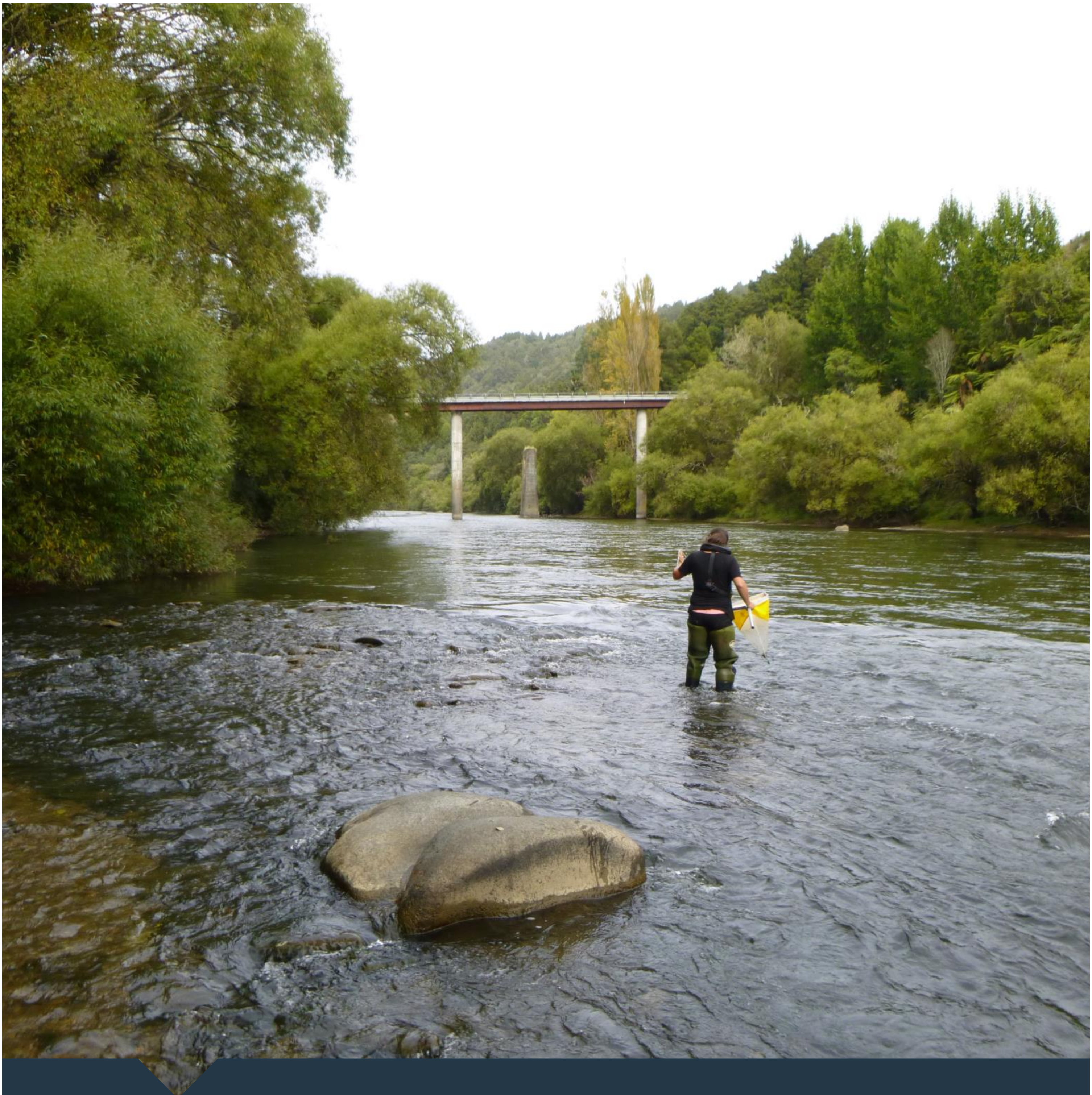

Assessment of Nutrient Load Reductions to Achieve Freshwater Objectives in the Rivers and Lakes of the Manawatū-Whanganui Region

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Executive Summary

This report describes nutrient (nitrogen and phosphorus) load reductions predicted to achieve options for freshwater objectives (FWO) in rivers and lakes of the Manawatū-Whanganui Region. The analysis does not consider how the nutrient load reductions would be achieved and only aims to inform the Horizons Regional Council (HRC) about the magnitude of the load reductions needed for each option and how these vary across the region.

The study assesses nutrient load reductions required to achieve four sets of options for Freshwater Objectives (FWO) pertaining to the effects of the nitrogen and phosphorus for rivers and lakes across the region. The relevant FWOs are for nitrate toxicity in rivers and plant biomass as phytoplankton in lakes and periphyton in rivers. The first set of FWOs are consistent with the operative One Plan targets. The remaining sets of FWOs are based on the A, B and C attribute states as defined by the National Objectives Framework (NOF).

This study assesses nutrient load reductions pertaining to the above FWOs based on two options for the nutrient criteria to achieve the objectives. First, spatially variable criteria that are applicable to all rivers nationally were used and are referred to as the 'national criteria'. The national criteria apply to both nutrients (nitrogen and phosphorus), and two sets of these criteria were used the 20% and 30% under-protection risk criteria. Under-protection risk can be understood as the risk that adopted nutrient criteria will fail to achieve the required periphyton outcomes (i.e., the FWO) with the 30% criterion accepting a higher level of this risk, and therefore a higher nutrient concentration criterion, than the 20% criterion. Second, criteria for nitrogen (not phosphorus) that were derived from regional analysis were used and are referred to as regional criteria.

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 and lakes across the region. The concentrations and loads were combined with criteria associated with objectives. Calculations were made of the amounts by which current loads would need to be reduced to allow the objectives to be achieved (i.e., the load reduction required).

The load reductions required were assessed for all individual river segment and lake receiving environments in the region. The results for the individual receiving environments were aggregated to report on individual water management sub-zones (WMSZs) freshwater management units (FMUs) and the whole region. The results for the whole region 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 a lake or river that has the most sensitive FWO and has therefore driven the load reduction required in each catchment.

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

The load reductions required for TN and TP to achieve the One Plan targets for the seven FMUs and the whole region are shown in Table A. The load reductions required associated with the national criteria and 30% risk generally had slightly lower TN and considerably lower for TP compared to the 20% spatial exceedance criteria. The TN load reductions required associated with the regional criteria were lower than either of the TN load reductions that were based on either of the national criteria. Part of the reason for this is that the underlying level of under-protection risk associated with the regional criteria is 50% and therefore these are less stringent than either of the national criteria. Differences are also likely due to differences in the datasets that were used to derive the two sets of criteria.

The choice of which risk is acceptable, and therefore which criteria should be used, is not a science question, it is a management decision that must be made by the decision maker. The obvious trade-off associated with this decision is between over- and under-protection. Reducing the risk of under-protection correspondingly increases over-protection and vice-versa. In addition, reducing over-protection increases the amount by which under-protected sites can be expected to exceed the target attribute state.

Table A. The load reductions required for TN and TP to achieve the One Plan targets for the seven FMUs and the whole region based on the national criteria and 20% and 30% risk and the regional criteria. 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).

FMU	TN			TP	
	National 20	National 30	Regional	National 20	National 30
Kai Iwi	79 (68 - 85)	74 (63 - 84)	58 (36 - 74)	92 (84 - 97)	81 (66 - 91)
Whanganui	67 (43 - 85)	46 (5 - 80)	5 (0 - 35)	109 (95 - 115)	4 (0 - 23)
Whangaehu	56 (38 - 76)	42 (29 - 60)	21 (1 - 55)	93 (86 - 96)	35 (29 - 38)
Rangitīkei-Turakina	61 (35 - 87)	38 (13 - 75)	25 (11 - 55)	133 (123 - 142)	34 (6 - 86)
Manawatū	52 (35 - 69)	41 (20 - 57)	36 (6 - 53)	96 (91 - 100)	15 (1 - 48)
Waiopehu	34 (25 - 46)	26 (17 - 36)	23 (15 - 33)	55 (42 - 65)	17 (9 - 26)
Puketoi ki Tai	32 (9 - 54)	11 (0 - 33)	9 (0 - 34)	59 (39 - 70)	0 (0 - 0)
Whole region	60 (47 - 71)	43 (25 - 59)	23 (9 - 36)	106 (99 - 115)	16 (6 - 32)

The load reductions required for TN and TP to achieve the One Plan targets compared to FWOs based on the A, B and C band attribute states for the whole region are shown in Table B. In general, the load reductions required to achieve the C band are considerably lower than all the other FWOs, including the One Plan targets, irrespective of the choice of criteria. The load reductions required to achieve the One Plan targets are generally between those required to achieve the A and the B bands. This indicates that the One Plan targets are quite aspirational relative to the options for FWOs set out in the NOF.

Table B. The load reductions required for TN and TP to achieve the One Plan targets and FWOs that are consistent with A, B and C target attribute states for the whole region based on the national criteria and 20% and 30% risk and the regional criteria. 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).

FMU	TN			TP	
	National 20	National 30	Regional	National 20	National 30
One Plan	60 (47 - 71)	43 (25 - 59)	23 (9 - 36)	106 (99 - 115)	16 (6 - 32)
C band	23 (10 - 40)	8 (2 - 19)	3 (1 - 6)	75 (41 - 92)	1 (1 - 2)
B band	52 (35 - 63)	30 (17 - 47)	9 (5 - 17)	100 (93 - 106)	6 (1 - 16)
A band	84 (79 - 89)	73 (66 - 80)	36 (20 - 52)	114 (109 - 119)	85 (69 - 97)

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

There are also uncertainties associated with the nutrient criteria to achieve the plant biomass objectives assessed in this study for lakes and rivers. The uncertainties associated with these criteria mean that some locations may develop biomass greater than specified by the objective 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 objective will not be achieved and that the appropriate management response is to reduce the current nutrient level (i.e., the nutrient load reduction).

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

1 Introduction

This report describes an assessment of nutrient (nitrogen and phosphorus) load reductions required to achieve objectives in rivers and lakes of the Manawatū-Whanganui Region. The purpose is to inform Horizons Regional Council (HRC) about the magnitude of the load reductions needed for each option and how these vary across the region. This report does not consider how the nutrient load reductions would be achieved; this will be the subject of subsequent studies.

High nitrogen and phosphorus concentrations in aquatic receiving environments can have at least two types of impacts. First, nitrate concentrations can reach toxic levels that impair aquatic animal survival, growth and reproduction. Second, when not limited by light or other nutrients, hydrological disturbance and/or invertebrate grazing control, primary production can be stimulated by nitrogen and phosphorus enrichment, causing excessive plant biomass and ecological degradation associated with shifts from low productivity or oligotrophic states to eutrophic or hypertrophic states. In rivers, algae are primarily present as periphyton (slime), which grows attached to the bed. In lakes algae are primarily present as phytoplankton (algae suspended in the water column). Some periphyton and phytoplankton are a natural component of river and lake ecosystems and are an essential component of the food web. However, over-abundant algal biomass degrades rivers and lakes from ecological, recreational and cultural perspectives. Nitrogen and phosphorus concentration criteria are defined to achieve objectives for either limiting toxic effects or ‘trophic state’, which this study quantifies as the level of plant biomass in rivers and lakes.

The study assesses nutrient load reductions required to achieve four sets of freshwater objectives (FWO). The first set of FWOs are consistent with the operative One Plan targets. The remaining FWOs that are consistent with A, B and C target attribute states as defined in the National Objectives Framework (NOF) table xx for Rivers and xx for Lakes. In addition, this study assesses nutrient load reductions pertaining to three options for nutrient criteria to achieve river periphyton objectives, which are referred to as the national criteria based on 20% and 30% levels of risk (for nitrogen and phosphorus) and regional criteria (for nitrogen only). The two levels of risk can be understood as different expectations for the proportion of locations that will fail to achieve the nominated periphyton objectives despite being compliant with the nutrient criteria. The study includes an assessment of uncertainty of the outputs based on the uncertainties associated with the various input models describing current nutrient loads and concentrations.

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

The documentation associated with the MFE (2019) and Snelder *et al.* (2020) studies contain detailed description of the methodology that was used by the study described in this report.

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

2 Methods

2.1 Overview

This study's methodology is based on a spatial framework that represents the drainage network (i.e., streams and rivers) and its' associated catchments and the connected freshwater (river and lakes) receiving environments of the region. This study used the same spatial datasets as Snelder (2020), MFE (2019) and Snelder *et al.* (2020) to represent the drainage network and lakes. The spatial framework includes HRC's Freshwater Management Units (FMU) and Water Management Sub-zones (WMSZs), which provide a spatial delineation of the region into large and small catchment subdivisions, respectively (Figure 1). There are seven FMUs that subdivide the region into large catchments and 124 WMSZs, which are smaller subdivisions that are associated with objectives, policies and rules in the operative regional water plan known as the One Plan. The FMUs and WMSZs are used in this study as a framework for reporting the study results, primarily the load reduction requirements.

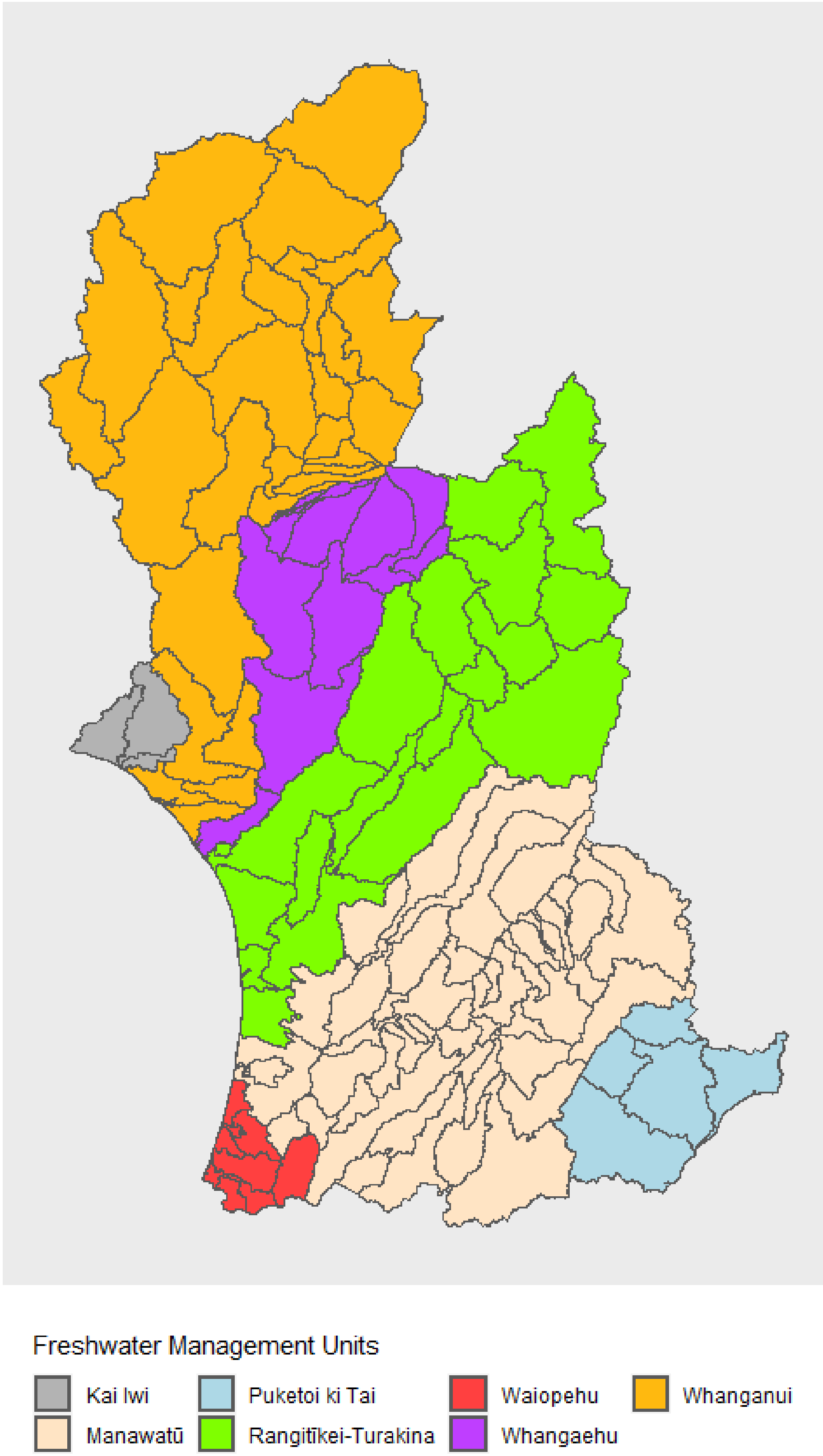


Figure 1. HRC's Freshwater Management Units (FMU) and Water Management Sub-zones (WMSZs).

Conceptually, nutrient (nitrogen and phosphorus) loads derive from the upstream catchments and are transported to the receiving environments by the drainage network (Figure 2). Models are used to predict the current concentrations and loads of nutrients at each segment of the drainage network, each of which also represents a river receiving environment. The nutrient loads predicted for the drainage network are used to estimate the nutrient loads delivered to lake receiving environments.

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

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

Finally, the WMSZ load reduction status is an indicative load reduction requirement that is based on complying with concentration criteria for each WMSZ and for all downstream receiving environments. The WMSZ load reduction status is based on defining critical points, which is the receiving environment downstream from the WMSZ that has the largest load reduction required. The load reduction status of the WMSZ is the load reduction required at the critical point. The WMSZ load reduction status also identifies the limiting environment (i.e., whether it is a lake or river receiving environment that determines the load reduction requirement). The WMSZ load reduction status provides information that is relevant to provision 3.13(3)(b) 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 objectives in the downstream receiving environments (NZ Government, 2020).

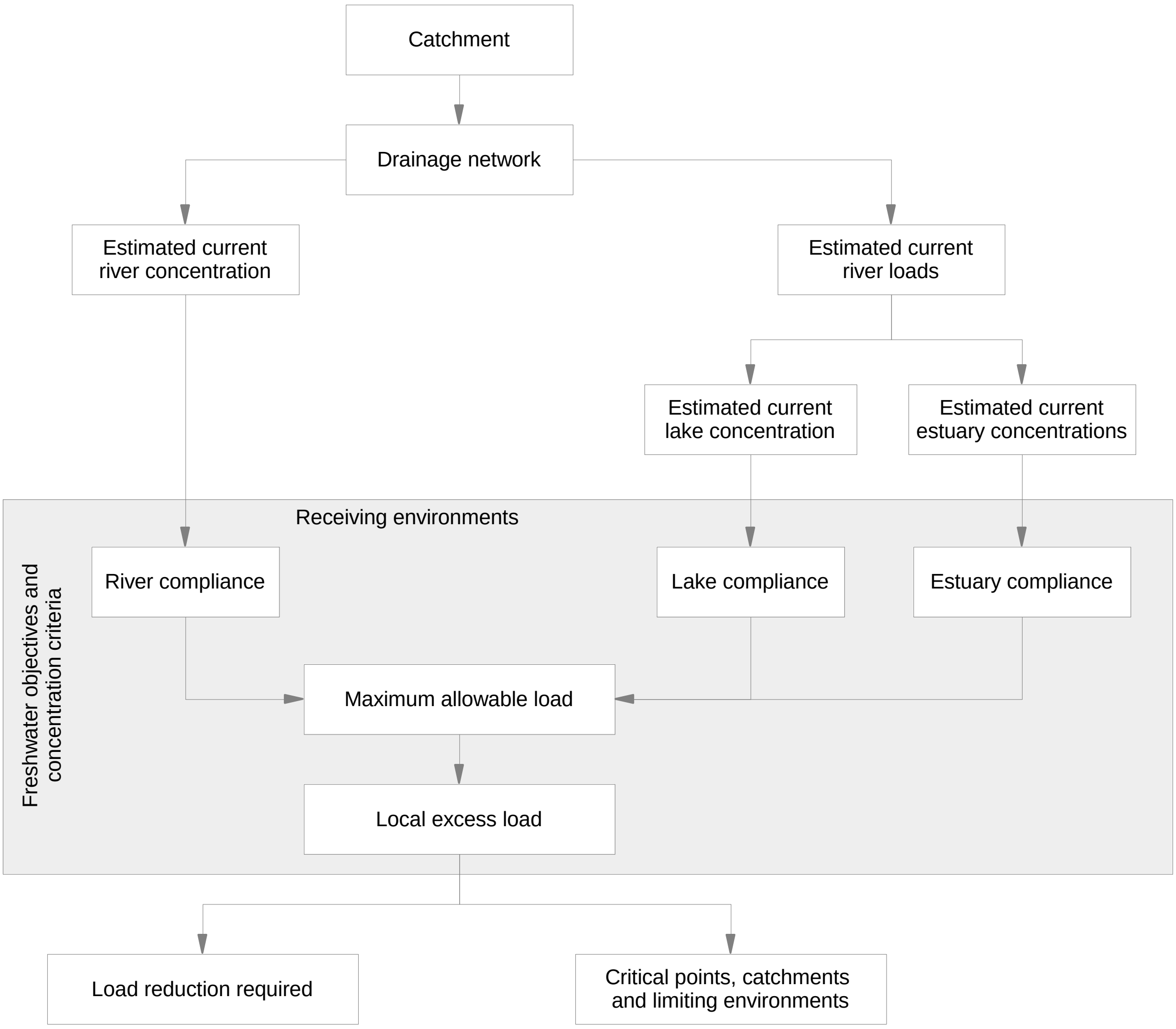


Figure 2. Schematic diagram of the assessment of nutrient load reductions required to achieve freshwater objectives. The following sections describe the various components of the analysis shown in Figure 2 in more detail.

2.2 Spatial framework

The study area comprised the Manawatū-Whanganui region (Figure 1). 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 region as 53,600 segments bounded by upstream and downstream confluences, each of which is associated with a sub-catchment (Figure 3). The terminal segments of the river network (i.e., the most downstream points in each drainage network that discharges to the ocean) were identified.

Lakes were represented in the spatial framework by the lakes layer of the Freshwater Environments of New Zealand GIS database (FENZ; Leathwick *et al.*, 2010). The FENZ lake polygons were intersected with the river network and the river segments that terminate at lakes were identified. Of the 226 lakes with surface area greater than 1 hectare in the region, there were 41 within the region for which inflow segments in the drainage network could be defined

(Figure 3). The remaining lakes had catchment areas that were too small to be represented by the drainage network and were not included in the analysis.

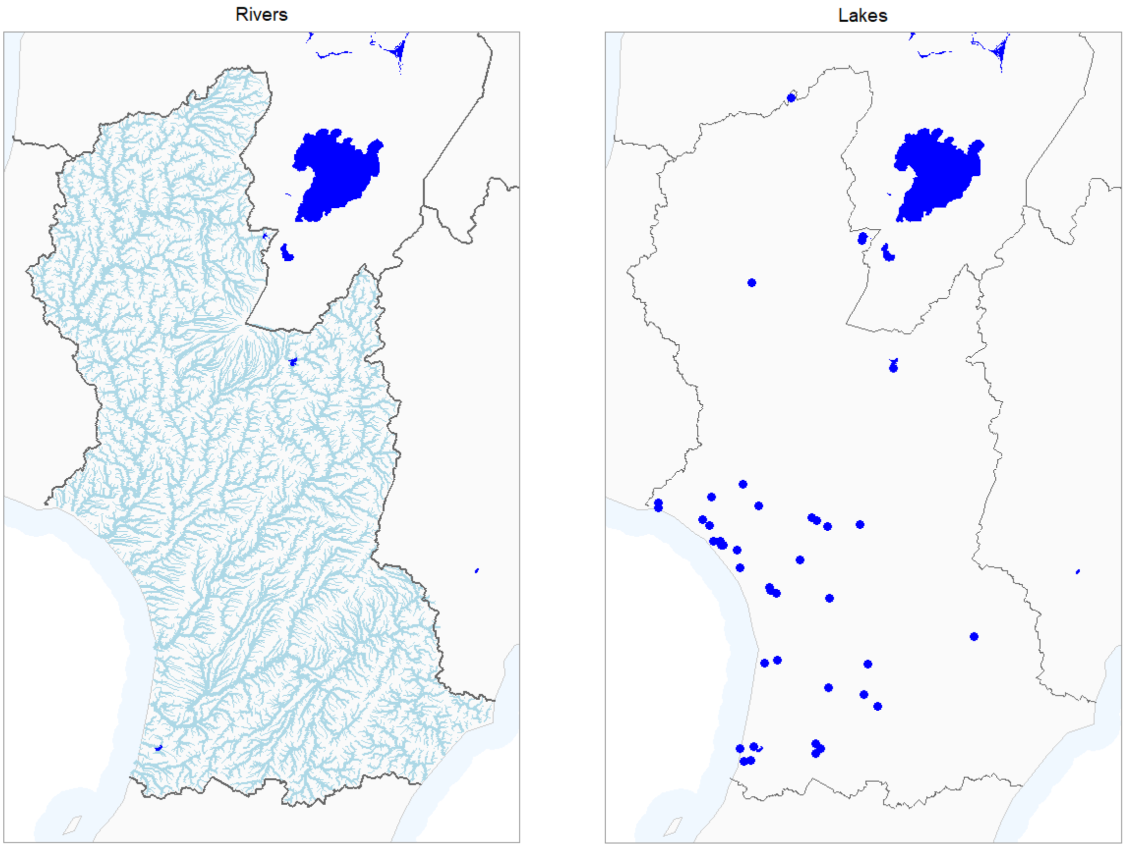


Figure 3. Components of the spatial framework. Note that lakes are represented by blue points because many are too small to be visible if they were represented by the lake outline.

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 and lakes; Figure 3) to the whole region. 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, and Freshwater Management Units (FMU; Figure 1). These summaries were evaluated by summing the load reductions required over all terminal segments (i.e., network of segments intersecting the coastline) or terminal segments of each FMU.

2.3 Estimated current river nutrient concentrations

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

The approach to statistical regression modelling approach was similar to several similar national and regional studies (e.g., Whitehead, 2018) and spatial modelling of contaminant concentrations and loads in the Manawatū-Whanganui (Fraser and Snelder, 2020). For each water quality variable, a type of regression model called a random forest (RF) was fitted to the observed monitoring site median values.

A total of 135 river water quality monitoring sites were used to fit the models for all nutrient concentrations (Figure 4). These sites had monthly observations of all four nutrients for the five-year period ended December 2019 from which the median values were calculated (for details see Fraser and Snelder, 2021). The sites represented both state of environment monitoring (SoE) sites and impact sites downstream of large point source discharges.

The regression model predictor variables describe various aspects of each site's catchment including the climate, geology and land cover. In addition, this study included five predictors that quantified the density of pastoral livestock in 2017 to indicate land use intensity. These predictors were based on publicly available information describing the density of pastoral livestock (https://statisticsnz.shinyapps.io/livestock_numbers/). These predictors improve the discrimination of catchment land use intensity compared to previous studies that have only had access to descriptions of the proportion of catchment occupied by different land cover categories (e.g., Whitehead, 2018). The densities of four livestock types (dairy, beef, sheep and deer) in each catchment were standardised using 'stock unit (SU) equivalents', which is a commonly used measure of metabolic demand by New Zealand's livestock (Parker, 1998). These five predictors express land use intensity as the total stock units and the stock units by each of the four livestock types divided by catchment area (i.e., SU ha^{-1}).

Predictor variables included estimates of contributions from point sources for all locations downstream of 36 point source discharges consented to discharge > $20m^3\ d^{-1}$. These estimates were made based on calculating the annual loads of each of the four contaminants discharged at each point source and converting these to concentration contributions at all downstream river network segments (see Fraser and Snelder, 2021 for details).

The RF models were fitted to site median values of TN, TP, NO3N DRP, NO3N in TN and DRP in TP calculated from the monitoring site data pertaining to only the Manawatū-Whanganui region because predictions of concentrations at Manawatū-Whanganui sites using national-scale models were found to be slightly biased. The values NO3N in TN and DRP in TP for each site were derived in two steps. First, for each observation date the ratio of the soluble component to total was evaluated (i.e., NO3N/TN and DRP/TP). Second, NO3N in TN and DRP in TP for each site was calculated as the median of these ratios.

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 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, DRP were $\log_{10}$ transformed. A logit transformation was applied to the values to increase the normality of the distributions. A logit transformation is defined as:

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

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

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

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

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

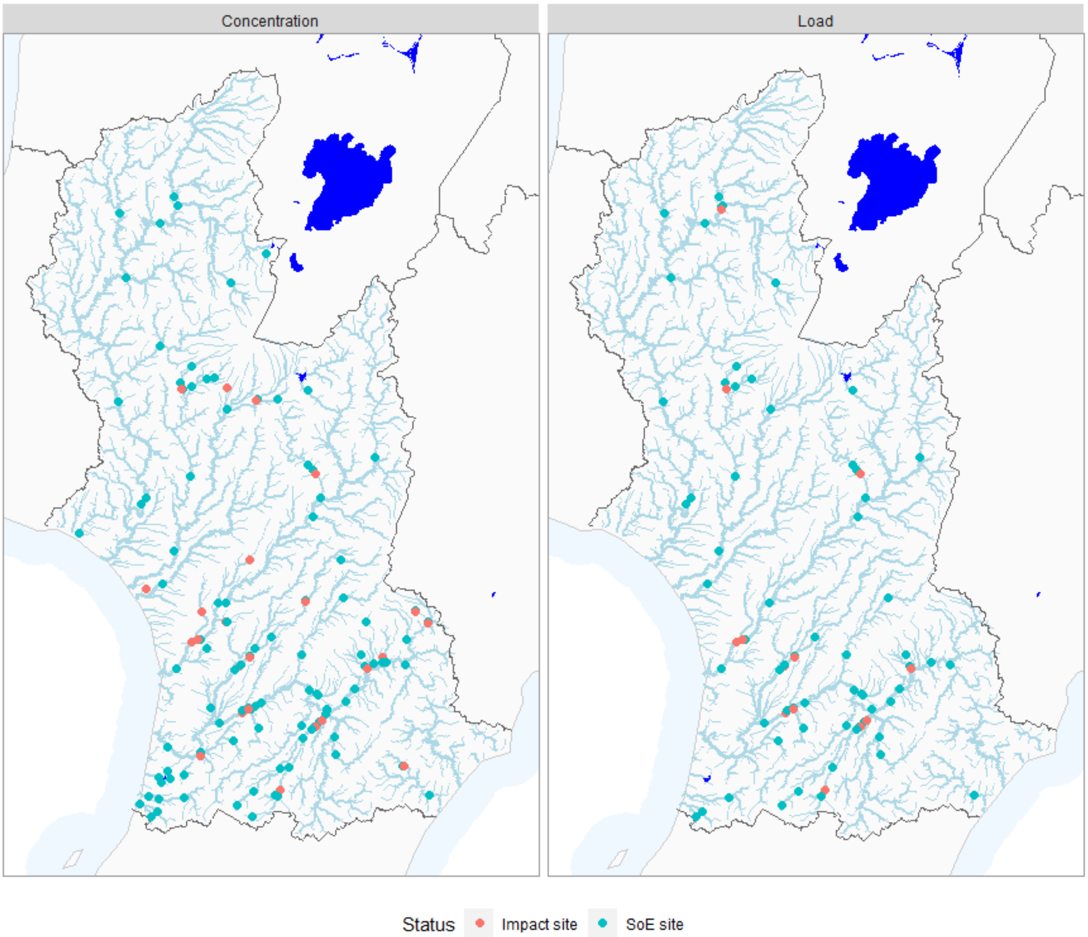


Figure 4. Locations of the 135 river water quality monitoring stations used to fit the concentration models and the 79 river water quality monitoring stations used to fit the load models.

The performance of the RF models was evaluated and the uncertainty of the predictions using three measures: regression R^2, Nash-Sutcliffe efficiency (NSE), and bias. The regression R^2 value is the coefficient of determination derived from a regression of the observations against the predictions. The R^2 value indicates the proportion of the total variance explained by the model, but is not a complete description of model performance (Piñeiro *et al.*, 2008). NSE indicates how closely the observations coincide with predictions (Nash and Sutcliffe, 1970). NSE values range from −∞ to 1. An NSE of 1 corresponds to a perfect match between predictions and the observations. An NSE of 0 indicates the model is only as accurate as the mean of the observed data, and values less than 0 indicate the model predictions are less accurate than using the mean of the observed data. Bias measures the average tendency of the predicted values to be larger or smaller than the observed values. Optimal bias is zero, positive values indicate underestimation bias and negative values indicate overestimation bias (Piñeiro *et al.*, 2008). PBIAS is computed as the sum of the differences between the observations and predictions divided by the sum of the observations (Moriasi *et al.*, 2007). The normalization associated with R^2, NSE and PBIAS allows the performance of TN, DRP and TP models to be directly compared and evaluated against the three performance measures following the criteria proposed by Moriasi et al. (2015), outlined in Table 1.

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

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

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

2.4 Estimated current river TN and TP loads

Estimates of current loads of TN and TP for all segments of the drainage network were made using river water quality monitoring data from the Manawatū-Whanganui 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 (Fraser, 2021). Loads were calculated for sites that had at least 10 years of monthly concentration observations up to the end of 2019. Load calculations were based on mean daily flows for each monitoring site provided by HRC, which were based on flow records or, where this was not available, modelled flows. 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 2018[1]. 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 and predictor variables as for concentrations to fit RF models to calculated monitoring site loads for TN, DRP and TP. The RF models were fitted to data pertaining only to monitoring sites in the Manawatū-Whanganui region because national-scale models were found to be slightly biased. The site yield values were $\log_{10}$ transformed to improve model performance (Snelder *et al.,* 2018). A total of 74 river water quality monitoring sites were the input data for the load models (Figure 4).

The fitted RF models were combined with a database of predictor variables for every network segment in the region and used to predict current yields of TN and TP for all segments. Model predictions were back-transformed and corrected for re-transformation bias as described by

[1] This report refers to 'current loads and concentrations' because the loads and concentrations estimated for 2018 are unlikely to be appreciably or statistically significantly different to loads at the time this study was conducted (2020).

Snelder *et al.* (2018). The load model predictions were evaluated following the same criteria used for the concentration predictions (Table 1).

2.5 Estimated current lake TN and TP concentrations

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

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

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

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

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

where TP_{lake} and TN_{lake} are median concentrations of TN and TP (mg m^{-3}), k_1, Δk_1, k_2, and all β are fitted parameters provided by Abell *et al.* (2019, 2020), τ_w is water residence time (years) derived from the WONI database, and Z_{max} is the maximum depth of the lake derived from the WONI database. The variable d is a dummy variable that indicates whether a lake is shallow (d = 0) or deep (d = 1). We used the same threshold as Abell *et al.* (2019, 2020) of >7.5 m to define deep lakes.

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

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

To proceed with an analysis of load reduction requirements, it is necessary to nominate FWOs. FWOs could be set individually for each river and lake and for each type of effect (e.g., toxicity and trophic state). Therefore, there are a very large number of potential combinations of FWOs that could be applied. To make the analysis and presentation of results manageable, this study has nominated four sets of FWOs (Figure 5). The first group of FWOs are based on the periphyton biomass targets set in HRC's operative One Plan. These One Plan targets are consistent with the NOF periphyton or phytoplankton attribute states (i.e., A, B and C bands) that are defined in Appendix 2 of the NPS-FM for both. The FWOs representing the operative One Plan have therefore been specified as A, B or C bands.

The assessment of load reductions required is comprehensive in that it considers the current concentrations and loads at every receiving environment represented in the analysis. However, the One Plan targets are defined at the level of HRC's 124 Water Management Sub-Zones (WMSZ). It was assumed therefore that the FWOs specified for each WMSZ applied to every receiving environment within each sub-zone (i.e., every river segment and lake; Figure 3). It has been assumed that FWOs for lake trophic state have the same band (i.e., A, B or C) as the One Plan periphyton targets for each WMSZ. In addition, it has been assumed that FWOs for nitrate toxicity have the same band as the One Plan periphyton targets unless that band is C, in which case the FWO is set to the B state for the nitrate toxicity FWO. This is because under the latest version of the NOF (NZ Government, 2020), the national bottom line for nitrate toxicity is the B attribute state.

The second, third and fourth groups of FWOs are consistent across all receiving environments as A, B or C bands, respectively (Figure 5). The purpose of these additional groups of FWOs is to provide information about the potential impact of objectives that are generally more stringent than the current One Plan targets (i.e., A band) through to those that are generally less stringent than the current One Plan targets (i.e., C band).

For the analyses that follow, it has been assumed that both the nominated nitrogen and phosphorus criteria need to apply to achieve trophic FWOs. It is also noted that these criteria are the actual basis for the analysis of compliance and load reductions required (i.e., the plant biomass is not predicted for any receiving environment as part of the analyses).

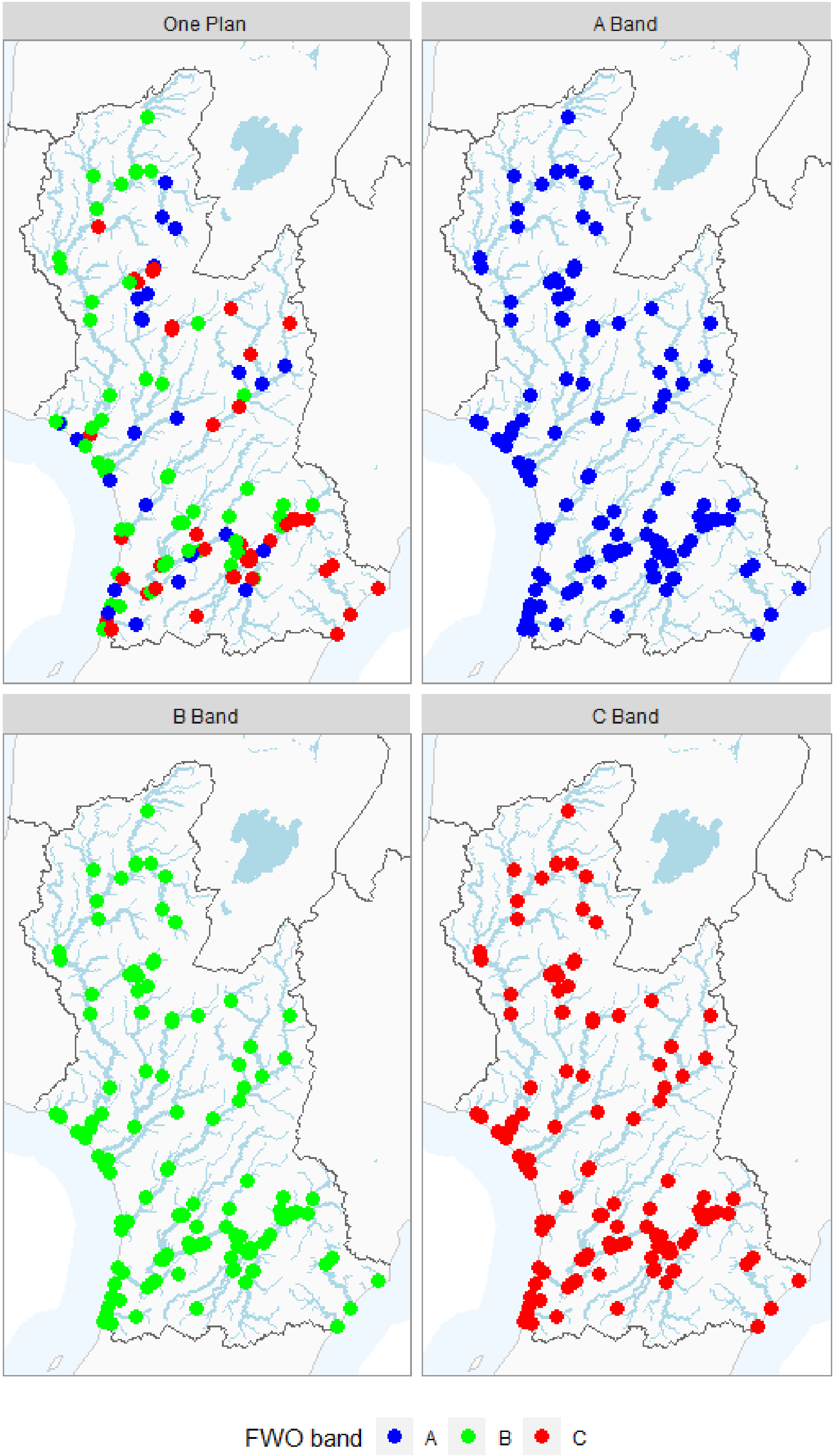


Figure 5. FWOs assessed in this study. The points indicate the downstream end of each of HRC's 124 WMSZ. The band indicated for each WMSZ has been applied to all receiving environments withing the sub-zone.

The following sections tabulate the concentration criteria associated with each FWO and describe how the concentration criteria were used to assess compliance and define the maximum allowable load (MAL) for river and lake receiving environments. The details of the assessment of compliance and the calculation of MAL differed by receiving environment type.

2.6.1 Rivers

The NOF target attribute states (Bands A, B and C) for nitrate toxicity are defined by the nitrate-nitrogen concentration thresholds shown in Table 2. The lower thresholds were used in the study as the criteria to achieve the corresponding target attribute state. It is noted that these concentrations are generally considerably higher than nitrogen concentrations associated with excessive plant biomass in rivers.

Table 2. Nitrate toxicity target attribute state thresholds defined by nitrate-nitrogen concentrations (mg NO_3-N m^{-3}).

Target attribute state	Nitrate concentration criteria
A	≤1,000
B National Bottom line (NZ Government, 2020)	>1,000 and ≤ 2,400
C	>2,400 ≤ 6,900

The second type of concentration criteria that is relevant to rivers is associated with the periphyton biomass objectives. The periphyton attribute stipulates the levels of periphyton biomass in terms of a concentration of chlorophyll-*a* (the green pigment in plants) on the bed of rivers. The lower thresholds were used in the study as the criteria to achieve the corresponding target attribute state (Bands A, B and C, Table 3). In this study, it was assumed that river segments with fine bed substrates (i.e., soft-bottomed segments) cannot support appreciable periphyton biomass (referred to as conspicuous periphyton by MFE, 2019). River segments with coarse and fine bed substrates were discriminated using substrate size index values of <3 and ≥3 respectively. Substrate size index values were based on modelled estimates that are available in the Freshwater Environments of New Zealand database (FENZ; Leathwick *et al.*, 2010).

Table 3. Periphyton target attribute state thresholds defined by chlorophyll-a concentrations (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).

Target attribute state	Periphyton biomass thresholds
A	≤50
B	>50 and ≤120
C	>120 and ≤200 National Bottom line (NZ Government, 2020)

Two sets of nutrient criteria to achieve periphyton biomass objectives were used in this study: National and Regional criteria. First, Snelder *et al.* (2019) developed criteria for nitrogen and phosphorus that apply nationally but which vary spatially according to 21 river classes defined by the second (Source-of-flow) level of the River Environment Classification (REC; Snelder and Biggs, 2002). The ‘National criteria’ are specified in terms of median concentrations of total nitrogen (TN) and dissolved reactive phosphorus (DRP). They vary according to the periphyton biomass objectives which are defined by the target attribute states shown in Table 3.

The national criteria provide for the uncertainty of the nutrient-biomass relationships on which they are based. The uncertainty means that there is a risk that a proportion of locations will exceed a nominated biomass threshold even when they are compliant with the associated TN and DRP criteria. This is a feature of most environmental criteria but is often overlooked because if a criterion is specified by regulation, it tends to not be contested. Under the NPS-FM, nutrient criteria for rivers to achieve periphyton objectives have not been set in regulation. The NPS-FM requires that councils establish nutrient criteria at the regional level and, therefore, these criteria are likely to be subject to scrutiny and to be contested.

The national criteria provide for the uncertainty of the underlying nutrient-biomass relationships by providing for differing levels of risk that locations will exceed a nominated biomass threshold when they are compliant with the associated TN and DRP criteria (Snelder et al., 2019). The risk is referred to as an under-protection risk[2], which is an estimate of the proportion of locations that will exceed the nominated biomass threshold when compliant with the nutrient criteria. The under-protection risk indicates the proportion of randomly drawn locations that will exceed the specified periphyton biomass when compliant with the concentration criteria. Because the level of acceptable risk is a management, rather than a scientific, decision, the analyses in this study that used the national criteria were performed with two choices of under-protection risk: 20% and 30%. The 20% under-protection risk is always a lower concentration than the concentrations corresponding to the 30% risk and, therefore, assessments based on the 20% under-protection risk generally have higher load reduction requirements.

A test of the national criteria indicated they were overly stringent relative to the periphyton biomass and TN concentrations observed at 173 river monitoring sites across New Zealand (59 of which were in the Manawatū-Whanganui region; Snelder *et al.* 2019). As suggested by Snelder *et al.* (2019), the original TN criteria were recalibrated to match the observations at the monitoring sites.

In the analysis, periphyton biomass objectives are specified as NOF target attribute states (i.e., A, B or C, Table 3). The relevant TN and DRP concentration criteria for each segment were defined by obtaining each segment's REC class and looking up the relevant concentration criteria from the tables shown in Appendix B (Table 22 and Table 23).

The second source of nutrient criteria were based on regional analyses of nutrient versus periphyton biomass relationships developed by (Kilroy *et al.*, 2018). These relationships incorporate a range of variables in addition to nutrient concentrations including electrical conductivity, temperature, substrate size and the frequency of 'effective flows' (EF, high flows that reduce biomass to low levels). The models that included nitrogen (either as TN or dissolved inorganic nitrogen (DIN)) performed well (R^2 ranged between 0.74 and 0.87). However, the study failed to define functional relationships between phosphorus and periphyton biomass.

Nitrogen concentration criteria for individual sites were developed using three of the models by Kilroy (2019). The model identified by Kilroy (2019) as Model 2 was general (i.e., it applied to all the sites in the study) and can therefore be used to define criteria for every segment of

[2] Note that Snelder et al. (2019) refer to spatial exceedance criteria (not risk).

the river network in the region, which is a requirement for criteria used in this study. The equation representing Model 2 is as follows:

$$log_{10}(Chla92) = -1.444 + \left(0.084 \times \sqrt{EC}\right) + \left(0.726 \times log_{10}(TN)\right) + (0.008 \times pccoarse) \quad \text{Equation 5}$$

where Chla92 is the 92nd percentile of the monthly chlorophyll observations at each site, *EC* is the median site electrical conductivity and *pccoarse* is a measure of stream substrate composition (the mean percentage of streambed covered by bedrock, boulders and large cobbles combined). The variables *EC* and *pccoarse* are site specific measures of local conditions at the 58 periphyton monitoring sites that Kilroy (2019) used to fit Model 2. In the present study random forest models were used to predict *EC* and *pccoarse* for all segments of the digital river network using the same methods that were used to predict current nutrient concentrations and loads (see Section 2.3 and 2.4).

We used Model 2 to derive concentration criteria (hereafter the 'Regional criteria') to achieve the periphyton biomass objectives for every segment of the river network in two steps. First, we rearranged the equation describing Model 2 above to make the nitrogen term (i.e., TN) the subject of the equation. Second, we set *Chla92* to three values (50, 120 and 200 m^3 m^{-3}) corresponding to the NOF band thresholds (Table 3) and solved for the nitrogen concentration corresponding to each biomass threshold for every network segment. More detail including a comparison of criteria derived using Kilroy (2019) with those derived using Snelder *et al.* (2019) are contained in Appendix A.

Compliance for each river segment was assessed by comparing the current estimated concentrations of TN and DRP with the concentration criteria; where the TN criteria were both the criterion derived using Kilroy (2019) and using Snelder *et al.* (2019). Where the current concentration was less than the concentration criteria, the segment was assessed as compliant and vice versa.

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

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

$$\frac{Concentration_1}{Load_1} = \frac{Concentration_2}{Load_2} \qquad \text{Equation 6}$$

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

$$MAL = Concentration_{Criterion} \times \frac{Current\ \ load}{Current\ concentration} \qquad \text{Equation 7}$$

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

2.6.2 Lakes

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

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

Target attribute state	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

Compliance for each lake is derived from its objective, which is specified by one of three attribute band thresholds shown in Table 4. The attribute band thresholds specifies the TN and TP concentration criteria (Table 4) by lake type (stratified or polymictic). Lakes were assigned to the stratified type if their depth was > 7.5m for consistency with Abell *et al.* (2019, 2020), otherwise were assigned to the polymictic type.

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

The MAL for each lake was derived in two steps. First, the TN and TP concentration criteria were obtained from Table 4 based on each lake's objective. Second, these TN and TP concentration criteria were converted into equivalent TN and TP loads (the MALs) by rearranging Equation 3 and 4 to make the mean flow weighted concentration of TN and TP (i.e., TN_{in} and TP_{in}), the subject of each equation and solving for the required TN and TP concentration criteria. Local excess loads were calculated for each lake as the current TN and TP loads minus the respective MALs.

2.7 Derivation of WMSZ load reduction status

Derivation of the WMSZ load reduction status begins by identifying the critical points in each sea-draining catchment in the region. A critical point is defined as the receiving environment for which the ratio of the current load to the MAL is not exceeded by any upstream receiving environment. The load reduction status for all WMSZs upstream of the critical point indicates the magnitude of the load reduction needed to comply with the concentration criteria at the downstream critical point and, therefore, in all receiving environments on the WMSZ's downstream drainage path. This load reduction requirement can be expressed as a percentage of current TN and TP load at the critical point or as a reduction in yield (kg ha^{-1} yr^{-1}). When expressed as a percentage or yield, the critical point load reduction requirement represents the spatial average reduction rate if reductions were to occur uniformly over the entire catchment upstream of the critical point. However, load reductions can only be achieved from resource using activities such as land use and point sources. Because there are generally parts of catchments upstream of critical points that are not subject to resource use (e.g., areas of natural vegetation and/or conservation estate), actual reduction rates from resource using areas will need to be higher than indicated by the spatial average rate.

The limiting environment indicates whether the critical point is a 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 locations.

The process of identifying the critical points and WMSZ load reduction status is as follows. The terminal segment of every sea-draining catchment (the river mouth) is defined as a critical point and the ratio of the current load to the MAL at that point is noted. The load reduction status upstream of this point is the local excess load of this critical point. From the terminal segment, the ratio of the current load to the MAL at successive upstream receiving environment are obtained. Note that successive receiving environments may be river segments or lakes. At each receiving environment, the ratio of the current load to the MAL is compared with the ratio for the downstream critical point. If the ratio at the local receiving environment is greater than that of the downstream critical point, the receiving environment is defined as a critical point and the load reduction status upstream of this point is the local excess load of the local (new critical point) receiving environment. If the local ratio of the current load to the MAL at the receiving environment is less than that of the downstream critical point, the 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)[3].

For reporting in this study, the WMSZ load reduction status is expressed in both absolute terms as a yield (mass per area per year; kg ha^{-1} yr^{-1}) and as a percentage of the current load. The yield has special relevance to agricultural land use because it has the same units as nutrient loss rate estimates that are commonly estimated using nutrient budgeting models

[3] 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.

such as OVERSEER. It should be kept in mind that the absolute load reduction status values that are reported indicate the load reduction divided by the whole catchment area. 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.

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, DRP 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. The models were derived from differing numbers of sites due to data availability. However, 75 of these sites were in common to all models and it was expected that the residual errors from each model would be correlated to a degree with the errors of the other seven models. A correlation matrix derived from the eight sets of model errors for the sites in common 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 values of the four nutrient concentrations (TN, NO3N, TP and DRP), the soluble proportion of TP and TN (i.e., DRP in TP and NO3N in TN), and the current loads. At the third step, the procedure described above was repeated for each realisation using the perturbed values. At the fourth step, the distribution of values of the concentrations, current loads, local excess loads, and load reductions required obtained from the 100 realisations were used to provide a best estimate and the uncertainty of the assessments. The uncertainty of the assessments of compliance were quantified by estimating the probability that each segment was compliant across the 100 realisations. Segment compliance was therefore assessed as a value between one (100% confident the segment is compliant or suitable) to zero (100% confident the segment is non-compliant). For the current state, local excess loads, and load reduction required assessments, the best estimate was represented by the median value from the distribution of values. This median is the middle value of the distribution and is therefore greater than and less than 50% of the realised values. The uncertainty of these two assessments was quantified by their 90% confidence intervals. For the load reduction required assessment, the best estimates and the uncertainties were estimated from the 100 realisations for the reporting catchments, estuary catchments and the entire region.

3 Results

3.1 Performance of current nutrient concentration models

The RF models of median concentrations of TN, TP, NO3N and DRP and median soluble proportions of TP and TN had at least satisfactory performance (Table 5), as indicated by the criteria of Moriasi et al. (2015; Table 1). The mapped predictions of four nutrient concentrations had similar coarse-scale spatial patterns. Contaminant concentrations tended to be lowest in the catchment headwaters and highest in the lowland coastal areas (Figure 6). TP had strong dependence on catchment and river size, with the main stems of the large rivers consistently having the highest concentrations. In addition to high export coefficients in the coastal plains areas, high concentrations of NO3N and TN were associated with the inland farming areas around Taumarunui in the upper Wanganui catchment. The effect of urban areas and point sources was also evident in many of the spatial distributions (Figure 6). These patterns were consistent prior modelling of Fraser and Snelder (2020) and with the expectation that increasing enrichment of rivers and streams occurs in association with increasing proportions of catchments occupied by agricultural and other land uses as well as point source discharges.

Table 5. 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	135	0.76	0.76	1.43	0.21	log10
NO3N	135	0.55	0.55	1.16	0.36	log10
TP	135	0.70	0.70	0.70	0.23	log10
DRP	135	0.58	0.58	0.51	0.26	log10
NO3N in TN	134	0.36	0.36	-11.71	0.91	logit
DRP in TP	134	0.56	0.56	18.32	0.65	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 6). The predictions of soluble proportion of TP had highest values around the volcanic plateau (Figure 6). The predictions of soluble proportion of TN had highest values in parts of the river network with upstream catchments dominated by agricultural land use (Figure 6).

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 259 mg m^{-3} to 4,250 mg m^{-3} (Figure 7). The logit transformations of the site median soluble proportions of TP and TN means 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 7).

Model bias (i.e., systematic error) was greatest for the models of the soluble proportion of TP and TN and was low for all other variables (Table 5). Model bias was small compared to the random component of error for all models, which indicates that the predictions are reliable descriptions of broad scale patterns but that there is considerable uncertainty associated with individual locations.

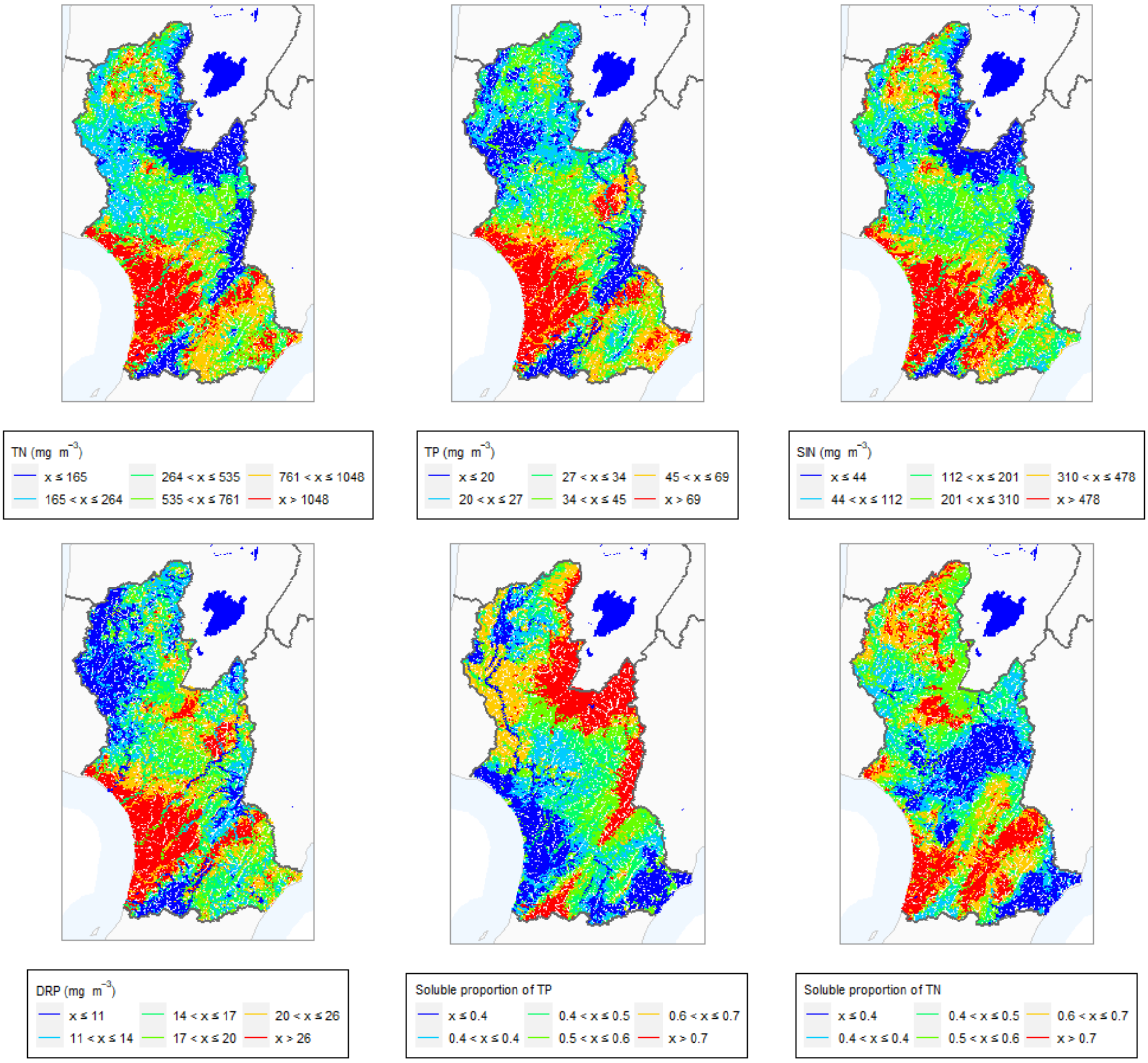


Figure 6. Predicted patterns of the current median concentrations of TN, TP, NO3N and DRP and the soluble proportions of TP and TN, respectively. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

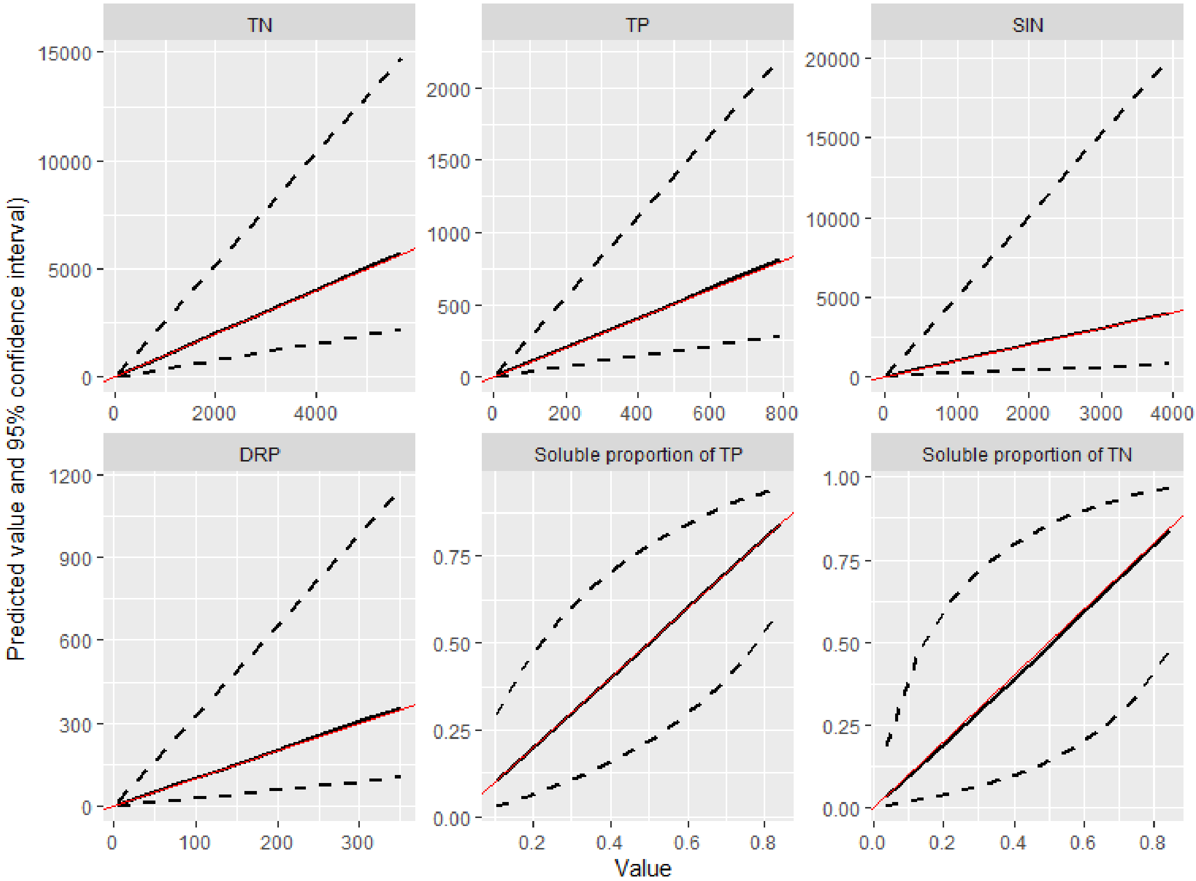


Figure 7. The characteristic statistical error (i.e., uncertainty) of the predictions for the concentration and soluble proportions of TP and TN models. The x-axis of each panel shows the range in the region of actual (observed) concentrations of TN, TP, NO3N, and DRP and DRP in TP and NO3N in TP, respectively. The y-axis characterises the statistical error of the predictions along the range of the observations. The solid central line indicates mean prediction associated with an observed value. The red line is one to one and indicates a perfect prediction. The gap between the red line and the solid black line indicates the systematic error (the bias), which is small. The dashed lines indicate the random component of error based on the 95% confidence interval for individual predictions.

3.2 Performance of TN and TP current load models

The RF models of TN and TP annual yield had satisfactory performance (Table 6), as indicated by the criteria of Moriasi et al. (2015; Table 1). The mapped predictions of annual yields of all three nutrients had relatively high values in the large main stem rivers (Figure 8). These patterns were consistent with expectations and reflect the increasing enrichment of rivers and streams in association with increasing proportions of catchments occupied by agricultural and other land uses.

Table 6. Performance of random forest models of loads of TN and TP.

Variable	N	R^2	NSE	PBIAS	RMSD	Transformation
TN	78	0.64	0.62	-1.75	0.15	78
TP	78	0.60	0.60	2.04	0.17	78

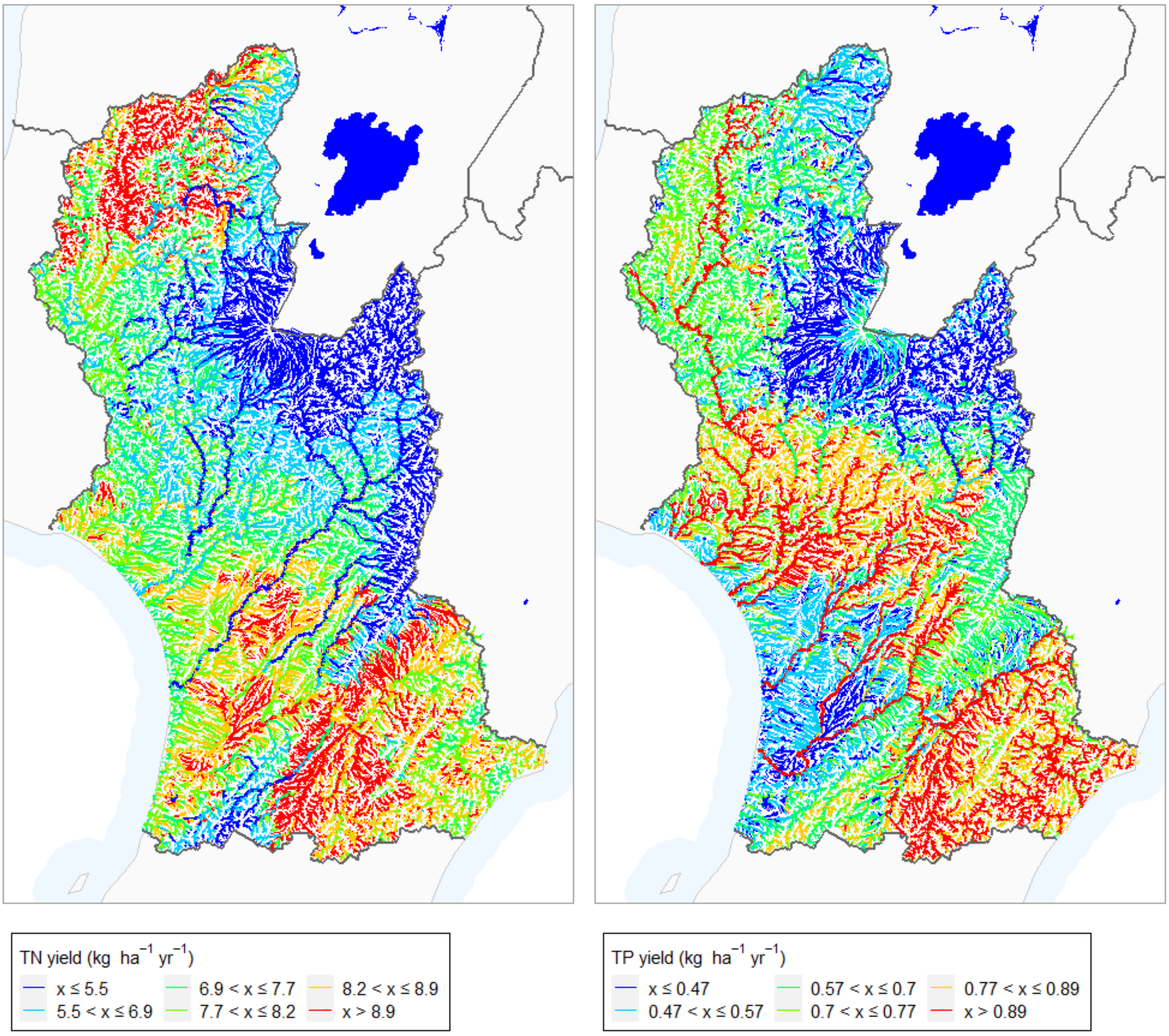


Figure 8. Predicted patterns of the current TN and TP loads (as yields kg ha-1 yr-1) Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

The log_{10}-transformation of the site TN and TP yields and the fourth root transformation for DRP mean both the systematic and random components of the prediction uncertainty, when expressed in the original units of the variables, vary in proportion to the predicted value and the confidence intervals are asymmetric (Figure 9). The uncertainty of predictions of all three 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 5 kg ha^{-1} yr^{-1} has a 95% confidence interval of 2.2kg ha^{-1} yr^{-1} to 11.2 kg ha^{-1} yr^{-1} (Figure 9). However, model bias (i.e., systematic error) was low for all variables (Table 6, Figure 9). This indicates that the predictions are reliable descriptions of broad scale patterns in TN, TP and DRP loads, but that there is considerable uncertainty associated with load predictions for individual locations.

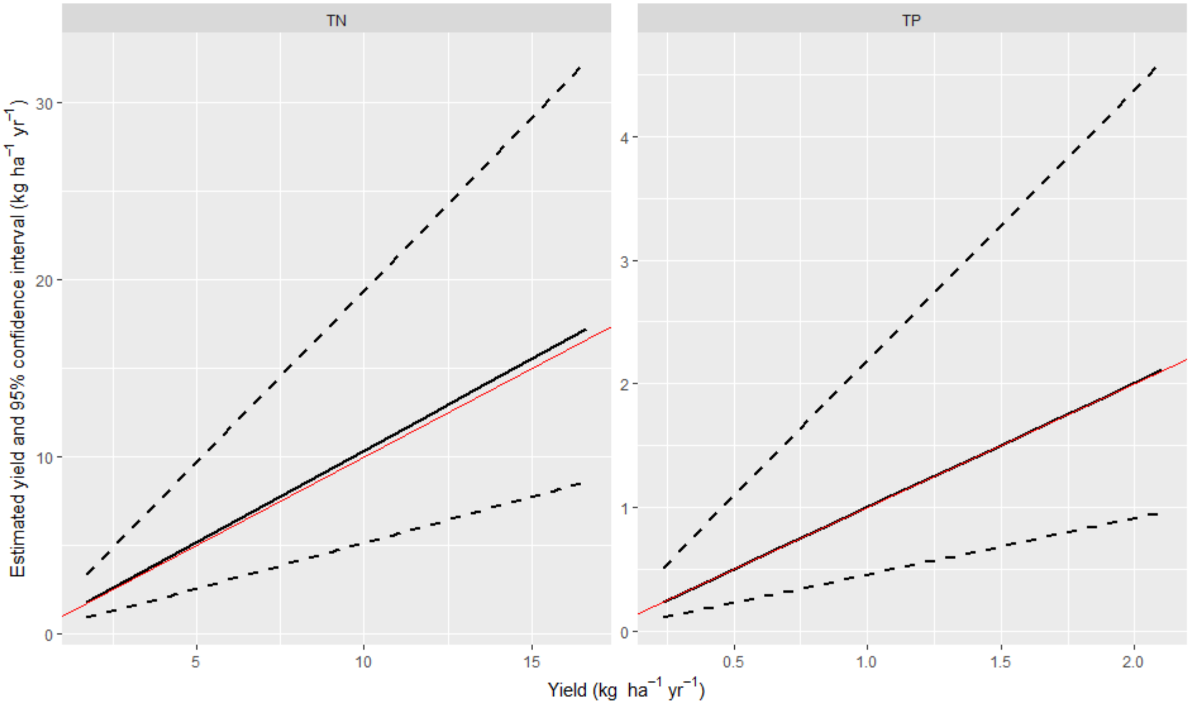


Figure 9. The characteristic statistical error (i.e., uncertainty) of the current load model predictions. The x-axis of each panel shows the range in actual (observed) yields of TN and TP in the region. The y-axis characterises the statistical error of the predictions along the range of the observations. 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 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 7). The soluble proportions of TP and TN were strongly negatively correlated with the corresponding soluble component concentrations. The correlation structure shown in Table 7 was used to generate random normal deviates (ε_r) for each model in the Monte Carlo analysis.

Table 7. 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	**DRP concentration**	**SIN concentration**	**TN concentration**	**TP concentration**	**DRP in TP**	**DIN in TN**	**TN load**	**TP load**
SIN concentration	0.30							
TN concentration	0.32	0.90						
TP concentration	0.73	0.36	0.46					
Soluble proportion of TP	-0.58	-0.05	-0.07	-0.11				
Soluble proportion of TN	-0.37	-0.89	-0.84	-0.33	0.25			
TN load	0.19	0.68	0.70	0.34	0.01	-0.64		
TP load	0.32	0.23	0.30	0.51	0.03	-0.15	0.50	
DRP load	0.64	0.15	0.19	0.47	-0.48	-0.21	0.31	0.36

3.4 One Plan targets using national criteria and 20% risk

3.4.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of exceeding the criteria associated with the One Plan options (i.e., were non-compliant) for 49% and 66% of segments in the region, respectively (Figure 10). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the One Plan options for the nitrate toxicity FWO for 1% of segments. However, the probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at only 0.1% of river segments (Figure 10).

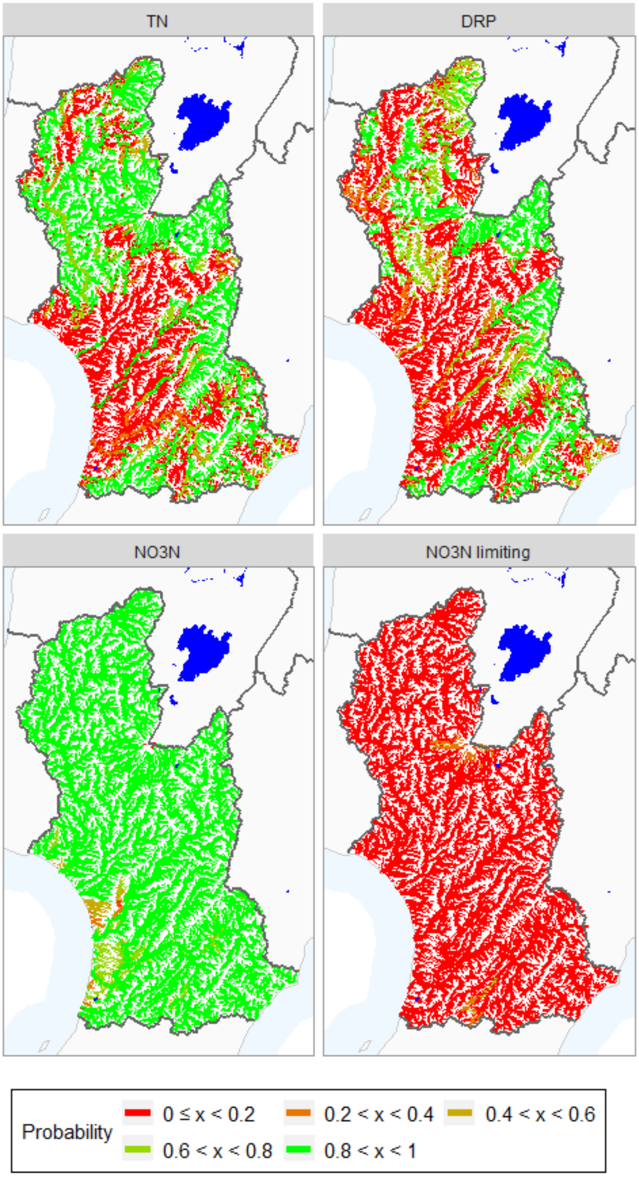


Figure 10. Probability that segments comply with river concentration criteria associated with the One Plan targets using national criteria and 20% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations are compliant with the criteria associated with the One Plan options was less than 50% (i.e., were non-compliant) for 35 and 33 of the 41 assessed lakes in the region, respectively (Figure 11).

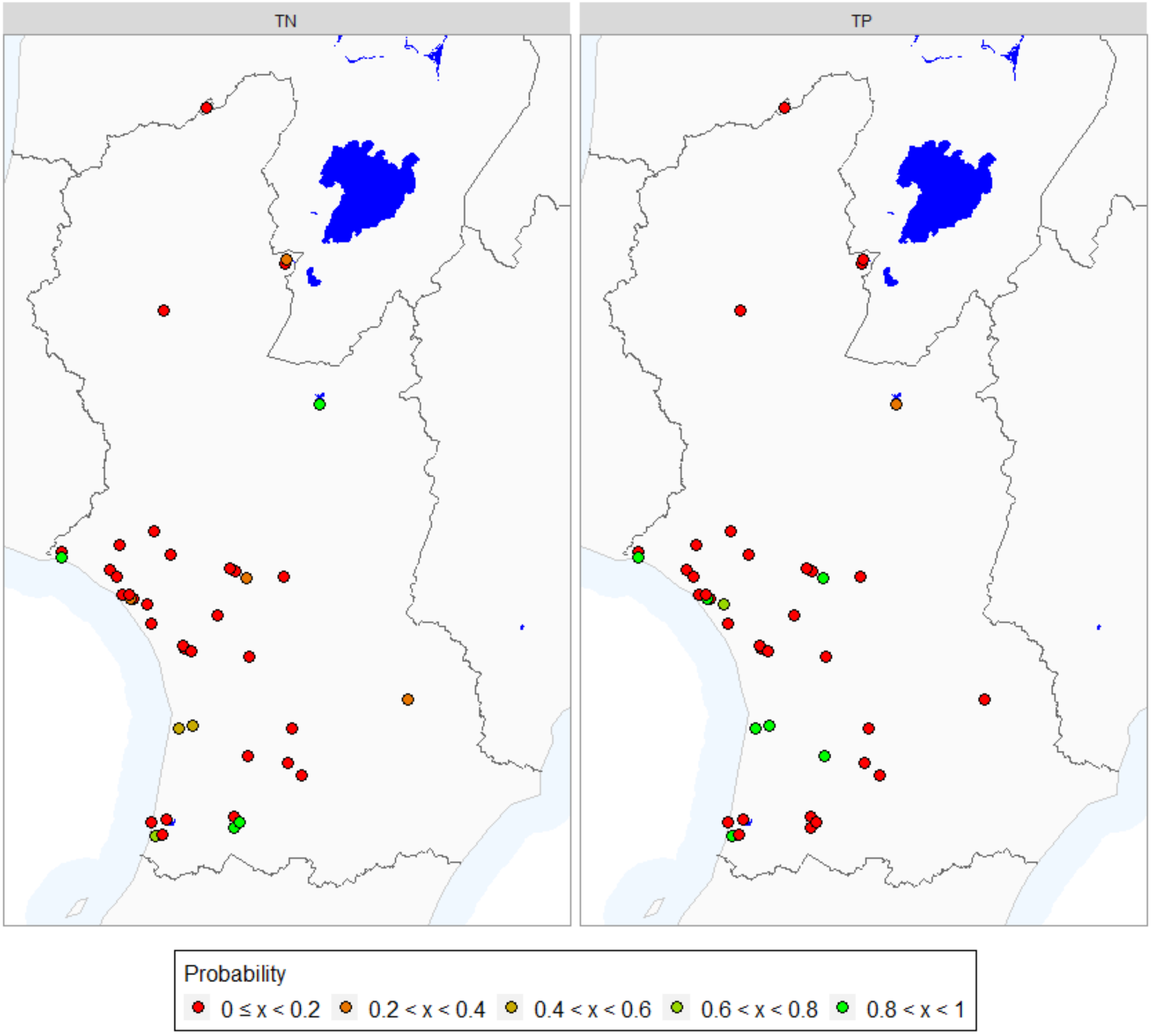


Figure 11. Probability of compliance with lake TN and TP concentration criteria associated with the One Plan target options.

3.4.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the objective for that receiving environment. For the One Plan targets using national criteria and 20% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 19% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 8% of river segments (Figure 12). 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 12. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 42% of segments.

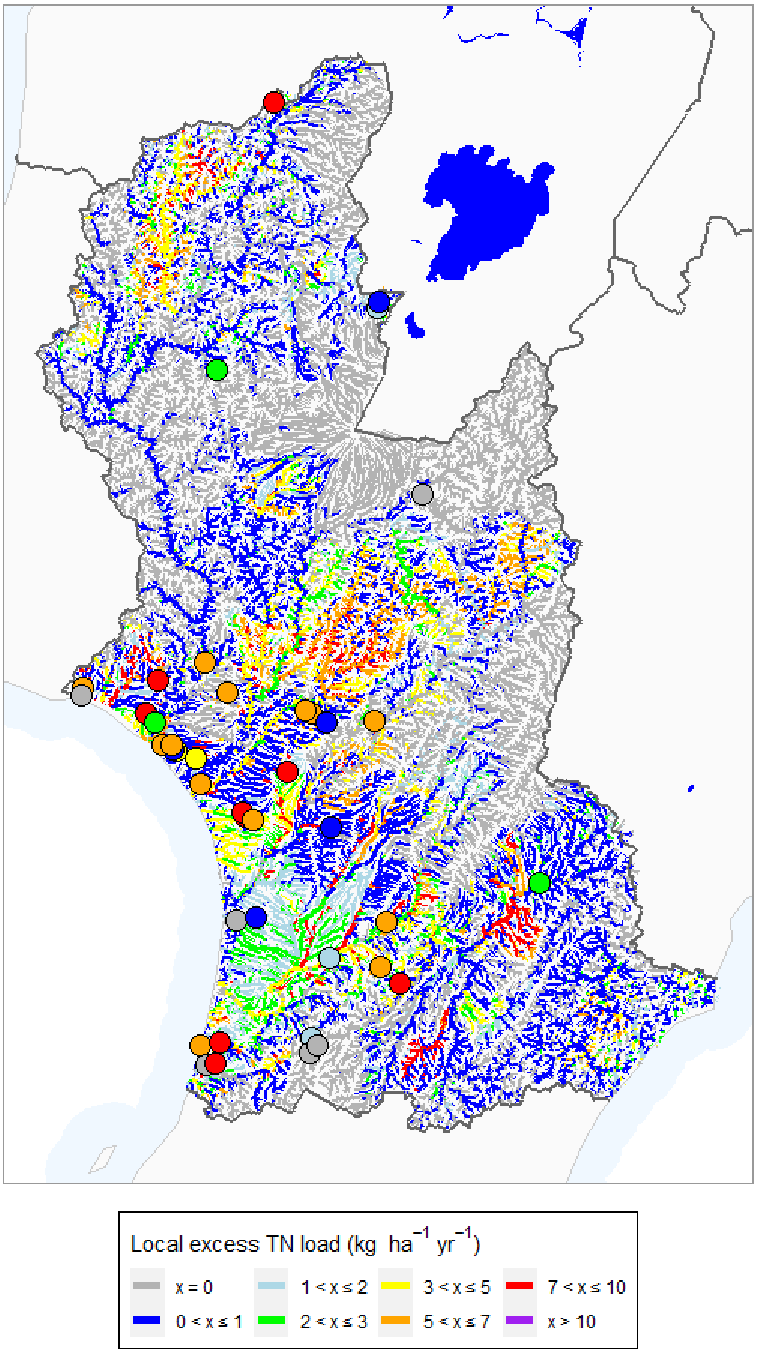


Figure 12. Local excess TN loads for rivers and lakes for the One Plan target using national criteria and 20% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the One Plan targets using national criteria and 20% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 37% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 32% of river segments (Figure 13). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 41% of segments.

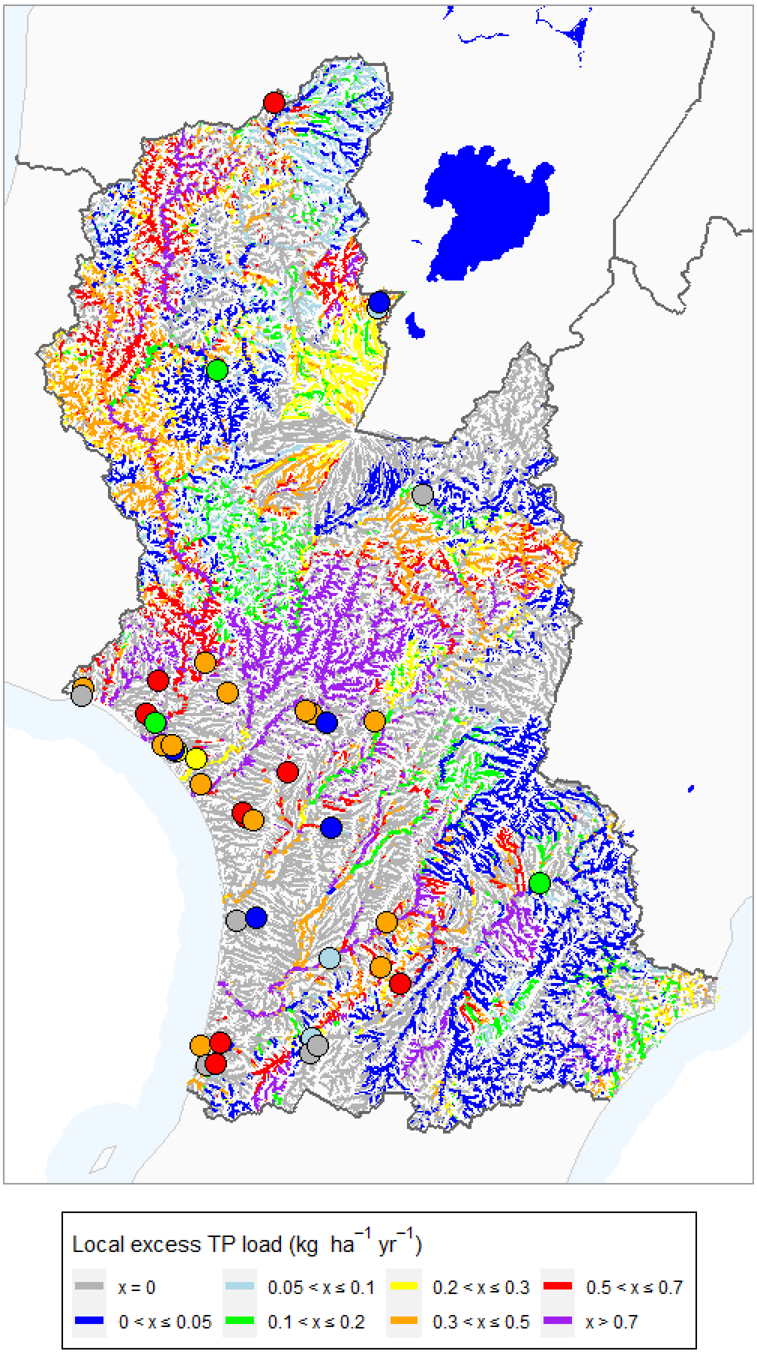


Figure 13. Local excess TP loads for rivers and lakes for the One Plan target using national criteria and 20% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.4.3 FMU and regional load reductions required

The load reductions required by the One Plan targets using national criteria and 20% risk for each FMU and for the whole region are shown in Table 8. For the whole region, the TN and TP load reductions required were estimated to be 10,336 t yr^{-1} and 3,401 t yr^{-1}, which represent 60% and 106% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 8. The uncertainties indicate, for example that the 90% confidence interval for the current regional load of TN extends between 5,697 t yr^{-1} and 14,620 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 47% and 71% (best estimate 60%) and the regional TP load reduction requirement extends between 99% and 115% (best estimate 106%). Load reductions of over 100% occurred for some FMUs and the whole region because model predictions of TP load 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 and this would lead to reduction in loads in the downstream direction.

For the One Plan targets using national criteria and 20% risk, the best estimates of TN load reductions required were very high (>50%) in the Kai Iwi, Whanganui, Whangaehu, Rangītikei-Turakina, and Manawatū FMUs. The TP load reductions required were higher than 60% in all FMUs except Waiopehu and Puketoi ki Tai.

Table 8. Current load and load reduction required for TN and TP for FMUs and the whole region for the One Plan targets using national criteria and 20% risk. 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 (%)**
Kai Iwi	234 (149 - 319)	187 (107 - 275)	79 (68 - 85)	32 (18 - 51)	30 (16 - 49)	92 (84 - 97)
Whanganui	5,934 (3,101 - 9,491)	4,142 (1,404 - 7,980)	67 (43 - 85)	1,352 (696 - 2,196)	1,463 (756 - 2,385)	109 (95 - 115)
Whangaehu	1,191 (692 - 2,084)	703 (262 - 1,420)	56 (38 - 76)	287 (120 - 481)	266 (113 - 458)	93 (86 - 96)
Rangitīkei-Turakina	3,216 (2,046 - 4,624)	2,052 (725 - 3,675)	61 (35 - 87)	629 (335 - 1,086)	844 (432 - 1,487)	133 (123 - 142)
Manawatū	5,087 (2,738 - 7,793)	2,774 (1,001 - 5,050)	52 (35 - 69)	701 (376 - 1,161)	674 (357 - 1,134)	96 (91 - 100)
Waiopehu	334 (253 - 437)	113 (73 - 164)	34 (25 - 46)	26 (18 - 36)	14 (9 - 22)	55 (42 - 65)
Puketoi ki Tai	980 (692 - 1,363)	329 (62 - 623)	32 (9 - 54)	176 (106 - 250)	104 (60 - 160)	59 (39 - 70)
Whole region	17,048 (12,428 - 21,899)	10,336 (5,697 - 14,620)	60 (47 - 71)	3,212 (2,295 - 4,161)	3,401 (2,350 - 4,627)	106 (99 - 115)

3.4.4 WMSZ load reduction status

WMSZ load reduction status are an indicative spatial average load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 12 and Figure 13) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

It is reiterated that the WMSZ load reduction status is spatial average reduction rate that is derived by considering the load reductions required in both the WMSZ and the downstream drainage path. It may not be possible to achieve the load reductions indicated by a particular WMSZ load reduction status because it comprises areas that are not subject to resource use (e.g., areas of natural vegetation and/or conservation estate). The WMSZ load reduction status should therefore be interpreted as indicating that there are load reduction requirements downstream and therefore, the potential to decrease discharges from resource use within the WMSZ will need to be considered.

The WMSZ load reductions required for TN under the One Plan targets using national criteria and 20% risk are shown on Figure 14 and Figure 15. There were 77 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these collectively occupied 60% of the region. The majority of these WMSZs were in in the Manawatū (38) and the Whanganui FMUs (29). There were 5 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 2% of the region (Figure 14). When load reductions required for TN were expressed as a proportion of current loads, 99 WMSZs required reductions of greater than 50% and these occupied 86% of the region (Figure 15). The comparison of WMSZ 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.

There were 115 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} and these collectively occupied 96% of the region (Figure 16). The majority of these WMSZs were in the Manawatū (49) and the Whanganui FMUs (29). There were 9 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 4% of the region (Figure 16). When load reductions required for TP were expressed as a proportion of current loads, 115 WMSZs required reductions of greater than 50% and these occupied 96% of the region (Figure 17). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

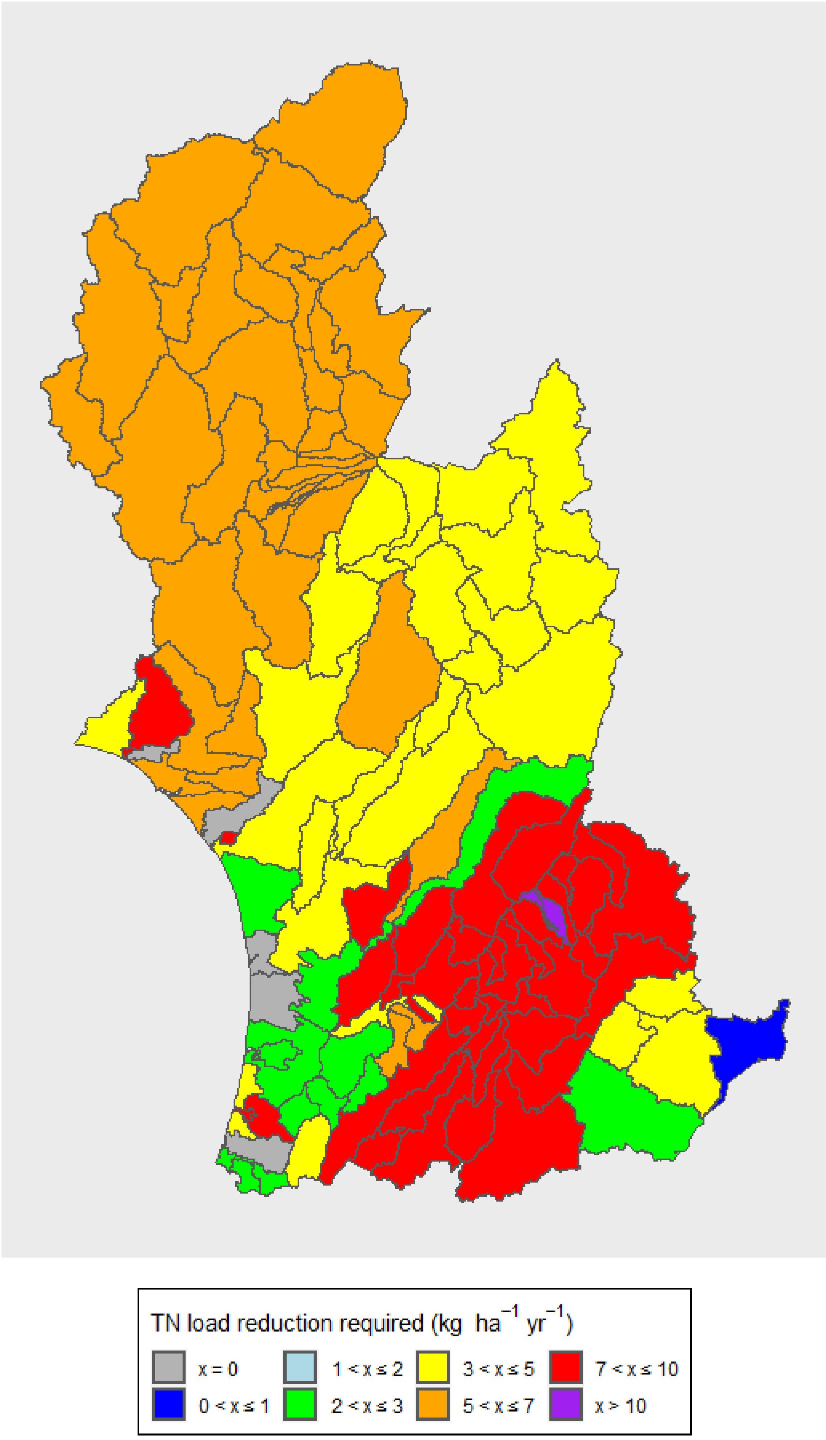


Figure 14. The TN WMSZ load reductions, expressed as yields, for the One Plan targets using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

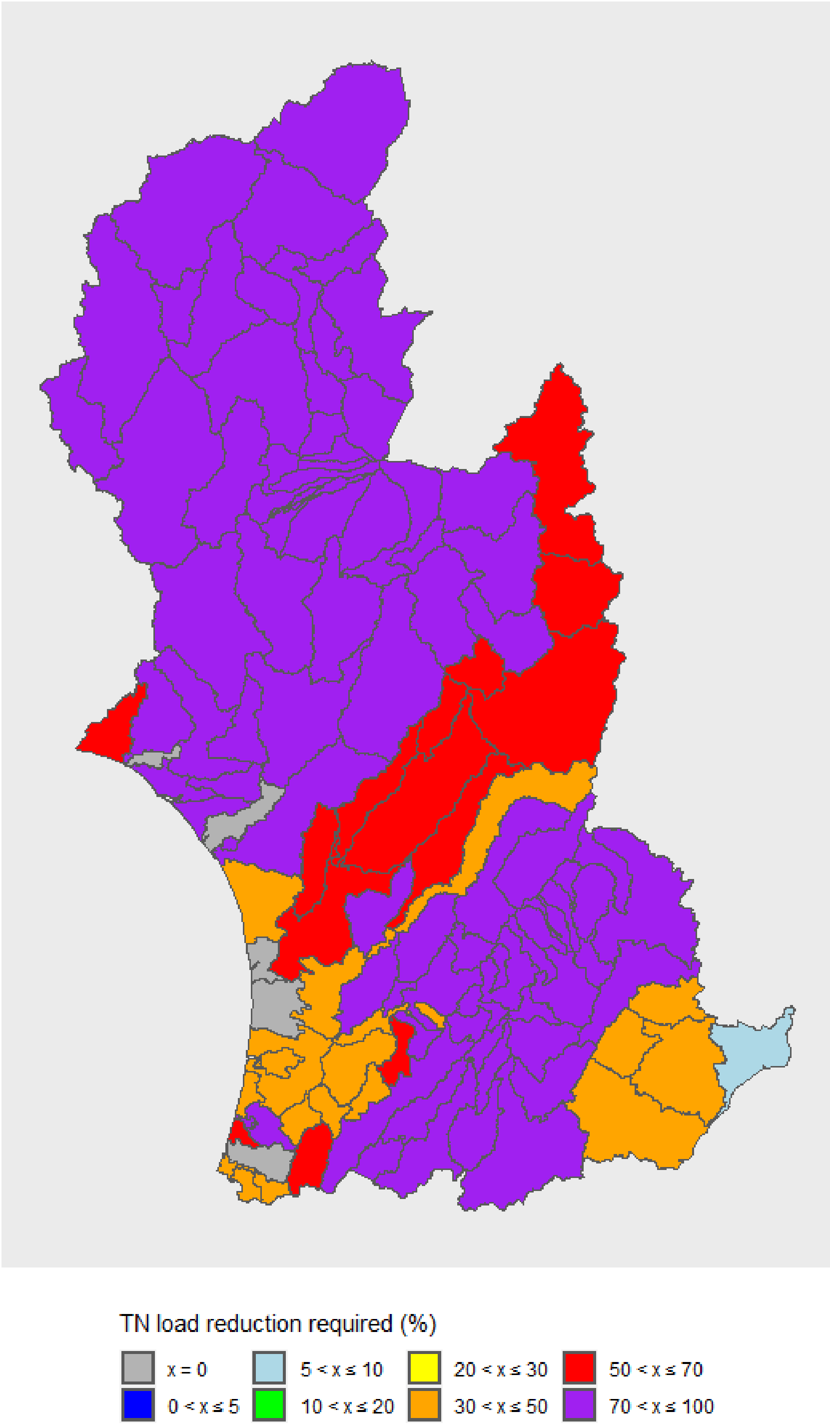


Figure 15. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the One Plan targets using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

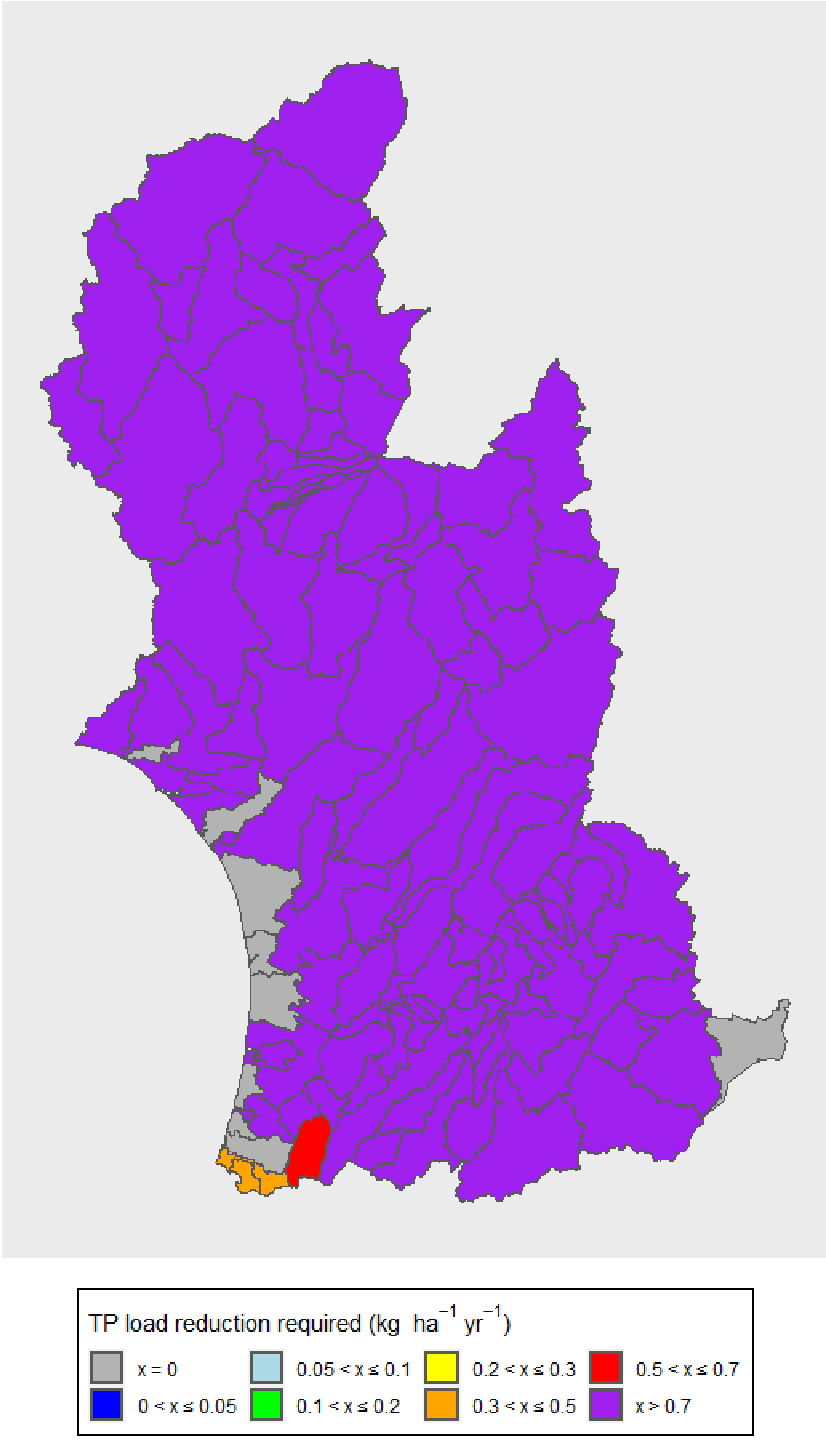


Figure 16. The TP WMSZ load reductions, expressed as yields, for the One Plan targets using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

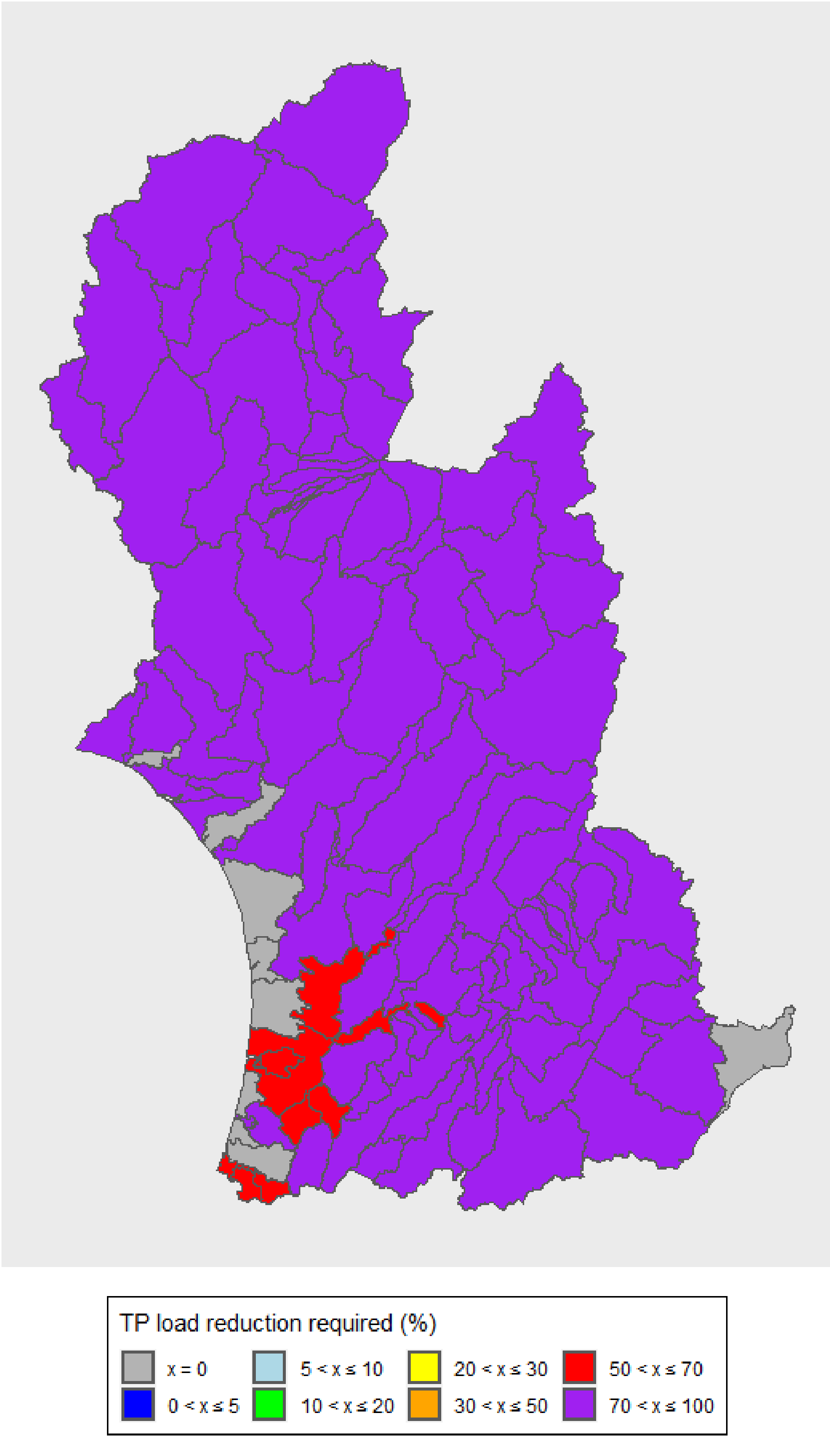


Figure 17. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the One Plan targets using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.4.5 Limiting environments

For the One Plan targets using national criteria and 20% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for three WMSZs (Hoki_1a, Mana_11b and

West_4) for TN and two for TP (Hoki_1a and West_4; Figure 18). At the maximum level of detail of the analysis, determined by the spatial framework's river network, lakes were the limiting receiving environments for TN for a small proportion (1%) of the region, and TP (0.5%).

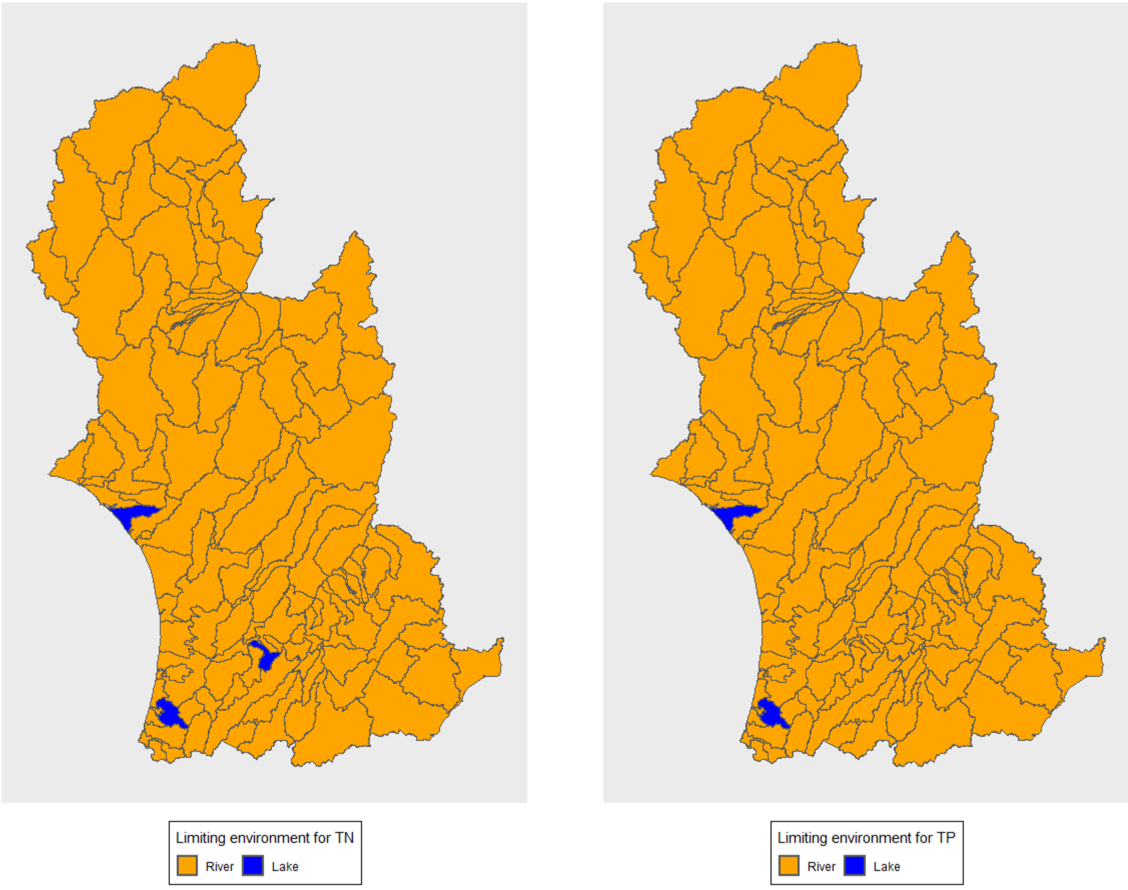


Figure 18. Limiting environment type for TN and TP load reduction requirements for WMSZs for the One Plan targets using national criteria and 20% risk.

3.5 One Plan targets using national criteria and 30% risk

3.5.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of exceeding the criteria associated with the One Plan targets using national criteria and 30% risk (i.e., were non-compliant) for 43% and 36% of segments in the region, respectively (Figure 19). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the One Plan options for the nitrate toxicity FWO for 0.9% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 1.3% of river segments (Figure 19).

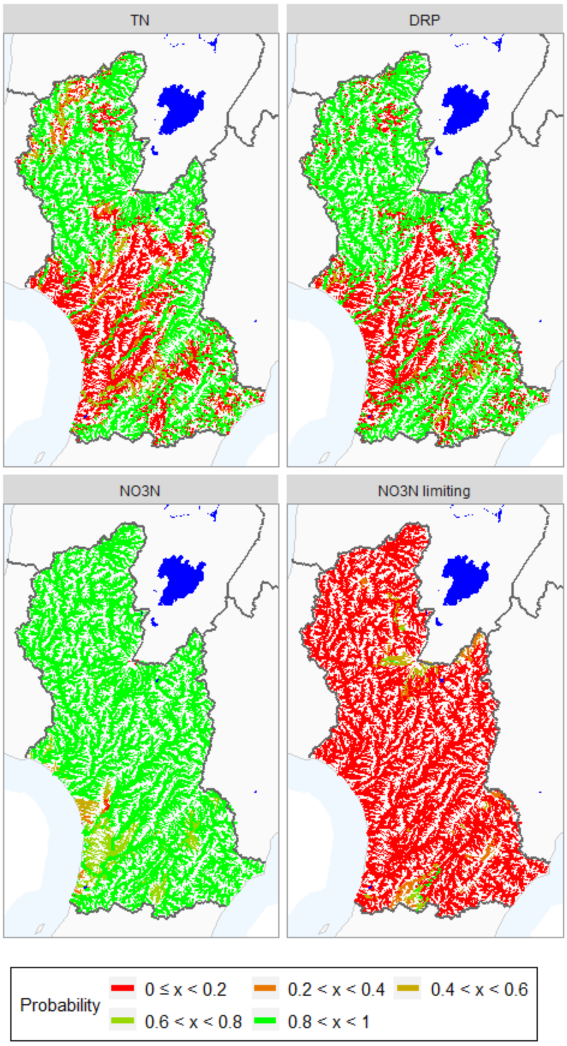


Figure 19. Probability that segments comply with river concentration criteria associated with the One Plan targets using national criteria and 30% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the One Plan targets was less than 50% (i.e., were non-compliant) for 35 and 33 of the 41 lakes, respectively (Figure 20).

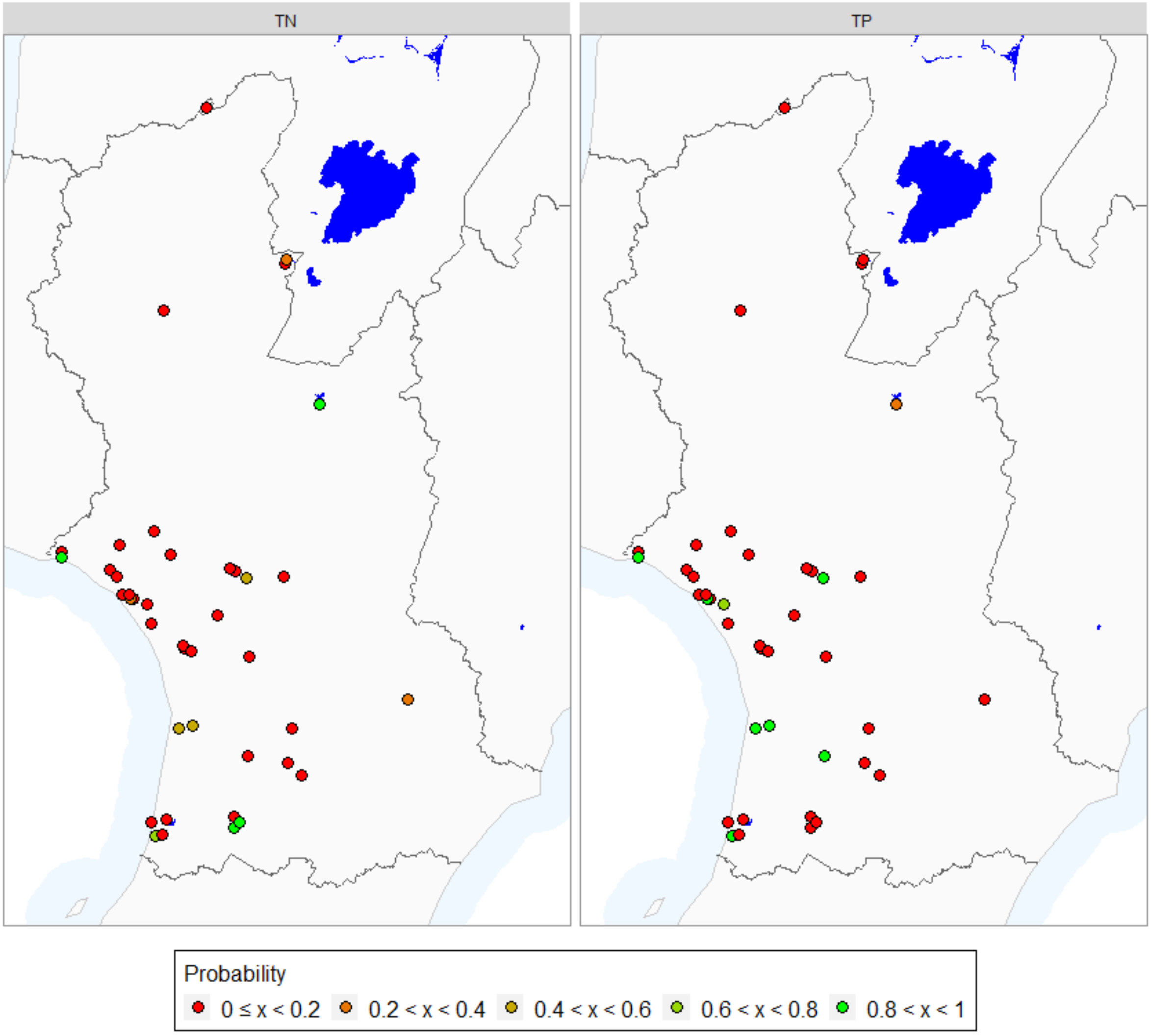


Figure 20. Probability of compliance with lake TN and TP load criteria associated with the One Plan options.

3.5.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the One Plan targets using national criteria and 30% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 14% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 5% of river segments (Figure 21). 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 21. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 39% of segments.

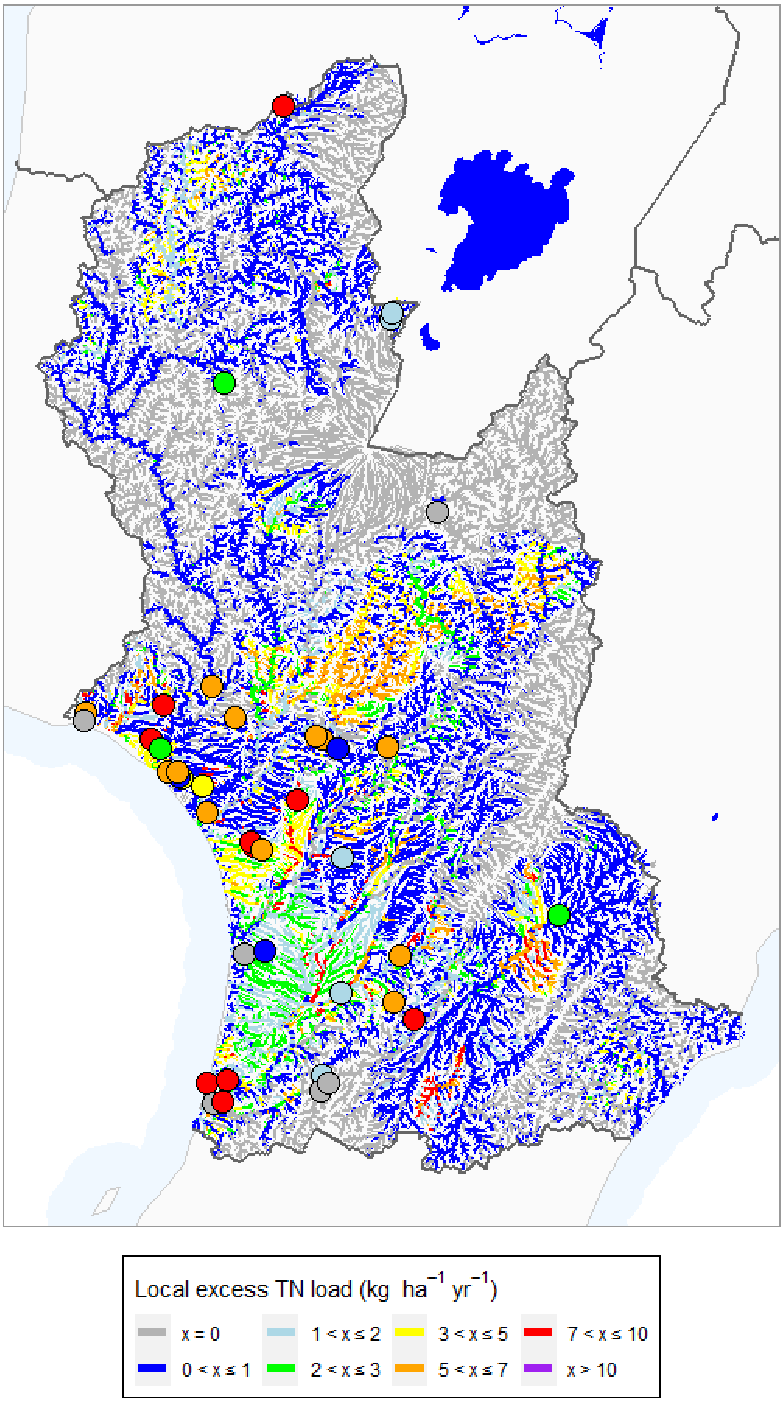


Figure 21. Local excess TN loads for rivers and lakes for the One Plan targets using national criteria and 30% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the One Plan targets using national criteria and 30% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 6% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 5% of river segments (Figure 22). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 88% of segments.

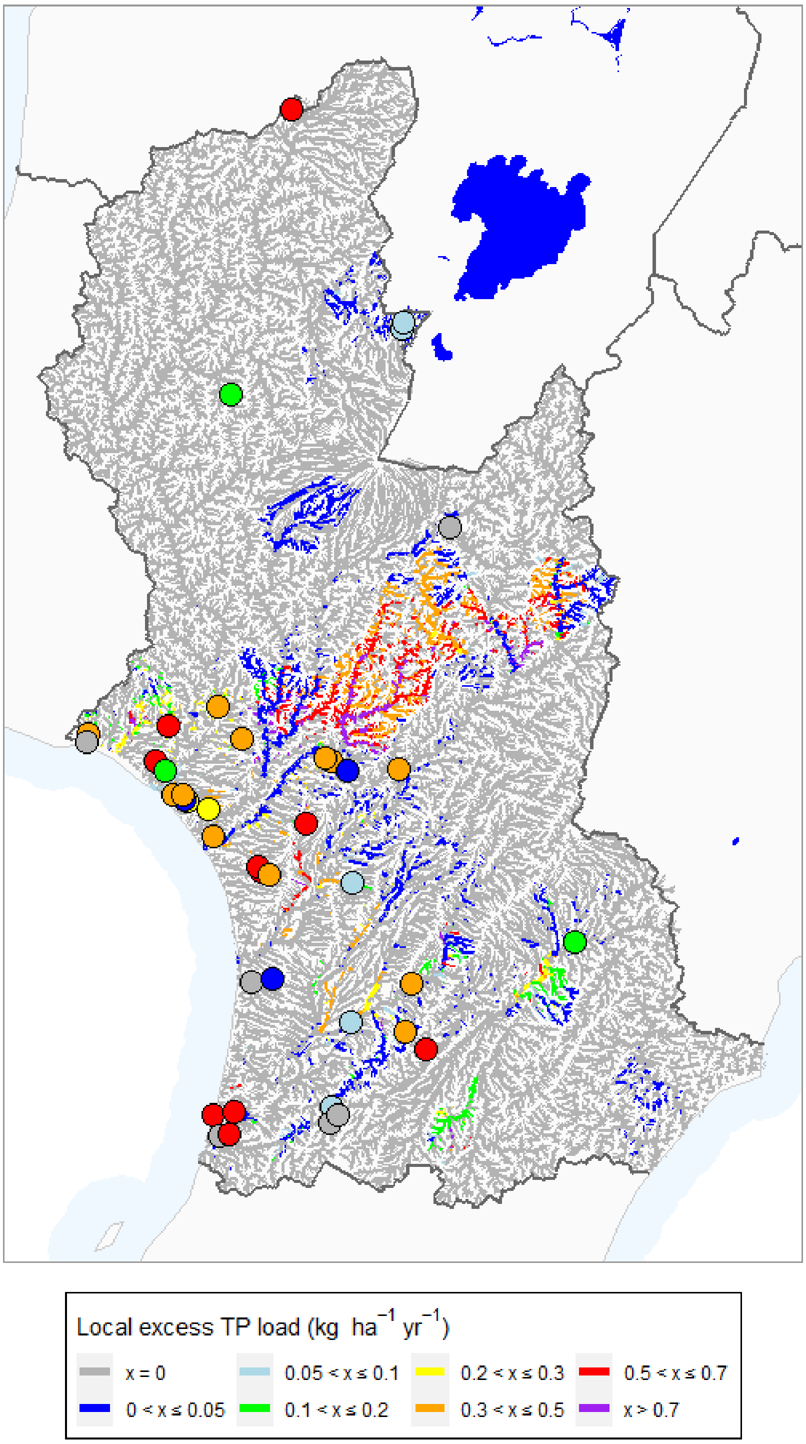


Figure 22. Local excess TP loads for rivers and lakes for the One Plan targets using national criteria and 30% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.5.3 FMU and regional load reductions required

The load reductions required by the One Plan targets using national criteria and 30% risk for each FMU and for the whole region are shown in Table 9. For the whole region, the TN and TP load reductions required were estimated to be 7,697 t yr^{-1} and 514 t yr^{-1}, which represent

43% and 16% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 9. Load reductions of over 100% occurred for some FMUs and the region as a whole because model predictions of TP load 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 and this would lead to reduction in loads in the downstream direction.

For the One Plan targets using national criteria and 30% risk, the best estimates of TN load reductions required exceeded 30% in all FMUs except Waiopehu and Puketoi ki Tai. The TP load reductions required were higher than 30% in only the Whangaehu, Rangitīkei-Turakina, and Kai Iwi FMUs.

Table 9. Current load and load reduction required for TN and TP for FMUs and the whole region for the One Plan targets using national criteria and 30% risk. 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 (%)**
Kai Iwi	221 (152 - 317)	165 (97 - 270)	74 (63 - 84)	31 (18 - 51)	25 (13 - 44)	81 (66 - 91)
Whanganui	6,332 (3,634 - 10,769)	3,210 (273 - 7,530)	46 (5 - 80)	1,305 (714 - 2,119)	52 (2 - 355)	4 (0 - 23)
Whangaehu	1,169 (547 - 2,016)	516 (193 - 1,164)	42 (29 - 60)	260 (133 - 448)	92 (43 - 156)	35 (29 - 38)
Rangitīkei-Turakina	3,270 (2,112 - 4,719)	1,323 (337 - 2,936)	38 (13 - 75)	693 (394 - 1,150)	237 (34 - 729)	34 (6 - 86)
Manawatū	5,198 (2,792 - 8,778)	2,262 (712 - 4,640)	41 (20 - 57)	729 (355 - 1,409)	102 (12 - 275)	15 (1 - 48)
Waiopehu	341 (236 - 455)	87 (51 - 138)	26 (17 - 36)	27 (18 - 36)	4 (2 - 7)	17 (9 - 26)
Puketoi ki Tai	971 (664 - 1,383)	119 (3 - 420)	11 (0 - 33)	176 (115 - 279)	0 (0 - 0)	0 (0 - 0)
Whole region	17,571 (13,226 - 24,676)	7,697 (3,237 - 12,961)	43 (25 - 59)	3,229 (2,383 - 4,566)	514 (192 - 1,057)	16 (6 - 32)

3.5.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 21 and Figure 22) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the One Plan targets using national criteria and 30% risk are shown on Figure 23 and Figure 24. There were 47 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 26% pf the region. The majority of these WMSZs were in in the Manawatū (36) FMU. There were 22 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 13% of the region. When load reductions required for TN were expressed as a proportion of current loads, 85 WMSZs required reductions of greater than 50% and these occupied 70% of the region (Figure 24).

There were 36 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} and these collectively occupied 28% of the region (Figure 25). The majority of these WMSZs were in in the Manawatū (17) and Whangaehu (10) FMUs. There were 83 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 68% of the region. When load reductions required for TP were expressed as a proportion of current loads, 35 WMSZs required reductions of greater than 50% and these occupied 28% of the region (Figure 26). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

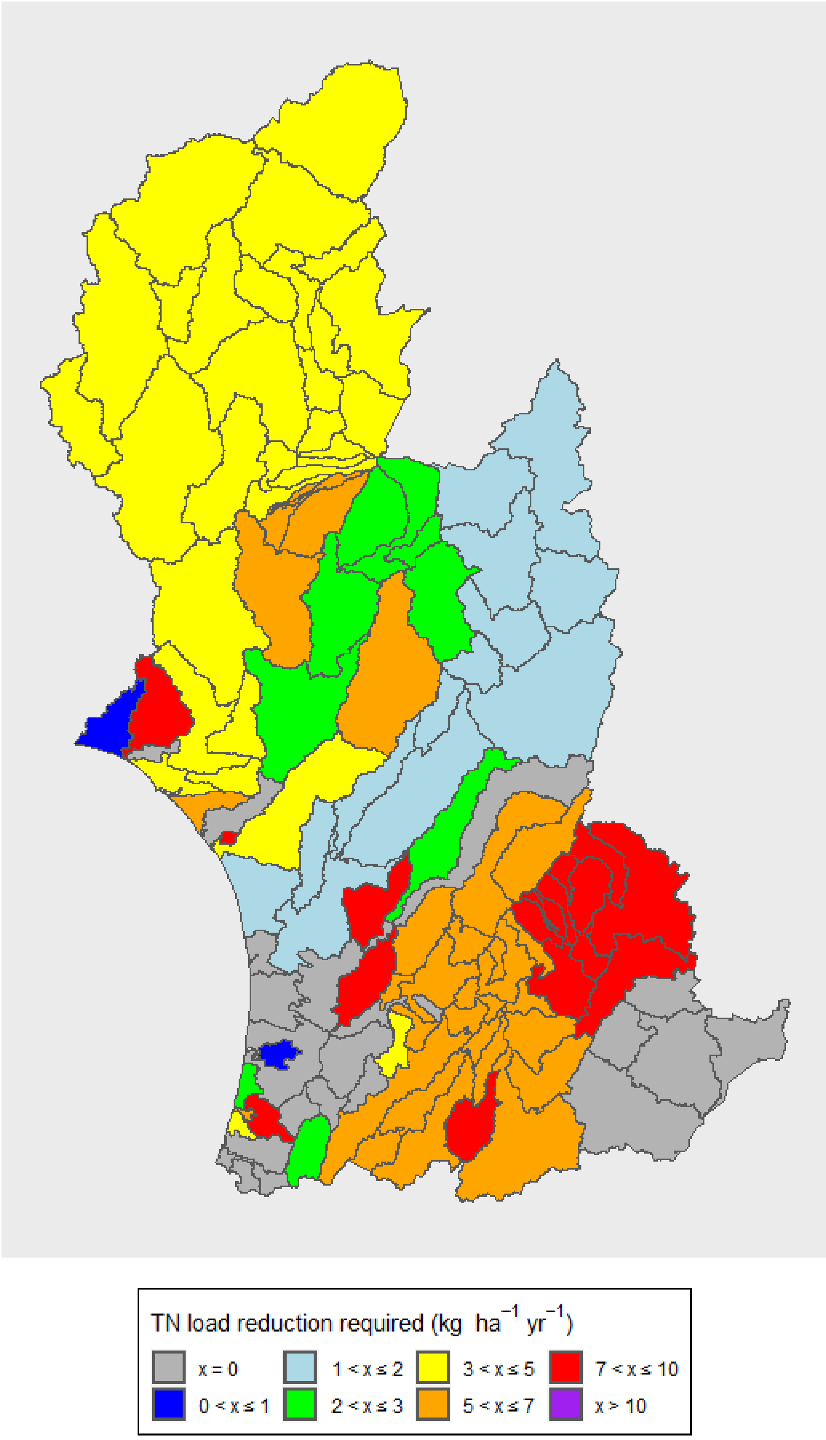


Figure 23. The TN WMSZ load reductions, expressed as yields, for the One Plan targets using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

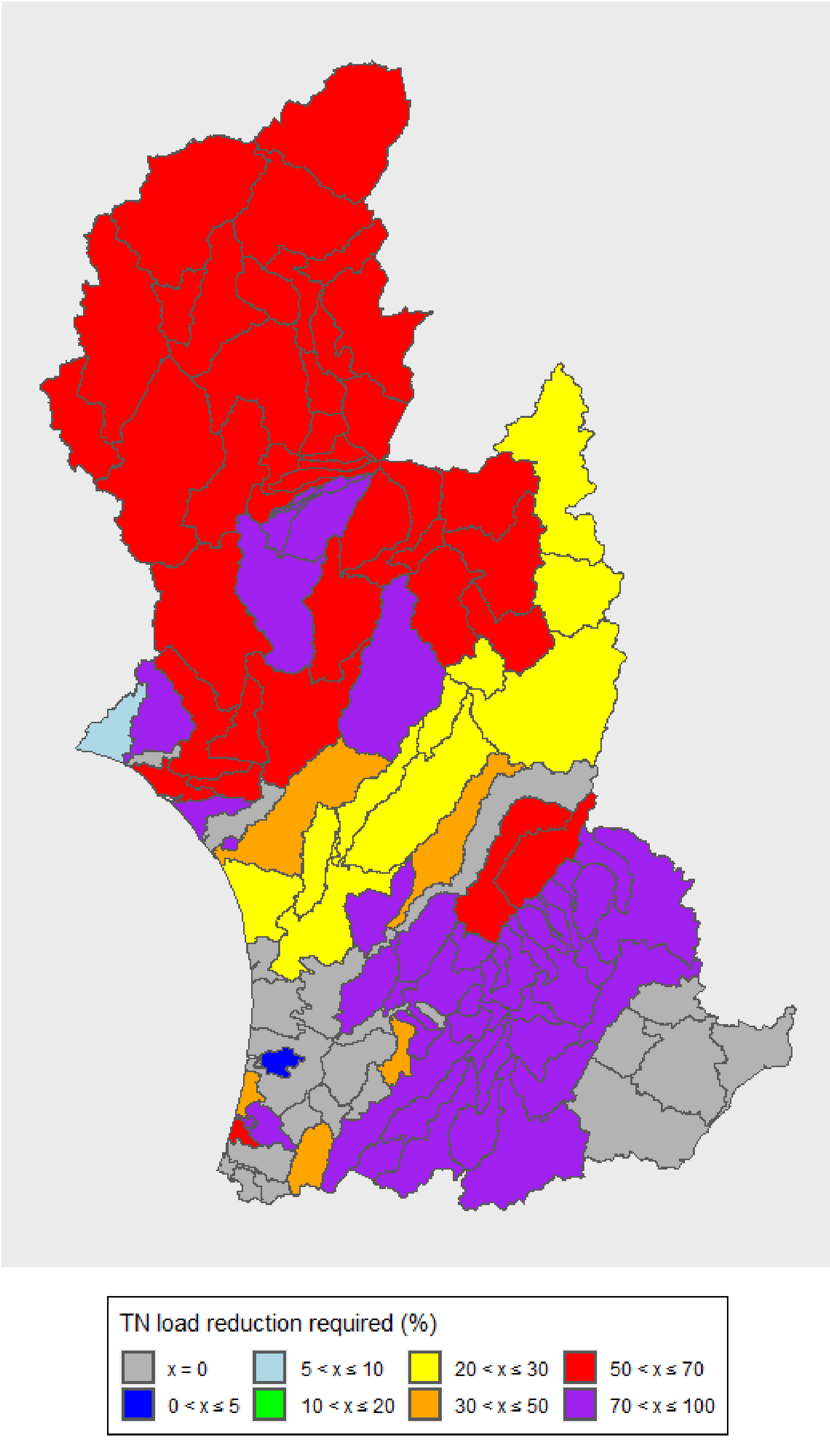


Figure 24. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the One Plan targets using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

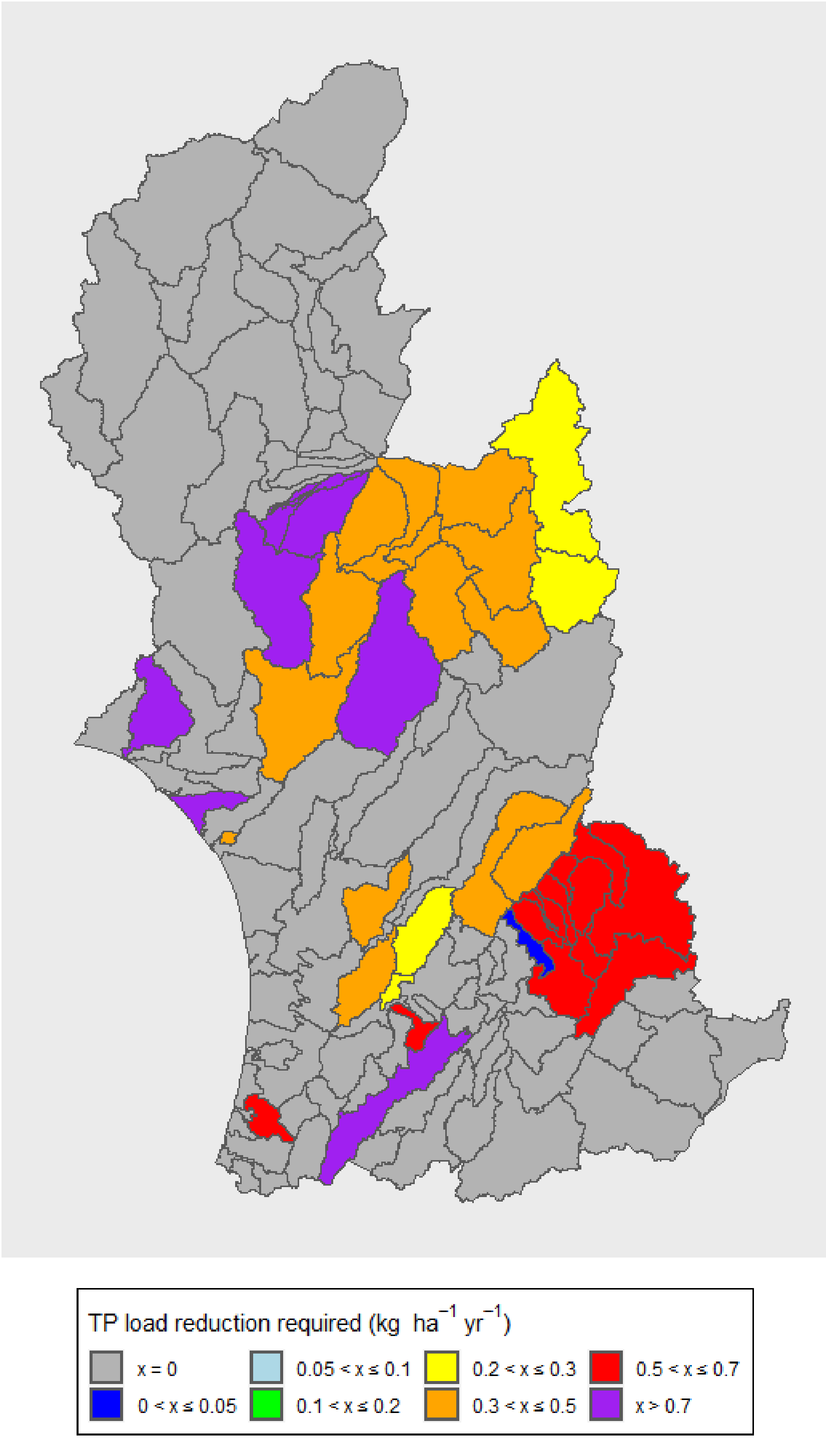


Figure 25. The TP WMSZ load reductions, expressed as yields, for the One Plan targets using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

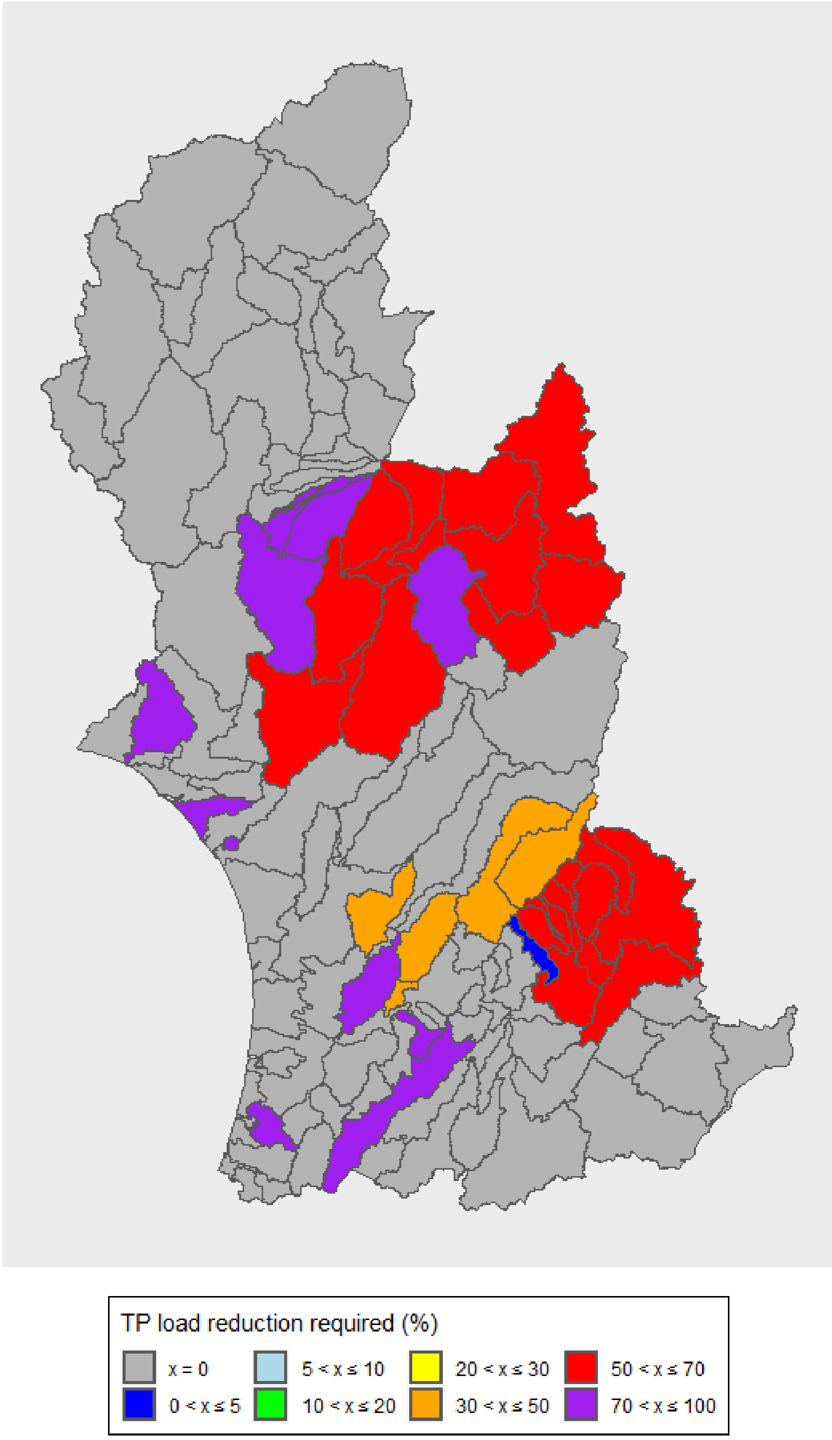


Figure 26. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the One Plan targets using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.5.5 Limiting environments

For the One Plan targets using national criteria and 30% risk, the limiting receiving environments for TN for all WMSZs (i.e., the receiving environment type that determines the TN load reduction requirements) were rivers except for four WMSZs (Hoki_1a, Mana_11b West_4 and West_6), and five WMSZs for TP (West_4 and Hoki_1a, Mana_11b Mana_9d, and Tura_1c, Figure 27).

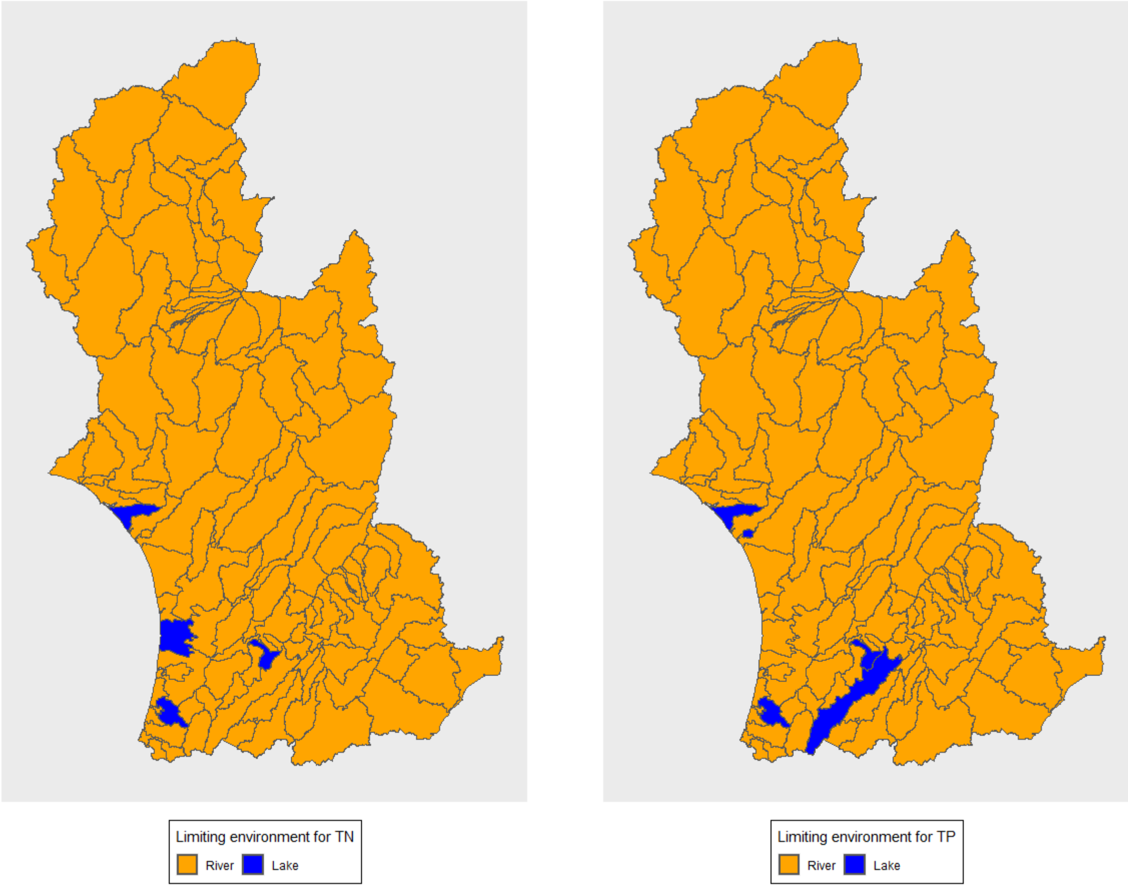


Figure 27. Limiting environment type for TN and TP load reduction requirements for WMSZs for the One Plan targets using national criteria and 30% risk.

3.6 One Plan targets and Regional TN criteria

3.6.1 Compliance

Because the regional criteria apply only to TN, this section describes only nitrogen load reduction requirements. Current river concentrations of TN had a greater than 50% probability of exceeding the criteria associated with the One Plan targets using regional criteria (i.e., were non-compliant) for 41% of segments in the region (Figure 28).

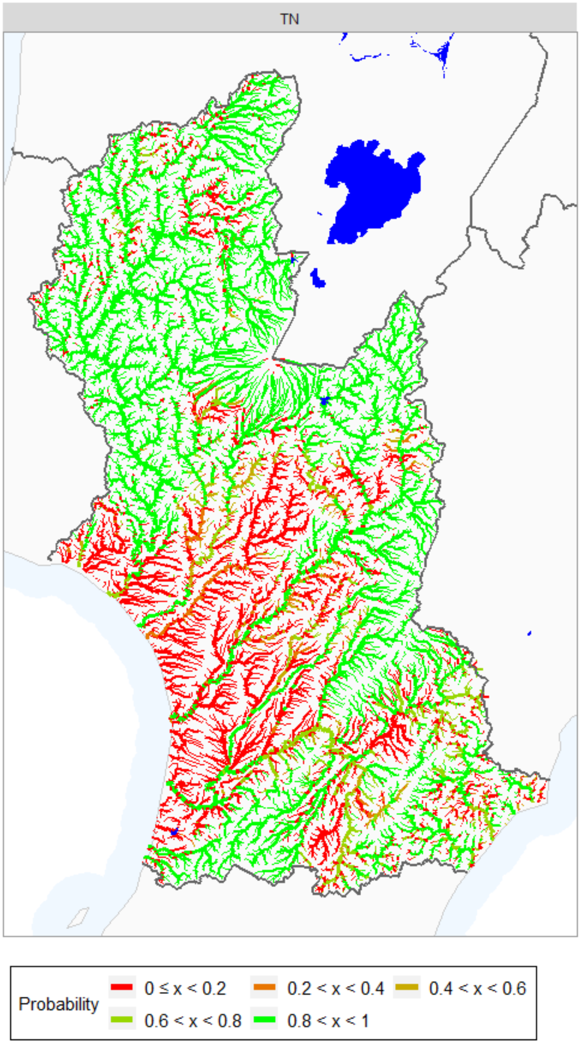


Figure 28. Probability that segments comply with the One Plan targets using Regional TN criteria.

3.6.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the One Plan targets and Regional TN criteria, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 10% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 3% of river segments (Figure 29). 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 29. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 52% of segments.

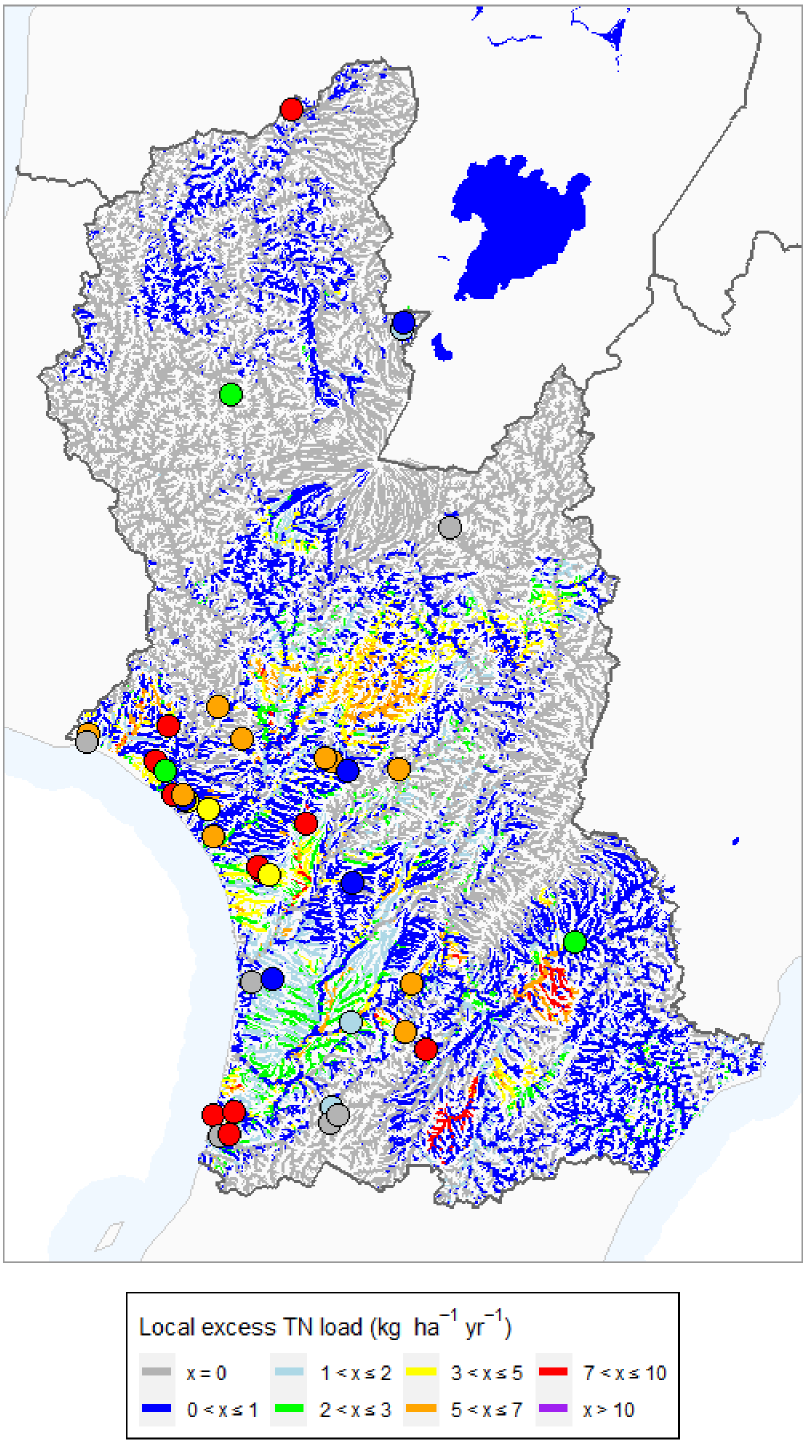


Figure 29. Local excess TN loads for rivers and lakes for the One Plan targets using Regional TN criteria. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.6.3 FMU and regional load reductions required

The load reductions required by the One Plan targets using Regional TN criteria for each FMU and for the whole region are shown in Table 10. For the whole region, the TN load reductions required were estimated to be 3,993 t yr^{-1}, which represent 23% of the current loads delivered to the coast. The uncertainties on the estimated current loads of TN and the load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 10. The best estimates of TN load reductions required exceeded 30% in two FMUs; Kai Iwi and Manawatū.

Table 10. Current load and load reduction required for TN for FMUs and the whole region for the One Plan targets using Regional TN criteria. 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		
	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)
Kai Iwi	221 (144 - 320)	132 (58 - 218)	58 (36 - 74)
Whanganui	6,022 (3,177 - 10,503)	453 (26 - 3,253)	5 (0 - 35)
Whangaehu	1,161 (671 - 1,850)	286 (8 - 960)	21 (1 - 55)
Rangitīkei-Turakina	3,125 (2,250 - 4,526)	814 (293 - 1,869)	25 (11 - 55)
Manawatū	5,382 (2,935 - 8,527)	2,118 (218 - 4,109)	36 (6 - 53)
Waiopehu	317 (225 - 429)	71 (41 - 103)	23 (15 - 33)
Puketoi ki Tai	993 (713 - 1,294)	105 (4 - 428)	9 (0 - 34)
Total	17,292 (13,012 - 23,011)	3,993 (1,504 - 8,051)	23 (9 - 36)

3.6.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 12 and Figure 13) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the One Plan targets using Regional TN criteria are shown on Figure 30. There were 39 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 22% of the region. The majority of these WMSZs were in in the Manawatū (33) FMU. There were 66 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 64% of the region (Figure 30). When load reductions required for TN were expressed as a proportion of current loads, 40 WMSZs required reductions of greater than 50% and these occupied 22% of the region (Figure 31).

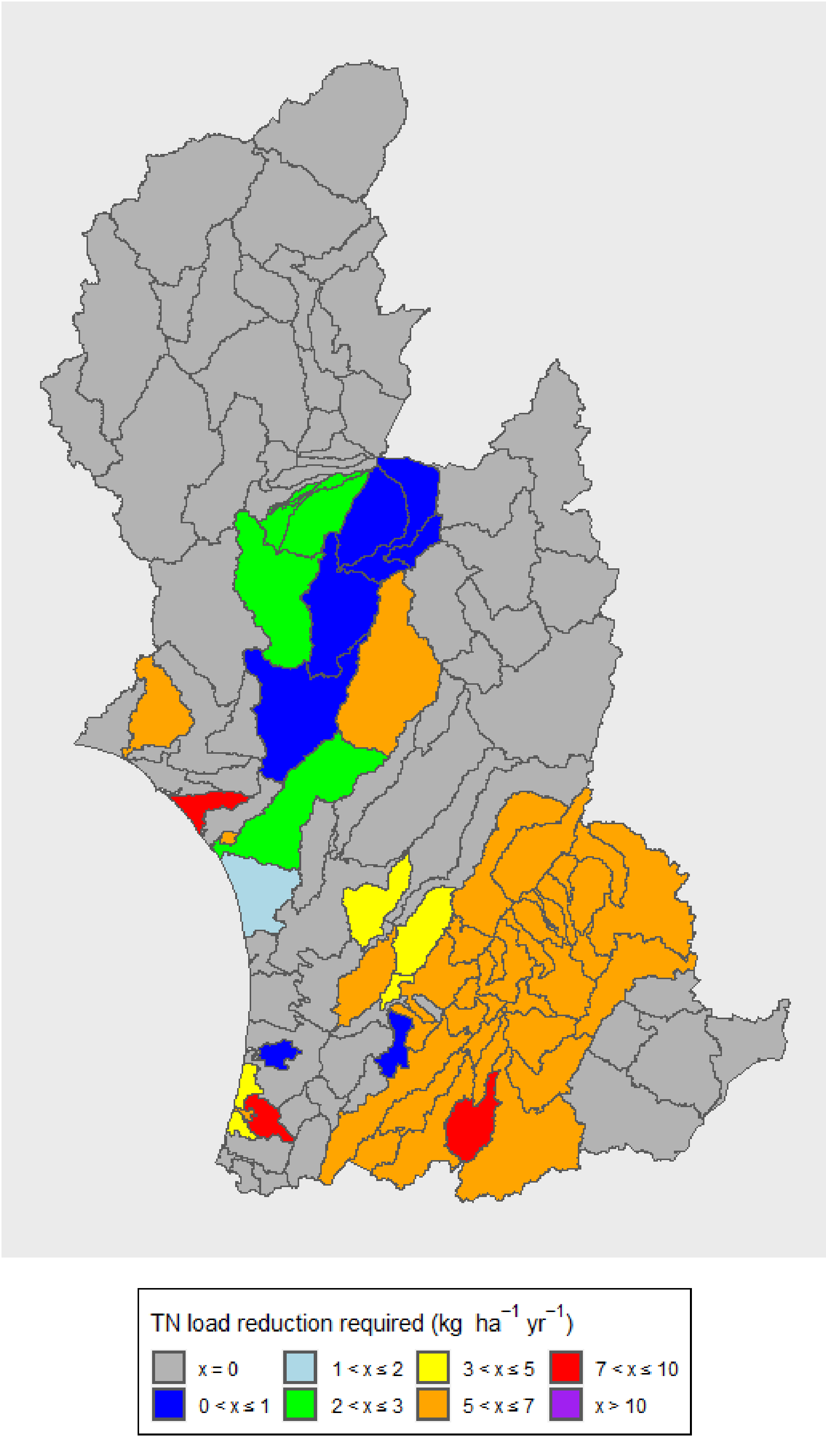


Figure 30. The TN WMSZ load reductions, expressed as yields, for the One Plan targets using Regional criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

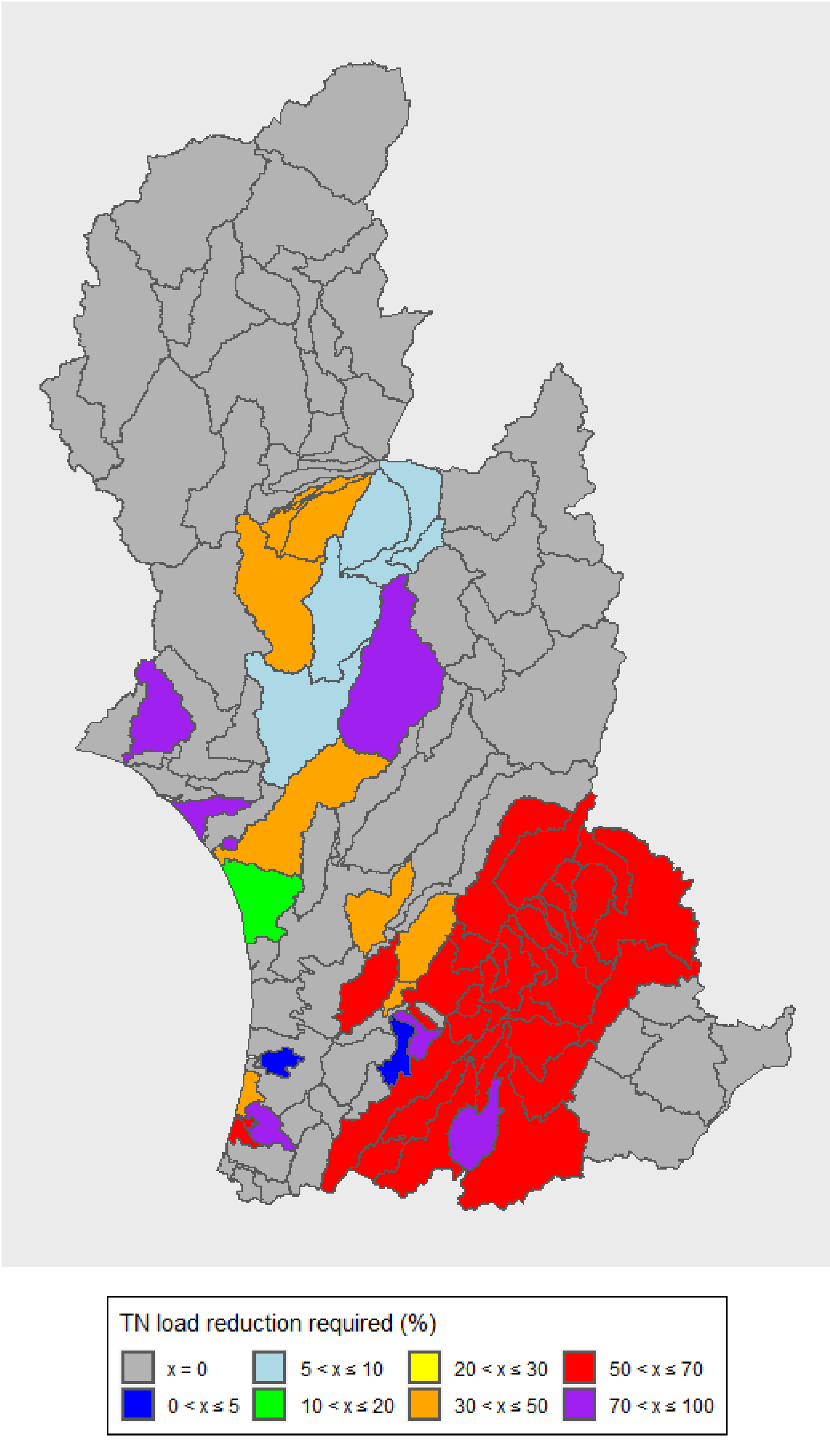


Figure 31. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the One Plan targets using Regional criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.6.5 Limiting environments

For the One Plan targets using Regional TN criteria, the limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for TN and all WMSZs were rivers except for four WMSZs (Hoki_1a, Mana_11b, Tura_1c and West_4) (Figure 32). At the maximum level of detail of the analysis, determined by the spatial framework's river network, lakes were the limiting receiving environments for TN for a small proportion (2%) of the region.

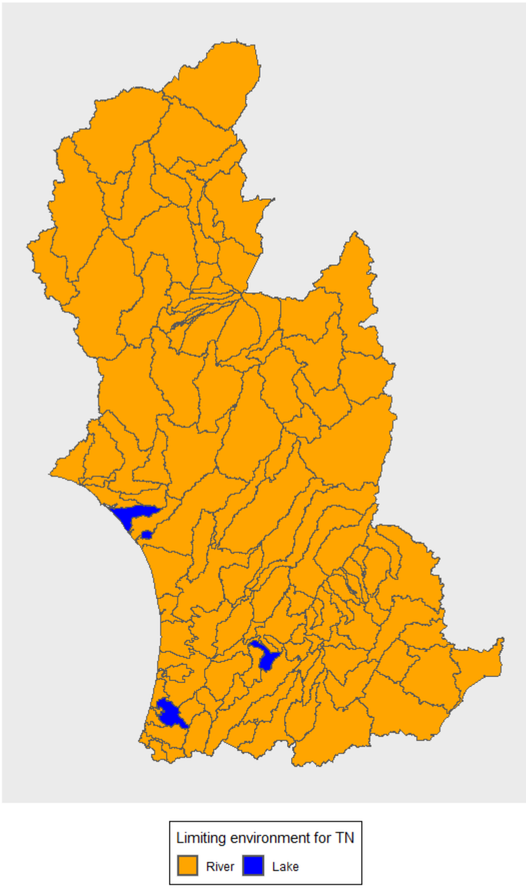


Figure 32. Limiting environment type for TN load reduction requirements for WMSZs for the One Plan targets using Regional criteria.

3.7 C band using national criteria and 20% risk

3.7.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the C band using national criteria and 20% risk for 36% and 43% of segments in the region, respectively (Figure 33). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the C band options for the nitrate toxicity FWO for 0.3% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 0.4% of river segments (Figure 33).

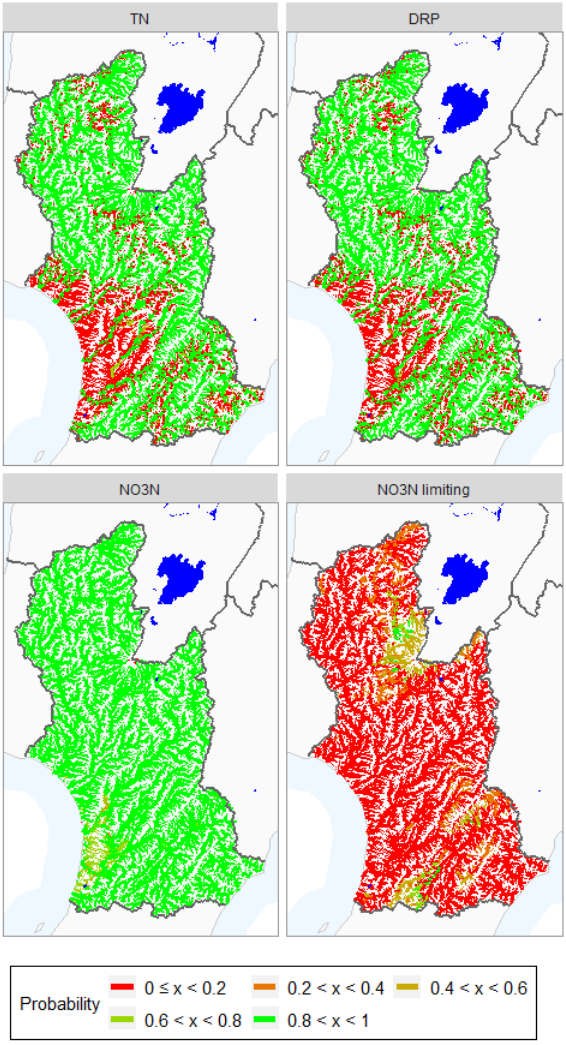


Figure 33. Probability that segments comply with river concentration criteria associated with the C band using national criteria and 20% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the C band was less than 50% (i.e., were non-compliant) for 18 and 25 of the 41 lakes, respectively (Figure 34).

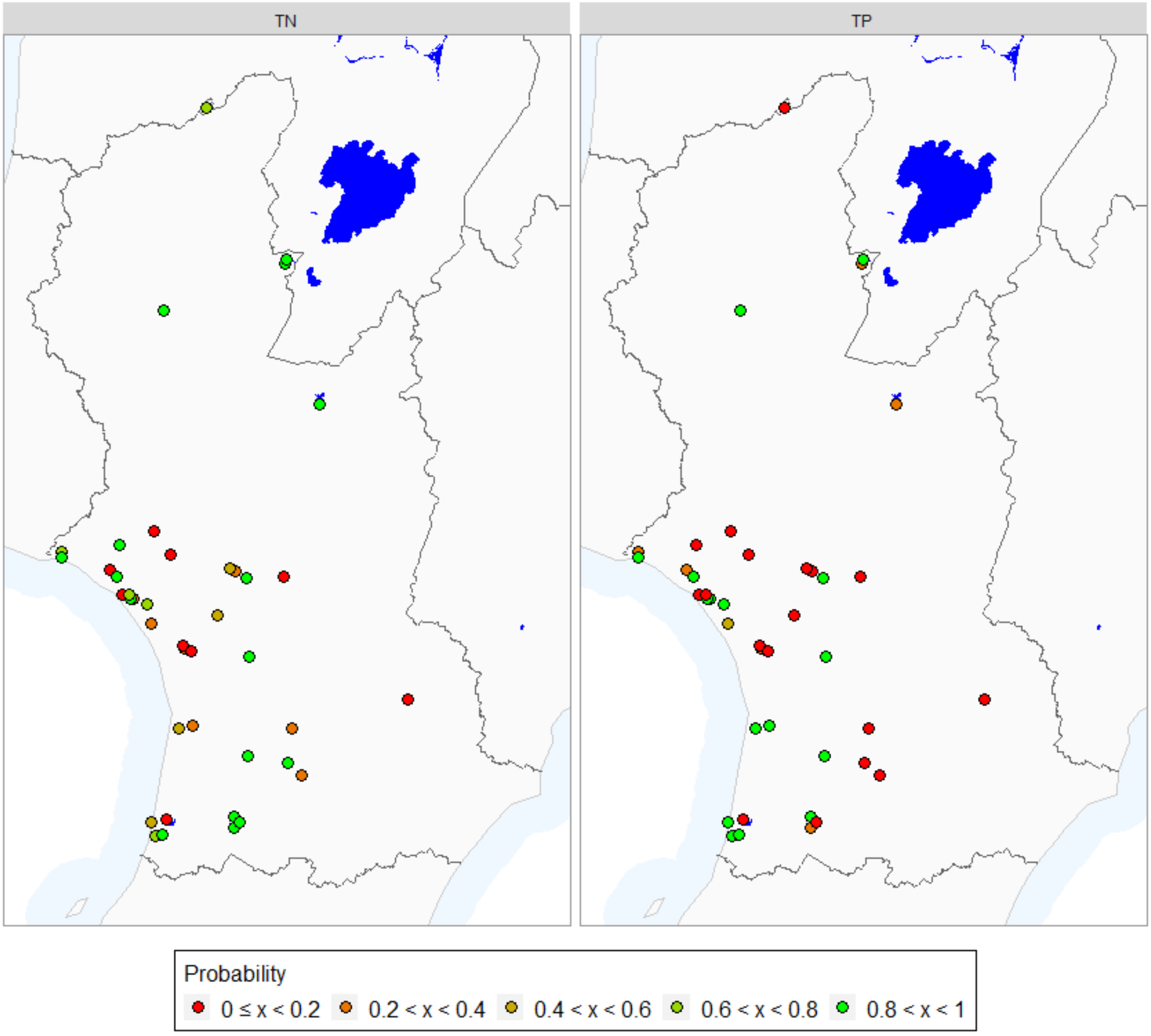
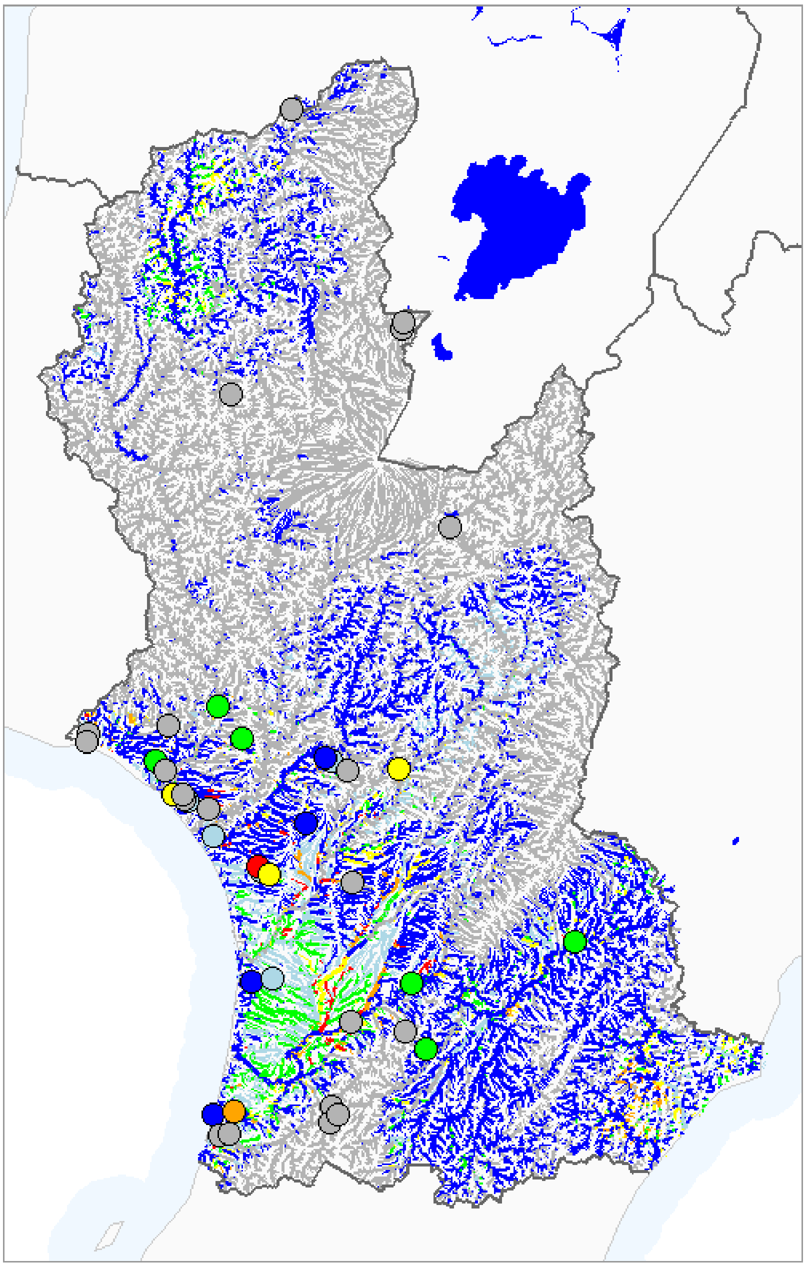


Figure 34. Probability of compliance with lake TN and TP concentration criteria associated with the C band.

3.7.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the C band using national criteria and 20% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 6% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 1% of river segments (Figure 35). 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 35. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 56% of segments.



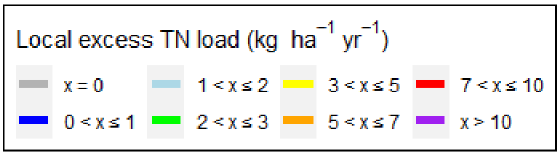


Figure 35. Local excess TN loads for rivers and lakes for the C band using national criteria and 20% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the C band using national criteria and 20% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 13% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 8% of river segments (Figure 36). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 54% of segments.

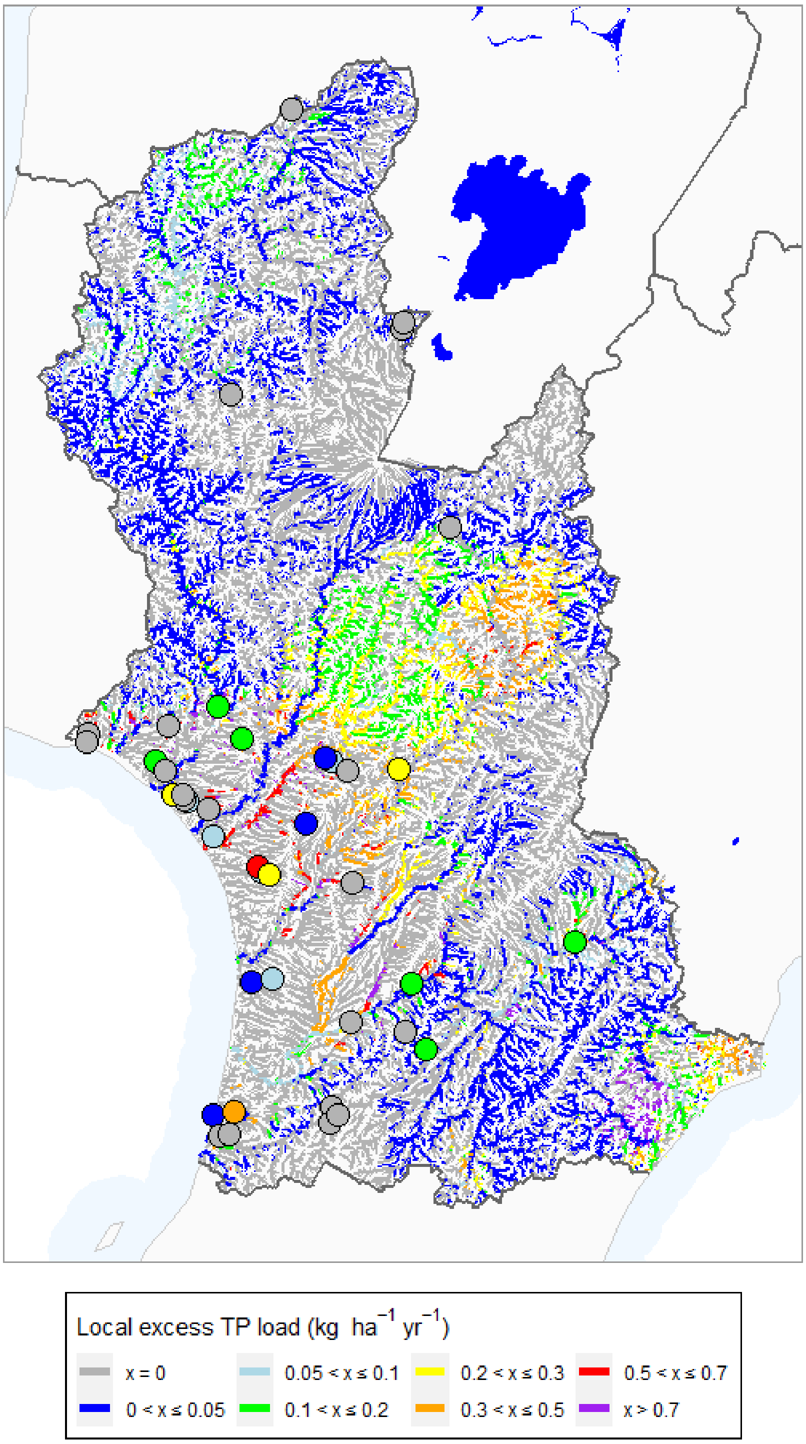


Figure 36. Local excess TP loads for rivers and lakes for the C band using national criteria and 20% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.7.3 FMU and regional load reductions required

The load reductions required by the C band using national criteria and 20% risk for each FMU and for the whole region are shown in Table 11. For the whole region, the TN and TP load reductions required were estimated to be 4,172 t yr^{-1} and 2,424 t yr^{-1}, which represent 23%

and 75% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 11.

For the C band using national criteria and 20% risk, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs except for Whanganui and Whangaehu FMUs). The 95% confidence TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs.

Table 11. Current load and load reduction required for TN and TP for FMUs and the whole region for the C band using national criteria and 20% risk. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5^{th} and 95^{th} confidence limits for the reported values (i.e., the range is the 90% confidence interval).

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 (%)**
Kai Iwi	216 (142 - 324)	86 (18 - 161)	38 (9 - 60)	30 (17 - 51)	24 (14 - 39)	81 (67 - 89)
Whanganui	6,166 (3,462 - 9,516)	1,215 (9 - 4,928)	16 (0 - 57)	1,275 (660 - 2,266)	940 (12 - 1,847)	74 (1 - 107)
Whangaehu	1,112 (611 - 1,687)	133 (0 - 383)	10 (0 - 29)	260 (118 - 450)	86 (35 - 146)	33 (25 - 38)
Rangitīkei-Turakina	3,283 (2,223 - 4,349)	469 (145 - 1,276)	14 (5 - 33)	688 (437 - 1,092)	656 (386 - 1,122)	95 (73 - 108)
Manawatū	5,284 (2,960 - 8,884)	1,837 (87 - 4,302)	32 (2 - 54)	753 (375 - 1,273)	610 (256 - 1,051)	82 (59 - 94)
Waiopehu	334 (235 - 455)	76 (43 - 115)	23 (14 - 32)	27 (18 - 41)	5 (3 - 8)	20 (14 - 31)
Puketoi ki Tai	1,005 (723 - 1,392)	345 (57 - 719)	32 (7 - 54)	174 (119 - 241)	102 (49 - 157)	58 (38 - 69)
Whole region	17,470 (13,748 - 22,181)	4,172 (1,277 - 8,328)	23 (10 - 40)	3,216 (2,274 - 4,547)	2,424 (1,331 - 3,645)	75 (41 - 92)

3.7.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 35 and Figure 36) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the C band using national criteria and 20% risk are shown on Figure 37 and Figure 38. There were 8 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 3% of the region. There were 39 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 31% of the region (Figure 37). When load reductions required for TN were expressed as a proportion of current loads, 38 WMSZs required reductions of greater than 50% and these occupied 20% of the region (Figure 38).

There were 92 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 39) and these occupied 84% of the region. There were 26 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 11% of the region. When load reductions required for TP were expressed as a proportion of current loads, 89 WMSZs required reductions of greater than 50% and these occupied 82% of the region (Figure 40). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

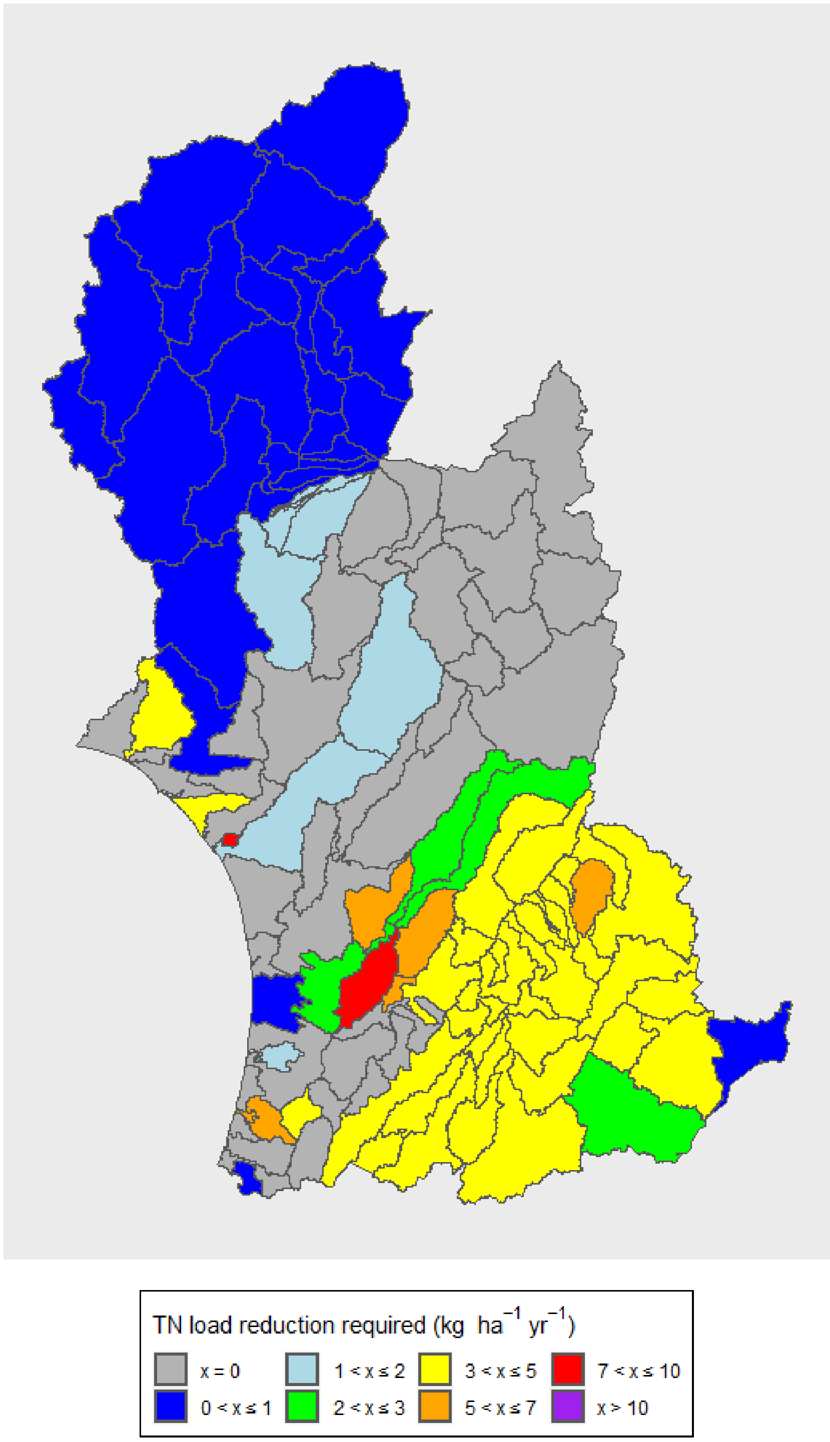


Figure 37. The TN WMSZ load reductions, expressed as yields, for the C band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

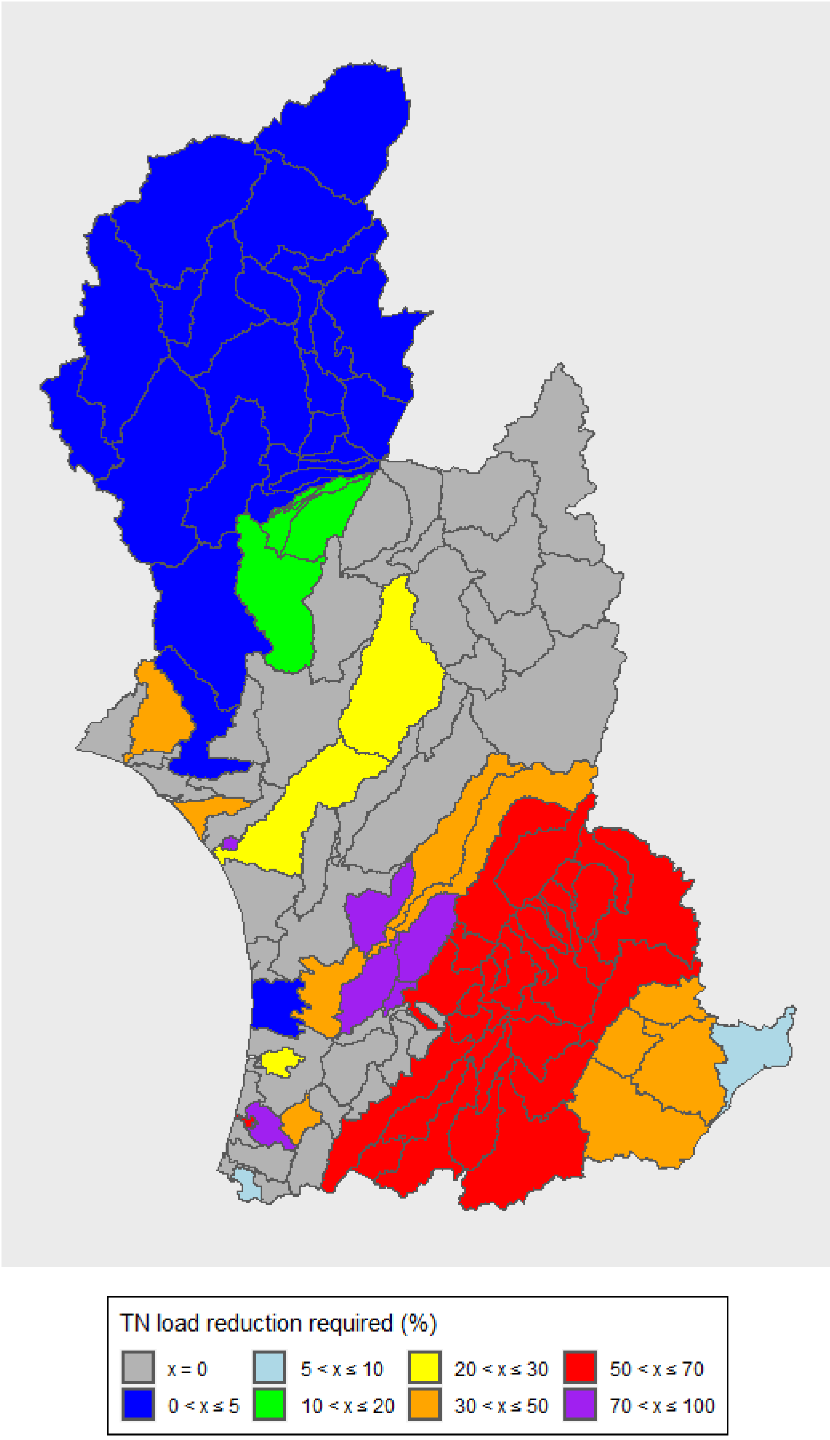


Figure 38. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the C band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

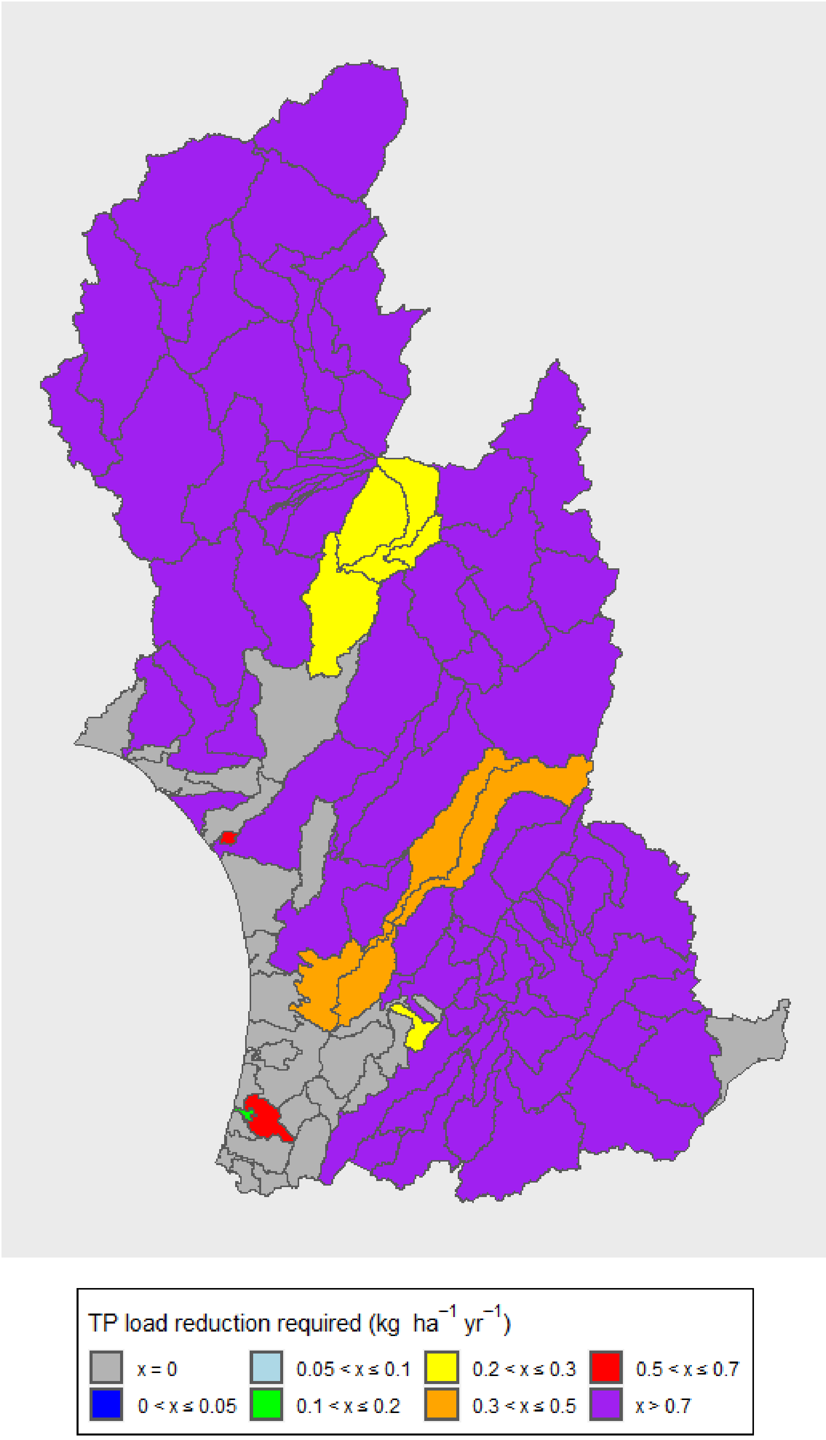


Figure 39. The TP WMSZ load reductions, expressed as yields, for the C band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

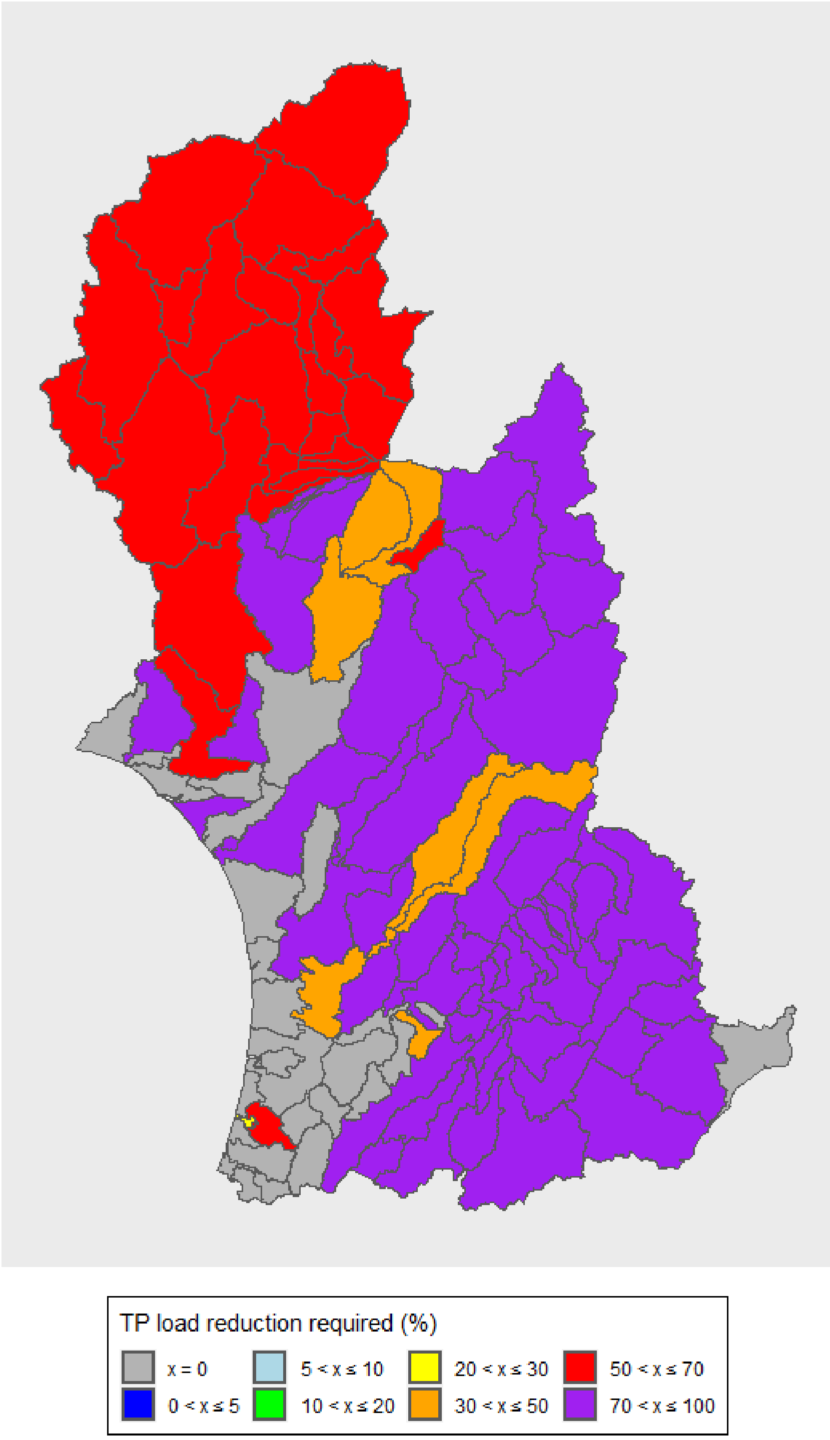


Figure 40. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the C band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ

3.7.5 Limiting environments

For the C band using national criteria and 20% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for three WMSZs (Hoki_1a, West_4 and West_6) for TN and three WMSZs for TP (West_4, Mana_11b and Hoki_1a, Figure 41).

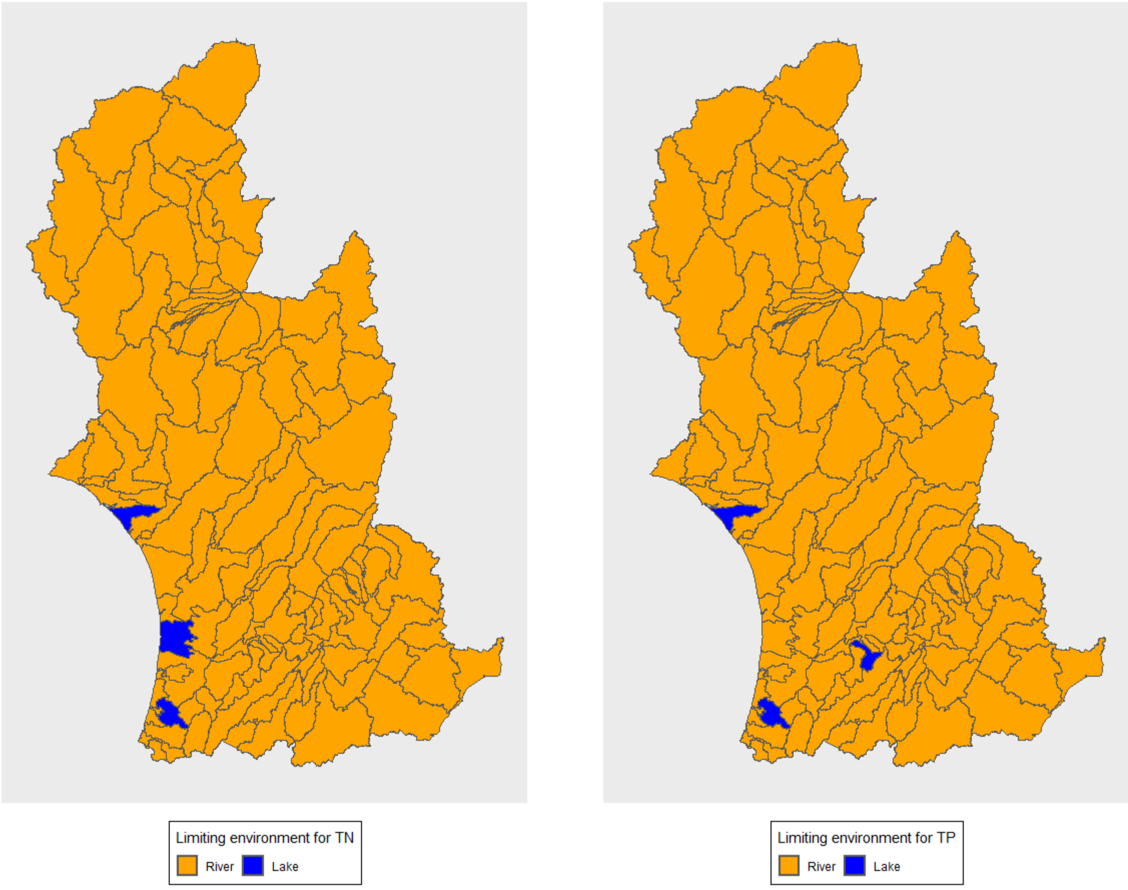


Figure 41. Limiting environment type for TN and TP load reduction requirements for WMSZs for the C band using national criteria and 20% risk.

3.8 C band using national criteria and 30% risk

3.8.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the C band using national criteria and 30% risk for 33% and 31% of segments in the region, respectively (Figure 42). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the C band optionsfor the nitrate toxicity FWO for 0.3% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 3% of river segments (Figure 42).

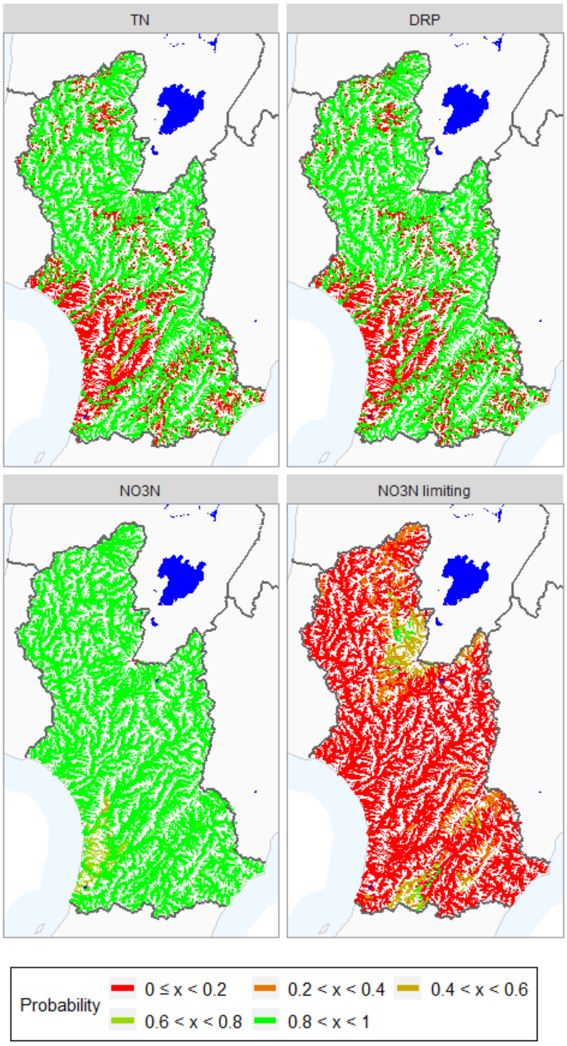


Figure 42. Probability that segments comply with river concentration criteria associated with the C band using national criteria and 30% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the C band was less than 50% (i.e., were non-compliant) for 16 and 24 of the 41 lakes, respectively (Figure 34). Note that differences in results for lakes between the 20% risk and

30% risk assessments are associated with random perturbations in the Monte Carlo analysis only because the criteria for lakes is unchanged.

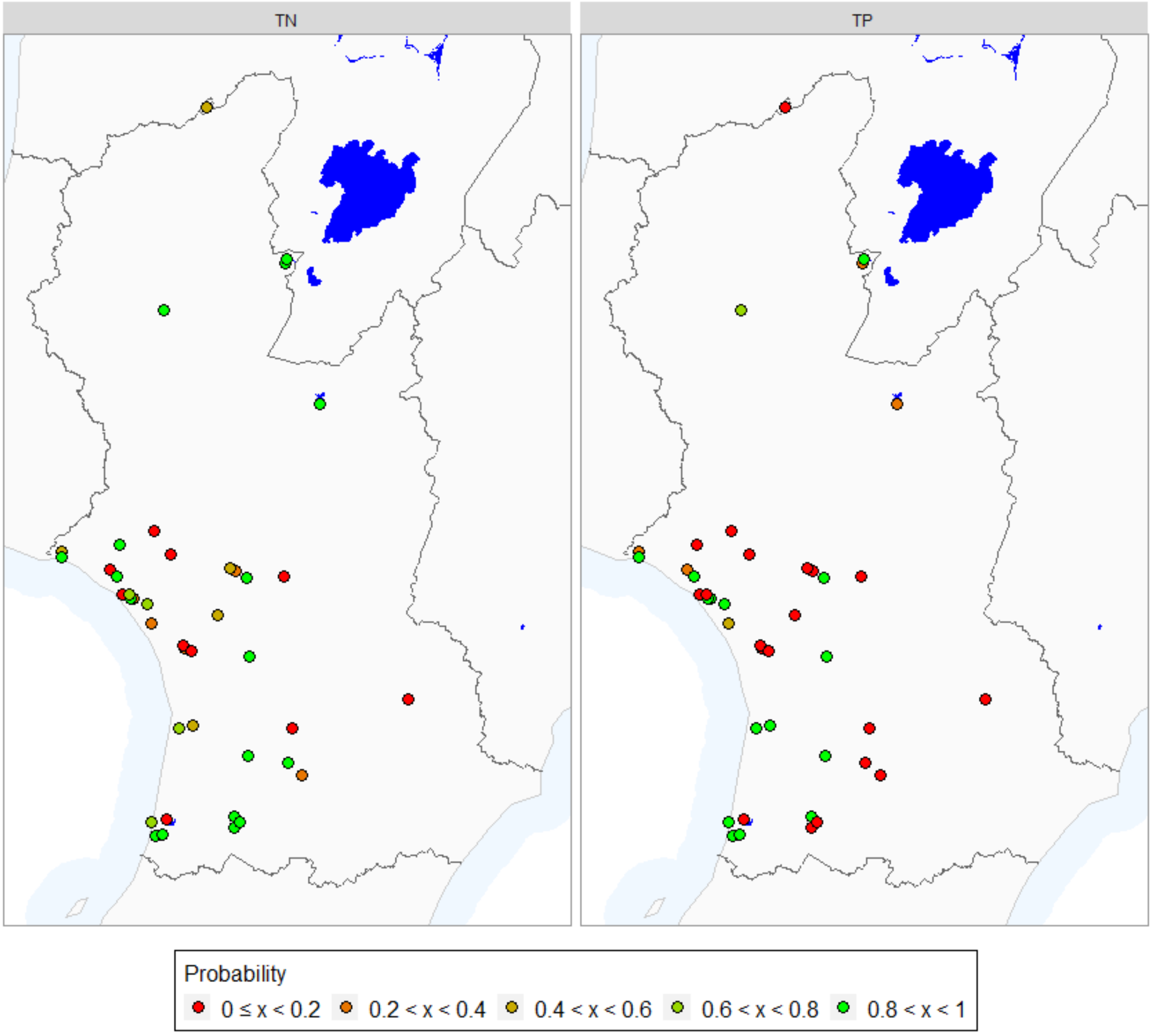


Figure 43. Probability of compliance with lake TN and TP concentration criteria associated with the C band.

3.8.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the C band using national criteria and 30% risk, 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 35). 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 35. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 62% of segments.

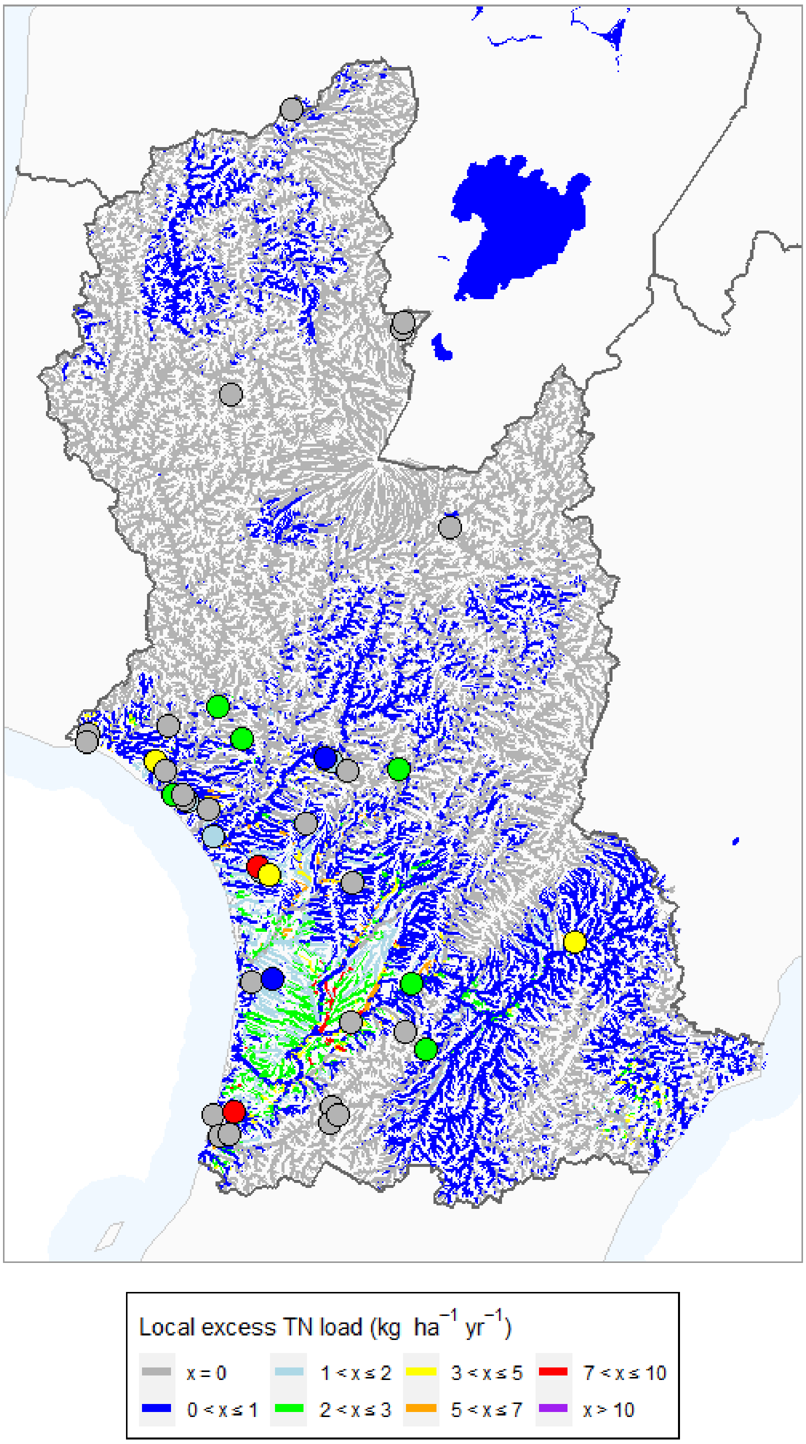


Figure 44. Local excess TN loads for rivers and lakes for the C band using national criteria and 30% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the C band using national criteria and 30% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 0.2% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 0.06% of river segments (Figure 36). Note that these breakpoints are nominal and have no special

significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 95% of segments.

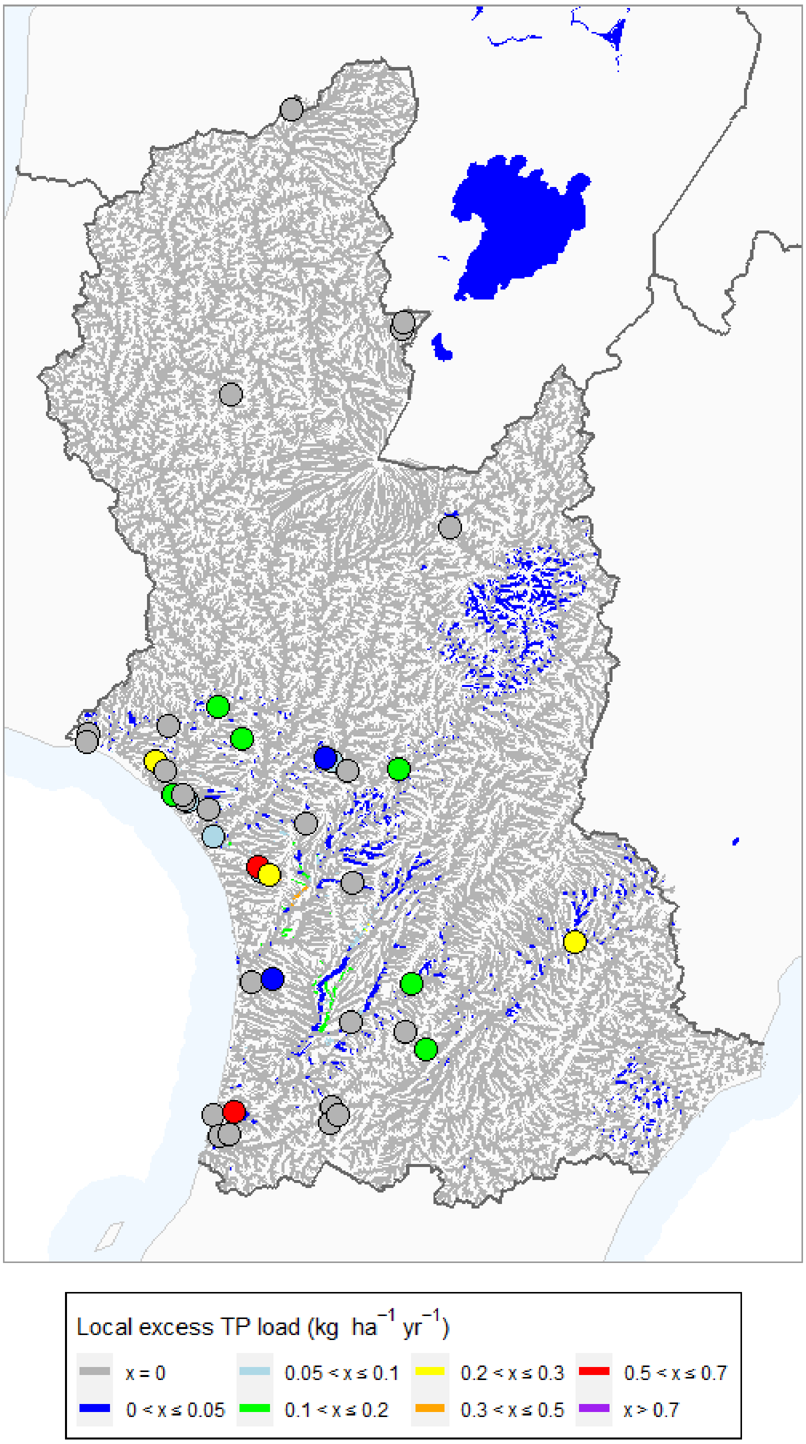


Figure 45. Local excess TP loads for rivers and lakes for the C band using national criteria and 30% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.8.3 FMU and regional load reductions required

The load reductions required by the C band using national criteria and 30% risk for each FMU and for the whole region are shown in Table 12. For the whole region, the TN and TP load reductions required were estimated to be 1,436 t yr^{-1} and 39 t yr^{-1}, which represent 8% and 1% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 11.

For the C band using national criteria and 30% risk, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs except for Whanganui and Whangaehu FMUs). The 95% confidence TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for the Kai Iwi, Manawatū, and Waiopehu FMUs.

Table 12. Current load and load reduction required for TN and TP for FMUs and the whole region for the C band using national criteria and 30% risk. 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 (%)**
Kai Iwi	222 (148 - 327)	43 (7 - 118)	18 (4 - 46)	30 (19 - 43)	10 (5 - 15)	32 (26 - 36)
Whanganui	6,261 (3,405 - 9,607)	142 (0 - 967)	2 (0 - 14)	1,359 (692 - 2,557)	4 (2 - 6)	0 (0 - 1)
Whangaehu	1,146 (685 - 1,810)	32 (0 - 167)	2 (0 - 15)	267 (131 - 492)	0 (0 - 0)	0 (0 - 0)
Rangitīkei-Turakina	3,151 (2,090 - 4,782)	218 (107 - 460)	7 (4 - 13)	658 (386 - 1,066)	10 (2 - 22)	1 (0 - 2)
Manawatū	5,568 (3,032 - 8,585)	833 (43 - 3,020)	12 (1 - 40)	822 (414 - 1,388)	13 (3 - 19)	1 (1 - 1)
Waiopehu	322 (218 - 440)	63 (38 - 94)	20 (13 - 28)	27 (20 - 40)	3 (2 - 6)	13 (5 - 21)
Puketoi ki Tai	966 (670 - 1,261)	100 (2 - 321)	9 (0 - 28)	176 (106 - 265)	0 (0 - 0)	0 (0 - 0)
Whole region	17,706 (13,360 - 22,247)	1,436 (389 - 3,520)	8 (2 - 19)	3,348 (2,483 - 4,522)	39 (23 - 57)	1 (1 - 2)

3.8.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 44 and Figure 45) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the C band using national criteria and 30% risk are shown on Figure 46 and Figure 47. There were 6 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 2.5% of the region. There were 84 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 79% of the region (Figure 46). When load reductions required for TN were expressed as a proportion of current loads, six WMSZs required reductions of greater than 50% and these occupied 2.5% of the region (Figure 47).

There were four WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 48) and these occupied 2% of the region. There were 118 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 97% of the region. When load reductions required for TP were expressed as a proportion of current loads, four WMSZs required reductions of greater than 50% and these occupied 2% of the region (Figure 49). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

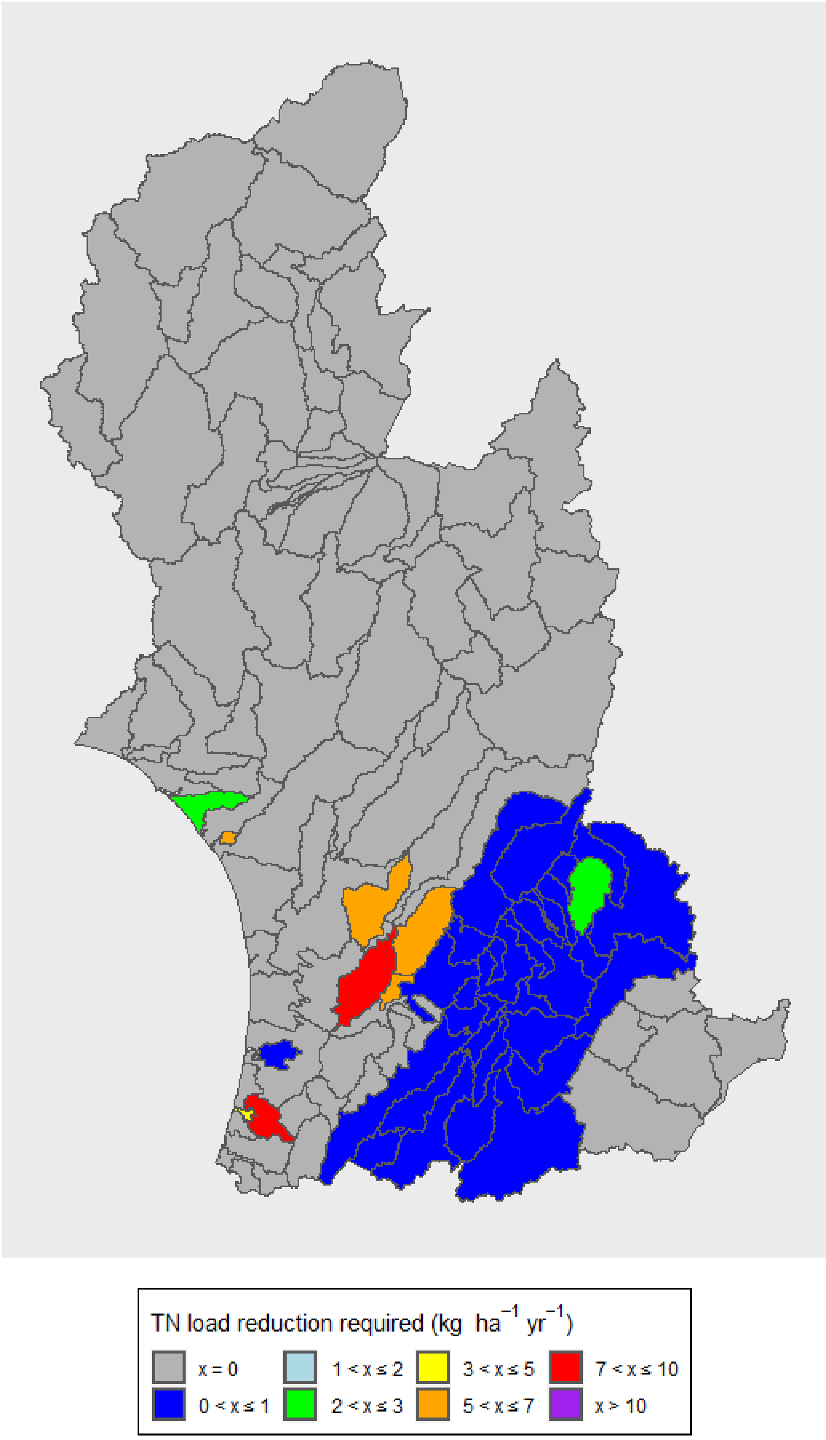


Figure 46. The TN WMSZ load reductions, expressed as yields, for the C band using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

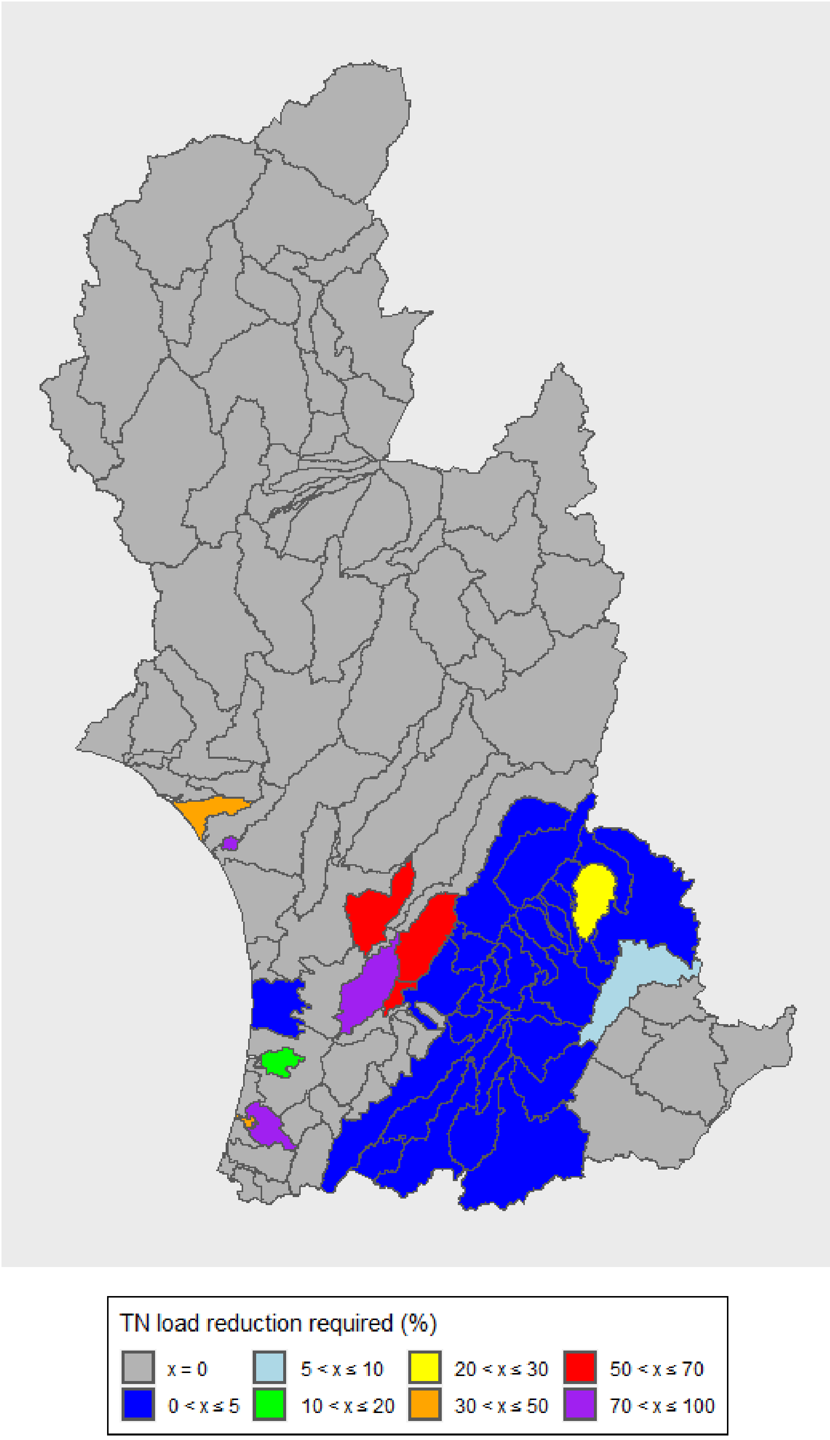


Figure 47. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the C band using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

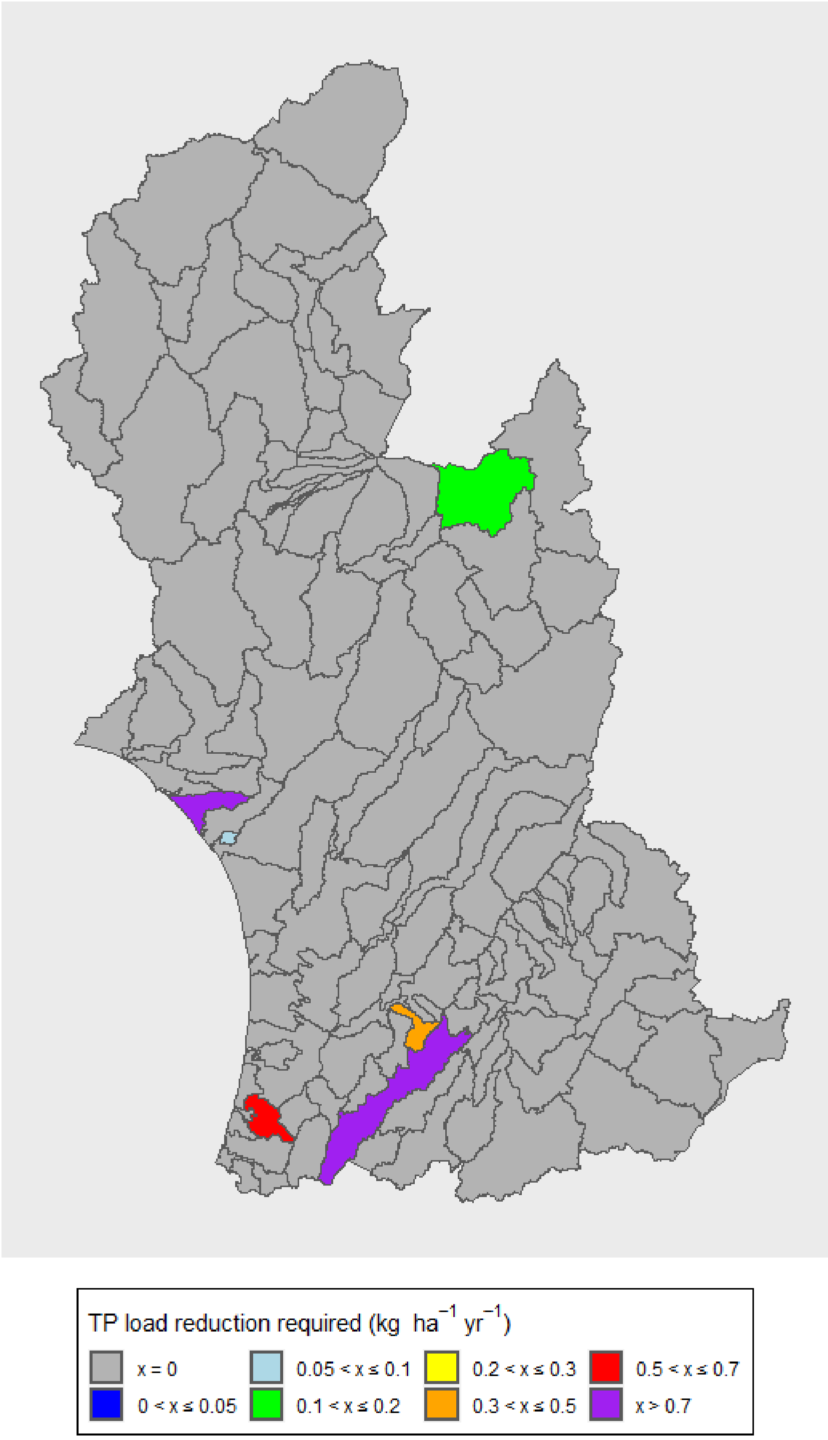


Figure 48. The TP WMSZ load reductions, expressed as yields, for the C band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

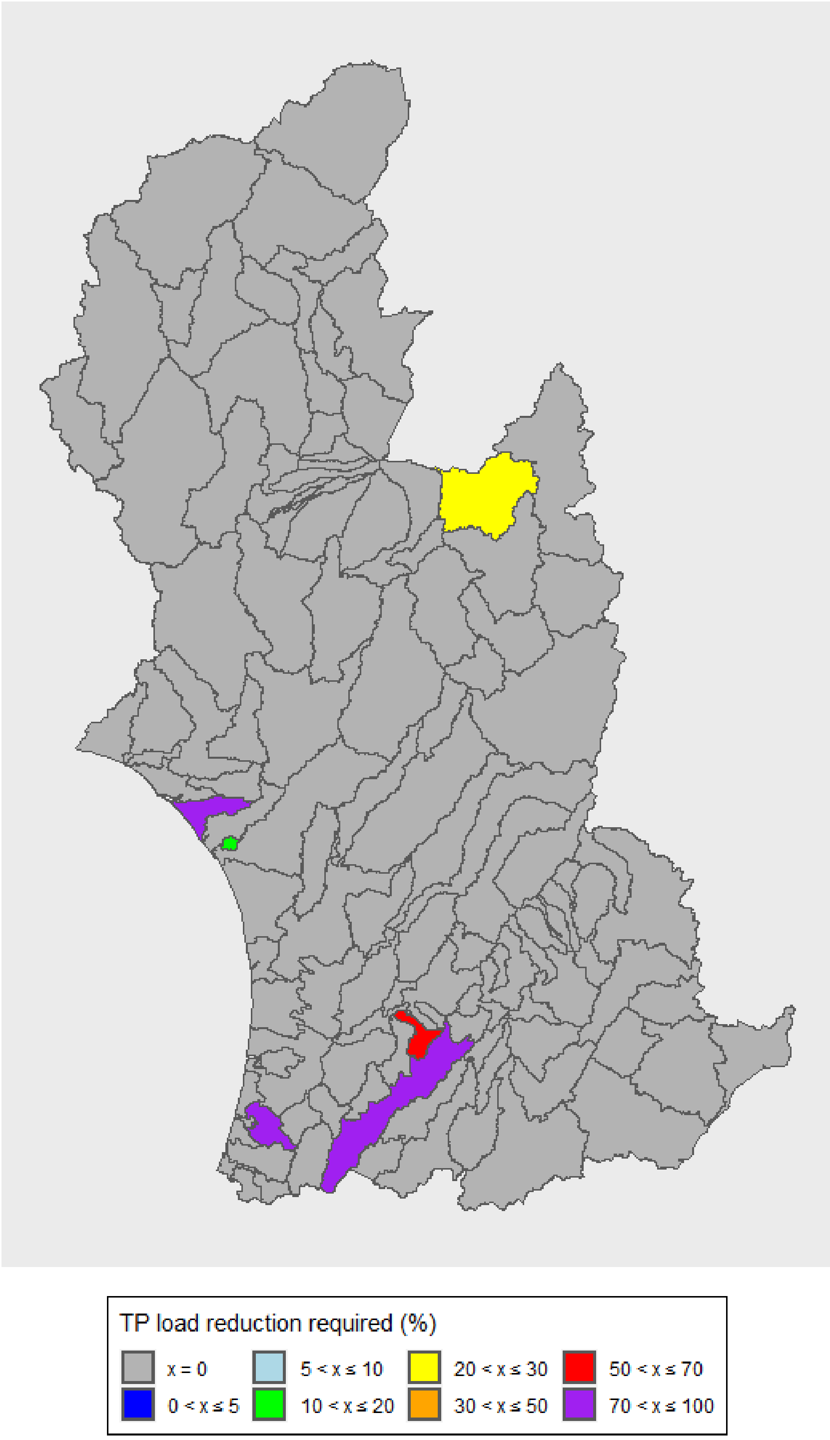


Figure 49. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the C band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ

3.8.5 Limiting environments

For the C band using national criteria and 30% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for two WMSZs (Hoki_1a and West_4) for TN and six WMSZs for TP (West_4, Mana_11b, Hoki_1a, Mana_9d, Rang_2c and Tura_1c, Figure 50).

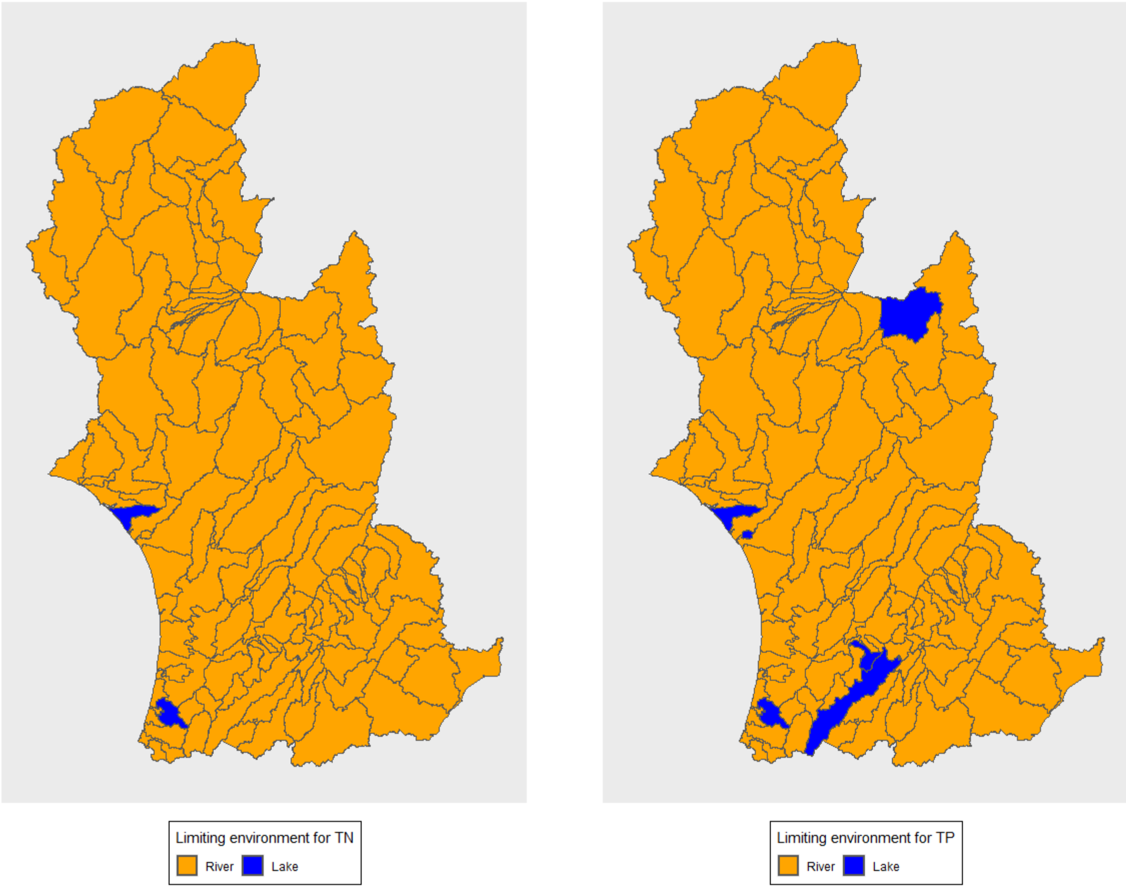


Figure 50. Limiting environment type for TN and TP load reduction requirements for WMSZs for the C band using national criteria and 30% risk.

3.9 C band using Regional TN criteria

3.9.1 Compliance

Because the regional criteria apply only to TN, this section describes only nitrogen load reduction requirements. Current river concentrations of TN had a greater than 50% probability of exceeding the criteria associated with the One Plan targets using regional criteria (i.e., were non-compliant) for 33% of segments in the region (Figure 51).

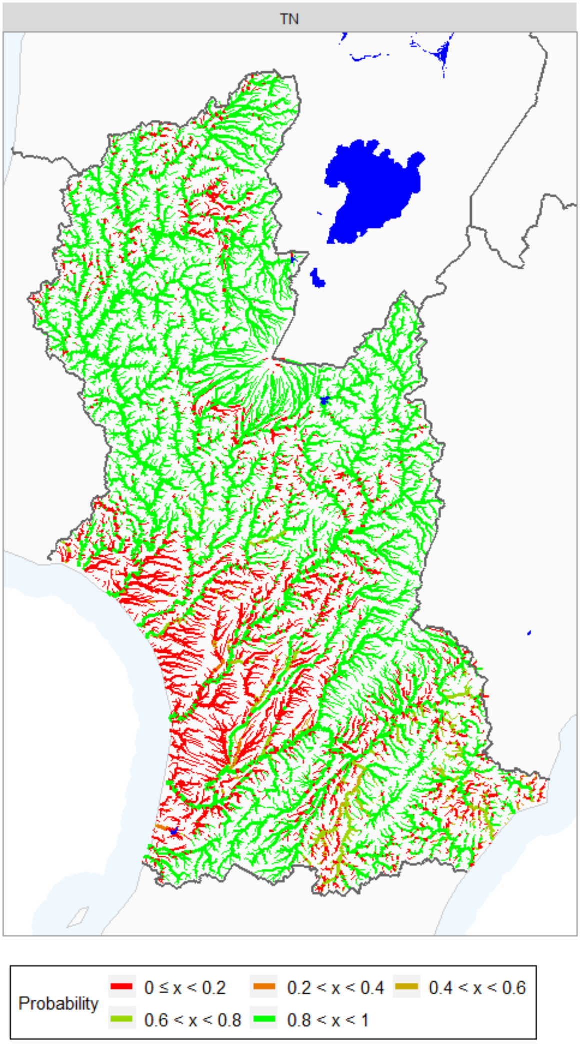


Figure 51. Probability that segments comply with the C band using Regional TN criteria.

3.9.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the objective for that receiving environment. For the *C* band using Regional TN criteria, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 2% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for no river segments (Figure 52). 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 52. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 57% of segments.

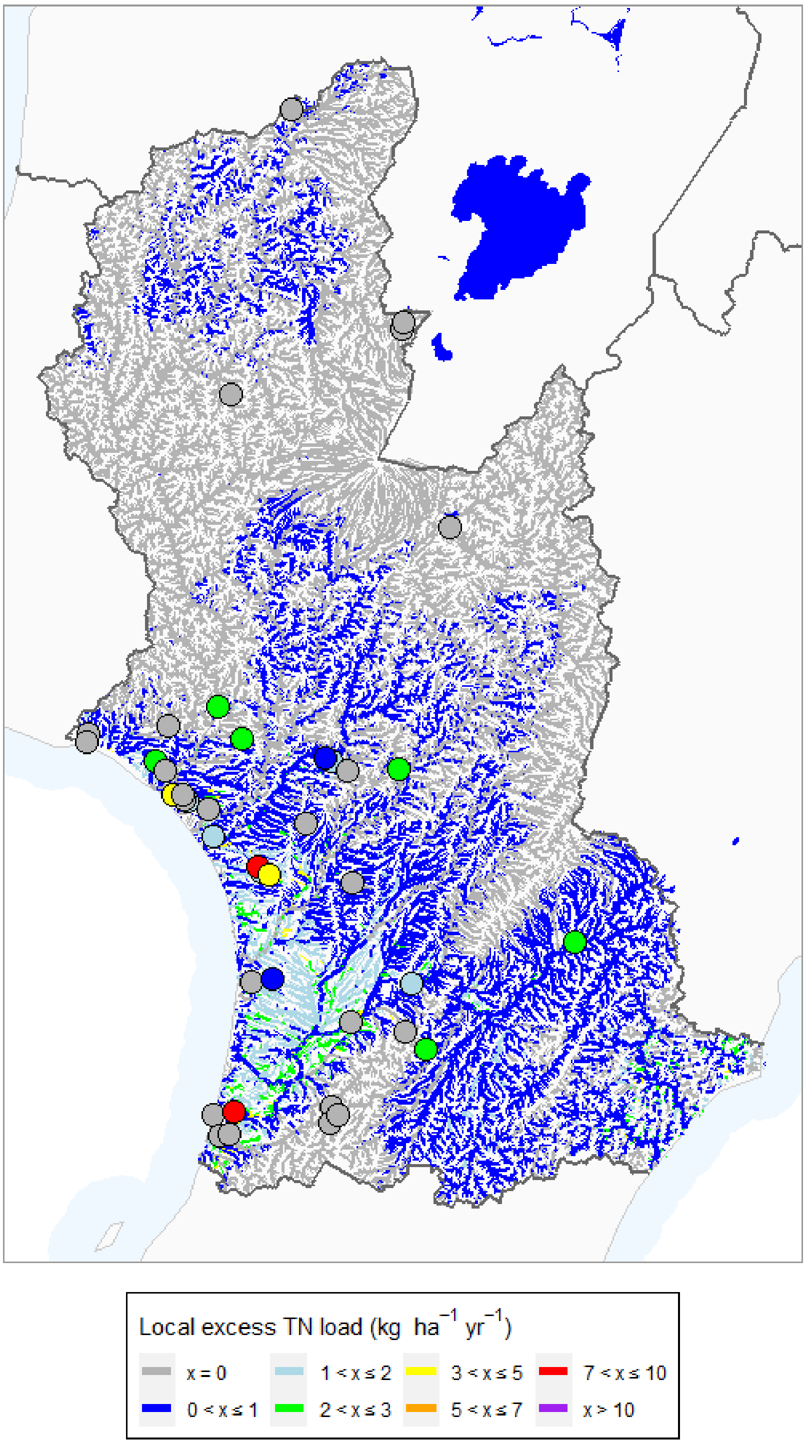


Figure 52. Local excess TN loads for rivers and lakes for the C band using Regional TN criteria. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.9.3 FMU and regional load reductions required

The load reductions required by the C band using Regional TN criteria for each FMU and for the whole region are shown in Table 13. For the whole region, the TN load reductions required were estimated to be 476 t yr^{-1}, which represent 3% of the current loads delivered to the coast. The uncertainties on the estimated current loads of TN and the load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 13.

For the C band using Regional TN criteria, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for four FMUs: Whanganui, Rangitīkei-Turakina, Waiopehu and Puketoi ki Tai.

Table 13. Current load and load reduction required for TN for FMUs and the whole region for the C band using Regional TN criteria. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5^{th} and 95^{th} confidence limits for the reported values (i.e., the range is the 90% confidence interval).

FMU	TN		
	Current load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Kai Iwi	215 (137 - 321)	11 (0 - 45)	5 (0 - 14)
Whanganui	6,114 (3,495 - 10,707)	17 (5 - 36)	0 (0 - 1)
Whangaehu	1,231 (618 - 2,075)	5 (0 - 11)	0 (0 - 1)
Rangitīkei-Turakina	3,200 (2,079 - 4,402)	163 (42 - 481)	5 (2 - 13)
Manawatū	5,205 (2,690 - 7,724)	129 (0 - 474)	2 (0 - 7)
Waiopehu	334 (244 - 434)	55 (31 - 93)	17 (10 - 24)
Puketoi ki Tai	986 (720 - 1,406)	94 (4 - 360)	8 (0 - 30)
Whole region	17,356 (13,556 - 21,745)	476 (167 - 1,015)	3 (1 - 6)

3.9.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 52) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the C band using Regional TN criteria are shown on Figure 53. There was one WMSZ with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and this occupied 0.3% pf the region. There were 118 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 98% of the region (Figure 53). When load reductions required for TN were expressed as a proportion of current loads, one WMSZ required reductions of greater than 50% and these occupied 0.3% of the region (Figure 54).

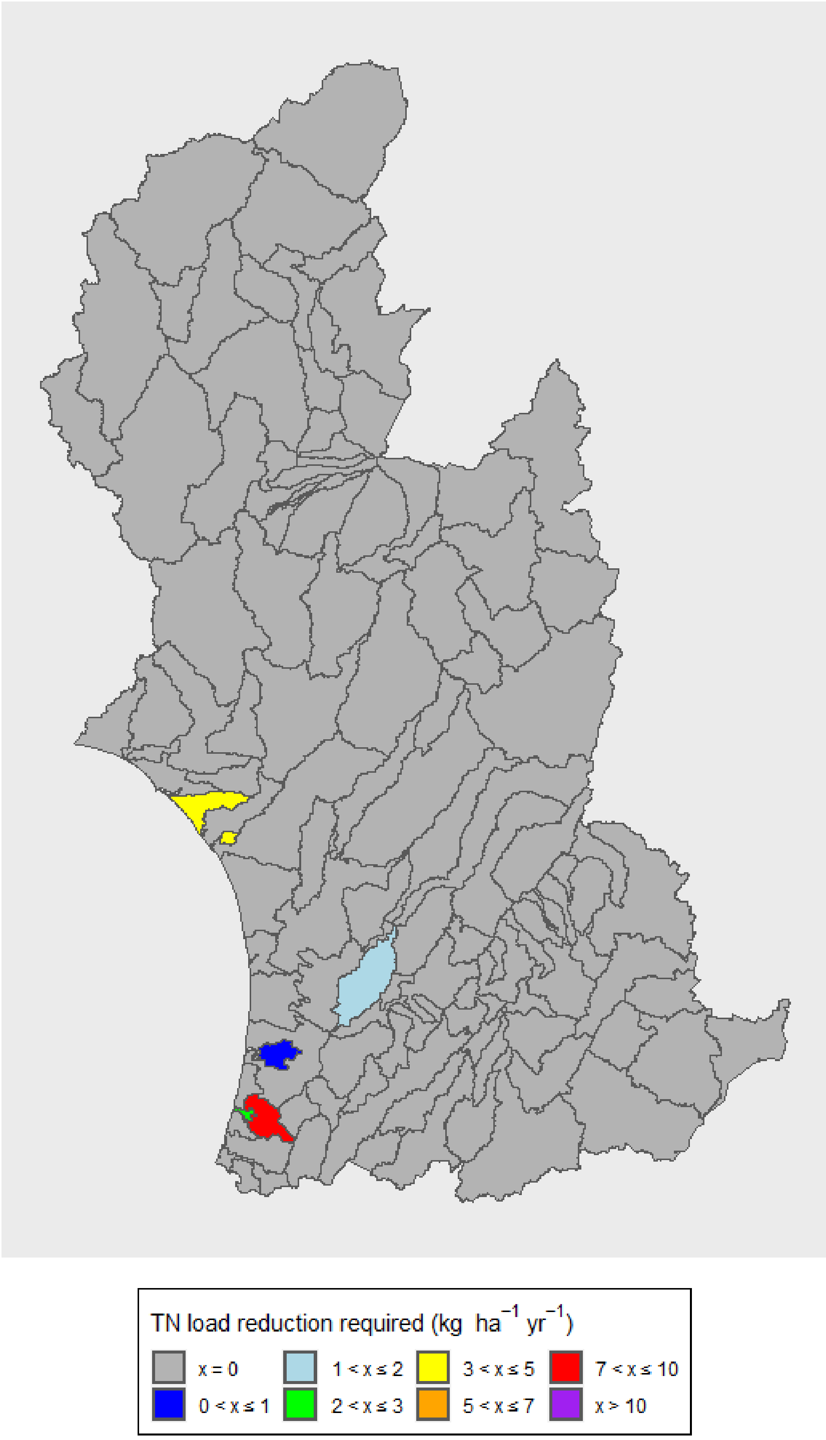


Figure 53*. The TN WMSZ load reductions, expressed as yields, for the C band using Regional TN criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.*

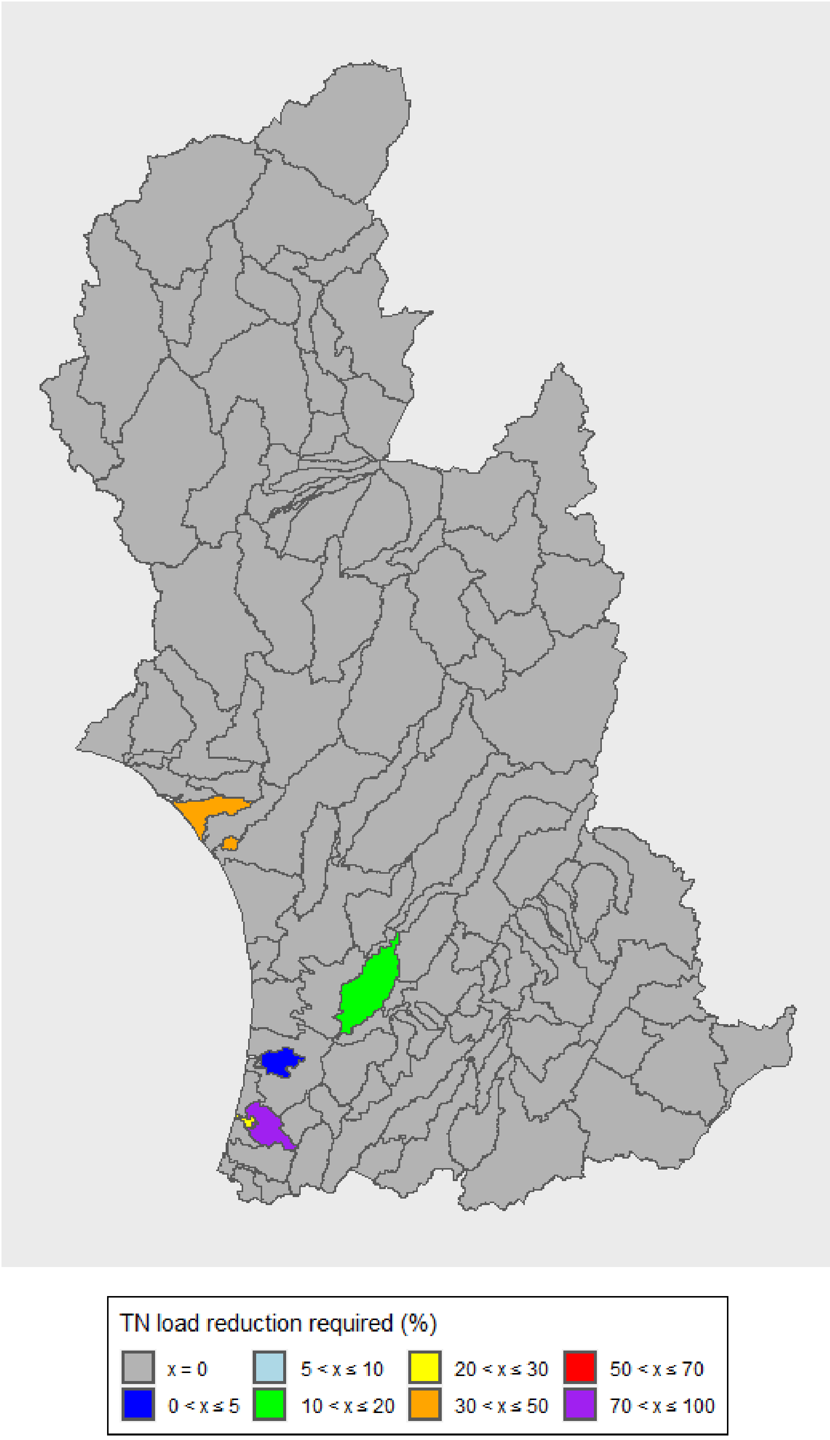


Figure 54. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the C band using Regional TN criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.9.5 Limiting environments

For the C band using Regional TN criteria, the limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for TN and all WMSZs were rivers except for three WMSZs (Hoki_1a, West_4 and West_6; Figure 55).

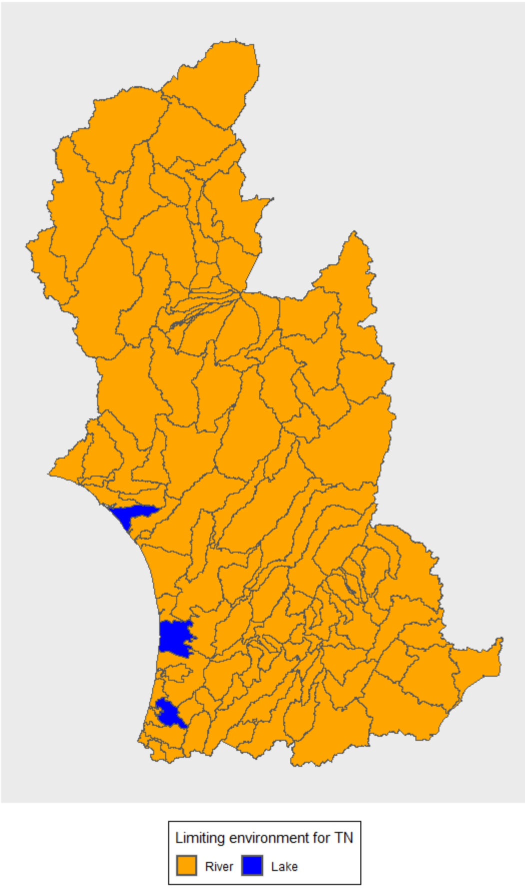


Figure 55. Limiting environment type for TN load reduction requirements for WMSZs for the C band using Regional TN criteria.

3.10 B band using national criteria and 20% risk

3.10.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the B band using national criteria and 20% risk for 54% and 73% of segments in the region, respectively (Figure 56). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the B band options for the nitrate toxicity FWO for 0.3% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at no river segments (Figure 56).

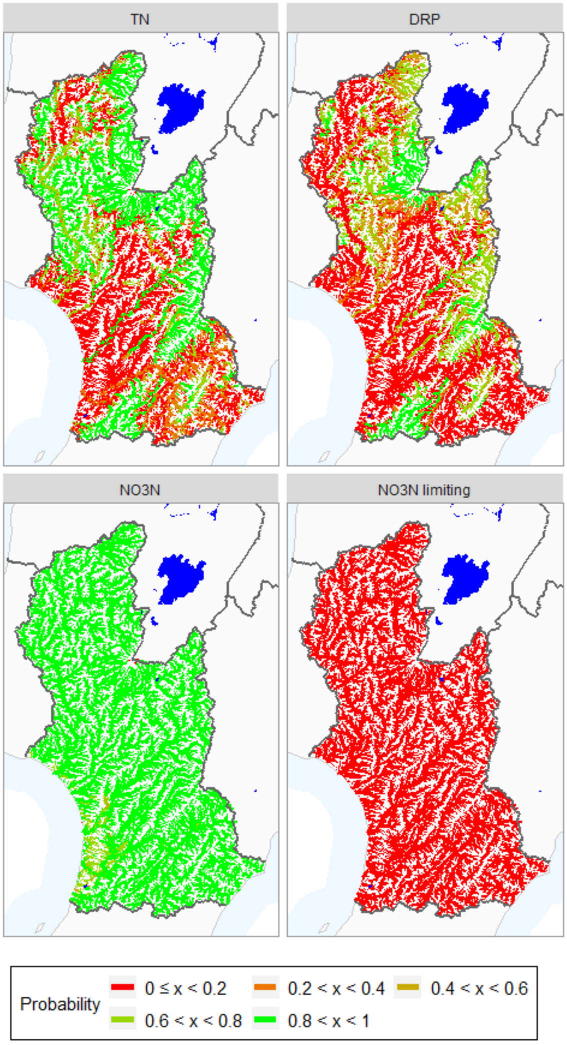


Figure 56. Probability that segments comply with river concentration criteria associated with the B band using national criteria and 20% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the B band was less than 50% (i.e., were non-compliant) for 34 and 33 of the 41 lakes, respectively (Figure 57).

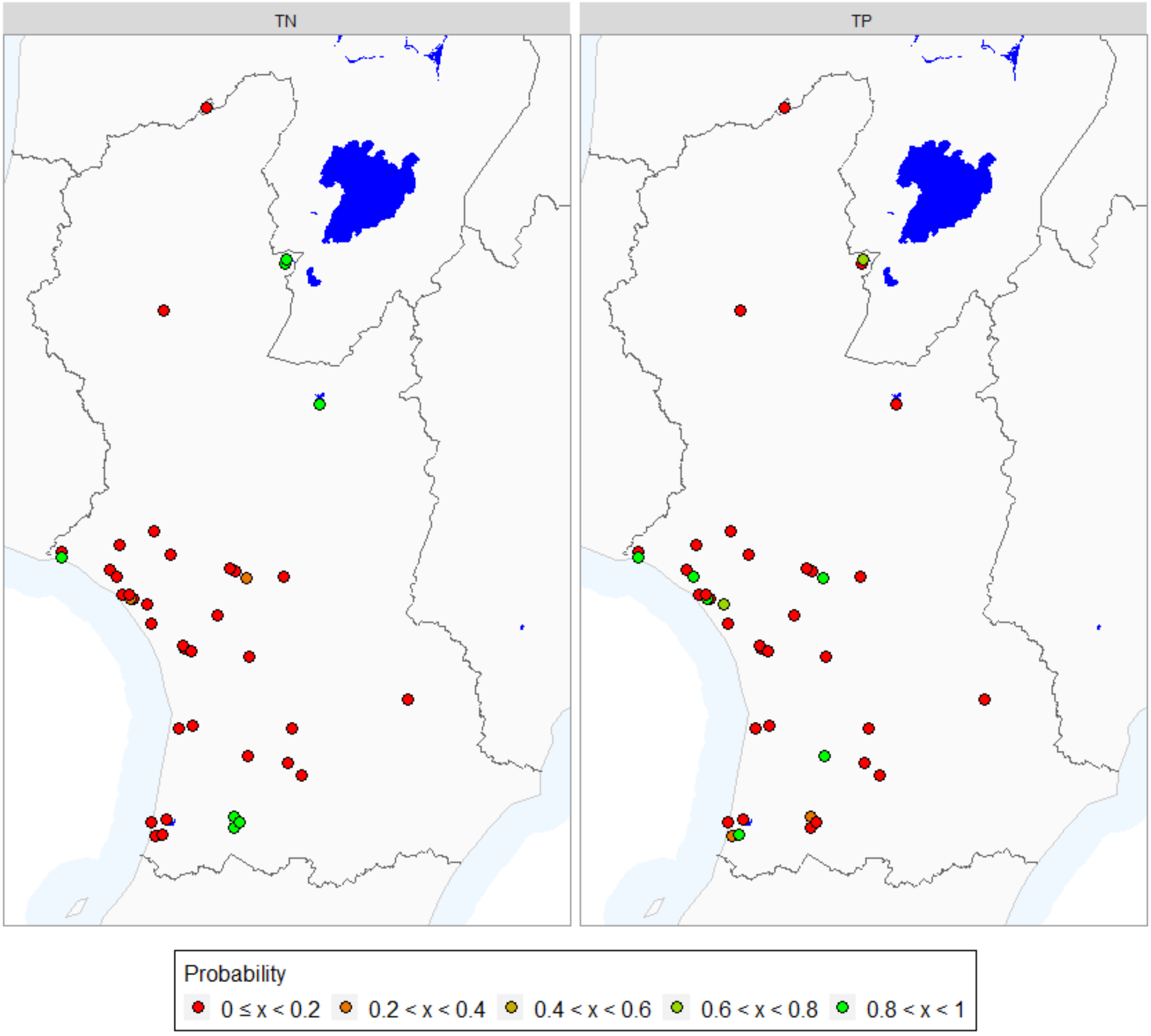


Figure 57. Probability of compliance with lake TN and TP concentration criteria associated with the B band.

3.10.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the B band using national criteria and 20% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 23% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 6% of river segments (Figure 58). 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 58. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 38% of segments.

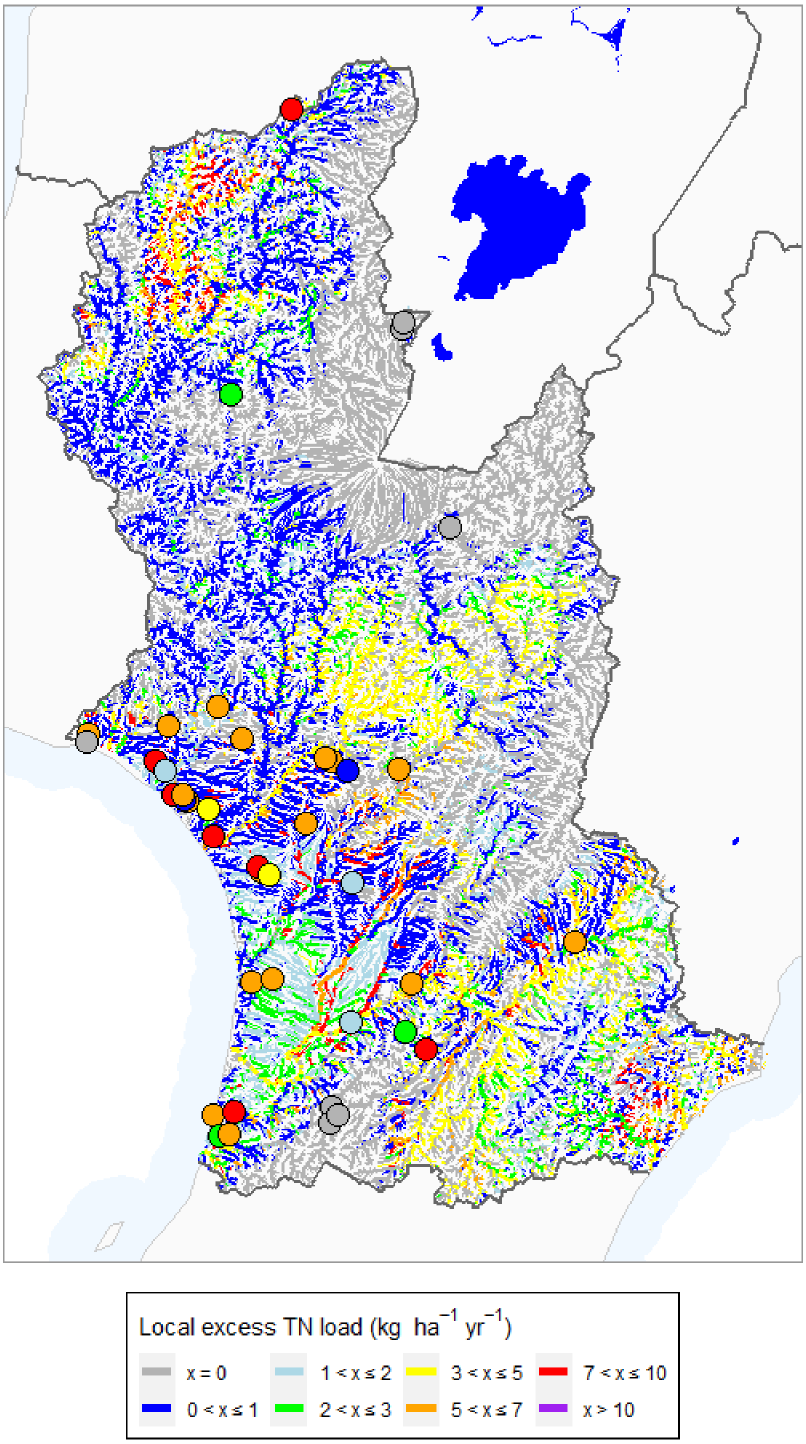


Figure 58. Local excess TN loads for rivers and lakes for the B band using national criteria and 20% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the B band using national criteria and 20% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 48% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 36% of river segments (Figure 59). Note that these breakpoints are nominal and have no special

significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 35% of segments.

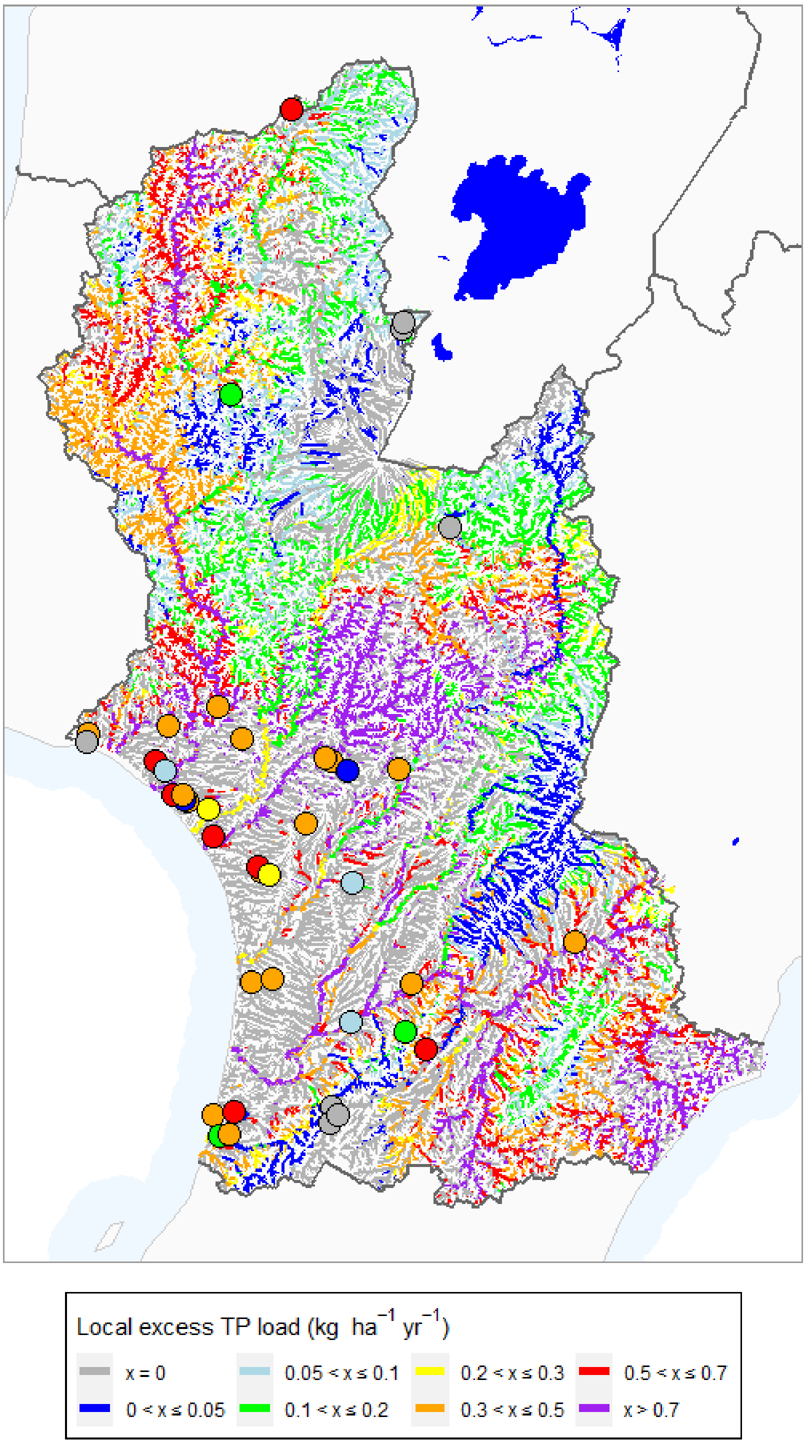


Figure 59. Local excess TP loads for rivers and lakes for the B band using national criteria and 20% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.10.3 FMU and regional load reductions required

The load reductions required by the B band using national criteria and 20% risk for each FMU and for the whole region are shown in Table 14. For the whole region, the TN and TP load reductions required were estimated to be 9,292 t yr^{-1} and 3,246 t yr^{-1}, which represent 52% and 100% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 14.

Load reductions of 100% or more 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 and this would lead to reduction in loads in the downstream direction.

For the B band using national criteria and 20% risk, there was 95% confidence TN and TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs.

Table 14. Current load and load reduction required for TN and TP for FMUs and the whole region for the B band using national criteria and 20% risk. 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 (%)**
Kai Iwi	222 (140 - 318)	147 (73 - 220)	65 (48 - 75)	29 (18 - 43)	27 (14 - 40)	90 (82 - 96)
Whanganui	6,249 (3,475 - 10,654)	3,658 (804 - 7,767)	54 (17 - 78)	1,288 (663 - 2,421)	1,421 (625 - 2,732)	110 (98 - 115)
Whangaehu	1,197 (739 - 1,956)	387 (88 - 737)	31 (10 - 40)	264 (134 - 424)	117 (51 - 219)	44 (36 - 69)
Rangitīkei-Turakina	3,348 (2,242 - 4,780)	1,424 (453 - 2,729)	41 (15 - 60)	684 (349 - 1,149)	769 (372 - 1,335)	112 (105 - 118)
Manawatū	5,244 (2,612 - 9,187)	2,899 (1,118 - 5,916)	53 (36 - 69)	773 (322 - 1,578)	743 (317 - 1,529)	96 (92 - 100)
Waiopehu	327 (235 - 439)	124 (71 - 201)	37 (26 - 50)	26 (17 - 34)	15 (8 - 24)	56 (32 - 76)
Puketoi ki Tai	985 (723 - 1,281)	623 (406 - 866)	63 (53 - 74)	175 (115 - 251)	148 (97 - 205)	85 (76 - 93)
Whole region	17,641 (13,434 - 22,364)	9,292 (5,184 - 13,665)	52 (35 - 63)	3,248 (2,174 - 4,378)	3,246 (2,157 - 4,545)	100 (93 - 106)

3.10.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 58 and Figure 36) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the B band using national criteria and 20% risk are shown on Figure 60 and Figure 61. There were 78 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 65% of the region. There were 11 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 4% of the region (Figure 37). When load reductions required for TN were expressed as a proportion of current loads, 88 WMSZs required reductions of greater than 50% and these occupied 71% of the region (Figure 38).

There were 116 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 62) and these occupied 97% of the region. There were 6 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 2% of the region. When load reductions required for TP were expressed as a proportion of current loads, 113 WMSZs required reductions of greater than 50% and these occupied 96% of the region (Figure 63). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

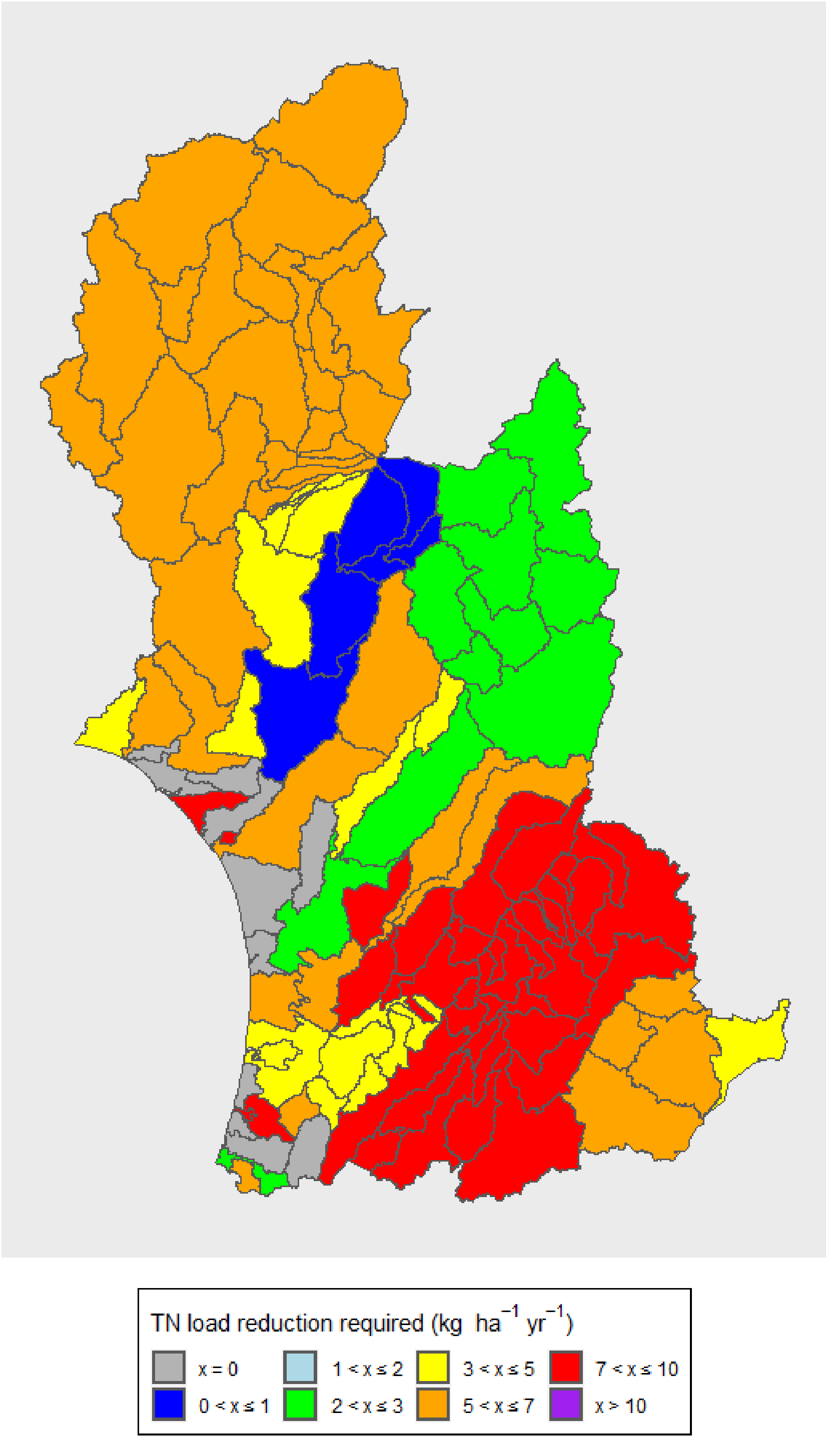


Figure 60. The TN WMSZ load reductions, expressed as yields, for the B band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

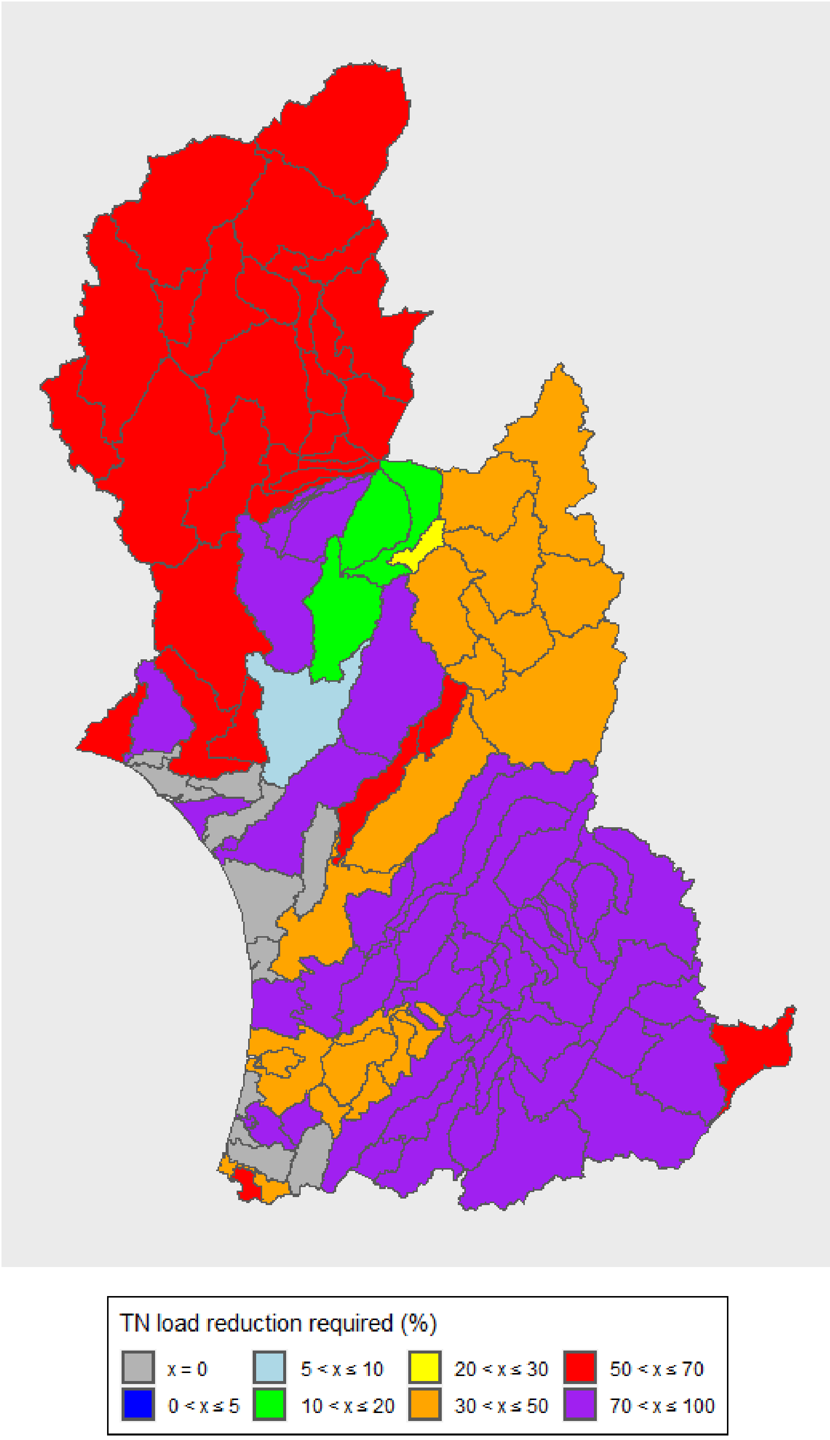


Figure 61. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the B band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

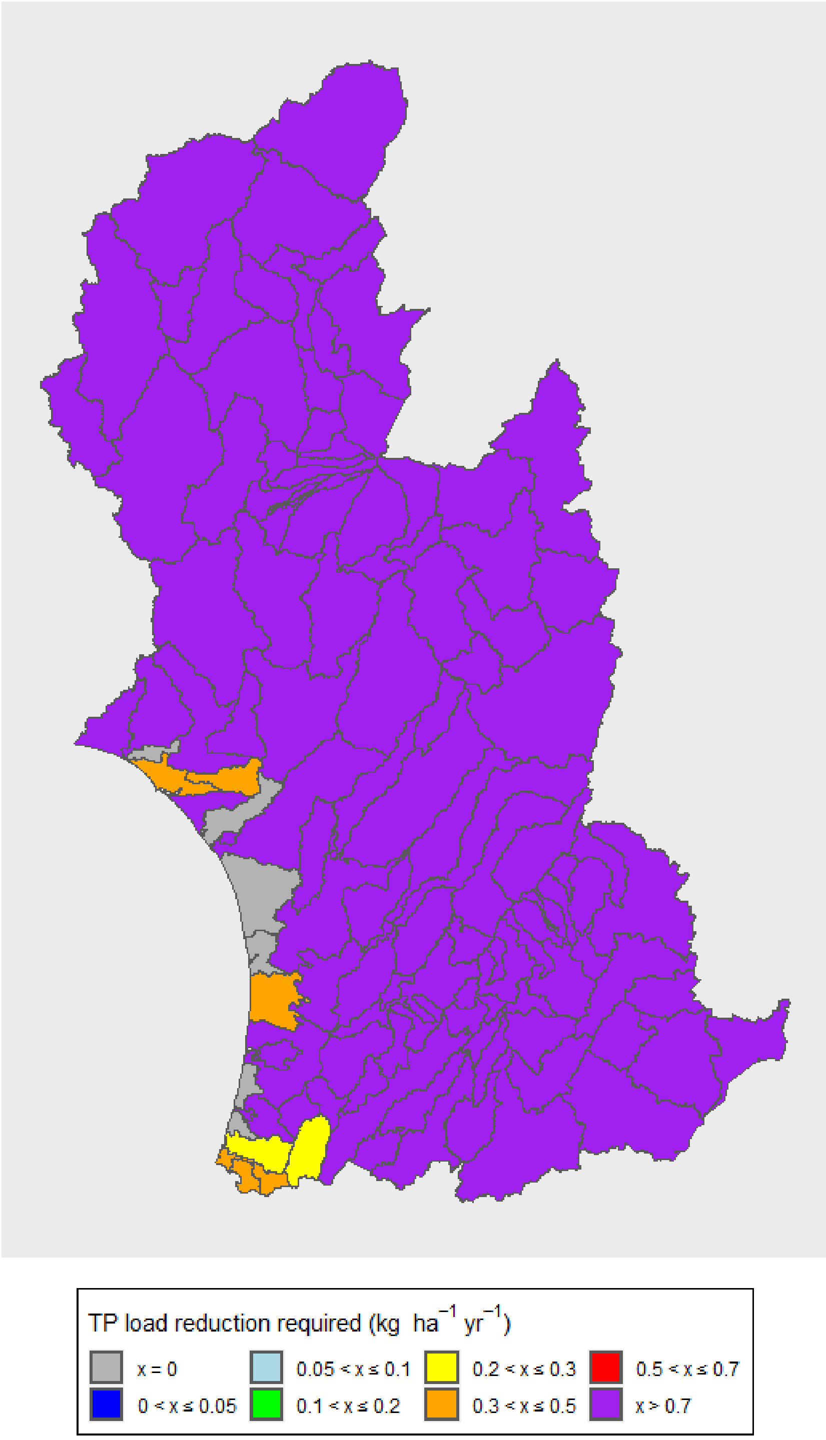


Figure 62. The TP WMSZ load reductions, expressed as yields, for the B band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

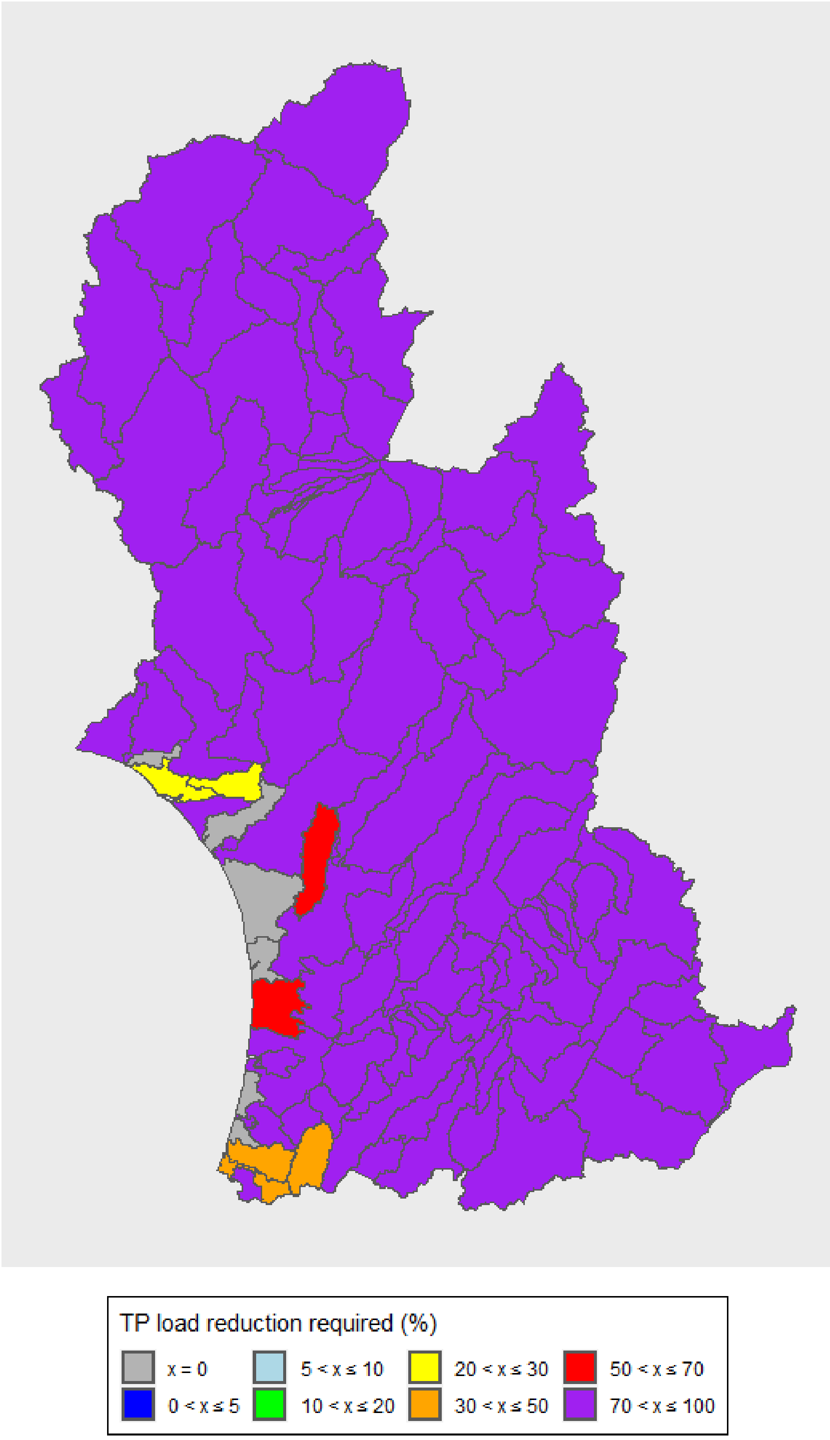


Figure 63. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the B band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.10.5 Limiting environments

For the B band using national criteria and 20% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for three WMSZs (Hoki_1a, West_4 and West_6) for TN and four WMSZs for TP (Hoki_1a, West_4 and West_6 and Mana_11b, Figure 64).

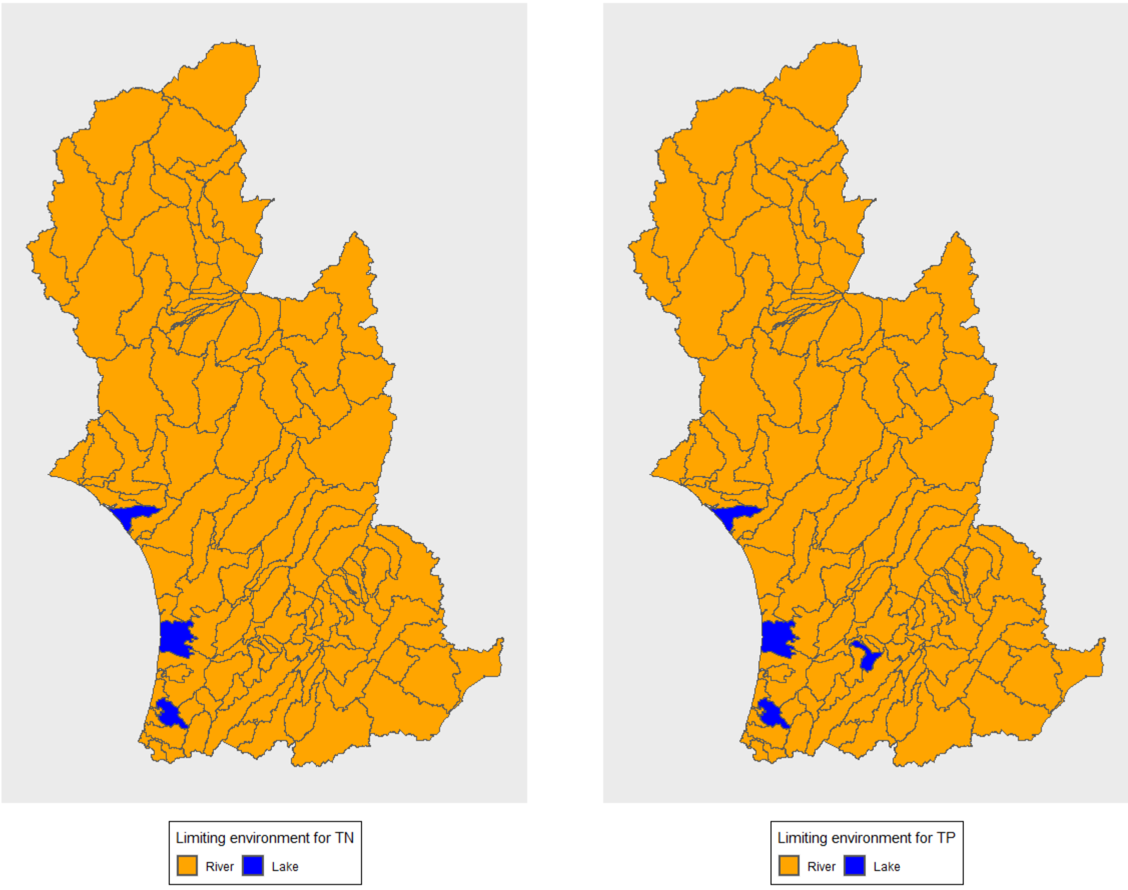


Figure 64. Limiting environment type for TN and TP load reduction requirements for WMSZs for the B band using national criteria and 20% risk.

3.11 B band using national criteria and 30% risk

3.11.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the B band using national criteria and 30% risk for 40% and 32% of segments in the region, respectively (Figure 65). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the B band options for the nitrate toxicity FWO for 0.2% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at 0.8% of river segments (Figure 65).

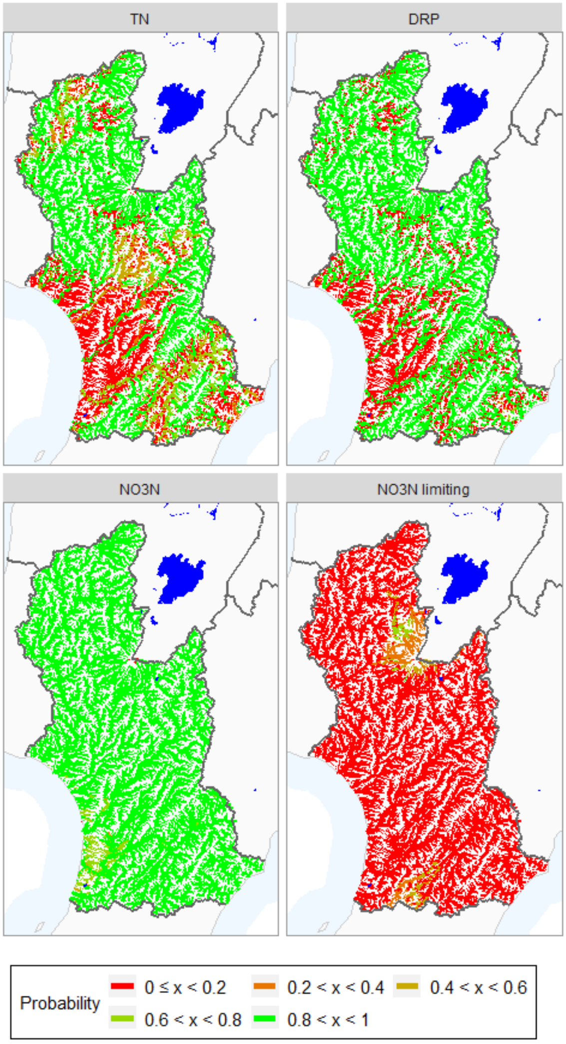


Figure 65. Probability that segments comply with river concentration criteria associated with the B band using national criteria and 30% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the B band was less than 50% (i.e., were non-compliant) for 34 and 33 of the 41 lakes, respectively (Figure 66). Note that differences in results for lakes between the 20% risk and

30% risk assessments are associated with random perturbations in the Monte Carlo analysis only because the criteria for lakes is unchanged.

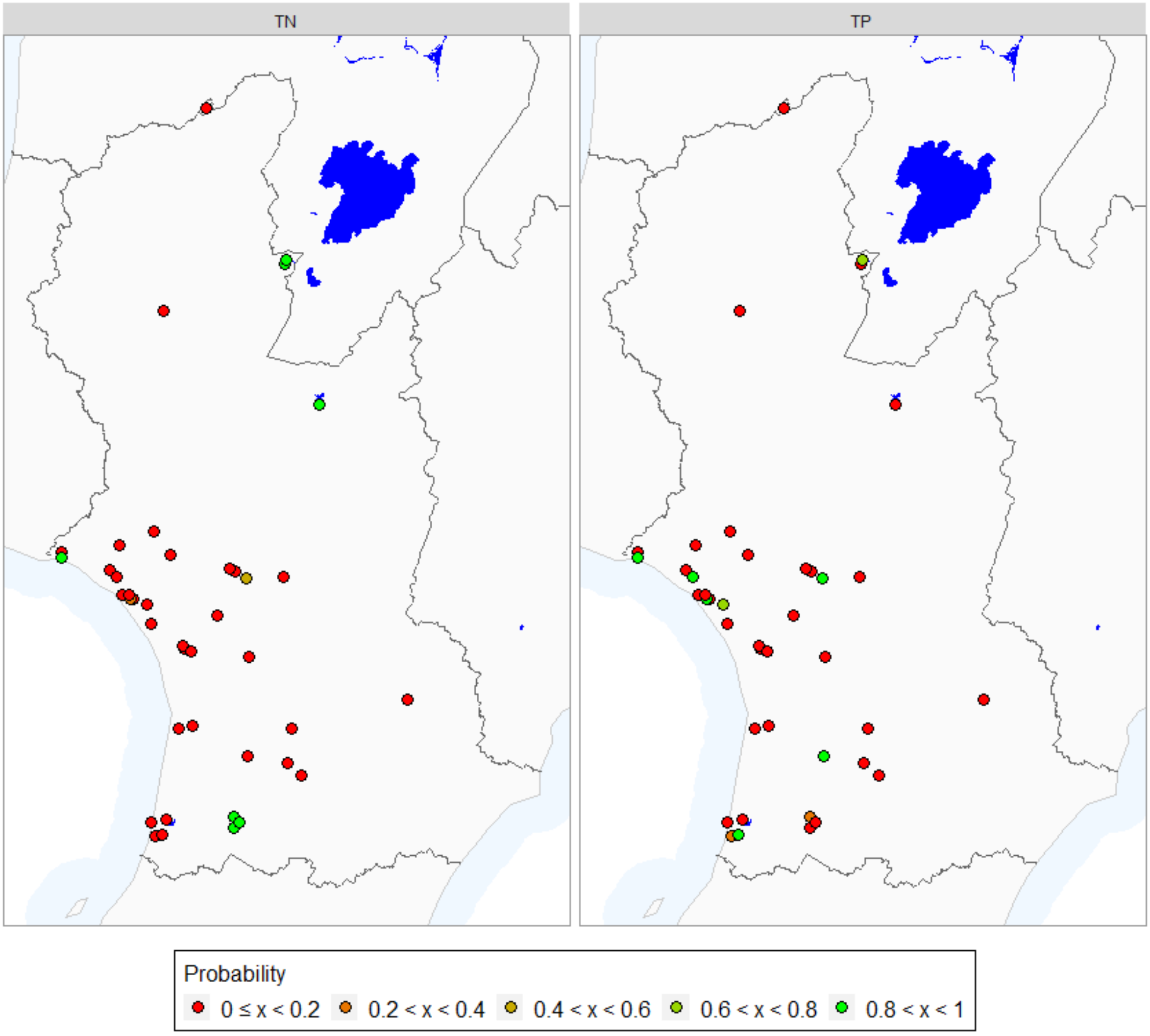


Figure 66. Probability of compliance with lake TN and TP concentration criteria associated with the B band.

3.11.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the B band using national criteria and 30% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 7% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 1.6% of river segments (Figure 67). 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 67. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 47% of segments.

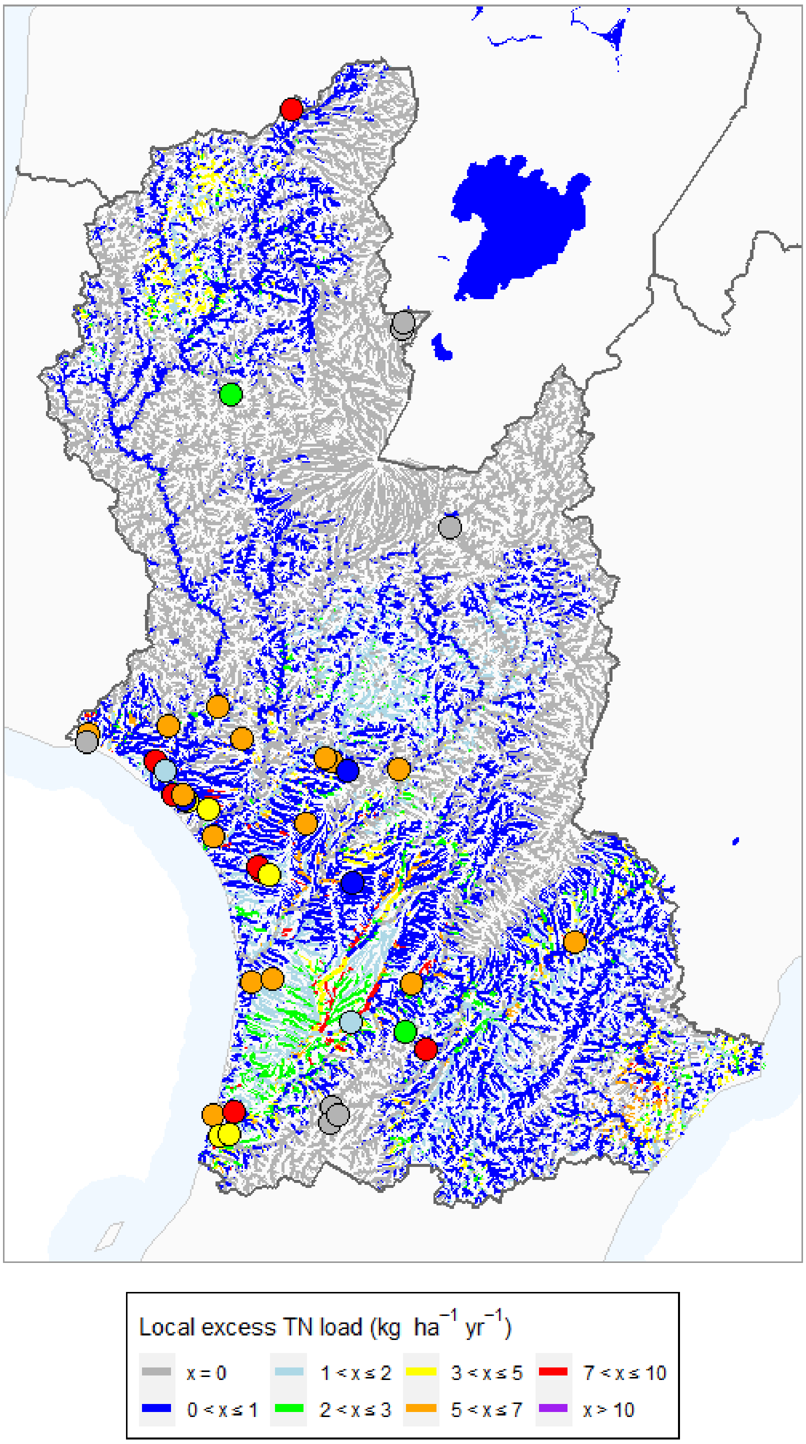


Figure 67. Local excess TN loads for rivers and lakes for the B band using national criteria and 30% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the B band using national criteria and 30% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 1.5% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 0.9% of river segments (Figure 36). Note that these breakpoints are nominal and have no special

significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 91% of segments.

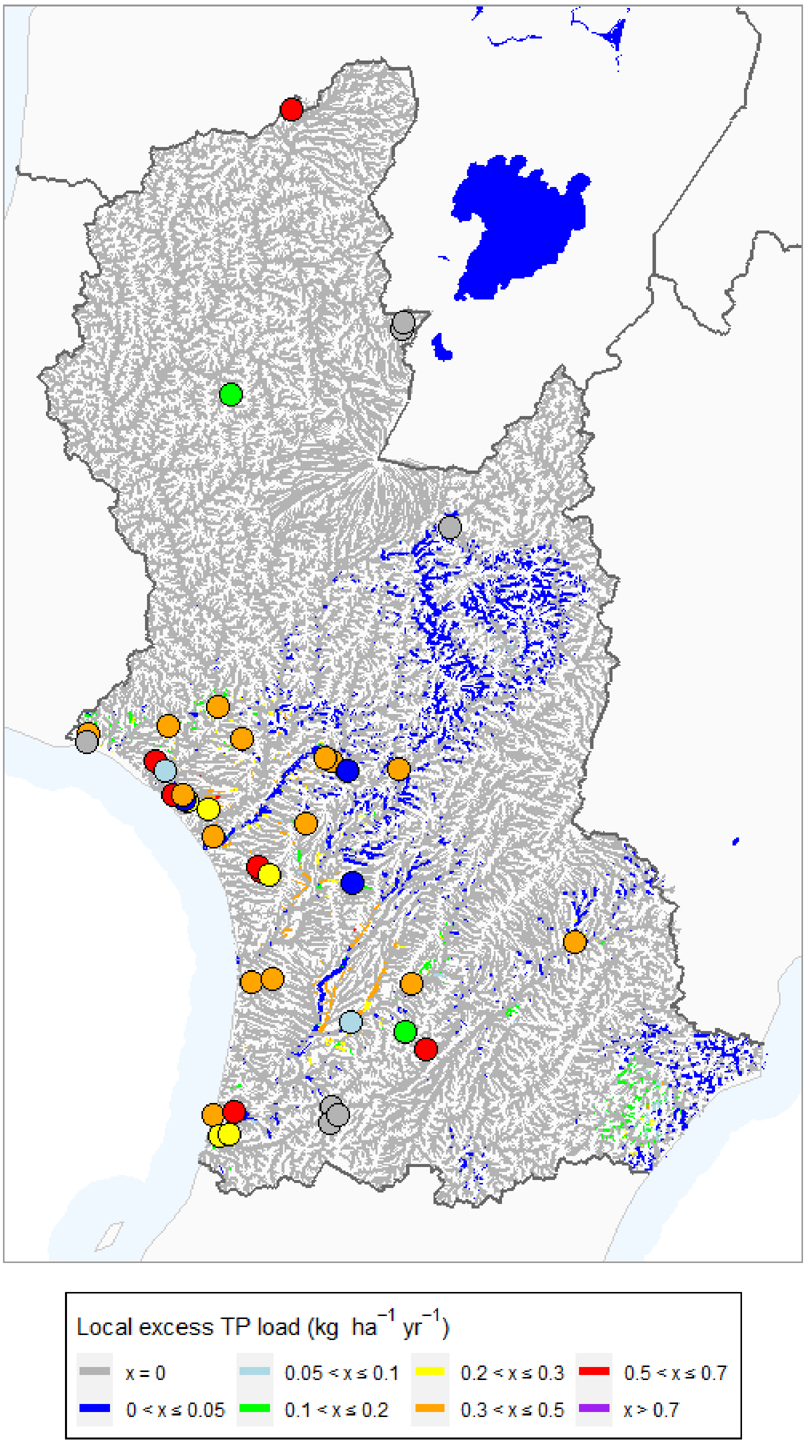


Figure 68. Local excess TP loads for rivers and lakes for the B band using national criteria and 30% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.11.3 FMU and regional load reductions required

The load reductions required by the B band using national criteria and 30% risk for each FMU and for the whole region are shown in Table 11. For the whole region, the TN and TP load reductions required were estimated to be 5,327 t yr^{-1} and 184 t yr^{-1}, which represent 30% and 6% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 15.

For the B band using national criteria and 30% risk, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs except for Whanganui and Whangaehu FMUs). There was 95% confidence TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs except for Whanganui, Whangaehu and Puketoi ki Tai.

Table 15. Current load and load reduction required for TN and TP for FMUs and the whole region for the C band using national criteria and 20% risk. 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 (%)**
Kai Iwi	218 (143 - 330)	105 (39 - 240)	46 (26 - 70)	30 (17 - 47)	11 (6 - 19)	37 (31 - 41)
Whanganui	5,829 (3,250 - 9,118)	1,691 (22 - 4,797)	24 (0 - 63)	1,253 (638 - 2,183)	6 (2 - 10)	1 (0 - 1)
Whangaehu	1,216 (613 - 1,901)	243 (1 - 525)	18 (0 - 33)	266 (127 - 486)	11 (0 - 54)	4 (0 - 19)
Rangitīkei-Turakina	3,024 (1,997 - 4,102)	569 (194 - 1,223)	18 (8 - 35)	641 (376 - 911)	93 (11 - 306)	15 (2 - 47)
Manawatū	5,290 (2,874 - 8,685)	2,180 (382 - 4,832)	38 (10 - 57)	775 (377 - 1,325)	54 (5 - 315)	7 (1 - 41)
Waiopehu	341 (251 - 471)	91 (59 - 129)	27 (20 - 37)	27 (20 - 43)	4 (2 - 7)	16 (6 - 25)
Puketoi ki Tai	981 (728 - 1,367)	434 (163 - 734)	43 (20 - 60)	177 (115 - 254)	5 (0 - 24)	3 (0 - 18)
Whole region	16,967 (12,753 - 21,588)	5,327 (2,320 - 9,799)	30 (17 - 47)	3,178 (2,397 - 4,456)	184 (45 - 454)	6 (1 - 16)

3.11.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 67 and Figure 68) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the B band using national criteria and 30% risk are shown on Figure 69 and Figure 70. There were 40 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 21% of the region. There were 36 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 29% of the region (Figure 69). When load reductions required for TN were expressed as a proportion of current loads, 45 WMSZs required reductions of greater than 50% and these occupied 26% of the region (Figure 70).

There were 11 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 71) and these occupied 6% of the region. There were 112 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 93% of the region. When load reductions required for TP were expressed as a proportion of current loads, eight WMSZs required reductions of greater than 50% and these occupied 5% of the region (Figure 72). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

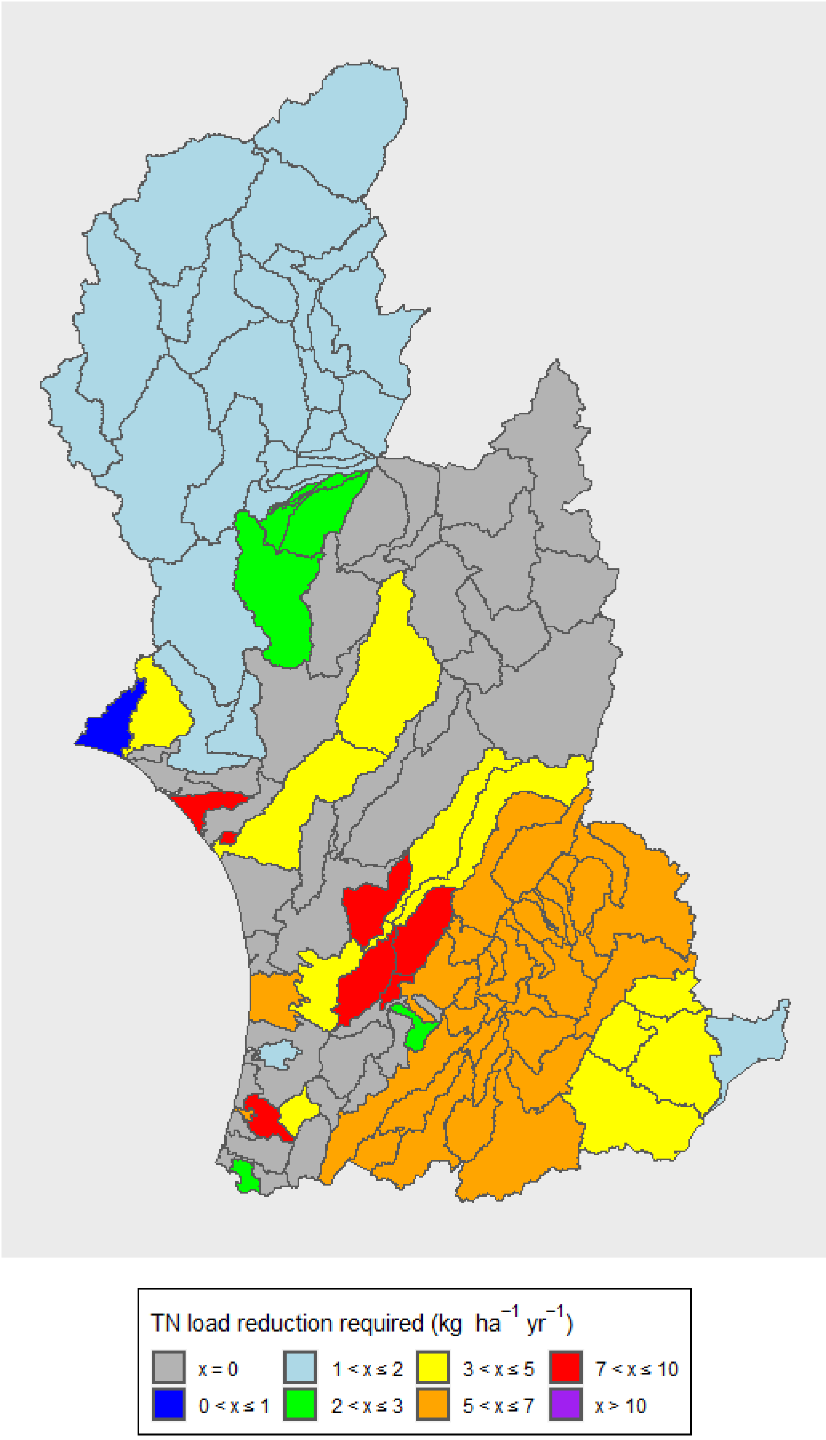


Figure 69. The TN WMSZ load reductions, expressed as yields, for the B band using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

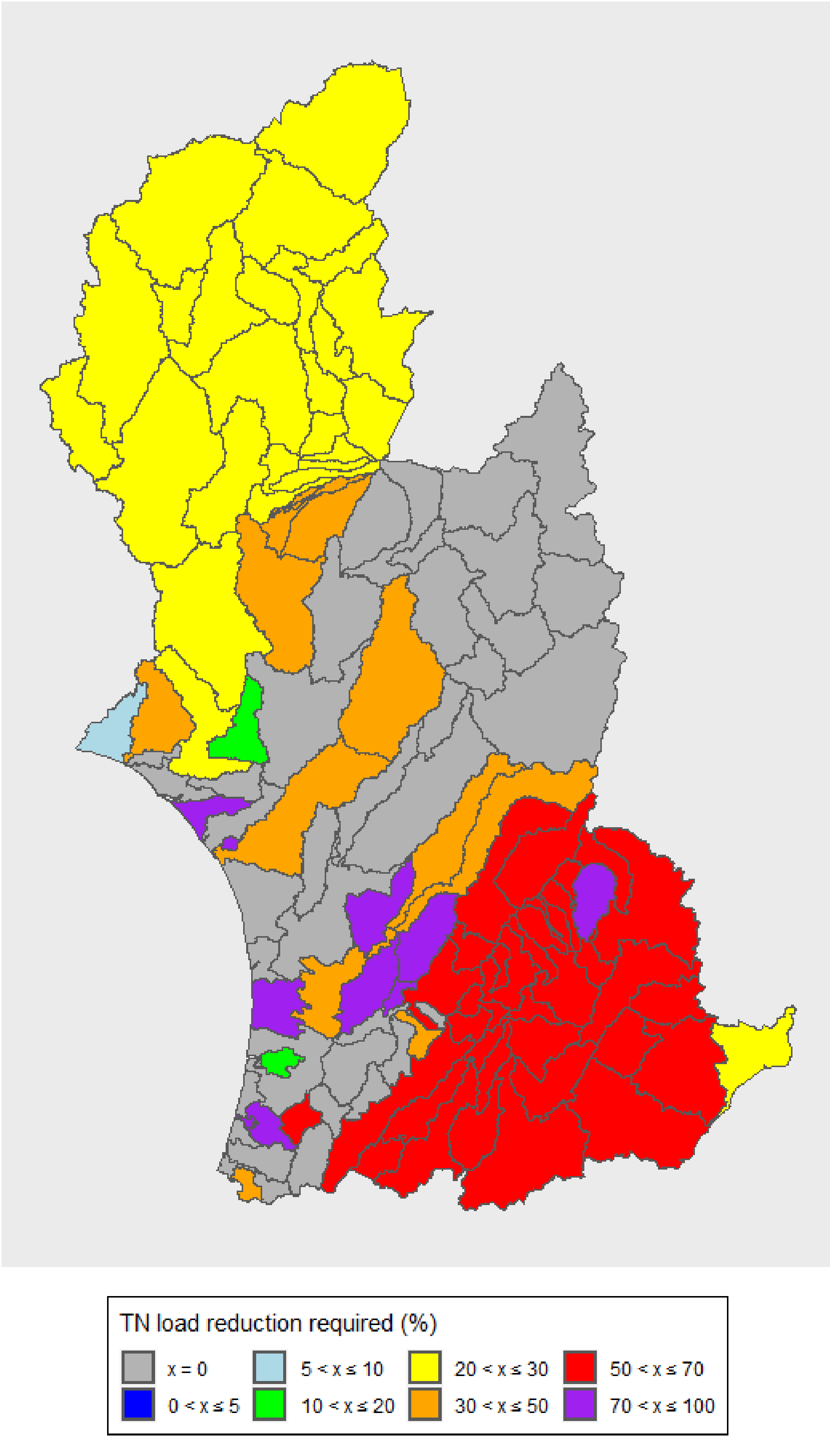


Figure 70. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the B band using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

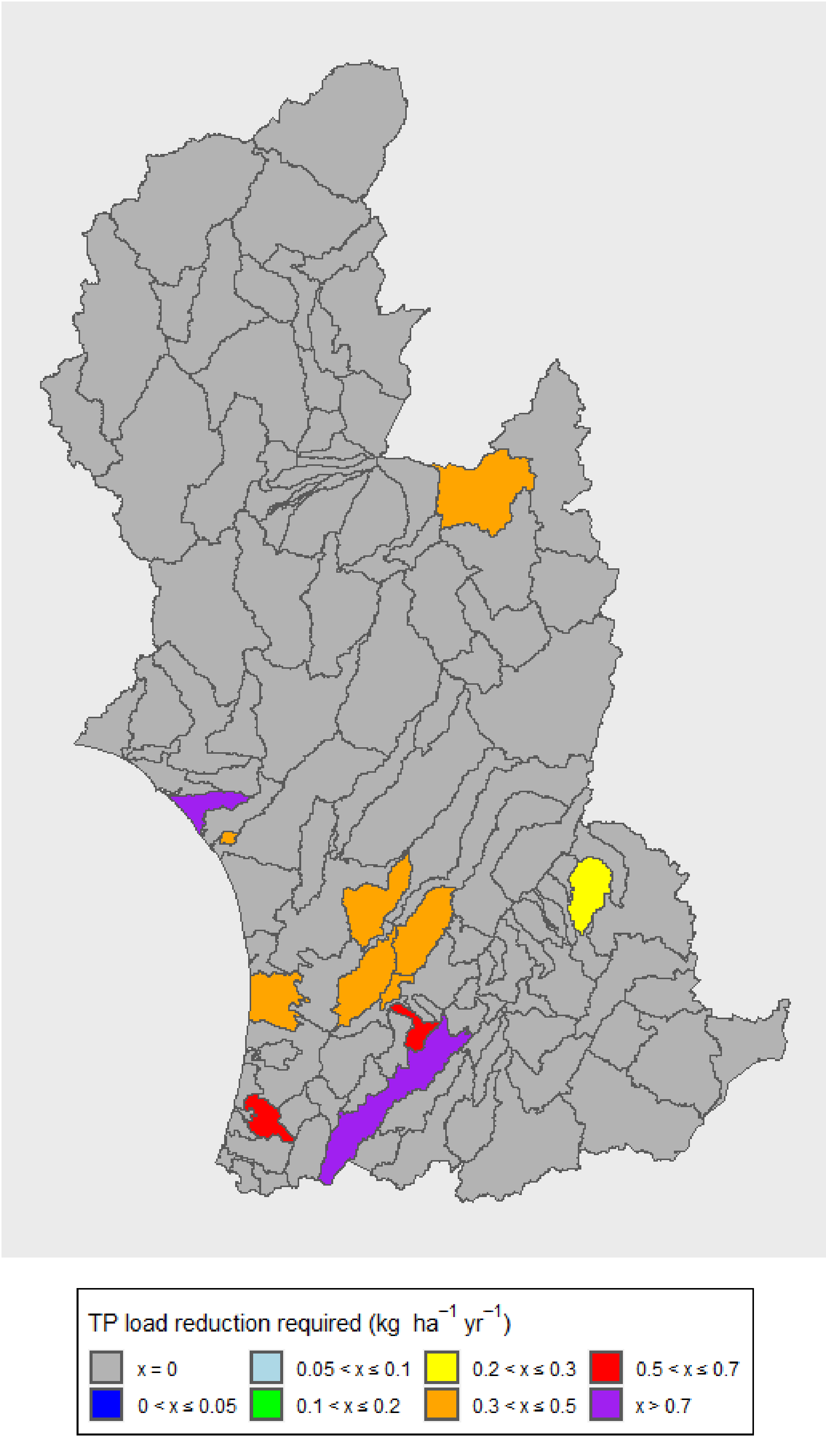


Figure 71. The TP WMSZ load reductions, expressed as yields, for the B band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

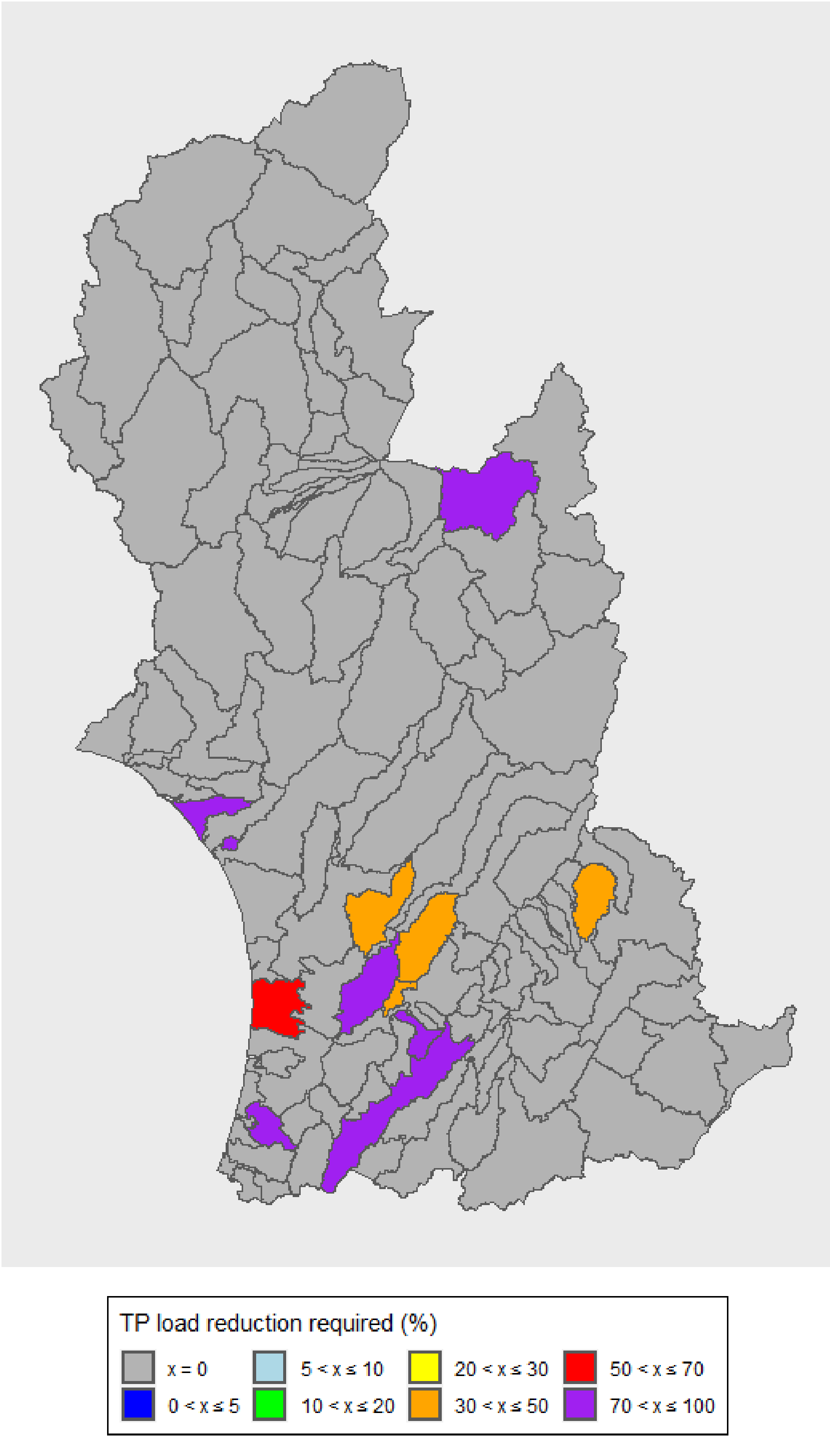


Figure 72. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the B band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.11.5 Limiting environments

For the B band using national criteria and 30% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) was rivers except for four WMSZs (Hoki_1a, Mana_11b, West_4 and West_6) for TN and seven WMSZs for TP (Hoki_1a, West_4, West_6, Mana_11b, Mana_9d, Rang_2c and Tura_*1c,* Figure 73*).*

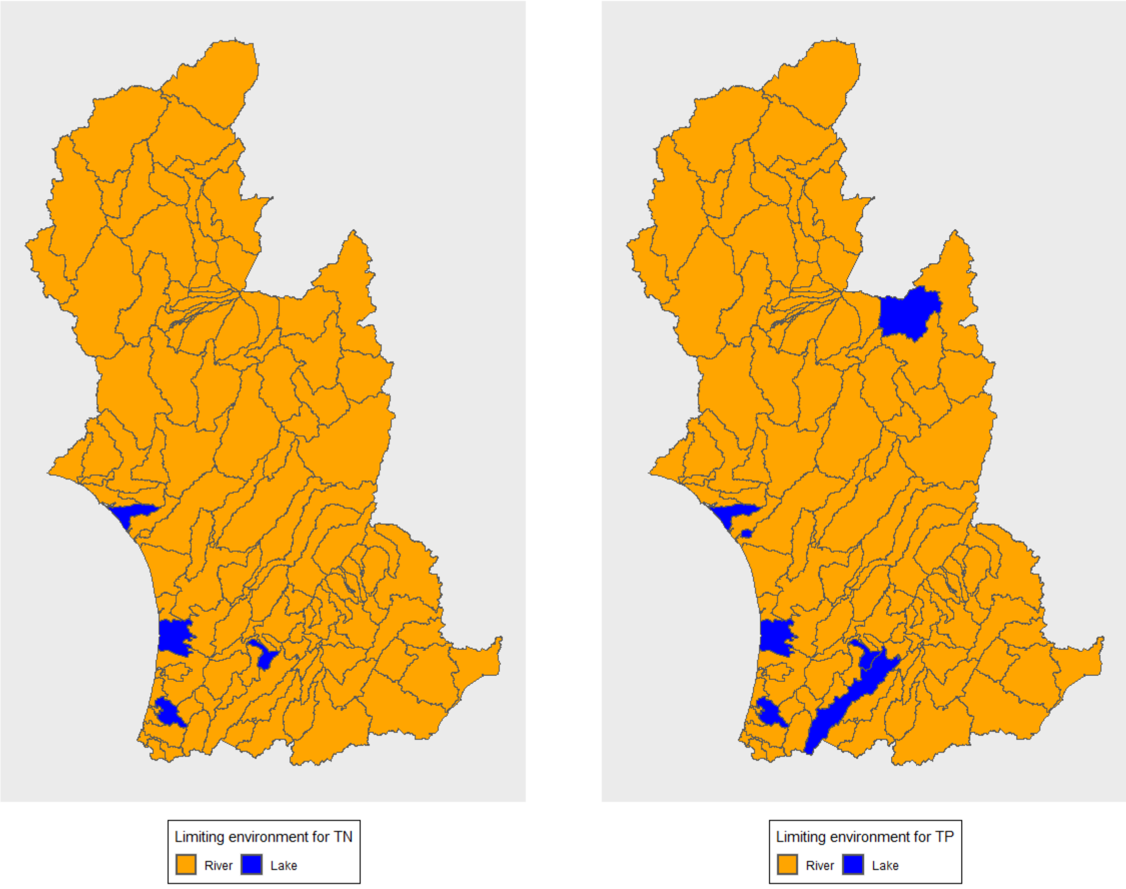


Figure 73. Limiting environment type for TN and TP load reduction requirements for WMSZs for the B band using national criteria and 30% risk.

3.12 B band using Regional TN criteria

3.12.1 Compliance

Because the regional criteria apply only to TN, this section describes only nitrogen load reduction requirements. Current river concentrations of TN had a greater than 50% probability of exceeding the criteria associated with the B band using regional criteria (i.e., were non-compliant) for 43% of segments in the region (Figure 74).

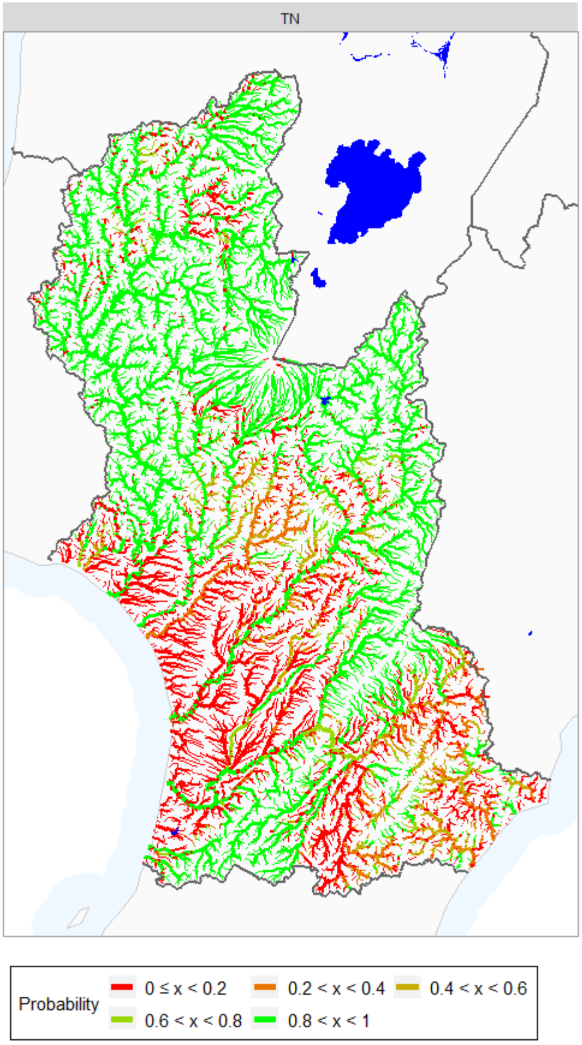
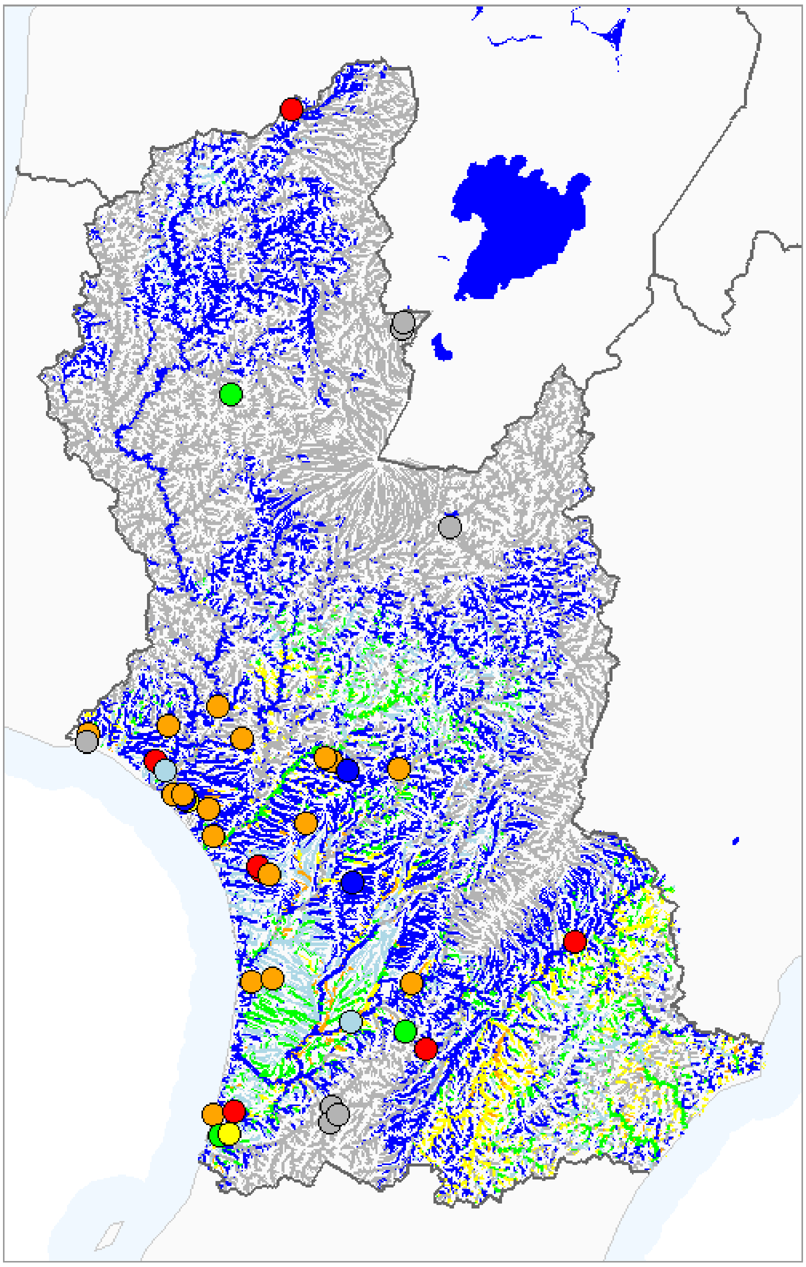


Figure 74. Probability that segments comply with the B band using Regional TN criteria.

3.12.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the objective for that receiving environment. For the B band using Regional TN criteria, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 11% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 1% of river segments (Figure 75). 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 75. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 47% of segments.



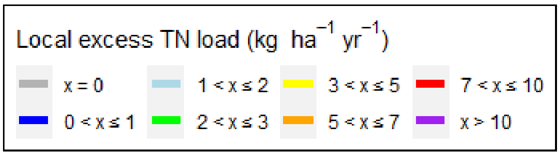


Figure 75. Local excess TN loads for rivers and lakes for the B band using Regional TN criteria. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.12.3 FMU and regional load reductions required

The load reductions required by the B band using Regional TN criteria for each FMU and for the whole region are shown in Table 16. For the whole region, the TN load reductions required were estimated to be 1,616 t yr^{-1}, which represent 9% of the current loads delivered to the coast. The uncertainties on the estimated current loads of TN and the load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 16.

For the B band using Regional TN criteria, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for no FMUs.

Table 16. Current load and load reduction required for TN for FMUs and the whole region for the B band using Regional TN criteria. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of current load (%). The values shown in parentheses are the 5^{th} and 95^{th} confidence limits for the reported values (i.e., the range is the 90% confidence interval).

FMU	TN		
	Current load (t yr^{-1})	Load reduction required (t yr^{-1})	Load reduction required (%)
Kai Iwi	224 (157 - 325)	73 (28 - 168)	30 (19 - 55)
Whanganui	6,292 (3,504 - 10,951)	55 (18 - 58)	1 (0 - 1)
Whangaehu	1,259 (720 - 2,085)	24 (2 - 106)	2 (0 - 6)
Rangitīkei-Turakina	3,185 (2,085 - 4,446)	438 (150 - 894)	13 (6 - 26)
Manawatū	5,487 (3,221 - 9,139)	624 (4 - 2,308)	10 (0 - 34)
Waiopehu	327 (233 - 442)	69 (40 - 110)	21 (14 - 30)
Puketoi ki Tai	921 (644 - 1,274)	322 (69 - 617)	32 (9 - 54)
Whole region	17,765 (14,220 - 23,572)	1,616 (751 - 3,404)	9 (5 - 17)

3.12.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 75) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the B band using Regional TN criteria are shown on Figure 76. There were nine WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and this occupied 5% pf the region. There were 94 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 77% of the region (Figure 76). When load reductions required for TN were expressed as a proportion of current loads, nine WMSZs required reductions of greater than 50% and these occupied 5% of the region (Figure 77).

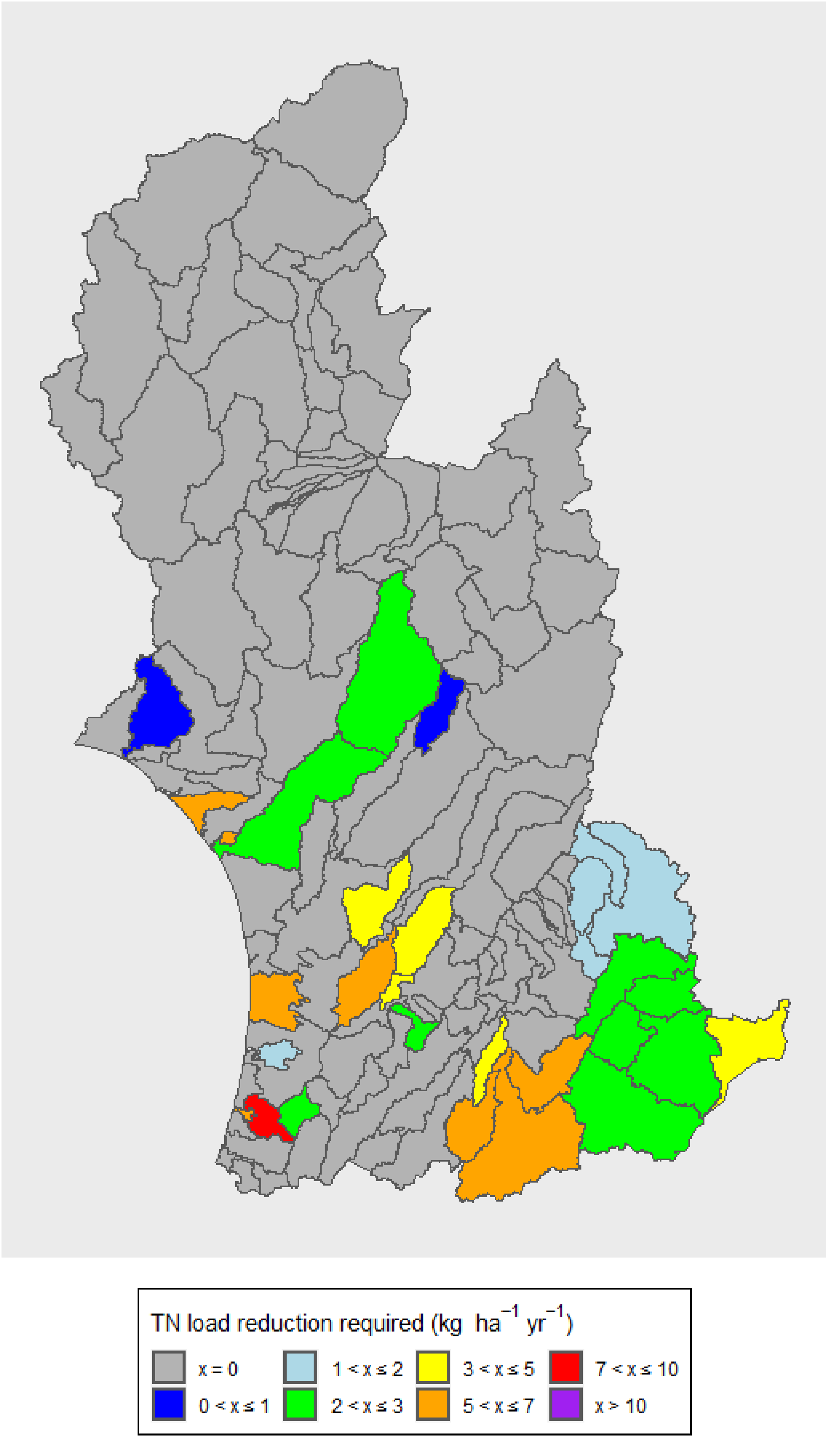


Figure 76. The TN WMSZ load reductions, expressed as yields, for the B band using Regional criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

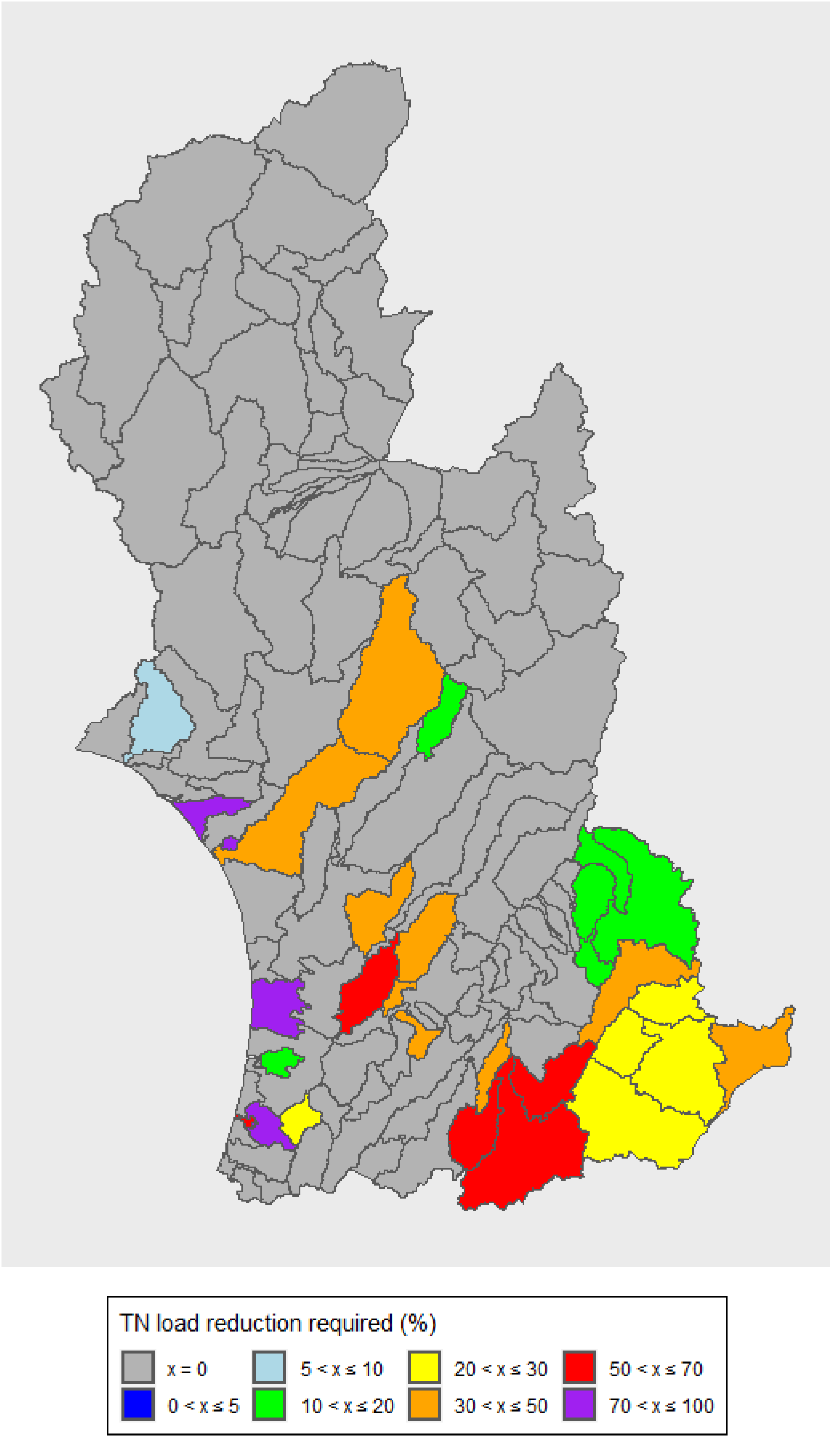


Figure 77. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the B band using Regional TN criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.12.5 Limiting environments

For the B band using Regional TN criteria, the limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for TN and all WMSZs were rivers except for five WMSZs (Hoki_1a, Mana_11b, Tura_1c, West_4 and West_6) (Figure 78).

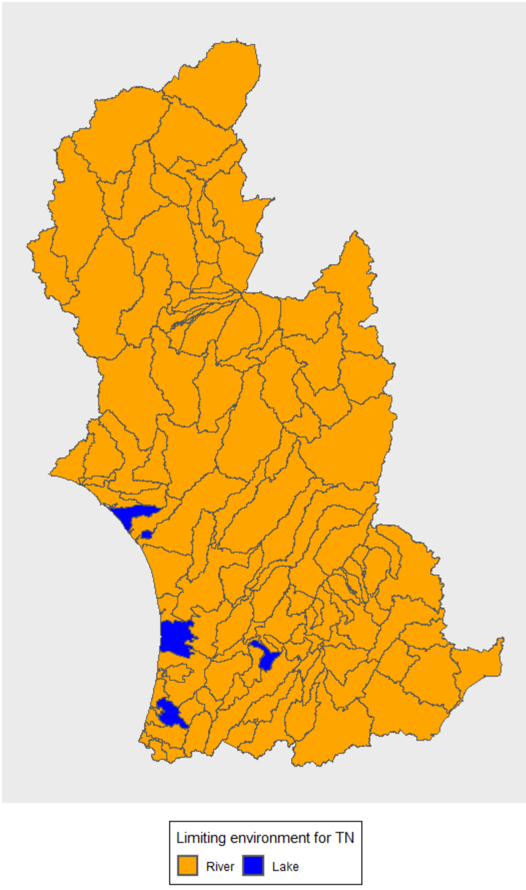


Figure 78. Limiting environment type for TN load reduction requirements for WMSZs for the B band using Regional TN criteria.

3.13 A band using national criteria and 20% risk

3.13.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the A band using national criteria and 20% risk for 84% and 99% of segments in the region, respectively (Figure 102). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the A band options for the nitrate toxicity FWO for 6% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at no river segments (Figure 79).

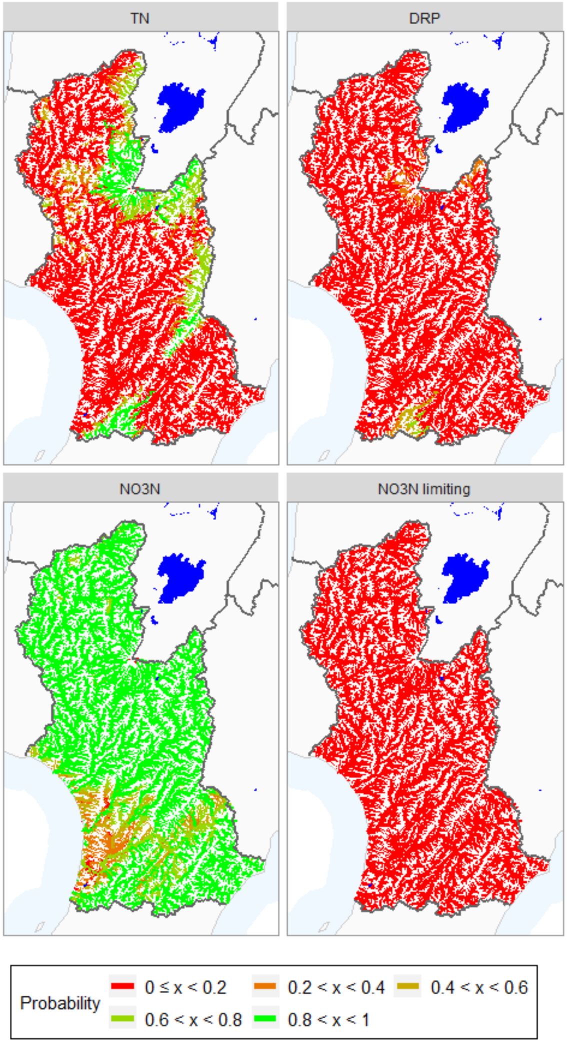


Figure 79. Probability that segments comply with river concentration criteria associated with the A band using national criteria and 20% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the C band was less than 50% (i.e., were non-compliant) for 39 and 40 of the 41 lakes, respectively (Figure 80).

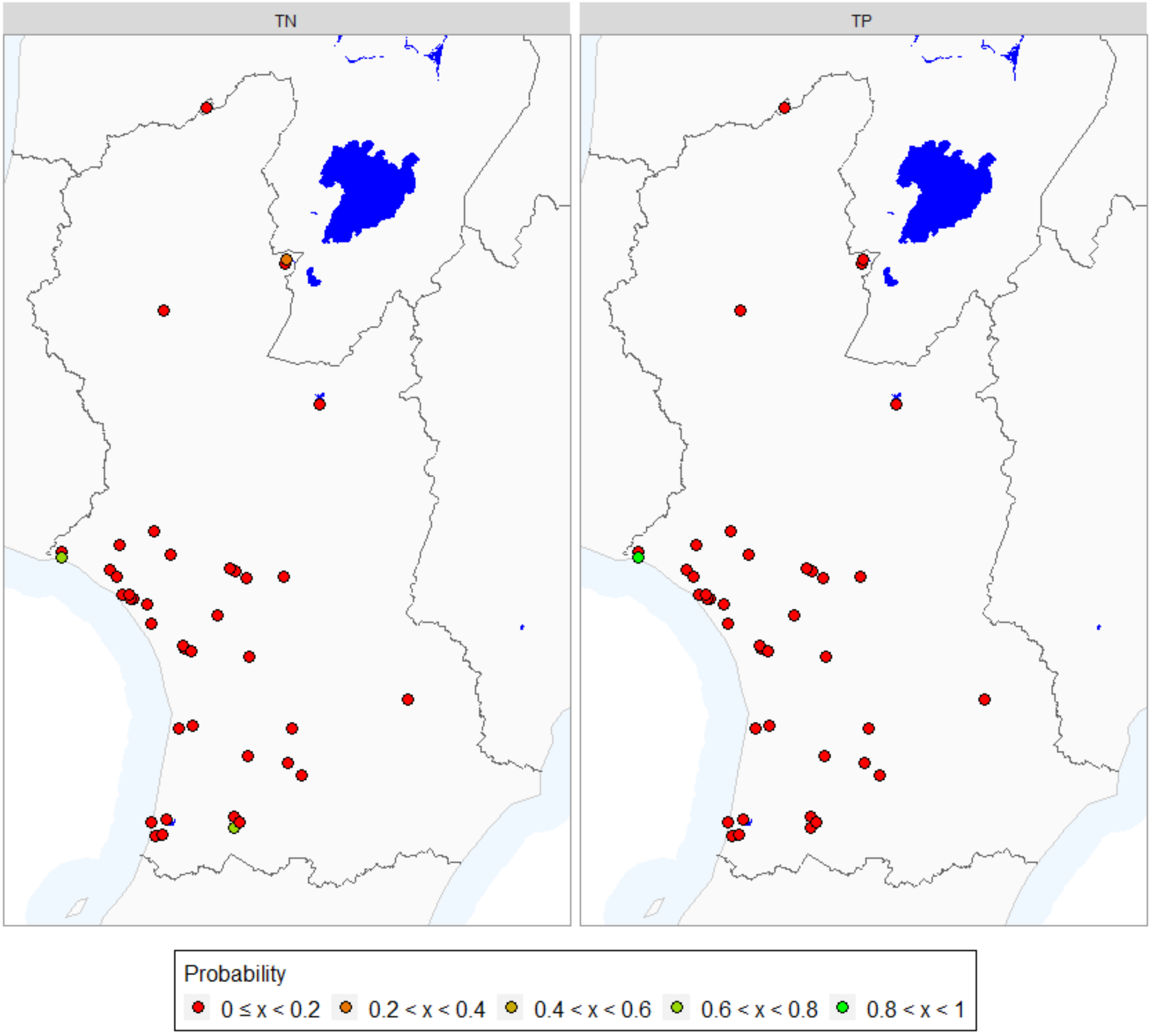


Figure 80. Probability of compliance with lake TN and TP concentration criteria associated with the A band.

3.13.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the A band using national criteria and 20% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 56% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 33% of river segments (Figure 81). 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 107. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 6% of segments.

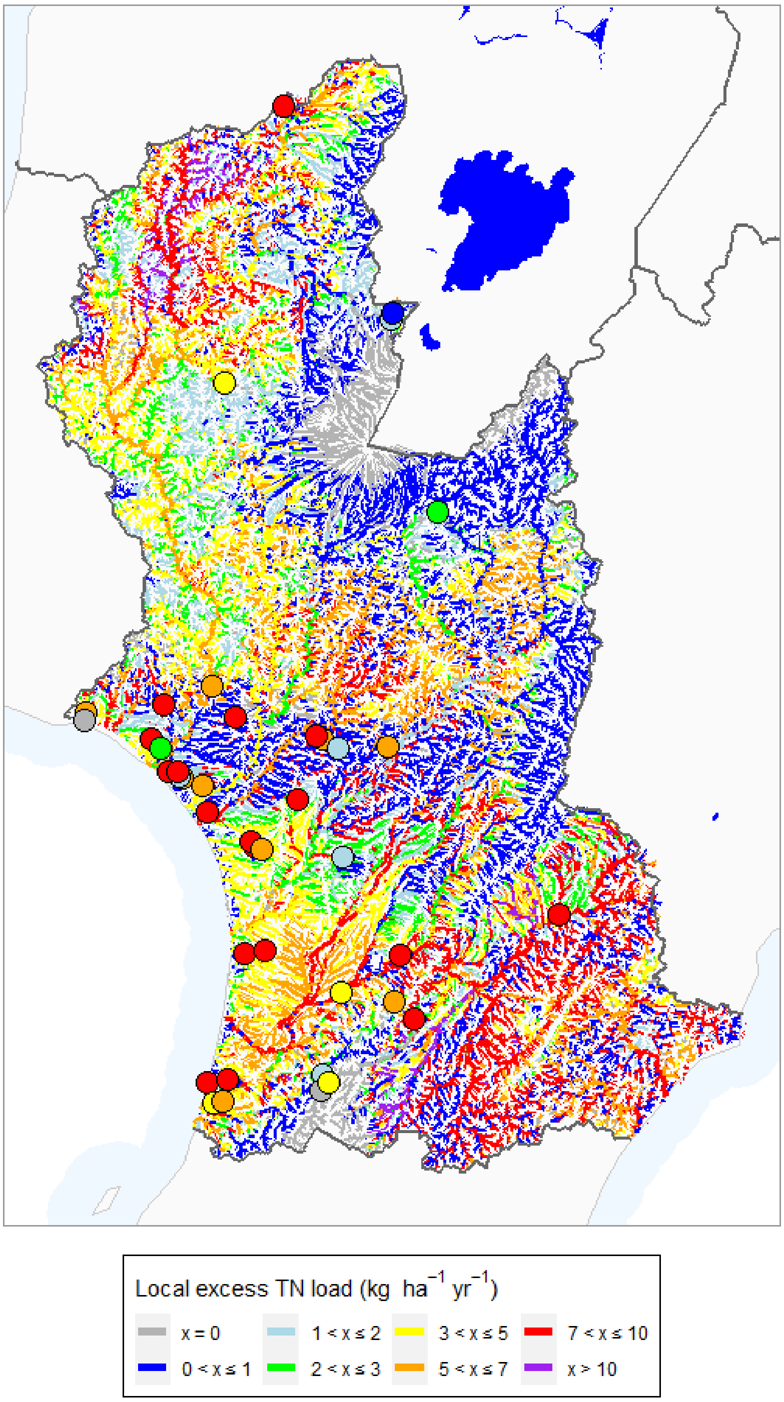


Figure 81. Local excess TN loads for rivers and lakes for the A band using national criteria and 20% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the A band using national criteria and 20% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 69% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 66% of river segments (Figure 82). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 31% of segments.

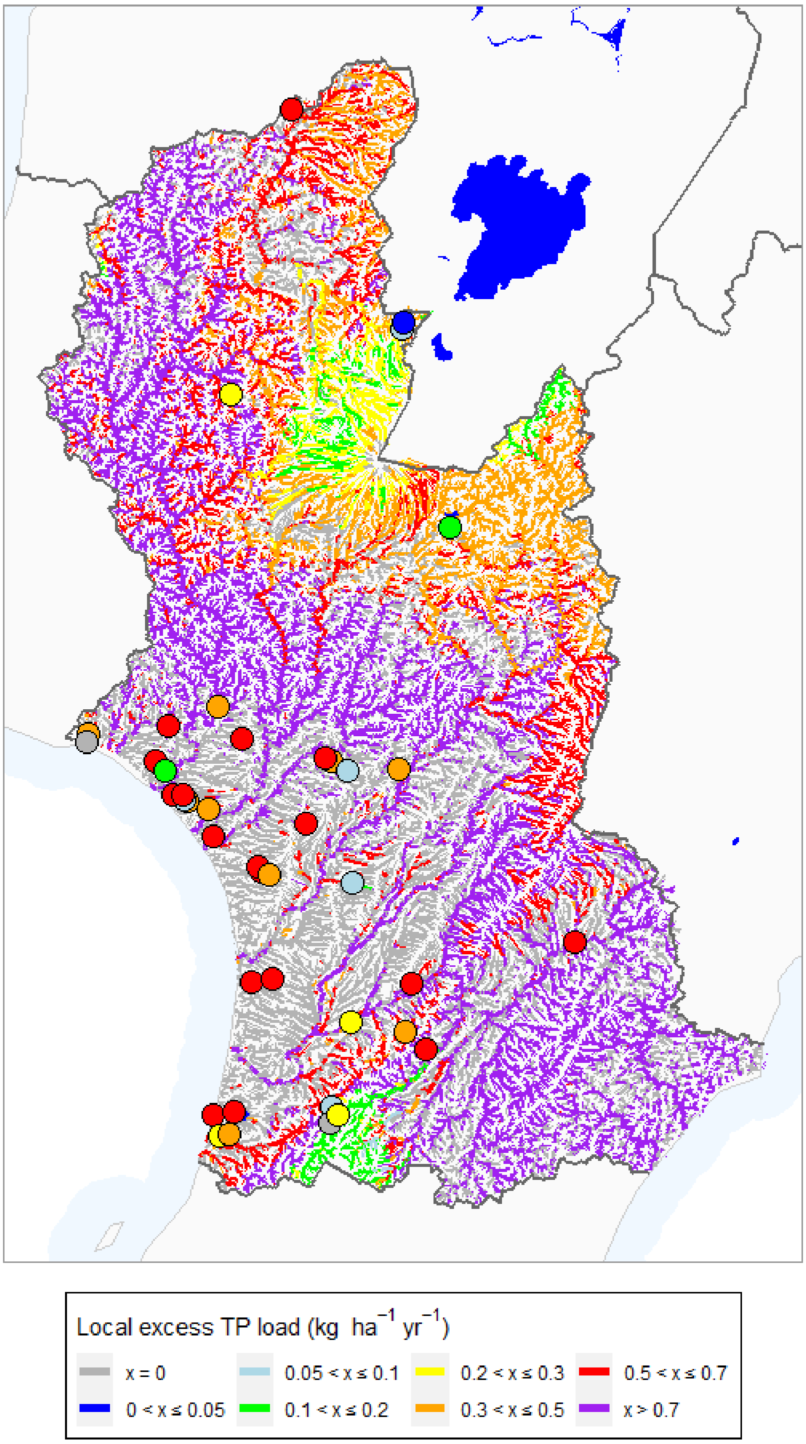


Figure 82. Local excess TP loads for rivers and lakes for the A band using national criteria and 20% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.13.3 FMU and regional load reductions required

The load reductions required by the A band using national criteria and 20% risk for each FMU and for the whole region are shown in Table 17. For the whole region, the TN and TP load reductions required were estimated to be 14,762t yr^{-1} and 3,660 t yr^{-1}, which represent 84%

and 114% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 17.

Load reductions of 100% or more occurred for some FMUs and the whole region 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 and this would lead to reduction in loads in the downstream direction.

For the A band using national criteria and 20% risk, there was 95% confidence TN and TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs.

Table 17. Current load and load reduction required for TN and TP for FMUs and the whole region for the A band using national criteria and 20% risk. 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 (%)**
Kai Iwi	219 (148 - 320)	182 (114 - 279)	83 (76 - 88)	28 (18 - 44)	26 (15 - 42)	92 (85 - 97)
Whanganui	6,017 (3,461 - 9,068)	5,211 (2,896 - 7,983)	86 (79 - 91)	1,263 (567 - 2,159)	1,445 (659 - 2,507)	115 (110 - 116)
Whangaehu	1,207 (686 - 1,892)	790 (299 - 1,585)	63 (38 - 82)	266 (136 - 448)	255 (124 - 422)	96 (89 - 99)
Rangitīkei-Turakina	3,317 (2,350 - 4,483)	2,712 (1,684 - 3,962)	81 (71 - 94)	652 (398 - 988)	892 (527 - 1,415)	136 (126 - 143)
Manawatū	5,414 (3,136 - 8,282)	4,710 (2,231 - 7,614)	86 (72 - 93)	788 (415 - 1,447)	840 (443 - 1,554)	107 (105 - 108)
Waiopehu	323 (229 - 437)	247 (155 - 357)	76 (65 - 84)	26 (18 - 37)	23 (16 - 34)	90 (84 - 94)
Puketoi ki Tai	952 (692 - 1,272)	851 (580 - 1,167)	89 (83 - 94)	172 (113 - 222)	170 (112 - 223)	99 (97 - 101)
Whole region	17,522 (13,817 - 21,886)	14,762 (11,228 - 19,167)	84 (79 - 89)	3,205 (2,205 - 4,320)	3,660 (2,532 - 4,897)	114 (109 - 119)

3.13.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 81 and Figure 82) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the A band using national criteria and 20% risk are shown on Figure 83 and Figure 84. There were 102 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 76% of the region. There was one WMSZ with TN load reductions required of zero kg ha^{-1} yr^{-1} (Figure 83). When load reductions required for TN were expressed as a proportion of current loads, 120 WMSZs required reductions of greater than 50% and these occupied 98% of the region (Figure 84).

There were 120 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 85) and these occupied 99% of the region. There were four WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 1.3% of the region. When load reductions required for TP were expressed as a proportion of current loads, 120 WMSZs required reductions of greater than 50% and these occupied 99% of the region (Figure 86). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

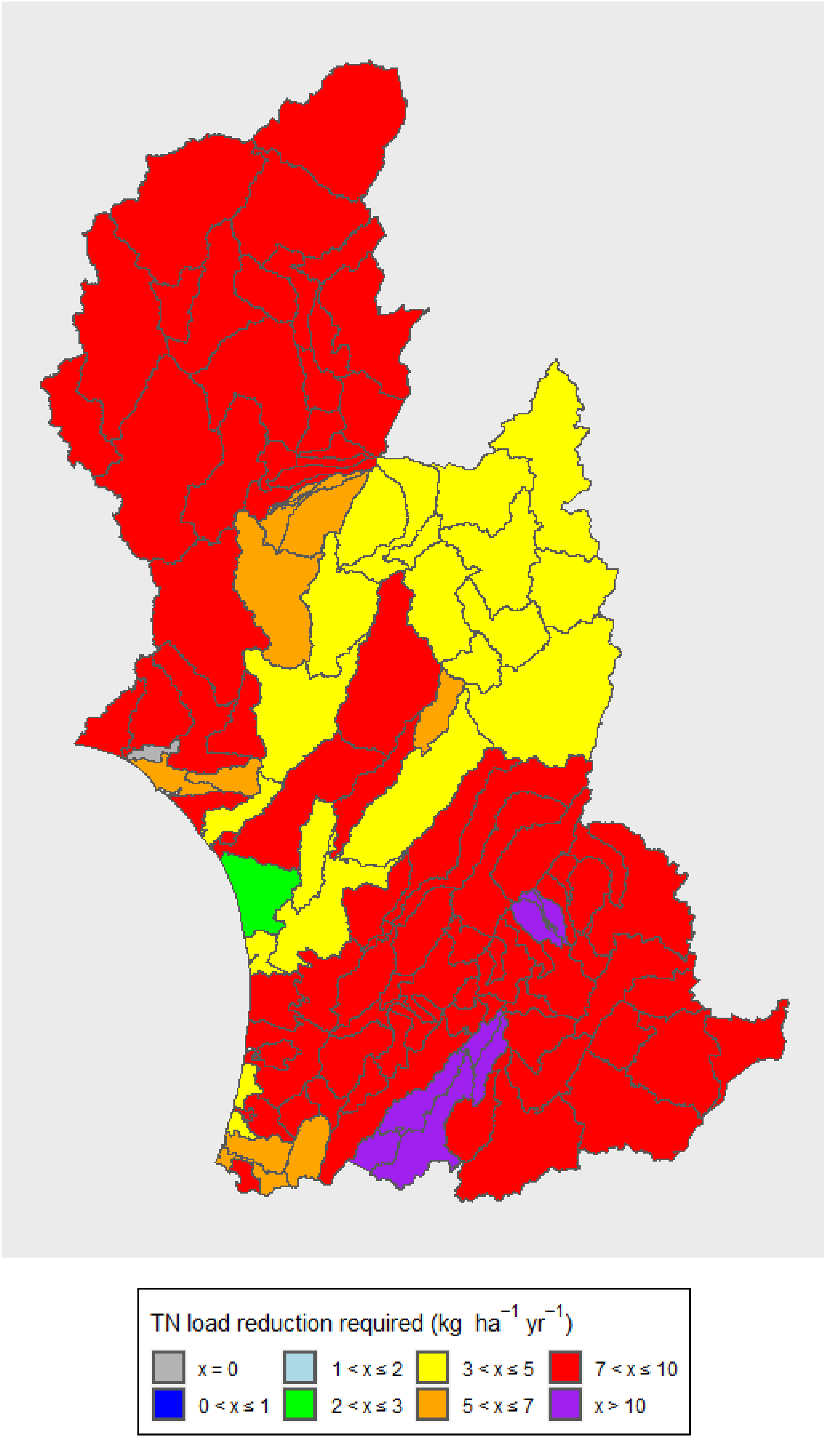


Figure 83. The TN WMSZ load reductions, expressed as yields, for the A band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

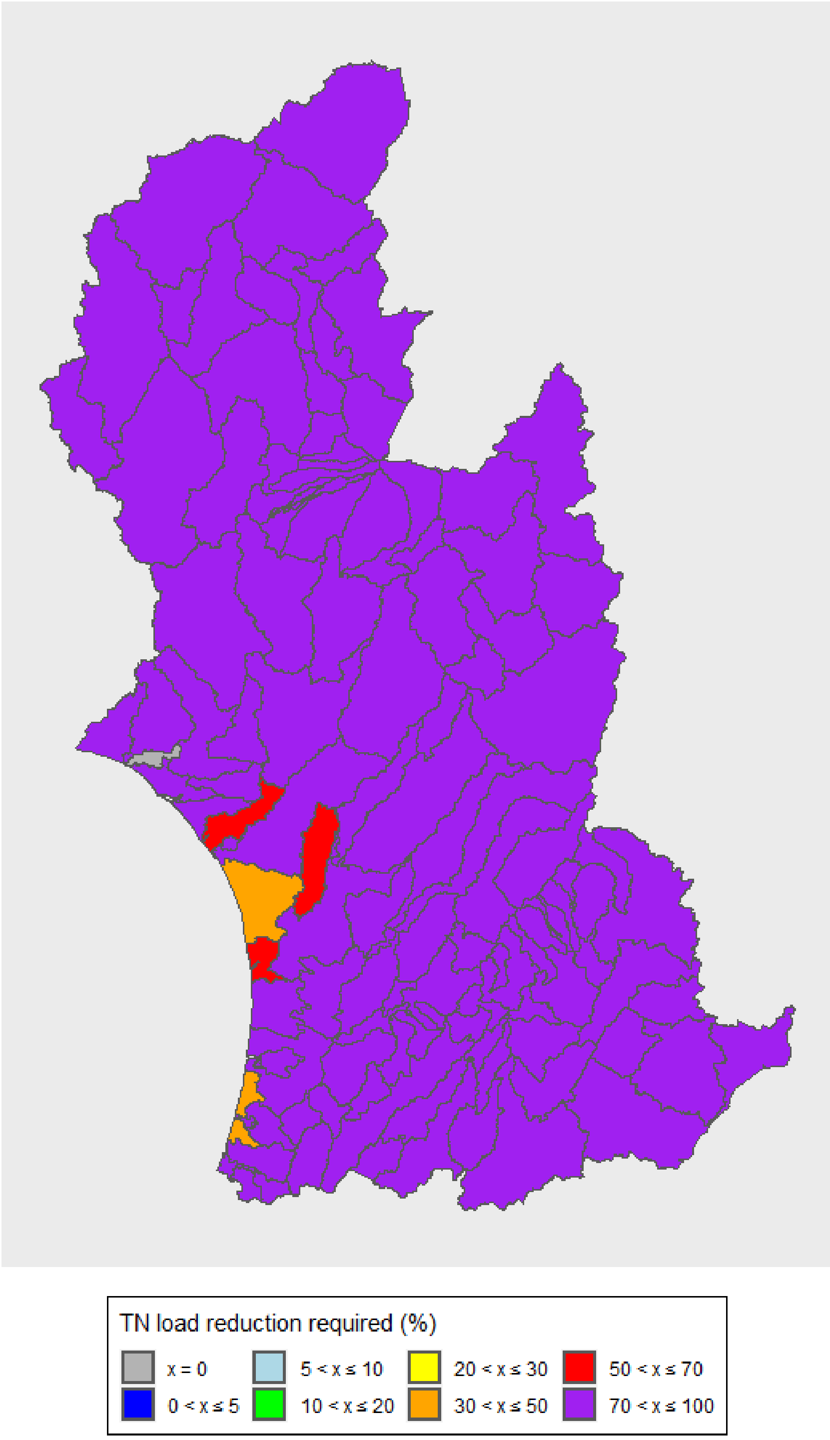


Figure 84. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the A band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

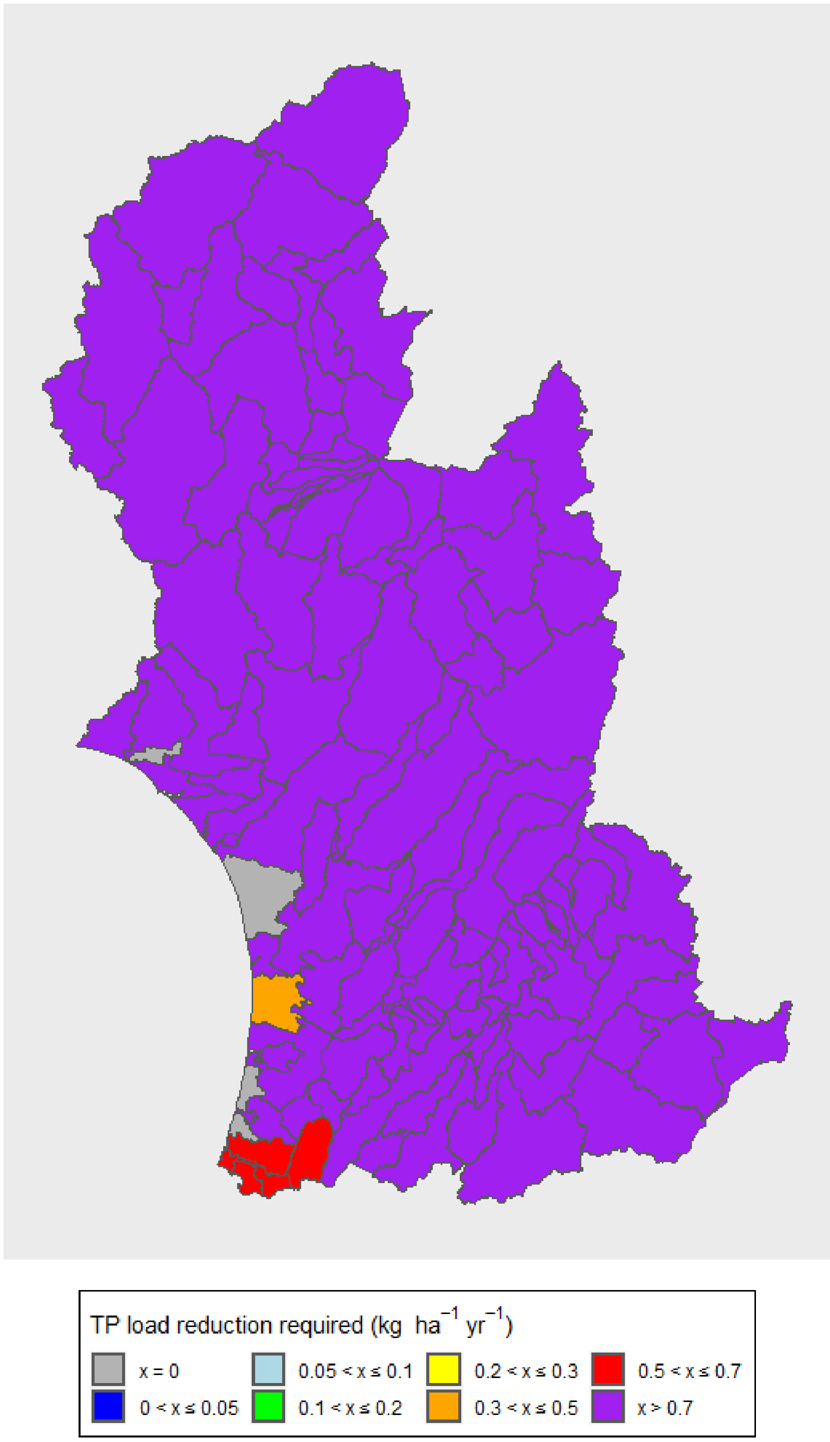


Figure 85. The TP WMSZ load reductions, expressed as yields, for the A band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

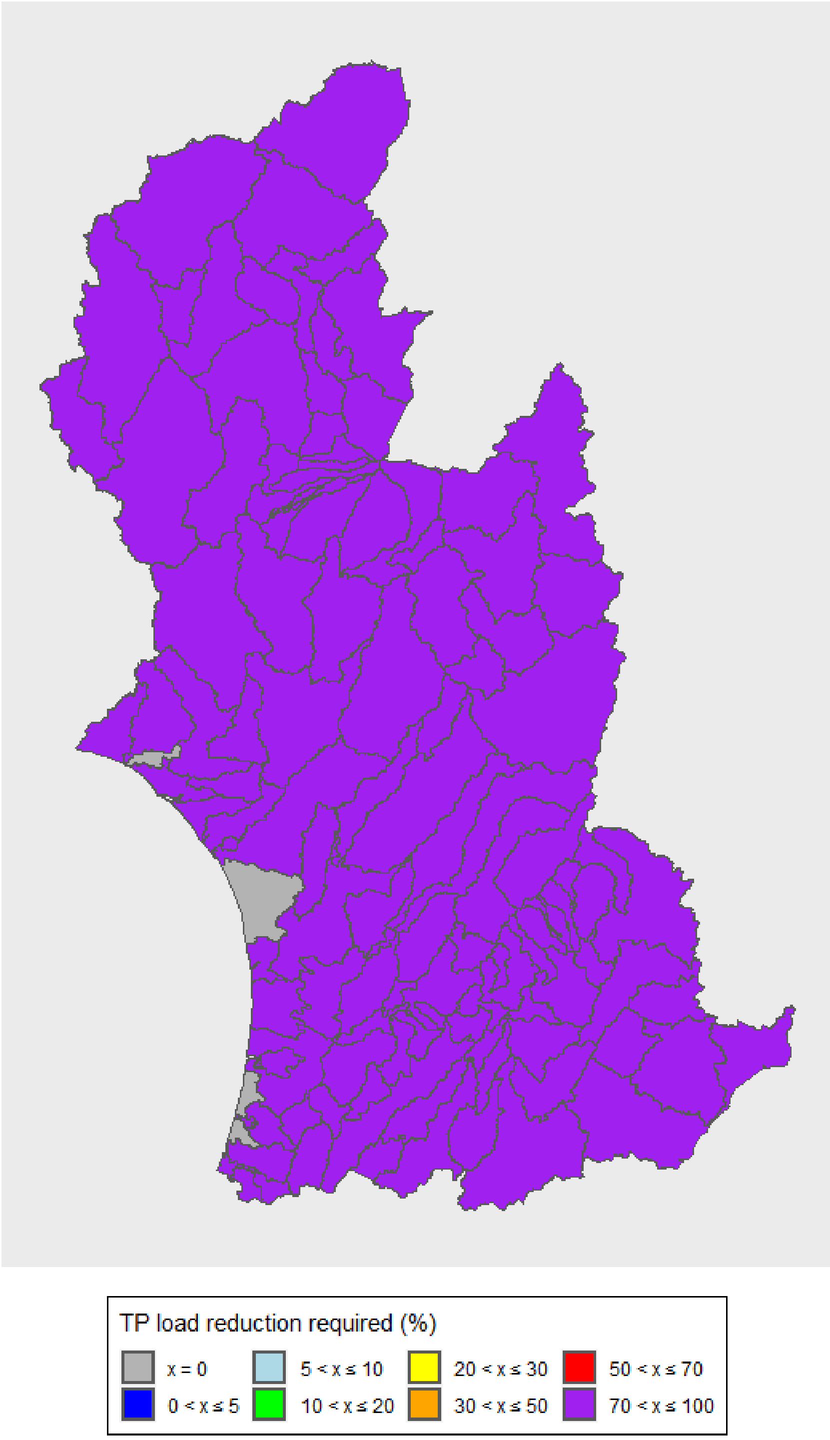


Figure 86. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the A band using national criteria and 20% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.13.5 Limiting environments

For the A band using national criteria and 20% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for three WMSZs (Hoki_1a, West_4 and West_6) for TN and two WMSZs for TP (West_4 and West_4, Figure 87).

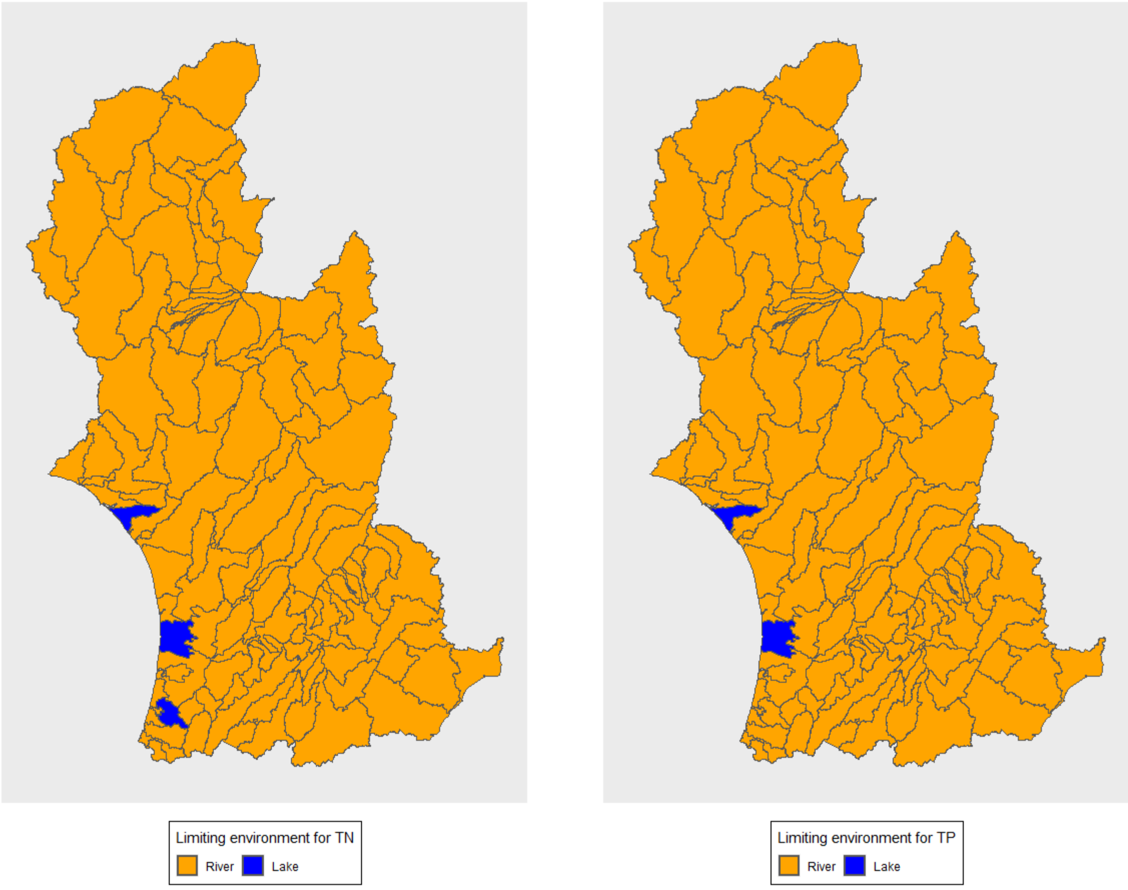


Figure 87. Limiting environment type for TN and TP load reduction requirements for WMSZs for the A band using national criteria and 20% risk.

3.14 A band using national criteria and 30% risk

3.14.1 Compliance

Current river concentrations of TN and DRP had a greater than 50% probability of non-compliance associated with the A band using national criteria and 30% risk for 70% and 50% of segments in the region, respectively (Figure 88). Current river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the A band options for the nitrate toxicity FWO for 5% of segments. The probability that nitrate toxicity is a more limiting FWO than periphyton exceeded 50% at no river segments (Figure 88).

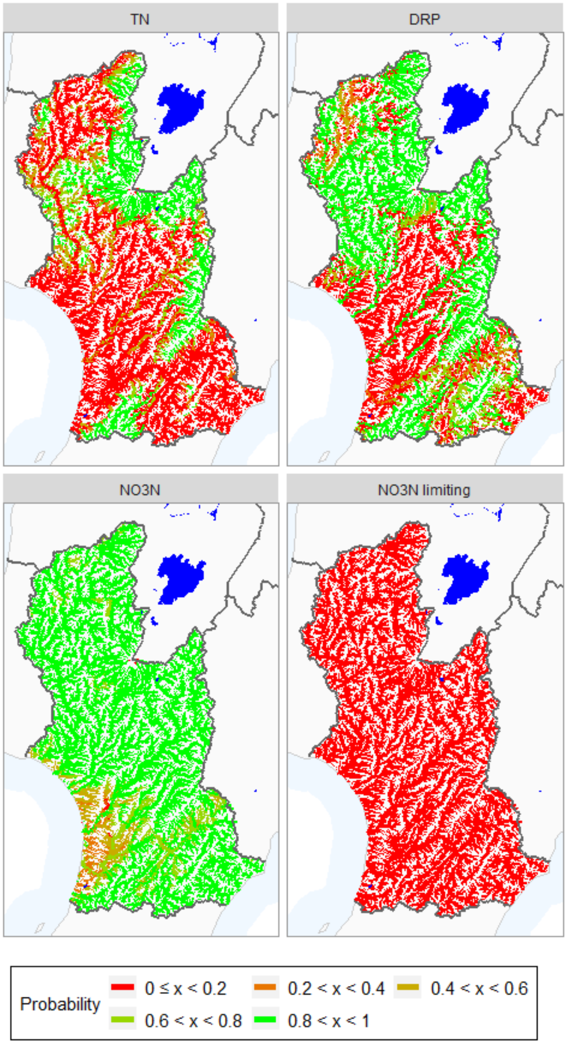


Figure 88. Probability that segments comply with river concentration criteria associated with the A band using national criteria and 30% risk. Compliance with TN and DRP are shown top left and right and compliance with NO3N concentration criteria associated with the corresponding toxicity objectives is shown lower left. The lower right-hand panel shows the probability that NO3N is the more limiting FWO than periphyton.

The probability that current lake TN and TP concentrations complied with criteria associated with the A band was less than 50% (i.e., were non-compliant) for 40 of the 41 lakes, respectively (Figure 89). Note that differences in results for lakes between the 20% risk and

30% risk assessments are associated with random perturbations in the Monte Carlo analysis only because the criteria for lakes is unchanged.

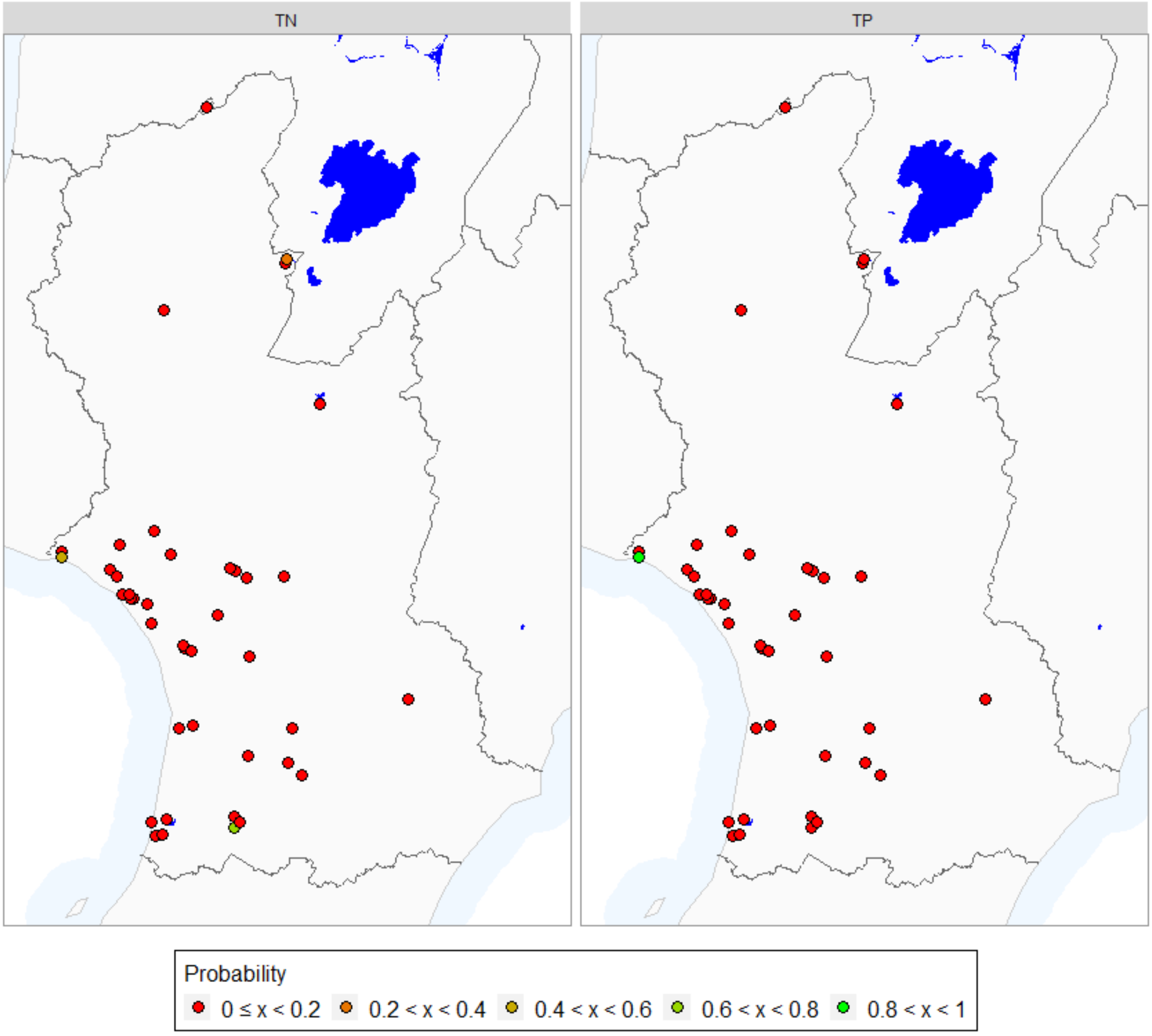


Figure 89. Probability of compliance with lake TN and TP concentration criteria associated with the A band.

3.14.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the FWO for that receiving environment. For the A band using national criteria and 30% risk, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 43% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 22% of river segments (Figure 90). 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 90. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 8% of segments.

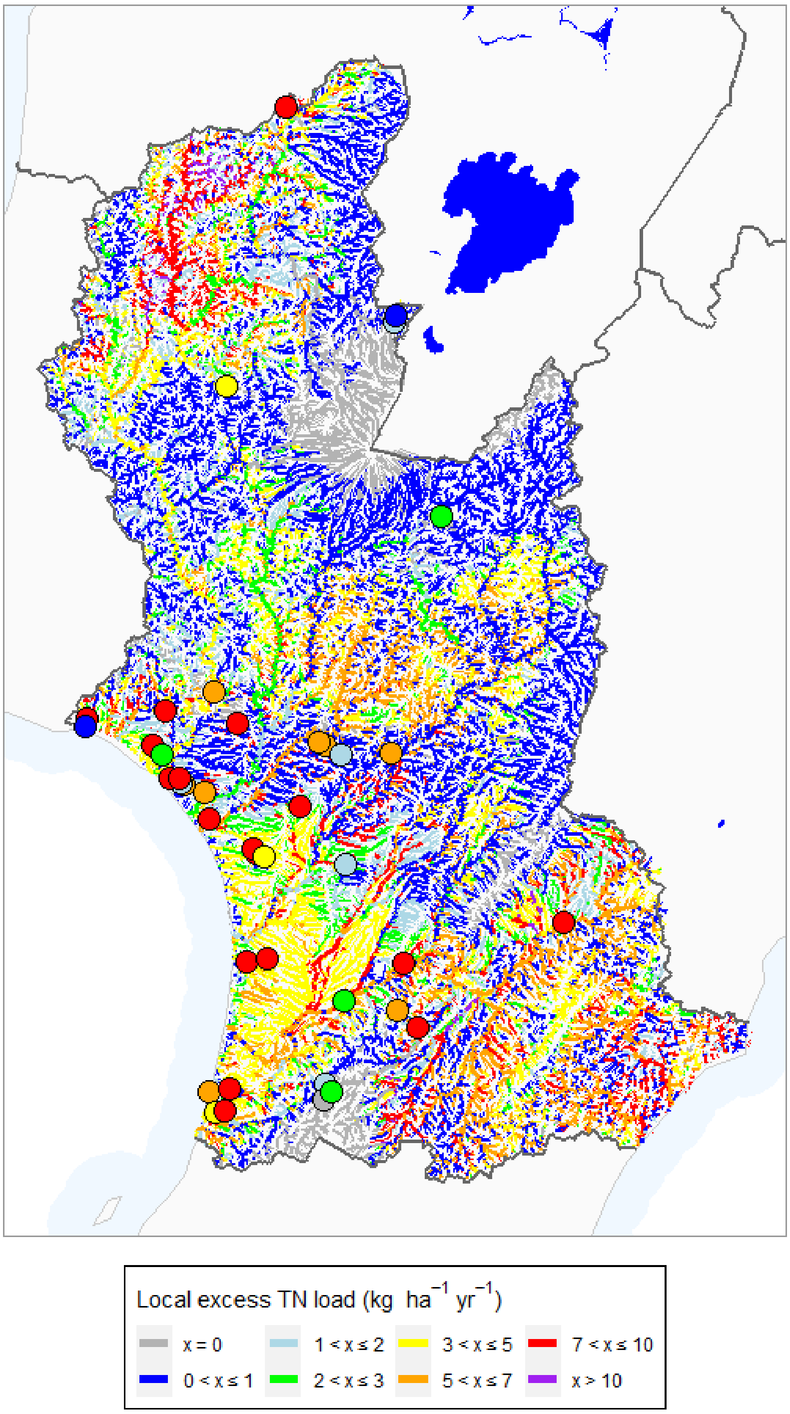


Figure 90. Local excess TN loads for rivers and lakes for the A band using national criteria and 30% risk. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the A band using national criteria and 30% risk, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 22% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 16% of river segments (Figure 91). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 42% of segments.

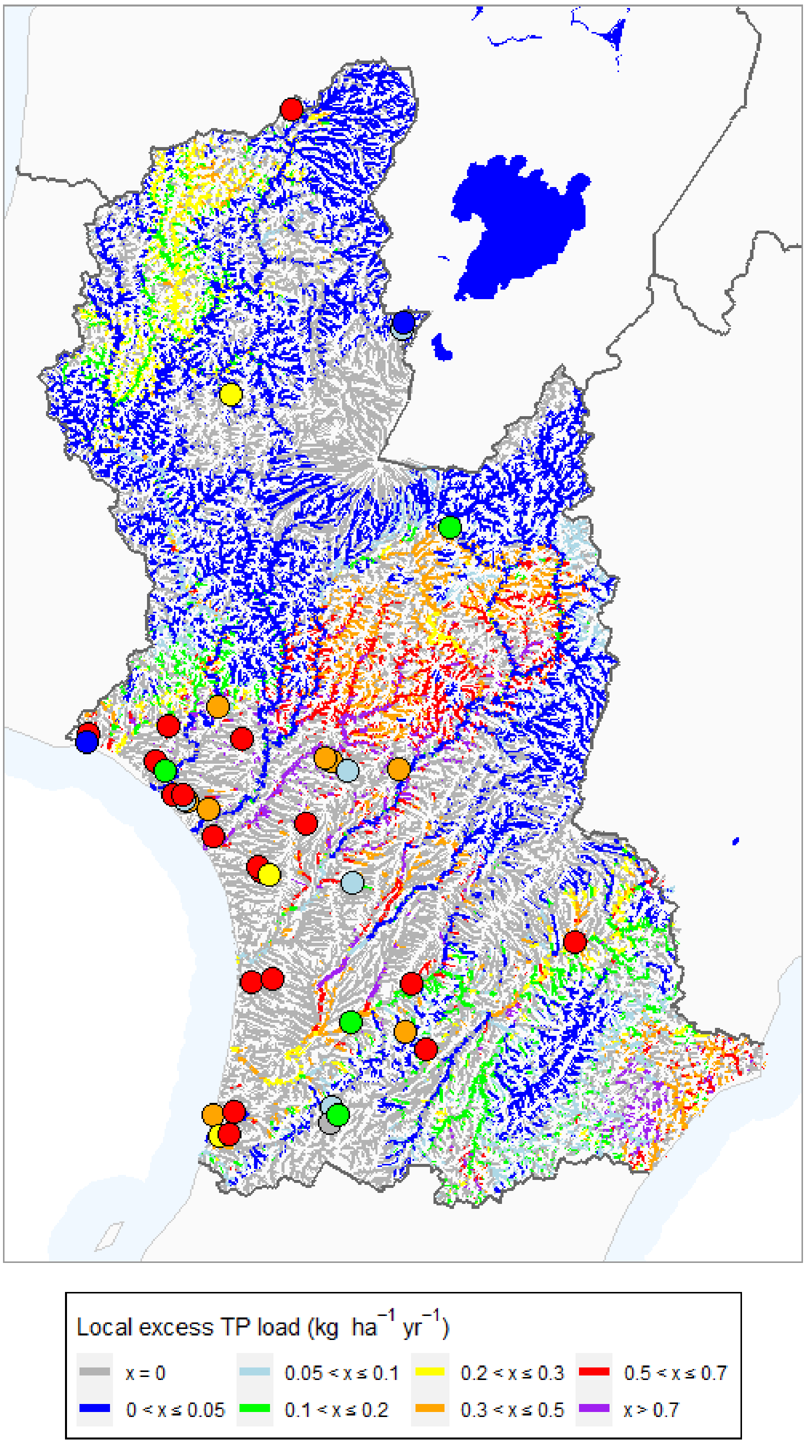


Figure 91. Local excess TP loads for rivers and lakes for the A band using national criteria and 30% risk. Lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.14.3 FMU and regional load reductions required

The load reductions required by the A band using national criteria and 30% risk for each FMU and for the whole region are shown in Table 18. For the whole region, the TN and TP load reductions required were estimated to be 12,708 t yr^{-1} and 2,699 t yr^{-1}, which represent 73%

and 85% of the current loads delivered to the coast, respectively. The uncertainties on the estimated current loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 18.

Load reductions of 100% or more 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 and this would lead to reduction in loads in the downstream direction.

For the A band using national criteria and 30% risk, there was 95% confidence TN and TP load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs.

Table 18. Current load and load reduction required for TN and TP for FMUs and the whole region for the A band using national criteria and 20% risk. 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 (%)**
Kai Iwi	232 (145 - 336)	185 (106 - 289)	79 (69 - 87)	31 (16 - 55)	27 (12 - 50)	85 (73 - 95)
Whanganui	6,161 (3,135 - 9,012)	4,927 (2,158 - 7,736)	78 (64 - 88)	1,263 (535 - 2,384)	1,117 (392 - 1,880)	89 (47 - 110)
Whangaehu	1,203 (616 - 1,923)	587 (215 - 1,232)	46 (34 - 71)	275 (145 - 479)	99 (46 - 176)	36 (30 - 39)
Rangitīkei-Turakina	3,182 (2,107 - 4,561)	2,200 (1,148 - 3,590)	68 (54 - 82)	653 (392 - 1,044)	676 (388 - 1,194)	103 (91 - 112)
Manawatū	5,127 (2,849 - 8,169)	3,721 (1,622 - 6,448)	70 (54 - 87)	745 (360 - 1,293)	652 (322 - 1,088)	89 (74 - 96)
Waiopehu	321 (228 - 415)	200 (111 - 286)	62 (44 - 76)	27 (18 - 38)	8 (4 - 13)	29 (19 - 43)
Puketoi ki Tai	1,008 (691 - 1,433)	836 (499 - 1,259)	82 (73 - 90)	172 (106 - 243)	116 (73 - 172)	68 (53 - 77)
Whole region	17,308 (13,434 - 21,249)	12,708 (8,730 - 16,507)	73 (66 - 80)	3,174 (2,367 - 4,469)	2,699 (1,916 - 4,092)	85 (69 - 97)

3.14.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 90 and Figure 91) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the current load.

The WMSZ load reductions required for TN under the A band using national criteria and 30% risk are shown on Figure 92 and Figure 93. There were 98 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and these occupied 75% of the region. There was one WMSZ with TN load reductions required of zero kg ha^{-1} yr^{-1} (Figure 92). When load reductions required for TN were expressed as a proportion of current loads, 118 WMSZs required reductions of greater than 50% and these occupied 98% of the region (Figure 93).

There were 103 WMSZs with TP load reductions required of greater than 0.3 kg ha^{-1} yr^{-1} region (Figure 94) and these occupied 93% of the region. There were 20 WMSZs with TP load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 7% of the region. When load reductions required for TP were expressed as a proportion of current loads, 101 WMSZs required reductions of greater than 50% and these occupied 92% of the region (Figure 95). As for TN, WMSZs with low TP load reduction requirements expressed as yields (kg ha^{-1} yr^{-1}) have nevertheless generally large requirements when these are expressed in relative terms.

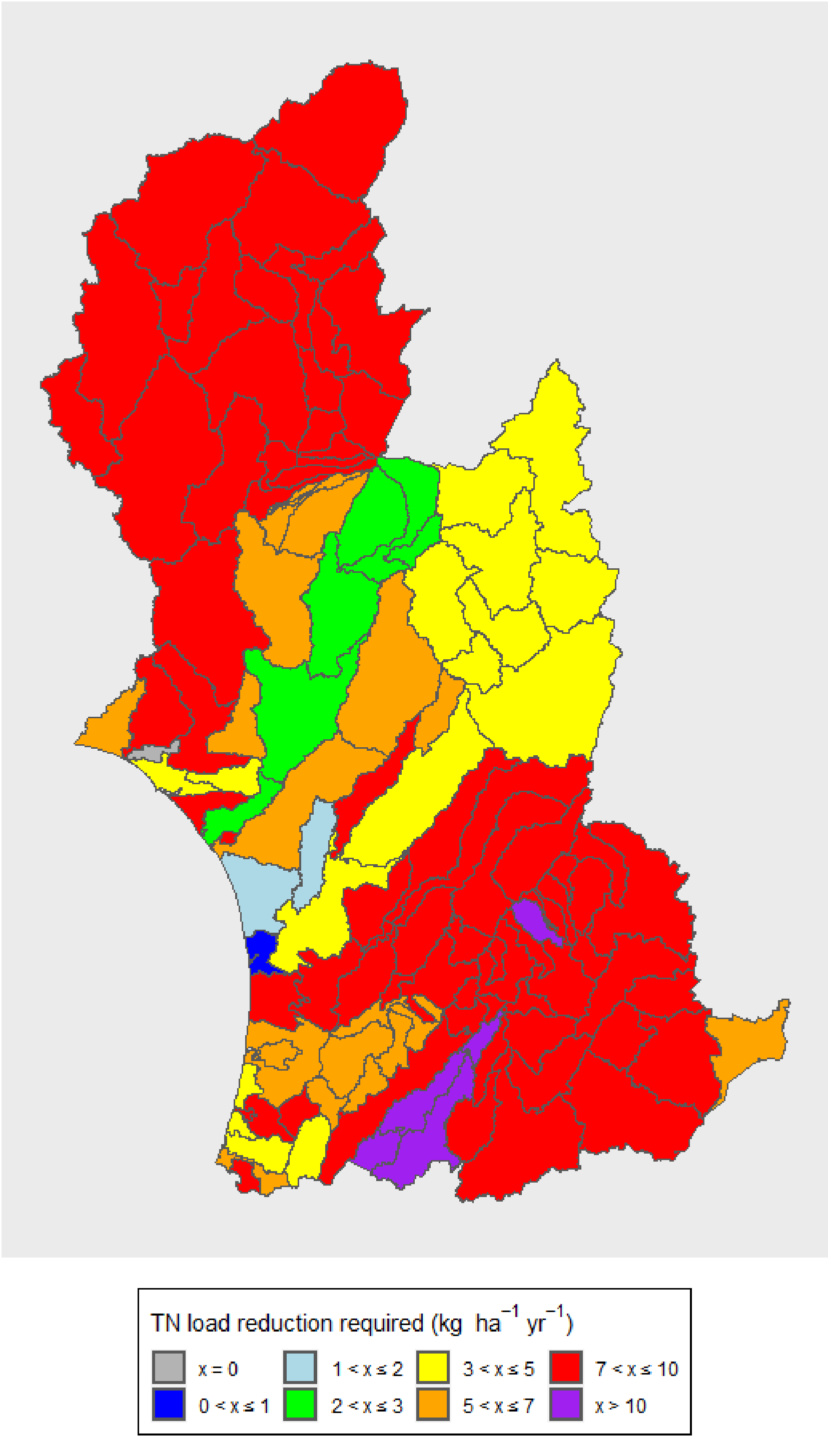


Figure 92. The TN WMSZ load reductions, expressed as yields, for the A band using national criteria and 20% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

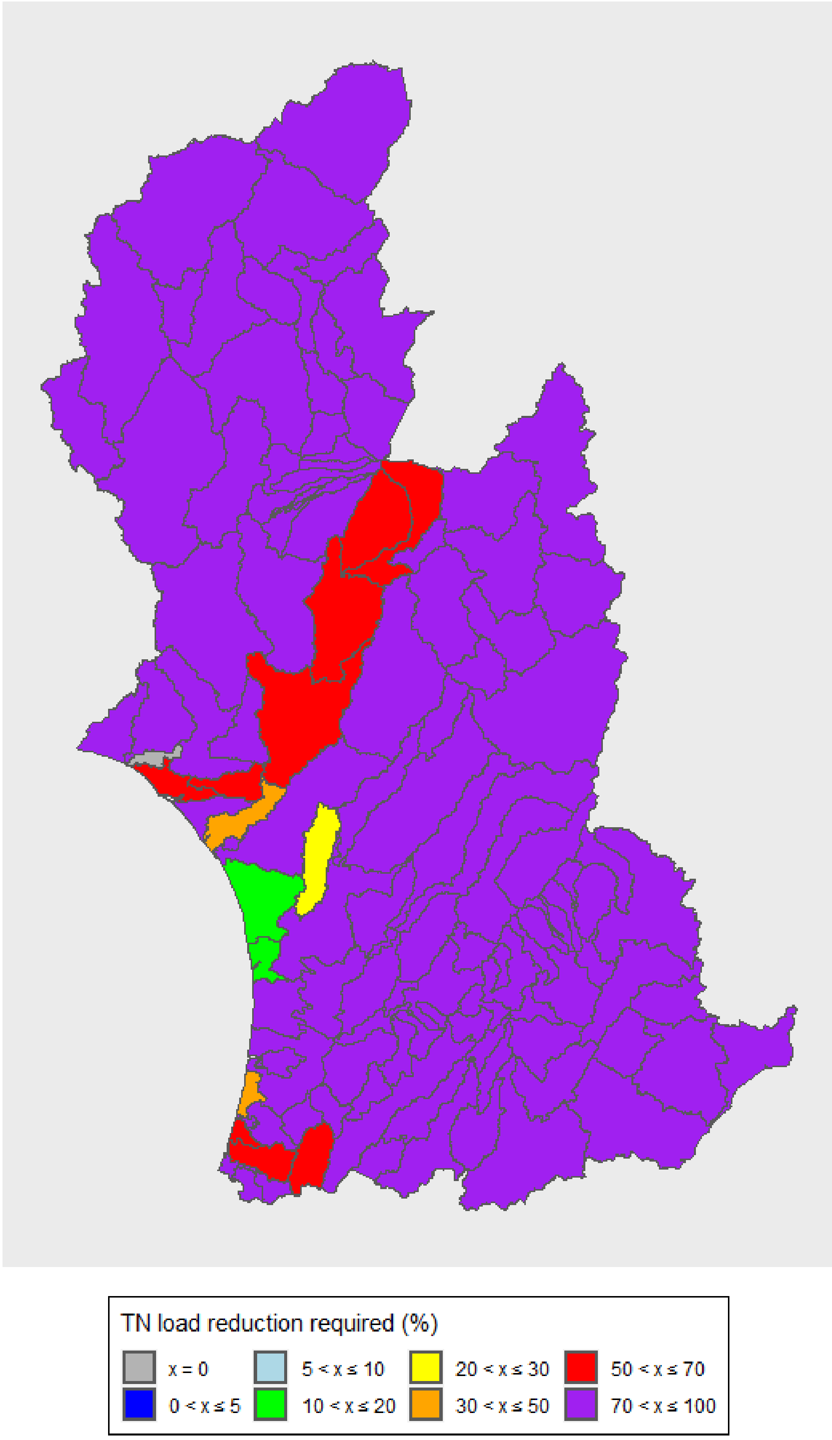


Figure 93. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the A band using national criteria and 30% risk. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

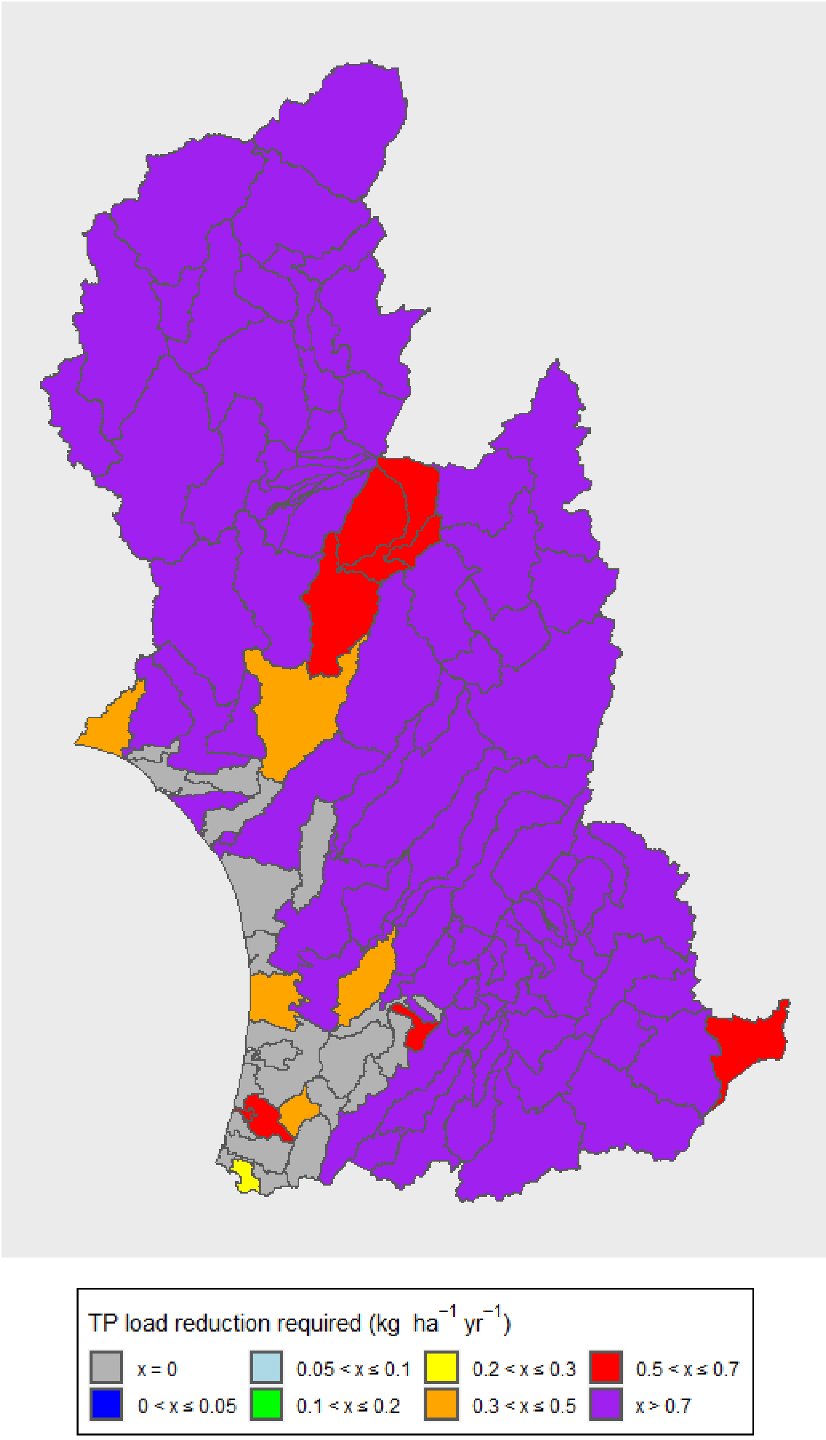


Figure 94. The TP WMSZ load reductions, expressed as yields, for the A band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

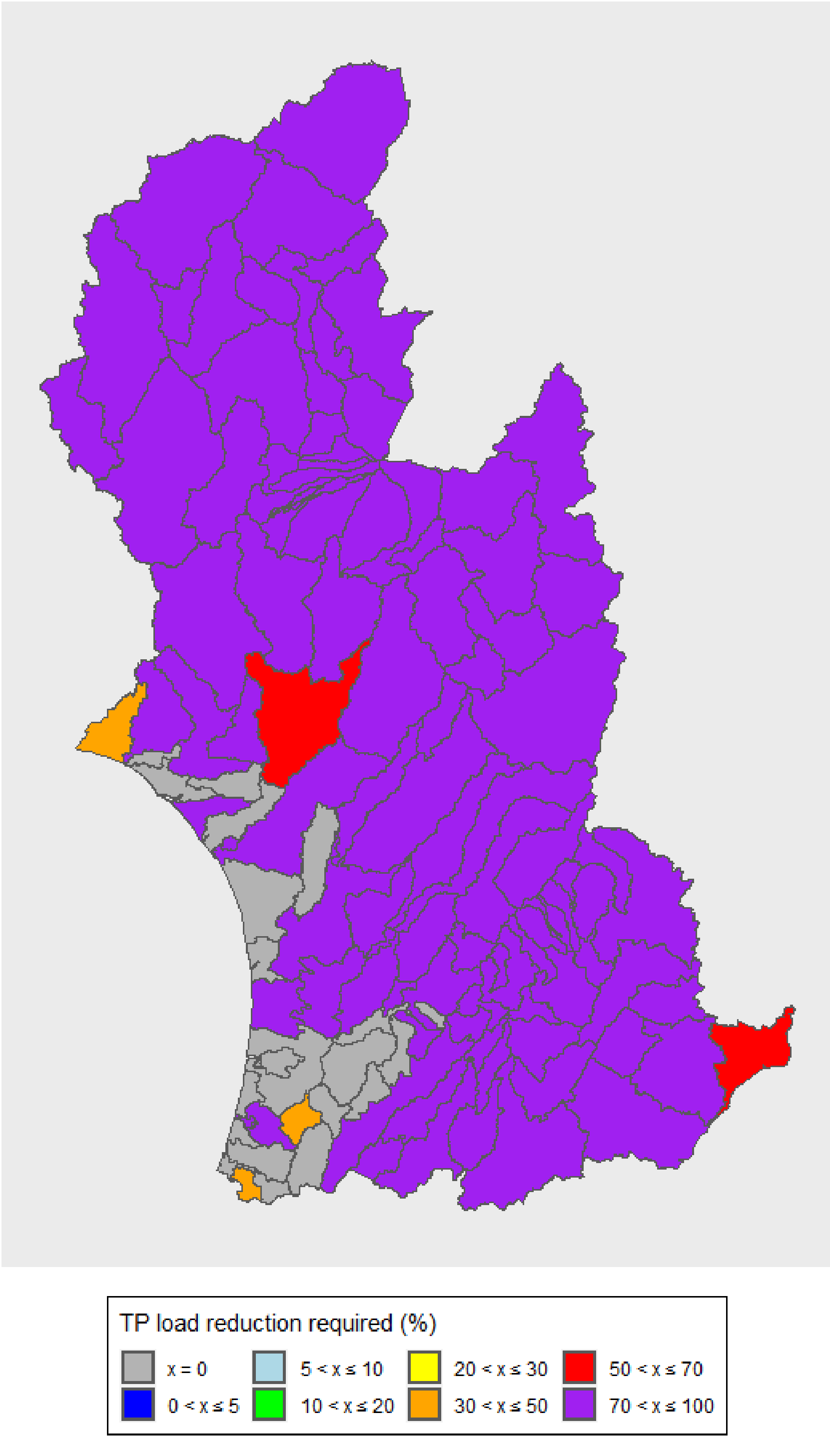
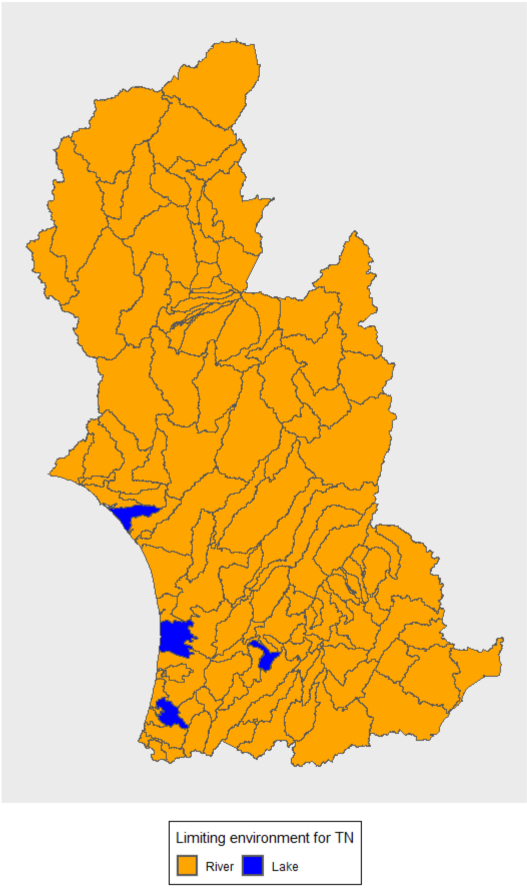


Figure 95. The TP WMSZ load reductions, expressed as proportion of the current load (%), for the A band using national criteria and 30% risk. The WMSZ colours indicate the TP load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.14.5 Limiting environments

For the A band using national criteria and 30% risk, the limiting receiving environments for all WMSZs (i.e., the receiving environment type that determines the load reduction requirements) were rivers except for four WMSZs (Hoki_1a, Mana_11b, West_6 and West_4) for TN and five WMSZs for TP (West_4, West_6, Mana_9d, Mana_11b and Hoki_1a, Figure 96*).*



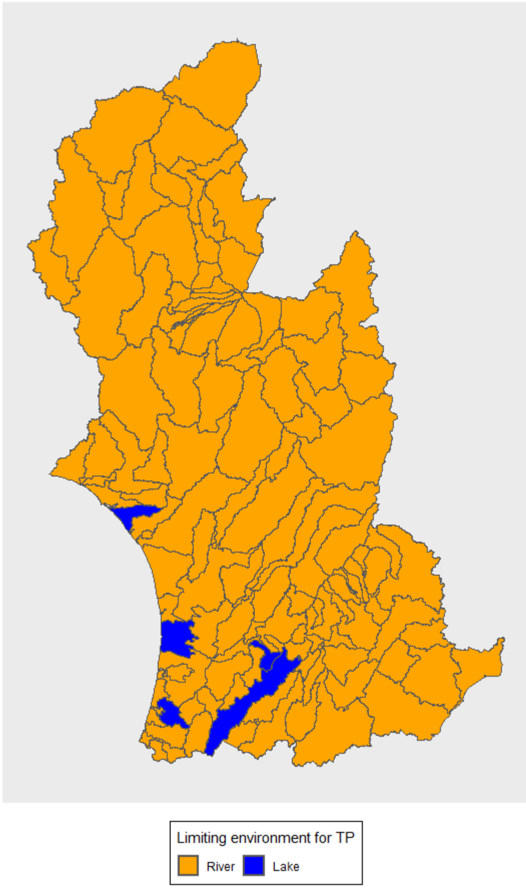


Figure 96. Limiting environment type for TN and TP load reduction requirements for WMSZs for the A band using national criteria and 30% risk.

3.15 A band using Regional TN criteria

3.15.1 Compliance

Because the regional criteria apply only to TN, this section describes only nitrogen load reduction requirements. Current river concentrations of TN had a greater than 50% probability of exceeding the criteria associated with the A band using regional criteria (i.e., were non-compliant) for 61% of segments in the region (Figure 97).

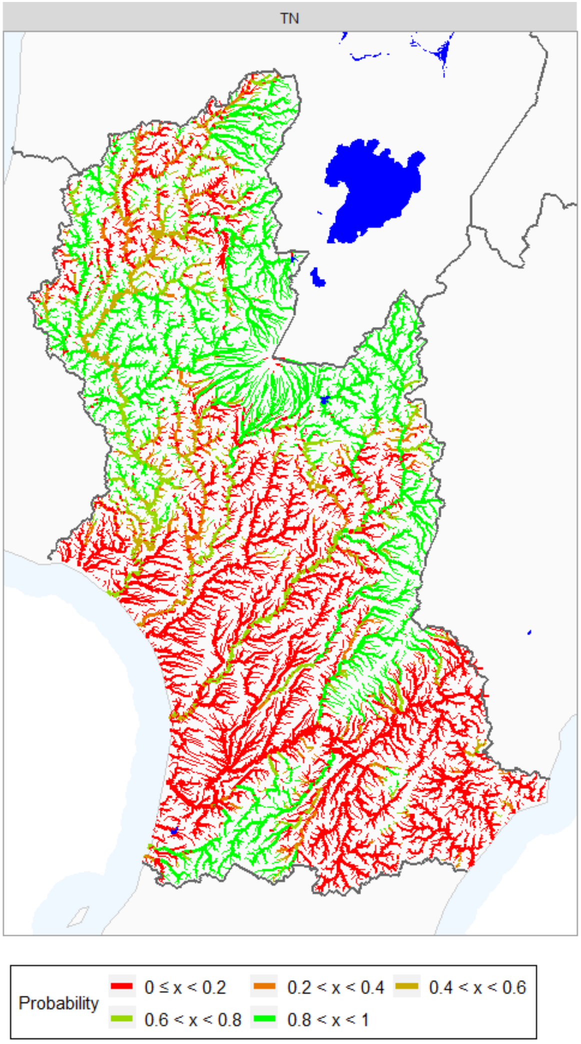


Figure 97. Probability that segments comply with the A band using Regional TN criteria.

3.15.2 Local excess loads

The local excess load is the amount by which the current load at a receiving environment would need to be reduced to achieve the objective for that receiving environment. For the A band using Regional TN criteria, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 36% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 19% of river segments (Figure 98). 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 98. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 24% of segments.

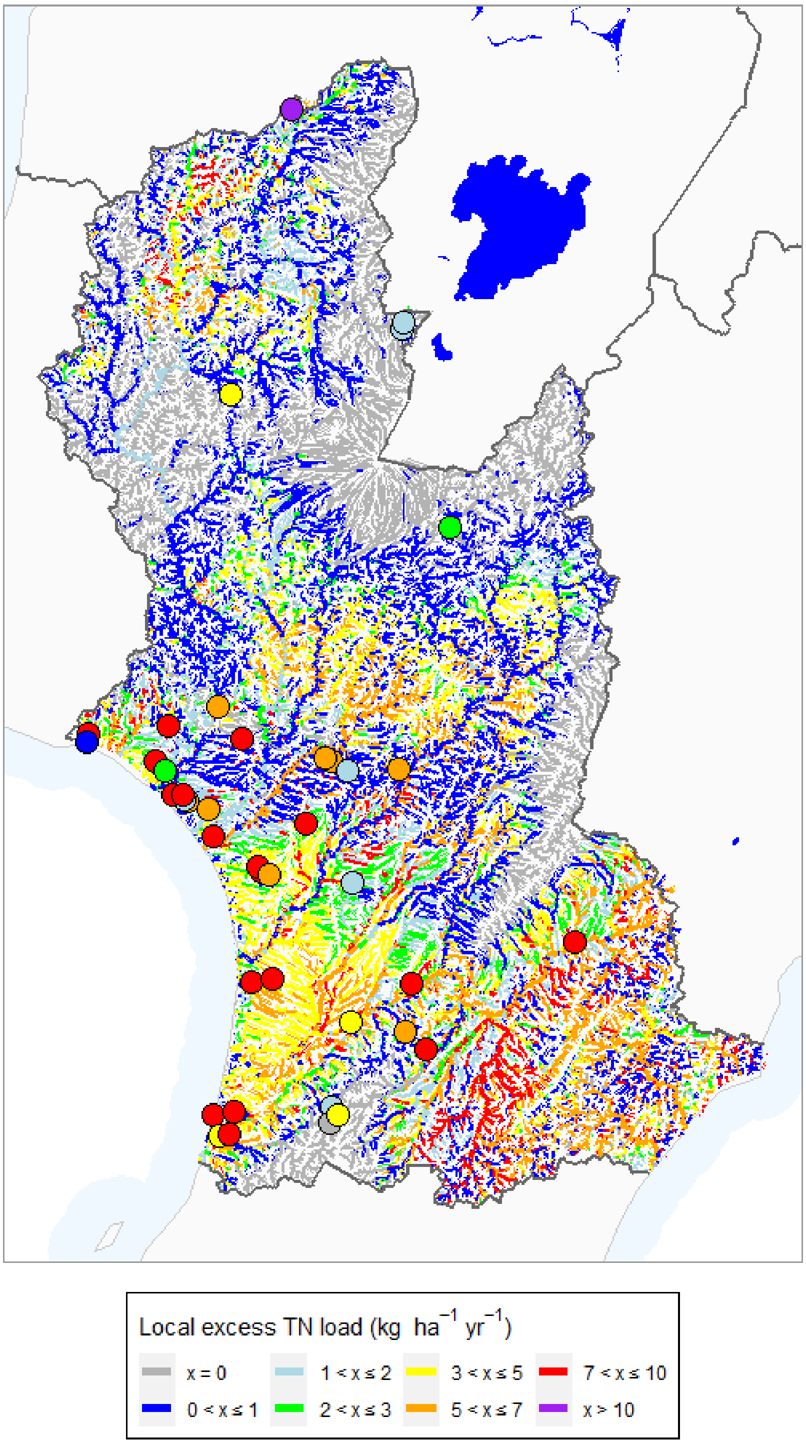


Figure 98. Local excess TN loads for rivers and lakes for the A band using Regional TN criteria. The lakes are indicated by round points. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.15.3 FMU and regional load reductions required

The load reductions required by the A band using Regional TN criteria for each FMU and for the whole region are shown in Table 22. For the whole region, the TN load reductions required were estimated to be 6,473 t yr^{-1}, which represent 36% of the current loads delivered to the coast. The uncertainties on the estimated current loads of TN and the load reductions, in terms of both absolute yields and percentage of current load, are expressed as the 90% confidence intervals in Table 22.

For the A band using Regional TN criteria, there was 95% confidence TN load reduction requirements were greater than zero (i.e., the lower (5%) confidence limit was > 0) for all FMUs.

Table 19. Current load and load reduction required for TN for FMUs and the whole region for the A band using Regional TN criteria. 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		
	Current load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Kai Iwi	230 (149 - 329)	159 (75 - 265)	67 (46 - 83)
Whanganui	6,408 (3,545 - 10,509)	926 (38 - 3,409)	12 (1 - 40)
Whangaehu	1,153 (583 - 2,229)	347 (13 - 1,538)	24 (2 - 68)
Rangitīkei-Turakina	3,276 (2,322 - 4,693)	1,405 (610 - 3,061)	41 (20 - 73)
Manawatū	5,336 (2,790 - 8,523)	2,770 (368 - 5,728)	47 (9 - 78)
Waiopehu	335 (233 - 472)	122 (77 - 211)	36 (26 - 49)
Puketoi ki Tai	899 (636 - 1,241)	696 (437 - 1,058)	77 (67 - 85)
Whole region	17,712 (13,031 - 22,872)	6,473 (2,946 - 10,960)	36 (20 - 52)

3.15.4 WMSZ load reduction status

WMSZ load reductions required are an indicative load reduction requirement that is based on achieving the FWO in the WMSZ and in all downstream receiving environments. The WMSZ load reductions required differ from the local excess loads (Figure 99) in that they consider the load reductions required for all receiving environments within each WMSZ and the load reduction requirements of all receiving environments downstream of the WMSZ. The WMSZ load reduction required is expressed below in absolute terms (i.e., kg ha-1 yr-1) and as a percentage of the current load.

The WMSZ load reductions required for TN under the A band using Regional TN criteria are shown on Figure 99. There were 62 WMSZs with TN load reductions required of greater than 5 kg ha^{-1} yr^{-1} and this occupied 38% of the region. There were 16 WMSZs with TN load reductions required of zero kg ha^{-1} yr^{-1} and these occupied 12% of the region (Figure 99). When load reductions required for TN were expressed as a proportion of current loads, 69 WMSZs required reductions of greater than 50% and these occupied 42% of the region (Figure 100).

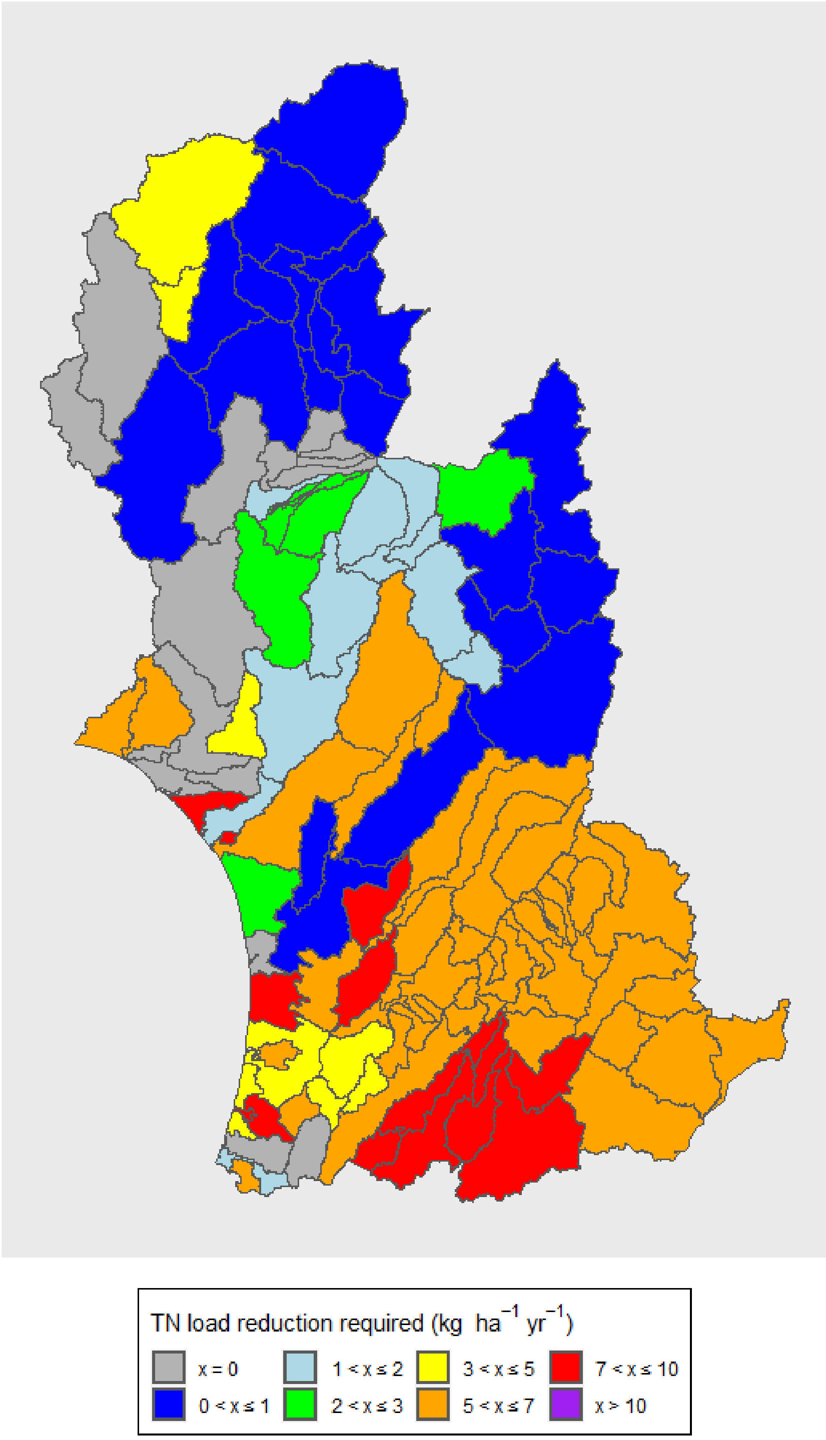


Figure 99. The TN WMSZ load reductions, expressed as yields, for the A band using Regional criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

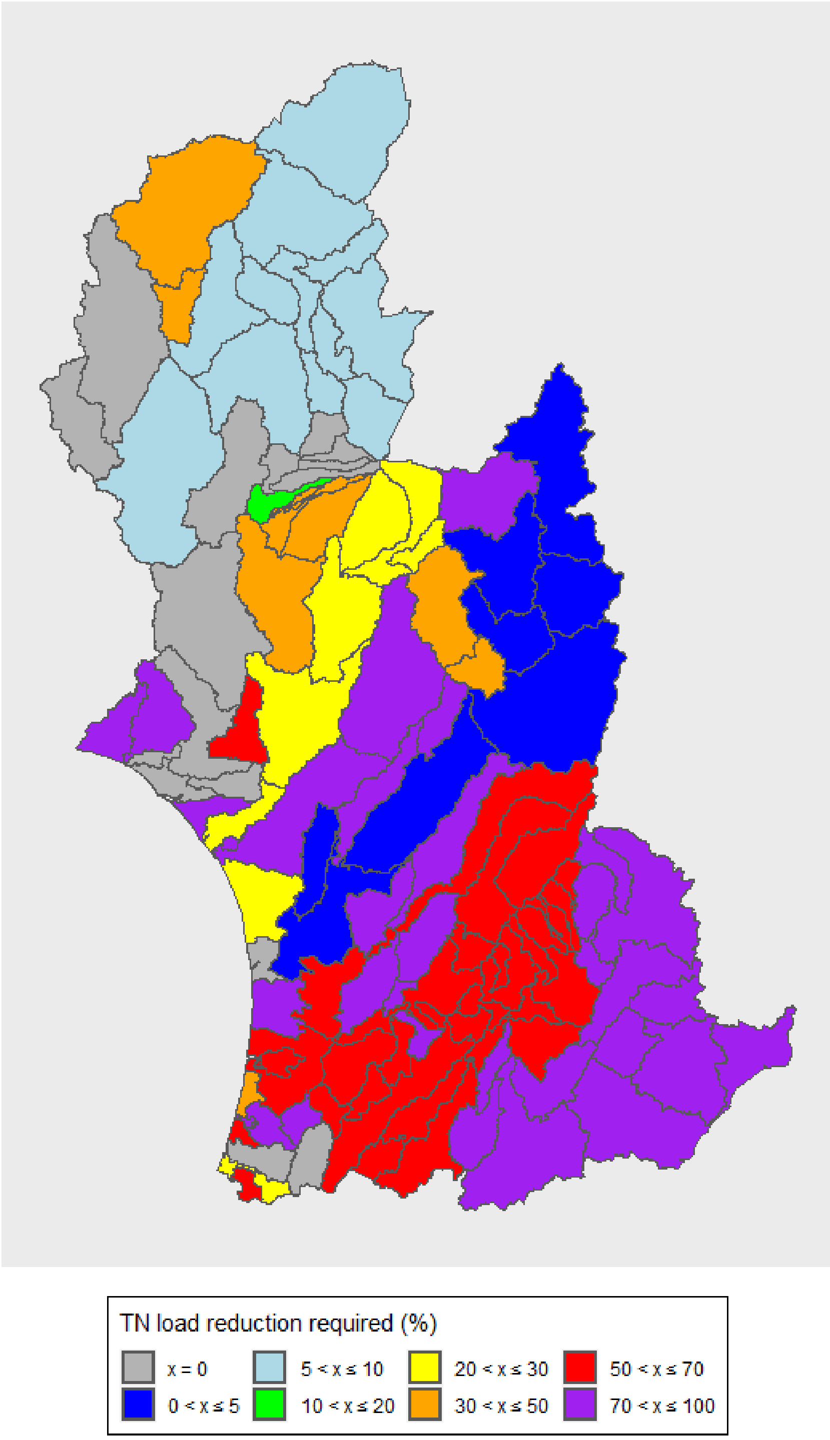


Figure 100. The TN WMSZ load reductions, expressed as proportion of the current load (%), for the A band using Regional TN criteria. The WMSZ colours indicate the TN load reductions required to allow all FWOs to be achieved in the subzone and at all locations downstream of the WMSZ.

3.15.5 Limiting environments

For the A band using Regional TN criteria, the limiting receiving environments (i.e., the receiving environment type that determines the load reduction requirements) for TN and all WMSZs were rivers except for six WMSZs (Hoki_1a, Mana_11b, Rang_2c, Tura_1c, West_4 and West_6, Figure 101).

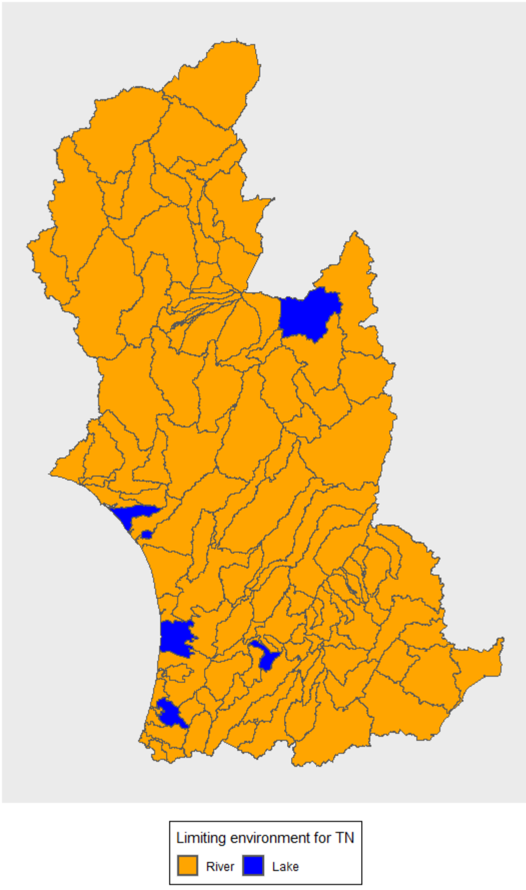


Figure 101. Limiting environment type for TN load reduction requirements for WMSZs for the A band using Regional TN criteria

4 Comparison between options

The TN and TP load reductions required for the One Plan targets using national criteria and 20% risk compared with those using national criteria and 30% risk are shown in Figure 102. In this study, the 30% risk generally had lower TN and TP load reductions required compared to the 20% risk (points are below the red one-to-one line in Figure 102). This is because the 30% risk have more lenient concentration criteria associated with the periphyton objectives than the 20% risk.

However, in some WMSZs, there was very little, or no, difference in load reductions required between the 20% and 30% risk (points plotted on or very close to the one-to-one line in Figure 102). This occurs because river periphyton is not always the 'limiting environment' (e.g., see Figure 18) and the lake nutrient concentration criteria were unchanged between the 20% and 30% risks. There are also cases where the load reduction for 30% risk is slightly higher than for the 20% risk (points are above the red one-to-one line in Figure 102). These arise because in these cases the lake is the limiting environment and the small differences between the two assessments is due to the random variation associated with the Monte Carlo analysis.

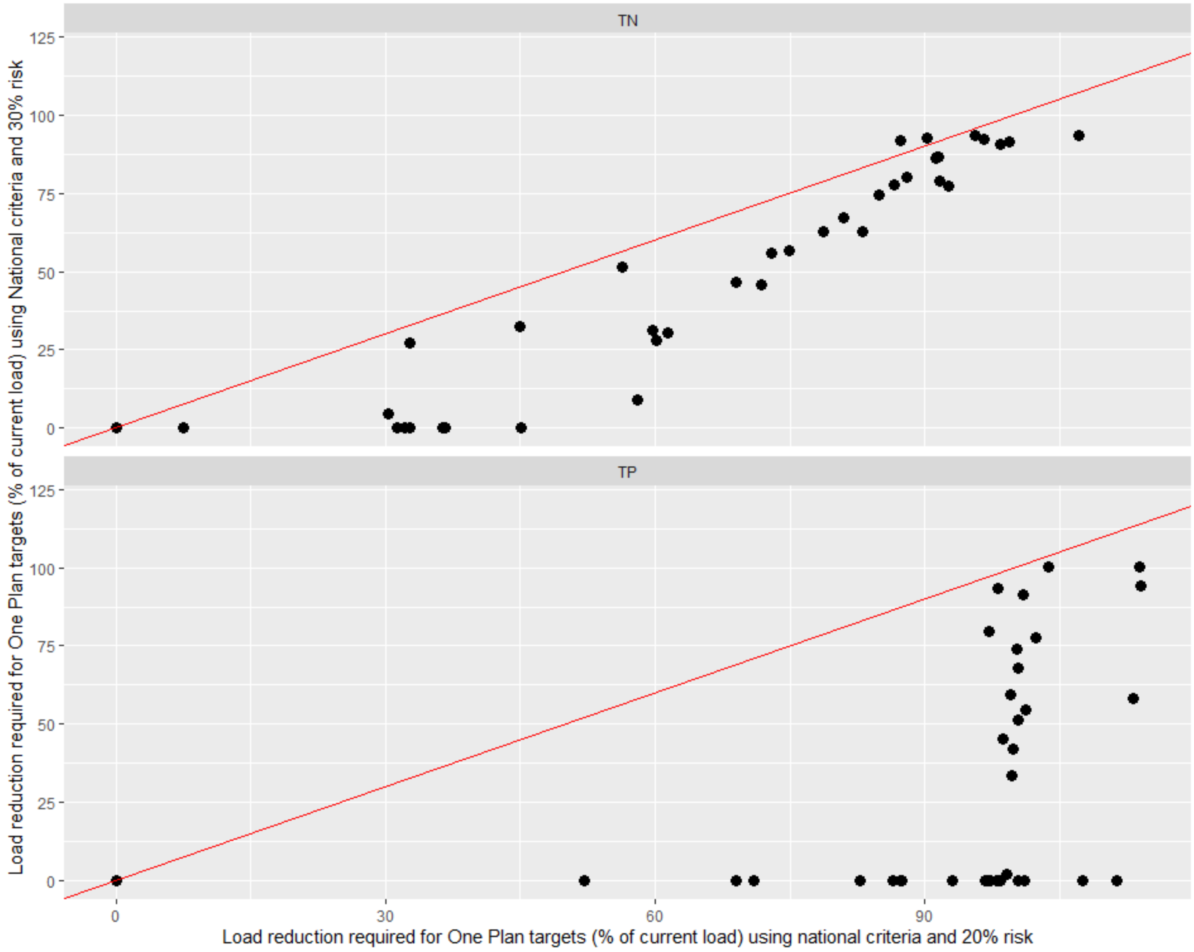


Figure 102. Comparison of the best estimates of TN and TP load reductions required for the WMSZs for the One Plan targets using national criteria showing 20% versus 30% risk. The red diagonal line is one to one (i.e., indicating equal load reductions for 20% and 30% risk).

The TN load reductions required for the One Plan targets using national criteria (and both the 20% and 30% risk levels) compared with those using the regional criteria are shown in Figure

103. In this study, the national criteria generally had higher TN load reductions required compared to the regional criteria (points are below the red one-to-one line in Figure 103). This is partly because the regional criteria have approximately a 50% under-protection risk and are therefore more lenient than both sets of national criteria (see Appendix A for further discussion).

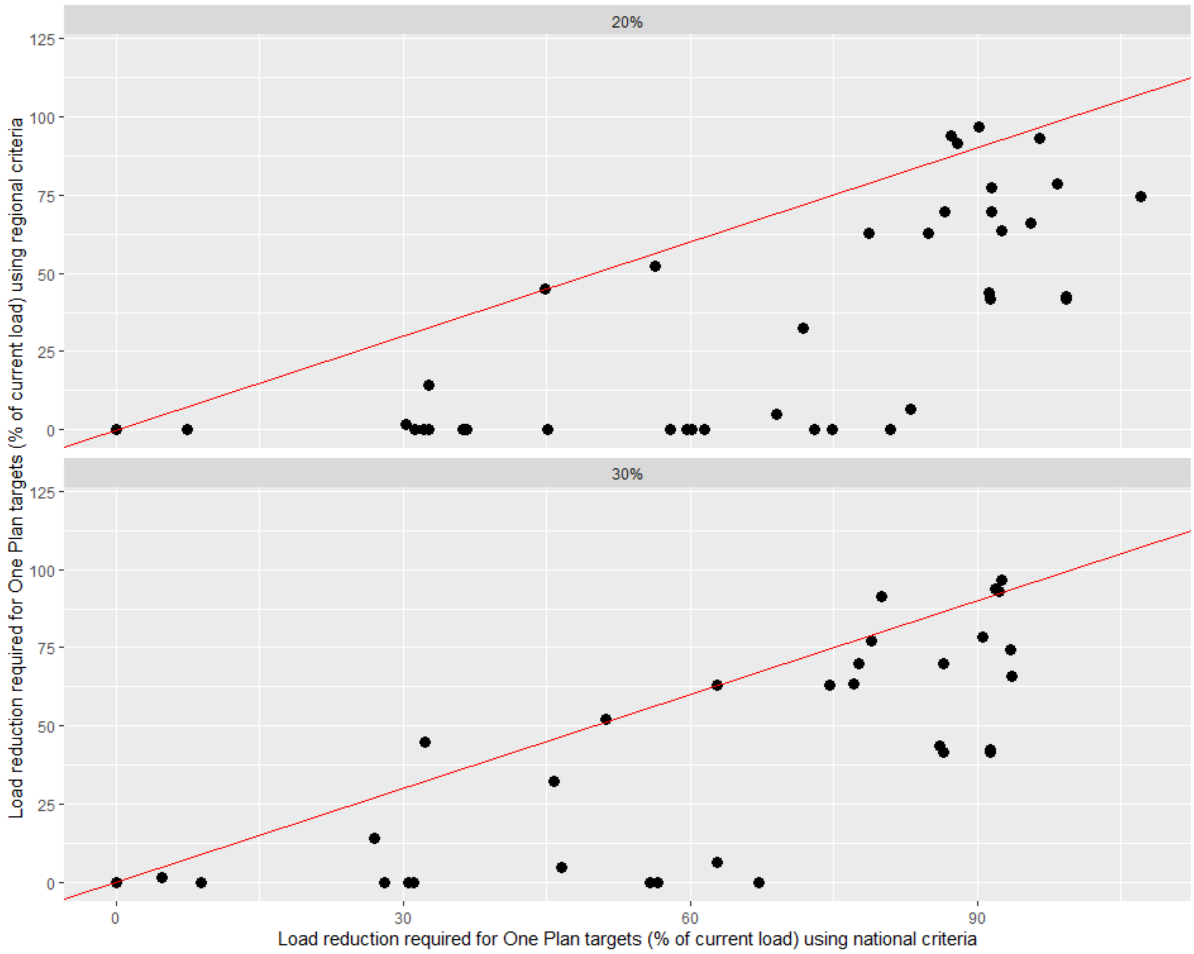


Figure 103. Comparison of the best estimates of TN load reductions required for the WMSZs for the One Plan targets using national criteria and 20% and 30% risk (x-axes) compared to the regional criteria (y-axes). The red diagonal line is one to one (i.e., equal load reductions for criteria corresponding to 20% and 30% under-protection risk).

Lower TN load and TP load reductions required for the C band compared to the One Plan targets reflects the less aspirational FWO associated with the C band (Figure 104). In some WMSZs, there was no, or very little, difference in load reductions required between the One Plan targets and C band (points plotted on or very close to the one-to-one line in Figure 104). This occurs because the One Plan targets are the same as the C band and therefore the load reduction requirements are identical. There are also cases where the load reduction for the C band was slightly higher than for the One Plan targets (points are above the red one-to-one line in Figure 104). These arise because in the nutrient criteria are the same under both options and there is random variation associated with the Monte Carlo analysis.

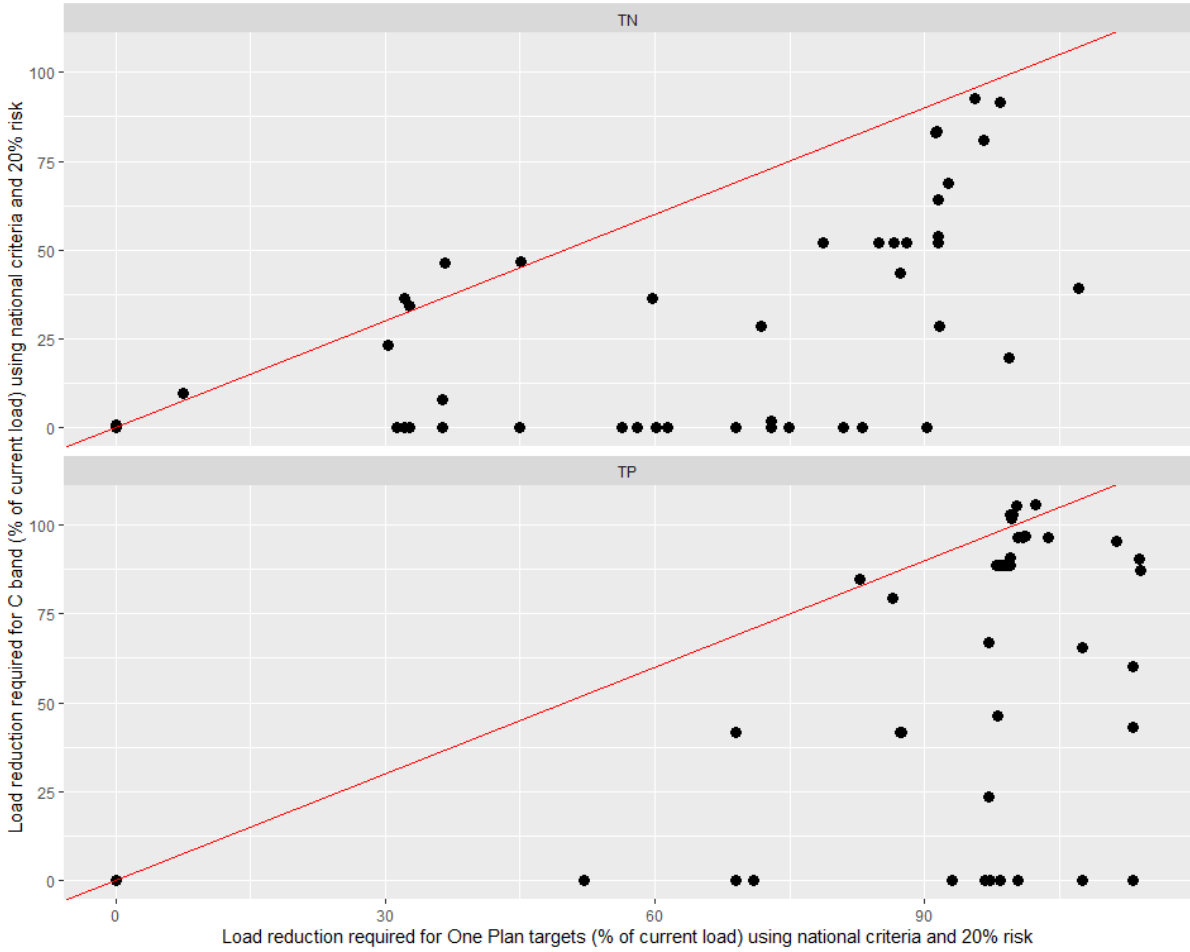


Figure 104. Comparison of WMSZ load reductions required for the One Plan targets and C band, both using the national criteria and 20% risk. The red diagonal line is one to one (i.e., equal load reductions for One Plan and C band options).

There was an even mix of higher and lower TN load and TP load reductions required when comparing the B band to the One Plan targets (Figure 105). In some WMSZs, the load reductions required by the B band were greater than those required by the One Plan targets (points plotted above the one-to-one line in Figure 105). This occurs because the B band in those WMSZ are more stringent than the One Plan targets and therefore the load reduction requirements are greater. The reverse also occurred for some WMSZs (i.e., points plotted above the one-to-one line in Figure 105). Note that there are also WMSZs where the target attribute states were the same and small differences in load reduction requirements occurred only because there is random variation associated with the Monte Carlo analysis.

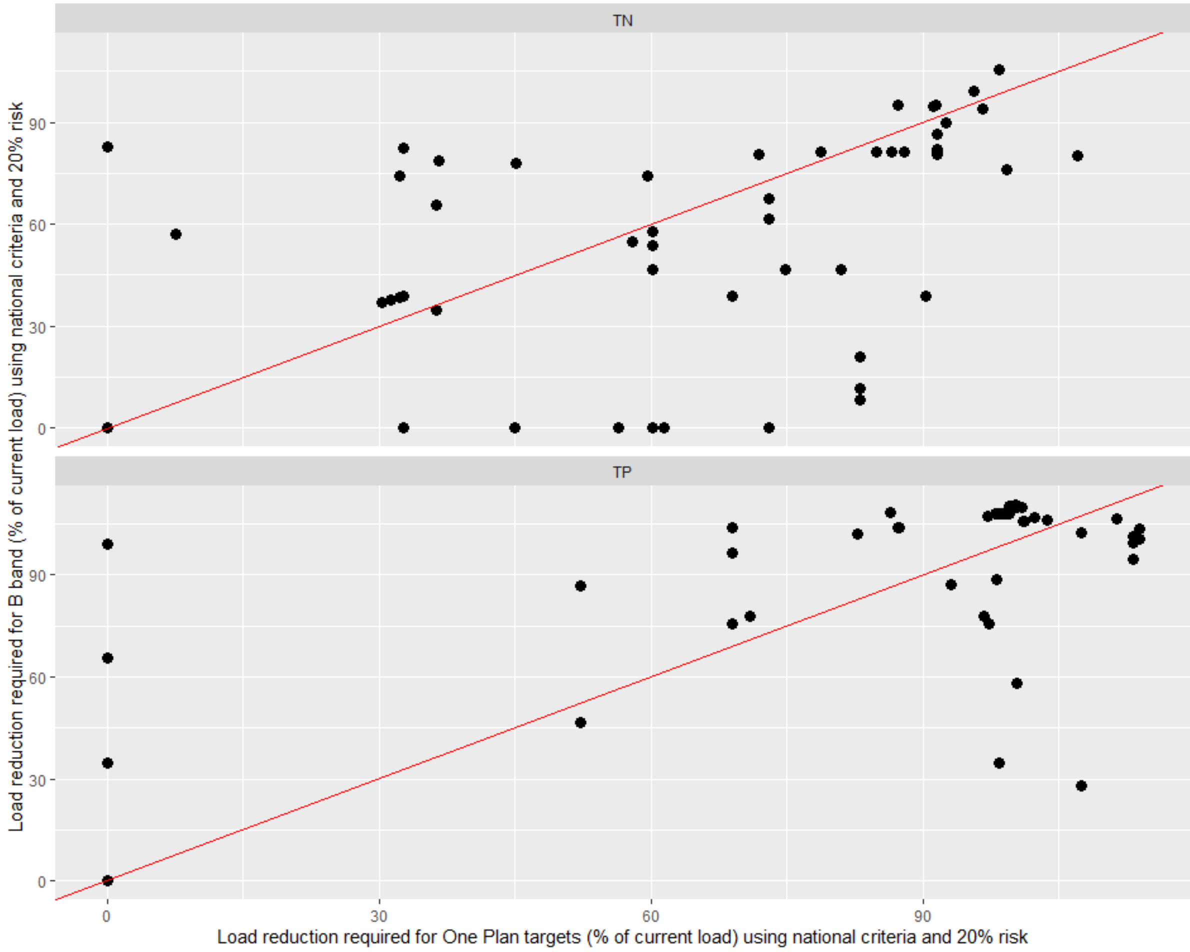


Figure 105. Comparison of WMSZ load reductions required for the One Plan targets and B band, both using the national criteria and 20% risk. The red diagonal line is one to one (i.e., equal load reductions for One Plan and C band options).

The TN load and TP load reductions required were generally higher for the A band compared to the One Plan targets (Figure 106). In some WMSZs, the load reductions required by the A band were similar to those required by the One Plan targets (points plotted close the one-to-one line in Figure 106). This occurs because the One Plan targets in those WMSZs is the A band and therefore the load reduction requirements are the same. Note that small differences arise only because there is random variation associated with the Monte Carlo analysis.

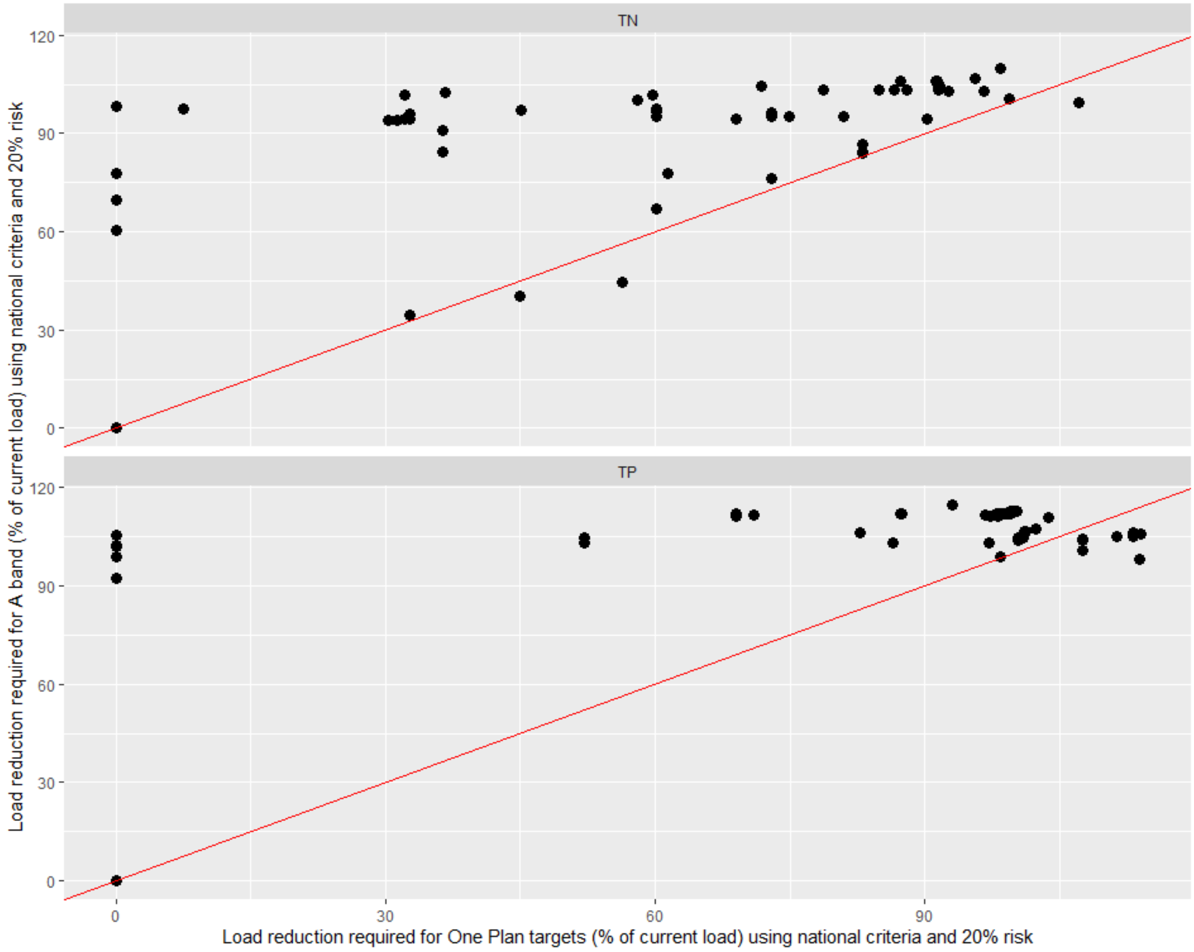


Figure 106. Comparison of WMSZ load reductions required for the One Plan targets and A band, both using the national criteria and 20% risk. The red diagonal line is one to one (i.e., equal load reductions for One Plan and C band options).

5 Summary and discussion

5.1 Load reductions required

This study has assessed nutrient (nitrogen and phosphorus) load reductions needed to achieve options for river periphyton and lake phytoplankton objectives in the Manawatū-Whanganui Region. The options for objectives are defined in terms of target attribute states defined by the NOF (i.e., A, B or C bands) for all river and lake receiving environments in the region.

The study assessed load reduction requirements for four sets of objectives for rivers and lakes, which are presented as options. These options were the existing operative One Plan targets and then three options based on achieving the A, B and C band NOF target attribute states in all receiving environments (i.e., all river segments and lakes in the Region). As well as the four sets of objectives, the analyses incorporated three choices of nutrient criteria for achieving the periphyton objectives: national criteria and 20% risk, national criteria and 30% risk and regional criteria. The national criteria specified TN and DRP concentrations in rivers whereas the regional criteria only specified TN criteria. Collectively then, this study comprises 12 sets of assessments of load reduction requirements (i.e., four options for objectives and three sets of criteria).

Load reductions assessed for the One Plan targets represent the expectations as set out in the operative regional plan. Load reductions assessed for the NOF C band are consistent with the national bottom line attribute states for river and lake receiving environments and provide an assessment of the least acceptable load reduction required. Load reductions assessed for the NOF B and A bands represent more aspirational options. The results for the individual receiving environments aggregated to report on individual 'FMUs', WMSZs, and the whole region.

The results for the region are the most succinct and broad summaries of the load reductions required and are shown in Table 20. The study also identified the 'limiting environment'; i.e., whether it is a lake or river that has the most sensitive FWO and has therefore driven the load reduction required in each catchment.

Table 20. The load reductions required for TN and TP to achieve the One Plan targets for the seven FMUs and the whole region using the national criteria and 20% and 30% risk and the regional criteria. 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).

FMU	TN			TP		
	National 20	**National 30**	**Regional**	**National 20**	**National 30**	**Regional**
Kai Iwi	79 (68 - 85)	74 (63 - 84)	58 (36 - 74)	92 (84 - 97)	81 (66 - 91)	79 (63 - 91)
Whanganui	67 (43 - 85)	46 (5 - 80)	5 (0 - 35)	109 (95 - 115)	4 (0 - 23)	5 (0 - 36)
Whangaehu	56 (38 - 76)	42 (29 - 60)	21 (1 - 55)	93 (86 - 96)	35 (29 - 38)	35 (28 - 38)
Rangitīkei-Turakina	61 (35 - 87)	38 (13 - 75)	25 (11 - 55)	133 (123 - 142)	34 (6 - 86)	26 (3 - 76)
Manawatū	52 (35 - 69)	41 (20 - 57)	36 (6 - 53)	96 (91 - 100)	15 (1 - 48)	14 (1 - 36)
Waiopehu	34 (25 - 46)	26 (17 - 36)	23 (15 - 33)	55 (42 - 65)	17 (9 - 26)	17 (10 - 28)
Puketoi ki Tai	32 (9 - 54)	11 (0 - 33)	9 (0 - 34)	59 (39 - 70)	0 (0 - 0)	0 (0 - 0)
Whole region	60 (47 - 71)	43 (25 - 59)	23 (9 - 36)	106 (99 - 115)	16 (6 - 32)	14 (6 - 31)

The load reductions required associated with the 30% under-protection risk options generally had slightly lower TN and considerably lower for TP compared to the 20% under-protection risk =. The lower load reduction requirements for the 30% under-protection risk compared to the 20% under-protection risk is because the former represents an increased risk tolerance and therefore the nutrient criteria are more lenient. The greater proportional difference in load reduction requirements for TP compared to TN arises from the statistical models that underlie these criteria. The fitted coefficient for DRP was much larger than for TN which results in larger changes of periphyton biomass per unit of change in DRP than for TN (Snelder *et al.*, 2019). This then means there is a larger proportional change in the DRP criteria than the TN criteria between the 20% and 30% under-protection risk options. However, in some WMSZs, there was no, or very little, difference in load reductions required between the 20% and 30% under-protection risk (e.g., Figure 102 and Figure 103). This is because river periphyton is not always the 'limiting environment' (e.g., Figure 101) and the lake nutrient concentration criteria was unchanged between the 20% and 30% under-protection risk options.

The TN and TP load reductions required were higher for the One Plan targets compared to the NOF C band option due to the more aspirational FWO associated with some WMSZs than the C band option. However, for some reporting catchments, there was no, or very little, difference in load reductions required between the One Plan targets and the C band options (Figure 10). This is because the FWOs for the two options and the same for some WMSZs and this results in no impact on the load reduction requirements.

5.2 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 24.4% for the Manawatū-Whanganui Region and the NOF C band (national bottom line). The present study produced a very similar result (23%; Table 11) to Snelder et al. (2020). Some differences between the two analyses are to be expected for two reasons. First, Snelder *et al.* (2020) estimated the TN load reduction required for the estuaries as well as rivers and lakes and an estuary was found to be a limiting environment in that study. Second, concentrations and loads were calculated from different datasets in the two studies with the present study having used more up to date data.

5.3 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 modelled regional river nutrient concentrations and loads (see Sections 3.1 and 3.2). The statistical uncertainty of these models is associated with their inability to perfectly predict the concentrations and load observed at water quality monitoring sites; the error associated with these predictions is quantified by the model RMSD values (Table 5 and Table 6). The errors associated with each of the eight RF models were combined using Monte Carlo analyses. The Monte Carlo analyses simulated 100 ‘realisations’ of the calculations, which were then used to define the probability distributions of all load reduction estimates. The probability distribution describes the range over which the true values of the load reductions are expected to lie. The best estimate of the load reduction is the mean value of the distribution and the lower and upper limits of the estimates were represented by the 5^{th} and 95^{th} percentiles of the distribution (i.e., these are the limits of the 90% confidence interval).

In this study, a lower limit of the 90% confidence 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 options included in this study for the region as a whole and for many of the WMSZs irrespective of the under-protection risk criterion (level of risk of not achieving the periphyton objective) that is chosen (Table 20). We can also have high confidence that TP load reductions are required under all options except the NOF C band using 30% under-protection risk for the region as a whole and for most of the WMSZs.

The confidence intervals for regional load reduction estimates in this study were slightly narrower than that obtained for the Manawatū-Whanganui region in the national study of Snelder *et al.* (2020). In the national study a 20% TN load reduction to achieve NOF bottom lines had a 95% confidence interval from 4% to 41%. In this study, the C band and 20% under-protection risk produced a TN load reduction requirement of 23% with a 90% confidence interval from 10% to 40% (Table 11). There are at least two reasons that this study achieved narrower confidence intervals. First, we used the 90% confidence interval (in order to be able to have 95% confidence that the load reduction was greater than zero). This is therefore a slightly narrower interval. Second, the underlying (regional) concentration and load models used in this study had slightly lower characteristic uncertainties (i.e., RMSD values; Table 5 and Table 6) than the equivalent models in the national study and this leads to slightly lower uncertainties.

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

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

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

5.4 Differences between criteria

This study indicates that the choice of criteria makes large differences to the assessed load reductions that are necessary. The criteria are therefore a source of management uncertainty because there is not a “correct” criterion. In addition, although criteria are derived using scientific methods, criteria are not entirely objective and therefore the choice of criteria ultimately lies with the decision maker.

This study has presented three choices of nitrogen criteria for periphyton and two for phosphorus. The methods of derivation and the scientific uncertainties associated with these criteria mean that some sites will be under-protected and some sites will be over-protected despite being compliant with the nutrient criteria. Under-protection means that a site will exceed the nominated target attribute state (i.e., the A, B or C bands) despite being compliant with the nutrient criteria. Over-protection means some sites would achieve the nominated target attribute state at nutrient concentrations that are higher than the criteria.

The methods of derivation mean that the national criteria with the 20% risk is the most conservative (i.e., has the lowest expected rate of under-protection). The 20% risk refers to the expectation that 20% of locations will exceed the nominated target attribute state despite being compliant with the nutrient criteria (i.e., will be under-protected; see Appendix A for a fuller explanation). The 30% risk means that 30% of locations are expected to exceed the nominated target attribute state despite being compliant with the nutrient criteria. The regional criteria are the most lenient - there is an expectation that 50% of locations will exceed the nominated target attribute state despite being compliant with the nutrient criteria.

The choice of which risk is acceptable, and therefore which criteria should be used, is not a science question, it is a management decision that must be made by the decision maker. The obvious trade-off associated with this decision is between over- and under-protection. Reducing the risk of under-protection correspondingly increases over-protection and vice-versa. In addition, reducing over-protection increases the amount by which under-protected sites can be expected to exceed the target attribute state.

It is noted that the criteria for lakes were taken directly from the NOF attribute tables for TN and TP and it was assumed that compliance with these criteria would achieve the target attribute state for phytoplankton in lakes. However, this is uncertain, and lakes will be under-protected or over-protected to varying degrees under the criteria used by this study.

5.5 Informing decision-making on limits

The NPS-FM requires regional councils to set limits on resource use to achieve environmental outcomes (e.g., FWOs). This report helps inform Horizons Regional Council's process of setting limits by assessing the approximate magnitude of nitrogen and phosphorus load reductions needed to achieve several options for objectives, 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.

6 Acknowledgements

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7 References

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

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

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

Fraser, C., 2021. Load Calculations for Rivers of the Manawatū-Whanganui Region to 31 December 2019. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

Fraser, C. and T. Snelder, 2020. Load Calculations and Spatial Modelling of State, Trends and Contaminant Yields. For the Manawatū-Whanganui Region to December 2017. Client Report, LWP Ltd, Christchurch, New Zealand.

Fraser, C. and T. Snelder, 2021. Updated State and Trends of River Water Quality in the Manawatū-Whanganui Region. For Records up to 31 December 2019. LWP Client Report, LWP Ltd, Christchurch, New Zealand.

Kilroy, C., 2019. Using Empirical Relationships to Develop Nutrient Targets for Periphyton Management. A Case Study from the Horizons Region. NIWA Client Report, NIWA, Christchurch, New Zealand.

Kilroy, C., M.T. Greenwood, J. Wech, T. Stephens, L. Brown, A. Mathews, M. Patterson, and M. Patterson, 2018. Periphyton - Environment Relationships in the Horizons Region. Analysis of a Seven-Year Dataset. NIWA Client Report, Christchurch, New Zealand.

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

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

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

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

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

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

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

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

NZ Government, 2020. National Policy Statement for Freshwater Management 2020.

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

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

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

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

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

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

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

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

Appendix A Comparison of nitrogen criteria used in this study with regional criteria

A1 Region specific periphyton biomass models

Relationships between periphyton biomass and nitrogen concentrations have been developed based on monitoring data collected by HRC at up to 58 sites across the region (Kilroy *et al.*, 2018). These relationships incorporate a range of variables in addition to nutrient (i.e., nitrogen and phosphorus) concentrations including electrical conductivity, temperature, substate size and the frequency of 'effective flows' (EF, high flows that reduce biomass to low levels). Kilroy (2019) used three models that included functional relationships between nitrogen concentrations (either as TN or dissolved inorganic nitrogen (DIN)) and biomass to define nitrogen concentration criteria (Table 21). Kilroy *et al.* (2018) did not define functional relationships between periphyton biomass and phosphorus. Therefore, Kilroy (2019) did not derive phosphorus concentration criteria.

The three models that were used to derive nitrogen concentration criteria applied to differing numbers of sites: Model 1 applied to 42 sites for which effective flows could be identified, Model 2 applies to all 58 sites and Model 3 applies to only 14 sites that were classified as insensitive to flow. The models performed well (R^2 ranged between 0.74 and 0.87; Table 21). The explanatory variables used by these models included a measure of stream substrate composition (pccoarse: the mean percentage of streambed covered by bedrock, boulders and large cobbles combined) and accrual time (DaEF, the mean time in days between events exceeding the EF).

Table 21. The three periphyton biomass models used by Kilroy (2019) to define nitrogen concentration criteria. Chla92 is the 92nd percentile of observed monthly, DaEF is the mean time in days between events exceeding the effective flow (EF), EC is the site median electrical conductivity, DIN is the site median dissolved organic nitrogen, TN is the site median total nitrogen, pccoarse is the percentage of streambed covered by bedrock, boulders and large cobbles combined. R^2 and NSE are the coefficient of determination and the Nash Sutcliff Efficiency for the models respectively (see Table 1 for interpretation of model performance based on these measures).

Model	Equation	R^2 (NSE)	Applies to
1	$log_{10}(Chla92) = -0.897 + (0.485 \times log_{10}(DaEF)) + (0.097 \times \sqrt{EC}) + (0.413 \times log_{10}(DIN)) - (0.004 \times pccoarse)$	0.74(0.58)	42 sites for which an EF was identified and *DaEF* was derived.
2	$log_{10}(Chla92) = -1.444 + (0.084 \times \sqrt{EC}) + (0.726 \times log_{10}(TN)) + (0.008 \times pccoarse)$	0.74(0.64)	All 58 sites.
3	$log_{10}(Chla92) = -1.921 + (0.113 \times \sqrt{EC}) + (0.816 \times log_{10}(DIN)) + (0.017 \times pccoarse)$	0.87(0.63)	14 sites classed as insensitive to flow.

A2 Comparison of criteria based on models of Kilroy with those used in this study

This study used the criteria derived from Model 2 (Table 21) because this model was applicable to all 58 sites represented in the fitting data and was therefore assumed to be applicable to all segments of the river network. The criteria derived from Model 2 are called the 'regional criteria' in the main body of this report. The criteria derived from this model were compared to the national criteria used in this study, which vary for each REC class (Snelder *et al.*, 2019). This comparison was made for two levels of under-protection risk defined by the national criteria (20% and 30%) and was performed in four steps. First, criteria for the three periphyton target attribute states (A, B and C) were derived for each site in the fitting dataset using the Model 2 by rearranging the equation representing Model 2 to make the nitrogen term (i.e., TN) the subject of the equation. Second, we set *Chla92* to three values (50, 120 and 200 m^3 m^{-3}), which are the periphyton biomass thresholds corresponding to the target attribute states (A, B and C) and solved for the TN concentration for each site. At the third step we obtained the TN concentration criteria from the national criteria for the three periphyton target attribute states for each of the fitting data sites. We obtained these criteria from the REC class for each site and by looking up the corresponding criteria from the tables in Appendix B. At the forth step we compared the criteria derived from Model 2 with the national criteria by plotting the two sets of criteria and the overall level of correspondence between them was quantified by the Pearson correlation coefficient.

A3 Results

A comparison of TN criteria derived from Model 2 with the national criteria is shown in Figure 107. Because the REC class criteria vary by Source of flow class, they occupy a limited number of discrete points on the y-axis. In contrast the TN criteria derived from Model 2 vary by site and therefore take many values on the x-axis. Two levels of under-protection risk are shown for the national criteria (20% and 30%; Figure 107). The national criteria corresponding to the 30% under-protection risk (right panels Figure 107) are less stringent (higher values) than the 20% under-protection risk option.

Model 2 produced TN criteria with ranges that are similar to the national criteria (Figure 107). For example, for the B band, the Model 2 TN criteria ranged between 171 and 4,150 mg m^{-3} (median for Source of flow classes between 465 and 2,700 mg m^{-3}) compared to a range from 316 to 2,400 mg m^{-3} for the REC class 20% exceedance criteria. The two sets of criteria were weakly positively correlated (Pearson correlation coefficient ~0.3) indicating some consistency in the implied sensitivity of site biomass to TN concentrations between the two sets of criteria.

The national criteria were generally, more stringent than the Model 2 criteria (the points tend to be to the right of the one-to-one line in Figure 107) although this was not always the case. The national criteria based on 30% risk were generally closer to the Model 2 criteria than those based on the 20% risk (the points are generally closer to the one-to-one line in the right-hand panels compared to the left hand panels).

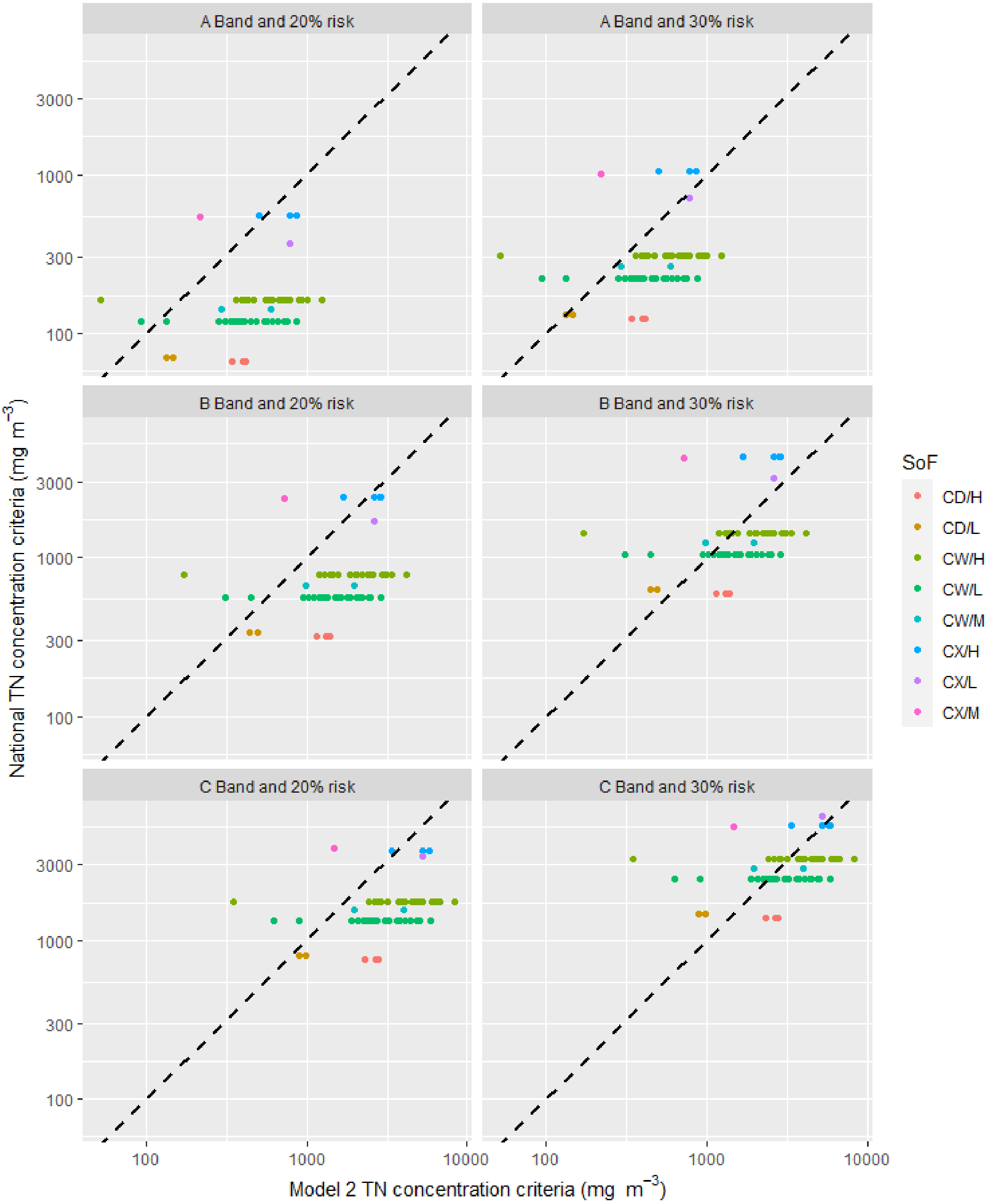

Figure 107. Comparison of TN criteria derived from Model 2 with the national criteria. The dots indicate two sets of criteria corresponding to each of the 58 fitting sties. Colours indicate the REC Source of flow class used to derive the relevant national criteria for each site. Each panel represents criteria derived for the three target attribute state bands (A, B and C) and the choice of risk associated with the national criteria (20% and 30%). The black dotted line is one to one, indicating perfect agreement between the two sets of criteria.

A4 Differences in approach to defining criteria

Differences in the underlying modelling approaches are a key reason that criteria derived from Model 2 above are less stringent than the national criteria. Model 2 was defined using ordinary least squares regression (OLS) (Kilroy et al., 2018). In OLS, the model represents the mean value of the response for a given value of the explanatory variable as shown in Figure 108.

There are often problems associated with application of OLS to ecological data. Ecological variables, such as periphyton biomass, are generally controlled by multiple factors but these are not all measured. This leads to OLS models with heterogenous variance and an incomplete picture of the relationship between the measure factors and the response. A simple example of this is shown in Figure 108. The biomass shown on the y-axis is the 92nd percentile of monthly observations at 58 sites in the Manawatū-Whanganui region over the period from 2009 to 2017 and the TN concentration is the median of observations at the same sites over the same period (the same data that Model 2 is derived from). The plot indicates that peak biomass is limited by factors other than the TN concentrations because some sites have low biomass at high values of TN. However, TN appears to be a limiting factor; sites tend to have low biomass at sites with low TN and the highest values of biomass increase with increasing TN.

A regression model is used to define nutrient criteria by nominating a target biomass (y-axis) and reading off the corresponding concentration from the x-axis (see red dotted lines in Figure 108). A practical implication of the use of OLS to define criteria in this way is that there should be an expectation that 50% of locations would exceed the target biomass when being compliant with the criteria because the regression line is fitted to the mean of the data (conditional on the concentration). It can also be seen in Figure 108 that some sites will exceed the target biomass by a large amount due to the heterogenous variance. In this report, we refer to the locations above the regression line as ‘under-protected’ (by the criteria).

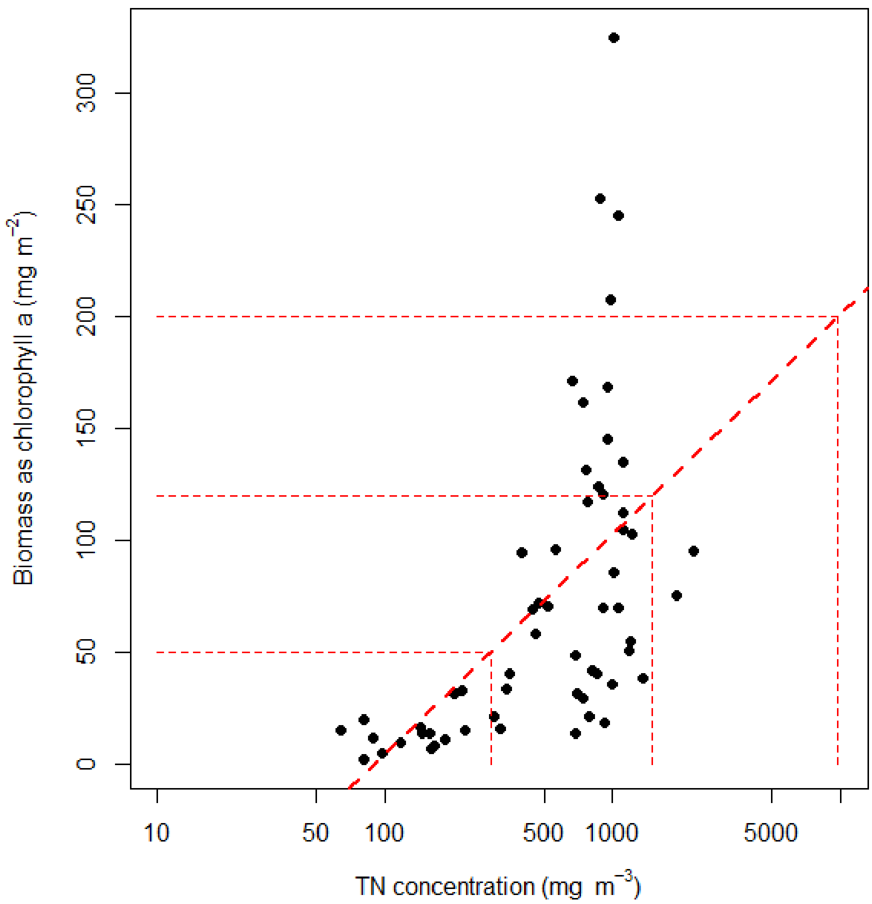

Figure 108. Ordinary linear regression applied to Horizons the 92nd percentile of monthly periphyton biomass and the median of monthly TN concentrations observed at 58 sites in the Manawatū region. The red dashed line represents an ordinary least squares regression with an R^2 of 0.31. The red dotted lines indicate the criteria derived from this model for target attribute states corresponding to 50, 120 and 200 mg Chla m^{-2} (i.e., A, B and C bands).

Quantile regression can be used to estimate multiple response rates from the minimum to the maximum response, thereby providing a more complete picture of the relationship than OLS. A simple example of this is shown in Figure 109, which is based on the same data as used in Figure 108. The three lines shown in Figure 109 are regressions fitted to the 70th, 80th and 90th percentiles of the data. These regression lines describe TN criteria such that only a small proportion (30%, 20% and 10%) of sites have biomass higher than indicated by the regression line (i.e., are under-protected). This type of model is similar in principle to the approach used to define the national criteria with the national criteria using the term “under-protection risk” to describe the proportion of sites (20% and 30%) that are expected to have biomass higher than the nominated target attribute state (i.e., A, B and C). It is noted that the model that the national criteria were derived from for both TN and DRP included variables in addition to nutrient concentration. These additional variables improve the fit of the model and allow the definition of criteria that differ by REC Source of flow class, but the principles remain the same.

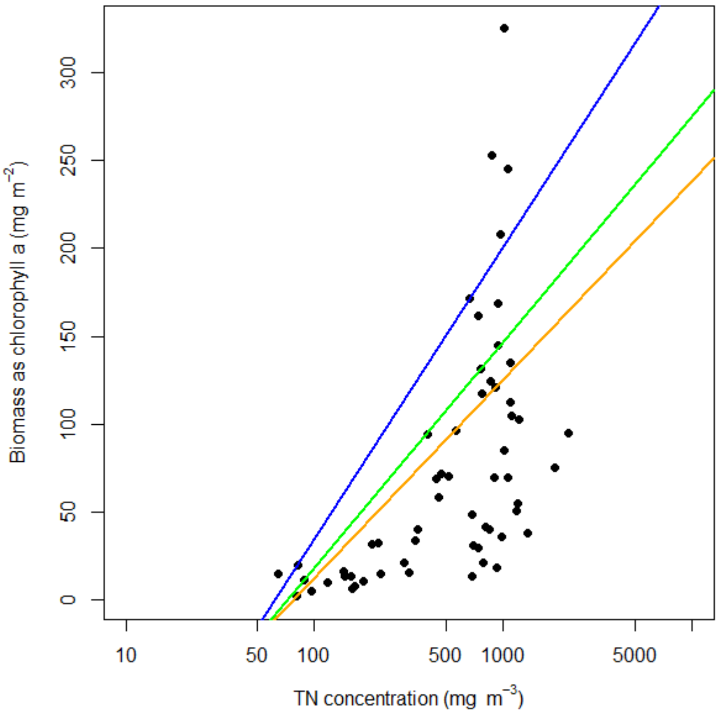

Figure 109. Quantile regression applied to Horizons the 92nd percentile of monthly periphyton biomass and the median of monthly TN concentrations observed at 58 sites in the Manawatū-Whanganui region. The blue, green and orange lines indicate models fitted to the 90th, 80th and 70th quantiles.

The use of the quantile regression models to define the nutrient criteria compared to OLS is shown in Figure 110. The principle for quantile regression models is the same as for OLS: a target biomass is nominated (y-axis) and the modelled concentration corresponding to that biomass is read from the x-axis (dotted lines in Figure 110). Depending on what quantile is used, the criteria derived from the quantile regression sets the expectation for the proportion of locations that will exceed the target biomass when the criteria is met; this proportion is called the risk for the national criteria.

The choice of which under-protection risk is acceptable is not a science question, it is a management decision that must be made by the decision-maker. The obvious trade-off associated with this decision is that reducing the risk that locations will exceed the target biomass is associated with increasing the degree of “over-protection” at some sites (i.e., those that are below the regression lines shown in Figure 110.

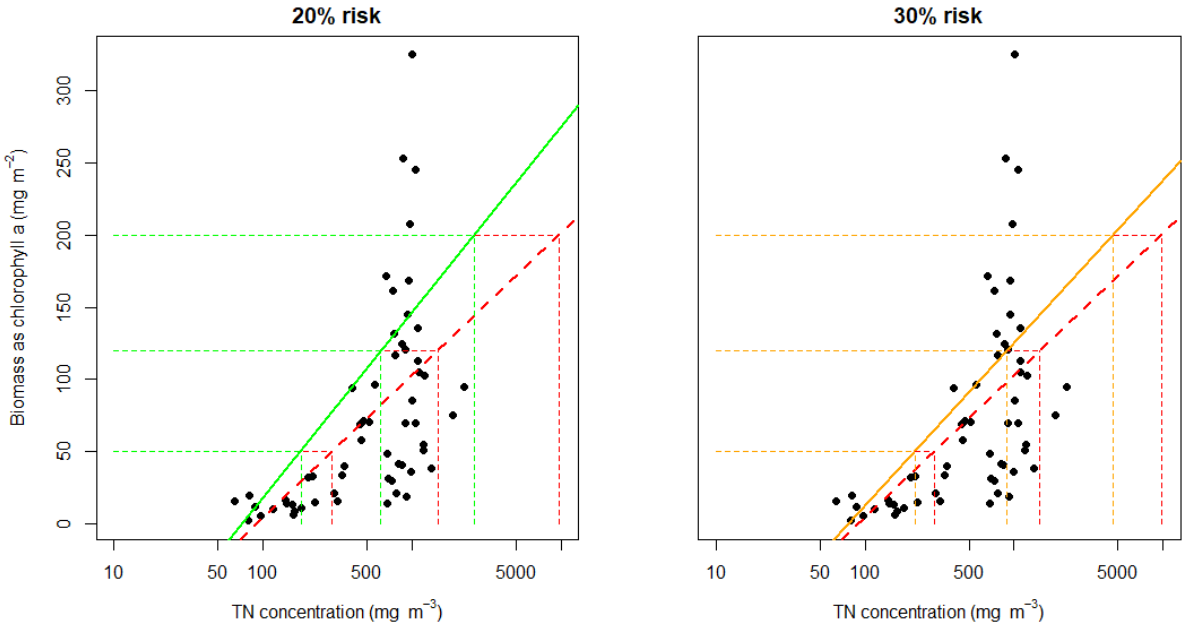

Figure 110. Definition of criteria to achieve target biomass states of 50, 120 and 200 mg m^{-3} using quantile regression compared to OLS. The green and orange lines in the left and right panels indicate models fitted to the 80th and 70th quantiles and therefore representing a 20% and 30% risk that a location will exceed the target biomass given the criteria. The red dashed and dotted lines indicate the OLS models and corresponding criteria. Note that for the OLS criteria, there is a 50% risk that a location will exceed the target biomass given the criteria.

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

The criteria for periphyton FWOs are shown for each REC Source-of-flow class that occurs in the Manawatū-Whanganui region and corresponding to the A, B and C bands (Table 22). The values in the table represent the recalibration of the criteria of Snelder *et al.* (2019) and the 20% under-protection risk. Values are median concentrations in units of mg m^{-3}.

Table 22. The total nitrogen and dissolved reactive phosphorus criteria for periphyton FWOs for each REC Source-of-flow class that occurs in the Manawatū-Whanganui region corresponding to the A, B and C bands and the 20% under-protection risk.

River Environment Classification Source-of-flow class	Total nitrogen (mg m^{-3})			Dissolved reactive phosphorus (mg m^{-3})		
	A	B	C	A	B	C
CW/H	161	781	1764	0.3	15.8	68.9
CW/L	118	559	1325	0.2	5.2	37.6
CW/M	141	666	1556	0.3	14.5	69.1
WW/L	77	364	871	0.2	1.6	15.6
CX/H	550	2385	3664	7.2	107.3	273.4
CX/L	369	1691	3363	2.4	67.3	186.8
CX/M	538	2340	3843	8.2	114.1	289.3
CD/H	67	316	758	0.2	1.2	12.7
CD/M	75	355	851	0.2	2.4	23.7
CD/L	71	339	811	0.2	1.2	12.6
WD/L	36	172	414	0.1	0.2	1.5
WD/Lk	87	409	974	0.2	1.2	13.1

Table 23. The total nitrogen and dissolved reactive phosphorus criteria for periphyton FWOs for each REC Source-of-flow class that occurs in the Manawatū-Whanganui region corresponding to the A, B and C bands and the 30% under-protection risk.

River Environment Classification Source-of-flow class	Total nitrogen (mg m^{-3})			Dissolved reactive phosphorus (mg m^{-3})		
	A	B	C	A	B	C
CW/H	311	1428	3243	41	252	322
CW/L	223	1045	2426	20	160	273
CW/M	262	1242	2833	37	245	318
WW/L	143	689	1636	8	89	243
CX/H	1044	4324	5346	195	359	356
CX/L	710	3144	6040	118	312	375
CX/M	1019	4252	5188	207	336	373
CD/H	124	589	1394	6	76	221
CD/M	139	648	1551	10	108	273
CD/L	132	633	1474	6	77	221
WD/L	68	317	751	1	23	82
WD/Lk	161	761	1822	7	84	235

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