Assessment of Nutrient Load Reductions to Achieve Target Attribute States in the Rivers, Lakes and Estuaries of Otago

Using revised periphyton nutrient criteria

December 20233

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LWP Client Report Number:	2023-13
Report Date:	December 2023

Quality Assurance Statement

Version	Reviewed By	
Client Draft	Oliver Floerl	

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Executive Summary

This report describes nutrient (nitrogen and phosphorus) load reductions predicted to achieve options for target attribute states in rivers, lakes and estuaries in the Otago region. The analysis does not consider how the nutrient load reductions would be achieved and only aims to inform the Otago Regional Council 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 assessed nutrient load reductions required to achieve four sets of options for target attribute states pertaining to the effects of the nitrogen and phosphorus for rivers, lakes, and estuaries across the region. The relevant target attribute states are for nitrate toxicity in rivers and maximum plant biomass in all receiving environments: phytoplankton in lakes and some estuaries, macroalgae in some estuaries and periphyton in rivers. 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 target attribute states. Calculations were made of the amounts by which current loads would need to be reduced to allow the target attribute states to be achieved (i.e., the load reduction required). The uncertainty of the various input models describing current nutrient loads and concentrations and the associated uncertainties of various study outputs were quantified.

The options for target attribute states are defined in terms of a band (A, B or C) for all river, lake and estuary receiving environments in the study area. These represent spatially uniform target attribute states. The fourth option provides for target attribute states that vary spatially to account for both variation in natural state and expected protection level. Lower target attribute states (i.e., B or C bands) are applied to parts of the region that have naturally higher nitrogen concentrations, loads, and periphyton biomass, which potentially lead to lower levels of environmental protection being deemed acceptable.

The load reductions required were assessed for all individual river segment, lake and estuary receiving environments in the region. The results for the individual receiving environments were aggregated to report on: (i) individual freshwater management units, (ii) the catchments of 20 individual estuaries, and (iii) the whole region. 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 target attribute state and therefore drives the load reduction required in each catchment.

Our assessments of the reductions in total nitrogen and total phosphorus loads required to achieve the target attribute state options were associated with multiple types of uncertainty. Uncertainty is unavoidable because the analyses are based on models that are simplifications of reality and 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 analysis. The resulting 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 total nitrogen (TN) and total phosphorus (TP) for the region for the A, B and C band and spatially variable target attribute state options. The load reductions are expressed as percentages 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).

Target attribute state option	TN	TP
C band	26 (17 - 38)	4 (-6 - 26)
B band	78 (54 - 90)	122 (79 - 166)
A band	81 (63 - 92)	185 (143 - 223)
Spatially variable	25 (14 - 35)	57 (22 - 102)

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 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 to achieve the plant biomass target attribute states assessed in this study. These criteria represent the best assessment of the nutrient concentration or load that will achieve the nominated biomass. The uncertainties associated with these criteria mean that some locations may develop biomass greater than specified by the target attribute state 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 target attribute state will not be achieved and that the appropriate management response is to reduce the current nutrient load.

The analysis presented here 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 target attribute states, with a quantified level of confidence and risk associated with each option. However, this project did 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 National Policy Statement for Freshwater Management 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.

Glossary

The table below defines the terms according to how they are used in this report.

Term	Definition
Attribute	Measurable characteristic that describes the state of a river, lake or estuary.
Compliance	The adherence of a receiving environment (river, lake or estuary) with a criterion
Criteria	A measured or predicted (by a model) quantity by which the achievement of the TAS is judged
Critical catchment	The land draining to a receiving environment for which the local excess load, is not exceeded by any upstream receiving environment.
Critical catchment load reduction required	The load reduction required at the critical point.
Critical point	A receiving environment for which the local excess load is not exceeded by any upstream receiving environment (the downstream most point in a critical catchment).
Limiting environment	The identification of whether it is an estuary, lake or river criterion that defines a critical point and that therefore drives the load reduction required for the critical catchment.
Local excess load	The amount by which the current load at the receiving environment would need to be reduced to comply with the criteria.
Maximum allowable load (MAL)	The maximum contaminant (nitrogen or phosphorus) load that will allow the target attribute state to be achieved.
Point load reduction	The amount by which the current load at a receiving environment to be reduced to comply with the criteria at that and all upstream receiving environments
Spatial framework	Digital representation of the drainage network (i.e., streams and rivers and their catchments) and the connected freshwater receiving environments (rivers, lakes and estuaries) of the study area.
Target attribute state (TAS)	Outcome (defined by the attribute) sought for the state of a river, lake or estuary

1 Introduction

High loads of the nutrients nitrogen and phosphorus in aquatic ecosystems can have at least two types of impacts. First, nitrogen concentrations in the form of nitrate can reach toxic levels that impair aquatic animal survival, growth and reproduction (Camargo and Alonso, 2006). Second, when not limited by light or other nutrients, primary production in lakes, rivers and estuaries can be stimulated by nitrogen and/or phosphorus enrichment, causing excessive plant biomass and ecological degradation associated with shifts from low productivity or oligotrophic states to eutrophic or hypertrophic states (Abell *et al.*, 2020; Biggs, 2000; Plew *et al.*, 2020). Consequently, managing the anthropogenic component of nitrogen and phosphorus loads to achieve toxicity and trophic state targets in lakes, rivers and estuaries is a requirement of the National Policy Statement – Freshwater Management (NPS-FM; NZ Government, 2020).

This study, undertaken for Otago Regional Council (ORC), assessed nutrient (nitrogen and phosphorus) load reductions required to achieve four options of target attribute states (TAS) in the rivers, lakes and estuaries of the Otago region. These TAS are defined based on National Objective Framework (NOF) attributes that are appended to the NPS-FM. Our study included an assessment of the uncertainties of the nutrient load reduction estimates. This was achieved by combining the uncertainties of the various input models that describe current nutrient loads and concentrations. Our assessment did not consider how the nutrient load reductions would be achieved. However, our analysis can be used as a basis for comparing the efficacy of different actions or strategies for reducing nutrient loads in a future scenario testing process.

The methodology used to carry out this assessment is based on two previous national-scale studies of nitrogen load reduction requirements (MFE, 2019; Snelder *et al.*, 2020). A first study (MFE 2019) evaluated the impact of the periphyton attribute of the NPS-FM (NZ Government, 2017) and the proposed addition of a dissolved inorganic nitrogen (DIN) attribute. It determined 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. A second national-scale study (Snelder *et al.* 2020) 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 TASs for estuaries. This methodology has also been applied to the Southland region and refined using regional data (Snelder, 2020). The analyses described in this report involved some modifications to methods used by MFE (2019) and Snelder *et al.* (2020) to represent the Otago region in greater detail, to add phosphorus as a target nutrient, and to examine a range of options for TAS.

2 Methods

2.1 Overview

This study's methodology is based on river state of environment (SOE) monitoring data, a spatial framework that represents the drainage network (i.e., streams and rivers), the connected freshwater receiving environments (rivers, lakes and estuaries) of the study area, and spatial predictions of nutrient concentrations and loads (Figure 1). 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, nitrogen and phosphorus loads derive from upstream catchments and are transported to receiving environments by the drainage network (Figure 1). Models that are fitted to observations of concentrations and loads at long-term state of environment (SOE) monitoring sites are used to predict the current concentrations and loads 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 TAS in river, lake and estuary receiving environments are primarily defined in terms of nutrient concentrations. The compliance of rivers, lakes and estuaries with the concentration criteria is assessed by comparison to current 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 maximum load that will allow the TAS to be achieved; Figure 1). Receiving environments with concentrations that are less than or greater than the criteria or the MAL are compliant or non-compliant, respectively. The current annual loads 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 the receiving environment would need to be reduced to comply with the criteria).

The point load reduction required differs from the local excess load in that it considers the excess load of all receiving environments upstream of a point in the drainage network. 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 point load reduction required is used to report the load reduction needed at a specific point in the network such as the downstream end of a freshwater management unit (FMU).

In this report, we report the point load reductions required at the scale of the catchments of estuaries, for the Draft FMUs and for the whole region[1]. We also report the point load reductions required for the upstream catchments of estuaries compared to the requirements to achieve TAS for the estuary (at the bottom of the catchment). This analysis provides information that is relevant to provision 3.13 of the NPS-FM, which requires that where there are nutrient-sensitive downstream receiving environments, nutrient concentration criteria for upstream contributing water bodies must be set so as to achieve environmental outcomes sought for the downstream receiving environments (Ministry for Environment, 2020).

Our analysis also identifies critical catchments, their load reductions required and their limiting environments. A critical catchment is the land draining to a receiving environment for which the local excess load, is not exceeded by any upstream receiving environment. The limiting environment identifies whether it is an estuary, lake or river criterion that defines the local excess load at the critical point and that therefore drives the load reduction required for the critical catchment. The critical catchment analysis provides further information relevant to provision 3.13 of the NPS-FM. The analysis 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 is not exceeded by any upstream receiving environment (i.e., the downstream most point in a critical catchment). The catchment upstream of the critical point is a critical catchment and has a critical catchment load reduction required (Figure 1), which

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[1] We quantified point load reductions for all points in the drainage network (i.e., for all receiving environments). This is available as supplementary data.

is the load reduction required at the critical point. The critical catchment load reduction required indicates the spatially averaged reduction rate that would be required over the entire area of the critical catchment to reduce the load to the MAL (i.e., to allow the TAS to be achieved) for all receiving environments within the critical catchment. The limiting environment of the critical catchment indicates whether its 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 loads (expressed as yields) at successive upstream receiving environments (which may be river segments or lakes) are obtained. 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)[2].

The critical catchment load reduction required 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 for individual farms. However, this yield should be understood as the mass of contaminant that is delivered to downstream receiving environments rather than the initial loss at the land surface. The initial loss at the land surface is sometimes referred to as a leaching rate or root-zone loss, and not all of this loss is delivered to downstream receiving environments due to attenuation in the drainage network. It should be kept in mind that the absolute load reduction values that are reported for critical catchments are averages over the whole 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.

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[2] 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.

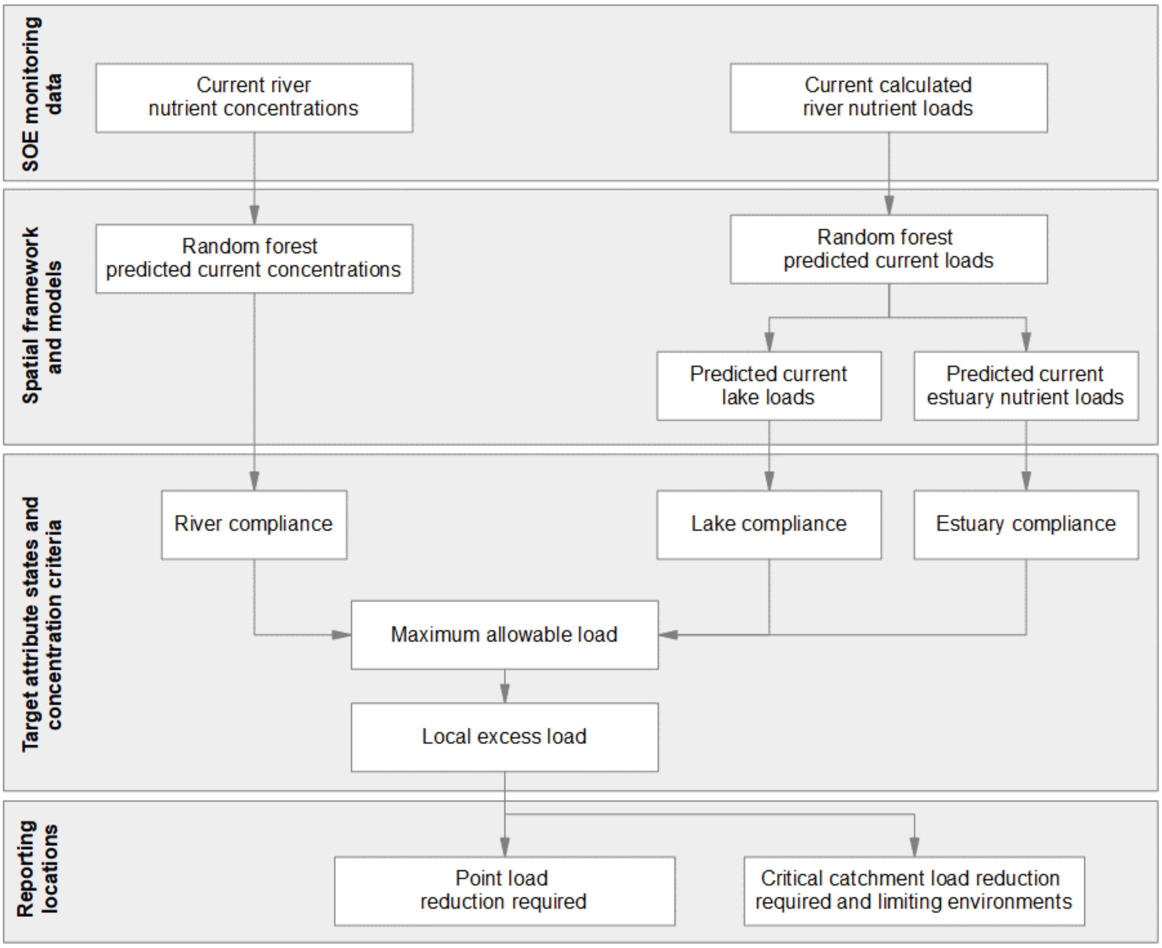

Figure 1. Schematic diagram of the assessment of nutrient load reductions required to achieve TASs.

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 whole of the Otago region (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 70,600 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 discharge 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 approximately 387 lakes with a surface area greater than 1 hectare in the Otago region, there were 124 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 20 estuaries in the study area (Figure 2). Estuaries were represented by a GIS layer, which defines 421 estuaries on the New Zealand coastline, that is associated with the national classification of coastal hydrosystems (Hume *et al.*, 2016). The drainage network segments that terminated at these estuaries were identified by intersecting the 20 estuary polygons on the Otago coast with the river network.

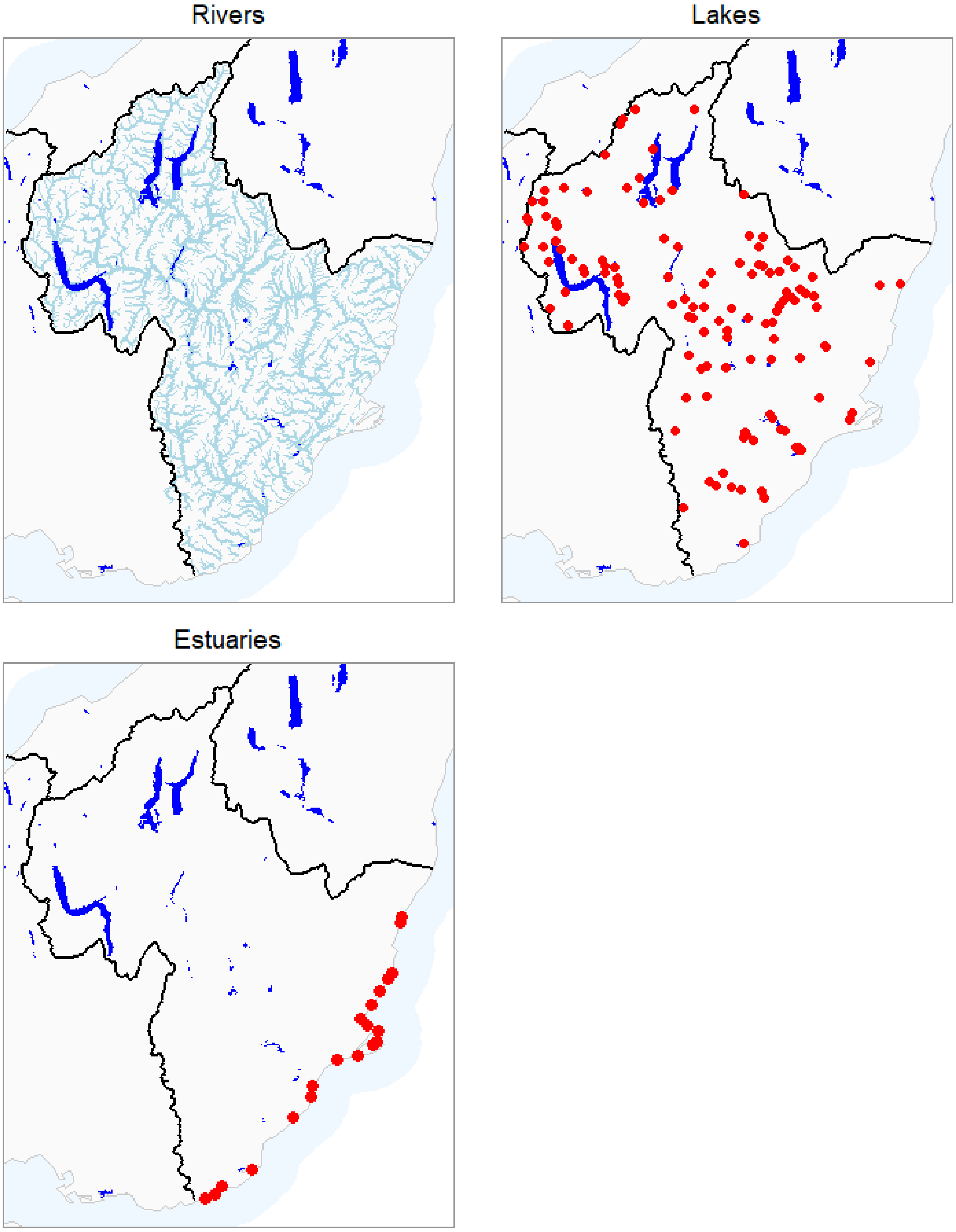

Figure 2. Components of the spatial framework used in this study. Note that lakes are represented by points that are located at lake outlets for clarity.

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 region, ORC's FMUs (Figure 3), and the catchments of estuaries (see Section 2.10.2 for details). These summaries were evaluated by obtaining the load reductions required at the terminal segments of the summary area (i.e., the downstream-most segment of FMUs or the network of segments intersecting the coastline for catchments of estuaries or the region as a whole).

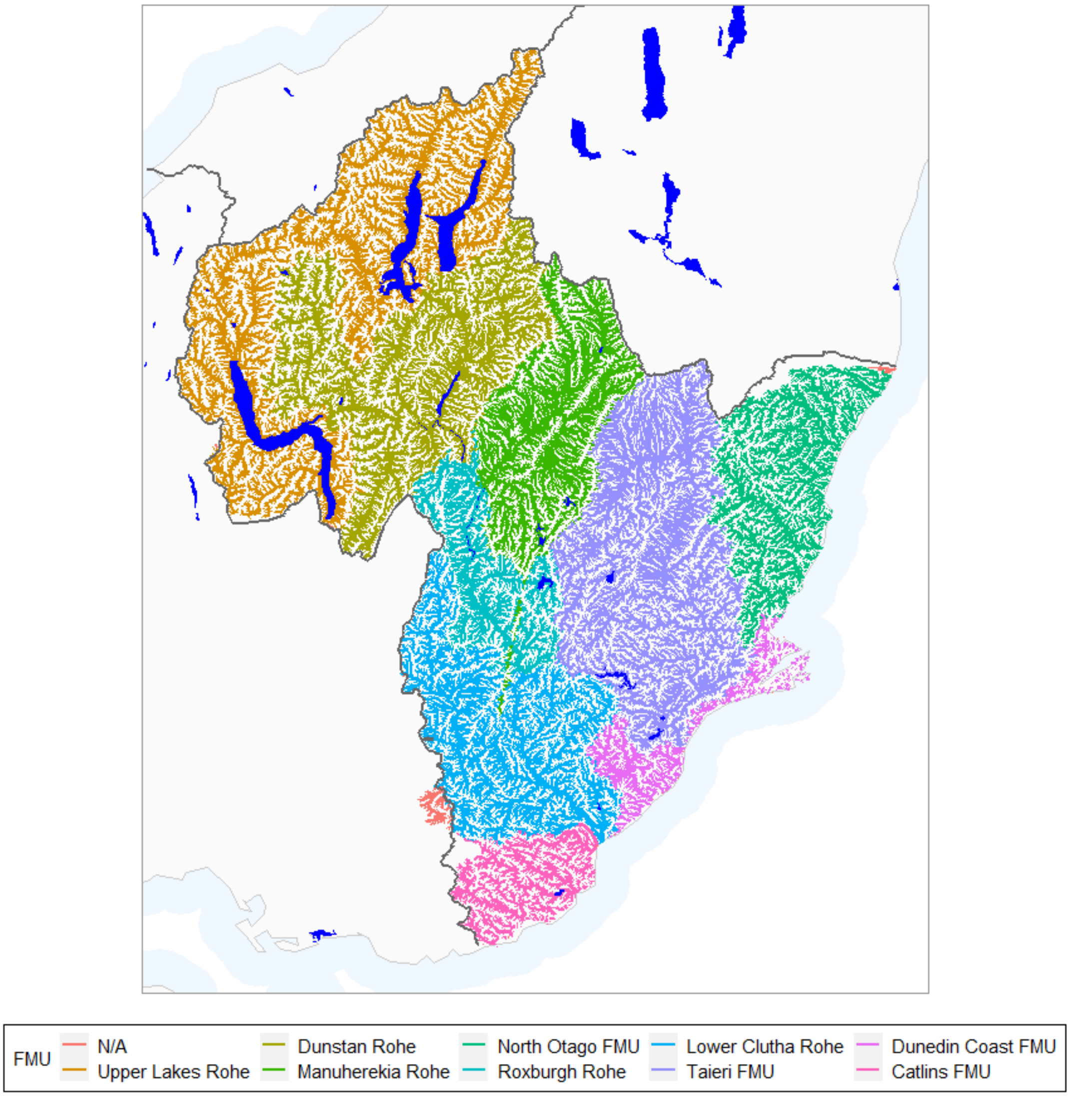

Figure 3. Freshwater management units (FMUs) used for summarising the results of the analysis. Note that N/A indicates part of the Lower Clutha catchment area that is within the Southland jurisdictional region and therefore not part of the Lower Clutha Rohe. Large lakes are indicated as blue polygons and lines, which are simply provided for orientation.

2.3 Estimated current river nutrient concentrations

Estimates of the current median concentrations of the nutrients: total nitrogen (TN), nitrate-nitrogen (NO3N) and total phosphorus (TP), were made for all segments of the drainage network using statistical regression modelling of river water quality monitoring data. In addition, estimates of the median soluble proportion of TN (NO3N/TN) were made for all segments of the drainage network. Because the site median values of NO3N/TN represent proportions (i.e., ratios), 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). The models in this study were fitted to data pertaining only to river monitoring sites in the Otago region because predictions made by national-scale models were found to be slightly biased at the regional level. For each water quality variable, a type of regression model called a random forest (RF) was fitted to median values of monthly observations made at river water quality monitoring sites. The regression model predictor variables describe various aspects of each monitoring site's catchment including the climate, geology, and land cover. In addition, five predictors were included 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}).

A total of 107 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 5-year period 2015 to 2020 from which the median values were calculated (Ozanne, 2021).

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 variable NO3N/TN to increase the normality of its' distribution. A logit transformation is defined as:

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

where x are the site NO3N/TN 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, dissolved reactive phosphorus (DRP), and the values of NO3N/TN 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 and NO3N 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/TN 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.

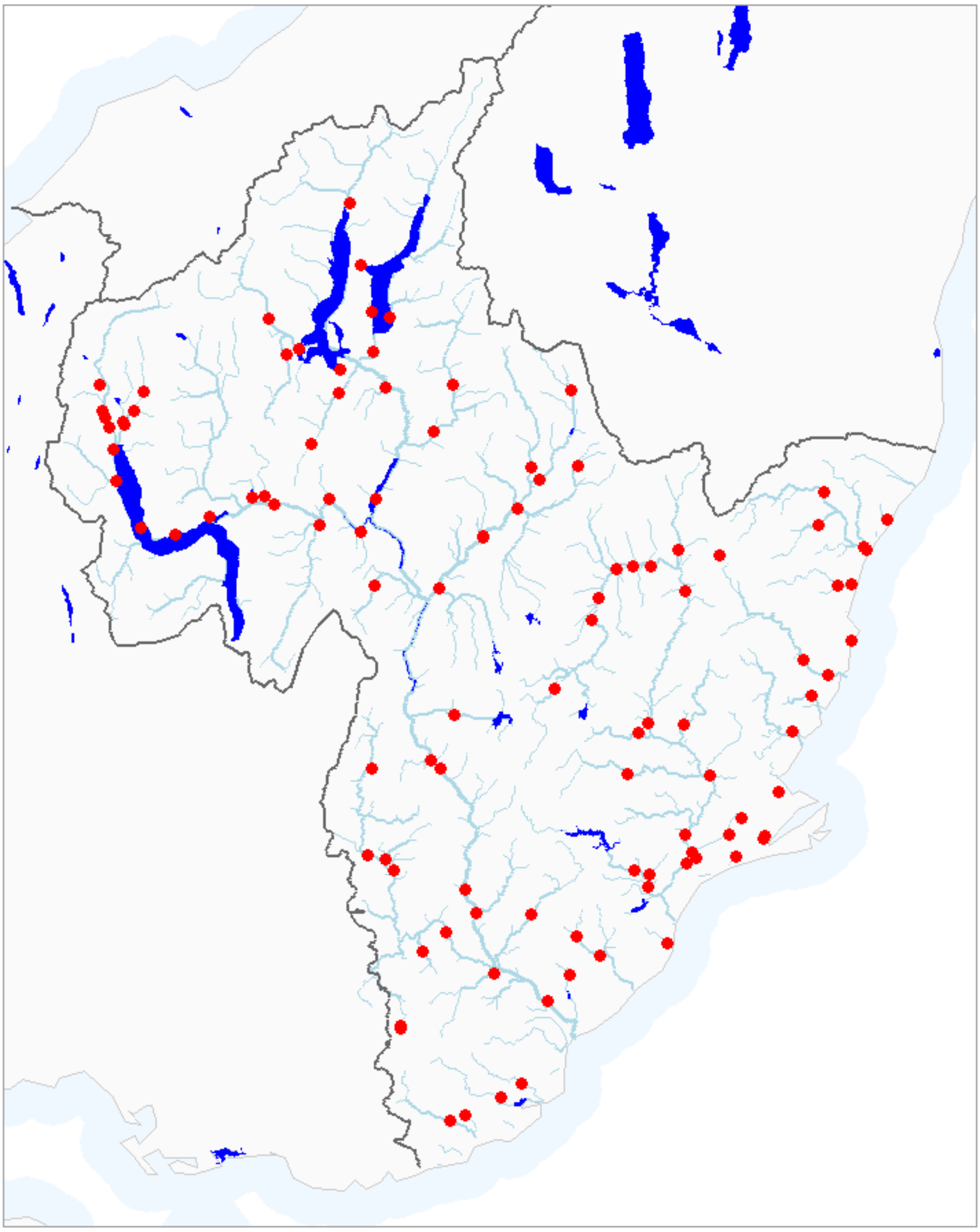

Figure 4. Locations of the 107 river water quality monitoring stations used to fit the concentration models. Large lakes and rivers are indicated as blue polygons and lines, which are simply provided for orientation

The performance of the RF models, and the uncertainty of their predictions were evaluated 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). The NSE indicates how closely the observations coincide with predictions (Nash and Sutcliffe, 1970). NSE values range from −∞ 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). Bias can also be expressed in a standardised way as percent bias (PBIAS). 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 standardisation 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 all 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 Otago 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 of TN and TP were calculated for 50 and 51 sites, respectively, 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 site that were either provided by ORC 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[3]. 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 described above for nutrient concentrations to fit RF models to calculated monitoring site yields of TN and TP. RF models were fitted to site yields of TN and TP pertaining only to monitoring sites in the Otago region because predictions made by national-scale models were found to be slightly

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[3] 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 (2023).

biased at the regional level. The site yield values were $\log_{10}$ transformed to improve model performance (Snelder *et al.,* 2018). Due to recent changes in the sites in the ORC river water quality monitoring network, only 45 of the sites that were included in the load dataset were also included in the sites that were used to model concentrations (Figure 5).

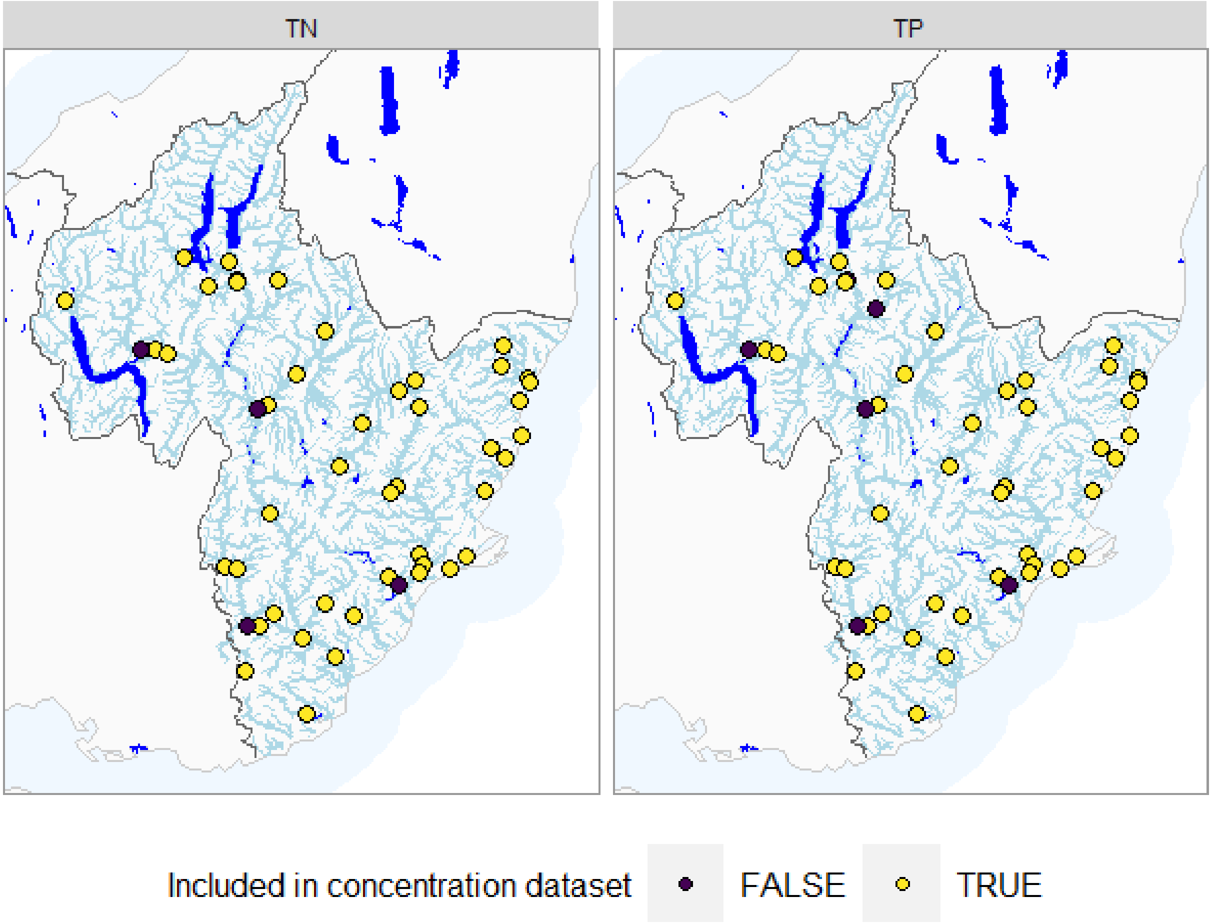

Figure 5. Locations of the 50 and 51 river water quality monitoring stations used to fit the TN and TP load models, respectively. Sites that were also included in the concentration data are indicated. The 45 sites that were included in the concentration dataset (i.e., the red coloured sites) are common to the eight regression models used in the analysis. Large lakes and rivers are indicated as blue polygons and lines, which are simply provided for orientation.

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 yield model predictions were evaluated following the same criteria used for the concentration predictions (Table 1).

2.5 Estimated current lake TN and TP concentrations

Estimates of in-lake nutrient concentrations were made by coupling estimated input loads from the drainage network with the national 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, τ_w is water residence time (years) derived from the FENZ 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.

Actual water quality measures are available for eight monitored lakes across Otago (Figure 6). We used these observations to test the parameterisation provided by Abell *et al.* (2019, 2020) of the models represented by Equation 3 and 4. We compared the observed in-lake median concentrations of TN and TP over the period (2015 – 2020) from Ozanne (2021) with the predictions from these models. Where a lake had more than one monitoring site, the median of values over all sites was used. The performance of the models parameterised using the β values provided by Abell *et al.* (2019, 2020) was quantified using the statistics shown in Table 1. Where the performance was unsatisfactory according to the criteria proposed by Moriasi et al. (2015), outlined in Table 1, we refitted the model to the Otago data and used that resulting Otago-specific model in the analyses that follow.

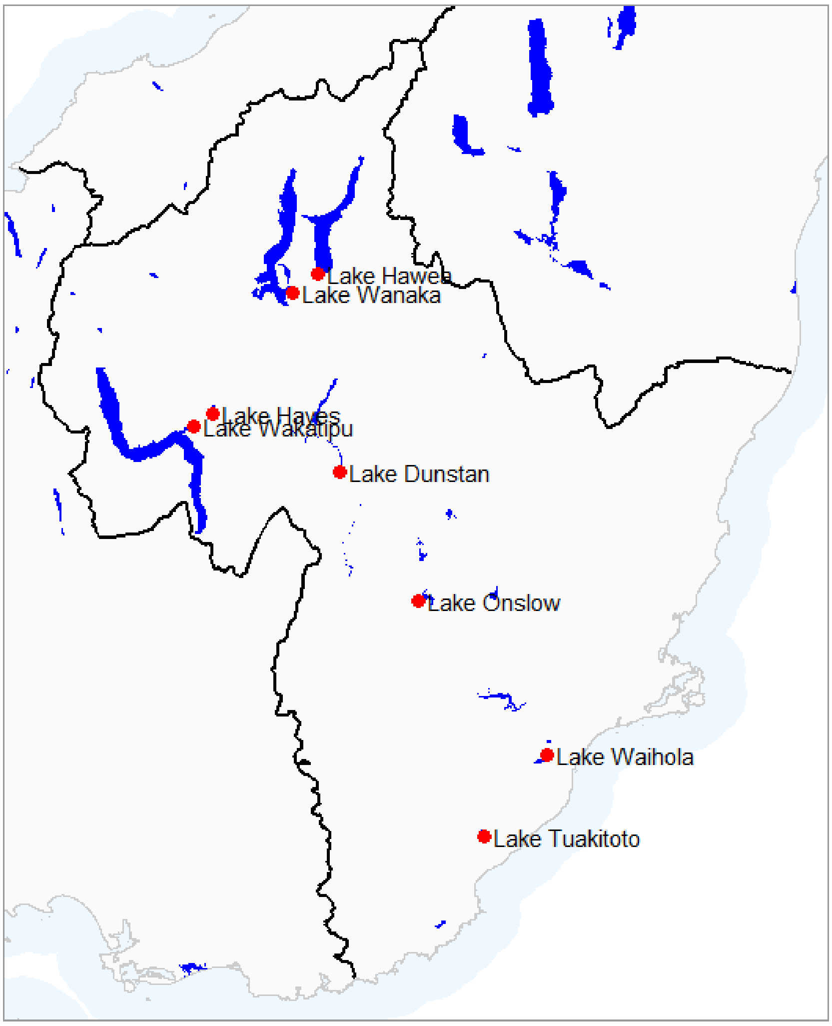

Figure 6. Lakes with water quality measurements (red points) in the Otago region. Large lakes are also indicated as blue polygons, which are simply provided for orientation.

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, 2020). 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 20 estuaries that were included in the study was represented by separate models, which are fully described by Plew (2021).

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

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

In this study a range of potential TAS (‘options’) were nominated for different receiving environments and nominated categories of rivers, lakes and estuaries across the region (hereafter ‘management classes’ and discussed in Section 2.10.2). The TASs 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 estuaries, and are expressed using A, B C and D bands for each attribute following the NOF system. The following sections tabulate the concentration criteria associated with the A, B and C bands that were used as potential TAS in this study. The NPS-FM defines the boundary between the C and D bands as the national bottom line, which means the D band is generally an unacceptable state (i.e., cannot be adopted as the TAS). In addition, this section describes how the nutrient concentration criteria were used to assess compliance and define the MAL for river, lake, and estuary receiving environments. The details of the assessment of compliance and the calculation of MAL differed between receiving environment types.

2.7.1 Rivers

There are two effects of nitrogen for which concentration criteria are applied for rivers depending on the circumstances. First, 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, C and D) are shown in Table 2. These concentrations are generally considerably higher than nitrate concentrations associated with excessive plant biomass in rivers. As of 2020, the national bottom line for Nitrate toxicity is the NOF B band (Table 2, NZ Government, 2020). Therefore, in this study the NOF C band was never used as a potential TAS for nitrate toxicity.

Table 2. Nitrate toxicity bands used as potential TAS for rivers in this study and associated concentration thresholds (mg NO_3-N m^{-})^{3}.

Attribute band	Nitrate concentration thresholds
A	≤1,000
B	>1,000 and ≤ 2,400
C	>2,400 ≤ 6,900
D	➢ 6,900

The second type of concentration criteria that is relevant to rivers is associated with the periphyton attribute. In brief, periphyton is attached algae growing on the beds of rivers (slime)[4]. Some periphyton is a natural feature of rivers and is an essential component of the riverine food web. However, over-abundant periphyton degrades ecological, recreational, and cultural values associated with rivers. The periphyton attribute stipulates the levels of

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[4] Periphyton is often a complex matrix consisting of algae, cyanobacteria, heterotrophic microbes, and detritus.

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 bands used as potential TAS for rivers in this study and associated concentration 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).

Attribute band	Periphyton biomass thresholds
A	≤50
B	>50 and ≤120
C	>120 and ≤200
D	>200

In this study, the nutrient criteria to achieve the periphyton biomass bands were based on Snelder and Kilroy (2023). The criteria are specified in terms of median concentrations of total nitrogen (TN) and total phosphorus (TP) and vary across 14 river classes defined by the second (Source-of-flow) level of the River Environment Classification (REC; Snelder and Biggs, 2002) that occur in the Otago region (see Appendix A).

The periphyton-nutrient criteria were derived from nutrient-biomass relationships that were subject to considerable uncertainty. There is therefore a risk that a proportion of locations will exceed a target biomass threshold even when they are compliant with the associated TN and TP criteria. Snelder and Kilroy (2023) provided for differing levels of this risk by incorporating a ‘under-protection risk’ criterion for the TN and TP concentration criteria. The under-protection risk is an estimate of the proportion of locations that will exceed a nominated biomass target when all locations are compliant with the nutrient criteria. The under-protection risk indicates the risk that a location will exceed the periphyton biomass specified for by the TAS. The level of acceptable risk is a management, rather than a scientific, decision. In this study, the analyses were based on the under-protection risk of 20%, which is the same as that used in the recent ORC SOE report (Ozanne, 2021)[5]. The 20% under-protection risk is always a lower concentration (i.e., more stringent) than the concentrations corresponding a higher risk (e.g., 30% under-protection risk) and, therefore, assessments based on the 20% under-protection risk will generally have higher load reduction requirements than those based on higher levels of under-protection risk.

Tests of the criteria defined by Snelder and Kilroy (2023), based on both the data that were used to define the criteria and an independent test dataset, showed they performed better than previously derived criteria. Overall, Snelder and Kilroy (2023) recommended the use of their criteria based on the consistency of the improved performance and the underlying technical explanation for why the improved performance was expected.

A detail of the criteria derived by Snelder and Kilroy (2023) was that the underlying models tended to over-estimate low periphyton biomass[6] values (i.e., ≤ 50 mg m^{-2}). Over-estimation

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[5] Note that this report has used the same level of under-protection risk as Ozanne (2021) but has used different (i.e., revised) periphyton nutrient criteria.

[6] The biomass that is the response variable in these models is the 92nd percentile of monthly observations at 251 periphyton monitoring sites located throughout New Zealand. The 92nd percentile of monthly observations is how the river periphyton attribute state is defined by the NPS-FM.

of the low biomass values meant that the derived criteria for the lower biomass threshold (i.e., 50 mg m^{-2}) were too stringent (i.e., the concentrations were too low).

To address the issue of over-prediction of low biomass values, Snelder and Kilroy (2023) suggested that an alternative set of criteria for the 50 mg m^{-2} biomass threshold could be derived using quantile regression. This approach was used to derive TN and TP criteria for the subset of Otago and Southland sites taken from the fitting data used by Snelder and Kilroy (2023). Using these data, Otago and Southland-specific criteria were derived for the same levels of under-protection risk as the other thresholds (i.e., 120 and 200 mg m^{-2}). However, the quantile regression criteria are spatially uniform (i.e., one value applies to all REC Source-of-flow classes). The alternative set of spatially uniform Otago and Southland-specific criteria for TN and TP derived using quantile regression for the 50 mg m^{-2} threshold is provided in Appendix A.

It was assumed that river segments that have fine bed substrates (i.e., soft-bottomed streams and rivers) will not allow high periphyton biomass to develop due to substrate instability. We discriminated soft-bottomed streams and river segments from those with coarse substrates by using substrate size index values of <3 and ≥3 respectively. Substrate size index values were based on modelled estimates that are available in the FENZ database as described by MFE (2019).

Compliance for each river segment was derived from the nominated TAS. The TAS specifies the periphyton biomass as chlorophyll-*a* and from this, and the segment's REC class, the TN and TP concentration criteria were obtained (Appended Table 29). 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 nitrate toxicity concentration criteria for rivers is defined in terms of nitrate-nitrogen (NO3N), which is the majority of the dissolved component of TN. However, the nitrogen criteria for river periphyton, lakes and estuaries are defined in terms of TN. In addition, the effectiveness of nutrient mitigations on agricultural land for both nitrogen and phosphorus is generally specified in terms of TN and TP (e.g., McDowell *et al.*, 2020; Monaghan *et al.*, 2021). Therefore, the nitrate toxicity concentration criteria were converted to an equivalent TN concentration to make all nitrogen criteria commensurate and to allow the load reductions to be comparable to mitigation effectiveness. The NO3N criteria were converted to TN equivalents by dividing them 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 the ratio of NO3N to TN will remain the same if the loads of 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 TAS obtained from Table 2 or Appended Table 1 and where necessary converted to equivalent TN (i.e., where the criterion was initially defined in terms of NO3N). The local excess loads were calculated as the current TN and TP loads minus the respective MALs.

2.7.2 Lakes

The NOF specifies the thresholds for 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 these phytoplankton biomass thresholds (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 compliance with the associated phytoplankton biomass TAS. 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.

Compliance for each lake is derived from the TN and TP TAS thresholds (Table 4) by lake type (stratified or polymictic). The upper threshold for the TN and TP attribute bands were used as the nutrient criteria. 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*.

Table 4. Lake phytoplankton biomass bands used as potential TAS in this study and associated concentration thresholds as mg Chl-a m^{-3} (annual median) and corresponding TN and TP thresholds as mg m^{-3} (annual median). The upper threshold for the TN and TP attribute bands were used as the nutrient criteria.

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

The MAL for each lake was derived from the TN and TP concentration criteria by lake type (stratified or polymictic). The TN and TP concentration criteria were converted into equivalent TN and TP loads (the MALs) by inverting Equations 3 and 4. Local excess loads were calculated for each lake as the current TN and TP loads minus the respective MALs.

2.7.3 Estuaries

Many estuaries in Otago are shallow and have extensive intertidal areas. When enriched with nutrients (particularly nitrogen) from the upstream catchment, they are susceptible to eutrophication. Symptoms of eutrophication include proliferations of benthic macro- and micro-algae, leading to organic enrichment of sediments, reduced sediment oxygenation, and sulphide production due to organic matter breakdown. Other Otago estuaries are deeper and predominantly subtidal. Depending on the flushing time of these deep estuaries, the primary expression of excessive nutrient loading and eutrophic conditions is high phytoplankton biomass, which may lead to water column deoxygenation and reduced water clarity.

There are no NOF attributes or nationally applicable numeric TAS for New Zealand estuaries. Plew *et al.* (2020) developed attributes describing trophic state for estuaries using a conceptually similar system to the NOF for rivers and lakes based on two types of attributes: macroalgae and phytoplankton. In addition, Plew *et al.* (2020) developed nutrient concentration criteria and estuary annual loading rates to achieve different attribute states. This study used Plew *et al.* (2020) to propose options for trophic state TASs and to define associated nutrient criteria.

For macroalgae, the options for TAS correspond to levels of Ecological Quality Rating (EQR), which is a combined metric of macroalgal cover and biomass. Plew *et al.* (2020) derived TN criteria that are based on ‘potential concentrations’ to achieve EQR bands (Table 5). Potential TN 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. Macroalgal 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 also generally 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 TAS.

Potential TN concentrations were calculated using a single-compartment dilution model for each estuary (Plew *et al.*, 2018, 2020). These models estimate the volume-averaged TN concentration at high tide under mean flow and spring tide conditions, accounting for the mixing of river inflows with sea water within the estuary. Potential TN concentrations calculated in this way were compared with observed EQR values to derive the TN thresholds in Table 5.

Table 5. EQR bands used as potential TAS for estuaries in this study and associated thresholds and corresponding potential TN concentration criteria as mg m^{-3}.

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

Plew *et al.* (2020) also suggested phytoplankton bands that are analogous to the NOF band system for rivers and lakes. Band thresholds for estuary phytoplankton are based on annual 90th 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). In the absence of New Zealand specific phytoplankton bands, band thresholds for high saline (euhaline) and moderately saline (meso/polyhaline) estuaries are based on those developed for Basque estuaries. Basque estuaries are generally shallow and well drained like most New Zealand estuaries (Borja *et al.*, 2004; Robertson *et al.*, 2016) hence were used here in favour of bands based on US estuaries, which are representative of deeper, less well flushed systems. Thresholds for freshwater or brackish systems are taken from NOF attribute bands for maximum chlorophyll-*a* concentrations in lakes (MFE, 2018). While the bands in Table 6 are based on estuary salinity, estuary type was used to determine the appropriate band to apply to each estuary (Figure 7). Deep sub-tidally dominated estuaries (DSDE) typically have high, near oceanic salinities. Consequently, euhaline bands were applied to this category. Estuaries or coastal lakes that are normally closed to the sea typically have low salinities. For this reason, oligohaline bands were applied to all coastal lakes. The meso/polyhaline bands were applied to Shallow Intertidally Dominated Estuaries (SIDE) and Shallow Short Residence-time Tidal River Estuaries (SSRTRE).

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 and phosphorus inflows from both rivers and the ocean and for estuary hydrodynamics. The model predicts the maximum likely phytoplankton concentration (as chlorophyll-a) for summer flows (February mean flows). Compliance for TN and TP was assessed based on ‘potential concentrations’ to achieve the phytoplankton bands.

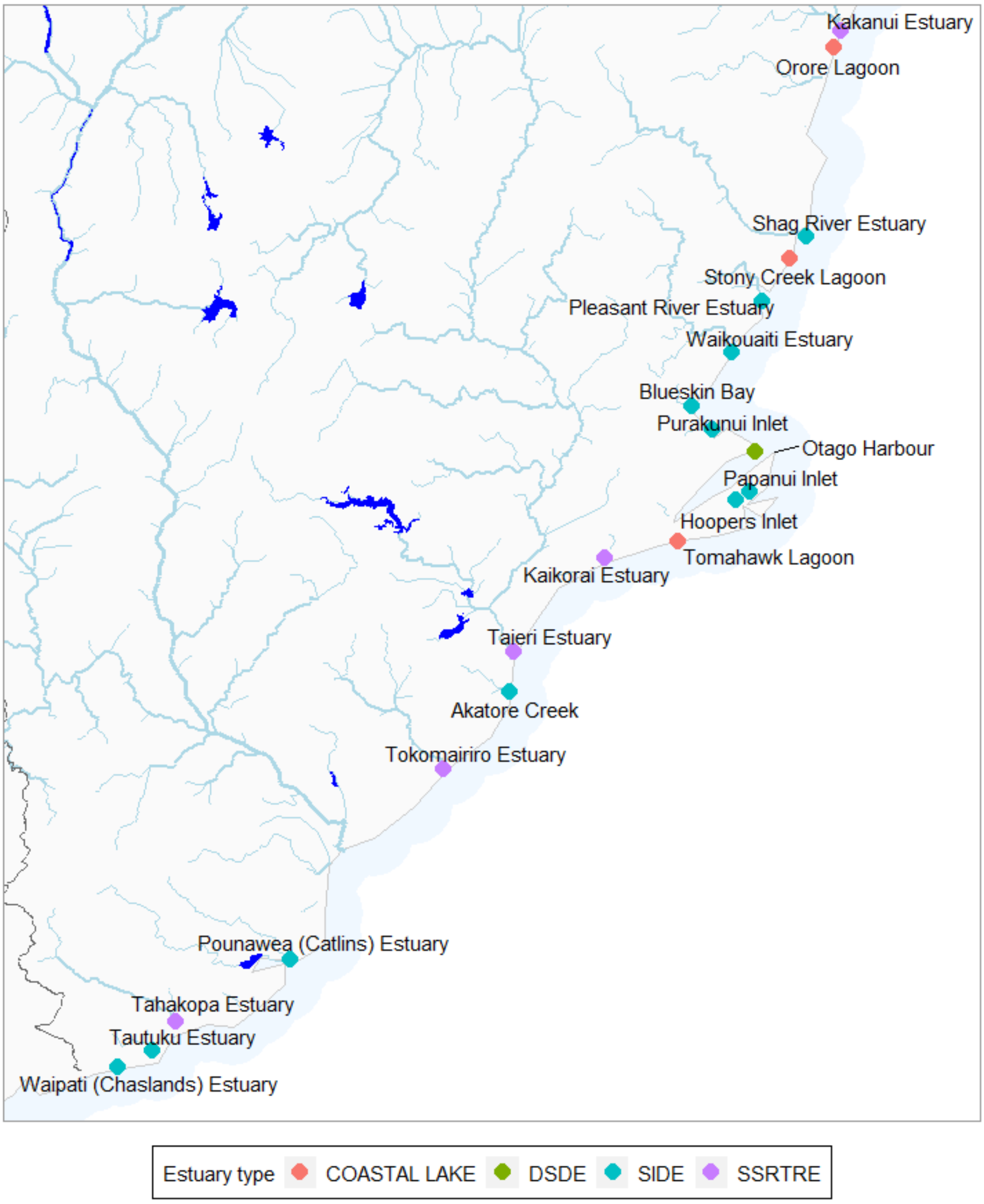

Figure 7. Estuaries on the Otago coast that are represented in this study classified by type. Large lakes and rivers are also indicated as blue polygons and lines, which are simply provided for orientation.

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

Attribute 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
D	>12	>16	>60

Compliance for each estuary was derived from two relevant measures that describe macroalgae and phytoplankton biomass that were adopted for this study as TAS (and for simplicity are referred to hereafter as TAS although they are not defined by the NPS-FM, Table 5 and Table 6). These TAS specify the EQR and phytoplankton thresholds while the respective potential TN and TP concentration criteria were provided by Plew (2021). The TN and TP loads that are consistent with the respective criteria were derived for each estuary using simple dilution models of (Plew, 2021). These loads are detailed in Appendix B (Table 31) for each of the 20 estuaries in the region. More details of the procedures used to derive the TN and TP thresholds for each estuary are described in (Plew, 2021).

For estuaries where intertidal area constitutes >40% of total area, the TAS was based on the macroalgae EQR bands (Table 5) because nuisance macroalgal blooms are the most common eutrophic response in these systems. Because macroalgae are not considered to be limited by phosphorus, the MAL is only defined for TN loads. While phytoplankton blooms may occur in estuaries with high intertidal area, the impact of excessive phytoplankton is low because water is shallow and well mixed.

For estuaries where intertidal area is <5% of total area, and in low salinity/brackish systems such as coastal lakes, the TAS was based on phytoplankton and the MAL was defined for both TN and TP. Such systems are more prone to stratification, and oxygen depletion in bottom waters driven by high phytoplankton biomass is common. Macroalgal growth is limited by lack of suitable habit or low salinity.

For estuaries with an intertidal area between 5% and 40% of total area, the TAS was based on both macroalgae and phytoplankton. In these estuaries, the MAL for TN was defined by the lower of the TN load criteria for macroalgae and phytoplankton, and the MAL for TP was defined by the criteria for phytoplankton. While Otago Harbour has an estimated 45% intertidal area (Hume *et al.*, 2016), it is a DSDE with a long flushing time and likely susceptible to both macroalgal and phytoplankton blooms. The TAS for this estuary was based on both macroalgae and phytoplankton.

Two of the Otago estuaries (Kakanui and Kaikorai) are known to be Intermittently Closed and Open Estuaries (ICOE) with frequent closures. For these estuaries, the MAL for TN was based on macroalgae response for the open state, and the MAL for TP based on phytoplankton response for the closed state.

For some estuaries, the MAL for TP could not be calculated for the most restrictive TAS (Band A) because the ocean supplies sufficient TP for phytoplankton growth even if there were no TP inputs from rivers. The relevant MALs for these estuaries are therefore zero, indicating that the TAS would not be achieved even if the current TN and TP loads were zero (Appendix B, Table 31).

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. All models had a common set of 45 sites (Figure 5) and it was expected that the residual errors from each model pertaining to these sites would be correlated to a degree across the eight models. A correlation matrix derived from the eight sets of model errors and 45 common sites 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.

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

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

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 and TP), the soluble proportion of TN (NO3N/TN), and the current loads (TP and TN). At the third step, the procedure described above was repeated for each realisation using the perturbed values. At the fourth and final 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% confidence that the segment is compliant) to zero (100% confidence that the segment is non-compliant).

For the current state, local excess loads, and load reduction required assessments, the best estimate was represented by the mean value from the distribution of values. The uncertainty of these two assessments was quantified by their 90% confidence intervals. For the assessment of load reductions required, the best estimates and the uncertainties were derived as the mean value over all 100 realisations for each FMU, estuary catchments and the entire region.

2.9 Preliminary assessment of current state

An assessment of the current state (of the attributes described above) for all rivers, lakes and estuaries included in the study was made using the models described above. This assessment derived a best estimate of TN and TP concentrations in rivers, and TN and TP loads in lakes and estuaries. These best estimates were then used to assess the current state of each relevant attribute in all receiving environments. The state of each attribute in each receiving environment was graded based on their current concentrations compared to the nutrient criteria to achieve: NOF periphyton biomass bands for rivers (Table 3), NOF phytoplankton biomass bands for lakes (Table 4) and EQR or phytoplankton bands for estuaries (Table 5, Table 6). The results were mapped to provide a basis for comparing the results of the load reduction requirements that were assessed for different nominated freshwater TAS settings described in the following section.

2.10 Target attribute state settings

2.10.1 Definition of target attribute states

To proceed with the analysis, it is necessary to nominate TAS that can be linked to associated concentration criteria for rivers, lakes and estuaries (i.e., Table 2 to Table 6). As part of the NPS-FM implementation, ORC will need to define TAS for all for rivers, lakes, and estuaries. TAS could be set for each river, lake, and estuary individually; however, this would result in a very large number of potential combinations of TAS. ORC currently have a schedule of characteristics, numerical limits, and targets for good quality water in Otago lakes and rivers embedded as Schedule 15 in the current Water Plan. To make our analysis and presentation of results manageable, we nominated four sets of TAS that are specific to nutrients and that are consistent with the NPS-FM for which load reduction requirement assessments across rivers, lakes, and estuaries were made. These nominated TAS have no statutory weight and should be regarded as possible options that are devised to show the range of possible nutrient load reduction requirements.

We adopted the approach used in the NPS-FM and used the upper thresholds for the A, B or C bands as shorthand to define TAS for all receiving environments. For the analyses that follow, the nutrient criteria that are associated with these bands (i.e., Table 2 to Table 6) are the basis for our analysis of compliance and load reductions required. This means that where attributes are based on plant biomass (i.e., periphyton in rivers, phytoplankton biomass in lakes, and algal biomass in estuaries), the nutrient criteria are the basis for the calculations and biomass is not predicted for any receiving environment as part of the analyses.

The first three sets of TAS are spatially uniform and are defined by uniform requirements of the A, B and C bands across all river, lake and estuary receiving environments. The A, B and C band options for TAS require that all receiving environments achieve at least the nominated band. The fourth set of TAS are spatially variable with the A, B and C bands applying variably to river, lake and estuary receiving environments depending on the classification systems described in the next section. The spatially variable option for TAS requires that each receiving environment achieves at least the band to which it has been assigned (see Section 2.10.3 for details).

2.10.2 Classification systems

Three management classification systems pertaining to rivers, lakes, and estuaries have been proposed to provide an example of an option for TAS that vary spatially. We note that the management classification systems described below are examples for the purpose of demonstrating spatially variable TAS and are not a framework that is used by ORC.

2.10.2.1 Rivers

We followed the approach taken by Southland and Canterbury Regional Councils and used the second ("Source-of-flow") level of the REC to define a management classification of the individual segments of the river network. Individual segments were assigned to one of five management classes based primarily on their REC Source-of-flow category (Figure 8). Some pragmatic modifications to the original REC Source-of-flow categories were made. First, the "Glacial Mountain" and "Mountain" Source-of-flow categories were combined and called simply "Mountain" (M, Figure 8). Second, the Lake-fed Source-of-flow category was subdivided into upper lakes (Lk Upper) and lower lakes (Lk Lower; Figure 8). The other two river management classes were defined by the Hill (H) and Lowland (L) Source-of-flow categories (Figure 8).

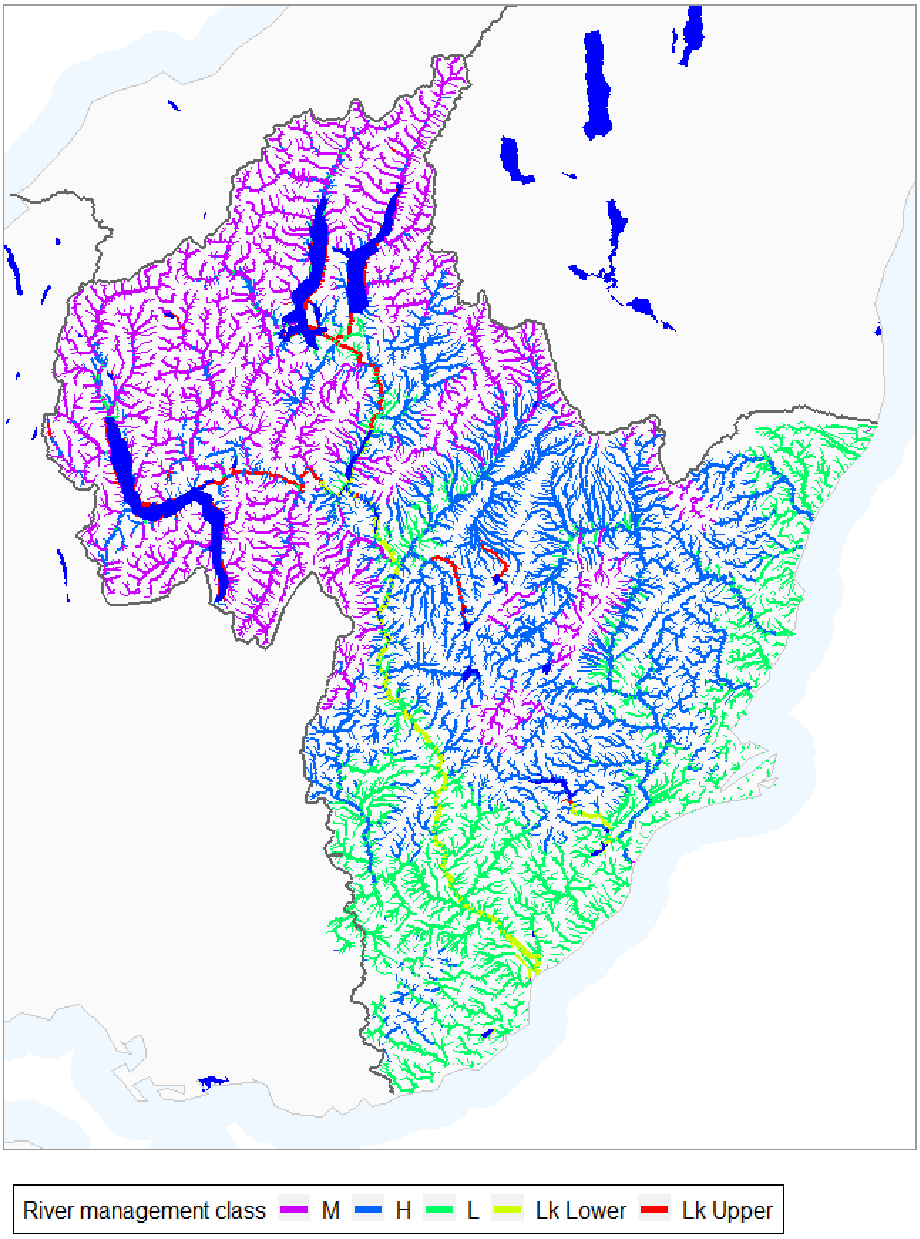

Figure 8. Nominated river management classes applied in this study. Large lakes are also indicated as blue polygons, which are simply provided for orientation.

2.10.2.2 Lakes

A lake classification system based on environmental distinctions such as lake depth could be derived, and this would be consistent with the use of the REC to define a management classification for rivers. However, we used the FMU structure to demonstrate an alternative framework. We grouped lakes into Upper-Lakes if they were within the Upper Lakes or Dunstan Rohe, into Mid-Lakes if they were within the Manuherekia or Roxburgh Rohe, and into Lower-Lakes if they were within the Dunedin Coast, Taieri and North Otago FMUs, Catlins FMU or the Lower Clutha Rohe.

The individual lakes were assigned to one of three lake management classes (Figure 9). The analysis allowed TAS to be independently set for each lake management class. The number of lakes that were included in the analysis by management class is shown in Table 7.

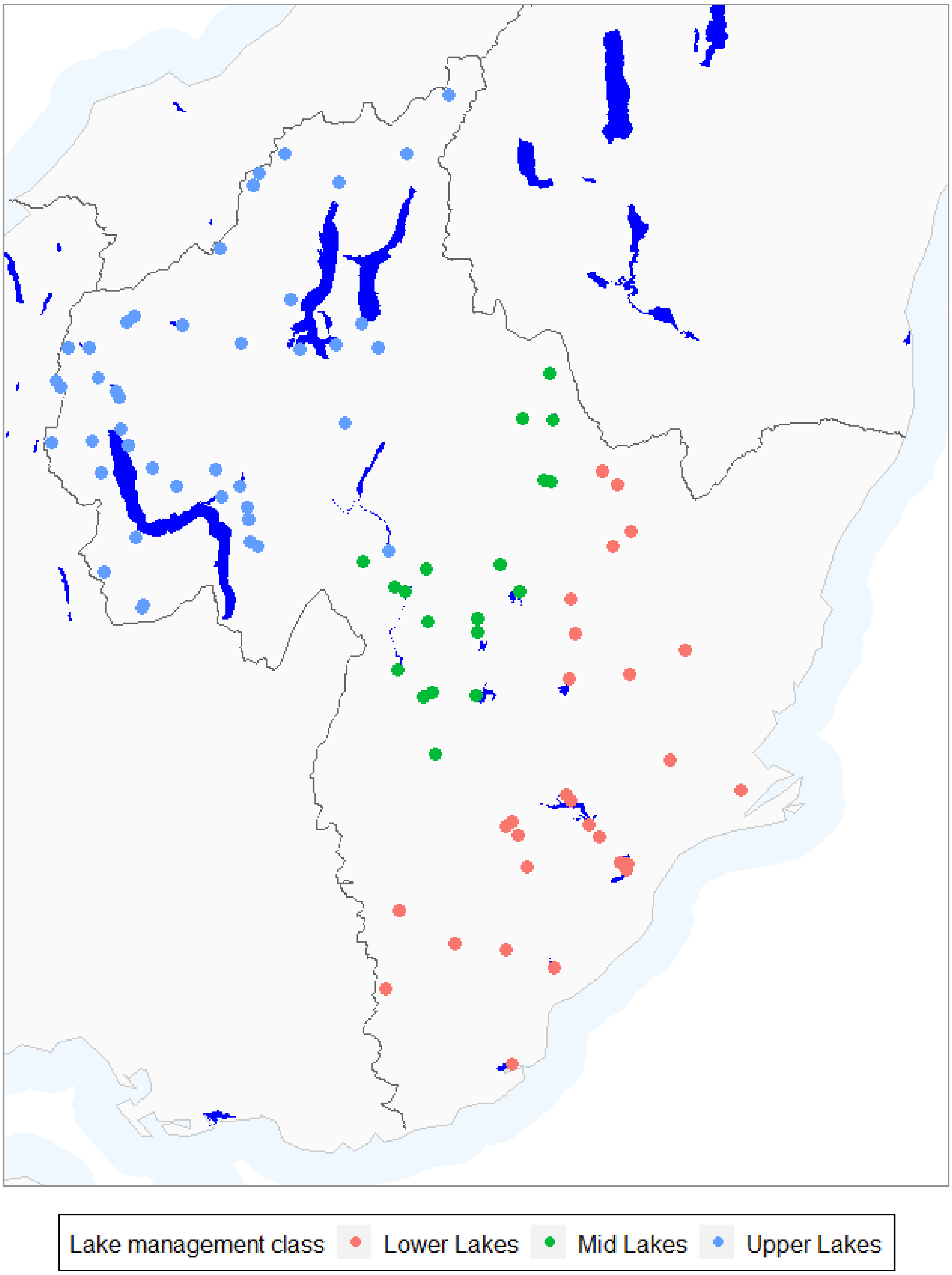

Figure 9. Nominated lake management classes applied in this study. Note that all lakes are indicated in this and all subsequent maps as points located at the lake outlet. Large lakes are also indicated as blue polygons, which are simply provided for orientation.

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

Management Class	Number of lakes
Upper Lakes	43
Mid Lakes	19
Lower Lakes	28

2.10.2.3 Estuaries

The individual estuaries were assigned to one of three estuary management classes that are based on the estuary type (Figure 7). The TAS for estuaries could be independently set for each estuary management class. Estuaries in the Otago region were classified as shallow intertidally dominated estuaries (SIDE), shallow short residence-time tidal river estuaries (SSRTRE), coastal lakes or Deep, subtidal dominated, longer residence time estuaries (DSDE) (Table 8).

Table 8. Number of estuaries in each management class represented in this analysis.

Management Class	Number of estuaries
Coastal lake	3
DSDE	1
SIDE	11
SSRTRE	5

2.10.3 Spatially variable target attribute states

The fourth set of TAS are spatially variable with the A, B and C bands, i.e. vary between river, lake and estuary receiving environments depending on the FMU and management class (Table 9). This option provides for TAS that vary spatially to account for both variation in natural state and expected protection level. Lower TAS (i.e., B or C bands) are applied to parts of the region that have naturally higher nitrogen concentrations, loads, and periphyton biomass, which potentially lead to lower levels of environmental protection being deemed acceptable.

For the spatially variable TAS, more stringent TAS were generally applied to the upper catchment areas whereas less stringent TAS were applied to receiving environments in the lower catchments (e.g., for the periphyton attribute, the B band was applied to all rivers in the Mountain management classes and to the Hill management class in the Upper Lakes Rohe, but the C band was applied to the Hill management class in all other FMUs, Table 9). For lakes the C, B and A bands were applied to the Lower, Mid and Upper Lake management classes, respectively, Table 9).

Table 9. Spatially variables TAS assessed in this study for each FMU and management class for rivers, lakes and estuaries.

Attribute	FMU	Management class	Band
River periphyton	All except Upper Lakes Rohe	Mountain	B
		Hill	C
		Lowland	C
	Upper Lakes Rohe	Mountain	B
		Hill	B
		Lowland	C
	All	Lake Upper	B
		Lake Lower	C
River nitrate toxicity	All	Mountain	A
		Hill	A
		Lowland	A
		Lake Upper	A
		Lake Lower	A
Lake phytoplankton	All	Lower lakes	C
		Mid lakes	B
		Upper lakes	A
Estuary	All	Coastal lake	C
		DSDE	C
		SIDE	C
		SSRTRE	C

3 Results

3.1 Performance of current nutrient concentration models

The RF models of median concentrations of TN, TP, NO3N and DRP had at least good performance (Table 10), based on the criteria defined in Table 1 and based on Moriasi et al. (2015). The performance of the median soluble proportion of TN was satisfactory, and that of the median soluble proportion of TP was unsatisfactory. The mapped predictions for all four nutrient concentrations had similar coarse-scale spatial patterns, with relatively high values in low-elevation coastal areas of Otago and values decreasing with increasing elevation and distance inland (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 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	107	0.81	0.81	0.41	0.22	log10
NO3N	107	0.64	0.64	-0.18	0.49	log10
TP	107	0.66	0.65	0.31	0.25	log10
DRP	107	0.54	0.54	0.71	0.27	log10
NO3N in TN	107	0.50	0.49	-2.32	0.95	logit
DRP in TP	107	0.25	0.25	-5.62	0.86	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 11). 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 365 mg m^{-3} to 2,736 mg m^{-3} (Figure 11). 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 11).

Model bias (i.e., systematic error) was highest for the model of the soluble proportion of TP (i.e., DRP in TP) (Table 10). Model bias was small compared to the random component of error for all models (Figure 11) and was always very good as indicated by the criteria shown in Table 1. These results indicate that all predictions are reliable descriptions of broad scale patterns but that there is considerable uncertainty associated with individual locations, particularly for the median soluble proportion of TP.

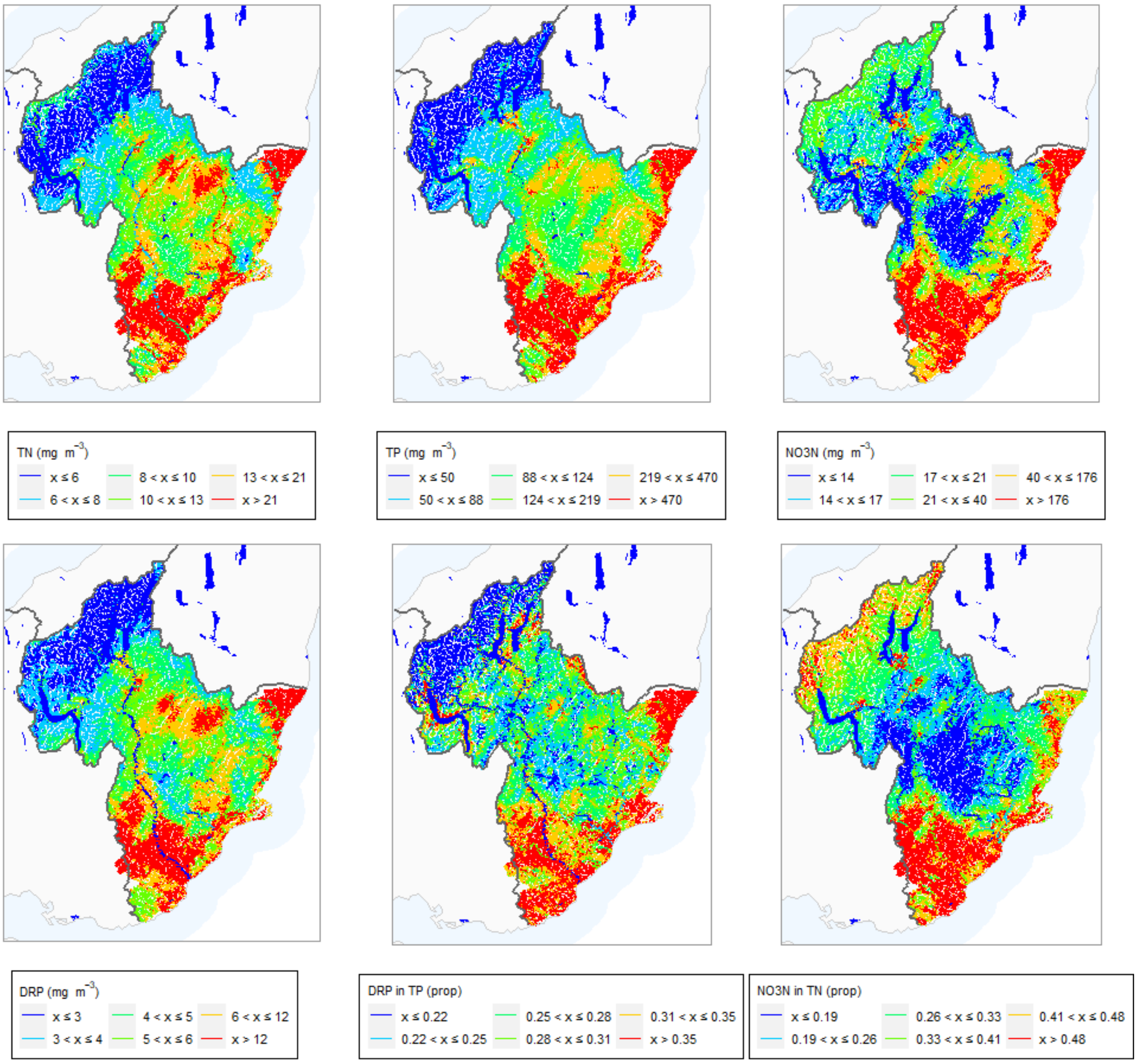

Figure 10. Predicted patterns of the current median concentrations of TN, TP, NO3N and DRP and the soluble proportions of TP and TN, respectively. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

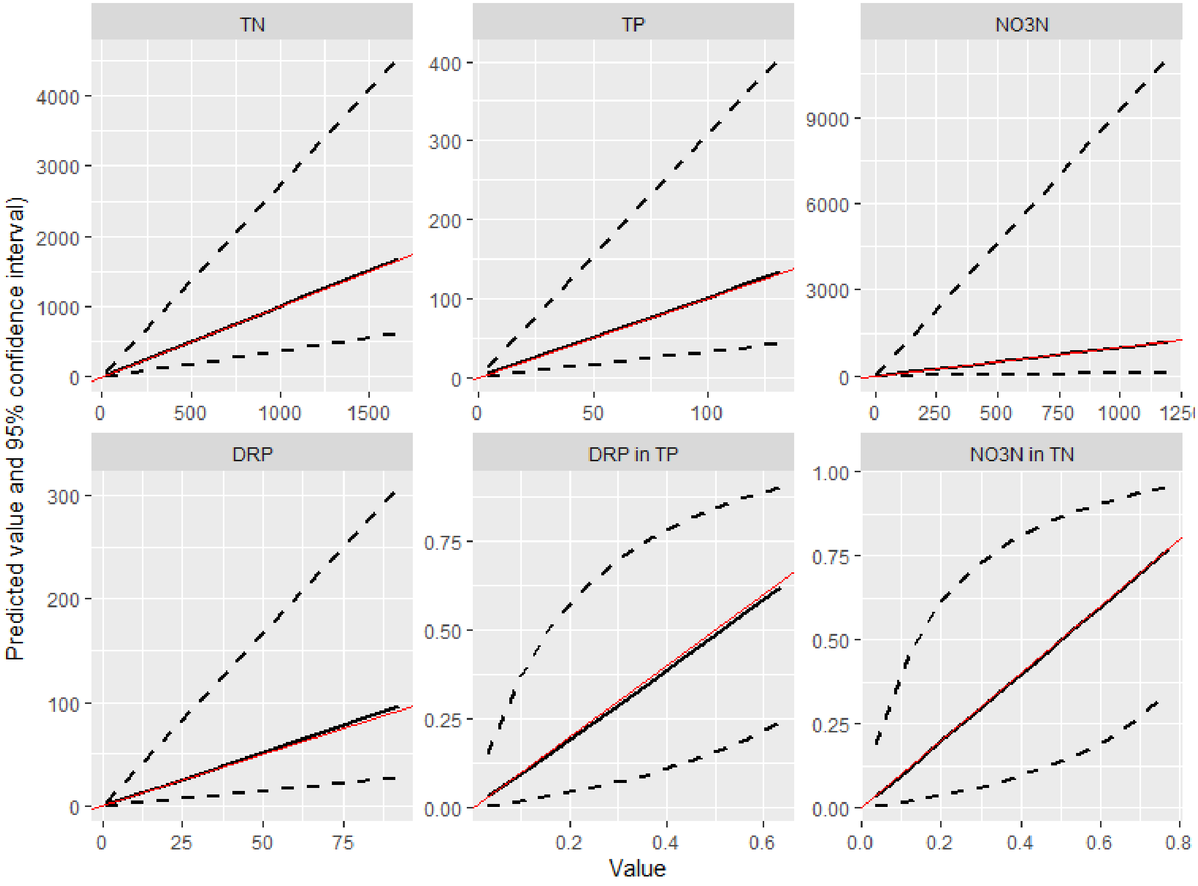

Figure 11. The characteristic statistical error (i.e., uncertainty) of the predictions for the concentration and soluble proportions of TP and TN models.The x-axis of each panel shows the range in the study area of actual (observed) concentrations of TN, TP, NO3N, and DRP and DRP in TP and NO3N in TP, 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 Current river TN and TP loads and performance of load models

The estimated current loads of TN and TP (expressed as yields) exhibited substantial variation across the river water quality monitoring sites (Figure 12). In relative terms, the uncertainty of the load estimates was generally higher for TP than for TN (Figure 12).

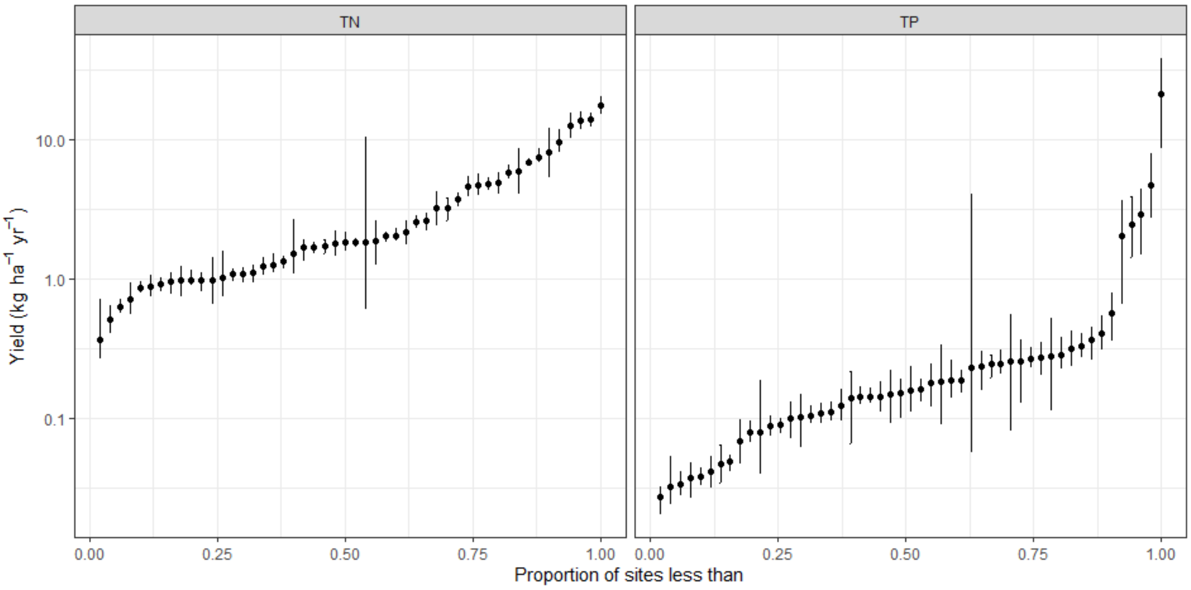

Figure 12. Cumulative distribution of TN and TP yields estimated at 50 and 51 river water quality monitoring sites, respectively. The error bars indicate the 95% confidence intervals for the estimated yields.

There were distinct differences in the patterns in water quality monitoring site loads of TN and TP, expressed as yields, across the region (Figure 13). In general, high yields of TN (i.e., > 5 kg ha^{-1} yr^{-1}) occurred at sites draining catchments dominated by pastoral land use in the low elevation parts of the region. The exception to this was the Dart at the Hillocks, which has a catchment that is almost entirely natural land cover and that had an estimated TN yield of 8 kg ha^{-1} yr^{-1}. High yields of TP (i.e., > 2 kg ha^{-1} yr^{-1}) generally occurred at sites draining steep high-elevation headwater catchments that were dominated by natural land cover. Five sites with yields greater than 2 kg ha^{-1} yr^{-1} are shown as orange or red shades in Figure 13. Four of these sites are draining steep high-elevation headwater catchments; Kawarau at Chards Rd, Shotover at Bowens Peak, Matukituki at West Wanaka and Dart at The Hillocks.

The RF models of TN and TP yields had good performance (Table 11). Consistent with the observed export coefficients at the water quality sites (Figure 13), the mapped predictions of annual yield of TN and TP had contrasting coarse-scale spatial patterns. TN yields had generally high values in low-elevation coastal areas of the region and values decreased with increasing elevation and distance from the coast and in association with reduction in pastoral land cover (Figure 14). 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. However, yields of TN were relatively high in the mountainous areas in the west of the region. This result is probably due to the influence of the single Dart at the Hillocks sites, which drains a mountainous catchment but has a relatively high estimated TN yield of 8 kg ha^{-1} yr^{-1} (Figure 13).

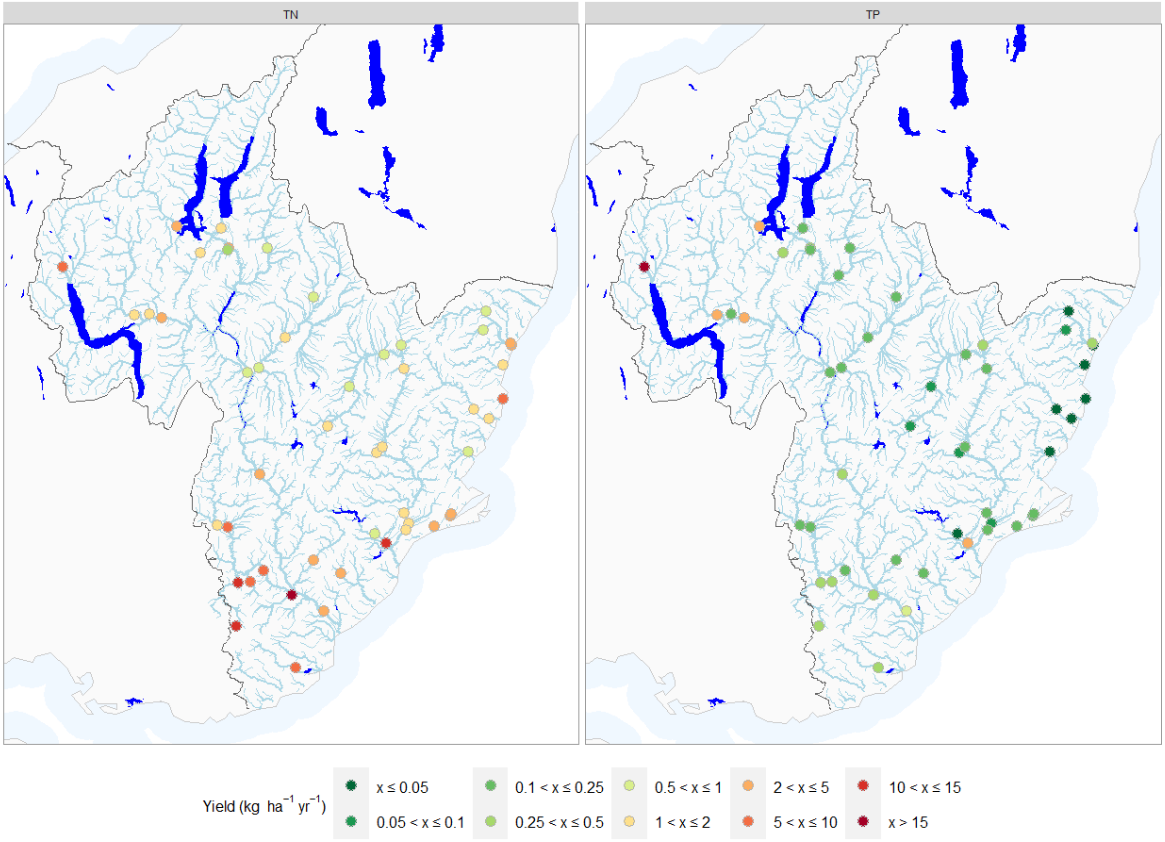

Figure 13. Maps of the water quality monitoring sites coloured according to their estimated TN and TP loads (as yields). The Dart at the Hillocks site is the western-most site at the northern end of Lake Wakatipu.

TP yields were generally high in elevated mountainous parts of the region, low in higher elevation areas of central Otago that are not occupied by pastoral land use, and at intermediate levels in lower elevation areas associated with pastoral land cover (Figure 14). These predicted patterns are consistent with the observed yields at the water quality sites (Figure 13), in particular the high yields at sites draining mountainous catchments.

Table 11. Performance of random forest models of loads of TN and TP.

Variable	N	R^2	NSE	PBIAS	RMSD	Transformation
TN	50	0.69	0.68	1.76	0.23	log10
TP	51	0.63	0.59	-2.00	0.36	log10

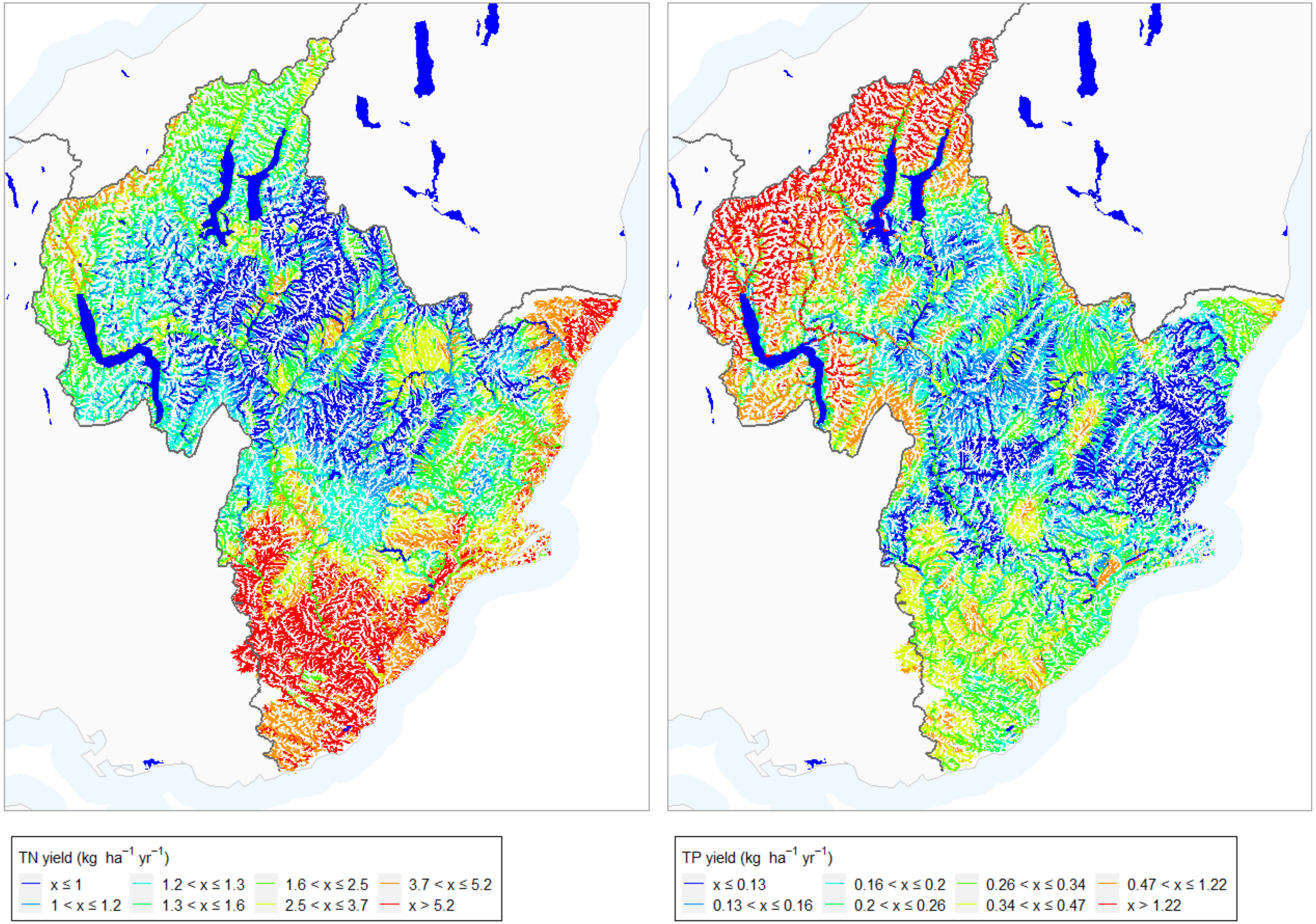

Figure 14. Predicted current TN and TP loads (as yields kg ha^{-1} yr^{-1}) for rivers in Otago. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

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 resulted in asymmetric confidence intervals (Figure 15). 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 15). However, model bias (i.e., systematic error) was low for both variables (Table 11, Figure 15). 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.

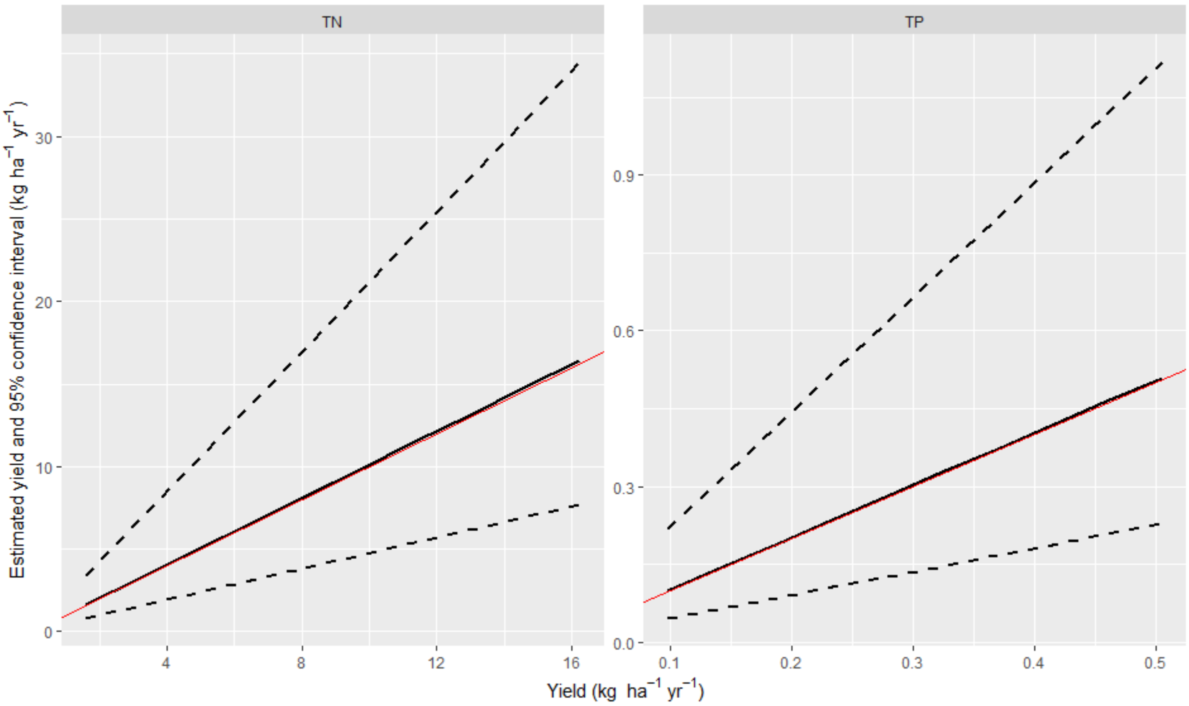

Figure 15. The characteristic statistical error (i.e., uncertainty) of the current load model predictions. The x-axis of each panel shows the range in actual (observed) yields of TN and TP in the study area. The y-axis characterises the statistical error of the predictions along the range of the observations. 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.

3.3 Performance of lake TN and TP models

The predicted TN concentrations for lakes compared favourably with the observations of median in-lake TN concentrations for the period 2015 – 2020 (Table 12). However, the predicted TP concentrations were strongly negatively biased with predicted concentrations for Lakes Hawea, Wakatipu, Wanaka and Dunstan being much higher than the observations. Based on specified criteria (Table 1), the performance of the TN model was good, but the TP model performance was unsatisfactory. We fitted two Otago-specific TP models using the structures shown in Equation 3 and 4 to the available data. The model with the same structure as Equation 4 (Equation 7) performed the best of these two models.

$$log_{10}(TP_{lake}) = \beta_0 + \beta_1 log_{10}(TP_{in}) + \beta_2(Z_{max}) \qquad \text{Equation 7}$$

The fitted model parameters for the Otago specific TP model, β_0, β_1 and β_2 were 0.83, 0.43 and -0.0049, respectively, and the model had very good performance (Table 12). For the analyses that follow, the original TN model (Equation 3) with parameters provided by Abell *et al.* (2019, 2020) was used to predict in-lake concentrations from loads of TN delivered to lakes. The original TP model (Equation 4) was replaced with the new fitted model (Equation 7) and was used to predict in-lake concentrations from loads of TP delivered to lakes.

Table 12. Performance of the original in-lake TN and TP models (using the models of Abell et al. 2019, 2020), and the fitted TP model based on observed concentrations for eight Otago lakes. The eight lakes for which TN and TP observations were available are shown in Figure 6.

Variable	Parameters	N	R^2	NSE	PBIAS	RMSD
TN	Abell et al.	8	0.86	0.59	-11	0.32
TP	Abell et al.	8	0.13	-0.9	-85	1.07
TP	Fitted	8	0.76	0.76	0	0.37

3.4 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 13). The correlation structure shown in Table 13 was used to generate random normal deviates (ε_r) for each model in the Monte Carlo analysis.

Table 13. 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

3.5 Current state assessment

Patterns in the grading of current state of rivers were consistent with predicted variation in concentrations (Figure 10) and reflect the increasing enrichment of rivers and streams in association with increasing proportions of catchments occupied by agricultural and other land uses (Figure 16). None of the region’s rivers were graded A for periphyton TN and 63% of river segments were graded B, which were generally located in mountainous and hilly areas with no, or low, land use pressure. Segments graded D for TN comprised 13% of the region’s river segments and were in catchments dominated by pastoral land use in the low elevation parts of the region (Figure 16).

Patterns in river grades for TP were similar to TN with 14% of rivers segments being assigned to the A grade and 50% to B grade, which were predominantly located in mountainous and hilly areas. The D grade was assigned to 12% of river segments being prevalent in catchments dominated by pastoral land use (Figure 16).

Estuaries were graded across the range from A to D for TN (Figure 17). Only six estuaries were graded in terms of TP. The other 15 estuaries were not graded in terms of phosphorus because macroalgal blooms are considered more impactful to estuary health than phytoplankton blooms in those estuaries, and macroalgae are seldom phosphorus limited (see Appendix B, Table 26).

Lakes were graded across the range from A to D for TN and TP (Figure 18). The pattern of grades for TN was consistent with expectations with lakes graded A in mountainous and hilly areas with no, or low, land use pressure and poorer grades becoming dominant in low elevation parts of the region. The pattern of grades for TP was not consistent with expectations in that many small lakes that were graded in the C and D band are located (i) in mountainous and hilly areas, and (ii) in areas with no or low land use pressure. The latter prediction is likely due to the low representation of C and D lakes across Otago by the fitted lake TP model (Figure 6).

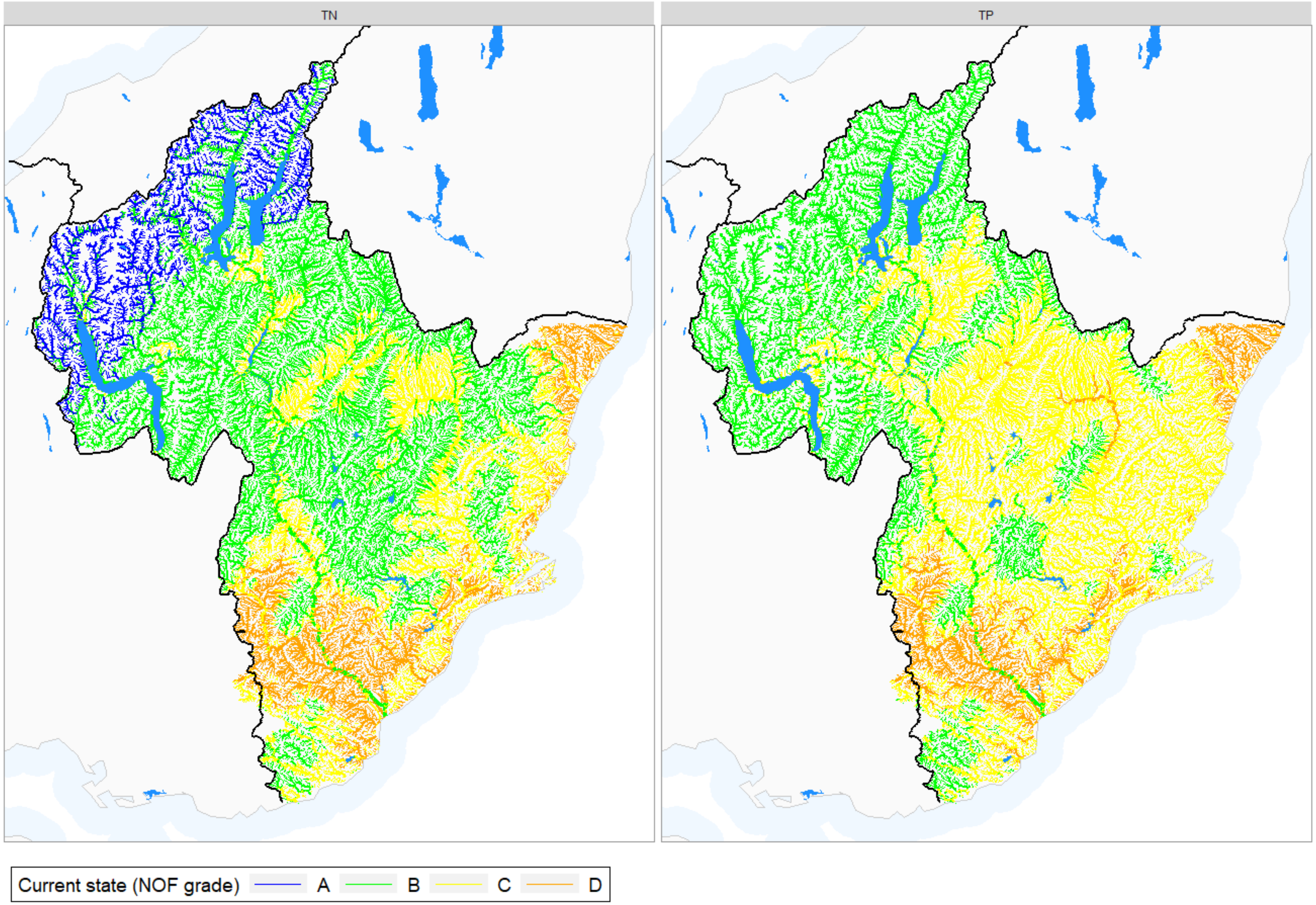

Figure 16. Estimated current state of river periphyton in all segments in the river network based on assessment against nitrogen and phosphorus criteria for periphyton TAS used by this study.

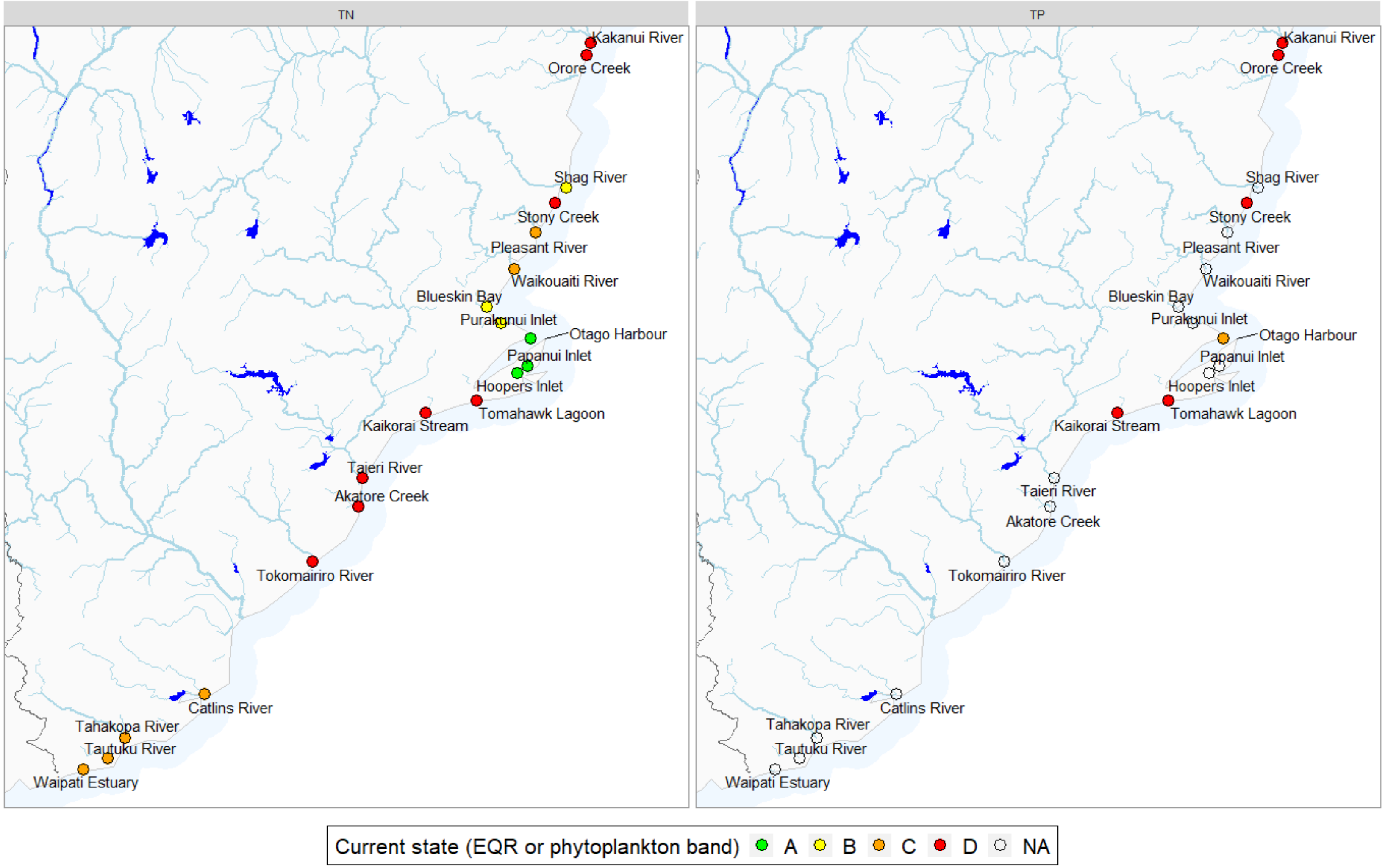

Figure 17. Estimated current state of the 20 estuaries included in this study, based on assessment against TN and TP concentration criteria for estuary trophic state TAS used by this study.

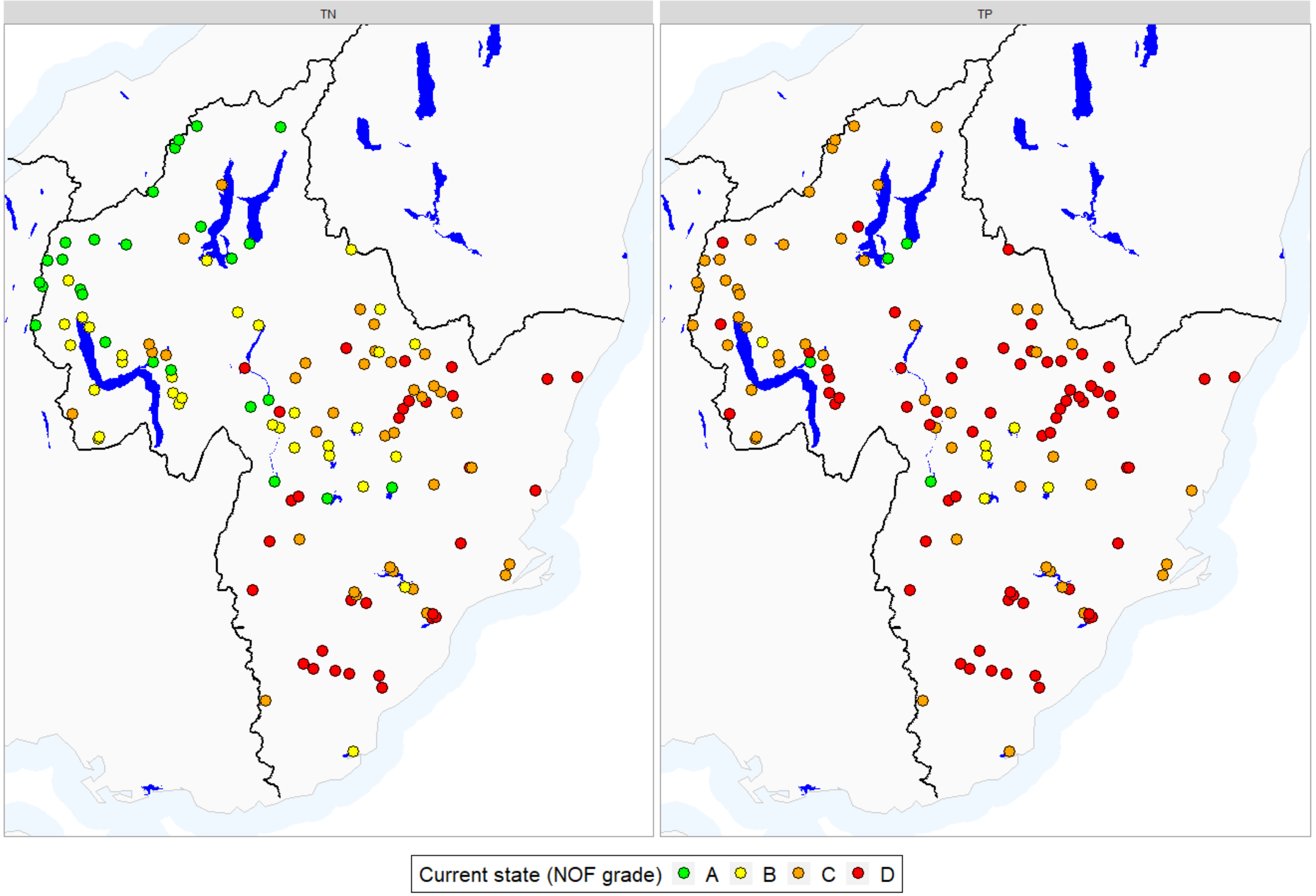

Figure 18. Estimated current state of lake phytoplankton in the 124 lakes included in this study, based on assessment against TN and TP concentration criteria for lake trophic state TAS used by this study.

3.6 Assessment of C band option

3.6.1 Compliance

The C band TAS option required that all receiving environments achieve at least a C grade. For 6% and 4% of segments in the region, current river concentrations of TN and TP had a greater than 50% probability of exceeding the C band criteria associated with periphyton TAS, respectively (i.e., were non-compliant, Figure 19). No segments had current river concentrations of NO3N with greater than 50% probability of exceeding the B band[7] (i.e., national bottom line) associated with nitrate toxicity. The probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% for no river segments (Figure 19).

For 28 and 54 of the 124 assessed lakes in the region, the probability that current lake TN and TP loads are compliant with the MAL associated with the C band TAS option was less than 50%, respectively (Figure 20).

For 8 of the 20 assessed estuaries, the probability that current estuary TN loads are compliant with the MAL associated with the C band TAS option was less than 50% (Figure 21). For 4 of the 20 assessed estuaries, the probability that current estuary TP loads are compliant with the MAL associated with the C band TAS option was less than 50% (Figure 21). Note that TAS for phytoplankton, and therefore a MAL for TP, were only relevant for six estuaries (see Appendix B, Table 31 for details).

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[7] As of 2020, the national bottom line for the nitrate toxicity attribute is the NOF B-band (Table 2, NZ Government, 2020). Therefore, for this C-band option the NOF C-band was not used as a potential target attribute state and the B-band threshold was assessed.

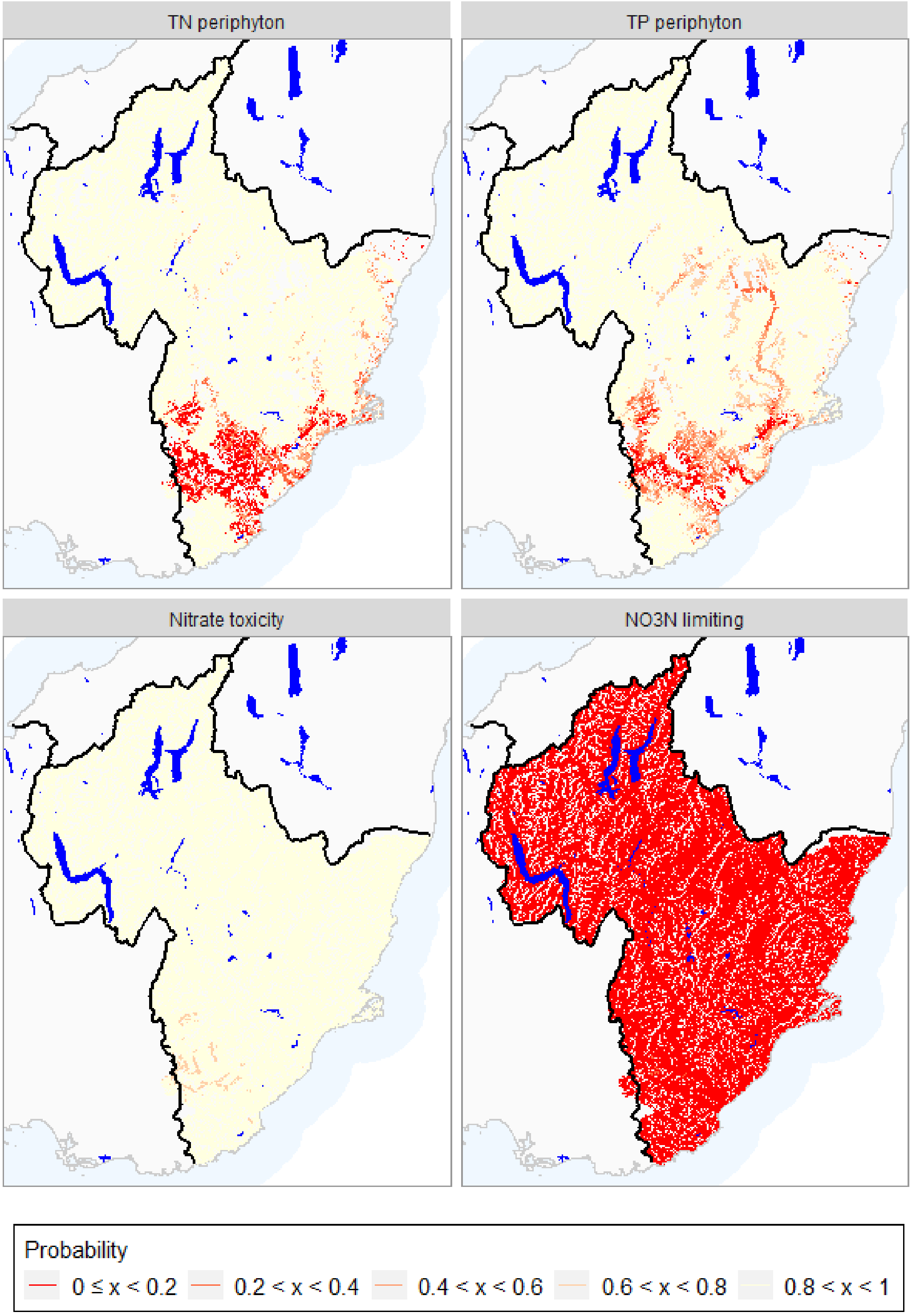

Figure 19. Probability that segments comply with river TN and TP concentration criteria associated with the periphyton TAS (top left and right) and NO3N concentration criteria associated with the nitrate toxicity TAS (lower left) for the C band option. The lower right-hand panel shows the probability that NO3N is a more limiting TAS than periphyton (in this scenario this was true for no segments).

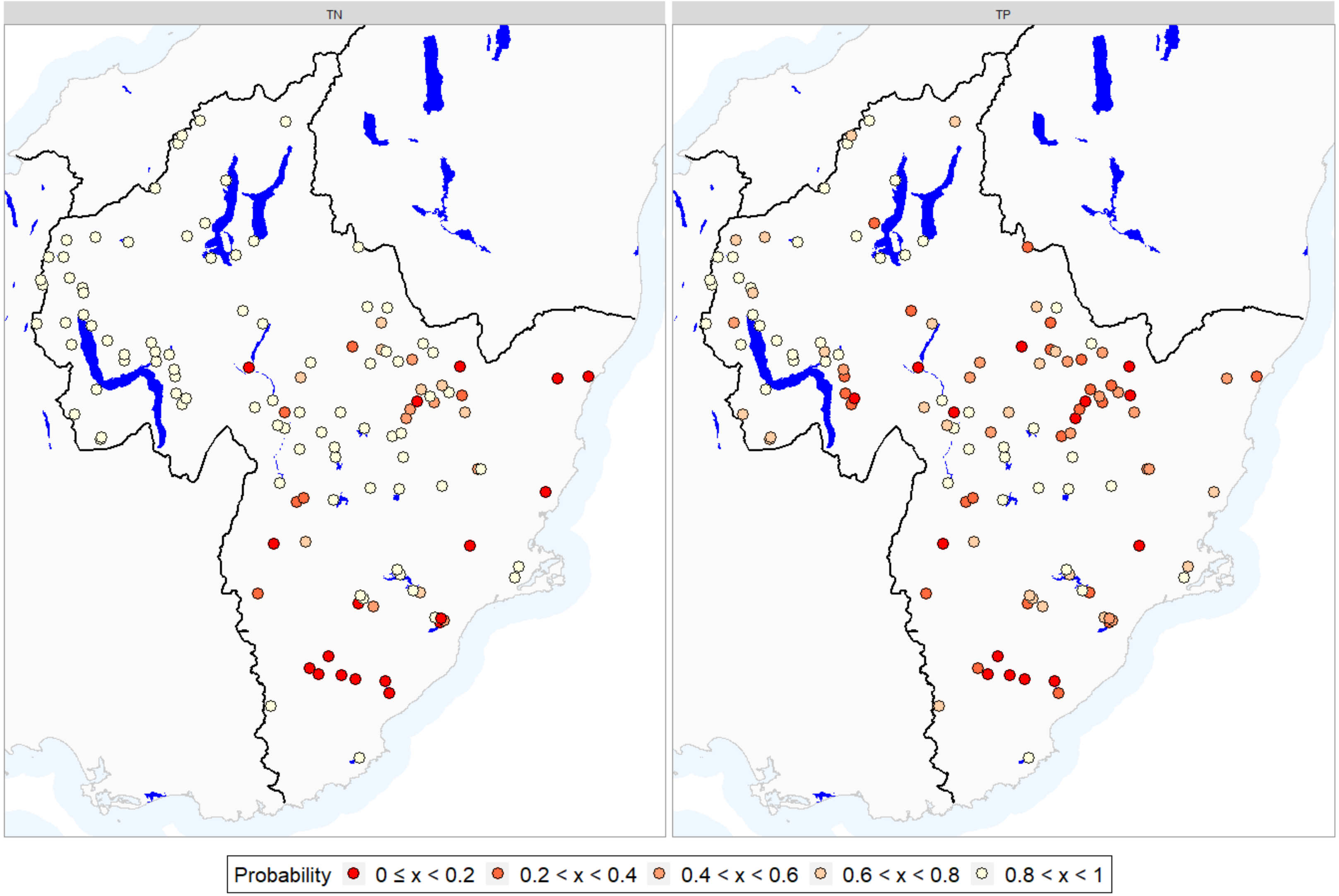

Figure 20. Probability that current lake TN and TP loads are compliant with the MAL associated with the C band TAS option.

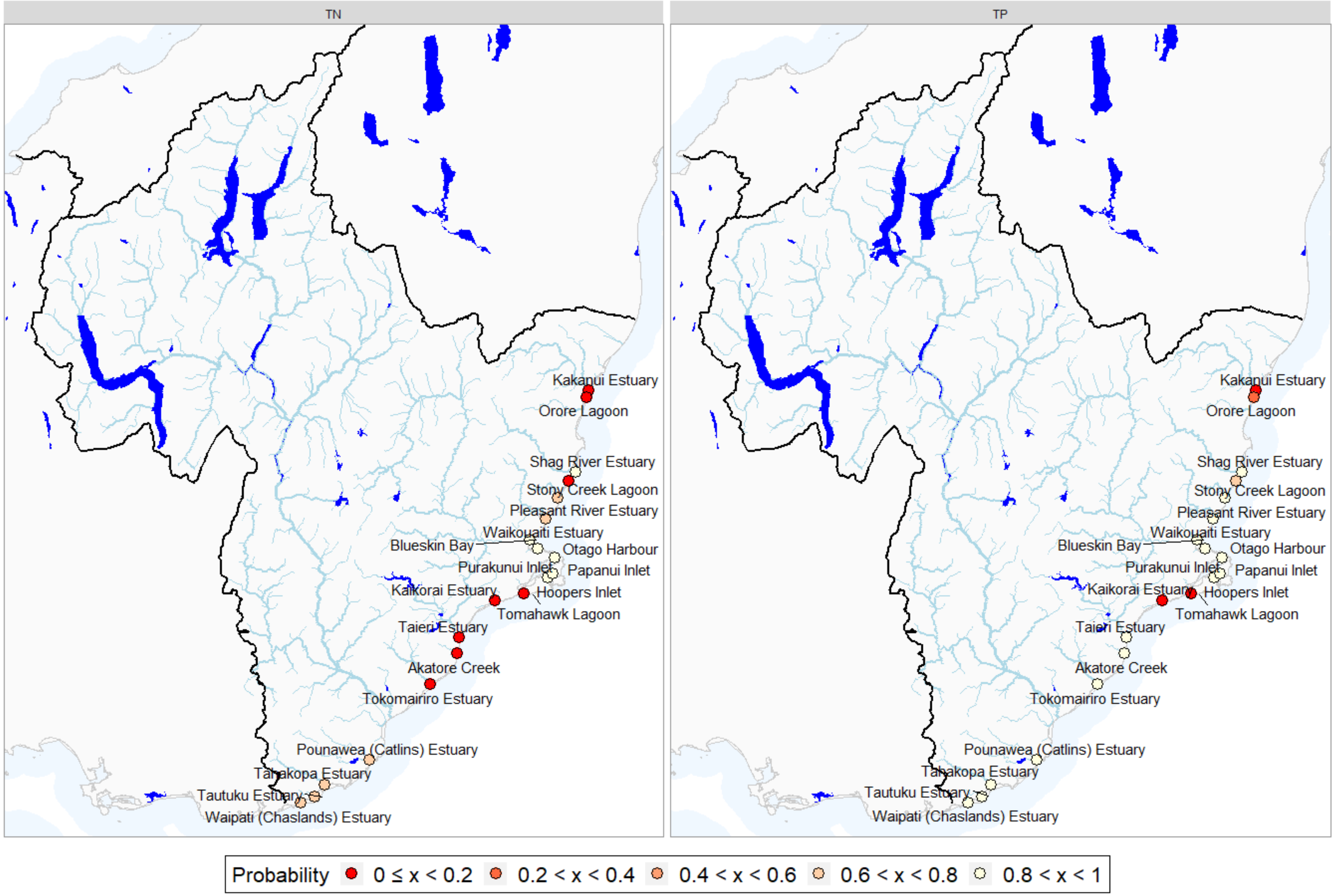

Figure 21. Probability that current estuary TN and TP loads are compliant with the MAL associated with the C band TAS option.

3.6.2 Local excess loads

For the C band option, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 4% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 0.8% of river segments (Figure 22). Local excess TN loads were zero for 94% of segments. Local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 3.4% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 2% of river segments (Figure 23). Local excess TP loads were zero for 74% of segments. Note that the 2 and 5 kg ha^{-1} yr^{-1} are nominal breakpoints for communication purposes and correspond to the legend thresholds on Figure 22.

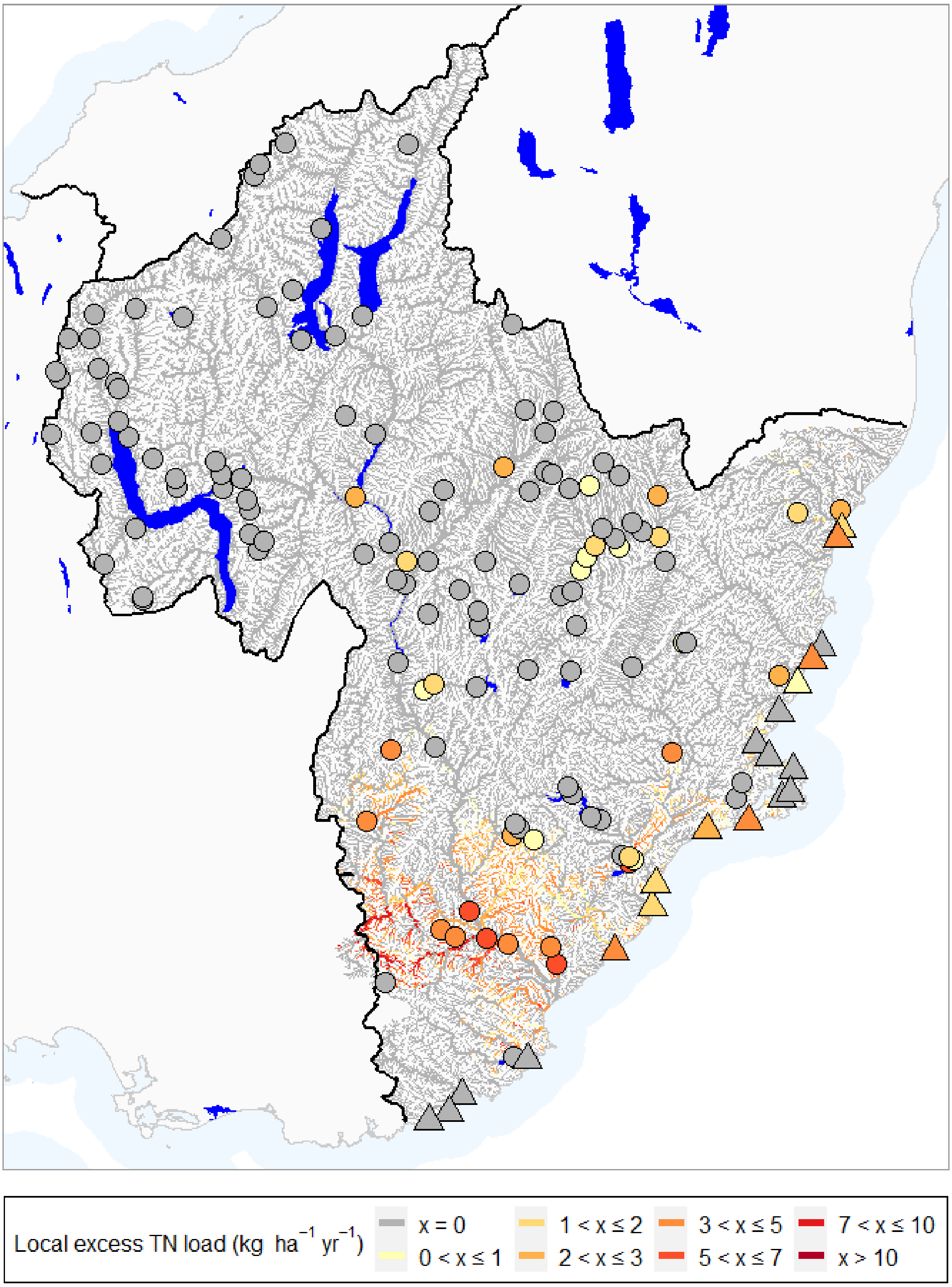

Figure 22. Local excess TN loads for rivers, lakes and estuaries for the C band option. The lakes and estuaries are indicated by round and triangular symbols, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

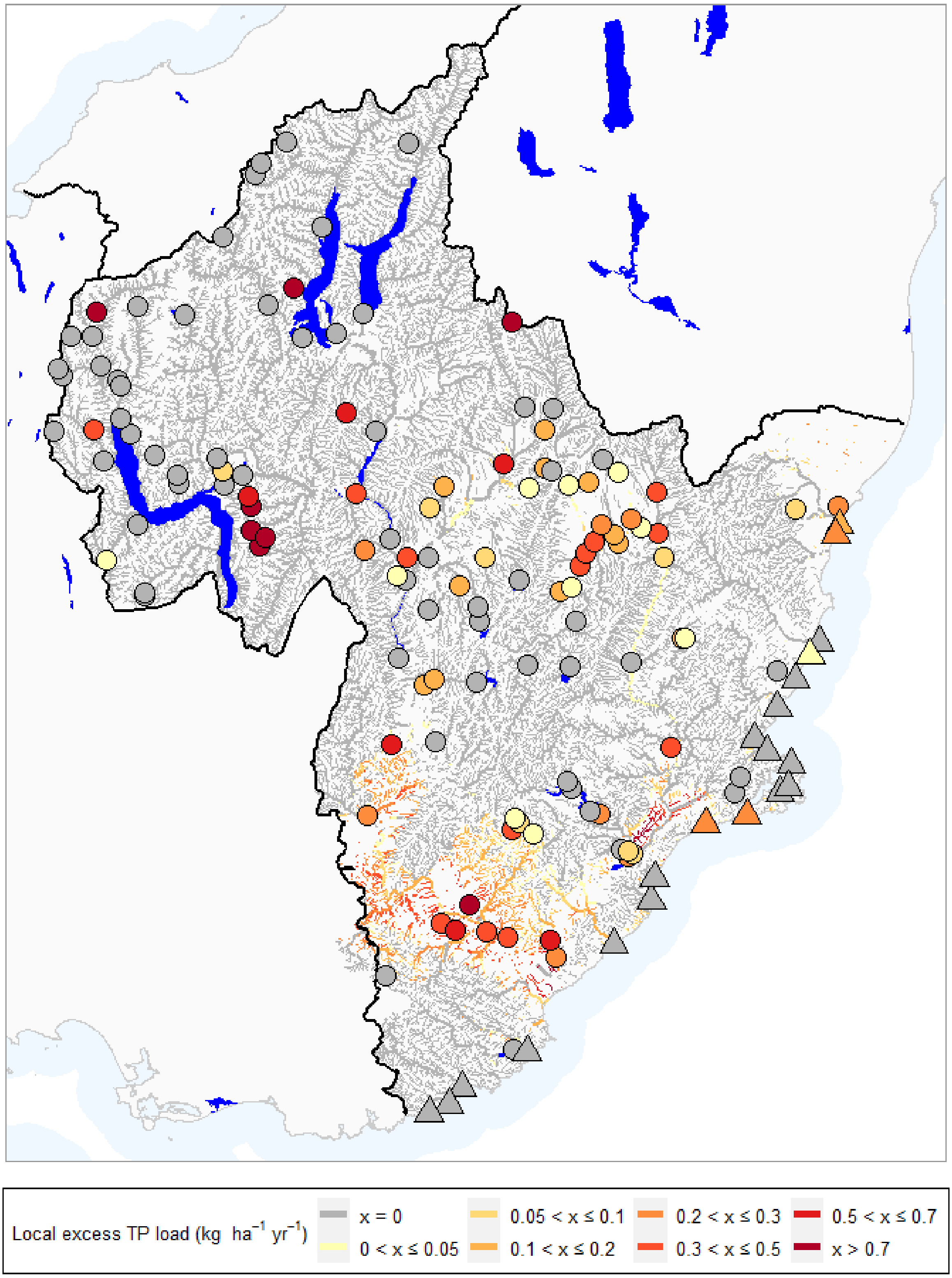

Figure 23. Local excess TP loads for rivers, lakes and estuaries for the C band option. The lakes and estuaries are indicated by round and triangular symbols respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). Note that blank areas on this map indicate river segments with substrate size index values of <3, which we assumed do not support conspicuous periphyton and therefore for which there are no applicable phosphorus criteria.

3.6.3 Critical point catchments and catchment status

Critical point catchments that required TN load reductions of greater than 5 kg ha^{-1} yr^{-1} occupied 3% of the region and critical point catchments with TN load reductions of greater than 2 kg ha^{-1} yr^{-1} occupied 15% of the region (Figure 24). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 50% occupied 30% of the region (Figure 25). 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 0.2 kg ha^{-1} yr^{-1} occupied 9% of the region and critical point catchments with TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 19% of the region (Figure 26). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 50% occupied 25% of the region (Figure 27). 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.

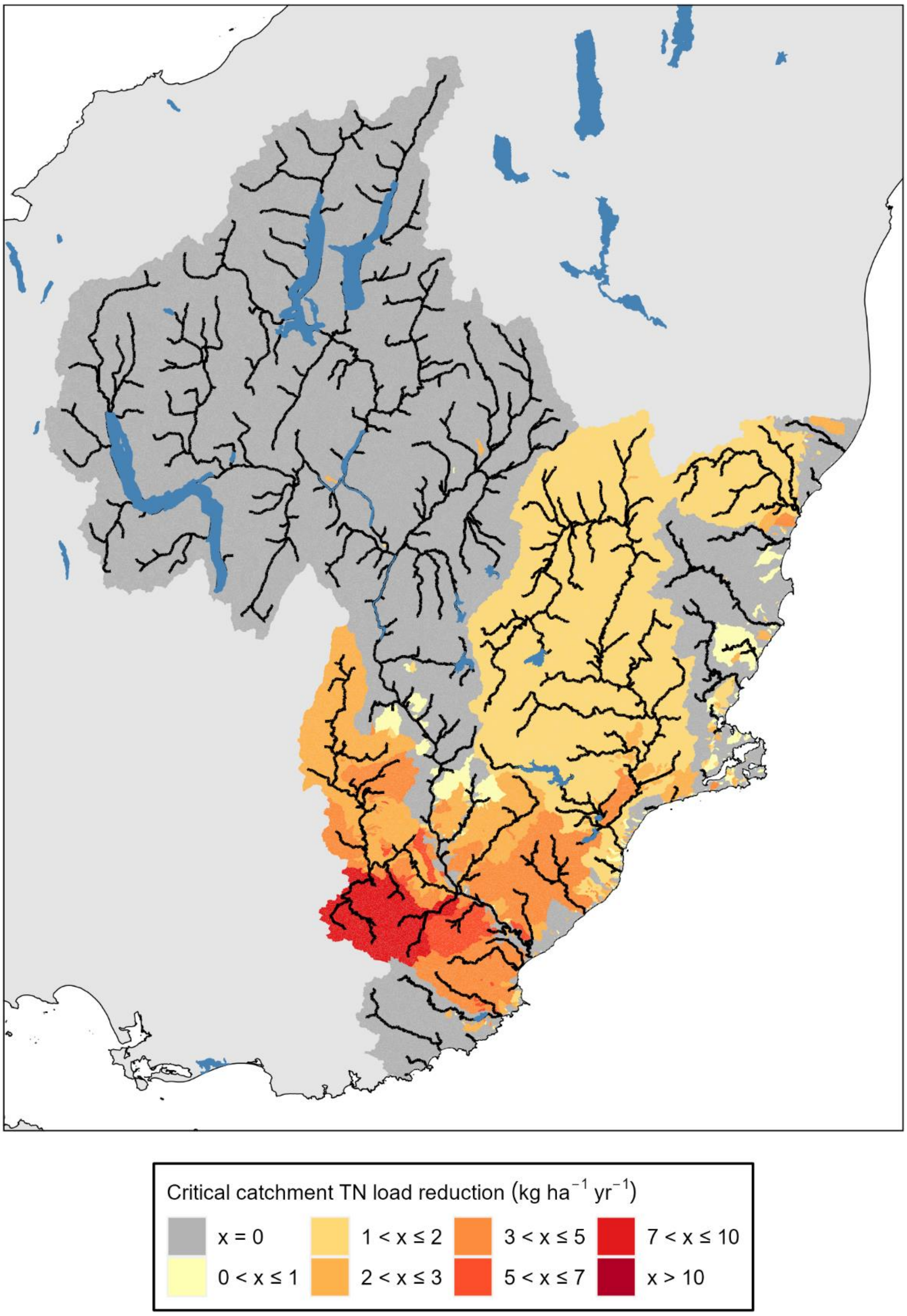

Figure 24. The TN load reduction required for the C band option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

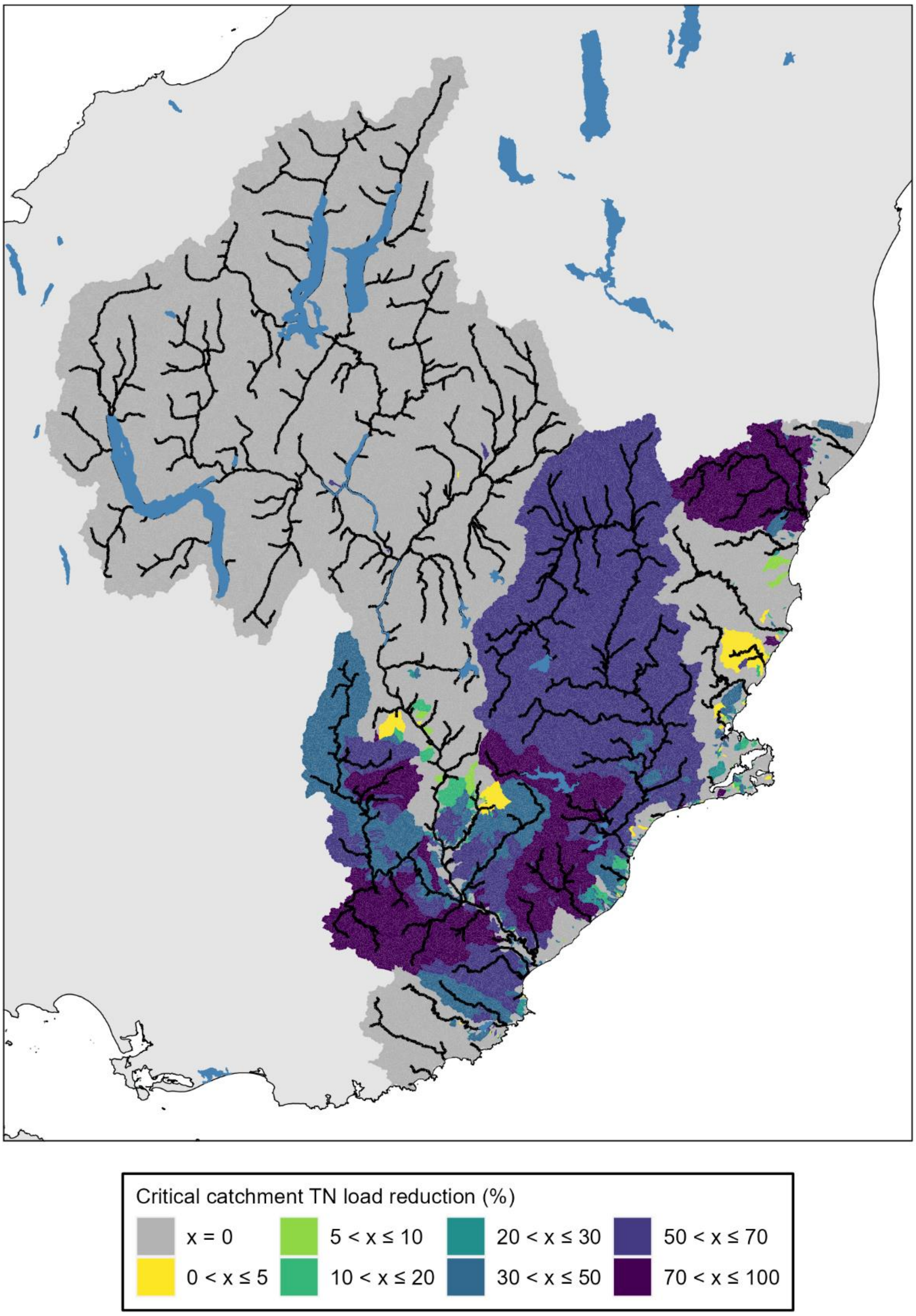

Figure 25. The TN load reduction required for the C band option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

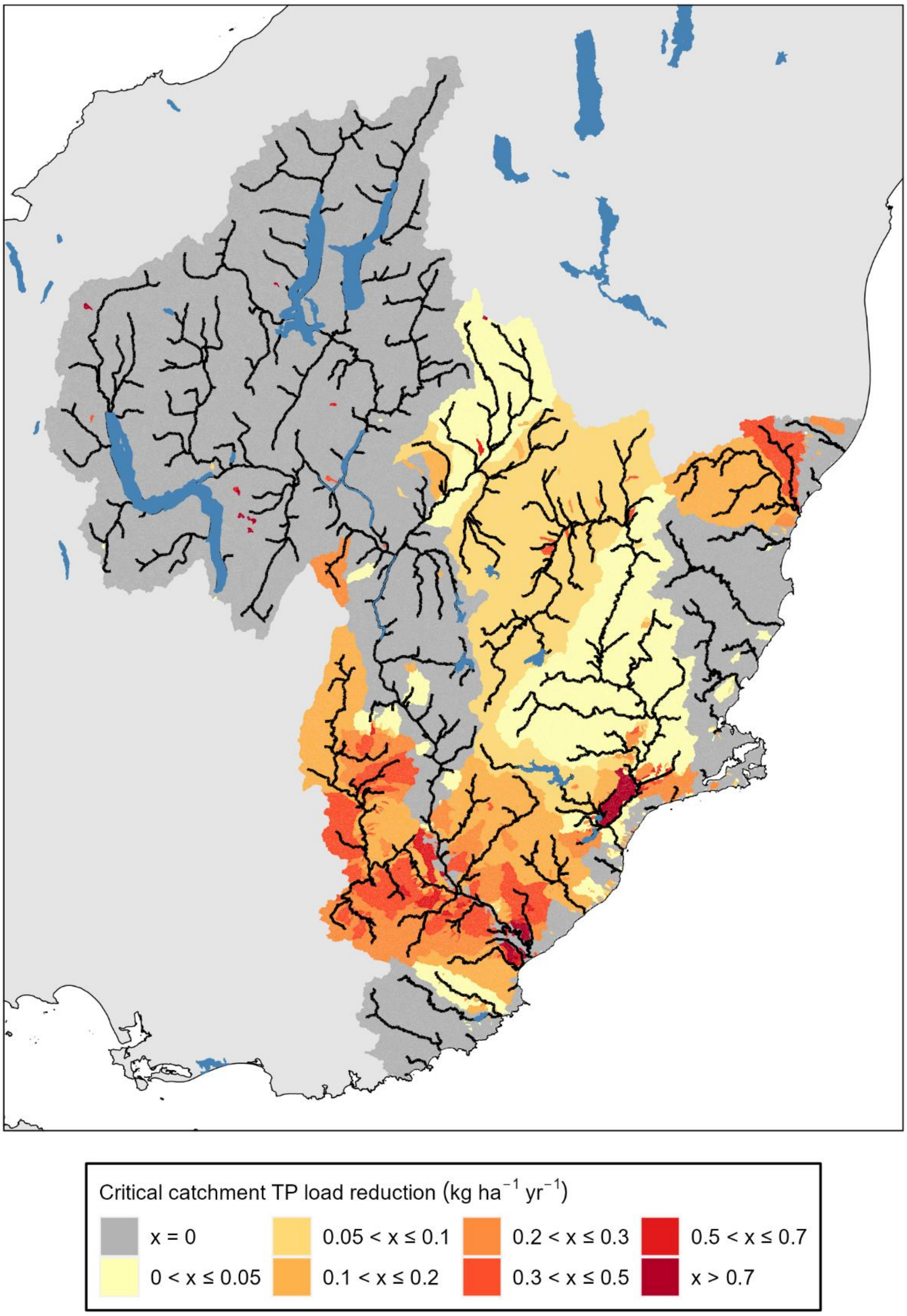

Figure 26. The TP load reduction required for the C band option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

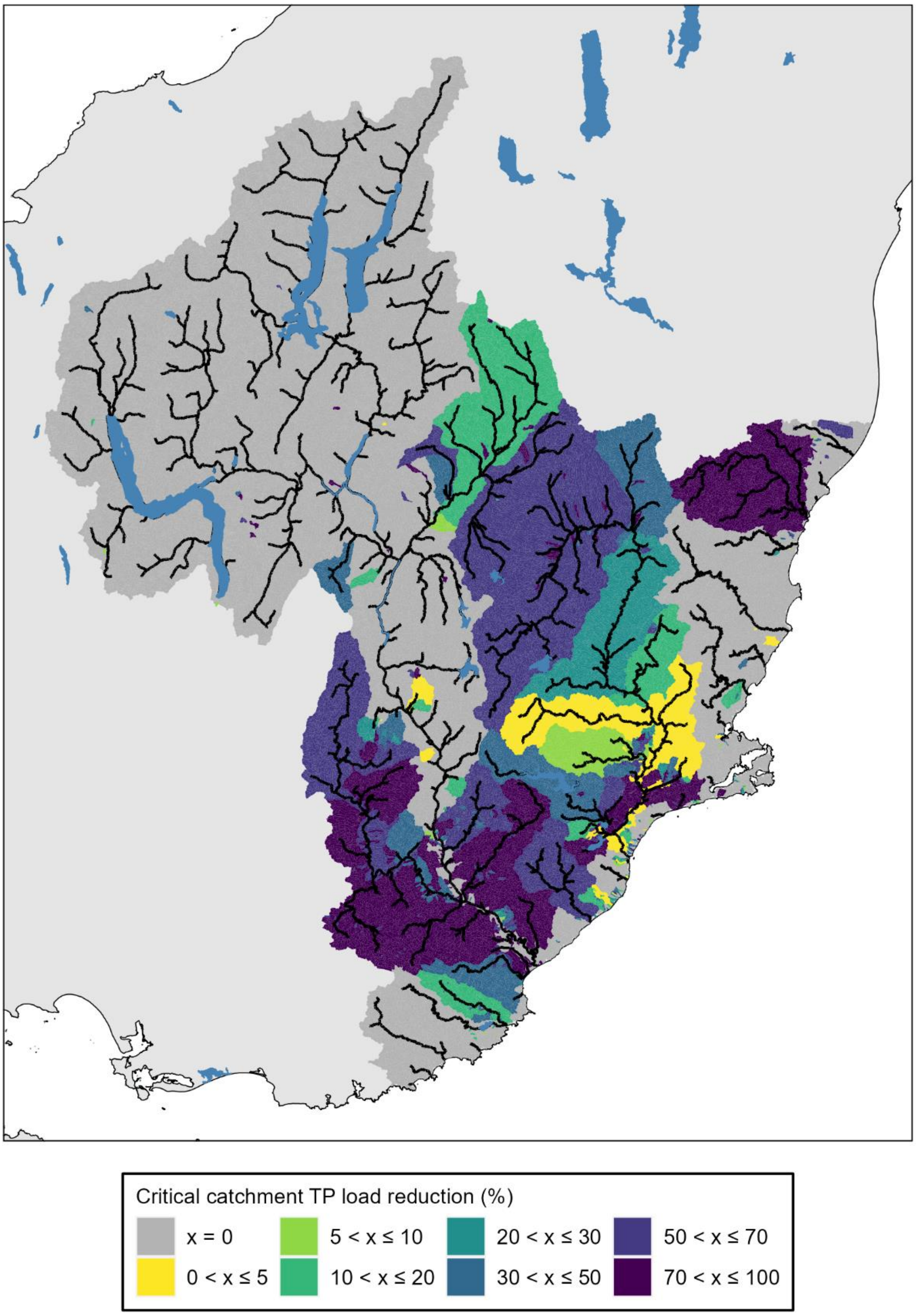

Figure 27. The TP load reduction required for the C band option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment types that determine the load reduction requirements) for the C band are shown in Figure 28 and Figure 29 for TN and TP, respectively. For TN, 77% of the critical point catchment area were associated with TAS for rivers, 20% were for estuaries, and only 2% were for lakes (Figure 28). For TP, 95% of the critical point catchment area were associated with rivers, 2% were for estuaries, and 3% were for lakes (Figure 29).

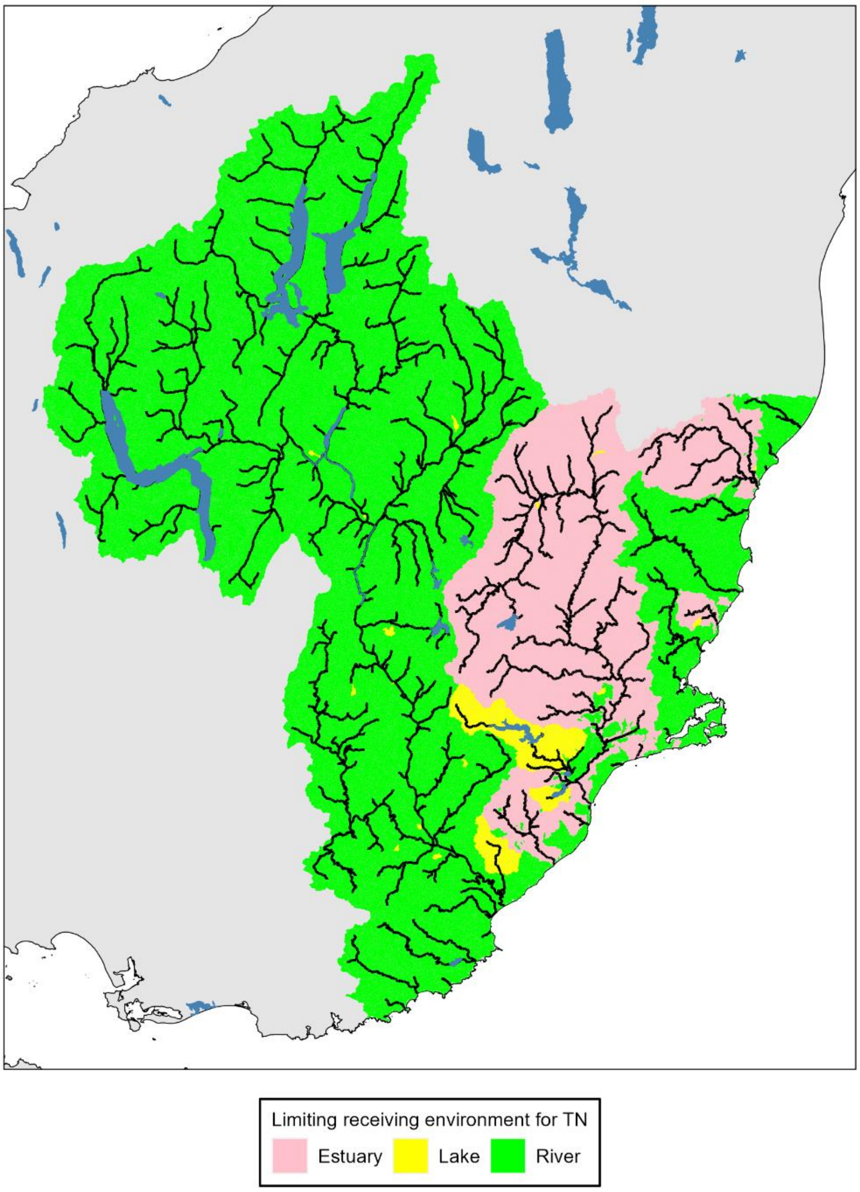

Figure 28. Limiting environment type for TN load reduction required for the C band option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TN load reductions).

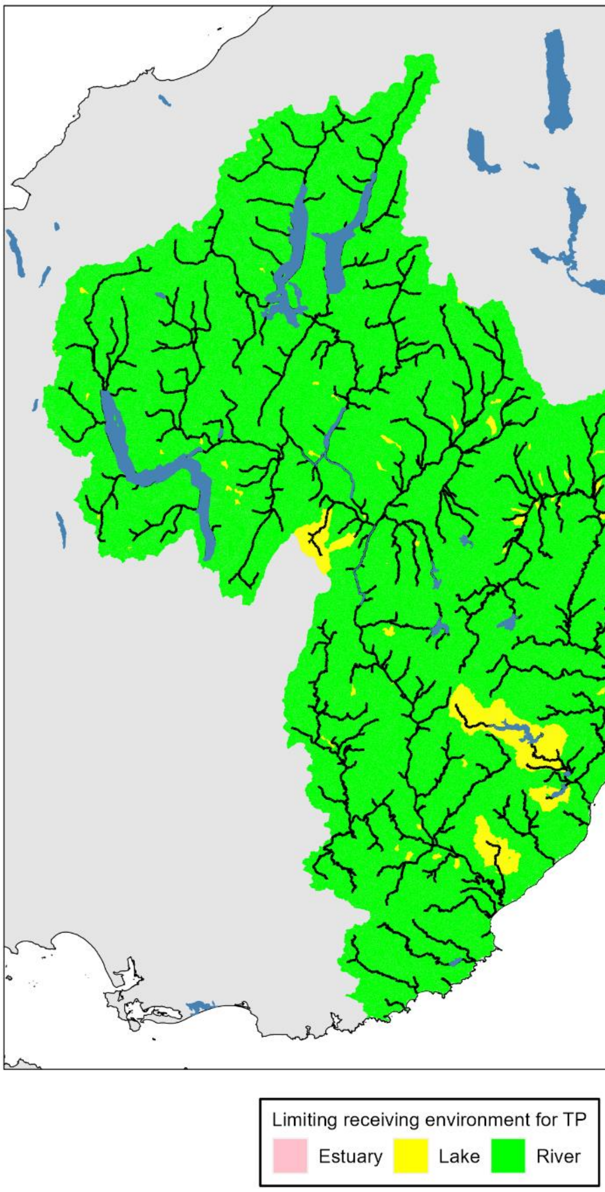

Figure 29. Limiting environment type for TP load reduction required for the C band option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TP load reductions).

3.6.4 FMU and regional load reductions required

For the whole study area (the Otago region), the TN and TP load reductions required to achieve the C band option were 3,099 t yr^{-1} and 209 t yr^{-1}, which represent 26% and 4% of the current loads, respectively (Table 14). The uncertainties for 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 14. These uncertainties indicate, for example, that the current regional load of TN extends between 6,774 t yr^{-1} and 22,958 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 17% and 38% (best estimate 26%) and the regional TP load reduction requirement extends between 0% and 26% (best estimate 4%).

For the C band option, the TN load reductions required were greatest and exceeded 10% in the Dunedin Coast and Taieri FMUs. The TP load reductions required were greatest and >10% in the Dunedin Coast, North Otago FMU and Taieri FMUs.

Table 14. Current load and load reduction required for TN and TP by FMU and for the C band TAS option 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).

FMU	**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 (%)**
Catlins FMU	585 (364 - 868)	160 (16 - 398)	25 (4 - 48)	45 (21 - 86)	4 (0 - 12)	8 (0 - 25)
Dunedin Coast FMU	544 (376 - 775)	251 (97 - 490)	43 (24 - 64)	31 (20 - 50)	9 (2 - 23)	26 (10 - 50)
Dunstan Rohe	3,235 (1,088 - 7,919)	7 (0 - 36)	0 (0 - 1)	771 (108 - 2,954)	65 (0 - 248)	3 (0 - 11)
Lower Clutha Rohe	8,255 (2,776 - 20,209)	1,446 (53 - 4,000)	16 (1 - 25)	1,378 (194 - 5,279)	180 (1 - 862)	7 (0 - 19)
Manuherekia Rohe	3,346 (1,125 - 8,191)	8 (0 - 40)	0 (0 - 1)	769 (108 - 2,947)	73 (0 - 261)	3 (0 - 12)
North Otago FMU	769 (532 - 1,048)	228 (54 - 472)	28 (9 - 48)	45 (25 - 83)	16 (2 - 38)	30 (8 - 57)
Roxburgh Rohe	4,577 (1,539 - 11,206)	34 (0 - 154)	1 (0 - 2)	916 (129 - 3,508)	99 (0 - 408)	4 (0 - 16)
Taieri FMU	1,562 (521 - 2,818)	884 (25 - 2,119)	45 (5 - 75)	155 (26 - 471)	49 (1 - 194)	23 (3 - 56)
Upper Lakes Rohe	958 (322 - 2,345)	0 (0 - 1)	0 (0 - 0)	901 (126 - 3,450)	20 (0 - 100)	1 (0 - 3)
Total	11,928 (6,774 - 22,958)	3,099 (1,440 - 5,808)	26 (17 - 38)	1,666 (387 - 5,687)	209 (0 - 951)	4 (0 - 26)

The load reductions required for the C band option for the 20 estuaries and to achieve all river and lake TAS in the catchment of each estuary are shown in Table 15. For 13 of the 20 estuaries examined, the TN load reductions required to achieve the TAS under the C band option are of greater magnitude for the estuary compared to the river and lake TAS in the upstream catchment (Table 15). In contrast, TN load reductions required to achieve river and lake TAS are of greater magnitude than the associated estuaries for the following seven estuaries: Shag River Estuary, Blueskin Bay, Purakunui Inlet, Otago Harbour, Papanui Inlet, Hoopers Inlet and Pounawea (Catlins) Estuary. Several estuaries have zero TN load reductions required, indicating that they currently achieve the C band target or better.

TP load reductions required to achieve the TAS for four estuaries (Kakanui Estuary, Orore Lagoon, Tomahawk Lagoon and Kaikorai Estuary) were larger than those required to achieve the river and lake targets in the upstream catchment (Table 15). The Otago Harbour has a zero TP load reduction required and already achieves the C band TAS or better. The TP load reductions required for 14 estuaries are zero because it is considered unlikely that phytoplankton growth in these estuaries will drive severe secondary symptoms of eutrophication (like deoxygenation and light attenuation), and therefore no MAL has been defined for TP (see Appendix B, Table 31).

The load reductions required to achieve the TAS for rivers (only) are shown in Table 16. The reductions for the FMUs and for the region are generally lower than those shown in Table 14 because lakes and estuaries are excluded from the figures. Note that there are some exceptions to this due to the large uncertainties associated with the analysis.

Table 15. Load reductions required to achieve the TAS for estuaries and for all rivers and lakes in their upstream catchments for the C band option.

Estuary	**TN load reduction required (t yr^{-1})**		**TP load reduction required (t yr^{-1})**	
	Estuary	**Lakes and rivers**	**Estuary**	**Lakes and rivers**
Kakanui Estuary	159 (1 - 418)	34 (0 - 128)	13.3 (0.0 - 35.2)	8.9 (1.0 - 23.0)
Orore Lagoon	8 (2 - 18)	0 (0 - 0)	0.5 (0.0 - 1.7)	0.0 (0.0 - 0.0)
Shag River Estuary	3 (0 - 11)	13 (0 - 75)	0.0 (0.0 - 0.0)	0.1 (0.0 - 0.0)
Stony Creek Lagoon	3 (1 - 7)	0 (0 - 1)	0.0 (0.0 - 0.2)	0.0 (0.0 - 0.0)
Pleasant River Estuary	8 (0 - 38)	6 (0 - 24)	0.0 (0.0 - 0.0)	0.2 (0.0 - 1.0)
Waikouaiti Estuary	12 (0 - 67)	7 (0 - 25)	0.0 (0.0 - 0.0)	0.4 (0.0 - 2.0)
Blueskin Bay	0 (0 - 0)	6 (1 - 17)	0.0 (0.0 - 0.0)	0.2 (0.0 - 1.0)
Purakunui Inlet	0 (0 - 0)	1 (0 - 2)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Otago Harbour	0 (0 - 0)	6 (2 - 14)	0.0 (0.0 - 0.0)	0.1 (0.0 - 1.0)
Papanui Inlet	0 (0 - 0)	0 (0 - 1)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Hoopers Inlet	0 (0 - 0)	0 (0 - 1)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tomahawk Lagoon	2 (1 - 4)	0 (0 - 2)	0.1 (0.0 - 0.3)	0.0 (0.0 - 0.0)
Kaikorai Estuary	13 (0 - 37)	8 (0 - 27)	1.4 (0.2 - 3.7)	0.6 (0.0 - 2.0)
Taieri Estuary	880 (0 - 2,119)	212 (25 - 713)	0.0 (0.0 - 0.0)	48.8 (1.0 - 194.2)
Akatore Estuary	14 (0 - 49)	4 (0 - 16)	0.0 (0.0 - 0.0)	0.1 (0.0 - 1.0)
Tokomairiro Estuary	180 (27 - 404)	79 (0 - 227)	0.0 (0.0 - 0.0)	5.6 (0.0 - 18.2)
Pounawea (Catlins) Estuary	27 (0 - 153)	111 (0 - 340)	0.0 (0.0 - 0.0)	3.4 (0.0 - 11.0)
Tahakopa Estuary	22 (0 - 141)	0 (0 - 0)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tautuku Estuary	5 (0 - 29)	0 (0 - 0)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Waipati (Chaslands) Estuary	5 (0 - 25)	0 (0 - 0)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)

Table 16. Current load and load reduction required to achieve target attribute states for rivers for TN and TP by FMU and for the C band TAS option 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).

FMU	**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 (%)**
Catlins FMU	585 (364 - 868)	128 (7 - 346)	20 (2 - 46)	45 (21 - 86)	4 (0 - 12)	8 (0 - 25)
Dunedin Coast FMU	544 (376 - 775)	133 (38 - 305)	23 (9 - 43)	31 (20 - 50)	8 (2 - 21)	23 (7 - 46)
Dunstan Rohe	3,235 (1,088 - 7,919)	6 (0 - 33)	0 (0 - 1)	771 (108 - 2,954)	42 (0 - 27)	2 (0 - 10)
Lower Clutha Rohe	8,255 (2,776 - 20,209)	1,414 (23 - 3,905)	15 (1 - 25)	1,378 (194 - 5,279)	144 (1 - 582)	6 (0 - 18)
Manuherekia Rohe	3,346 (1,125 - 8,191)	7 (0 - 37)	0 (0 - 1)	769 (108 - 2,947)	42 (0 - 28)	2 (0 - 10)
North Otago FMU	769 (532 - 1,048)	79 (16 - 193)	10 (3 - 22)	45 (25 - 83)	11 (2 - 25)	21 (7 - 39)
Roxburgh Rohe	4,577 (1,539 - 11,206)	29 (0 - 132)	0 (0 - 2)	916 (129 - 3,508)	63 (0 - 185)	3 (0 - 14)
Taieri FMU	1,562 (521 - 2,818)	138 (0 - 669)	7 (0 - 29)	155 (26 - 471)	43 (1 - 161)	21 (3 - 56)
Upper Lakes Rohe	958 (322 - 2,345)	0 (0 - 1)	0 (0 - 0)	901 (126 - 3,450)	11 (0 - 0)	0 (0 - 0)
Total	11,928 (6,774 - 22,958)	2,021 (508 - 4,392)	16 (7 - 24)	1,666 (387 - 5,687)	214 (25 - 661)	11 (4 - 27)

3.7 Assessment of B band option

3.7.1 Compliance

For 20% and 40% of segments in the region, current river concentrations of TN and TP had a greater than 50% probability of exceeding the B band option associated with periphyton TAS, respectively (Figure 30). Current river concentrations of NO3N had a greater than 50% probability of exceeding the B band (i.e., national bottom line) associated with nitrate toxicity TAS for no segments. The probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% at no river segments (Figure 30).

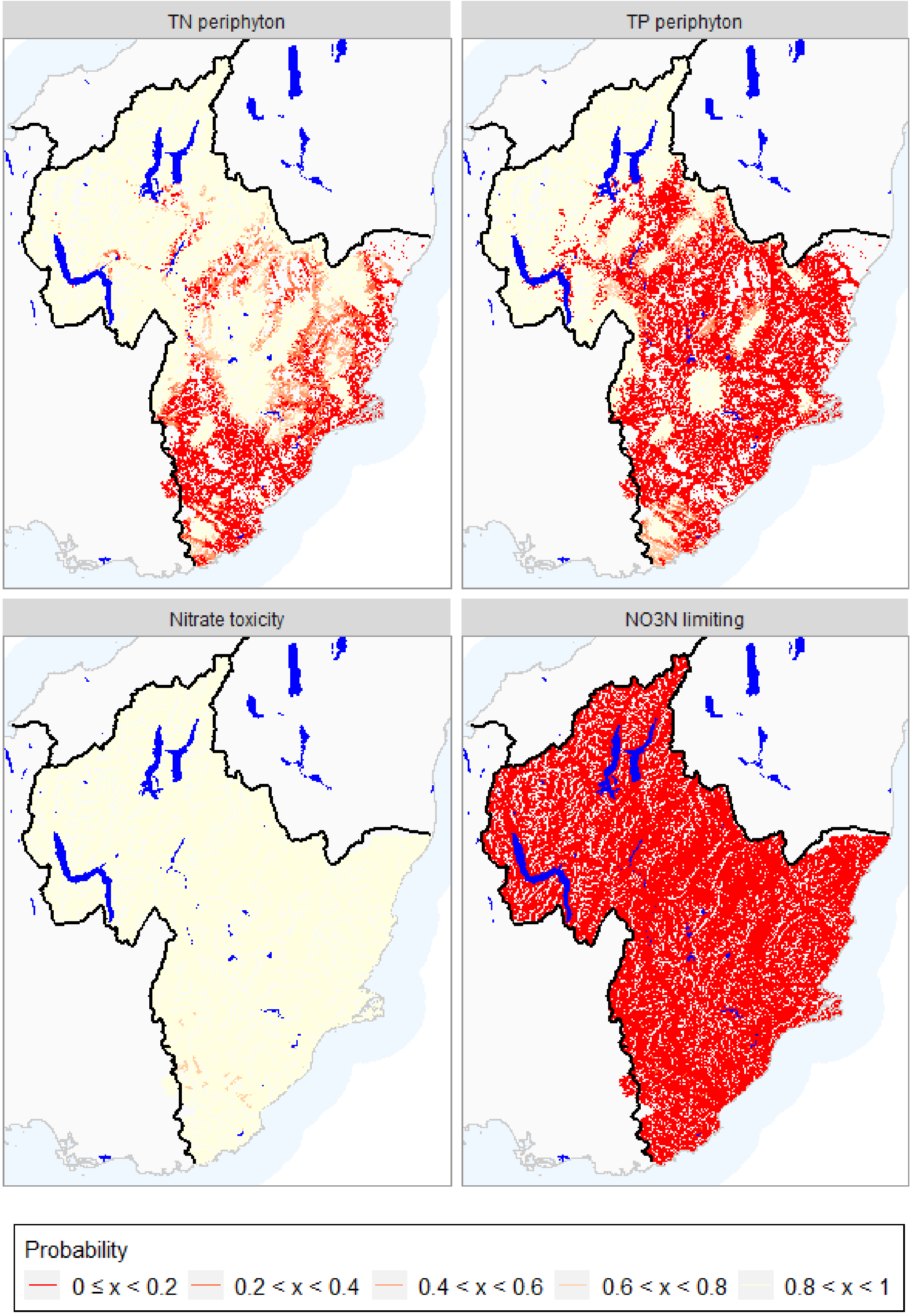

Figure 30. Probability that segments comply with river TN and TP concentration criteria associated with the periphyton target (top left and right) and NO3N concentration criteria associated with the nitrate toxicity target (lower left) for the B band option. The lower right-hand panel shows the probability that NO3N is the more limiting TAS than periphyton (in this scenario this was true for no of segments).

The probability that current TN and TP loads are compliant with the maximum allowable load associated with the B band criteria for the lake phytoplankton TAS was less than 50% (i.e., were non-compliant) for 58 and 112 of the 124 assessed lakes in the region, respectively (Figure 31).

The probability that current TN and TP loads are compliant with the maximum allowable load associated with the B band for estuary phytoplankton and macroalgae targets was less than 50% (i.e., were non-compliant) for 14 and 6 of the 20 assessed estuaries, respectively (Figure 32). The MAL for TP for Otago Harbour is zero, indicating that the B band cannot be achieved due to the phosphorus contributed by the ocean. TAS for phytoplankton, and therefore a MAL for TP, was only relevant for six estuaries (see Appendix B, Table 31 for details).

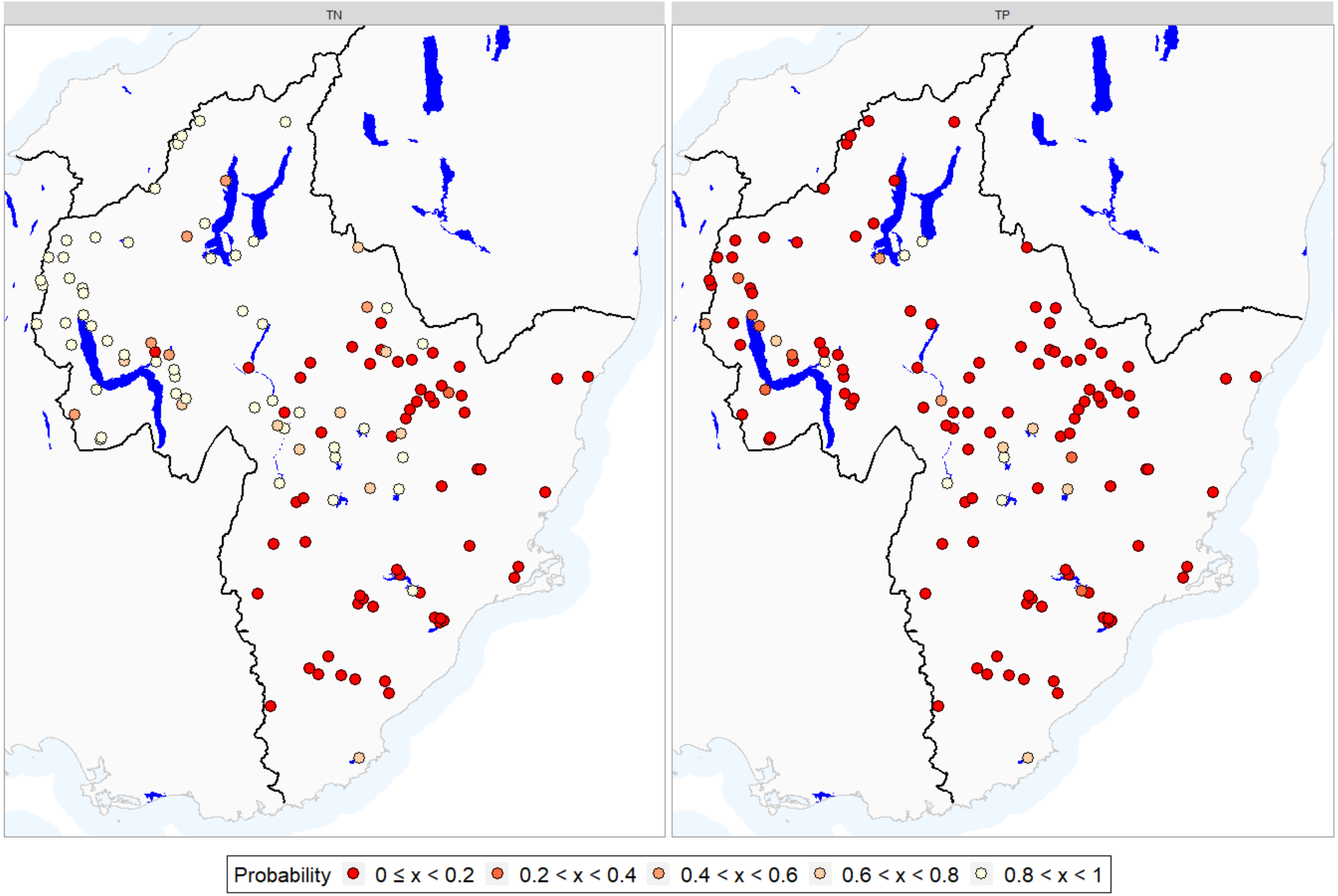

Figure 31. Probability that current lake TN and TP loads are compliant with the maximum allowable load associated with the B band TAS option.

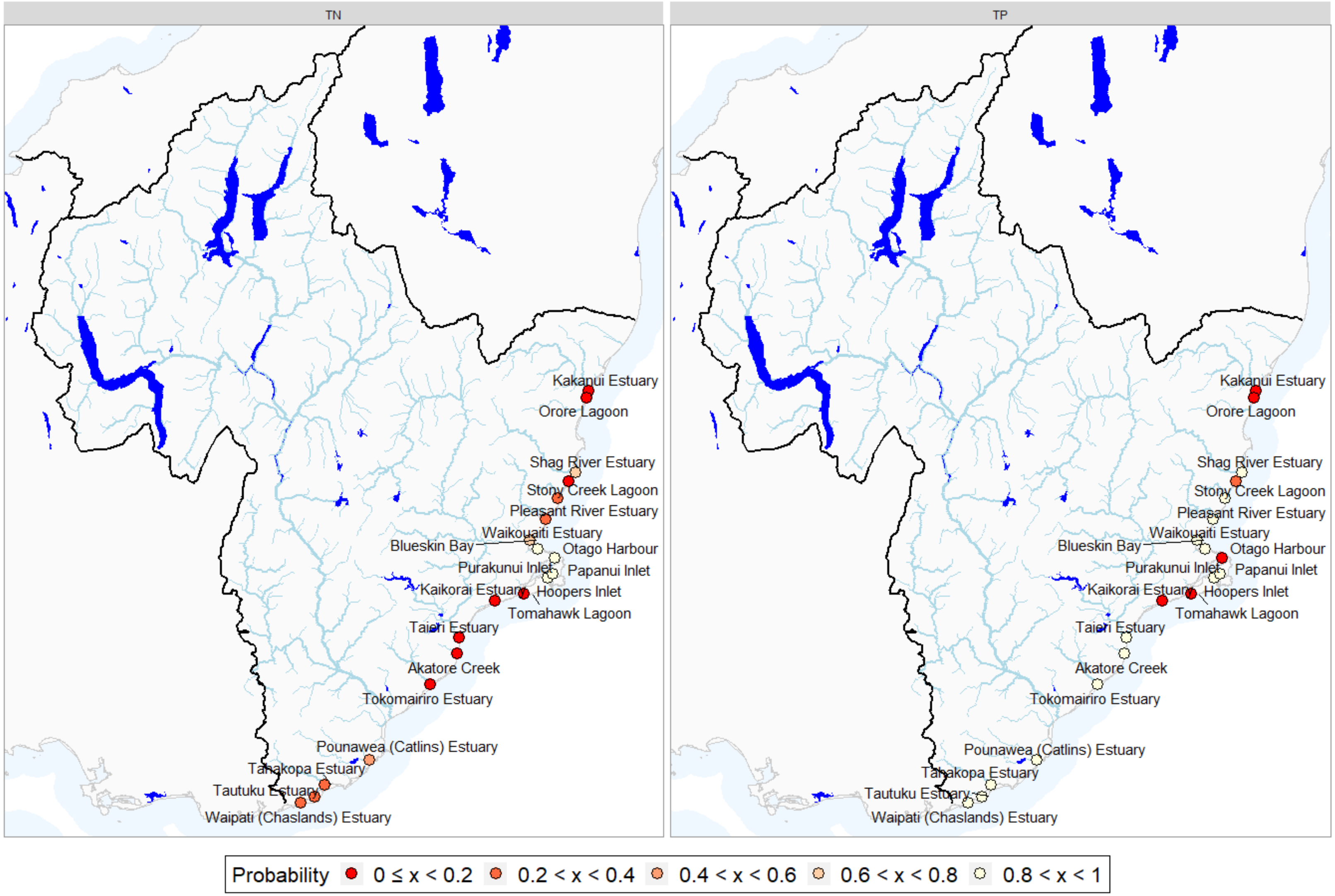

Figure 32. Probability that current estuary TN and TP loads are compliant with the maximum allowable load associated with the B band TAS option.

3.7.2 Local excess loads

For the B band option, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 12% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 7% of river segments (Figure 33). Local excess TN loads were zero for 81% of segments. Local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 33% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 13% of river segments (Figure 34). Local excess TP loads were zero for 39% of segments.

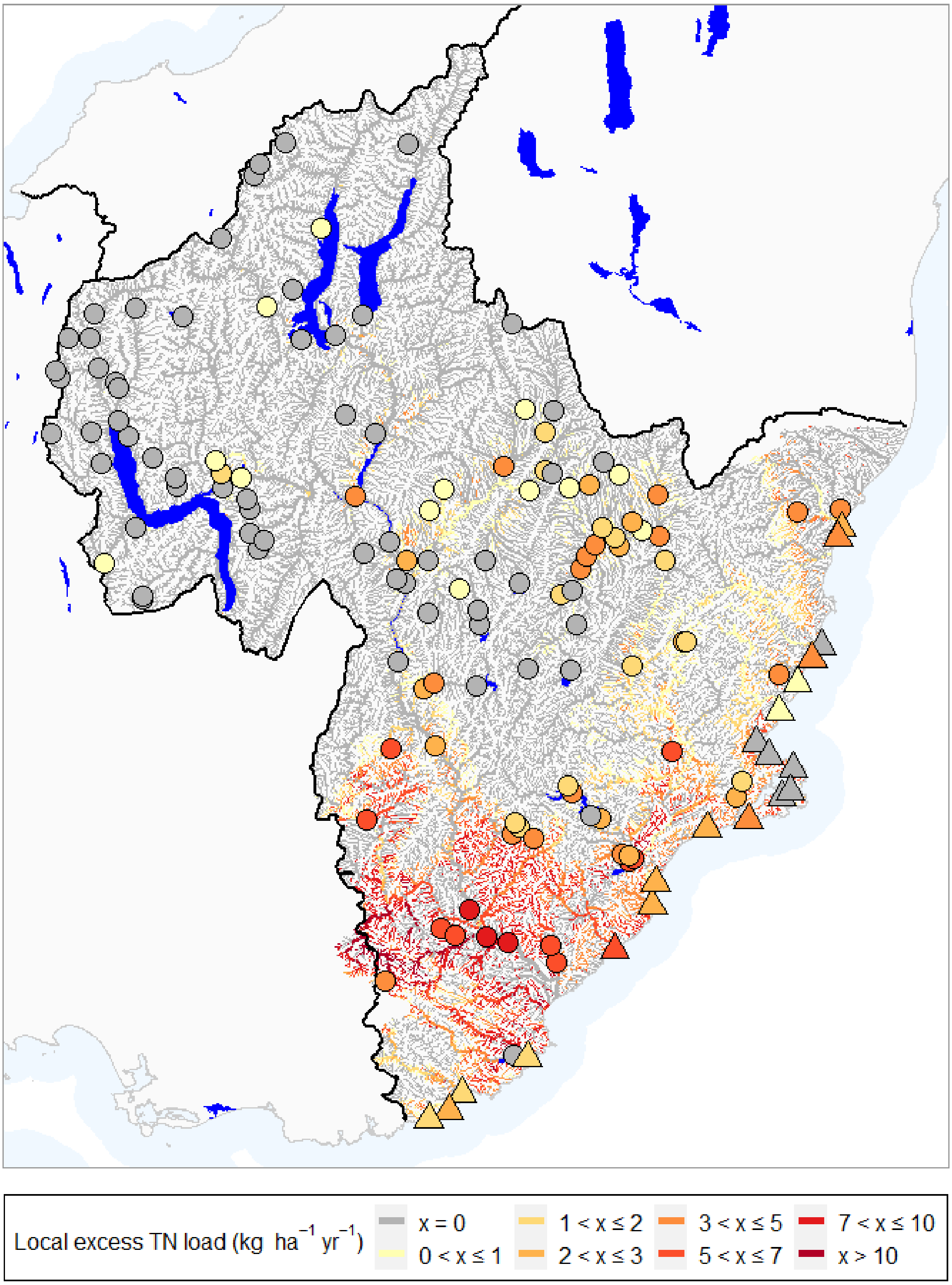

Figure 33. Local excess TN loads for rivers, lakes and estuaries for the B band TAS option. The lakes and estuaries are indicated by round and triangular symbols, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

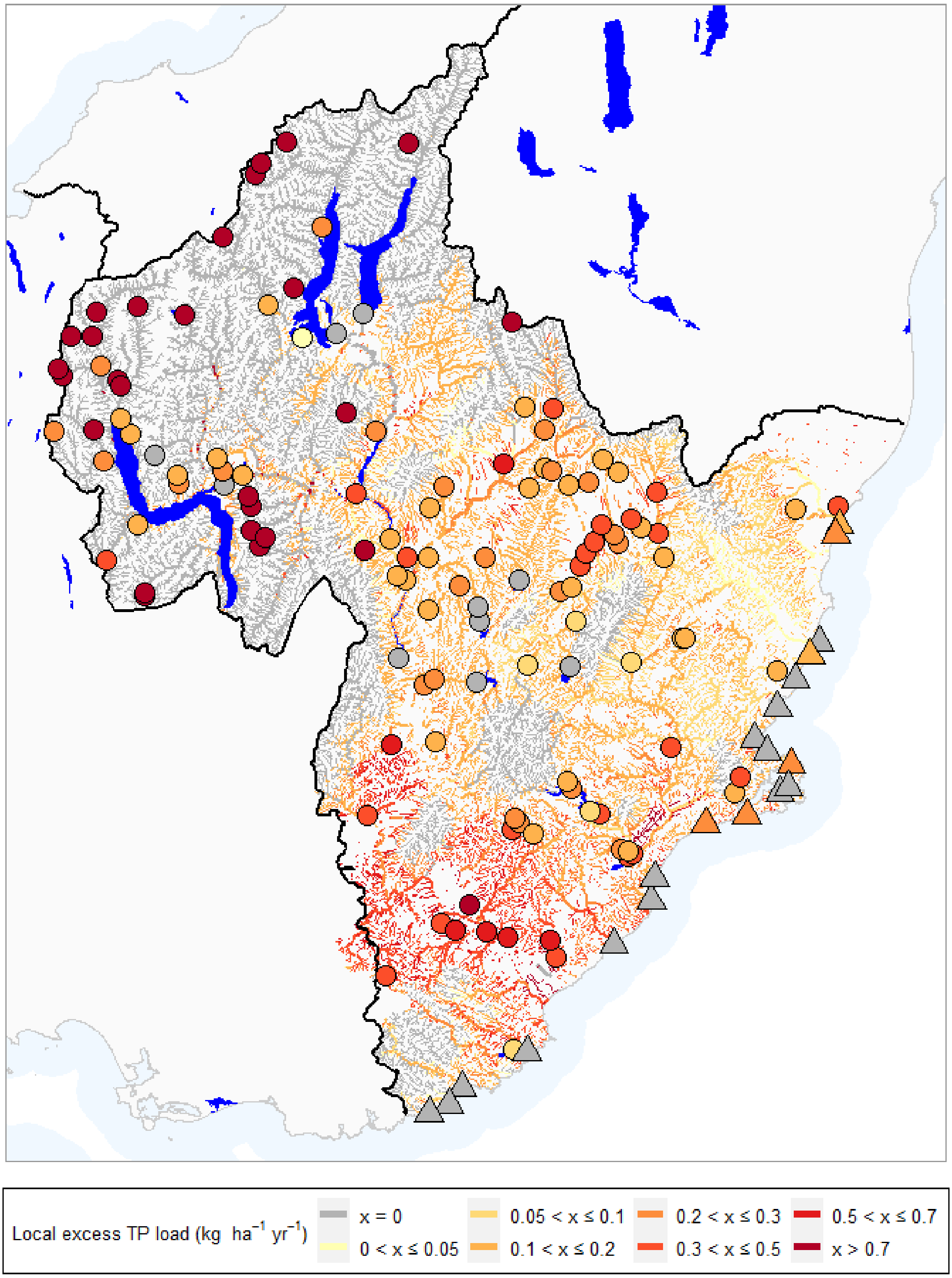

Figure 34. Local excess TP loads for rivers, lakes and estuaries for the B band TAS option. The lakes and estuaries are indicated by round and triangular symbols respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). Note that blank areas on this map indicate

river segments with substrate size index values of <3, which we assumed do not support conspicuous periphyton and therefore for which there are no applicable phosphorus criteria.

3.7.3 Critical point catchments and catchment status

Critical point catchments that required TN load reductions of greater than 5 kg ha^{-1} yr^{-1} occupied 18% of the region and critical point catchments with TN load reductions of greater than 2 kg ha^{-1} yr^{-1} occupied 95% of the region (Figure 35). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 50% occupied 98% of the region (Figure 36). 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 0.2 kg ha^{-1} yr^{-1} occupied 91% of the region and critical point catchments with TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 95% of the region (Figure 37). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 50% occupied 98% of the region (Figure 38). 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.

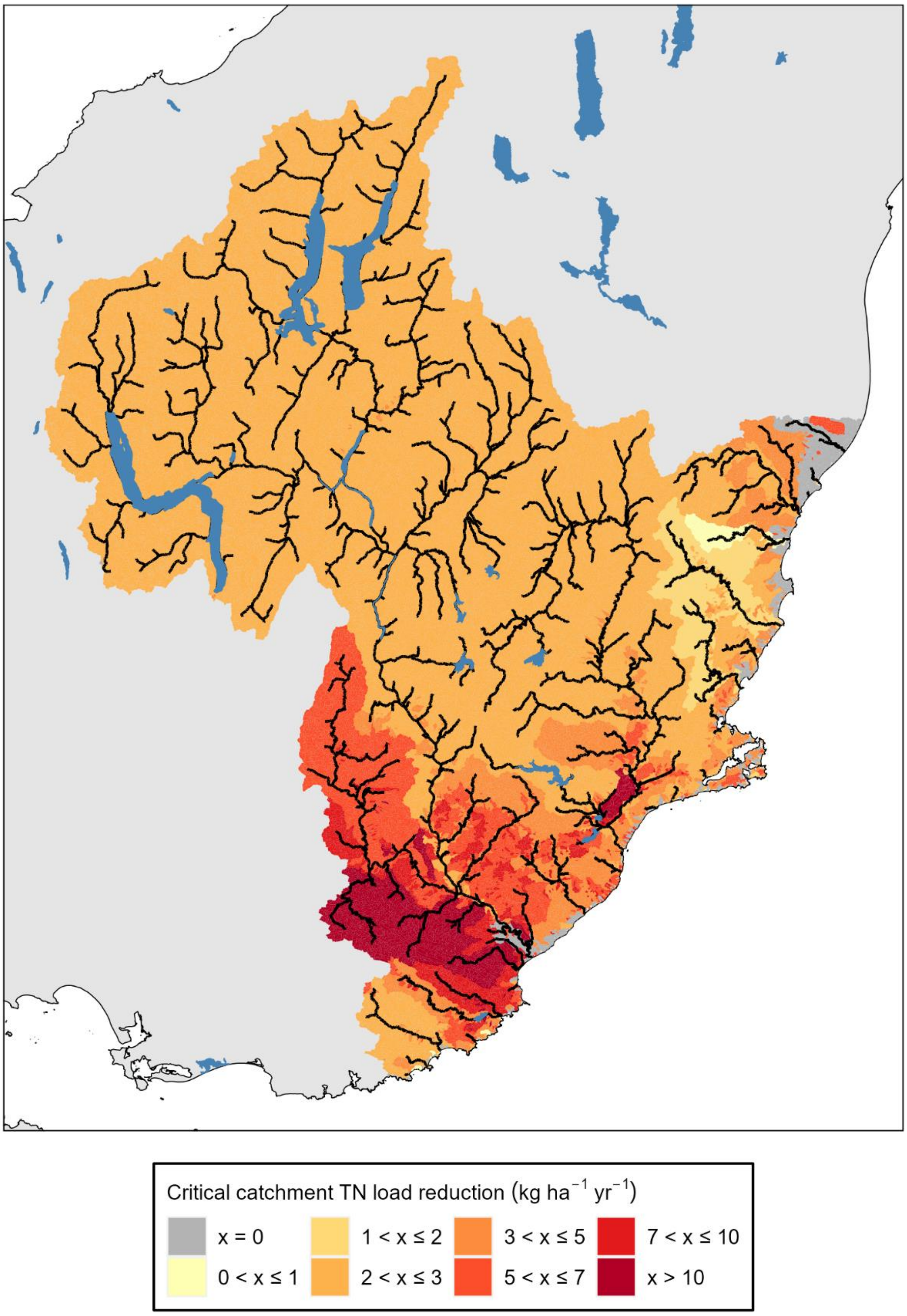

Figure 35*. The TN load reduction required for the B band option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).*

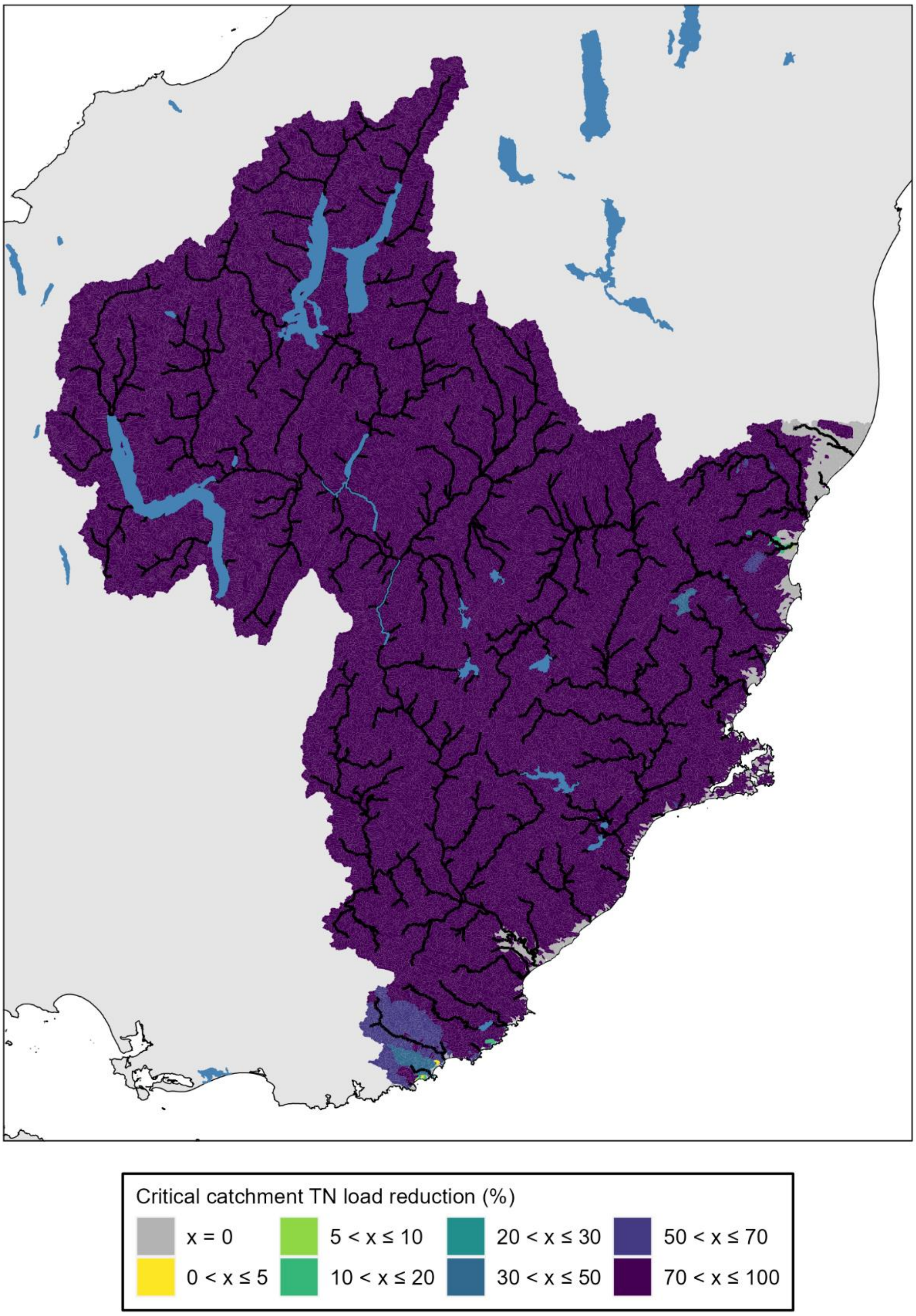

Figure 36. The TN load reduction required for the B band option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all targets to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

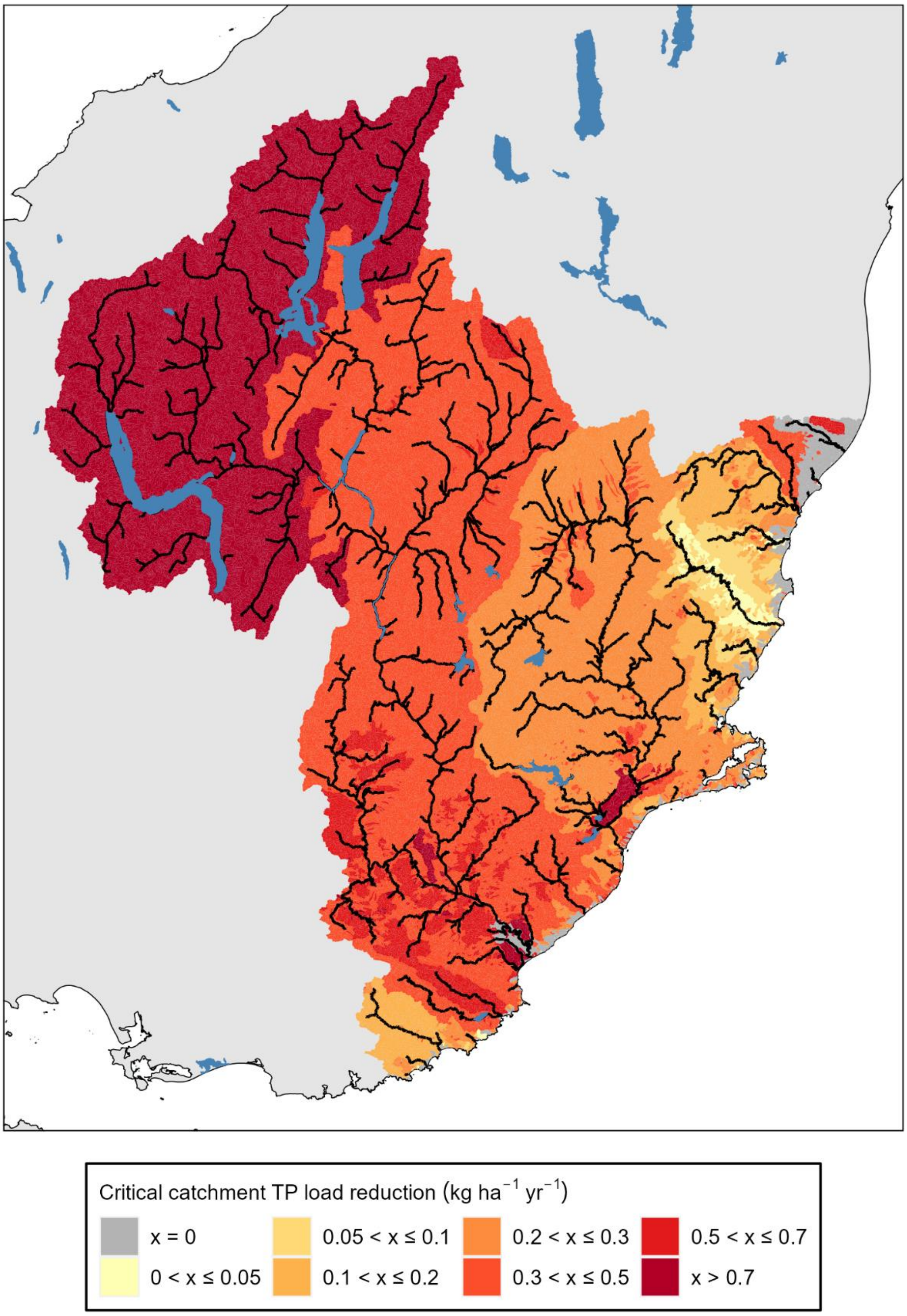

Figure 37. The TP load reduction required for the B band option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

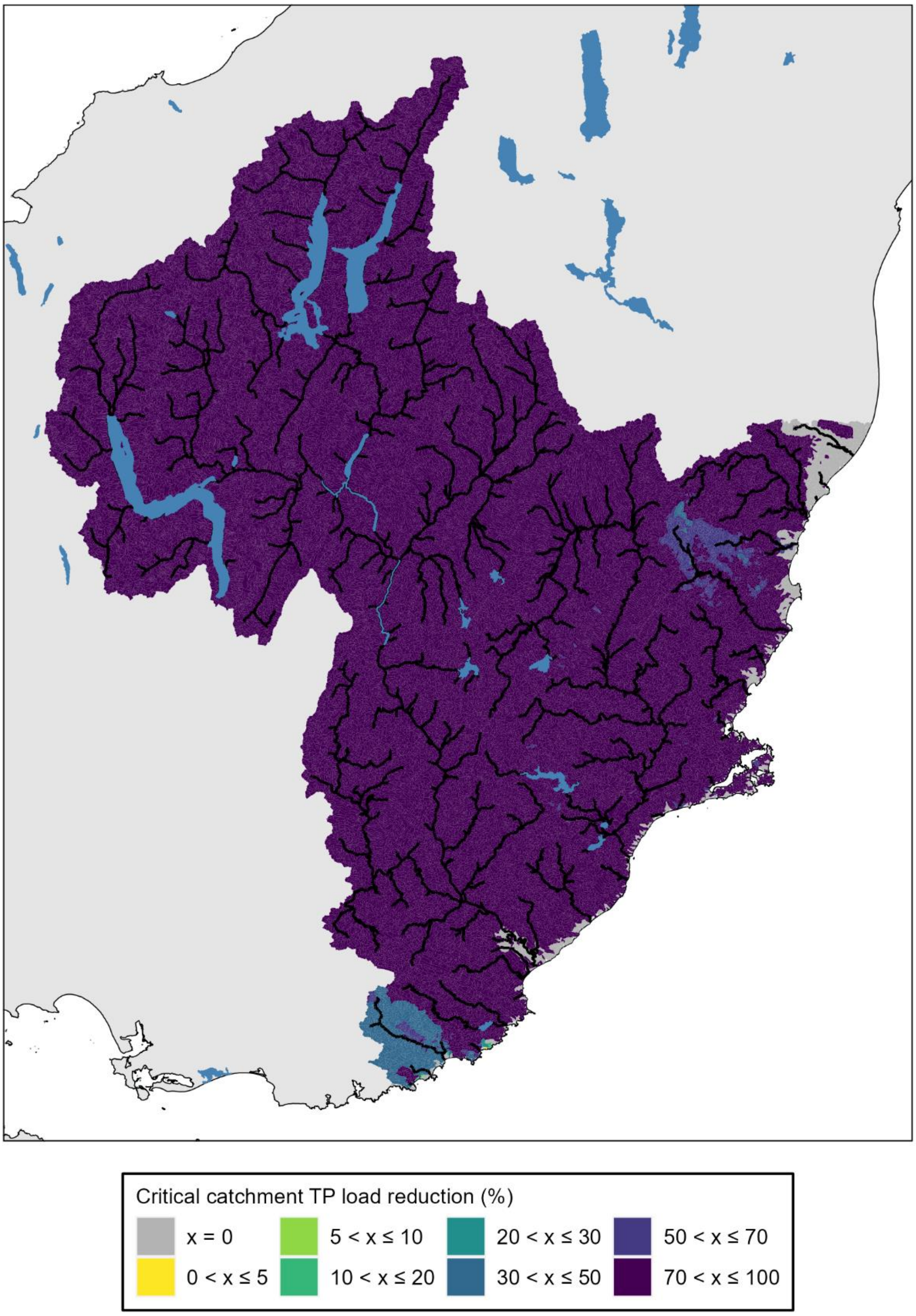

Figure 38. The TP load reduction required for the B band option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all targets to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment types that determine the load reduction requirements) for the B band are shown in Figure 39 and Figure 40 for TN and TP, respectively. For TN, 97% of the critical point catchment area were associated with rivers, 2% were for estuaries, and 2% were for lakes (Figure 39). For TP, 96% of the critical point catchment area were associated with rivers, 0.4% were for estuaries, and 4% were for lakes (Figure 40).

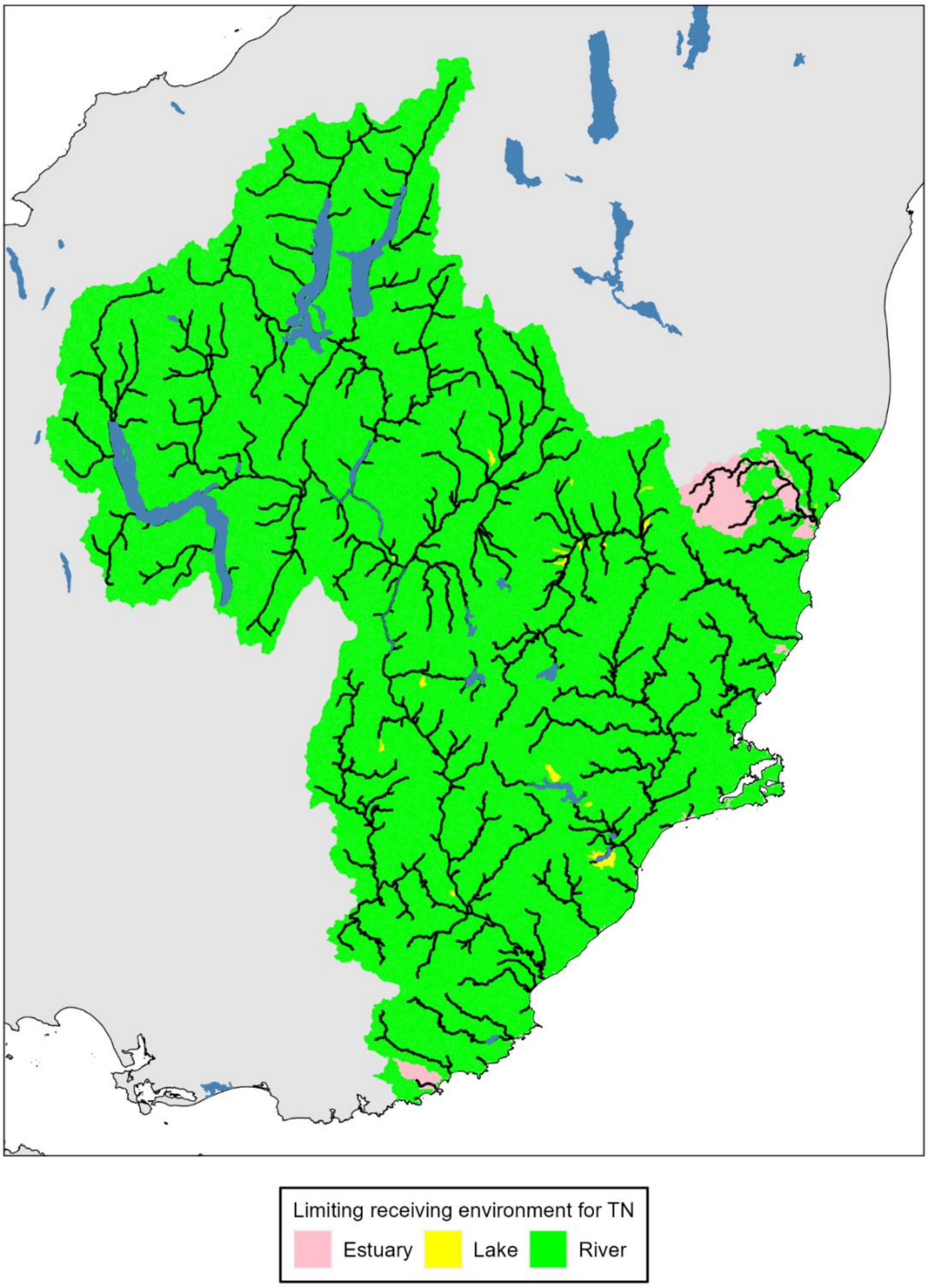

Figure 39. Limiting environment type for TN load reduction required for the B band TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TN load reductions).

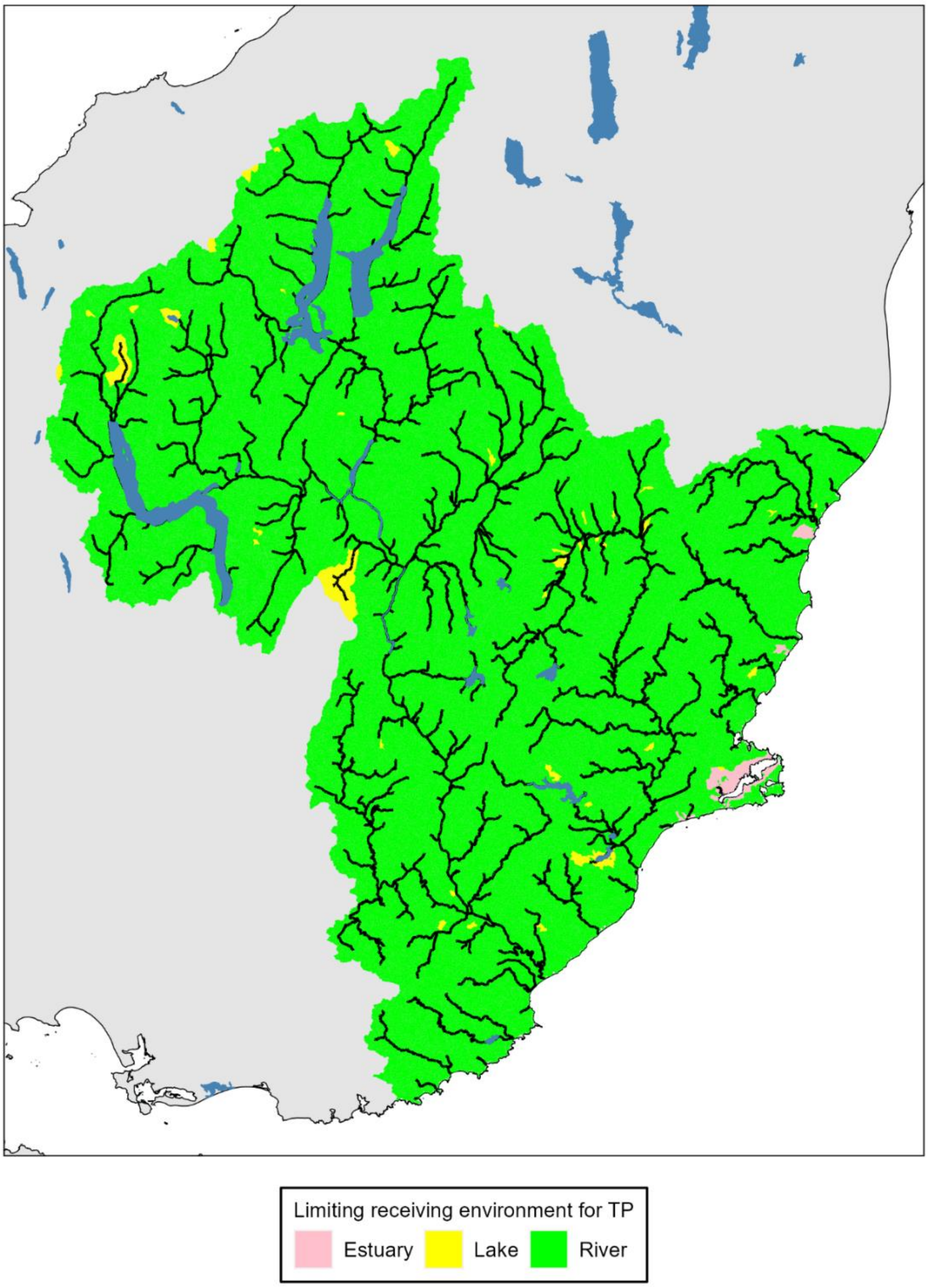

Figure 40. Limiting environment type for TP load reduction required for the B band TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TP load reductions).

3.7.4 FMU and regional load reductions required

For the whole study area, the TN and TP load reductions required to achieve the B band option were 9,193 t yr^{-1} and 1,892 t yr^{-1}, which represent 78% and 122 of the current TN and TP loads, respectively (Table 17). The uncertainties for 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 17. These uncertainties indicate, for example, that the 90% confidence interval for the current regional load of TN extends between 4,808 t yr^{-1} and 15,245 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 54% and 90% (best estimate 78%) and the regional TP load reduction requirement extends between 79% and 166% (best estimate 122%).

Load reductions of over 100% occurred for some FMUs and the region as a whole because model predictions of TP loads sometimes decreased toward the lower end of main stem rivers compared to predictions upstream. This means that the estimated upstream reductions can be larger than the predicted current load at the bottom of the catchment. This is not necessarily an error. Loads of TP are likely to be attenuated as they travel downstream from their source, particularly when there are large lakes in the drainage network that trap sediment and associated phosphorus, and this means loads reduce in the downstream direction.

For the B band option, the best estimates of TN load reductions required were high (>25%) for all FMUs except the Upper Lakes Rohe. The TP load reductions required were high (≥25%) in all FMUs.

Table 17. Current load and load reduction required for TN and TP by FMUs and for the B band TAS option 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).

FMU	**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 (%)**
Catlins FMU	597 (352 - 989)	494 (267 - 905)	81 (68 - 93)	48 (18 - 96)	28 (7 - 71)	55 (32 - 74)
Dunedin Coast FMU	535 (389 - 788)	456 (305 - 694)	85 (80 - 89)	31 (19 - 55)	27 (15 - 54)	85 (76 - 96)
Dunstan Rohe	3,058 (1,182 - 5,850)	1,829 (144 - 3,702)	57 (7 - 81)	656 (154 - 1,472)	1,432 (243 - 3,670)	202 (98 - 277)
Lower Clutha Rohe	7,804 (3,019 - 14,928)	6,022 (1,733 - 11,657)	75 (35 - 94)	1,173 (275 - 2,632)	1,669 (285 - 4,253)	132 (72 - 177)
Manuherekia Rohe	3,163 (1,223 - 6,050)	1,888 (147 - 3,822)	57 (7 - 81)	655 (153 - 1,469)	1,448 (246 - 3,714)	204 (100 - 281)
North Otago FMU	787 (575 - 1,109)	536 (342 - 886)	67 (55 - 80)	45 (27 - 74)	32 (13 - 62)	68 (48 - 86)
Roxburgh Rohe	4,327 (1,673 - 8,277)	2,634 (356 - 5,279)	58 (11 - 82)	779 (183 - 1,749)	1,532 (260 - 3,938)	182 (92 - 248)
Taieri FMU	1,671 (590 - 3,692)	1,438 (438 - 3,270)	84 (68 - 93)	133 (26 - 343)	125 (23 - 276)	91 (65 - 104)
Upper Lakes Rohe	905 (350 - 1,732)	28 (2 - 83)	2 (0 - 8)	766 (180 - 1,720)	540 (93 - 1,383)	65 (31 - 88)
Total	11,623 (6,853 - 18,351)	9,193 (4,808 - 15,245)	78 (54 - 90)	1,444 (520 - 2,868)	1,892 (463 - 4,446)	122 (79 - 166)

The load reductions required for the B band option for the 20 estuaries and to achieve all river and lake TAS in the catchment of each estuary are shown in Table 18. For 4 of the 20 estuaries (Orore Lagoon, Stony Creek Lagoon, Tomahawk Lagoon and Tautuku Estuary) the TN load reductions required to achieve the TAS under the B band option are of greater magnitude for the estuary compared to the river and lake TAS in the upstream catchment. In contrast, TN load reductions required to achieve river and lake TAS are of greater magnitude than for all other estuaries. Several estuaries have zero TN load reductions required, indicating that they currently achieve the B band TAS or better.

TP load reductions required to achieve the TAS for four estuaries (Orore Lagoon, Stony Creek Lagoon, Otago Harbour and Tomahawk Lagoon) were larger those required to achieve the river and lake targets in the upstream catchment (Table 18). The TP load reductions required for 14 estuaries are zero because it is considered unlikely that phytoplankton growth in these estuaries will drive severe secondary symptoms of eutrophication (like deoxygenation and light attenuation), and therefore no MAL has been defined for TP (see Appendix B, Table 31).

The load reductions required to achieve the TAS for rivers (only) are shown in Table 19. The reductions for the FMUs and for the region are generally lower than those shown in Table 17 because lakes and estuaries are excluded from the values. Note that there are some exceptions to this due to the large uncertainties associated with the analysis.

Table 18. Load reductions required to achieve the TAS for estuaries and for all rivers and lakes in their upstream catchments for the B band option.

Estuary	**TN load reduction required (t yr^{-1})**		**TP load reduction required (t yr^{-1})**	
	Estuary	**Lakes and rivers**	**Estuary**	**Lakes and rivers**
Kakanui Estuary	186 (43 - 476)	224 (79 - 538)	12.9 (0.0 - 36.8)	16.6 (2.0 - 43.1)
Orore Lagoon	9 (3 - 16)	0 (0 - 0)	0.5 (0.0 - 1.3)	0.0 (0.0 - 0.0)
Shag River Estuary	19 (0 - 87)	98 (29 - 195)	0.0 (0.0 - 0.0)	2.8 (0.0 - 8.0)
Stony Creek Lagoon	4 (1 - 10)	1 (0 - 1)	0.1 (0.0 - 0.4)	0.0 (0.0 - 0.0)
Pleasant River Estuary	14 (0 - 46)	30 (11 - 63)	0.0 (0.0 - 0.0)	1.0 (0.0 - 3.0)
Waikouaiti Estuary	30 (0 - 100)	67 (22 - 138)	0.0 (0.0 - 0.0)	5.6 (0.0 - 19.1)
Blueskin Bay	3 (0 - 18)	32 (17 - 57)	0.0 (0.0 - 0.0)	1.6 (1.0 - 3.0)
Purakunui Inlet	0 (0 - 0)	3 (1 - 6)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Otago Harbour	0 (0 - 0)	38 (25 - 58)	2.5 (1.5 - 4.4)	1.7 (1.0 - 4.0)
Papanui Inlet	0 (0 - 0)	3 (2 - 5)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Hoopers Inlet	0 (0 - 0)	2 (1 - 3)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tomahawk Lagoon	2 (1 - 4)	1 (1 - 3)	0.1 (0.0 - 0.3)	0.0 (0.0 - 0.0)
Kaikorai Estuary	16 (3 - 39)	20 (8 - 42)	1.2 (0.2 - 3.3)	1.2 (0.0 - 3.0)
Taieri Estuary	1,245 (163 - 3,266)	1,402 (436 - 3,214)	0.0 (0.0 - 0.0)	124.8 (22.9 - 275.5)
Akatore Creek	19 (1 - 55)	29 (11 - 64)	0.0 (0.0 - 0.0)	1.4 (0.0 - 3.0)
Tokomairiro Estuary	198 (68 - 458)	213 (87 - 451)	0.0 (0.0 - 0.0)	14.0 (2.0 - 39.3)
Pounawea (Catlins) Estuary	101 (0 - 382)	294 (100 - 626)	0.0 (0.0 - 0.0)	17.3 (2.0 - 54.2)
Tahakopa Estuary	60 (0 - 173)	85 (3 - 204)	0.0 (0.0 - 0.0)	5.3 (0.0 - 21.0)
Tautuku Estuary	15 (0 - 49)	10 (0 - 42)	0.0 (0.0 - 0.0)	1.2 (0.0 - 5.0)
Waipati (Chaslands) Estuary	12 (0 - 42)	20 (1 - 54)	0.0 (0.0 - 0.0)	1.4 (0.0 - 5.1)

Table 19. Current load and load reduction required to achieve target attribute states for rivers for TN and TP by FMU and for the B band TAS option 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).

FMU	**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 (%)**
Catlins FMU	597 (352 - 989)	481 (259 - 877)	78 (62 - 91)	48 (18 - 96)	28 (7 - 71)	55 (32 - 74)
Dunedin Coast FMU	535 (389 - 788)	461 (311 - 687)	86 (82 - 90)	31 (19 - 55)	27 (14 - 54)	82 (72 - 95)
Dunstan Rohe	3,058 (1,182 - 5,850)	1,829 (144 - 3,702)	57 (7 - 81)	656 (154 - 1,472)	1,431 (243 - 3,669)	202 (97 - 277)
Lower Clutha Rohe	7,804 (3,019 - 14,928)	6,022 (1,733 - 11,657)	75 (35 - 94)	1,173 (275 - 2,632)	1,664 (285 - 4,247)	132 (71 - 177)
Manuherekia Rohe	3,163 (1,223 - 6,050)	1,888 (147 - 3,822)	57 (7 - 81)	655 (153 - 1,469)	1,446 (246 - 3,705)	204 (99 - 281)
North Otago FMU	787 (575 - 1,109)	522 (331 - 872)	65 (53 - 78)	45 (27 - 74)	31 (13 - 61)	67 (46 - 85)
Roxburgh Rohe	4,327 (1,673 - 8,277)	2,633 (355 - 5,279)	58 (11 - 82)	779 (183 - 1,749)	1,528 (260 - 3,916)	182 (91 - 248)
Taieri FMU	1,671 (590 - 3,692)	1,404 (438 - 3,215)	83 (64 - 93)	133 (26 - 343)	124 (23 - 272)	91 (65 - 103)
Upper Lakes Rohe	905 (350 - 1,732)	28 (2 - 83)	2 (0 - 8)	766 (180 - 1,720)	540 (93 - 1,383)	65 (31 - 88)
Total	11,623 (6,853 - 18,351)	9,137 (4,796 - 14,790)	78 (54 - 90)	1,444 (520 - 2,868)	1,886 (468 - 4,438)	122 (79 - 166)

3.8 Assessment of A band option

3.8.1 Compliance

Current river concentrations of TN and TP had a greater than 50% probability of exceeding the A band TAS option associated with periphyton TAS (i.e., were non-compliant) for 68% and 80% of segments in the region, respectively (Figure 41). Current river concentrations of NO3N had a greater than 50% probability of exceeding the nitrate toxicity A band target for 0.2% of segments. The probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% for 0.04% of river segments (Figure 41).

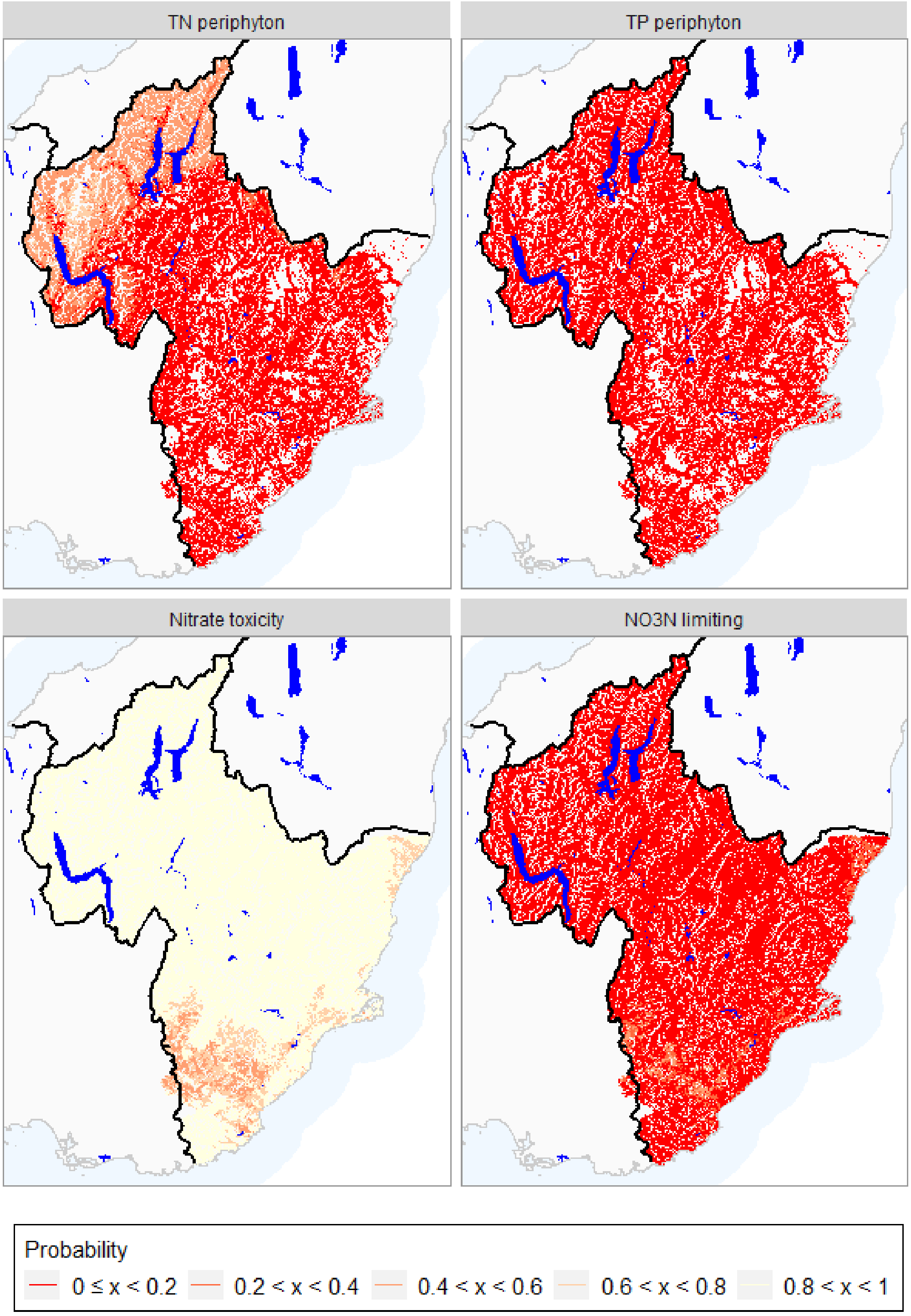

Figure 41. Probability that segments comply with river TN and TP concentration criteria associated with the periphyton TAS (top left and right) and NO3N concentration criteria associated with the nitrate toxicity TAS (lower left) for the A band option. The lower right-hand panel shows the probability that NO3N is the more limiting TAS than periphyton (in this scenario this was true for 0.04% of segments).

The probability that current lake TN and TP loads are compliant with the A band criteria associated with the lake phytoplankton TAS was less than 50% (i.e., were non-compliant) for 97 and 119 of the 124 assessed lakes in the region, respectively (Figure 42).

The probability that current TN and TP loads are compliant with the criteria associated with the A band phytoplankton and macroalgae TAS was less than 50% (i.e., were non-compliant) for 17 and 6 of the 20 assessed estuaries, respectively (Figure 43). The MAL for TP for Otago Harbour is zero, indicating that the A band cannot be achieved due to the phosphorus contributed by the ocean. TAS for phytoplankton, and therefore a MAL for TP, was only relevant for six estuaries (see Appendix B, Table 31 for details).

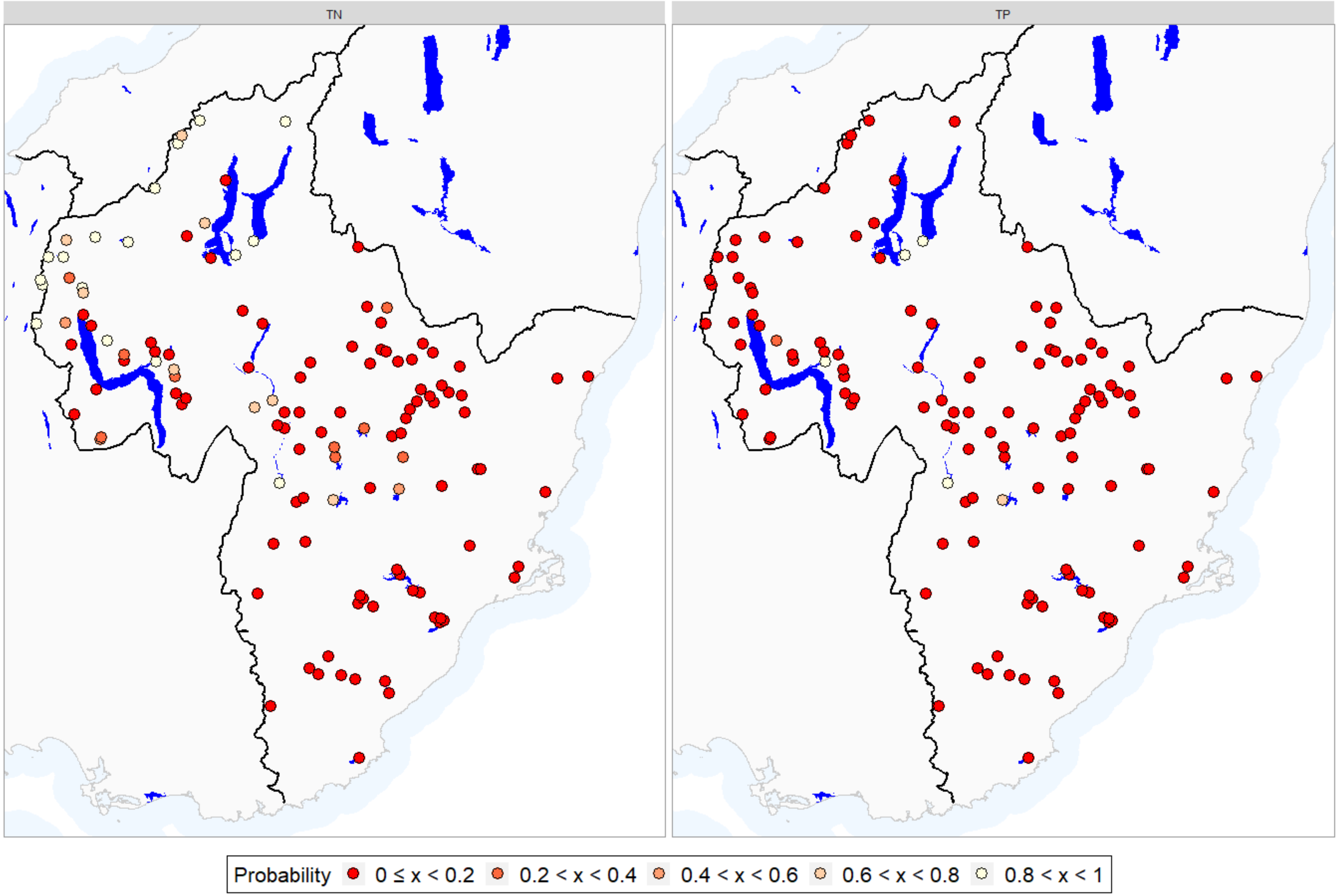

Figure 42. Probability that current lake TN and TP loads are compliant with the maximum allowable load associated with the Aband TAS option.

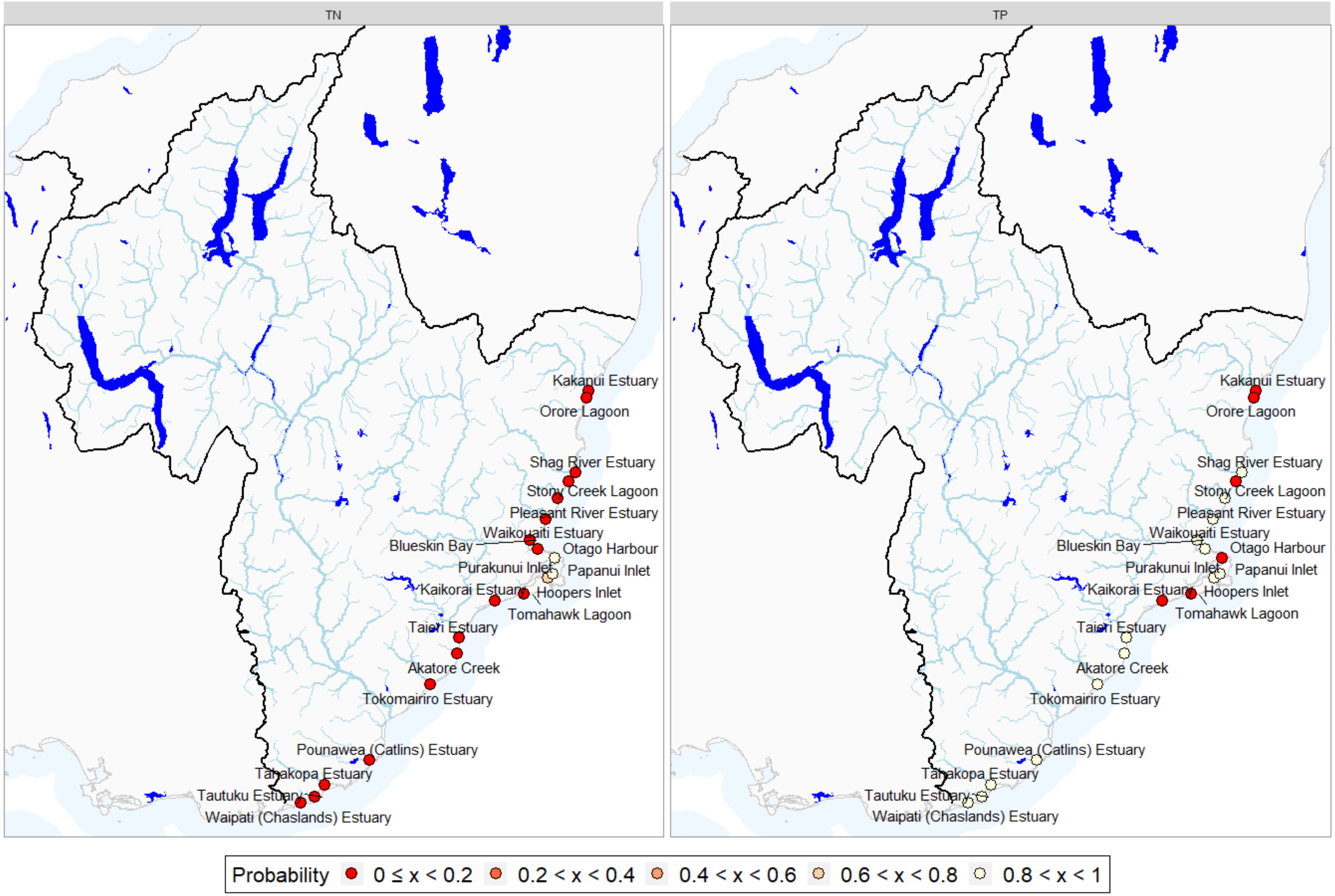

Figure 43. Probability that current estuary TN and TP loads are compliant with the maximum allowable load associated with the Aband TAS option.

3.8.2 Local excess loads

For the A band option, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 20% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 8% of river segments (Figure 44). Local excess TN loads were zero for 30% of segments. Local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 78% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 62% of river segments (Figure 45). Local excess TP loads were zero for no segments.

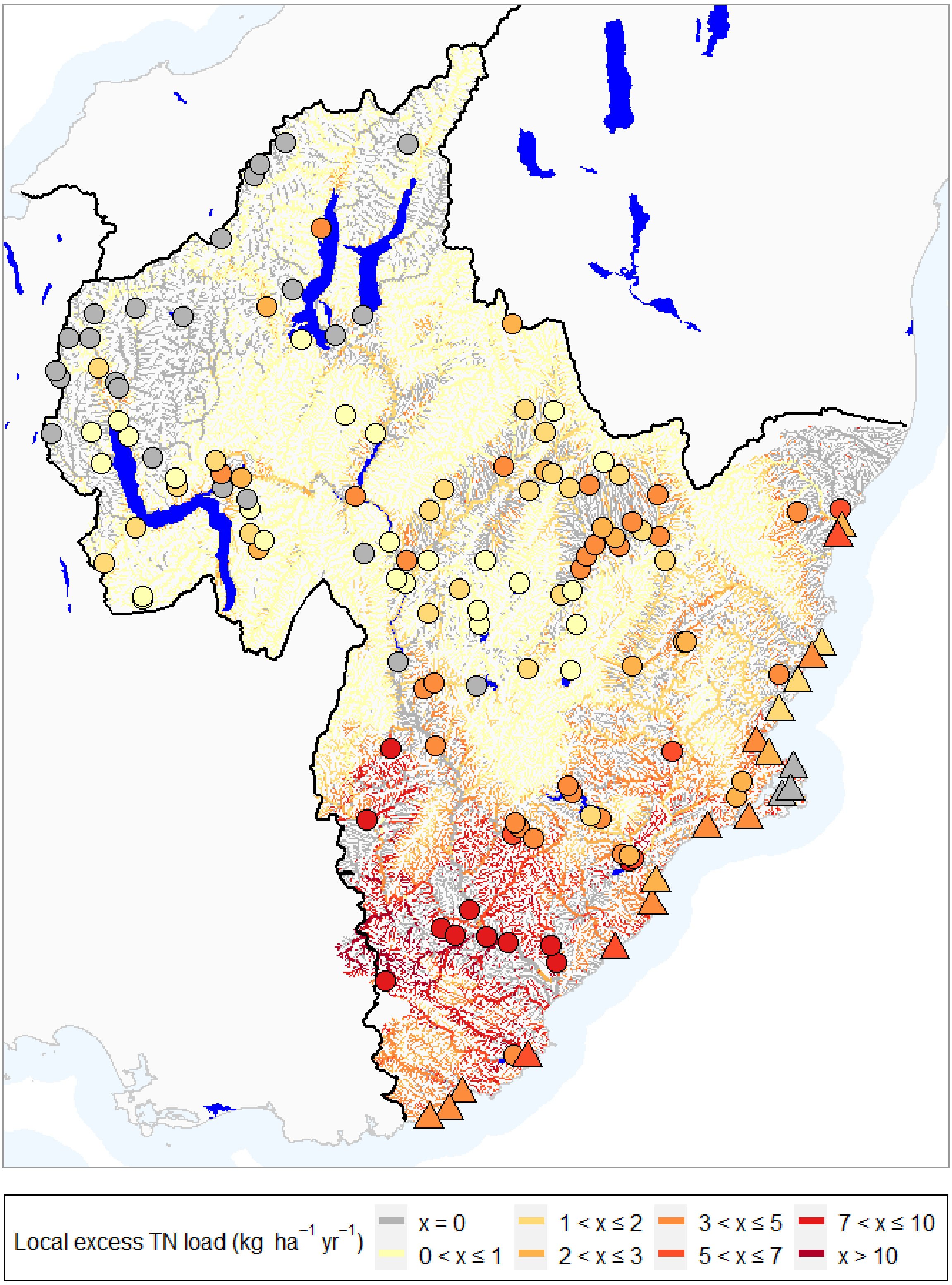

Figure 44. Local excess TN loads for rivers, lakes and estuaries for the A band TAS option. The lakes and estuaries are indicated by round and triangular points, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

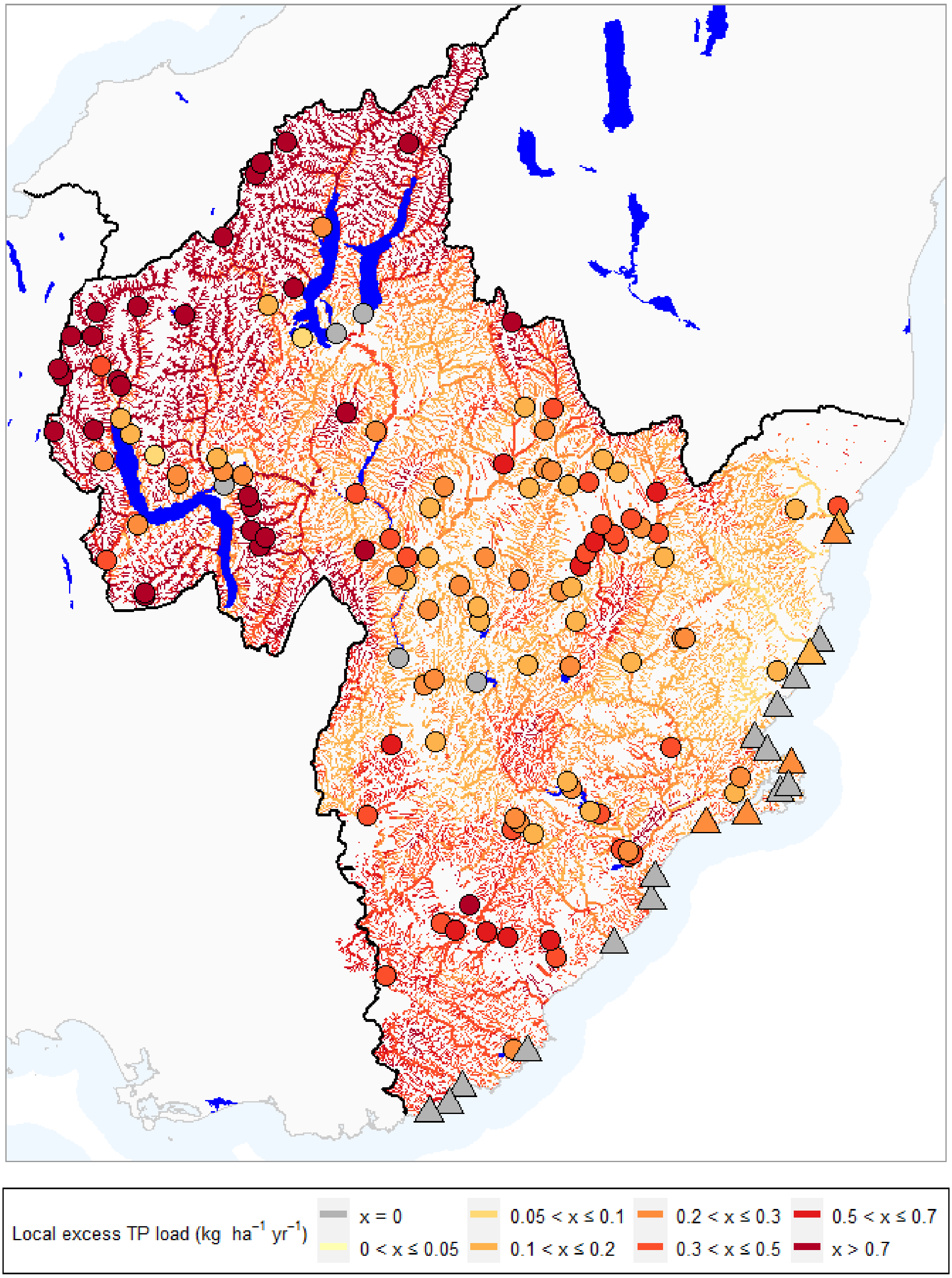

Figure 45. Local excess TP loads for rivers, lakes and estuaries for the A band TAS option. The lakes and estuaries are indicated by round and triangular points respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). Note that blank areas on this map indicate river segments with substrate size index values of <3, which we assumed do not support conspicuous periphyton and therefore for which there are no applicable phosphorus criteria.

3.8.3 Critical point catchments and catchment status

Critical point catchments that required TN load reductions of greater than 5 kg ha^{-1} yr^{-1} occupied 19% of the region and critical point catchments with TN load reductions of greater than 2 kg ha^{-1} yr^{-1} occupied 97% of the region (Figure 46). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 50% occupied 99% of the region (Figure 47). 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 0.2 kg ha^{-1} yr^{-1} occupied 94% of the region and critical point catchments with TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 98% of the region (Figure 48). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 50% occupied 99% of the region (Figure 49). 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.

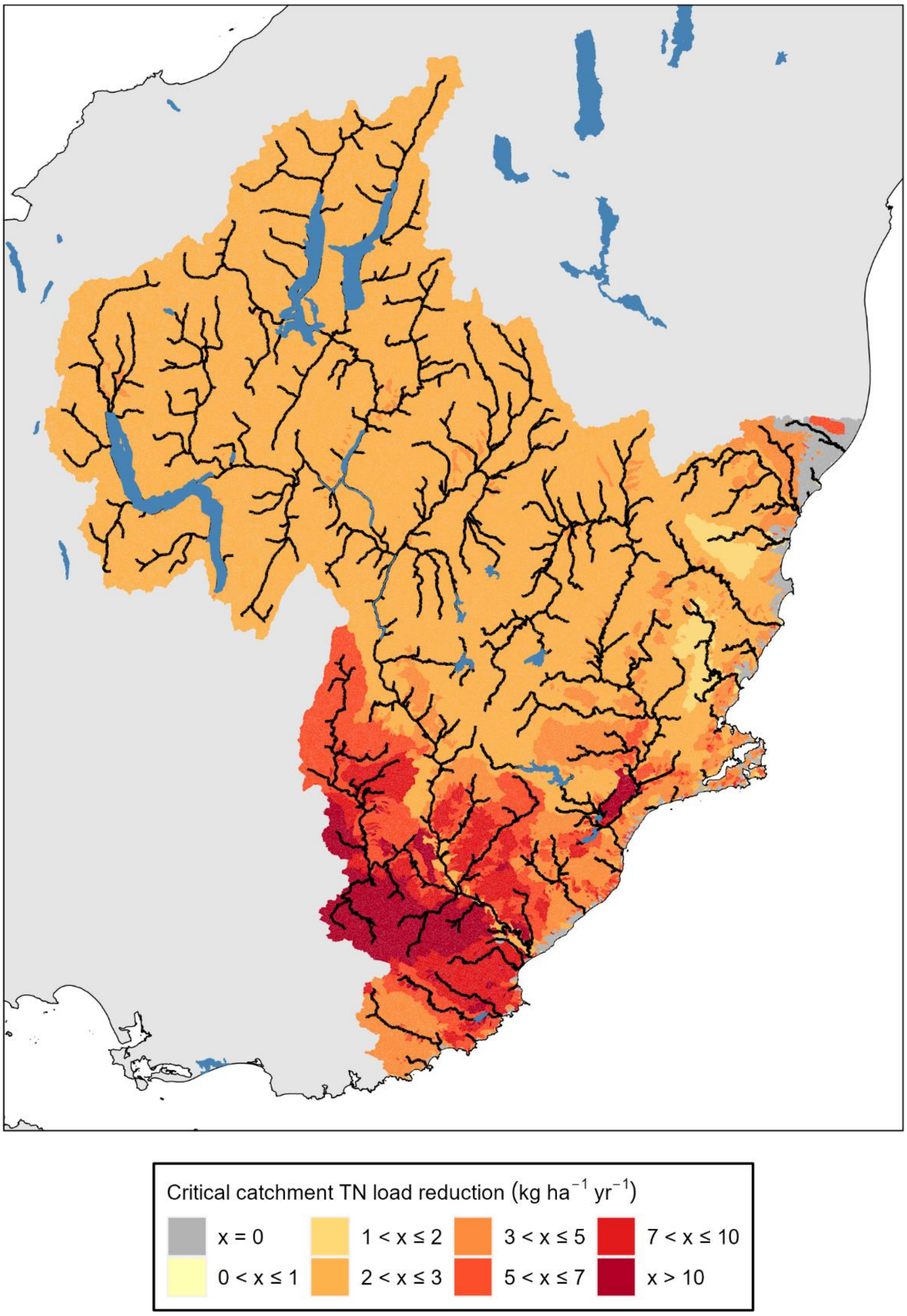

Figure 46*. The TN load reduction required for the A band TAS option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).*

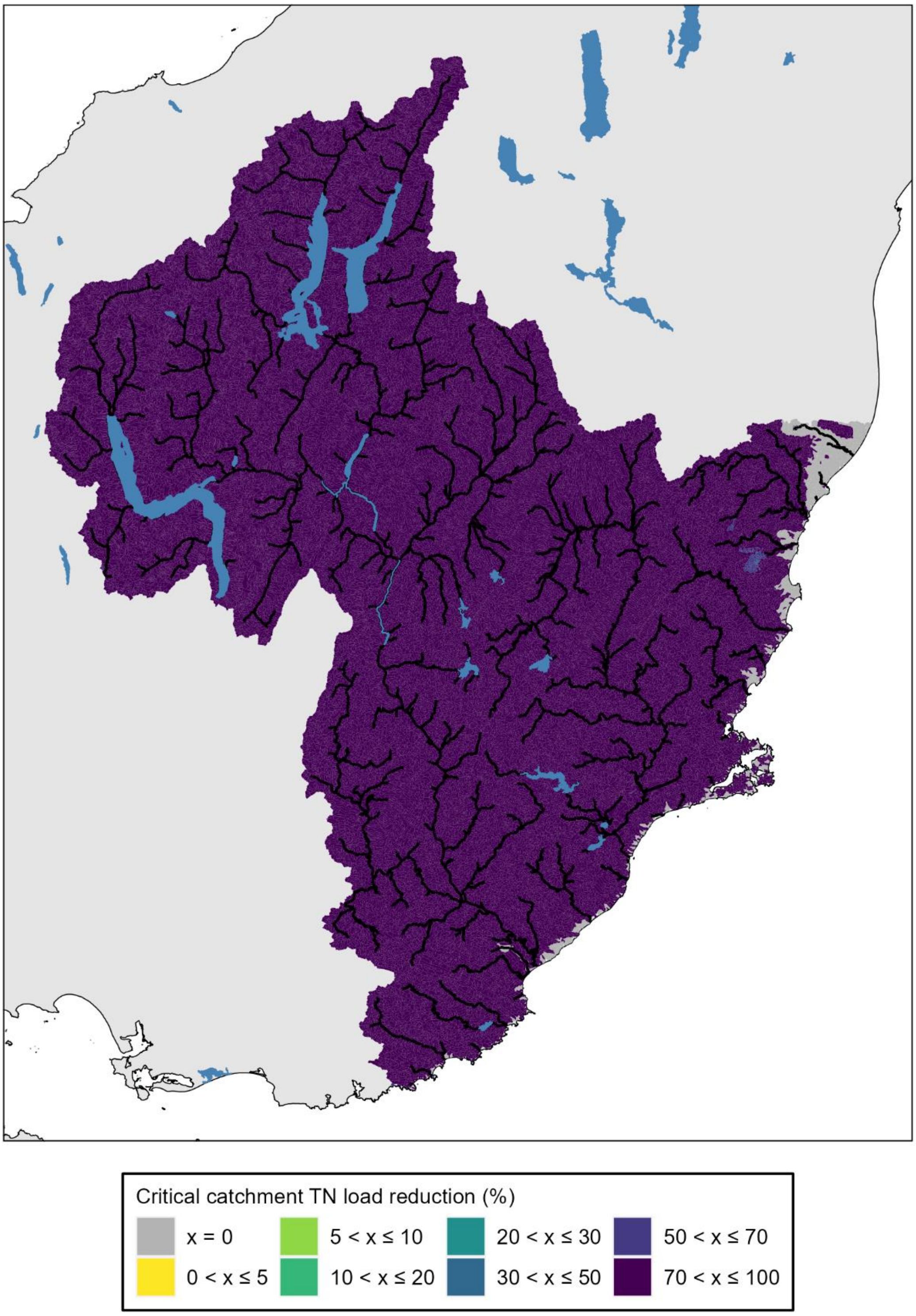

Figure 47. The TN load reduction required for the A band TAS option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

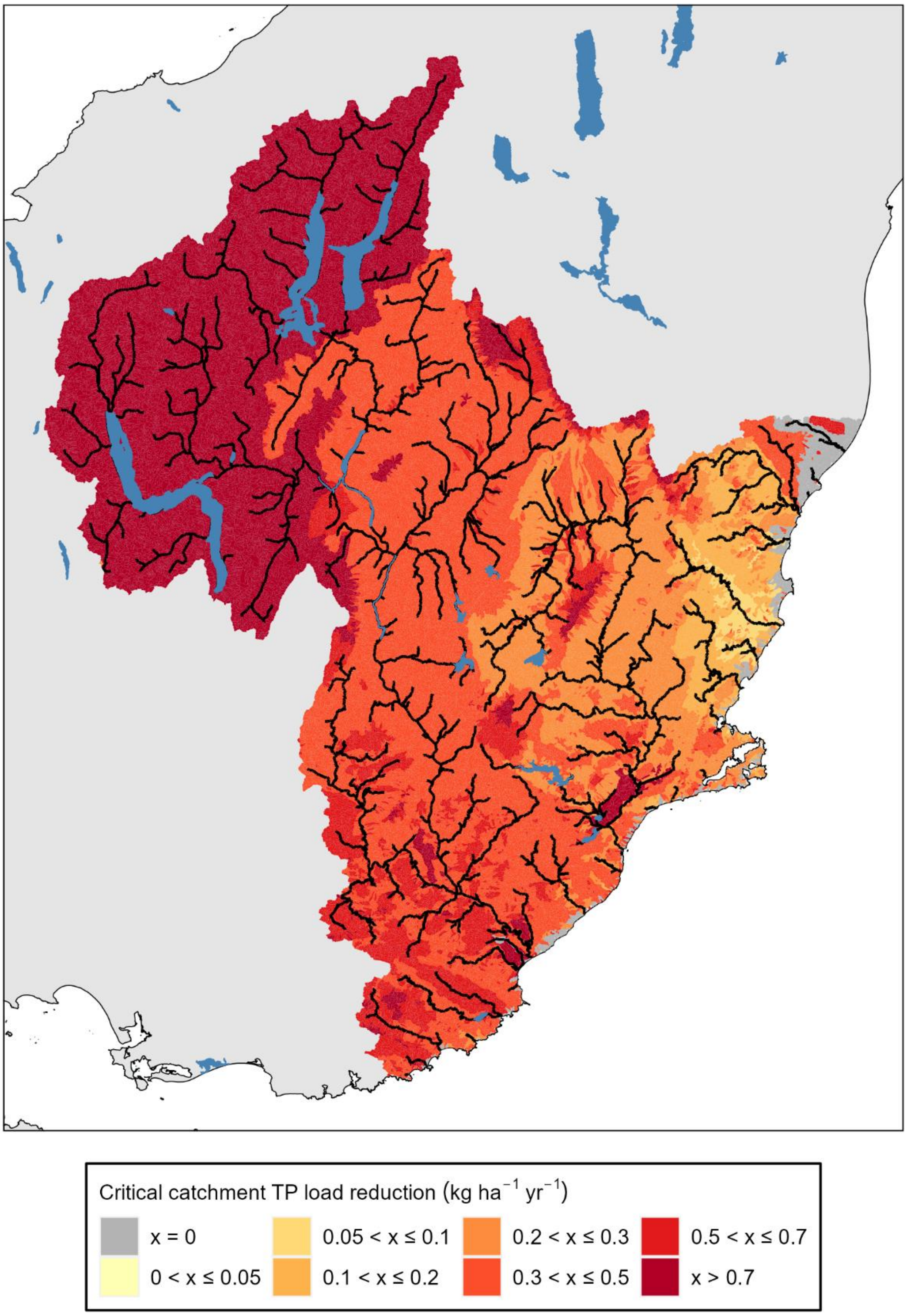

Figure 48. The TP load reduction required for the A band TAS option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

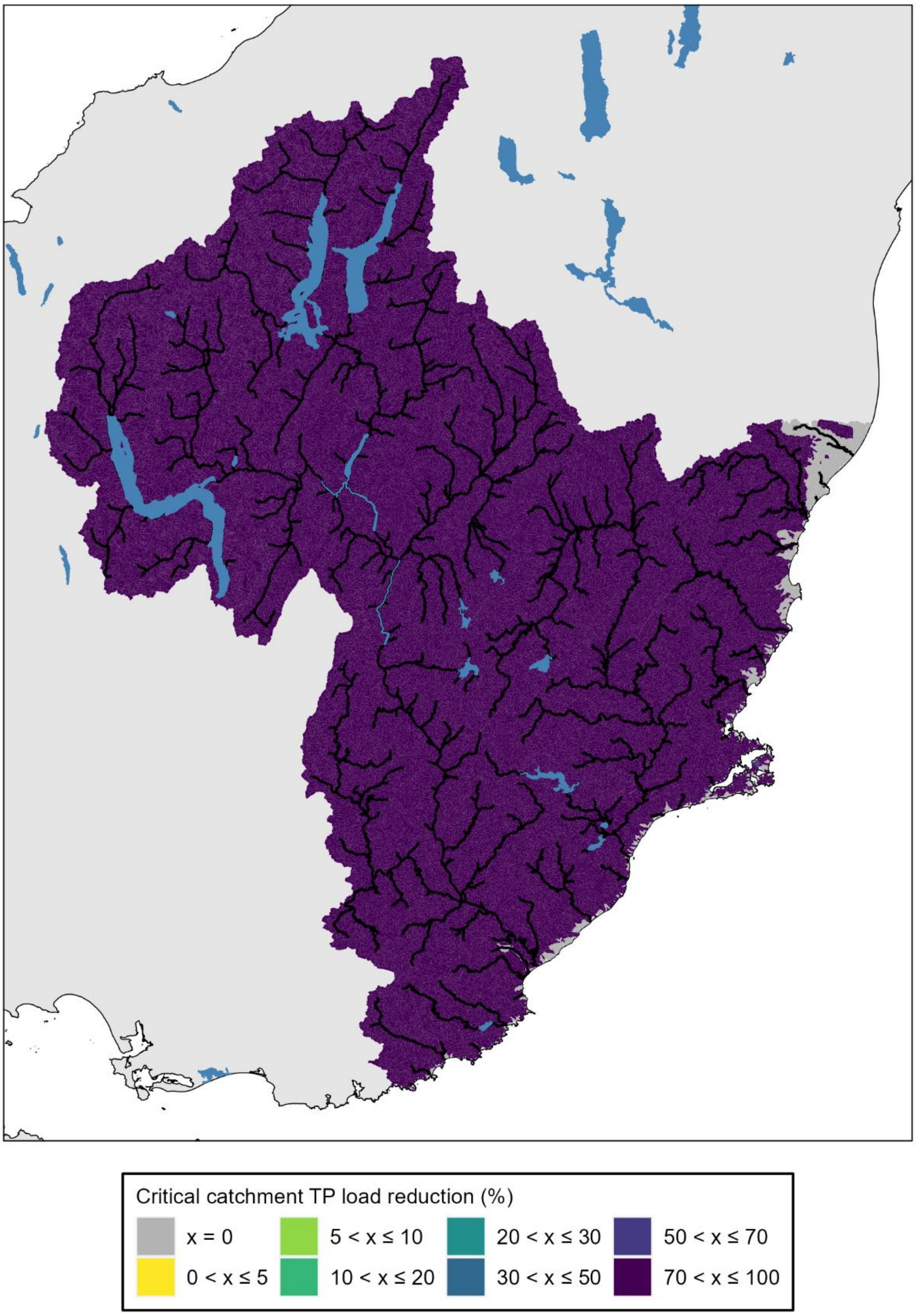

Figure 49. The TP load reduction required for the A band TAS option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment types that determine the load reduction requirements) for the A band are shown in Figure 39 and Figure 40 for TN and TP, respectively. For TN, 87% of the critical point catchment area were associated with rivers (Figure 50), 13% with estuaries and 0% with lakes. For TP, 99% of the critical point catchment area were associated with rivers, 0.4% with estuaries, and 0.4% with lakes (Figure 51).

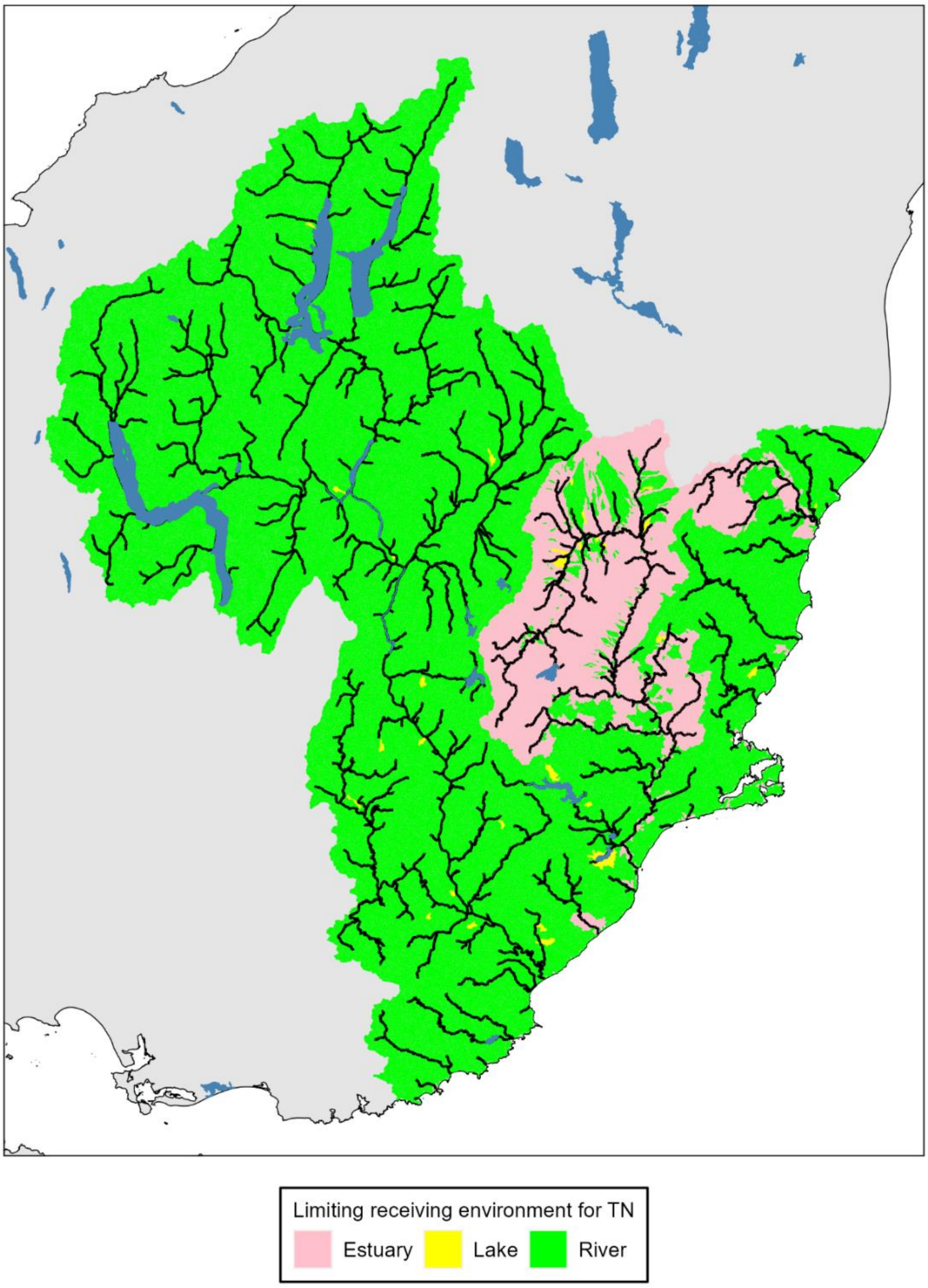

Figure 50. Limiting environment type for TN load reduction required for the A band TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TN load reductions).

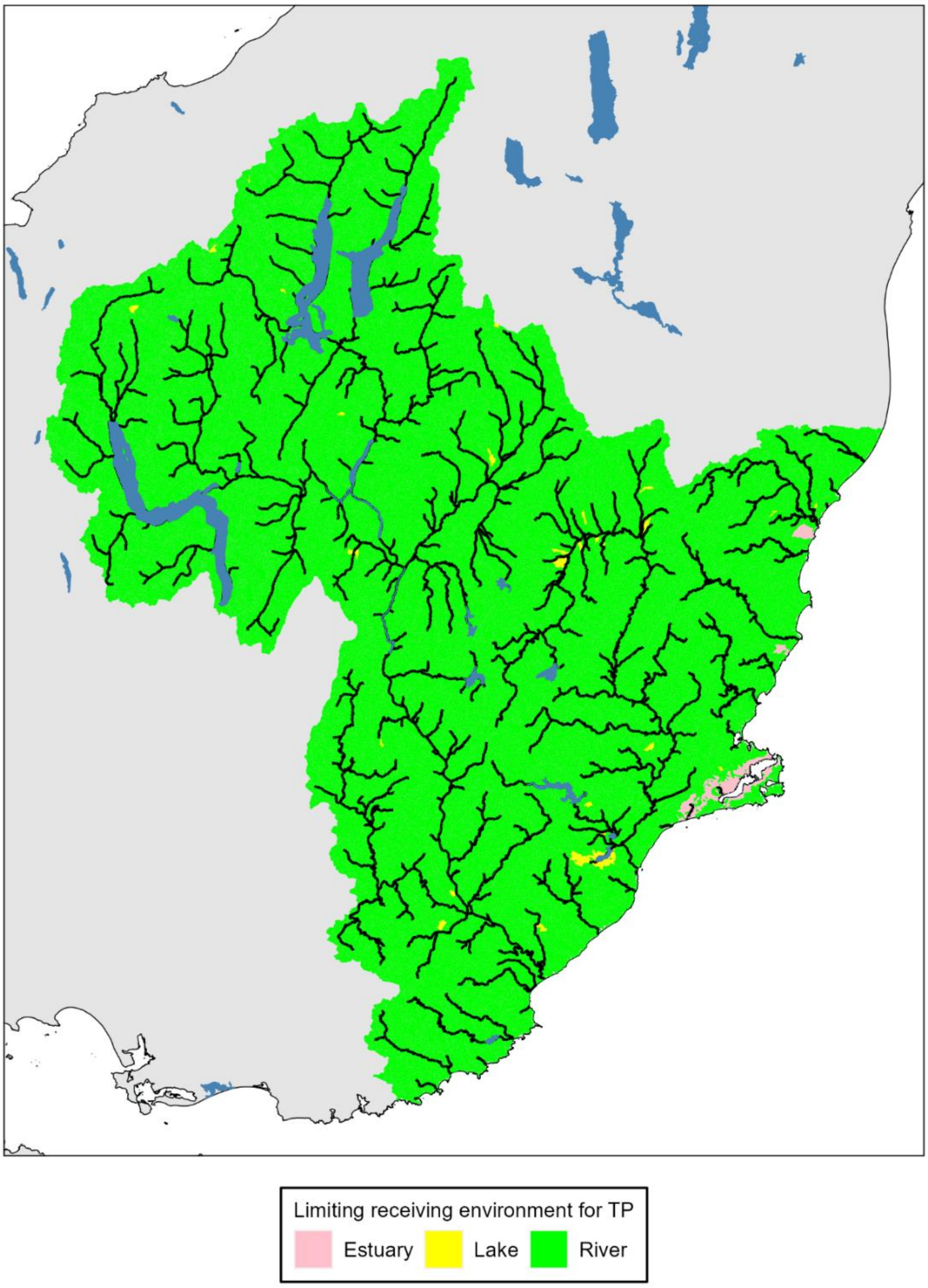

Figure 51. Limiting environment type for TP load reduction required for the A band TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TP load reductions).

3.8.4 FMU and regional load reductions required

For the whole study area, the TN and TP load reductions required to achieve the A band option were 10,281 t yr^{-1} and 1,421 t yr^{-1}, which represent 81% and 185% of the current loads respectively. The uncertainties for 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 20. These uncertainties indicate, for example, that the 90% confidence interval for the current regional load of TN extends between 5,284 t yr^{-1} and 18,945 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 63% and 92% (best estimate 81%) and the regional TP load reduction requirement extends between 143% and 223% (best estimate 185%). Load reductions of over 100% occurred for several FMUs and the region as a whole because model predictions of TP loads sometimes decreased toward the lower end of main stem rivers compared to predictions upstream. This means that the estimated upstream reductions can be larger than the predicted current load at the bottom of the catchment. This is not necessarily an error. Loads of TP are likely to be attenuated as they travel downstream from their source, particularly when there are large lakes in the drainage network that trap sediment and associated phosphorus, and this means loads reduce in the downstream direction.

For the A band option, the best estimates of both TN and TP load reductions required were high (>25%) for all FMUs.

Table 20. Current load and load reduction required for TN and TP by FMUs and for the A band TAS option 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).

FMU	**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 (%)**
Catlins FMU	620 (421 - 961)	613 (396 - 988)	98 (92 - 104)	47 (20 - 97)	45 (18 - 93)	96 (91 - 99)
Dunedin Coast FMU	528 (374 - 695)	458 (306 - 623)	86 (81 - 91)	31 (20 - 47)	29 (17 - 45)	92 (85 - 100)
Dunstan Rohe	3,461 (1,360 - 7,823)	2,164 (505 - 5,296)	59 (27 - 79)	636 (141 - 1,530)	2,243 (389 - 5,834)	342 (274 - 382)
Lower Clutha Rohe	8,833 (3,474 - 19,964)	6,849 (2,010 - 15,265)	75 (48 - 92)	1,136 (252 - 2,734)	2,503 (439 - 6,480)	214 (174 - 238)
Manuherekia Rohe	3,580 (1,407 - 8,092)	2,231 (518 - 5,359)	59 (27 - 79)	634 (141 - 1,526)	2,263 (393 - 5,884)	346 (277 - 387)
North Otago FMU	766 (546 - 1,007)	605 (389 - 892)	78 (66 - 89)	45 (26 - 73)	39 (17 - 76)	85 (61 - 107)
Roxburgh Rohe	4,897 (1,925 - 11,070)	3,050 (725 - 7,045)	59 (30 - 80)	755 (167 - 1,817)	2,364 (411 - 6,138)	304 (245 - 339)
Taieri FMU	1,656 (598 - 3,281)	1,517 (472 - 3,129)	89 (80 - 96)	149 (26 - 325)	163 (28 - 358)	108 (101 - 112)
Upper Lakes Rohe	1,025 (403 - 2,316)	664 (158 - 1,589)	62 (22 - 86)	742 (165 - 1,787)	793 (132 - 2,065)	103 (80 - 116)
Total	12,625 (6,621 - 22,843)	10,281 (5,284 - 18,945)	81 (63 - 92)	1,421 (480 - 3,374)	2,792 (626 - 7,011)	185 (143 - 223)

The load reductions required for the A band option for the 20 estuaries and to achieve all river and lake TAS in the catchment of each estuary are shown in Table 21. For four of the 20 estuaries (Orore Lagoon,Stony Creek Lagoon, Taieri Estuary and Tokomairiro Estuary), the TN load reductions required to achieve the TAS under the A band option are of greater magnitude for the estuary compared to the river and lake TAS in the upstream catchment. In contrast, TN load reductions required to achieve river and lake TAS are of greater magnitude than the associated estuaries for 18 of the estuaries. Three estuaries had zero TN load reductions required (Otago Harbour, Papanui Inlet and Hoopers Inlet).

TP load reductions required to achieve the TAS for five estuaries (Orore Lagoon, Stony Creek Lagoon, Otago Harbour, Tomahawk Lagoon and Kaikorai Estuary) were larger than that required to achieve the river and lake TAS in the upstream catchment (Table 21). The TP load reductions required for 14 estuaries are zero because it is considered unlikely that phytoplankton growth in these estuaries will drive severe secondary symptoms of eutrophication (like deoxygenation and light attenuation), and therefore no MAL has been defined for TP (see Appendix B, Table 31).

The load reductions required to achieve the TAS for rivers (only) are shown in Table 22. The reductions for the FMUs and for the region are generally lower than those shown in Table 20 because lakes and estuaries are excluded from the figures. Note that there are some exceptions to this due to the large uncertainties associated with the analysis.

Table 21. Load reductions required to achieve the TAS for estuaries and for all rivers and lakes in their upstream catchments for the A band option.

Estuary	**TN load reduction required (t yr^{-1})**		**TP load reduction required (t yr^{-1})**	
	Estuary	**Lakes and rivers**	**Estuary**	**Lakes and rivers**
Kakanui Estuary	200 (68 - 442)	256 (93 - 562)	14.1 (0.7 - 46.0)	19.9 (3.0 - 60.2)
Orore Lagoon	10 (3 - 23)	1 (0 - 5)	0.5 (0.1 - 1.3)	0.0 (0.0 - 0.0)
Shag River Estuary	87 (11 - 228)	110 (37 - 249)	0.0 (0.0 - 0.0)	6.2 (1.0 - 18.0)
Stony Creek Lagoon	4 (2 - 8)	1 (0 - 1)	0.1 (0.0 - 0.2)	0.0 (0.0 - 0.0)
Pleasant River Estuary	24 (6 - 55)	28 (10 - 58)	0.0 (0.0 - 0.0)	1.0 (0.0 - 3.0)
Waikouaiti Estuary	58 (11 - 157)	78 (24 - 206)	0.0 (0.0 - 0.0)	4.7 (1.0 - 12.0)
Blueskin Bay	31 (10 - 72)	38 (19 - 79)	0.0 (0.0 - 0.0)	2.4 (1.0 - 6.0)
Purakunui Inlet	2 (0 - 4)	3 (1 - 6)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Otago Harbour	0 (0 - 0)	37 (24 - 62)	2.3 (1.5 - 3.6)	1.9 (1.0 - 3.0)
Papanui Inlet	0 (0 - 1)	3 (2 - 5)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Hoopers Inlet	0 (0 - 1)	2 (1 - 3)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tomahawk Lagoon	2 (1 - 4)	1 (0 - 3)	0.1 (0.0 - 0.3)	0.0 (0.0 - 0.0)
Kaikorai Estuary	23 (10 - 42)	23 (10 - 41)	1.6 (0.4 - 3.4)	1.5 (0.0 - 3.0)
Taieri Estuary	1,503 (446 - 3,128)	1,414 (445 - 3,020)	0.0 (0.0 - 0.0)	162.7 (27.9 - 358.0)
Akatore Creek	28 (6 - 64)	29 (8 - 62)	0.0 (0.0 - 0.0)	1.7 (0.0 - 5.0)
Tokomairiro Estuary	199 (56 - 355)	196 (60 - 349)	0.0 (0.0 - 0.0)	12.7 (2.0 - 28.1)
Pounawea (Catlins) Estuary	241 (49 - 665)	318 (108 - 775)	0.0 (0.0 - 0.0)	19.5 (3.0 - 60.4)
Tahakopa Estuary	128 (23 - 296)	151 (42 - 329)	0.0 (0.0 - 0.0)	14.7 (2.0 - 49.0)
Tautuku Estuary	25 (6 - 61)	25 (5 - 58)	0.0 (0.0 - 0.0)	3.5 (1.0 - 10.1)
Waipati (Chaslands) Estuary	26 (4 - 61)	33 (10 - 76)	0.0 (0.0 - 0.0)	3.2 (1.0 - 8.0)

Table 22. Current load and load reduction required to achieve target attribute states for rivers for TN and TP by FMU and for the A band TAS option 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).

FMU	**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 (%)**
Catlins FMU	620 (421 - 961)	611 (392 - 986)	98 (91 - 103)	47 (20 - 97)	45 (18 - 93)	96 (91 - 99)
Dunedin Coast FMU	528 (374 - 695)	456 (310 - 616)	86 (82 - 90)	31 (20 - 47)	28 (16 - 45)	90 (82 - 98)
Dunstan Rohe	3,461 (1,360 - 7,823)	2,102 (505 - 4,967)	58 (24 - 79)	636 (141 - 1,530)	2,243 (389 - 5,834)	342 (274 - 382)
Lower Clutha Rohe	8,833 (3,474 - 19,964)	6,813 (2,010 - 15,265)	75 (46 - 92)	1,136 (252 - 2,734)	2,502 (439 - 6,479)	214 (174 - 238)
Manuherekia Rohe	3,580 (1,407 - 8,092)	2,171 (518 - 5,125)	58 (24 - 79)	634 (141 - 1,526)	2,262 (392 - 5,884)	346 (277 - 387)
North Otago FMU	766 (546 - 1,007)	591 (376 - 875)	76 (64 - 87)	45 (26 - 73)	39 (17 - 75)	83 (60 - 106)
Roxburgh Rohe	4,897 (1,925 - 11,070)	3,003 (725 - 7,028)	59 (28 - 80)	755 (167 - 1,817)	2,363 (411 - 6,137)	304 (244 - 339)
Taieri FMU	1,656 (598 - 3,281)	1,415 (448 - 3,022)	83 (66 - 93)	149 (26 - 325)	162 (27 - 356)	108 (100 - 111)
Upper Lakes Rohe	1,025 (403 - 2,316)	664 (158 - 1,589)	62 (22 - 86)	742 (165 - 1,787)	792 (131 - 2,064)	103 (79 - 116)
Total	12,625 (6,621 - 22,843)	10,125 (5,262 - 18,661)	80 (58 - 91)	1,421 (480 - 3,374)	2,789 (625 - 7,005)	185 (143 - 223)

3.9 Assessment of spatially variable target attribute states option

3.9.1 Compliance

For 6% and 5% of segments in the region, current river concentrations of TN and TP had a greater than 50% probability of exceeding the criteria associated with the spatially variable TAS option associated with periphyton targets respectively (Figure 52). Current river concentrations of NO3N had a greater than 50% probability of exceeding the A band associated with nitrate toxicity TAS for 0.1% of segments. The probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% for 0.04% of river segments (Figure 52).

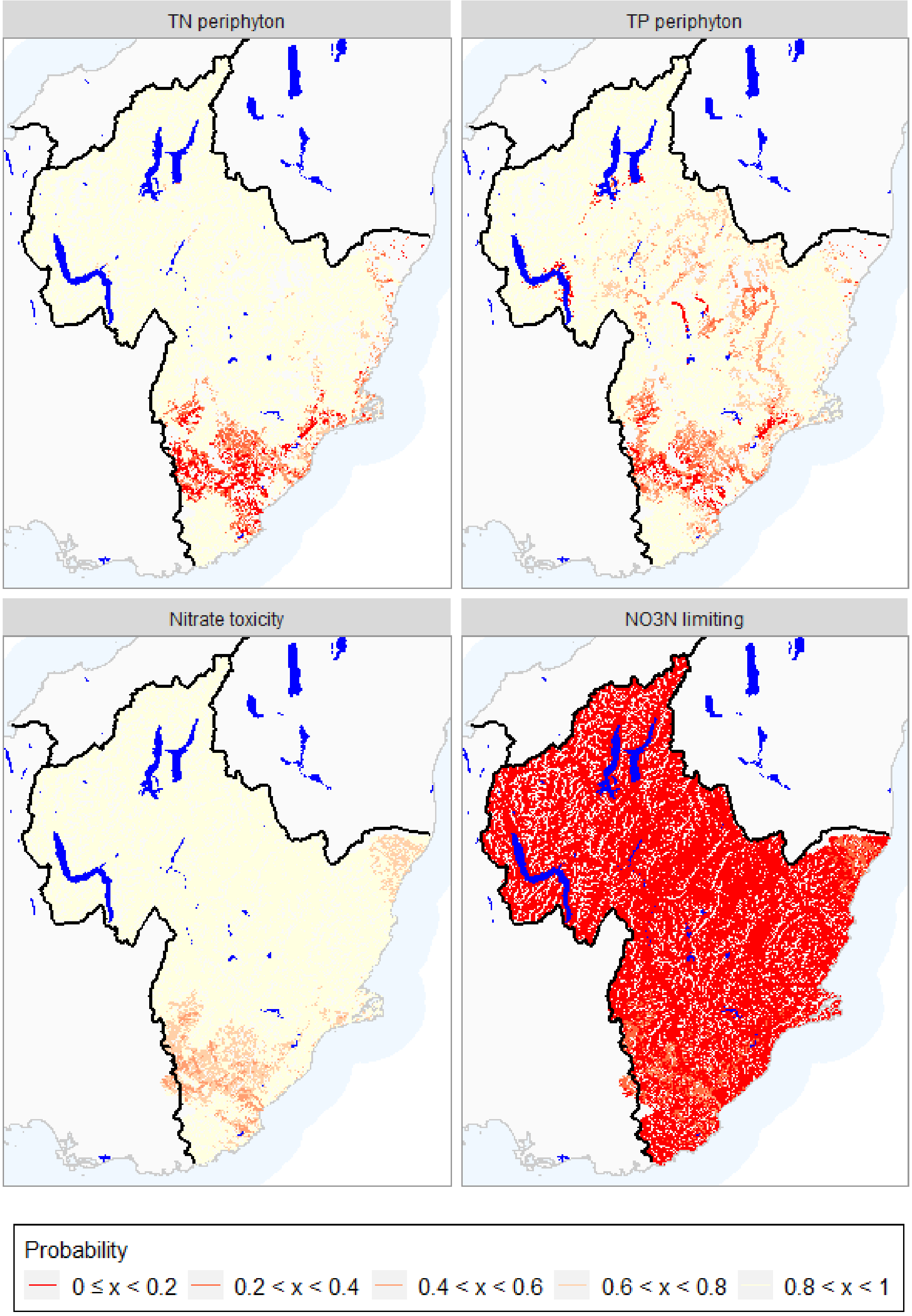

Figure 52. Probability that segments comply with river TN and TP concentration criteria associated with the periphyton targets (top left and right) and NO3N concentration criteria associated with the toxicity targets (lower left) for the spatially variable TAS option. The lower right-hand panel shows the probability that NO3N is the more limiting target than periphyton (in this scenario this was true for 0.04% of segments).

The probability that current TN and TP loads are compliant with the maximum allowable load associated with the spatially variable TAS for lake phytoplankton was less than 50% (i.e., were non-compliant) for 57 and 90 of the 124 assessed lakes in the region, respectively (Figure 53).

The probability that current TN and TP loads are compliant with the maximum allowable loads associated with the spatially variable TAS for estuary phytoplankton and macroalgae was less than 50% (i.e., were non-compliant) for 8 and 4 of the 20 assessed estuaries, respectively (Figure 54). Note that TAS for phytoplankton, and therefore a MAL for TP, was only relevant for six estuaries (see Appendix B, Table 31 for details).

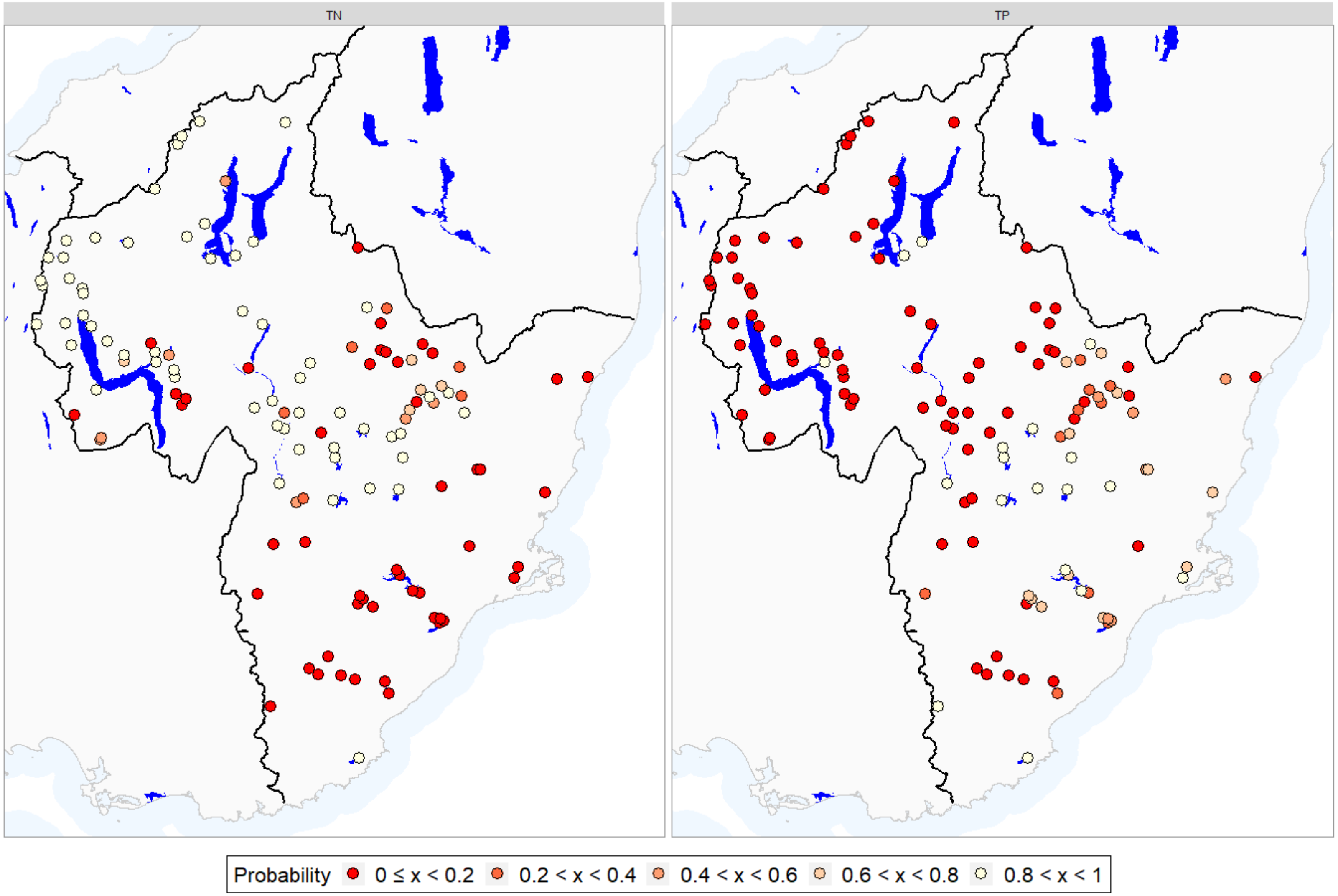

Figure 53. Probability that current lake TN and TP loads are compliant with the maximum allowable load associated with the spatially variable TAS option.

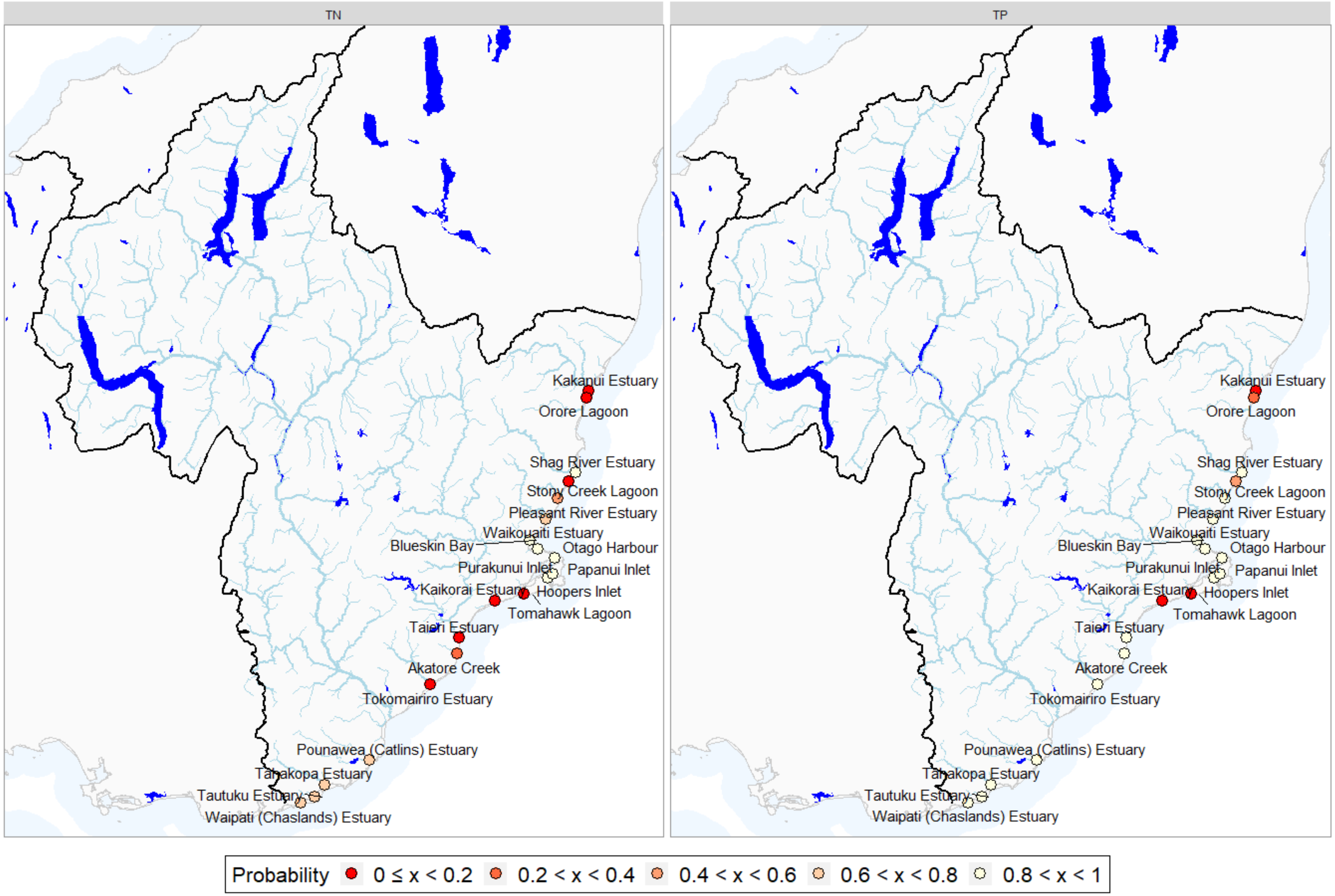

Figure 54. Probability that current estuary TN and TP loads are compliant with the maximum allowable load associated with the spatially variable TAS option.

3.9.2 Local excess loads

For the spatially variable TAS option, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 3% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 0.4% of river segments (Figure 55). Local excess TN loads were zero for 94% of segments. Local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 2% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 1% of river segments (Figure 56). Local excess TP loads were zero for 74% of segments.

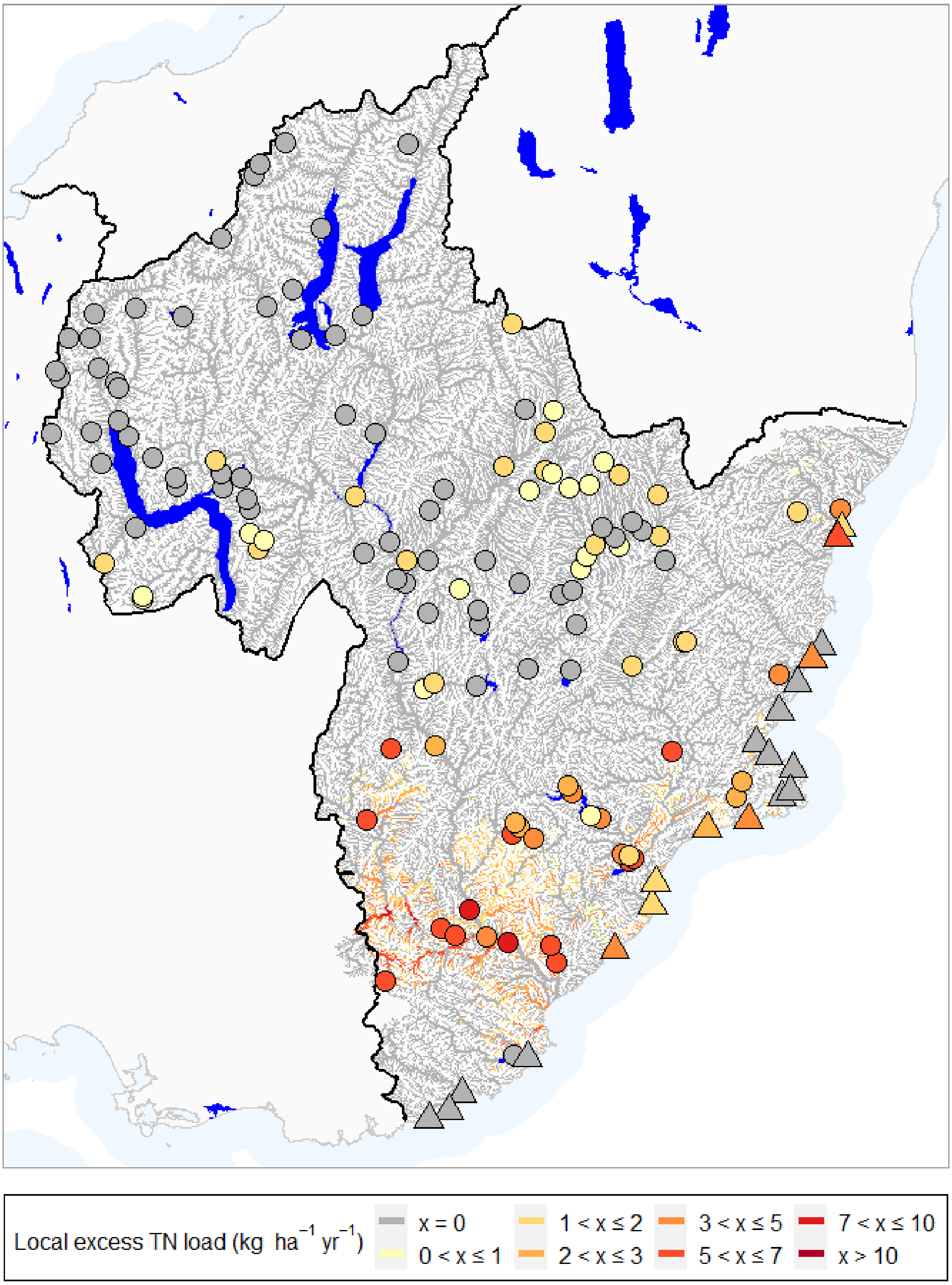

Figure 55. Local excess TN loads for rivers, lakes and estuaries for the spatially variable TAS option. The lakes and estuaries are indicated by round and triangular symbols, respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

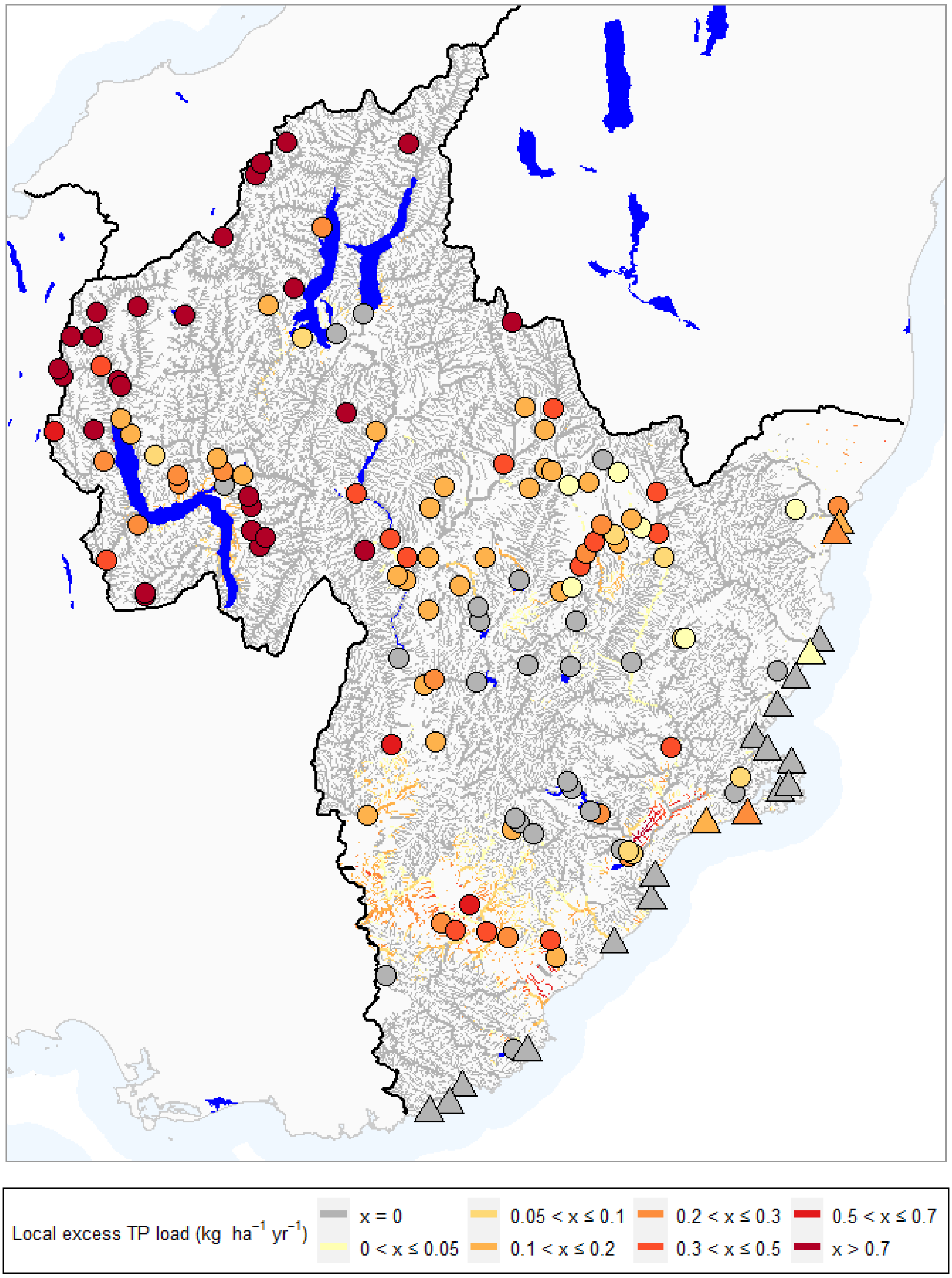

Figure 56. Local excess TP loads for rivers, lakes and estuaries for the spatially variable TAS option. The lakes and estuaries are indicated by round and triangular symbols respectively. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). Note that blank areas on this map indicate river segments with substrate size index values of <3, which we assumed do not support conspicuous periphyton and therefore for which there are no applicable phosphorus criteria.

3.9.3 Critical point catchments and catchment status

Critical point catchments that required TN load reductions of greater than 5 kg ha^{-1} yr^{-1} occupied 4% of the region and critical point catchments with TN load reductions of greater than 2 kg ha^{-1} yr^{-1} occupied 11% of the region (Figure *57*). When TN load reductions required were expressed as a proportion of current loads, critical point catchments that require reductions of greater than 50% occupied 29% of the region (Figure 58). 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 0.2 kg ha^{-1} yr^{-1} occupied 44% of the region and critical point catchments with TP load reductions of greater than 0.1 kg ha^{-1} yr^{-1} occupied 60% of the region (Figure 59). When TP load reductions required were expressed as a proportion of current loads, critical point catchments with reduction requirements of greater than 50% occupied 48% of the region (Figure 60). 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.

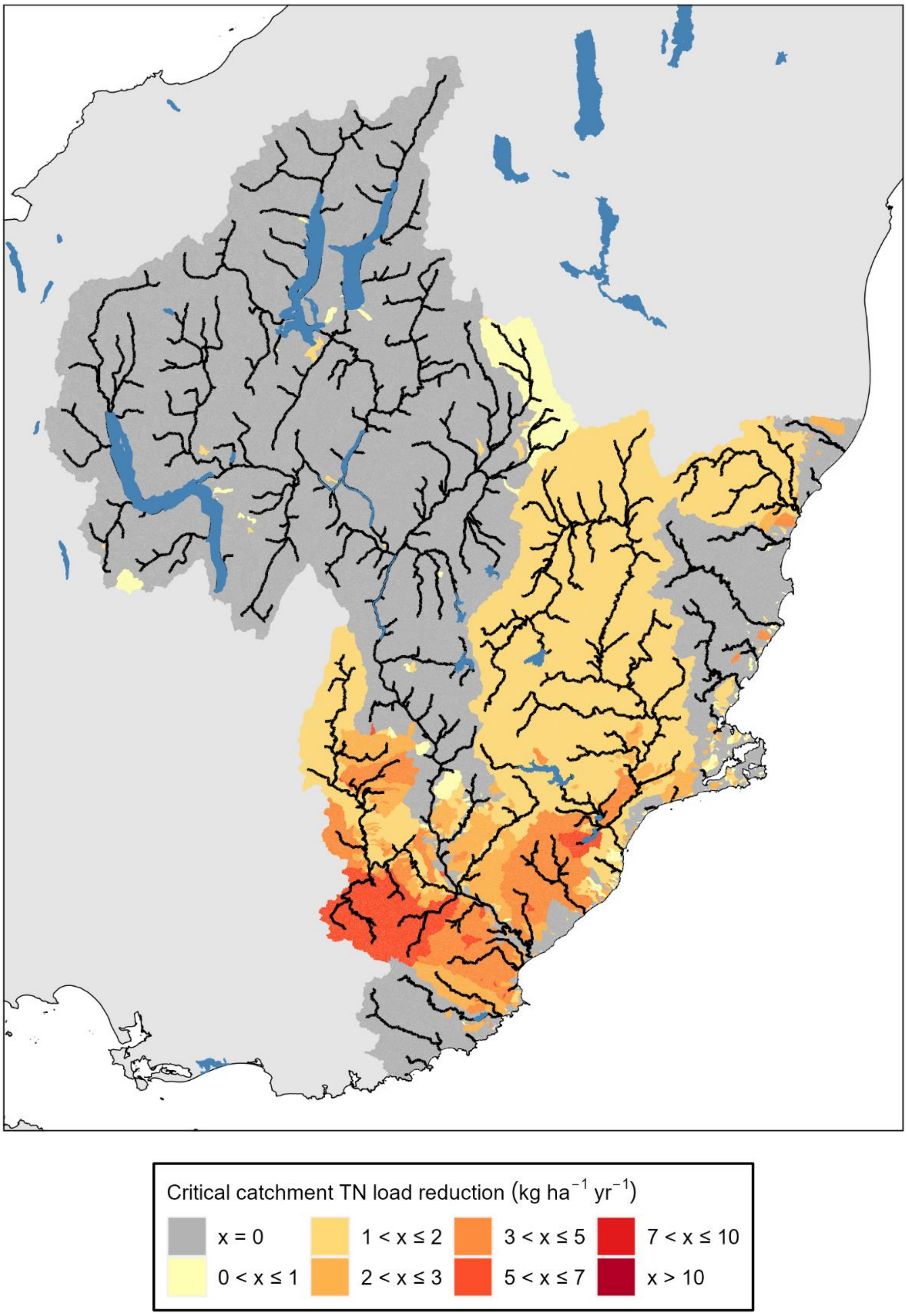

Figure 57*. The TN load reduction required for the spatially variable TAS option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).*

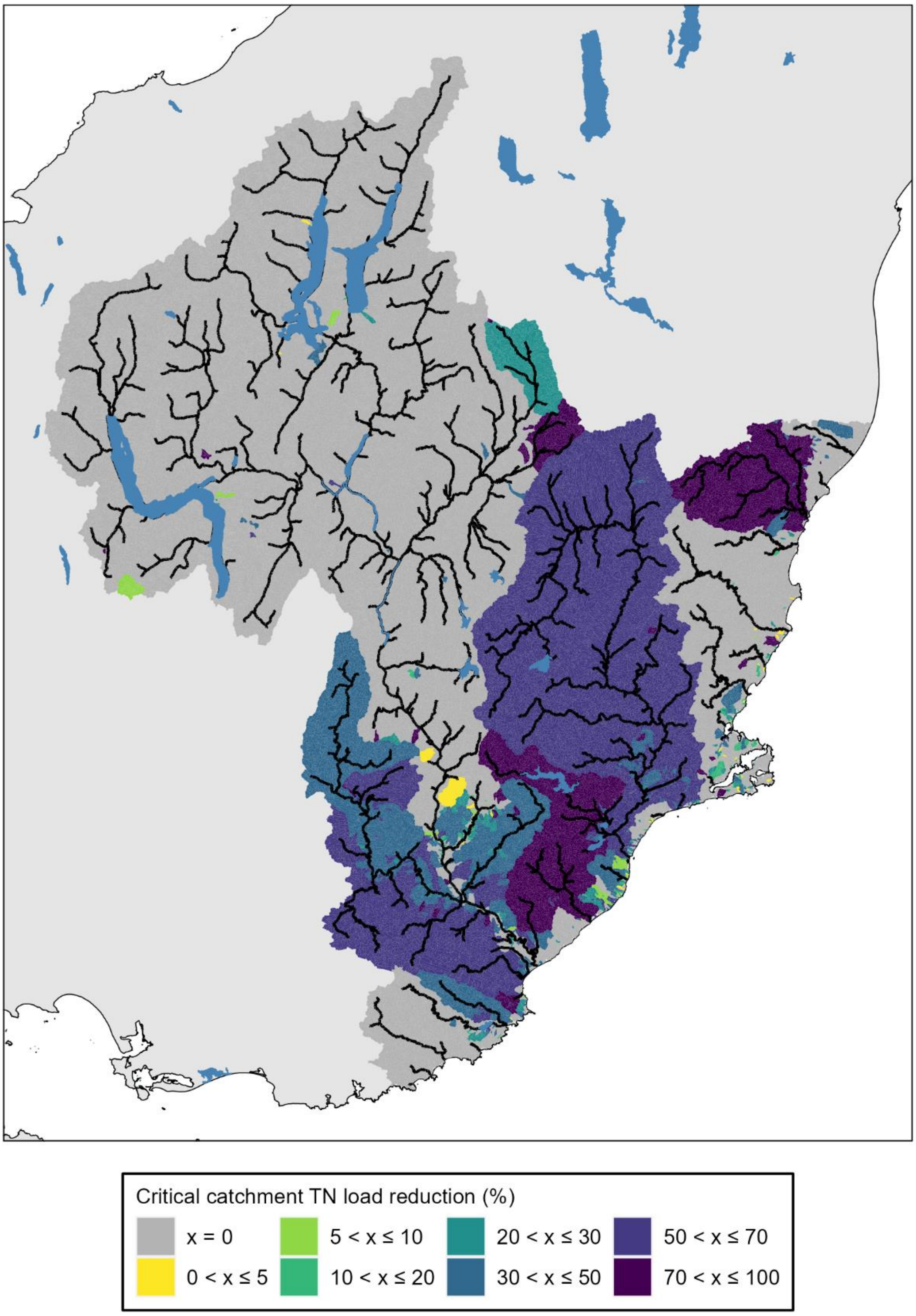

Figure 58. The TN load reduction required for the spatially variable TAS option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TN load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

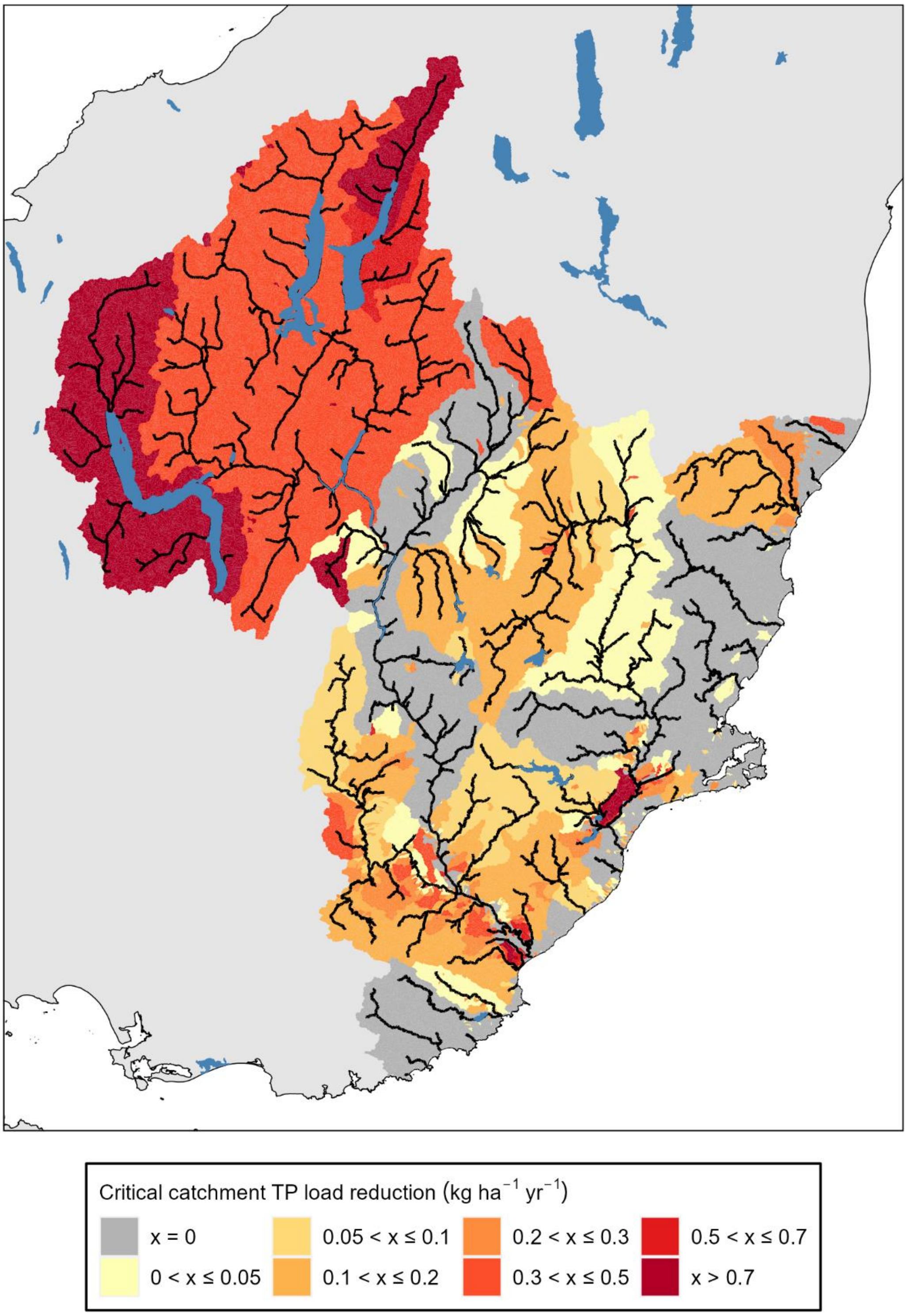

Figure 59. The TP load reduction required for the spatially variable TAS option for critical point catchments, expressed as yields. The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

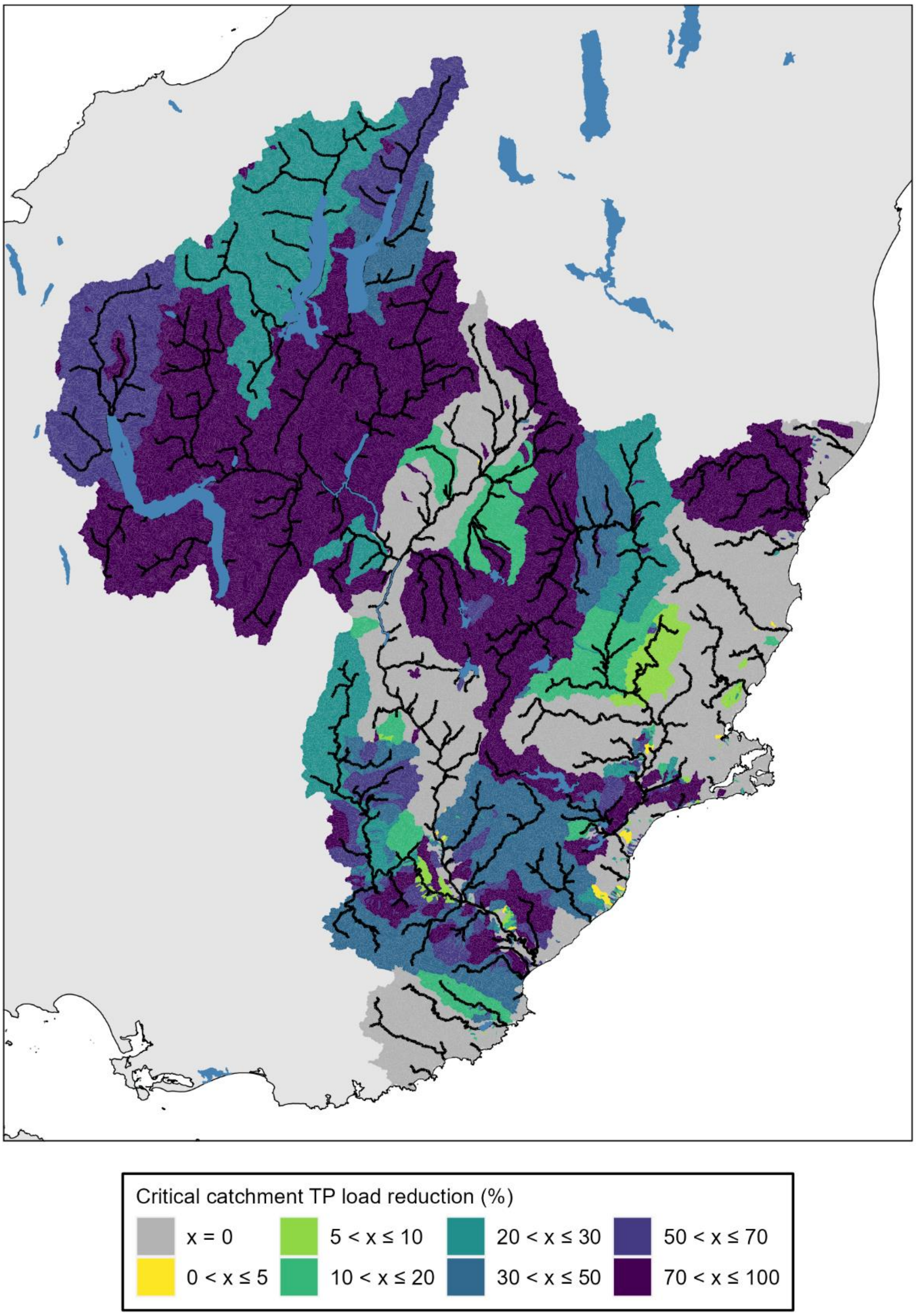

Figure 60. The TP load reduction required for the spatially variable TAS option for critical point catchments, expressed as proportion of the current load (%). The critical point catchment colours indicate the best estimate of the TP load reductions required to allow all TAS to be achieved in the critical point catchment (including the critical point at the bottom of the catchment).

The limiting receiving environments (i.e., the receiving environment types that determine the load reduction requirements) for the spatially variable TAS option are shown in Figure 61 and Figure 62 for TN and TP respectively. For TN, 77% of the critical point catchment area were associated with rivers, 20% were for estuaries, and 3% were for lakes (Figure 61). For TP, 76% of the critical point catchment area were associated with rivers, 2% with estuaries, and 21% with lakes (Figure 62).

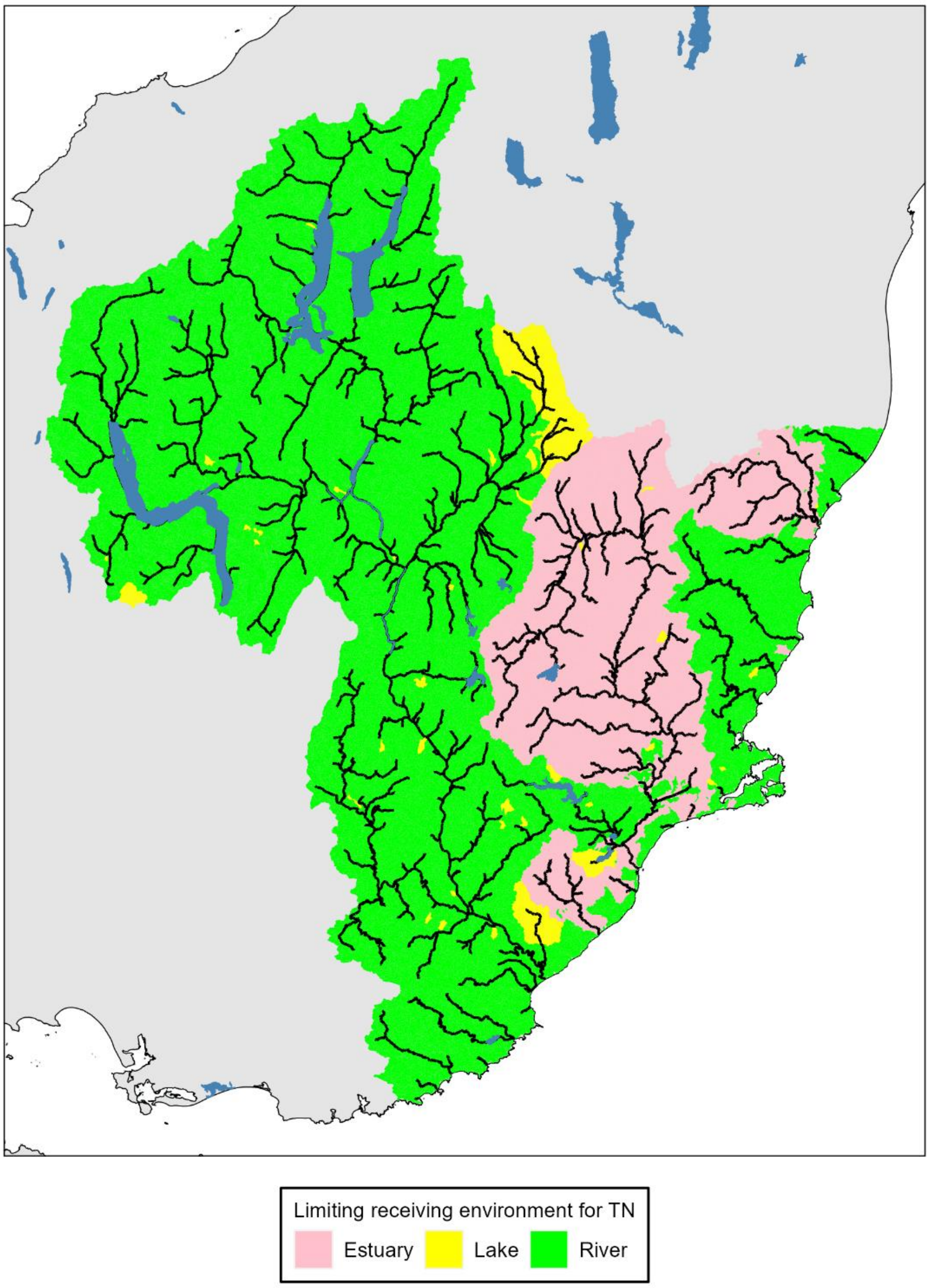

Figure 61. Limiting environment type for TN load reduction required for the spatially variable TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TN load reductions).

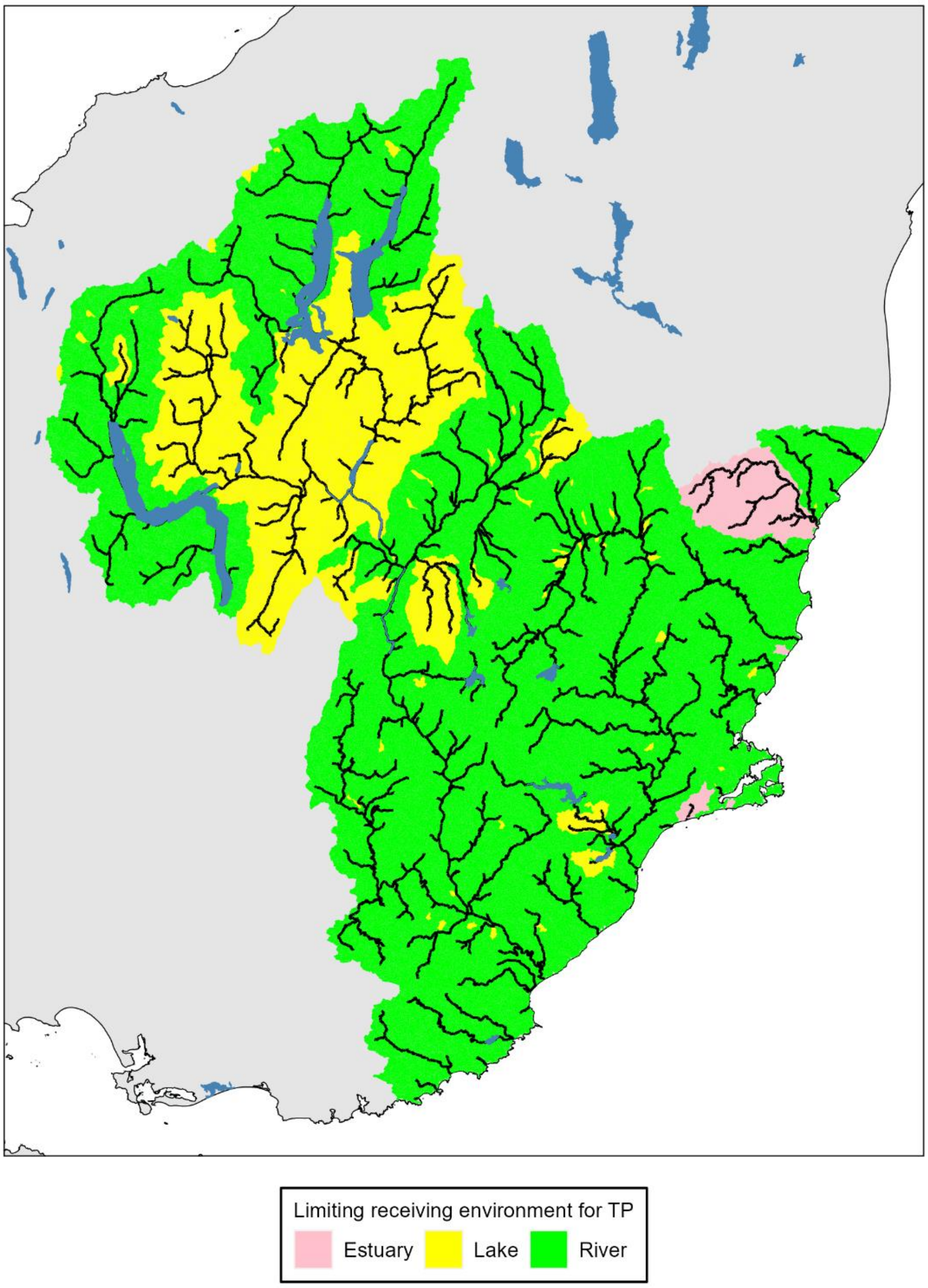

Figure 62. Limiting environment type for TP load reduction required for the spatially variable TAS option. The critical point catchment colours indicate the environment type with the most stringent TAS (i.e., most demanding of TP load reductions).

3.9.4 FMU and regional load reductions required

For the whole study area, the TN and TP load reductions required were estimated to be 2,754 t yr^{-1} and 844 t yr^{-1}, which represent 25% and 57% of the current loads, respectively (Table 23). The uncertainties for 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 23. These uncertainties indicate, for example, that the 90% confidence interval for the current regional load of TN extends between 1,074 t yr^{-1} and 5,042 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 14% and 35% (best estimate 25%) and the regional TP load reduction requirement extends between 22% and 102% (best estimate 57%).

For the spatially variable TAS option, the best estimates of TN load reductions required were high (>20%) in the Catlins, Dunedin Coast, North Otago and Taieri FMUs. The TP load reductions required were high (≥20%) in all FMUs except the Catlins FMU.

Table 23. Current load and load reduction required for TN and TP by FMUs and for the spatially variable TAS option 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).

FMU	**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 (%)**
Catlins FMU	581 (366 - 942)	159 (18 - 438)	24 (5 - 49)	43 (19 - 87)	4 (0 - 16)	7 (0 - 39)
Dunedin Coast FMU	526 (375 - 711)	243 (100 - 433)	44 (27 - 61)	30 (19 - 50)	7 (2 - 16)	23 (8 - 44)
Dunstan Rohe	2,874 (1,118 - 5,257)	19 (0 - 62)	1 (0 - 1)	568 (129 - 1,322)	708 (67 - 1,797)	112 (45 - 182)
Lower Clutha Rohe	7,335 (2,856 - 13,414)	1,197 (72 - 3,060)	15 (3 - 24)	1,016 (230 - 2,363)	799 (74 - 2,037)	71 (27 - 115)
Manuherekia Rohe	2,972 (1,156 - 5,437)	19 (0 - 65)	0 (0 - 1)	567 (128 - 1,319)	720 (70 - 1,821)	114 (46 - 185)
North Otago FMU	766 (570 - 981)	226 (52 - 445)	28 (9 - 49)	41 (24 - 63)	12 (3 - 33)	26 (9 - 56)
Roxburgh Rohe	4,066 (1,582 - 7,438)	65 (6 - 220)	1 (0 - 3)	675 (153 - 1,570)	751 (73 - 1,905)	100 (40 - 162)
Taieri FMU	1,488 (650 - 3,330)	810 (75 - 2,631)	43 (11 - 79)	148 (22 - 388)	52 (3 - 173)	27 (7 - 64)
Upper Lakes Rohe	851 (331 - 1,556)	9 (0 - 18)	1 (0 - 1)	664 (150 - 1,544)	407 (17 - 1,108)	56 (4 - 82)

The load reductions required for the spatially variable TAS option for the 20 estuaries and to achieve all river and lake targets in the catchment of each estuary are shown in Table 24. For 12 of the 20 estuaries, the TN load reductions required to achieve the spatially variable TAS option are of greater magnitude for the estuary compared to the river and lake targets in the upstream catchment. In contrast, TN load reductions required to achieve river and lake targets are of greater magnitude than the associated estuaries for the following six estuaries: Shag River Estuary, Pleasant River Estuary, Blueskin Bay, Purakunui Inlet, Otago Harbour, and Pounawea (Catlins) Estuary. Several estuaries have zero TN load reductions required indicating that they achieve the spatially variable TAS or better for TN (see Figure 17).

TP load reductions required to achieve the TAS for five estuaries (Kakanui Estuary, Orore Lagoon, Stony Creek Lagoon, Tomahawk Lagoon and Kaikorai Estuary) were larger than that required to achieve the river and lake targets in the upstream catchment (Table 24). The TP load reductions required for 15 estuaries are zero because it is considered unlikely that phytoplankton growth in these estuaries will drive severe secondary symptoms of eutrophication (like deoxygenation and light attenuation), and therefore no MAL has been defined for TP (see Appendix B, Table 31).

The load reductions required to achieve the TAS for rivers (only) are shown in Table 25. The reductions for the FMUs and for the region are generally lower than those shown in Table 23 because lakes and estuaries are excluded from the figures. Note that there are some exceptions to this due to the large uncertainties associated with the analysis.

Table 24. Load reductions required to achieve the TAS for estuaries and for all rivers and lakes in their upstream catchments for the spatially variable TAS option.

Estuary	**TN load reduction required (t yr^{-1})**		**TP load reduction required (t yr^{-1})**	
	Estuary	**Lakes and rivers**	**Estuary**	**Lakes and rivers**
Kakanui Estuary	150 (8 - 385)	48 (0 - 196)	9.3 (0.0 - 31.5)	6.2 (1.0 - 20.0)
Orore Lagoon	10 (1 - 25)	1 (0 - 7)	0.5 (0.0 - 1.6)	0.0 (0.0 - 0.0)
Shag River Estuary	3 (0 - 4)	8 (0 - 42)	0.0 (0.0 - 0.0)	0.3 (0.0 - 2.0)
Stony Creek Lagoon	4 (0 - 9)	0 (0 - 1)	0.1 (0.0 - 0.3)	0.0 (0.0 - 0.0)
Pleasant River Estuary	6 (0 - 31)	8 (1 - 37)	0.0 (0.0 - 0.0)	0.1 (0.0 - 1.0)
Waikouaiti Estuary	7 (0 - 48)	6 (0 - 21)	0.0 (0.0 - 0.0)	0.2 (0.0 - 1.0)
Blueskin Bay	0 (0 - 0)	5 (1 - 15)	0.0 (0.0 - 0.0)	0.2 (0.0 - 1.0)
Purakunui Inlet	0 (0 - 0)	1 (0 - 3)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Otago Harbour	0 (0 - 0)	8 (3 - 18)	0.0 (0.0 - 0.0)	0.1 (0.0 - 0.0)
Papanui Inlet	0 (0 - 0)	0 (0 - 1)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Hoopers Inlet	0 (0 - 0)	0 (0 - 1)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tomahawk Lagoon	2 (1 - 4)	0 (0 - 2)	0.1 (0.0 - 0.4)	0.0 (0.0 - 0.0)
Kaikorai Estuary	12 (0 - 30)	6 (0 - 18)	0.9 (0.1 - 2.4)	0.3 (0.0 - 1.0)
Taieri Estuary	798 (0 - 2,630)	249 (74 - 639)	0.0 (0.0 - 0.0)	52.1 (3.0 - 172.5)
Akatore Creek	12 (0 - 45)	4 (0 - 21)	0.0 (0.0 - 0.0)	0.2 (0.0 - 1.0)
Tokomairiro Estuary	174 (36 - 377)	57 (1 - 165)	0.0 (0.0 - 0.0)	4.4 (0.0 - 14.2)
Pounawea (Catlins) Estuary	29 (0 - 223)	97 (0 - 297)	0.0 (0.0 - 0.0)	3.5 (0.0 - 16.2)
Tahakopa Estuary	28 (0 - 145)	1 (0 - 3)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Tautuku Estuary	4 (0 - 20)	0 (0 - 0)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)
Waipati (Chaslands) Estuary	4 (0 - 25)	0 (0 - 1)	0.0 (0.0 - 0.0)	0.0 (0.0 - 0.0)

Table 25. Current load and load reduction required to achieve target attribute states for rivers for TN and TP by FMU and for the spatially variable TAS option 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).

FMU	**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 (%)**
Catlins FMU	581 (366 - 942)	120 (12 - 315)	19 (3 - 42)	43 (19 - 87)	4 (0 - 16)	7 (0 - 39)
Dunedin Coast FMU	526 (375 - 711)	110 (43 - 229)	20 (9 - 36)	30 (19 - 50)	7 (1 - 16)	20 (5 - 43)
Dunstan Rohe	2,874 (1,118 - 5,257)	15 (0 - 51)	0 (0 - 1)	568 (129 - 1,322)	658 (0 - 1,782)	103 (0 - 180)
Lower Clutha Rohe	7,335 (2,856 - 13,414)	1,106 (35 - 2,933)	14 (2 - 24)	1,016 (230 - 2,363)	723 (1 - 1,985)	63 (0 - 113)
Manuherekia Rohe	2,972 (1,156 - 5,437)	15 (0 - 53)	0 (0 - 1)	567 (128 - 1,319)	660 (0 - 1,790)	104 (0 - 182)
North Otago FMU	766 (570 - 981)	102 (20 - 265)	12 (3 - 31)	41 (24 - 63)	8 (2 - 22)	18 (7 - 38)
Roxburgh Rohe	4,066 (1,582 - 7,438)	25 (0 - 112)	0 (0 - 2)	675 (153 - 1,570)	675 (1 - 1,847)	89 (0 - 158)
Taieri FMU	1,488 (650 - 3,330)	140 (1 - 557)	8 (0 - 27)	148 (22 - 388)	48 (3 - 160)	26 (7 - 64)
Upper Lakes Rohe	851 (331 - 1,556)	8 (0 - 14)	1 (0 - 1)	664 (150 - 1,544)	406 (0 - 1,108)	56 (0 - 82)
Total	10,904 (5,680 - 16,984)	1,697 (555 - 3,637)	15 (8 - 22)	1,290 (478 - 2,643)	796 (33 - 2,119)	55 (7 - 101)

3.10 Comparison between scenarios

In this study, the best estimate of the load reductions required for the C band option consistently had lower TN and TP load reductions required compared to the B band, which again had lower reduction requirements than the A band (the round symbols are respectively below each option in Figure 63 and best estimates for C, B and A bands always increased Table 26 and Table *27*). This is because the C, B and A band criteria represent increasing levels of environmental quality and therefore increasingly stringent criteria, respectively. The load reductions required for the spatially variable TAS option were generally similar to the C band. Where there were differences in the load reductions required between the C band and the spatially variable TAS options, these are attributable to the FMUs and management classes shown in Table 9 for which the choice of target differs from the C band. While there were consistent patterns in the best estimates, the uncertainty of the estimates often resulted in overlapping of the 90% confidence intervals (Figure 63). The overlapping error bars indicates that the uncertainty associated with the load reduction estimates means that, from a practical perspective, they are equivalent. The differences in load reductions required for the estuary catchments were also often small with strongly overlapping confidence intervals (Table 26 and Table *27*), which also indicates our estimates of load reductions are practically equivalent.

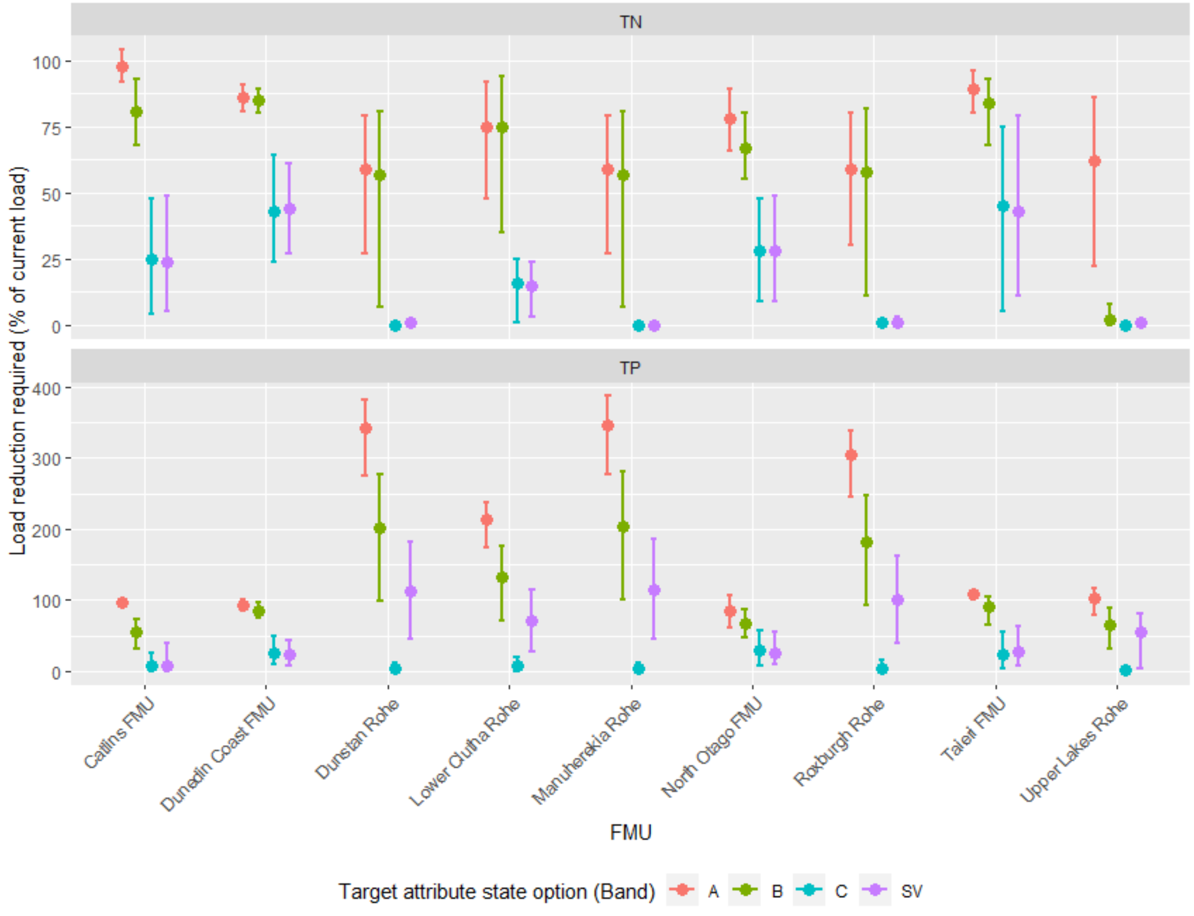

Figure 63. Comparison of the best estimates of TN and TP load reductions required for the FMUs for the A, B and C band and spatially variable TAS options. The round symbols represent the best estimate of the load reductions required error bars indicate the 90% confidence intervals for the estimated load reductions.

Table 26. Comparison of the TN load reductions required for the A, B and C band and spatially variable TAS options 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 5^th^ and 95^th^ confidence limits (i.e., the range is the 90% confidence interval).

Estuary	**Estuary**				**Rivers and lakes**			
	C	**B**	**A**	**Spatially variable**	**C**	**B**	**A**	**Spatially variable**
Kakanui Estuary	55 (1 - 84)	73 (46 - 90)	89 (78 - 96)	54 (9 - 82)	0 (0 - 40)	92 (74 - 107)	116 (106 - 123)	0 (0 - 59)
Orore Lagoon	75 (49 - 90)	89 (79 - 95)	96 (90 - 98)	74 (40 - 93)	0 (0 - 0)	0 (0 - 0)	0 (0 - 38)	0 (0 - 41)
Shag River Estuary	1 (0 - 5)	8 (0 - 41)	62 (24 - 86)	1 (0 - 2)	0 (0 - 40)	88 (77 - 96)	88 (76 - 96)	0 (0 - 37)
Stony Creek Lagoon	71 (47 - 88)	88 (75 - 96)	95 (91 - 98)	70 (32 - 90)	0 (0 - 9)	13 (12 - 14)	14 (12 - 14)	0 (0 - 8)
Pleasant River Estuary	12 (0 - 53)	29 (0 - 70)	73 (48 - 90)	10 (0 - 48)	2 (0 - 55)	92 (81 - 99)	92 (81 - 98)	18 (7 - 65)
Waikouaiti Estuary	8 (0 - 44)	26 (0 - 66)	71 (41 - 91)	5 (0 - 35)	0 (0 - 23)	85 (71 - 98)	101 (79 - 117)	0 (0 - 24)
Blueskin Bay	0 (0 - 0)	5 (0 - 29)	66 (45 - 85)	0 (0 - 0)	0 (0 - 6)	54 (19 - 78)	77 (63 - 88)	0 (0 - 19)
Purakunui Inlet	0 (0 - 0)	1 (0 - 0)	46 (13 - 71)	0 (0 - 0)	0 (0 - 0)	0 (0 - 45)	21 (0 - 71)	0 (0 - 8)
Otago Harbour	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 48)	51 (25 - 73)	0 (0 - 0)
Papanui Inlet	0 (0 - 0)	0 (0 - 0)	2 (0 - 15)	0 (0 - 0)	0 (0 - 0)	14 (0 - 62)	47 (0 - 72)	0 (0 - 0)
Hoopers Inlet	0 (0 - 0)	0 (0 - 0)	2 (0 - 11)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Tomahawk Lagoon	92 (84 - 98)	97 (95 - 99)	99 (98 - 100)	93 (85 - 97)	0 (0 - 54)	72 (67 - 76)	72 (65 - 76)	0 (0 - 53)
Kaikorai Estuary	47 (0 - 77)	63 (33 - 85)	90 (81 - 95)	41 (0 - 73)	0 (0 - 41)	35 (0 - 78)	73 (46 - 91)	0 (0 - 46)
Taieri Estuary	45 (0 - 75)	66 (28 - 88)	88 (75 - 95)	41 (0 - 79)	12 (5 - 29)	83 (64 - 93)	83 (66 - 93)	15 (11 - 29)
Akatore Creek	30 (0 - 71)	51 (4 - 83)	84 (62 - 95)	25 (0 - 70)	2 (0 - 42)	92 (80 - 100)	91 (75 - 98)	0 (0 - 45)
Tokomairiro Estuary	72 (37 - 90)	84 (71 - 94)	94 (86 - 97)	72 (44 - 89)	19 (0 - 67)	93 (85 - 98)	93 (85 - 98)	17 (0 - 62)
Pounawea (Catlins) Estuary	5 (0 - 30)	20 (0 - 65)	72 (44 - 92)	5 (0 - 39)	18 (0 - 71)	101 (92 - 107)	103 (94 - 109)	16 (0 - 73)
Tahakopa Estuary	8 (0 - 46)	29 (0 - 63)	73 (41 - 90)	10 (0 - 47)	0 (0 - 0)	49 (3 - 83)	91 (65 - 102)	0 (0 - 2)
Tautuku Estuary	7 (0 - 41)	27 (0 - 67)	70 (42 - 89)	6 (0 - 33)	0 (0 - 0)	1 (0 - 62)	70 (40 - 92)	0 (0 - 0)
Waipati (Chaslands) Estuary	8 (0 - 37)	22 (0 - 63)	68 (33 - 88)	7 (0 - 37)	0 (0 - 0)	49 (7 - 93)	95 (75 - 109)	0 (0 - 2)

Table 27. Comparison of the TP load reductions required for the A, B and C band and spatially variable TAS options for individual estuaries and for the rivers and lakes within the catchment of each estuary. 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).

Estuary	**Estuary**				**Rivers and lakes**			
	C	**B**	**A**	**Spatially variable**	**C**	**B**	**A**	**Spatially variable**
Kakanui Estuary	59 (0 - 90)	67 (0 - 93)	74 (26 - 96)	53 (0 - 89)	42 (17 - 71)	101 (74 - 119)	121 (114 - 127)	44 (21 - 65)
Orore Lagoon	42 (0 - 86)	68 (8 - 92)	86 (57 - 97)	40 (0 - 86)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Shag River Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 15)	104 (60 - 142)	157 (124 - 170)	0 (0 - 17)
Stony Creek Lagoon	13 (0 - 63)	41 (0 - 87)	67 (9 - 91)	14 (0 - 70)	0 (0 - 6)	14 (11 - 16)	16 (15 - 16)	0 (0 - 7)
Pleasant River Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 47)	86 (74 - 95)	95 (90 - 99)	0 (0 - 45)
Waikouaiti Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 19)	74 (50 - 92)	91 (79 - 96)	0 (0 - 13)
Blueskin Bay	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 30)	83 (65 - 97)	98 (89 - 111)	0 (0 - 19)
Purakunui Inlet	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 11)	70 (52 - 86)	84 (68 - 94)	0 (0 - 0)
Otago Harbour	0 (0 - 0)	100 (100 - 100)	100 (100 - 100)	0 (0 - 0)	0 (0 - 0)	70 (56 - 81)	83 (70 - 98)	0 (0 - 0)
Papanui Inlet	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	52 (37 - 66)	60 (44 - 76)	0 (0 - 0)
Hoopers Inlet	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	37 (19 - 58)	46 (20 - 67)	0 (0 - 0)
Tomahawk Lagoon	77 (37 - 95)	90 (75 - 98)	95 (89 - 99)	76 (23 - 96)	0 (0 - 27)	58 (43 - 64)	65 (61 - 67)	0 (0 - 37)
Kaikorai Estuary	71 (41 - 91)	79 (54 - 95)	100 (100 - 100)	63 (27 - 87)	21 (0 - 68)	76 (51 - 92)	82 (60 - 96)	9 (0 - 59)
Taieri Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	23 (3 - 56)	91 (65 - 104)	108 (101 - 112)	27 (7 - 64)
Akatore Creek	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 34)	82 (56 - 95)	94 (87 - 99)	0 (0 - 42)
Tokomairiro Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	32 (0 - 73)	100 (82 - 108)	107 (104 - 109)	18 (0 - 73)
Pounawea (Catlins) Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 47)	76 (60 - 88)	95 (90 - 99)	0 (0 - 53)
Tahakopa Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	14 (0 - 76)	95 (88 - 100)	0 (0 - 0)
Tautuku Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	2 (0 - 67)	90 (79 - 95)	0 (0 - 0)
Waipati (Chaslands) Estuary	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	12 (0 - 83)	107 (97 - 113)	0 (0 - 0)

4 Summary and discussion

4.1 Load reductions required

This study assessed nutrient (nitrogen and phosphorus) load reductions needed to achieve options for TAS for all river, lake and estuary receiving environments in the Otago region. Four sets of TAS options were evaluated - the spatially uniform A, B, C band options, and a spatially variable option. These TAS options have no statutory weight and should be regarded as examples that are devised to show the range of potential nutrient load reduction requirements to achieve increasing levels of environmental protection. Reductions have been assessed to bring both nitrogen and phosphorus to the levels indicated by the various criteria and no assumptions have been made regarding whether there is a limiting nutrient in any receiving environment.

The C band TAS option is the national bottom line attribute state (rivers and lakes) or nominated equivalent state for estuaries for all receiving environments. The results for the C band option therefore indicate the lowest load reduction requirements that are necessary under the NPS-FM.

The results for the individual receiving environments are aggregated to report at the level of FMUs, the catchments of 20 individual estuaries, and the whole region. Across the region's rivers, 15% and 8% reductions in TN and TP are required, respectively, to achieve the national bottom line – i.e., the C band TAS. An 89% and 100% reduction of TN and TP would be required to achieve the A band TAS option, respectively (Table 28). However, for some FMUs, there was little difference in load reductions required between TAS options (Figure 63). This is because in these FMUs, the current state is already in the A or B band and little or zero load reduction was required for achieving a high relative level of environmental protection.

This study also identified the 'limiting environment'; i.e., whether it is an estuary, lake or river that constitutes the most restrictive TAS and has therefore driven the load reduction required in each catchment. As expected, this varied spatially and according to the TAS option.

Table 28. Best-estimate load reductions required for TN and TP for the region for the A, B and C band TAS options and the spatially variable TAS option, at the level of the Otago region. 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).

Target attribute state option	TN	TP
C band	26 (17 - 38)	4 (-6 - 26)
B band	78 (54 - 90)	122 (79 - 166)
A band	81 (63 - 92)	185 (143 - 223)
Spatially variable	25 (14 - 35)	57 (22 - 102)

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 9.2% for Otago for the C band option (i.e., national bottom line). The present study produced a higher TN load reduction estimate of 15% for the C band. However, the 90% confidence interval for this study included the estimate of 9.2% of the previous study (Table 28) and therefore the two studies are consistent, given the uncertainty. The reasons for differences include the region-specific modelling of concentrations and loads, rather than national scale modelling, and improvements to the estimates of maximum allowable loads in the region's estuaries (Plew, 2021).

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 TN and TP load reduction estimates that are associated with two key components of the analyses: the spatial models of river nutrient concentrations and loads (see Sections 3.1 and 3.2). The statistical uncertainty of these spatial 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 10 and Table 11).

The errors associated with each of the eight RF models were combined using Monte Carlo analyses. In this study, a lower limit of the 90% confidence interval that is greater than zero, indicates a 95% level of confidence that a load 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 (Table 28) and for the A and B band TAS settings for all FMUs (Table 17, Table 20). Similarly, we can have high confidence that:

(i) TN load reductions are required under all TAS options for the estuaries Kakanui Estuary, Orore Lagoon, Stony Creek Lagoon and Tokomairiro Estuary (Table 15);

(ii) TP load reductions are required under all TAS options for the region as a whole (Table 28) and for Dunedin Coast FMU, North Otago FMU and Taieri FMU (Table 14), and

(iii) TP load reductions are required under the A and B band TAS options for Otago Harbour and Kaikorai Estuary (Table 18).

The uncertainty of the load reductions presented in this study is associated with the statistical uncertainty of the spatial models. These are not a complete description of the uncertainty of the load reduction assessment for at least three reasons.

First, because both the concentration statistics (e.g., site median values) and loads are calculated from monthly water quality observations, they are subject to sample error and are therefore imprecise estimates of the population statistic they are representing. The estimated imprecision of the load estimates in is shown in Figure 12 and there is similar imprecision associated with the concentration statistics (not assessed in this study). In assessing the uncertainties of the spatial models, the imprecision of the loads and concentration statistics was ignored. The uncertainty of the spatial models is therefore only measuring the ability to predict the imprecise "observed" values rather than the unknown population statistic or load. Therefore, our uncertainty estimates are themselves uncertain and should be regarded as indicative.

The ignored component of uncertainty associated with the load estimate imprecision is shown in Figure 12 and indicates that, in relative terms, uncertainty was generally higher for TP than for TN. This occurs because, compared to TN, high TP concentrations are generally associated with high flows. When samples are taken punctually and monthly (as is the case with SOE monitoring) high flow samples are generally sparse and have high variance (Snelder *et al.*, 2017). Because load is calculated by multiplying concentration and flow, a large component of the TP load is associated with high flows. However, the high flow component of the TP load is very uncertain due to the sparse data and high variance of TP concentrations associated with high flow. This suggests that the uncertainty estimates for phosphorus load reduction requirements should be considered as more uncertain than the equivalent estimates for nitrogen.

The second reason that uncertainty of the load reductions presented in this study are themselves uncertain is that there are uncertainties associated with the assumptions used in the load reduction calculations that are not represented in the uncertainties reported above. Important assumptions used in the calculations are that (1) the ratio of 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 the same proportional change in the median nutrient concentration. 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 third aspect of uncertainty that is not represented in the uncertainties reported above is uncertainties associated with the nutrient criteria used for lakes, rivers and estuaries. The criteria represent the best estimate of the nutrient concentration or load that will achieve the TAS. Uncertainties associated with these criteria mean that there is uncertainty around whether the TAS will be achieved if the loads are reduced as indicated by the assessment. Some locations may fail to achieve the TAS (i.e., have greater biomass than specified) despite having nutrient concentrations that are less than the criteria. Equally, some locations may achieve the TAS despite having nutrient concentrations that are higher than specified. This means that in these less susceptible locations, the criteria are unnecessarily restrictive.

A specific example of this third aspect of uncertainty that is not represented in our quantification of uncertainties is the assessment of TP load reductions required for lakes. The pattern of grades indicating current state for TP was not consistent with expectations with many small lakes graded in the C and D bands in mountainous and hilly areas and areas with no or low land use pressure (Figure 18). This outcome is at least partly due to the small number of monitored lakes across Otago that were used to fit the Otago-specific lake TP model (Figure 6). This meant that the fitted model for lake TP had lake depth as the only explanatory variable, other that annual mean flow weighted concentration of TP inflow to the lake (TP_{in}, Equation 7; Table 12). In turn, this means that shallow lakes in any setting were generally predicted to have relatively high TP concentrations and therefore poor current state (Figure 18) and, consequently, large load reductions required (e.g., Figure 20). The lake model and therefore assessment of TP criteria for lakes might be able to be improved by obtaining data for more lakes and potentially lakes from outside the Otago region. However, the reason the Otago-specific lake TP model used was Equation 7, rather than the model fitted to a larger (national) dataset (Equation 3; Abell *et al.* 2019, 2020) was the poor performance of the latter when judged against Otago lake data (Table 12).

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 TAS 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 Representation of load reduction requirements

In this study we report load reduction requirements for critical point catchments, FMUs, estuary catchments, and the entire Otago region as yields and as percentages of current loads. Both representations of load reduction requirements need to be interpreted carefully. A yield has relevance to agricultural land use because it has the same units as nutrient loss rate estimates that are commonly estimated for individual farms. However, when load reductions are expressed in this study as yields, the denominator is always the area of the *entire* upstream 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 conditions. Where there is non-productive land in the upstream catchment, the same caveat regarding the interpretation of load reductions as yields applies to these percentage values. In addition, the use of the current load at a point as the denominator means that percentage load reductions of over 100% are reported for some combinations of TAS and FMUs and the whole region. Two factors combine to mean TP load reductions can exceed 100%. First, TP yields are generally high (i.e., > 2 kg ha^{-1} yr^{-1}) at sites draining steep high-elevation headwater catchments and tend to be lower at sites that at sites that are at the downstream end of main stem rivers (Figure 13). Consequently, our spatial models of TP loads represent decreasing yields in the downstream direction. This is consistent with the general observation that loads of both nutrients are attenuated as they travel downstream from their source. TP loads appear to decrease more strongly downstream than TN loads in the Otago region, possibly because they are strongly associated with sediment, some of which is trapped by lakes and behind dams as it is transported downstream. The second factor is that the load reduction requirement at a location is the minimum load reduction that ensures the current load at that, and all upstream, receiving environments do not exceed the MAL (Figure 1). Because loads upstream can be larger than loads downstream, the load reduction at a site can be larger than the current load at the site. TP load reductions of greater than 100% are therefore not necessarily an error but reflect the complexity of the system be assessed.

4.5 Informing decision-making on limits

The NPS-FM requires regional councils to set limits on resource use to achieve environmental outcomes (e.g., TAS). This report helps inform ORC’s process of setting limits by assessing the approximate magnitude of nitrogen and phosphorus load reductions needed to achieve several options for TAS, 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. Thanks also to Jason Augspurger and Rachel Ozanne of ORC for assistance with data and review comments on early drafts of this report and to Oliver Floerl (LWP Ltd) for review of the final draft.

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Appendix A Total nitrogen and total phosphorus criteria for periphyton target attribute states used in the analysis

The nutrient criteria for periphyton TASs are shown for each REC Source-of-flow class that occurs in the Otago region and corresponding to the A, B and C bands (Table 29). The values in the table are the criteria of Snelder and Kilroy (2023) and the 20% level of under-protection risk. Values are median concentrations in units of mg m^{-3}.

Table 29. The total nitrogen and total phosphorus criteria for each periphyton TAS assessed by this study and each REC Source-of-flow class that occurs in the Otago region corresponding to the A, B and C bands and the 20% level of under-protection risk.

River Environment Classification Source-of-flow class	**Total nitrogen**			**Total phosphorus**		
	A	**B**	**C**	**A**	**B**	**C**
CX/M	47.6	2988	4372	1	85	281
CX/Lk	47.6	2138	4322	1	37	180
CX/L	47.6	2061	4241	1	110	276
CX/H	47.6	1994	4272	1	69	247
CX/GM	47.6	4022	4360	1	90	270
CW/M	47.6	1693	4333	1	31	205
CW/Lk	47.6	934	4127	1	17	133
CW/L	47.6	179	1990	1	13	92
CW/H	47.6	376	3147	1	26	162
CW/GM	47.6	1988	4398	1	34	241
CD/M	47.6	1532	4297	1	11	93
CD/Lk	47.6	542	3187	1	6	49
CD/L	47.6	47.6	562	1	3	30
CD/H	47.6	231	1981	1	4	33

The criteria for the A band shown in Table 29 were derived using the subset of Otago and Southland sites taken from the fitting data used by Snelder and Kilroy (2023). Quantile regression was used to derive the criteria for the 50 mg m^{-2} threshold that are spatially uniform (i.e., one value applies to all REC Source-of-flow classes).

Plots of observed biomass at the Otago and Southland sites versus observed site median nutrient values were wedge-shaped (Figure 64). This indicates that there is a limiting relationship between biomass and nutrients at the regional (i.e., Otago and Southland) scale but that other factors influence the response (Phillips *et al.* 2018; Kelly *et al.* 2022). Quantile regression models were statistically significant ($p < 0.1$) for all quantiles for TN and most quantiles for TP (Table 30).

Sites with biomass values of 50 mg m^{-2} or less occurred across a wide range of nutrient concentrations and in most Source-of-flow classes (Figure 64). This indicates that there is no obvious landscape scale spatial pattern in the low biomass sites and that, in the absence of variables that can better explain low biomass at these sites, the uniform criteria derived from the quantile regression models are a justifiable approach to defining criteria for the 50 mg m^{-2} biomass target. Where possible, we derived alternative criteria from all QR models (Table 30) and used these values as the criteria pertaining to the 50 mg m^{-2} biomass target (see Table 29).

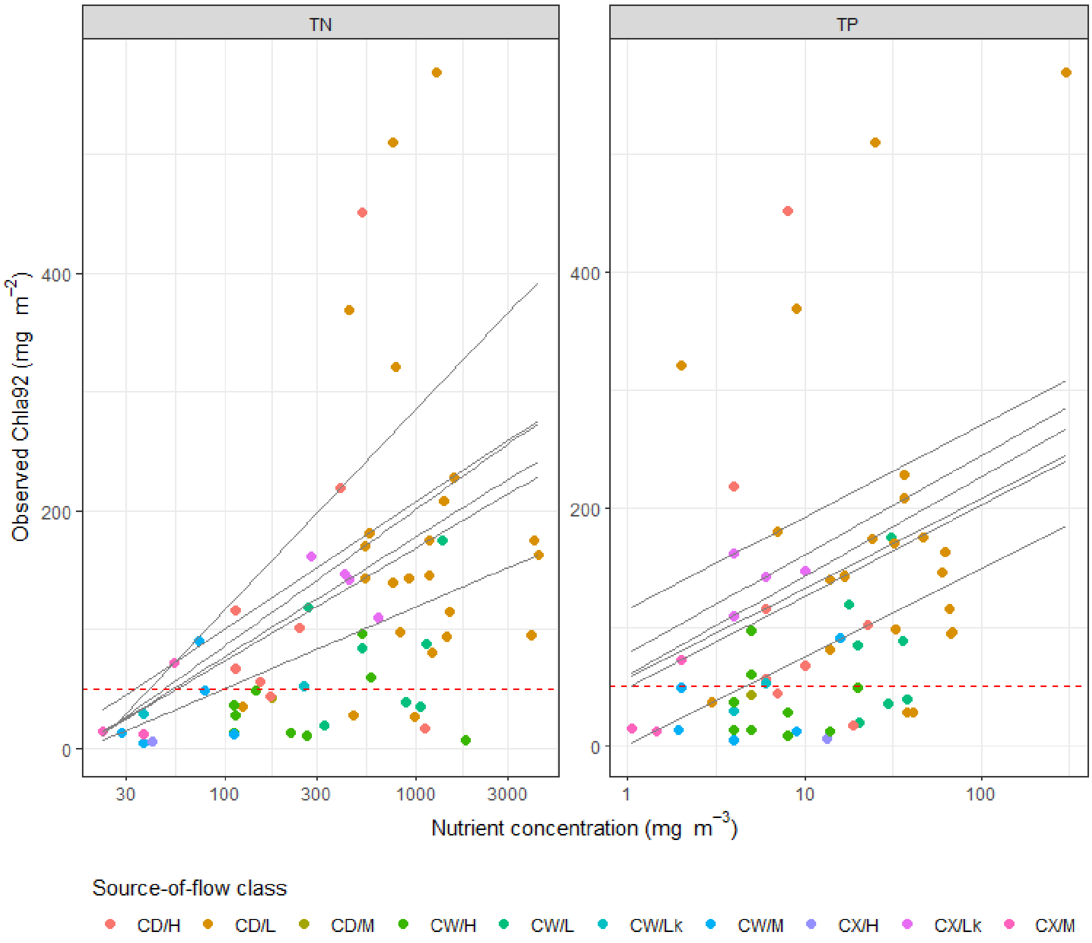

Figure 64. Relationships between biomass and median nutrient concentrations at Southland and Otago monitoring periphyton monitoring sites. The grey lines are quantile regressions fitted to the 0.95, 0.9, 0.85, 0.8, 0.7 and 0.5 quantiles. Not all of these regression lines are statistically significant (see Table 3). The red dashed line indicates a biomass of 50 mg m^{-2}. Points are coloured to indicate the Source-of-flow class of the monitoring site.

Table 30. Criteria derived from the QR models for the 50 mg m^{-2} periphyton biomass target state for TN and TP and each level of under-protection risk. The P-value indicates the confidence in the regression coefficient fitted to the nutrient concentration. The criteria have units of mg m^{-3}.

Nutrient	Quantile	Under-protection risk (%)	P value	Criteria
TN	0.5	50	**0**	97.7
	0.7	30	**0**	55.1
	0.75	25	**0**	52.4
	0.8	20	**0**	47.6
	0.85	15	**0.047**	33.4
	0.9	10	**0.044**	39.6
	0.95	5	**0**	29.9
TP	0.5	50	**0**	4.6
	0.7	30	**0.027**	1.1
	0.75	25	**0.078**	1
	0.8	20	0.139	1
	0.85	15	0.357	0.9
	0.9	10	0.493	0.8
	0.95	5	0.451	0.3

Appendix B Total nitrogen and total phosphorus loads to achieve estuary trophic state target attribute states 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 the best estimates of current loads made by this study. For 15 estuaries, MALs for TP are indicated by n/a. This is because it is considered unlikely that phytoplankton growth in these estuaries will drive severe secondary symptoms of eutrophication (like deoxygenation and light attenuation), and therefore no MAL has been defined for TP. In these estuaries, macroalgae is considered the dominant form of nuisance plant growth.

Table 31. 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 (2021). Macroalgae was assumed to be limited only by nitrogen. Phytoplankton may be limited by either nitrogen or phosphorus. In this study, n/a values lead to the conclusion that no load reduction is required to achieve the TAS.

Estuary	**Type**	**Current TN ($t\ y^{-1}$)**	**TN band thresholds ($t\ y^{-1}$)**			**Current TP ($t\ y^{-1}$)**	**TP band thresholds ($t\ y^{-1}$)**		
			A/B	**B/C**	**C/D**		**A/B**	**B/C**	**C/D**
Kakanui Estuary	SSRTRE	253 (77 - 390)	18.8	50.6	82.4	16 (2 - 44)	1.97	2.93	3.89
Orore Lagoon	COASTAL LAKE	11 (4 - 23)	0.4	0.9	2.0	1 (0 - 1)	0.04	0.11	0.27
Shag River Estuary	SIDE	119 (42 - 214)	36.0	124.5	213.1	3 (0 - 6)	n/a	n/a	n/a
Stony Creek Lagoon	COASTAL LAKE	5 (2 - 9)	0.2	0.4	1.0	0 (0 - 0)	0.02	0.06	0.14
Pleasant River Estuary	SIDE	32 (12 - 61)	6.1	19.8	33.5	1 (0 - 3)	n/a	n/a	n/a
Waikouaiti Estuary	SIDE	68 (26 - 134)	16.4	51.5	86.6	5 (1 - 15)	n/a	n/a	n/a
Blueskin Bay	SIDE	37 (23 - 56)	12.5	44.2	75.9	2 (0 - 3)	n/a	n/a	n/a
Purakunui Inlet	SIDE	4 (1 - 6)	1.8	6.5	11.2	0 (0 - 0)	n/a	n/a	n/a
Otago Harbour	DSDE	47 (34 - 64)	90.4	239	387	2 (1 - 3)	0.00	0.00	15.6
Papanui Inlet	SIDE	4 (3 - 6)	5.1	18.8	32.5	0 (0 - 0)	n/a	n/a	n/a
Hoopers Inlet	SIDE	5 (3 - 6)	5.2	19.1	33.0	0 (0 - 0)	n/a	n/a	n/a
Tomahawk Lagoon	COASTAL LAKE	2 (0 - 3)	0.0	0.0	0.1	0 (0 - 0)	0.00	0.01	0.01
Kaikorai Estuary	SSRTRE	22 (10 - 56)	2.2	6.7	11.2	1 (0 - 3)	0.00	0.17	0.35
Taieri Estuary	SSRTRE	1,410 (535 - 2,859)	151.7	424.6	697.5	139 (20 - 269)	n/a	n/a	n/a
Akatore Creek	SIDE	32 (11 - 62)	3.7	11.6	19.5	2 (0 - 4)	n/a	n/a	n/a
Tokomairiro Estuary	SSRTRE	247 (91 - 464)	9.3	27.8	46.3	12 (2 - 30)	n/a	n/a	n/a
Pounawea (Catlins) Estuary	SIDE	249 (110 - 620)	61.7	208.4	355.0	16 (2 - 52)	n/a	n/a	n/a
Tahakopa Estuary	SSRTRE	172 (63 - 328)	32.7	99.5	166.4	14 (3 - 30)	n/a	n/a	n/a
Tautuku Estuary	SIDE	36 (12 - 66)	7.6	24.1	40.6	5 (0 - 9)	n/a	n/a	n/a
Waipati (Chaslands) Estuary	SIDE	35 (14 - 81)	8.1	25.0	42.0	2 (0 - 7)	n/a	n/a	n/a