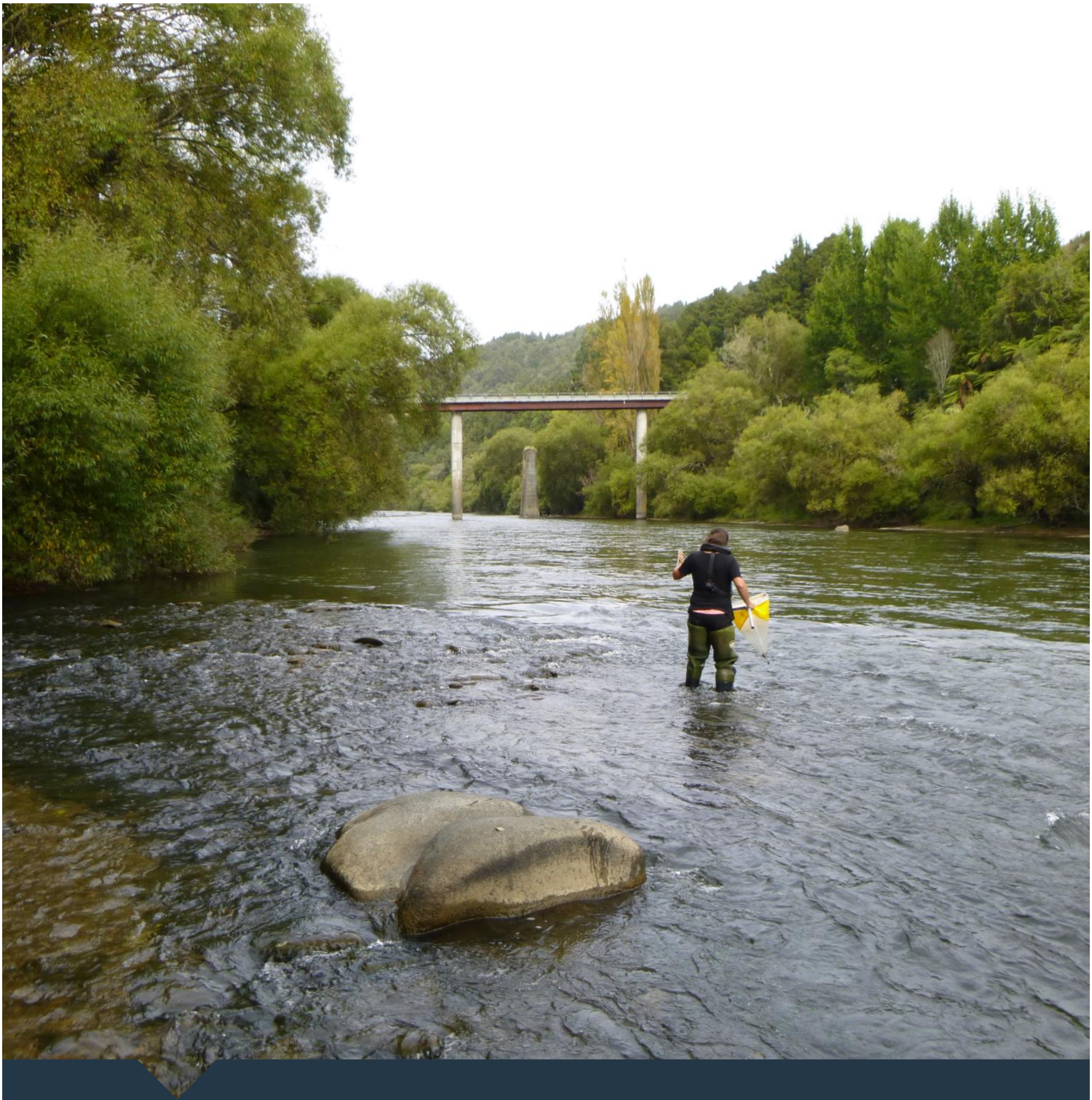

Assessment of nutrient load reductions to achieve freshwater objectives in the rivers of the Manawatū-Whanganui Region

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Executive Summary

This report describes nutrient (nitrogen and phosphorus) load reductions predicted to achieve options for target attribute states (TAS), in rivers in 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 about the magnitude of the load reductions needed for each option, how these vary across the region, and the uncertainty inherent in this assessment.

This study largely repeats an earlier study of load reduction requirements in the Manawatū-Whanganui Region by Snelder and Fraser (2021) but includes changes to the TASs and nutrient concentration criteria. The study adopted TASs for river periphyton and nitrate toxicity using attributes set out in the National Policy Statement for Freshwater Management 2020 (NPS-FM) and defined terms of a band (A, B or C) for all river receiving environments in the region. In addition, this study assesses nutrient load reductions required to achieve the adopted TASs for rivers for three options for under-protection risk[1] (UPR; 20%, 25% and 30%) associated with the nutrient concentration criteria for river periphyton. The three UPRs can be understood as different levels of risk that adopted nutrient criteria will fail to achieve the required river periphyton TASs with the 30% UPR accepting a higher level of this risk than the 20% UPR.

The study included all rivers in the Manawatū-Whanganui Region and 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 across the study area. The concentrations and loads were combined with criteria associated with TASs. For each TAS and UPR, calculations were made of the amounts by which current loads would need to be reduced to allow the TASs to be achieved (i.e., the load reduction required). The study also assessed the uncertainties associated with these calculations that are due to the collective uncertainty of the various input models.

The load reductions required were assessed for all individual river receiving environments in the study area. The results for the individual receiving environments were aggregated to report on individual Freshwater Management Units (FMUs), Water Management Sub-Zones (WMSZs), and the region. The results for the FMUs and whole region are the most succinct and broad summaries of the load reductions required and are shown in Table A below.

The study estimated the uncertainties associated with all assessments of the reductions in TN and TP loads required to achieve the nominated TASs for rivers. 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 headline results reported in Table A indicate that, the load reductions required for the 20% UPR were always greater than the 25% UPR and the reductions required for the 25% UPR

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[1] Note that in the earlier study of load reductions required for the Manawatū-Whanganui Region by Snelder and Fraser (2021) referred to the UPR as the spatial exceedance criteria.

were always greater than the 30% UPR. This is expected because the lower the UPR, the more stringent (i.e., the lower risk tolerance) the required nutrient concentration. Load reductions for both TN and TP were substantial for the 20% UPR (regionally 64% and 70%, respectively). The uncertainties of these estimates were considerable even at the regional level and were larger for TP that TN, reflecting the slightly lower performance of the phosphorus models in general. Even for the 30% UPR, load reductions in some FMU's were greater than 30%. It is also noteworthy that for all three UPRs, there were no FMUs for which the 90% confidence interval included zero. This means that we can be 95% confident that load reductions are required for all UPRs and in all FMUs. Based on projections of reductions in nitrogen and phosphorus that could be achieved under pastoral land use with existing and potential mitigations, these reductions are unlikely to be achievable without land use change.

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 for river periphyton used in this study. These criteria represent the best available assessment of the nutrient concentration that will achieve the TASs. The relevant TASs are maximum periphyton biomass in rivers. The uncertainties associated with these criteria mean that some locations may develop biomass greater than specified by the TAS 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. The risks of these outcomes occurring are quantified by the UPR and its complement the level of over-protection. These risks cannot be avoided and must be considered and adopted as part of the management decision.

Table A. The load reductions required for TN and TP to achieve the TASs for the seven FMUs and the whole region based on the adopted TASs and the 20%, 25% and 30% levels of under-protection risk and the nutrient concentration 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**		
	20% UPR	**25% UPR**	**30% UPR**	**20% UPR**	**25% UPR**	**30% UPR**
Kai Iwi	65 (47 - 79)	53 (31 - 69)	46 (24 - 65)	72 (43 - 88)	60 (39 - 81)	57 (40 - 68)
Whanganui	46 (11 - 80)	28 (3 - 65)	15 (3 - 34)	61 (4 - 99)	35 (2 - 81)	17 (1 - 62)
Whangaehu	46 (18 - 72)	35 (12 - 60)	24 (5 - 45)	48 (18 - 80)	33 (22 - 64)	26 (12 - 47)
Rangitīkei-Turakina	58 (44 - 71)	51 (34 - 68)	42 (27 - 56)	73 (37 - 117)	57 (36 - 100)	46 (31 - 68)
Manawatū	83 (56 - 96)	65 (30 - 86)	49 (21 - 82)	84 (49 - 109)	64 (19 - 95)	44 (11 - 89)
Waiopehu	74 (60 - 83)	66 (48 - 79)	60 (42 - 76)	61 (36 - 78)	54 (33 - 71)	48 (27 - 69)
Puketoi ki Tai	75 (62 - 87)	59 (40 - 77)	43 (22 - 65)	76 (61 - 88)	66 (44 - 83)	52 (33 - 73)
Whole region	64 (51 - 78)	48 (35 - 63)	36 (22 - 53)	70 (44 - 89)	49 (31 - 70)	33 (20 - 53)

Glossary

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

Term	Definition
Attribute	Measurable characteristic that describes the state of a river, lake or estuary.
Baseline	The baseline represents the state of water for the five-year period ending September 2017.
Point excess load	The cumulative load reduction at a point in the network that ensures the current load at that point, and all receiving environments in the upstream catchment, do not exceed their Maximum Allowable Loads
Compliance	The adherence of a receiving environment (river, lake or estuary) with a criterion
Criteria	A measured or predicted (by a model) quantity by which the achievement of the TAS is judged
Critical catchment	The land draining to a receiving environment for which the local excess load, is not exceeded by any downstream receiving environment. This takes into account the interconnectedness of the catchment and provision for downstream waterbodies clause xx.xx of the NPS.
Critical catchment load reduction required	The load reduction required at the critical point.
Critical point	A receiving environment for which the local excess load is not exceeded by any downstream receiving environment (the downstream most point in a critical catchment).
Limiting environment	The identification of whether it is an estuary, lake or river criterion that defines a critical point and that therefore drives the load reduction required for the critical catchment.
Local excess load	The amount by which the current load at the receiving environment would need to be reduced to comply with the criteria.
Maximum allowable load (MAL)	The maximum contaminant (nitrogen or phosphorus) load that will allow the target attribute state to be achieved.
Catchment load reduction	The amount by which the current load at a receiving environment to be reduced to comply with the criteria at that and all upstream receiving environments
Spatial framework	Digital representation of the drainage network (i.e., streams and rivers and their catchments) and the connected freshwater receiving environments (rivers, lakes and estuaries) of the study area.
Target attribute state (TAS)	Outcome (defined by the attribute) sought for the state of a river, lake or estuary

1 Introduction

The National Policy Statement for Freshwater Management 2020 (NPS-FM) requires Horizons Regional Council (HRC) set a target attribute state (TAS) for all attributes that are relevant to rivers and streams in the region and prescribe limits on resource use that will achieve these targets. As a first step in setting TASs and limits, this study has assessed load reductions for the two nutrients total nitrogen (TN) and total phosphorus (TP) that are required to achieve options for several TASs in streams and rivers of the Manawatū-Whanganui Region. The purpose is to provide information 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. Some periphyton is 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 periphyton biomass in rivers.

This study assesses nutrient load reductions required to achieve a nominated set of TASs that apply to each of 124 water management sub-zones (WMSZ). The TASs are defined for the periphyton and nitrate toxicity attributes that are defined in the National Objectives Framework (NOF) of the NPS-FM. The TASs are defined using the A, B and C-band target attribute states and apply to all the streams and rivers within each WMSZ.

This study assesses nutrient load reductions pertaining to the periphyton attribute based on nutrient concentration criteria (for nitrogen and phosphorus). These criteria incorporate a choice concerning the risk that the nutrient concentration criteria will not achieve the periphyton TAS at individual stream and river locations, which is referred to as the under-protection risk. This study has analysed the load reductions based on three levels of under-protection risk: 20%, 25% and 30%. The three levels of under-protection 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 analysis methodology is based on several previous national-scale studies of contaminant load reduction requirements (MFE, 2019; Snelder *et al.*, 2023, 2020) and a subsequent regional study of load reduction requirements in the Manawatū-Whanganui Region by Snelder and Fraser (2021). 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 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 Snelder *et al.* (2023) updated the earlier national scale Snelder *et al.* (2020) study and added three additional contaminants: phosphorus, *Escherichia coli* and sediment. Like most of the previous studies, this 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 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. This study and the earlier (Snelder and Fraser, 2021) study involved some modifications to methods used by the earlier studies to specifically represent the Manawatū-Whanganui region and the spatial framework represented by the WMSZs. 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

The study area comprised the Manawatū-Whanganui region (Figure 1). The study methodology is based on a spatial framework that represents the surface water drainage network (i.e., streams and rivers and its' associated catchments), HRC's Freshwater Management Units (FMU) and the 124 WMSZs, which provide a spatial delineation of the region into large and small catchment subdivisions, respectively (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. The terminal segments of the river network (i.e., the most downstream points in each drainage network that discharges to the ocean) were identified.

There are seven FMUs that subdivide the region into individual catchments or groups of catchments and 124 WMSZs, which are smaller sub-catchments, each of which is defined by a downstream-most point in the drainage network (Figure 1). The FMUs and WMSZs are used in this study as a framework for reporting the study results, primarily the load reduction requirements. Because WMSZs are associated with objectives, policies and rules in the operative regional water plan (the One Plan), the load reduction requirements for all 124 sub-zones are comprehensively reported.

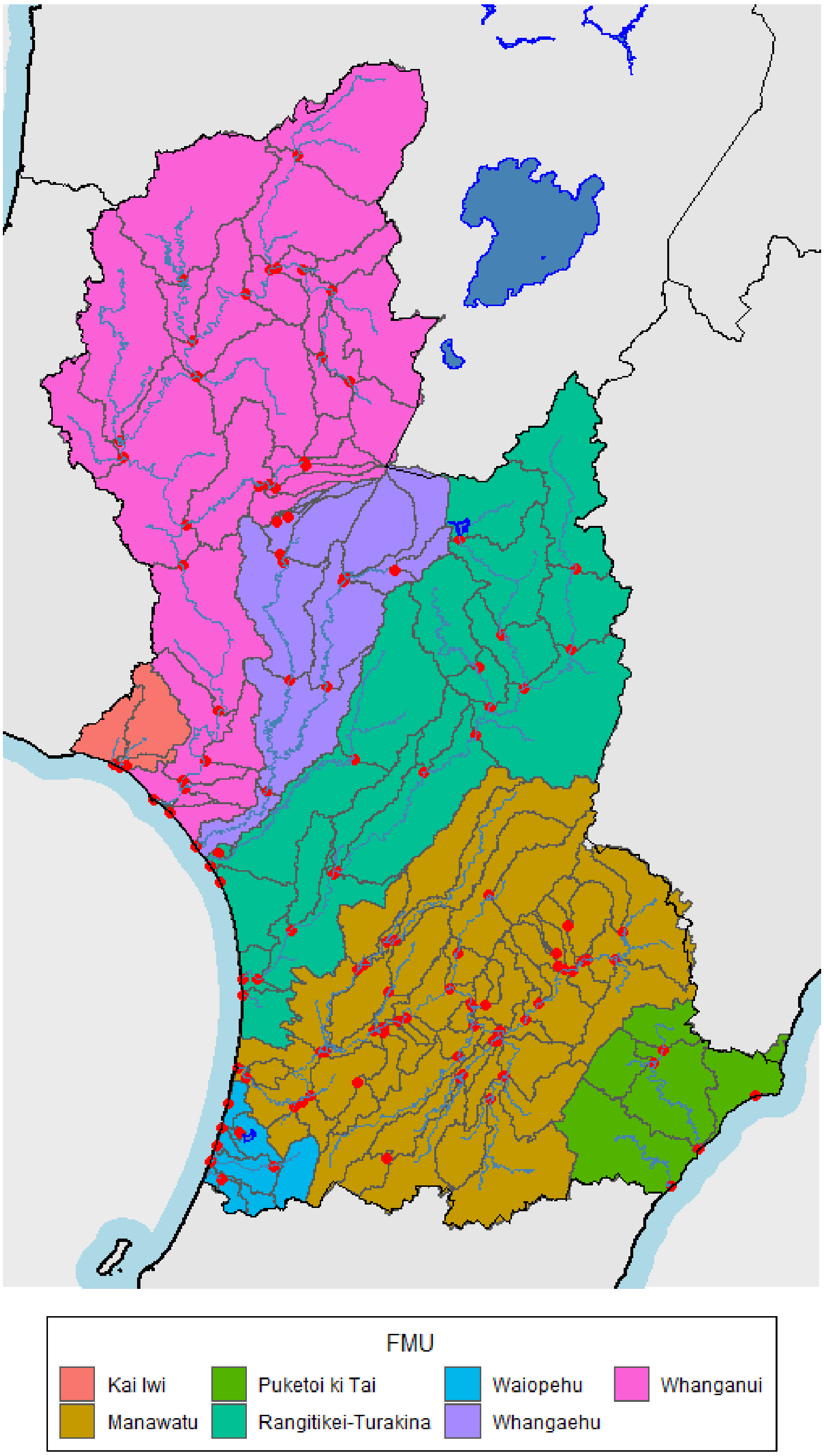

Figure 1. The components of the spatial framework for this study. The map shows the drainage network as blue lines (note only segments of stream order ≥ 5 are shown). The map also shows HRC's Freshwater Management Units (FMU) and Water Management Sub-zones (WMSZs, which are delineated by black boundaries). The red points indicate the points in the drainage network that are at the downstream-most end of each WMSZ.

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 baseline concentrations and loads of nutrients at each segment of the drainage network, each of which also represents a stream or river receiving environment. The nutrient loads predicted for the drainage network can also be used to estimate the nutrient loads delivered to lake and estuary receiving environments, but this has not been undertaken by this study.

The criteria to achieve TASs in river receiving environments are defined in terms of concentrations of nitrogen and phosphorus. 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 TAS to be achieved). The compliance of rivers with the concentration criteria is assessed by comparison to baseline concentrations. Receiving environments with baseline 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 baseline 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 point excess load is the cumulative load reduction at a point in the network that ensures the load at that point, and at all receiving environments in the upstream catchment, do not exceed their MALs. The point excess load 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 point excess load that reflects a reconciliation of those upstream local excess loads. The point excess loads can be reported at any location in the drainage network but in this study are reported at the downstream end of each WMSZ (see below). The point excess loads for all terminal segments within an FMU (i.e., network segments draining to the sea) are summed to obtain the FMU load reduction required.

The critical catchment load reduction required is the load reduction requirement that is based on complying with concentration criteria at all downstream receiving environments. The critical catchment load reduction status is based on defining critical points, which are point in the network where the local load reduction required is not exceeded by any downstream receiving environment. More specifically, the critical point is defined as a point in the drainage network for which the ratio of the current contaminant load to MAL is not exceeded by any downstream receiving environment. The catchment upstream of the critical point is the critical point catchment. The critical catchment excess load indicates the load reduction required at the critical point to allow all receiving environments downstream of the critical point to achieve their target attribute states. The critical catchment excess load is the local excess load at the critical point. If this excess load is greater than zero, there is an unacceptable level of contaminant loss in the critical catchment. The critical catchment excess load can be expressed as an absolute (excess) yield (the excess load divided by the total area of the upstream catchment; mass ha^{-1} yr^{-1}). The critical catchment excess load can also be expressed as a proportion of the current load (i.e., excess load/current load; %).

The critical catchment load reduction required 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 (Ministry for Environment, 2020). But note this study has not considered lakes and estuaries, the load reductions for which may be greater than those for rivers. This analysis will form part of future studies once TAS have been defined for estuaries and lakes.

Although the underlying analysis employed by this study has evaluated the point excess load and the critical catchment load reduction required based on every segment of the drainage network, the results are reported only for the downstream-most points in each of the 124 WMSZs (Figure 1). This reduces the resolution of the study outputs to the downstream-most points in each of the 124 WMSZs, which is appropriate if the WMSZs are the spatial scale at which management provisions (e.g., target attribute states and plan rules) are to be applied.

Two values indicating the WMSZ load reduction required are provided by this study. First, the point-WMSZ load reduction required is the load reduction requirement that is based on achieving the TAS for all segments of the river network upstream of each WMSZ. The point-WMSZ load reduction required is therefore equivalent to the point excess load but evaluated at the downstream end of each WMSZ. It is noted that where a WMSZ has upstream WMSZs, the point-WMSZ reduction required reflects the load reduction required to achieve all upstream TASs. Second, the critical-WMSZ load reduction required is the greater of the point-WMSZ catchment load reduction and the load reduction required at the next critical point downstream of the WMSZ. The critical-WMSZ load reduction required is therefore the load reduction that will achieve the TAS for all segments of the river network upstream of each WMSZ and the TASs in all receiving environments in the network downstream of the WMSZ.

Both the point- and critical-WMSZ load reductions required are estimated in terms of total mass per year but are expressed in tables and maps in absolute terms as a yield (i.e., 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 such as OVERSEER. The load reduction measured as a percentage of current load allows for comparison of the reductions between TN and TP on comparable scales.

It is noted that the point- and critical-WMSZ load reduction required measures are uniform spatial average reduction rates. Both the WMSZ load reduction measures should therefore be interpreted as indicating the general level of effort required and it is not expected that, in practice, this effort would be applied in a spatially uniform fashion. For example, mitigations cannot be applied on all land and the magnitude of achievable mitigation reductions will vary by land type. There may be large load reductions required downstream but very little potential to decrease discharges within a WMSZ because it is subject to low levels of resource use. In these circumstances, in practice, the load reductions that are required at a critical point will need to be achieved by reductions in downstream WMSZs at rates that are higher than the reported spatially uniform rates.

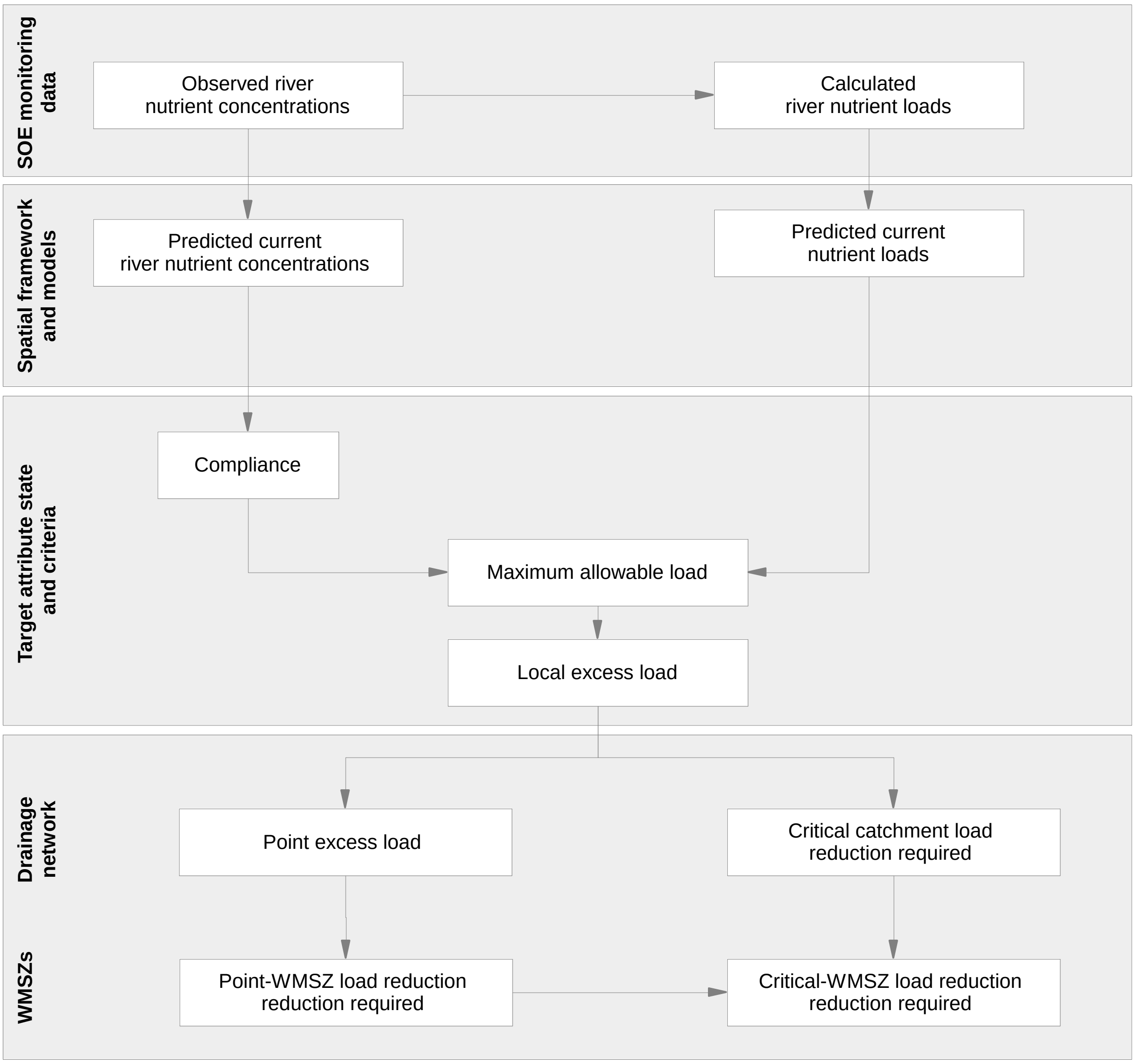

Figure 2. Schematic diagram of the assessment of nutrient load reductions required to achieve freshwater objectives.

The following sections describe the various components of the analysis shown in Figure 2 in more detail. 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; Figure 1) to the whole region. This report includes summaries of the load reductions required for the region, FMUs and WMSZs as absolute mass per year (t yr^{-1}), a yield reduction (kg ha^{-1} yr^{-1}) and as a reduction expressed as a proportion of baseline load (%).

2.2 Estimated baseline river nutrient concentrations

Estimates of the baseline median concentrations of the nutrients: total nitrogen (TN), nitrate-nitrogen (NO3N) and total phosphorus (TP), were made by HRC (Chawla *et al.*, 2024) 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/TN) were made for all segments of the drainage network. Because the site median values of NO3N in TN represent proportions, they ranged between zero and one.

The approach used by Chawla *et al.* (2024) to statistical regression modelling 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.

Chawla *et al.* (2024) used a total of 132 river water quality monitoring sites in the Manawatū-Whanganui region to fit the models for all four nutrient variables (i.e., TN, TP, NO3N and NO3N/TN). The baseline state represents the year 2017 and therefore, the input data were median values of the four variables calculated from monthly observations over the five-year period ending September 2017. 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).

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

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

The performance of the RF models was evaluated and the uncertainty of the predictions using three measures: regression R^2, Nash-Sutcliffe efficiency (NSE), and bias. The regression R^2 value is the coefficient of determination derived from a regression of the observations against the predictions. The R^2 value indicates the proportion of the total variance explained by the model, but is not a complete description of model performance (Piñeiro *et al.*, 2008). NSE indicates how closely the observations coincide with predictions (Nash and Sutcliffe, 1970). NSE values range from $-\infty$ to 1. A NSE of 1 corresponds to a perfect match between predictions and the observations. A 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	$\lvert PBIAS \rvert < 15$
Good	$0.60 < R^2 \leq 0.70$	0.50 < NSE ≤ 0.65	$15 \leq \lvert PBIAS \rvert < 20$
Satisfactory	$0.30 < R^2 \leq 0.60$	0.35 < NSE ≤ 0.50	$20 \leq \lvert PBIAS \rvert < 30$
Unsatisfactory	$R^2 < 0.30$	NSE ≤ 0.35	$\lvert PBIAS \rvert \geq 30$

2.3 Estimated baseline river TN and TP loads

Estimates of baseline 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[2]. The loads were expressed as yields by dividing by the catchment area (kg ha^{-1} yr^{-1}).

The second step used the same statistical regression modelling approach and predictor variables as for concentrations to fit RF models to calculated monitoring site loads for TN, and TP. The RF models were fitted to data pertaining only to monitoring sites in the 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 3).

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

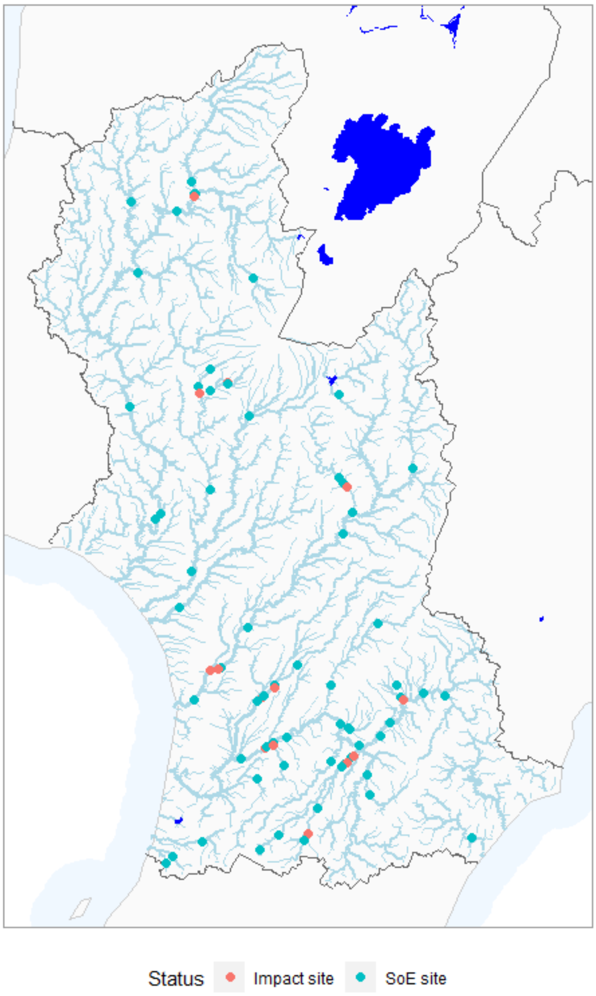

Figure 3. Locations of the 79 river water quality monitoring stations used to fit the load models.

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[2] This report refers to 'baseline loads and concentrations' because the loads and concentrations estimated for 2018 are unlikely to be appreciably or statistically significantly different to the baseline year (2017).

2.4 Target attribute states

To proceed with an analysis of load reduction requirements, it is necessary to adopt TASs. In this study, TASs for rivers were set at the level of the 124 WMSZs for each type of impact (i.e., toxicity and excessive plant biomass). The relevant NPS-FM attributes and levels were specified using the nitrate toxicity and periphyton attributes and the National Objectives Framework (NOF) attribute states (i.e., A, B and C bands) based on analysis and advice provided by Eveleens *et al.* (2023). The target attribute states for the WMSZs varied based on consideration of the values and the baseline state; providing for the requirement that that TAS must maintain or improve the baseline state (Figure 4).

The assessment of load reductions required is comprehensive in that it considers the baseline concentrations and loads at every receiving environment represented in the analysis. It was assumed therefore that the TASs specified for each WMSZ applied to every river segment within each sub-zone.

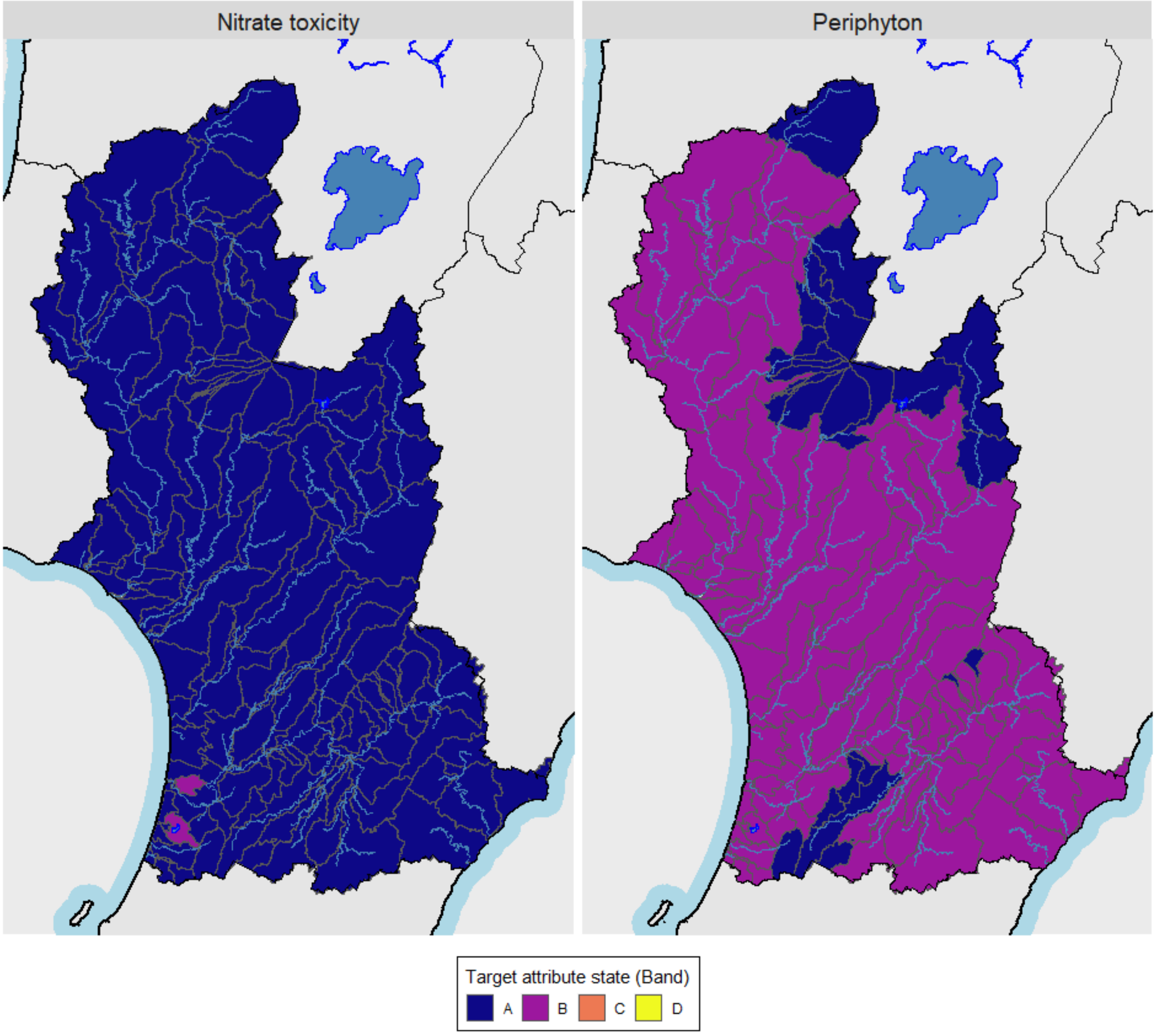

Figure 4. The TASs assessed in this study for periphyton and nitrate toxicity. The band indicated for each WMSZ has been applied to all receiving environments within the sub-zone.

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

The following sections tabulate the concentration criteria associated with each TAS and describe how the concentration criteria were used to assess compliance and define the maximum allowable load (MAL) for river segments.

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 upper thresholds (the higher value of the concentration range that defines the band) 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 periphyton 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 (Ministry for Environment, 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 upper 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

In this study, the nutrient criteria to achieve the periphyton biomass bands were based on Snelder and Kilroy (2023). The criteria are specified in terms of median concentrations of total nitrogen (TN) and total phosphorus (TP) and vary across 14 river classes defined by the second (Source-of-flow) level of the River Environment Classification (REC; Snelder and Biggs, 2002) that occur in the Manawatū-Whanganui region (see Appendix A). For the analyses that follow, it was assumed that both the nominated nitrogen and phosphorus criteria need to apply to achieve the periphyton TAS. It is also noted that these criteria are the actual basis for the analysis of compliance and load reductions required (i.e., the plant biomass is not predicted for any receiving environment as part of the analyses).

The periphyton-nutrient criteria were derived from nutrient-biomass relationships that were subject to considerable uncertainty. There is therefore a risk that a proportion of locations will exceed a target biomass threshold even when they are compliant with the associated TN and TP criteria. Snelder and Kilroy (2023) provided for differing levels of this risk by incorporating an 'under-protection risk' criterion for the TN and TP concentration criteria. The under-protection risk is an estimate of the proportion of locations that will exceed a nominated biomass target when all locations are compliant with the nutrient criteria. The under-protection risk indicates the risk that a location will exceed the periphyton biomass specified for by the TAS. The level of acceptable risk is a management, rather than a scientific, decision. In this study, analyses were performed for three possible choices of under-protection risk: 20%, 25% and 30%. The 20% under-protection risk is always a lower concentration (i.e., more stringent) than the concentrations corresponding a higher risk (e.g., 25% and 30% under-protection risk) and, therefore, assessments based on the 20% under-protection risk will generally have higher load reduction requirements than those based on higher levels of under-protection risk.

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

A detail of the criteria derived by Snelder and Kilroy (2023) was that the underlying models tended to over-estimate low periphyton biomass[3] values (i.e., ≤ 50 mg m^{-2}). Over-estimation of the low biomass values meant that the derived criteria for the lower biomass threshold (i.e., 50 mg m^{-2}) were too stringent (i.e., the concentrations were too low).

To address the issue of over-prediction of low biomass values, Snelder and Kilroy (2023) suggested that an alternative set of criteria for the 50 mg m^{-2} biomass threshold could be derived using quantile regression. This approach was used to derive TN and TP criteria for the subset of Manawatū-Whanganui region sites taken from the fitting data used by Snelder and Kilroy (2023). Using these data, Manawatū-Whanganui region-specific criteria were derived for the same levels of under-protection risk as the other thresholds (i.e., 120 and 200 mg m^{-2}). However, the quantile regression criteria are spatially uniform (i.e., one value applies to all REC Source-of-flow classes). The alternative set of spatially uniform Manawatū-Whanganui region-specific criteria for TN and TP derived using quantile regression for the 50 mg m^{-2} threshold is provided in Appendix A[4].

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 TP 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 A).

Compliance for each river segment was assessed by comparing the baseline estimated concentrations of TN and TP with the concentration criteria. Where the baseline concentration

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

[4] Note that where the region-specific A band criteria exceeded the B band criteria, the B band was set to the same criteria as the A band. See Appendix A for details.

was less than the concentration criteria, the segment was assessed as compliant and vice versa.

The nitrate toxicity concentration criteria concentration criteria for rivers is defined in terms of nitrate-nitrogen (NO3N), which is the majority of the dissolved component of TN (i.e., total nitrogen) concentration. However, the nitrogen criteria for river periphyton is defined in terms of TN. In addition, the effectiveness of nutrient mitigations on agricultural land for both nitrogen and phosphorus is generally specified in terms of TN and TP (e.g., McDowell *et al.*, 2020; Monaghan *et al.*, 2021). Therefore, the nitrate toxicity concentration criteria were converted to an equivalent TN concentration to make all nitrogen criteria commensurate and to allow the load reductions to be comparable to mitigation effectiveness. The NO3N criteria were converted to TN equivalents by dividing by the predicted median soluble proportion of TN (NO3N/TN) for each segment (see Section 2.2). Implicit in this conversion is the assumption that that the ratio of NO3N to TN will remain the same if the loads of TN are changed.

The MAL for TN and TP for river receiving environments was obtained by converting the concentration criteria into equivalent TN and TP loads. The conversion 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 baseline TN or TP load (kg yr^{-1}) for the network segment, $current\ concentration$ is the estimated baseline median concentration of TN or TP and $Concentration_{Criterion}$ is the criterion for TN or TP that is relevant to the TAS obtained from Table 2 or Appended Table 1 and where necessary converted to equivalent TN (i.e., where the criterion was initially defined in terms of NO3N). 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 baseline TN and TP loads minus the respective MALs.

2.6 Estimated baseline state for periphyton attribute

The periphyton attribute is a measure of peak periphyton biomass, which is defined by the 92nd percentile of monthly observations of the concentration of chlorophyll *a* on the riverbed over a period of at least three years (hereafter Chla92). As described above (Section 2.5), the load reduction analysis is performed by comparing estimated baseline nutrient concentrations to nutrient concentration criteria for both the periphyton and nitrate toxicity attributes. This means that the analysis does not need to estimate the baseline state of the periphyton attribute (i.e., Chla92). However, the baseline state for the periphyton attribute at the level of the WMSZs is a relevant consideration because the sub-zones are associated with objectives, policies and rules in the operative regional water plan (the One Plan), and therefore these might be regarded as “sites” to which a target attribute state applies (under clause 3.11 NPS-FM).

The baseline state of the periphyton attribute at the level of WMSZs must be estimated using models because periphyton is only monitored at 67 sites in the Region. In addition, no periphyton monitoring site can be considered to represent a WMSZ because of the heterogeneity of stream and rivers within every WMSZ. A modelling approach was therefore used to provide a ‘WMSZ-level assessment’ of the baseline periphyton attribute state for each WMSZ. The modelling approach was based on taking the predicted nutrient concentrations for segments within WMSZs and inverting the periphyton nutrient criteria of Snelder and Kilroy (2023) to estimate Chla92.

Two methods were used to define the WMSZ-level baseline state of the periphyton attribute. First, for all segments of stream order ≥ 3 in each WMSZ, we obtained the 75th percentile of the concentrations of each nutrient form (i.e., TN, TP) and the most frequently occurring REC Source-of-flow class. We then used this combination of concentration and Source-of-flow class to estimate Chla92 for the 50% UPR by interpolation of the Chla92 – nutrient criteria for of Snelder and Kilroy (2023) (i.e., inversion of the criteria). The 50% UPR is close to the best estimate of Chla92[5] and, therefore, the resulting value represents the expected value of Chla92 within each WMSZ that is exceeded at 25% of locations (because the concentration was the 75th percentile).

The second method took the segment level TN and TP concentrations and Source-of-flow class for each segment and estimated Chla92 by inverting the criteria for the 20%, 25% and 30% levels of UPR. Note that this produced an estimate of Chla92 for all segments (53,519) in the regional drainage network for each UPR. We took the median of these values within each WMSZ. These values represent the central tendency (the median) of the estimated Chla92 value that is predicted to be exceeded at 20%, 25% and 30% of locations (segments) in the WMSZ. It is noted that because the TN and TP criteria are independent of each other, we expected differences between Chla92 estimated using the two sets of criteria.

Both methods produce WMSZ-level baseline state of the periphyton attribute values that are a periphyton attribute state measure (in mg Chla m^{-2}). However, the values are a ‘characteristic’ value from the distribution of values within each WMSZ. These characteristic values can be expected to be exceeded at a proportion of locations within each sub-zone. We converted the estimated Chla92 values produced by both methods into NOF attribute bands (i.e., A, B, C and D) and compared the estimated WMSZ-level states to the target states.

A reasonable expectation is that the proportion of WMSZs with estimated WMSZ-level baseline attribute state of C or D be approximately equal to the proportion of WMSZs for which load reductions required would be greater than zero (because the adopted TAS for all WMSZs is the A or B band). This outcome would indicate that the estimated WMSZ-level baseline states are a reasonable estimate of the overall periphyton state within (the segments) of each WMSZ and therefore the estimates are consistent with the load reductions required analysis. If the proportion of WMSZs with estimated WMSZ-level attribute state of C and D was less than the proportion of WMSZs for which load reductions required are greater than zero it would indicate that the estimated WMSZ-level baseline states are “optimistic” with respect to the findings of the load reduction analysis. This would indicate WMSZ-level attribute state “misses” load reduction requirements that are found by the higher resolution (i.e., at the level of individual segments) load reduction analysis.

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[5] Note that because the models underlying the criteria of Snelder and Kilroy (2023) are based on site Chla92 values conforming to a gamma distribution, the 50% UPR is not exactly the best estimate (i.e., mean value). In fact, the mean value can be expected to be greater than the 50% prediction interval (from which the 50% UPR is derived) and therefore the true best estimate can be expected to be greater than the value derived from our procedure. We expect that this difference is small, so for the purpose of this exercise the difference was not considered.

2.7 Estimation of uncertainties

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

The RF models of median concentrations of TN, TP, NO3N and DRP and median soluble proportions of TP and TN had at least good performance (Table 4), as indicated by the criteria of Moriasi et al. (2015; Table 1). The mapped predictions of the 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 5). 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 5). 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 5). These patterns were consistent with 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.

Model bias (i.e., systematic error) was greatest for the models of the soluble proportion of TN (i.e., NO3N/TN) and was low for all other variables (Table 4). 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.

Table 4. Performance of the RF models of median concentrations of TN, TP and NO3N. N indicates the number of sites used to fit the model.

Variable	N	R^2	NSE	PBIAS	RMSD	Transformation
TN	128	0.71	0.71	1.9	0.24	log10
NO3N	132	0.68	0.67	0.1	0.41	log10
TP	128	0.63	0.63	0.2	0.25	log10
NO3N/TN	128	0.65	0.64	-5.7	0.91	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. 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 323 mg m^{-3} to 3,090 mg m^{-3}. The logit transformations of the site median soluble proportions of 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.

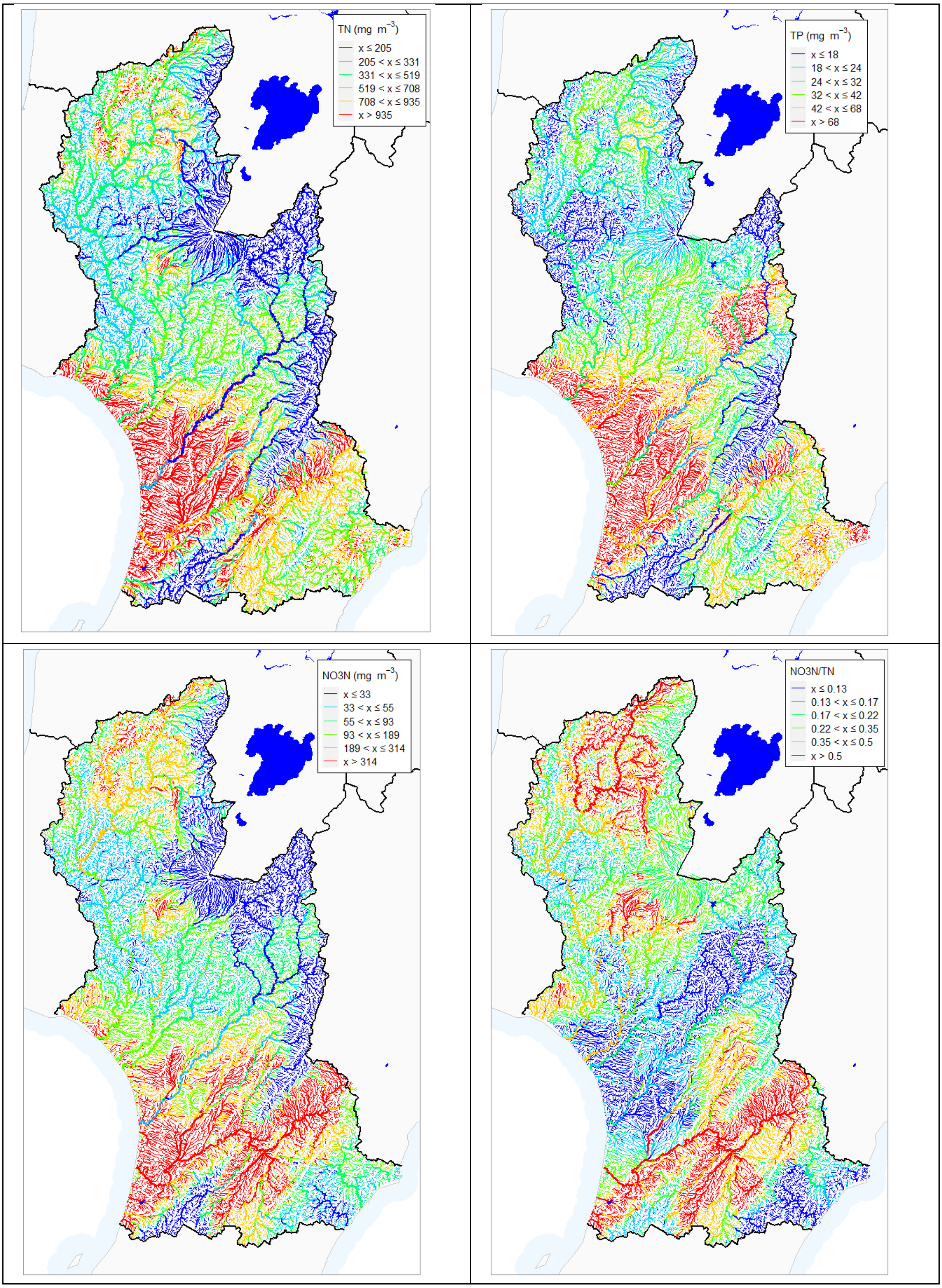

Figure 5. Predicted patterns of the baseline median concentrations of TN, TP, and NO3N and the soluble proportion of TN, respectively. Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

3.2 Performance of TN and TP baseline load models

The RF models of TN and TP yield had satisfactory performance (Table 5), as indicated by the criteria of Moriasi et al. (2015; Table 1). The mapped predictions of yields of all three nutrients had relatively high values in the large main stem rivers (Figure 6). 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 5. 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	log10
TP	78	0.60	0.60	2.04	0.17	log10

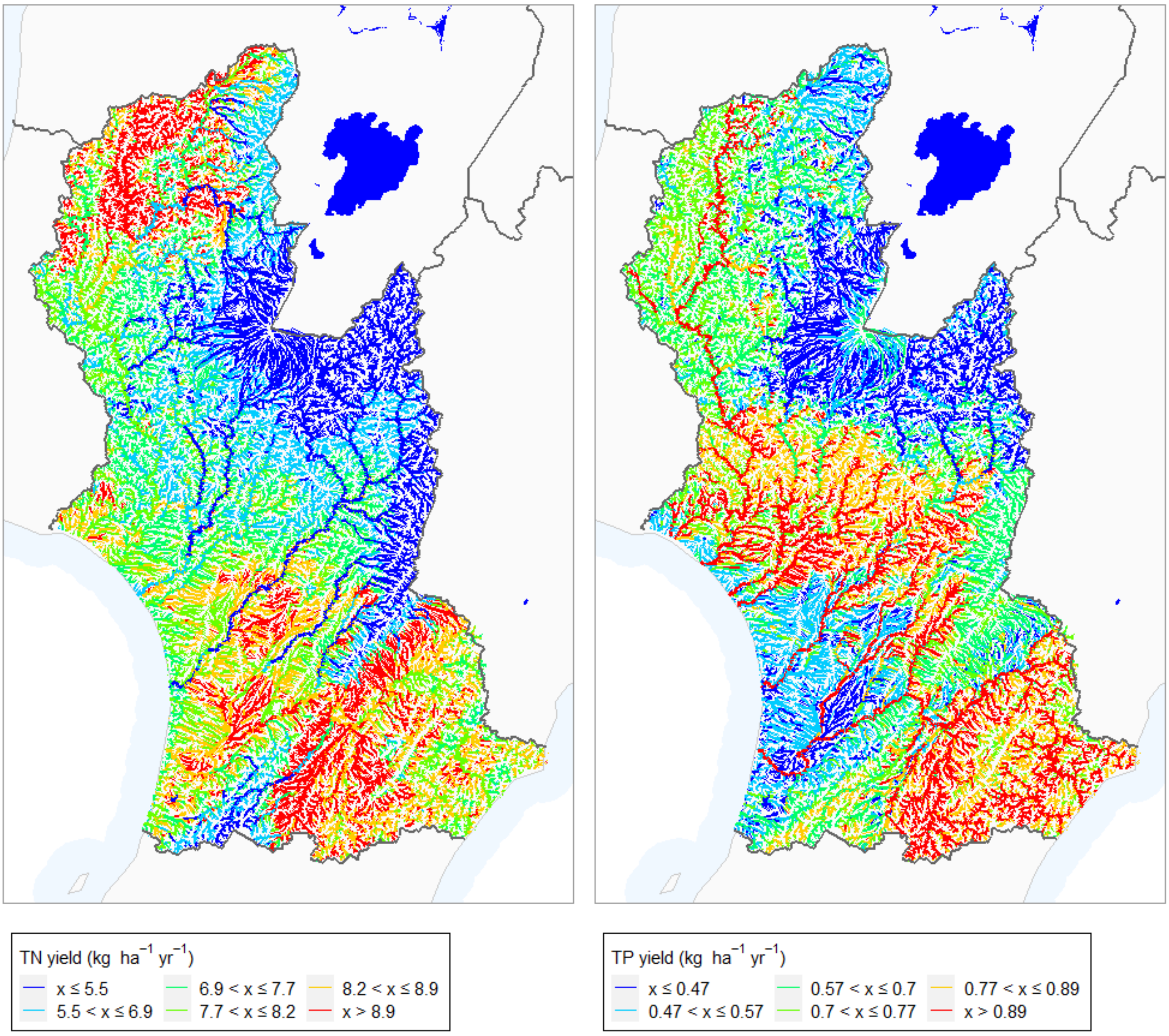

Figure 6. Predicted patterns of the baseline TN and TP loads (as yields kg ha^{-1} yr^{-1}) Note that the breakpoints shown in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

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, NO3N and TP concentrations and TN and TP loads (Table 6). The soluble proportion of TN was strongly negatively correlated with the NO3N and TN concentrations. The correlation structure shown in Table 6 was used to generate random normal deviates (ε_r) for each model in the Monte Carlo analysis.

Table 6. Correlation of errors between all pairs of models used in the analysis. The table is a lower triangular matrix showing the correlations of model errors between all pairs of RF models.

Model	**NO3N concentration**	**TN concentration**	**TP concentration**	**NO3N in TN**	**TN load**
TN concentration	0.90				
TP concentration	0.36	0.46			
NO3N in TN	-0.89	-0.84	-0.33		
TN load	0.68	0.70	0.34	-0.64	
TP load	0.23	0.30	0.51	-0.15	0.50

3.4 Estimated baseline state for periphyton

The first method for estimating the baseline state of the periphyton attribute at the level of WMSZs produced 36 and 43 sub-zones that were graded C or D band (Table 7, Figure 7) for TN and TP, respectively. WMSZs that were graded C and D were consistently those with high predicted concentrations of both nutrients (compared with Figure 5 and Figure 7). The results based on the TN and TP criteria were similar in terms of the total numbers of sub-zones that were graded C or D (Table 7) but the patterns of WMSZ grades exhibited more significant differences between the two nutrients (Figure 7).

Table 7. Comparison of estimated WMSZ-level attribute state with target attribute states for results of method 1. The values show the numbers of WMSZs. The columns indicating TN and TP criteria pertain to which nutrient criteria was inverted to estimate the Chla92 values. The columns TAS A and TAS B indicate the adopted TAS for the WMSZs.

Estimated WMSZ-level attribute state	**Target attribute state**			
	TN criteria		**TP criteria**	
	TAS A	**TAS B**	**TAS A**	**TAS B**
A	8	1	0	0
B	19	60	26	55
C	0	23	1	23
D	1	13	0	19

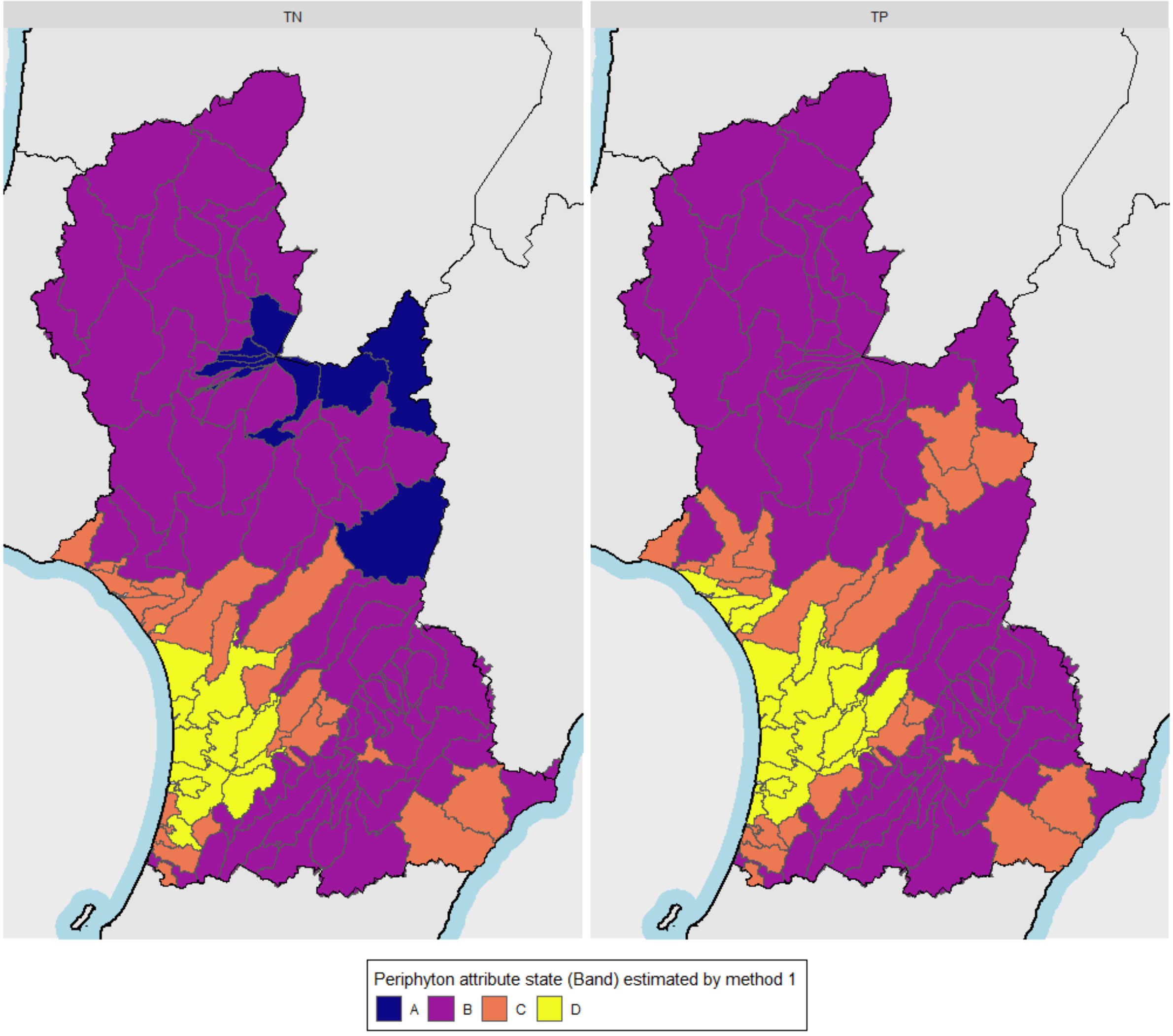

Figure 7. Periphyton attribute state estimated by method 1. The Chla92 values were estimated by inversion of the TN and TP criteria of Snelder and Kilroy (2023) and converted to NOF periphyton attribute bands.

The second method for estimating the baseline state of the periphyton attribute at the level of WMSZs produced varying proportions of sub-zones that were graded C or D band (Table 8, Figure 8) depending on UPR (20%, 25%, 30%) and nutrient (TN or TP). The number of WMSZs that were assigned WMSZ-level states of C or D was 96, 80 and 63 and for TP was 96, 78 and 71 for UPRs of 20%, 25% and 30%, respectively (Table 8). The decreasing number of sub-zones graded C or D band with increasing UPR is consistent with decreasing criteria stringency with increasing UPR.

The results based on the TN and TP criteria were similar in terms of the total numbers of sub-zones that were graded C or D (Table 8) but the patterns of WMSZ grades exhibited more significant differences between the two nutrients (Figure 8). As for method 1, WMSZs that were graded C and D were consistently those with high predicted concentrations of both nutrients (compare Figure 5 and Figure 8).

Table 8. Comparison of estimated WMSZ-level attribute state with target attribute states for method 2. The values show the numbers of WMSZs that were estimated to have WMSZ-level state (A, B, C or D). The columns indicating TN and TP criteria pertain to which nutrient criteria was inverted to estimate the Chla92 values. The columns TAS A and TAS B indicate the adopted TAS for the WMSZs.

UPR	**Estimated WMSZ-level attribute state**	**Target attribute state**			
		TN criteria		**TP criteria**	
		TAS A	**TAS B**	**TAS A**	**TAS B**
20	A	0	0	0	0
	B	21	7	20	8
	C	6	58	6	53
	D	0	32	1	36
25	A	0	0	0	0
	B	26	18	26	20
	C	1	52	1	45
	D	0	27	0	32
30	A	0	0	0	0
	B	27	34	26	27
	C	0	41	1	40
	D	0	22	0	30

The estimated WMSZ-level baseline states for periphyton are compared to the results of the load reduction analyses in Section 4. The comparisons consider the expectations of the relationship between assessed WMSZ-level baseline state and load reduction required set out in Section 2.6.

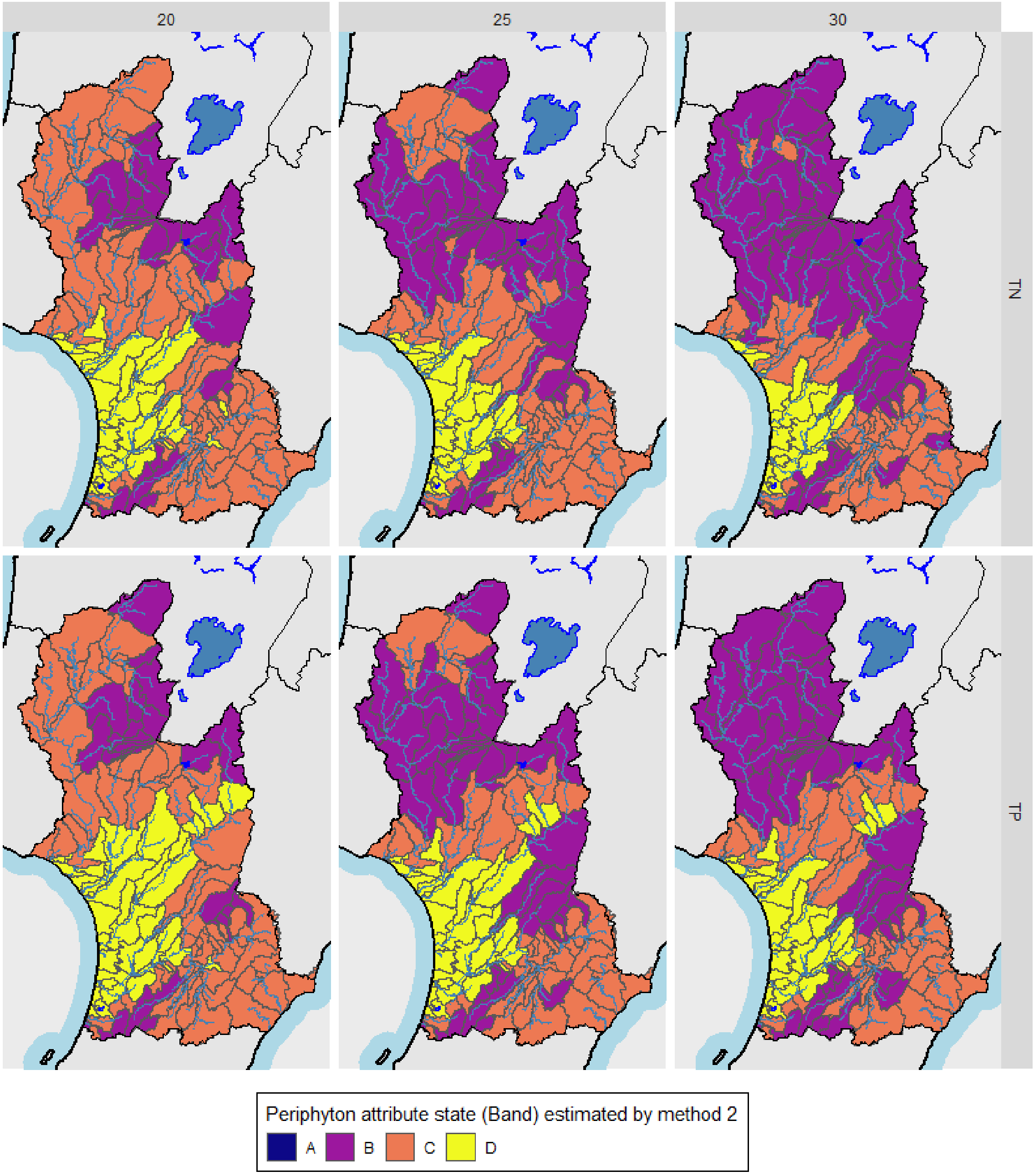

Figure 8. Periphyton attribute state estimated by method 2. The Chla92 values were estimated by inversion of the TN and TP criteria of Snelder and Kilroy (2023) and converted to NOF periphyton attribute bands.

3.5 Adopted targets and 20% under-protection risk

3.5.1 Compliance

For the adopted TAS and the 20% UPR, baseline river concentrations of TN and TP had a greater than 50% probability of exceeding the criteria associated with the TAS (i.e., were non-compliant) for 53% and 55% of segments in the region, respectively (Figure 16). Baseline river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the nitrate toxicity TAS for 2% of segments. However, the probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% at only 0.1% of river segments (Figure 9).

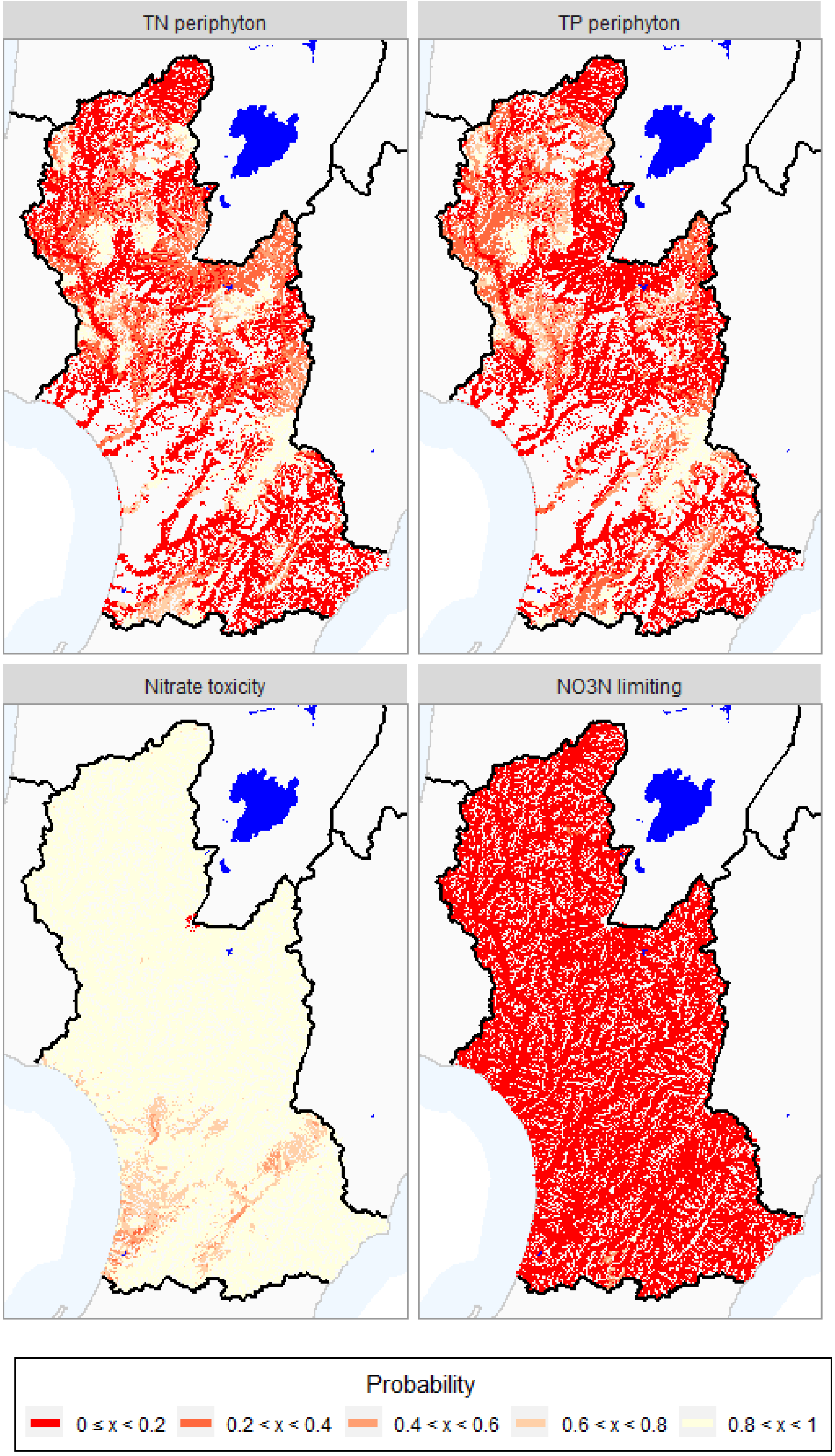

Figure 9. Probability that segments comply with river concentration criteria associated with the TAS based on a 20% UPR. Compliance with TN and TP are shown top left and right and compliance with NO3N concentration criteria associated with the nitrate toxicity TAS is shown lower left. The lower right-hand panel shows the probability that nitrate toxicity TAS is the more limiting than the periphyton TAS. The blank areas on the periphyton maps are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.5.2 Local excess loads

The local excess load is the amount by which the baseline load at a receiving environment would need to be reduced to achieve the TAS for that receiving environment. For the adopted TASs and the 20% UPR, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 39% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 20% of river segments (Figure 17). 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 17. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 46% of segments.

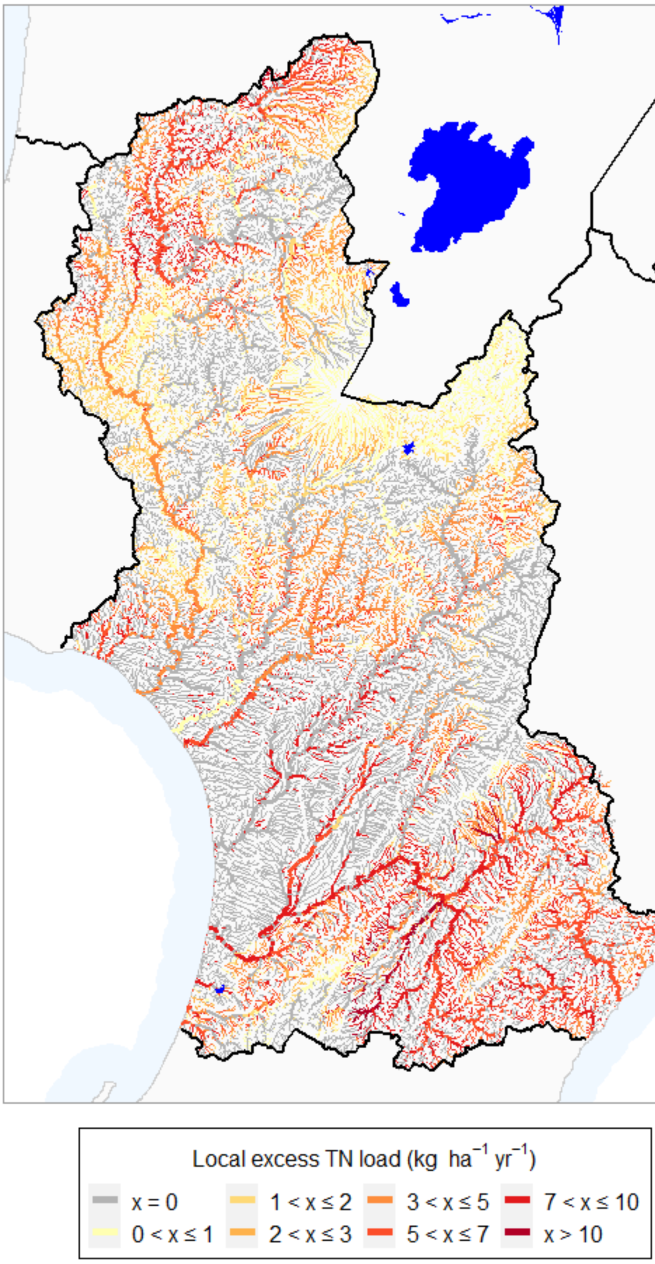

Figure 10. Local excess TN loads for rivers and lakes for the adopted TASs and the 20% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the adopted TASs and the 20% UPR, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 49% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 17% of river segments (Figure 18). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 16% of segments.

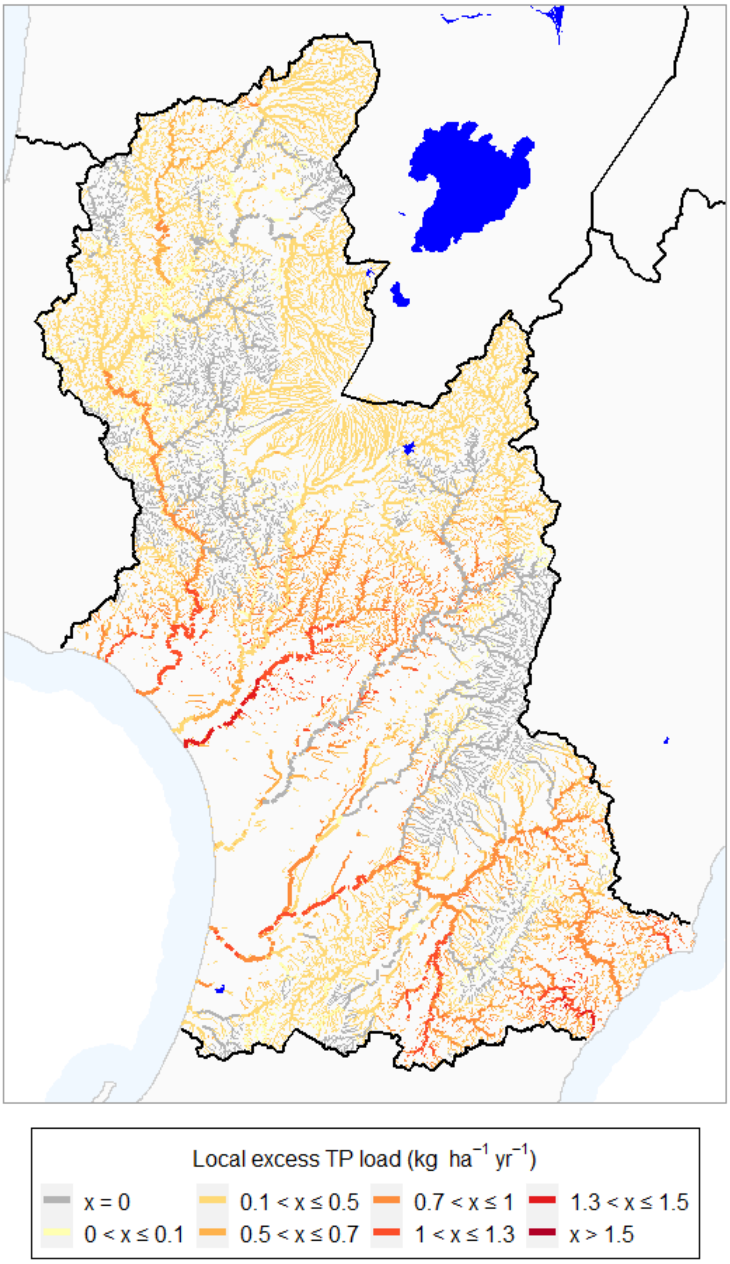

Figure 11. Local excess TP loads for rivers and lakes for the adopted TASs and the 20% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). The blank areas on this map are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.5.3 FMU and regional load reductions required

The load reductions required by the adopted TASs and the 20% UPR 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 11,328 t yr^{-1} and 3,185 t yr^{-1}, which represent 64% and 70% of the baseline loads delivered to the coast, respectively. The uncertainties on the estimated baseline loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of baseline load, are expressed as the 90% confidence intervals in Table 9. The uncertainties indicate, for example that the 90% confidence interval for the baseline regional load of TN extends between 6,493 t yr^{-1} and 16,383 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 51% and 78% (best estimate 64%) and the regional TP load reduction requirement extends between 44% and 89% (best estimate 70%).

For the adopted TASs and the 20% UPR, the best estimates of TN load reductions required were very high (>50%) in the Kai Iwi, Rangitīkei-Turakina, Manawatū, Waiopehu, and Puketoi ki Tai FMUs. The TP load reductions required were higher than 50% in all FMUs except Whangaehu.

Table 9. Baseline load and load reduction required for TN and TP for FMUs and the whole region for the adopted TASs and the 20% UPR. Note that loads are expressed in absolute terms in units of tonnes per year ($t\ yr^{-1}$) and as a proportion of baseline 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**		
	Baseline load ($t\ yr^{-1}$)	**Load reduction required ($t\ yr^{-1}$)**	**Load reduction required (%)**	**Baseline load ($t\ yr^{-1}$)**	**Load reduction required ($t\ yr^{-1}$)**	**Load reduction required (%)**
Kai Iwi	223 (154 - 319)	149 (78 - 249)	65 (47 - 79)	31 (17 - 52)	22 (10 - 46)	72 (43 - 88)
Whanganui	6,039 (3,341 - 10,241)	3,053 (452 - 7,399)	46 (11 - 80)	1,312 (704 - 2,292)	811 (35 - 1,794)	61 (4 - 99)
Whangaehu	1,151 (671 - 1,949)	567 (139 - 1,385)	46 (18 - 72)	254 (119 - 456)	125 (35 - 281)	48 (18 - 80)
Rangitīkei-Turakina	3,314 (2,075 - 4,758)	1,971 (1,047 - 3,031)	58 (44 - 71)	651 (392 - 1,041)	486 (218 - 989)	73 (37 - 117)
Manawatū	5,332 (2,886 - 8,462)	4,548 (1,711 - 7,723)	83 (56 - 96)	730 (331 - 1,264)	622 (214 - 1,124)	84 (49 - 109)
Waiopehu	321 (231 - 407)	241 (141 - 333)	74 (60 - 83)	27 (19 - 37)	16 (8 - 24)	61 (36 - 78)
Puketoi ki Tai	989 (710 - 1,459)	755 (456 - 1,241)	75 (62 - 87)	172 (111 - 263)	131 (75 - 223)	76 (61 - 88)
Whole region	17,442 (12,553 - 23,079)	11,328 (6,493 - 16,383)	64 (51 - 78)	3,185 (2,349 - 4,221)	2,219 (1,349 - 3,311)	70 (44 - 89)

3.5.4 WMSZ load reductions required

For the adopted TASs and the 20% UPR the point- and critical-WMSZ load reductions required differ from the local excess loads (Figure 10 and Figure 11). The point-WMSZ load reduction required is the point excess load at the downstream end of the WMSZ. The critical-WMSZ load reduction is the greater of the point-WMSZ load reduction required and the local excess load at the next critical point downstream of the WMSZ. Both types of WMSZ load reduction required are expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the baseline load. A complete tabulation of WMSZ load reduction required for TN and TP for the adopted TASs and the 25% UPR is provided in Appendix B.

The point- and critical-WMSZ load reductions required for TN under the adopted TASs and the 25% UPR are shown on Figure 12 and Figure 13. There were 71 WMSZs with critical-WMSZ load reductions required for TN of greater than 5 kg ha^{-1} yr^{-1} and these collectively occupied 46% of the land area of the region. The majority of these WMSZs were in in the Manawatū (49) and the Waiopehu (6) FMUs. There were two WMSZs with critical-WMSZ load reductions required for TN of zero kg ha^{-1} yr^{-1} (West_5, West_6) and these occupied 1% of the region (Figure 12).

When critical-WMSZ load reductions required for TN were expressed as a proportion of baseline loads, 91 WMSZs required reductions of greater than 50% and these occupied 66% of the region (Figure 13). The comparison of WMSZ load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of baseline 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 91 WMSZs with critical-WMSZ load reductions required for TP of greater than 0.5 kg ha^{-1} yr^{-1} and these collectively occupied 79% of the region (Figure 14). The majority of these WMSZs were in the Manawatū (46) and the Rangitīkei-Turakina FMUs (14). There were three WMSZs with critical-WMSZ load reductions required for TP of zero kg ha^{-1} yr^{-1} (West_5, West_6, West_8) and these occupied 1.5% of the region (Figure 14).

When critical-WMSZ load reductions required for TP were expressed as a proportion of baseline loads, 113 WMSZs had reductions required of greater than 50% and these occupied 88% of the region (Figure 15). 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.

It is noted that load reductions of over 100% occurred for two WMSZs (Mana_11e, Mana_12e) 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 baseline load at the bottom of the catchment. Reductions of over 100% are not an error. Nutrient loads, in particular 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.

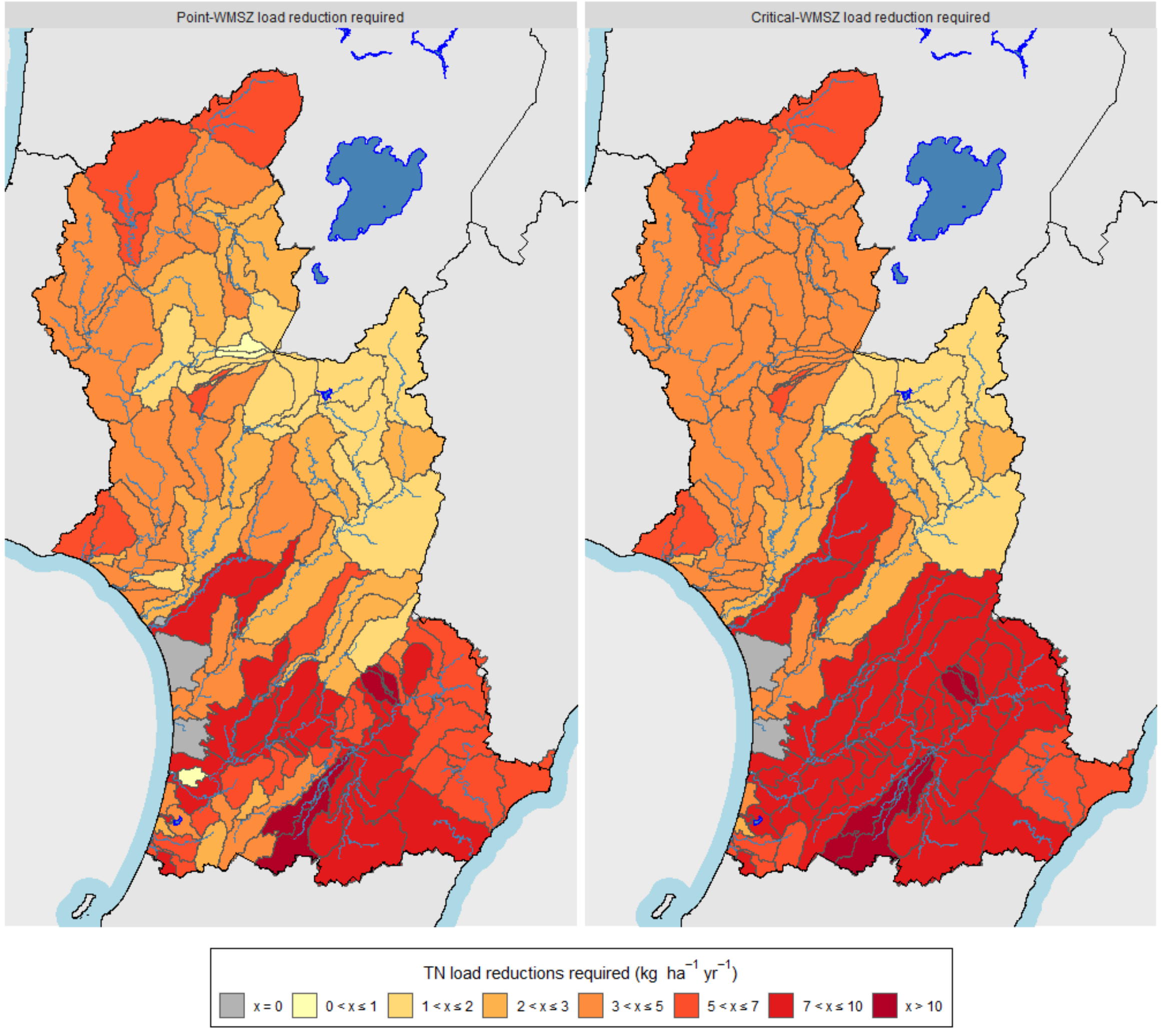

Figure 12. The TN WMSZ load reductions required, expressed as yields, for the adopted TASs and the 20% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

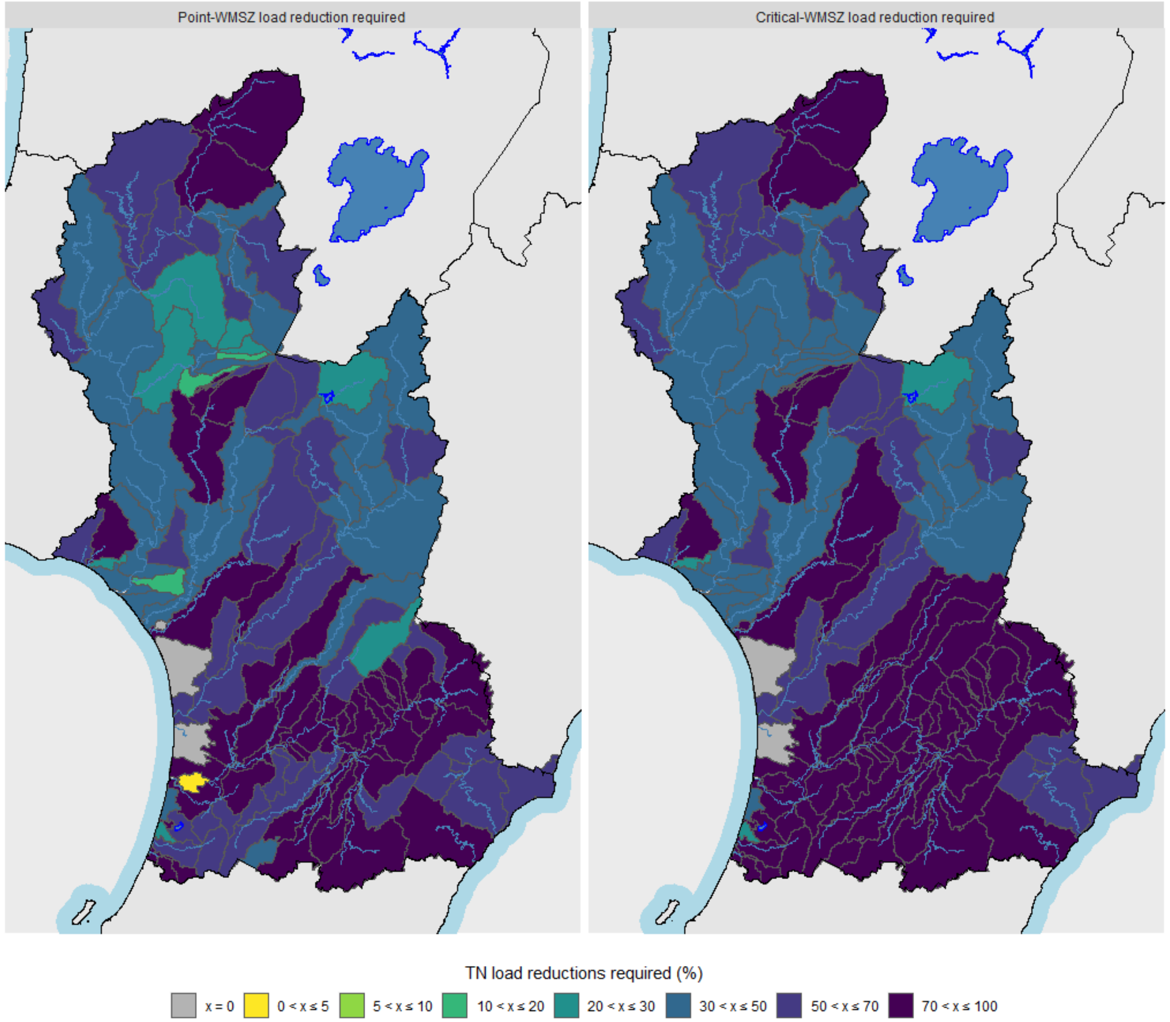

Figure 13. The TN WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 20% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

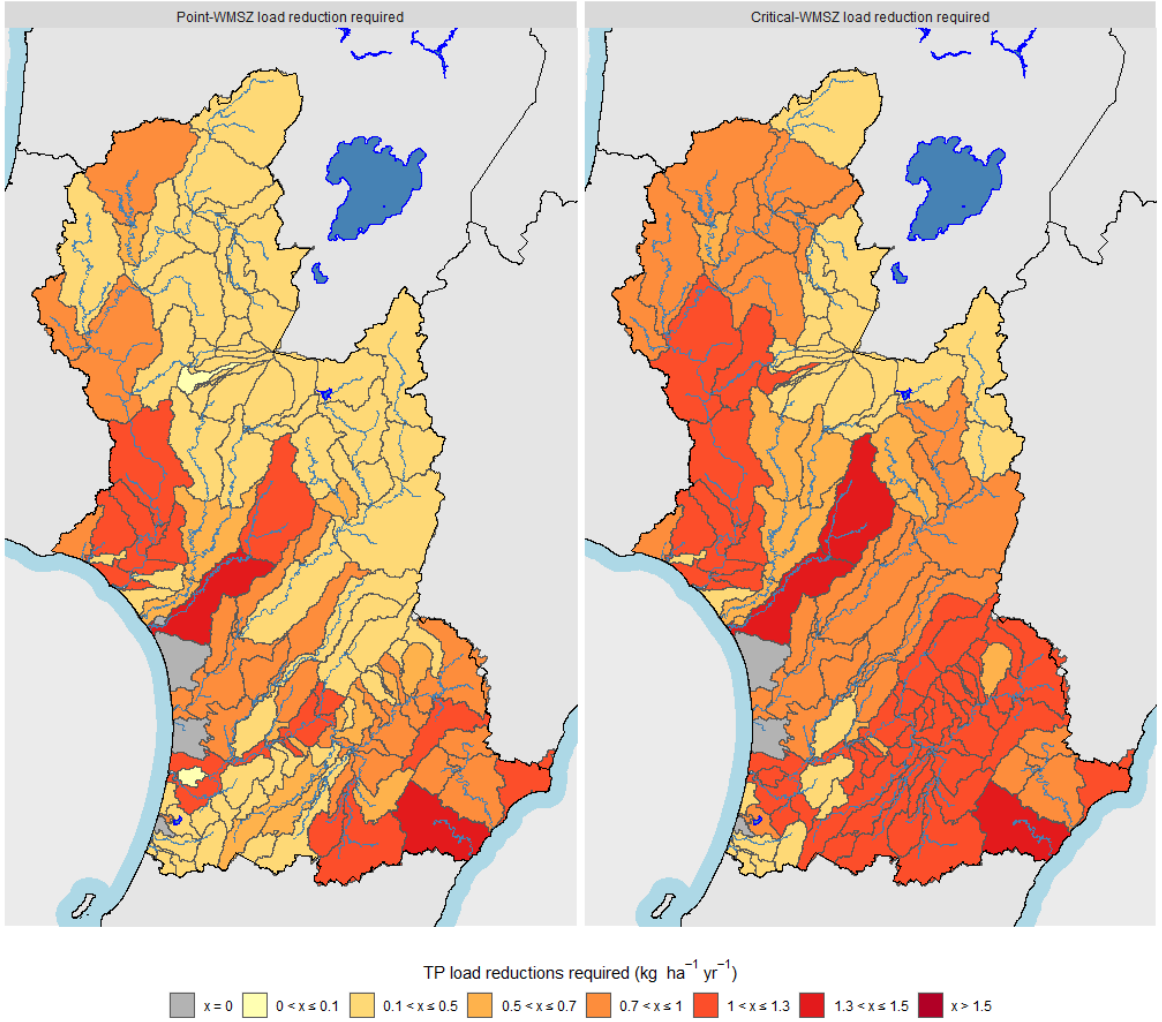

Figure 14. The TP WMSZ load reductions, expressed as yields, for the adopted TASs and the 20% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

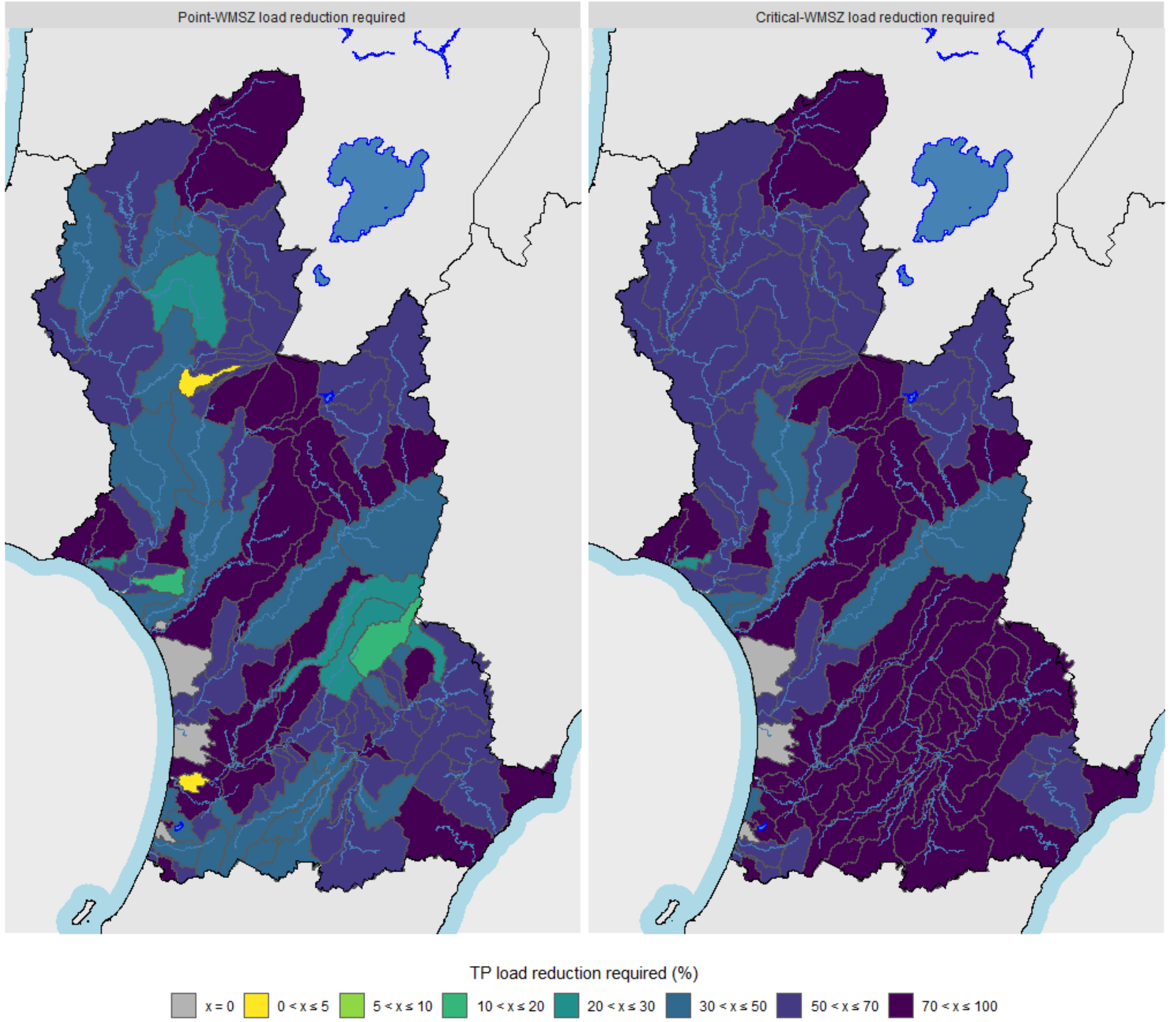

Figure 15. The TP WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 20% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

3.6 Adopted targets and 25% under-protection risk

3.6.1 Compliance

For the adopted TAS and the 25% UPR, baseline river concentrations of TN and TP had a greater than 50% probability of exceeding the criteria associated with the TAS (i.e., were non-compliant) for 40% and 43% of segments in the region, respectively (Figure 16). Baseline river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the nitrate toxicity TAS for 0.6% of segments. However, the probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% at only 0.3% of river segments (Figure 16).

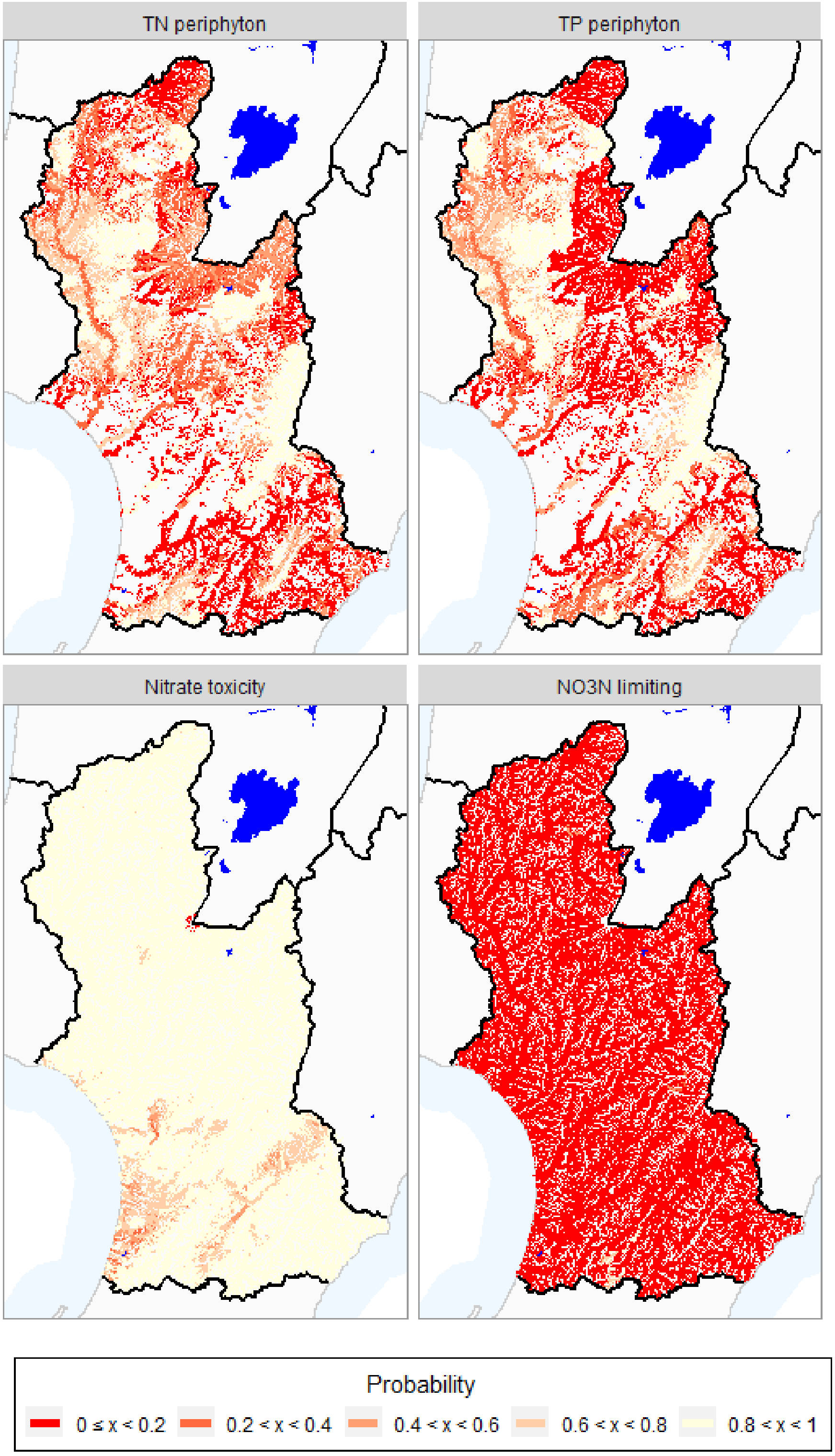

Figure 16. Probability that segments comply with river concentration criteria associated with the TAS based on a 25% UPR. Compliance with TN and TP are shown top left and right and compliance with NO3N concentration criteria associated with the nitrate toxicity TAS is shown lower left. The lower right-hand panel shows the probability that nitrate toxicity TAS is the more limiting than the periphyton TAS. The blank areas on the periphyton maps are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.6.2 Local excess loads

The local excess load is the amount by which the baseline load at a receiving environment would need to be reduced to achieve the TAS for that receiving environment. For the adopted TASs and the 25% UPR, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 25% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 11% of river segments (Figure 17). 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 17. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 61% of segments.

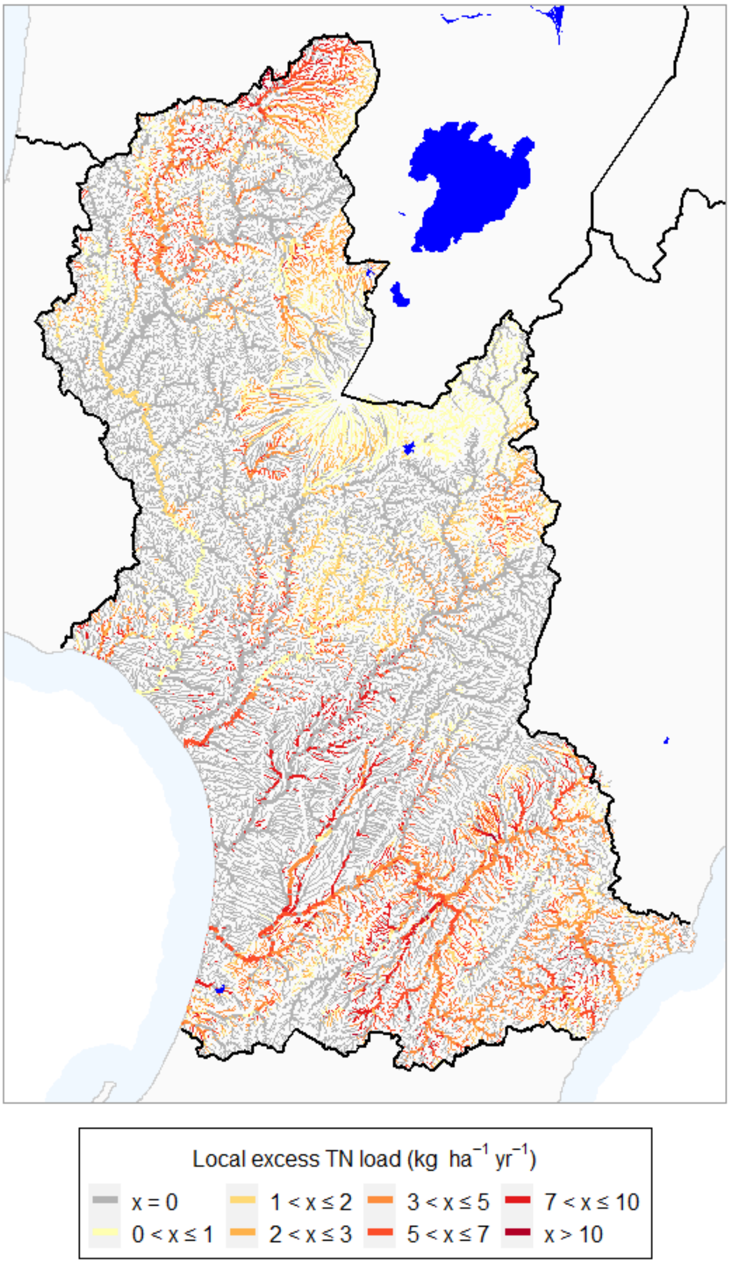

Figure 17. Local excess TN loads for rivers and lakes for the adopted TASs and the 25% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the adopted TASs and the 25% UPR, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 37% of river segments and exceeded 0.5 kg ha^{-1} yr^{-1} for 11% of river segments (Figure 18). Note that these breakpoints are nominal and have no special significance (i.e., are not guidelines or standards). Local excess TP loads were zero for 29% of segments.

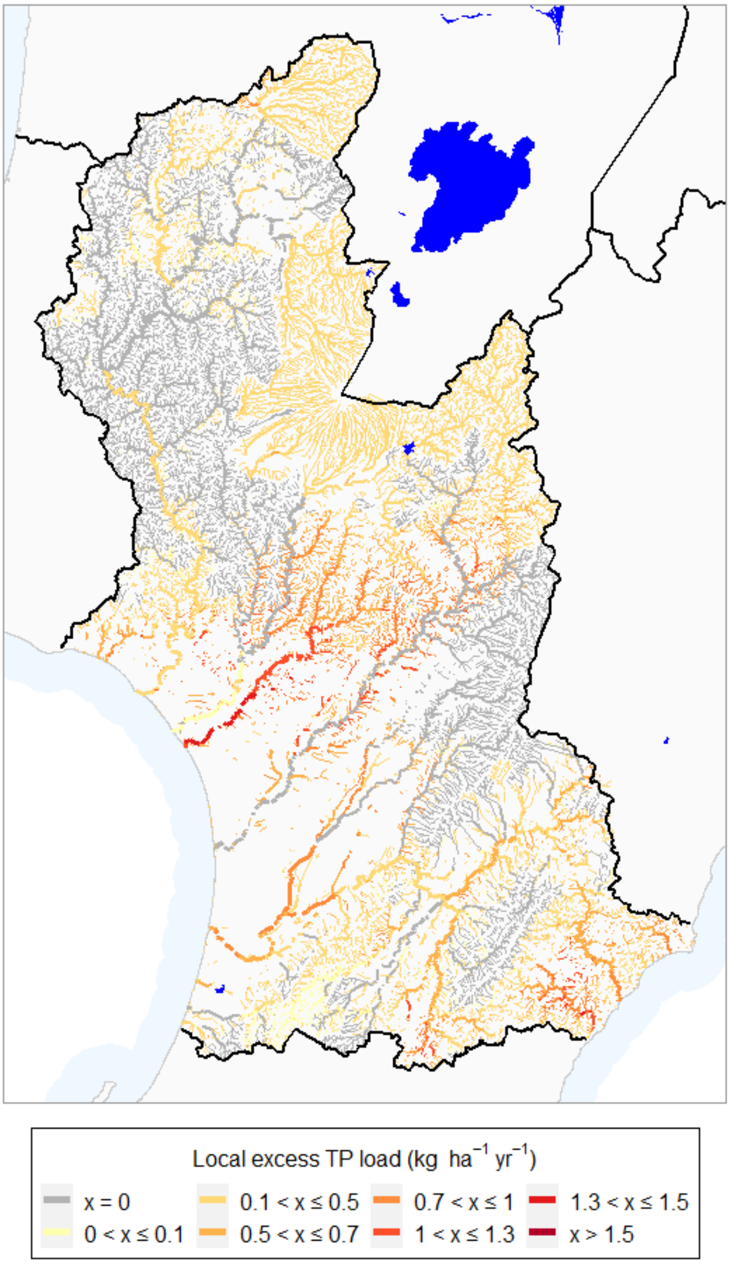

Figure 18. Local excess TP loads for rivers and lakes for the adopted TASs and the 25% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). The blank areas on this map are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.6.3 FMU and regional load reductions required

The load reductions required by the adopted TASs and the 25% UPR for each FMU and for the whole region are shown in Table 10. For the whole region, the TN and TP load reductions required were estimated to be 8,556 t yr^{-1} and 3,252 t yr^{-1}, which represent 48% and 49% of the baseline loads delivered to the coast, respectively. The uncertainties on the estimated baseline loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of baseline load, are expressed as the 90% confidence intervals in Table 10. The uncertainties indicate, for example that the 90% confidence interval for the baseline regional load of TN extends between 4,851 t yr^{-1} and 13,296 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 35% and 63% (best estimate 48%) and the regional TP load reduction requirement extends between 31% and 70% (best estimate 49%).

For the adopted TASs and the 25% UPR, the best estimates of TN load reductions required were very high (>50%) in the Kai Iwi, Rangitīkei-Turakina, Manawatū, Waiopehu, and Puketoi ki Tai FMUs. The TP load reductions required were ≥60% in all FMUs except the Whanganui and Whangaehu FMU.

Table 10. Baseline load and load reduction required for TN and TP for FMUs and the whole region for the adopted TASs and the 25% UPR. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of baseline 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**		
	Baseline load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**	**Baseline load (t yr^{-1})**	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Kai Iwi	210 (135 - 286)	116 (53 - 189)	53 (31 - 69)	29 (16 - 46)	18 (8 - 33)	60 (39 - 81)
Whanganui	6,228 (3,737 - 9,573)	1,975 (142 - 5,764)	28 (3 - 65)	1,361 (665 - 2,430)	507 (15 - 1,376)	35 (2 - 81)
Whangaehu	1,212 (666 - 2,007)	452 (109 - 1,149)	35 (12 - 60)	270 (116 - 486)	92 (31 - 214)	33 (22 - 64)
Rangitīkei-Turakina	3,294 (2,169 - 4,822)	1,719 (828 - 2,731)	51 (34 - 68)	675 (406 - 1,028)	387 (168 - 751)	57 (36 - 100)
Manawatū	5,119 (3,094 - 8,188)	3,473 (1,283 - 6,729)	65 (30 - 86)	715 (368 - 1,288)	470 (94 - 983)	64 (19 - 95)
Waiopehu	313 (222 - 424)	212 (117 - 315)	66 (48 - 79)	26 (16 - 35)	14 (7 - 22)	54 (33 - 71)
Puketoi ki Tai	951 (693 - 1,294)	575 (317 - 930)	59 (40 - 77)	167 (110 - 253)	112 (58 - 180)	66 (44 - 83)
Whole region	17,400 (13,442 - 22,281)	8,556 (4,851 - 13,296)	48 (35 - 63)	3,252 (2,296 - 4,578)	1,605 (895 - 2,727)	49 (31 - 70)

3.6.4 WMSZ load reductions required

For the adopted TASs and the 25% UPR the point- and critical-WMSZ load reductions required differ from the local excess loads (Figure 17 and Figure 18). The point-WMSZ load reduction required is the point excess load at the downstream end of the WMSZ. The critical-WMSZ load reduction is the greater of the point-WMSZ load reduction required and the local excess load at the next critical point downstream of the WMSZ. Both types of WMSZ load reduction required are expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the baseline load. A complete tabulation of WMSZ load reduction required for TN and TP for the adopted TASs and the 20% UPR is provided in Appendix B.

The point- and critical-WMSZ load reductions required load reductions required for TN under the adopted TASs and the 25% UPR are shown on Figure 19 and Figure 20. There were 63 WMSZs with critical-WMSZ load reductions required for TN of greater than 5 kg ha^{-1} yr^{-1} and these collectively occupied 38% of the land area of the region. The majority of these WMSZs were in in the Manawatū (49) and the Waiopehu (6) FMUs. There were three WMSZs with critical-WMSZ load reductions required for TN of zero kg ha^{-1} yr^{-1} (Rang_2d, West_5, West_6) and these occupied 3% of the region (Figure 19).

When critical-WMSZ load reductions required for TN were expressed as a proportion of baseline loads, 73 WMSZs required reductions of greater than 50% and these occupied 47% of the region (Figure 20). The comparison of WMSZ load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of baseline 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 69 WMSZs with critical-WMSZ load reductions required for TP of greater than 0.5 kg ha^{-1} yr^{-1} and these collectively occupied 50% of the region (Figure 21). The majority of these WMSZs were in the Manawatū (44) and the Rangitīkei-Turakina FMUs (10). There were three WMSZs with critical-WMSZ load reductions required for TP of zero kg ha^{-1} yr^{-1} (West_5, West_6, West_8) and these occupied 1.5% of the region (Figure 21).

When critical-WMSZ load reductions required for TP were expressed as a proportion of baseline loads, 93 WMSZs had reductions required of greater than 50% and these occupied 63% of the region (Figure 22). 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.

It is noted that load reductions of over 100% occurred for two WMSZs (Mana_11e, Mana_12e) 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 baseline 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.

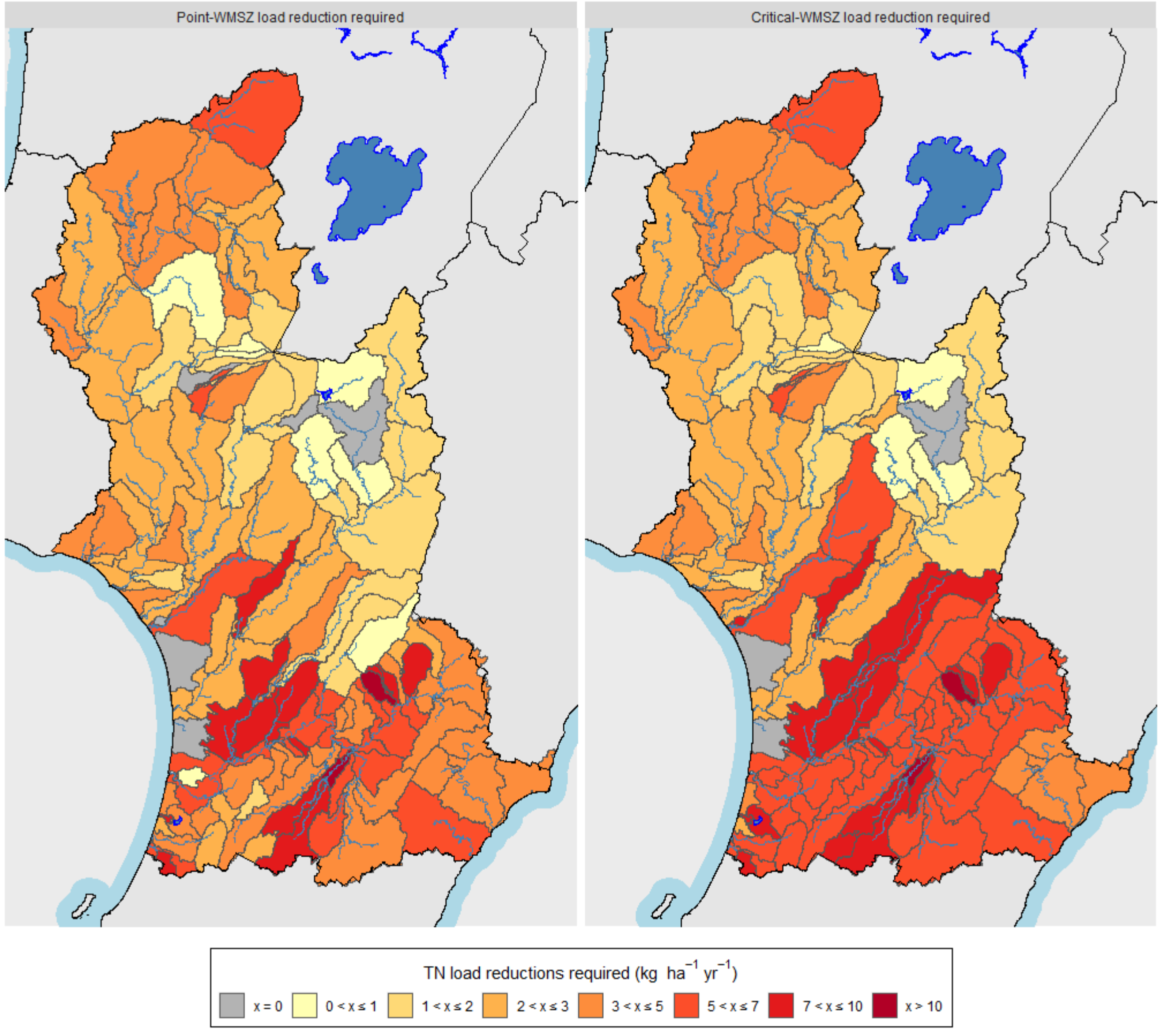

Figure 19. The TN WMSZ load reductions required, expressed as yields, for the adopted TASs and the 25% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

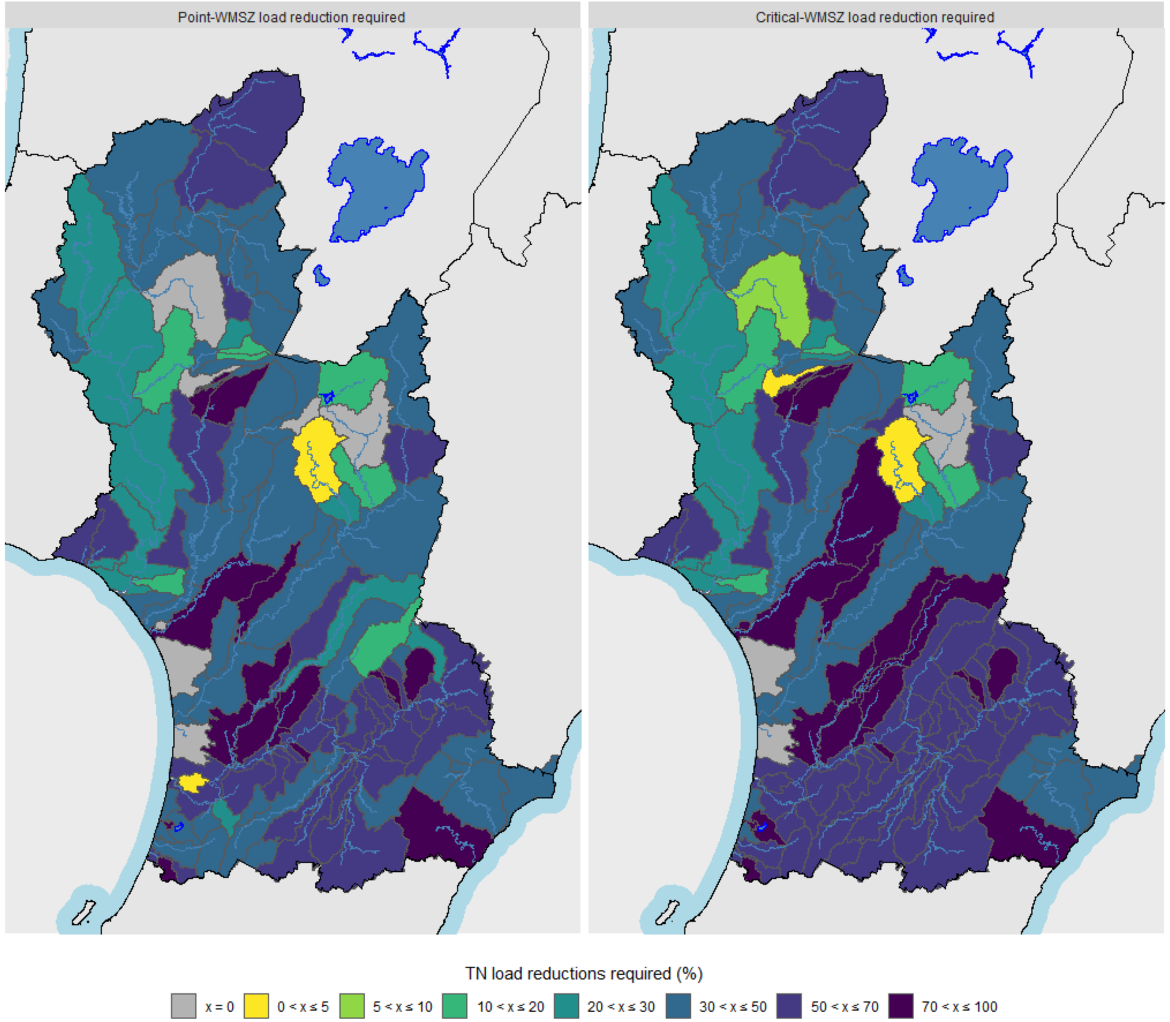

Figure 20. The TN WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 25% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

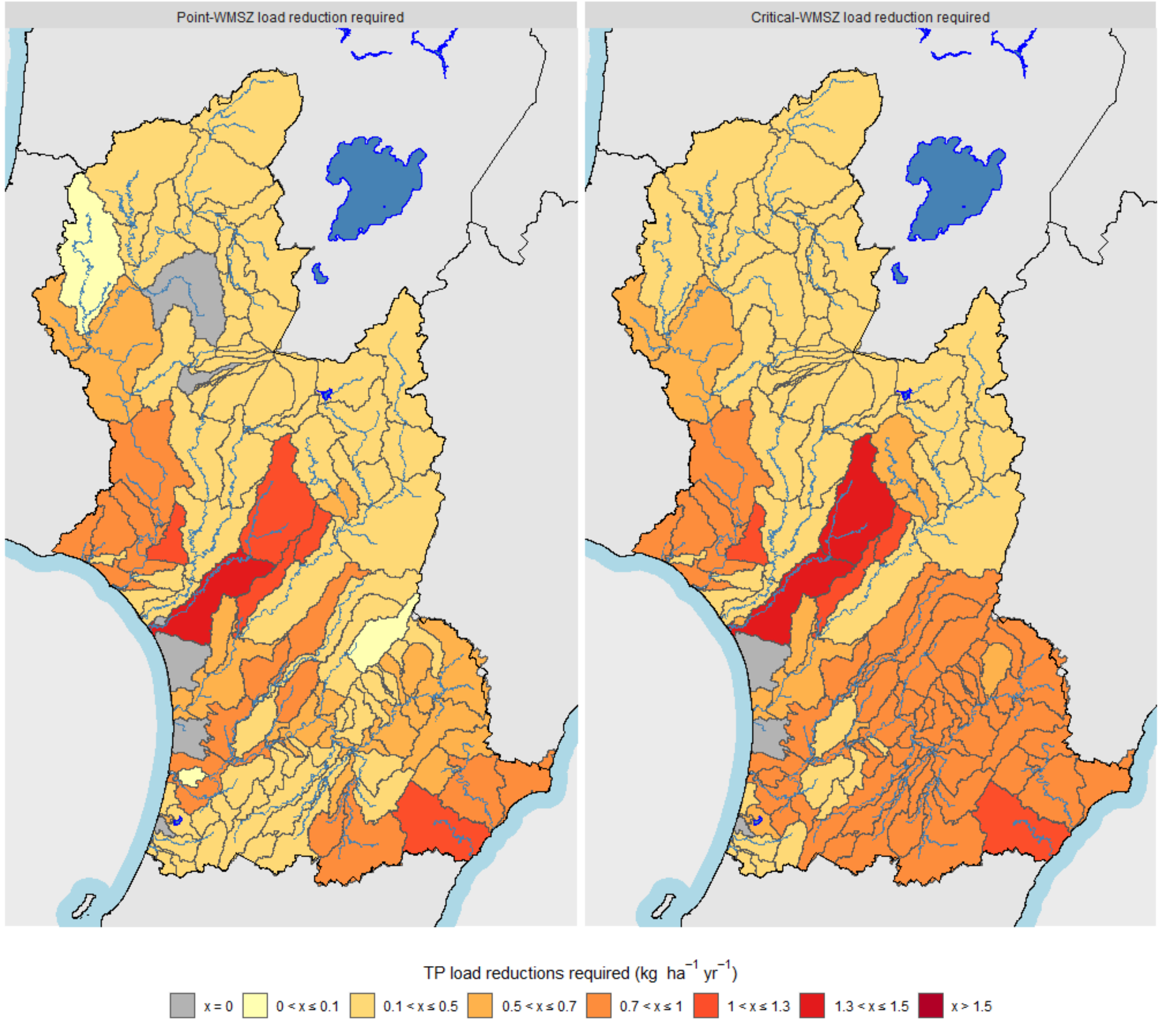

Figure 21. The TP WMSZ load reductions, expressed as yields, for the adopted TASs and the 25% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

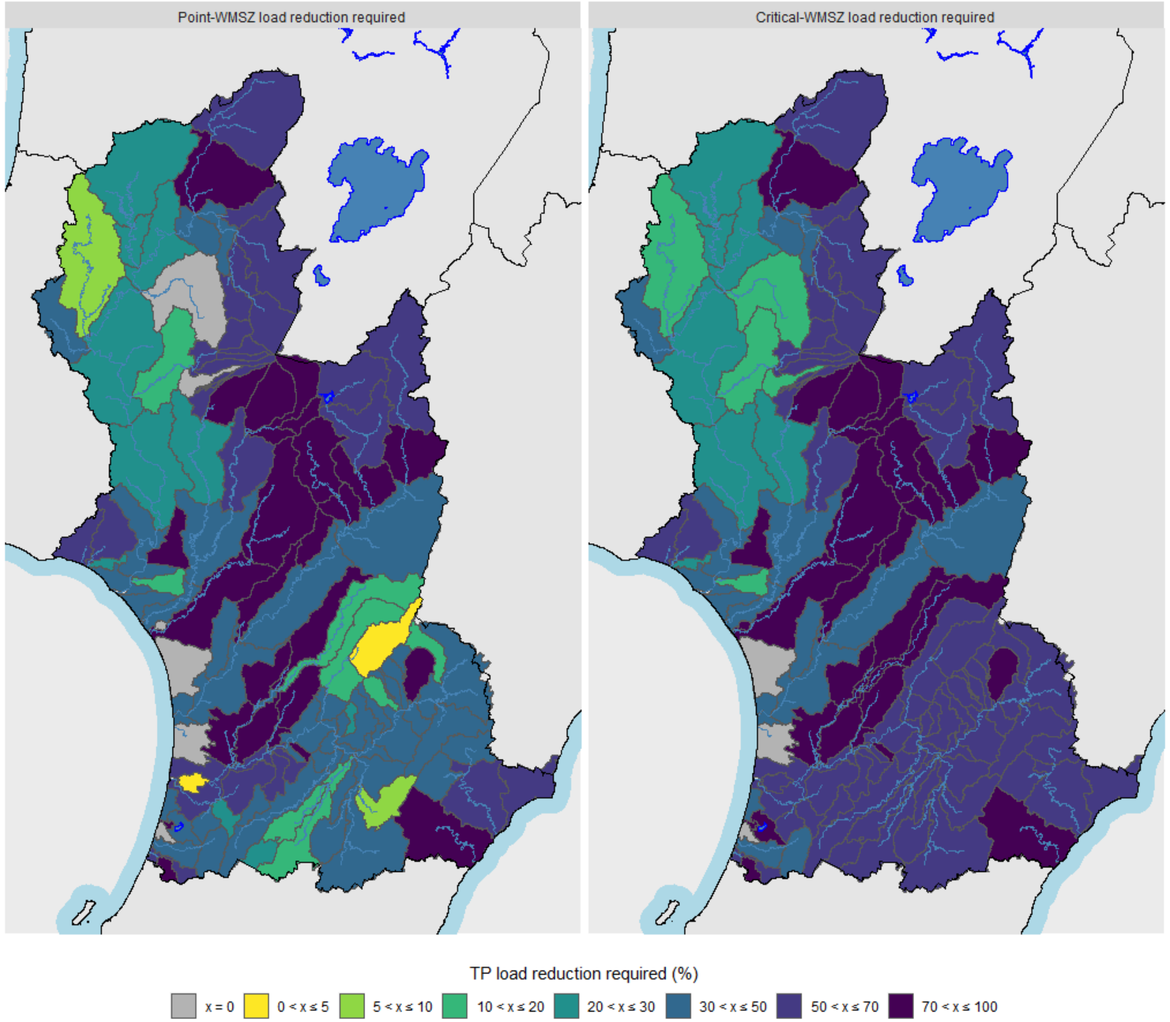

Figure 22. The TP WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 25% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

3.7 Adopted targets and 30% under-protection risk

3.7.1 Compliance

For the adopted TAS and the 30% UPR, baseline river concentrations of TN and TP had a greater than 50% probability of exceeding the criteria associated with the TAS (i.e., were non-compliant) for 21% and 34% of segments in the region, respectively (Figure 23). Baseline river concentrations of NO3N had a greater than 50% probability of exceeding the criteria associated with the nitrate toxicity TAS for 1.3% of segments. However, the probability that nitrate toxicity is a more limiting TAS than periphyton exceeded 50% at only 0.3% of river segments (Figure 23).

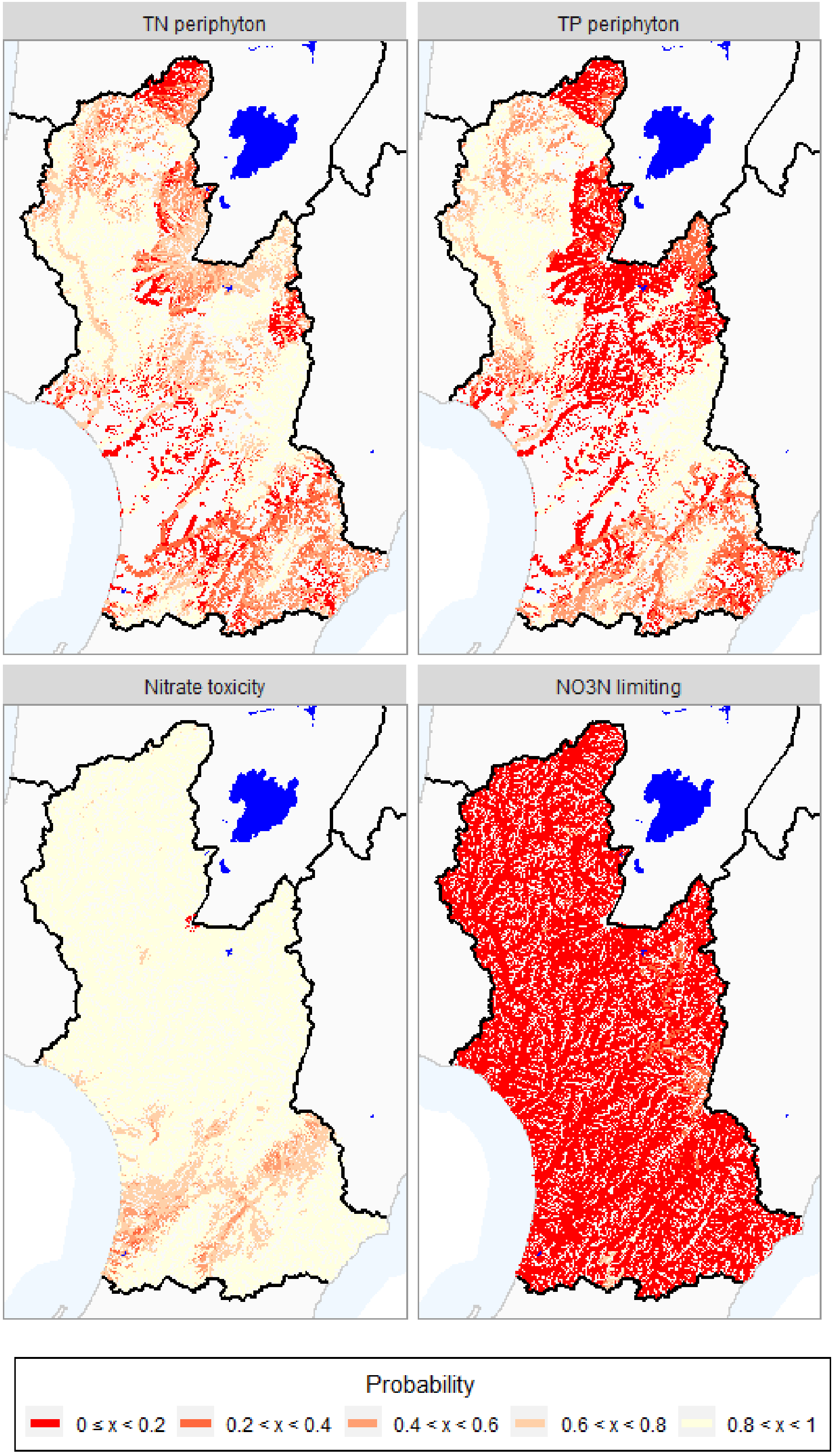

Figure 23. Probability that segments comply with river concentration criteria associated with the TAS based on a 30% UPR. Compliance with TN and TP are shown top left and right and compliance with NO3N concentration criteria associated with the nitrate toxicity TAS is shown lower left. The lower right-hand panel shows the probability that nitrate toxicity TAS is the more limiting than the periphyton TAS. The blank areas on the periphyton maps are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.7.2 Local excess loads

The local excess load is the amount by which the baseline load at a receiving environment would need to be reduced to achieve the TAS for that receiving environment. For the adopted TASs and the 30% UPR, local excess TN loads for rivers exceeded 2 kg ha^{-1} yr^{-1} for 15% of river segments and exceeded 5 kg ha^{-1} yr^{-1} for 6% of river segments (Figure 24). 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 24. These values have no special significance (i.e., are not guidelines or standards). Local excess TN loads were zero for 78% of segments.

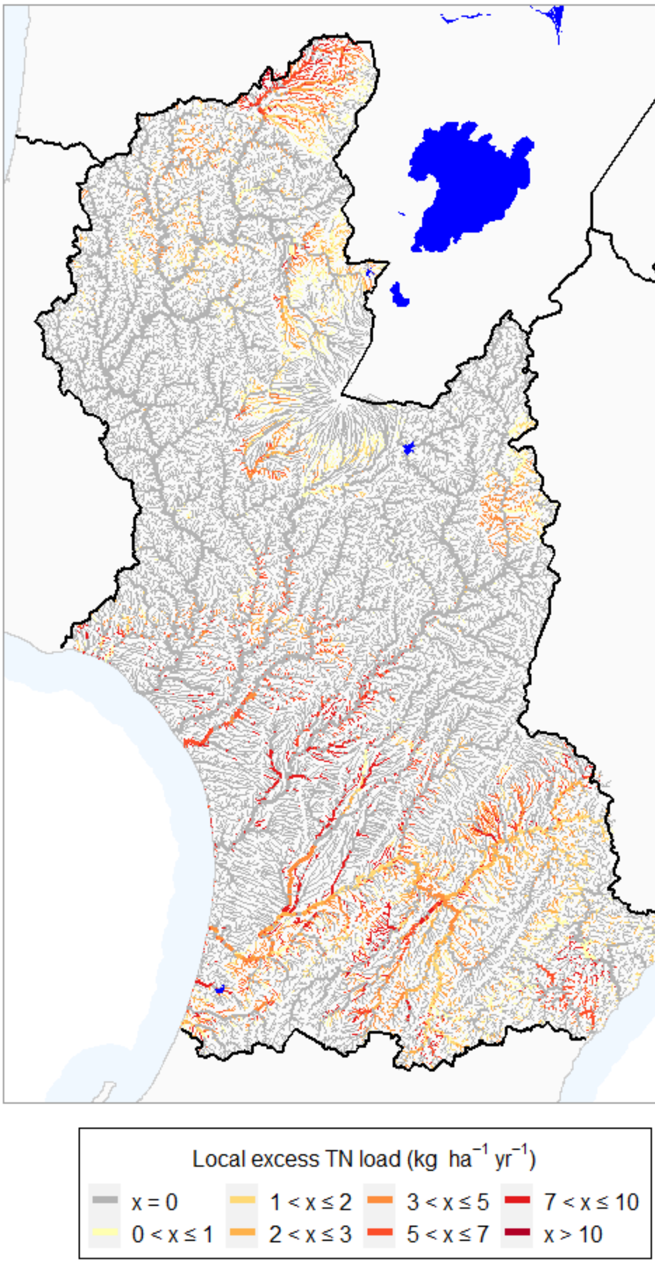

Figure 24. Local excess TN loads for rivers and lakes for the adopted TASs and the 30% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards).

For the adopted TASs and the 30% UPR, local excess TP loads for rivers exceeded 0.1 kg ha^{-1} yr^{-1} for 26% of river segments and exceeded 0.2 kg ha^{-1} yr^{-1} for 8% of river segments (Figure 25). 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 39% of segments.

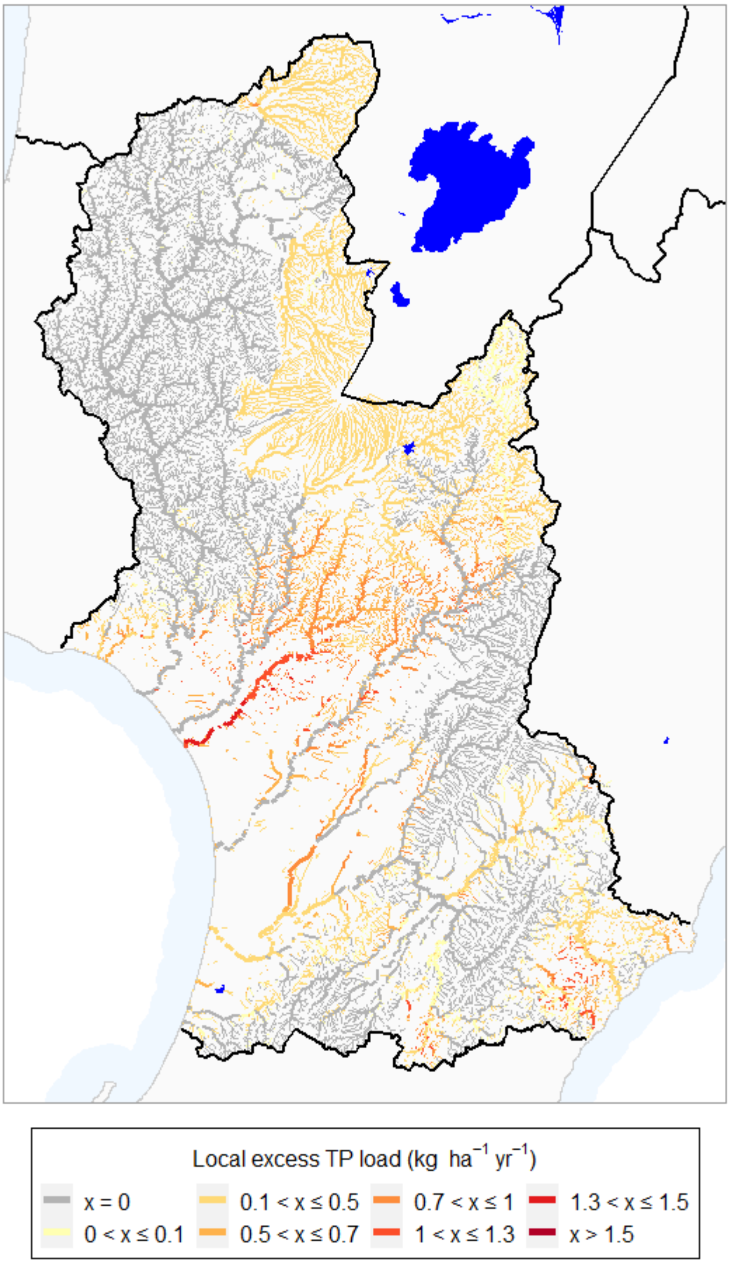

Figure 25. Local excess TP loads for rivers and lakes for the adopted TASs and the 30% UPR. Note that the breakpoints for the local excess loads in the map legend are nominal and have no special significance (i.e., are not guidelines or standards). The blank areas on this map are river segments that were estimated to have fine bed substrates that are assumed to not support appreciable periphyton biomass.

3.7.3 FMU and regional load reductions required

The load reductions required by the adopted TASs and the 30% UPR for each FMU and for the whole region are shown in Table 10. For the whole region, the TN and TP load reductions required were estimated to be 6,502 t yr^{-1} and 1,090 t yr^{-1}, which represent 36% and 33% of the baseline loads delivered to the coast, respectively. The uncertainties on the estimated baseline loads of TN and TP and the respective load reductions, in terms of both absolute yields and percentage of baseline load, are expressed as the 90% confidence intervals in Table 10. The uncertainties indicate, for example that the 90% confidence interval for the baseline regional load of TN extends between 3,544 t yr^{-1} and 11,397 t yr^{-1}. The 90% confidence interval for the regional TN load reduction requirement extends between 22% and 53% (best estimate 36%) and the regional TP load reduction requirement extends between 20% and 53% (best estimate 33%).

The best estimates of TN load reductions required were very high (>50%) in the Waiopehu FMU. The TP load reductions required were higher than 50% in the Kai Iwi and Puketoi ki Tai FMUs.

Table 11. Baseline load and load reduction required for TN and TP for FMUs and the whole region for the adopted TASs and the 30% UPR. Note that loads are expressed in absolute terms in units of tonnes per year (t yr^{-1}) and as a proportion of baseline 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**		
	Baseline load (t yr^{-1})	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**	**Baseline load (t yr^{-1})**	**Load reduction required (t yr^{-1})**	**Load reduction required (%)**
Kai Iwi	216 (139 - 303)	103 (39 - 180)	46 (24 - 65)	31 (16 - 51)	18 (9 - 35)	57 (40 - 68)
Whanganui	6,281 (3,173 - 9,897)	1,076 (117 - 2,918)	15 (3 - 34)	1,301 (582 - 2,578)	239 (14 - 880)	17 (1 - 62)
Whangaehu	1,149 (644 - 2,029)	310 (51 - 731)	24 (5 - 45)	268 (129 - 526)	72 (16 - 158)	26 (12 - 47)
Rangitīkei-Turakina	3,217 (2,199 - 4,760)	1,379 (653 - 2,596)	42 (27 - 56)	663 (365 - 1,007)	306 (154 - 532)	46 (31 - 68)
Manawatū	5,400 (2,998 - 9,781)	2,962 (660 - 7,380)	49 (21 - 82)	747 (384 - 1,462)	345 (59 - 1,009)	44 (11 - 89)
Waiopehu	330 (235 - 464)	202 (104 - 324)	60 (42 - 76)	27 (18 - 41)	13 (6 - 23)	48 (27 - 69)
Puketoi ki Tai	1,011 (735 - 1,342)	448 (195 - 857)	43 (22 - 65)	181 (112 - 270)	93 (45 - 167)	52 (33 - 73)
Whole region	17,676 (13,326 - 22,649)	6,502 (3,544 - 11,397)	36 (22 - 53)	3,229 (2,318 - 4,150)	1,090 (566 - 2,009)	33 (20 - 53)

3.7.4 WMSZ load reductions required

For the adopted TASs and the 30% UPR the point- and critical-WMSZ load reductions required differ from the local excess loads (Figure 24 and Figure 25). The point-WMSZ load reduction required is the point excess load at the downstream end of the WMSZ. The critical-WMSZ load reduction is the greater of the point-WMSZ load reduction required and the local excess load at the next critical point downstream of the WMSZ. Both types of WMSZ load reduction required are expressed below in absolute terms (i.e., kg ha^{-1} yr^{-1}) and as a percentage of the baseline load. A complete tabulation of WMSZ load reduction required for TN and TP for the adopted TASs and the 30% UPR is provided in Appendix B.

The point- and critical-WMSZ load reductions required load reductions required for TN under the adopted TASs and the 25% UPR are shown on Figure 26 and Figure 27. There were 30 WMSZs with critical-WMSZ load reductions required for TN of greater than 5 kg ha^{-1} yr^{-1} and these collectively occupied 18% of the land area of the region. The majority of these WMSZs were in in the Manawatū (19) and the Waiopehu (6) FMUs. There were 10 WMSZs with critical-WMSZ load reductions required for TN of zero kg ha^{-1} yr^{-1} and these occupied 19% of the region (Figure 26).

When critical-WMSZ load reductions required for TN were expressed as a proportion of baseline loads, 29 WMSZs required reductions of greater than 50% and these occupied 19% of the region (Figure 27). The comparison of WMSZ load reductions expressed as yields (kg ha^{-1} yr^{-1}) with those expressed as proportion of baseline 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 25 WMSZs with critical-WMSZ load reductions required for TP of greater than 0.5 kg ha^{-1} yr^{-1} and these collectively occupied 22% of the region (Figure 28). The majority of these WMSZs were in the Manawatū (11) and the Rangitīkei-Turakina FMUs (7). There were eight WMSZs with critical-WMSZ load reductions required for TP of zero kg ha^{-1} yr^{-1} and these occupied 10% of the region (Figure 28).

When critical-WMSZ load reductions required for TP were expressed as a proportion of baseline loads, 42 WMSZs had reductions required of greater than 50% and these occupied 34% of the region (Figure 29). 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.

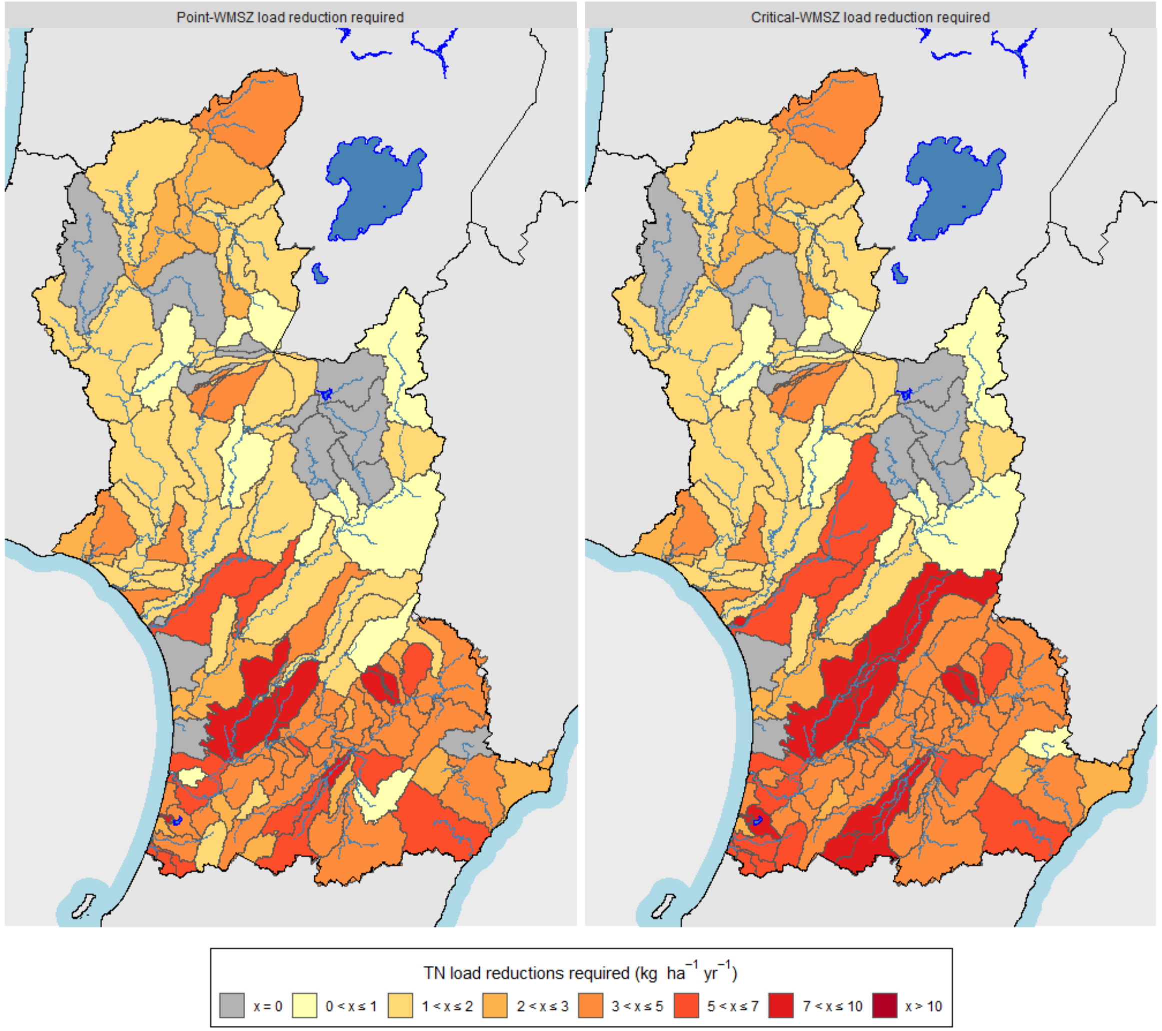

Figure 26. The TN WMSZ load reductions required, expressed as yields, for the adopted TASs and the 30% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

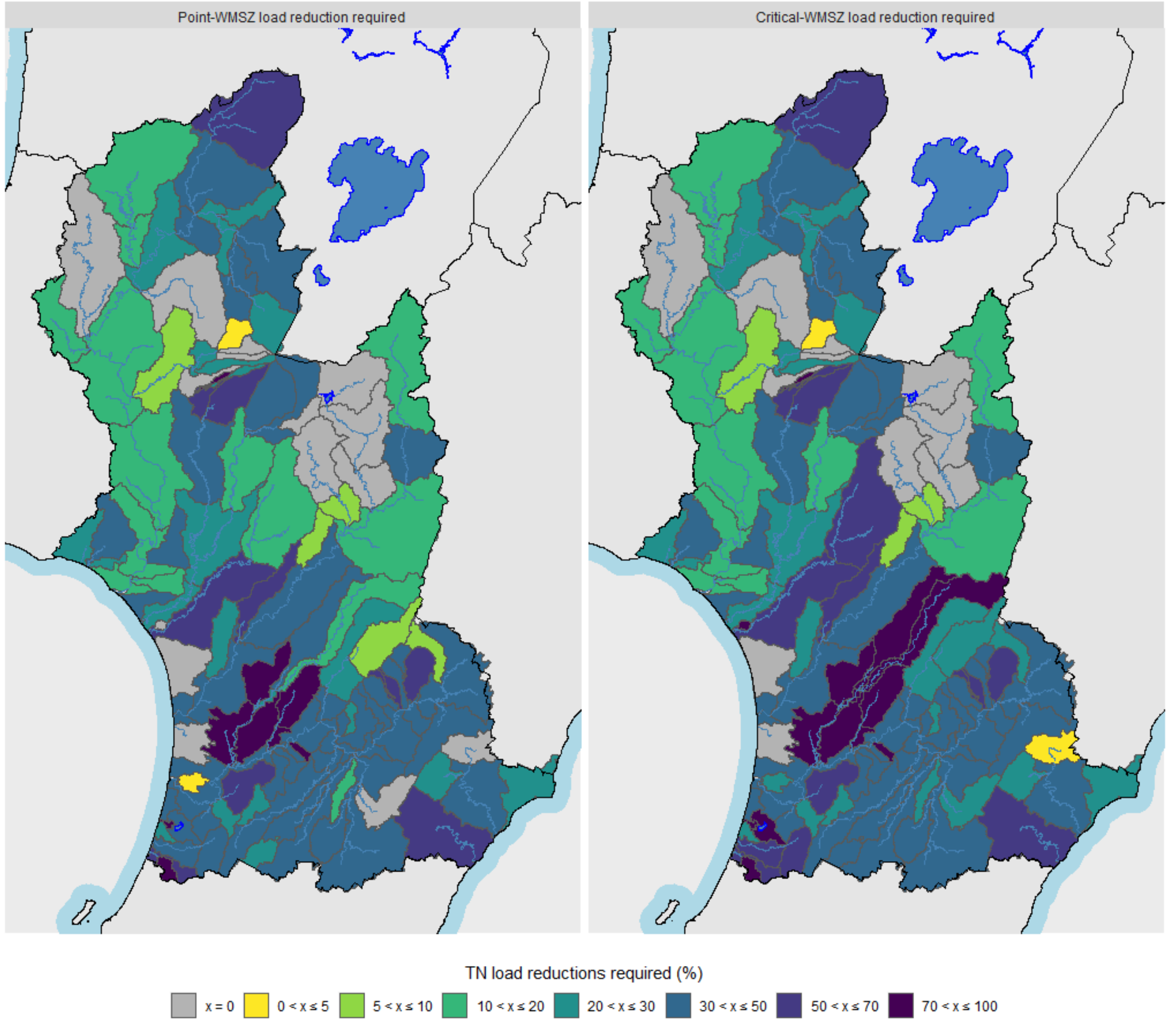

Figure 27. The TN WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 30% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

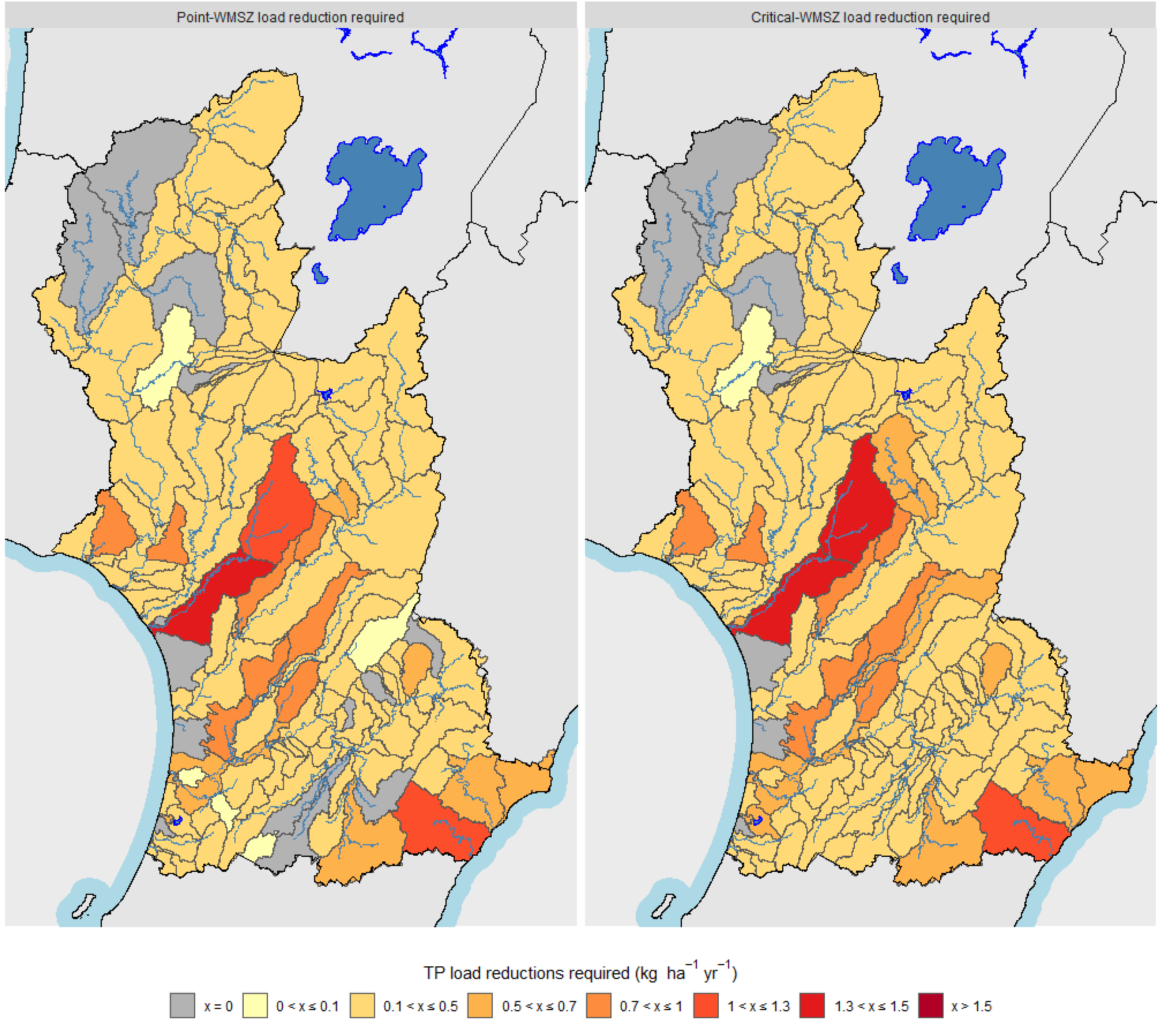

Figure 28. The TP WMSZ load reductions, expressed as yields, for the adopted TASs and the 30% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

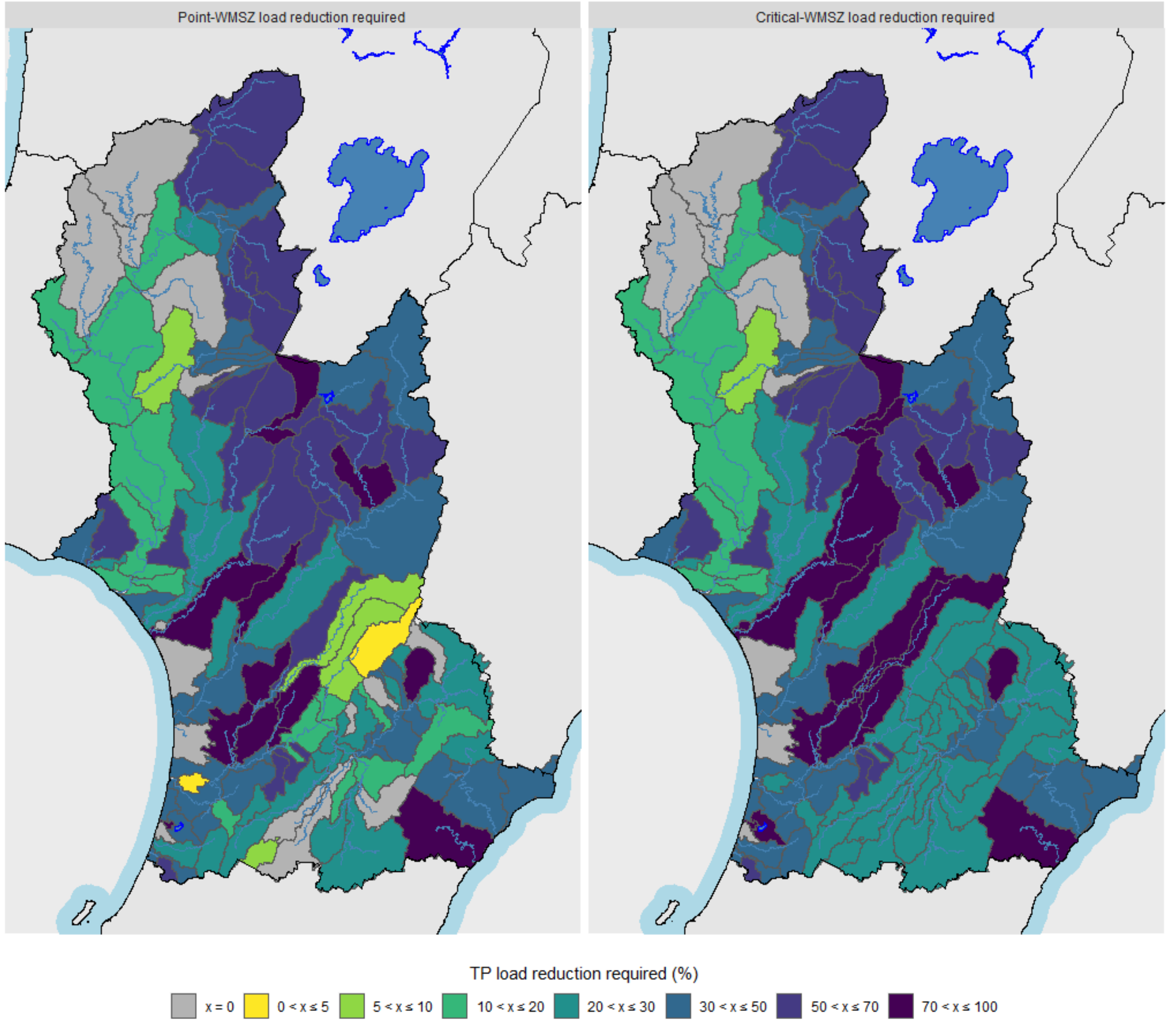

Figure 29. The TP WMSZ load reductions, expressed as proportion of the baseline load (%), for the adopted TASs and the 30% UPR. The WMSZ colours indicate the point-WMSZ load reductions required (left) and critical-WMSZ load reductions required (right) to allow all TASs to be achieved upstream and both upstream and downstream of the WMSZ, respectively.

4 Comparison between options

Comparisons between critical-WMSZ load reductions required for the three UPR options are shown in Figure 30 to Figure 33. The figures indicate that the critical-WMSZ load reductions required generally decrease as the UPR increases. The figures also indicate that there are blocks of WMSZs with the same critical-WMSZ load reduction required, for example many of the Manawatū WMZs have the same load reduction for a given UPR. This occurs if WMSZs are located upstream of the same critical point. In this case, the critical catchment load reduction required at the critical point determines the critical-WMSZ load reduction required for all upstream WMSZs.

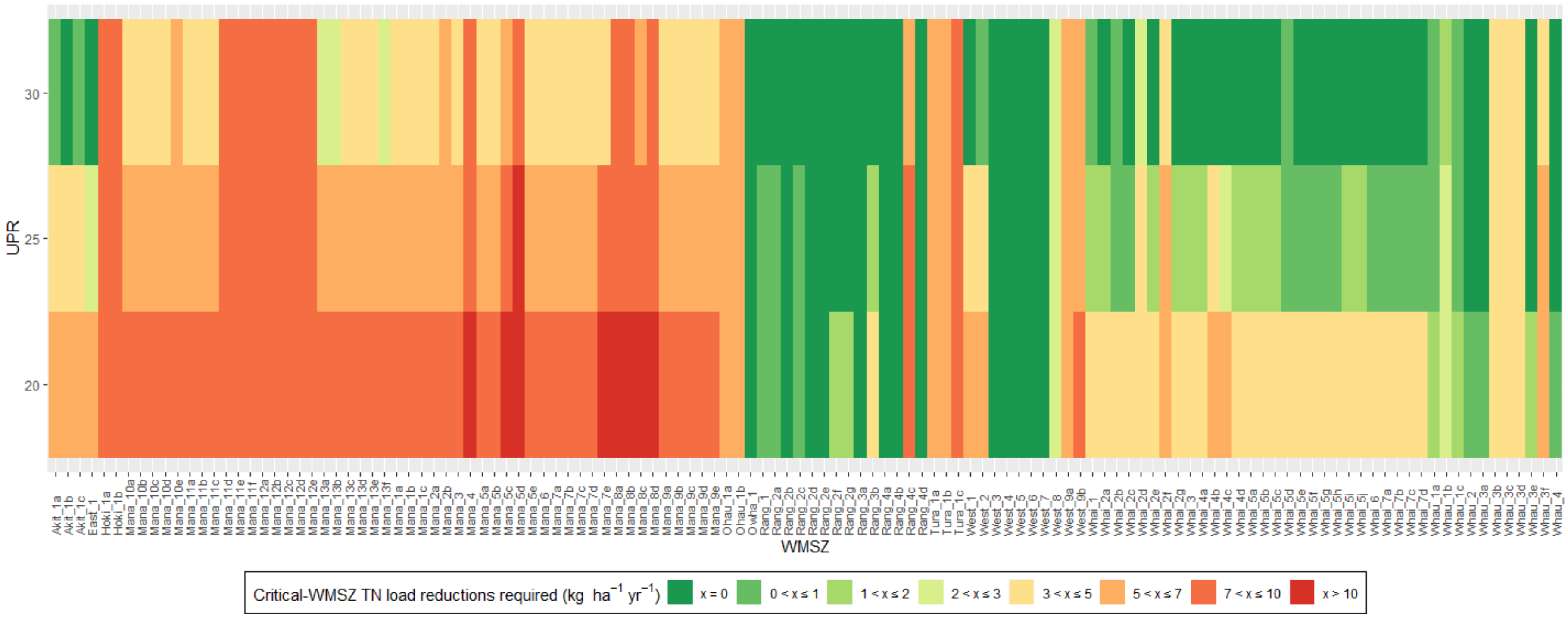

Figure 30. Comparison of critical-WMSZ load reductions required for TN for the three UPR levels. The reductions for each WMSZ and UPR level are indicated as yields (kg TN ha^{-1} yr^{-1}).

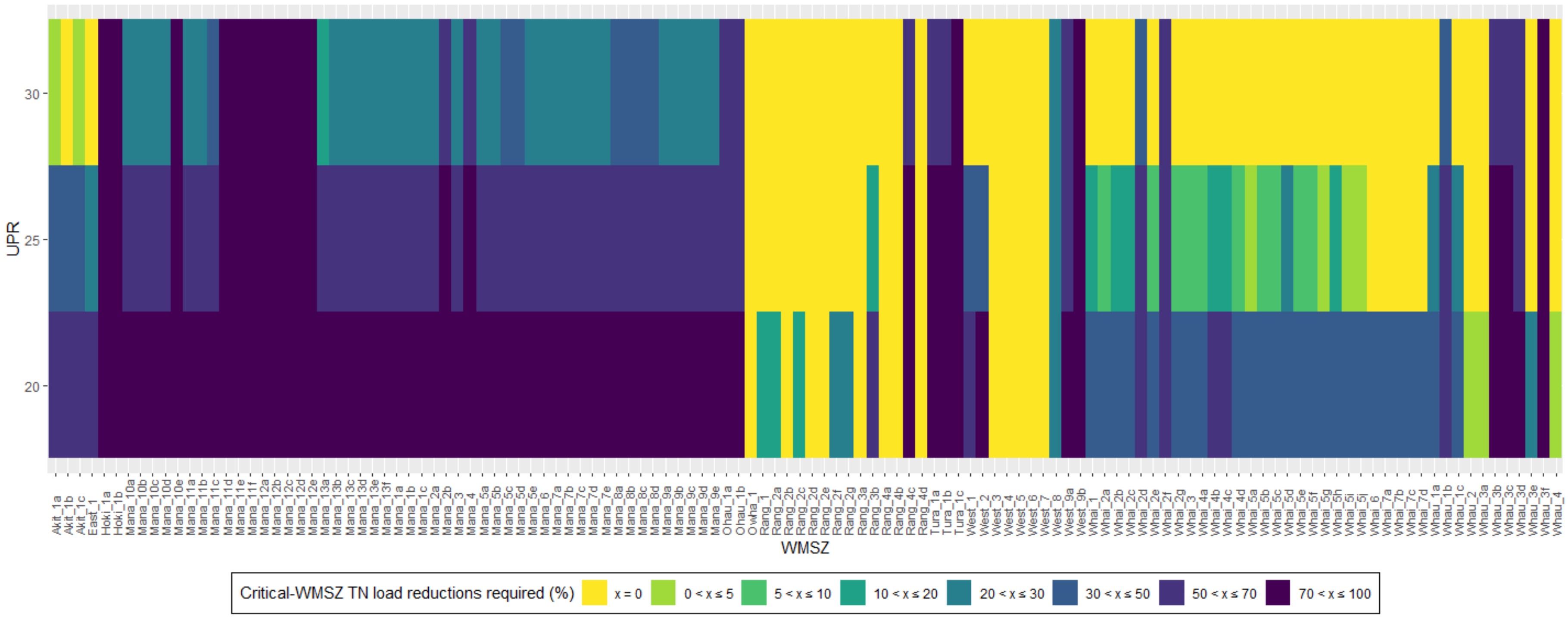

Figure 31. Comparison of critical-WMSZ load reductions required for TN for the three UPR levels. The reductions for each WMSZ and UPR level are indicated as proportion of baseline loads (%).

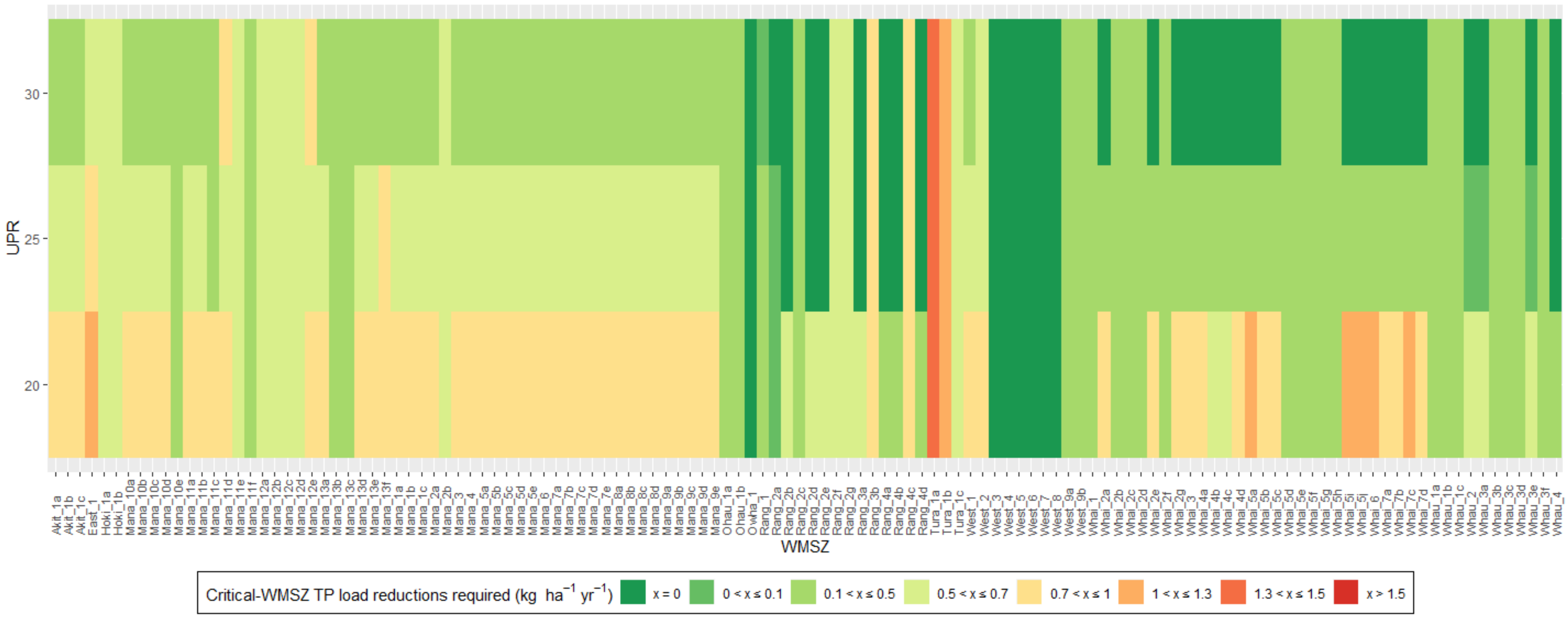

Figure 32. Comparison of critical-WMSZ load reductions required for TP for the three UPR levels. The reductions for each WMSZ and UPR level are indicated as yields (kg TP ha^{-1} yr^{-1}).

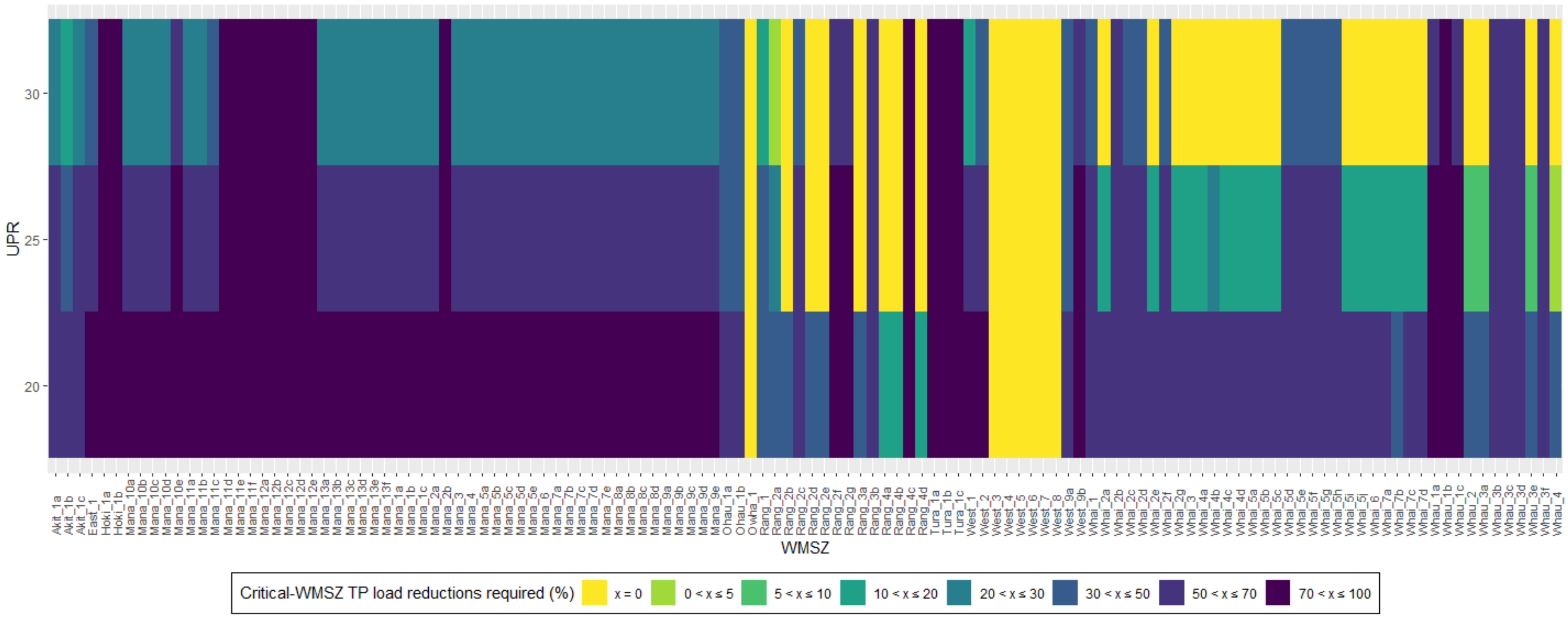

Figure 33. Comparison of critical WMSZ load reductions required for TP for the three UPR levels. The reductions for each WMSZ and UPR level are indicated as proportion of baseline loads (%).

5 Comparison of estimated WMSZ-level periphyton state to load reductions required

Table 12 compares the numbers of WMSZs with WMSZ-level attribute state of C or D with the numbers of WMSZs for which point-WMSZ load reductions required were greater than zero. For both methods for defining a WMSZ-level attribute state, the number of sub-zones in the C and D band were considerably fewer than the number for which the load reductions analysis indicated load reductions were required. This indicates that the estimated WMSZ-level baseline states are "optimistic" with respect to the findings of the load reduction analysis. This occurs because the estimated WMSZ-level baseline states represent a characteristic value from the distribution of predicted Chla92 values for all segments within each WMSZ. Because the load reductions analysis is carried out at the segment-scale, it detects and accounts for load reductions that are effectively "missed" by the estimated WMSZ-level baseline states. The implications of this are discussed in Section 6.

It is noted that the load reduction values shown in Table 12 are point-WMSZ load reductions. The point-WMSZ load reduction is properly interpreted as the load reduction requirement to achieve the TAS for all segments upstream of each WMSZ. The point-WMSZ load reduction required is therefore not always reflecting the load reduction requirements for a single WMSZ because some sub-zones are downstream of upstream sub-zones. This means that the point-WMSZ load reduction shown in Table 12 is not a perfect comparator because the WMSZ-level baseline attribute state pertains specifically to single WMSZ. However, for the purposes of the exercise, the comparison is reasonable and devising a more consistent comparison would introduce considerable extra complexity.

Table 12. Comparison of number of WMSZs with WMSZ-level baseline attribute state of C or D with numbers of WMSZs with load reductions required of greater than zero. For Method 1, the UPR column indicates the UPR of the load reductions analysis that was used as a comparator. For Method 2, the UPR refers to both the UPR that was used to estimate the WMSZ-level baseline attribute state and the UPR option of the load reductions analysis that was used as a comparator.

Method	Nutrient	UPR	Number of WMSZs with WMSZ-level baseline state of C or D	Number of WMSZs with point-WMSZ load reductions required greater than zero
1	TN	25	36	119
	TP	25	43	118
2	TN	20	96	121
	TN	25	80	119
	TN	30	63	110
	TP	20	96	120
	TP	25	78	118
	TP	30	71	108

6 Summary and discussion

6.1 Load reductions required

This study has assessed nutrient (nitrogen and phosphorus) load reductions needed to achieve options for target states pertaining to river periphyton and nitrate toxicity 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 receiving environments in the region.

The study assessed load reduction requirements to achieve TASs for river periphyton and nitrate toxicity that are specified at the level of WMZSs. A recently developed set of national nutrient concentration criteria (Snelder and Kilroy, 2023) were used to specify TN and TP concentrations to achieve the river periphyton TASs. As well as these two sets of TASs, the analyses incorporated three choices for under-protection risk for the nutrient criteria for periphyton: 20%, 25% and 30% risk. The load reductions were analysed at the level of the individual segments of the digital river network that represents stream and rivers of the region and the results for the individual segments were aggregated to report on individual ‘FMUs’, WMSZs, and the whole region.

The results for the FMUs and the whole region are the most succinct and broad summaries of the load reductions required and are shown in Table 13. The load reductions required for both TN and TP decreased with increasing under-protection risk. Load reductions for both TN and TP were substantial for the 20% UPR (regionally 64% and 70%, respectively). The uncertainties of these estimates were considerable even at the regional level and were larger for TP that TN, reflecting the slightly lower performance of the phosphorus models in general (Table 4, Table 5). Even for the 30% UPR, load reductions in some FMUs were greater than 30%. Based on projections of reductions in nitrogen and phosphorus that could be achieved under pastoral land use with existing and potential mitigations (Monaghan *et al.*, 2021), these reductions are unlikely to be achievable without land use change.

Table 13. The load reductions required for TN and TP to achieve the adopted TASs for the seven FMUs and the whole region for the 20%, 25% and 30% UPR levels. The load reductions are expressed as proportions of the baseline 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**		
	20% UPR	**25% UPR**	**30% UPR**	**20% UPR**	**25% UPR**	**30% UPR**
Kai Iwi	65 (47 - 79)	53 (31 - 69)	46 (24 - 65)	72 (43 - 88)	60 (39 - 81)	57 (40 - 68)
Whanganui	46 (11 - 80)	28 (3 - 65)	15 (3 - 34)	61 (4 - 99)	35 (2 - 81)	17 (1 - 62)
Whangaehu	46 (18 - 72)	35 (12 - 60)	24 (5 - 45)	48 (18 - 80)	33 (22 - 64)	26 (12 - 47)
Rangitīkei-Turakina	58 (44 - 71)	51 (34 - 68)	42 (27 - 56)	73 (37 - 117)	57 (36 - 100)	46 (31 - 68)
Manawatū	83 (56 - 96)	65 (30 - 86)	49 (21 - 82)	84 (49 - 109)	64 (19 - 95)	44 (11 - 89)
Waiopehu	74 (60 - 83)	66 (48 - 79)	60 (42 - 76)	61 (36 - 78)	54 (33 - 71)	48 (27 - 69)
Puketoi ki Tai	75 (62 - 87)	59 (40 - 77)	43 (22 - 65)	76 (61 - 88)	66 (44 - 83)	52 (33 - 73)
Whole region	64 (51 - 78)	48 (35 - 63)	36 (22 - 53)	70 (44 - 89)	49 (31 - 70)	33 (20 - 53)

6.2 Baseline state of periphyton

Two methods for estimating the WMSZ-level baseline state for periphyton were found to produce more optimistic assessments of current state than indicated by the load reduction analysis. This is because of the differences in the spatial scales implied by both analyses. This is because the two methods used to estimate the WMSZ-scale periphyton state were “point estimates” (i.e., a value representing a characteristic location on the distribution of values estimated for all segments within a WMSZ). The consequence of the finer spatial scale assessment undertaken by the load reduction analysis is that for some WMSZs, a load reduction is driven by a relatively small number of non-complying segments (e.g., see Figure 9 and Figure 16) and correspondingly a small number of segments with local load reductions greater than zero (e.g., see Figure 10, Figure 11).

It is concluded that a WMSZ-level estimate of attribute state that is based on a characteristic location on the distribution of values estimated for all segments within a WMSZ will always produce a more optimistic assessment of current state than the segment-scale load reduction analysis – because of the difference in spatial scales implied by the two assessments. It is noted that the segment scale analysis that was used to assess the load reductions required is the finest scale that can be analysed with existing data. It is also important to acknowledge that first and second order streams were included in this analysis, but the underlying models were poorly informed by data representing those small streams. Caution is needed in adopting the results of this study as load reduction targets because there is uncertainty in the derived numbers. Uncertainty is quantified formally by the confidence intervals provided by this study. However, it should be kept in mind that those uncertainty estimates do not account for assumptions such as whether the models provide reasonable estimates of conditions in first and second order streams, which cannot be tested due to data limitations.

The best available estimate of periphyton state at any location is provided by the models underlying the criteria of Snelder and Kilroy (2023). These models have large uncertainties, which are reflected in the probability distribution associated with estimates provided by those models. Those probability distributions are then reflected in the UPR values associated with the nutrient criteria. The uncertainty means that there is not an absolute (or “true”) baseline state for a WMSZ or any specific unmonitored location. It also means that monitoring data needs to be interpreted as a sample of a population (of biomass values) that has a probability distribution described by the models underlying the criteria of Snelder and Kilroy (2023). The idea that state is described by a probability distribution rather than an absolute (measured) value is difficult to reconcile with the (absolute value) interpretation associated with various clauses of the NPS-FM. However, monitoring data is always a sample of the population in both space and time and to treat the sample as the true value of state is incorrect. Furthermore, the inclusion of the UPR with the periphyton criteria is a technically appropriate mechanism for acknowledging that state cannot be known in absolute terms and should be treated as a probability.

6.3 Comparison with previous studies

A recent national scale study by Snelder *et al.* (2023) estimated load reductions required to achieve the NOF C band for rivers, lakes and estuaries for TN and TP for the Manawatū-Whanganui Region of 15% and 12%. The present study produced much larger load reduction requirements than Snelder *et al.* (2023). The reason for the differences between the two analyses are that Snelder *et al.* (2023) estimated load reduction required to achieve the NOF C band (national bottom line), which is a less ambitious objective. It is also noted that the study by Snelder *et al.* (2023) included estuaries and lakes, as well as rivers.

An earlier study by Snelder and Fraser (2021) estimated load reductions required to achieve the One Plan targets for rivers and lakes for TN and TP for the Manawatū-Whanganui Region. The One Plan targets are not the same as the adopted TASs that were assessed by this study but are considerably more ambitious than the NOF C band (NBL). The Snelder and Fraser (2021) study used two sets of possible TN concentration criteria to achieve periphyton TASs including an older set of nationally applicable criteria derived by Snelder *et al.* (2019) and a set of regionally-specific criteria derived by Kilroy *et al.* (2018). For TN and the nationally applicable criteria, Snelder and Fraser (2021) estimated regional load reductions of 60% and 43% for the 20% and 30% UPR, respectively which is reasonably consistent with this study. For TP and the nationally applicable criteria, Snelder and Fraser (2021) estimated regional load reductions of 106% and 16% for the 20% and 30% UPR, respectively which are inconsistent with this study. Using the regionally-specific criteria, Snelder and Fraser (2021) estimated regional load reductions of 23% and 16%, which are low compared to this study. This difference between studies is at least partly because the regionally-specific criteria of Kilroy *et al.* (2018) imply a very lenient 50% UPR (these details are discussed by Snelder and Fraser (2021).

6.4 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 loads observed at water quality monitoring sites; the error associated with these predictions is quantified by the model RMSD values (Table 4 and Table 5). The errors associated with each of the six 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 5th and 95th 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. There is therefore 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 all of the FMUs irrespective of the under-protection risk chosen (Table 13). There is also high confidence that TP load reductions are required under all UPR choices and for the region as a whole and all FMUs. It is noted that although there is high confidence that all FMUs require TN and TP load reductions, not all WMSZs require load reductions to achieve the TAS (Figure 30 to Figure 33). This reflects the increased spatial resolution of the results for the WMSZs compared to the FMUs.

The confidence intervals for regional load reduction estimates in this study were wider than that obtained for the Manawatū-Whanganui region in the national study of Snelder *et al.* (2023). For example, the national study’s best estimate of the TN load reduction required to achieve NOF bottom lines with a 20% UPR was 15%, and the 95% confidence interval ranged from 8% to 25%. In this study, the best estimate of the regional TN load reduction required to achieve the adopted targets with a 20% under-protection risk was 48%, and the 90% confidence interval ranged from 35% to 63% (Table 13). The wider confidence intervals produced by this study occurred despite the characteristic model errors (i.e., RMSD values; Table 4 and Table 5) being lower for the regional models than the national models used by Snelder *et al.* (2023). The reason that this study had wider confidence intervals is that the targets differed compared to the national study of Snelder *et al.* (2023). This meant that a larger proportion of catchments were generally indicated as requiring load reductions in this study than the Snelder *et al.* (2023) study and, in turn, this produces more variability in the uncertainties estimated by this study.

The statistical quantifications of the study uncertainties provided by this study are not the only uncertainties associated with the analyses. 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 river periphyton nutrient criteria. Neither of these uncertainties are represented in the reported uncertainties. Important assumptions used in the calculations are that (1) the ratio of NO3N to TN will remain the same if the loads of 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 simplifications of reality. However, there is a lack of scientific understanding and data needed significantly improve the representation of these relationships or to quantify the associated uncertainty.

6.5 Choice nutrient criteria and UPR

The nutrient criteria to achieve the periphyton TAS represent the best available information at the current time. It is noted that this study modified the national criteria for the A-band of Snelder and Kilroy (2023) with regionally specific values. Uncertainties associated with these criteria mean that there is uncertainty around whether the TASs will be achieved if the loads are reduced as indicated by the assessment. Some locations may fail to achieve the TAS (i.e., have greater biomass than specified) despite having nutrient concentrations that are less than the criteria. Equally, some locations may achieve the TAS despite having nutrient concentrations that are higher than specified. This means that in these less susceptible locations, the criteria are unnecessarily restrictive.

There is always uncertainty associated with environmental criteria. For example, most criteria are based on finding the stressor value for which the mean response exceeds a threshold value. This means that 50% of cases will not exhibit the threshold response at the stressor value. Generally, the exceedance of a criteria is treated as an unacceptably high risk of an adverse effect and appropriate action is taken, despite this uncertainty. This was the approach taken by this study. It has been assumed that the exceedance of a criteria represents an unacceptably high risk that the TAS will not be achieved and that the appropriate management response is to reduce the baseline 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.

This study indicates that the choice of UPR makes large differences to the assessed load reductions that are necessary. The choice of UPR is therefore a management decision that concerns the consideration of the acceptable level of risk that the stated TASs will not be achieved. It is noted that, although the UPRs are derived using scientific methods, the choice of the “right” level of risk is not a scientific question and ultimately lies with the decision maker.

6.6 Interpretation of the critical-WMSZ load reduction required

The critical-WMSZ load reduction required should be interpreted as an indicator of the effort required to achieve the TASs that can be used to compared between UPR options and nutrients (TN and TP). However, it should not be interpreted as the necessary or only load reduction option that can achieve the TASs. This is because the critical catchment load reduction required (which potentially defines the critical-WMSZ load reduction required) expresses reduction as an effort spread uniformly over the whole of the area upstream of the critical point. However, this does not consider the possibility that upstream critical points will have larger percentage load reductions required. If this is the case, implementation of these load reductions will reduce loads at all downstream critical points (i.e., upstream critical catchments will contribute disproportionately to the total effort required). However, in this study, the approach taken to define critical-WMSZ load reductions required did not provide for spatially variable effort (i.e., it treats critical points independently). This means that in some locations the critical-WMSZ estimates are conservative (i.e., may be less if implementation of load reductions at upstream critical points were accounted for). Exploration of this is best achieved by catchment scenario modelling because this distributes load reductions in a practical and achievable, rather than theoretical, manner. For example, catchment scenario modelling will distribute mitigations across catchments by land type, which automatically means that some parts of the landscape will contribute disproportionately to the total effort required.

It is emphasised that this study does not consider how the nutrient load reductions would be achieved. The spatial distribution of load reduction effort to achieve the load reductions required (and therefore the TASs) at each critical point is properly the subject of subsequent studies.

6.7 Informing decision-making on limits

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

7 Acknowledgements

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Appendix A Total nitrogen and total phosphorus criteria for periphyton TASs used in the analysis

The criteria for periphyton TASs 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 and three levels of under-protection risk (Table 14). The values in the table were obtained from the criteria of Snelder and Kilroy (2023) and are median concentrations in units of mg m^{-3}. Note that region-specific spatially uniform A band criteria for TN and TP were derived for the Manawatū-Whanganui region using quantile regression. In addition, where the region-specific A band criteria exceeded the B band criteria, the B band was set to the same criteria as the A band. The derivation of the region-specific spatially uniform A band criteria is explained below.

Table 14. The total nitrogen and total phosphorus criteria for periphyton TASs 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})			Total phosphorus (mg m^{-3})		
	A	B	C	A	B	C
WW/L	111	208	2281	8	14	107
WD/Lk	111	146	1914	8	8	63
WD/L	111	111	447	8	8	18
CX/M	111	2988	4372	8	85	281
CX/L	111	2061	4241	8	110	276
CX/H	111	1994	4272	8	69	247
CW/M	111	1693	4333	8	31	205
CW/L	111	179	1990	8	13	92
CW/H	111	376	3147	8	26	162
CD/M	111	1532	4297	8	11	93
CD/L	111	111	562	8	8	30
CD/H	111	231	1981	8	8	33

Table 15. The total nitrogen and total phosphorus criteria for periphyton TASs for each REC Source-of-flow class that occurs in the Manawatū-Whanganui region corresponding to the A, B and C bands and the 25% under-protection risk.

River Environment Classification Source-of-flow class	**Total nitrogen (mg m^{-3})**			**Total phosphorus (mg m^{-3})**		
	A	**B**	**C**	**A**	**B**	**C**
WW/L	137.5	399	2846	8.4	23	153
WD/Lk	137.5	291	2753	8.4	12	102
WD/L	137.5	137.5	742	8.4	8.4	29
CX/M	137.5	3778	4359	8.4	132	294
CX/L	137.5	3181	4291	8.4	170	287
CX/H	137.5	2827	4362	8.4	109	274
CW/M	137.5	2625	4373	8.4	52	254
CW/L	137.5	343	2616	8.4	21	132
CW/H	137.5	687	3732	8.4	42	213
CD/M	137.5	2409	4339	8.4	19	146
CD/L	137.5	137.5	1028	8.4	8.4	49
CD/H	137.5	420	2676	8.4	8.4	53

Table 16. The total nitrogen and dissolved reactive phosphorus criteria for periphyton TASs for REC Source-of-flow classes that occur 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})			Total phosphorus (mg m^{-3})		
	A	B	C	A	B	C
WW/L	189.1	726	3251	11	38	191
WD/Lk	189.1	528	3315	11	20	146
WD/L	189.1	189.1	1123	11	11	44
CX/M	189.1	4165	4371	11	189	297
CX/L	189.1	3770	4354	11	220	293
CX/H	189.1	3399	4387	11	152	289
CW/M	189.1	3429	4366	11	82	279
CW/L	189.1	601	3100	11	33	173
CW/H	189.1	1181	4092	11	68	252
CD/M	189.1	3207	4359	11	30	208
CD/L	189.1	189.1	1610	11	11	75
CD/H	189.1	694	3294	11	11	81

The criteria for the A band shown in Table 14, Table 15 and

Table 16 were derived using the subset of sites in the Manawatū-Whanganui region taken from the fitting data used by Snelder and Kilroy (2023). Quantile regression was used to derive the criteria for the 50 mg m^{-2} threshold that are spatially uniform (i.e., one value applies to all REC Source-of-flow classes). Plots of observed biomass at the Manawatū-Whanganui region sites versus observed site median nutrient values were wedge-shaped (Figure 34). This indicates that there is a limiting relationship between biomass and nutrients at the regional (i.e., Manawatū-Whanganui) scale but that other factors influence the response (Kelly *et al.*, 2022; Phillips *et al.*, 2018). Quantile regression models were statistically significant ($p < 0.1$) for all most quantiles for TN and TP (Table 17).

Sites with biomass values of 50 mg m^{-2} or less occurred across a wide range of nutrient concentrations and in most Source-of-flow classes (Figure 34). This indicates that there is no obvious landscape scale spatial pattern in the low biomass sites and that, in the absence of variables that can better explain low biomass at these sites, the uniform criteria derived from the quantile regression models are a justifiable approach to defining criteria for the 50 mg m^{-2} biomass target. Where possible, we derived alternative criteria from all QR models (Table 17) and used these values as the criteria pertaining to the 50 mg m^{-2} biomass target (see Table 14).

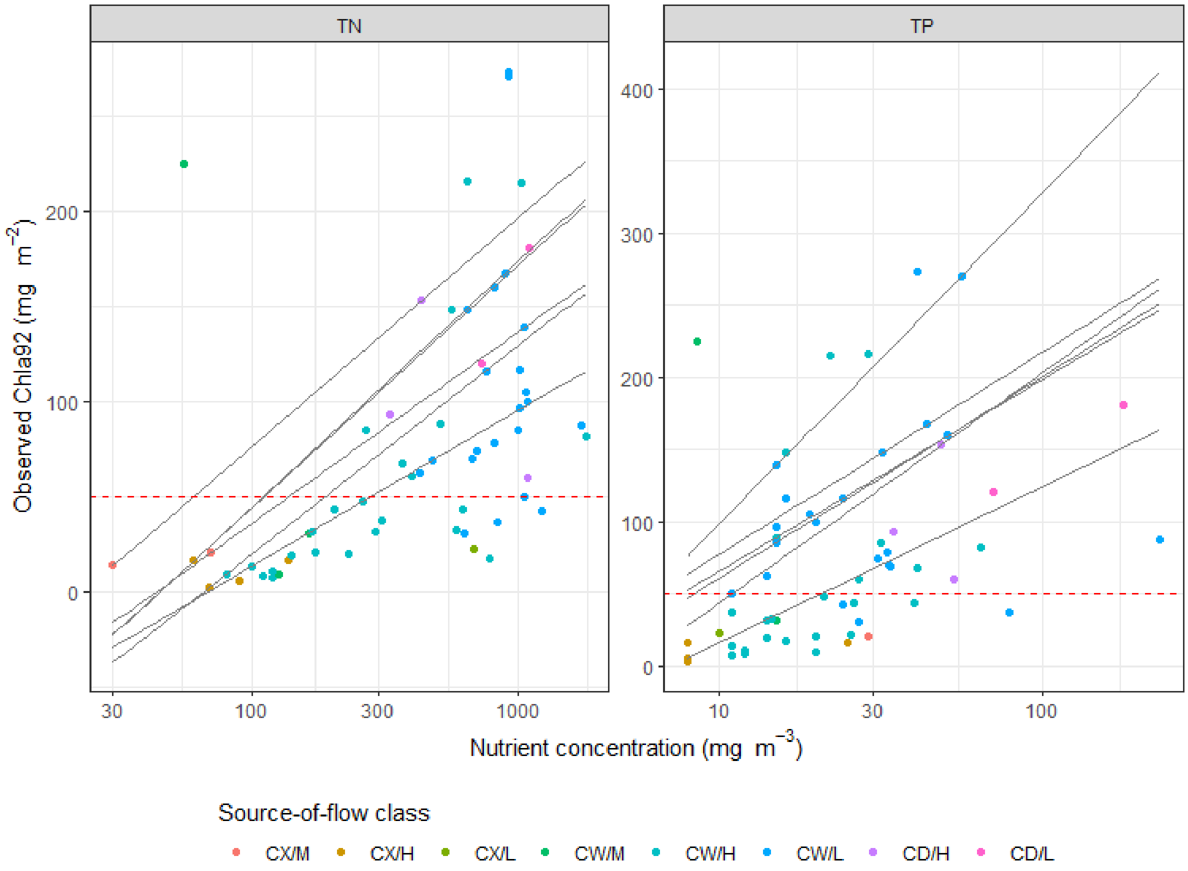

Figure 34. Relationships between biomass and median nutrient concentrations at monitoring periphyton monitoring sites in the Manawatū-Whanganui region. The grey lines are quantile regressions fitted to the 0.95, 0.9, 0.85, 0.8, 0.7 and 0.5 quantiles. Not all of these regression lines are statistically significant (see Table 3). The red dashed line indicates a biomass of 50 mg m^{-2}. Points are coloured to indicate the Source-of-flow class of the monitoring site.

Table 17. Criteria derived from the QR models for the 50 mg m^{-2} periphyton biomass target state for TN and TP and each level of under-protection risk. The P-value indicates the confidence in the regression coefficient fitted to the nutrient concentration; values with p<0.1 are considered significant and are shown in bold. The criteria have units of mg m^{-3}.

Nutrient	Quantile	Under-protection risk (%)	P value	Criteria
TN	0.5	50	**0**	279.7
	0.7	30	**0**	189.1
	0.75	25	**0.001**	137.5
	0.8	20	**0.001**	111
	0.85	15	**0.005**	110
	0.9	10	0.133	60
	0.95	5	0.93	NA
TP	0.5	50	**0**	20.7
	0.7	30	**0.006**	11
	0.75	25	**0.024**	8.4
	0.8	20	**0.088**	8
	0.85	15	0.168	7.8
	0.9	10	**0.09**	7.8
	0.95	5	0.311	6.4

Appendix B Loads and load reductions required

Table 18. TN load reductions required for all WMSZs and 20% UPR

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	99 (54 - 158)	5.2 (1.5 - 10.4)	61 (27 - 83)	5.9 (2 - 11.2)	68 (36 - 86)
Akit_1b	481 (263 - 763)	5.9 (2.2 - 11.1)	69 (39 - 86)	5.4 (1.7 - 10.7)	63 (27 - 84)
Akit_1c	102 (56 - 162)	5.5 (1.9 - 10.5)	66 (35 - 84)	5.9 (2 - 11.2)	68 (36 - 86)
East_1	87 (50 - 141)	6.4 (0.9 - 12.8)	70 (23 - 93)	6 (0.7 - 12.1)	66 (16 - 88)
Hoki_1a	53 (26 - 97)	4.4 (2.1 - 8.4)	51 (43 - 64)	8 (3.8 - 14.9)	94 (87 - 98)
Hoki_1b	59 (29 - 108)	8.1 (3.8 - 15)	94 (87 - 98)	8.1 (3.8 - 15)	94 (87 - 98)
Mana_10a	3,686 (1,995 - 5,850)	7.4 (2.5 - 12.9)	76 (46 - 91)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_10b	113 (61 - 180)	1.4 (0.3 - 3)	25 (9 - 43)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_10c	246 (133 - 391)	2.8 (0.6 - 5.4)	53 (20 - 79)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_10d	3,556 (1,924 - 5,644)	7.3 (2.5 - 12.6)	74 (46 - 89)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_10e	14 (8 - 23)	7.7 (3.3 - 12.7)	85 (66 - 94)	7.7 (3.3 - 12.7)	85 (66 - 94)
Mana_11a	4,134 (2,237 - 6,561)	8.1 (2.9 - 13.8)	84 (54 - 97)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_11b	32 (17 - 51)	5.2 (1.3 - 9.5)	65 (28 - 83)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_11c	36 (19 - 58)	5.5 (1.1 - 9.9)	67 (24 - 86)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_11d	132 (71 - 210)	8.1 (4 - 13.1)	92 (82 - 97)	8.1 (4.3 - 13.1)	94 (87 - 98)
Mana_11e	155 (84 - 247)	8.1 (4.3 - 13.1)	94 (87 - 98)	8.1 (4.3 - 13.1)	94 (87 - 98)
Mana_11f	147 (79 - 234)	9.3 (5 - 14.9)	97 (93 - 99)	9.3 (5 - 14.9)	97 (93 - 99)
Mana_12a	185 (100 - 293)	2.4 (0.5 - 4.6)	40 (16 - 56)	7.8 (3.6 - 12.7)	88 (74 - 95)
Mana_12b	595 (322 - 945)	6.3 (1.2 - 12.1)	59 (21 - 82)	7.8 (3.6 - 12.7)	88 (74 - 95)
Mana_12c	784 (424 - 1,244)	7.8 (3.6 - 12.7)	89 (74 - 96)	7.8 (3.6 - 12.7)	88 (74 - 95)
Mana_12d	209 (113 - 331)	6.6 (2.2 - 11.5)	76 (45 - 92)	7.8 (3.6 - 12.7)	88 (74 - 95)
Mana_12e	131 (71 - 208)	8.3 (4.3 - 13.4)	94 (86 - 98)	8.3 (4.3 - 13.4)	94 (86 - 98)
Mana_13a	5,331 (2,885 - 8,461)	7.7 (2.9 - 13.1)	83 (56 - 96)	7.3 (2.6 - 12.5)	78 (50 - 91)
Mana_13b	26 (14 - 42)	2.7 (0.2 - 5.8)	51 (7 - 85)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_13c	137 (74 - 218)	5.9 (1.9 - 10.4)	74 (42 - 89)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_13d	40 (21 - 64)	4.5 (0.7 - 9)	53 (16 - 79)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_13e	49 (26 - 77)	5.8 (2 - 10.3)	62 (39 - 73)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_13f	35 (19 - 56)	0.3 (0.1 - 0.4)	3 (3 - 3)	7.3 (2.6 - 12.5)	78 (50 - 91)
Mana_1a	600 (325 - 953)	6.8 (2.3 - 11.8)	78 (47 - 93)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_1b	81 (44 - 129)	5.2 (0.8 - 10.5)	52 (15 - 78)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_1c	172 (93 - 274)	6.7 (2.2 - 11.5)	82 (48 - 98)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_2a	745 (403 - 1,183)	6.9 (2.4 - 12)	79 (50 - 93)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_2b	106 (57 - 169)	8.5 (3.9 - 13.8)	88 (72 - 95)	8.5 (3.9 - 13.8)	88 (72 - 95)
Mana_3	20 (10 - 31)	3.8 (0.7 - 7.3)	58 (19 - 82)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_4	19 (10 - 30)	10.8 (4.2 - 18.2)	81 (56 - 92)	10.2 (4.2 - 17)	83 (62 - 93)
Mana_5a	1,111 (601 - 1,764)	7.3 (2.5 - 12.6)	80 (50 - 95)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_5b	815 (441 - 1,293)	6.8 (2.3 - 11.8)	77 (47 - 92)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_5c	55 (29 - 87)	11 (4.5 - 18.4)	90 (66 - 100)	10.2 (4.2 - 17)	83 (62 - 93)
Mana_5d	95 (51 - 152)	15 (6.2 - 25)	83 (62 - 93)	14.3 (5.9 - 23.8)	83 (62 - 93)
Mana_5e	46 (24 - 73)	7.8 (2.4 - 13.6)	75 (42 - 90)	7.4 (2.7 - 12.6)	78 (51 - 91)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_6	1,151 (623 - 1,827)	7.2 (2.5 - 12.4)	79 (49 - 93)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_7a	513 (277 - 814)	7.2 (2.3 - 12.4)	78 (45 - 92)	8.2 (3 - 13.9)	79 (53 - 92)
Mana_7b	1,367 (740 - 2,171)	9.4 (3.6 - 16)	91 (62 - 105)	8.2 (3 - 13.9)	79 (53 - 92)
Mana_7c	124 (67 - 198)	7.5 (2.5 - 12.9)	77 (46 - 91)	8.2 (3 - 13.9)	79 (53 - 92)
Mana_7d	185 (100 - 294)	7.1 (1.6 - 13.2)	60 (24 - 82)	8.2 (3 - 13.9)	79 (53 - 92)
Mana_7e	57 (30 - 90)	7.5 (2.5 - 13)	75 (45 - 89)	10.4 (4 - 17.6)	80 (54 - 92)
Mana_8a	36 (19 - 57)	3.2 (0.5 - 6.7)	46 (13 - 76)	12.8 (5.2 - 21.3)	83 (61 - 93)
Mana_8b	278 (150 - 442)	11.3 (4.2 - 19.2)	80 (53 - 92)	12.8 (5.2 - 21.3)	83 (61 - 93)
Mana_8c	619 (335 - 983)	13.1 (5.3 - 22)	87 (63 - 98)	12.6 (5.1 - 21)	82 (60 - 93)
Mana_8d	279 (151 - 443)	11.3 (4.2 - 19.2)	79 (53 - 92)	12.8 (5.2 - 21.3)	83 (61 - 93)
Mana_9a	3,053 (1,652 - 4,845)	7.9 (2.8 - 13.6)	80 (51 - 94)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_9b	23 (12 - 37)	6.5 (1.6 - 11.7)	71 (30 - 88)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_9c	130 (70 - 206)	7 (2.2 - 12.3)	77 (44 - 93)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_9d	209 (113 - 332)	4.8 (1.3 - 9)	60 (29 - 82)	7.4 (2.7 - 12.6)	78 (51 - 91)
Mana_9e	250 (135 - 397)	5.1 (1.4 - 9.3)	63 (32 - 83)	7.4 (2.7 - 12.6)	78 (51 - 91)
Ohau_1a	51 (28 - 83)	2.9 (0.6 - 6.2)	54 (16 - 92)	6.5 (2.4 - 11.8)	74 (39 - 90)
Ohau_1b	156 (86 - 255)	5.4 (1.5 - 10.5)	61 (25 - 83)	6.5 (2.4 - 11.8)	74 (39 - 90)
Owha_1	362 (178 - 591)	7.6 (2.5 - 14)	82 (55 - 98)	0 (0 - 0)	0 (0 - 0)
Rang_1	143 (78 - 237)	1.3 (0.1 - 3.1)	39 (5 - 77)	0.7 (0 - 2.8)	16 (0 - 67)
Rang_2a	227 (124 - 377)	2.1 (0.5 - 4.3)	67 (25 - 103)	0.6 (0 - 2.7)	13 (0 - 65)
Rang_2b	923 (503 - 1,530)	2 (0.3 - 4.2)	50 (13 - 82)	0 (0 - 3)	0 (0 - 40)
Rang_2c	80 (44 - 133)	1 (0 - 3)	28 (0 - 74)	0.6 (0 - 2.6)	13 (0 - 65)
Rang_2d	189 (103 - 314)	1.3 (0 - 3.2)	36 (2 - 72)	0 (0 - 3)	0 (0 - 40)
Rang_2e	305 (166 - 506)	1.9 (0.2 - 4.2)	45 (7 - 77)	0 (0 - 3)	0 (0 - 40)
Rang_2f	104 (57 - 174)	2.1 (0.2 - 4.9)	53 (8 - 93)	1.9 (0 - 5.6)	29 (0 - 71)
Rang_2g	211 (115 - 350)	2.7 (0.4 - 5.7)	46 (10 - 73)	1.9 (0 - 5.5)	28 (0 - 71)
Rang_3a	1,283 (699 - 2,127)	2.7 (0.7 - 5.2)	64 (28 - 93)	0 (0 - 3)	0 (0 - 40)
Rang_3b	68 (37 - 113)	4.2 (0.4 - 8.4)	56 (7 - 82)	3.9 (0 - 8.1)	51 (0 - 80)
Rang_4a	2,270 (1,237 - 3,763)	3.3 (1.3 - 6.1)	54 (31 - 71)	0 (0 - 3)	0 (0 - 40)
Rang_4b	2,243 (1,222 - 3,718)	3.3 (1.3 - 6.1)	55 (32 - 72)	0 (0 - 3)	0 (0 - 40)
Rang_4c	142 (77 - 236)	7.8 (3.7 - 13.4)	81 (59 - 92)	7.8 (3.7 - 13.4)	81 (59 - 92)
Rang_4d	2,204 (1,201 - 3,654)	3.2 (1.1 - 5.9)	51 (28 - 69)	0 (0 - 3)	0 (0 - 40)
Tura_1a	398 (210 - 658)	4.4 (0.9 - 9)	57 (22 - 81)	7 (3.3 - 12)	82 (66 - 93)
Tura_1b	807 (426 - 1,332)	7 (3.3 - 12)	82 (66 - 93)	7 (3.3 - 12)	82 (65 - 93)
Tura_1c	5 (2 - 8)	0 (0 - 0)	0 (0 - 0)	8 (4.1 - 13.2)	96 (92 - 98)
West_1	58 (34 - 96)	6 (2.3 - 10.6)	70 (36 - 87)	5.9 (1.9 - 10.5)	67 (28 - 86)
West_2	160 (93 - 254)	6.3 (2.1 - 11.7)	72 (42 - 88)	6.2 (1.9 - 11.7)	71 (39 - 88)
West_3	17 (10 - 28)	2.7 (1.5 - 4.6)	28 (24 - 30)	0 (0 - 0)	0 (0 - 0)
West_4	39 (19 - 63)	3.5 (1.6 - 6)	43 (39 - 45)	0 (0 - 0)	0 (0 - 0)
West_5	40 (24 - 66)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	82 (45 - 124)	0 (0 - 0.2)	0 (0 - 3)	0 (0 - 0)	0 (0 - 0)
West_7	11 (6 - 19)	3.8 (1.9 - 6.8)	44 (40 - 48)	0 (0 - 2.4)	0 (0 - 33)
West_8	12 (7 - 22)	2.5 (0.2 - 5.8)	27 (2 - 56)	2.1 (0 - 5.8)	22 (0 - 56)
West_9a	158 (87 - 259)	6.5 (2.4 - 11.8)	74 (39 - 90)	6.5 (2.4 - 11.8)	74 (39 - 90)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
West_9b	24 (14 - 35)	7.6 (3.7 - 11.7)	84 (65 - 95)	7.6 (3.7 - 11.7)	84 (65 - 95)
Whai_1	174 (95 - 296)	2.7 (0.3 - 6.6)	53 (8 - 93)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_2a	494 (271 - 841)	2.4 (0.3 - 5.9)	43 (8 - 77)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_2b	31 (17 - 54)	1.1 (0.1 - 3.2)	48 (6 - 127)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_2c	140 (77 - 239)	2.1 (0.3 - 5.1)	49 (10 - 87)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_2d	46 (25 - 78)	3.4 (0.6 - 7.5)	58 (15 - 86)	3.3 (0.5 - 7.5)	56 (9 - 86)
Whai_2e	388 (213 - 662)	2.5 (0.3 - 6.1)	48 (8 - 84)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_2f	462 (253 - 788)	5.6 (1.8 - 11.1)	73 (39 - 94)	5.2 (1.5 - 10.5)	66 (30 - 89)
Whai_2g	1,040 (570 - 1,772)	3.9 (0.9 - 8.6)	73 (28 - 108)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_3	1,437 (788 - 2,448)	4 (1 - 8.8)	57 (22 - 84)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_4a	2,808 (1,540 - 4,783)	4.6 (1 - 10.3)	51 (18 - 76)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_4b	705 (386 - 1,201)	6.3 (1.2 - 14.1)	55 (17 - 84)	6.3 (0.2 - 14.6)	52 (1 - 84)
Whai_4c	833 (457 - 1,420)	6.4 (1.3 - 14.4)	56 (17 - 84)	6.1 (0.1 - 14.3)	52 (1 - 84)
Whai_4d	329 (180 - 561)	2.1 (0.2 - 5.5)	25 (4 - 57)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_5a	4,988 (2,735 - 8,497)	4.3 (0.7 - 10.4)	48 (11 - 81)	4 (0 - 10.3)	42 (0 - 81)
Whai_5b	522 (286 - 890)	4.6 (0.5 - 11)	50 (8 - 85)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_5c	3,931 (2,155 - 6,695)	4.7 (0.8 - 11.1)	51 (14 - 82)	4.5 (0 - 11.1)	46 (0 - 82)
Whai_5d	5 (3 - 9)	0.7 (0 - 2.7)	19 (0 - 71)	4 (0 - 10.3)	42 (0 - 81)
Whai_5e	12 (6 - 20)	0.9 (0 - 3.1)	22 (0 - 81)	4 (0 - 10.3)	42 (0 - 81)
Whai_5f	26 (14 - 44)	1.3 (0 - 3.9)	27 (0 - 72)	4 (0 - 10.3)	42 (0 - 81)
Whai_5g	92 (50 - 156)	1.7 (0.2 - 4.4)	43 (6 - 82)	4 (0 - 10.3)	42 (0 - 81)
Whai_5h	18 (10 - 31)	1.7 (0.1 - 4.5)	46 (3 - 97)	4 (0 - 10.3)	42 (0 - 81)
Whai_5i	320 (175 - 545)	1.5 (0.1 - 4.4)	27 (2 - 65)	4 (0 - 10.3)	42 (0 - 81)
Whai_5j	37 (20 - 64)	1.3 (0 - 5.6)	13 (0 - 71)	4 (0 - 10.3)	42 (0 - 81)
Whai_6	5,593 (3,067 - 9,526)	4.3 (0.6 - 10.4)	46 (10 - 80)	3.9 (0 - 10.2)	40 (0 - 80)
Whai_7a	5,808 (3,185 - 9,892)	4.3 (0.6 - 10.4)	47 (11 - 81)	3.9 (0 - 10.2)	40 (0 - 80)
Whai_7b	5,967 (3,272 - 10,163)	4.3 (0.6 - 10.3)	46 (11 - 80)	3.9 (0 - 10.3)	40 (0 - 80)
Whai_7c	78 (43 - 134)	4.9 (1.4 - 10)	60 (26 - 81)	3.9 (0 - 10.2)	40 (0 - 80)
Whai_7d	63 (34 - 108)	1.3 (0.6 - 2.3)	15 (12 - 17)	3.9 (0 - 10.2)	40 (0 - 80)
Whau_1a	127 (74 - 215)	1.7 (0.2 - 4.3)	58 (11 - 98)	1.3 (0 - 3.5)	43 (0 - 82)
Whau_1b	23 (13 - 39)	1.5 (0 - 4.8)	33 (1 - 76)	2.6 (0.6 - 5.9)	63 (23 - 88)
Whau_1c	60 (35 - 102)	1.8 (0.2 - 4.7)	60 (9 - 105)	1.3 (0 - 3.5)	43 (0 - 82)
Whau_2	327 (190 - 555)	2.2 (0.2 - 5.6)	49 (9 - 84)	0.8 (0 - 6.1)	5 (0 - 70)
Whau_3a	1,059 (616 - 1,795)	2.9 (0.7 - 7.2)	49 (19 - 77)	0.8 (0 - 6.1)	5 (0 - 70)
Whau_3b	7 (4 - 13)	1.8 (0.1 - 4.5)	53 (2 - 85)	5 (2.3 - 9.4)	80 (59 - 94)
Whau_3c	52 (30 - 89)	5.1 (2.4 - 9.6)	83 (63 - 96)	5 (2.3 - 9.4)	80 (59 - 94)
Whau_3d	158 (92 - 268)	4.8 (1.9 - 9.4)	77 (49 - 95)	4.5 (1.8 - 9.1)	73 (45 - 92)
Whau_3e	291 (169 - 493)	3.4 (1 - 8.5)	74 (33 - 118)	1.4 (0 - 6.1)	21 (0 - 75)
Whau_3f	8 (4 - 13)	5.1 (2.5 - 9.5)	85 (67 - 97)	5.1 (2.5 - 9.4)	84 (66 - 95)
Whau_4	1,149 (668 - 1,946)	2.8 (0.7 - 7)	46 (18 - 72)	0.8 (0 - 6.1)	5 (0 - 70)

Table 19. TP load reductions required for all WMSZs and 20% UPR

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	15 (8 - 27)	0.81 (0.22 - 1.69)	62 (22 - 84)	0.9 (0.4 - 1.9)	69 (37 - 87)
Akit_1b	82 (42 - 144)	0.97 (0.36 - 1.94)	68 (36 - 87)	1 (0.4 - 1.9)	68 (35 - 87)
Akit_1c	13 (7 - 24)	0.73 (0.25 - 1.49)	67 (31 - 88)	0.9 (0.4 - 1.9)	69 (37 - 87)
East_1	13 (6 - 23)	1.1 (0.43 - 2.1)	82 (62 - 94)	1.1 (0.4 - 2.1)	82 (62 - 94)
Hoki_1a	5 (2 - 8)	0.33 (0.13 - 0.61)	40 (32 - 45)	0.7 (0.3 - 1.3)	90 (78 - 97)
Hoki_1b	5 (2 - 9)	0.71 (0.32 - 1.29)	94 (80 - 101)	0.7 (0.3 - 1.2)	90 (77 - 97)
Mana_10a	741 (336 - 1,283)	1.12 (0.17 - 2.25)	57 (12 - 87)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_10b	21 (9 - 37)	0.15 (0.01 - 0.52)	14 (1 - 46)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_10c	53 (24 - 92)	0.28 (0.04 - 0.81)	24 (6 - 59)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_10d	701 (318 - 1,213)	1.08 (0.16 - 2.2)	55 (13 - 86)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_10e	1 (0 - 1)	0.5 (0.2 - 0.91)	80 (57 - 94)	0.5 (0.2 - 0.9)	80 (57 - 94)
Mana_11a	617 (280 - 1,069)	1.2 (0.36 - 2.2)	84 (40 - 112)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_11b	2 (1 - 4)	0.46 (0.14 - 0.84)	67 (30 - 88)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_11c	2 (1 - 4)	0.38 (0.1 - 0.71)	67 (26 - 90)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_11d	12 (5 - 22)	0.79 (0.34 - 1.39)	92 (83 - 98)	0.8 (0.3 - 1.4)	93 (85 - 98)
Mana_11e	12 (5 - 21)	0.69 (0.3 - 1.23)	102 (93 - 107)	0.6 (0.3 - 1.1)	92 (83 - 98)
Mana_11f	7 (3 - 12)	0.47 (0.21 - 0.82)	98 (95 - 99)	0.5 (0.2 - 0.8)	98 (95 - 99)
Mana_12a	34 (15 - 60)	0.27 (0.04 - 0.87)	23 (6 - 66)	0.7 (0.3 - 1.3)	84 (66 - 96)
Mana_12b	61 (27 - 106)	0.57 (0.17 - 1.2)	52 (29 - 93)	0.7 (0.3 - 1.3)	84 (66 - 96)
Mana_12c	78 (35 - 136)	0.77 (0.32 - 1.39)	88 (66 - 101)	0.7 (0.3 - 1.3)	84 (66 - 96)
Mana_12d	28 (12 - 49)	0.92 (0.35 - 1.67)	79 (54 - 94)	0.7 (0.3 - 1.3)	84 (66 - 96)
Mana_12e	11 (5 - 20)	0.8 (0.35 - 1.41)	102 (98 - 105)	0.8 (0.3 - 1.3)	97 (92 - 99)
Mana_13a	729 (331 - 1,263)	1.06 (0.36 - 1.91)	84 (49 - 109)	0.9 (0.3 - 1.7)	74 (43 - 92)
Mana_13b	2 (1 - 4)	0.3 (0.02 - 0.67)	55 (4 - 95)	0.4 (0.2 - 0.8)	76 (46 - 93)
Mana_13c	10 (4 - 17)	0.42 (0.15 - 0.77)	72 (37 - 92)	0.4 (0.2 - 0.8)	76 (46 - 93)
Mana_13d	3 (1 - 5)	0.28 (0.04 - 0.6)	45 (9 - 75)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_13e	3 (1 - 5)	0.42 (0.14 - 0.76)	64 (35 - 81)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_13f	2 (0 - 3)	0.01 (0.01 - 0.02)	2 (2 - 3)	1 (0.4 - 1.9)	75 (45 - 93)
Mana_1a	93 (42 - 162)	0.89 (0.21 - 1.68)	66 (22 - 92)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_1b	5 (2 - 10)	0.2 (0.04 - 0.56)	28 (11 - 67)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_1c	40 (18 - 70)	1.14 (0.18 - 2.23)	61 (11 - 88)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_2a	105 (48 - 183)	0.86 (0.25 - 1.57)	69 (30 - 93)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_2b	8 (3 - 13)	0.66 (0.29 - 1.17)	91 (81 - 98)	0.7 (0.3 - 1.2)	91 (81 - 98)
Mana_3	2 (1 - 4)	0.36 (0.01 - 0.86)	45 (2 - 83)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_4	1 (0 - 1)	0.43 (0 - 0.9)	54 (0 - 87)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_5a	150 (68 - 261)	0.86 (0.25 - 1.57)	70 (30 - 93)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_5b	117 (53 - 203)	0.85 (0.24 - 1.57)	68 (28 - 91)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_5c	4 (1 - 6)	0.53 (0.11 - 1.05)	59 (17 - 87)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_5d	4 (2 - 7)	0.42 (0.05 - 0.96)	47 (10 - 83)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_5e	5 (2 - 10)	0.73 (0.13 - 1.5)	56 (15 - 87)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_6	155 (70 - 269)	0.86 (0.26 - 1.59)	71 (31 - 94)	1 (0.4 - 1.8)	75 (45 - 93)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_7a	95 (43 - 164)	1.09 (0.28 - 2.05)	65 (24 - 89)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_7b	193 (87 - 335)	0.81 (0.14 - 1.67)	55 (14 - 85)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_7c	20 (9 - 35)	1.05 (0.26 - 1.94)	66 (24 - 90)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_7d	23 (10 - 41)	0.52 (0.01 - 1.29)	34 (1 - 68)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_7e	7 (3 - 12)	0.83 (0.18 - 1.57)	63 (20 - 89)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_8a	3 (1 - 6)	0.26 (0.01 - 0.73)	35 (2 - 82)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_8b	20 (9 - 35)	0.5 (0.04 - 1.15)	47 (4 - 83)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_8c	37 (16 - 64)	0.39 (0.03 - 0.97)	42 (5 - 80)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_8d	19 (8 - 34)	0.49 (0.04 - 1.11)	47 (4 - 83)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_9a	437 (198 - 757)	0.88 (0.18 - 1.73)	62 (19 - 92)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_9b	1 (0 - 3)	0.45 (0.04 - 0.93)	57 (7 - 91)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_9c	13 (6 - 23)	0.64 (0.19 - 1.18)	69 (31 - 91)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_9d	30 (14 - 53)	0.5 (0.05 - 1.23)	43 (7 - 81)	1 (0.4 - 1.8)	75 (45 - 93)
Mana_9e	35 (16 - 61)	0.5 (0.07 - 1.17)	44 (9 - 79)	1 (0.4 - 1.8)	75 (45 - 93)
Ohau_1a	6 (3 - 10)	0.25 (0.01 - 0.62)	41 (2 - 84)	0.4 (0 - 0.9)	54 (0 - 85)
Ohau_1b	12 (6 - 22)	0.28 (0.06 - 0.65)	40 (12 - 76)	0.4 (0 - 0.9)	54 (0 - 85)
Owha_1	68 (36 - 118)	1.41 (0.56 - 2.61)	83 (57 - 97)	0 (0 - 0)	0 (0 - 0)
Rang_1	20 (11 - 36)	0.24 (0.05 - 0.54)	56 (11 - 90)	0.2 (0 - 0.5)	38 (0 - 83)
Rang_2a	32 (17 - 57)	0.33 (0.13 - 0.69)	77 (36 - 104)	0.1 (0 - 0.5)	33 (0 - 81)
Rang_2b	195 (106 - 348)	0.38 (0.16 - 0.77)	49 (26 - 69)	0.7 (0 - 2.4)	33 (0 - 81)
Rang_2c	14 (7 - 25)	0.32 (0.03 - 0.7)	62 (7 - 89)	0.3 (0 - 0.7)	61 (2 - 89)
Rang_2d	26 (14 - 47)	0.31 (0.11 - 0.63)	67 (25 - 97)	0.7 (0 - 2.4)	33 (0 - 81)
Rang_2e	38 (21 - 69)	0.4 (0.19 - 0.8)	82 (48 - 105)	0.7 (0 - 2.4)	33 (0 - 81)
Rang_2f	14 (7 - 26)	0.4 (0.17 - 0.82)	78 (41 - 97)	0.6 (0.3 - 1.2)	77 (44 - 94)
Rang_2g	30 (16 - 54)	0.62 (0.28 - 1.23)	78 (44 - 94)	0.6 (0.3 - 1.2)	77 (44 - 94)
Rang_3a	451 (245 - 803)	0.49 (0.21 - 1.24)	34 (19 - 60)	0.7 (0 - 2.4)	33 (0 - 81)
Rang_3b	13 (7 - 23)	0.98 (0.4 - 2)	73 (38 - 91)	0.9 (0.3 - 2)	69 (23 - 91)
Rang_4a	536 (292 - 954)	0.92 (0.25 - 2.25)	64 (21 - 116)	0.3 (0 - 1.5)	18 (0 - 77)
Rang_4b	488 (266 - 870)	0.91 (0.25 - 2.23)	70 (23 - 127)	0.2 (0 - 1.4)	17 (0 - 77)
Rang_4c	18 (9 - 32)	0.99 (0.51 - 1.88)	82 (56 - 95)	1 (0.5 - 1.9)	82 (56 - 95)
Rang_4d	580 (316 - 1,033)	0.95 (0.25 - 2.34)	58 (18 - 106)	0.3 (0 - 1.6)	20 (0 - 77)
Tura_1a	79 (43 - 143)	1.16 (0.56 - 2.36)	77 (51 - 94)	1.4 (0.8 - 2.7)	88 (73 - 97)
Tura_1b	144 (78 - 260)	1.35 (0.73 - 2.58)	89 (73 - 99)	1.3 (0.7 - 2.5)	86 (71 - 96)
Tura_1c	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.6 (0.3 - 1)	97 (93 - 99)
West_1	8 (4 - 15)	0.89 (0.26 - 1.81)	72 (34 - 90)	0.9 (0.3 - 1.8)	72 (34 - 90)
West_2	25 (11 - 46)	1.06 (0.4 - 2.22)	79 (42 - 95)	1 (0.4 - 2.1)	75 (36 - 92)
West_3	1 (0 - 3)	0.24 (0.11 - 0.44)	23 (19 - 25)	0 (0 - 0)	0 (0 - 0)
West_4	3 (1 - 5)	0.3 (0.14 - 0.48)	45 (42 - 46)	0 (0 - 0)	0 (0 - 0)
West_5	3 (1 - 5)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	5 (2 - 10)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_7	0 (0 - 1)	0.19 (0.08 - 0.34)	40 (34 - 42)	0 (0 - 0)	0 (0 - 0)
West_8	1 (0 - 2)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_9a	13 (6 - 22)	0.4 (0.08 - 0.87)	57 (11 - 85)	0.4 (0 - 0.9)	54 (0 - 85)
West_9b	1 (0 - 2)	0.47 (0.21 - 0.94)	79 (58 - 93)	0.5 (0.2 - 0.9)	79 (58 - 93)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Whai_1	19 (10 - 34)	0.35 (0.08 - 0.68)	66 (23 - 92)	0.3 (0.1 - 0.6)	60 (15 - 86)
Whai_2a	54 (29 - 96)	0.3 (0.07 - 0.61)	51 (18 - 76)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_2b	7 (4 - 13)	0.31 (0.1 - 0.59)	69 (33 - 92)	0.3 (0.1 - 0.6)	68 (33 - 89)
Whai_2c	17 (9 - 31)	0.33 (0.08 - 0.63)	65 (25 - 88)	0.3 (0.1 - 0.6)	64 (24 - 88)
Whai_2d	4 (2 - 7)	0.31 (0.08 - 0.6)	65 (26 - 88)	0.3 (0.1 - 0.6)	65 (26 - 88)
Whai_2e	45 (24 - 79)	0.32 (0.07 - 0.63)	57 (20 - 79)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_2f	37 (20 - 65)	0.43 (0.1 - 0.84)	71 (27 - 97)	0.4 (0.1 - 0.8)	65 (25 - 88)
Whai_2g	77 (41 - 136)	0.35 (0.07 - 0.72)	92 (28 - 135)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_3	162 (86 - 283)	0.35 (0.07 - 0.72)	47 (14 - 69)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_4a	392 (209 - 687)	0.45 (0.06 - 0.97)	37 (8 - 67)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_4b	84 (44 - 147)	0.72 (0.06 - 1.51)	56 (5 - 85)	0.7 (0.1 - 1.5)	56 (7 - 85)
Whai_4c	95 (51 - 167)	0.69 (0.06 - 1.46)	55 (7 - 84)	0.7 (0 - 1.4)	54 (3 - 84)
Whai_4d	42 (22 - 75)	0.2 (0 - 0.65)	21 (0 - 57)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_5a	1,025 (547 - 1,796)	0.88 (0.04 - 1.95)	51 (3 - 82)	1.1 (0 - 2.3)	51 (0 - 83)
Whai_5b	55 (29 - 97)	0.37 (0 - 0.93)	41 (1 - 78)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_5c	698 (372 - 1,223)	0.84 (0.04 - 1.8)	55 (4 - 84)	0.8 (0 - 1.8)	54 (1 - 84)
Whai_5d	0 (0 - 1)	0.25 (0.05 - 0.49)	62 (18 - 87)	0.2 (0 - 0.5)	62 (18 - 87)
Whai_5e	1 (0 - 3)	0.26 (0.05 - 0.53)	61 (16 - 88)	0.3 (0.1 - 0.6)	61 (16 - 86)
Whai_5f	3 (1 - 5)	0.29 (0.05 - 0.57)	60 (15 - 86)	0.3 (0.1 - 0.6)	61 (16 - 86)
Whai_5g	12 (6 - 21)	0.29 (0.05 - 0.59)	59 (15 - 85)	0.3 (0 - 0.6)	58 (11 - 85)
Whai_5h	2 (1 - 4)	0.29 (0.05 - 0.57)	61 (17 - 86)	0.3 (0.1 - 0.6)	61 (17 - 86)
Whai_5i	55 (29 - 97)	0.29 (0.02 - 0.75)	33 (3 - 65)	1.1 (0 - 2.3)	51 (0 - 83)
Whai_5j	3 (1 - 5)	0.02 (0 - 0.32)	2 (0 - 57)	1.1 (0 - 2.3)	51 (0 - 83)
Whai_6	1,504 (803 - 2,636)	1.16 (0.04 - 2.58)	50 (2 - 82)	1.1 (0 - 2.3)	51 (0 - 83)
Whai_7a	1,434 (766 - 2,513)	1.16 (0.05 - 2.56)	55 (3 - 90)	1 (0 - 2.3)	51 (0 - 83)
Whai_7b	1,306 (697 - 2,288)	1.14 (0.05 - 2.51)	61 (4 - 99)	0.9 (0 - 2.1)	50 (0 - 83)
Whai_7c	14 (7 - 25)	1.09 (0.51 - 1.85)	77 (57 - 88)	1.1 (0 - 2.3)	51 (0 - 83)
Whai_7d	8 (4 - 14)	0.15 (0.08 - 0.28)	14 (12 - 15)	1 (0 - 2.3)	51 (0 - 83)
Whau_1a	24 (11 - 43)	0.4 (0.18 - 0.76)	78 (54 - 93)	0.4 (0.2 - 0.8)	78 (53 - 93)
Whau_1b	2 (1 - 4)	0.35 (0.16 - 0.66)	78 (53 - 93)	0.4 (0.2 - 0.8)	83 (63 - 94)
Whau_1c	11 (5 - 19)	0.39 (0.17 - 0.75)	76 (49 - 92)	0.4 (0.2 - 0.8)	78 (53 - 93)
Whau_2	54 (25 - 97)	0.46 (0.2 - 0.89)	66 (41 - 87)	0.6 (0 - 1.5)	41 (0 - 80)
Whau_3a	251 (117 - 450)	0.64 (0.18 - 1.45)	47 (17 - 80)	0.6 (0 - 1.5)	41 (0 - 80)
Whau_3b	0 (0 - 1)	0.17 (0.03 - 0.37)	63 (13 - 94)	0.2 (0.1 - 0.5)	66 (27 - 89)
Whau_3c	2 (1 - 4)	0.18 (0.07 - 0.36)	67 (30 - 91)	0.2 (0.1 - 0.5)	66 (27 - 89)
Whau_3d	9 (4 - 17)	0.29 (0.11 - 0.57)	79 (38 - 104)	0.2 (0.1 - 0.5)	66 (27 - 89)
Whau_3e	44 (20 - 79)	0.27 (0.08 - 0.68)	40 (14 - 75)	0.6 (0 - 1.5)	41 (0 - 80)
Whau_3f	0 (0 - 0)	0.19 (0.07 - 0.39)	67 (28 - 91)	0.2 (0.1 - 0.5)	66 (27 - 89)
Whau_4	254 (118 - 455)	0.63 (0.18 - 1.41)	48 (18 - 80)	0.5 (0 - 1.4)	37 (0 - 79)

Table 20. TN load reductions required for all WMSZs and 25% UPR

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	98 (53 - 161)	3.2 (0.1 - 9.1)	34 (1 - 76)	3.9 (0 - 10.1)	40 (0 - 80)
Akit_1b	475 (259 - 777)	4.3 (0.7 - 10.1)	48 (14 - 81)	3.2 (0 - 9.4)	31 (0 - 77)
Akit_1c	101 (55 - 165)	3.8 (0.1 - 9.4)	43 (3 - 78)	3.9 (0 - 10.1)	40 (0 - 80)
East_1	84 (47 - 129)	3.9 (0.1 - 9.4)	42 (2 - 80)	3.1 (0 - 8.8)	30 (0 - 76)
Hoki_1a	53 (31 - 86)	4.2 (2.1 - 7.1)	48 (39 - 57)	7.6 (4 - 12.5)	88 (76 - 95)
Hoki_1b	60 (34 - 97)	7.6 (4 - 12.7)	88 (76 - 95)	7.6 (4 - 12.7)	88 (76 - 95)
Mana_10a	3,717 (1,975 - 6,488)	5.7 (1.6 - 11)	56 (25 - 80)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_10b	114 (60 - 199)	0.8 (0.1 - 2.1)	14 (2 - 24)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_10c	248 (132 - 434)	1.9 (0.5 - 4.4)	34 (14 - 57)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_10d	3,586 (1,905 - 6,260)	5.6 (1.6 - 10.7)	56 (24 - 78)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_10e	15 (8 - 26)	7.4 (3.3 - 13.1)	81 (65 - 92)	7.4 (3.3 - 13.1)	81 (65 - 92)
Mana_11a	4,168 (2,215 - 7,277)	6.4 (1.9 - 11.8)	63 (30 - 88)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_11b	32 (17 - 57)	4.7 (1.4 - 8.7)	57 (26 - 80)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_11c	37 (19 - 64)	4.8 (1.1 - 9.2)	58 (19 - 82)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_11d	133 (70 - 233)	8 (4 - 14)	90 (81 - 96)	8.1 (4.2 - 14.2)	93 (86 - 97)
Mana_11e	156 (83 - 273)	8.1 (4.2 - 14.2)	93 (86 - 97)	8.1 (4.2 - 14.2)	93 (86 - 97)
Mana_11f	148 (79 - 259)	9.4 (4.9 - 16.4)	96 (93 - 98)	9.4 (4.9 - 16.4)	96 (93 - 98)
Mana_12a	186 (99 - 325)	1.7 (0.5 - 3.8)	27 (15 - 44)	7.6 (3.5 - 12.9)	85 (72 - 94)
Mana_12b	600 (319 - 1,048)	4 (1 - 10)	36 (15 - 65)	7.6 (3.5 - 12.9)	85 (72 - 94)
Mana_12c	790 (420 - 1,380)	7.6 (3.5 - 13)	85 (72 - 94)	7.6 (3.5 - 12.9)	85 (72 - 94)
Mana_12d	210 (111 - 367)	5.2 (1.6 - 9.9)	58 (29 - 81)	7.6 (3.5 - 12.9)	85 (72 - 94)
Mana_12e	132 (70 - 231)	8.3 (4.3 - 14.5)	92 (86 - 97)	8.3 (4.3 - 14.5)	92 (86 - 97)
Mana_13a	5,376 (2,856 - 9,384)	6.4 (2.2 - 11.6)	66 (37 - 88)	5.6 (1.2 - 10.7)	57 (18 - 82)
Mana_13b	26 (14 - 46)	2.1 (0.2 - 5.7)	38 (6 - 76)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_13c	138 (73 - 242)	5.3 (1.8 - 9.6)	64 (34 - 85)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_13d	40 (21 - 71)	2.8 (0.6 - 7.2)	32 (14 - 60)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_13e	49 (26 - 86)	4.9 (1.4 - 9)	51 (23 - 70)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_13f	36 (19 - 63)	0.3 (0.1 - 0.4)	3 (3 - 3)	5.6 (1.3 - 10.7)	57 (19 - 82)
Mana_1a	605 (321 - 1,057)	5.2 (1.5 - 10.1)	58 (25 - 83)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_1b	82 (43 - 143)	2.9 (0.6 - 8.5)	27 (10 - 58)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_1c	174 (92 - 304)	4.9 (0.7 - 9.8)	58 (10 - 87)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_2a	751 (399 - 1,312)	5.4 (1.7 - 10.2)	60 (28 - 84)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_2b	107 (57 - 188)	7.5 (3 - 13.5)	76 (54 - 90)	7.5 (3 - 13.5)	76 (54 - 90)
Mana_3	20 (10 - 35)	3.2 (0.7 - 6.9)	48 (17 - 76)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_4	19 (10 - 34)	10.3 (4.1 - 18.4)	76 (54 - 90)	10.3 (4.1 - 18.4)	76 (54 - 90)
Mana_5a	1,121 (595 - 1,957)	5.6 (1.7 - 10.7)	60 (27 - 84)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_5b	822 (436 - 1,435)	5.2 (1.6 - 10)	58 (27 - 82)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_5c	55 (29 - 96)	9.2 (3.4 - 16.8)	73 (43 - 93)	8.5 (3.1 - 15.6)	67 (38 - 86)
Mana_5d	96 (51 - 168)	12.5 (4.6 - 22.9)	67 (38 - 86)	12 (4.4 - 21.8)	68 (38 - 87)
Mana_5e	46 (24 - 81)	5.8 (1.2 - 11.6)	53 (17 - 80)	5.7 (1.3 - 10.8)	58 (20 - 83)
Mana_6	1,161 (616 - 2,026)	5.6 (1.7 - 10.6)	59 (27 - 83)	5.7 (1.3 - 10.8)	58 (20 - 83)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_7a	517 (275 - 903)	5.4 (1.2 - 10.6)	56 (20 - 82)	6.4 (1.7 - 11.9)	59 (23 - 83)
Mana_7b	1,379 (732 - 2,407)	7.5 (2.1 - 13.9)	70 (29 - 96)	6.4 (1.7 - 11.9)	59 (23 - 83)
Mana_7c	126 (66 - 219)	5.7 (1.5 - 11.1)	56 (22 - 81)	6.4 (1.7 - 11.9)	59 (23 - 83)
Mana_7d	186 (99 - 326)	4.3 (0.3 - 10.9)	34 (4 - 65)	6.4 (1.7 - 11.9)	59 (23 - 83)
Mana_7e	57 (30 - 100)	5.6 (0.9 - 11.1)	53 (12 - 79)	8.2 (2.3 - 15.3)	61 (25 - 84)
Mana_8a	36 (19 - 63)	2.6 (0.5 - 6.6)	36 (13 - 68)	10.6 (3.8 - 19.4)	66 (37 - 86)
Mana_8b	281 (149 - 490)	8.9 (2.4 - 16.5)	61 (25 - 84)	10.6 (3.8 - 19.4)	66 (37 - 86)
Mana_8c	624 (332 - 1,090)	10.9 (3.8 - 19.9)	69 (37 - 91)	10.4 (3.6 - 19)	66 (35 - 86)
Mana_8d	282 (149 - 492)	8.9 (2.4 - 16.5)	60 (24 - 83)	10.6 (3.8 - 19.4)	66 (37 - 86)
Mana_9a	3,078 (1,635 - 5,374)	6.2 (1.8 - 11.7)	61 (26 - 85)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_9b	23 (12 - 41)	4.4 (0.3 - 9.8)	44 (5 - 76)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_9c	131 (69 - 229)	5.3 (0.9 - 10.5)	56 (14 - 84)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_9d	211 (112 - 368)	4.2 (1.2 - 8.4)	51 (28 - 77)	5.7 (1.3 - 10.8)	57 (19 - 82)
Mana_9e	252 (134 - 441)	4.3 (1.3 - 8.6)	52 (27 - 77)	5.7 (1.3 - 10.8)	57 (19 - 82)
Ohau_1a	51 (30 - 79)	2.3 (0.5 - 5.8)	43 (15 - 88)	5.9 (2 - 10.9)	67 (38 - 89)
Ohau_1b	156 (94 - 241)	3.6 (1.2 - 8.1)	41 (24 - 71)	5.9 (2 - 10.9)	67 (38 - 89)
Owha_1	329 (169 - 546)	6.2 (2 - 12.9)	73 (41 - 95)	0 (0 - 0)	0 (0 - 0)
Rang_1	139 (81 - 274)	0.9 (0 - 3)	24 (2 - 65)	0 (0 - 2.7)	0 (0 - 55)
Rang_2a	221 (129 - 436)	1.7 (0.3 - 4.7)	51 (16 - 93)	0 (0 - 2.5)	0 (0 - 53)
Rang_2b	896 (525 - 1,770)	1.2 (0.1 - 3.6)	28 (5 - 63)	0 (0 - 0)	0 (0 - 0)
Rang_2c	78 (45 - 154)	0.4 (0 - 2.9)	5 (0 - 62)	0 (0 - 2.4)	0 (0 - 54)
Rang_2d	183 (107 - 363)	0 (0 - 2.6)	0 (0 - 51)	0 (0 - 0)	0 (0 - 0)
Rang_2e	296 (173 - 586)	0.6 (0 - 3.5)	4 (0 - 57)	0 (0 - 0)	0 (0 - 0)
Rang_2f	101 (59 - 201)	0.4 (0 - 3.4)	0 (0 - 60)	0 (0 - 3.8)	0 (0 - 44)
Rang_2g	205 (120 - 405)	1.4 (0 - 4.6)	20 (0 - 52)	0 (0 - 3.8)	0 (0 - 44)
Rang_3a	1,246 (729 - 2,460)	1.8 (0.4 - 5.1)	43 (19 - 76)	0 (0 - 0)	0 (0 - 0)
Rang_3b	66 (39 - 131)	2.1 (0.1 - 7.4)	25 (2 - 65)	0.9 (0 - 6.8)	2 (0 - 62)
Rang_4a	2,204 (1,291 - 4,353)	2.5 (0.9 - 6.4)	41 (25 - 62)	0 (0 - 0)	0 (0 - 0)
Rang_4b	2,178 (1,276 - 4,301)	2.5 (0.9 - 6.4)	42 (26 - 63)	0 (0 - 0)	0 (0 - 0)
Rang_4c	138 (81 - 273)	7.1 (2.7 - 16.2)	74 (49 - 90)	7.1 (2.7 - 16.2)	74 (49 - 90)
Rang_4d	2,140 (1,253 - 4,226)	2.4 (0.8 - 6.2)	38 (22 - 59)	0 (0 - 0)	0 (0 - 0)
Tura_1a	402 (212 - 693)	3.3 (0.3 - 8)	40 (5 - 71)	6.9 (3 - 12.5)	80 (54 - 92)
Tura_1b	813 (429 - 1,402)	6.9 (3 - 12.5)	79 (54 - 92)	6.9 (3 - 12.5)	79 (53 - 92)
Tura_1c	5 (2 - 9)	0 (0 - 0)	0 (0 - 0)	8 (4.2 - 14.2)	95 (89 - 98)
West_1	57 (31 - 91)	4.3 (0.8 - 10.2)	46 (15 - 78)	3.4 (0 - 10.1)	32 (0 - 77)
West_2	158 (95 - 262)	5 (1.6 - 10)	58 (31 - 80)	4.1 (0 - 10)	44 (0 - 80)
West_3	17 (9 - 27)	2.5 (1.2 - 4.3)	26 (21 - 29)	0 (0 - 0)	0 (0 - 0)
West_4	37 (20 - 61)	3.3 (1.6 - 5.4)	42 (35 - 45)	0 (0 - 0)	0 (0 - 0)
West_5	37 (21 - 60)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	79 (44 - 114)	0 (0 - 0.2)	0 (0 - 2)	0 (0 - 0)	0 (0 - 0)
West_7	12 (5 - 19)	4 (1.9 - 6.7)	43 (40 - 49)	0 (0 - 3.2)	0 (0 - 37)
West_8	13 (6 - 20)	2.7 (0.3 - 5.7)	30 (4 - 54)	2.4 (0 - 5.7)	26 (0 - 54)
West_9a	159 (95 - 244)	5.9 (2 - 10.9)	67 (38 - 89)	5.9 (2 - 10.9)	67 (38 - 89)
West_9b	26 (14 - 48)	8 (3.2 - 16.4)	82 (62 - 94)	8 (3.2 - 16.4)	82 (62 - 94)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Whai_1	172 (92 - 272)	2.4 (0.1 - 5.2)	47 (5 - 89)	1.2 (0 - 4)	17 (0 - 71)
Whai_2a	489 (261 - 773)	2 (0.1 - 4.4)	36 (4 - 69)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_2b	31 (16 - 49)	0.9 (0 - 2.6)	39 (3 - 117)	0.9 (0 - 3.4)	15 (0 - 71)
Whai_2c	139 (74 - 220)	1.9 (0.2 - 4)	45 (7 - 82)	0.9 (0 - 3.4)	13 (0 - 70)
Whai_2d	45 (24 - 72)	3.1 (0.3 - 6.2)	53 (9 - 83)	3 (0 - 6.2)	51 (0 - 83)
Whai_2e	385 (205 - 608)	2.2 (0.1 - 4.7)	42 (5 - 79)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_2f	458 (244 - 724)	5.3 (1.2 - 9.4)	70 (29 - 92)	4.8 (0.9 - 8.8)	62 (17 - 87)
Whai_2g	1,031 (549 - 1,628)	3.3 (0.4 - 6.4)	61 (15 - 99)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_3	1,424 (759 - 2,249)	3.3 (0.4 - 6.5)	47 (11 - 77)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_4a	2,783 (1,484 - 4,394)	3.5 (0.3 - 7.3)	38 (6 - 67)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_4b	699 (372 - 1,103)	3.8 (0.1 - 9.2)	32 (1 - 71)	2.8 (0 - 9.5)	18 (0 - 72)
Whai_4c	826 (440 - 1,304)	4 (0.1 - 9.3)	33 (1 - 72)	2.7 (0 - 9.3)	17 (0 - 71)
Whai_4d	326 (174 - 515)	0.3 (0 - 3.4)	0 (0 - 38)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_5a	4,945 (2,636 - 7,806)	2.6 (0.2 - 6.6)	29 (3 - 65)	0.8 (0 - 6.6)	0 (0 - 65)
Whai_5b	518 (276 - 817)	2.2 (0 - 7)	19 (0 - 69)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_5c	3,896 (2,077 - 6,151)	3.1 (0.2 - 7.1)	33 (4 - 68)	1.4 (0 - 7.1)	7 (0 - 68)
Whai_5d	5 (2 - 8)	0.5 (0 - 2.2)	12 (0 - 66)	0.9 (0 - 2.8)	21 (0 - 73)
Whai_5e	11 (6 - 18)	0.6 (0 - 2.5)	14 (0 - 75)	0.5 (0 - 2.9)	4 (0 - 67)
Whai_5f	26 (13 - 41)	1 (0 - 3.2)	19 (0 - 67)	0.5 (0 - 2.9)	4 (0 - 67)
Whai_5g	91 (48 - 144)	1.5 (0.1 - 3.4)	36 (4 - 78)	0.4 (0 - 2.9)	2 (0 - 66)
Whai_5h	18 (9 - 28)	1.4 (0 - 3.5)	40 (1 - 91)	0.6 (0 - 2.6)	9 (0 - 69)
Whai_5i	317 (169 - 501)	0.7 (0 - 2.8)	9 (1 - 45)	0.8 (0 - 6.6)	0 (0 - 65)
Whai_5j	37 (19 - 58)	0 (0 - 3.3)	0 (0 - 46)	0.8 (0 - 6.6)	0 (0 - 65)
Whai_6	5,544 (2,955 - 8,751)	2.5 (0.2 - 6.6)	27 (3 - 64)	0.6 (0 - 6.5)	0 (0 - 64)
Whai_7a	5,757 (3,069 - 9,088)	2.6 (0.2 - 6.6)	28 (3 - 65)	0.6 (0 - 6.5)	0 (0 - 64)
Whai_7b	5,915 (3,153 - 9,337)	2.5 (0.2 - 6.6)	28 (4 - 64)	0.6 (0 - 6.6)	0 (0 - 64)
Whai_7c	78 (41 - 123)	4.6 (0.8 - 8.4)	58 (14 - 79)	0.6 (0 - 6.5)	0 (0 - 64)
Whai_7d	62 (33 - 99)	1.3 (0.6 - 2.1)	15 (11 - 17)	0.6 (0 - 6.5)	0 (0 - 64)
Whau_1a	134 (75 - 229)	1.7 (0.2 - 3.8)	53 (9 - 91)	1.2 (0 - 3.1)	33 (0 - 76)
Whau_1b	24 (13 - 41)	0.1 (0 - 3.3)	0 (0 - 53)	2.6 (0.5 - 5.4)	57 (16 - 84)
Whau_1c	63 (35 - 108)	1.8 (0.1 - 4.1)	55 (8 - 97)	1.2 (0 - 3.1)	33 (0 - 76)
Whau_2	347 (194 - 590)	1.8 (0.2 - 4.6)	36 (6 - 71)	0 (0 - 3.3)	0 (0 - 40)
Whau_3a	1,122 (628 - 1,909)	2.5 (0.5 - 5.6)	39 (15 - 65)	0 (0 - 3.3)	0 (0 - 40)
Whau_3b	8 (4 - 14)	1.8 (0 - 4)	47 (1 - 80)	5.1 (2.1 - 9.4)	77 (55 - 92)
Whau_3c	55 (31 - 94)	5.3 (2.2 - 9.7)	80 (59 - 94)	5.1 (2.1 - 9.4)	77 (55 - 92)
Whau_3d	167 (94 - 285)	4.9 (1.7 - 9.2)	73 (44 - 92)	4.6 (1.5 - 8.8)	69 (40 - 89)
Whau_3e	308 (172 - 524)	2.9 (0.8 - 6.5)	58 (27 - 96)	0 (0 - 4.1)	0 (0 - 50)
Whau_3f	8 (4 - 14)	5.3 (2.3 - 9.6)	82 (64 - 95)	5.3 (2.3 - 9.5)	81 (63 - 93)
Whau_4	1,216 (681 - 2,069)	2.5 (0.6 - 5.5)	37 (15 - 61)	0 (0 - 3.3)	0 (0 - 40)

Table 21. TP load reductions required for all WMSZs and 25% UPR

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	15 (8 - 28)	0.55 (0 - 1.27)	41 (0 - 80)	0.7 (0 - 1.5)	50 (0 - 84)
Akit_1b	80 (44 - 148)	0.74 (0.12 - 1.51)	52 (11 - 83)	0.7 (0 - 1.5)	47 (0 - 83)
Akit_1c	13 (7 - 24)	0.53 (0 - 1.15)	49 (0 - 84)	0.7 (0 - 1.5)	50 (0 - 84)
East_1	12 (5 - 20)	0.84 (0.25 - 1.58)	67 (35 - 89)	0.8 (0.3 - 1.6)	67 (35 - 89)
Hoki_1a	5 (2 - 9)	0.29 (0.11 - 0.52)	36 (24 - 43)	0.7 (0.3 - 1.2)	84 (65 - 94)
Hoki_1b	5 (2 - 9)	0.66 (0.31 - 1.19)	87 (67 - 98)	0.6 (0.3 - 1.1)	83 (64 - 94)
Mana_10a	735 (407 - 1,205)	0.65 (0.08 - 1.73)	33 (6 - 69)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_10b	21 (11 - 35)	0.05 (0 - 0.15)	4 (0 - 15)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_10c	53 (29 - 87)	0.16 (0.04 - 0.44)	14 (6 - 27)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_10d	695 (385 - 1,139)	0.62 (0.07 - 1.68)	32 (6 - 68)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_10e	1 (0 - 1)	0.48 (0.22 - 0.91)	78 (58 - 92)	0.5 (0.2 - 0.9)	78 (58 - 92)
Mana_11a	612 (339 - 1,003)	0.85 (0.13 - 2.07)	60 (11 - 95)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_11b	2 (1 - 4)	0.43 (0.14 - 0.88)	63 (32 - 84)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_11c	2 (1 - 4)	0.35 (0.1 - 0.74)	63 (28 - 85)	0.3 (0.1 - 0.7)	62 (28 - 85)
Mana_11d	12 (7 - 20)	0.77 (0.41 - 1.32)	91 (84 - 97)	0.8 (0.4 - 1.3)	92 (85 - 97)
Mana_11e	12 (6 - 19)	0.68 (0.36 - 1.16)	101 (93 - 106)	0.6 (0.3 - 1.1)	91 (83 - 97)
Mana_11f	7 (4 - 11)	0.46 (0.26 - 0.75)	97 (95 - 99)	0.5 (0.3 - 0.8)	97 (95 - 99)
Mana_12a	34 (19 - 56)	0.13 (0.04 - 0.34)	12 (6 - 21)	0.7 (0.3 - 1.3)	82 (67 - 93)
Mana_12b	60 (33 - 99)	0.45 (0.2 - 0.89)	43 (30 - 54)	0.7 (0.3 - 1.3)	82 (67 - 93)
Mana_12c	77 (43 - 127)	0.74 (0.35 - 1.37)	86 (68 - 98)	0.7 (0.3 - 1.3)	82 (67 - 93)
Mana_12d	28 (15 - 46)	0.88 (0.4 - 1.68)	77 (56 - 91)	0.7 (0.3 - 1.3)	82 (67 - 93)
Mana_12e	11 (6 - 18)	0.79 (0.44 - 1.3)	102 (98 - 104)	0.7 (0.4 - 1.2)	96 (93 - 99)
Mana_13a	723 (400 - 1,185)	0.8 (0.18 - 1.82)	64 (20 - 94)	0.7 (0.1 - 1.6)	55 (15 - 83)
Mana_13b	2 (1 - 4)	0.25 (0.01 - 0.62)	47 (4 - 86)	0.3 (0.1 - 0.8)	58 (20 - 84)
Mana_13c	10 (5 - 16)	0.33 (0.12 - 0.73)	57 (31 - 81)	0.3 (0.1 - 0.8)	58 (20 - 84)
Mana_13d	3 (1 - 4)	0.15 (0.03 - 0.45)	24 (6 - 57)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_13e	3 (1 - 5)	0.31 (0.07 - 0.71)	48 (17 - 72)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_13f	2 (1 - 3)	0.01 (0.01 - 0.02)	2 (2 - 3)	0.8 (0.1 - 1.8)	56 (18 - 83)
Mana_1a	93 (51 - 152)	0.59 (0.1 - 1.41)	44 (11 - 77)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_1b	5 (3 - 9)	0.11 (0.03 - 0.25)	15 (6 - 25)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_1c	40 (22 - 66)	0.68 (0.01 - 1.81)	36 (1 - 73)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_2a	104 (58 - 172)	0.61 (0.14 - 1.46)	49 (15 - 79)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_2b	8 (4 - 13)	0.61 (0.3 - 1.08)	85 (72 - 94)	0.6 (0.3 - 1.1)	85 (72 - 94)
Mana_3	2 (1 - 4)	0.29 (0.01 - 0.78)	37 (2 - 74)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_4	1 (0 - 1)	0.37 (0 - 0.94)	49 (1 - 80)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_5a	149 (82 - 245)	0.6 (0.1 - 1.46)	49 (12 - 80)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_5b	116 (64 - 190)	0.59 (0.13 - 1.44)	48 (14 - 78)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_5c	3 (2 - 6)	0.36 (0.05 - 0.83)	40 (7 - 71)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_5d	4 (2 - 7)	0.18 (0.03 - 0.69)	19 (5 - 60)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_5e	5 (3 - 9)	0.42 (0.07 - 1.14)	32 (9 - 68)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_6	154 (85 - 252)	0.61 (0.1 - 1.48)	50 (12 - 81)	0.8 (0.1 - 1.7)	57 (18 - 83)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_7a	94 (52 - 154)	0.74 (0.17 - 1.75)	44 (14 - 75)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_7b	192 (106 - 315)	0.48 (0.08 - 1.26)	33 (7 - 66)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_7c	20 (11 - 33)	0.71 (0.13 - 1.73)	45 (12 - 77)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_7d	23 (13 - 38)	0.17 (0 - 0.88)	10 (0 - 45)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_7e	7 (4 - 12)	0.52 (0 - 1.34)	40 (0 - 74)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_8a	3 (2 - 6)	0.19 (0.01 - 0.63)	27 (2 - 69)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_8b	20 (11 - 33)	0.19 (0 - 0.83)	18 (0 - 60)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_8c	36 (20 - 60)	0.18 (0 - 0.65)	19 (1 - 53)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_8d	19 (10 - 32)	0.19 (0 - 0.8)	18 (0 - 60)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_9a	434 (240 - 711)	0.55 (0.08 - 1.34)	39 (8 - 74)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_9b	1 (1 - 3)	0.21 (0.01 - 0.71)	26 (2 - 71)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_9c	13 (7 - 21)	0.45 (0.05 - 1.1)	49 (9 - 79)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_9d	30 (17 - 50)	0.41 (0.06 - 1.06)	35 (8 - 71)	0.8 (0.1 - 1.7)	57 (18 - 83)
Mana_9e	34 (19 - 57)	0.39 (0.05 - 1.02)	35 (7 - 70)	0.8 (0.1 - 1.7)	57 (18 - 83)
Ohau_1a	6 (3 - 9)	0.24 (0.02 - 0.63)	40 (5 - 86)	0.4 (0 - 0.8)	55 (7 - 86)
Ohau_1b	12 (6 - 19)	0.25 (0.05 - 0.58)	36 (13 - 65)	0.4 (0 - 0.8)	55 (7 - 86)
Owha_1	65 (31 - 123)	1.29 (0.45 - 2.35)	79 (46 - 96)	0 (0 - 0)	0 (0 - 0)
Rang_1	21 (9 - 41)	0.24 (0.05 - 0.55)	53 (11 - 85)	0.2 (0 - 0.5)	35 (0 - 77)
Rang_2a	34 (14 - 65)	0.33 (0.11 - 0.69)	75 (36 - 100)	0.1 (0 - 0.5)	29 (0 - 75)
Rang_2b	206 (87 - 393)	0.37 (0.14 - 0.76)	47 (27 - 60)	0 (0 - 1.8)	0 (0 - 61)
Rang_2c	15 (6 - 28)	0.32 (0.05 - 0.69)	59 (8 - 85)	0.3 (0 - 0.7)	58 (3 - 85)
Rang_2d	28 (12 - 53)	0.3 (0.11 - 0.63)	64 (26 - 85)	0 (0 - 1.8)	0 (0 - 61)
Rang_2e	40 (17 - 77)	0.4 (0.16 - 0.8)	79 (48 - 96)	0 (0 - 1.8)	0 (0 - 61)
Rang_2f	15 (6 - 29)	0.41 (0.15 - 0.84)	76 (42 - 94)	0.6 (0.2 - 1.3)	76 (44 - 91)
Rang_2g	32 (13 - 61)	0.64 (0.25 - 1.27)	76 (45 - 92)	0.6 (0.2 - 1.3)	76 (44 - 91)
Rang_3a	475 (202 - 907)	0.45 (0.17 - 0.92)	31 (19 - 39)	0 (0 - 1.8)	0 (0 - 61)
Rang_3b	13 (5 - 26)	1.01 (0.38 - 2.04)	71 (38 - 88)	0.9 (0.3 - 2)	67 (23 - 88)
Rang_4a	565 (240 - 1,077)	0.66 (0.18 - 1.74)	45 (21 - 88)	0 (0 - 1)	0 (0 - 52)
Rang_4b	515 (219 - 981)	0.65 (0.18 - 1.72)	49 (23 - 96)	0 (0 - 0.9)	0 (0 - 52)
Rang_4c	19 (8 - 36)	1.03 (0.41 - 2.03)	81 (56 - 93)	1 (0.4 - 2)	81 (56 - 93)
Rang_4d	611 (260 - 1,166)	0.68 (0.19 - 1.8)	40 (18 - 80)	0 (0 - 1.1)	0 (0 - 53)
Tura_1a	80 (44 - 136)	1.15 (0.51 - 2.12)	76 (54 - 90)	1.4 (0.8 - 2.5)	87 (75 - 95)
Tura_1b	145 (80 - 247)	1.35 (0.71 - 2.38)	88 (75 - 97)	1.3 (0.7 - 2.3)	85 (72 - 94)
Tura_1c	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.6 (0.3 - 1)	96 (93 - 99)
West_1	8 (3 - 15)	0.7 (0.08 - 1.52)	55 (9 - 84)	0.7 (0 - 1.5)	52 (0 - 84)
West_2	24 (12 - 39)	0.84 (0.32 - 1.57)	65 (38 - 87)	0.7 (0 - 1.5)	54 (1 - 84)
West_3	2 (1 - 3)	0.26 (0.12 - 0.46)	23 (20 - 24)	0 (0 - 0)	0 (0 - 0)
West_4	3 (1 - 5)	0.29 (0.13 - 0.52)	45 (42 - 46)	0 (0 - 0)	0 (0 - 0)
West_5	2 (1 - 5)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	5 (2 - 9)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_7	0 (0 - 1)	0.2 (0.1 - 0.35)	40 (36 - 42)	0 (0 - 0)	0 (0 - 0)
West_8	1 (0 - 2)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_9a	12 (6 - 20)	0.39 (0.05 - 0.77)	56 (13 - 86)	0.4 (0 - 0.8)	55 (7 - 86)
West_9b	1 (0 - 3)	0.51 (0.16 - 0.96)	79 (54 - 93)	0.5 (0.2 - 1)	79 (54 - 93)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Whai_1	18 (9 - 31)	0.3 (0.09 - 0.6)	61 (21 - 89)	0.3 (0.1 - 0.6)	54 (12 - 83)
Whai_2a	51 (26 - 88)	0.24 (0.07 - 0.51)	44 (15 - 69)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_2b	7 (3 - 12)	0.27 (0.1 - 0.52)	64 (31 - 89)	0.3 (0.1 - 0.5)	64 (31 - 87)
Whai_2c	16 (8 - 28)	0.28 (0.09 - 0.56)	59 (24 - 85)	0.3 (0.1 - 0.6)	59 (22 - 85)
Whai_2d	3 (1 - 6)	0.27 (0.09 - 0.53)	60 (24 - 86)	0.3 (0.1 - 0.5)	60 (24 - 86)
Whai_2e	42 (22 - 73)	0.27 (0.08 - 0.55)	51 (18 - 76)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_2f	35 (18 - 60)	0.37 (0.12 - 0.74)	66 (25 - 95)	0.3 (0.1 - 0.7)	59 (23 - 85)
Whai_2g	73 (38 - 126)	0.27 (0.07 - 0.59)	74 (23 - 121)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_3	152 (79 - 262)	0.26 (0.06 - 0.59)	37 (11 - 62)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_4a	369 (193 - 635)	0.27 (0.04 - 0.71)	24 (5 - 46)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_4b	79 (41 - 136)	0.33 (0 - 1.15)	27 (0 - 71)	0.3 (0 - 1.1)	21 (0 - 72)
Whai_4c	90 (47 - 155)	0.31 (0 - 1.1)	26 (0 - 70)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_4d	40 (21 - 69)	0 (0 - 0.29)	0 (0 - 27)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_5a	966 (504 - 1,660)	0.43 (0.03 - 1.29)	26 (2 - 67)	0.3 (0 - 1.7)	13 (0 - 69)
Whai_5b	52 (27 - 90)	0.1 (0 - 0.57)	12 (0 - 59)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_5c	658 (343 - 1,130)	0.44 (0.03 - 1.35)	29 (3 - 70)	0.3 (0 - 1.3)	18 (0 - 70)
Whai_5d	0 (0 - 1)	0.21 (0.05 - 0.44)	56 (16 - 84)	0.2 (0.1 - 0.4)	56 (16 - 84)
Whai_5e	1 (0 - 2)	0.22 (0.05 - 0.47)	55 (13 - 85)	0.2 (0.1 - 0.5)	55 (14 - 84)
Whai_5f	3 (1 - 5)	0.24 (0.05 - 0.51)	54 (13 - 83)	0.2 (0.1 - 0.5)	55 (14 - 84)
Whai_5g	11 (6 - 20)	0.25 (0.05 - 0.53)	53 (13 - 83)	0.2 (0 - 0.5)	52 (8 - 83)
Whai_5h	2 (1 - 4)	0.25 (0.06 - 0.51)	55 (15 - 84)	0.2 (0.1 - 0.5)	55 (14 - 84)
Whai_5i	52 (27 - 89)	0.15 (0.02 - 0.45)	18 (3 - 48)	0.3 (0 - 1.7)	13 (0 - 69)
Whai_5j	3 (1 - 5)	0 (0 - 0.13)	0 (0 - 26)	0.3 (0 - 1.7)	13 (0 - 69)
Whai_6	1,418 (740 - 2,436)	0.54 (0.02 - 1.69)	24 (1 - 67)	0.3 (0 - 1.7)	13 (0 - 69)
Whai_7a	1,352 (705 - 2,322)	0.56 (0.03 - 1.7)	28 (2 - 73)	0.2 (0 - 1.6)	13 (0 - 69)
Whai_7b	1,231 (642 - 2,115)	0.55 (0.03 - 1.67)	31 (3 - 81)	0.2 (0 - 1.5)	12 (0 - 68)
Whai_7c	13 (7 - 23)	0.99 (0.47 - 1.72)	74 (56 - 87)	0.3 (0 - 1.7)	13 (0 - 69)
Whai_7d	7 (4 - 13)	0.14 (0.07 - 0.23)	13 (12 - 14)	0.2 (0 - 1.6)	13 (0 - 69)
Whau_1a	25 (13 - 47)	0.42 (0.19 - 0.85)	78 (51 - 91)	0.4 (0.2 - 0.8)	77 (49 - 91)
Whau_1b	2 (1 - 4)	0.37 (0.16 - 0.74)	77 (49 - 91)	0.5 (0.2 - 0.9)	82 (60 - 93)
Whau_1c	11 (6 - 21)	0.41 (0.17 - 0.83)	76 (45 - 91)	0.4 (0.2 - 0.8)	77 (49 - 91)
Whau_2	57 (30 - 105)	0.48 (0.2 - 0.97)	64 (38 - 79)	0.2 (0 - 1.2)	7 (0 - 64)
Whau_3a	266 (140 - 487)	0.51 (0.17 - 1.2)	35 (16 - 64)	0.2 (0 - 1.2)	7 (0 - 64)
Whau_3b	0 (0 - 1)	0.18 (0.01 - 0.42)	62 (6 - 91)	0.3 (0.1 - 0.6)	65 (22 - 87)
Whau_3c	2 (1 - 4)	0.19 (0.06 - 0.42)	67 (25 - 89)	0.3 (0.1 - 0.6)	65 (22 - 87)
Whau_3d	10 (5 - 18)	0.31 (0.1 - 0.66)	78 (32 - 102)	0.3 (0.1 - 0.6)	65 (22 - 87)
Whau_3e	47 (24 - 86)	0.22 (0.06 - 0.49)	31 (11 - 55)	0.2 (0 - 1.2)	7 (0 - 64)
Whau_3f	0 (0 - 0)	0.21 (0.06 - 0.45)	67 (22 - 89)	0.3 (0.1 - 0.6)	65 (22 - 87)
Whau_4	269 (142 - 493)	0.5 (0.16 - 1.17)	35 (16 - 65)	0.1 (0 - 1.1)	1 (0 - 62)

Table 22. TN load reductions required for all WMSZs and 30% UPR

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	110 (66 - 156)	0 (0 - 6.5)	0 (0 - 58)	0.8 (0 - 7.8)	1 (0 - 65)
Akit_1b	531 (320 - 754)	3 (0.5 - 7.9)	31 (10 - 68)	0 (0 - 6.7)	0 (0 - 59)
Akit_1c	112 (68 - 160)	2.3 (0 - 7.2)	23 (0 - 63)	0.8 (0 - 7.8)	1 (0 - 65)
East_1	88 (51 - 146)	2.3 (0.1 - 7)	22 (2 - 60)	0 (0 - 6.6)	0 (0 - 57)
Hoki_1a	56 (31 - 93)	4.3 (1.9 - 7.7)	46 (34 - 59)	7.4 (3.4 - 12.8)	81 (62 - 92)
Hoki_1b	63 (34 - 104)	7.5 (3.5 - 12.9)	80 (61 - 92)	7.5 (3.5 - 12.9)	80 (61 - 92)
Mana_10a	3,733 (2,072 - 6,762)	4.1 (0.4 - 11.2)	37 (8 - 72)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_10b	114 (63 - 208)	0.5 (0 - 1.6)	7 (0 - 20)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_10c	249 (138 - 452)	1.4 (0.2 - 3.7)	23 (7 - 49)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_10d	3,602 (1,999 - 6,525)	4.1 (0.4 - 11.3)	36 (7 - 72)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_10e	15 (8 - 27)	6.9 (2.2 - 14.6)	73 (42 - 92)	6.9 (2.2 - 14.6)	73 (42 - 92)
Mana_11a	4,186 (2,323 - 7,584)	4.7 (0.8 - 12.7)	43 (14 - 81)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_11b	33 (18 - 59)	4 (0.6 - 10.1)	46 (13 - 77)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_11c	37 (20 - 67)	4 (0.2 - 10.7)	44 (4 - 81)	3.7 (0 - 10.7)	38 (0 - 81)
Mana_11d	134 (74 - 242)	7.7 (3.4 - 15.1)	85 (69 - 95)	7.9 (3.6 - 15.1)	89 (77 - 97)
Mana_11e	157 (87 - 285)	7.9 (3.6 - 15.1)	89 (77 - 97)	7.9 (3.6 - 15.1)	89 (77 - 97)
Mana_11f	149 (82 - 270)	9.3 (4.7 - 17.2)	94 (88 - 98)	9.3 (4.7 - 17.2)	94 (88 - 98)
Mana_12a	187 (104 - 339)	1.3 (0.4 - 3.3)	20 (11 - 37)	7.2 (2.8 - 14.6)	79 (55 - 94)
Mana_12b	603 (334 - 1,092)	2.9 (0.7 - 8.4)	24 (12 - 53)	7.2 (2.8 - 14.6)	79 (55 - 94)
Mana_12c	794 (440 - 1,439)	7.2 (2.8 - 14.6)	79 (55 - 94)	7.2 (2.8 - 14.6)	79 (55 - 94)
Mana_12d	211 (117 - 383)	4.2 (1.2 - 10.7)	43 (25 - 76)	7.2 (2.8 - 14.6)	79 (55 - 94)
Mana_12e	132 (73 - 240)	8.1 (3.7 - 15.4)	89 (77 - 97)	8.1 (3.7 - 15.4)	89 (77 - 97)
Mana_13a	5,399 (2,996 - 9,780)	5 (1.1 - 12.6)	49 (21 - 82)	3 (0 - 11.3)	20 (0 - 75)
Mana_13b	26 (14 - 48)	1.6 (0.1 - 5.5)	23 (2 - 73)	2.7 (0 - 9.7)	23 (0 - 76)
Mana_13c	139 (77 - 252)	4.5 (1.1 - 10.8)	51 (25 - 81)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_13d	41 (22 - 74)	2.2 (0.5 - 5.5)	24 (10 - 43)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_13e	49 (27 - 90)	3.9 (0.8 - 9.5)	38 (15 - 62)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_13f	36 (20 - 65)	0.3 (0.1 - 0.5)	3 (2 - 3)	3 (0 - 11.4)	21 (0 - 76)
Mana_1a	608 (337 - 1,102)	3.8 (0.6 - 10.3)	38 (13 - 75)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_1b	82 (45 - 149)	1.2 (0 - 6.8)	6 (0 - 44)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_1c	175 (97 - 317)	3.1 (0 - 10.1)	31 (0 - 79)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_2a	754 (419 - 1,367)	4 (0.6 - 10.7)	41 (12 - 76)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_2b	108 (60 - 196)	6.1 (0.6 - 14.3)	57 (10 - 86)	6 (0.3 - 14.3)	56 (6 - 86)
Mana_3	20 (11 - 36)	2.7 (0.2 - 7.6)	36 (4 - 74)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_4	19 (10 - 35)	9.3 (1.9 - 20.6)	65 (25 - 89)	9.3 (1.9 - 20.6)	65 (25 - 89)
Mana_5a	1,126 (625 - 2,039)	4.1 (0.5 - 11.1)	40 (10 - 77)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_5b	825 (458 - 1,495)	3.9 (0.5 - 10.3)	39 (11 - 74)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_5c	55 (30 - 101)	7.5 (1.2 - 18)	56 (18 - 88)	5.9 (0 - 16.7)	40 (0 - 81)
Mana_5d	97 (53 - 175)	9.2 (0.4 - 24.6)	44 (4 - 81)	8.4 (0 - 23.4)	40 (0 - 82)
Mana_5e	46 (25 - 84)	4 (0.4 - 11.7)	33 (7 - 72)	3.2 (0 - 11.6)	22 (0 - 76)
Mana_6	1,166 (647 - 2,112)	4.1 (0.5 - 11)	39 (10 - 75)	3.2 (0 - 11.6)	22 (0 - 76)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_7a	519 (288 - 941)	3.8 (0.5 - 10.9)	35 (9 - 75)	3.7 (0 - 12.9)	26 (0 - 77)
Mana_7b	1,385 (768 - 2,509)	5.3 (0.3 - 15)	43 (5 - 89)	3.7 (0 - 12.9)	26 (0 - 77)
Mana_7c	126 (70 - 229)	4 (0.5 - 11.4)	36 (9 - 74)	3.7 (0 - 12.9)	26 (0 - 77)
Mana_7d	187 (104 - 339)	0.9 (0 - 9.2)	0 (0 - 54)	3.7 (0 - 12.9)	26 (0 - 77)
Mana_7e	57 (32 - 104)	2.9 (0 - 11.5)	17 (0 - 72)	5 (0 - 16.5)	28 (0 - 78)
Mana_8a	36 (20 - 66)	2.1 (0.3 - 6.3)	27 (7 - 65)	7.3 (0 - 20.8)	38 (0 - 81)
Mana_8b	282 (156 - 511)	5.9 (0.1 - 17.8)	33 (1 - 78)	7.3 (0 - 20.8)	38 (0 - 81)
Mana_8c	627 (348 - 1,136)	7.9 (0.2 - 21.4)	45 (2 - 85)	7 (0 - 20.4)	37 (0 - 81)
Mana_8d	283 (157 - 513)	5.9 (0.1 - 17.9)	33 (1 - 77)	7.3 (0 - 20.8)	38 (0 - 81)
Mana_9a	3,092 (1,716 - 5,601)	4.5 (0.4 - 12.5)	40 (7 - 78)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_9b	23 (13 - 42)	2.6 (0 - 9.2)	22 (1 - 67)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_9c	131 (73 - 239)	3.5 (0.1 - 10.7)	32 (3 - 75)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_9d	212 (117 - 384)	3.6 (0.7 - 9.4)	42 (16 - 75)	3.1 (0 - 11.6)	22 (0 - 76)
Mana_9e	253 (140 - 460)	3.6 (0.6 - 9.5)	41 (14 - 74)	3.1 (0 - 11.6)	22 (0 - 76)
Ohau_1a	53 (30 - 88)	1.9 (0.3 - 5.3)	32 (8 - 80)	5.6 (1.2 - 11.5)	59 (21 - 86)
Ohau_1b	163 (93 - 269)	3.3 (1.2 - 7.4)	35 (21 - 57)	5.6 (1.2 - 11.5)	59 (21 - 86)
Owha_1	332 (183 - 530)	5.7 (0.8 - 11.2)	65 (20 - 92)	0 (0 - 0)	0 (0 - 0)
Rang_1	136 (81 - 219)	0.5 (0 - 2.1)	11 (0 - 52)	0 (0 - 1.7)	0 (0 - 41)
Rang_2a	217 (130 - 348)	1.2 (0.1 - 3.4)	38 (5 - 81)	0 (0 - 1.6)	0 (0 - 39)
Rang_2b	883 (528 - 1,415)	0.7 (0 - 2.3)	16 (2 - 46)	0 (0 - 0)	0 (0 - 0)
Rang_2c	77 (46 - 123)	0 (0 - 1.9)	0 (0 - 47)	0 (0 - 1.5)	0 (0 - 39)
Rang_2d	181 (108 - 290)	0 (0 - 1.5)	0 (0 - 34)	0 (0 - 0)	0 (0 - 0)
Rang_2e	292 (174 - 468)	0 (0 - 2.1)	0 (0 - 39)	0 (0 - 0)	0 (0 - 0)
Rang_2f	100 (60 - 160)	0 (0 - 1.8)	0 (0 - 34)	0 (0 - 0.9)	0 (0 - 11)
Rang_2g	202 (121 - 324)	0.5 (0 - 2.6)	8 (0 - 34)	0 (0 - 0.9)	0 (0 - 11)
Rang_3a	1,227 (734 - 1,966)	1.3 (0.3 - 3.4)	31 (14 - 61)	0 (0 - 0)	0 (0 - 0)
Rang_3b	65 (39 - 105)	0.9 (0 - 4.4)	10 (1 - 45)	0 (0 - 3.8)	0 (0 - 39)
Rang_4a	2,171 (1,298 - 3,480)	2 (0.8 - 4.5)	34 (21 - 53)	0 (0 - 0)	0 (0 - 0)
Rang_4b	2,145 (1,283 - 3,438)	2 (0.8 - 4.5)	35 (22 - 54)	0 (0 - 0)	0 (0 - 0)
Rang_4c	136 (81 - 218)	6.3 (2.1 - 12.4)	66 (34 - 87)	6.2 (2 - 12.4)	65 (32 - 87)
Rang_4d	2,108 (1,261 - 3,378)	1.9 (0.7 - 4.3)	30 (18 - 50)	0 (0 - 0)	0 (0 - 0)
Tura_1a	400 (213 - 626)	1.5 (0.1 - 5.9)	15 (2 - 56)	6.1 (1.9 - 11.5)	69 (32 - 89)
Tura_1b	809 (431 - 1,268)	6.1 (1.9 - 11.5)	69 (32 - 89)	6 (1.8 - 11.5)	68 (31 - 89)
Tura_1c	5 (2 - 8)	0 (0 - 0)	0 (0 - 0)	7.8 (3.9 - 12.6)	92 (83 - 97)
West_1	58 (31 - 98)	2.9 (0.6 - 7.6)	29 (12 - 64)	0 (0 - 7)	0 (0 - 60)
West_2	154 (79 - 233)	3.9 (0.7 - 7.9)	45 (13 - 71)	0.7 (0 - 6.7)	0 (0 - 66)
West_3	16 (8 - 28)	2.3 (0.7 - 4.2)	25 (17 - 29)	0 (0 - 0)	0 (0 - 0)
West_4	38 (23 - 60)	3.3 (1.9 - 5.5)	41 (36 - 44)	0 (0 - 0)	0 (0 - 0)
West_5	39 (20 - 66)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	80 (36 - 129)	0 (0 - 0.2)	0 (0 - 3)	0 (0 - 0)	0 (0 - 0)
West_7	12 (6 - 20)	3.8 (1.8 - 6.5)	43 (37 - 51)	0 (0 - 3.2)	0 (0 - 44)
West_8	13 (7 - 22)	2.9 (0.1 - 6.3)	30 (2 - 57)	2.4 (0 - 6.3)	24 (0 - 57)
West_9a	165 (94 - 273)	5.7 (1.3 - 11.5)	61 (21 - 86)	5.6 (1.2 - 11.5)	59 (21 - 86)
West_9b	23 (12 - 35)	6.6 (2.8 - 11.2)	76 (59 - 90)	6.6 (2.8 - 11.2)	76 (59 - 90)

WMSZ	TN load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Whai_1	181 (90 - 286)	1.9 (0.1 - 5.4)	35 (4 - 77)	0.2 (0 - 4)	0 (0 - 59)
Whai_2a	514 (257 - 813)	1.5 (0.1 - 4.3)	24 (3 - 55)	0 (0 - 4.8)	0 (0 - 41)
Whai_2b	33 (16 - 52)	0.7 (0 - 2.3)	25 (2 - 87)	0.1 (0 - 3.3)	0 (0 - 57)
Whai_2c	146 (73 - 231)	1.5 (0.1 - 4.1)	33 (5 - 69)	0 (0 - 3.3)	0 (0 - 56)
Whai_2d	47 (24 - 75)	2.6 (0.2 - 6.4)	42 (6 - 75)	2.5 (0 - 6.4)	37 (0 - 75)
Whai_2e	404 (202 - 640)	1.7 (0.1 - 4.7)	29 (4 - 65)	0 (0 - 4.8)	0 (0 - 41)
Whai_2f	481 (241 - 761)	4.9 (1 - 10.2)	60 (22 - 86)	4.4 (0.5 - 9.6)	51 (9 - 81)
Whai_2g	1,082 (542 - 1,712)	2.6 (0.3 - 6.4)	44 (11 - 82)	0 (0 - 4.8)	0 (0 - 41)
Whai_3	1,495 (748 - 2,365)	2.5 (0.3 - 6.4)	33 (8 - 63)	0 (0 - 4.8)	0 (0 - 41)
Whai_4a	2,922 (1,463 - 4,621)	2.3 (0.2 - 6.5)	23 (4 - 51)	0 (0 - 4.8)	0 (0 - 41)
Whai_4b	734 (367 - 1,160)	1.9 (0 - 7)	13 (0 - 45)	0 (0 - 6.9)	0 (0 - 46)
Whai_4c	867 (434 - 1,372)	2 (0 - 7)	13 (0 - 46)	0 (0 - 6.7)	0 (0 - 45)
Whai_4d	343 (171 - 542)	0 (0 - 1.9)	0 (0 - 20)	0 (0 - 4.8)	0 (0 - 41)
Whai_5a	5,191 (2,598 - 8,209)	1.5 (0.1 - 4.4)	15 (2 - 37)	0 (0 - 4.1)	0 (0 - 36)
Whai_5b	544 (272 - 860)	0 (0 - 4.6)	0 (0 - 41)	0 (0 - 4.8)	0 (0 - 41)
Whai_5c	4,091 (2,047 - 6,469)	1.9 (0.2 - 5.4)	18 (3 - 43)	0 (0 - 4.8)	0 (0 - 41)
Whai_5d	5 (2 - 9)	0 (0 - 1.9)	0 (0 - 50)	0.3 (0 - 2.9)	0 (0 - 60)
Whai_5e	12 (6 - 19)	0 (0 - 2.3)	0 (0 - 57)	0 (0 - 2.6)	0 (0 - 52)
Whai_5f	27 (13 - 43)	0.4 (0 - 3)	1 (0 - 54)	0 (0 - 2.6)	0 (0 - 52)
Whai_5g	95 (48 - 151)	1.2 (0.1 - 3.5)	27 (3 - 65)	0 (0 - 2.6)	0 (0 - 51)
Whai_5h	19 (9 - 30)	1.1 (0 - 3.5)	26 (0 - 76)	0 (0 - 2.5)	0 (0 - 55)
Whai_5i	333 (166 - 527)	0.6 (0 - 1.7)	9 (1 - 24)	0 (0 - 4.1)	0 (0 - 36)
Whai_5j	39 (19 - 61)	0 (0 - 0.9)	0 (0 - 11)	0 (0 - 4.1)	0 (0 - 36)
Whai_6	5,820 (2,913 - 9,204)	1.4 (0.1 - 4.1)	14 (2 - 34)	0 (0 - 3.8)	0 (0 - 34)
Whai_7a	6,044 (3,025 - 9,557)	1.5 (0.1 - 4.1)	15 (2 - 35)	0 (0 - 3.8)	0 (0 - 34)
Whai_7b	6,210 (3,108 - 9,819)	1.5 (0.1 - 4.1)	15 (3 - 35)	0 (0 - 3.9)	0 (0 - 34)
Whai_7c	82 (41 - 129)	4.1 (0.5 - 9.1)	47 (6 - 74)	0 (0 - 3.8)	0 (0 - 34)
Whai_7d	66 (33 - 104)	1.3 (0.5 - 2.2)	14 (10 - 16)	0 (0 - 3.8)	0 (0 - 34)
Whau_1a	127 (71 - 224)	1 (0 - 2.9)	33 (1 - 77)	0.3 (0 - 2.3)	0 (0 - 63)
Whau_1b	23 (12 - 41)	0 (0 - 0.7)	0 (0 - 15)	1.7 (0 - 4.7)	34 (0 - 76)
Whau_1c	60 (33 - 106)	1.1 (0 - 3.1)	33 (2 - 81)	0.3 (0 - 2.3)	0 (0 - 63)
Whau_2	327 (183 - 578)	0.9 (0 - 2.6)	19 (1 - 51)	0 (0 - 0)	0 (0 - 0)
Whau_3a	1,057 (592 - 1,869)	1.6 (0.2 - 3.7)	25 (5 - 47)	0 (0 - 0)	0 (0 - 0)
Whau_3b	7 (4 - 14)	1.1 (0 - 3.2)	26 (0 - 69)	4.2 (0.7 - 8.8)	65 (18 - 87)
Whau_3c	52 (29 - 92)	4.4 (1.3 - 9.1)	69 (24 - 89)	4.2 (0.7 - 8.8)	65 (18 - 87)
Whau_3d	158 (88 - 279)	3.8 (0.8 - 8.4)	59 (15 - 86)	3.5 (0 - 8.1)	53 (0 - 83)
Whau_3e	290 (162 - 513)	1.9 (0.4 - 4.1)	39 (10 - 65)	0 (0 - 0.4)	0 (0 - 5)
Whau_3f	8 (4 - 14)	4.4 (1.5 - 9.1)	72 (32 - 91)	4.4 (1.5 - 9)	71 (33 - 89)
Whau_4	1,146 (642 - 2,026)	1.6 (0.3 - 3.7)	24 (5 - 45)	0 (0 - 0)	0 (0 - 0)

Table 23. TP load reductions required for all WMSZs and 30% UPR

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Akit_1a	19 (9 - 35)	0.32 (0 - 1.32)	21 (0 - 68)	0.4 (0 - 1.8)	27 (0 - 74)
Akit_1b	98 (50 - 181)	0.64 (0.12 - 1.7)	38 (9 - 72)	0.3 (0 - 1.7)	20 (0 - 71)
Akit_1c	16 (8 - 30)	0.43 (0 - 1.31)	34 (0 - 73)	0.4 (0 - 1.8)	27 (0 - 74)
East_1	13 (6 - 27)	0.62 (0.05 - 1.57)	48 (3 - 79)	0.6 (0 - 1.6)	45 (0 - 79)
Hoki_1a	4 (2 - 9)	0.25 (0.05 - 0.6)	31 (8 - 42)	0.6 (0.2 - 1.3)	75 (42 - 92)
Hoki_1b	5 (2 - 10)	0.59 (0.19 - 1.33)	77 (41 - 96)	0.6 (0.2 - 1.3)	74 (39 - 92)
Mana_10a	758 (389 - 1,485)	0.4 (0.04 - 1.47)	19 (3 - 62)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_10b	22 (11 - 43)	0.02 (0 - 0.11)	2 (0 - 8)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_10c	54 (28 - 107)	0.12 (0.01 - 0.3)	10 (1 - 21)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_10d	717 (368 - 1,404)	0.38 (0.04 - 1.42)	18 (3 - 60)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_10e	1 (0 - 2)	0.45 (0.13 - 1)	69 (27 - 91)	0.5 (0.1 - 1)	69 (27 - 91)
Mana_11a	632 (324 - 1,237)	0.58 (0.07 - 1.91)	37 (6 - 89)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_11b	2 (1 - 5)	0.37 (0.04 - 0.94)	52 (8 - 83)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_11c	2 (1 - 5)	0.3 (0.01 - 0.79)	51 (3 - 85)	0.3 (0 - 0.8)	47 (0 - 85)
Mana_11d	13 (6 - 25)	0.77 (0.37 - 1.5)	88 (72 - 97)	0.8 (0.4 - 1.5)	89 (75 - 97)
Mana_11e	12 (6 - 24)	0.68 (0.33 - 1.32)	98 (81 - 106)	0.6 (0.3 - 1.2)	88 (71 - 97)
Mana_11f	7 (3 - 14)	0.47 (0.24 - 0.93)	96 (91 - 99)	0.5 (0.2 - 0.9)	96 (91 - 99)
Mana_12a	35 (18 - 69)	0.1 (0.02 - 0.23)	9 (3 - 16)	0.7 (0.3 - 1.4)	75 (43 - 93)
Mana_12b	62 (32 - 122)	0.41 (0.1 - 0.93)	37 (13 - 52)	0.7 (0.3 - 1.4)	75 (43 - 93)
Mana_12c	80 (41 - 157)	0.71 (0.27 - 1.51)	78 (43 - 98)	0.7 (0.3 - 1.4)	75 (43 - 93)
Mana_12d	29 (14 - 57)	0.82 (0.2 - 1.83)	68 (24 - 91)	0.7 (0.3 - 1.4)	75 (43 - 93)
Mana_12e	11 (6 - 23)	0.8 (0.41 - 1.58)	100 (93 - 104)	0.8 (0.4 - 1.5)	95 (87 - 98)
Mana_13a	746 (383 - 1,462)	0.59 (0.1 - 1.72)	44 (11 - 89)	0.4 (0 - 1.6)	24 (0 - 79)
Mana_13b	2 (1 - 5)	0.17 (0 - 0.66)	29 (1 - 85)	0.2 (0 - 0.7)	29 (0 - 80)
Mana_13c	10 (5 - 20)	0.28 (0.08 - 0.72)	46 (19 - 76)	0.2 (0 - 0.7)	29 (0 - 80)
Mana_13d	3 (1 - 6)	0.09 (0.02 - 0.37)	14 (5 - 49)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_13e	3 (1 - 6)	0.22 (0.04 - 0.66)	31 (7 - 67)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_13f	2 (1 - 4)	0.01 (0.01 - 0.03)	2 (2 - 3)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_1a	96 (49 - 188)	0.39 (0.05 - 1.32)	27 (5 - 71)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_1b	6 (3 - 11)	0 (0 - 0.2)	0 (0 - 20)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_1c	41 (21 - 81)	0.38 (0 - 1.64)	18 (0 - 66)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_2a	108 (55 - 212)	0.43 (0.07 - 1.35)	32 (8 - 74)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_2b	8 (4 - 16)	0.56 (0.22 - 1.18)	75 (41 - 93)	0.6 (0.2 - 1.2)	75 (41 - 93)
Mana_3	2 (1 - 4)	0.2 (0 - 0.84)	22 (0 - 73)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_4	1 (0 - 2)	0.27 (0 - 0.96)	31 (0 - 79)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_5a	154 (79 - 302)	0.41 (0.05 - 1.35)	31 (6 - 75)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_5b	120 (61 - 235)	0.41 (0.06 - 1.34)	31 (7 - 73)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_5c	4 (2 - 8)	0.23 (0 - 0.78)	23 (0 - 64)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_5d	4 (2 - 9)	0 (0 - 0.55)	0 (0 - 51)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_5e	5 (3 - 11)	0.26 (0.01 - 0.96)	18 (1 - 60)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_6	159 (81 - 311)	0.41 (0.05 - 1.37)	31 (6 - 76)	0.4 (0 - 1.7)	27 (0 - 79)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Mana_7a	97 (49 - 190)	0.52 (0.09 - 1.63)	29 (8 - 69)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_7b	198 (101 - 388)	0.31 (0.04 - 1.07)	20 (4 - 58)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_7c	20 (10 - 40)	0.49 (0.06 - 1.61)	29 (6 - 72)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_7d	24 (12 - 47)	0 (0 - 0.69)	0 (0 - 38)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_7e	7 (3 - 14)	0.24 (0 - 1.25)	15 (0 - 68)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_8a	3 (2 - 7)	0.1 (0 - 0.6)	9 (0 - 68)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_8b	21 (10 - 41)	0 (0 - 0.66)	0 (0 - 51)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_8c	38 (19 - 74)	0 (0 - 0.5)	0 (0 - 44)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_8d	20 (10 - 39)	0 (0 - 0.64)	0 (0 - 51)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_9a	448 (230 - 877)	0.36 (0.04 - 1.18)	23 (4 - 67)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_9b	2 (1 - 3)	0 (0 - 0.59)	0 (0 - 63)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_9c	13 (7 - 27)	0.29 (0 - 1.02)	29 (0 - 74)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_9d	31 (16 - 62)	0.32 (0.02 - 1.13)	25 (2 - 70)	0.4 (0 - 1.7)	27 (0 - 79)
Mana_9e	36 (18 - 70)	0.3 (0.02 - 1.07)	25 (2 - 68)	0.4 (0 - 1.7)	27 (0 - 79)
Ohau_1a	6 (3 - 13)	0.2 (0 - 0.66)	28 (0 - 77)	0.3 (0 - 0.9)	41 (0 - 81)
Ohau_1b	13 (6 - 27)	0.23 (0.04 - 0.58)	29 (9 - 57)	0.3 (0 - 0.9)	41 (0 - 81)
Owha_1	62 (30 - 107)	1.12 (0.39 - 2.34)	72 (36 - 94)	0 (0 - 0)	0 (0 - 0)
Rang_1	20 (9 - 35)	0.18 (0.03 - 0.46)	41 (8 - 79)	0.1 (0 - 0.4)	12 (0 - 70)
Rang_2a	32 (15 - 55)	0.28 (0.08 - 0.57)	64 (30 - 96)	0 (0 - 0.4)	4 (0 - 68)
Rang_2b	196 (94 - 338)	0.32 (0.1 - 0.61)	41 (22 - 56)	0 (0 - 1)	0 (0 - 38)
Rang_2c	14 (6 - 24)	0.25 (0 - 0.58)	46 (1 - 81)	0.2 (0 - 0.6)	44 (0 - 81)
Rang_2d	27 (13 - 46)	0.25 (0.06 - 0.5)	54 (19 - 79)	0 (0 - 1)	0 (0 - 38)
Rang_2e	38 (18 - 67)	0.35 (0.12 - 0.67)	72 (42 - 92)	0 (0 - 1)	0 (0 - 38)
Rang_2f	14 (7 - 25)	0.36 (0.1 - 0.69)	68 (30 - 91)	0.6 (0.2 - 1.1)	68 (32 - 89)
Rang_2g	30 (14 - 52)	0.56 (0.16 - 1.07)	69 (32 - 89)	0.6 (0.2 - 1.1)	68 (32 - 89)
Rang_3a	454 (218 - 781)	0.39 (0.12 - 0.74)	28 (15 - 36)	0 (0 - 1)	0 (0 - 38)
Rang_3b	13 (6 - 22)	0.87 (0.25 - 1.69)	63 (26 - 85)	0.8 (0.1 - 1.6)	56 (7 - 85)
Rang_4a	539 (259 - 927)	0.46 (0.14 - 1.08)	31 (18 - 56)	0 (0 - 0.5)	0 (0 - 24)
Rang_4b	491 (236 - 845)	0.45 (0.14 - 1.07)	35 (20 - 62)	0 (0 - 0.4)	0 (0 - 24)
Rang_4c	18 (8 - 31)	0.92 (0.33 - 1.67)	75 (46 - 91)	0.9 (0.3 - 1.7)	75 (46 - 91)
Rang_4d	583 (281 - 1,004)	0.46 (0.14 - 1.1)	28 (15 - 51)	0 (0 - 0.5)	0 (0 - 27)
Tura_1a	84 (42 - 165)	1.07 (0.19 - 2.4)	66 (14 - 90)	1.4 (0.6 - 2.9)	81 (54 - 95)
Tura_1b	153 (77 - 300)	1.34 (0.58 - 2.69)	83 (54 - 97)	1.3 (0.5 - 2.6)	79 (48 - 94)
Tura_1c	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.6 (0.3 - 1.1)	95 (88 - 99)
West_1	9 (4 - 16)	0.44 (0.06 - 1.17)	32 (8 - 68)	0.3 (0 - 1.2)	18 (0 - 68)
West_2	25 (12 - 46)	0.82 (0.31 - 1.72)	60 (39 - 74)	0.6 (0 - 1.5)	43 (0 - 71)
West_3	2 (0 - 3)	0.25 (0.1 - 0.41)	22 (18 - 24)	0 (0 - 0)	0 (0 - 0)
West_4	3 (1 - 5)	0.31 (0.15 - 0.57)	44 (42 - 46)	0 (0 - 0)	0 (0 - 0)
West_5	3 (1 - 5)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_6	5 (2 - 10)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_7	0 (0 - 1)	0.22 (0.1 - 0.45)	39 (35 - 42)	0 (0 - 0)	0 (0 - 0)
West_8	1 (0 - 2)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
West_9a	14 (6 - 27)	0.37 (0.04 - 0.86)	47 (9 - 81)	0.3 (0 - 0.9)	41 (0 - 81)
West_9b	1 (0 - 2)	0.39 (0.06 - 0.74)	69 (17 - 91)	0.4 (0.1 - 0.7)	69 (17 - 91)

WMSZ	TP load (t yr^{-1})	Point-WMSZ load reduction required		Critical-WMSZ load reduction required	
		Yield (kg ha^{-1} yr^{-1})	Proportion (%)	Yield (kg ha^{-1} yr^{-1})	Proportion (%)
Whai_1	19 (8 - 38)	0.27 (0.01 - 0.66)	52 (1 - 85)	0.2 (0 - 0.6)	42 (0 - 80)
Whai_2a	54 (24 - 107)	0.21 (0 - 0.53)	37 (1 - 62)	0 (0 - 0.9)	0 (0 - 57)
Whai_2b	7 (3 - 15)	0.25 (0.01 - 0.58)	55 (3 - 86)	0.2 (0 - 0.6)	54 (2 - 84)
Whai_2c	17 (7 - 35)	0.26 (0.01 - 0.62)	51 (2 - 82)	0.2 (0 - 0.6)	49 (0 - 82)
Whai_2d	4 (1 - 7)	0.25 (0 - 0.59)	52 (1 - 82)	0.2 (0 - 0.6)	50 (0 - 82)
Whai_2e	45 (20 - 89)	0.25 (0.01 - 0.6)	43 (1 - 71)	0 (0 - 0.9)	0 (0 - 57)
Whai_2f	37 (16 - 73)	0.34 (0.03 - 0.82)	56 (4 - 91)	0.3 (0 - 0.7)	49 (0 - 82)
Whai_2g	77 (34 - 153)	0.23 (0.01 - 0.55)	59 (3 - 108)	0 (0 - 0.9)	0 (0 - 57)
Whai_3	160 (71 - 318)	0.22 (0.01 - 0.54)	29 (1 - 55)	0 (0 - 0.9)	0 (0 - 57)
Whai_4a	389 (173 - 771)	0.2 (0.01 - 0.51)	16 (1 - 38)	0 (0 - 0.9)	0 (0 - 57)
Whai_4b	83 (37 - 165)	0 (0 - 0.77)	0 (0 - 55)	0 (0 - 0.9)	0 (0 - 57)
Whai_4c	94 (42 - 188)	0 (0 - 0.73)	0 (0 - 54)	0 (0 - 0.9)	0 (0 - 57)
Whai_4d	42 (18 - 84)	0 (0 - 0.14)	0 (0 - 15)	0 (0 - 0.9)	0 (0 - 57)
Whai_5a	1,017 (453 - 2,018)	0.26 (0 - 0.95)	14 (0 - 52)	0 (0 - 1.2)	0 (0 - 54)
Whai_5b	55 (24 - 109)	0 (0 - 0.36)	0 (0 - 40)	0 (0 - 0.9)	0 (0 - 57)
Whai_5c	692 (308 - 1,373)	0.27 (0 - 0.95)	17 (0 - 57)	0 (0 - 0.9)	0 (0 - 57)
Whai_5d	0 (0 - 1)	0.19 (0 - 0.48)	46 (0 - 81)	0.2 (0 - 0.5)	45 (0 - 81)
Whai_5e	1 (0 - 3)	0.19 (0 - 0.51)	44 (0 - 82)	0.2 (0 - 0.6)	43 (0 - 80)
Whai_5f	3 (1 - 6)	0.21 (0 - 0.56)	44 (0 - 80)	0.2 (0 - 0.6)	43 (0 - 80)
Whai_5g	12 (5 - 24)	0.22 (0 - 0.57)	44 (0 - 79)	0.2 (0 - 0.6)	40 (0 - 79)
Whai_5h	2 (1 - 5)	0.22 (0 - 0.56)	46 (0 - 80)	0.2 (0 - 0.6)	44 (0 - 80)
Whai_5i	55 (24 - 109)	0.08 (0 - 0.3)	9 (0 - 31)	0 (0 - 1.2)	0 (0 - 54)
Whai_5j	3 (1 - 6)	0 (0 - 0.01)	0 (0 - 3)	0 (0 - 1.2)	0 (0 - 54)
Whai_6	1,492 (665 - 2,961)	0.32 (0 - 1.25)	13 (0 - 51)	0 (0 - 1.2)	0 (0 - 54)
Whai_7a	1,422 (633 - 2,822)	0.34 (0.01 - 1.25)	15 (1 - 56)	0 (0 - 1.1)	0 (0 - 54)
Whai_7b	1,295 (577 - 2,570)	0.33 (0.02 - 1.23)	17 (1 - 62)	0 (0 - 1.1)	0 (0 - 53)
Whai_7c	14 (6 - 28)	0.97 (0.39 - 1.86)	69 (40 - 86)	0 (0 - 1.2)	0 (0 - 54)
Whai_7d	8 (3 - 16)	0.15 (0.06 - 0.28)	13 (11 - 14)	0 (0 - 1.1)	0 (0 - 54)
Whau_1a	25 (12 - 50)	0.39 (0.11 - 0.82)	71 (43 - 90)	0.4 (0.1 - 0.8)	69 (40 - 89)
Whau_1b	2 (1 - 5)	0.33 (0.09 - 0.7)	70 (40 - 90)	0.4 (0.1 - 0.9)	76 (52 - 92)
Whau_1c	11 (5 - 23)	0.37 (0.09 - 0.78)	67 (35 - 89)	0.4 (0.1 - 0.8)	69 (40 - 89)
Whau_2	57 (27 - 112)	0.43 (0.1 - 0.91)	57 (29 - 76)	0 (0 - 0.7)	0 (0 - 47)
Whau_3a	265 (127 - 519)	0.37 (0.08 - 0.82)	26 (12 - 46)	0 (0 - 0.7)	0 (0 - 47)
Whau_3b	0 (0 - 1)	0.15 (0 - 0.37)	48 (0 - 87)	0.2 (0 - 0.5)	53 (8 - 84)
Whau_3c	2 (1 - 4)	0.17 (0.02 - 0.37)	56 (17 - 85)	0.2 (0 - 0.5)	53 (8 - 84)
Whau_3d	10 (4 - 19)	0.27 (0.04 - 0.59)	67 (20 - 99)	0.2 (0 - 0.5)	53 (8 - 84)
Whau_3e	46 (22 - 92)	0.17 (0.03 - 0.38)	23 (8 - 38)	0 (0 - 0.7)	0 (0 - 47)
Whau_3f	0 (0 - 0)	0.18 (0.01 - 0.4)	56 (8 - 86)	0.2 (0 - 0.5)	53 (8 - 84)
Whau_4	268 (128 - 525)	0.36 (0.08 - 0.79)	26 (12 - 47)	0 (0 - 0.6)	0 (0 - 43)

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