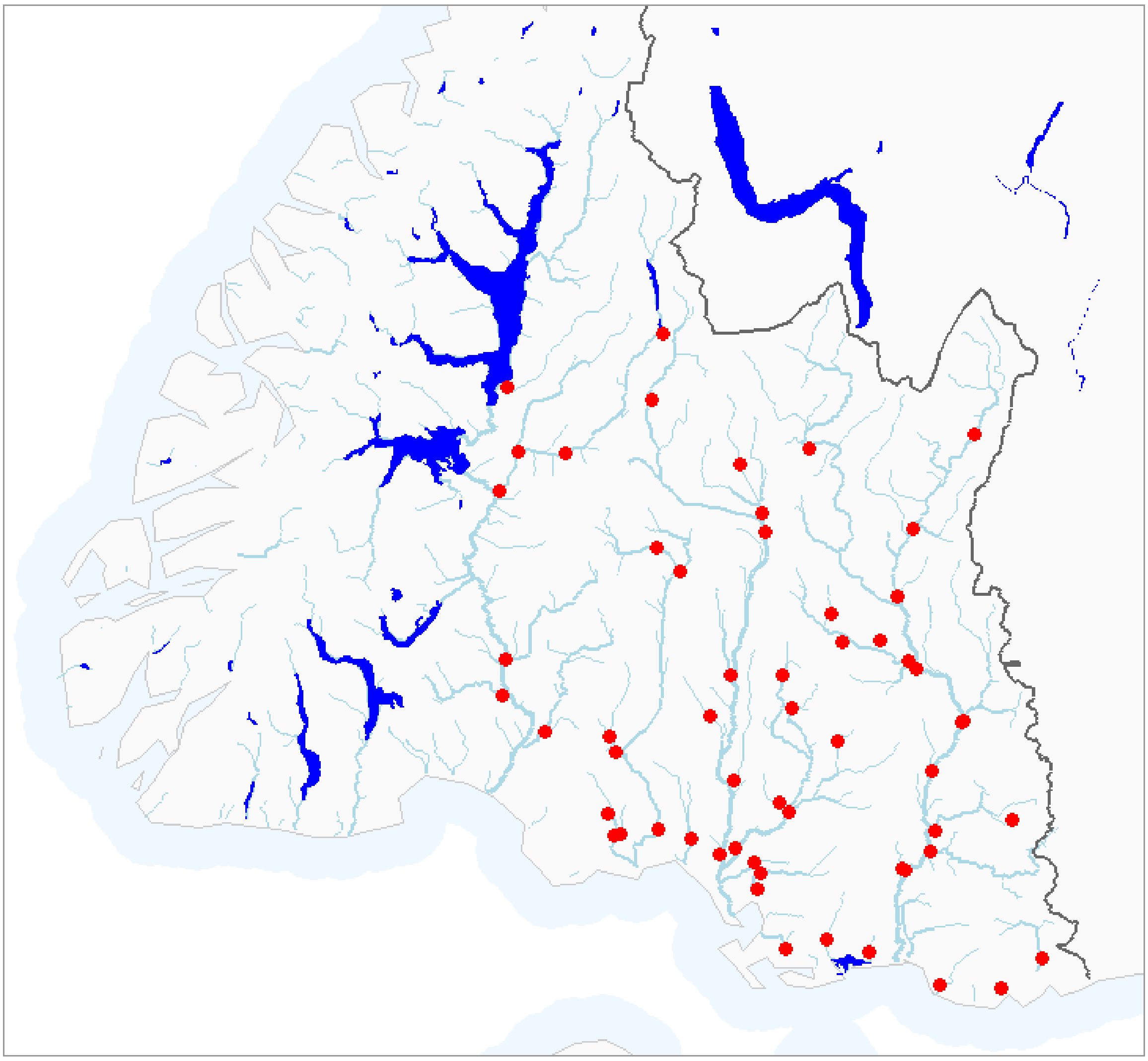

Figure 4. Locations of the 58 river water quality monitoring stations used to fit the concentration models.

The performance of the RF models was evaluated and the uncertainty of the predictions using three measures: regression R^2, Nash-Sutcliffe efficiency (NSE), and bias. The regression R^2 value is the coefficient of determination derived from a regression of the observations against the predictions. The R^2 value indicates the proportion of the total variance explained by the model, but is not a complete description of model performance (Piñeiro *et al.*, 2008). NSE indicates how closely the observations coincide with predictions (Nash and Sutcliffe, 1970). NSE values range from $-\infty$ to 1. An NSE of 1 corresponds to a perfect match between predictions and the observations. An NSE of 0 indicates the model is only as accurate as the mean of the observed data, and values less than 0 indicate the model predictions are less accurate than using the mean of the observed data. Bias measures the average tendency of the predicted values to be larger or smaller than the observed values. Optimal bias is zero, positive values indicate underestimation bias and negative values indicate overestimation bias (Piñeiro *et al.*, 2008). PBIAS is computed as the sum of the differences between the observations and predictions divided by the sum of the observations (Moriasi *et al.*, 2007).

The normalization associated with R^2, NSE and PBIAS allows the performance of TN, DRP and TP models to be directly compared and evaluated against the three performance measures following the criteria proposed by Moriasi et al. (2015), outlined in Table 1.

The uncertainty of the RF models was quantified by the root mean square deviation (RMSD). RMSD is the mean deviation of the predicted values from their corresponding observations and is therefore a measure of the characteristic model uncertainty (Piñeiro *et al.*, 2008).

Table 1: Performance ratings for the measures of model performance used in this study. The performance ratings are from Moriasi et al. *(2015).*

Performance Rating	R^2	NSE	PBIAS
Very good	$R^2 \geq 0.70$	NSE > 0.65	|PBIAS| <15
Good	$0.60 < R^2 \leq 0.70$	0.50 < NSE ≤ 0.65	15 ≤ |PBIAS| < 20
Satisfactory	$0.30 < R^2 \leq 0.60$	0.35 < NSE ≤ 0.50	20 ≤ |PBIAS| < 30
Unsatisfactory	$R^2 < 0.30$	NSE ≤ 0.35	|PBIAS| ≥ 30

2.4 Estimated current river TN and TP loads

Estimates of current loads of TN and TP for all segments of the drainage network were made using river water quality monitoring data from the Southland region and statistical regression modelling in two steps. The first step calculated loads of TN and TP for each river water quality monitoring site using the methods described by Snelder *et al.* (2018). Loads were calculated for sites that had at least 10 years of monthly concentration observations up to the end of 2017. Load calculations were based on mean daily flows for each monitoring that were either provided by SRC or, where this was not available, predicted site using the TopNet hydrological model (McMillan *et al.*, 2013). The load calculation method estimated the mean annual load but accounted for trends in the concentration data so that the final load estimates pertain to 2017[2]. The loads were expressed as yields by dividing by the catchment area (kg ha^{-1} yr^{-1}).

The second step used the same statistical regression modelling approach as for concentrations to fit RF models to calculated monitoring site loads for TN and TP. The RF models were fitted to data pertaining only to monitoring sites in the Southland region because national-scale models were found to be slightly biased. The site yield values were $\log_{10}$ transformed to improve model performance (Snelder *et al.,* 2018). The same 58 river water quality monitoring sites that were used to model concentrations were the input data for the load models (Figure 4).

The fitted RF models were combined with a database of predictor variables for every network segment in the region and used to predict current yields of TN and TP for all segments. Model predictions were back-transformed and corrected for re-transformation bias as described by Snelder *et al.* (2018). The load model predictions were evaluated following the same criteria used for the concentration predictions (Table 1).

2.4.1 Loads in the Waiau River main stem

Load predictions made for the Waiau River main stem were not representative of actual loads because the predictor variables represent the characteristics of the unmodified catchment

[2] Note that this report refers to 'current loads and concentrations' because the loads and concentrations estimated for 2017 are unlikely to be appreciably or statistically significantly different to loads at the time this study was conducted (2020).

whereas a large proportion of the natural flow is diverted to Doubtful/Patea Sound by the Manapōuri Power Scheme. The RF model predictions for the main stem of the Waiau River downstream of the Mararoa Weir control structure were discarded and replaced as follows.

The natural mean flow at the Mararoa Weir control structure is estimated to be 455 $m^3 s^{-1}$ (Booker and Woods, 2014), whereas the measured mean flow at this location is 67 $m^3 s^{-1}$ (i.e., 15% of the natural flow). The TN and TP loads for the segment representing the location of the Mararoa Weir control structure were set to 15% of that predicted by the random forest models. The TN and TP load for each segment downstream of the Mararoa Weir were calculated by adding the load estimated for the upstream segment (starting with the segment representing the location of the Mararoa Weir location) to the predicted loads for the local tributary joining the main stem of the Waiau River at that segment. The Waiau River main stem loads that were estimated as described were verified at two locations (Waiau River at Sunnyside, Waiau River at Tuatapere) by comparing the estimates with the loads calculated for these sites from actual concentration and flow records.

2.5 Estimated current lake TN and TP concentrations

Actual water quality measures are available for only a small number of monitored lakes across Southland. However, estimates of in-lake nutrient concentrations were made by coupling estimated input loads from the drainage network with empirical lake nutrient loading models ('box models') of Abell *et al.* (2019, 2020).

The primary input to the models of Abell *et al.* (2019, 2020) is the mean flow weighted concentration of TN and TP (hereafter TN_{in} and TP_{in}), which were obtained by dividing the estimated loads of TN and TP to each lake by the mean annual inflow volume. Annual inflow volumes were obtained from estimates of mean flow made for every segment of the drainage network by Booker and Woods (2014).

For each lake, the concentration of TN and TP were predicted using the following models:

$$log_{10}(TP_{lake}) = \frac{log_{10}(TP_{in})}{1+(k_1+\Delta k_1 d)\tau_w{}^{k_2}} \qquad \text{Equation 3}$$

$$log_{10}(TN_{lake}) = \beta_0 + \beta_1 log_{10}(TN_{in}) + \beta_2 log_{10}(Z_{max}) \qquad \text{Equation 4}$$

where TP_{lake} and TN_{lake} are median concentrations of TN and TP (mg m^{-3}), k_1, Δk_1, k_2, and all β are fitted parameters provided by Abell *et al.* (2019, 2020), τ_w is water residence time (years) derived from the WONI database, and Z_{max} is the maximum depth of the lake derived from the WONI database. The variable d is a dummy variable that indicates whether a lake is shallow (d = 0) or deep (d = 1). We used the same threshold as Abell *et al.* (2019, 2020) of >7.5 m to define deep lakes. Note that Environment Southland's lake classification defines deep lakes as 15 m or greater for management purposes but this conflict in definition does not affect the analyses that follow.

2.6 Estimated current estuary TN and TP concentrations

Estimates of in-estuary nutrient concentrations were made by coupling estimated input loads from the drainage network with simple estuary dilution models (Plew *et al.*, 2018; Plew, *in prep*). The dilution model predicts the TN and TP concentrations in the estuary based on annual catchment TN and TP loads, mean flow, ocean nitrogen and phosphorus concentrations, and dilution in the estuary. Each of the eight estuaries that were included in the study was represented by separate models, which are fully described by Plew (2020).

It is noted that Plew (2020) included three brackish lakes (Te Waewae Lagoon, Lake Brunton and Waituna Lagoon) as well as eight other estuaries. The results of the analyses that follow are based on assessments for these three brackish lakes that are based on the models of Plew (2020). However, when the results for these entities are reported below, they are included as ‘lakes’ to be consistent with Environment Southland’s management classification system.

2.7 Concentration criteria, compliance, maximum allowable loads, and local excess load

High nitrogen and phosphorus concentrations in aquatic receiving environments can have at least two types of impacts. First, nitrate concentrations can reach toxic levels that impair aquatic animal survival, growth and reproduction. Second, when not limited by light or other nutrients, hydrological disturbance and/or invertebrate grazing control, primary production can be stimulated by nitrogen and phosphorus enrichment, causing excessive plant biomass and ecological degradation associated with shifts from low productivity or oligotrophic states to eutrophic or hypertrophic states. Nitrogen and phosphorus concentration criteria are defined to achieve FWOs that either limit toxic effects or ‘trophic state’, which this study quantifies as the level of plant biomass in rivers, lakes and estuaries.

Nitrogen and phosphorus concentration criteria for rivers, lakes and estuaries vary spatially and with FWOs. Spatial variation (i.e., variation in the criteria between receiving environments) accounts for variation in the sensitivity of receiving environments to the effects of nutrients. For example, for a FWO defined as a specific level of biomass, nutrient concentration criteria tend to be lower in rivers that have less variable flow regimes and lakes and estuaries that have longer residence times. Spatial variation in the sensitivity of receiving environments also means that there is a degree of natural variation in the level of variation of plant biomass. This in turn means that it is reasonable to assume spatial variation in the acceptable or preferred levels of biomass, and therefore FWOs. Concentration criteria also vary with the level of biomass that is nominated by the FWO; lower concentrations are required to restrict biomass to low levels compared to higher levels.

The basis for choosing varying FWOs across different receiving environment management classes is discussed in Section 2.9. The definition of FWOs that represent differing levels of protection for river, lakes and estuary receiving environments of the Southland region is summarised in Bartlett et al., (2020) and described more fully in Norton and Wilson (2019). Norton and Wilson (2019) proposed initial draft numeric FWOs that are based on indicators of environmental quality (termed “attributes” in the NPS-FM). The attributes are largely taken from the NOF appendix to the NPS-FM, plus some derived specifically for Southland, and are expressed using an A, B and C grading system for each attribute following the NOF system. The following sections tabulate grades and associated concentration criteria from Norton and Wilson (2019) as options for FWOs that were analysed by this study. In addition, this section describes how the concentration criteria were used to assess compliance and define the maximum allowable load (MAL) for river, lake and estuary receiving environments. The details of the assessment of compliance and the calculation of MAL differed by receiving environment type.

2.7.1 Rivers

There are two effects of nitrogen for which concentration criteria are applied for rivers depending on the circumstances. First, Norton and Wilson (2019) specify the nitrate toxicity attribute to protect aquatic ecosystems from chronic toxicity effects under exposure to nitrate.

The nitrate toxicity criteria that define the thresholds between bands (A/B, B/C and C/D) are shown in Table 2. It is noted that these concentrations are generally considerably higher than nitrate concentrations associated with excessive plant biomass in rivers.

Table 2. Nitrate toxicity concentration criteria as mg NO_3-N m^{-3}.

Environmental quality band threshold	Nitrate concentration criteria
A/B	≤1,000
B/C	>1,000 and ≤ 2,400
C/D	>2,400 ≤ 6,900

The second type of concentration criteria that is relevant to rivers is associated with the periphyton attribute. Periphyton is attached algae growing on the beds of rivers (slime). Some periphyton is a natural feature of rivers and is an essential component of the riverine food web. However, over-abundant periphyton degrades rivers from ecological, recreational and cultural perspectives. The periphyton attribute stipulates the levels of periphyton biomass in terms of a concentration of chlorophyll-*a* (the green pigment in plants) on the bed of rivers for NOF bands (Table 3).

Table 3. Periphyton biomass thresholds as mg Chl-a m^{-2}. The NOF requires that this biomass threshold be not exceeded in 92% of monthly samples (i.e., not more than once per year on average for monthly sampling).

Environmental quality band threshold	Periphyton biomass thresholds
A/B	≤50
B/C	>50 and ≤120
C/D	>120 and ≤200

In this study, the nutrient criteria to achieve the periphyton biomass bands were based on Snelder *et al.* (2019). The criteria are specified in terms of median concentrations of total nitrogen (TN) and dissolved reactive phosphorus (DRP) and vary across 21 river classes defined by the second (Source-of-flow) level of the River Environment Classification (REC; Snelder and Biggs, 2002). The criteria were based on nutrient-biomass relationships that were subject to considerable uncertainty. There is therefore a risk that a proportion of locations will exceed a nominated biomass threshold even when they are compliant with the associated TN and DRP criteria. Snelder et al. (2019) provided for differing levels of this risk by incorporating spatial exceedance criterion for the TN and DRP concentration criteria. The spatial exceedance is an estimate of the proportion of locations that will exceed a nominated biomass threshold when all locations are compliant with the nutrient criteria. The spatial exceedance criterion indicates the risk that a randomly drawn location will exceed the periphyton biomass specified for the nominated band. The level of acceptable risk is a management, rather than a scientific, decision. In this study the analyses were based on two spatial exceedance criteria: 20% and 30%. The 20% spatial exceedance criterion is always a lower concentration than the concentrations corresponding to the 30% criterion and, therefore, assessments based on the 20% spatial exceedance criterion generally have higher load reduction requirements.

A test of Snelder *et al.'s* (2019) criteria indicated they were overly stringent relative to the periphyton biomass and TN concentrations observed at 173 river monitoring sites across New

Zealand (30 of which were in Southland). As suggested by Snelder *et al.* (2019), the original TN targets were recalibrated to match the observations at the monitoring sites (see appended Table 25 and Table 26 for the concentration criteria). In the analysis the TN and DRP concentration criteria for each segment were derived by obtaining the segment's REC class and looking up the associated concentrations from the concentration criteria table.

Compliance for each river segment was derived from its FWO. The FWO specifies the periphyton biomass as chlorophyll-*a* and from this, and the segment's REC class, the TN and DRP concentration criteria were obtained (Appended Table 25 and Table 26). Compliance was assessed by comparing the current estimated concentration with the concentration criteria. Where the current concentration was less than the concentration criteria, the segment was assessed as compliant and vice versa.

The phosphorus concentration criteria for river periphyton of Snelder *et al.* (2019) is defined in terms of DRP (i.e., the dissolved reactive component of the phosphorus). However, phosphorus criteria for lakes and estuaries are defined in terms of TP (i.e., total phosphorus). In addition, the effectiveness of nutrient mitigations on agricultural land for phosphorus is generally specified in terms of TP (e.g., McDowell *et al.*, 2020; Monaghan *et al.*, 2021). Therefore, the DRP concentration criteria were converted to an equivalent TP concentration to make the criteria commensurate across receiving environment types (i.e., rivers, lakes and estuaries) and to allow the load reductions to be comparable to mitigation effectiveness. The DRP concentration criteria were converted to a TP equivalent by dividing by the predicted median soluble proportion of TP (DRP in TP) for each segment (see Section 2.3). Similarly, the nitrate toxicity concentration criteria were converted to equivalent TN concentration values at every network segment to make them consistent with the nitrogen criteria for river periphyton and for lakes and estuaries. The NO3N criteria were converted to TN equivalents by dividing by the predicted median soluble proportion of TN (NO3N in TN) for each segment (see Section 2.3). Implicit in this conversion is the assumption that that the ratio of DRP to TP and NO3N to TN will remain the same if the loads of TP and TN are changed.

The MAL for TN and TP for river receiving environments was obtained by converting the concentration criteria into equivalent TN and TP loads. The conversion was based on the assumption that, because load is the integral of concentration discharge, the median concentration increases in proportion to the load, i.e., the following relationship applies:

$$\frac{Concentration_1}{Load_1} = \frac{Concentration_2}{Load_2} \qquad \text{Equation 5}$$

Therefore, the MAL for each segment of the river network was derived as:

$$MAL = Concentration_{Criterion} \times \frac{Current\ load}{Current\ concentration} \qquad \text{Equation 6}$$

where $current\ load$ is the estimated current TN or TP load (kg yr^{-1}) for the network segment, $current\ concentration$ is the estimated current median concentration of TN or TP and $Concentration_{Criterion}$ is the criterion for TN or TP that is relevant to the FWO obtained from Table 2 or Appended Table 1 and where necessary converted to equivalent TN and TP (i.e., where the criterion was initially defined in terms of NO3N or DRP). Implicit in this conversion is the assumption that that the change in median concentration of the nutrients with change in load is in proportion to change in the loads of TN and TP. The local excess loads were calculated as the current TN and TP loads minus the respective MALs.

2.7.2 Lakes

The NOF specifies levels of phytoplankton (algae suspended in the water column) biomass in lakes to protect these ecosystems from eutrophication. In addition, the NOF specifies nutrient concentration criteria for TN and TP that are commensurate with the algae biomass levels (Table 4). In this study, only the TN and TP criteria were used, and it was assumed that compliance with these nutrient criteria would achieve the associated phytoplankton biomass criteria. The reason for this is that the available lake nutrient – phytoplankton biomass models represent biomass as a combined outcome of both TN and TP concentrations (Abell *et al.* 2019, 2020). These models are therefore not amenable to the analyses performed in this study because biomass cannot be specified by a unique concentration of TN and TP.

Table 4. Algae biomass thresholds for lakes as mg Chl-a m^{-3} (annual median) and corresponding TN and TP criteria as mg m^{-3} (annual median).

Environmental quality band threshold	Chlorophyll-*a* thresholds	TN thresholds		TP thresholds
		Stratified	Polymictic	
A/B	≤2	≤160	≤300	≤10
B/C	>2 and ≤5	>160 and ≤350	>300 and ≤500	>10 and ≤20
C/D	>5 and ≤12	>350 and ≤750	>500 and ≤800	>20 and ≤50

Compliance for each lake is derived from its FWO. The FWO specifies the TN and TP concentration criteria (Table 4) by lake type (stratified or polymictic). Lakes were assigned to the stratified type if their depth was > 7.5m for consistency with Abell *et al.* (2019, 2020), otherwise were assigned to the polymictic type.

Compliance was assessed by comparing the current estimated in-lake concentration with the concentration criteria. Where the current concentration was less than the concentration criteria, the lake was assessed to be compliant and vice versa.

The MAL for each lake was derived from the TN and TP concentration thresholds (Table 4). The TN and TP concentrations were converted into equivalent TN and TP loads (the MALs) by inverting Equation 1 and 2. Local excess loads were calculated for each lake as the current TN and TP loads minus the respective MALs.

The assessment for lakes described in this section applies to lakes in three of the four defined lake classes for Southland (i.e., Lowland shallow, Upland shallow, and Deep lakes) but was not applied to the ‘Brackish Lakes and Lagoons’ class (which comprises Te Waewae Lagoon, Lake Brunton and Waituna Lagoon). These latter brackish lakes/lagoons were assessed using a method for very low salinity (oligohaline) estuaries that is described in the following section.

2.7.3 Estuaries

Many estuaries in Southland are shallow and have extensive intertidal areas. When enriched with nutrients (particularly nitrogen) from the upstream catchment, estuaries are susceptible to eutrophication. Symptoms of eutrophication in shallow estuaries include proliferations of benthic macro- and micro-algae and phytoplankton, reduced dissolved oxygen levels, and sulphide production due to organic matter breakdown. Other Southland estuaries are deeper and predominantly subtidal. Depending on the flushing time of deep estuaries, the expression of excessive nutrient loading and eutrophic conditions in these estuaries is high phytoplankton biomass.

There are no NOF attributes or nationally applicable numeric objectives for New Zealand estuaries. Norton and Wilson (2019) developed attributes and draft FWOs for Southland's estuaries using a conceptually similar system to the NOF, and which correspond to thresholds for estuarine algae proposed by Plew *et al.* (2020). The draft FWOs are based on two types of attributes that pertain to estuary primary production: macroalgae and phytoplankton. For macroalgae, the draft FWOs correspond to levels of Ecological Quality Rating (EQR), which is a combined metric of macroalgae cover and biomass.

Plew *et al.* (2020) derived TN criteria that are based on 'potential concentrations' to achieve EQR bands that are similar to the NOF band system for rivers and lakes, and the same as those proposed for macroalgae FWOs for Southland estuaries by Norton and Wilson (2019) (Table 5). Potential concentrations were defined as the concentration that would occur in the absence of uptake by algae, or losses or gains due to non-conservative processes such as denitrification and nitrogen fixation. Macroalgae growth is not considered to be limited by phosphorus because macroalgae are very efficient at extracting phosphorus from the water column, even at low concentrations, and have a low phosphorus requirement in relation to nitrogen, compared to phytoplankton. Estuaries generally also have a sufficient supply of phosphorus due to the constant exchange of water with the ocean. There are therefore no phosphorus criteria associated with the macroalgae FWO.

Table 5. EQR thresholds for estuaries and corresponding potential TN concentration criteria as mg m^{-3}.

Environmental quality band threshold	EQR thresholds	TN thresholds
A/B	1.0 > and ≥0.8	≥80
B/C	0.8 > and ≥0.6	80 < and ≤200
C/D	0.6 > and ≥0.4	200 < and ≤320

Plew *et al.* (2020) also suggested phytoplankton bands that are similar to the NOF band system for rivers and lakes, and the same as those proposed for phytoplankton FWOs for Southland estuaries by Norton and Wilson (2019). Band thresholds for estuary phytoplankton are based on annual 90^{th} percentile biomass (as mg Chl-a m^{-3}). The phytoplankton bands differ for highly saline and less saline estuaries, and for low salinity estuaries and brackish lakes/lagoons respectively (Table 6).

The TN and TP concentration criteria to achieve the phytoplankton bands differ for individual estuaries, primarily due to differences in estuary residence time. This study used the approach of Plew *et al.* (2020) to derive the MAL for TN and TP for each individual estuary based on combining a phytoplankton model with a simple dilution model that accounted for nitrogen inflows from both rivers and the ocean and for estuary hydrodynamics. Compliance for TN and TP was assessed based on 'potential concentrations' to achieve the phytoplankton bands.

Table 6. Phytoplankton biomass thresholds for estuaries and brackish lakes/lagoons as mg Chl-a m^{-3}.

Band	Thresholds for saline estuaries (euhaline; >30ppt salinity)	Thresholds for less saline estuaries (meso/polyhaline; 5-30ppt salinity)	Thresholds for low salinity estuaries and brackish lakes/lagoons (oligohaline; <5ppt salinity)
A	≤4	≤8	≤10
B	>4 and ≤8	>8 and ≤12	>10 and ≤25
C	>8 and ≤12	>12 and ≤16	>25 and ≤60

Compliance for each estuary was derived from the two relevant FWOs; macroalgae and phytoplankton (Table 5 and Table 6). These FWOs specify the EQR and phytoplankton thresholds while the respective potential TN and TP concentration criteria were provided by Plew (2020). The TN and TP loads that are consistent with the respective criteria were derived for each estuary using the simple dilution models of Plew (2020) and Plew *et al.*, (2020) described above. These loads are detailed in Appendix B for each of the 11 estuaries (including the three brackish lakes/lagoons) that are within the study area. The lower of the two TN loads (i.e., to achieve the macroalgae or phytoplankton FWO) was used to define the MAL for TN for each estuary. Similarly, the TP loads to achieve the phytoplankton FWO were used to define the MAL for TP. Compliance was assessed by comparing the current estimated TN and TP loads with their respective MAL. Where the current load was less than the MAL, the estuary (or brackish lake/lagoon) was assessed to be compliant and vice versa. Local excess loads were calculated for each estuary as the current TN and TP loads minus the respective MALs.

Thresholds for TN and TP could not be derived for every estuary and FWO (i.e., for both macroalgae and phytoplankton). Some estuaries are unlikely to support macroalgae due to low salinity; these include Waimatuku and Waiau estuaries, and the three brackish lakes/lagoons (Te Waewae, Brunton and Waituna) which do not have FWOs set for macroalgae. These estuaries and brackish lakes/lagoons therefore do not have a MAL assessed for TN for the macroalgae FWO (see Appendix B). Some estuaries have low flushing times and are therefore unlikely to support high phytoplankton biomass (e.g., Toetoes (Fortrose), Waimatuku, Jacobs River and Waiau estuaries). These estuaries therefore do not have a MAL assessed for TN or TP for the phytoplankton FWO (see Appendix B). There are also estuaries that naturally exceed one or more band thresholds for TN and/or TP associated with the phytoplankton objectives due to nutrient input from the ocean. The relevant MALs for these estuaries are therefore zero, indicating that the FWO would not be achieved even if the current TN and TP loads were zero (see Appendix B).

2.8 Estimation of uncertainties

The analysis was based on eight statistical models (i.e., RF models to predict current median values of TN, TP, NO3N, and DRP concentrations and current median soluble proportion of TP and TN, and RF models to predict the current TN and TP yields). These models were all associated with uncertainties that were quantified by their respective RMSD values. These uncertainties propagate to all the assessments produced in this study including the assessments of current state and compliance, and the assessment of the load reduction required.

There was no apparent geographic pattern in the residual errors of each of the models and the pattern of errors was not explained by catchment characteristics. Because all models were derived from data pertaining to the same 58 sites it was expected that the residual errors from each model would be correlated to a degree with the errors of the other seven models. A correlation matrix derived from the eight sets of model errors was used to describe the relationship between all pairs of model errors. It was assumed that this correlation structure represents the correlation in the uncertainties when the models were combined in the assessment process.

The same simple Monte Carlo analysis approach as Snelder *et al.* (2020) was applied to estimate uncertainties in the assessments based on 100 'realisations' of the entire series calculations in four steps. First, for a realisation (r), predictions made by all eight RF models were perturbed by a random error. Random errors were obtained by generating random normal deviates (ε_r) and applying these to predictions made using the models. Because the response variables in the RF models were either $\log_{10}$ or logit transformed, the perturbed predictions for a realisation were derived as follows.

$$Prediction_r = CF \times 10^{[log_{10}(x) + (\varepsilon_r \times RMSD)]} \quad \text{Equation 5}$$

$$Prediction_r = \frac{e^{x + \varepsilon_r \times RMSD}}{(1+e^{x + \varepsilon_r \times RMSD})} \quad \text{Equation 6}$$

where x is the prediction returned by the RF models and CF is a factor to correct for retransformation bias (Duan, 1983).

Random normal deviates representing errors for each model (ε_r) were drawn from a multi-variate distribution with the same correlation structure as that between the observed errors. Because a concentration or load at any point in a catchment is spatially dependent on corresponding values at all other points in the catchment's drainage network, the values of the random normal deviates were held constant for each realisation within the river network representing a sea-draining catchment but differed randomly between sea-draining catchments.

The second step stored the perturbed predicted median values of the four nutrient concentrations (TN, NO3N, TP and DRP), the soluble proportion of TP and TN (i.e., DRP in TP and NO3N in TN), and the current loads. At the third step, the procedure described above was repeated for each realisation using the perturbed values. At the fourth step, the distribution of values of the concentrations, current loads, local excess loads, and load reductions required obtained from the 100 realisations were used to provide a best estimate and the uncertainty of the assessments. The uncertainty of the assessments of compliance were quantified by estimating the probability that each segment was compliant across the 100 realisations. Segment compliance was therefore assessed as a value between one (100% confident the segment is compliant or suitable) to zero (100% confident the segment is non-compliant). For the current state, local excess loads, and load reduction required assessments, the best estimate was represented by the median value from the distribution of values. This median is the middle value of the distribution and is therefore greater than and less than 50% of the realised values. The uncertainty of these two assessments was quantified by their 90% confidence intervals. For the load reduction required assessment, the best estimates and the uncertainties were estimated from the 100 realisations for the reporting catchments, estuary catchments and the entire region.

2.9 Freshwater objectives settings

2.9.1 Classification systems

The individual segments of the river network were assigned to one of seven management classes (Figure 5). The analysis allowed FWOs to be independently set for each river management class.

The individual lakes were assigned to one of five lake management classes (Figure 6). The analysis allowed FWOs to be independently set for each lake management class. The majority of lakes were classified 'Natural state' and the predominant lake type in the developed parts of the region were 'Lowland Shallow' lakes (Table 7).

The individual estuaries were assigned to one of two estuary management classes (Figure 7). The analysis allowed FWOs to be independently set for each estuary management class. Estuaries in the study area[3] were classified as Tidal Lagoon Estuaries (also referred to as shallow intertidally dominated estuaries (SIDE)) or Tidal River Estuaries (or shallow short residence-time tidal river estuaries (SSRTRE)).

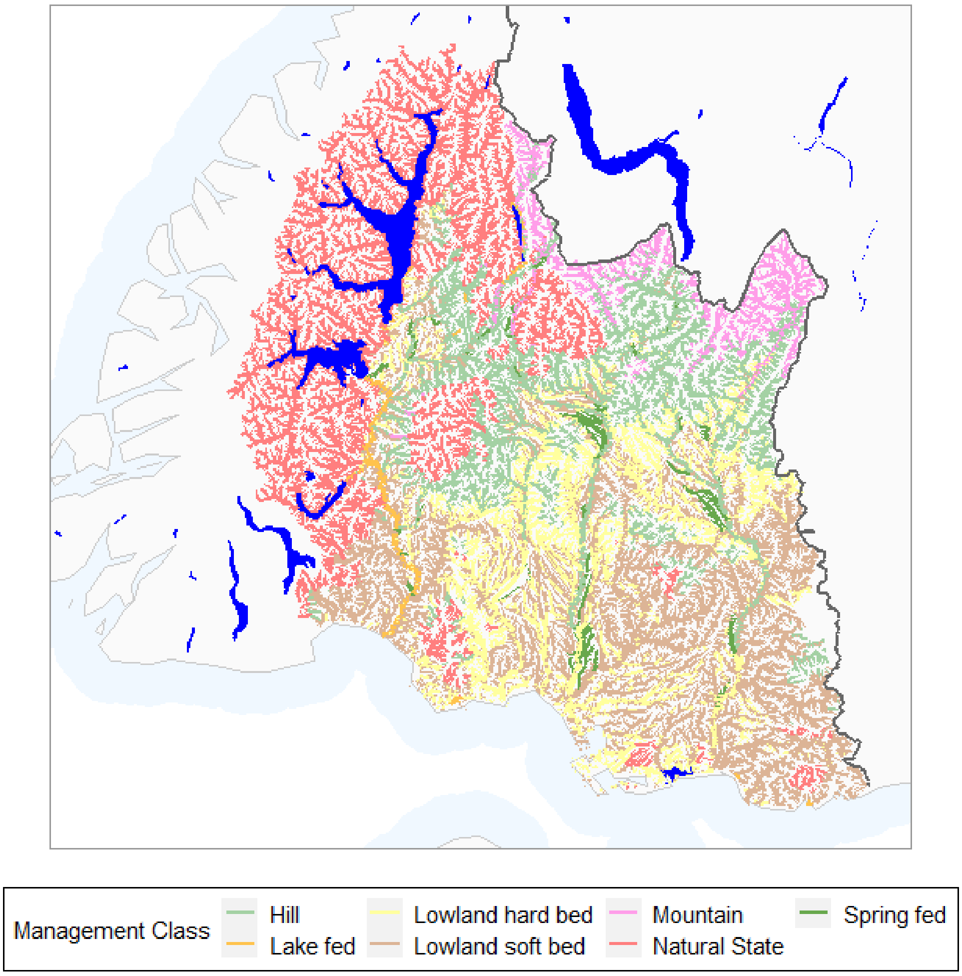

Figure 5. River management classes represented in this study.

[3] It is noted that Environment Southland's proposed estuary classification system also includes a third class, the Fiords and Bays (or deep sub-tidal dominated estuaries DSDE) but all Southland estuaries in this class occur in Fiordland or the offshore islands and so are not part of the scope of this report.

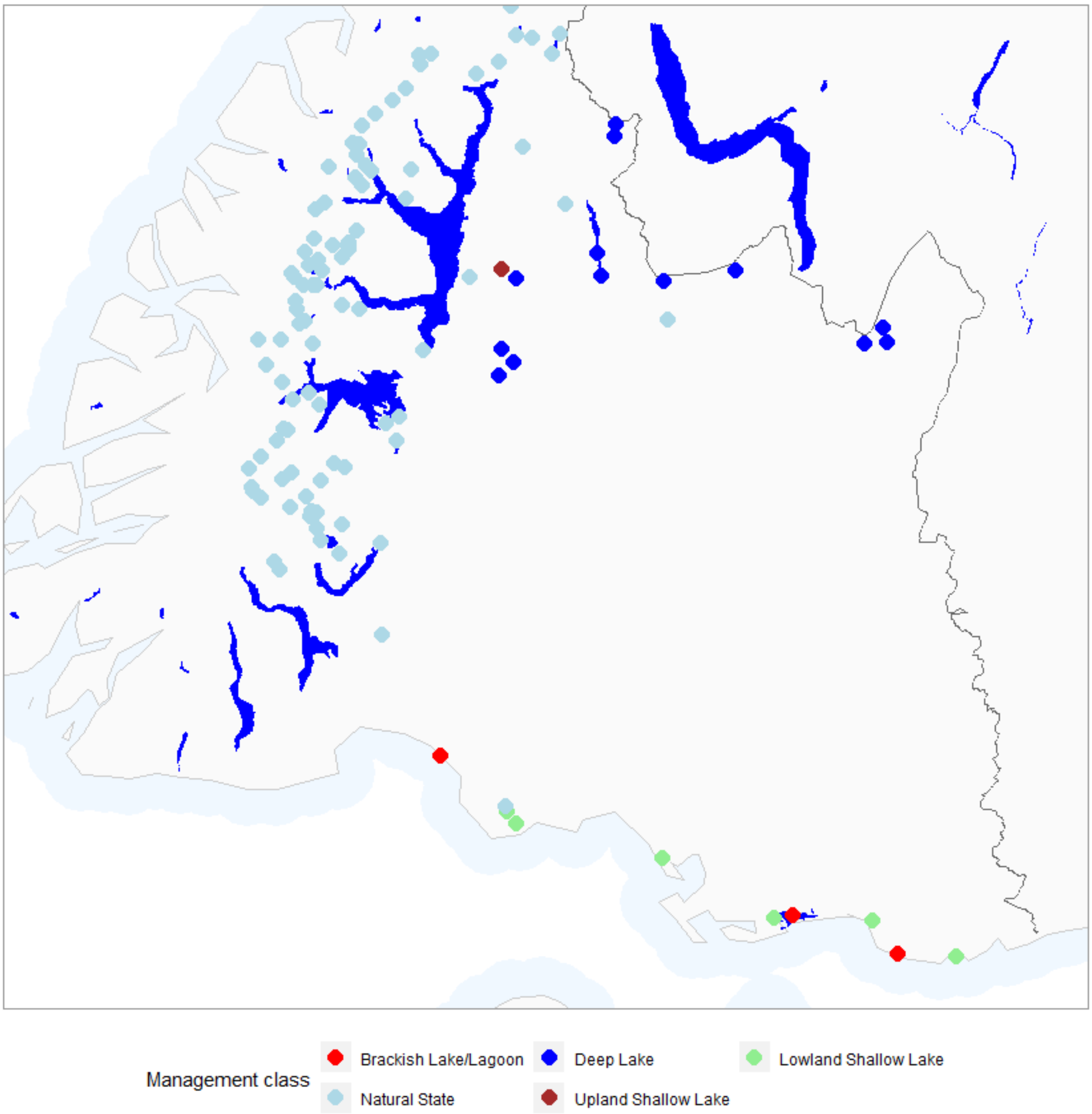

Figure 6. Lake management classes represented in this study. Note that all lakes are indicated in this and all subsequent maps as points. Large lakes are also indicated as blue polygons, which are simply provided for orientation.

Table 7. Number of lakes in each management class represented in this analysis.

Management Class	Number of lakes
Brackish Lake/Lagoons	3
Deep Lake	14
Lowland Shallow Lake	6
Natural State	92
Upland Shallow Lake	1

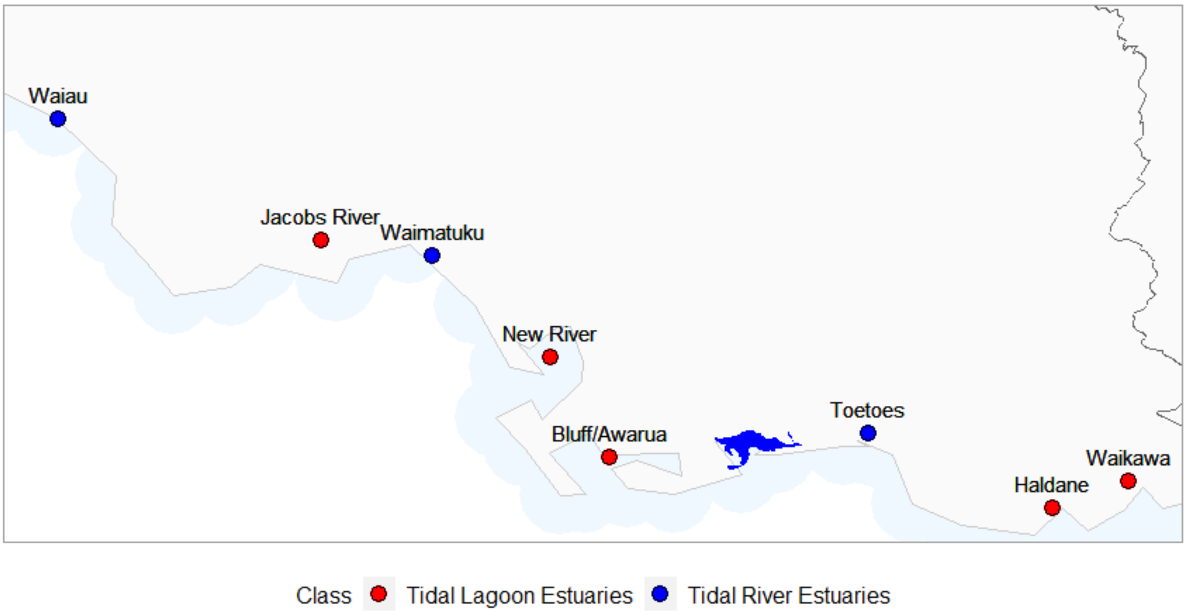

Figure 7. Estuary management classes represented in this study. Note the three brackish lakes (Te Waewae Lagoon, Lake Brunton and Waituna Lagoon) are not shown on this map because they are lakes for management purposes but are analysed using estuary models. Note also that Te Waewae Lagoon is part of a larger system that includes the Waiau Estuary.

2.9.2 Objectives

To proceed with the analysis, it is necessary to nominate FWOs in terms of a band (A, B or C) for all receiving environments in the study area. Because FWOs could be set for each river, lake and estuary management class individually, there was a very large number of potential combinations of FWO by management class. For this reason, and to make the analysis and presentation of results manageable, it is useful to nominate the specific set, or sets, of FWOs for which load reduction estimates are desired.

In November 2020, Environment Southland and the Te Ao Marama Inc (TAMI) board approved a directive to the Regional Forum to test the implications of achieving "a state of hauora (well-being) for water across the region within a generation (25-30 years)"[4]. The 'approval in principle' sets the minimum level of hauora for the draft FWOs for the region. However, because the setting of FWOs is an iterative process that must include consideration of implications, the analysis here took an 'envelope' approach by generating load reduction results for a range of options. The definition of the minimum level of hauora was based on hauora principles as reported in Bartlett *et al.* (2020) and is represented by the minimum state (in A, B or C terms) necessary to support hauora for the nutrient-related ecosystem health attributes assessed in this report (i.e., river periphyton, lake and estuary phytoplankton and estuary macroalgae). This is referred to hereafter as the Hauora option (Table 8). Another option was defined using a method based primarily on the Proposed Southland Water and Land Plan water quality standards, while also ensuring the NPS-FM minimum requirement of "maintain or improve" was satisfied, hereafter referred to as the "pSWLP option" (Table 8). The derivation of both the Hauora and the pSWLP options are summarised in Bartlett *et al.*

[4] https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/about-us/meetings/2020/November/Strategy%20and%20Policy%20Committee%20-%2025%20November%202020/Strategy%20and%20Policy%20Committee%20Agenda%20-%202020%20November%2025.pdf

(2020) and further detail is provided in Norton and Wilson (2019). These two sets of objectives represent scenarios (i.e., possible future states). It is possible to re-run the analyses and produce load reduction estimates for scenarios comprising any combination of FWOs.

For the analyses that follow, the FWO band has been assumed to apply to both the nitrogen and phosphorus criteria. It is also noted that these criteria are the actual basis for the analysis of compliance and load reductions required (i.e., the plant biomass is not predicted for any receiving environment as part of the analyses). The FWOs for rivers and lakes belonging to the respective Natural State management classes were assumed to be no change in current state for both the top of the envelope and bottom of the envelope scenarios. This means there are no bands associated with FWOs for rivers or lakes in the Natural State management classes. Therefore, there is no assessment of compliance and no load reduction required for any river segments or lakes belonging to the respective Natural State management class. This is appropriate from a practical perspective because there is little to no resource use, and therefore no potential for load reductions, in the catchments of rivers and lakes belonging to the respective Natural State management classes.

As well as the two sets of FWOs, the analyses incorporated two choices of spatial exceedance criteria for defining nutrient criteria to achieve river periphyton objectives. Collectively the combination of the FWO options (Hauroa and pSWLP) and the two sets of periphyton criteria (20% and 30% spatial exceedance criteria) are referred to as settings.

Table 8. Nominated bands defining the ‘Hauora and ‘pSWLP standards’ FWO settings for all river, lake and estuary management classes. The NA bands for the river and lake Natural State management classes indicate the objective is no change in current state.

FWO	Management Class	Hauora settings	pSWLP standards
River periphyton	Natural State	NA	NA
River periphyton	Lowland hard bed	C	C
River periphyton	Lowland soft bed	C	C
River periphyton	Hill	B	B
River periphyton	Lake fed	A	A
River periphyton	Mountain	A	A
River periphyton	Spring fed	A	A
River Nitrate Toxicity	Natural State	NA	NA
River Nitrate Toxicity	Lowland hard bed	A	B
River Nitrate Toxicity	Lowland soft bed	A	B
River Nitrate Toxicity	Hill	A	A
River Nitrate Toxicity	Lake fed	A	A
River Nitrate Toxicity	Mountain	A	A
River Nitrate Toxicity	Spring fed	A	B
Lake Phytoplankton	Natural State	NA	NA
Lake Phytoplankton	Lowland Shallow Lake	B	B
Lake Phytoplankton	Upland Shallow Lake	B	B
Lake Phytoplankton	Deep Lake	A	A
Lake Phytoplankton	Brackish lakes/lagoons (Coastal lake)	B	B
Estuary Macroalgae	Tidal lagoon estuaries (SIDE)	B	C
Estuary Macroalgae	Tidal river estuaries (SSRTRE)	B	B
Estuary Phytoplankton	Tidal lagoon estuaries (SIDE)	C	C
Estuary Phytoplankton	Tidal river estuaries (SSRTRE)	A	C

3 Results

3.1 Performance of current nutrient concentration models

The RF models of median concentrations of TN, TP, NO3N and DRP and median soluble proportions of TP and TN had at least good performance (Table 9), as indicated by the criteria of Moriasi et al. (2015; Table 1). The mapped predictions for all four nutrient concentrations had similar coarse-scale spatial patterns, with relatively high values in low-elevation areas on the Southland plains and low values in Fiordland, Stewart Island and other high elevation areas (Figure 8). These patterns were consistent with expectations and reflect the increasing enrichment of rivers and streams in association with increasing proportions of catchments occupied by agricultural and other land uses.

Table 9. Performance of the RF models of median concentrations of TN, TP, NO3N and DRP. N indicates the number of sites used to fit the model.

Variable	N	R^2	NSE	PBIAS	RMSD	Transformation
TN	58	0.86	0.85	9.12	0.17	log10
NO3N	58	0.74	0.73	5.38	0.36	log10
TP	58	0.80	0.80	0.47	0.18	log10
DRP	58	0.67	0.67	0.55	0.20	log10
DRP in TP	58	0.56	0.56	0.86	0.86	logit
NO3N in TN	58	0.50	0.49	-21.23	0.93	logit

The $\log_{10}$ transformations of the site median concentration values prior to model fitting means that both the systematic and random components of the prediction uncertainty, when expressed in the original units of the variables, vary in proportion to the predicted value and the confidence intervals are asymmetric (Figure 9). The uncertainty of predictions of median concentration for individual river segments can be large. For example, a prediction of median TN concentration at a site with an observed (i.e., true) value of 1000 mg m^{-3} has a 95% confidence interval of 470 mg m^{-3} to 2125 mg m^{-3} (Figure 9). The logit transformations of the site median soluble proportions of TP and TN mean that the random components of the prediction uncertainty, when expressed in the original units of the variables, are largest for values of 0.5 and least for values approaching zero and one (Figure 9).

Model bias (i.e., systematic error) was highest for the model of the soluble proportion of TN (i.e., NO3N in TN; Table 9) and was low for all other variables (Table 9). Model bias was small compared to the random component of error for all models (Figure 9), which indicates that the predictions are reliable descriptions of broad scale patterns but that there is considerable uncertainty associated with individual locations.

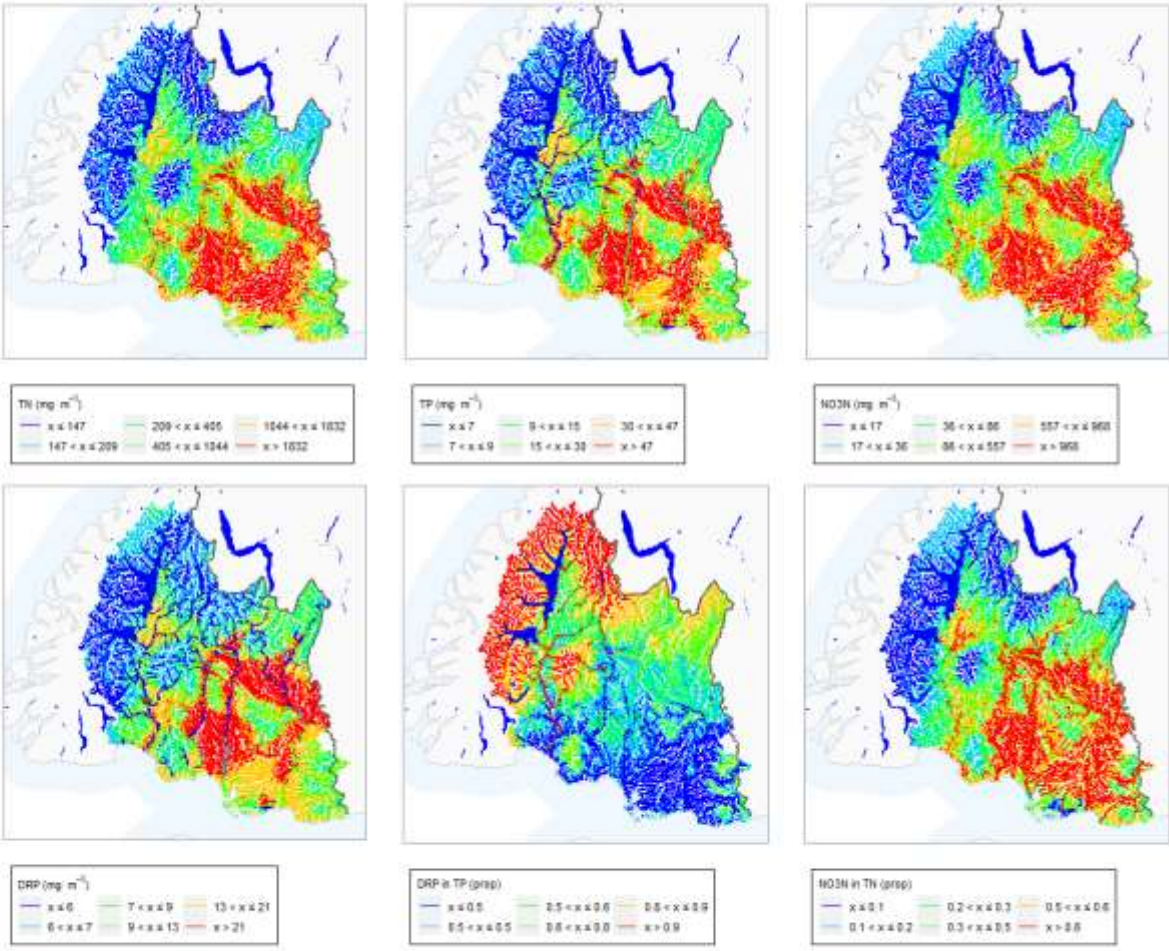

Figure 8. Predicted patterns of the current median concentrations of TN, TP, NO3N and DRP and the soluble proportions of TP and TN, respectively. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

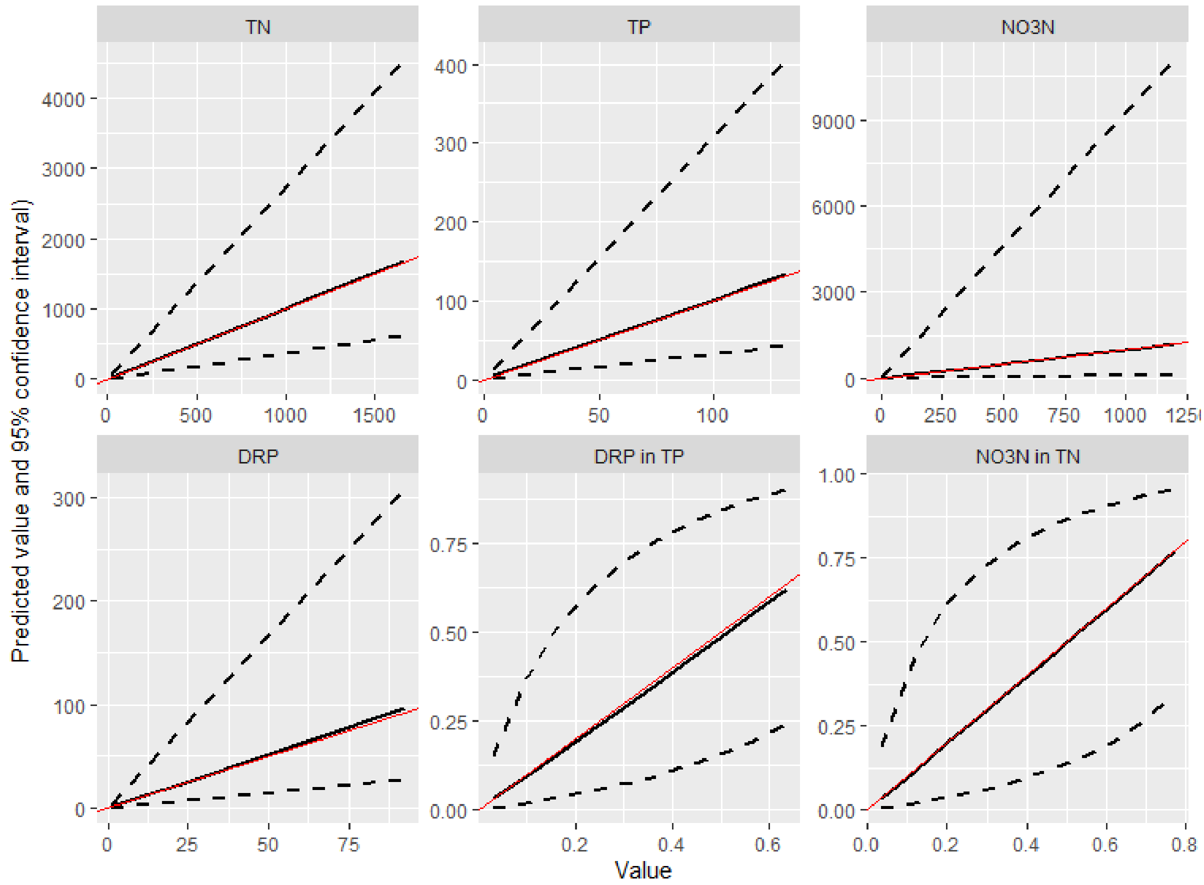

Figure 9. The characteristic statistical error (i.e., uncertainty) of the predictions for the concentration and soluble proportions of TP and TN models.The x-axis of each panel shows the range in the study area of actual (observed) concentrations of TN, TP, NO3N, and DRP and DRP in TP and NO3N in TP, respectively. The y-axis characterises the statistical error of the predictions along the range of the observations. The solid central line indicates mean prediction associated with an observed value. The red line is one to one and indicates a perfect prediction. The gap between the red line and the solid black line indicates the systematic error (the bias), which is small. The dashed lines indicate the random component of error based on the 95% confidence interval for individual predictions.

3.2 Performance of TN and TP current load models

The RF models of TN annual yield had very good performance (Table 10), as indicated by the criteria of Moriasi et al. (2015; Table 1). In contrast, RF model of TP annual yield had performance that was close to unsatisfactory, as indicated by an only just satisfactory R^2 value and a slightly less than satisfactory NSE value (Table 10).

The mapped predictions of annual yield of TN and TP had similar coarse-scale spatial patterns, with relatively high values in low-elevation areas on the Southland plains and low values in Fiordland, Stewart Island and other high elevation areas (Figure 10). These patterns were consistent with expectations and reflect the increasing enrichment of rivers and streams in association with increasing proportions of catchments occupied by agricultural and other land uses.

Table 10. Performance of random forest models of loads of TN and TP.

Variable	N	R^2	NSE	PBIAS	RMSD	Transformation
TN	58	0.73	0.72	-0.62	0.17	log10
TP	58	0.32	0.31	0.62	0.18	log10

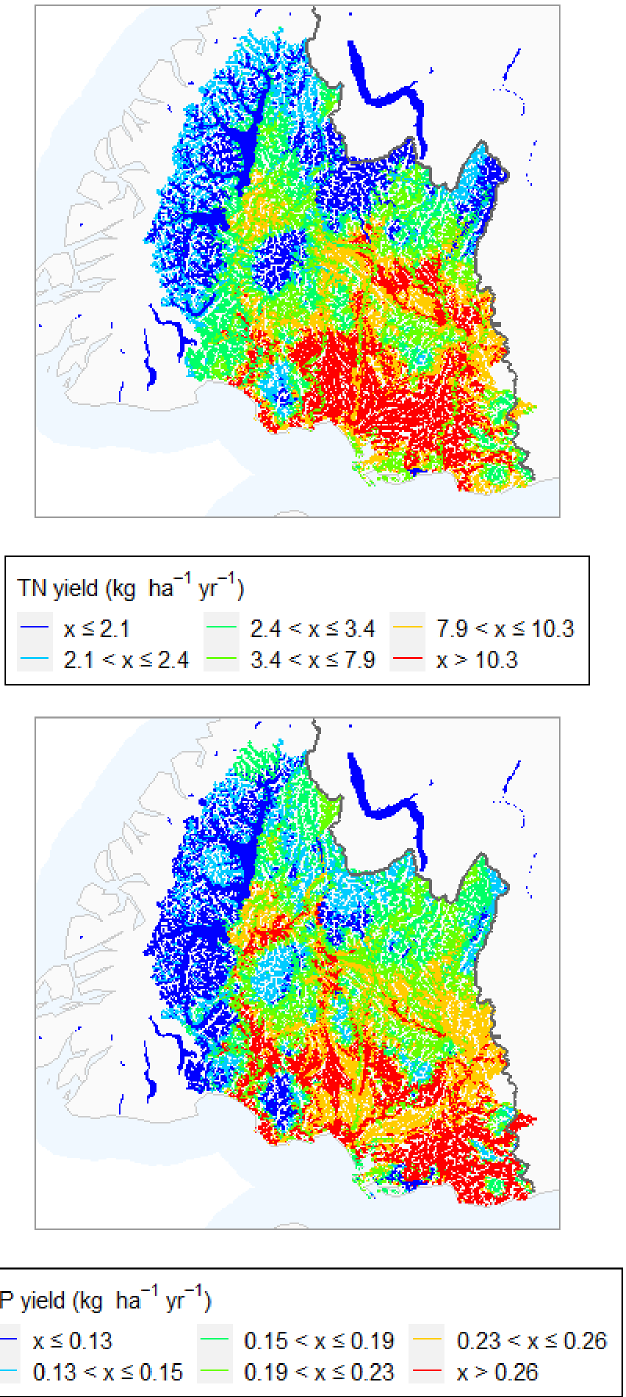

Figure 10. Predicted patterns of the current TN and TP loads (as yields kg ha^{-1} yr^{-1}) Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

The $\log_{10}$-transformation of the site TN and TP yields means both the systematic and random components of the prediction uncertainty, when expressed in the original units of the variables, vary in proportion to the predicted value and the confidence intervals are asymmetric (Figure 11). The uncertainty of predictions of TN and TP yields for individual river segments can be large. For example, a prediction of TN yield at a site with an observed (i.e., true) value of 10 kg ha^{-1} yr^{-1} has a 95% confidence interval of 4.7kg ha^{-1} yr^{-1} to 21.0 kg ha^{-1} yr^{-1} (Figure 11). However, model bias (i.e., systematic error) was low for both variables (Table 10, Figure 11). This indicates that the predictions are reliable descriptions of broad scale patterns in TN and TP loads, but that there is considerable uncertainty associated with load predictions for individual locations.

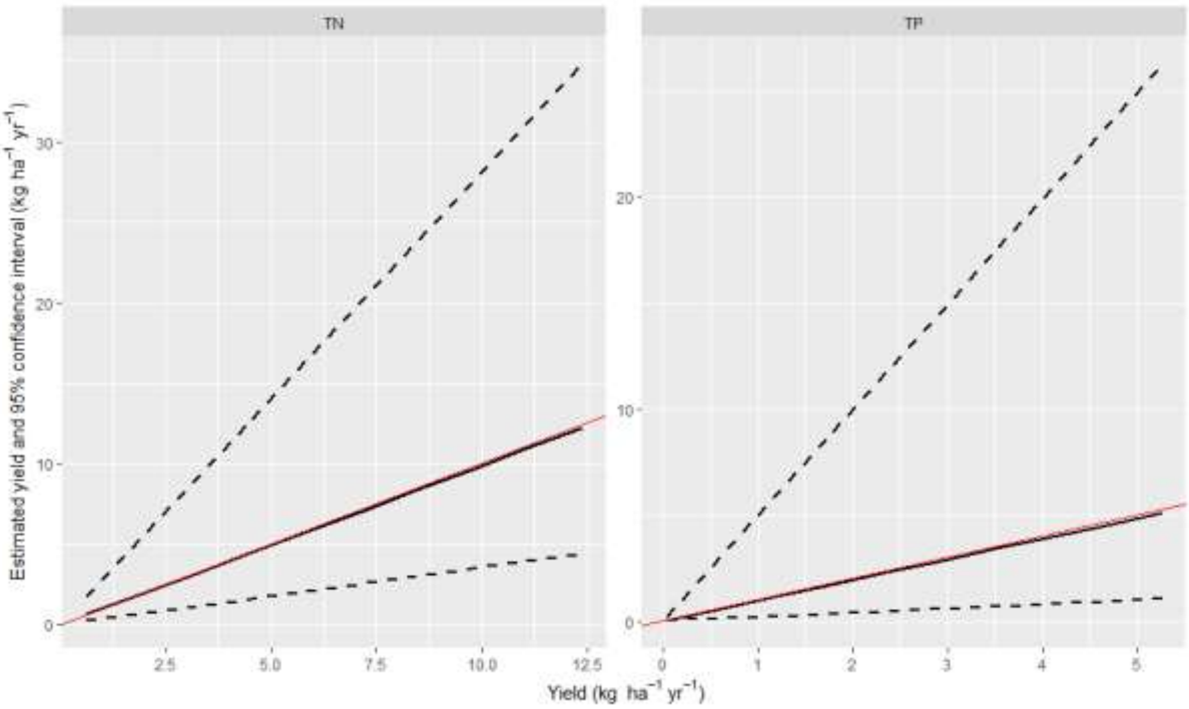

Figure 11. The characteristic statistical error (i.e., uncertainty) of the current load model predictions. The x-axis of each panel shows the range in actual (observed) yields of TN and TP in the study area. The y-axis characterises the statistical error of the predictions along the range of the observations. The solid central line indicates mean prediction associated with an observed value. The red line is one to one and indicates a perfect prediction. The gap between the red line and the solid black line indicates the systematic error (the bias), which is small. The dashed lines indicate the random component of error based on the 95% confidence interval for individual predictions.

The estimated TN and TP loads for two monitoring stations on the main stem of the Waiau River (Waiau River at Sunnyside, Waiau River at Tuatapere) were close to the 'observed loads' (i.e., loads calculated from the observed concentrations and flows at the sites (

Figure 12). It is noted that although the observed loads were higher than the estimated loads, there is considerable uncertainty associated with all load estimates (Figure 11).

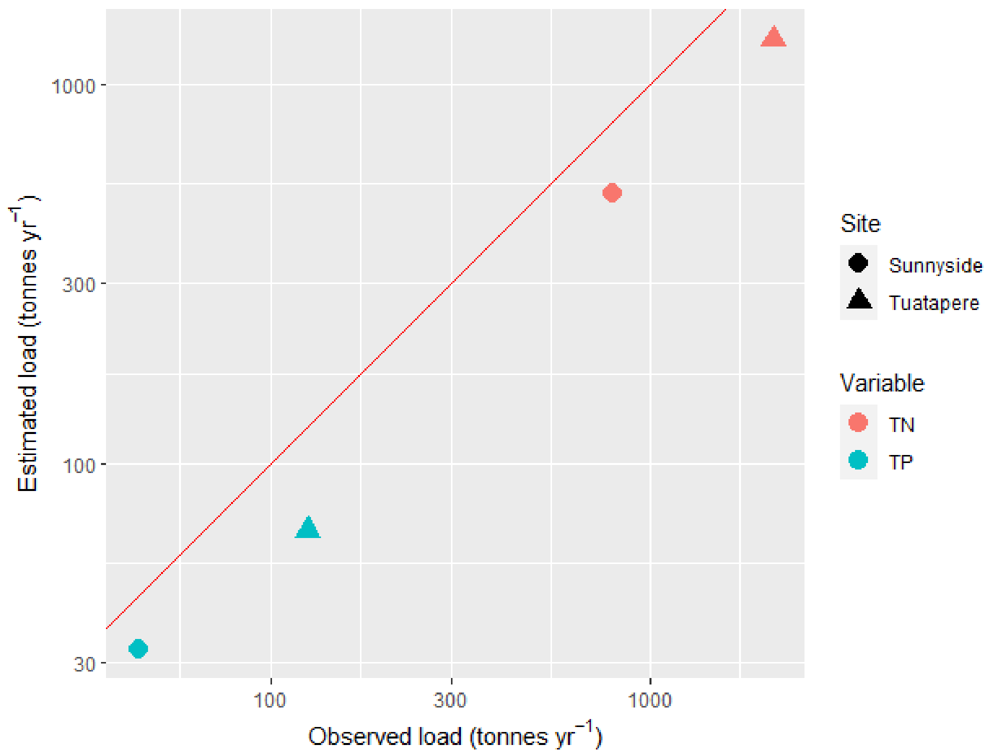

Figure 12. Comparison of observed and estimated loads at two monitoring stations on the main stem of the Waiau River (Waiau River at Sunnyside, Waiau at Tuatapere).

3.3 Correlation of model errors

The RF model errors were strongly correlated (Pearson correlation coefficient > 0.6) between some pairs of models including those for TN and NO3N concentrations, TP and DRP concentrations and TN and NO3N concentrations and TN loads (Table 11). The correlation structure shown in Table 11 was used to generate random normal deviates (ε_r) for each model in the Monte Carlo analysis.

Table 11. Correlation of errors between all pairs of models used in the analysis. The table is a lower triangular matrix showing the correlations of model errors between all pairs of RF models.

Model	**NO3N concentration**	**TN concentration**	**DRP concentration**	**TP concentration**	**NO3N in TN**	**DRP in TP**	**TN load**
TN concentration	0.74						
DRP concentration	0.23	0.15					
TP concentration	0.28	0.29	0.85				
NO3N in TN	-0.92	-0.57	-0.18	-0.14			
DRP in TP	0.15	0.27	-0.17	0.22	0.01		
TN load	0.64	0.67	-0.03	0.02	-0.63	0.04	
TP load	0.25	-0.01	0.46	0.45	-0.26	-0.08	0.29

3.4 Hauora and 20% spatial exceedance settings

3.4.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of exceeding the Hauora and 20% spatial exceedance criteria settings associated with periphyton objectives (i.e., were non-compliant) for 61% and 54% of segments in the study area that were not in the Natural State management class, respectively (Figure 13). Current river concentrations of NO3N had a greater than 50% probability of exceeding the Hauora settings associated with nitrate toxicity FWO for 26% of segments that were not in the Natural State management class. However, the probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at only 0.5% of river segments (Figure 13).

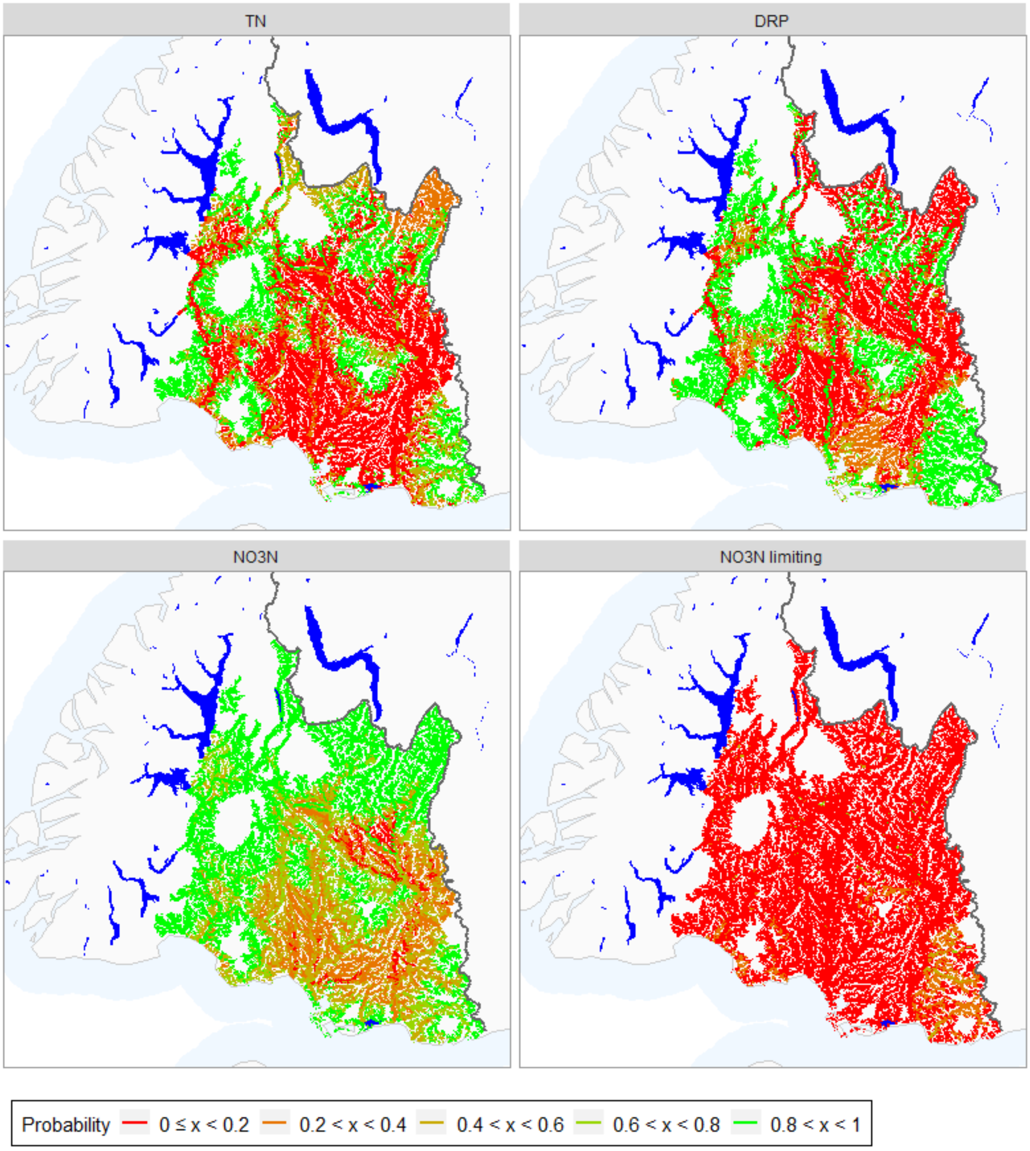

Figure 13. Probability that segments comply with river TN and DRP concentration criteria associated with the periphyton objectives (top left and right) and NO3N concentration criteria associated with the toxicity objectives (lower left) for the Hauora and 20% spatial exceedance criteria settings. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton (in this scenario this was true for 1.5% of segments).

The probability the current loads of TN and TP complied with the Hauora and 20% spatial exceedance criteria settings for rivers and lakes was less than 50% (i.e., were non-compliant) for 61% and 54% of segments in the study area that were not in the Natural State management class, respectively (Figure 14).

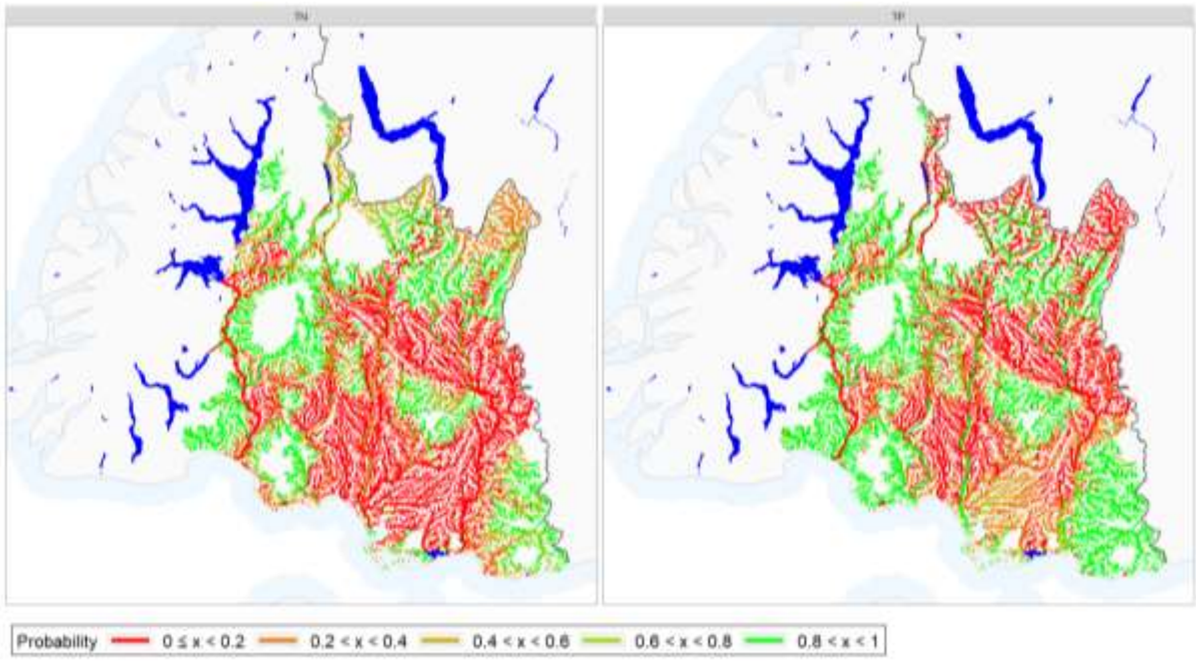

Figure 14. Probability that current nitrogen and phosphorus loads comply with criteria for both rivers and lakes for the Hauora settings and 20% spatial exceedance.

The probability that current lake TN and TP loads complied with the Hauora settings was less than 50% (i.e., were non-compliant) for 17 and 13 of the 21 lakes that were not in the Natural State class, respectively (Figure 15).

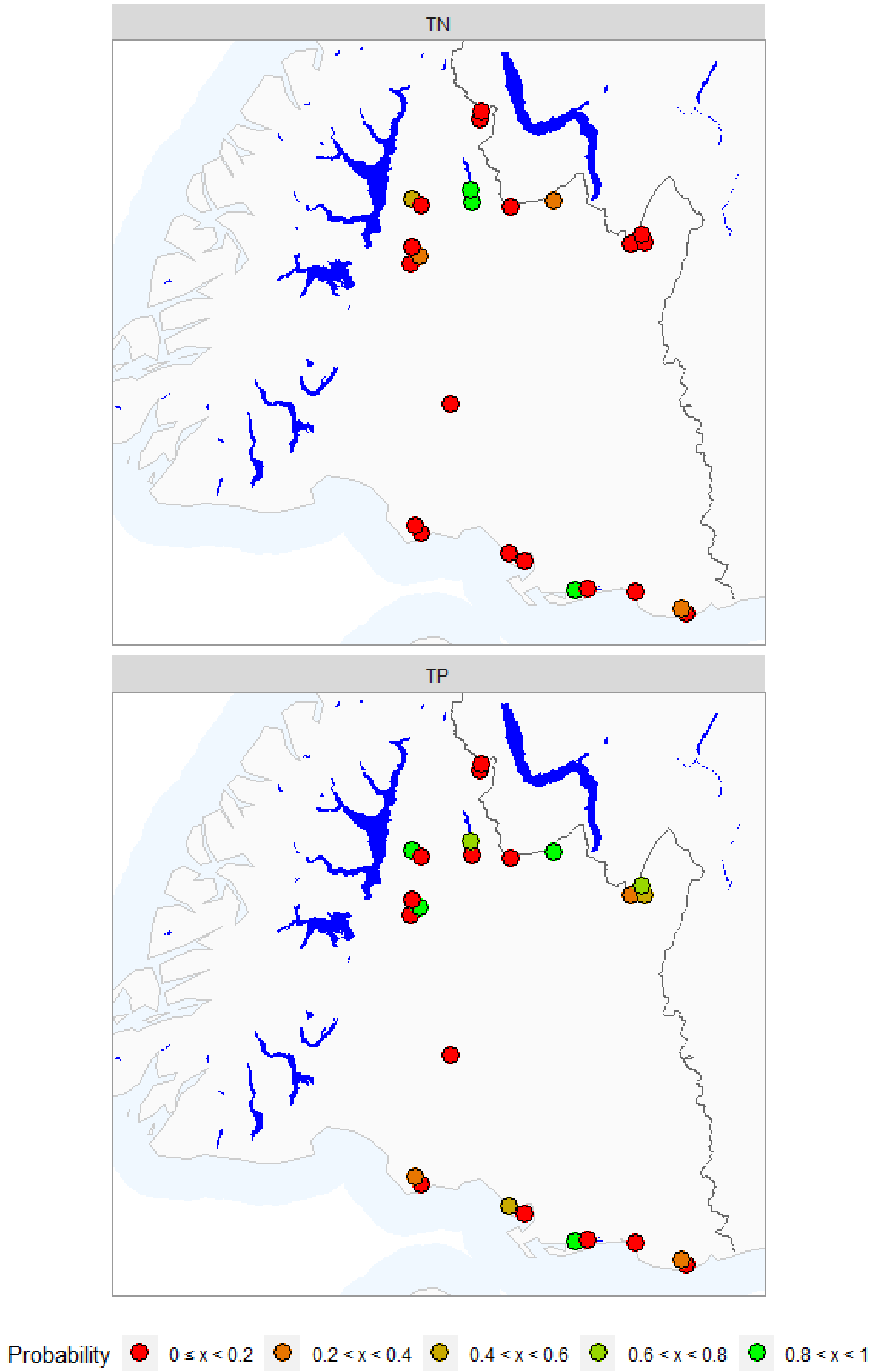

Figure 15. Probability of compliance with lake TN and TP load criteria associated with the phytoplankton objectives for the Hauora settings.

The probability that current estuary TN loads complied with the Hauora settings was less than 50% (i.e., were non-compliant) for 4 of the 8 estuaries (Figure 16). The probability that current estuary TP loads complied with the Hauora settings criteria was less than 50% (i.e., were non-compliant) for 4 of the 8 estuaries (Figure 16).

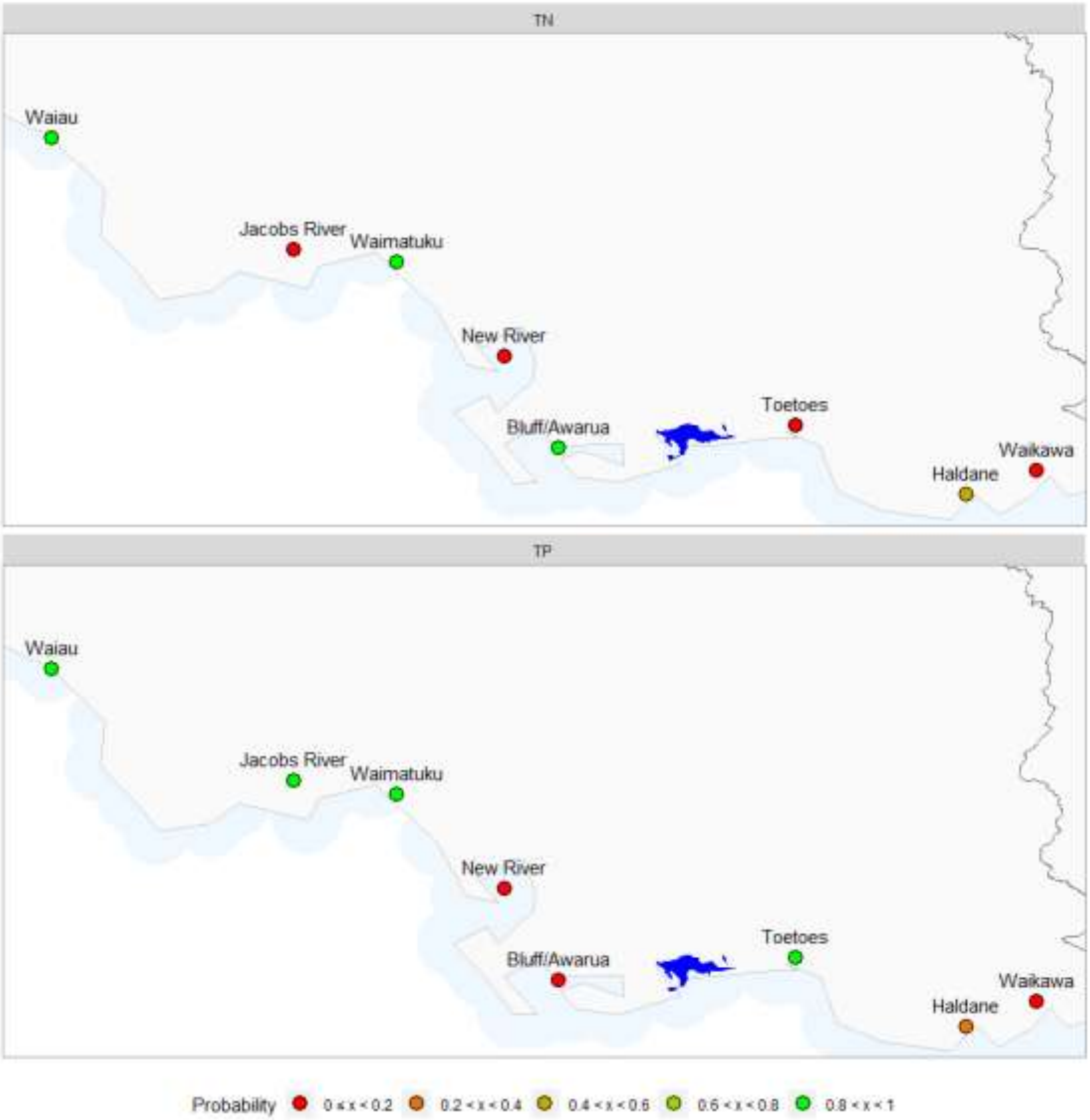

Figure 16. Probability of compliance with estuary TN and TP concentration criteria associated with the phytoplankton and macroalgae objectives for the Hauora settings.

3.4.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the Hauora and 20% spatial exceedance criteria settings, local excess TN loads for rivers exceeded 5 kg ha^{-1} yr^{-1} for 21% of river segments and exceeded 10 kg ha^{-1} yr^{-1} for 1.2% of river segments (Figure 17). Note that the 5 and 10 kg ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 17. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 42% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

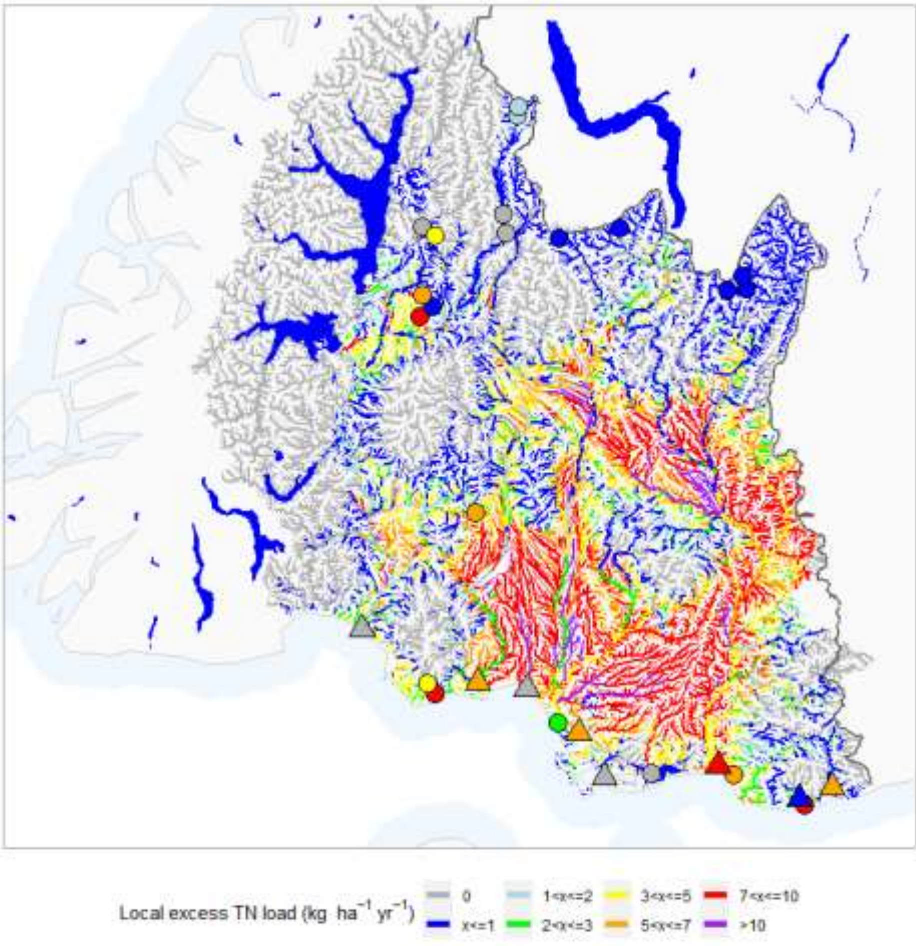

Figure 17. Local excess TN loads for rivers, lakes and estuaries for the Hauora and 20% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the Hauora and 20% spatial exceedance criteria settings, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 30% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 5.2% of river segments (Figure 18). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 43% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

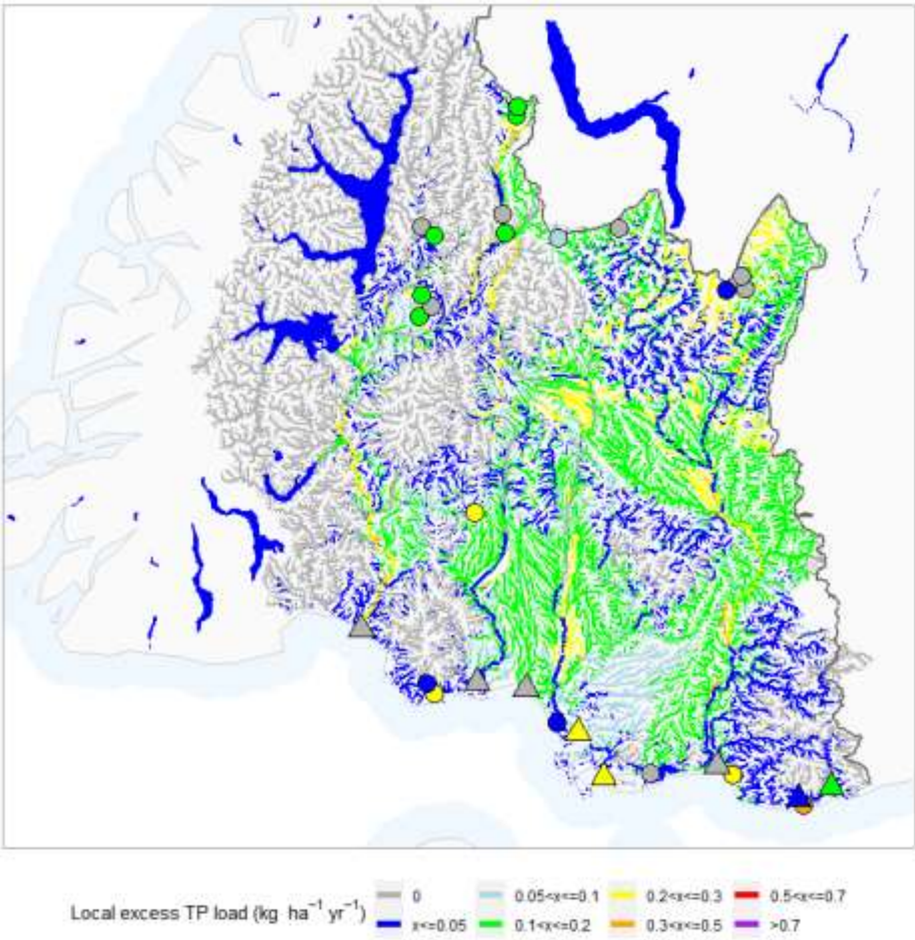

Figure 18. Local excess TP loads for rivers, lakes and estuaries for the Hauora and 20% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.4.3 Critical point catchments and catchment status

The critical point catchment status is the load reduction that ensures the loads for all receiving environments in the catchment do not exceed the MAL (and therefore all FWOs in the catchment to be achieved). The critical point catchment load reductions required differ from the local excess loads (Figure 17 and Figure 18) in that they consider all receiving environments in a critical point catchment. The load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The TN load reductions required by the Hauora and 20% spatial exceedance criteria settings for critical point catchments are shown on Figure 19 and Figure 20. Critical point catchments that required TN load reductions of greater than 10 kg ha^{-1} yr^{-1} occupied 13% of the study area and critical point catchments with TN load reductions of less than 4 kg ha^{-1} yr^{-1} occupied 35% of the study area (Figure 19). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 70% occupied 93% of the study area (Figure 20). The comparison of load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of current load (%) indicates that reduction requirements in areas with low yield reductions (e.g., much of the headwater areas of all main catchments) are nevertheless large in relative terms.

Critical point catchments that require TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 91% of the study area and critical point catchments with TP load reductions of less than 0.07 kg ha^{-1} yr^{-1} occupied 9% of the study area (Figure 21). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 70% occupied 83% of the study (Figure 22). As for TN, critical point catchments with low load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

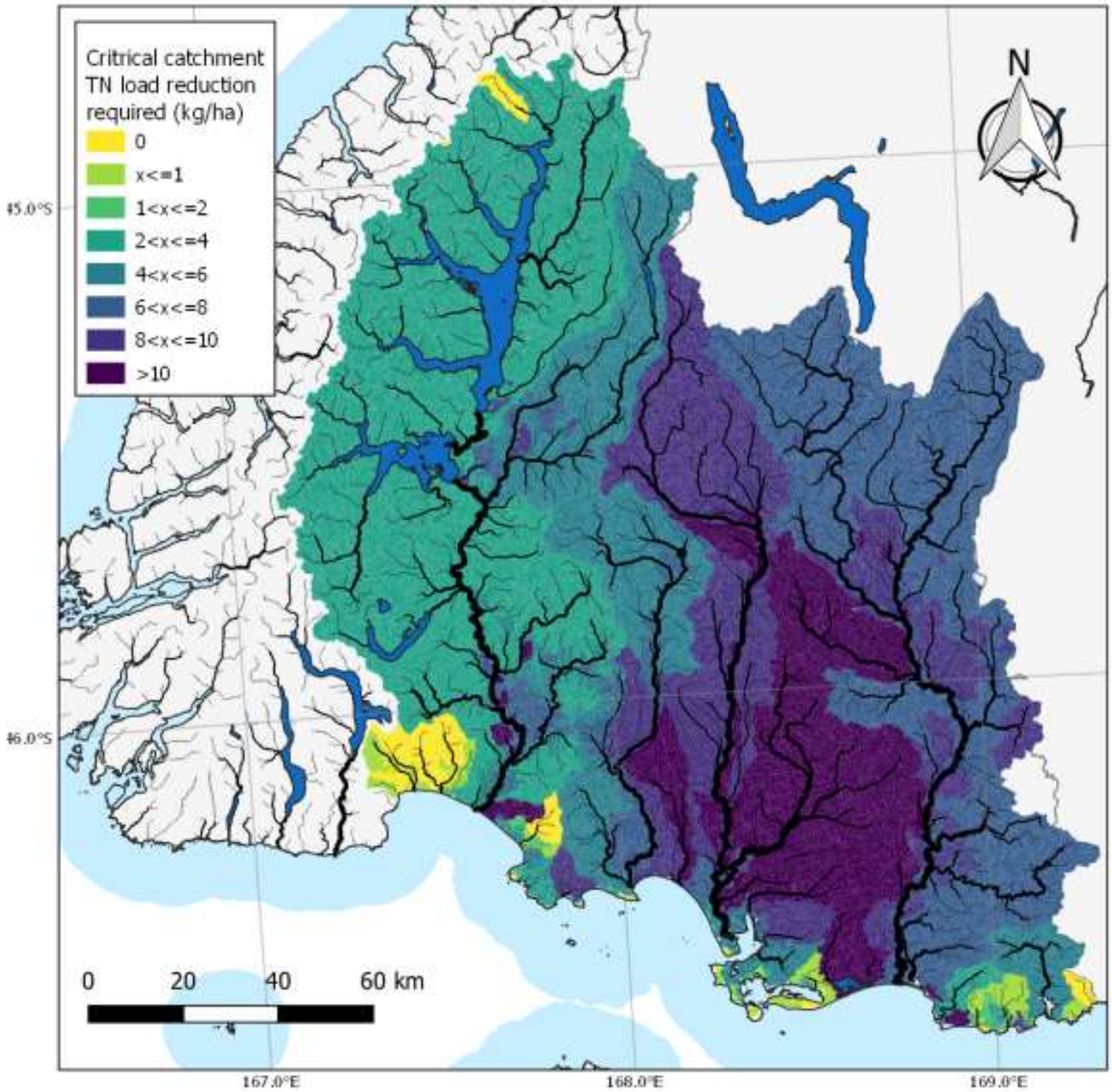

Figure 19*. The TN load reduction required for the Hauora and 20% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).*

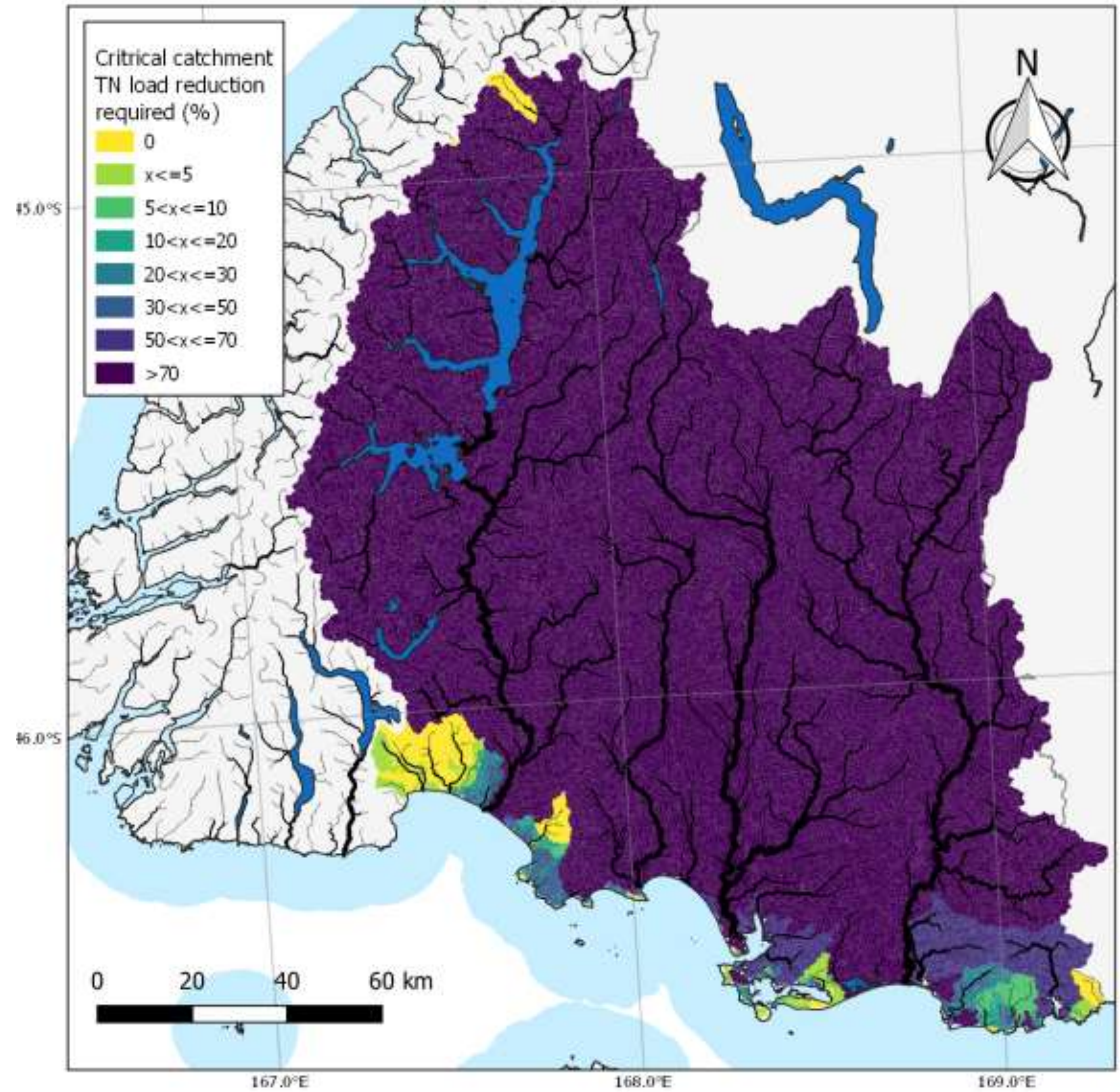

Figure 20. The TN load reduction required for the Hauora and 20% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

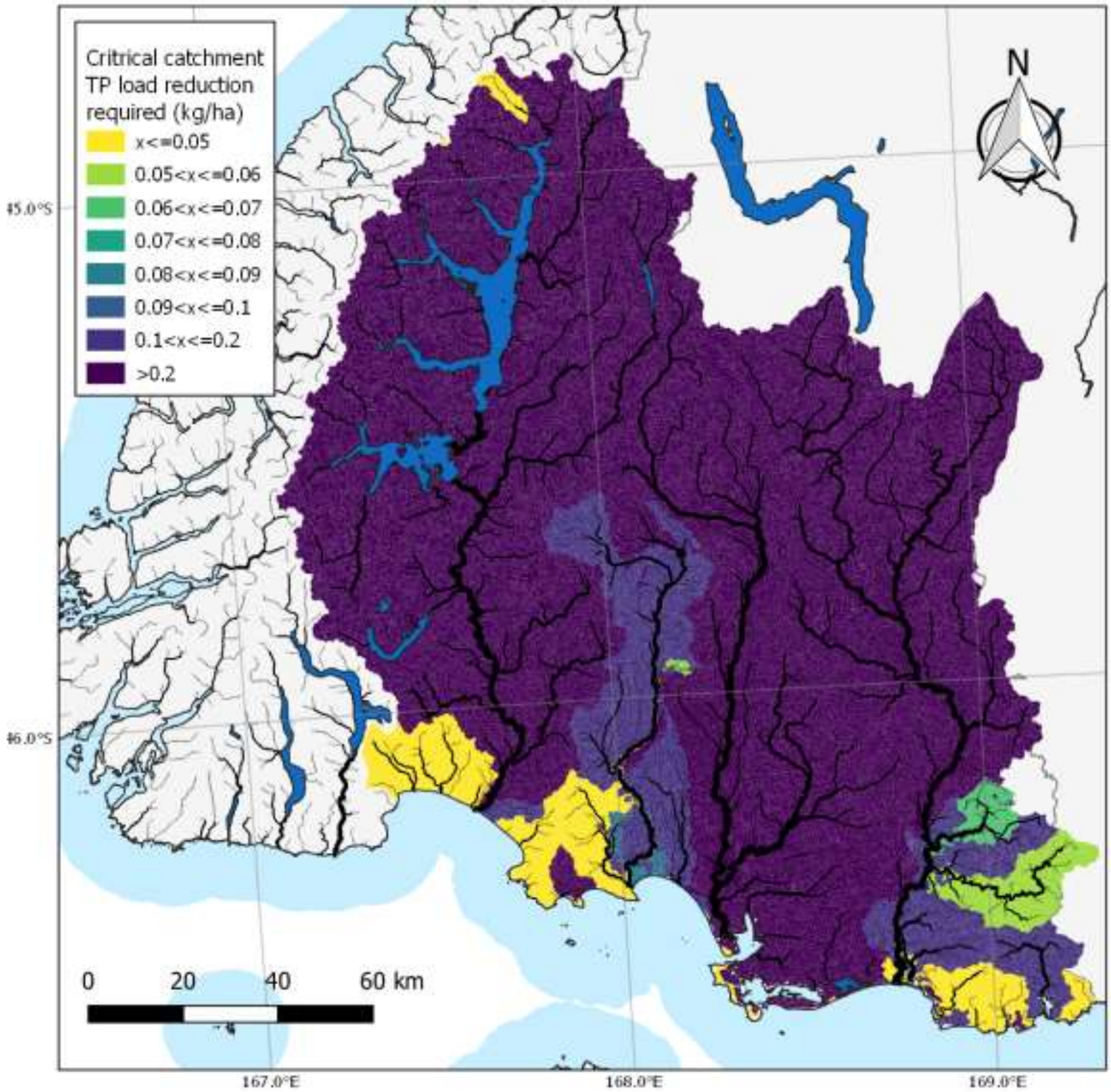

Figure 21. The TP load reduction required for the Hauora and 20% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

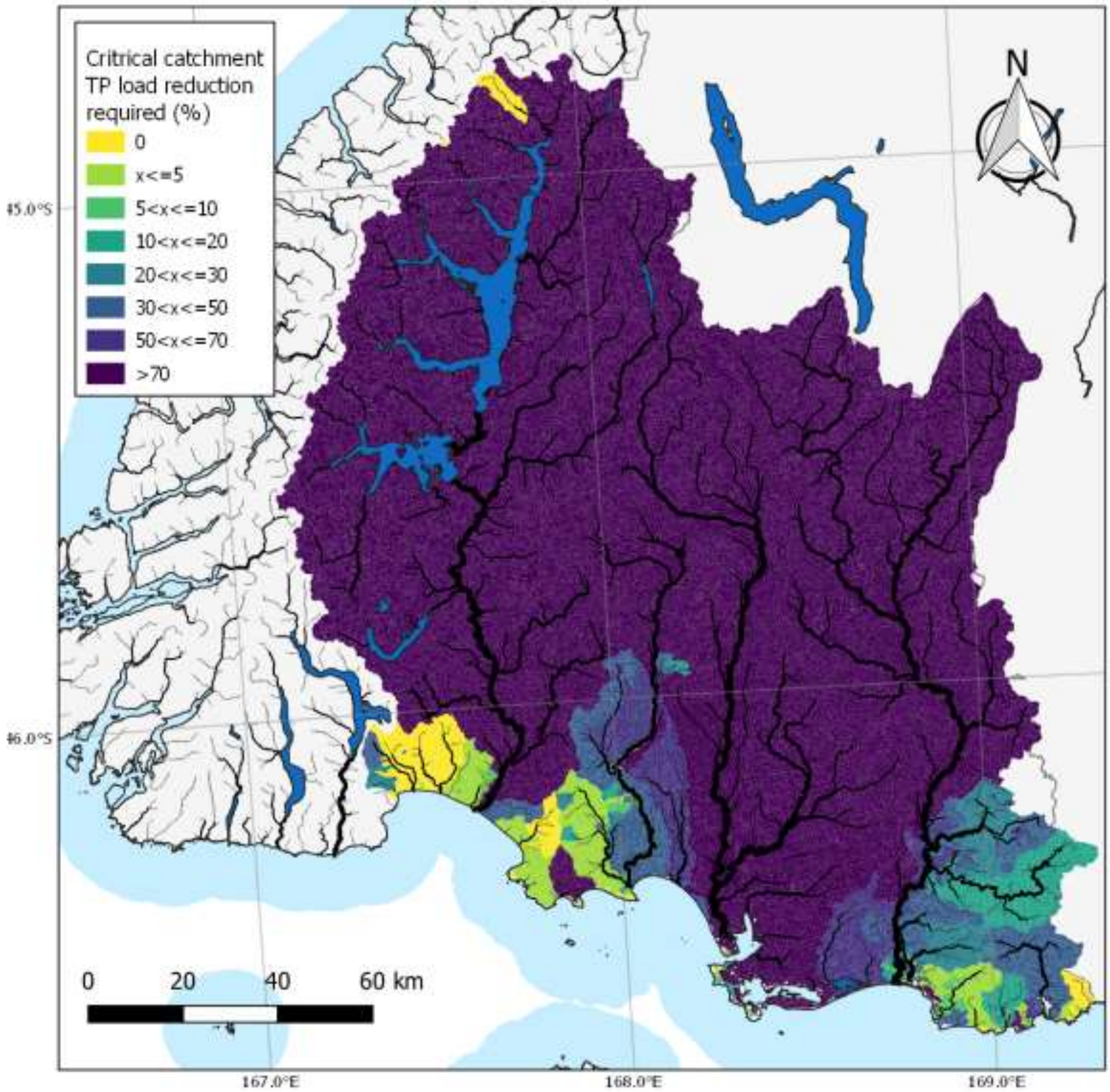

Figure 22. The TP load reduction required for the Hauora and 20% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for the Hauora and 20% spatial exceedance criteria settings are shown on Figure 23 and Figure 24 for TN and TP respectively. For TN, and 74% of the critical point catchment area, the most stringent FWOs (i.e., most demanding of TN load reductions) were for rivers, 25% were for estuaries, and only 1% were for lakes (Figure 23). For TP, and 93% of the critical point catchment area, the most stringent FWOs were for rivers, 6% were for estuaries, and 1% were for lakes (Figure 24).

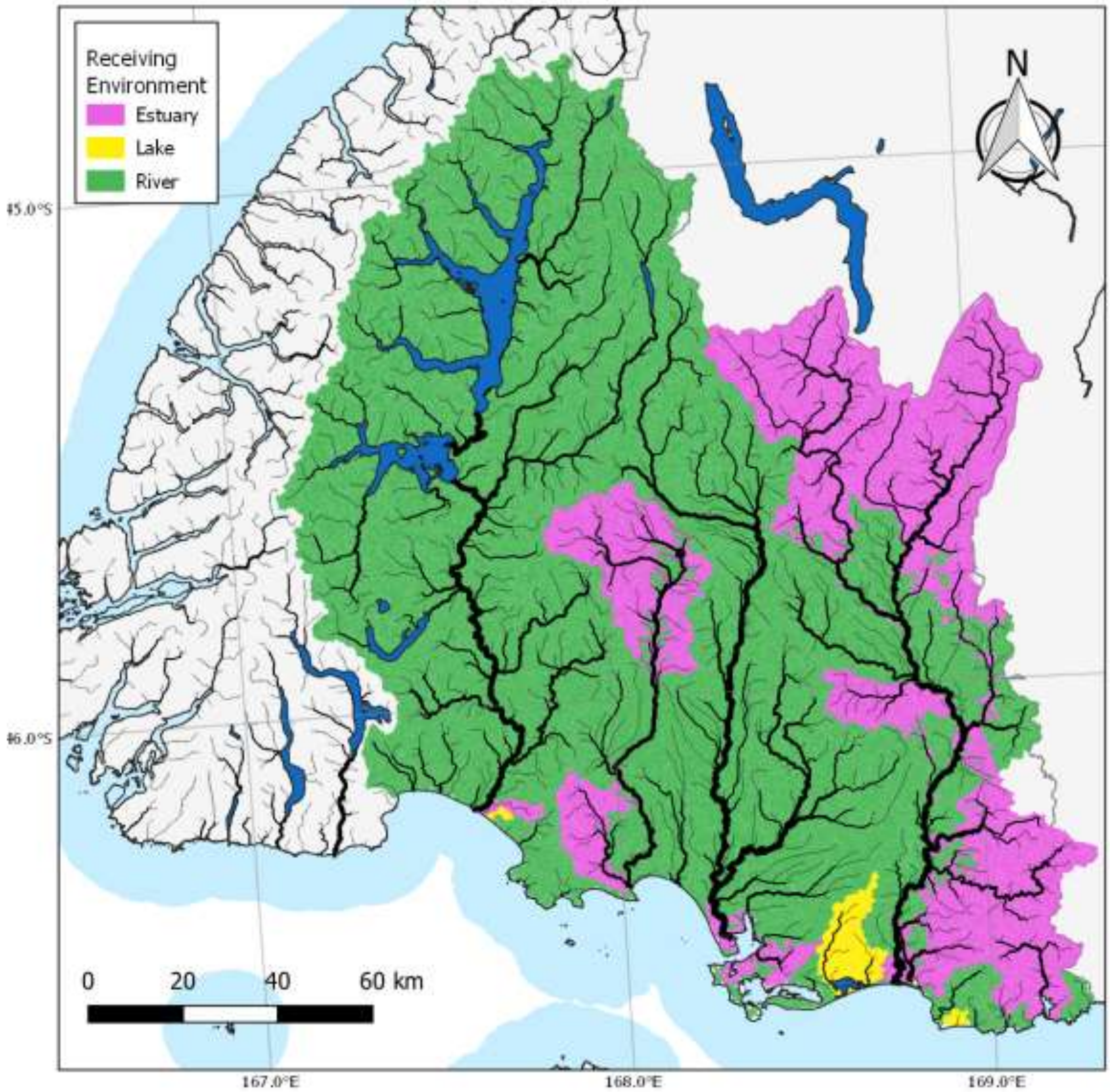

Figure 23. Limiting environment type for TN load reduction required for the Hauora and 20% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TN load reductions).

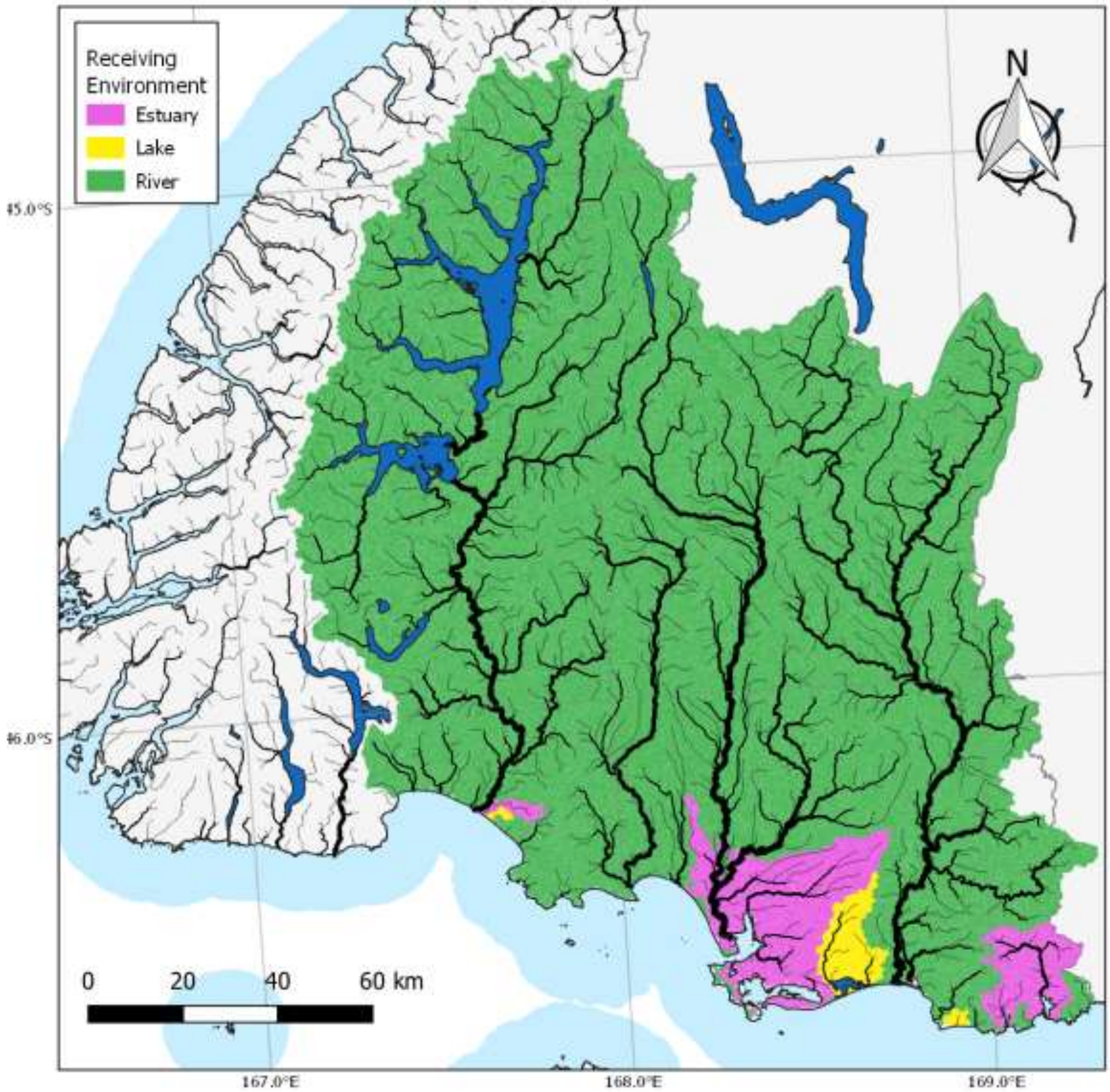

Figure 24. Limiting environment type for TP load reduction required for the Hauora and 20% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TP load reductions).

3.4.4 Reporting catchments and regional load reductions required

The load reductions required by the Hauora and 20% spatial exceedance criteria settings for each reporting catchment and for the whole study area are shown in **Error! Reference source n ot found.**. For the whole study area, the TN and TP load reductions required were estimated to be 10,111 t yr^{-1} and 411 t yr^{-1}, which represent 70% and 70% of the current loads respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reduction estimates, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in **Error! Reference source not found.**. The u ncertainties indicate, for example that the 90% confidence interval for the current regional load of TN extends between 11,118 t yr^{-1} and 18,992 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 61% and 78% (best estimate 70%) and the regional TP load reduction requirement extends between 62% and 77% (best estimate 70%).

For the Hauora and 20% spatial exceedance criteria settings, the best estimates of TN load reductions required were very high (>65%) in the Waituna Catchments, Waimatuku & Taunamau Catchments, Waiau Catchment, and Matāura Catchments. The TP load reductions required were highest (≥60%) in Bluff Zone, Matāura Catchments, Waiau Catchment and Waituna Catchments. It is noted that the TP load reductions required were very high for Bluff Zone (93%) because the estuary (Bluff Harbour) has a MAL for TP of zero for the B band (i.e., the nominated estuary FWO, see Appendix B, Table 27). This indicates that the B band FWO for this estuary is an unrealistic objective (i.e., it cannot be achieved because the catchment contribution of TP would be greater than zero even under natural conditions).

Table 12. Current load and load reduction required for TN and TP by reporting catchment and for the Hauora and 20% spatial exceedance criteria settings including the uncertainties at the 90% level of confidence. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5th and 95th confidence limits for the reported values (i.e., the range is the 90% confidence interval).

Reporting catchment	**TN**			**TP**		
	Current load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**	**Current load (t yr^{-1})**	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Aparima & Pourakino Catchments	1,279 (609 - 2,099)	879 (209 - 1,699)	64 (34 - 81)	40 (20 - 67)	14 (4 - 25)	34 (18 - 43)
Bluff Zone	38 (30 - 48)	6 (3 - 9)	14 (8 - 21)	2 (1 - 2)	2 (1 - 2)	94 (91 - 95)
Catlins Zone	21 (17 - 29)	0 (0 - 2)	2 (0 - 8)	1 (1 - 2)	0 (0 - 0)	0 (0 - 0)
Matāura Catchments	4,914 (2,730 - 8,397)	4,020 (1,836 - 7,503)	79 (67 - 89)	190 (95 - 362)	113 (47 - 234)	58 (37 - 70)
Orepuki Coastal Zone	218 (180 - 260)	94 (60 - 134)	42 (32 - 52)	7 (5 - 9)	2 (1 - 4)	28 (14 - 48)
Ōreti & Invercargill Catchments	3,577 (2,098 - 6,620)	2,337 (1,180 - 5,254)	62 (54 - 79)	110 (62 - 184)	85 (38 - 158)	75 (61 - 86)
Te Waewae Bay Western Coastal Zone	117 (81 - 172)	1 (0 - 4)	1 (0 - 4)	5 (3 - 7)	0 (0 - 0)	3 (0 - 7)
Tokanui Coastal Zone	214 (156 - 276)	52 (22 - 102)	23 (11 - 43)	9 (6 - 12)	1 (0 - 3)	13 (5 - 26)
Waiau Catchment	2,848 (1,444 - 4,926)	1,982 (609 - 3,738)	66 (38 - 83)	189 (90 - 328)	176 (80 - 307)	92 (89 - 95)
Waikawa Catchment	246 (122 - 408)	140 (15 - 301)	50 (12 - 74)	11 (6 - 19)	4 (0 - 12)	32 (0 - 63)
Waimatuku & Taunamau Catchments	348 (206 - 565)	248 (107 - 455)	69 (50 - 82)	8 (4 - 13)	4 (0 - 8)	43 (3 - 71)
Waituna Catchments	240 (132 - 429)	220 (112 - 409)	90 (85 - 95)	8 (4 - 13)	5 (1 - 11)	62 (37 - 80)
Total	14,294 (11,118 - 18,992)	10,111 (6,767 - 14,734)	70 (61 - 78)	585 (413 - 794)	411 (261 - 601)	70 (62 - 77)

The load reductions required for the Hauora and 20% spatial exceedance criteria settings for the eight estuaries and the three brackish lakes are shown in Table 13. The table also shows the load reductions required to achieve all river and lake FWOs in the catchment of each estuary and brackish lake.

Table 13 indicates that for seven of the 11 estuaries and brackish lakes, the TN load reductions required to achieve the FWOs under the Hauora settings and 20% spatial exceedance are of greater magnitude for the estuary or brackish lake compared to the river and lake FWOs in the catchment. Exceptions to this are the Waimatuku, Haldane, Bluff/Awarua and Waiau estuaries which all have zero or small TN load reductions required for the estuary, but significant reductions required for river FWOs in their catchments. The Waimatuku and Waiau estuaries have zero TN load reductions required because they have low salinity and low flushing time, which indicates that they are unlikely to sustain high macroalgae or phytoplankton (see Appendix B, Table 27). In contrast, the Waikawa estuary and the three coastal lakes (Lake Brunton and Waituna and Te Waewae lagoons) require significantly greater reductions to achieve the estuary/coastal lake FWOs than for the river FWOs in their catchments.

Table 13 indicates more variation in the TP load reductions required to achieve the FWOs for estuaries and brackish lakes compared to the river and lake FWOs in the catchment. The TP load reductions required for Waimatuku, Toetoes, Jacobs River and Waiau estuaries are zero because the flushing times of these estuaries are too short to sustain phytoplankton blooms (see Appendix B, Table 27).

Table 13. Load reductions required to achieve estuary and brackish lake FWOs and FWOs for rivers and lakes in their upstream catchment for the Hauora and 20% spatial exceedance criteria settings.

Estuary	TN load reduction required (t yr^{-1})		TP load reduction required (t yr^{-1})	
	Estuary	Lakes and rivers	Estuary	Lakes and rivers
Waimatuku	0 (0 - 0)	228 (92 - 429)	0 (0 - 0)	3 (0 - 8)
Waikawa	139 (15 - 301)	16 (1 - 76)	4 (0 - 12)	0 (0 - 0)
Haldane	2 (0 - 16)	5 (1 - 11)	0 (0 - 2)	0 (0 - 0)
Brunton	15 (5 - 27)	5 (0 - 15)	0 (0 - 0)	0 (0 - 0)
Toetoes	4,020 (1,835 - 7,502)	2,573 (1,074 - 4,780)	0 (0 - 0)	113 (48 - 234)
Waituna	220 (112 - 409)	103 (23 - 235)	5 (1 - 11)	4 (0 - 10)
Bluff/Awarua	0 (0 - 0)	5 (3 - 9)	2 (1 - 2)	0 (0 - 0)
New River	2,388 (920 - 5,385)	2,208 (1,312 - 4,323)	90 (42 - 164)	55 (28 - 93)
Jacobs River	879 (209 - 1,699)	481 (70 - 1,254)	0 (0 - 0)	14 (5 - 25)
Waiau	0 (0 - 0)	1,979 (609 - 3,735)	0 (0 - 0)	176 (80 - 307)
Te Waewae	38 (19 - 67)	2 (0 - 7)	0 (0 - 1)	0 (0 - 0)

3.5 Hauora and 30% spatial exceedance settings

3.5.1 Compliance

Current river concentrations of TN, and DRP had a greater than 50% probability of exceeding the Hauora and 30% spatial exceedance criteria settings associated with periphyton objectives (i.e., were non-compliant) for 34% and 2% of segments in the study area that were not in the Natural State management class, respectively (Figure 25). Current river concentrations of NO3N had a greater than 50% probability of exceeding the Hauora settings associated with nitrate toxicity FWO for 22% of segments that were not in the Natural State management class. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 23% of river segments (Figure 25).

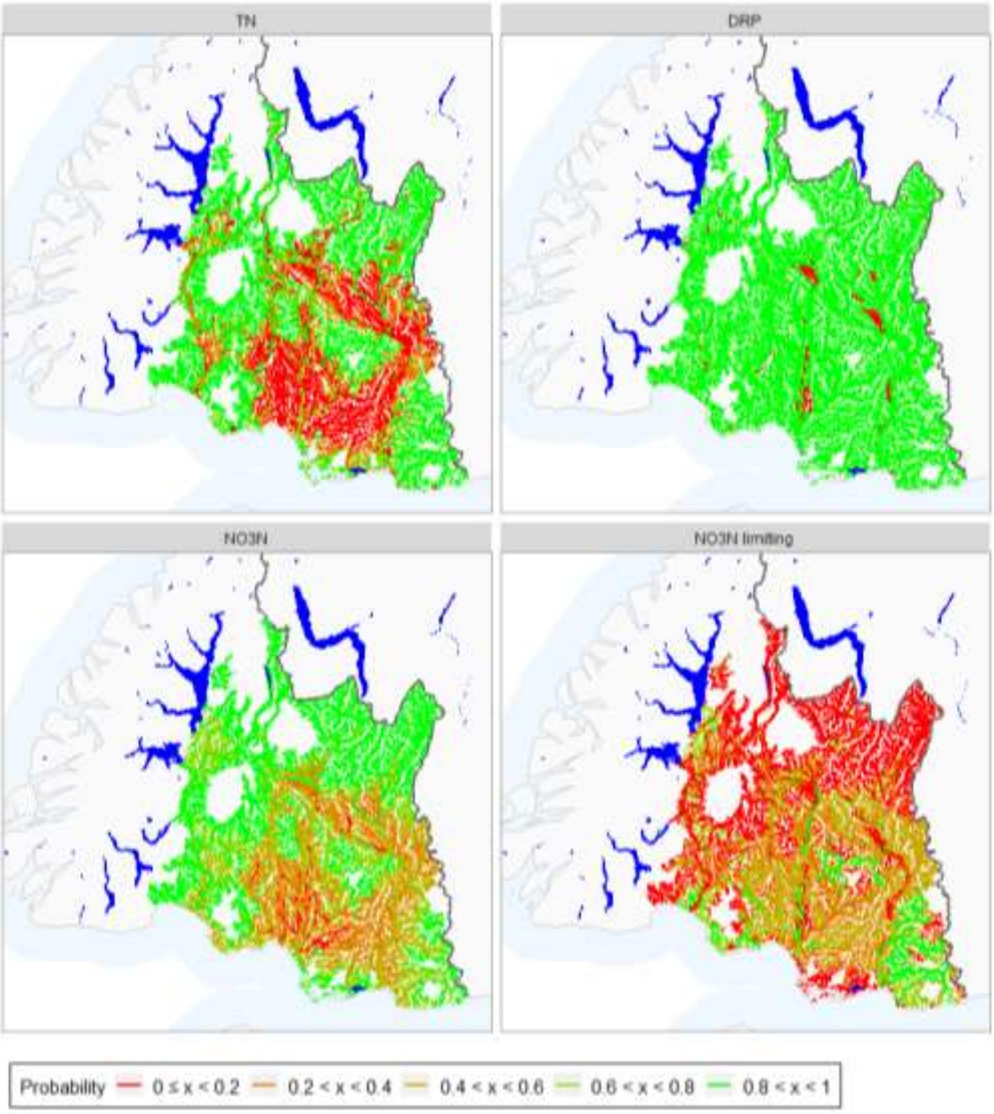

Figure 25. Probability that segments comply with river TN and DRP concentration criteria associated with the periphyton objectives (top left and right) and NO3N concentration criteria associated with the toxicity objectives (lower left) for the Hauora and 30% spatial exceedance settings. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton (for these settings, this was true for 0.01% of segments).

The probability the current loads of TN and TP complied with the Hauora settings and 30% spatial exceedance criteria for rivers and lakes was less than 50% (i.e., were non-compliant) for 37% and 2% of segments in the study area that were not in the Natural State management class, respectively (Figure 26).

Compliance estimates for lakes and estuaries for the Hauora settings were the same as for Hauora and 20% spatial exceedance criteria settings.

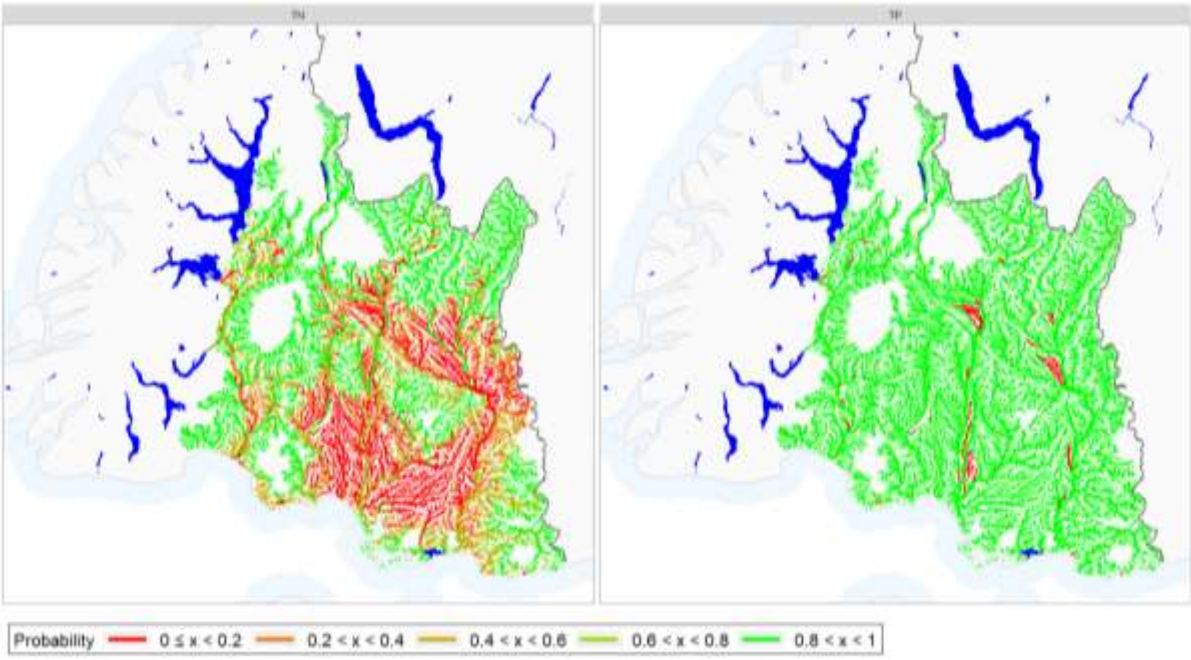

Figure 26. Probability that current nitrogen and phosphorus loads comply with criteria for both rivers and lakes for the Hauora settings and 30% spatial exceedance.

3.5.2 Local excess loads

For the Hauora and 30% spatial exceedance criteria settings, local excess TN loads for rivers exceeded 5 kg ha^{-1} yr^{-1} for 7% of river segments and exceeded 10 kg ha^{-1} yr^{-1} for 0.7% of river segments (Figure 27). Note that the 5 and 10 kg ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 27. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 49% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

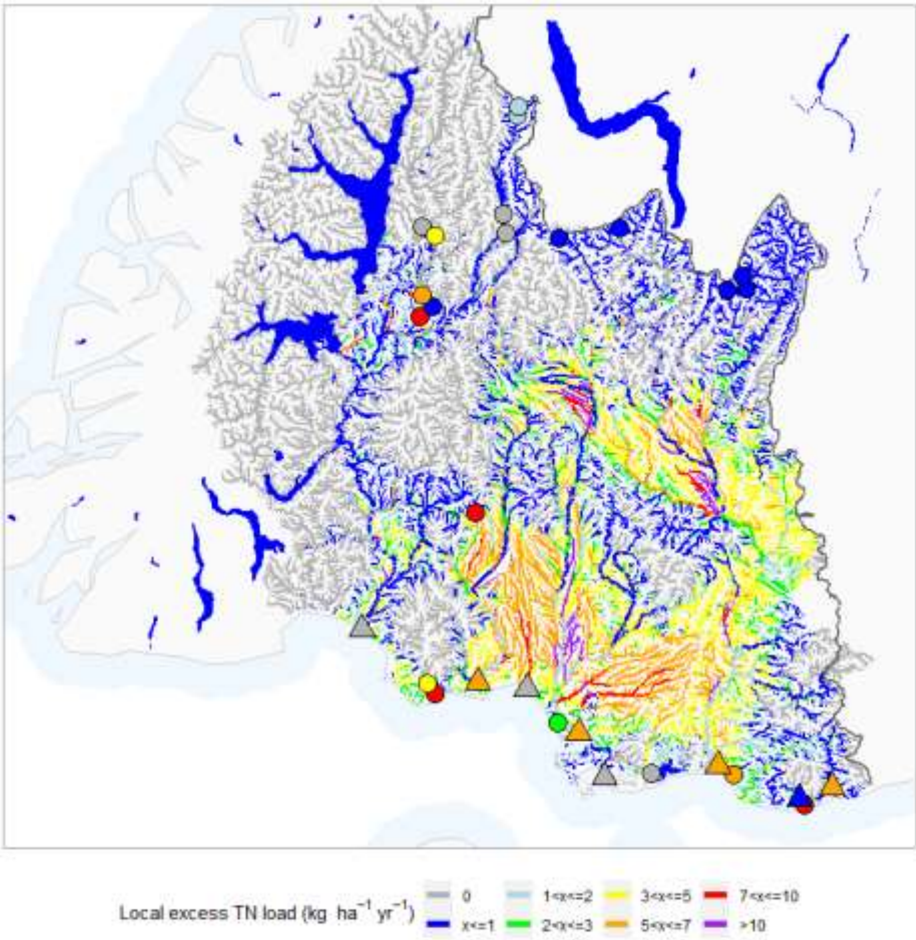

Figure 27. Local excess TN loads for rivers, lakes and estuaries for the Hauora and 30% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the Hauora and 30% spatial exceedance criteria settings, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 1% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 0.8% of river segments (Figure 28). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 98% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

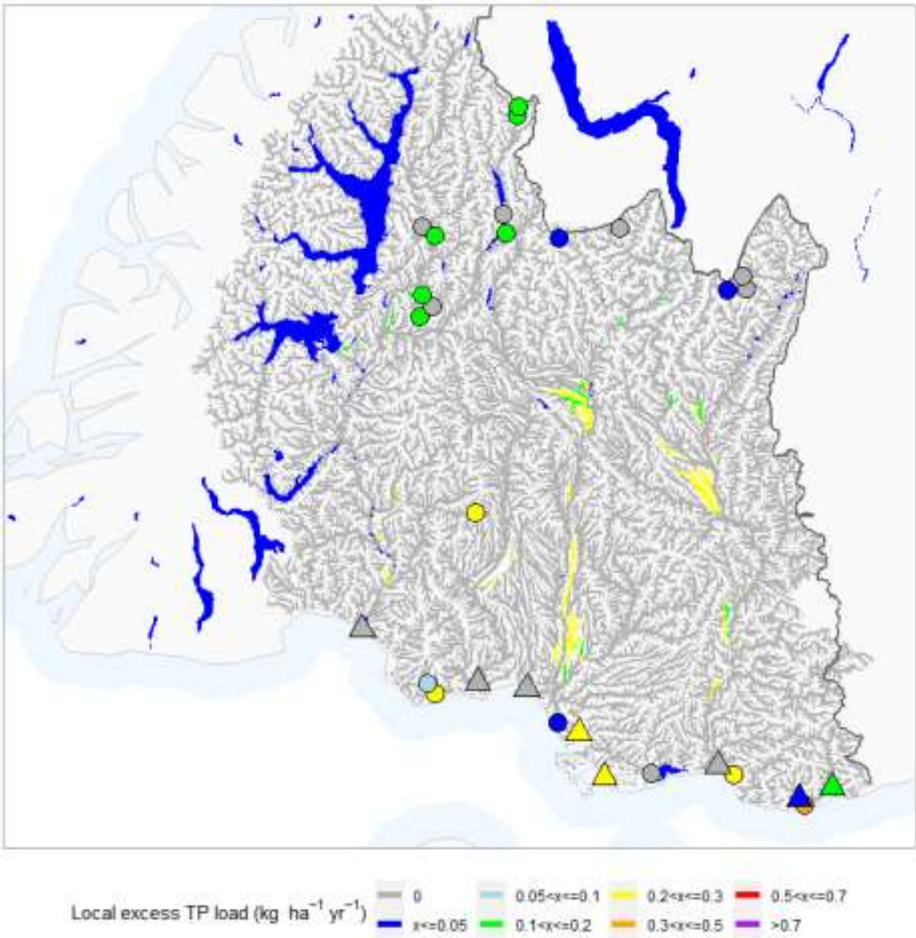

Figure 28. Local excess TP loads for rivers, lakes and estuaries for the Hauora and 30% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.5.3 Critical point catchments and catchment status

The load reductions required for critical point catchments is the minimum load reduction that ensures the loads for all receiving environments in the catchment do not exceed the MAL (and therefore all FWOs in the catchment to be achieved). The critical point catchment load reductions required differ from the local excess loads (Figure 27 and Figure 28) in that they consider all receiving environments in a critical point catchment. The load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The TN load reductions required by the Hauora and 30% spatial exceedance criteria settings for critical point catchments are shown on Figure 29 and Figure 30. Critical point catchments that required TN load reductions of greater than 10 kg ha^{-1} yr^{-1} occupied 12% of the study area and critical point catchments with TN load reductions of less than 2 kg ha^{-1} yr^{-1} occupied 35% of the study area (Figure 29). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 70% occupied 90% of the study area (Figure 30). The comparison of load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of current load (%)

indicates that reduction requirements in areas with low yield reductions (e.g., much of the headwater areas of all main catchments) are nevertheless large in relative terms.

Critical point catchments that require TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 28% of the study area and critical point catchments with TP load reductions of less than 0.07 kg ha^{-1} yr^{-1} occupied 72% of the study area (Figure 31). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 70% occupied 51% of the study (Figure 32). As for TN, critical point catchments with low load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

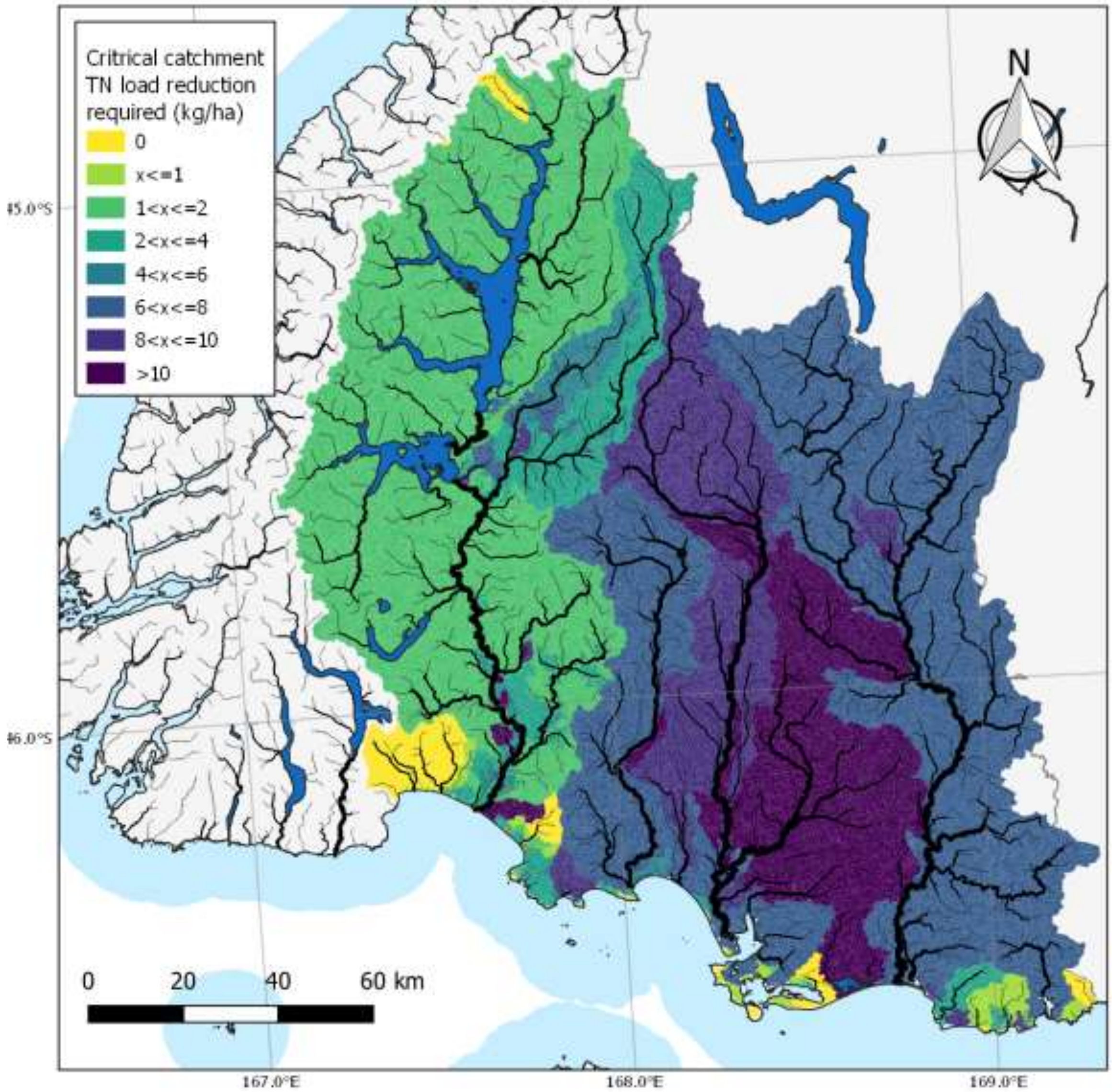

Figure 29. The TN load reduction required for the Hauora and 30% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

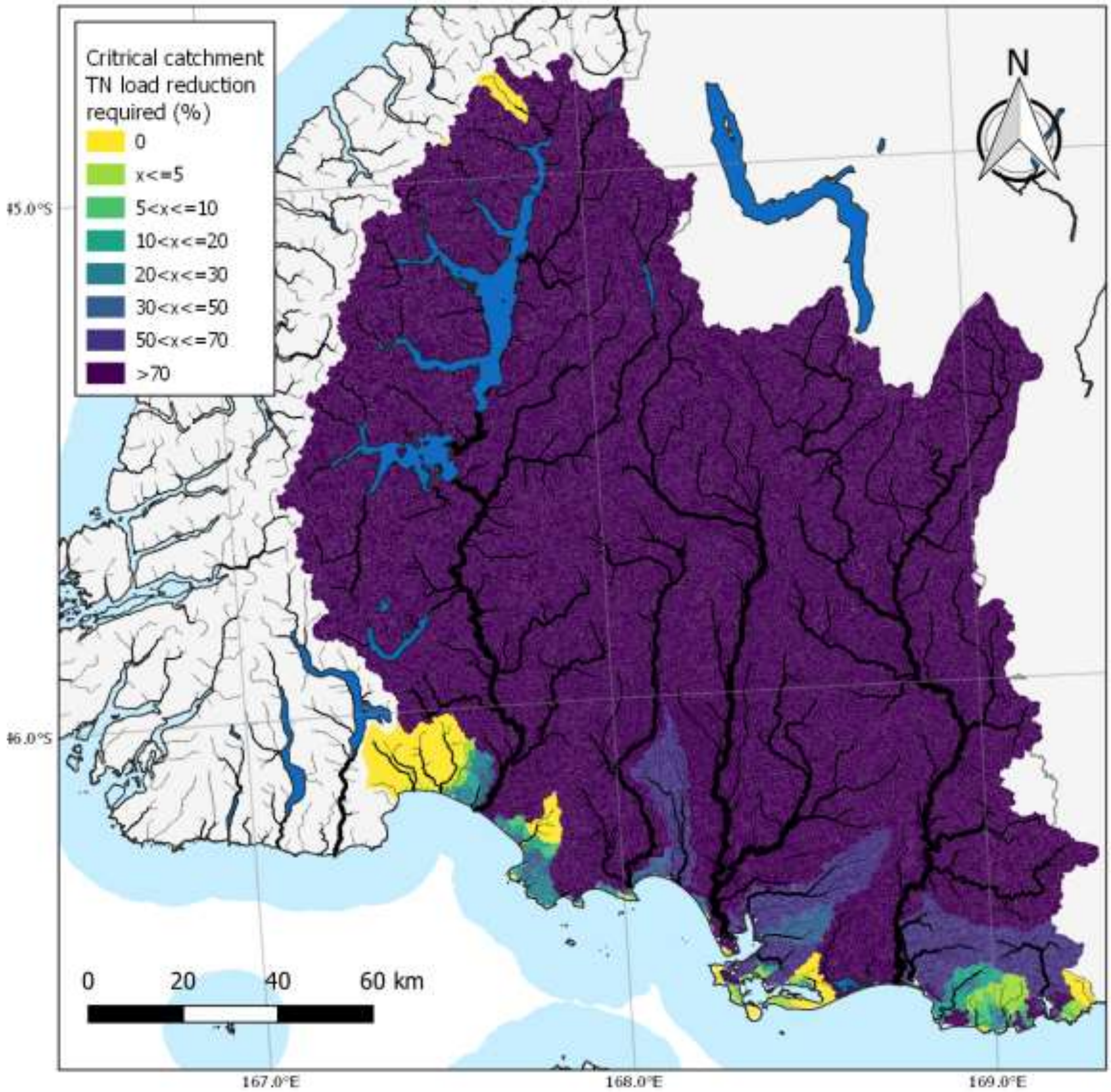

Figure 30. The TN load reduction required for the Hauora and 30% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

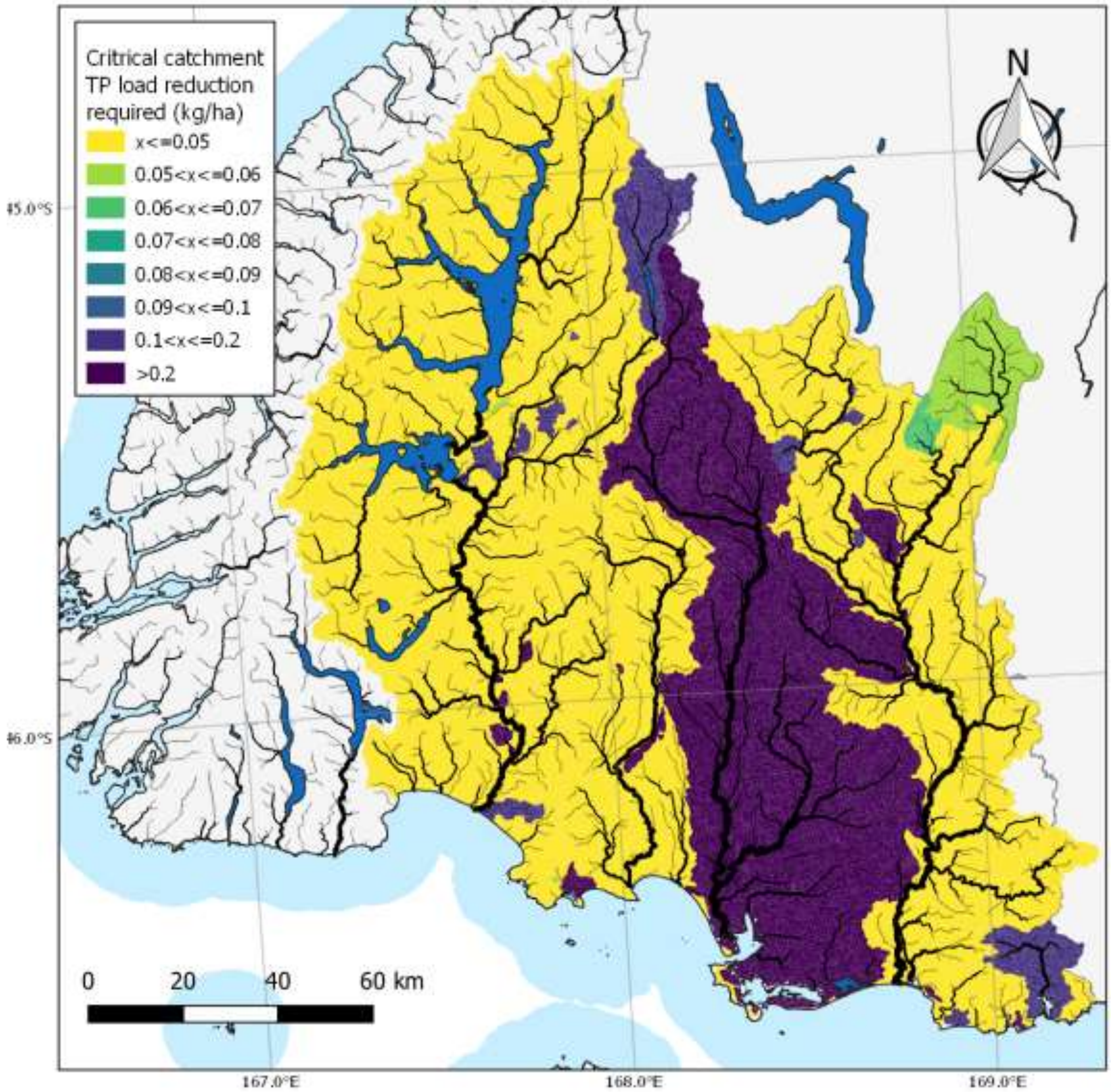

Figure 31. The TP load reduction required for the Hauora and 30% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

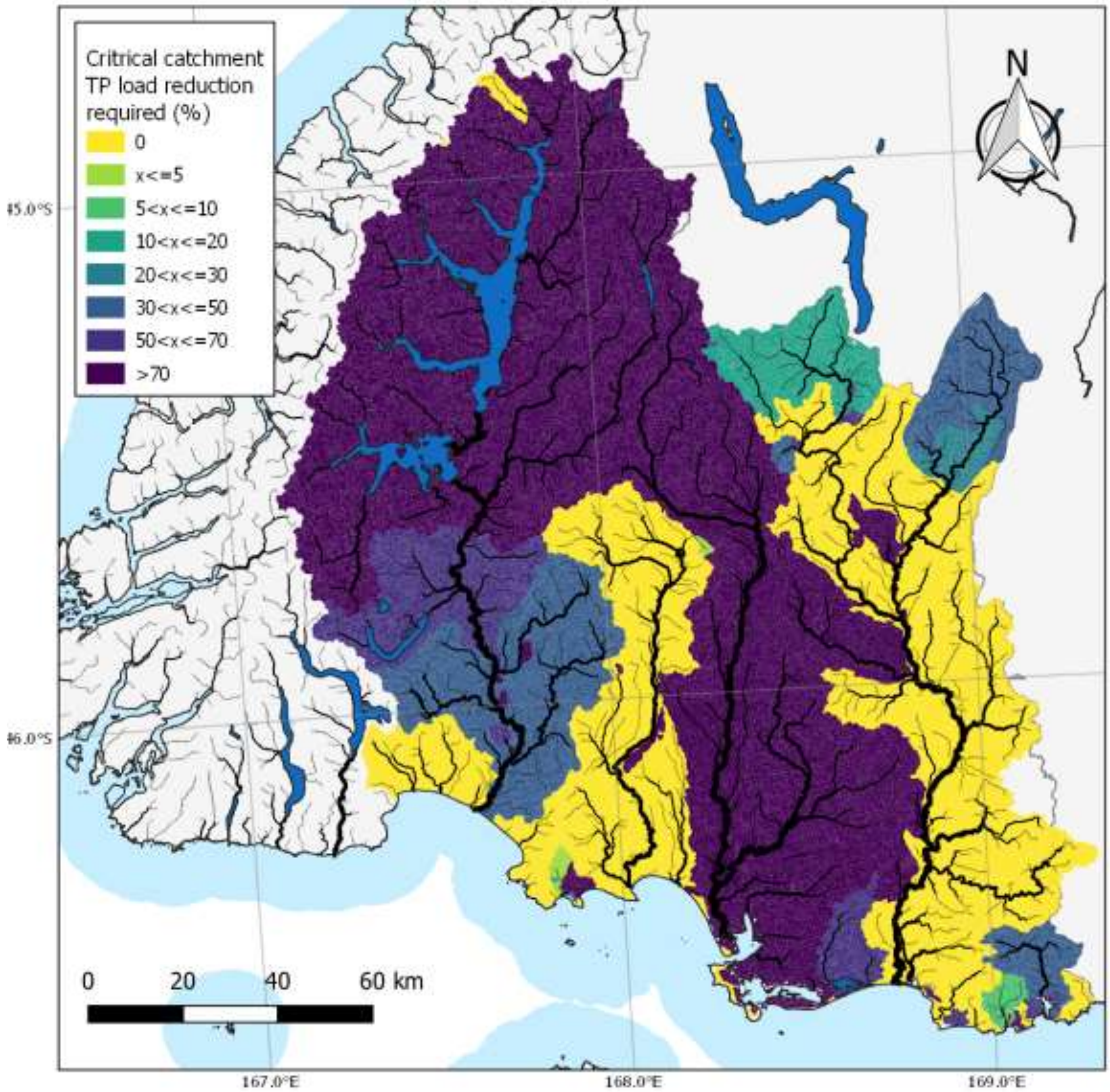

Figure 32. The TP load reduction required for the Hauora and 30% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for the Hauora and 30% spatial exceedance criteria settings are shown on Figure 33 and Figure 34 for TN and TP respectively. For TN, and 66% of the critical point catchment area, the most stringent FWOs (i.e., most demanding of TN load reductions) were for rivers, 33% were for estuaries, and only 1% were for lakes (Figure 33). For TP, and 83% of the critical point catchment area, the most stringent FWOs were for rivers, 16% were for estuaries, and 1% were for lakes (Figure 34).

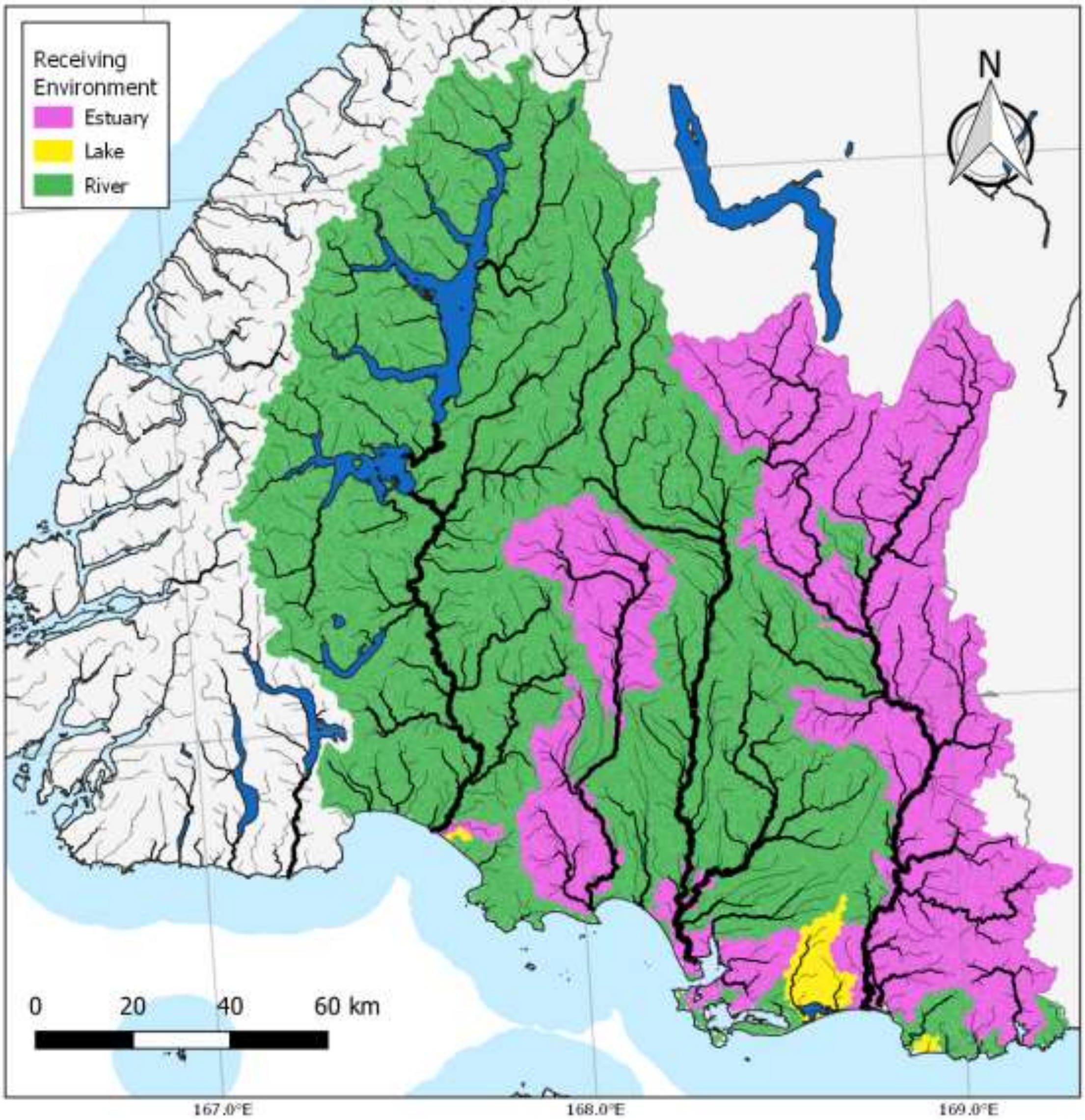

Figure 33. Limiting environment type for TN load reduction required for the Hauora and 30% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TN load reductions).

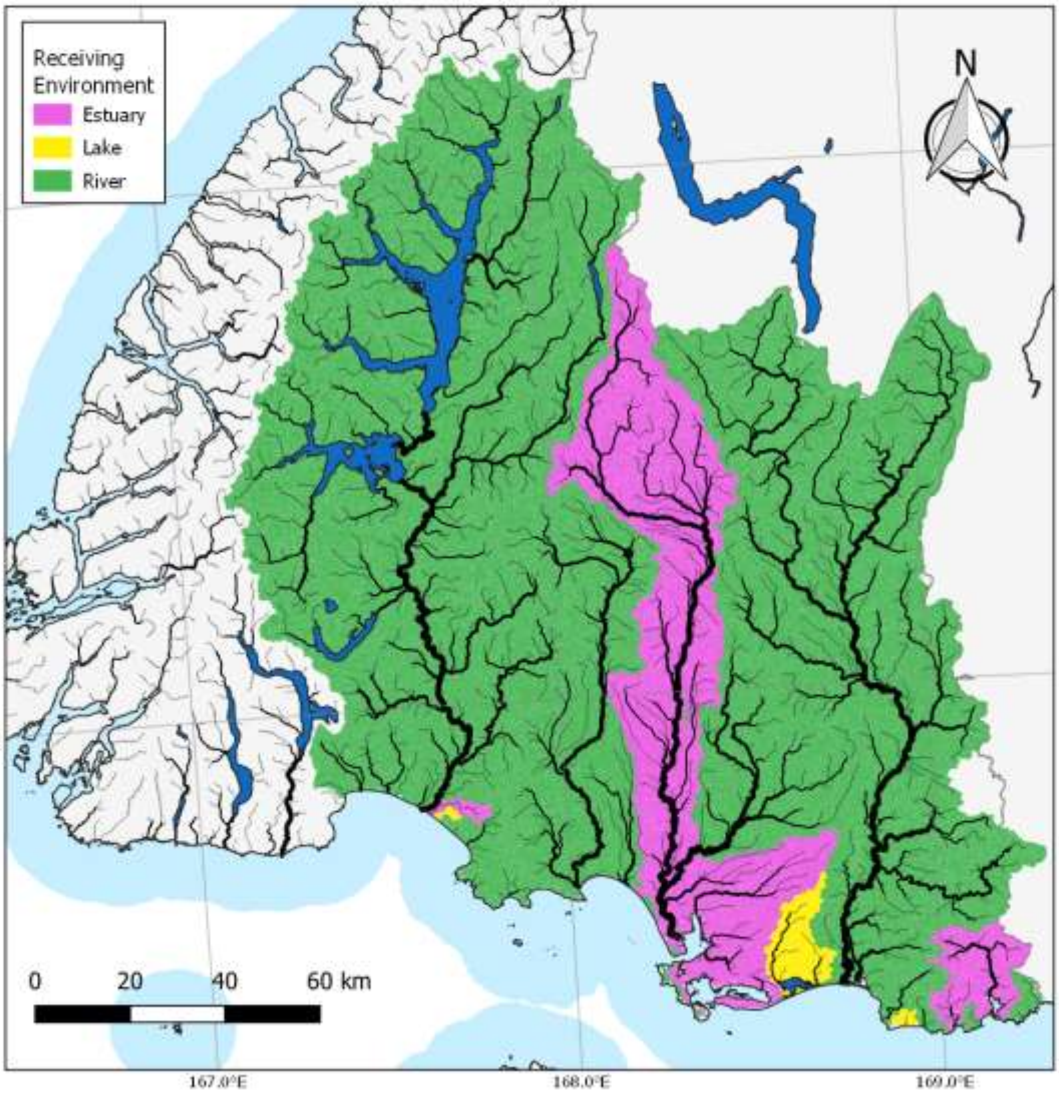

Figure 34. Limiting environment type for TP load reduction required for the Hauora and 30% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TP load reductions).

3.5.4 Reporting catchments and regional load reductions required

The load reductions required by the Hauora and 30% spatial exceedance criteria settings for each reporting catchment and for the whole study area are shown in Table 14. For the whole study area, the TN and TP load reductions required were estimated to be 9,030 t yr^{-1} and 140 t yr^{-1}, which represent 64% and 24% of the current loads respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reduction estimates, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals (Table 14). The 90% confidence interval for the regional TN load reduction requirement extends between 55% and 72% (best estimate 64%) and the regional TP load reduction requirement extends between 14% and 38% (best estimate 24%).

For the Hauora and 30% spatial exceedance criteria settings, the best estimates of TN load reductions required were very high (>60%) in the Waituna Catchments, Ōreti & Invercargill Catchments, Matāura Catchments and Aparima & Pourakino Catchment. The TP load reductions required were highest (≥70%) in Bluff Zone and Ōreti & Invercargill Catchments.

Table 14. Current load and load reduction required for TN and TP by reporting catchment and for the Hauora and 30% spatial exceedance criteria settings including the uncertainties at the 90% level of confidence. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5^{th} and 95^{th} confidence limits for the reported values (i.e., the range is the 90% confidence interval).

Reporting catchment	TN			TP		
	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)
Aparima & Pourakino Catchment	1,400 (665 - 2,517)	1,000 (265 - 2,117)	66 (40 - 84)	42 (21 - 82)	0 (0 - 1)	1 (0 - 1)
Bluff Zone	39 (32 - 51)	1 (0 - 3)	4 (1 - 8)	2 (1 - 2)	2 (1 - 2)	93 (90 - 95)
Caitlins Zone	21 (16 - 29)	0 (0 - 3)	2 (0 - 12)	1 (1 - 2)	0 (0 - 0)	0 (0 - 0)
Mataura Catchments	4,532 (2,443 - 7,174)	3,637 (1,548 - 6,279)	78 (63 - 88)	178 (84 - 309)	10 (3 - 21)	5 (3 - 7)
Orepuki Coastal Zone	226 (184 - 282)	88 (47 - 136)	38 (25 - 49)	7 (5 - 9)	1 (0 - 1)	11 (6 - 18)
Ōreti & Invercargill Catchments	3,603 (2,055 - 5,573)	2,305 (1,022 - 4,192)	62 (48 - 75)	113 (67 - 179)	88 (43 - 154)	76 (64 - 86)
Te Waewae Bay Western Coastal Zone	114 (84 - 152)	1 (0 - 4)	1 (0 - 3)	5 (3 - 7)	0 (0 - 0)	0 (0 - 0)
Tokanui Coastal Zone	215 (156 - 304)	45 (18 - 111)	20 (9 - 42)	9 (6 - 12)	1 (0 - 2)	9 (3 - 19)
Waiau Catchment	2,787 (1,496 - 4,962)	1,275 (47 - 2,984)	42 (2 - 68)	188 (72 - 361)	24 (0 - 108)	9 (0 - 43)
Waikawa Catchment	258 (155 - 407)	152 (49 - 300)	54 (31 - 74)	12 (6 - 19)	5 (0 - 12)	34 (0 - 63)
Waimatuku & Taunamau Catchments	336 (182 - 568)	176 (36 - 380)	48 (20 - 72)	8 (4 - 13)	0 (0 - 0)	1 (1 - 2)
Waituna Catchments	237 (101 - 379)	217 (81 - 359)	90 (80 - 95)	8 (4 - 13)	5 (1 - 10)	59 (28 - 78)
Total	13,999 (10,705 - 17,226)	9,030 (6,242 - 12,172)	64 (55 - 72)	576 (421 - 783)	140 (76 - 244)	24 (14 - 38)

The load reductions required for the Hauora and 30% spatial exceedance criteria settings for the eight estuaries and the three brackish lakes are shown in Table 15. The table also shows the load reductions required to achieve all river and lake FWOs in the catchment of each estuary and brackish lake.

Table 15 indicates that for seven of the 11 estuaries and brackish lakes, the TN load reductions required to achieve the FWOs under the Hauora settings and 30% spatial exceedance are of greater magnitude for the estuary or brackish lake compared to the river and lake FWOs in the catchment. Exceptions to this are the Waimatuku, Haldane, Bluff/Awarua and Waiau estuaries which all have zero or small TN load reductions required for the estuary, but significant reductions required for river FWOs in their catchments. The Waimatuku and Waiau estuaries have zero TN load reductions required because they have low salinity and low flushing time, which indicates that they are unlikely to sustain high macroalgae or phytoplankton (see Appendix B, Table 27). In contrast, the Waikawa estuary and the three coastal lakes (Lake Brunton and Waituna and Te Waewae lagoons) require significantly greater reductions to achieve the estuary/coastal lake FWOs than for the river FWOs in their catchments.

Table 15 indicates variation in the TP load reductions required to achieve the FWOs for estuaries and brackish lakes compared to the river and lake FWOs in the catchment. The TP load reductions required for Waimatuku, Toetoes, Jacobs River and Waiau estuaries are zero because the flushing times of these estuaries are too short to sustain phytoplankton blooms (see Appendix B, Table 27).

Table 15. Load reductions required to achieve estuary and brackish lake FWOs and FWOs for rivers and lakes in their upstream catchment for the Hauora and 30% spatial exceedance criteria settings.

Estuary	TN load reduction required (t yr^{-1})		TP load reduction required (t yr^{-1})	
	Estuary	Lakes and rivers	Estuary	Lakes and rivers
Waimatuku	0 (0 - 0)	166 (31 - 376)	0 (0 - 0)	0 (0 - 0)
Waikawa	152 (49 - 300)	21 (0 - 86)	5 (0 - 12)	0 (0 - 0)
Haldane	1 (0 - 15)	3 (0 - 9)	0 (0 - 2)	0 (0 - 0)
Lake Brunton	14 (6 - 23)	3 (0 - 13)	0 (0 - 1)	0 (0 - 0)
Toetoes	3,637 (1,548 - 6,279)	1,581 (353 - 3,439)	0 (0 - 0)	10 (3 - 21)
Waituna Lagoon	217 (81 - 359)	51 (0 - 153)	5 (1 - 10)	0 (0 - 0)
Bluff/Awarua	0 (0 - 0)	2 (0 - 3)	2 (1 - 2)	0 (0 - 0)
New River	2,411 (892 - 4,304)	1,962 (1,055 - 2,994)	92 (46 - 160)	25 (1 - 51)
Jacobs River	1,000 (265 - 2,117)	278 (7 - 1,147)	0 (0 - 0)	0 (0 - 1)
Waiau	0 (0 - 0)	1,272 (43 - 2,982)	0 (0 - 0)	24 (0 - 108)
Te Waewae Lagoon	39 (19 - 69)	4 (0 - 14)	0 (0 - 1)	0 (0 - 0)

3.6 pSWLP and 20% spatial exceedance settings

3.6.1 Compliance

Current river concentrations of TN, and DRP had a greater than 50% probability of exceeding the pSWLP and 20% spatial exceedance criteria settings associated with periphyton objectives (i.e., were non-compliant) for 59% and 55% of segments in the study area that were not in the Natural State management class, respectively (Figure 35). Current river concentrations of NO3N had a greater than 50% probability of exceeding the pSWLP settings associated with nitrate toxicity FWO for 0.6% of segments that were not in the Natural State management class. However, the probability that nitrate toxicity is a more limiting FWO than periphyton did not exceed 50% for any river segments (Figure 35).

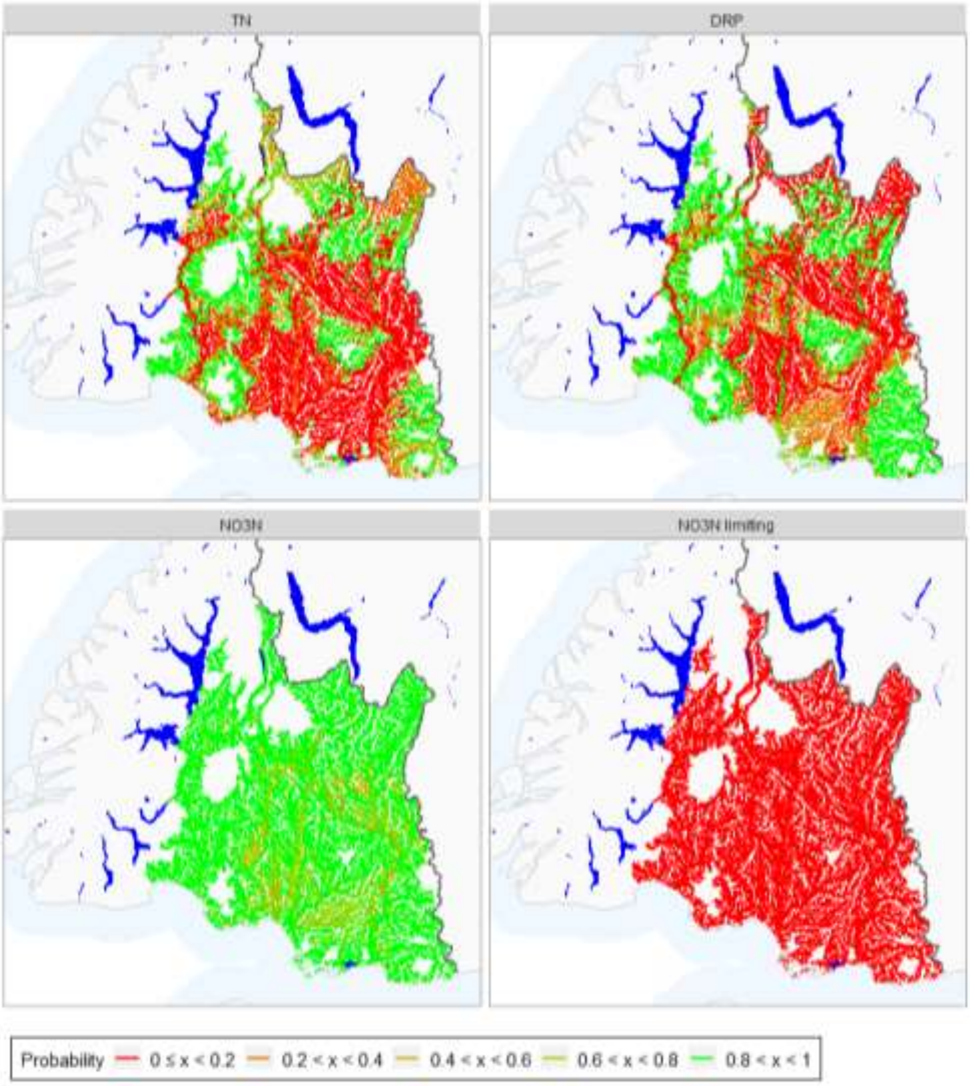

Figure 35. Probability that segments comply with river TN and DRP concentration criteria associated with the periphyton objectives (top left and right) and NO3N concentration criteria associated with the toxicity objectives (lower left) for the pSWLP and 20% spatial exceedance criteria settings. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton (for these settings, this was true for 0.01% of segments).

The probability the current loads of TN and TP complied with the pSWLP standards and 20% spatial exceedance criteria for rivers and lakes was less than 50% (i.e., were non-compliant) for 58% and 55% of segments in the study area that were not in the Natural State management class, respectively (Figure 36).

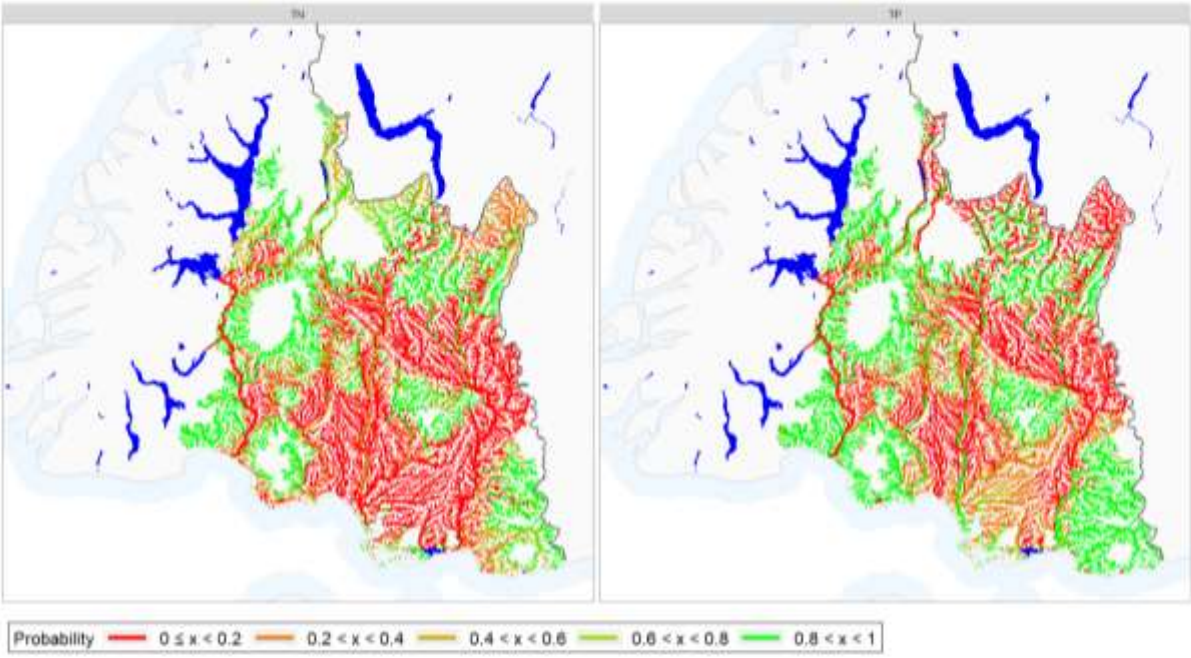

Figure 36. Probability that current nitrogen and phosphorus loads comply with criteria for both rivers and lakes for the pSWLP standards and 20% spatial exceedance criteria.

The probability that current lake TN and TP loads complied with the pSWLP standards was less than 50% (i.e., were non-compliant) for 17 and 13 of the 21 lakes that were not in the Natural State class, respectively (Figure 37).

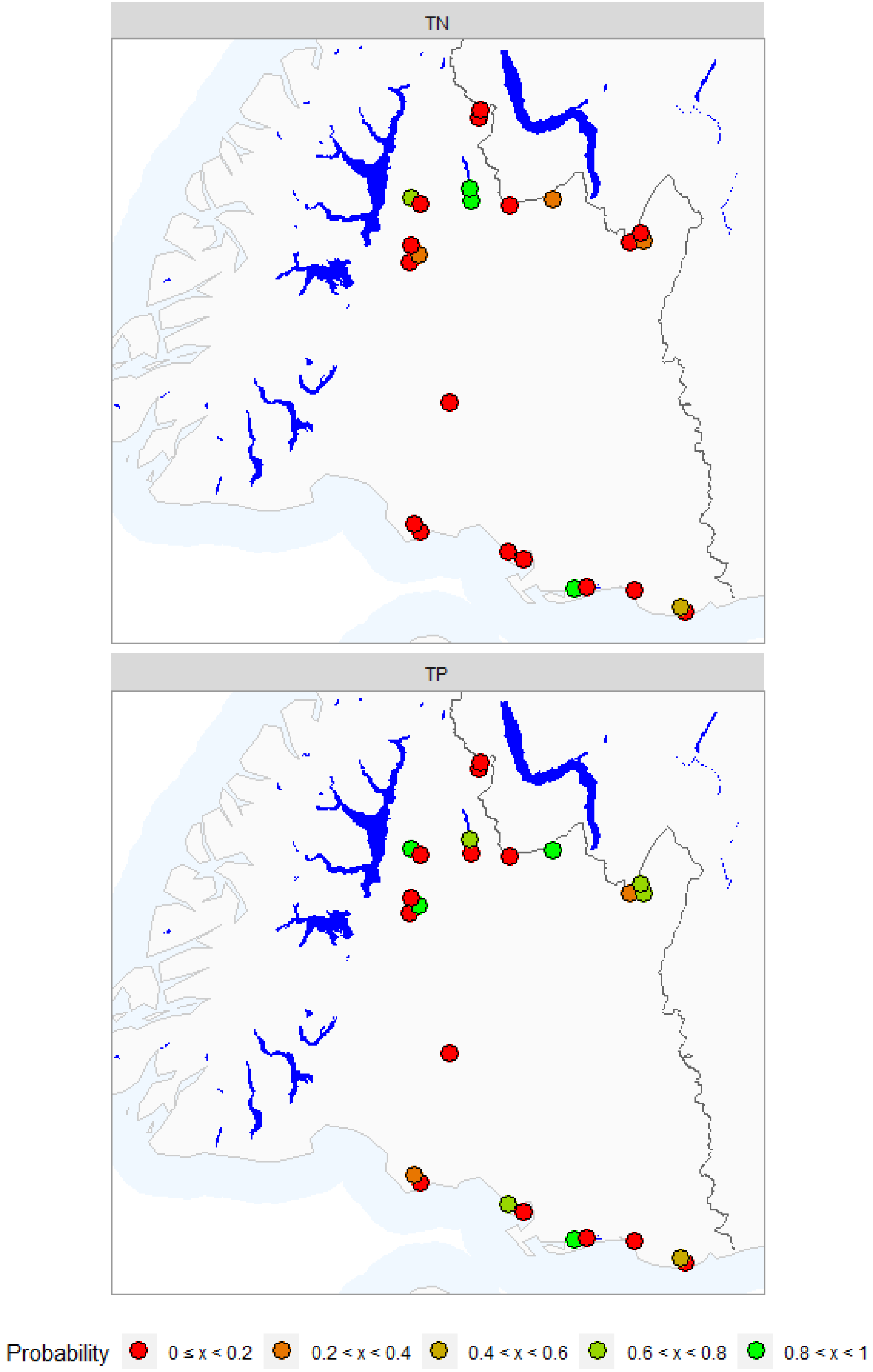

Figure 37. Probability of compliance with lake TN and TP load criteria associated with the phytoplankton objectives for the pSWLP standards and 20% spatial exceedance criteria.

The probability that current estuary TN loads complied with the pSWLP standards was less than 50% (i.e., were non-compliant) for 4 of the 8 estuaries (Figure 38). The probability that current estuary TP loads complied with the pSWLP standards was less than 50% (i.e., were non-compliant) for 4 of the 8 estuaries (Figure 38).

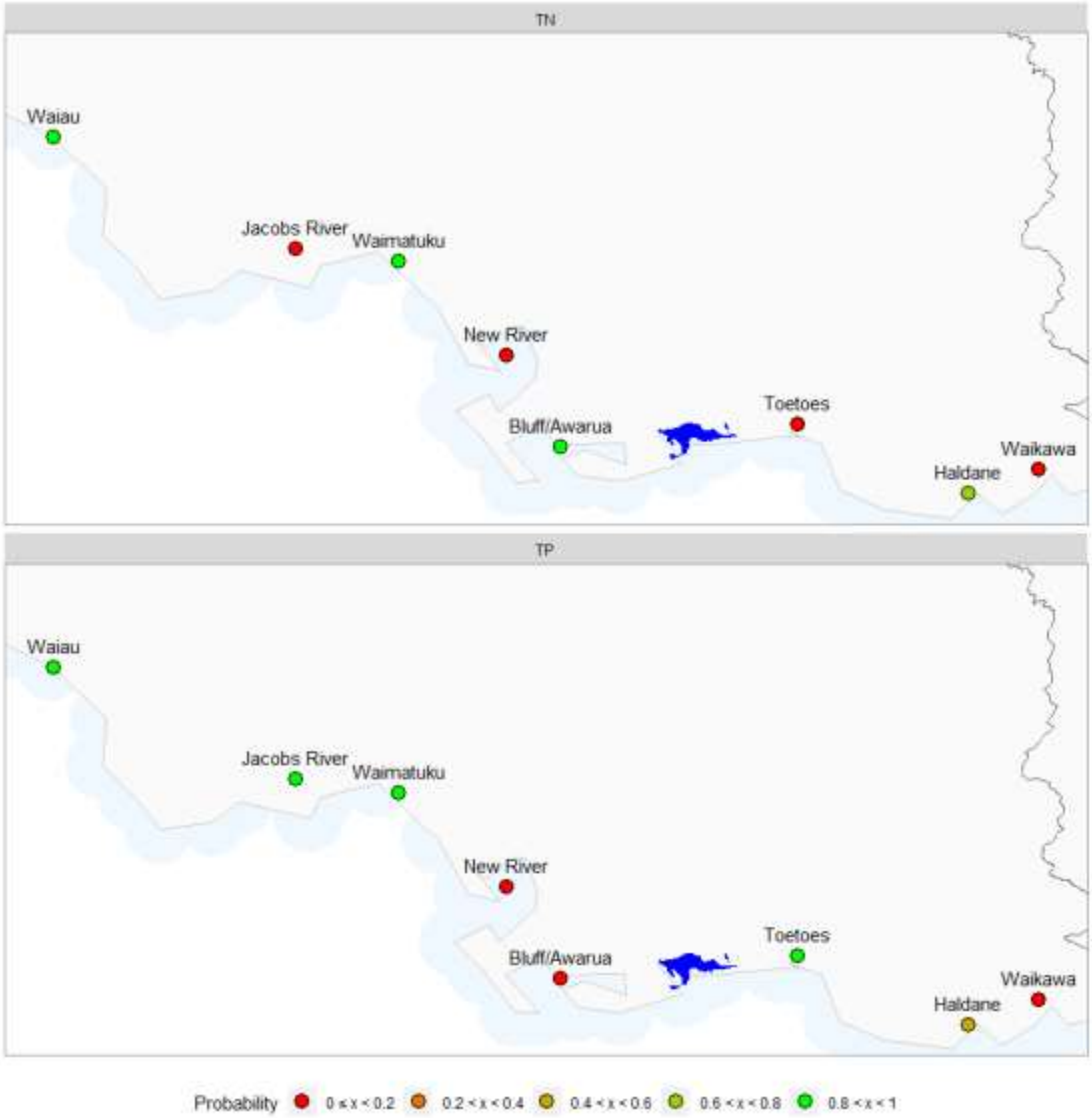

Figure 38. Probability of compliance with estuary TN and TP concentration criteria associated with the phytoplankton and macroalgae objectives for the pSWLP standards.

3.6.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the pSWLP standards and 20% spatial exceedance, local excess TN loads for rivers exceeded 5 kg ha^{-1} yr^{-1} for 20% of river segments and exceeded 10 kg ha^{-1} yr^{-1} for 1% of river segments (Figure 39). Note that the 5 and 10 kg ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 39. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 45% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

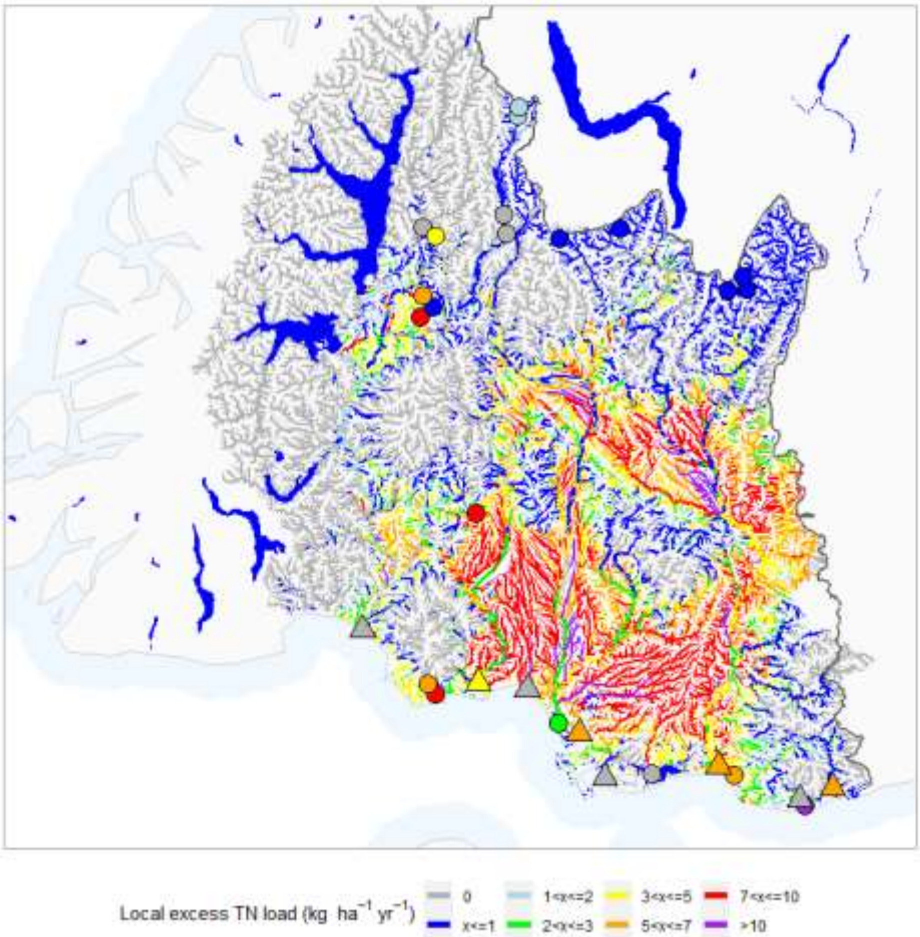

Figure 39. Local excess TN loads for rivers, lakes and estuaries for the pSWLP and 20% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the pSWLP and 20% spatial exceedance criteria settings, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 29% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 4.7% of river segments (Figure 40). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 44% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

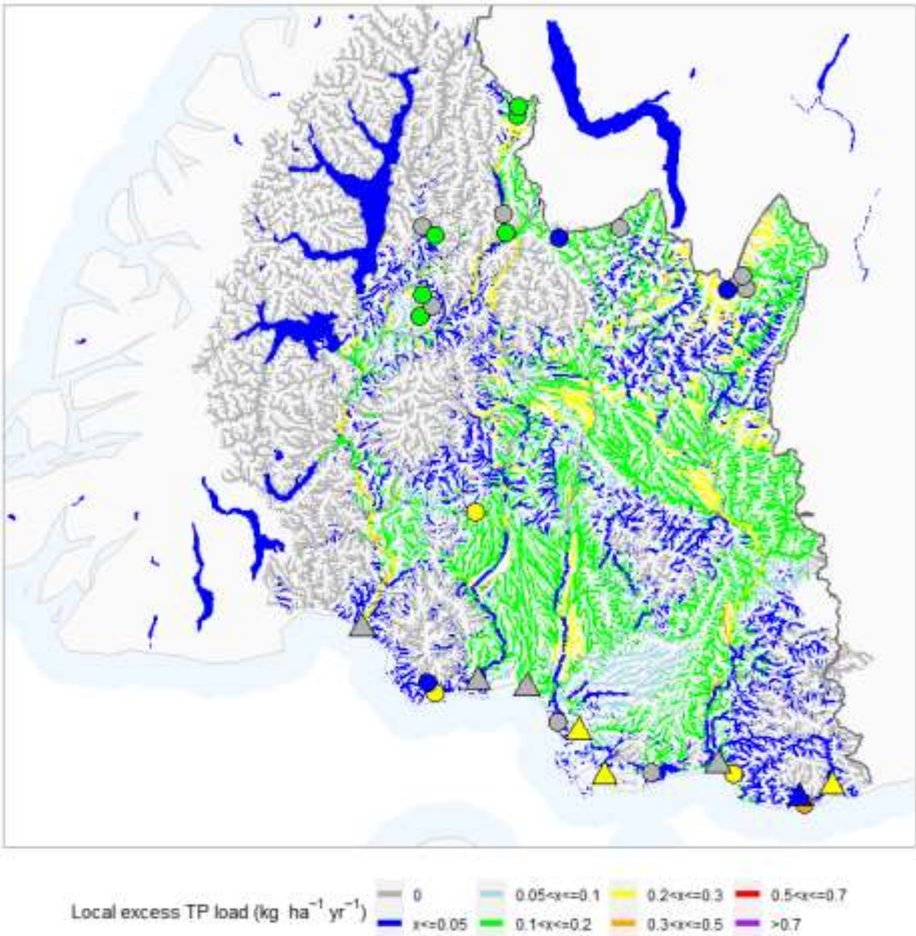

Figure 40. Local excess TP loads for rivers, lakes and estuaries for pSWLP and 20% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.6.3 Critical point catchments and catchment status

The critical point catchment status is the load reduction that ensures the loads for all receiving environments in the catchment do not exceed the MAL (and therefore all FWOs in the catchment to be achieved). The load reductions required therefore differ from the local excess loads Figure 39 and Figure 40) in that they consider all receiving environments in a critical point catchment. The load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The TN load reductions required by the pSWLP and 20% spatial exceedance criteria settings for critical point catchments are shown on Figure 41 and Figure 42. Critical point catchments that required TN load reductions of greater than 10 kg ha^{-1} yr^{-1} occupied 14% of the study area and critical point catchments with TN load reductions of less than 2 kg ha^{-1} yr^{-1} occupied 3% of the study area (Figure 41). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 70% occupied 90% of the study area (Figure 42Figure 20).

Critical point catchments that require TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 91% of the study area and critical point catchments with TP load reductions of less than 0.07 kg ha^{-1} yr^{-1} occupied 8% of the study area (Figure 43). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 70% occupied 83% of the study (Figure 44). As for TN, critical point catchments with low load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

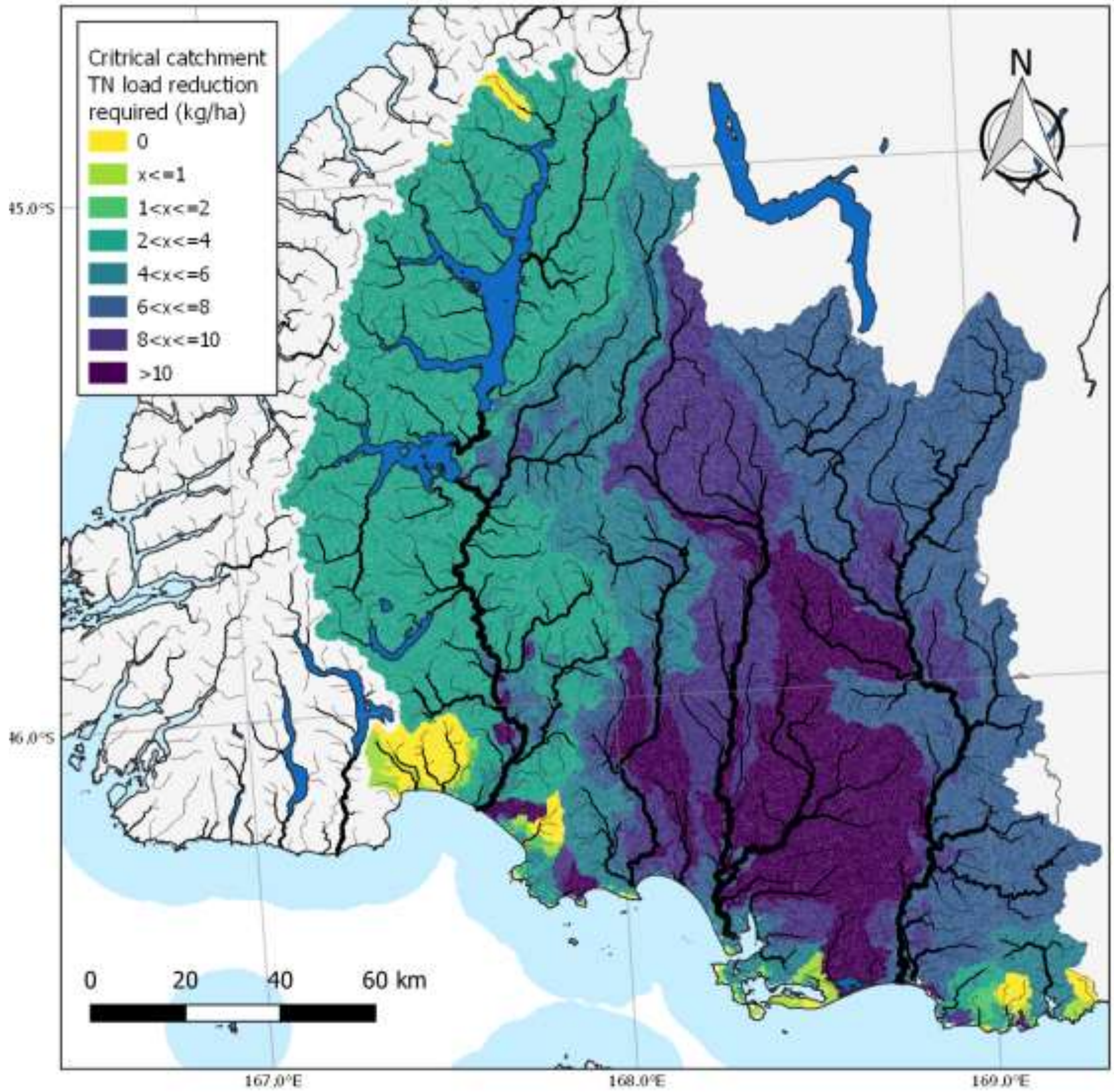

Figure 41. The TN load reduction required for the pSWLP and 20% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

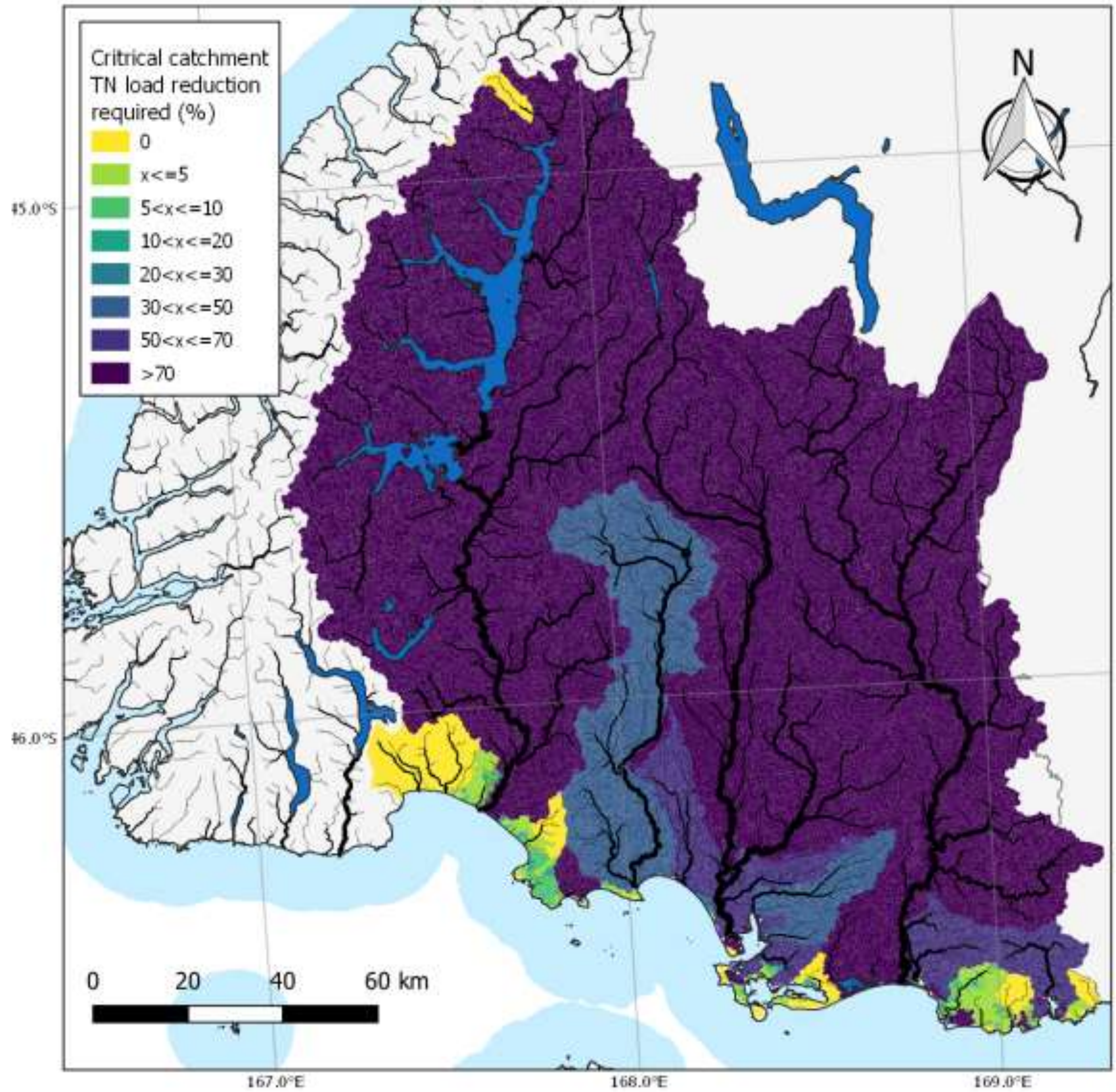

Figure 42. The TN load reduction required for the pSWLP and 20% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

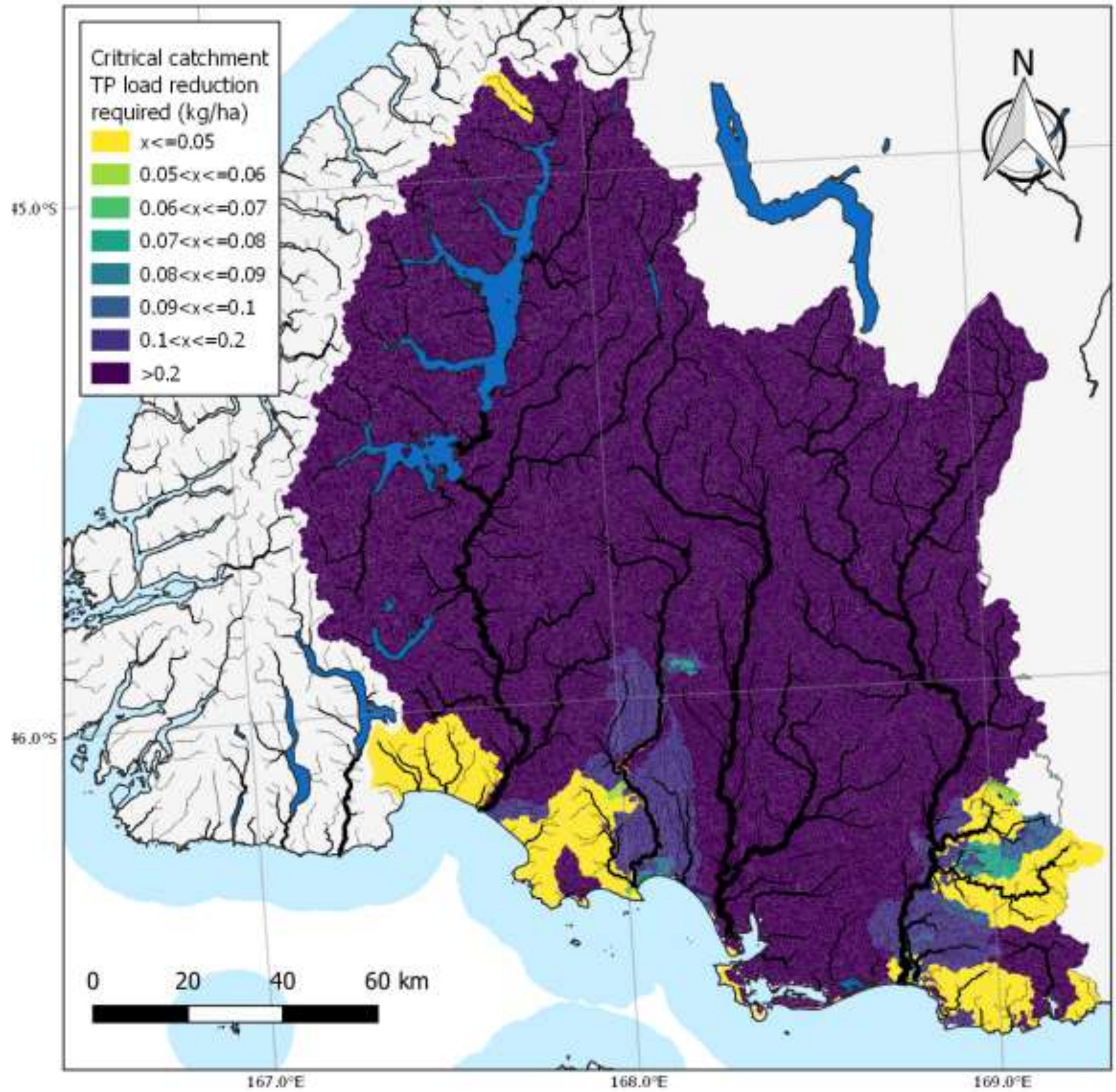

Figure 43. The TP load reduction required for the pSWLP and 20% spatial exceedance criteria settings for critical point catchments, expressed as yields (kg/ha/yr). The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

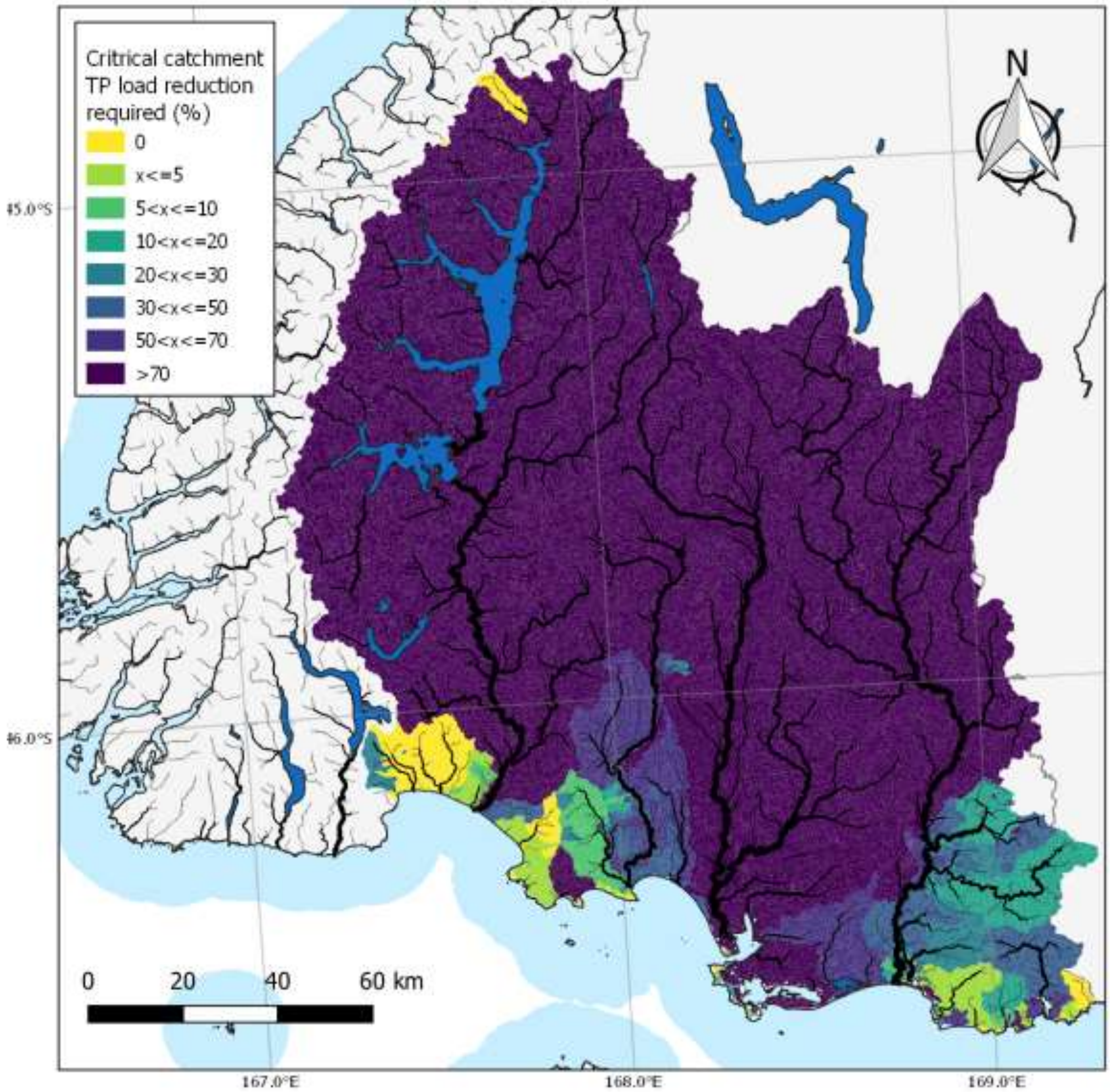

Figure 44. The TP load reduction required for the pSWLP and 20% spatial exceedance criteria settings, expressed as proportion of the current load (%), for critical point catchments. The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for the pSWLP and 20% spatial exceedance criteria settings are shown on Figure 45 and Figure 46 for TN and TP respectively. For TN, and 78% of the critical point catchment area, the most stringent FWOs (i.e., most demanding of TN load reductions) were for rivers, 21% were for estuaries, and only 1% were for lakes (Figure 45). For TP, and 93% of the critical point catchment area, the most stringent FWOs were for rivers, 6% were for estuaries, and 1% were for lakes (Figure 46).

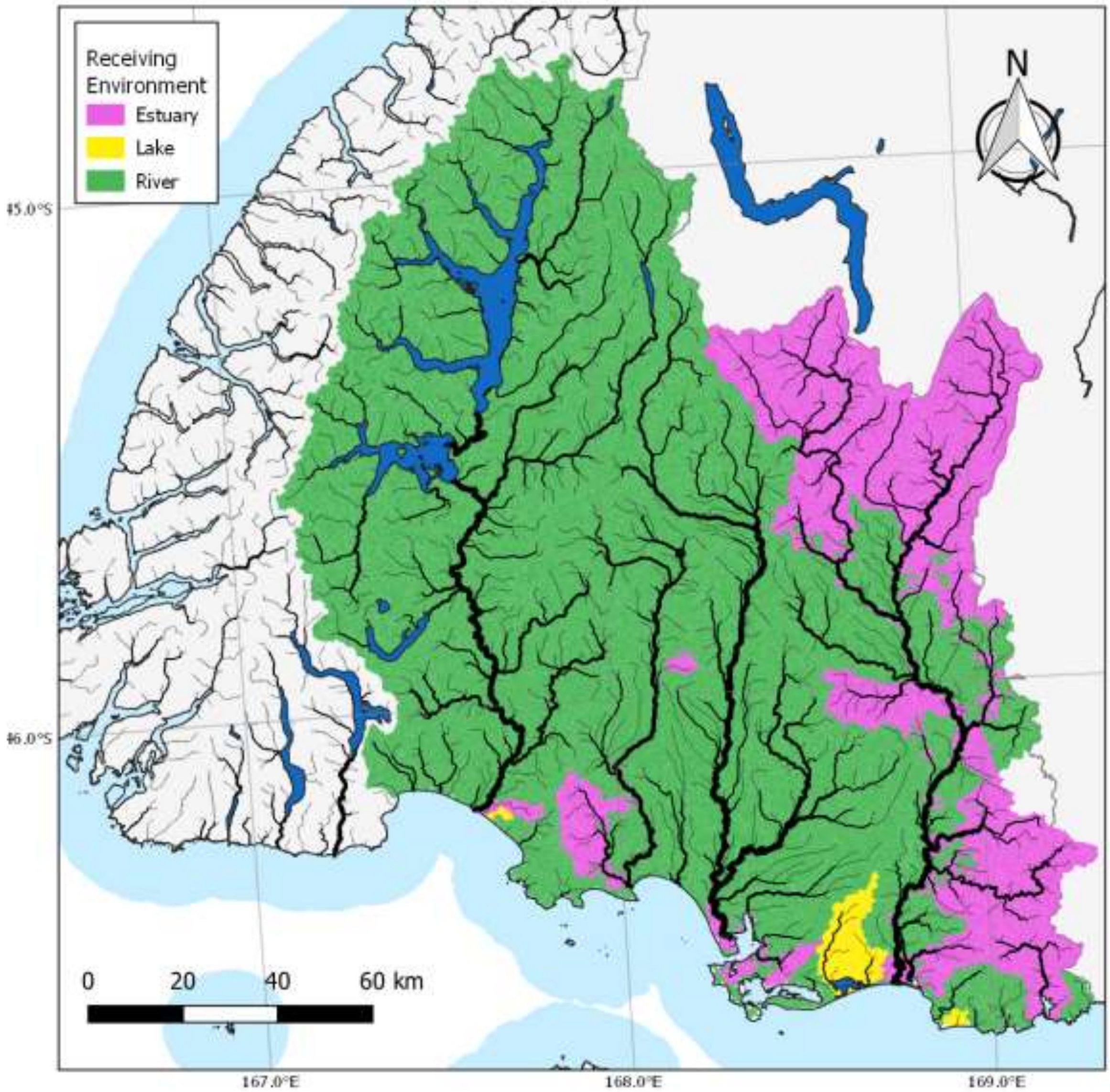

Figure 45. Limiting environment type for TN load reduction required for the pSWLP and 20% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TN load reductions).

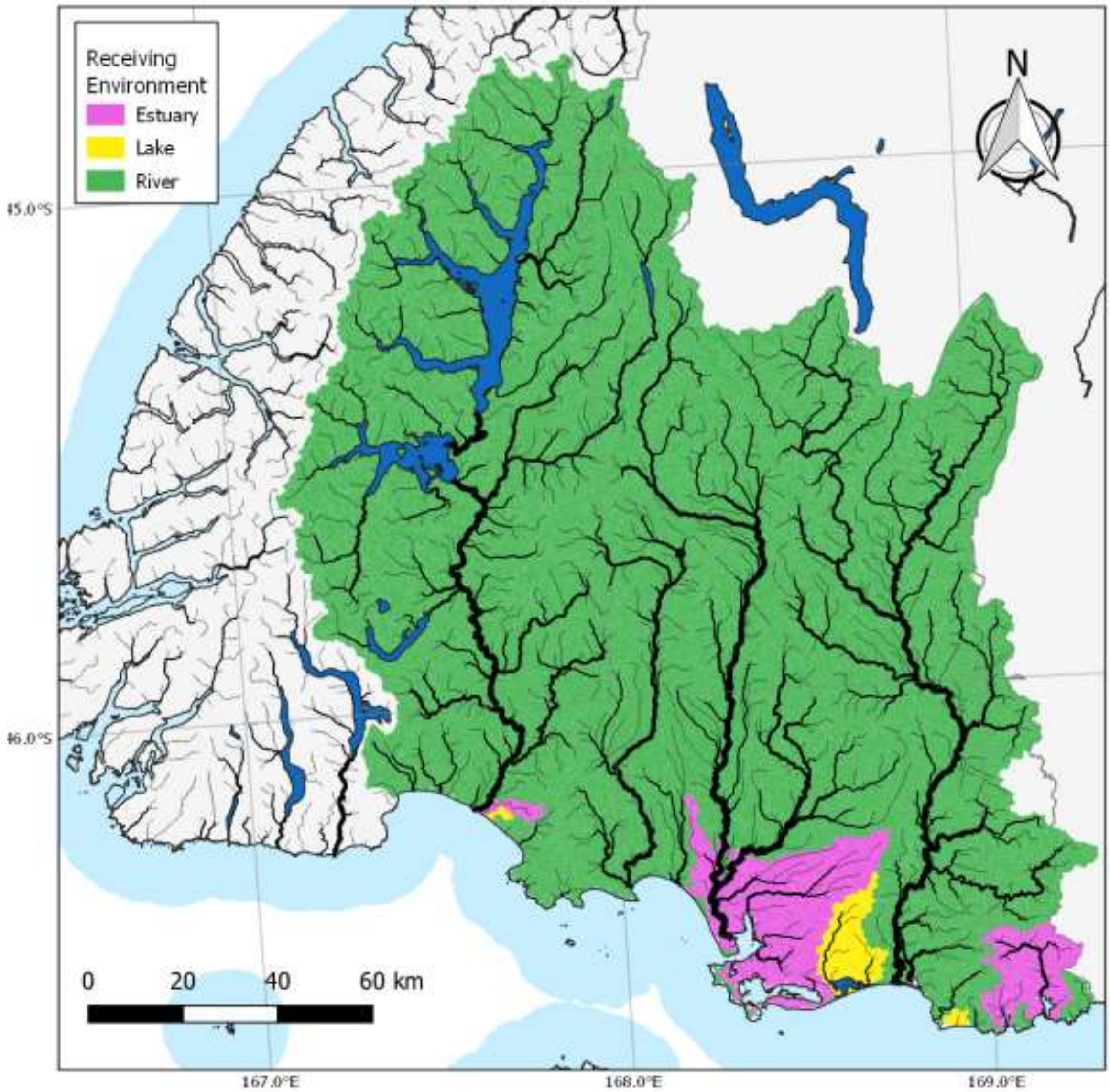

Figure 46. Limiting environment type for TP load reduction required for the pSWLP and 20% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TP load reductions).

3.6.4 Reporting catchments and regional load reductions required

The load reductions required by the pSWLP and 20% spatial exceedance criteria settings for each reporting catchment and for the whole study area are shown in Table 16. For the whole study area, the TN and TP load reductions required were estimated to be 9,400 t yr^{-1} and 578 t yr^{-1}, which represent 66% and 69% of the current loads respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reduction estimates, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 16. The uncertainties indicate, for example that the 90% confidence interval for the regional load of TN extends between 6,102 t yr^{-1} and 13,091 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 58% and 74% (best estimate 66%) and the regional TP load reduction requirement extends between 59% and 77% (best estimate 69%).

For the pSWLP and 20% spatial exceedance criteria settings, the best estimates of TN load reductions required were very high (>65%) in the Waituna Catchments, Waimatuku & Taunamau Catchments, Waiau Catchment, and Mataura Catchments. The TP load reductions required were highest (≥60%) in Bluff Zone, Ōreti & Invercargill Catchments, and Waiau Catchment.

Table 16. Current load and load reduction required for TN and TP by reporting catchment and for the pSWLP and 20% spatial exceedance criteria settings including the uncertainties at the 90% level of confidence. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5^{th} and 95^{th} confidence limits for the reported values (i.e., the range is the 90% confidence interval).

Reporting catchment	TN			TP		
	Current load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**	**Current load (t yr^{-1})**	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Aparima & Pourakino Catchments	1,425 (646 - 2,587)	755 (69 - 1,880)	45 (10 - 73)	45 (22 - 75)	16 (4 - 31)	34 (10 - 44)
Bluff Zone	38 (31 - 50)	6 (3 - 9)	14 (9 - 21)	2 (1 - 2)	2 (1 - 2)	94 (91 - 96)
Catlins Zone	21 (16 - 28)	0 (0 - 2)	2 (0 - 5)	1 (1 - 2)	0 (0 - 0)	0 (0 - 1)
Mataura Catchments	4,628 (2,565 - 8,176)	3,734 (1,671 - 7,282)	78 (65 - 89)	182 (77 - 327)	110 (36 - 223)	58 (39 - 70)
Orepuki Coastal Zone	228 (180 - 280)	100 (61 - 149)	43 (34 - 53)	7 (5 - 9)	2 (1 - 3)	27 (14 - 42)
Ōreti & Invercargill Catchments	3,487 (2,081 - 5,043)	2,145 (1,170 - 3,507)	60 (54 - 69)	106 (50 - 190)	81 (27 - 164)	73 (53 - 86)
Te Waewae Bay Western Coastal Zone	110 (80 - 142)	1 (0 - 4)	1 (0 - 3)	5 (3 - 6)	0 (0 - 0)	3 (0 - 7)
Tokanui Coastal Zone	225 (161 - 299)	49 (17 - 106)	20 (9 - 37)	9 (6 - 12)	1 (0 - 2)	11 (4 - 26)
Waiau Catchment	2,782 (1,389 - 4,863)	1,893 (608 - 3,934)	65 (43 - 82)	188 (100 - 290)	174 (90 - 272)	92 (89 - 95)
Waikawa Catchment	250 (147 - 425)	142 (39 - 316)	52 (26 - 75)	12 (7 - 21)	5 (0 - 14)	35 (0 - 67)
Waimatuku & Taunamau Catchments	332 (183 - 563)	233 (84 - 453)	68 (52 - 82)	8 (4 - 13)	3 (0 - 8)	43 (9 - 69)
Waituna Catchments	242 (134 - 386)	221 (114 - 366)	91 (85 - 95)	8 (4 - 14)	5 (1 - 11)	60 (28 - 80)
Total	13,995 (11,022 - 17,697)	9,400 (6,102 - 13,091)	66 (58 - 74)	578 (424 - 776)	404 (255 - 585)	69 (59 - 77)

The load reductions required for the pSWLP and 20% spatial exceedance criteria settings for the eight estuaries and the three brackish lakes are shown in Table 17. The table also shows the load reductions required to achieve all river and lake FWOs in the catchment of each estuary and brackish lake.

Table 17 indicates that for six of the 11 estuaries and brackish lakes, the TN load reductions required to achieve the FWOs under the pSWLP settings and 20% spatial exceedance are of greater magnitude for the estuary or brackish lake compared to the river and lake FWOs in the catchment. Exceptions to this are the Waimatuku, Haldane, Bluff/Awarua, New River and Waiau estuaries which all have zero or small TN load reductions required for the estuary, but significant reductions required for river FWOs in their catchments. The Waimatuku and Waiau estuaries have zero TN load reductions required because they have low salinity and low flushing time, which indicates that they are unlikely to sustain high macroalgae or phytoplankton (see Appendix B, Table 27). In contrast, the Waikawa estuary and the three coastal lakes (Lake Brunton and Waituna and Te Waewae lagoons) require significantly greater reductions to achieve the estuary/coastal lake FWOs than for the river FWOs in their catchments.

Table 17 indicates more variation in the TP load reductions required to achieve the FWOs for estuaries and brackish lakes compared to the river and lake FWOs in the catchment. The TP load reductions required for Waimatuku, Toetoes, Jacobs River and Waiau estuaries are zero because the flushing times of these estuaries are too short to sustain phytoplankton blooms (see Appendix B, Table 27).

Table 17. Load reductions required to achieve estuary and brackish lake FWOs and FWOs for rivers and lakes in their upstream catchment for the pSWLP and 20% spatial exceedance criteria settings.

Estuary	TN load reduction required (t yr^{-1})		TP load reduction required (t yr^{-1})	
	Estuary	Lakes and rivers	Estuary	Lakes and rivers
Waimatuku	0 (0 - 0)	215 (74 - 432)	0 (0 - 0)	3 (0 - 8)
Waikawa	142 (39 - 316)	16 (1 - 101)	5 (0 - 14)	0 (0 - 0)
Haldane	0 (0 - 13)	4 (0 - 10)	0 (0 - 2)	0 (0 - 0)
Lake Brunton	14 (5 - 27)	5 (0 - 13)	0 (0 - 1)	0 (0 - 0)
Toetoes	3,734 (1,670 - 7,281)	2,322 (988 - 4,548)	0 (0 - 0)	110 (36 - 223)
Waituna Lagoon	221 (114 - 366)	94 (18 - 203)	5 (1 - 11)	3 (0 - 8)
Bluff/Awarua	0 (0 - 0)	5 (3 - 9)	2 (1 - 2)	0 (0 - 1)
New River	2,072 (725 - 3,671)	2,115 (1,262 - 3,006)	86 (30 - 168)	53 (25 - 94)
Jacobs River	717 (0 - 1,879)	578 (48 - 1,562)	0 (0 - 0)	16 (4 - 31)
Waiau	0 (0 - 0)	1,889 (607 - 3,930)	0 (0 - 0)	174 (90 - 272)
Te Waewae Lagoon	38 (18 - 64)	3 (0 - 10)	0 (0 - 1)	0 (0 - 0)

3.7 pSWLP and 30% spatial exceedance criteria settings

3.7.1 Compliance

Current river concentrations of TN, and DRP had a greater than 50% probability of exceeding the pSWLP and 30% spatial exceedance criteria settings associated with periphyton objectives (i.e., were non-compliant) for 34% and 1.8% of segments in the study area that were not in the Natural State management class, respectively (Figure 47). Current river concentrations of NO3N had a greater than 50% probability of exceeding the pSWLP settings associated with nitrate toxicity FWO for 0.2% of segments that were not in the Natural State management class. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 0.5% of river segments (Figure 47).

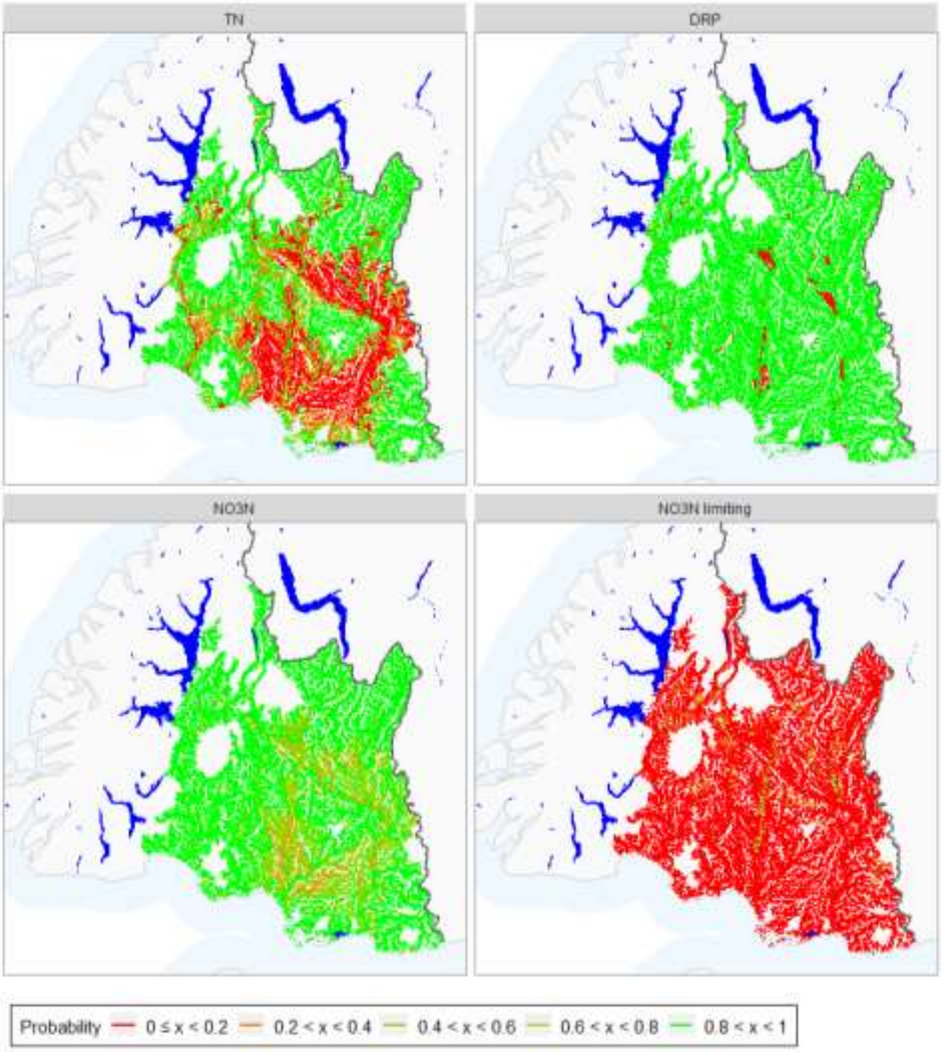

Figure 47. Probability that segments comply with river TN and DRP concentration criteria associated with the periphyton objectives (top left and right) and NO3N concentration criteria associated with the toxicity objectives (lower left) for the pSWLP and 30% spatial exceedance criteria settings. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton (for these settings, this was true for 1% of segments).

The probability the current loads of TN and TP complied with the pSWLP standards and 30% spatial exceedance criteria for rivers and lakes was less than 50% (i.e., were non-compliant) for 34% and 1.7% of segments in the study area that were not in the Natural State management class, respectively (Figure 48).

Compliance estimates for lakes and estuaries for the pSWLP standards and 30% spatial exceedance criteria were the same as for pSWLP standards and 20% spatial exceedance criteria.

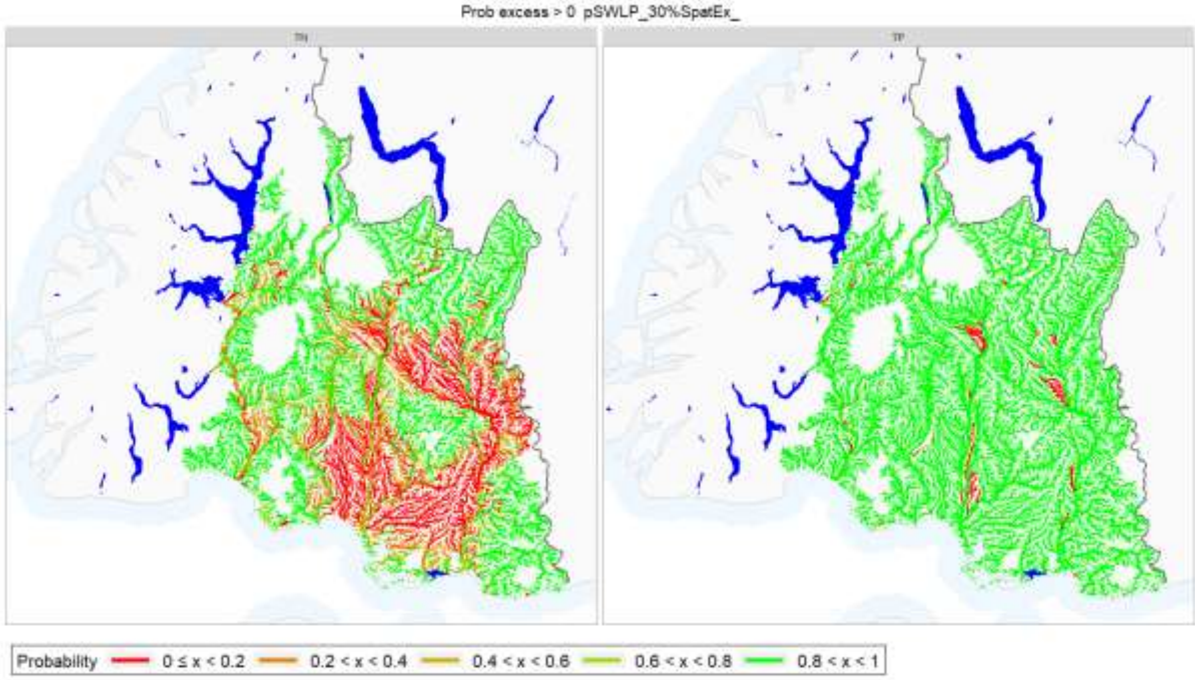

Figure 48. Probability that current nitrogen and phosphorus loads comply with criteria for both rivers and lakes for the pSWLP standards and 30% spatial exceedance criteria.

3.7.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the pSWLP standards and 30% spatial exceedance criteria, local excess TN loads for rivers exceeded 5 kg ha^{-1} yr^{-1} for 4.4% of river segments and exceeded 10 kg ha^{-1} yr^{-1} for 0.7% of river segments (Figure 49). Note that the 5 and 10 kg ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 49. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 50% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

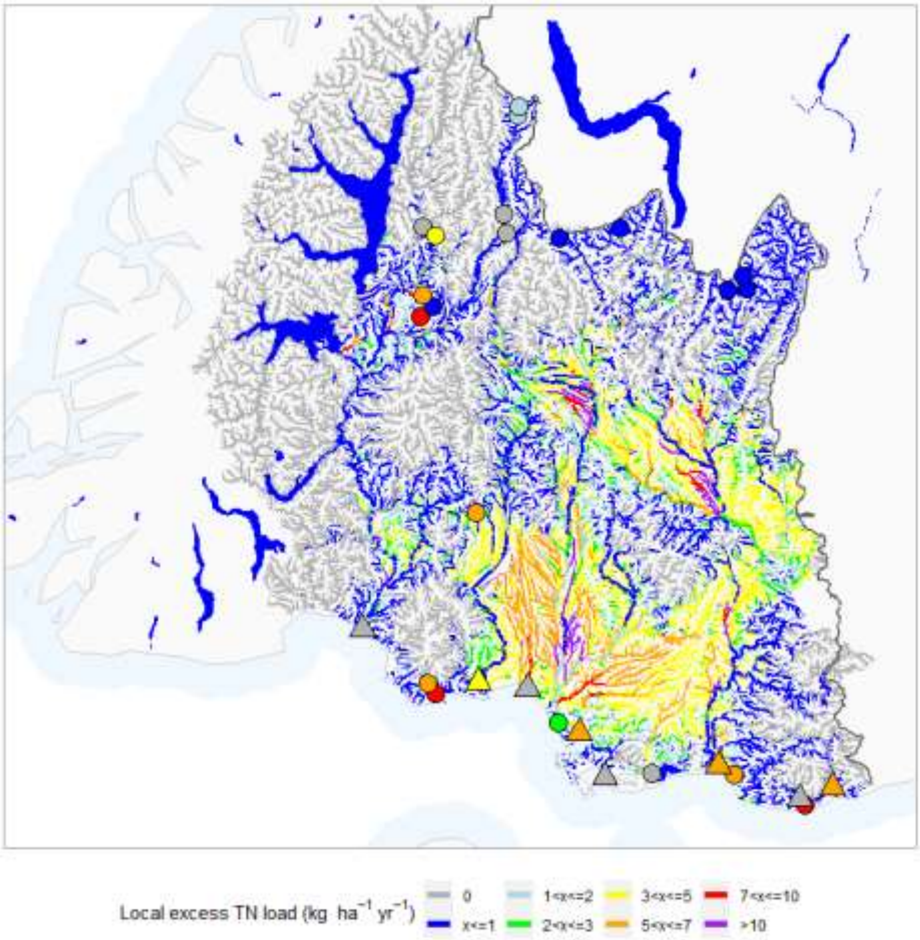

Figure 49. Local excess TN loads for rivers, lakes and estuaries for the pSWLP and 30% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the pSWLP and 30% spatial exceedance criteria settings, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 1.1% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 0.5% of river segments (Figure 50). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 98% of segments; it is noted that 32% of river segments are in the Natural State management class and therefore have no assessment of compliance and no load reduction required.

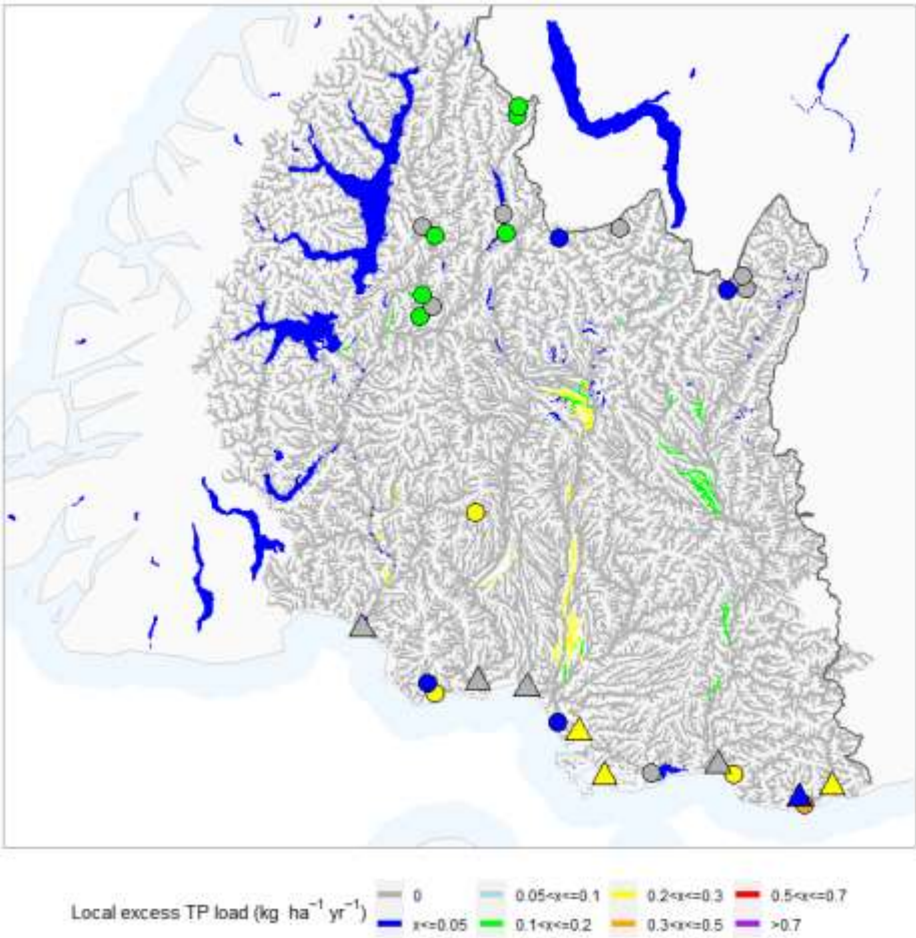

Figure 50. Local excess TP loads for rivers, lakes and estuaries for the pSWLP and 30% spatial exceedance criteria settings. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.7.3 Critical point catchments and catchment status

The critical point catchment status is the load reduction that ensures the loads for all receiving environments in the catchment do not exceed the MAL (and therefore all FWOs in the catchment to be achieved). The load reductions required therefore differ from the local excess loads (Figure 49 and Figure 50) in that they consider all receiving environments in a critical point catchment. The load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The TN load reductions required by the pSWLP and 30% spatial exceedance criteria settings for critical point catchments are shown on Figure *51* and Figure 52. Critical point catchments that required TN load reductions of greater than 10 kg ha^{-1} yr^{-1} occupied 11% of the study area and critical point catchments with TN load reductions of less than 2 kg ha^{-1} yr^{-1} occupied 37% of the study area (Figure 49). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 70% occupied 81% of the study area (Figure 50, Figure 20). The comparison of load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of current load

(%) indicates that reduction requirements in areas with low yield reductions (e.g., much of the headwater areas of all main catchments) are nevertheless large in relative terms.

Critical point catchments that require TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 22% of the study area and critical point catchments with TP load reductions of less than 0.07 kg ha^{-1} yr^{-1} occupied 72% of the study area (Figure 53). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 70% occupied 53% of the study (Figure 54). As for TN, critical point catchments with low load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

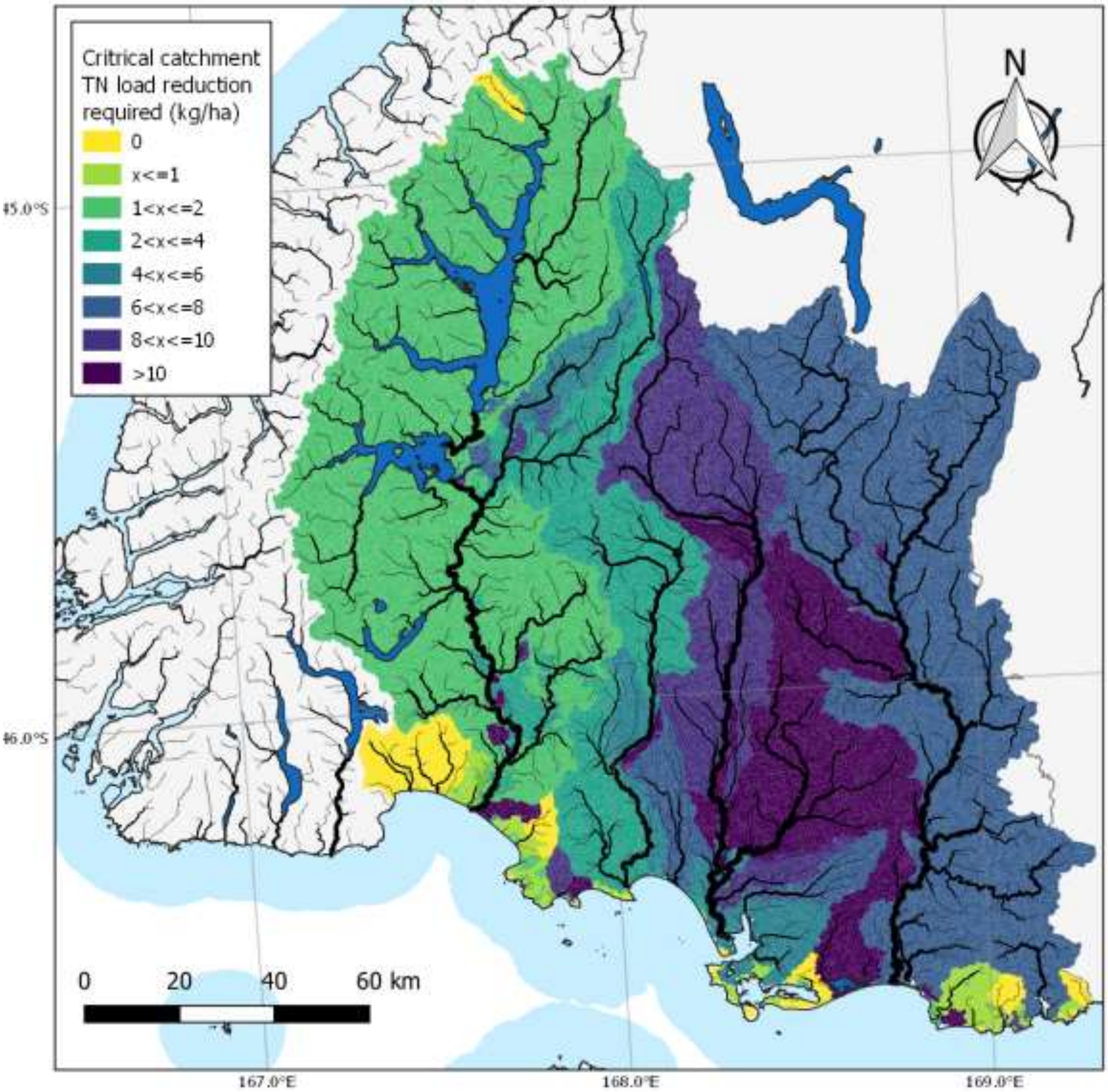

Figure 51*. The TN load reduction required, for the pSWLP and 30% spatial exceedance criteria settings, expressed as yields, for critical point catchments. The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).*

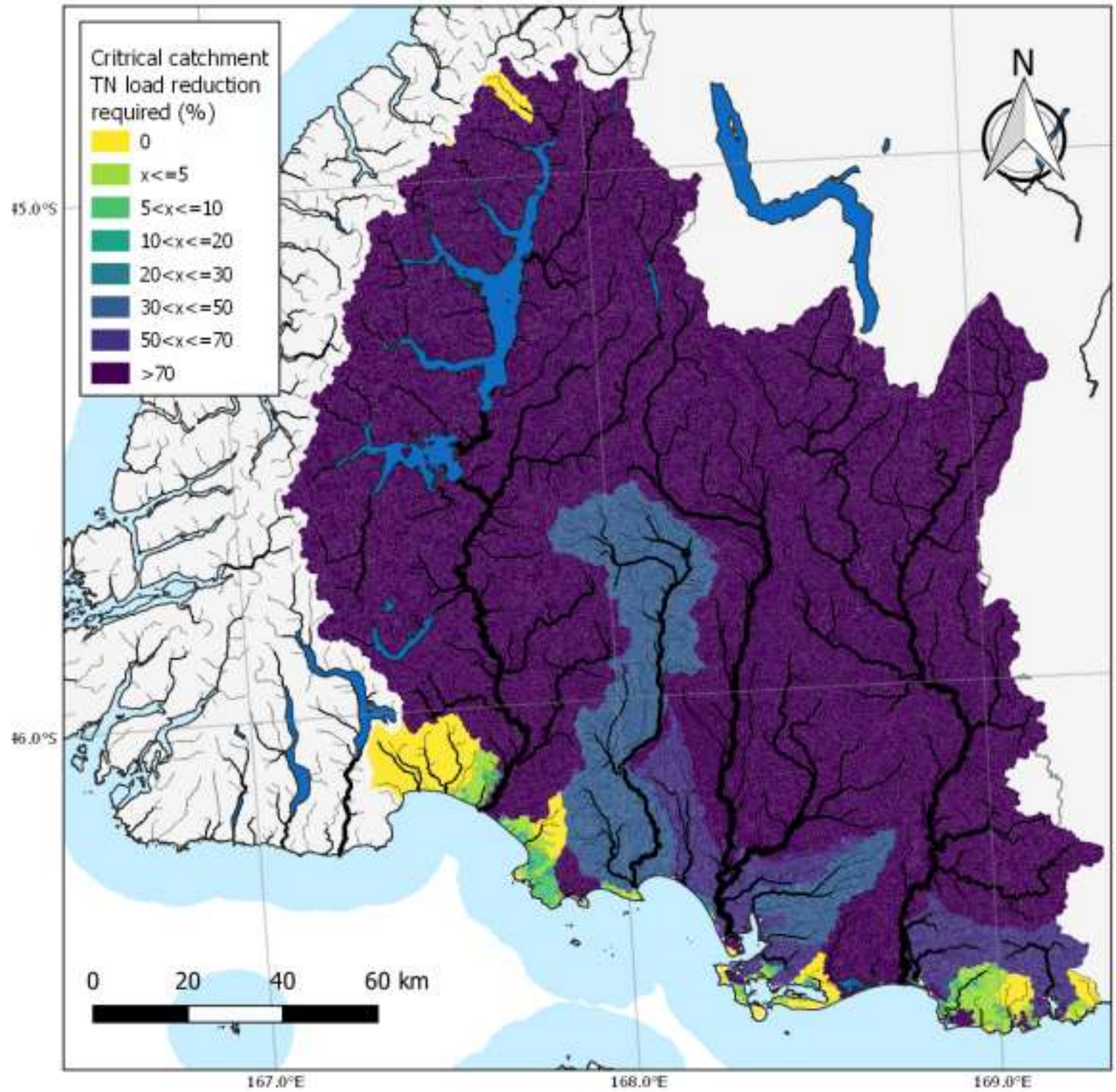

Figure 52. The TN load reduction required for the pSWLP standards and 30% spatial exceedance criteria for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TN load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

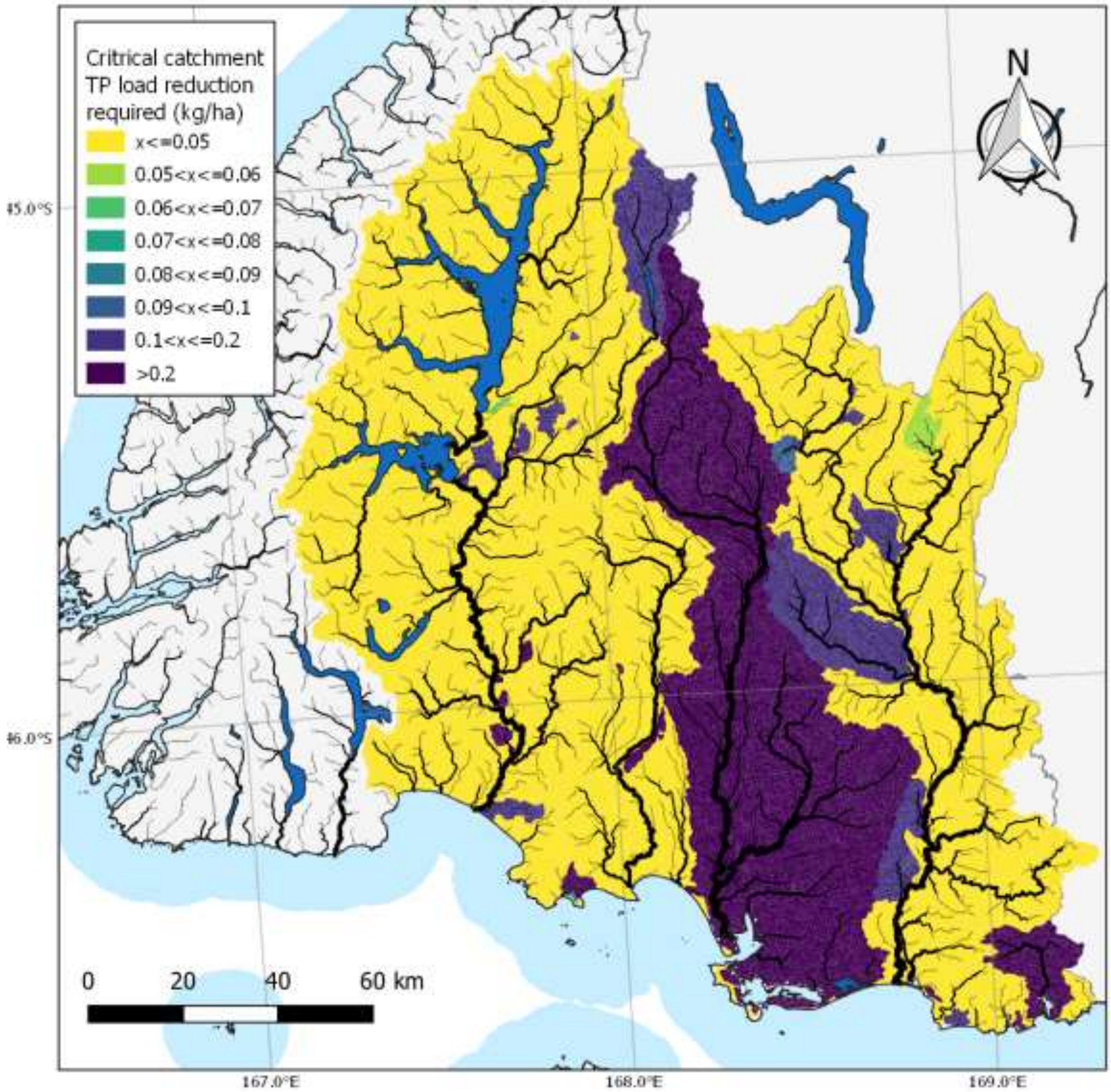

Figure 53. The TP load reduction required for the pSWLP and 30% spatial exceedance criteria settings for critical point catchments, expressed as yields. The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

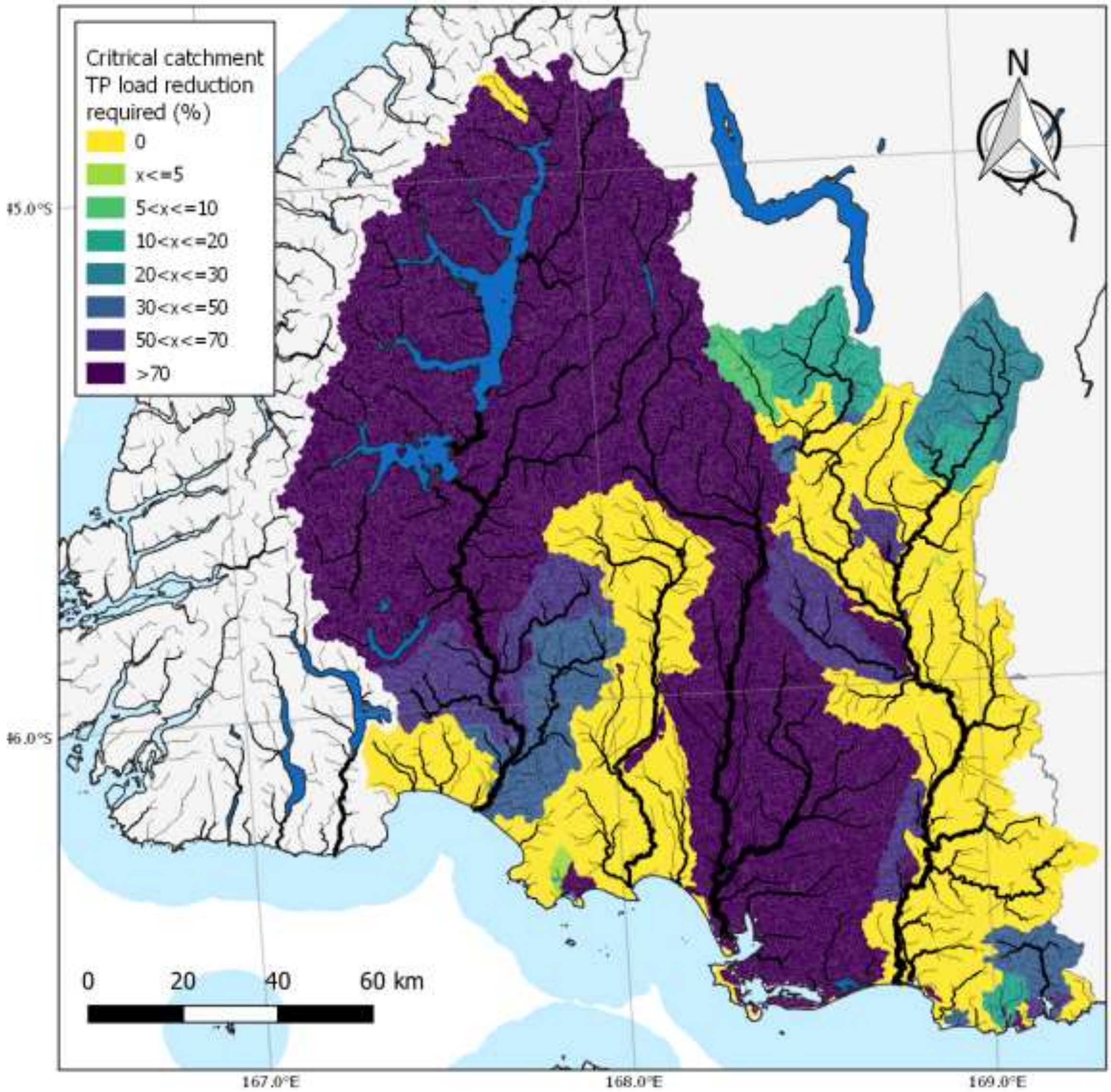

Figure 54. The TP load reduction required for the pSWLP and 30% spatial exceedance criteria settings for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the mean TP load reductions required to allow all FWOs to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for the pSWLP and 30% spatial exceedance criteria settings are shown on Figure 55 and Figure 56 for TN and TP respectively. For TN, and 67% of the critical point catchment area, the most stringent FWOs (i.e., most demanding of TN load reductions) were for rivers, 32% were for estuaries, and only 1% were for lakes (Figure 55). For TP, and 83% of the critical point catchment area, the most stringent FWOs were for rivers, 16% were for estuaries, and 1% were for lakes (Figure 56).

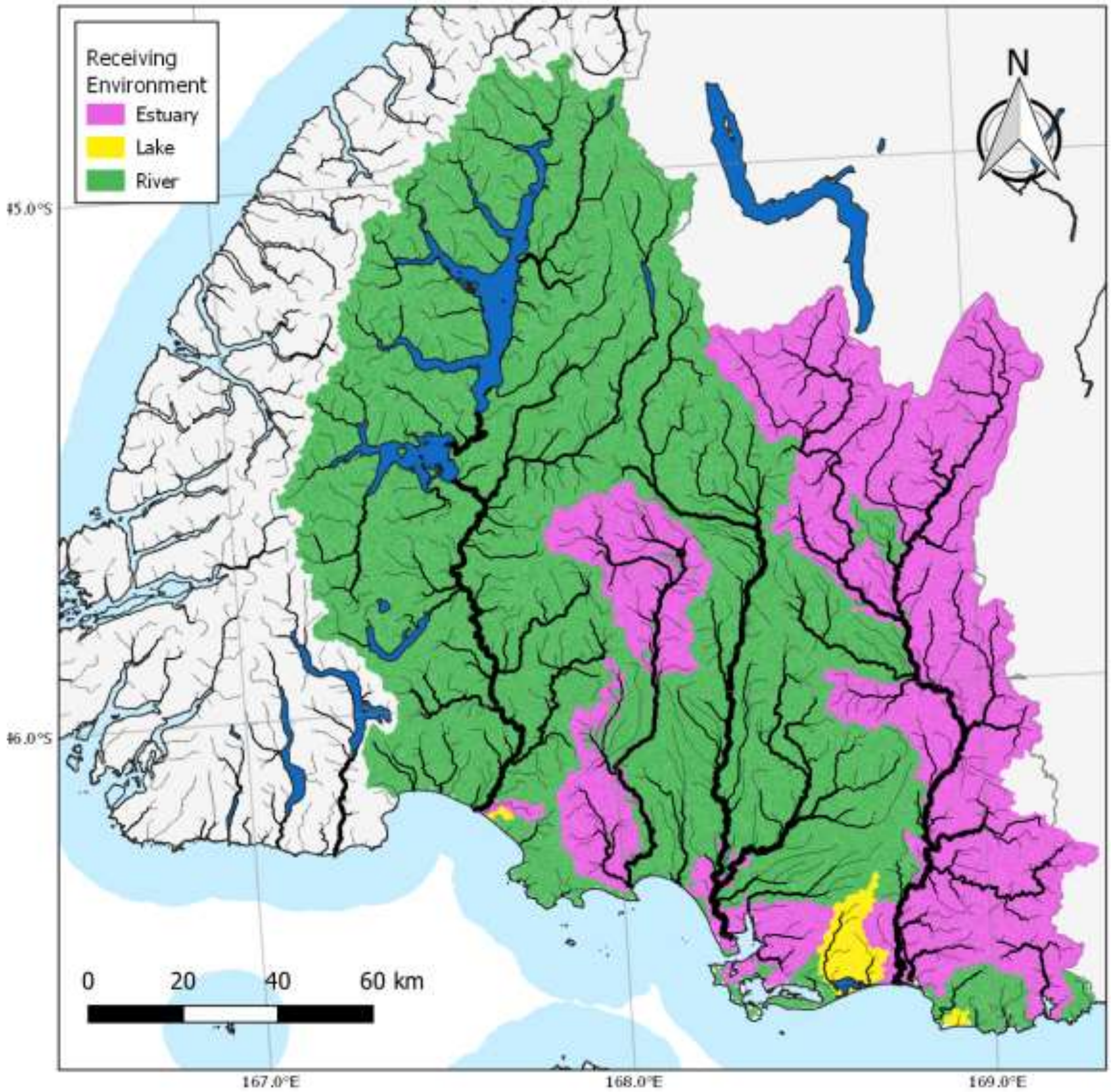

Figure 55. Limiting environment type for TN load reduction required for the pSWLP and 30% spatial exceedance criteria settings. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TN load reductions).

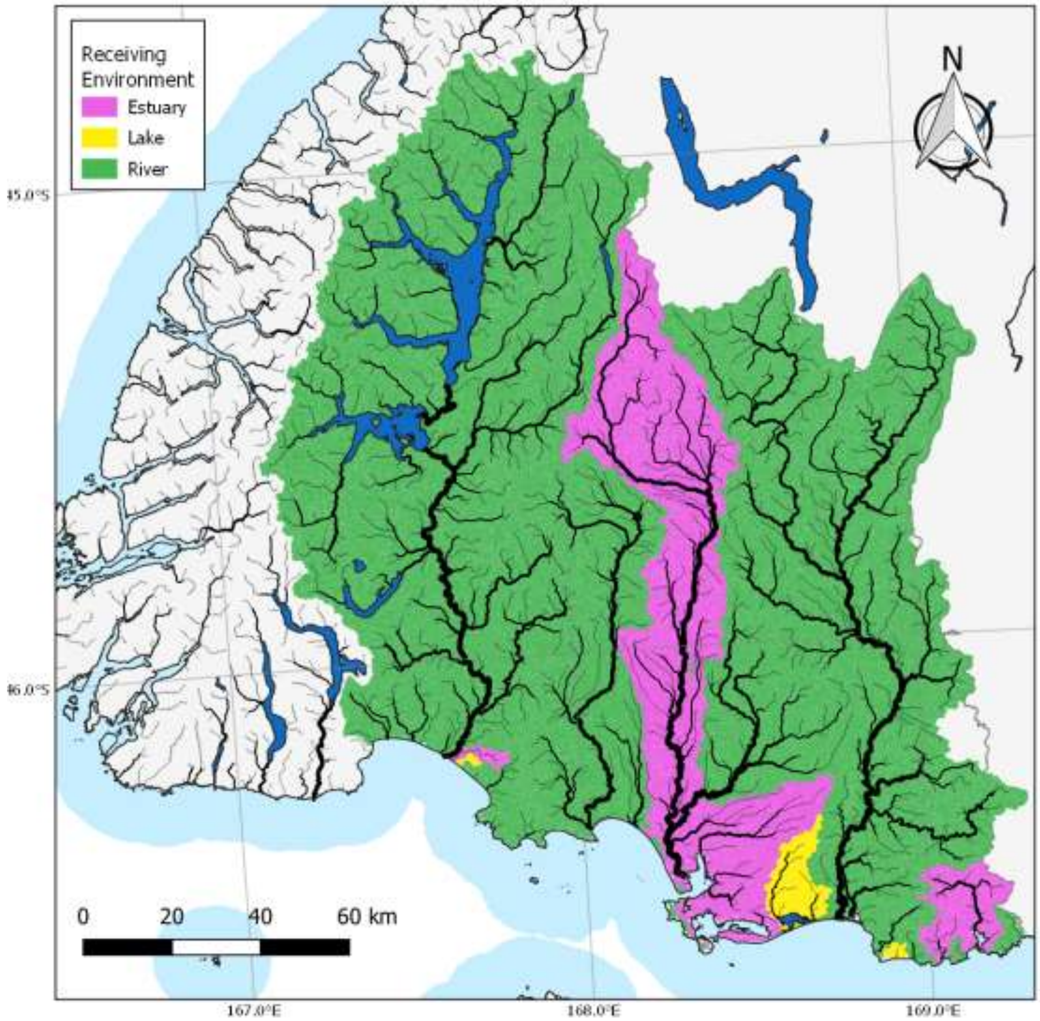

Figure 56. Limiting environment type for TP load reduction required for the pSWLP standards and 30% spatial exceedance criteria. The critical point catchment colours indicate the environment type with the most stringent FWOs (i.e., most demanding of TP load reductions).

3.7.4 Reporting catchments and regional load reductions required

The load reductions required by the pSWLP and 30% spatial exceedance criteria settings for each reporting catchment and for the whole study area are shown in Table 18. For the whole study area, the TN and TP load reductions required were estimated to be 8,430 t yr^{-1} and 149 t yr^{-1}, which represent 60% and 26% of the current loads respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reduction estimates, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 18. The uncertainties indicate, for example that the 90% confidence interval for the regional load of TN extends between 5,486 t yr^{-1} and 12,898 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 49% and 70% (best estimate 60%) and the regional TP load reduction requirement extends between 15% and 44% (best estimate 26%).

For the pSWLP and 30% spatial exceedance criteria settings, the best estimates of TN load reductions required were very high (>70%) in the Waituna Catchments and Mataura Catchments. The TP load reductions required were highest (≥70%) in Bluff Zone and Ōreti & Invercargill Catchments.

Table 18. Current load and load reduction required for TN and TP by reporting catchment and for the pSWLP and 30% spatial exceedance criteria settings including the uncertainties at the 90% level of confidence. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The first value shown is the best estimate and the values in parentheses are the 5th and 95th confidence limits (i.e., the range is the 90% confidence interval).

Reporting catchment	TN			TP		
	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)
Aparima & Pourakino Catchments	1,239 (690 - 2,116)	540 (10 - 1,408)	37 (1 - 67)	42 (18 - 85)	0 (0 - 1)	1 (0 - 1)
Bluff Zone	38 (30 - 49)	1 (0 - 3)	4 (1 - 8)	2 (1 - 2)	2 (1 - 2)	93 (90 - 95)
Catlins Zone	22 (17 - 30)	0 (0 - 0)	0 (0 - 1)	1 (1 - 2)	0 (0 - 0)	0 (0 - 0)
Mataura Catchments	4,474 (2,683 - 7,173)	3,580 (1,789 - 6,279)	78 (67 - 88)	150 (78 - 246)	8 (3 - 16)	5 (3 - 7)
Orepuki Coastal Zone	224 (189 - 282)	68 (35 - 117)	30 (17 - 42)	7 (5 - 8)	1 (0 - 1)	11 (6 - 17)
Ōreti & Invercargill Catchments	3,681 (2,006 - 6,823)	2,254 (934 - 5,243)	57 (45 - 77)	114 (55 - 209)	90 (32 - 184)	75 (58 - 88)
Te Waewae Bay Western Coastal Zone	111 (80 - 149)	0 (0 - 0)	0 (0 - 0)	5 (3 - 7)	0 (0 - 0)	0 (0 - 0)
Tokanui Coastal Zone	223 (151 - 322)	26 (15 - 51)	12 (6 - 22)	9 (7 - 13)	1 (0 - 2)	10 (3 - 19)
Waiau Catchment	2,803 (1,298 - 4,711)	1,316 (140 - 3,051)	42 (9 - 72)	190 (99 - 355)	33 (0 - 110)	13 (0 - 47)
Waikawa Catchment	252 (144 - 403)	145 (36 - 295)	52 (25 - 73)	12 (7 - 19)	5 (0 - 13)	35 (0 - 64)
Waimatuku & Taunamau Catchments	343 (194 - 621)	161 (21 - 353)	43 (9 - 68)	7 (3 - 12)	0 (0 - 0)	1 (1 - 2)
Waituna Catchments	255 (122 - 452)	234 (102 - 432)	90 (83 - 96)	8 (4 - 15)	5 (1 - 12)	60 (27 - 82)
Total	13,890 (10,514 - 18,341)	8,430 (5,486 - 12,898)	60 (49 - 70)	552 (406 - 749)	149 (66 - 268)	26 (15 - 44)

The load reductions required for the pSWLP and 30% spatial exceedance criteria settings for the eight estuaries and the three brackish lakes are shown in Table 19. The table also shows the load reductions required to achieve all river and lake FWOs in the catchment of each estuary and brackish lake.

Table 19 indicates that for seven of the 11 estuaries and brackish lakes, the TN load reductions required to achieve the FWOs under the Hauora settings and 20% spatial exceedance are of greater magnitude for the estuary or brackish lake compared to the river and lake FWOs in the catchment. Exceptions to this are the Waimatuku, Haldane, Bluff/Awarua and Waiau estuaries which all have zero or small TN load reductions required for the estuary, but considerable reductions are required for river FWOs in their catchments. The Waimatuku and Waiau estuaries have zero TN load reductions required because they have low salinity and low flushing time, which indicates that they are unlikely to sustain high macroalgae or phytoplankton (see Appendix B, Table 27). In contrast, the Waikawa estuary and the three coastal lakes (Lake Brunton and Waituna and Te Waewae lagoons) require considerably greater reductions to achieve the estuary/coastal lake FWOs than for the river FWOs in their catchments.

Table 19 indicates more variation in the TP load reductions required to achieve the FWOs for estuaries and brackish lakes compared to the river and lake FWOs in the catchment. The TP load reductions required for Waimatuku, Toetoes, Jacobs River and Waiau estuaries are zero because the flushing times of these estuaries are too short to sustain phytoplankton blooms (see Appendix B, Table 27).

Table 19. Load reductions required to achieve estuary and brackish lake FWOs and FWOs for rivers and lakes in their upstream catchment for the pSWLP and 30% spatial exceedance criteria settings. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}). The first value shown is the best estimate and the values in parentheses are the 5^{th} and 95^{th} confidence limits (i.e., the range is the 90% confidence interval).

Estuary	TN load reduction required (t yr^{-1})		TP load reduction required (t yr^{-1})	
	Estuary	Lakes and rivers	Estuary	Lakes and rivers
Waimatuku	0 (0 - 0)	152 (13 - 325)	0 (0 - 0)	0 (0 - 0)
Waikawa	144 (36 - 295)	1 (0 - 3)	5 (0 - 13)	0 (0 - 0)
Haldane	0 (0 - 15)	0 (0 - 1)	0 (0 - 1)	0 (0 - 0)
Lake Brunton	15 (6 - 26)	2 (0 - 6)	0 (0 - 1)	0 (0 - 0)
Toetoes	3,579 (1,789 - 6,279)	1,538 (512 - 3,130)	0 (0 - 0)	8 (3 - 16)
Waituna Lagoon	234 (102 - 432)	52 (0 - 203)	5 (1 - 12)	0 (0 - 0)
Bluff/Awarua	0 (0 - 0)	1 (0 - 3)	2 (1 - 2)	0 (0 - 0)
New River	2,265 (610 - 5,439)	1,969 (1,015 - 3,859)	94 (36 - 187)	25 (0 - 64)
Jacobs River	531 (0 - 1,408)	155 (6 - 464)	0 (0 - 0)	0 (0 - 1)
Waiau	0 (0 - 0)	1,316 (140 - 3,049)	0 (0 - 0)	33 (1 - 110)
Te Waewae Lagoon	38 (20 - 64)	1 (0 - 2)	0 (0 - 1)	0 (0 - 0)

3.8 Comparison between scenarios

Comparisons of the TN and TP load reductions required for the Hauora and pSWLP settings for the reporting catchments are shown in Table 20 and Table 21, respectively and Figure 57 and Figure 58. A comparison of the TN and TP load reductions required for the Hauora and pSWLP settings for individual estuaries and for the rivers and lakes within each estuary's catchment is shown in Table 22 and Table 23, respectively.

In this study, the 30% spatial exceedance criteria settings generally had lower TN and TP load reductions required compared to the 20% spatial exceedance criteria (points are below the red one-to-one line in Figure 57). This is because the 30% spatial exceedance criteria have more lenient concentration criteria associated with the periphyton FWOs than the 20% spatial exceedance criteria.

However, in some reporting catchments, there was very little, or no, difference in load reductions required between the 20% and 30% spatial exceedance criteria (points plotted on or very close to the one-to-one line in Figure 57). This occurs because river periphyton is not always the 'limiting environment' (e.g., Figure 23 and Figure 24) and the lake and estuary nutrient concentration criteria were unchanged between the 20% and 30% spatial exceedance criteria settings. There are also cases where the load reduction for 30% spatial exceedance criteria is slightly higher than for the 20% spatial exceedance criteria (points are above the red one-to-one line in Figure 57). For example, the Waikawa Catchment for TN and TP. These arise because in both cases the estuary is the limiting environment (Jacobs River Estuary and Waikawa Estuary, respectively) and the small differences between the two sets of settings is due to the random variation associated with the Monte Carlo analysis.

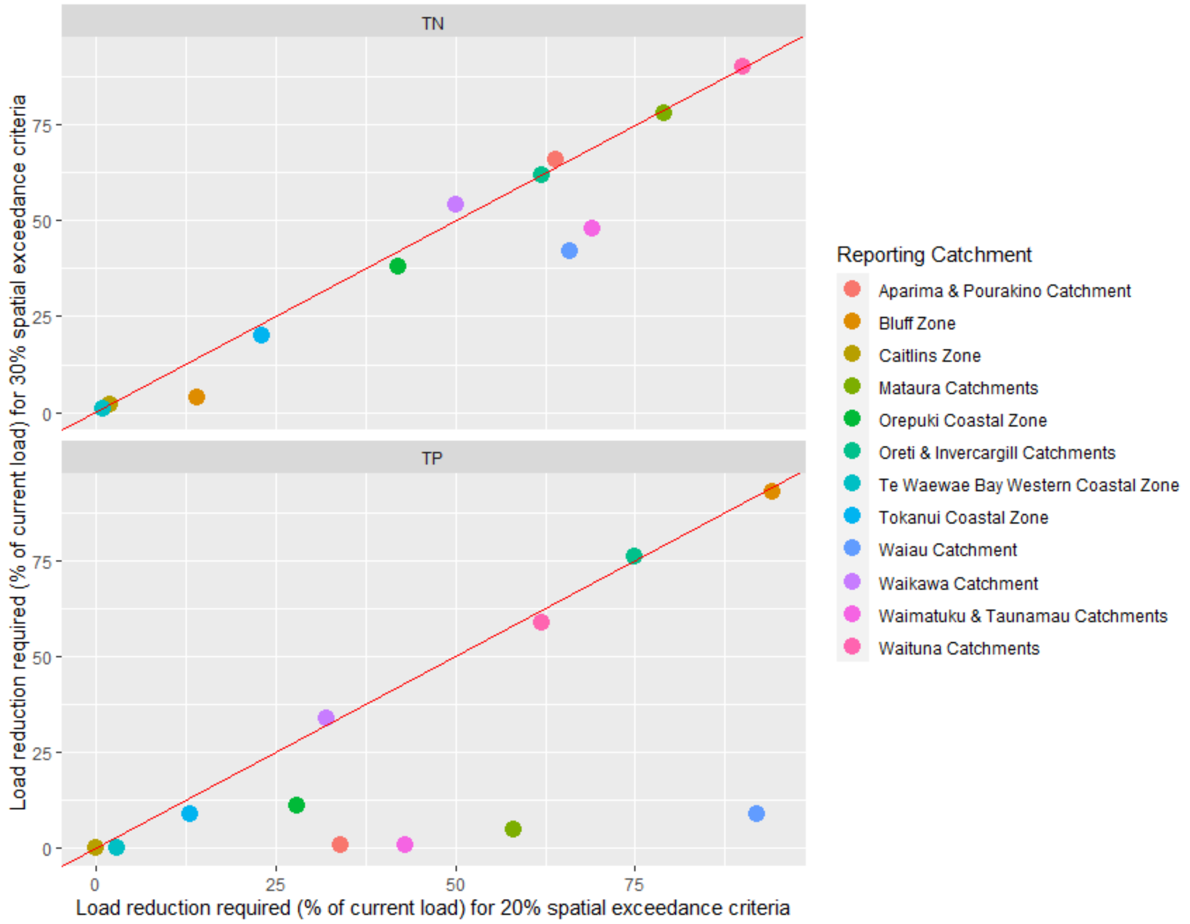

Figure 57. Comparison of the best estimates of TN and TP load reductions required for the reporting catchments for the Hauora option and 20% versus 30% spatial exceedance criteria. The red diagonal line is one to one (i.e., equal load reductions for 20% and 30% spatial exceedance criteria).

The slightly lower TN load reductions required for the pSWLP option compared to the Hauora option reflects the less aspirational FWO associated with some management classes than the Hauora option (Table 8). In some reporting catchments, there was no, or very little, difference in load reductions required between the Hauora and pSWLP options (points plotted on or very close to the one-to-one line in Figure 58). This occurs because there are only small differences between the FWOs for the two options and in some reporting catchments these differences had no impact on the load reduction requirements. There are also cases where the load reduction for the pSWLP option was slightly higher than for the Hauora (points are above the red one-to-one line in Figure 58). For example, Waiau and Ōreti and Invercargill Catchment for TP. These arise because in both cases the estuary is the limiting environment and the small differences between the two sets of settings is due to the random variation associated with the Monte Carlo analysis.

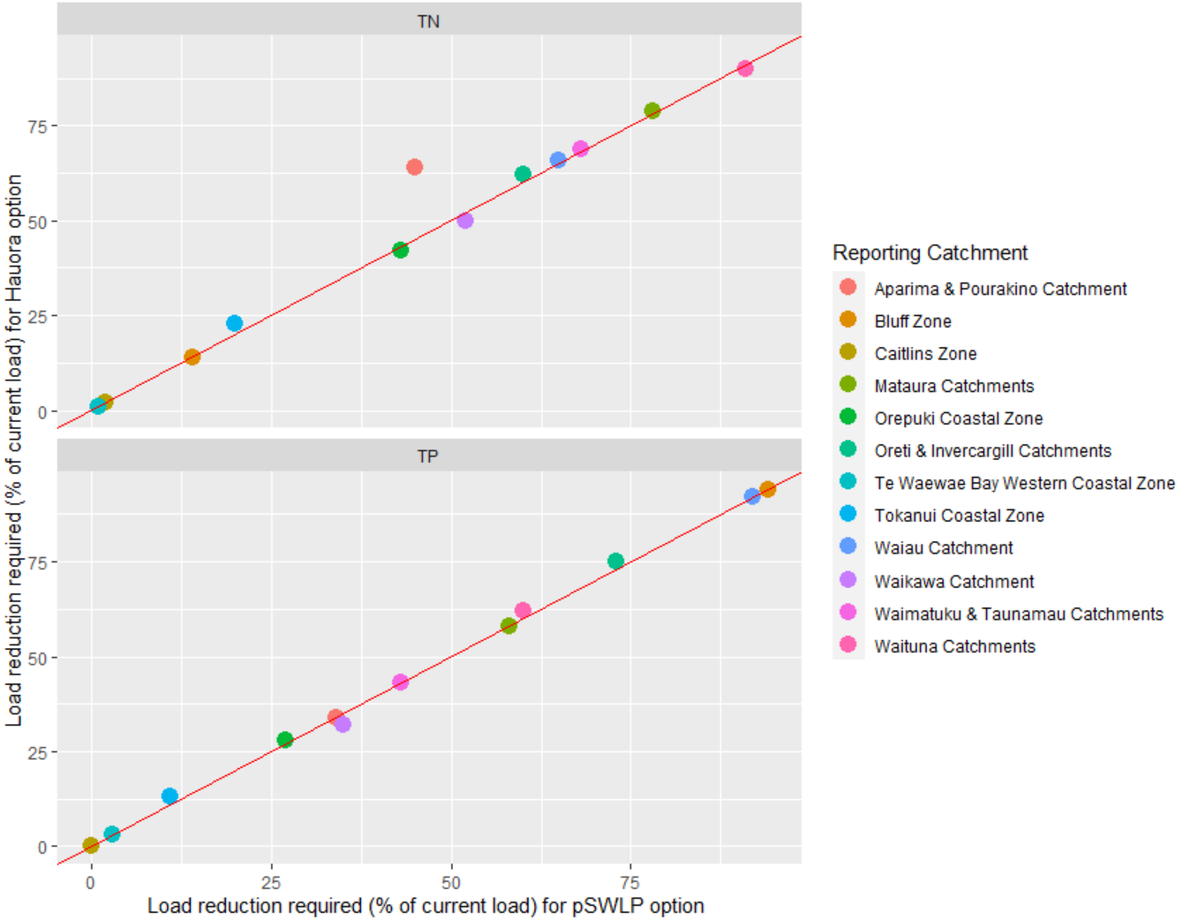

Figure 58. Comparison of reporting catchment load reductions required for the Hauora and pSWLP options, both with the 20% spatial exceedance criteria setting. The red diagonal line is one to one (i.e., equal load reductions for Hauora and pSWLP options).

Table 20. Comparison of the TN load reductions required for reporting catchments for the Hauora and pSWLP settings. The load reductions are shown as proportion of current load (%). The first value shown is the best estimate and the values in parentheses are the 5th and 95th confidence limits (i.e., the range is the 90% confidence interval). The reductions are shown for the 20% and 30% spatial exceedance criteria used to define the nutrient criteria for river periphyton.

Reporting catchment	Hauora 20%	Hauora 30%	pSWLP 20%	pSWLP 30%
Aparima & Pourakino Catchment	64 (34 - 81)	66 (40 - 84)	45 (10 - 73)	37 (1 - 67)
Bluff Zone	14 (8 - 21)	4 (1 - 8)	14 (9 - 21)	4 (1 - 8)
Caitlins Zone	2 (0 - 8)	2 (0 - 12)	2 (0 - 5)	0 (0 - 1)
Mataura Catchments	79 (67 - 89)	78 (63 - 88)	78 (65 - 89)	78 (67 - 88)
Orepuki Coastal Zone	42 (32 - 52)	38 (25 - 49)	43 (34 - 53)	30 (17 - 42)
Ōreti & Invercargill Catchments	62 (54 - 79)	62 (48 - 75)	60 (54 - 69)	57 (45 - 77)
Te Waewae Bay Western Coastal Zone	1 (0 - 4)	1 (0 - 3)	1 (0 - 3)	0 (0 - 0)
Tokanui Coastal Zone	23 (11 - 43)	20 (9 - 42)	20 (9 - 37)	12 (6 - 22)
Waiau Catchment	66 (38 - 83)	42 (2 - 68)	65 (43 - 82)	42 (9 - 72)
Waikawa Catchment	50 (12 - 74)	54 (31 - 74)	52 (26 - 75)	52 (25 - 73)
Waimatuku & Taunamau Catchments	69 (50 - 82)	48 (20 - 72)	68 (52 - 82)	43 (9 - 68)
Waituna Catchments	90 (85 - 95)	90 (80 - 95)	91 (85 - 95)	90 (83 - 96)
Total	70 (61 - 78)	64 (55 - 72)	66 (58 - 74)	60 (49 - 70)

Table 21. Comparison of the TP load reductions required for reporting catchments for the Hauora and pSWLP settings. The load reductions are shown as proportion of current load (%). The first value shown is the best estimate and the values in parentheses are the 5th and 95th confidence limits (i.e., the range is the 90% confidence interval). The reductions are shown for the 20% and 30% spatial exceedance criteria used to define the nutrient criteria for river periphyton.

Reporting catchment	Hauora 20%	Hauora 30%	pSWLP 20%	pSWLP 30%
Aparima & Pourakino Catchment	34 (18 - 43)	1 (0 - 1)	34 (10 - 44)	1 (0 - 1)
Bluff Zone	94 (91 - 95)	93 (90 - 95)	94 (91 - 96)	93 (90 - 95)
Caitlins Zone	0 (0 - 0)	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)
Mataura Catchments	58 (37 - 70)	5 (3 - 7)	58 (39 - 70)	5 (3 - 7)
Orepuki Coastal Zone	28 (14 - 48)	11 (6 - 18)	27 (14 - 42)	11 (6 - 17)
Ōreti & Invercargill Catchments	75 (61 - 86)	76 (64 - 86)	73 (53 - 86)	75 (58 - 88)
Te Waewae Bay Western Coastal Zone	3 (0 - 7)	0 (0 - 0)	3 (0 - 7)	0 (0 - 0)
Tokanui Coastal Zone	13 (5 - 26)	9 (3 - 19)	11 (4 - 26)	10 (3 - 19)
Waiau Catchment	92 (89 - 95)	9 (0 - 43)	92 (89 - 95)	13 (0 - 47)
Waikawa Catchment	32 (0 - 63)	34 (0 - 63)	35 (0 - 67)	35 (0 - 64)
Waimatuku & Taunamau Catchments	43 (3 - 71)	1 (1 - 2)	43 (9 - 69)	1 (1 - 2)
Waituna Catchments	62 (37 - 80)	59 (28 - 78)	60 (28 - 80)	60 (27 - 82)
Total	70 (62 - 77)	24 (14 - 38)	69 (59 - 77)	26 (15 - 44)

Table 22. Comparison of the TN load reductions required for the Hauora and pSWLP settings for individual estuaries and for the rivers and lakes within the catchment of each estuary. The load reductions are shown as proportion of current load (%). The first value shown is the best estimate and the values in parentheses are the 5th and 95th confidence limits (i.e., the range is the 90% confidence interval). For the columns pertaining to the rivers and lakes within the catchment of each estuary, the reductions are shown for the 20% and 30% spatial exceedance criteria used to define the nutrient criteria for river periphyton.

Estuary	Management class	Estuary		Rivers and lakes			
		Hauora	pSWLP	Hauora 20%	Hauora 30%	pSWLP 20%	pSWLP 30%
Bluff/Awarua	Tidal lagoon estuary	0 (0 - 0)	0 (0 - 0)	15 (9 - 22)	4 (1 - 9)	15 (9 - 22)	4 (1 - 8)
Brunton	Brackish lake/lagoon	85 (70 - 93)	84 (70 - 93)	26 (3 - 55)	13 (0 - 53)	24 (1 - 57)	7 (0 - 24)
Haldane	Tidal lagoon estuary	10 (0 - 34)	5 (0 - 27)	13 (3 - 27)	8 (1 - 24)	11 (2 - 27)	1 (0 - 4)
Jacobs River	Tidal lagoon estuary	63 (34 - 81)	42 (0 - 73)	33 (12 - 63)	16 (1 - 45)	35 (9 - 67)	10 (1 - 26)
New River	Tidal lagoon estuary	59 (39 - 79)	52 (31 - 69)	57 (53 - 66)	51 (46 - 57)	57 (53 - 62)	50 (43 - 55)
Te Waewae	Brackish lake/lagoon	80 (69 - 89)	80 (69 - 89)	20 (5 - 48)	23 (0 - 70)	23 (5 - 58)	7 (0 - 20)
Toetoes	Tidal river estuary	79 (67 - 89)	78 (65 - 89)	50 (33 - 67)	32 (14 - 50)	48 (37 - 62)	33 (14 - 48)
Waiau	Tidal river estuary	0 (0 - 0)	0 (0 - 0)	67 (38 - 83)	42 (2 - 68)	65 (43 - 82)	42 (9 - 72)
Waikawa	Tidal lagoon estuary	50 (12 - 74)	52 (26 - 75)	5 (1 - 24)	5 (0 - 26)	5 (0 - 26)	0 (0 - 1)
Waimatuku	Tidal river estuary	0 (0 - 0)	0 (0 - 0)	70 (49 - 83)	49 (17 - 75)	68 (51 - 85)	44 (6 - 69)
Waituna	Brackish lake/lagoon	90 (85 - 95)	91 (85 - 95)	39 (15 - 64)	17 (0 - 45)	36 (13 - 61)	16 (0 - 41)

Table 23. Comparison of the TP load reductions required for the Hauora and pSWLP settings for individual estuaries and for the rivers and lakes within the catchment of each estuary. The load reductions are shown as proportion of current load (%). The first value shown is the best estimate and the values in parentheses are the 5th and 95th confidence limits (i.e., the range is the 90% confidence interval). For the columns pertaining to the rivers and lakes within the catchment of each estuary, the reductions are shown for the 20% and 30% spatial exceedance criteria used to define the nutrient criteria for river periphyton.

Estuary	Management class	Estuary		Rivers and lakes			
		Hauora	pSWLP	Hauora 20%	Hauora 30%	pSWLP 20%	pSWLP 30%
Bluff/Awarua	Tidal lagoon estuary	100 (100 - 100)	100 (100 - 100)	10 (4 - 21)	0 (0 - 0)	10 (4 - 27)	0 (0 - 0)
Brunton	Brackish lake/lagoon	34 (0 - 61)	39 (0 - 71)	11 (0 - 21)	0 (0 - 0)	12 (0 - 22)	0 (0 - 0)
Haldane	Tidal lagoon estuary	15 (0 - 51)	13 (0 - 48)	0 (0 - 2)	0 (0 - 0)	1 (0 - 2)	0 (0 - 0)
Jacobs River	Tidal lagoon estuary	0 (0 - 0)	0 (0 - 0)	34 (18 - 43)	1 (0 - 1)	34 (10 - 44)	1 (0 - 1)
New River	Tidal lagoon estuary	75 (62 - 86)	73 (54 - 87)	47 (42 - 50)	20 (1 - 30)	47 (42 - 50)	19 (0 - 32)
Te Waewae	Brackish lake/lagoon	13 (0 - 41)	11 (0 - 39)	4 (0 - 9)	0 (0 - 0)	4 (0 - 9)	0 (0 - 0)
Toetoes	Tidal river estuary	0 (0 - 0)	0 (0 - 0)	58 (37 - 70)	5 (3 - 7)	58 (39 - 70)	5 (3 - 7)
Waiau	Tidal river estuary	0 (0 - 0)	0 (0 - 0)	93 (90 - 95)	9 (0 - 44)	93 (90 - 95)	13 (0 - 47)
Waikawa	Tidal lagoon estuary	32 (0 - 63)	35 (0 - 67)	0 (0 - 1)	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)
Waimatuku	Tidal river estuary	0 (0 - 0)	0 (0 - 0)	44 (2 - 73)	2 (1 - 2)	44 (4 - 73)	2 (1 - 2)
Waituna	Brackish lake/lagoon	60 (30 - 79)	59 (27 - 80)	42 (0 - 74)	0 (0 - 0)	39 (0 - 73)	0 (0 - 0)

4 Summary and discussion

4.1 Load reductions required

This study has assessed current nutrient (nitrogen and phosphorus) loads and the reductions of those loads needed to achieve options for freshwater objectives (FWO) in rivers, lakes and estuaries in Southland excluding the Fiordland and Islands FMU. The options for FWOs are defined in terms of a band (A, B or C) for all river, lake and estuary receiving environments in the study area. Two sets of FWO options for rivers, lakes and estuaries were nominated and are referred to as the Hauroa option and the Proposed Southland Water and Land Plan water quality standards (pSWLP option). The Hauora option was based on hauora principles as reported in Bartlett *et al.* (2020) and represents the minimum state necessary to support hauora for the nutrient-related ecosystem health attributes assessed in this report (i.e., river periphyton, lake and estuary phytoplankton and estuary macroalgae). The pSWLP option represents possible minimum FWOs based on water quality standards in the pSWLP and the NPS-FM "maintain or improve" requirement as reported in detail in Norton and Wilson (2019)). In December 2020, the Southland Regional Council and the Te Ao Marama Inc (TAMI) board approved in principle the minimum level of hauora as the draft FWOs for the region. These FWOs will remain draft until they are set through a plan process.

As well as the two sets of FWOs, the analyses incorporated two choices of spatial exceedance criteria for defining nutrient criteria to achieve river periphyton objectives. Collectively the combination of the FWO options (Hauroa and pSWLP) and the two sets of periphyton criteria (20% and 30% spatial exceedance criteria) are referred to as settings.

The load reductions required for each of the four settings were assessed for all individual river segment, lake and estuary receiving environments in the study area. Load reductions were also assessed for FWOs set at the national bottom line attribute states (rivers and lakes) or nominated equivalent states for estuaries for all receiving environments. The results for the individual receiving environments aggregated to report on individual 'reporting catchments', the catchments of eight individual estuaries, and the whole study area. The results for the whole study area are the most succinct and broad summaries of the load reductions required and at shown in Table 24. The study also identified the 'limiting environment'; i.e., whether it is an estuary, lake or river that has the most sensitive FWO and has therefore driven the load reduction required in each catchment.

Table 24. The load reductions required for TN and TP for the study area for the Hauora and pSWLP settings and the 20% and 30% spatial exceedance criteria settings. The last line is the load reductions required for the national bottom line attribute states and the 20% spatial exceedance. The load reductions are expressed as proportions of the current load and the values shown in parentheses are the 5th and 95th confidence limits for the reported values (i.e., the range is the 90% confidence interval).

Setting	TN reduction (%)	TP reduction (%)
Hauora – using 20%	70 (61-78)	70 (62-77)
Hauora – using 30%	64 (55-72)	24 (14-38)
pSWLP – using 20%	66 (58-74)	69 (59-77)
pSWLP – using 30%	60 (49-70)	26 (15-44)
NBL (C/D) – using 20%	47 (33 – 61)	21 (13 -33)

The load reductions required associated with the 30% spatial exceedance criteria settings generally had slightly lower TN and considerably lower for TP compared to the 20% spatial exceedance criteria. The lower load reduction requirements for the 30% spatial exceedance criteria compared to the 20% spatial exceedance criteria is because the former represents an increased risk tolerance and therefore the nutrient criteria are more lenient. The greater proportional difference in load reduction requirements for TP compared to TN arises from the statistical models that underlie these criteria. The fitted coefficient for DRP was much larger than for TN which results in larger changes of periphyton biomass per unit of change in DRP than for TN (Snelder *et al.*, 2019). This then means there is a larger proportional change in the DRP criteria than the TN criteria between the 20% and 30% spatial exceedance settings. However, in some reporting catchments, there was no, or very little, difference in load reductions required between the 20% and 30% spatial exceedance criteria (Table 20, Table 21 and Figure 57). This is because river periphyton is not always the 'limiting environment' (e.g., Figure 23 and Figure 24) and the lake and estuary nutrient concentration criteria was unchanged between the 20% and 30% spatial exceedance criteria settings.

The TN load reductions required were slightly higher for the Hauora option compared to the pSWLP option due to the more aspirational FWO associated with some management classes than the pSWLP option (Table 8). However, for some reporting catchments, there was no, or very little, difference in load reductions required between the Hauora and pSWLP options (Figure 58). This is because there are only small differences between the FWOs for the two options and in some reporting catchments these differences had no impact on the load reduction requirements. For TP, there was negligible difference in load reductions required for the Hauora option compared to the pSWLP option (Figure 58).

4.2 Comparison with previous studies and national policy bottom lines

A national scale study by Snelder *et al.* (2020) estimated a TN load reduction required (termed regional excess load in that study) of 20% for Southland. The present study produced higher load reductions required than the Snelder et al. (2020), which is to be expected for two reasons. First, Snelder *et al.* (2020) estimated the TN load reduction required for the entirety of Southland which included Fiordland and Stewart Island. The Fiordland and Stewart Island areas in the Snelder *et al.* (2020) study were not associated with load reduction requirements due to being largely undeveloped, and therefore current concentrations were compliant with the criteria in these areas. The inclusion of large areas with no required load reduction lowers the overall load reduction requirement when expressed as a proportion of the current load in the Snelder *et al.*, (2020) study compared to this study. Second, the criteria for the Snelder *et al.* (2020) study for rivers, lakes and estuaries were based on NOF bottom lines (i.e., C/D threshold), which is less stringent than both the Hauora option and pSWLP option for FWOs used by this study. It is noted that the regional load reduction requirement of 20% derived by Snelder *et al.* (2020) study was based on the periphyton spatial exceedance criteria of 20%.

When the FWOs specified in this study were all set to the NOF bottom line, the regional TN load reduction required for the study area was 47% and the regional TP load reduction required was 21% (results not detailed in this report). The 90% confidence intervals for the regional load reductions for TN and TP were 33% to 61% and 13% to 33% respectively. The FWOs associated with the Hauora and pSLWP options evaluated by this study are therefore quite restrictive compared to NOF bottom lines.

4.3 Uncertainties

Uncertainty is an unavoidable aspect of this study because it is based on simplifications of reality and because it has been informed by limited data. The study estimated the statistical uncertainty of the current TN and TP loads and their required reductions with respect to two key components of the analyses: the modelled regional river nutrient concentrations and loads (see Sections 3.1 and 3.2). The statistical uncertainty of these models is associated with their inability to perfectly predict the concentrations and load observed at water quality monitoring sites; the error associated with these predictions is quantified by the model RMSD values (Table 9 and Table 10). The errors associated with each of the eight RF models were combined using Monte Carlo analyses. The Monte Carlo analyses simulated 100 ‘realisations’ of the calculations, which were then used to define the probability distributions of all current loads and load reduction estimates. The probability distribution describes the range over which the true values of the current loads and the load reductions are expected to lie. The best estimate of the current load and the load reduction is the mean value of the distribution, and the lower and upper limits of the estimates were represented by the 5th and 95th percentiles of the distribution (i.e., these are the limits of the 90% confidence interval).

The best estimates for current loads differ by small amounts for results shown for the different setting assessed by this study (e.g., Table 12, Table 14, Table 16, Table 18). This is because the current load is estimated for each setting independently using a Monte Carlo analysis, which includes a component of random error. The small differences in the best load estimates between settings can be regarded as insignificant they are always much smaller than the differences between the associated 5th and 95th confidence limits.

In this study, a lower limit of the 90% confidence interval for the load reduction required that is greater than zero, indicates a 95% level of confidence that a reduction is required. We can therefore have high confidence (i.e., ≥ 95%) that TN load reductions are required under all settings included in this study for the region as a whole and for most of the reporting catchments irrespective of the spatial exceedance criterion (level of risk of not achieving the periphyton objective) that is chosen (Table 20). Similarly, we can have high confidence that TN load reductions are required under all settings included in this study for all estuaries except Bluff/Awarua, Haldane, Waiau and Waimatuku (Table 22).

We can also have high confidence that TP load reductions are required under all settings for the region as a whole and for most of the reporting catchments except Catlins Zone, Te

Waewae Bay Western Coastal Zone, Waiau Catchment (under the 30% spatial exceedance criteria only), and Waikawa Catchment (Table 21). Similarly, we can have high confidence that TP load reductions are required under all settings included in this study for New River Estuary and Waituna Lagoon (Table 23).

The confidence intervals for regional load reduction estimates in this study were narrower than that obtained for the Southland region in the national study of Snelder *et al.* (2020). In the national study a 20% TN load reduction to achieve NOF bottom lines had a 95% confidence interval from 4% to 33%. In this study, the Hauora option and 20% spatial exceedance criteria produced a TN load reduction requirement of 70% with a 90% confidence interval from 61% to 78% (Table 24). There are at least two reasons that this study achieved narrower confidence intervals. First, we used the 90% confidence interval (in order to be able to have 95% confidence that the load reduction was greater than zero). This is therefore a slightly narrower interval. Second, the underlying (regional) concentration and load models used in this study had slightly lower characteristic uncertainties (i.e., RMSD values; Table 9 and Table 10) than the equivalent models in the national study and this leads to slightly lower uncertainties.

The statistical uncertainties however are not the only uncertainties associated with the analysis. There are at least two other sources of uncertainty; uncertainties associated with the assumptions used in the load reduction calculations and uncertainties associated with the nutrient criteria used for lakes, rivers and estuaries. Neither of these uncertainties are represented in the uncertainties reported above. Important assumptions used in the calculations are that (1) the ratio of DRP to TP and NO3N to TN will remain the same if the loads of TP and TN are changed and (2) a change in the nutrient load will produce a change in the median nutrient concentration of the same proportion to the load change. These assumptions are very likely simplifications of reality. However, we lack the scientific understanding and data needed to significantly improve the representation of these relationships or to quantify the associated uncertainty.

The criteria represent the best estimate of the nutrient concentration or load that will achieve the FWO. Uncertainties associated with these criteria mean that there is uncertainty around whether the FWOs will be achieved if the loads are reduced as indicated by the assessment. Some locations may fail to achieve the FWO (i.e., have greater biomass than specified) despite having nutrient concentrations that are less than the criteria. Equally, some locations may achieve the FWO despite having nutrient concentrations that are higher than specified. This means that in these less susceptible locations, the criteria are unnecessarily restrictive.

There is always uncertainty associated with environmental criteria. For example, most criteria are based on finding the stressor value for which the mean response exceeds a threshold value. This means that 50% of cases will not exhibit the threshold response at the stressor value. Generally, the exceedance of a criteria is treated as an unacceptably high risk of an adverse effect and appropriate action is taken, despite this uncertainty. This was the approach taken by this study. It has been assumed that the exceedance of a criteria represents an unacceptably high risk that the FWO will not be achieved and that the appropriate management response is to reduce the current nutrient level (i.e., the nutrient load reduction), despite the uncertainty. We lack the scientific understanding and data needed to significantly reduce the uncertainties associated with the nutrient criteria.

4.4 Informing decision-making on limits

The NPS-FM requires regional councils to set limits on resource use to achieve environmental outcomes (e.g., FWOs). This report helps inform Environment Southland's process of setting limits by assessing the approximate magnitude of nitrogen and phosphorus load reductions needed to achieve several options for FWOs, with a quantified level of confidence and risk associated with each option. However, this report does not consider what kinds of limits on resource might be used to achieve any load reductions, how such limits might be implemented, over what timeframes and with what implications for other values. The NPS-FM requires regional councils to have regard to these and other things when making decisions on setting limits. This report shows that these decisions will ultimately need to be made in the face of uncertainty about the magnitude of load reductions needed.

Acknowledgements

Thanks is due to David Plew of NIWA for the development and use of the estuary models and assistance with incorporating them into this assessment. Thank you to Roger Hodson for assistance with water quality data and load calculations and to Andrew Wilson for assistance with spatial data. Thanks to Caroline Fraser for preparation of the critical point maps. Early versions of the report were reviewed by Dr Keryn Roberts, Roger Hodson, Nick Ward, Ned Norton, and Karen Wilson. Their comments and corrections greatly improved this report.

References

Abell, J.M., P. van Dam-Bates, D. Özkundakci, and D.P. Hamilton, 2020. Reference and Current Trophic Level Index of New Zealand Lakes: Benchmarks to Inform Lake Management and Assessment. New Zealand Journal of Marine and Freshwater Research:1–22.

Abell, J.M., D. Özkundakci, D.P. Hamilton, P. van Dam-Bates, and R.W. Mcdowell, 2019. Quantifying the Extent of Anthropogenic Eutrophication of Lakes at a National Scale in New Zealand. Environmental Science & Technology.

Bartlett, M., J. Kitson, N. Norton, and K. Wilson, 2020. Draft Murihiku Southland Freshwater Objectives: Providing for Hauora, the Health and Well-Being of Waterbodies in Murihiku Southland. Environment Southland and Te Ao Marama Inc, Invercargill, New Zealand.

Booker, D.J. and R.A. Woods, 2014. Comparing and Combining Physically-Based and Empirically-Based Approaches for Estimating the Hydrology of Ungauged Catchments. Journal of Hydrology 508:227–239.

Hume, T., P. Gerbeaux, D. Hart, H. Kettles, and D. Neale, 2016. A Classification of New Zealand's Coastal Hydrosystems. NIWA Client Report, NIWA, Hamilton, New Zealand.

Leathwick, J., D. West, L. Chadderton, P. Gerbeaux, D. Kelly, H. Robertson, and D. Brown, 2010. Freshwater Ecosystems of New Zealand (FENZ) Geodatabase: Version One User Guide. Department of Conservation, Hamilton, New Zealand.

McDowell, R.W., R.M. Monaghan, C. Smith, A. Manderson, L. Basher, D.F. Burger, S. Laurenson, P. Pletnyakov, R. Spiekermann, and C. Depree, 2020. Quantifying Contaminant Losses to Water from Pastoral Land Uses in New Zealand III. What Could Be Achieved by 2035? New Zealand Journal of Agricultural Research:1–21.

McMillan, H.K., E. Hreinsson, M.P. Clark, S.K. Singh, C. Zammit, and M.J. Uddstrom, 2013. Operational Hydrological Data Assimilation with the Recursive Ensemble Kalman Filter. Hydrology and Earth System Sciences 17:21–38.

MFE, 2019. Essential Freshwater: Impact of Existing Periphyton and Proposed Dissolved Inorganic Nitrogen Bottom Lines. Ministry for the Environment & Statistics NZ, Wellington, New Zealand.

Monaghan, R.M., L. Basher, R. Spiekermann, R. Smith, J.R. Dymond, R. Muirhead, D. Burger, and R. McDowell, 2021. Quantifying Contaminant Losses to Water from Pastoral Landuses in New Zealand II. The Effects of Some Farm Mitigation Actions over the Past Two Decades. New Zealand Journal of Agricultural Research. doi:10.1080/00288233.2021.1876741.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith, 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE 50:885–900.

Moriasi, D.N., M.W. Gitau, N. Pai, and P. Daggupati, 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE 58:1763–1785.

Nash, J.E. and J.V. Sutcliffe, 1970. River Flow Forecasting through Conceptual Models Part I—A Discussion of Principles. Journal of Hydrology 10:282–290.

Norton, N. and K. Wilson, 2019. Developing Draft Freshwater Objectives for Southland. Environment Southland publication, Environment Southland, Invercargill, New Zealand.

NZ Government, 2017. National Policy Statement for Freshwater Management 2014 (Amended 2017).

Parker, W.J., 1998. Standardisation between Livestock Classes: The Use and Misuse of the Stock Unit System. Proceedings of the Conference New Zealand Grassland Association., pp. 243–248.

Piñeiro, G., S. Perelman, J. Guerschman, and J. Paruelo, 2008. How to Evaluate Models: Observed vs. Predicted or Predicted vs. Observed? Ecological Modelling 216:316–322.

Plew, D., 2020. Models for Evaluating Impacts of Nutrient and Sediment Loads to Southland Estuaries. NIWA Client Report, NIWA, Christchurch, New Zealand.

Plew, D.R., J.R. Zeldis, B.D. Dudley, A.L. Whitehead, L.M. Stevens, B.M. Robertson, and B.P. Robertson, 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts.

Plew, D.R., J.R. Zeldis, U. Shankar, and A.H. Elliott, 2018. Using Simple Dilution Models to Predict New Zealand Estuarine Water Quality. Estuaries and Coasts:1–17.

Snelder, T., 2020. Assessment of Nutrient Load Reductions to Achieve Freshwater Objectives in the Rivers, Lakes and Estuaries of Southland. To Inform the Southland Regional Forum Process. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

Snelder, T.H. and B.J.F. Biggs, 2002. Multi-Scale River Environment Classification for Water Resources Management. Journal of the American Water Resources Association 38:1225–1240.

Snelder, T.H., S.T. Larned, and R.W. McDowell, 2018. Anthropogenic Increases of Catchment Nitrogen and Phosphorus Loads in New Zealand. New Zealand Journal of Marine and Freshwater Research 52:336–361.

Snelder, T.H., C. Moore, and C. Kilroy, 2019. Nutrient Concentration Targets to Achieve Periphyton Biomass Objectives Incorporating Uncertainties. JAWRA Journal of the American Water Resources Association 55:1443–1463.

Snelder, T.H., A.L. Whitehead, C. Fraser, S.T. Larned, and M. Schallenberg, 2020. Nitrogen Loads to New Zealand Aquatic Receiving Environments: Comparison with Regulatory Criteria. New Zealand Journal of Marine and Freshwater Research:1–24.

Whitehead, A., 2018. Spatial Modelling of River Water-Quality State. Incorporating Monitoring Data from 2013 to 2017. NIWA Client Report, NIWA, Christchurch, New Zealand.

Appendix A Total nitrogen and dissolved reactive phosphorus criteria for periphyton FWOs used in the analysis

The criteria for periphyton FWOs are shown for each REC Source-of-flow class that occurs in Southland and corresponding to the A, B and C bands (Table 25). The values in the table represent the recalibration of the criteria of Snelder *et al.* (2019) and the 20% spatial exceedance criteria. Values are median concentrations in units of mg m^{-3}.

Table 25. The total nitrogen and dissolved reactive phosphorus criteria for periphyton FWOs for each REC Source-of-flow class that occurs in the Southland region corresponding to the A, B and C bands and the 20% spatial exceedance criteria.

River Environment Classification Source-of-flow class	**Total nitrogen**			**Dissolved reactive phosphorus**		
	A	**B**	**C**	**A**	**B**	**C**
CX/GM	294	1372	2890	2.2	57.5	161.7
CX/M	538	2340	3843	8.9	114.8	289.5
CX/H	550	2385	3664	7.9	108	273.7
CX/Lk	105	504	1182	0.3	7.1	44
CX/L	369	1691	3363	2.8	68.1	187.3
CW/M	141	666	1556	0.4	15.3	69.9
CW/H	161	781	1764	0.5	16.7	69.7
CW/L	118	559	1325	0.3	5.8	38.5
CW/Lk	71	335	798	0.2	2.6	22.6
CD/H	67	316	758	0.2	1.5	13.5
CD/L	71	339	811	0.2	1.5	13.4
CD/Lk	61	287	681	0.2	1.4	12.5

Table 26. The total nitrogen and dissolved reactive phosphorus criteria for periphyton FWOs for each REC Source-of-flow class that occurs in the Southland region corresponding to the A, B and C bands and the 30% spatial exceedance criteria.

River Environment Classification Source-of-flow class	Total nitrogen			Dissolved reactive phosphorus		
	A	B	C	A	B	C
CX/GM	555	2519	5233	104.5	300.7	366.7
CX/M	1019	4252	5188	206.5	336.4	373
CX/H	1044	4324	5346	194.8	359.3	356.1
CX/Lk	195	918	2171	21.1	169.9	298.6
CX/L	710	3144	6040	117.7	311.8	374.6
CW/M	262	1242	2833	36.6	245.3	317.5
CW/H	311	1428	3243	41	252	321.8
CW/L	223	1045	2426	20.1	159.5	272.9
CW/Lk	131	617	1450	9.3	104.5	265.6
CD/H	124	589	1394	5.5	76	221.3
CD/L	132	633	1474	6	76.7	220.9
CD/Lk	111	521	1257	5.6	72.4	212.2

Appendix B Total nitrogen and total phosphorus loads to achieve estuary trophic state objectives used in the analysis.

The load criteria shown for each estuary are maximum allowable loads (MAL) in units of tonnes $year^{-1}$ corresponding to the nominated A, B and C bands. The values in the column headed 'current' are current loads estimated by Plew (2020). Missing values indicate the model was not able to estimate the annual load corresponding to the criteria. Note that macroalgae conditions in estuaries are not considered to be phosphorus limited and therefore no MAL is provided for TP for macroalgae.

Table 27. Load band thresholds for each estuary. Nutrient loads (tonnes per year) corresponding to the thresholds between bands A, B, C and D were derived by Plew (2020). Macroalgae was assumed to be limited only by nitrogen. Phytoplankton may be limited by either nitrogen or phosphorus, and the resulting phytoplankton banding is the lower of the bandings indicated by TN or TP loads. Low salinity indicates that macroalgae are likely to be suppressed due to low salinity in the estuary. Low flushing time indicates that the estuary flushing time is likely too short to sustain phytoplankton blooms. n/a indicates that band threshold cannot be achieved even at a zero load (due to nutrient input from other sources such as the ocean). In this study, n/a values were replaced by zero values which leads to the conclusion that the load reduction required is 100% of the current load and that FWO will not be achieved.

Estuary	Management class	Macroalgae				Phytoplankton						
		Current TN	TN band thresholds (t y^{-1})			TN band thresholds (t y^{-1})			Current TP	TP band thresholds (t y^{-1})		
			A/B	B/C	C/D	A/B	B/C	C/D		A/B	B/C	C/D
Waikawa Harbour	Tidal lagoon estuary	152	20.5	106.5	192.7	43.0	26	108.2	216	n/a	2.43	6.94
Haldane Estuary	Tidal lagoon estuary	35	5.9	30.6	55.2	16.5	3	34.7	70	n/a	0.73	1.99
Lake Brunton (closed)	Brackish lake/lagoon	11	Low salinity			0.91	2.16	5.07	1	0.115	0.288	0.690
Toetoes (Fortrose) Estuary	Tidal river estuary	4126	269	894	1516	Low flushing time			136	Low flushing time		
Waituna Lagoon	Brackish lagoon/lagoon	105	Low salinity			8.15	20.25	48.5	3	1.11	2.78	6.67
Bluff Harbour	Tidal lagoon estuary	47	32	368	705	n/a	3	236	3	n/a	n/a	n/a
New River (Ōreti) Estuary	Tidal lagoon estuary	4392	248	1410	2570	400	333	1630	26	n/a	n/a	26
Waimatuku Estuary	Tidal river estuary	230	Low salinity			Low flushing time			3	Low flushing time		
Jacobs River Estuary	Tidal lagoon estuary	1456	92	400	708	Low flushing time			70	Low flushing time		
Waiau Estuary	Tidal river estuary	1437	Low salinity			Low flushing time			24	Low flushing time		
Te Waewae Lagoon	Brackish lake/lagoon	751	Low salinity			n/a	8.3	28.25	24	0.025	1.205	3.955