

**IN THE ENVIRONMENT COURT
WELLINGTON REGISTRY**

**I TE KŌTI TAIAO O AOTEAROA
TE WHANGANUI-A-TARA ROHE**

UNDER	the Resource Management Act 1991
IN THE MATTER	of appeals under sch 1, cl 14(1) against the decision of Manawatū-Whanganui Regional Council on Plan Change 2 to the One Plan
BETWEEN	TE RUNANGA O RAUKAWA ENV-2021-WLG-20 NGĀTI TURANGA ENV-2021-WLG-21 ANDREW DAY ENV-2021-WLG-22 WELLINGTON FISH AND GAME COUNCIL ENV-2021-WLG-23 Appellants
AND	MANAWATŪ-WHANGANUI REGIONAL COUNCIL Respondent

**STATEMENT OF EVIDENCE OF DR ANTONIUS HUGH SNELDER ON BEHALF OF THE
MANAWATŪ-WHANGANUI REGIONAL COUNCIL**

STATE OF ENVIRONMENT AND WATER QUALITY MODELLING

Dated: 6 October 2023



Cooper Rapley Lawyers
227-231 Broadway Avenue
PO Box 1945
Palmerston North
DX PP80001

S Johnston / A J R Sinclair
 06 353 5210
 06 356 4345
sjohnston@crlaw.co.nz

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STATEMENT OF EVIDENCE OF DR ANTONIUS HUGH SNELDER**A. INTRODUCTION**

- [1] My name is Antonius Hugh Snelder. I am currently employed as an environmental management researcher and consultant. I have been in that position since 2014. Prior to that I was employed by Aqualinc Research Limited (2012–2014) and NIWA (1995–2013) in similar positions. Prior to this I was employed as a water resources engineer by Auckland Regional Council (1992–1995), the consulting company Connell Wagner (1988–1991) and Auckland Regional Water Board (1985–1988).
- [2] My role involves undertaking research and consulting to regional councils, central government and other organisations on issues concerning the management of land, water quality and water quantity.
- [3] I hold a Bachelor of Agricultural Engineering degree from the University of Canterbury, a post graduate diploma in hydrology from the University of New South Wales (Australia) and a PhD in environmental management from Lincoln University. I am a member of the New Zealand Freshwater Sciences Society and the New Zealand Hydrological Society. In my current and previous positions, I was the leader of many projects that have assessed water quality in freshwater environments, and the association between water quality and land use at catchment, regional and national scales. I have written several guidelines for the management of water quality and quantity and developed several tools for water management purposes. I have authored or co-authored 59 scientific publications in the field of water resources management, including those that address water quality.
- [4] I have been engaged by Manawatū-Whanganui Regional Council (**Horizons**) to develop, apply, and interpret catchment models for the Horizons region (**Region**) including those associated with management of nitrogen leaching from intensive farming land uses (**IFLU**) under Plan Change 2 (**PC2**). More recently I have assessed the water quality impacts arising out of proposed amendments to the decisions version of PC2 (**DV-PC2**) following expert discussions and mediation. In both modelling and assessing water quality

impacts of PC2 I have also considered the current regional water quality state and trends.

[5] As part of my role, I authored the following reports:

- (a) I led the development of four catchment nitrogen models for the Region (Snelder et al., 2020a) and their subsequent updates (Cox et al. 2022). The details of these models are described in the evidence of Dr Timothy Cox; and
- (b) I led the simulation of several scenarios concerning nitrogen management in the Region (Snelder et al. 2020b). The results of these simulations were discussed in my Section 42A evidence. I have attached these reports at **Attachment A** of my evidence.

[6] I have been involved in five studies of water quality and its relationships to resource use in the Region over the previous six years:

- (a) A study investigating recent reductions in the microbial indicator *Escherichia coli* and sediment in rivers of the Region and the relationship between these trends and Horizons' water quality interventions (Snelder 2018).
- (b) Two state of environment (**SoE**) studies of water quality for the Region. The first study (Fraser and Snelder 2018) analysed water quality records for all river and lake monitoring sites in the Region. This study assessed state and trends for all sites and monitored water quality variables. The second study (Fraser and Snelder 2020) used statistical modelling methods to relate water quality state and trends to catchment characteristics such as climate, geology, land use and point sources. The outputs of this study were relationships linking water quality state and trends with catchment character and resource use, or changes in resource use in the case of trends, and maps of predicted current water quality at unmonitored locations across the Region.

- (c) In 2021 I led a regional study that assessed the nutrient load reductions that are required to achieve a range of potential objectives in the rivers and lakes of the Region (Snelder and Fraser, 2021).
 - (d) I also reviewed a recent analysis of water quality state and trends in the Rivers, Lakes, Coastal and Estuary sites in the Manawatū-Whanganui Region (Fraser 2023).
- [7] I participated in the Council-level hearing for PC2. I prepared s 42A reports on the water quality state and trends in the Region in 2020, including an analysis of water quality outcomes anticipated to result under a range of scenarios concerning management of nitrogen leaching from IFLU on land across the Region.
- [8] I have not been involved in the expert discussions between farm system and planning experts or the mediations since the appeals were commenced. As I explain below, I am familiar with the proposed risk assessment tool, through ongoing discussions with Professor Horne, Dr Jolly and Ms Patterson.

B. CODE OF CONDUCT

- [9] I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2023. This evidence has been prepared in accordance with that Code. I confirm that I have not omitted to consider material facts that might alter or detract from the opinions that I express. The evidence I am giving is within my area of expertise, except where I state I am relying on the opinion or evidence of other witnesses. I understand it is my duty to assist the Court impartially on relevant matters within my areas of expertise.

C. SCOPE OF EVIDENCE

- [10] My evidence provides an overview and update of the water quality assessment and analysis carried out in relation to PC2, and discusses:
- (a) current water quality state and trends in the Region;

- (b) an assessment of water quality outcomes anticipated to result under a range of scenarios concerning management of nitrogen leaching from IFLU on land across the Region;
 - (i) the baseline;
 - (ii) a scenario relevant to the decision version of PC2 (**DV-PC2**); and
 - (iii) a scenario relevant to amendments to DV-PC2 proposed by Horizons and other parties.

[11] In addition to my own observations, I rely on the evidence of my colleague Dr Timothy Cox, who constructed and applied the water quality model and ran the original scenarios, Professor David Horne, Dr Anne-Maree Jolly, and Ms Maree Patterson provided.

[12] This evidence is limited to technical matters and I do not provide recommendations on matters of policy.

D. BACKGROUND

[13] I have been involved in several studies on the water quality effects of agriculture throughout New Zealand and in the Region. One of the most consistent markers of agricultural land use on water quality is enrichment of nitrogen in downstream receiving environments (groundwater, lakes, rivers and estuaries). Differences between background (i.e., natural) nitrogen concentrations and loads and current levels are generally predictable using knowledge of the amount and intensity of agricultural land use in a catchment.¹ It is generally observed in New Zealand that receiving environments in catchments with appreciable levels of agricultural land use have levels of nitrogen that exceed regulatory thresholds.²

¹ Snelder, T.H., S.T. Larned, and R.W. McDowell, 2018. *Anthropogenic Increases of Catchment Nitrogen and Phosphorus Loads in New Zealand*. New Zealand Journal of Marine and Freshwater Research 52:336–361.

² Snelder, T.H., A.L. Whitehead, C. Fraser, S.T. Larned, and M. Schallenberg, 2020. *Nitrogen Loads to New Zealand Aquatic Receiving Environments: Comparison with Regulatory Criteria*. New Zealand Journal of Marine and Freshwater Research:1–24.

- [14] PC2 will have effects on instream loads and concentrations of nitrogen in freshwater receiving environments across the Region. These effects will be spatially variable for two reasons. First, changes in land use practices resulting from PC2 will not be evenly distributed across the Region, meaning that future land use intensity will vary between the Region's catchments. Second, there is environmentally mediated variation in both potential nitrogen losses from land use and the processing of nitrogen (attenuation) as it moves through the drainage network. Because these two factors interact, the water quality outcomes of PC2 are complex and their detailed evaluation requires catchment water quality modelling.
- [15] Along with my colleague Dr Cox, I used a water quality model to predict nitrogen loads and concentrations at 124 river assessment points under a range of nitrogen leaching management scenarios in the development of PC2. The model was used to evaluate water quality outcomes of a number of scenarios as part of the evidence Dr Cox and I presented for the DV-PC2. Development of the water quality models used for this purpose is described in the evidence of Dr Cox.
- [16] I understand that, following the Government's response to the Overseer peer review report being released, and through expert discussions since lodgement of the appeals on PC2, amendments to the DV-PC2 are now proposed, to include a risk assessment tool. This tool is discussed further in the evidence of Dr Jolly and Associate Professor Horne.
- [17] On the basis of discussions with Dr Jolly and Professor Horne, I understand that the risk assessment tool assesses risk of nitrogen leaching at the farm scale based on scoring a number of management factors, while also accounting for biophysical factors (rainfall and soil type) as part of a broader risk matrix. The risk assessment tool generates an assessed risk profile for nitrogen leaching, with the accompanying rule framework requiring reductions to a specified risk level (being Low).
- [18] I also understand that the risk assessment tool would be an alternative consenting pathway to the Overseer-based cumulative nitrogen leaching maximums (**CNLM**) contained in existing Table 14.2 within the One Plan. It is

proposed that the risk assessment tool would replace the specified nitrogen reduction pathways (20% for pastoral and 35% for commercial vegetable growing (CVG)) included in the DV-PC2.

[19] My colleague Dr Cox explains in his evidence how, as part of evidence presented during the Council level hearing for DV-PC2, we used a water quality model to predict nitrogen loads and concentrations under several scenarios that simulated the then proposed regulations.

[20] The modelling provided a way of quantifying the impact of recent actions (i.e., consenting of some IFLU and changes to points sources) and on nitrogen loads and concentrations in the Region's rivers, and other scenarios, including changes that might occur under PC2. The model allowed the specific impacts of management actions to be isolated and quantified. Monitoring data cannot be used to assess the impact of any one management action because the effects are confounded by the impacts of multiple resource uses and variable natural processes, both of which influence nitrogen levels over time. However, congruence between the model's predictions of changes due to management actions and observations of changes in monitoring data provide insights into the impacts that nitrogen management has already had on in-stream nitrogen loads and concentrations across the Region. I discuss the outcomes of the scenario modelling in section H in my evidence.

[21] The equivalent water quality modelling has not been undertaken to assess the water quality impacts of the risk management tool that is now proposed by Horizons. As I explain below, drawing on the previous modelling work, I was able to use a simplified approach to assess the water quality impacts of the proposed amendments to the DV-PC2. At section I of my evidence, I explain the assessment I have undertaken and the conclusions I have been able to make regarding the impact of the proposed risk assessment tool on catchment nitrogen loads and concentrations.

E. EXECUTIVE SUMMARY

[22] The key conclusions of my evidence are:

- (a) An analysis of water quality data for the 20-year period ending 30 June 2022 indicates that a majority of SoE sites, both within the Region generally and within the target catchments, fail to achieve the One Plan targets for four water quality indicators that are relevant to PC2 (being soluble inorganic nitrogen and periphyton biomass as quantified by cover of mats and filaments and concentration of chlorophyll *a*). Importantly, a high proportion of sites both within the Region (71%) and within the target catchments (78%) were assigned a fail state grade for SIN and a large proportion of these failed by a large margin, indicating that current SIN concentrations are considerably higher than the One Plan targets.
- (b) Water quality temporal trends in SIN, chlorophyll *a* and periphyton mats over the 10-year trend period ending 30 June 2022 were predominantly degrading. In contrast, trends in SIN over the 20-year period were predominantly improving. Trends only indicate the detection of a change in water quality and provide no insight into the causes of those changes. It is understood that climatic variation has a considerable impact on water quality, especially at time scales of a decade due to the influence of climatic processes such as the El Niño southern oscillation.
- (c) I am therefore cautious about inferring that changes in nitrogen management are responsible for the observed generally degrading conditions pertaining to nutrient concentrations over the last 10 years. However, the SIN improvements at the 20-year time scale are less likely to be influenced by short-term climatic variation than those at the 10-year time scale and are consistent with decreasing total stocking pressure in the region reported by Snelder et al (2021). The 20-year time-scale result is evidence that over the long run, changes in nitrogen management will result in reductions of nitrogen loads and concentrations in the region's rivers and all other things being equal, this should result in decreases in periphyton biomass.

- (d) As part of the earlier development of PC2, I worked with Dr Cox to simulate water quality across the Region for a range of historic conditions and nitrogen management scenarios that could occur under the then proposed PC2 provisions. We used the CASM water quality model to simulate the water quality impacts of several scenarios and predicted that for most of these scenarios the mean relative difference between SIN concentrations and the One Plan SIN targets were in the order of 40% to 41% at assessment points downstream of the target catchments under these scenarios (i.e. on average SIN concentrations would exceed the One Plan SIN target by 40% to 41%). These predicted water quality outcomes were a modest improvement on both pre-regulation (45% mean relative difference) and post-regulation (43% mean relative difference) estimates of SIN concentrations.
- (e) In this evidence, I present assessments of water quality outcomes for three scenarios concerning management of nitrogen leaching from IFLU on land across the Region;
- (i) the baseline;
 - (ii) a scenario relevant to DV-PC2; and
 - (iii) a scenario relevant to the proposed amendments to the DV-PC2.
- (f) To inform my water quality assessment, Professor Horne and Dr Jolly have quantified reductions in nitrogen loss from IFLU for the baseline scenario (representing nominally the year 2012 for pastoral and 2018 for CVG) and their best estimate of the likely nitrogen losses associated with implementation of DV-PC2, and implementation of the proposed amendments to DV-PC2. Whereas the previous modelling that was carried out for DV-PC2 considered a wide range of potential scenarios, the assessments of nitrogen loss for IFLU made by Professor Horne and Dr Jolly included two scenarios that represented their opinions concerning the most likely outcomes for the “future” scenarios (i.e., DV-PC2 and the proposed

amendments to the DV-PC2). These reductions in loss are quantified at the spatial-scale of five “sub-regions” that host most of the IFLU land in the Region.

- (g) My assessment of the water quality impacts of these three scenarios indicates that the future scenarios represent modest improvements to baseline water quality, that are consistent with the improvements that were predicted from the earlier modelling performed for DV-PC2. I emphasise that many aspects of the earlier modelling and my assessment presented here are uncertain. Therefore, in my opinion, the two sets of results representing the DV-PC2, and the proposed amendments to DV-PC2 are not significantly or practically different to one another.
- (h) In my opinion, implementing PC2 with the risk assessment tool would result in similarly modest water quality improvements in the target catchments of the Region to those that were predicted for DV-PC2.

F. ASSUMPTIONS AND METHODOLOGY

- [23] The analyses of current state and trend in water quality presented in my evidence were derived from Fraser (2023). All analyses performed by Fraser (2023) were based on standard methods of water quality analysis that are used by the Ministry for the Environment and most regional councils to quantify current water quality state and water quality trends. These methods are also used by Land Air Water Aotearoa to provide assessments of the current state and trends for all regional council river water quality monitoring sites in New Zealand.
- [24] The water quality state is quantified for water quality monitoring sites by calculating statistics such as the median and mean values from the time series of monthly water quality observations. The water quality state statistics are calculated from five years of observations which provide a reasonable trade-off between sample size (and therefore confidence in the statistic) versus the potential influence of trends in the variable over time.

- [25] Water quantity trends are evaluated for water quality monitoring sites using the nonparametric Kendall correlation coefficient and these statistics are used to assign trend direction and assess the statistical confidence in that assessment.
- [26] The simulation of water quality outcomes under nitrogen leaching scenarios associated with the earlier development of PC2 was based on the use of water quality models of the four major catchments in the Region. These models are explained by Dr Cox in his evidence. The assumptions described apply to each of the nitrogen leaching scenarios. Water quality outcomes were simulated using the models by altering the nitrogen leaching rates from specific types of land to reflect the assumptions for each scenario.

G. WATER QUALITY STATE AND TRENDS IN THE MANAWATŪ-WHANGANUI REGION

- [27] Horizons operates an extensive network of water quality monitoring sites throughout the Manawatū-Whanganui Region for monitoring the state and trends in river water quality and reporting on policy effectiveness.
- [28] The most up to date water quality state and trends information is recorded in a report from Fraser (2023).³ This evidence presents only the most salient findings and results pertaining only to nitrogen concentrations and periphyton biomass in the Region's rivers of Fraser's (2023) study, as these measures are the most relevant aspect of water quality in the context of PC2.
- [29] Fraser (2023) analysed data for the soluble inorganic nitrogen (**SIN**) and periphyton biomass at up to 112 river water quality state of environment monitoring sites in the Region. SoE sites were selected as they were considered to not be significantly affected by point source discharges, so they reflect state and trends arising from the combination of diffuse and point sources of contaminants occurring in their catchments. This 2023 study represents the most up to date information on water quality state and

³ Fraser, C. 2023. State and Trends for Water Quality in Rivers, Lakes, Coastal and Estuary sites in the Manawatū-Whanganui Region, Attachment A to the Statement of Evidence of Maree Patterson dated 6 October 2023.

changes in water quality in the Region over the 20-year period ending 30 June 2022.

- [30] Nitrogen is a plant nutrient that stimulates the growth of periphyton (slime attached to the bed of rivers). Periphyton is the base of the food chain and is therefore an important part of the ecosystem. However, if its periphyton growth is excessively stimulated, it can achieve a level of biomass that has adverse effects on ecological health, cultural and recreational values.
- [31] SIN is a dissolved form of nitrogen that is largely composed of nitrate. SIN is readily available for plant growth and its concentration is therefore of direct concern when considering water quality. The state of rivers based on monthly measurements of SIN concentration was assessed at 112 of Horizons' SoE water quality monitoring sites.
- [32] Periphyton is a water quality measure because its biomass (i.e. the abundance of slime in the river) is the biological outcome that is strongly associated with river ecosystem health and other values, and is most directly linked to the management of nutrients in a catchment. Although periphyton responds to levels of nutrients in the water column, the exact relationship between biomass and nitrogen concentrations is complex because other factors such as the flow regime, temperature, light and substrate availability and stability also strongly influence its abundance.
- [33] Horizons' SoE monitoring makes monthly observations of periphyton biomass using two methods. First, biomass "cover" observations are measured as the proportion of the riverbed covered by two categories that describe the type of periphyton: filaments and mats. Second, biomass observations are made as the concentration of Chlorophyll a^4 per unit area of the riverbed. Periphyton biomass measured as filaments and mats was observed monthly at 61 SoE river water quality monitoring sites. Periphyton biomass measured as Chlorophyll a was observed monthly at 60 SoE water quality monitoring sites.

⁴ Chlorophyll a is the pigment that gives the slime its green colour.

- [34] The One Plan has targets for SIN and periphyton biomass (as cover and Chlorophyll *a*). These targets are all defined in terms of a threshold number and a compliance statistic. For SIN the threshold is a set concentration when the river flow is equal to or less than the 20th flow exceedance percentile and the compliance statistic is the mean concentration. For periphyton filaments and mats, the threshold is a maximum cover of filamentous algae more than 2 centimetres long and diatoms or cyanobacteria mats more than 0.3 centimetres thick, respectively. The compliance statistics for both periphyton filaments and mats is all observations, (i.e., the thresholds are maximum values that must not be exceeded). For chlorophyll *a*, the threshold is a mass per unit area of the riverbed and the compliance statistic is all observations, (i.e., the thresholds are maximum values that must not be exceeded). The One Plan target thresholds for SIN, periphyton filaments, mats and chlorophyll *a* are spatially variable reflecting spatial variation in the way rivers are valued and relative differences in expectations concerning their condition.
- [35] For each water quality indicator (SIN and periphyton biomass) and site, Fraser (2023) calculated the relevant compliance statistic (such as the mean concentration of SIN observations when the river flow is equal to or less than the 20th flow exceedance percentile) using the five years of data collected for the period ending 30th of June 2022. The compliance statistic was compared to the relevant target and the site and indicator were assigned a state category of either pass (i.e. the site complies with the target) or fail (i.e. the water quality is worse than the target). This evidence does not describe the details of the exceedance criteria and thresholds, and simply presents maps and tables of the sites Fraser (2023) found passed and failed.
- [36] The One Plan target threshold for SIN is based on assessing the mean of monthly SIN concentrations for which river flow is equal to or less than the 20th flow exceedance percentile). However, some monitoring sites are not associated with appropriate river flow data. For these sites the mean of monthly SIN concentrations was evaluated against all available data; sites for which this has been done are highlighted in the results.

- [37] Fraser (2023) calculated grades at sites using data collected over the five-year period ending 30th of June 2022. In this evidence, sites that had at least 30 observations in that period are given a grade status of “final”. In addition, “interim” results are provided for sites with at least 10 observations in the time period. The interim results are less reliable assessments of state than the those with the final status.
- [38] State was assessed based on 5 years of observations because the statistical precision of the compliance statistics depends on the variability of the water quality observations and the number of observations. In addition to the maps and tables of pass and fail sites, the data describes the ‘relative state’ for SIN. The relative state of SIN at a site indicates the difference between the compliance statistic and the One Plan target, divided by the One Plan target. The relative state is therefore the SIN concentration relative to the target concentration and, where the relative state is greater than zero, it provides a measure of the extent to which SIN currently exceeds the target. The relative state is linked to a measure of the impact on water quality (SIN concentrations) used in the second part of this evidence concerning my assessment of water quality outcomes under DV-PC2 and the proposed amendments to include the risk assessment tool.
- [39] Figure 1 and Table 1 indicate that for SIN, and Chlorophyll *a*, there is a mixture of sites that pass and fail. For SIN, sites are predominantly assigned a fail state grade both regionally (71% of sites) and within the target catchments (78% of sites). For Chlorophyll *a*, sites are predominantly assigned a fail grade regionally (60% of sites) and within the target catchments (61% of sites).
- [40] Figure 1 and Table 1 indicate that for Periphyton Filaments, sites predominantly fail the One Plan targets both regionally (75%) and within the target catchments (78%). For Periphyton Mats, sites predominantly pass the One Plan targets both regionally (77%) and within the target catchments (78%).

Figure 1: Maps showing SoE site state grades based on the Horizons One Plan targets for the four water quality indicators. The state grade of each site is indicated as either a pass or fail. Flow compliant indicates whether the mean SIN concentration was calculated from observations for which river flow is equal to or less than the 20th flow exceedance percentile (True) or was calculated from all observations (False). Observation compliant indicates that the assessment was based on at least 30 observations (Final) or between 10 and 30 observations (Interim).

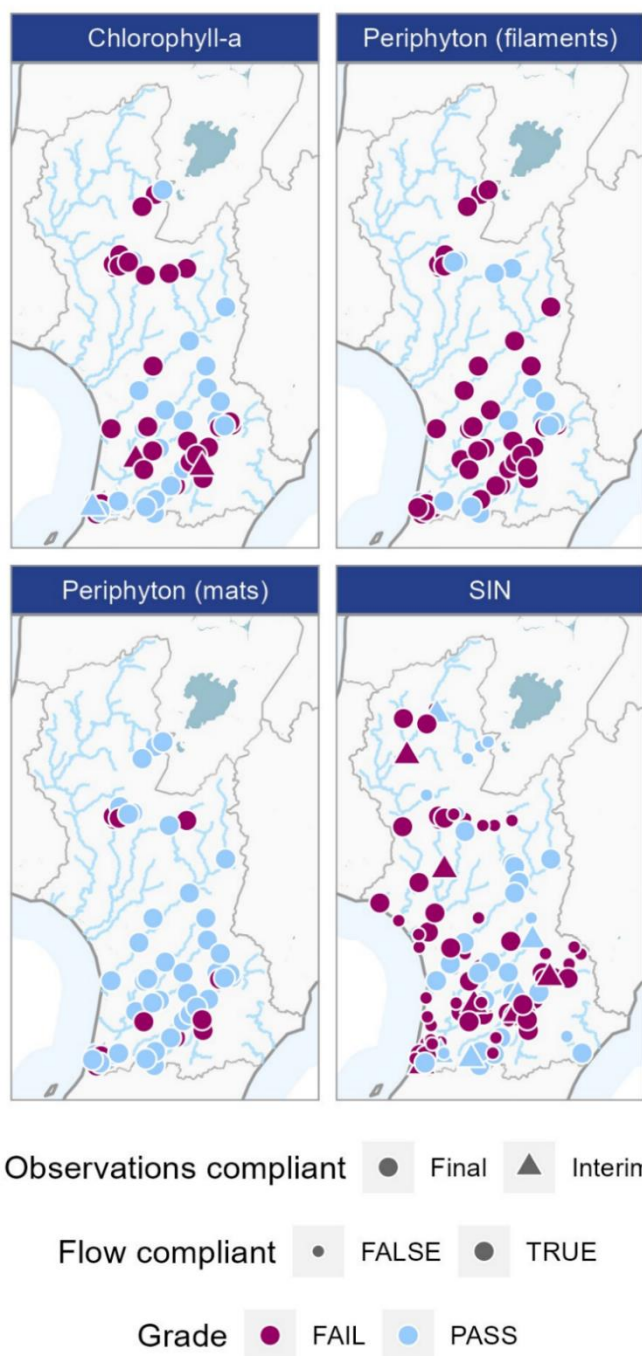


Table 1: Number and proportion (in parentheses, %) of sites in each state grade.

The state grade of each site is indicated as either a pass or fail. Numbers and proportions are shown for all sites in the region and sites within the target catchments.

Water quality indicator	All sites		Target catchments	
	Fail	Pass	Fail	Pass
Soluble Inorganic Nitrogen	97 (71)	40 (29)	47 (78)	13 (22)
Chlorophyll a	40 (60)	27 (40)	17 (61)	11 (39)
Periphyton Filaments	49 (75)	16 (25)	21 (78)	6 (22)
Periphyton Mats	15 (23)	50 (77)	6 (22)	21 (78)

- [41] Figure 2 and Table 2 indicate that sites that are assigned a fail state grade for SIN often have concentrations that are much higher than the One Plan target. For example, 54% of sites regionally and 64% of sites in the target catchments have current SIN concentrations that are more than 50% higher than their One Plan target.

Figure 2: Map showing the state of SoE sites across the region relative to their One Plan targets. The colours are categories indicating the difference between each site's current SIN concentrations compared to their One Plan targets.

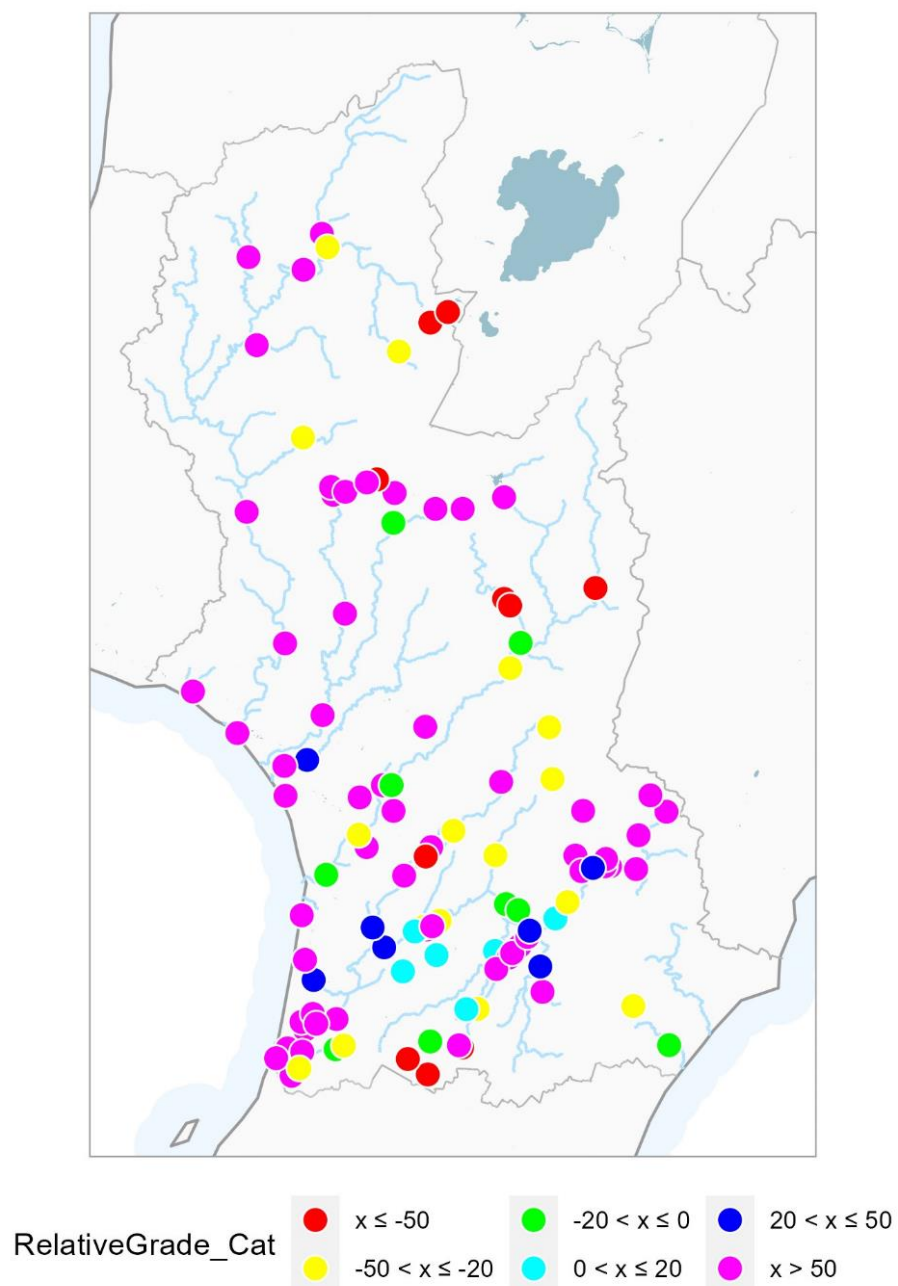


Table 2: Table showing the number and proportion (value in parentheses) of sites in each of six relative state categories.

Relative state category	All sites	Target catchments
< -50%	10 (9)	3 (6)
-50% to -20%	17 (15)	5 (11)
-20% to 0%	9 (8)	4 (9)
0% to 20%	6 (5)	2 (4)
20% to 50%	9 (8)	3 (6)
>50%	59 (54)	30 (64)

- [42] For each water quality indicator and site, Fraser (2023) assessed the trend over two time periods: the 10-years and 20-years ending 30 June 2022. The statistic describing the trend that is presented below is the confidence the trend direction indicated improvement in the variable of interest. This statistic was calculated for each site, time period and water quality indicator, provided there were observations for measurements for at least 80% of the years and at least 80% of months. For all indicators, improvement is indicated by decreasing values over time.
- [43] The confidence the trend was improving is a statistic that varies between zero and one, but it is presented below as the categories shown in Table 3. It is noted that the complement of improvement is degradation and therefore, when confidence the trend was improving is less than 50%, there is the complementary confidence the trend was degrading. For example, a trend categorised as 'unlikely' to be improving is 'likely' to be degrading. This is indicated by the categories shown in Table 3 that indicate the complementary confidence that the trend was degrading.

Table 3: Level of confidence categories used to convey trend confidence and direction.

Categorical level of trend confidence and direction	Confidence the trend was improving (%)
Very likely improving	0.90–1.00
Likely improving	0.67–0.90
Low confidence in direction	0.33–0.67
Likely degrading	0.10–0.33
Very likely degrading	0.0–0.10

- [44] Figure 3 indicates that for the 122 sites for which 10-year SIN trends could be analysed, confidence that the direction was degrading was at least 'Likely' for the majority (72%). For the 34 sites for which 10-year chlorophyll *a* trends could be analysed, confidence that the direction was degrading was at least 'Likely' for the majority (59%). For the 49 sites for which 10-year periphyton mats trends could be analysed, confidence that the direction was degrading was at least 'Likely' for the majority (56%). In contrast, for the 39 sites for which 10-year periphyton filament trends could be analysed, confidence that the direction was degrading was at least 'Likely' for a minority of sites (31%). Across the water quality indicators generally (i.e., for SIN, chlorophyll *a*, and periphyton mats), these results indicate degrading 10-year trends associated with nutrient enrichment.
- [45] Figure 4 indicates that the general pattern of degrading 10-year trends associated with nutrient enrichment (i.e., for SIN, chlorophyll *a*, and periphyton mats) was true for sites in the target catchments as well as for sites located in other catchments. For example, for SIN, chlorophyll *a*, and periphyton mats, 55%, 80% and 65% of sites were at least 'Likely' to be degrading, respectively.

Figure 3: Map showing the 10-year trends at sites across the region for which there was sufficient data. The colours represent the categorical descriptors indicating the trend was improving shown in Table 3.

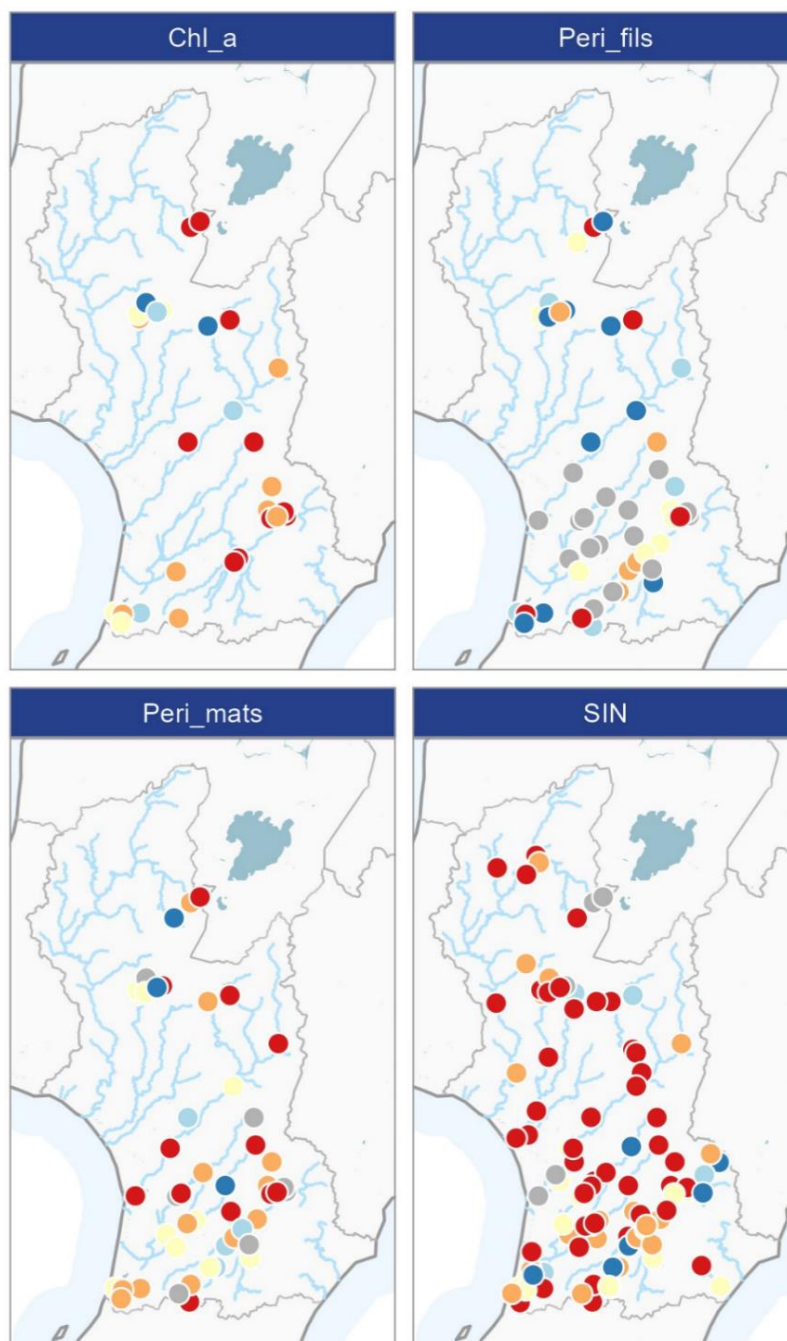
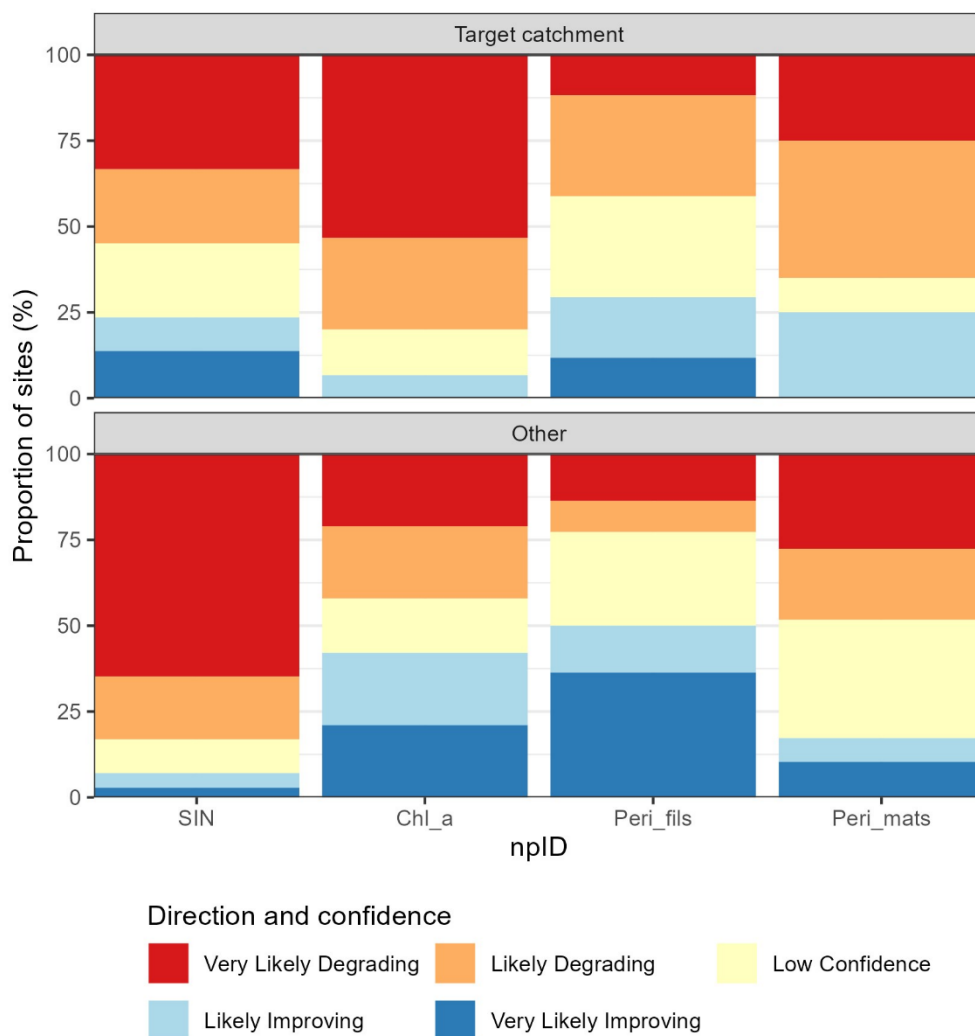
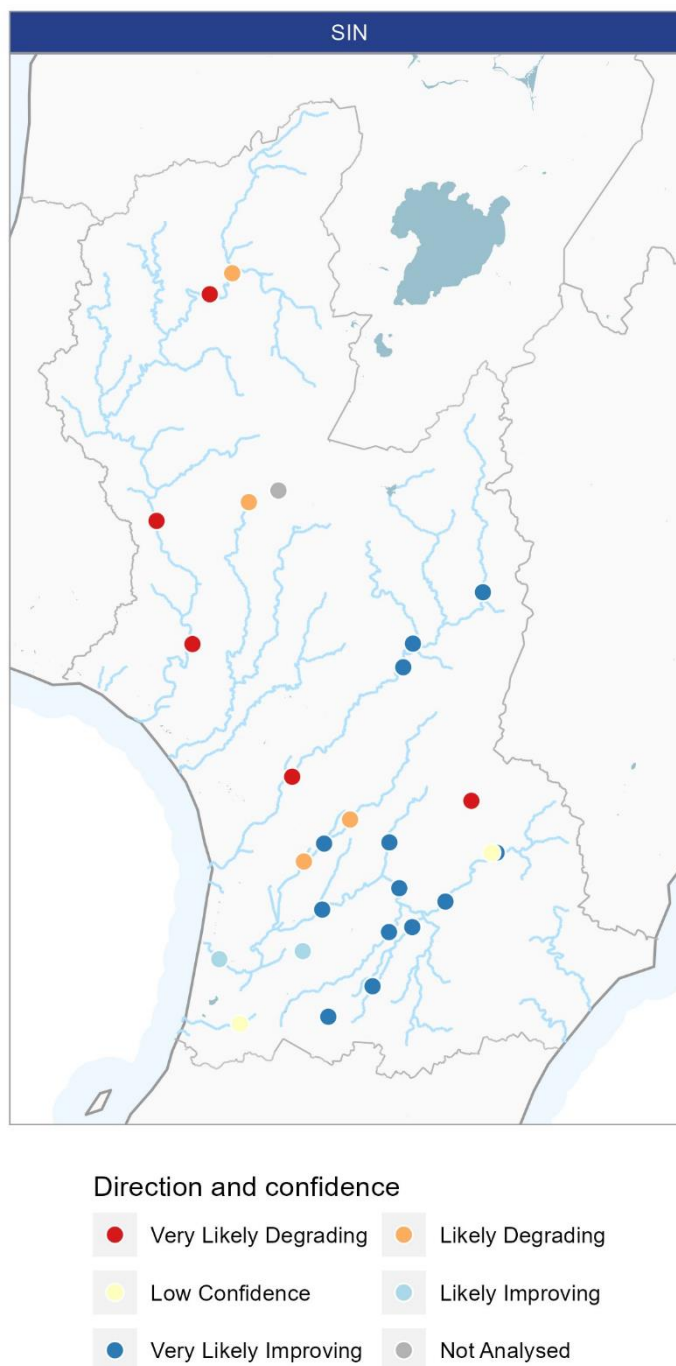


Figure 4: Summary plot representing the proportion of target catchment and other SoE sites with 10-year time period trends in each direction and confidence category defined in Table 3.



[46] For the 20-year period, trends could only be assessed for SIN. Figure 5 indicates that for the 27 sites for which 20-year SIN trends could be analysed, confidence that the direction was improving was at least 'Likely' for the majority (59%). It is noted that this indicates the opposite general pattern shown by the 10-year trends.

Figure 5: Map showing the 20-year trends at sites across the region for which there was sufficient data. The colours represent the categorical descriptors indicating the trend was improving shown in Table 3.



[47] In summary, a majority of SoE sites, both within the Region generally and within the target catchments, were assigned a fail state grade when compared to the One Plan targets for all water quality indicators. The

exception was for Periphyton Mats, for which 77% of sites regionally and 78% within the target catchments were assigned a pass state grade. A high proportion of sites both within the Region (71%) and within the target catchments (78%) were assigned a fail state grade for SIN and a large proportion of these failed by a large margin, indicating that current SIN concentrations are considerably higher than the One Plan targets.

- [48] Trends in SIN, chlorophyll *a* and periphyton mats over the 10-year trend period were predominantly degrading. In contrast, trends in SIN over the 20-year period were predominantly improving. Trends only indicate the detection of a change in water quality and provide no insight into the causes of those changes. It is understood that climatic variation has a considerable impact on water quality, especially at time scales of a decade due to the El Niño southern oscillation.
- [49] I am therefore cautious about inferring that changes in nitrogen management are responsible for the observed generally degrading conditions pertaining to nutrient over the last 10-years. It is noted that the SIN improvements at the 20-year time scale are less likely to be influenced by climatic effects than those at the 10-year time scale and are consistent with decreasing total stocking pressure in the region report by Snelder et al (2021). The 20-year time-scale result is evidence that over the long run, changes in nitrogen management will result in reductions of nitrogen in the Region's rivers and all other things being equal, this should result in decreases in periphyton biomass.

H. WATER QUALITY OUTCOMES UNDER NITROGEN MANAGEMENT SCENARIOS

- [50] In the development of PC2, I worked with Dr Cox to simulate water quality across the Region for a range of historic conditions and nitrogen management scenarios. The CASM water quality models that were used to simulate the various nitrogen management scenarios are described in Dr Cox's evidence. These simulations are fully documented in the report Snelder et al. (2020b) and were described in my evidence to the Council level hearing. At **Attachment B** I include a summary of the simulations we

undertook, as provided to the Hearing Panel (which I discuss in greater detail below). These simulations predicted the loads of nitrogen resulting from historic conditions or very specific nitrogen management scenarios for each of 43 Water Management Zones (**WMZ**) made up of 124 Sub-Zones (**WMSZ**).

- [51] The nitrogen management scenarios represented outcomes of potential rules or outcomes of implementation of rules under PC2 that could apply to existing and new IFLU activities in target catchments, and new IFLU throughout the Region.⁵ Target catchments comprise 32 WMSZs that are identified in Table 14.1 of the One Plan. They were identified as priority areas on the basis that they had poor water quality or were at risk of further degradation due to further intensification of farming land use, as described in the evidence of Ms Patterson.
- [52] The results of the earlier water quality modelling and scenario simulations, in brief, were that implementing the recalibrated Table 14.2 and a then proposed discretionary consent pathway (as PC2 was notified) resulted in modest water quality improvement in the target WMSZs.
- [53] The earlier water quality modelling and scenario simulations predicted a mean relative difference of between 41% and 40% at assessment points downstream of the target catchments under these scenarios (**Attachment B**). These predicted water quality outcomes were an improvement on both pre-regulation (45% mean relative difference) estimates of SIN concentrations.
- [54] Over the course of the Council-level hearing, we modelled the outcomes of additional simulations based on scenarios representing various pathways discussed during the course of the hearing. This included assessment of a then proposed alternative controlled consenting pathway, which required farms to achieve reductions of nitrogen leaching equal to 20% (pastoral) or 35% (CVG) below a set baseline. This is the scenario that was ultimately implemented in the DV-PC2.

⁵ I note that PC2 is focused on existing IFLU only.

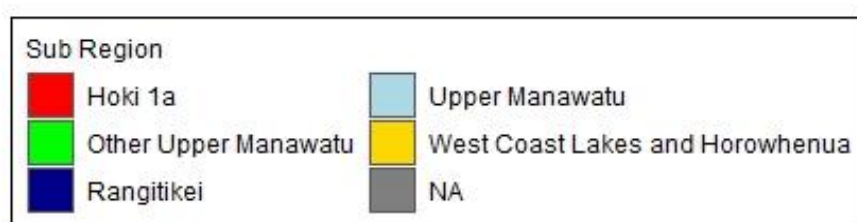
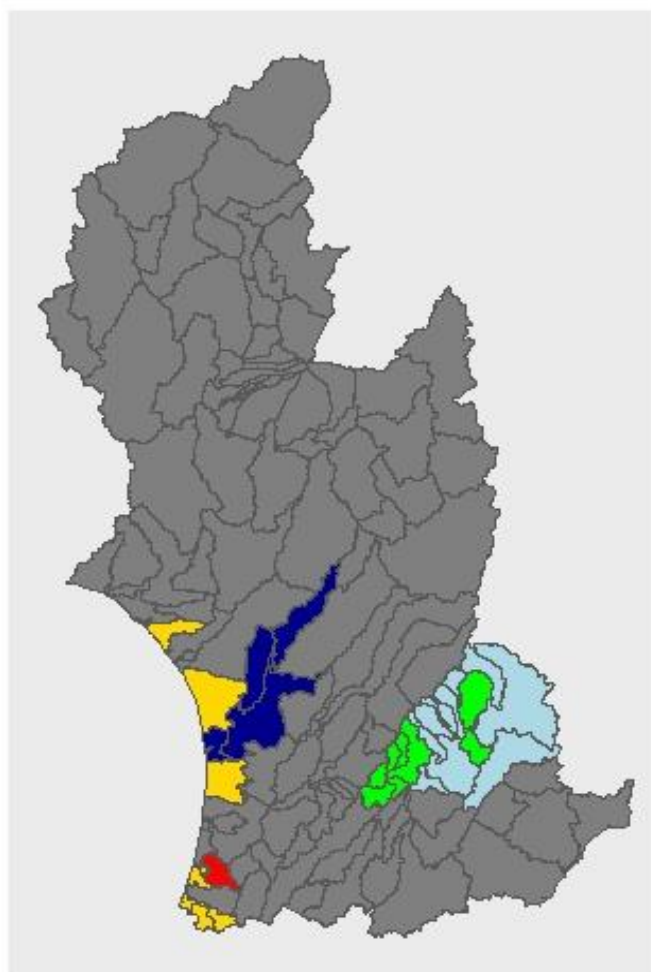
- [55] These scenarios showed similarly modest water quality improvements – i.e., also between 41% and 40% mean relative difference.

I. WATER QUALITY OUTCOMES – RISK MANAGEMENT TOOL

- [56] More recently, additional work has been undertaken around the proposed risk assessment tool, including analysis of farm scale nitrogen loss rates provided by Professor Horne and Dr Jolly. This has involved further analysis of farm data and modelling by Professor Horne and Dr Jolly, as described in their evidence.
- [57] To inform my water quality assessment, Professor Horne and Dr Jolly have quantified reductions in nitrogen loss for IFLU from the baseline scenario (representing nominally the year 2012 for pastoral and 2018 for CVG)⁶ their best estimate of the likely nitrogen losses associated with implementation of DV-PC2, and amendments to the DV-PC2. Note that, where the previous modelling that was carried out for DV-PC2 considered a wide range of potential scenarios, the assessments of nitrogen loss for IFLU made by Professor Horne and Dr Jolly comprised only two scenarios that represented their opinions concerning the most likely outcomes for the “future” scenarios (i.e., DV-PC2 and the proposed risk assessment tool).
- [58] The reductions in loss are quantified at the spatial-scale of five “sub-regions” that include 29 WMZSs that host most of the IFLU land in the Region (Figure 6). Sub-regions are groups of one or more WMSZs. It is noted that the West Coast Lakes and Horowhenua includes the Hoki_1a WMSZ. However, the sub-regions include Hoki_1a separately because this WMSZ hosts the majority of the Region’s CVG. The impact of the proposed reductions in nitrogen loss due to mitigations that apply specifically to CVG are therefore reported in this evidence at the level of the Hoki_1a WMSZ.

⁶ The baselines are described in the Statement of Evidence of Professor Horne (at page 7) and Dr Jolly (at pages 5-6), dated 6 October 2023.

Figure 6: Map showing the subdivision of the region into water management sub-zones and the amalgamation of sub-zones into sub-regions that are used in the water quality assessment.



- [59] Professor Horne and Dr Jolly explain how nitrogen loss from IFLU, for each sub-region, has been quantified across different scenarios (baseline, DV-PC2, and the proposed amendments to the DV-PC2). Table 4 shows the reductions, from the 2012 baseline, and the future scenarios. The data shown in Table 4 was the starting point for my water quality assessment.

Table 4: Reduction in nitrogen loss from IFLU land from the baseline (as percent of baseline; %) estimated for sub-regions under the DV-PC2 and the proposed amendments to the DV-PC2. Except for the Horowhenua CVG sub-region, the values represent the pastoral IFLU nitrogen reductions that were estimated by Prof Horne. The values shown for the Horowhenua CVG sub-region represent the reductions from CVG that were estimated by Dr Jolly for the proposed amendments to the DV-PC2 (the risk assessment tool) but not for DV-PC2.

Sub region	DV-PC2	Proposed amendments to the decisions version of PC2
Horowhenua CVG (Hoki_1a)	NA ⁷	70
Other Upper Manawatu	9	7
Rangitikei	1	1
Upper Manawatu	16	13
West Coast Lakes and Horowhenua	5	4

- [60] My assessment of water quality outcomes of the three scenarios has not involved the same water quality modelling that was undertaken for the DV-PC2 and which is explained in the evidence of Dr Cox. Rather, I undertook a simple analysis that demonstrates that the reductions in nitrogen from IFLU that can be anticipated under the proposed risk assessment tool are very similar to that anticipated under the DV-PC2. I was able to do so, given the estimates of the nitrogen loss reductions from IFLU provided by Professor Horne and Dr Jolly, in their modelling of the risk management tools.
- [61] The assessment demonstrates the differences in water quality outcomes between the two “scenarios” are so close that, when the considerable uncertainties of these assessments are taken into account, the two sets of regulations could be considered to have the same water quality outcomes. In addition, the assessment demonstrates that the outcome of the proposed

⁷ Dr Jolly did not produce an assessment of the change in nitrogen loss under DV-PC2 (but did for the proposed new provisions).

amendments to the DV-PC2 for water quality is positive (i.e., water quality will improve), but these improvements are modest.

[62] I have described below, the steps I have undertaken in my analysis.

(a) I commenced by calculating the total baseline nitrogen losses for each of the sub-regions shown in Table 4 in two steps.

(i) At step 1, I calculated the sum of baseline nitrogen losses over nine land use classes within each of the WMSZs making up each of the sub-regions. The 14 land use classes, and their baseline nitrogen loss rates, were obtained from the input data for the CASM water quality models and are described in the evidence of Dr Cox.

(ii) At step 2, I summed the values obtained at step 1 across the WMSZs comprising each sub-region to obtain each sub-zone's total baseline nitrogen loss.

(b) I then calculated the total nitrogen loss for each sub-region under the two scenarios defined by Table 4: DV-PC2, and the proposed amendments to the DV-PC2. This step was carried out in the same manner as the preceding calculation of the total baseline nitrogen loss with one modification. In the calculations for each sub-region, the baseline nitrogen loss rates for IFLU (i.e., pastoral farms and CVG) were reduced by the amounts shown in Table 4.

(c) The change in total nitrogen losses under the two scenarios for each sub-region were expressed as percent changes in total nitrogen loss from the baseline for each sub-region.

[63] The results of the changes in total nitrogen losses under the two future scenarios are shown in Table 5. Table 5 indicates that the changes in total nitrogen losses are modest in most sub-regions (i.e., ranging from 0.4% to 8.2%). This occurs because IFLU land makes up relatively small proportions of the sub-regions so that reductions shown in Table 4 for IFLU (under the two future scenarios) are “diluted” by large contributions of nitrogen from

all other land uses. The exception to this was the Hoki_1a WMSZ, which hosts the Horowhenua CVG area. Because CVG occupies a relatively large proportion of Hoki_1a, and is associated with a large reduction in nitrogen loss under the proposed amendments to the DV-PC2 (i.e., 70%, Table 4), the reduction in the total nitrogen loss was comparatively greater than the other sub-regions (21%).

Table 5. Reduction in total nitrogen loss from the baseline (as percent of baseline; %) estimated for sub-regions under DV-PC2 and the proposed amendments to the DV-PC2.

Sub-region	Decisions version of PC2	Proposed amendments to the decisions version of PC2
Horowhenua CVG (Hoki_1a)	NA	21
Other Upper Manawatu	4.2	3.2
Rangitikei	0.4	0.4
Upper Manawatu	8.2	6.6
West Coast Lakes and Horowhenua	2.0	4.1

[64] The reductions in total nitrogen loads were also expressed as estimated changes in the achievement of SIN targets for each of the sub-regions. This expression of the changes in nitrogen loss rates is equivalent to the measured relative differences in current SIN concentration to One Plan targets shown in Figure 2. I explain the calculations below.

[65] The calculations associated with the assessment of achievement of SIN targets were performed in four steps.

(a) First, the baseline SIN concentrations (as mean SIN for river flow is equal to or less than the 20th flow exceedance percentile) were obtained for the most downstream river segment of each of the WMSZs that comprised the sub-regions. These concentrations were predictions obtained from spatial statistical models of current state

water quality made by Fraser and Snelder (2020), and were also utilised by the modelling for the Council level hearing.

- (b) Second, these concentrations were compared to the One Plan SIN target for that WMSZ. The relative difference between the current concentration and the One Plan target was calculated as follows:

$$\frac{(\text{Current concentration} - \text{Target})}{\text{Current concentration}} \times 100$$

- (c) The relative difference is expressed as a percentage (%) and is the amount by which the current concentration differs from the target, relative to the current concentration and is positive when the current concentration exceeds the target (i.e., when the target state is not achieved).
- (d) Third, the mean of these values was calculated for each sub-region and is referred to hereafter as the “mean relative difference”.
- (e) At the fourth step, the mean relative differences were calculated in the same manner as the baseline scenario for the two future scenarios: DV-PC2, and the proposed amendments to the DV-PC2. This was achieved by modifying the estimated baseline SIN concentration according to the reduction in total nitrogen losses shown in Table 5. I note that this calculation is consistent with the way the CASM modelling (described by Dr Cox) estimates changes in loads and concentrations at the WMSZ level. The CASM model incorporates attenuation into the calculation of loads and concentrations at river locations that are downstream of multiple WMSZs. However, because my calculations were restricted to the WMSZ scale, in my opinion, they are consistent with results that would be derived from the CASM model and are robust. As the assessment on this occasion did not use the CASM model, results are not presented for river locations that are in “mainstem rivers” (i.e. rivers that are downstream of multiple WMSZs). Changes in SIN in mainstem rivers requires the incorporation of catchment

attenuation into calculations which is a feature of the CASM model that is described in the evidence of Dr Cox.

- [66] The results of the analysis of mean relative differences in SIN concentration to One Plan targets are shown in Table 6. There are three (3) important observations that are apparent in these results.
- (a) First, the mean relative differences in most sub-regions are positive (i.e., SIN concentrations generally exceed the One Plan targets) and by large amounts (e.g., $\geq 20\%$). This is consistent with the assessment of current state based on SoE when expressed the same way (i.e., as relative differences) shown in Figure 2. For example, Figure 2 indicates that a large proportion of SoE sites have relative differences in excess of 50%.
 - (b) Second, consistent with the reduction in nitrogen losses shown in Table 5, mean relative differences always decreased for the DV-PC2, and proposed risk assessment tool scenarios, compared to the Baseline scenario (of Table 14.2).
 - (c) Third, the mean relative differences for the scenarios representing DV-PC2, and the proposed amendments to the DV-PC2 are very close and for some sub-regions the same. This indicates that it is reasonable to conclude that the proposed amendments to the DV-PC2 have the same modest water quality benefits as the DV-PC2. It is noted that many aspects of my calculations and the previous CASM modelling are uncertain. In my opinion, these uncertainties mean that the two sets of results representing the DV-PC2, and the proposed amendments to the DV-PC2 are not significantly or practically different to one another.
- [67] A final component of my assessment involved simply quantifying the proportion of the 29 WMSZs that made up the sub-regions that were compliant with the One Plan SIN targets for each of the three scenarios. For this assessment I took the modelled baseline SIN at the most downstream river segment in each WMSZ, and their modified counterparts pertaining to the two future scenarios and compared these to the One Plan target. For the

Baseline scenario, 24 of the 29 WMSZs (83%) were non-compliant. For the two future scenarios 23 of the 29 WMSZs (79%) were non-compliant. These results are consistent with the other two sets of results. They indicate the two future scenarios are associated with modest improvements in water quality compared to the baseline. In addition, the two future scenarios are not distinguishable from one another in terms of their water quality impact.

Table 6. Summary of achievement of SIN targets for the sub-regions. The mean relative difference indicates the mean amount by which the predicted concentration at the most downstream river segment in the WMSZs that comprise each sub-region, deviate from the target. Positive values indicate the predicted SIN concentration exceeds the target (i.e., the target state is not achieved). The mean relative differences for each sub-region are shown for the baseline, the DV-PC2 and the proposed amendments to the DV-PC2.

Sub region	Baseline	Decisions version of PC2	Proposed amendments to the decisions version of PC2
Horowhenua CVG (Hoki_1a)	92	92	90
Other Upper Manawatu	-26	-32	-30
Rangitikei	20	20	20
Upper Manawatu	41	35	37
West Coast Lakes and Horowhenua	83	83	83

[68] In summary, the assessment I present above indicates that the proposed amendments to the DV-PC2 have the same modest water quality benefits as the DV-PC2. As I have noted, many aspects of the calculations and underlying modelling presented here are uncertain, and therefore, in my opinion, the two sets of results representing the DV-PC2, and the proposed amendments to the DV-PC2 are not significantly or practically different to one another.

[69] I was able to reach these conclusions without undertaking the more complex water quality modelling that was carried out for the Council-level hearing. Detailed modelling of the impacts of proposed amendments to the DV-PC2

to match the scenarios that were simulated in support of DV-PC2 could be undertaken. Such simulations would require more detailed information concerning nitrogen loss rates under differing sets of assumptions. However, it is in my view, unnecessary to undertake further simulations to show that the impacts of the proposed amendments to the DV-PC2 are equivalent to those of DV-PC2 given the similarities in water quality impacts between the general assessments of DV-PC2 and the proposed amendments to the DV-PC2 (the risk assessment tool) I have described above. I am confident that if the more complex water quality modelling undertaken to inform the PC2 scenarios was undertaken to simulate impacts under the proposed amendments to the DV-PC2, the same conclusions would be reached.

[70] I am also confident in this conclusion given that the calculations within my assessment are very consistent with the CASM model. The only difference is that the CASM model (as described by Dr Cox) can provide more spatial detail and can be used to estimate the water quality impacts downstream from the IFLU land in the main stems of the region's rivers. I note that the water quality impacts (i.e. the benefits of PC2) diminish moving downstream in the main stem rivers because the effects of reductions on upstream IFLU land becomes increasingly "diluted" by contributions from non-IFLU land (which are obviously not changed by PC2).

[71] In my opinion, implementing PC2 with the proposed amendments to the DV-PC2 would result in similarly modest water quality improvements in the target catchments of the Region to those that were predicted for DV-PC2.

6 October 2023

Dr Antonius Hugh Snelder

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K. ATTACHMENTS

Attachment A

- Manawatū-Whanganui Region Catchment Nitrogen Models (2020a);
- Scenario Modelling of Nitrogen Management in Manawatū-Whanganui Region (2020b).



Manawatū-Whanganui Region Catchment Nitrogen Models

Supporting Regional Plan Change 2

July 2020

Prepared By:

Ton Snelder

Tim Cox*

Tim Kerr

Caroline Fraser

Stephen Collins‡

*Streamlined Environmental Ltd

‡Horizons Regional Council

For any information regarding this report please contact:

Ton Snelder

Phone: 0275758888

Email: ton@lwp.nz

LWP Ltd

PO Box 70

Lyttelton 8092

New Zealand

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Version	Reviewed By	
Final	Ngaire Phillips*	

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Executive Summary

Catchment water quality models were developed for the four major river basins in the Horizons Region: the Manawatū (including the Horowhenua and Coastal Taranaki catchments), the Rangitikei, the Whanganui, and the Whangāehu (including the Turakina River catchment). The entire Manawatū- Whanganui region is encapsulated by the four models. The models use sub-catchment export and attenuation coefficients and point source load estimates to simulate the generation, transport, and downstream delivery of total nitrogen (TN) loads throughout the region. The models were developed to investigate the impact of regulating nitrogen discharge allowances from intensively farmed land throughout the region. It is anticipated that the models will be used to estimate loads and concentrations under a range of potential management scenarios.

A satisfactory calibration was achieved for all four basin models. Downstream calibration targets (observed TN loads) were all achieved with sensible adjustments to upstream attenuation coefficients, within expected ranges, and, in a limited number of cases, minor adjustments to independently derived export coefficients. Patterns of attenuation within, and between, basins have been noted but not yet fully explained.

Models are uncertain, and the uncertainty of the key model parameters (the attenuation coefficients) have been demonstrated in this report. This uncertainty is largely unavoidable and results from uncertainty in the water quality station TN loads and estimated sub-catchment TN export coefficients. This uncertainty needs to be considered when using the models to make predictions of TN loads and concentrations under different management scenarios. The estimated loads and concentrations in absolute terms should be regarded as less certain than the relative difference in loads and concentrations between locations and scenarios.

1 Introduction

Horizons Regional Council (HRC) has proposed a change to its Regional Policy Statement and Regional Plan (the One Plan) known as Plan Change 2. Proposed Plan Change 2 is focused on the One Plan's provisions that manage nutrient loss from existing intensive farming land uses (dairy farming, commercial vegetable growing, cropping, and intensive sheep and beef) in target water management sub-zones. These provisions are no longer working as intended when the One Plan was developed. Proposed Plan Change 2 will update the cumulative nitrogen leaching maximums in the One Plan Table 14.2 to reflect improvements in the nutrient modelling software tool Overseer; reinforce good management practices as part of intensive farming land use activities; and provide a workable pathway for landowners to apply for resource consent for intensive farming land use activities that cannot achieve Table 14.2 cumulative leaching maximums.

Proposed Plan Change 2 will have effects on instream loads and concentrations of nitrogen across the Manawatū-Whanganui Region. These effects will be spatially variable for two reasons. First, land use changes resulting from Proposed Plan Change 2 will not be evenly distributed across the region meaning that future land use intensity will vary between the region's catchments. Second, there is environmentally mediated variation in both potential nitrogen losses from land use and the processing of nitrogen (attenuation) as it moves through the drainage network. Because these two factors interact, the water quality outcomes of proposed Plan Change 2 are complex and their assessment requires catchment water quality modelling. This report describes the development and calibration of catchment water quality models for the purpose of assessing the impacts of the plan change on in-stream nitrogen loads and concentrations across the region. This report does not describe the use of the models to assess impacts; this will be the subject of other documentation.

Catchment water quality models were developed for the Manawatū-Whanganui region's four major river basins: the Manawatū (including the Horowhenua and Coastal Taranaki catchments), the Rangitikei, the Whanganui, and the Whangaehu (including the Turakina River catchment). The entire region is encapsulated by the four models. The models use sub-catchment export and attenuation coefficients to simulate the generation, transport, and downstream delivery of total nitrogen (TN) loads throughout the region. The models can be used to investigate the potential effects of nitrogen discharge from land (diffuse source discharges) and point source discharges. The models can also be used to assess the effects of differing discharge standards throughout the region and to test the effectiveness and feasibility of mitigations. The models were developed in a usable framework to allow for future application by a range of potential end users. In future use of the models, the primary input will be scenario assumptions about land use and nitrogen loss rates, and the primary outputs will be loads and concentrations at reporting locations distributed across throughout the river network.

2 Water quality models

2.1 Model software

The Horizon models were developed using Streamlined Environmental Limited's (SEL) Contaminant Allocation and Simulation Model (CASM) software. CASM is designed as a flexible, and usable, generalized modelling tool for simulating diffuse and point source contamination at a catchment scale.

CASM calculates the generation of a range of user-defined contaminants at a catchment scale and the fate and transport of the contaminants through the catchment's dendritic stream network. Contaminant sources are represented in the model as individual nodes, discharging to specific streams of any order. Contaminant sources can be either diffuse (e.g. farms) or point (e.g. municipal discharges). Sources can be aggregated for lower resolution models, including to a sub-catchment scale, or explicitly represented as individual property nodes for higher resolution models. Diffuse source contamination calculations follow the widely used "export coefficient" approach, with prescribed areal average mass loading rates ($\text{kg ha}^{-1} \text{ yr}^{-1}$) linked to land use categories. Point source loading rates are simply user defined for each node. Both diffuse and point source loading parameters can be prescribed as seasonally variable in CASM.

Three forms of contaminant attenuation are available in the model: diffuse pathway, instream, and reservoir. The first is applicable for diffuse sources only and represents potential mass losses occurring from the point of export or leaching to the point of discharge to the receiving stream. The second captures attenuation that may occur during downstream transport within the stream channel (e.g. due to settling, uptake, or transformation). The third provides for additional enhanced attenuation that may occur in intercepting reservoirs as a function of residence time. Like the source terms described above, all attenuation parameters can be defined seasonally in the model.

Note that, for the models described here, only diffuse pathway attenuation is included, except for two short reaches in the Manawātū River basin. Both export coefficients and attenuation coefficients are prescribed on an annual average basis. Parameter seasonality is not included in the current models. Additionally, no reservoirs are explicitly included in any of the models.

Any number of water quality "stations" can be defined in the model at any instream location. These model objects provide for output summaries specific to the given location. These summaries include total contaminant loads (kg/month), concentration (mg/L), and source tracking (a breakdown of contributing upstream sources). Instream target concentrations can also be prescribed at these stations for reference, or to trigger mitigation optimization calculations (described below).

The CASM software offers three modes of simulation: deterministic, stochastic, and optimization. Deterministic simulations involve the tracking of contaminant mass from point of export (diffuse) or discharge (point) through a dendritic stream network to a series of downstream monitoring stations. The model varies source loading seasonally, combines loads at appropriate locations, and attenuates the loads based on user-defined parameters, providing for time-varying loads (and/or concentrations) at any location in the modelled catchment. The model also provides useful source tracking output, showing relative contributions of load from upstream categories of diffuse and point sources. Up to five (5) different user-defined contaminants can be simulated in a single model run.

Stochastic simulations allow the user to perform a comprehensive uncertainty analysis for their constructed model and to frame model predictions in the form of highly useful probability distributions. Rather than single value outputs of modelled river concentrations, stochastic simulations present these outputs in terms of exceedance probabilities (or "risk"). For stochastic simulations, simple probability distributions can be defined for any combination of the following key model inputs: export coefficients, diffuse pathway attenuation coefficients, and instream attenuation coefficients. Optimization simulations perform the same fate and transport calculations as in deterministic and stochastic simulations but also provide an optimal mitigation strategy to achieve prescribed downstream water quality concentration

targets. Optimality is determined in the model based on user-defined mitigation cost tables associated with each source node. Note that only the deterministic mode of simulation was used for the modelling described here.

2.2 Modelled nutrient, basins and sub-catchments

Previous investigations of nitrogen attenuation in the region have considered soluble inorganic nitrogen (SIN) rather than TN (Collins *et al.*, 2017). In this study we calculated loads of TN and subsequently modelled TN loads, rather than SIN, because diffuse source nitrogen losses from farms are expressed in terms of TN, including the loss rates defined in the One Plan Table 14.2.

Each river basin model was subdivided into sub-catchments based on HRC's Water Management Zones (WMZ; Table 1). Each WMZ is represented in one of the four models (Figures 1 – 4).

Table 1. High-level summary of each of the four constructed models

Model characteristics	Manawatū River	Rangitikei River	Whanganui River	Whangaehu River
Total drainage area (ha)	733,600	401,500	750,400	312,800
Number of WMZ sub-catchments	50	15	32	15
Total number of diffuse nodes	1425	354	678	327
Number of point sources	22	8	2	5
Number of WQ calibration points	31	7	6	6
Number of explicit tributaries	28	8	12	7

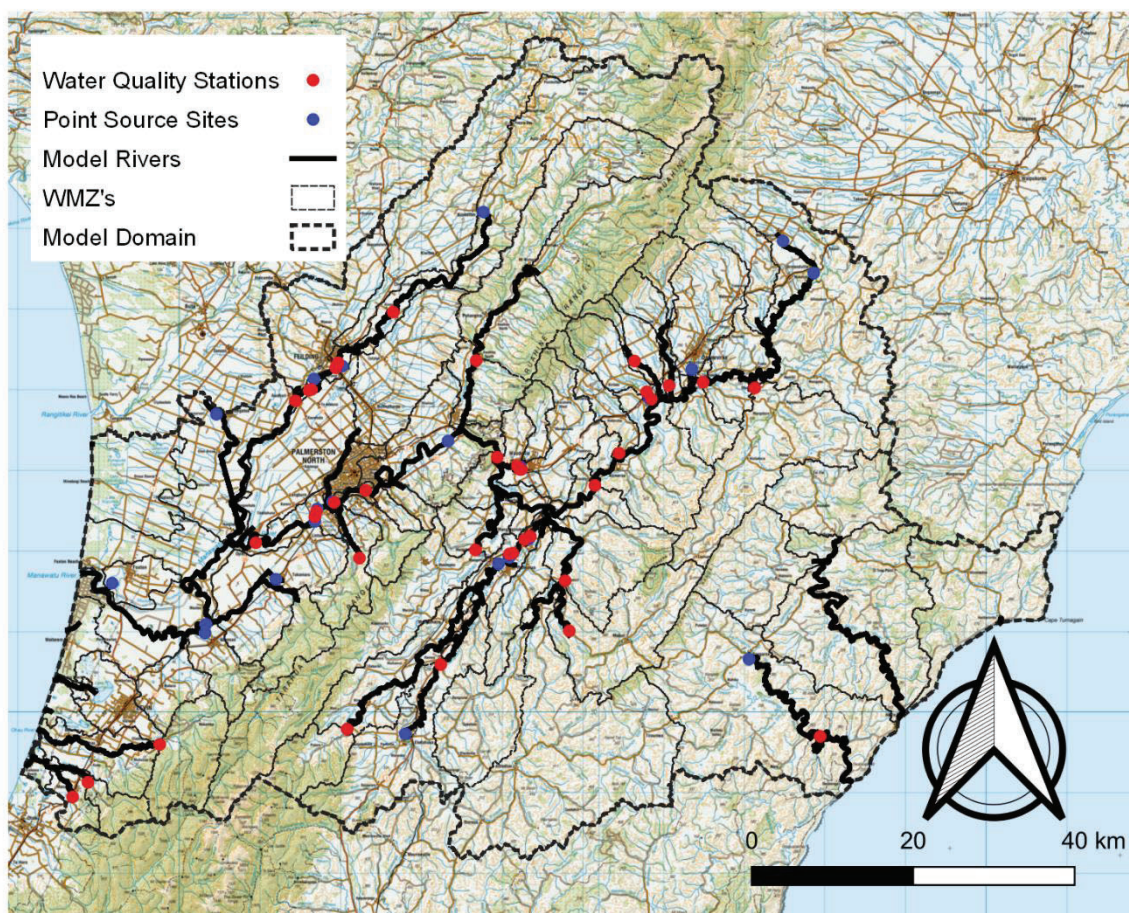


Figure 1. Map showing the Manawātū River basin model domain and spatial subdivision by WMZs. Note that this model includes the Horowhenua and Coastal Tararua catchments. The red points indicate the water quality stations and the blue points indicate the point sources.

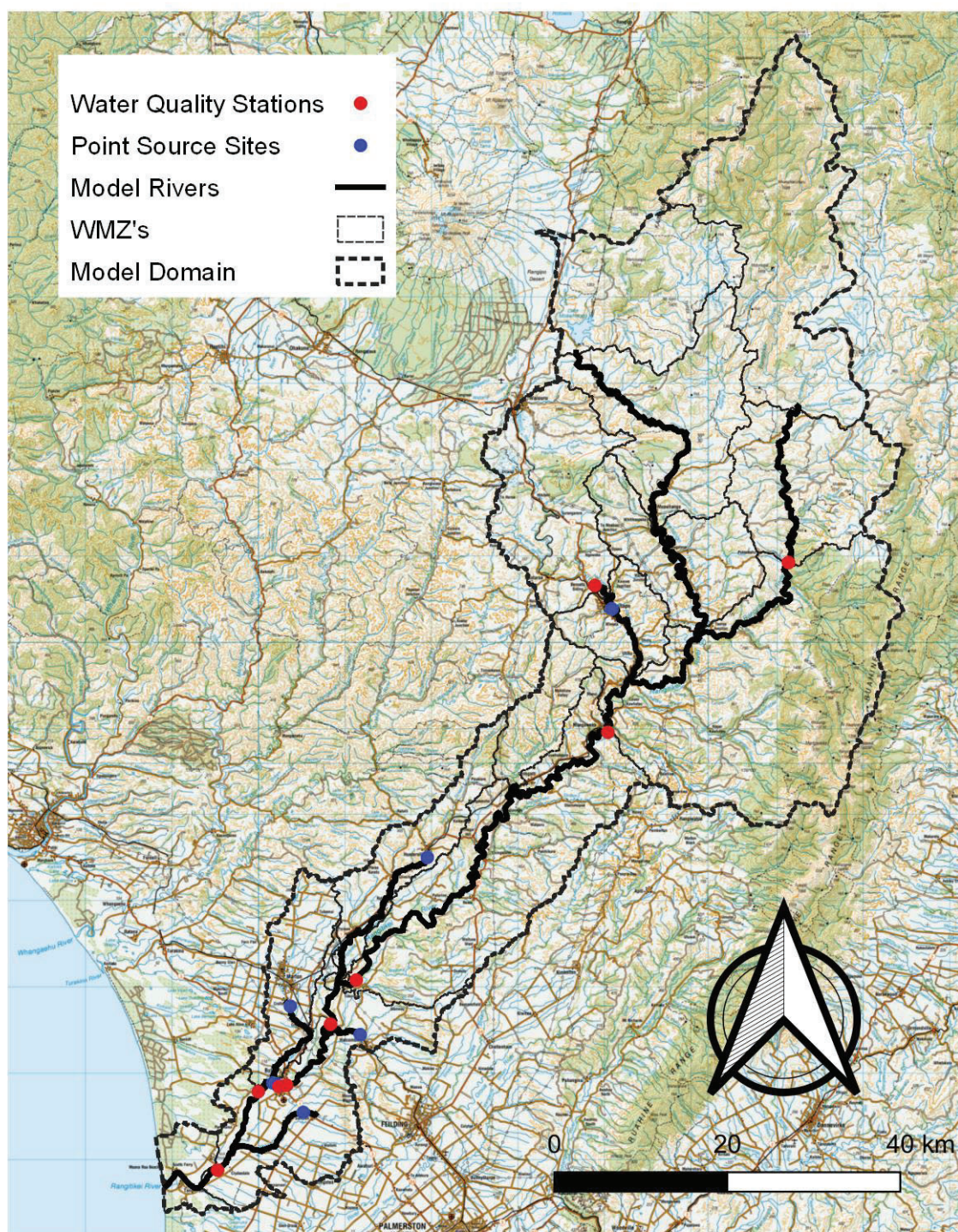


Figure 2. Map showing the Rangitikei River basin model domain and spatial subdivision by WMZs. The red points indicate the water quality stations and the blue points indicate the point sources.

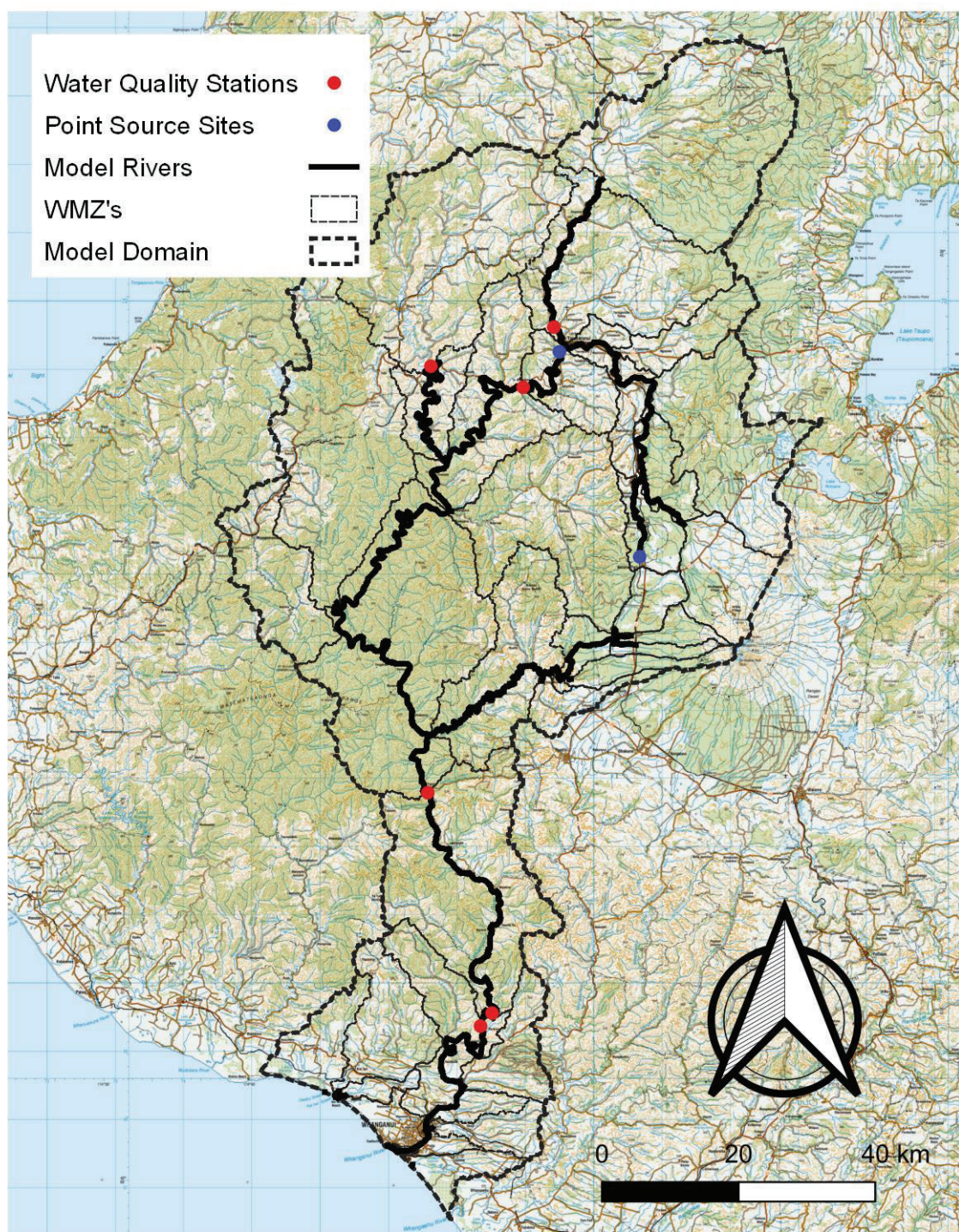


Figure 3. Map showing the Whanganui River basin model domain and spatial subdivision by WMZs. The red points indicate the water quality stations and the blue points indicate the point sources.

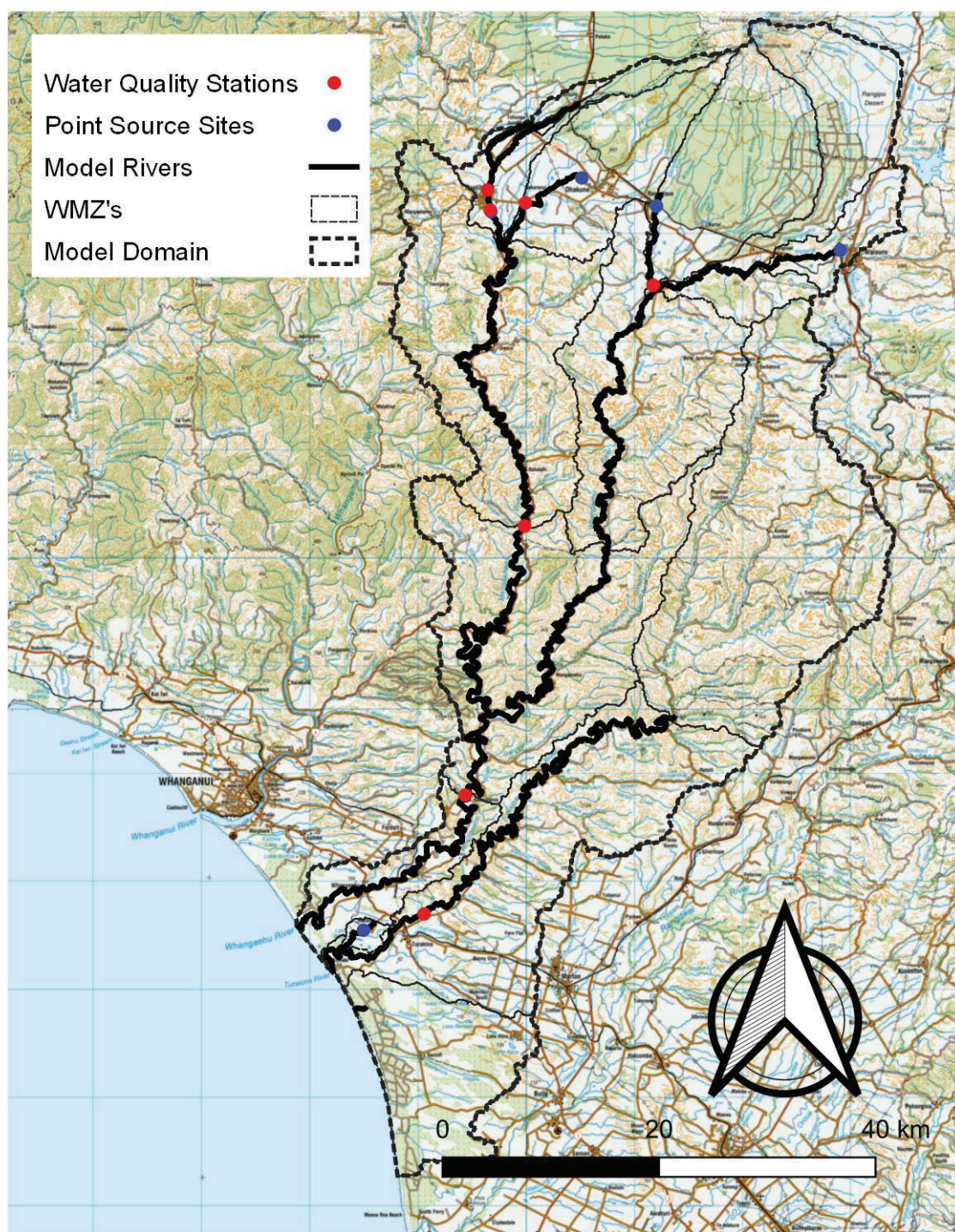


Figure 4. Map showing the Whangaehu River basin model domain and spatial subdivision by WMZs. Note that this includes both the Whangaehu and Turakina Rivers and their catchments. The red points indicate the water quality stations and the blue points indicate the point sources.

2.3 Point source discharges

Estimates of mean annual loads of TN discharged at 37 consented discharges $> 20\text{m}^3 \text{d}^{-1}$ across the region were made by Fraser and Snelder (2019) (Figure 1 to 4). Data describing discharge concentration of TN for these point source discharges were provided by HRC. The point source loads comprised consented discharges that were operating at any time during the period 2007-2017. Discharge volume estimates were provided by HRC (mean daily flows, based on consented volumes and/or spot observations). Mean concentrations were calculated based on continuous or sporadic monitoring records for these discharges. The locations and magnitudes of the point source discharges are shown in Figure 5. A summary of the discharge names, estimated discharge volumes and number of water quality observations are provided in Appendix A of Fraser and Snelder (2019).

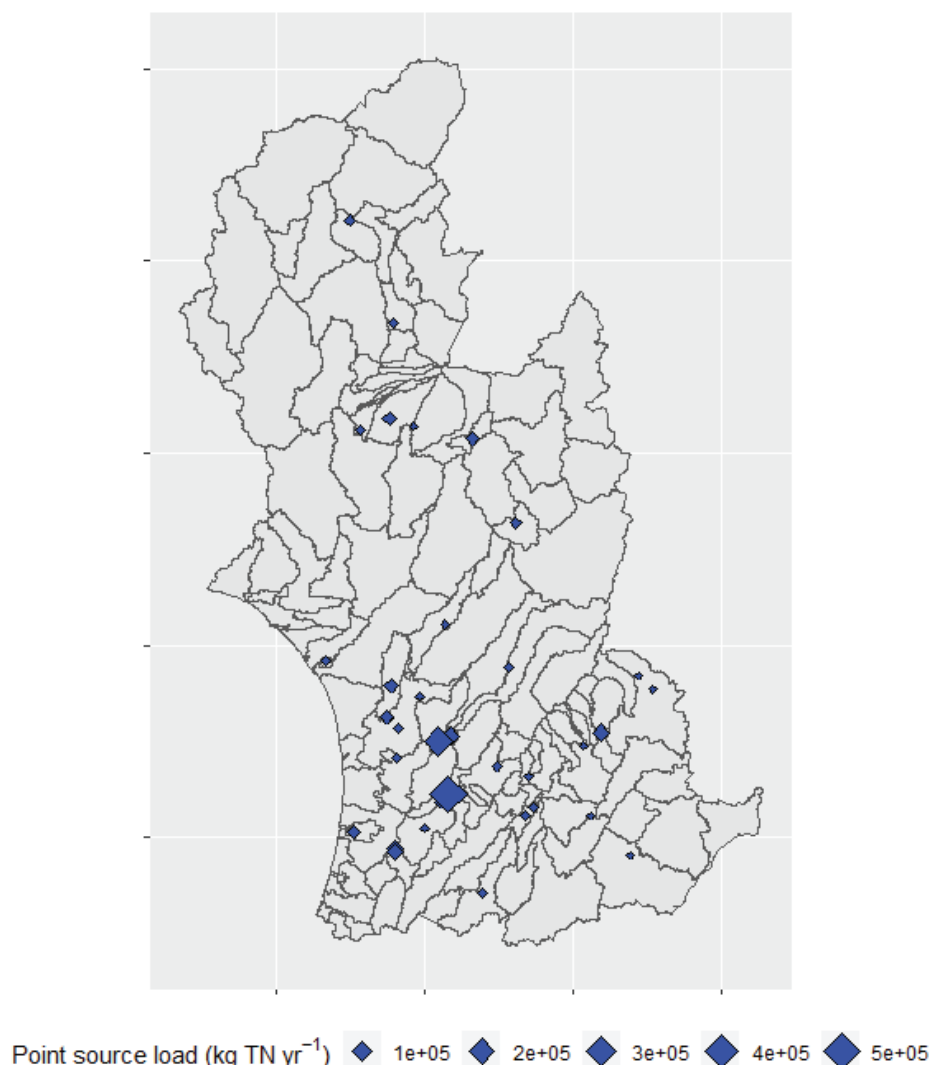


Figure 5. Location and loads (kg TN yr^{-1}) of 37 consented point-source discharges that were included in the models.

2.4 Water quality station loads

Estimates of mean annual loads of TN at 60 water quality stations were derived from monthly TN concentrations and observed or modelled daily flows (Figure 1 to 4). Details of the load calculation methods are provided in Appendix A and further details are contained in Fraser and Snelder (2019). The locations and magnitudes of the loads (as export coefficients $\text{kg N ha}^{-1} \text{yr}^{-1}$) at the water quality stations are shown in Figure 6.

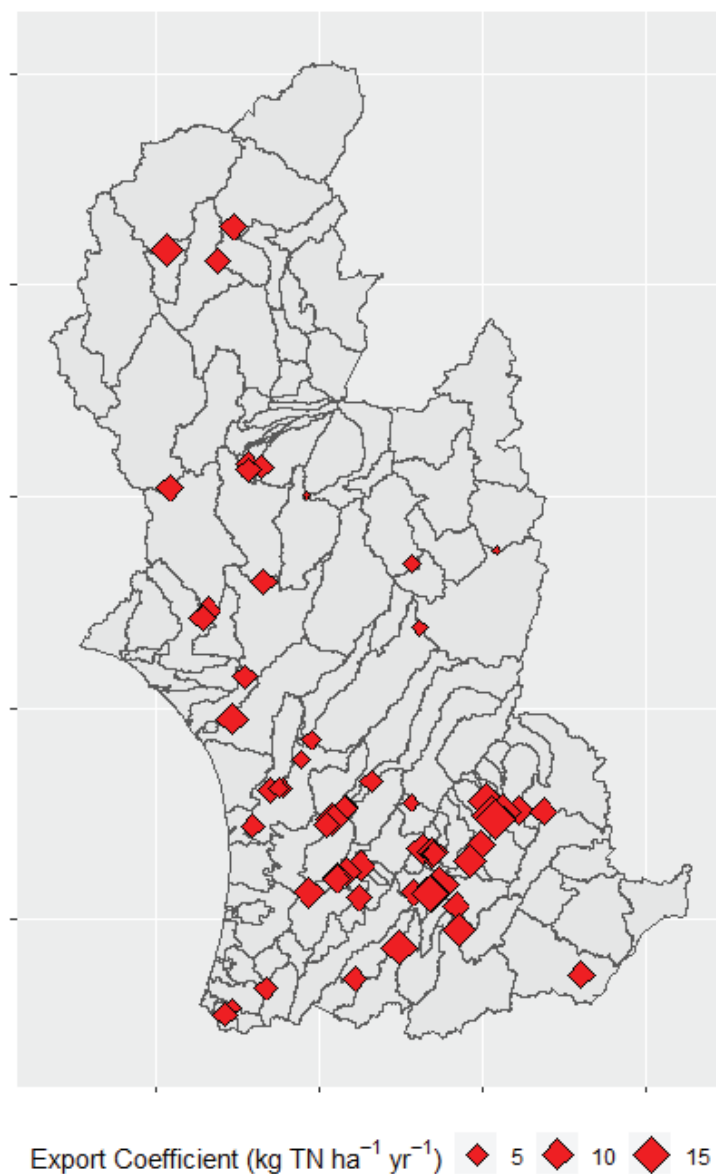


Figure 6. Location and loads ($\text{kg TN ha}^{-1} \text{yr}^{-1}$) at 60 water quality monitoring stations that were included in the models.

2.5 Land use and diffuse source nitrogen export coefficients

2.5.1 Land use map and changes in land use intensity

At the time of reporting, the best available land use data was HRC's 2008 land use map, which describes regional variation in land use in nine categories (Figure 7**Error! Reference source not found.**; See Appendix B for further consideration of land use).

2.5.2 Export coefficients

We used export coefficients based on Bright *et al.* (2018). Bright *et al.* (2018) provided estimates of nitrogen diffuse source export coefficients under the same nine land use categories shown on Figure 7**Error! Reference source not found.**, which apply New Zealand wide. For each land use category, the export coefficients defined by Bright *et al.* (2018) account for variation in export coefficients based on a classification defined by defined by four biophysical factors including: climate zone, plant available soil water capacity (PAW), and whether the land is irrigable and irrigated. Variation in these factors is captured by a small number of categories for each factor. Within the Manawatū-Whanganui Region, there are five climate zones, and three PAW categories (35mm, 60mm, 120mm). The factors irrigable and irrigated are binary and we use "Y" or "N" to discriminate irrigable from non-irrigable land and "Irrigated" and "Dryland" to discriminate irrigation status. Details concerning these natural and land use characteristics, and some adjustments to Bright *et al.*'s (2018) export coefficients to account for regionally specific conditions and information, are provided below.

Variation in climate was based on the NZ Meteorological Service Climate Regions map (NZMS 315/2) following modifications that were made and described by Bright *et al.* (2018; Figure 8).

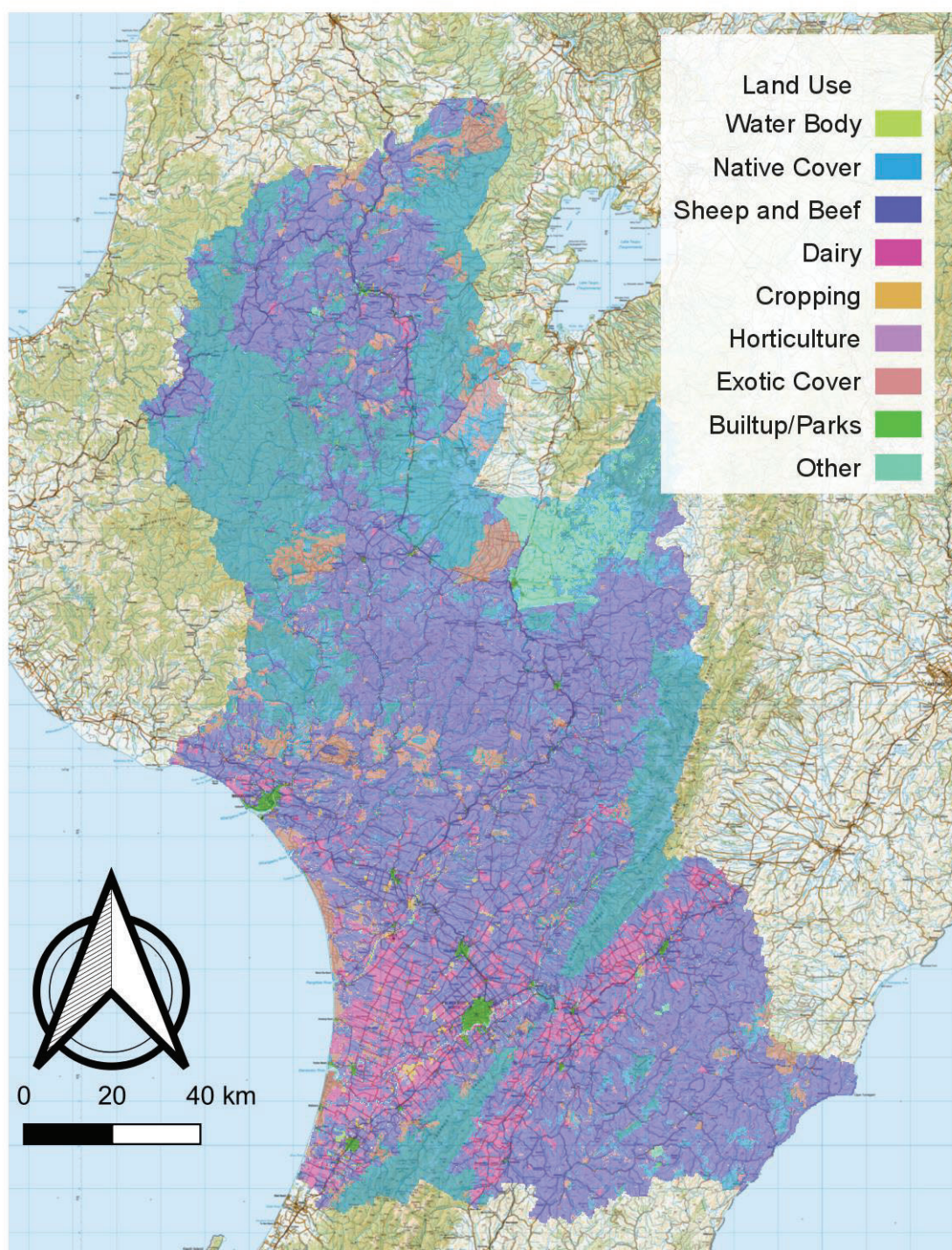


Figure 7. Land use map representing 9 land use/cover categories. This map represents land use in 2008. Note that horticultural land cover is very difficult to distinguish at this scale due to the small area of properties.

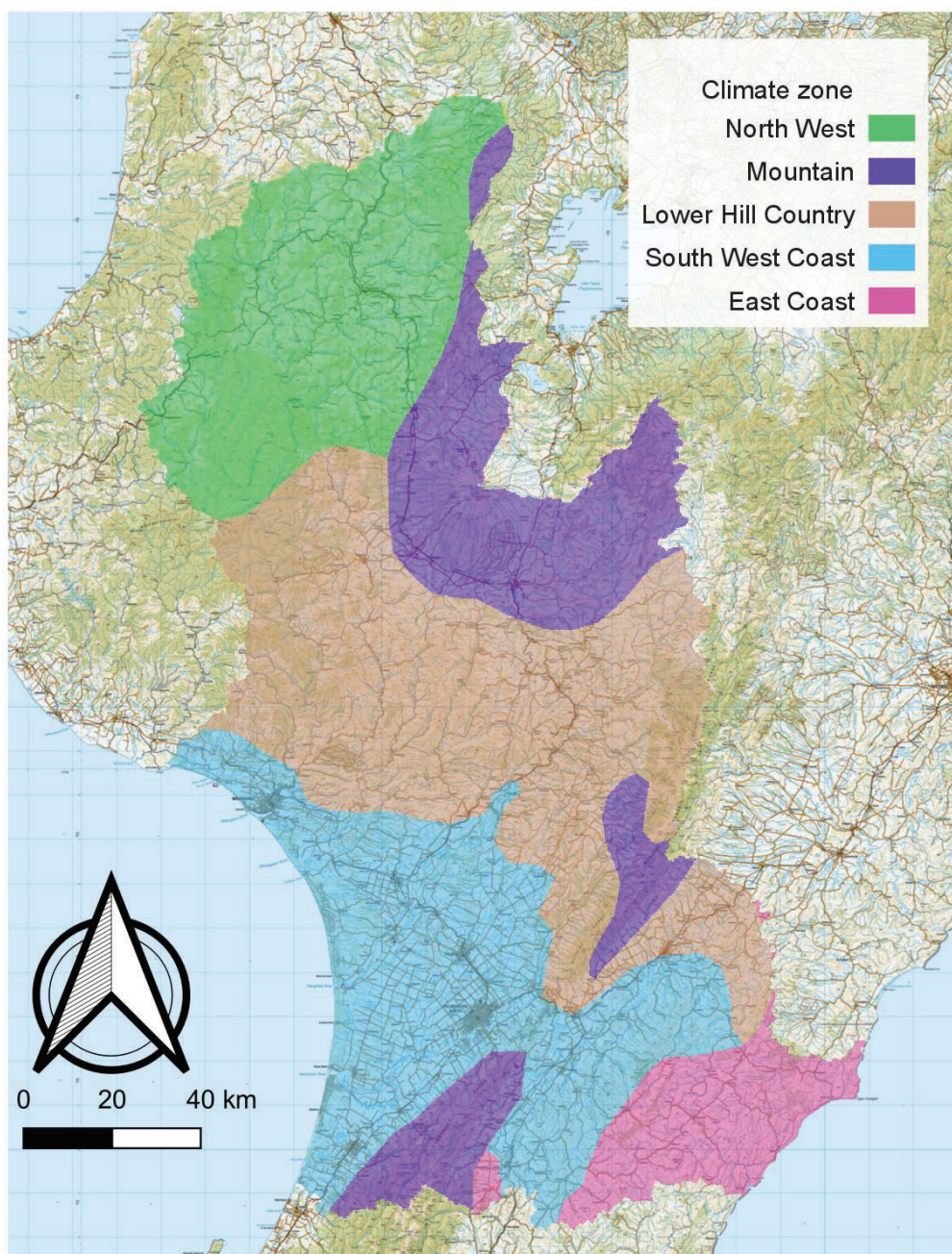


Figure 8. Climate variation described using five different categories.

Variation in soils described by the PAW was obtained from the fundamental soils layer (Figure 9). The FSL is described in <https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers> and the PAW dataset used in this modelling is available at <https://iris.scinfo.org.nz/layer/100-fsl-profile-available-water/>.

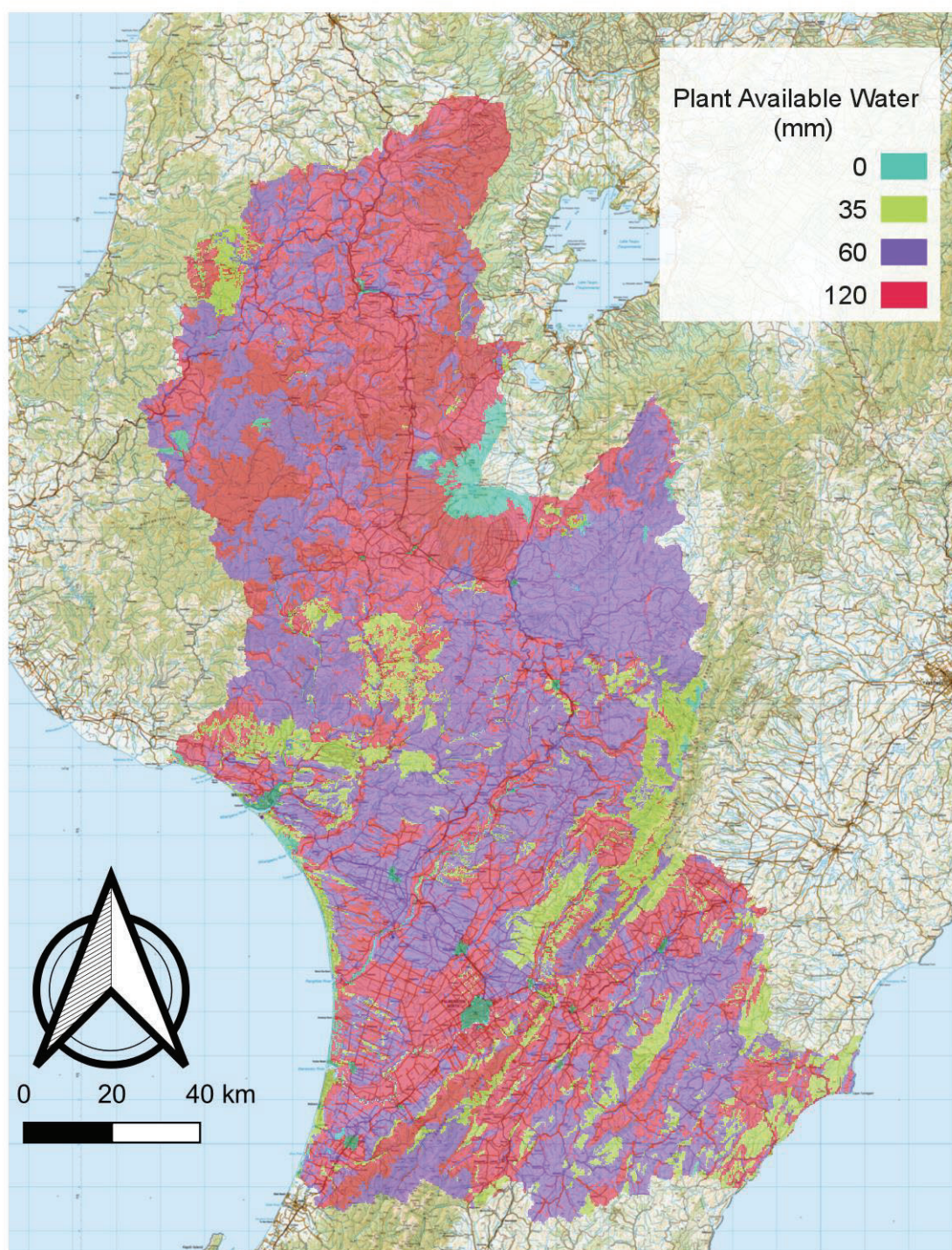


Figure 9. Soil layer representing variation in PAW in four categories.

Irrigable land was described by Bright *et al.* (2018) based on combining LUC and land slope (Figure 10).

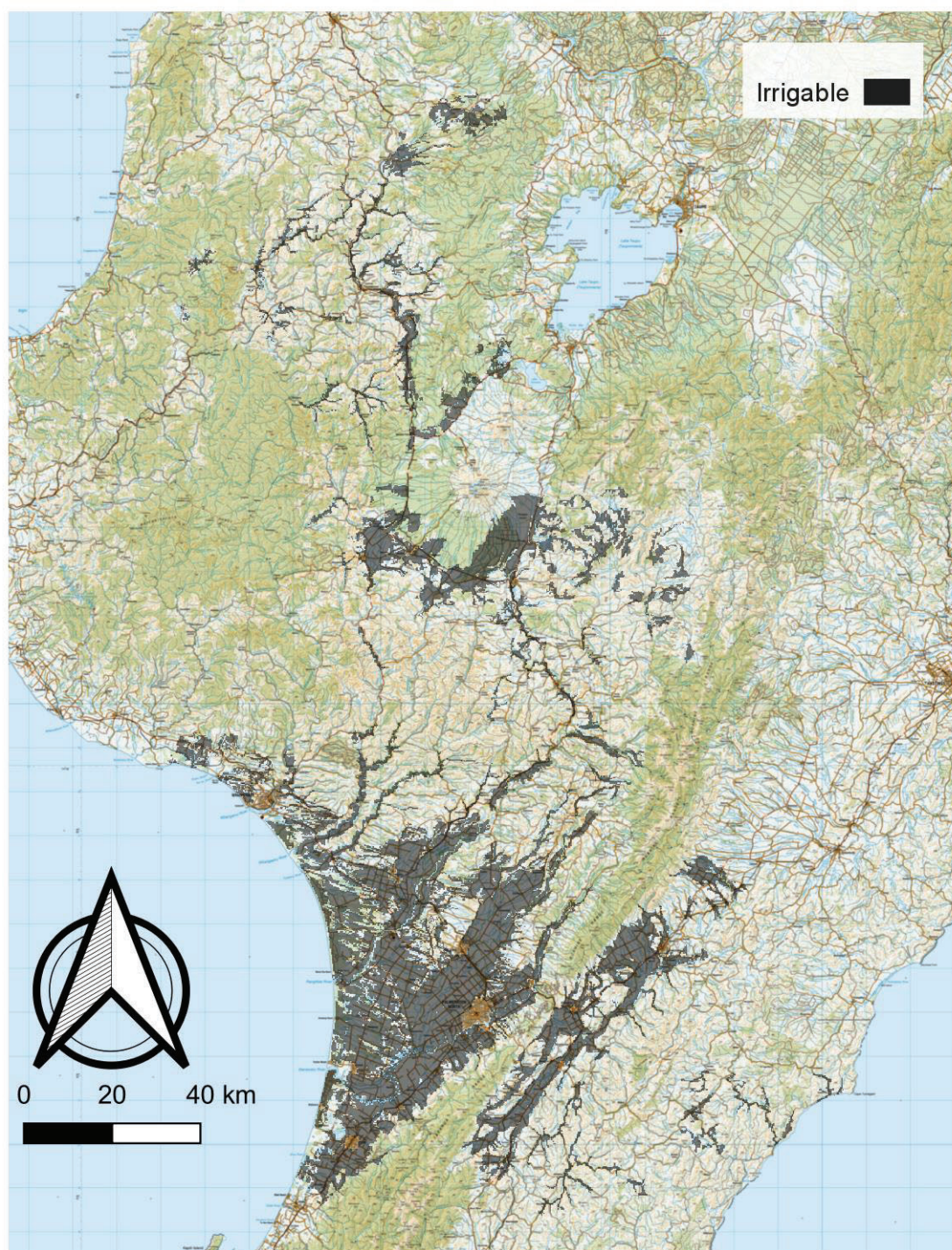


Figure 10. Irrigable land layer representing areas that are feasibly irrigated.

Irrigated land was obtained from <https://data.mfe.govt.nz/layer/90838-irrigated-land-area-2017/> (Figure 11). This layer pertains to 2017 however, there has not been a significant increase in irrigation since 2012 and it was therefore considered to be sufficiently representative (Figure 11).

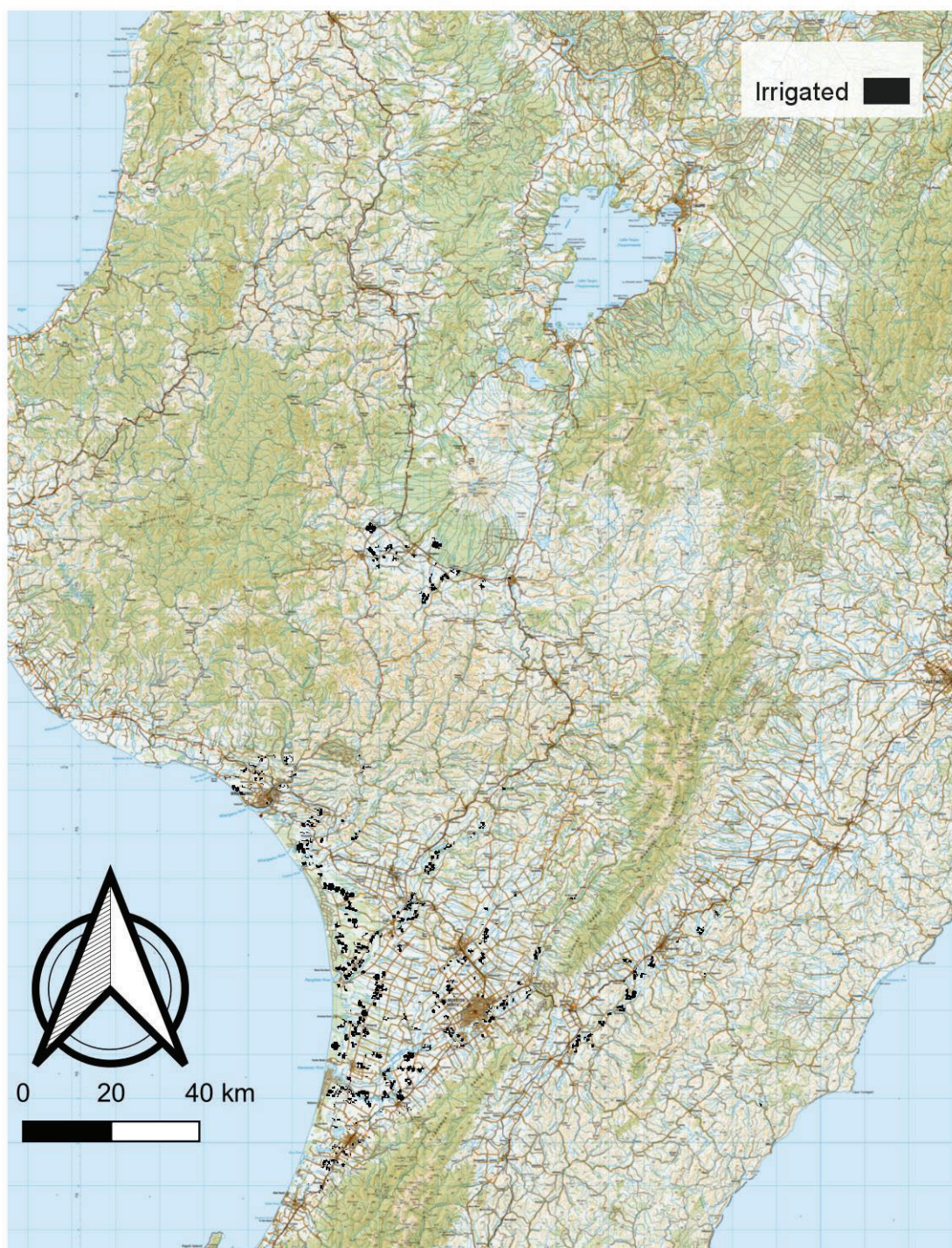


Figure 11. Irrigated land layer representing areas that are assessed to be irrigated.

Bright *et al.* (2018) provide tables of export coefficients for most combinations of the nine land use types and the categories for each of the four other biophysical factors (climate, PAW, irrigable and irrigated) that occur in the Manawatū-Whanganui Region. We made some adjustments to these export coefficients to provide a complete coverage and to incorporate regionally specific information. First, we used export coefficients from vegetable growing areas in Horowhenua based on loss rates estimated by Bloomer *et al.* (2020). Second, we increased export coefficients for non-productive land from the value of 1 kg N yr⁻¹ provided by Bright *et al.* (2018) to 2 kg N yr⁻¹, which is consistent with values used by Collins *et al.* (2017) and other regional analyses. Third, we assumed export coefficients for exotic cover were 3 kg N yr⁻¹ based on values used by Collins *et al.* (2017). Finally, there were areas that were classified as non-irrigable, but which were nevertheless irrigated according to the available data. We assumed that export coefficients for irrigated but non-irrigable land were the same as irrigated and irrigable land.

To assign export coefficients to all land in the region, we first subdivided each WMZ into a discrete number of grid cells based on a 250m by 250m grid. For each grid cell, the combination of the table of export coefficients with maps describing land use (Figure 7 **Error! Reference source not found.**) and the four additional biophysical factors (climate, PAW, irrigable and irrigated) resulted in the distribution of diffuse source export coefficients shown in Figure 12. For each land use category, the export coefficients account for variation in four biophysical factors including: climate zone, plant available soil water capacity (PAW), and whether the land is irrigable and irrigated.

The export coefficients used by this study are general in that they are estimates of average rates, within each combination of land use and factor categories, New Zealand wide (Bright *et al.*, 2018). However, Bright *et al.*'s (2018) export coefficients systematically account for variation in nitrogen loss rates due to different types biophysical conditions (i.e., variation in the four biophysical factors). All estimates of export coefficients are subject to uncertainty and will be imprecise when compared to a specific farm property or a more exactly defined biophysical context. To provide for a degree of validation of the adopted export coefficients, we compared them with the available regionally specific estimates made by other studies. The details of these comparisons are described in Appendix B of this report. These comparisons show that there is a reasonably high level of consistency in the average values for the nitrogen export coefficients provided by the various studies (including the export coefficients that were adopted by this study) but that there is also considerable range in these values. These and other uncertainties are compounded in the models and mean our confidence is highest when the model is used to assesses the difference in water quality outcomes between two scenarios in relative terms. A formal analysis of the model uncertainty and assessment of possible differences due to land use changes is possible with the CASM models but was beyond the scope of this study.

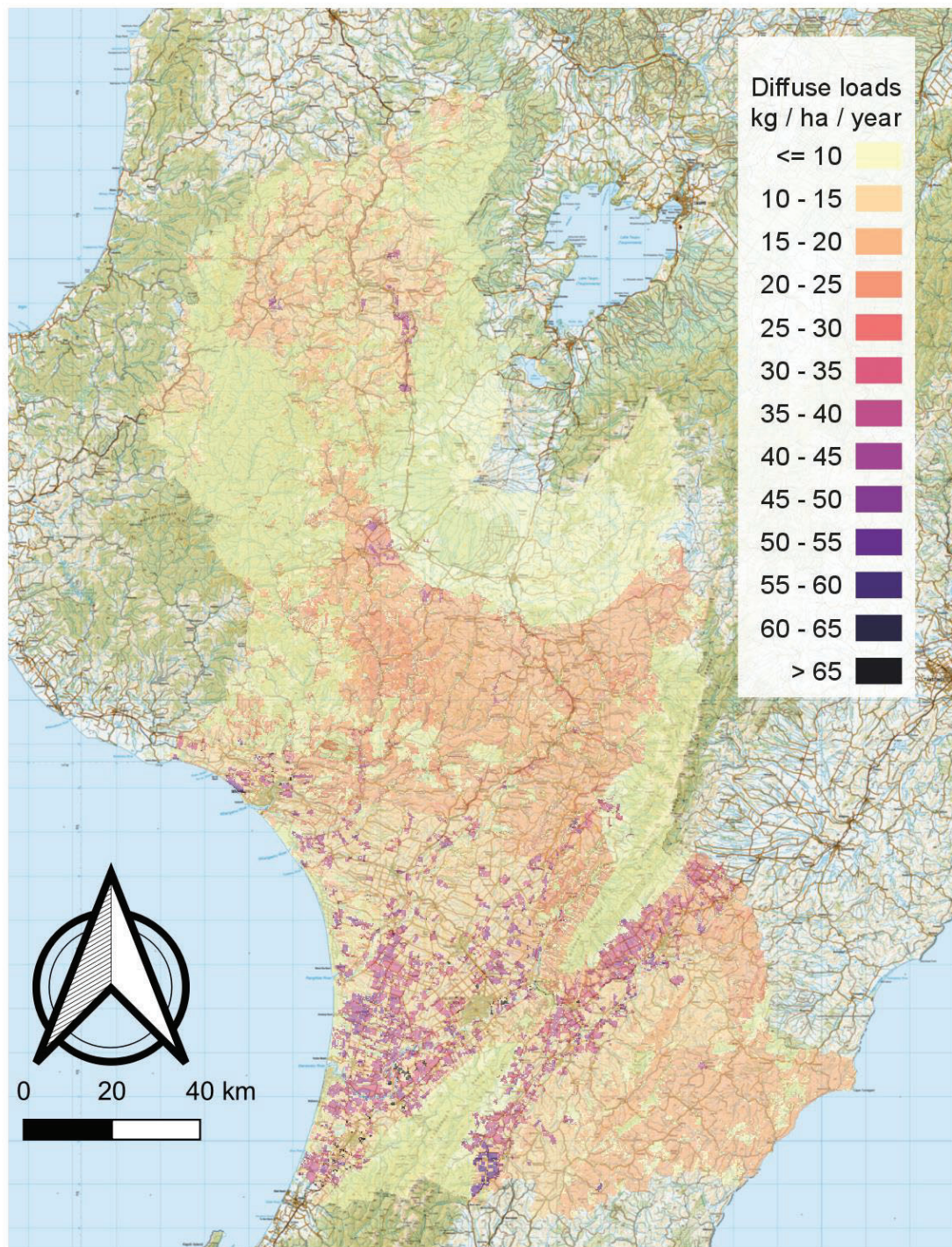


Figure 12. Variation of diffuse source export coefficients across the region. Export coefficients were derived by combining the 2012 land use map and modifications of export coefficients provided by Bright et al. (2018).

2.6 Model sub-catchment load aggregation

The land use capability (LUC) system is a national land classification framework that was developed in 1952 and has been refined since then to define biophysical constraints that may limit sustained productivity within farm management units (Lynn *et al.*, 2009; Mueller *et al.*, 2010). Table 14.2 of the One Plan allocates nitrogen loss rate limits to land based on LUC categories (categories from 1 to 8) (Figure 13). It was therefore necessary to represent LUC categories in the models so that analyses such as future scenario simulations could be defined based on LUC categories. Analyses also depend on assumptions about the land use category. Therefore, within each of the model sub-catchments (i.e., the WMZs shown in Figure 1 to Figure 4), each grid cell was assigned to the combination of its spatially dominant LUC and land use categories. Cells pertaining to each of these combined categories were aggregated within each sub-catchment and were represented in the models as separate “diffuse-source nodes”. Each diffuse-source model node was parameterised with a representative export coefficient (derived from Figure 12) and total land area.

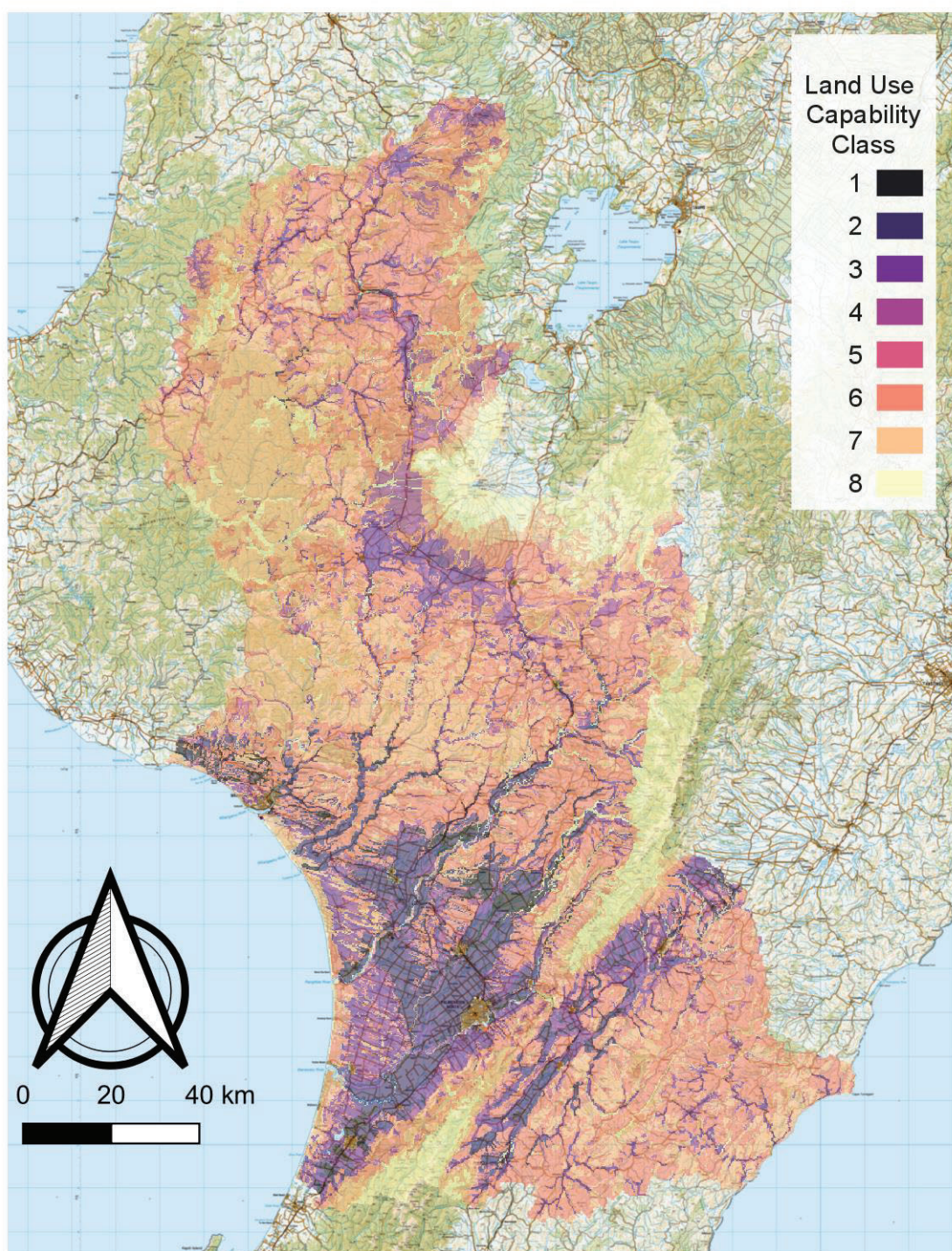


Figure 13. Land use capability (LUC) layer representing eight land use capability categories.

2.7 Model calibration

Each model was calibrated so that modelled downstream nitrogen loads and concentrations adequately matched measured data for a series of river monitoring stations. The primary calibration parameters were diffuse pathway attenuation coefficients, specific to each WMZ. Calibration proceeded from upstream to downstream with manual adjustments to upstream

attenuation coefficients, for each calibration point, to achieve an acceptable agreement in the water quality calibration targets. The calibration points, with total nitrogen (TN) concentration performance measures, are shown in Figures 5 – 8 and summarised in Tables 3 - 6. In a small number of cases, export coefficients also required adjustment to achieve an acceptable calibration.

Note that, for some water quality stations, river kilometre marker locations were adjusted slightly to be downstream of contributing WMZs. In such cases, we expect modelled concentrations to be slightly higher than measured (because the model has effectively artificially added additional diffuse load). In other cases, the water quality station includes drainage area not included in the upstream WMZ discretization. In these cases, we expect modelled concentrations to be lower than measured. These sites are indicated in the summary tables.

The calibration process generally followed the steps listed below.

1. The calibration was performed for each water quality station calibration point in sequence, moving from upstream to downstream.
2. For each calibration point, all upstream uncalibrated diffuse node attenuation coefficients were uniformly adjusted to achieve acceptable modelled vs. measured TN concentrations. For all nodes, the model default minimum attenuation of 0.1 was maintained.
3. If an acceptable calibration couldn't be achieved with adjustments to attenuation coefficients alone, sensible adjustments were made to node export coefficients. For this study, this step only ever involved an increase in export coefficients from original independent parameterisation. For example, for some WMZs the minimum export coefficient was increased from 1 to 2 kg ha⁻¹ yr⁻¹ to 4 kg ha⁻¹ yr⁻¹ (e.g. for native and exotic cover).
4. Calibration performance was assessed based on professional judgement, but in most cases modelled results were within 10 – 20% of measured values.
5. For unmonitored WMZs, without a corresponding downstream calibration point, attenuation coefficients were assigned based on nearest neighbour calibrated values.

3 Results

3.1 Calibration of attenuation

Summaries of calibrated diffuse attenuation coefficients are provided in Table 2 to Table 5 and on Figure 14 to Figure 17. A satisfactory calibration was achieved for all four basin models. Downstream calibration targets were all achieved with sensible adjustments to upstream attenuation coefficients, within expected ranges, and, in a limited number of cases, minor adjustments to independently derived export coefficients. In general, a pleasing consistency in calibrated attenuation coefficients was achieved within a given basin model. For example, a uniform attenuation coefficient of 0.1 (model minimum) was calibrated for the entirety of the Whanganui basin. For the Whangaehu basin, greater than 90% of catchment attenuation, by area, was calibrated within the range of 0.35 to 0.65. A general gradient of high to low attenuation from upland to lowland sub-catchments was apparent in both the Manawatū and Rangitikei basins (Figure 18). Variability in attenuation coefficients throughout the region is driven by a range of potential factors, including sub-catchment size,

land cover, hydrology, and physiography. Further investigation into this variability is beyond the scope of the current study.

Table 2. Manawatū River basin model calibration results: annual average TN concentrations and load.

<i>Water Quality Station</i>	<i>Modelled, (mg/L)</i>	<i>Measured (mg/L)</i>	<i>Unattenuated (t/y)</i>	<i>Attenuated (t/y)</i>
Manawatū at Weber Road	1.6	1.6	1196	652
Manawatū at Hopelands	1.6	1.6	2250	1421
Manawatū at Upper Gorge	1.3	1.2	5103	3305
Manawatū at Teachers College	1.2	1.3	5955	3812
Manawatū at u/s PNCC STP	1.1	1.21	5981	3491
Manawatū at ds Fonterra Longburn	1.1	1.0	6888	3881
Manawatū at Opiki Br	1.2	1.21	6999	3908
Mangatoro at Mangahei Road	1.5	1.4	341	181
Tamaki at Stephenson's	1.2	1.3	108	97
Kumeti at Te Rehunga	1.2	1.5	18	16
Oruakeretaki at d/s PPCS Oringi STP	2.0	2.1	107	96
Raparapawai at Jackson Rd	1.4	1.4	87	36
Makakahi at Hamua	1.6	1.32	385	289
Mangatainoka at Larsons Road	0.4	0.4	40	36
Mangatainoka at Brewery - S.H.2 Bridge	1.6	1.6	846	677
Makuri at Tuscan Hills	1.7	1.7	225	157
Tiraumea at Ngaturi	1.3	1.3	1057	574
Mangahao at Ballance	0.4	0.4	214	193
Mangapapa at Troup Rd	1.6	1.6	45	26
Pohangina at Mais Reach	0.4	0.3	484	174
Oroua at Almadale Slackline	0.8	0.7	464	164
Oroua at d/s AFFCO Feilding	1.0	1.0	978	365
Oroua at d/s Feilding STP	1.8	1.9	1273	647
Oroua at Awahuri Bridge	1.2	1.2	1495	483
Owahanga at Branscombe Bridge	1.4	1.3	617	247
Ohau at Gladstone Reserve	0.3	0.3	56	50

Table 3. Rangitikei Model River basin model calibration results: annual average TN concentrations and load.

<i>Water Quality Station</i>	<i>Modelled (mg/L)</i>	<i>Measured (mg/L)</i>	<i>Unattenuated (t/y)</i>	<i>Attenuated (t/y)</i>
Rangitikei at Pukeokahu	0.21	0.21	635	159
Rangitikei at Mangaweka	0.38	0.37	2493	795
Rangitikei at Onepuhi	0.51	0.54	3442	1270
Rangitikei at Kakariki	0.49	0.48	3382	1264
Rangitikei at McKelvies	0.84	0.87	4517	2320
Hautapu at Alabasters	0.68	0.68	313	94

Table 4. Whanganui River basin model calibration results: annual average TN concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Unattenuated (t/y)	Attenuated (t/y)
Whanganui at Te Maire	0.59	0.58	1641	1478
Whanganui at Pipiriki	0.68	0.67	4903	4415
Whanganui at Te Rewa	0.67	0.72	5350	4816
Whanganui at Paetawa	0.67	0.70	5350	4816
Ongarue at Taringamotu	0.75	0.76	949	854
Ohura at Tokorima	1.1	1.1	902	812

Table 5. Whangaeahu River basin model calibration results: annual average TN concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Unattenuated (t/y)	Attenuated (t/y)
Whangaeahu at Kauangaroa	0.84	0.84	2390	1194
Tokiahuru at Junction	0.19	0.19	54	49
Makotuku at d/s Raetihi STP	0.71	0.60	129	54
Mangawhero at Pakihi Rd Bridge	0.55	0.52	154	89
Mangawhero at Raupiu Road	0.82	0.82	986	459
Turakina at ONeills Bridge	3.6	3.5	1586	951

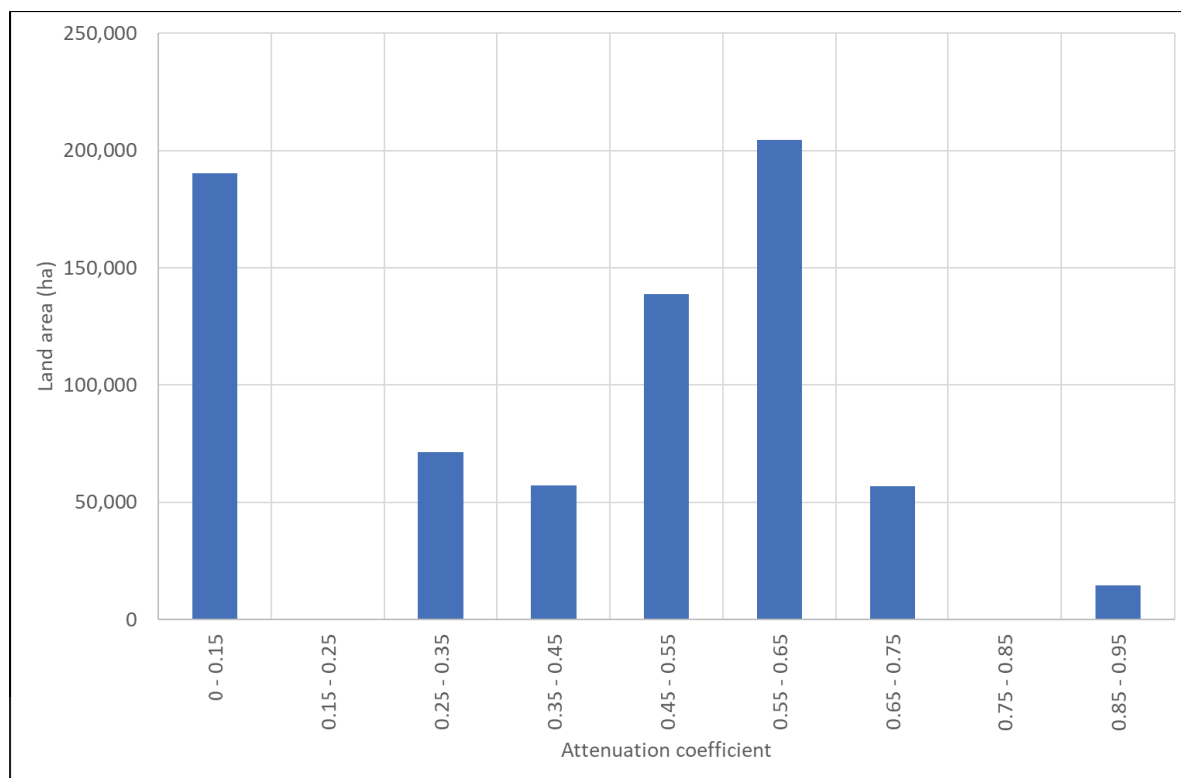


Figure 14. Areal distribution of calibrated attenuation coefficients, Manawatu River basin

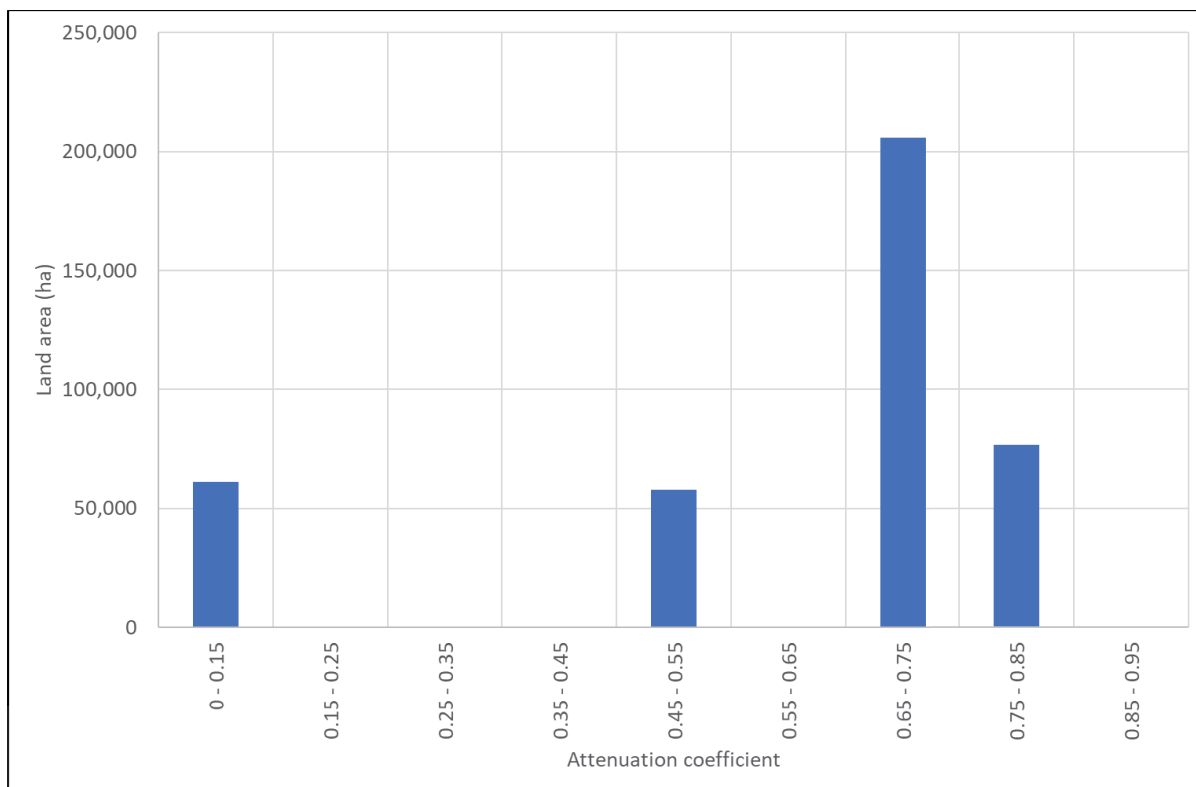


Figure 15. Areal distribution of calibrated attenuation coefficients, Rangitikei River basin

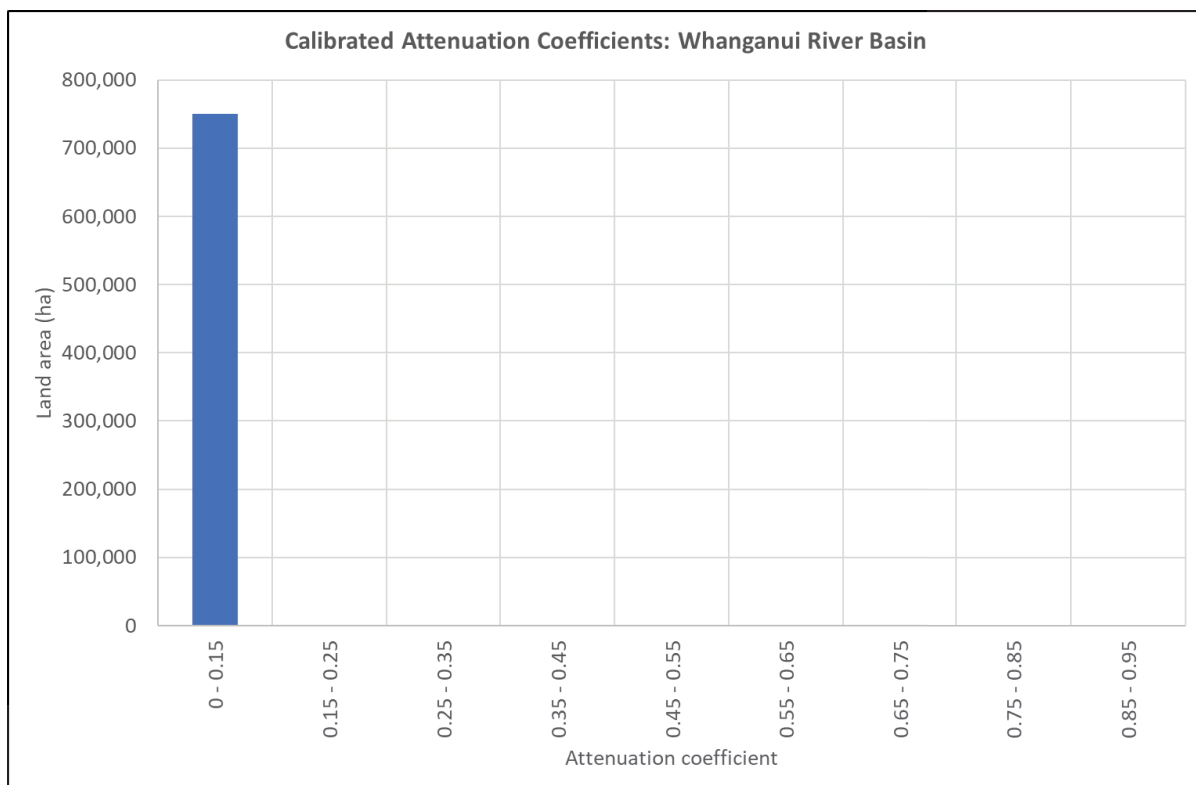


Figure 16. Areal distribution of calibrated attenuation coefficients, Whanganui River basin

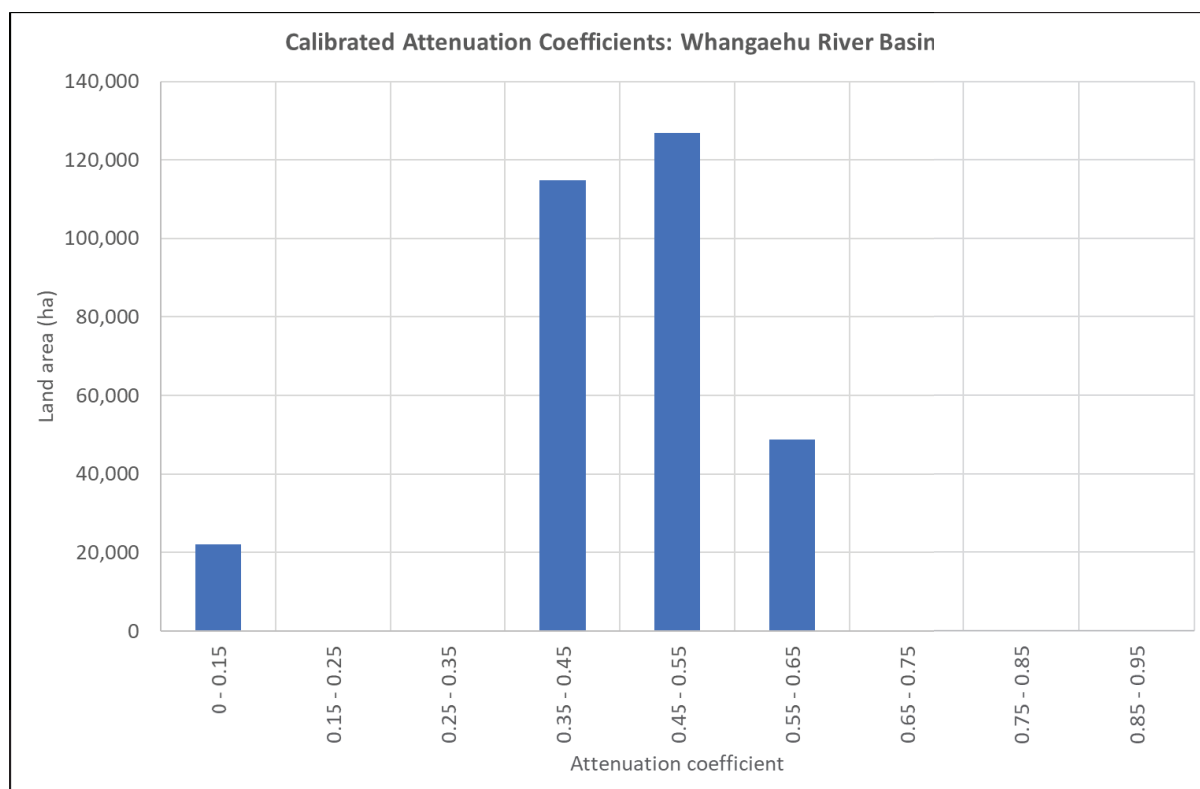


Figure 17. Areal distribution of calibrated attenuation coefficients, Whangaehu River basin

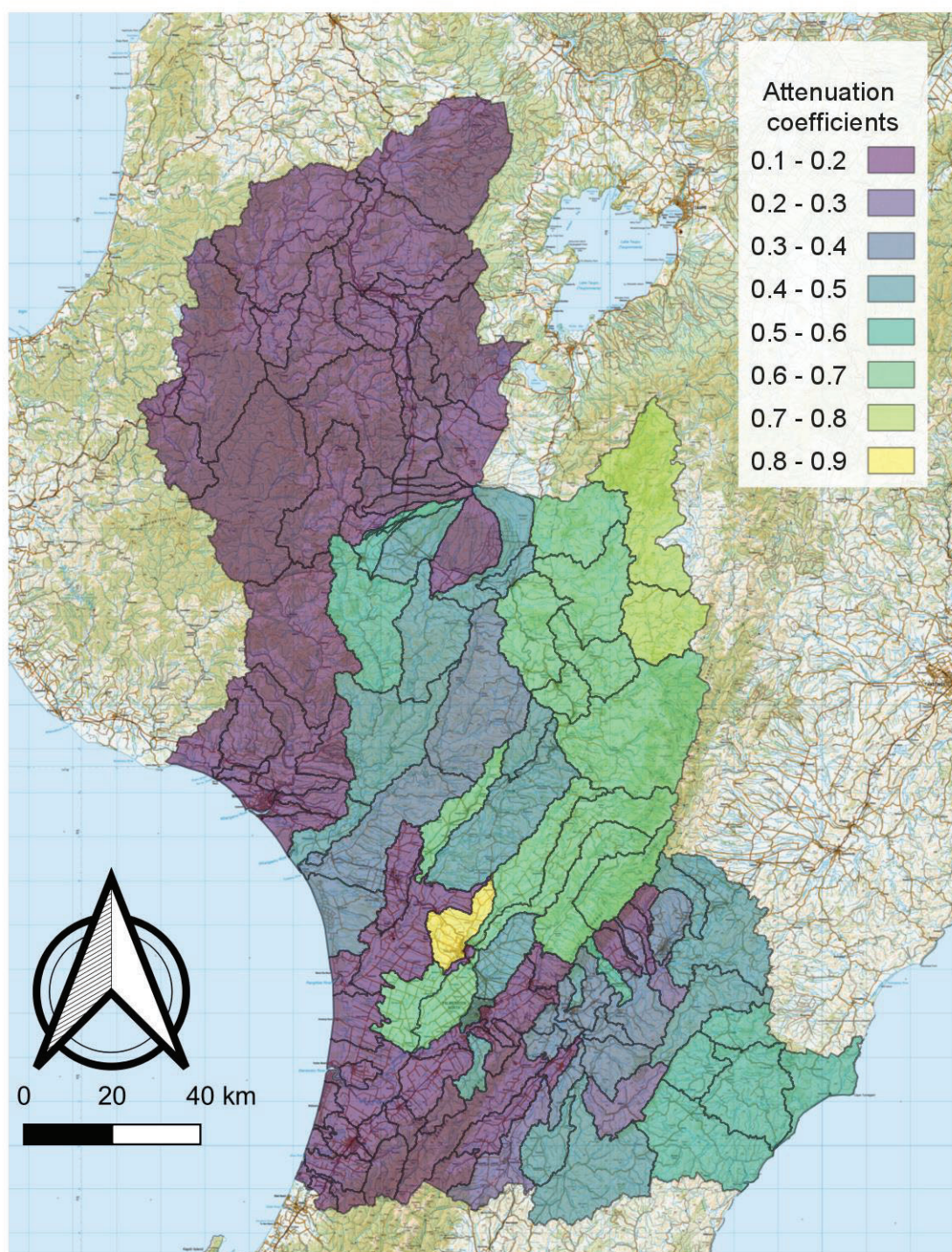


Figure 18. Map showing attenuation rates for each WMZ represented in the models.

3.2 Comparison with previous load calculations and uncertainties associated with attenuation estimates

Singh & Elwan (2017) calculated TN loads at 34 water quality stations that were common to this study. Singh & Elwan (2017) used the flow stratification method (see Appendix A) and concentration and flow data pertaining to the period from January 2012 to December 2016. We compared the water quality station loads estimated by Singh & Elwan (2017) with the loads estimated by this study.

This study's load estimates are systematically higher than those of Singh and Elwan (2017) (Figure 19). There are two potential explanations for these differences. First, even with identical input data, different load calculation methods produce different results and these differences can be systematic (i.e., leading to a consistent difference; Defew *et al.*, 2013; Roygard *et al.*, 2012). Second, loads estimated at the same site, but for different time periods can vary significantly (Snelder *et al.*, 2017). The loads estimated by the current study pertained to a specific year (2012), which was possible because the calculation methods involved a temporal term (see Appendix A). The flow stratification method used by Singh and Elwan (2017) does not involve a temporal term and therefore the load estimate can be considered to represent the mean annual load for the entire period of record used in the calculation.

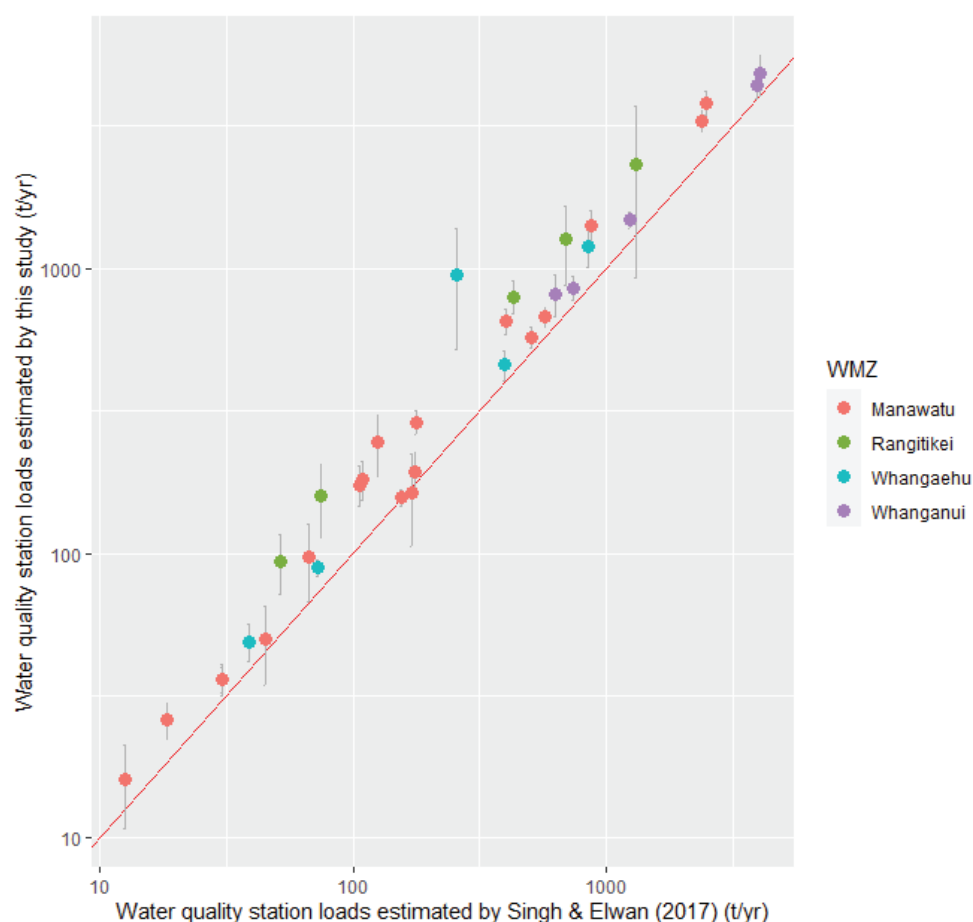


Figure 19. Comparison of load estimates for 34 water quality stations made by this study and Singh and Elwan (2017). The error bars indicate the 95% confidence interval for the load estimates made by this study. The red (1 to 1) line indicates perfect correspondence between the two estimates. Note that the axes are log scales.

We examined whether the systematic differences in loads estimated by the two studies could be associated with differences in the time-periods implied by the calculation methods. We examined trends in TN concentrations at the 34 water quality stations over the period used to calculate the loads by Singh and Elwan (2017). Raw (i.e., not flow adjusted) trends for these sites were produced by Fraser and Snelder (2018) for the five year period ending in 2017 (i.e. 2013 to 2017 inclusive), which closely corresponds to the period from January 2012 to December 2016 period used by Singh and Elwan (2017). We summarised the TN trends in two ways. First, we used the proportion of improving trends (PIT; Fraser and Snelder, 2018) to represent the overall trend direction over the 34 sites. The PIT statistic had a value of 82% (standard error = $\pm 5\%$), which indicates 82% of sites had improving (i.e., decreasing) TN trends in the period. Second, each of the 34 trends was assigned to a category indicating confidence that the trend was improving. The summary of the proportions of sites in each category indicates that ~75% of sites were at least likely to have improved over the period (Figure 19). Only ~9% of sites were unlikely (or less probable) to have had improving trends (i.e., the equivalent of the complementary probability they were at least likely to have degraded). The decreasing TN trends over most sites in the period between 2013 to 2017 is broadly consistent with the systematically higher load estimates made by this study. This study's higher estimates pertain to the start of the period (2012) whereas the estimates made by Singh and Elwan (2017) pertain to average over the period in which concentrations decreased at most sites.

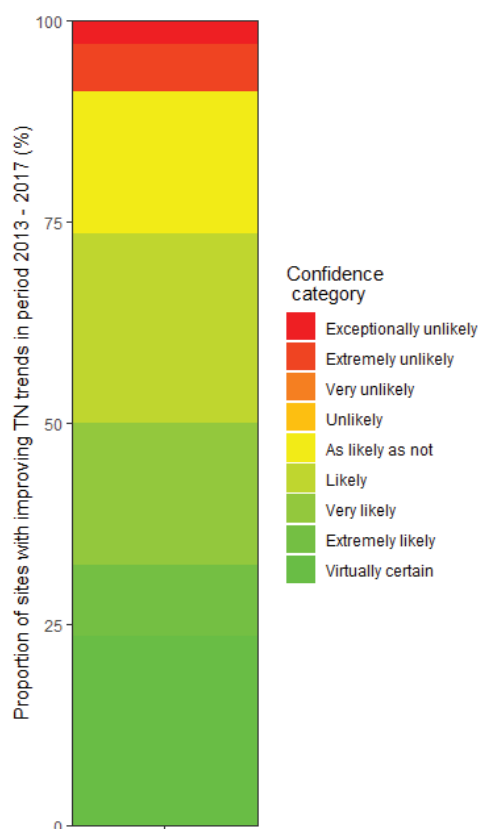


Figure 20. Summary plot representing the proportion of the 34 sites with improving 5-year time period trends at each categorical level of confidence. The plot shows the proportion of sites for which water quality was improving at nine levels of confidence defined by (Fraser and Snelder, 2018). Green colours indicate improving sites, and red-orange colours indicate degrading sites. Trends used in this graph are not flow adjusted.

Other studies have estimated nitrogen attenuation factors (AF_N) for the same water quality stations represented by this study (e.g., Elwan *et al.*, 2015). We calculated effective net attenuation coefficients, AF_N , for the 34 water quality stations in common to this study and Singh and Elwan (2017). These net attenuation coefficients represent the combined result of all upstream diffuse-source node calibrated attenuation coefficients, combined with upstream unattenuated point sources, and were calculated as follows:

$$AF_N = \frac{L_c - L_{wqs}}{L_c} \quad \text{Equation 1}$$

where L_c is the estimated catchment source load (including the diffuse and point sources) and L_{wqs} is the estimated water quality station load. These values have the same physical meaning as the attenuation coefficients derived by the CASM calibration. However, in the discussion that follows we refer to them as AF_N values because we are not referring directly to the CASM attenuation coefficients.

Close agreement between AF_N values estimated by different studies is unlikely due to two sources of uncertainty. First, as described above, estimates of loads for the same water quality station are likely to vary between load calculation methods and time periods. Second, to estimate attenuation, an estimate of the catchment source loads is required, and this calculation is likely to differ considerably between studies and to be uncertain.

We demonstrate the range of uncertainty of AF_N estimates made using the data provided by this study. We compare this study's AF_N values with those estimated using the same catchment source loads but with the 34 water quality station loads estimated by Singh and Elwan (2017) that are in common. We estimated the uncertainty of this study's AF_N values by combining the uncertainty of the water quality station load estimates with an assumed uncertainty of the catchment source loads using the following relationship:

$$\frac{u(AF_N)}{AF_N} = \sqrt{\left[\frac{u(L_{wqs})}{L_{wqs}} \right]^2 + \left[\frac{u(L_c)}{L_c} \right]^2} \quad \text{Equation 2}$$

where, $u(AF_N)/AF_N$ is the relative uncertainty in the estimate of the nitrogen attenuation factor, $u(L_{wqs})/L_{wqs}$ is the relative uncertainty in the estimated water quality station load and, $u(L_c)/L_c$ is the relative uncertainty in the estimated catchment source load. We assumed a relative uncertainty of the estimated catchment source load of 25%, which was based on an estimated characteristic uncertainty for the OVERSEER nutrient budgeting model (PCE, 2018).

Large uncertainty in the estimates of AF_N for most sites is shown in Figure 21. Figure 21 also indicates that AF_N estimated using water quality station loads estimated by Singh and Elwan (2017) are systematically lower (by about 0.2) compared to the estimates made using water quality station loads estimated by this study. The reason for this difference is the systematic difference in site loads between the two studies that is shown in Figure 19. Higher water quality station loads estimated by this study leads to lower AF_N estimates compared to estimates using the loads of Singh and Elwan (2017). However, the 95% confidence intervals indicate that for individual sites, the uncertainty in AF_N estimated by this study always encompass the value of AF_N if the water quality station loads estimated by Singh and Elwan (2017) were used. In other words, the published Singh and Elwan (2017) values fall within the estimated confidence intervals for this study.

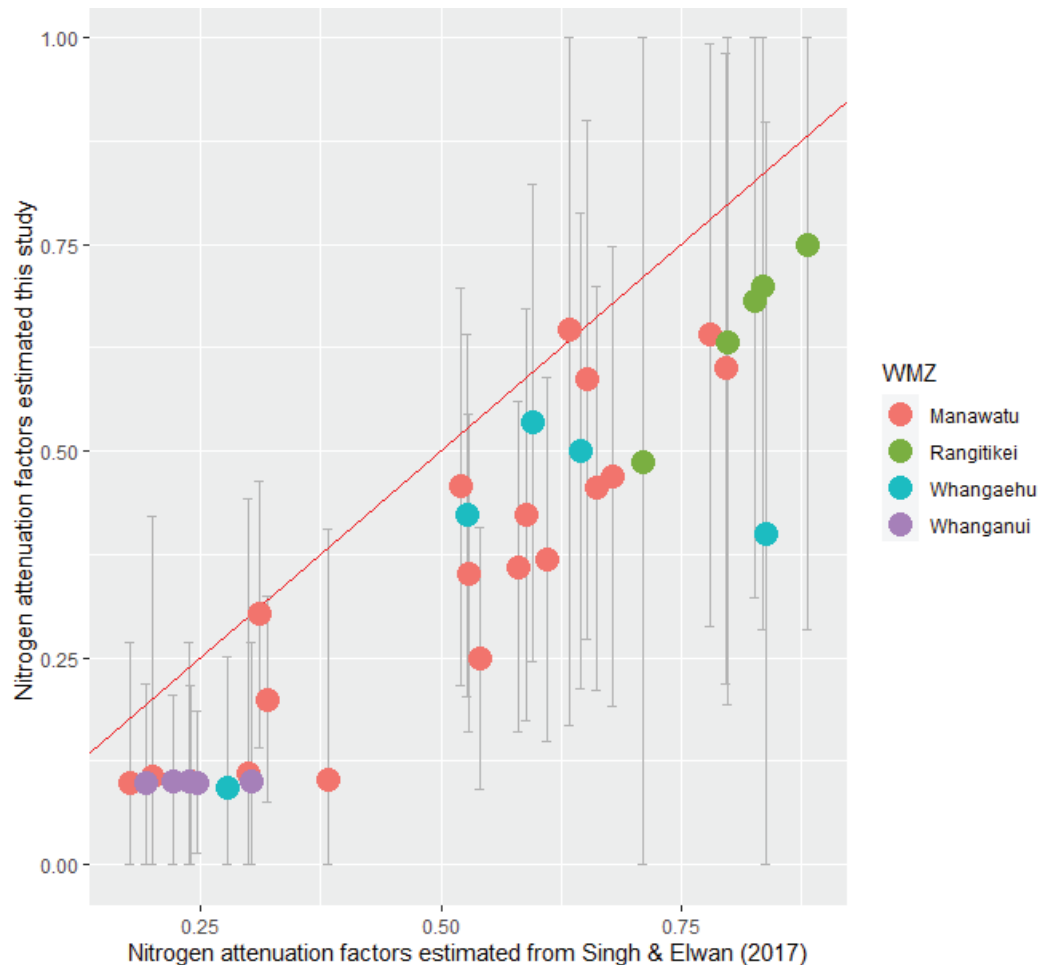


Figure 21. Comparison of AF_N estimated using load estimates for 34 water quality stations made by this study and (Singh and Elwan, 2017). The error bars indicate the 95% confidence intervals for AF_N estimates for this study.

4 Conclusion

Catchment water quality models were developed for the four major river basins in the Horizons Region: the Manawātū (including the Horowhenua and Coastal Tararua catchments), the Rangitikei, the Whanganui, and the Whangaehu (including the Turakina River catchment). The entire region is encapsulated by the four models. The models use sub-catchment export and attenuation coefficients to simulate the generation, transport, and downstream delivery of total nitrogen loads throughout the region. The models were developed to investigate the impact of regulating nitrogen discharge allowances from intensively farmed land throughout the region, particularly with respect to mitigation implications and feasibility. The models were developed in a usable framework to allow for future application by a range of potential end users.

A satisfactory calibration was achieved for all four basin models. Downstream calibration targets were all achieved with sensible adjustments to upstream attenuation coefficients, within expected ranges, and, in a limited number of cases, minor adjustments to independently derived export coefficients. Patterns of attenuation within, and between, basins have been noted but not yet fully explained.

Ideally, water quality models are calibrated to land use and catchment nitrogen emission estimates that are congruent and pertain to a specific point in time. In this study, the available land use map and catchment nitrogen emission data were not congruent in time. Limitations associated with data meant that models were calibrated to the land use pattern pertaining to 2008 and to diffuse source export coefficients and water quality station loads pertaining to 2012. However, we consider these inconsistencies are acceptable due to the relatively imprecise nature of the nitrogen emission estimates. Taken together, the uncertainties in the model input data mean that potential differences in model predictions resulting from the non-congruence of dates for the land use and catchment nitrogen emission estimates and the baseline are unlikely to be statistically significant (i.e., any differences would be within the model uncertainty). A formal analysis of the model uncertainty and assessment of possible differences due to land use changes is possible with the CASM models but was beyond the scope of this study.

Models are uncertain, and the uncertainty of the key model parameter (attenuation coefficient) has been demonstrated in this report. This uncertainty is largely unavoidable and results from uncertainty in the water quality station loads and estimated sub-catchment source loads. This uncertainty needs to be considered when using the models to make simulations of future scenarios. The absolute values of load and concentrations predicted for a scenario should be regarded as less certain than the relative change. Like most models, these catchment models are better suited for predicting relative changes in basin water quality rather than absolute values. In other words, it may be wise to frame future scenario simulation results in terms of relative changes compared to the “baseline” models presented here. Further, applying relative (e.g. percentage) changes to model input parameters (e.g. export coefficients) may be a more defensible approach for scenario simulations than prescribing absolute values. That said, these models represent the best available science for investigating the fundamental questions of the wider study and can serve as valuable supporting tools for decision-making.

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Appendix A Water quality station load calculations

A1 General approach

Mean annual TN loads at all water quality stations were derived from monthly TN concentrations and observed or modelled daily flows. Load calculation methods generally comprise two steps: (1) the generation of a series of flow and concentration pairs representing 'unit loads' and (2) the summation of the unit loads over time to obtain the total load. In practice step 1 precedes step two but in the explanation that follows, we describe step 2 first.

If flow and concentration observations were available for each day, the export coefficient, (the mean annual load, standardised by the upstream catchment area) would be the summation of the daily flows multiplied by their corresponding concentrations:

$$L = \frac{K}{A_c N} \sum_{j=1}^N C_j Q_j \quad (\text{Equation 3})$$

where L : mean annual export coefficient ($\text{kg yr}^{-1} \text{ha}^{-1}$ or $\text{Gcfu yr}^{-1} \text{ha}^{-1}$ for *E. coli* or $\text{t yr}^{-1} \text{ha}^{-1}$ for TSS), A_c : catchment area, ha, K : units conversion factor ($31.6 \text{ kg s mg}^{-1} \text{ yr}^{-1}$), C_j : contaminant concentration for each day in period of record (mg m^{-3}), Q_j : daily mean flow for each day in period of record ($\text{m}^3 \text{s}^{-1}$), and N : number of days in period of record.

In this summation, the individual products represent unit loads. Because concentration data are generally only available for infrequent days (i.e., generally in this study, monthly observations), unit loads can only be calculated for these days. However, flow is generally observed continuously, or the distribution of flows can be estimated for locations without continuous flow data, and there are often relationships between concentration and flow, time and/or season. Rating curves exploit these relationships by deriving a relationship between the sampled nutrient concentrations (c_i) and simultaneous observations of flow (q_i). Depending on the approach, relationships between concentration and time and season may be included in the rating curve. This rating curve is then used to generate a series of flow and concentration pairs (i.e., to represent Q_j and C_j in equation 1) for each day of the entire sampling period (i.e., step 1 of the calculation method; Cohn *et al.*, 1989). The estimated flow and concentration pairs are then multiplied to estimate unit loads, and these are then summed and transformed by K , N and A_c to estimate mean annual export coefficients (i.e., step 2 of the calculation method; Equation 1).

There are a variety of approaches to defining rating curves. Identifying the most appropriate approach to defining the rating curve requires careful inspection of the available data for each site and contaminant. The details of the approaches and the examination of the data are summarised below. Further details are provided by Fraser and Snelder (2019).

A2 Load calculation methods

A2.1 L7 model

Two regression model approaches to defining rating curves of (Cohn *et al.*, 1989, 1992) and (Cohn, 2005) are commonly used to calculate loads. The regression models relate the log of concentration to the sum of three explanatory variables: discharge, time, and season. The L7 model is based on seven fitted parameters given by:

$$\ln(\hat{C}_i) = \beta_1 + \beta_2 \left[\ln(q_i) - \overline{\ln(q)} \right] + \beta_3 \left[\ln(q_i) - \overline{\ln(q)} \right]^2 + \beta_4(t_i - \bar{T}) + \beta_5(t_i - \bar{T})^2 + \beta_6 \sin(2\pi t_i) + \beta_7 \cos(2\pi t_i) \quad (\text{Equation 4})$$

where, i is the index for the concentration observations, $\beta_{1,2,...,7}$: regression coefficients, t_i : time in decimal years, $\bar{T}$: mean value of time in decimal years, $\overline{\ln(q)}$ mean of the natural log of discharge on the sampled days, and $\hat{C}_i$: is the estimated i^{th} concentration.

The coefficients are estimated from the sample data by linear regression, and when the resulting fitted model is significant ($p < 0.05$), it is then used to estimate the concentration on each day in the sample period, $\ln(\hat{C}_j)$. The resulting estimates of $\ln(\hat{C}_j)$ are back-transformed (by exponentiation) to concentration units. Because the models are fitted to the log transformed concentrations the back-transformed predictions were corrected for retransformation bias. We used the smearing estimate (Duan, 1983) as a correction factor (S):

$$S = \frac{1}{n} \sum_{i=1}^n e^{\hat{\varepsilon}_i} \quad (\text{Equation 5})$$

where, $\hat{\varepsilon}$ are the residuals of the regression models, and n is the number of flow-concentration observations. The smearing estimate assumes that the residuals are homoscedastic and therefore the correction factor is applicable over the full range of the predictions.

The average annual load is then calculated by combining the flow and estimated concentration time series:

$$L = \frac{KS}{N} \sum_{j=1}^N \hat{C}_j Q_j \quad (\text{Equation 6})$$

If the fitted model is not significant, $\hat{C}_j$ is replaced by the mean concentration and S is unity.

To provide an estimate of the load at a specific date, (i.e. $t^{\text{est}} = 1/3/2004$) a transformation is performed so that the year components of all dates (t_j) are shifted such that all transformed dates lie within a one-year period centred on the proposed observation date (i.e. $Y=1/9/2003$ to $31/8/2004$). For example, flow at time $t=13/6/2007$ would have a new date of $Y=13/6/2004$, and a flow at time $t=12/11/1998$ would have a new date of $Y=12/11/2003$.

$$\ln(\hat{C}_j^Y) = \beta_1 + \beta_2 \left[\ln(q_j) - \overline{\ln(q)} \right] + \beta_3 \left[\ln(q_j) - \overline{\ln(q)} \right]^2 + \beta_4(Y_j - \bar{T}) + \beta_5(Y_j - \bar{T})^2 + \beta_6 \sin(2\pi Y_j) + \beta_7 \cos(2\pi Y_j) \quad (\text{Equation 7})$$

where $\hat{C}_j^Y$ is the estimated j^{th} concentration for the estimation year, and Y_j is the transformed date of the j^{th} observation, and all other variables are as per equation 6. We use this approach to estimate loads for the analysis that are representative of the middle of the state time period (i.e. the full calendar year of 2015). The regression coefficients ($\beta_{1,2,...,7}$) are those derived from fitting **Error! Reference source not found.** to the observation dataset. It follows that the estimated load for the year of interest can be calculated by:

$$L^Y = \frac{KS}{N} \sum_{j=1}^N \hat{C}_j^Y Q_j \quad (\text{Equation 8})$$

4.1.1.1 L5 Model

The L5 model is the same as the L7 model except that two quadratic terms are eliminated:

$$\ln(\hat{C}_i) = \beta_1 + \beta_2(\ln(q_i)) + \beta_3(t_i) + \beta_4\sin(2\pi t_i) + \beta_5\cos(2\pi t_i) \quad (\text{Equation 9})$$

The five parameters are estimated, and loads are calculated in the same manner as the L7 model. Following the approach outlined for the L7 model, the L5 model can be adjusted when used for prediction to provide estimates for a selected load estimation date:

$$\ln(\hat{C}_j^Y) = \beta_1 + \beta_2[\ln(q_j)] + \beta_4(Y_j - \bar{T}) + \beta_6\sin(2\pi Y_j) + \beta_7\cos(2\pi Y_j) \quad (\text{Equation 10})$$

A2.2 Flow stratification

Roygard *et al.* (2012) employed a flow stratification approach to defining rating curves. This approach is based on a non-parametric rating curve, which is defined by evaluating the mean concentration within equal increments of the flow probability distribution (flow ‘bins’). In their application, Roygard *et al.* (2012) employed ten equal time-based categories (flow decile bins), defined using flow distribution statistics and then calculated mean concentrations within each bin. This non-parametric rating curve can then be used to estimate nutrient concentrations, $\hat{C}$, for all days with flow observations. At step 2, the load is calculated using Equation 11 **Error! Reference source not found.**, providing an estimate of average annual load over the observation time period.

$$L = \frac{K}{N} \sum_{j=1}^N \hat{C}_j Q_j \quad (\text{Equation 11})$$

where $\hat{C}_j$ is calculated mean concentration associated with the flow quantile bin of the flow Q_j , and all other variables are as per equation 5.

4.1.1.2 Flow stratification with trend

We included a modified version of the flow stratification method to account for trends in water quality. This is useful when loads are required to be estimated for a particular point in time, rather than as an average over the complete observation period, particularly when there is a strong trend evident. We detrended the observation data by fitting it **Error! Reference source not found.** to the concentration time series.

$$\ln(\hat{C}_i) = \beta_1 + \beta_2(t_i) \quad (\text{Equation 12})$$

We then used the concentration residuals to develop a non-parametric rating curve. $\hat{C}_j$ is calculated as the mean residual concentration associated with the flow quantile bin of the flow Q_j , plus the predicted value of concentration at time T_j , which is multiplied by the smearing coefficient to account for the log transformation of **Error! Reference source not found.**

A3 Precision of load estimates

The statistical precision of a sample statistic, in this study the mean annual load, is the amount by which it can be expected to fluctuate from the population parameter it is estimating due to sample error. In this study, the precision represents the repeatability of the estimated load if it was re-estimated using the same method under the same conditions. Precision is characterised by the standard deviation of the sample statistic, commonly referred to as the standard error. We evaluated the standard error of each load estimate by bootstrap resampling (Efron, 1981). For each load estimate we constructed 100 resamples of the concentration data

(of equal size to the observed dataset), each of which was obtained by random sampling with replacement from the original dataset. Using each of these datasets, we recalculated the site load and estimated the 95% confidence intervals, using the boot r package. We represent precision in the results as the 95% confidence interval range, standardised by the load estimate (i.e., represented as a proportion).

A4 Selection of best load estimation methodology

TN loads were calculated for all sites using each of the four load estimation methods. We evaluated the performance of each rating curve method for predicting observed concentrations, using a range of model performance measures (see Fraser and Snelder (2019) for details). We identified site loads and method combinations that had any of:

1. large export coefficient values (i.e., site load divided by catchment area);
2. large differences in the loads calculated using different methods.

For these site and method combinations (approximately 10-20% of sites for each nutrient variable), we manually inspected diagnostic plots (e.g. C-Q plots, C-T plots, comparisons of sampled flow distributions relative to observed flow distributions). We used expert judgement to select the most appropriate load estimation method for each site that were outside of the two criteria outlined above. As well as selecting from one of the four rating curve methods described above, we also allowed sites to be discarded at this stage if no method appeared to satisfactorily describe the observed behaviour. This process also suggested that, for the manually inspected sites, the selection of the model with the lowest RMSD (in terms of performance in predicting observed concentrations) was the criteria most consistent with the outcomes of the expert judgement. For the remainder of the site and nutrient variable combinations that were not flagged by the above criteria (and for which the diagnostic plots were not inspected), the most appropriate load estimation method was selected as the rating curve method that yielded the lowest RMSD.

Appendix B Land use and export coefficient considerations

B1 Land use map

At the time of reporting, the best available land use data was HRC's 2008 land use map, which describes regional variation in land use in nine categories (Figure 7 **Error! Reference source not found.**). Changes in total stock numbers between 2007 and 2012 in the region were evaluated at the WMSZ level by Fraser and Snelder (2020). These data provide an indication of the change in land use intensity, and therefore, provide an indication of the potential difference in nitrogen emissions from land use between 2007 and 2012.

Data was available describing the number of animals in four stock type categories (dairy cows, beef cows, sheep and deer) that are collected on all enterprises involved in livestock farming by Statistics New Zealand as part of an annual agricultural production census (APC). Fraser and Snelder (2020) used these data to estimate the numbers of pastoral animals in each WMSZ and further modified these to indicate the land use intensity. To produce these measures, Fraser and Snelder (2020) used publicly available APC data, which are associated with a spatial layer comprising 960 hexagonal grid cells (35,000 ha) that cover all New Zealand (https://statisticsnz.shinyapps.io/livestock_numbers/). The grid cells were intersected with the polygons representing each WMSZ to evaluate the numbers of animals of each stock type in each zone in 2007 and 2012. The numbers of animals of each stock type were converted to 'stock units' which is a measure of metabolic demand that is commonly used in New Zealand (Parker, 1998). The stock units within each WMSZ were summed and divided by the area of the WMSZ to define the stock unit density (SU ha⁻¹) for 2007 and 2012. Differences in stock unit density between 2007 and 2012, expressed as percentages of 2012 density, were evaluated and used to represent change in land use intensity within each WMSZ.

The changes in stock unit density between 2007 and 2012 across the 124 WMSZs indicate that land use intensity generally decreased across the region (Table 6, Figure 22). Changes in land use intensity in either direction were less than 10% for 62% of the WMSZs and less than 20% for 91% of WMSZs (Table 6). The largest changes in land use intensity in relative terms occurred in WMSZs with the lowest levels of land use (Figure 22).

Table 6. Changes in land use intensity between 2007 and 2012 across the 124 WMSZs.

Change between 2007 and 2012 (%)	Proportion of WMZs (%)
< -20	7
-20 to -10	23
-10% to -5%	34
-5% to 0%	10
0% to 5%	9
5% to 10%	9
10% to 20%	6
>20%	3

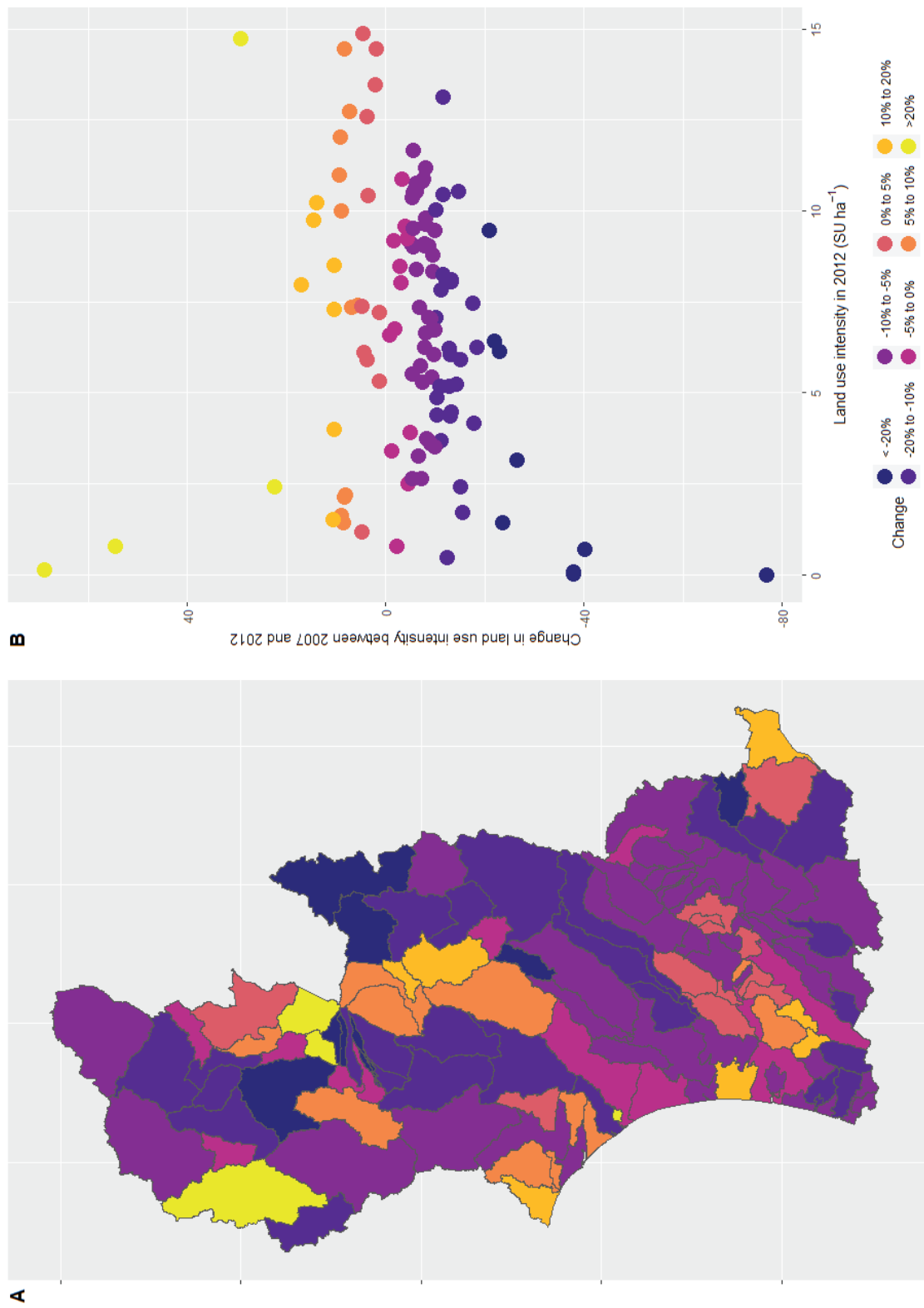


Figure 22. Changes in stock unit density between 2007 and 2012 across the 124 WMSZs.

The changes in stock between 2007 and 2012 (total stock unit density SU ha⁻¹; Table 6, Figure 22) indicate that changes in land use intensity were generally less than 20% across all WMSZs. A proportion of these changes will have been changes of management on farms and therefore land use *per se* can be expected to have changed by less than this amount between 2007 and 2012. The land use pattern is relevant to the water quality models because it is used to estimate the magnitude of the diffuse source nitrogen export coefficients, which are discussed further below.

B2 Comparison of available export coefficient estimates

Export coefficients for a given farming operation vary depending on the characteristics of the farm. For example, climate and soils strongly influence nitrogen leaching losses, and, therefore, export coefficients are expected to vary in response to these factors. The available regionally-specific export coefficient estimates were either farm or catchment specific and did not allow us to account for variation in farm characteristics that occur at the regional scale. In contrast, the export coefficients defined by Bright *et al.* (2018) accounted for variation due to four biophysical factors including: climate zone, plant available soil water capacity (PAW), and whether the land is irrigable and irrigated. We therefore considered that the export coefficients defined by Bright *et al.* (2018) were the most appropriate estimates for this regional scale study but that the regionally-specific estimates made by other studies provided the opportunity to verify this decision. In the following section we compare the export coefficients that were used in this study (based on Bright *et al.*, 2018) with the available regionally specific estimates.

There were several regionally-specific sources of diffuse source nitrogen emission estimates from farms. First, the dairy farm consents database contains estimated nitrogen emissions from 211 dairy farms in the region based on their operations in 2012 and the OVERSEER nutrient budgeting model. Nitrogen emissions as export coefficients (i.e., kg N ha⁻¹ yr⁻¹) were re-estimated for all farms in the database using version 6.2.2 of OVERSEER and the base files pertaining to 2012. This produced a set of export coefficients for the dairy farms that were consistent with the cumulative nitrogen leaching maximums in the updated One Plan Table 14 that is contained in Proposed Plan Change 2. Second, several studies have estimated average export coefficients from farms of different types (primarily sheep and/or beef and dairy) in different catchments within of the region (Collins *et al.*, 2017; Manderson, 2015; Singh and Elwan 2017).

We undertook a comparison of the estimated dairy farm export coefficients provided by the consents database with those defined by Bright *et al.* (2018) and those of Manderson *et al.* (2016) as reported by Singh *et al.* (2017). We first allocated the consents database farms to the same biophysical classes used by Bright *et al.* (2018), i.e. climate zone (Figure 8), a PAW category (Figure 9) irrigable (Figure 10) and irrigated (Figure 11). To do this we constructed a circular 800m buffer around the coordinates provided for each farm in the consents database (note that we did not have access to the farm boundaries). We chose 800m to emulate the mean area of the farms in the database of 200 ha. We intersected the buffer areas representing each farm with the spatial layers representing Climate zones, PAW, irrigable and irrigated areas. We allocated farms to a Climate, PAW, irrigable and irrigate category based on the dominant category of each layer within the buffered areas.

We then allocated all land in the region categorised as dairy land use (i.e., not just the dairy land represented in the consents database; Figure 7) to the stratification used by Bright *et al.* (2018). The relevant export coefficients defined by Bright *et al.* (2018) were assigned to all the strata in the region on which a dairy land use occurs and the area of dairy farms within each

strata were obtained. We then inspected the distribution of estimated nitrogen export coefficients for groups defined by the strata for the consents database, for all dairy land based on Bright *et al.* (2018) and rates estimated by Manderson *et al.* (2016).

The majority (71%) of the farms represented by the consents database were located within the South West Coast climate zone (Figure 8). The majority of all dairy farms are also located in the South West Coast climate zone (Figure 10). The remaining 14%, 8% and 7% of consented farms were in the Lower Hill Country, East Coast and Mountain climate zones. There were no consented farms in the North West climate zone and only a small proportion of all the dairy farms in the region were in this zone.

There was considerable variation in the export coefficients derived from the consents database even within climate zones, PAW and irrigation categories (Figure 23). The consents database export coefficients were, on average, lowest in the South West Coast climate zone. In the South West Coast climate zone, the central tendency of the consents database values were reasonably consistent with the median values of Manderson *et al.* (2016) as reported by (Singh *et al.*, 2017). The consistency within the South West Coast climate zone is expected because the dairy farms in the Rangitikei Catchment, on which the estimates of Manderson *et al.* (2016) were focussed, are mainly located within the South West Coast climate zone. Manderson *et al.* (2016) however reported a large range in the values and that level of variation was reasonably consistent with the variation in the values derived from the consents database. In the other climate zones, the majority of export coefficients derived from the consents database and Bright *et al.* (2018) were within the range of Manderson *et al.* (2016). The export coefficients derived from Bright *et al.* (2018) were generally reasonably consistent with those derived from the consents database (i.e., were generally within the interquartile range). The export coefficients derived from Bright *et al.* (2018) were always higher than the median values of Manderson *et al.* (2016) but were always within range of values except for one strata in the South West Coast zone.

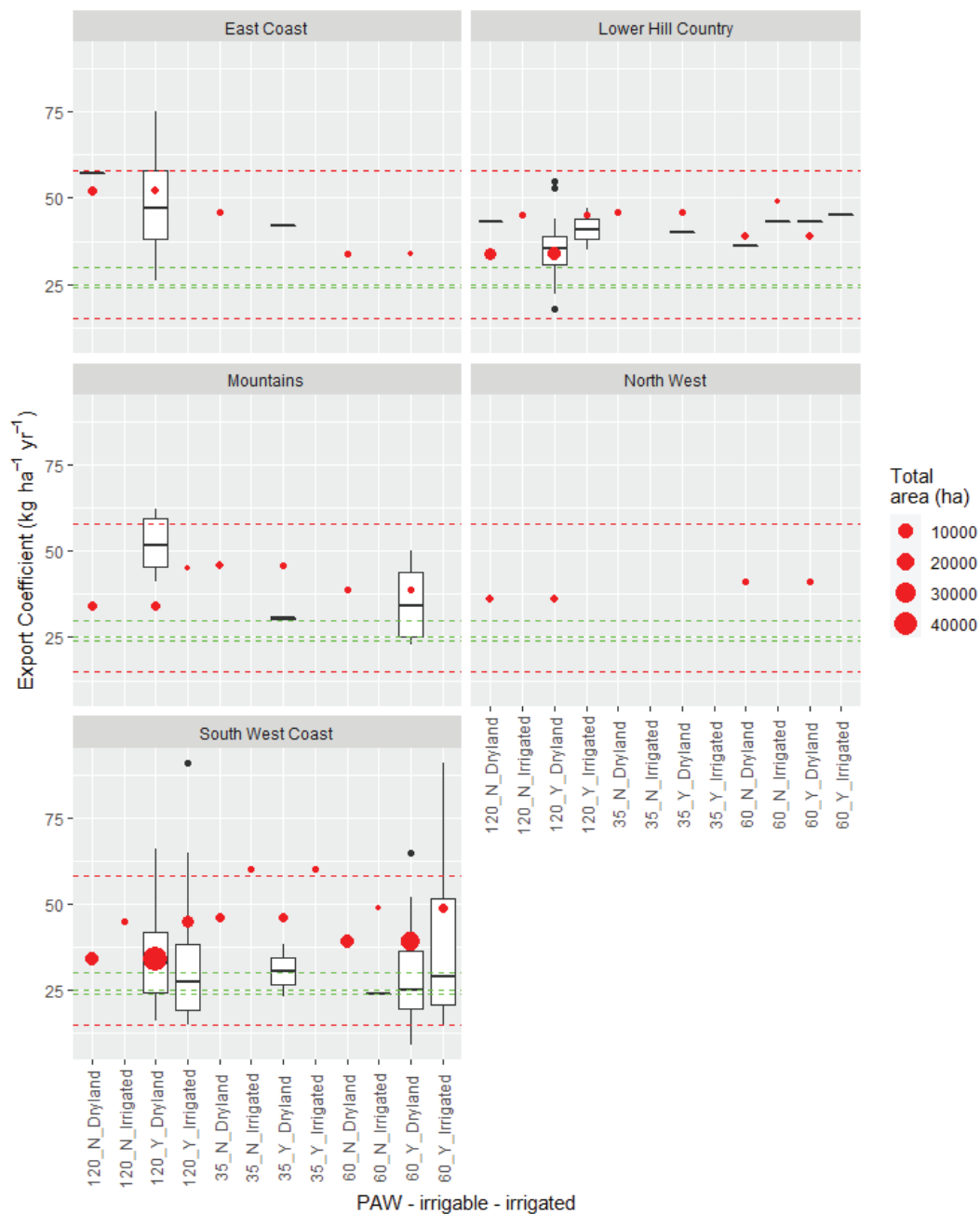


Figure 23. Comparison of diffuse source export coefficients for dairy farms provided from a range of sources within each strata (i.e., Climate, PAW, irrigable and irrigate categories) used by Bright et al. (2018). The box and whisker plots show the distributions of nitrogen leaching rates estimated for farms in the consents database. The box indicates the inter-quartile range and the horizontal bar within the box indicates the median. The whiskers indicate the lowest datum still within 1.5 IQR of the lower quartile, and the highest datum still within 1.5 IQR of the upper quartile. Outliers are indicated by black dots. The red dots show the equivalent rates defined by Bright et al. (2018). The dots are scaled to represent the total area of dairy farms in the region. The red dashed lines indicate the lower and upper bounds and the green dashed lines represent the median for low, medium and high intensity of dairy farm loss rates reported for the Rangitikei catchment by Manderson et al. (2016) as reported by (Singh et al., 2017). Note that dairy farms having some combinations of climate and PAW categories are not represented by any farm in the consents database.

We undertook a comparison of export coefficients for sheep and beef farming defined by Bright *et al.* (2018) with those estimated for the Mangatainoka catchment by Manderson (2015) and the Rangitikei catchment by Manderson *et al.* (2016). Manderson (2015) estimated export coefficients for sheep and beef farms in the Mangatainoka catchment using three methods. Methods 1 and 3 considered many farms but omitted consideration of farm management practice. These methods produced rates between 9.6 kg ha⁻¹ yr⁻¹ to 12.2 kg ha⁻¹ yr⁻¹. Method 2 was based on a more detailed consideration of a small number of farms on different types of terrain. The method produced higher N loss estimates of 20.2 kg ha⁻¹ yr⁻¹, which reduced to 17 kg ha⁻¹ yr⁻¹ when an annual rainfall of 1300 mm yr⁻¹ was assumed. This lower rainfall is consistent with the lower catchment and is within the South West Coast climate zone (Figure 8). Manderson (2015) suggested a “best” estimate of the export coefficient of 12.9 kg ha⁻¹ yr⁻¹, which was based on combining the strengths of Method 1 (large sample and strong extrapolation) with those of Method 2 (inclusion of farm management effects). Sheep and beef farming export coefficients for the Rangitikei catchment derived by Manderson *et al.* (2016) are reported by Singh *et al.* (2017). The export coefficients were estimated at between 9 kg ha⁻¹ yr⁻¹ and 10.5 kg ha⁻¹ yr⁻¹ under sheep and beef grazing and the range was between 5 kg ha⁻¹ yr⁻¹ and 18 kg ha⁻¹ yr⁻¹ depending on the farming intensity.

We allocated all land in the region categorised as sheep and beef land use to the stratification used by Bright *et al.* (2018). The relevant export coefficients defined by Bright *et al.* (2018) were assigned to all the strata in the region on which sheep and beef use occurs and the area of farms within each strata were obtained. We then compared estimated nitrogen export coefficients for groups defined by the strata based on Bright *et al.* (2018) and rates estimated by Manderson (2015) and Manderson *et al.* (2016).

The export coefficients estimated by Bright *et al.* (2018) were higher than those of Manderson (2015) and Manderson *et al.* (2016) for all climate zones except Mountains (Figure 24). The largest deviations between the estimates were associated with irrigated sheep and beef farms. This is probably because the estimates of Manderson (2015) and Manderson *et al.* (2016) were based only on dryland farms. The analysis indicated that irrigated sheep and beef farms made up only a small proportion of the total land used for sheep and beef farming (Figure 24). For the Mountains climate zone, the export coefficients estimated by Bright *et al.* (2018) were significantly lower than the Manderson estimates. The Bright *et al.* (2018) estimates for the South West Coast climate zone were most consistent with the best estimate of Manderson *et al.* (2016). This consistency is logical because Manderson *et al.*'s (2016) estimates were focussed on farms that are mainly located within the South West Coast climate zone.

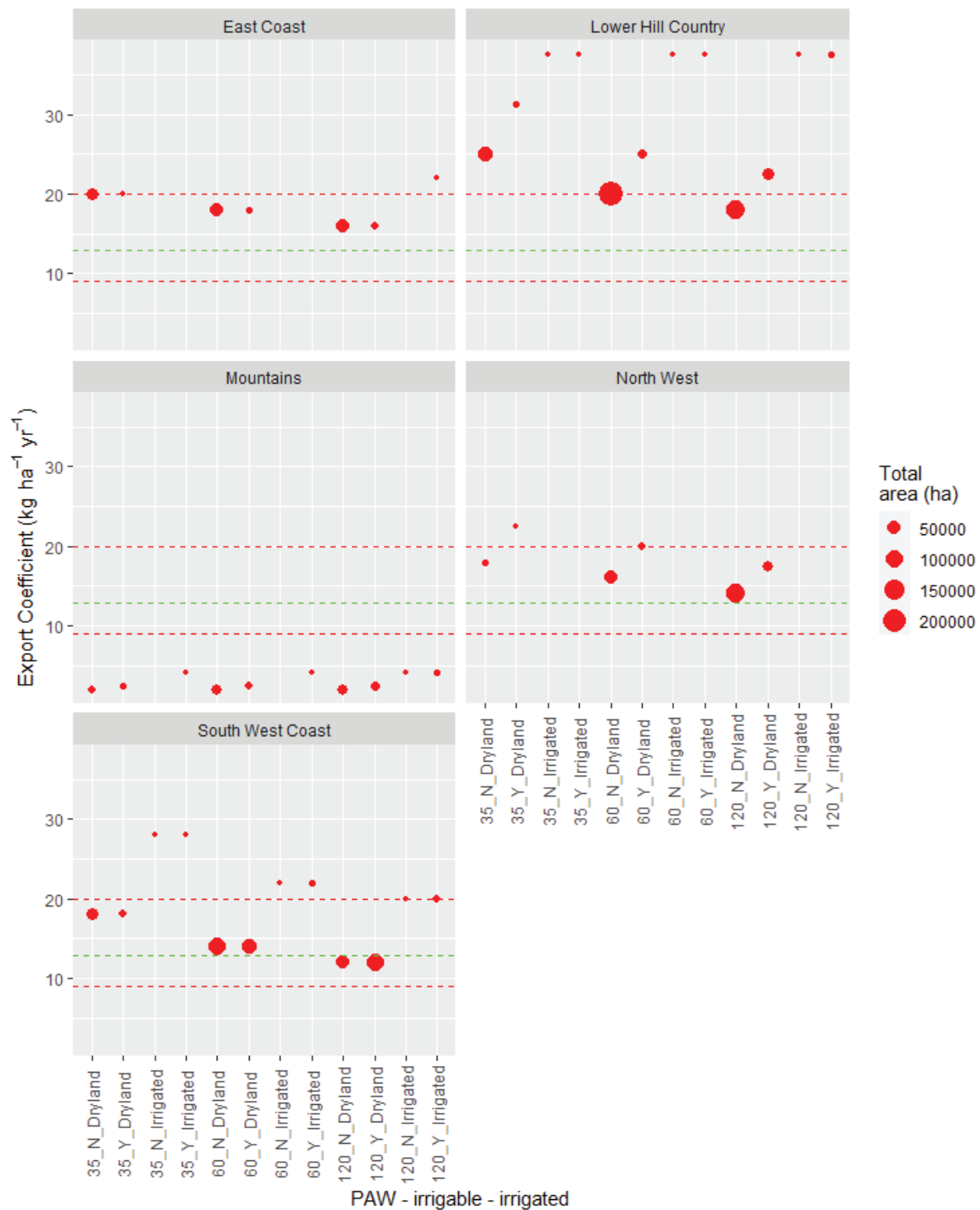


Figure 24. Comparison of diffuse source export coefficients for sheep and beef farms within each strata (i.e., Climate, PAW, irrigable and irrigate categories) used by Bright et al. (2018). Export coefficients for sheep and beef farms defined by Bright et al. (2018) are shown as red dots. The dots are scaled to represent the total area of sheep and beef farms in the region. The best estimate of Manderson (2015) for the Mangatainoka catchment (green dashed line) and the range in estimates of Manderson et al. (2016) for the Rangitikei Catchment (red dashed lines).

The analysis of nitrogen loss rates detailed in the dairy consents database, previous studies and adopted in this study based on Bright *et al.* (2018), show that there is a reasonably high level of consistency in the central tendency of the various estimates but that there is also considerable range in plausible nitrogen export coefficients. This indicates that the export coefficients that are key input data to the water quality models are highly uncertain. Taken together, the uncertainties in the model input data (i.e., land use map and export coefficients) mean that potential differences in model predictions resulting from the non-congruence of dates for the land use and catchment nitrogen emission estimates are unlikely to be statistically significant (i.e., any differences would be within the model uncertainty). In addition, the water quality models are calibrated to water quality station nitrogen loads, which are themselves uncertain (Figure 22). These uncertainties are all compounded in the models and mean our confidence is highest when the model is used to predict the relative difference in water quality outcomes between two scenarios. A formal analysis of the model uncertainty and assessment of possible differences due to land use changes is possible with the CASM models but was beyond the scope of this study.



horizons.govt.nz

24 hour freephone 0508 800 800
fax 06 952 2929 | **email** help@horizons.govt.nz
Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442



Scenario Modelling of Nitrogen Management in Manawatū-Whanganui Region

Supporting Regional Plan Change 2

September 2020

Prepared By:

Ton Snelder

Tim Cox*

Tim Kerr

*Streamlined Environmental Ltd

For any information regarding this report please contact:

Ton Snelder

Phone: 0275758888

Email: ton@lwp.nz

LWP Ltd

PO Box 70

Lyttelton 8092

New Zealand

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Executive Summary

Horizons Regional Council (HRC) has proposed a change to its Regional Policy Statement and Regional Plan (the One Plan) known as Proposed Plan Change 2 (PPC2). PPC2 will manage the discharge of nitrogen from intensive farming land use (IFLU) across the Manawatū-Whanganui Region. This will have effects on instream loads and concentrations of nitrogen in freshwater receiving environments across the Region. This report describes an evaluation of the water quality outcome for rivers, of management of nitrogen leaching from IFLU under PPC2. The study used a water quality model to predict nitrogen loads and concentrations at 124 river assessment points under a range of nitrogen leaching management scenarios.

Region-wide predictions made using the water quality model to represent conditions prior to regulation in 2012 indicate that soluble inorganic nitrogen (SIN) concentrations exceeded the One Plan targets at most assessment points (approximately 77% of assessment points). In addition, on average, assessment points had SIN concentrations that were 31% higher than the One Plan targets.

Region-wide, most scenarios were predicted to result in only small changes to river SIN concentrations. The model predicted modest reductions in SIN concentrations have already resulted from consenting processes that reduced nitrogen leaching rates from 213 dairy farms located in the 'Target Catchments'. The impact of this consenting was predicted to reduce the mean amount by which the concentration at assessment points deviates from the target, from 31% prior to regulation in 2012 to 30%. The changes however were insufficient to reduce the number of assessment points that do not comply with the One Plan SIN concentration targets.

The model also predicts small reductions in SIN concentration if nitrogen leaching rates for all unconsented IFLU are reduced to the limits specified in the PPC2 Table 14.2. Region wide, this would reduce the mean amount by which the concentration at assessment points is greater than the target to 28%. Downstream of target catchments, this scenario would reduce the mean amount by which the concentration at assessment points is greater than the target, from 45% prior to regulation in 2012 to 40%.

The above findings apply generally; however, under some of the scenarios, the model predicted increases in nitrogen leaching in some water management sub-zones and consequently increases SIN concentrations at some assessment points. These increases occur because the model indicates that there are areas of IFLU for which current nitrogen leaching rates are less than the nitrogen leaching rates specified in PPC2 Table 14.2. Under the scenarios, it was assumed that this IFLU would increase its current leaching rate up to the leaching limits in PPC2 Table 14.2, and this leads to localised increases in SIN concentrations.

1 Introduction

Horizons Regional Council (HRC) has proposed a change to its Regional Policy Statement and Regional Plan (the One Plan) known as Proposed Plan Change 2 (PPC2). PPC2 is focused on the One Plan's provisions that manage nutrient loss from existing intensive farming land uses (dairy farming, commercial vegetable growing, cropping, and intensive sheep and beef) in target water management sub-zones. These provisions are no longer working as intended when the One Plan was developed. PPC2 seeks to update the cumulative nitrogen leaching maximums (CNLM) in the One Plan Table 14.2 to reflect improvements in the nutrient modelling software tool Overseer; reinforce good management practices as part of intensive farming land use activities; and provide a workable pathway for landowners to apply for resource consent for intensive farming land use activities that cannot achieve Table 14.2 cumulative leaching maximums.

PPC2 will have effects on instream loads and concentrations of nitrogen across the Manawatū-Whanganui Region. These effects will be spatially variable for two reasons. First, land use changes resulting from PPC2 will not be evenly distributed across the region meaning that future land use intensity will vary between the region's catchments. Second, there is environmentally mediated variation in both potential nitrogen losses from land use and the processing of nitrogen (attenuation) as it moves through the drainage network. Because these two factors interact, the prediction of water quality outcomes of PPC2 is complex and their assessment requires catchment water quality modelling. A previous report has detailed the development and calibration of catchment water quality models for the purpose of assessing the impacts of the plan change on in-stream nitrogen loads and concentrations across the region (Snelder *et al.*, 2020).

This report describes analyses and reports results of several scenarios that have been defined to evaluate the potential outcome of PPC2 for nitrogen loads and concentrations at 124 assessment points across the region.

2 Water quality models

2.1 Model definition

Streamlined Environmental Limited's (SEL) Contaminant Allocation and Simulation Model (CASM) software was used to develop water quality models for the four major river basins in the Horizons Region: the Manawatū (including the Horowhenua and Coastal Tararua catchments), the Rangitīkei, the Whanganui, and the Whangaehu (including the Turakina River catchment) (Snelder *et al.*, 2020). The entire region is encapsulated by the four CASM models. The models use sub-catchment export and attenuation coefficients to simulate the generation, transport, and downstream delivery of total nitrogen (TN) loads throughout the region.

The calibration year was 2012. This year was chosen because it was prior to implementation of the One Plan provisions for management of nitrogen discharges to land. Therefore, 2012 was prior to regulation of intensive farming land use (IFLU) in the region. The calibrated model therefore represents the historical conditions prior to regulation and enables us to model changes in water quality that have actually occurred due to changes in nitrogen discharges since 2012 (which we refer to as historical conditions) and changes resulting from possible implementation of both the operative and proposed One Plan nutrient management provisions (which we refer to as scenarios).

The models represent all land across the region as a regular 250 m by 250 m grid. Each grid cell is assigned to one of nine land use categories (i.e., including dairy, sheep and beef, horticulture; see Snelder *et al.*, 2020 for details). Each grid cell was also assigned to categories describing variation in four biophysical factors that influence nitrogen leaching rates: climate zone, plant available soil water capacity (PAW), and whether the land is irrigable and irrigated. Each grid cell was also assigned to one of eight land use capability classes (LUC; I, II, III, ..., VIII), because the cumulative nitrogen leaching maximum values in Table 14.2 vary by LUC class.

The CASM models include a spatially distributed network of “assessment points” (Figure 1). Assessment points are located at the downstream end of each of the region’s 124 water management subzones (WMSZ). Some of these assessment points capture drainage from a single WMSZ while others capture the aggregate drainage from multiple upstream WMSZs. The model outputs TN loads and mean concentrations for each of the 124 assessment points.

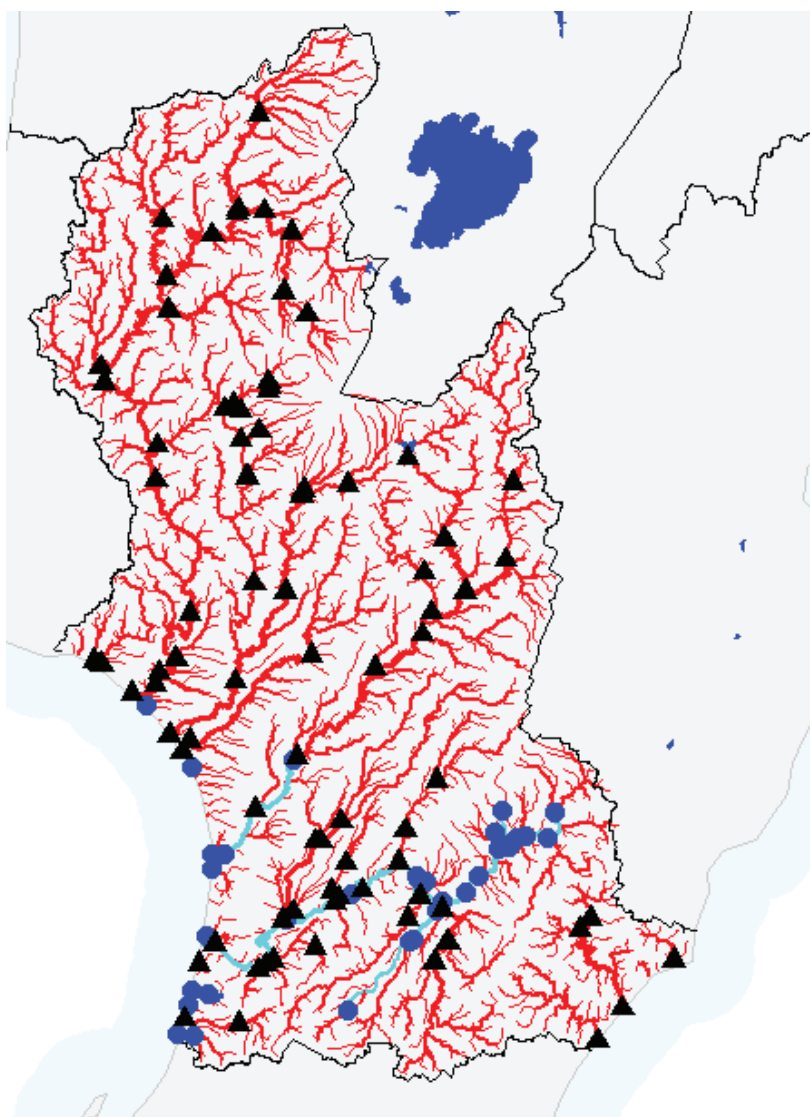


Figure 1. Map showing the location of the CASM model assessment points. Assessment points are located at the most downstream point of all WMSZs. River segments and assessment points that are located downstream of the Target Catchments are shown as light blue lines and dark blue points respectively.

The CASM models represent nitrogen sources in the region based on the widely used diffuse source “export coefficient” approach, with prescribed areal average TN mass loading rates (kg/ha/yr) linked to each model functional unit (“node”). The assigned TN export coefficients were based on Bright *et al.* (2018). Model nodes were developed for each combination of WMSZ, land use capability (LUC) category, and each of nine land use categories, as described in Snelder *et al.* (2020). Export coefficients were assigned to each model node based on values provided by Bright *et al.* (2018), which vary based on the combination of land use category and each of the four biophysical categories (i.e., climate zone, plant available soil water capacity (PAW), and whether the land is irrigable and irrigated). Some adjustments were made to Bright *et al.*’s (2018) export coefficients to account for regionally specific conditions and information and are described in Snelder *et al.* (2020). Point source loads are also represented in the models and are defined as mean annual loads of TN discharged at 38 consented discharges of greater than 20m³ d⁻¹ across the region.

The CASM models were calibrated to observed TN loads at 60 water quality stations in 2012 (i.e., the calibration year), which were derived from monthly TN concentrations and observed or modelled daily flows (Snelder *et al.*, 2020). Calibration was achieved by adjusting the attenuation coefficients and, in a limited number of cases, minor adjustments to export coefficients, as outlined in Snelder *et al.*, 2020.

Most of the scenarios described below were defined by adjusting the TN export coefficients for two types of agricultural land use: Intensive Farming Land Use (IFLU) and non-Intensive Farming Land Use (Non-IFLU). In the calibrated model, IFLU were defined by the following land uses types: Dairy Farming, Cropping, Horticulture and Intensive Sheep and Beef. Intensive Sheep and Beef was defined by the combination of the sheep and beef category that occurs on irrigated land. All land uses across the region, including all areas defined as IFLU, were identified using the land use and irrigated area maps described in Snelder *et al.* (2020).

IFLU land was distributed across many of the WMSZs in the Region (Figure 2). There was variation across the Region with respect to whether the TN export coefficients assigned to the IFLU land in the calibrated model were above or below the cumulative leaching maximums set under the recalibrated Table 14.2 of PPC2 (Figure 2).

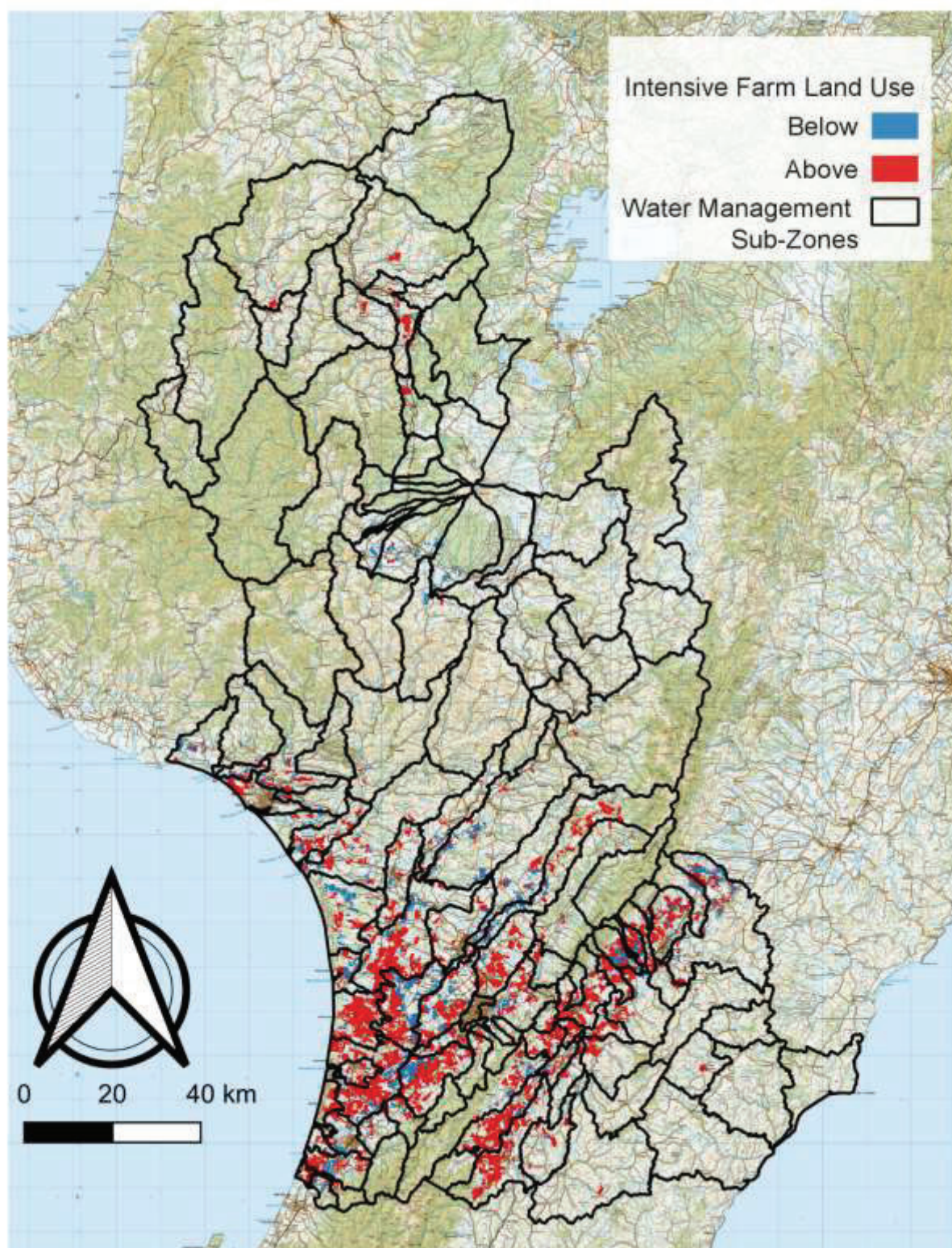


Figure 2. Map showing the location of all intensive farming land use (IFLU) in the region. IFLU with export coefficients in the calibrated model that are above and below the limits specified in Table 14.2 of PPC2 are shown in red and blue respectively.

2.2 Use of models to simulate scenarios

The CASM models were used to simulate water quality under historical conditions and in response to scenarios associated with the management of nitrogen discharges from diffuse sources (i.e., leached from land) and point sources. There are four groups of simulations: Historical Simulations, Operative Plan Scenarios, Proposed Plan Scenarios and Additional Scenarios. In the simulations that are reported here, changes in the management of nitrogen are simulated by changing the TN export coefficients from land (represented in the models by nodes) and/or by changing point source TN loading rates. The models allow for significant control of the assumed TN export coefficients from land. Export coefficients can be adjusted directly in the model for each combination of WMSZ, land use category, and LUC class. Additionally, they can be adjusted outside of the model (pre-processing) in consideration of the four biophysical factors.

The CASM models predict the annual TN load and mean TN concentrations at each assessment point for several scenarios described in detail below. Concentrations at each assessment point were estimated by dividing the load by the estimated mean discharge at that location (Snelder *et al.*, 2020).

2.3 Comparison of model predictions with One Plan water quality targets

The One Plan sets targets that pertain to river nitrogen concentrations for all WMSZ in the region. The first target is the soluble inorganic nitrogen (SIN) concentration. The One Plan SIN compliance statistic is specified as the annual average SIN concentration (g/m^3) when the river flow is at or below the 20th flow exceedance percentile. The One Plan also sets targets for periphyton: two region-wide targets for filamentous cover and diatoms and cyanobacteria (both measured as percentage cover) and WMSZ specific targets for maximum periphyton biomass (measured as chlorophyll-*a* in mg/m^2). The periphyton biomass target can be linked to a nitrogen concentration target using regional relationships between periphyton biomass and river water column nutrient concentrations. In this study, we have only reported against the One Plan SIN concentrations.

The CASM water quality model predictions were compared with the One Plan SIN targets by converting the model outputs to an equivalent One Plan SIN compliance statistic in four steps. First, we used existing regional water quality predictions made by Fraser and Snelder (2020) to estimate the calibration (i.e., 2012) SIN concentration (mg/m^3) for each assessment point. These SIN predictions were consistent with the One Plan compliance statistic (i.e., annual average SIN concentration (g/m^3) when the river flow is at or below the 20th flow exceedance percentile). The SIN concentration predictions were used as estimates of the One Plan SIN compliance statistic at each assessment point.

At the second step, we compared the One Plan SIN targets for each assessment point with SIN concentration predictions made by Fraser and Snelder (2020) to evaluate the pre-regulation (2012) water quality state. Water quality state was summarised as achieving or not achieving the One Plan targets depending on whether the predicted SIN concentration was less than or greater than the target.

At the third step we converted the CASM predictions for TN concentrations for each assessment point, and for each modelled scenario, to an equivalent SIN concentration. This conversion was made based on assumption that SIN concentration changes in proportion to the change in TN concentration changes, i.e., the following relationship applies:

$$\frac{SIN_{Scenario}}{TN_{Scenario}} = \frac{SIN_{Calibration}}{TN_{Calibration}} \quad (\text{Equation 1})$$

Therefore, the scenario SIN concentration for each assessment point was derived as:

$$SIN_{Scenario} = SIN_{Calibration} \times \frac{TN_{Scenario}}{TN_{Calibration}} \quad (\text{Equation 2})$$

where $TN_{Calibration}$ is the model calibration TN concentration (g/m^3) estimated by the CASM model for each assessment point, $TN_{Scenario}$ is the TN concentration (g/m^3) predicted by the CASM model for the scenario and $SIN_{Calibration}$ is the SIN concentration estimated by Fraser and Snelder (2020). At the fourth step, we evaluated the water quality state for each assessment point and scenario based on comparing $SIN_{Scenario}$ to its associated One Plan SIN target.

2.4 Presentation of scenario simulations and results

Most scenarios are summarised by three maps. The first map shows the spatial distribution of differences in the export coefficients at the level of the WMSZ relative to an appropriate comparison simulation (the comparator). The second map shows the difference in the predicted SIN concentrations at the assessment points compared to the same comparator.

The appropriate comparator varies by scenario as described in detail in the following section. For example, some scenarios are appropriately compared to the ‘calibrated model’, which is the pre-regulation situation in 2012. For other scenarios, the appropriate comparator is another scenario. In this report, each scenario is compared with at least one comparator (some scenarios are compared with one or two additional comparators). We note that the choice of the appropriate comparator is subjective. Some discussions may benefit from comparisons with alternative comparator scenarios. If this is necessary, maps and summaries of comparisons between any pair of simulations can be prepared.

The third map shows the predicted water quality ‘state’ (i.e., the $SIN_{Scenario}$) at all assessment points for the scenario. These maps show state in relative terms by expressing how much lower or higher the predicted SIN concentration is relative to the One Plan SIN target (as a percentage). When discussing the predicted water quality state, we use the terms ‘achieve’ to mean a predicted concentration is less than the target and ‘not achieve’ to mean the predicted concentration is greater than the target.

Results are also summarised numerically in three ways. First, we quantify the number of positive and negative differences in SIN values at assessment points compared to the comparator simulation. Second, we quantify the number of assessment points at which SIN does not comply with One Plan SIN target are quantified. Third, we quantify the mean relative difference for each simulation. The mean relative difference indicates the mean amount (as a percentage) by which the predicted SIN concentration at assessment points deviate from the target SIN concentration. Positive values indicate the predicted SIN concentration exceeds the target (i.e., the objective is not achieved).

3 Model Simulations

3.1 General definition of scenarios

In this section the general approach to definition of scenarios is described. Multiple and different types of scenarios are then described in more detail in section 3.2 to 3.5. A summary of all the different types of scenarios is provided in section 3.6.

For the purpose of defining scenarios, we identify two types of IFLU: Consented-IFLU and Unconsented-IFLU. We further subdivide the Unconsented-IFLU into Known and Unknown Unconsented IFLU and subdivide again the Known Unconsented IFLU into Compliant-IFLU and Noncompliant-IFLU (Figure 3). Compliant means the nitrogen leaching rate is up to but not exceeding the Table 14.2 limits and non-compliant means the rate exceeds the Table 14.2 limits.

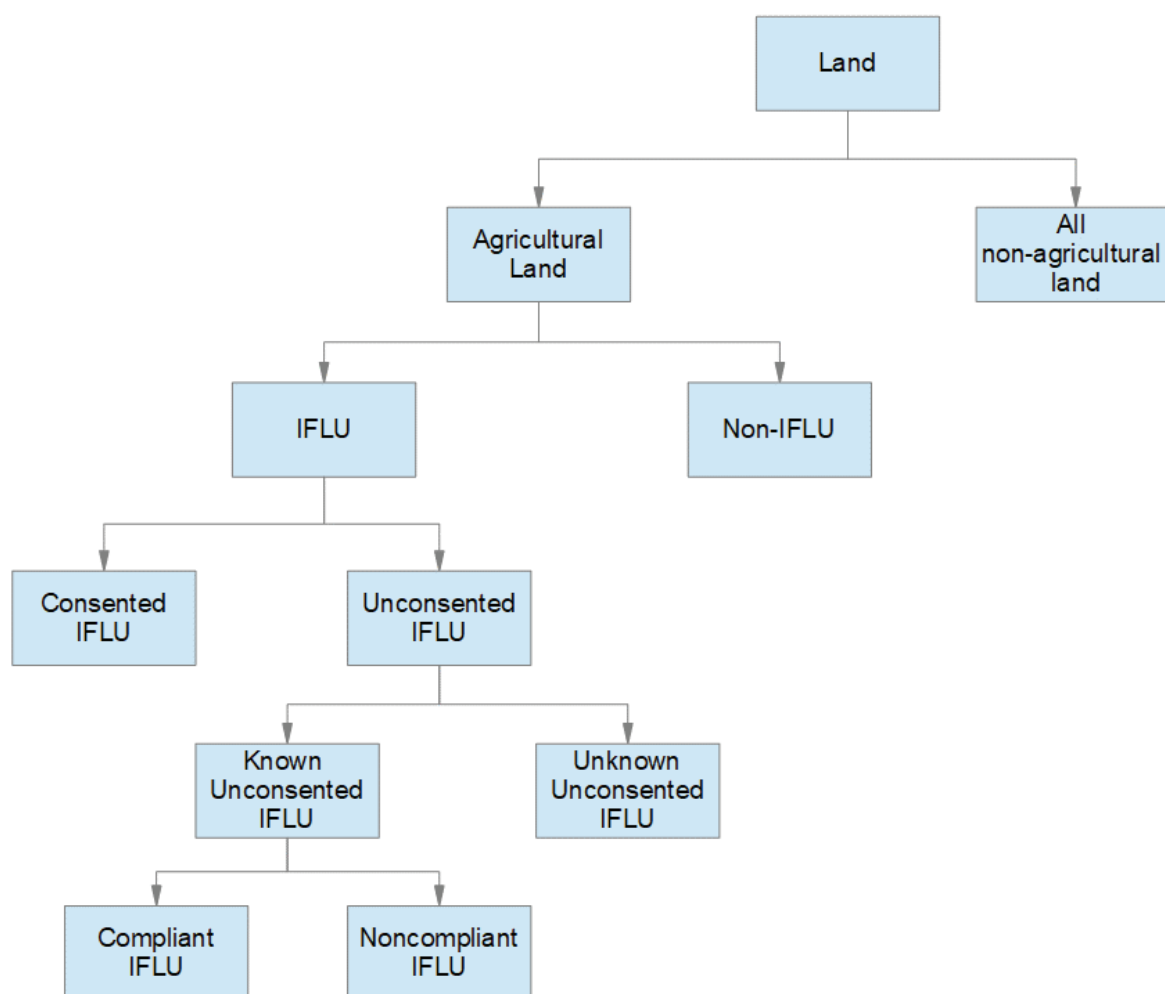


Figure 3. Types of land used to define the scenarios.

Consented-IFLU and Known Unconsented-IFLU were represented in the scenarios by 213 consented and 70 unconsented dairy farms that were described in a database provided by HRC¹ (the HRC database). The 213 consented dairy farms occupy a total area of 42,192 ha

¹ Both the consented and unconsented dairy farms are described in 20200417_Master. dairy farm data_Working Document – For Purposes of Pre-Hearing Conferences on PPC2.xlsx

and were all located in the target catchments (i.e., subzones shown in Figure 4). The 70 unconsented farms occupy an area of 12,902 ha located in subzones of the Upper Manawatū River catchment shown in Figure 4. This subset of farms represents the Compliant and Noncompliant-IFLU in the scenarios. The details of these farms were provided to HRC by DairyNZ (DNZ).

The HRC database detailed the OVERSEER basefile nitrogen leaching rate prior to regulation in 2012 (hereafter referred to as the “basefile” leaching rate) for all 283 farms (i.e., the 213 consented dairy farms and the 70 unconsented farms provided by DNZ). The HRC database also specified the consented (i.e., allowable) nitrogen leaching rate for the Consented-IFLU (i.e., consents issued after 2012 and referred to hereafter as post-regulation). For this study, the basefile nitrogen leaching rates for all farms were recalibrated based on OVERSEER v6.3.2 so that they are consistent with PPC2 Table 14.2. In addition, the consented nitrogen leaching rate was based on a recalibration of the original consented rate to a rate based on OVERSEER v6.3.2.

The consented nitrogen leaching rates varied across the Consented-IFLU and, in most scenarios, were assumed to continue unchanged through time. This is an assumption only because some consents expire before year 20 and may not be renewed at their current rate. In most scenarios described below, Consented-IFLU were simulated by setting the TN export coefficients from these areas to the consented nitrogen leaching rate.

The OVERSEER basefile nitrogen leaching rates for some of the 70 farms representing the Known Unconsented-IFLU in the DNZ database exceed the allowable nitrogen leaching rates in the proposed Table 14.2. In the modelled scenarios, it has been assumed that these Known Unconsented Noncompliant-IFLU will need to either reduce their nitrogen leaching to meet Table 14.2 or, alternatively, obtain a consent through the discretionary activity pathway provided by PPC2. In the scenarios, different assumptions are made concerning the nitrogen leaching rates for these Noncompliant-IFLU. For some scenarios, all Unconsented-IFLU was assumed to comply with Table 14.2, and this is simulated by adjusting TN export coefficients from these areas to the cumulative nitrogen leaching maximums set under the recalibrated Table 14.2). Other scenarios represent four choices of absolute reductions from the current loss rate for the Known Unconsented Noncompliant-IFLU: 9, 12, 15 and 18 kg/ha/yr. These choices represent differing levels of farm management practices with attendant implications for the farming system and its profitability. For some Known Unconsented Noncompliant-IFLU, one or more of the choices of absolute reduction may reduce the TN loss rate to the rate specified by Table 14.2.

Unknown Unconsented-IFLU was represented in the scenarios by all IFLU land shown on Figure 2 apart from those parcels that were accounted for in the HRC database. The nitrogen leaching rate for the Unknown Unconsented-IFLU land has been assumed to be the rate defined by the calibrated model prior to regulation in 2012 (i.e., at the rates defined by Bright *et al.* (2018) with some adjustments).

In most scenarios, the nitrogen leaching rate for non-IFLU land has been assumed to be the rate defined by the calibrated model prior to regulation in 2012 (i.e., at the rates defined by Bright *et al.* (2018) with some adjustments). There are three exceptions to this. First, Scenario 5 allows for an expansion of dairy farming and this is represented by increasing the TN loss rate on some sheep and beef farms to reflect this land use conversion. Second, Scenario 9 allows for an expansion of horticulture and this is represented by changing TN loss rates accordingly. Third, for Scenario 7, nitrogen export coefficients and point sources are set to

values corresponding to natural conditions across the entire region to represent water quality in the absence of anthropogenic pressure.

Some scenarios were based on the operative Table 14.2 (as currently defined in the One Plan), but most scenarios focussed on the outcomes of applying the proposed PPC2 Table 14.2 values. Different scenarios represent water quality outcomes at either Year 5 or Year 20² of plan implementation. The details of each scenario are described in the following sections.

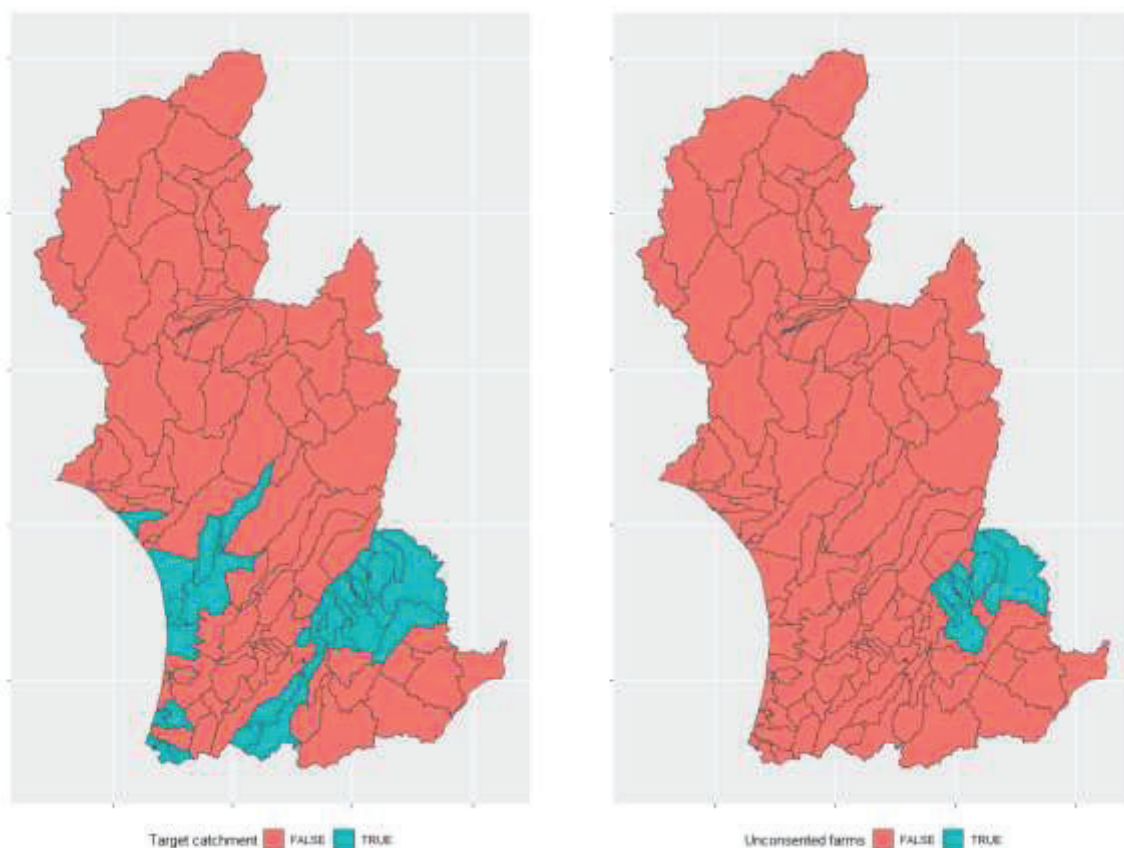


Figure 4. Maps of the region showing the 124 WMSZs. The left map indicates the WMSZs that are target catchments (blue). The right map indicates the WMSZs where the representative 70 currently unconsented dairy farms are located (blue).

3.2 Historical simulations

3.2.1 Calibrated Model Simulation

Simulations undertaken with the calibrated model represent the TN loads and concentrations prior to regulation in 2012. The Calibrated Model Simulation was made by obtaining the predicted TN loads for each WMSZ from the calibrated model.

3.2.2 Pre-regulation Simulation

The Pre-regulation Simulation represents the historical water quality outcome of the basefile leaching rate for Known Consented-IFLU and Known Unconsented-IFLU. The Pre-regulation Simulation is similar to the Calibrated Model Simulation except that nitrogen leaching rates for

² Year 5 and Year 20 is five or 20 years respectively after the Rules of the Plan have legal effect, as set out in Table 14.1 of the One Plan i.e. year zero ranges from 1 July 2014 to 1 July 2016.

Known Consented-IFLU and Known Unconsented-IFLU are set to their basefile leaching rates in 2012 rather than the export coefficients used in the calibration (i.e., the rates of Bright *et al.*, 2018).

The Pre-regulation Simulation was made by:

1. setting export coefficients for all non-IFLU and Unknown Unconsented-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all consented-IFLU (i.e., 213 consented dairy farms described by HRC database) to their 2012 basefile leaching rates.
3. setting export coefficients for the Known Unconsented-IFLU (i.e., 70 unconsented dairy farms described by HRC database) to the 2012 basefile leaching rates.

The comparator used to report the results for the Pre-regulation Simulation is the Calibrated Model Simulation. This means the Pre-regulation Simulation results highlight the differences between the export coefficients used in the calibration of the CASM models and the basefile leaching rates obtained from the HRC database.

3.2.3 Point Sources Simulation

The Point Sources Simulation represents the water quality outcome of changes to the large point sources between the model calibration date (2012) and the most recent estimate of annual point source loads (2017). The model included 38 point sources that either increased or decreased between 2012 and 2017. Details of these point sources and changes between 2012 and 2017 are contained in Appendix B of Snelder *et al.* (2020).

The Point Source Change Simulation was made by:

1. setting export coefficients for all land as for the calibrated model
2. updating all point sources to the 2017 estimate.

The comparator used to report the results for the Point Sources Simulation is the Calibrated Model Simulation. This means the Point Sources Simulation results highlight the water quality outcome the changes to point source contributions of nitrogen between 2012 and 2017.

3.2.4 Post-regulation Simulation

There are two Post-regulation simulations. Post-regulation Simulation A represents the historical water quality outcome of consenting the 213 consented dairy farms (the Consented-IFLU; Figure 3). The Post-regulation Simulation A is similar to the Pre-regulation Simulation except that nitrogen leaching rates for Consented-IFLU are set to their consented nitrogen leaching rates in 2012. The Unconsented-IFLU are set to their basefile leaching rates in 2012 rather than the export coefficients used in the calibration (i.e., rates Bright *et al.*, 2018). Post-regulation Simulation B combines with the Point Sources Simulation to provide an assessment of the combined impact of these two water quality management interventions.

Post-regulation Simulation A was made by:

1. setting export coefficients for all non-IFLU and Unknown Unconsented-IFLU to the rates defined by the calibrated model

2. setting export coefficients for all Consented-IFLU (i.e., 213 consented dairy farms described by HRC database) to their consented leaching rates.
3. setting export coefficients for the Known Unconsented-IFLU (i.e., 70 unconsented dairy farms described by DNZ database) to the 2012 basefile leaching rates.

Post-regulation Simulation B was made by:

1. Updating all point sources to the 2017 estimates, added to the settings used for Post-regulation Simulation A.

The comparator used to report the results for both the Post-regulation Simulations is the Pre-regulation Simulation. This means the Post-regulation Simulation A results highlight the water quality outcome of reducing the nitrogen leaching rates from the consented-IFLU and Post-regulation Simulation A results highlight the combined impact of consenting and the point source changes.

3.2.5 Horticulture Mitigation Scenarios

The Horticulture Mitigation Scenarios represent the water quality outcome of recent changes to the management of commercial vegetable growing (CVG) on horticultural land since the model calibration date (2012). The report by Bloomer *et al.* (2020) indicates that improvements in CVG practices can reduce the annual nitrogen leaching rate from the 71 kg/ha/yr used in the model calibration to 46 kg/ha/yr. In addition Jolly *et al.* (2020) indicates that good management practice (GMP) can reduce annual nitrogen leaching rates for CGV by 36%, which is consistent with Bloomer *et al.* (2020). Jolly *et al.* (2020) also indicates that Best Management Practice (BMP) can reduce annual nitrogen leaching rates for CGV by 55%. Horticulture Mitigation Simulation A represents the impact of the Bloomer *et al.* (2020) leaching rate of 46 kg/ha/yr and the equivalent GMP reduction of 36% on CVG land. Horticulture Mitigation Simulation B represents the application of the BMP reduction of 55% on CVG land which results in a nitrogen leaching rate of 32 kg/ha/yr.

The Horticulture Mitigation Scenarios were made by:

1. setting export coefficients for all horticultural land in South West Coast climate zone with a plant available water (PAW) of ≥ 35 (see Snelder *et al.* (2020) for details) to 46 kg/ha/yr (A Scenario) and to 32 kg/ha/yr (B Scenario). This reduction therefore represents the improvements in CVG practices in the Horowhenua district.
2. Leaving all other nitrogen discharge rates (export coefficients for all land and point sources) unchanged from the calibrated model.

The comparator used to report the results for the Horticulture Mitigation Scenarios is the Calibrated Model Simulation. This means the Horticulture Mitigation Scenario results highlight the water quality outcome of changes to CVG practices in the Horowhenua district since 2012.

3.3 Operative One Plan Scenarios

3.3.1 Operative Scenario

The Operative Scenario represents the outcome of implementing the Operative Plan and assumes that all IFLU can comply with the Operative Plan Table 14.2. The purpose of the Operative Scenario is to simulate the water quality impact anticipated to result in the absence of expansion of dairy farming or any other IFLU, where all IFLU comply with the operative Table 14.2 by Year 20.

The Operative Scenario simulations were made by:

1. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all IFLU to the operative One Plan Table 14.2 (year 20).

The comparator used to report the results for the Operative Scenario is the Calibrated Model Simulation. This means the Operative Scenario highlights the impact on water quality of the Operative Plan.

3.3.2 Operative Consented Scenario

The Operative Consented Scenario represents the water quality outcome anticipated to result from implementation of the operative One Plan, with consenting. There are two sub-scenarios (A and B), representing the outcome for year 5 of implementation and year 20 of implementation.

The Operative Consented Year-20 Scenario assumes compliance with the One Plan Table 14.2 at year 20 except for Consented-IFLU. PPC2 changed the regulatory settings from the date it was publicly notified (mid 2019). Therefore, the Operative Consented Year-20 Scenario reflects as accurately as practicable the nitrogen leaching rates anticipated to result from One Plan decision-making prior to PPC2. In particular, the Operative Consented Year-20 Scenario represents the effects of the consented IFLU when it is compared to the Operative Scenario.

The Operative Consented Year-20 Scenario simulations were made by:

1. setting TN export coefficients for all non-IFLU land to the rates defined by the calibrated model
2. setting TN export coefficients for all Consented-IFLU (i.e. 213 farms) to the consented rate until year 20³.
3. setting export coefficients for all Unconsented-IFLU to the rates specified by the operative One Plan Table 14.2.

The Operative Consented sub-scenarios A and B were distinguished by setting export coefficients for all Unconsented-IFLU (point 2 above) to the 5- and 20-year rates respectively. Only the 20-year results are reported below but the predictions for both years are provided in the supplementary data. The comparator used to report the results for Operative Consented Year-20 Scenario is the Operative Scenario. This means the Operative Consented Year-20 Scenario highlights the marginal impact of the increased nitrogen leaching due to consenting some IFLU above the rate specified in the Operative Plan Table 14.2.

3.3.3 Operative Dairy Expansion Scenario

The Operative Dairy Expansion Scenario represents the year 20 outcome of implementing the Operative Plan with two additional assumptions. First, it is assumed that there is an expansion of dairy farming within each water management subzone of 11%. Second, it is assumed all IFLU can comply with Table 14.2. The purpose of the Operative Dairy Expansion Scenario is to simulate the water quality impact anticipated to result when all IFLU comply with the operative One Plan Table 14.2 and there is some expansion of IFLU. This scenario is most closely aligned with Scenario 6 of Roygard and Clark (2012) and applies the same assumptions.

³ Note that this is an assumption because some consents expire before year 20 and may not be renewed at their current rate.

The Operative Dairy Expansion Scenario simulations were made by:

1. increasing dairy farming land use within each water management subzone that currently has dairy farming by 11%. This increase is simulated by changing land use from sheep and beef to dairy farming.
2. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
3. setting export coefficients for all IFLU to the rates shown in operative One Plan Table 14.2 (year 20).

The comparator used to report the results for the Operative Dairy Expansion Scenario is the Operative Scenario. This means the Operative Dairy Expansion Scenario results highlight the marginal impact of the increased nitrogen leaching resulting from increasing IFLU by 11%.

3.4 Proposed PPC2 Scenarios

3.4.1 Proposed Consented Scenario

The Proposed Consented Scenario represents the water quality outcome anticipated to result from implementing PPC2 Table 14.2 with no provision for a discretionary activity consent pathway for IFLU to discharge with loss rates higher than the Table 14.2. The Proposed Consented Scenario simulations were made by:

1. setting export coefficients for all non-IFLU land to the rates defined by the calibrated model
2. setting export coefficients for all Consented-IFLU (i.e. 213 consented dairy farms described by HRC database) to their consented rate (unless allowable nitrogen leaching rates specified by the Proposed Plan Table 14.2 are higher, in which case they were set to the rates specified in Table 14.2).
3. setting export coefficients for all Unconsented-IFLU to the cumulative leaching maximums set under the recalibrated Table 14.2 of PPC2.

The Proposed Consented Year-5 and Year-20 Scenarios were distinguished by setting export coefficients for all Unconsented-IFLU (point 3 above) to the 5- and 20-year rates respectively. Results are described below only for Proposed Consented Year-20 Scenario. The comparators used to report the results for the Proposed Consented Year-20 Scenario are the Operative Year-20 Consented Scenario and the Pre-regulation Scenario. This means that the Proposed Consented Scenario results highlight the impacts on water quality of the proposed plan change, compared to both the Operative Plan and un-regulated conditions.

3.4.2 Proposed Year-20 Pathway Scenarios

The Proposed Year-20 Pathway Scenarios represent the year 20 outcome of implementing the Proposed Plan (i.e., as proposed by PPC2) with provision for discretionary consent pathways for unconsented-IFLU that do not comply with Table 14.2. There are a number of sub-scenarios representing provision of discretionary consent pathways for dairy farming, CVG and to incorporate the outcome of changes to point source contributions of nitrogen between 2012 and 2017.

There are four sub-scenarios representing discretionary consent pathways for dairy farms that represent absolute reductions of 9, 12, 15 and 18 kg ha⁻¹ yr⁻¹ from the current nitrogen loss rates for farms that do not comply with the table. These are labelled Proposed Year-20

Pathway A, B, C and D. Results are described below only for Proposed Year-20 Pathway A and Proposed Year-20 Pathway D.

The Proposed Year-20 Pathway A, B, C and D Scenario simulations were made by:

1. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all Consented-IFLU (i.e. 213 consented dairy farms described by HRC database) to their consented rate
3. setting export coefficients for all Known Unconsented-IFLU (i.e., 70 unconsented dairy farms described by DNZ database) that do not comply with Table 14.2 to the larger of either the Table 14.2 value or their baseline nitrogen leaching rates less four choices of absolute reduction of 9, 12, 15 and 18 kg ha⁻¹ yr⁻¹.
4. setting export coefficients for all Unknown Unconsented-IFLU to the rates specified by the Proposed Plan Table 14.2.

The comparator used to report the results for Proposed Year-20 Pathway A is the Proposed Consented Year-20 Scenario. Proposed Year-20 Pathway D is compared to Proposed Year-20 Pathway A. In addition, Proposed Year-20 Pathway A is compared to the Pre-regulation Scenario and the Proposed Year-20 Consented Scenario B is compared to the Proposed Year-20 Consented Strict Scenario (see below for details). This means that the Proposed Year-20 Pathway Scenarios highlight the marginal impacts of potential discretionary pathways and the impacts of such an implementation of PPC2 compared to an un-regulated scenario.

Further variations on the Proposed Year-20 Pathway Scenarios represent provision for discretionary pathways for CVG and are referred to as the Proposed Year-20 Pathway GMP Scenario and the Proposed Year-20 Pathway BMP Scenario. The Proposed Year-20 Pathway GMP Scenario combines the Proposed Year-20 Pathway A Scenario (absolute reductions in dairy farm leaching rates of 9 kg/ha/yr) with the Horticulture Mitigation Simulation A (reducing CVG leaching rate to 46 kg/ha/yr, which is the same as the 36% reduction that Jolly et al. (2020) consider represents GMP of on CVG land). The Proposed Year-20 Pathway BMP Scenario combines the Proposed Year-20 Pathway D Scenario (absolute reductions in dairy farm leaching rates of 18 kg/ha/yr) with the Horticulture Mitigation Simulation B (a 55% reduction to 32 kg/ha/yr that Jolly et al. (2020) consider represents GMP of on CVG land).

These scenarios are compared to three simulations. Both scenarios are compared to the Operative Consented and the Proposed Consented. The third comparator varies for the GMP and BMP scenario variations. The Proposed Year-20 Pathway GMP Scenario is compared to the Proposed Year-20 A Pathway and the Proposed Year-20 Pathway BMP Scenario is compared to the Proposed Year-20 D Pathway.

Finally, two further variations on the above scenarios were simulated by adding the Point Sources Simulation. These are referred to as the Proposed Year-20 Pathway GMP and Point Sources Scenario and the Proposed Year-20 Pathway BMP and Point Sources Scenario. These scenarios represent the combination of implementation of PC2 with the outcome of changes to significant point source contributions of nitrogen across the Region between 2012 and 2017. The comparators used to report the results for these scenarios are the Proposed Year-20 GMP Pathway and the Proposed Year-20 Pathway BMP Scenario, respectively. This choice of comparator highlights the marginal impacts of the changes to point source contributions of nitrogen between 2012 and 2017.

3.4.3 Proposed Year-5 Pathway Scenarios

The Proposed Year-5 Pathway Scenarios represents the year 5 outcome of implementing the Proposed Plan (i.e., as proposed by PPC2) with provision for discretionary consent pathways for unconsented dairy farms that do not comply with Table 14.2. There are four sub-scenarios representing differing levels of reduction from the current nitrogen loss rates for unconsented-dairy farms that do not comply with the table.

The Proposed Year-5 Pathway Scenarios simulations were made by:

1. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all Consented-IFLU (i.e. 213 consented dairy farms described by HRC database) to their consented rate
3. setting export coefficients for all Known Unconsented-IFLU (i.e., 70 unconsented dairy farms described by HRC database) that do not comply with Table 14.2 to the larger of either the Table 14.2 value or the currently estimated rates less four choices of absolute reduction of 9, 12, 15 and 18 kg ha⁻¹ yr⁻¹.
4. setting export coefficients for all other Unconsented-IFLU to the rates specified by the Proposed Plan Table 14.2.

The four Proposed Year-5 Pathway Sub-scenarios represent the differing levels of reduction from the current nitrogen loss rates for the unconsented-dairy farms (i.e. HRC database) that are noncompliant with Table 14.2 (i.e., absolute reductions of 9, 12, 15 and 18 kg ha⁻¹ yr⁻¹; point 3 above). These are labelled Proposed Year-5 Pathway Scenario A, B, C, and D. Results are described below only for Proposed Year-5 Pathway Scenario A and Proposed Year-5 Pathway Scenario D. The comparator used to report the results for Proposed Year-5 Pathway Scenario A is the Proposed Year-20 Pathway A. The Proposed Year-5 Pathway Scenario D is compared to Proposed Year-20 Pathway D. This means that the Proposed Year-5 Pathway Scenarios highlight the differences between simulated Year-5 and Year-20 conditions under such a regulatory scenario.

3.4.4 Proposed Consented Strict Scenario

The Proposed Consented Strict Scenario represents the water quality outcome anticipated to result at year 20 from implementing the Proposed Plan (i.e., PPC2) Table 14.2 with no provision for a discretionary activity pathway and with strict adherence to the current consent where that consented nitrogen leaching rate is less than Table 14.2. Therefore, where any current consent is more restrictive than Table 14.2, it has been assumed that the consented nitrogen leaching rate applies. There are 76 farms with consented rates less than the table. The average nitrogen leaching rate for these farms is 9 kg/ha/yr less than Table 14.2.

The Proposed Consented Strict Scenario simulations were made by:

1. setting export coefficients for all non-IFLU land to the rates defined by the calibrated model
2. setting export coefficients for all Consented-IFLU that are above Table 14.2 to the rates specified by the Proposed Plan Table 14.2 and setting all consented-IFLU that are below Table 14.2 to maintain the consented rate
3. setting export coefficients for all Unconsented-IFLU to the rates specified by the Proposed Plan Table 14.2.

The comparator used to report the results for Proposed Consented Strict Scenario is the Proposed Consented Scenario. This means that the Proposed Consented Strict Scenario highlights the marginal difference in water quality impacts anticipated from strict enforcement of consented rates, where consented rates are lower than the Proposed Plan Table 14.2.

3.5 Additional scenarios proposed by submitters

3.5.1 Natural State Scenario

The Natural State Scenario represents the water quality outcome of removing all anthropogenic land use from the region and all point sources of nitrogen. The purpose of the Natural State Scenario is to provide an indication of water quality under an unmodified land use state. The Natural State Scenario is based on the assumption that nitrogen export coefficients are equivalent to natural conditions across the entire region.

The Natural State Scenario simulations were made by:

1. setting export coefficients for all land to the rates used in the calibrated model for Native Cover, and setting all point sources to zero (see Snelder *et al.*, 2020 for details).

The comparator used to report the results for The Natural State Scenario is the Calibrated Model Simulation.

3.5.2 Dairy Sector Pathway Scenarios

The Dairy Sector Pathway Scenarios represent an alternative approach to restricting the leaching rates for the unconsented-IFLU. There are two versions of this scenario. The first (A) version is based on applying an alternative pathway for the dairy farms comprising the Known Unconsented-IFLU (Figure 3). These are the 70 unconsented dairy farms described by the HRC database. The second (B) version of the Dairy Sector Pathway Scenario is based on applying an alternative pathway for both the Known Unconsented farms and dairy farms that are Unknown Unconsented-IFLU (Figure 3). In both scenarios it is assumed that the current leaching rates of the unconsented dairy farms are reduced to the PPC2 year 20 value or, if larger: the minimum of 90% of the farm's basefile nitrogen leaching rate or the 75th percentile of the basefile nitrogen leaching rate of all dairy farms within the water management zone⁴. The nitrogen basefile rate means leaching rate modelled with OVERSEER for 2012-2013 but updated with OVERSEER 6.3.2 and as described in the HRC database.

The Dairy Sector Pathway A Scenario simulation was made by:

1. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all Consented-IFLU (i.e. 213 consented dairy farms described by HRC database) to their consented rate.
3. setting export coefficients for all Unconsented-IFLU to the rates specified by the Proposed Plan Table 14.2
4. then, if larger: re-setting export coefficients for all Known-Unconsented-IFLU to whichever is the lesser of either
 - a. 90% of the land's nitrogen baseline rate or

⁴ Note that we have interpreted this to be the water management zone (not the WMSZ).

- b. The 75th percentile of the nitrogen baseline rate of all IFLU within the water management zone.

The Dairy Sector Pathway B Scenario simulation was made by:

1. setting export coefficients for all non-IFLU to the rates defined by the calibrated model
2. setting export coefficients for all IFLU to the rates specified by the Proposed Plan Table 14.2
3. For each of the 282 farms in the HRC database, apply the dairy sector pathway as described above to calculate the allowable nitrogen leaching rate.
4. From the above step, calculate the area weighted average allowable nitrogen leaching rate in each WMZ and use this value (if it is higher than the PPC2 Table 14.2 Year 20 rate) to set the export coefficients for all dairy farms in each WMZ. Note that this step is not applied to any WMZ that is not represented by farms in the HRC database and these therefore remain at the PPC2 Table 14.2 Year 20 rate.
5. Re-set export coefficients for all Consented-IFLU (i.e. 213 consented dairy farms described by HRC database) to their consented rate.
6. For each of the Known-Unconsented farms, reset export coefficients to that farm's specific dairy sector pathway rate (i.e., calculated at Step 3 above)

It is noted that the intent of the above steps is to use the farms in the HRC database as a representative sample of all farms in each WMZ. This representative sample is used to infer the outcome of the dairy sector pathway on the Unknown-Unconsented farms in each WMZ. Because the HRC database only has farms for some WMZs, all other IFLU across the region has export coefficients set to the PC2 Table 14.2 Year 20 rate.

The comparator used to report the results for the Dairy Sector Pathway Scenario is the Proposed Consented Scenario.

3.5.3 Horticulture Expansion Scenarios

The Horticulture Expansion Scenarios represent the water quality outcome of increasing commercial vegetable growing across the region. It is assumed that commercial vegetable growing is undertaken on LUC class I, II and III land across the region as a 5-year rotation in combination with the existing land use. The purpose of the Horticulture Expansion Scenarios is to provide bookend estimates of the water quality outcome of changing land use to commercial vegetable growing. The Horticulture Expansion A Scenario (lower bookend) assumes that commercial vegetable growing is undertaken on LUC class I, II and III land across the region that is currently in a Dairy Farming or Sheep and Beef land use. The Horticulture Expansion B Scenario (upper bookend) assumes that commercial vegetable growing is undertaken on LUC class I, II and III land across the region.

The Horticulture Expansion Scenario simulations were made by:

1. setting export coefficients for all non-IFLU on LUC class IV-VIII to the rates defined by the calibrated model
2. modifying export coefficients on all LUC class I-III that is:
 - a. currently in a Dairy Farming or Sheep and Beef land use (be Horticulture Expansion A Scenario)

- b. currently in in any land use (be Horticulture Expansion B Scenario)

Modification to export coefficients in both the Horticulture Expansion A Scenario and the Horticulture Expansion B Scenario was by adding 80% of their current estimated rate and 20%⁵ of the estimated nitrogen leaching rate for potato growing (46 kg/ha/yr; see Bloomer *et al.*, 2020 for details). The comparator used to report the results for the Horticulture Expansion A Scenario and the Horticulture Expansion B Scenario is the Calibrated Model Simulation.

3.5.4 Potato Expansion Scenarios

The Potato Expansion Scenarios represent the water quality outcome of increasing commercial potato growing across the region. It is assumed that commercial potato growing is undertaken on LUC class I, II and III land across the region as a 5-year rotation in combination with the existing land use. The purpose of the Potato Expansion Scenario is to provide bookend estimates of the water quality outcome of changing land use to commercial potato growing. The Potato Expansion A Scenario (upper bookend) assumes that commercial potato growing is undertaken on LUC class I, II and III land across the region that is currently in a Dairy Farming or Sheep and Beef land use and that the nitrogen leaching rate for the potato crop is 24 kg/ha/yr. The Potato Expansion B and C Scenarios (lower bookend) are the same as the A Scenario but assumes nitrogen leaching rate for the potato crop are 13 kg/ha/yr and 9 kg/ha/yr respectively.

The Potato Expansion Scenario simulations were made by:

1. setting export coefficients for all non-IFLU on LUC class IV-VIII to the rates defined by the calibrated model
2. modifying export coefficients on all LUC class I-III that is currently in a Dairy Farming or Sheep and Beef land use to
 - a. 24 kg/ha/yr
 - b. 13 kg/ha/yr
 - c. 9 kg/ha/yr

Modification to export coefficients in all the Potato Expansion Scenarios was by adding 80% of their current estimated rate and 20% of the estimate nitrogen leaching rate for the potato crops. The comparators used to report the results for the Potato Expansion Scenarios are the Calibrated Model Simulation.

⁵ 20% is used to represent a 1 in 5 year rotation.

3.6 Summary of scenarios

Table 1. Summary of scenarios.

Scenario	Description	Primary comparator
Calibrated Model	Simulation using the calibrated model representing conditions prior to regulation in 2012	NA
Pre-regulation	Nitrogen leaching rates for consented-IFLU and unconsented-IFLU are set to their 2012 basefile leaching rates rather than the export coefficients used in the calibration	Calibrated Model
Point sources	Change in point source loads between 2012 and 2017	Calibrated Model
Post-regulation A	Export coefficients as for calibrated except N leaching rates for consented-IFLU are set to consented rates and unconsented-IFLU are set to their basefile leaching rates.	Pre-regulation
Post-regulation B	As for Post-regulation A and with point sources are updated to 2017 rates (from calibration 2012 rates).	Pre-regulation
Horticulture Mitigation A	Reduction in leaching rates from horticulture land in South West Coast climate zone to simulate GMP applied to commercial vegetable growing practices in the Horowhenua district.	Calibrated Model
Horticulture Mitigation B	Reduction in leaching rates from horticulture land in South West Coast climate zone to simulate BMP applied to commercial vegetable growing practices in the Horowhenua district.	Calibrated Model
Operative	implementation of the operative One Plan assuming that all IFU complies with Table 14.2 by year 20.	Calibrated Model
Operative Consented	Implementation of the operative One Plan with all consented-IFLU at the consented rate for year 5 and year 20.	Operative year-20
Operative Dairy Expansion	Year 20 implementation of the operative One Plan with 11% expansion of IFU within each WMSZ and assumes all IFU complies with Table 14.2	Operative year-20
Proposed Consented	Implementation of PC2 with no provision for a discretionary activity pathway but existing consents at consented rates for Year 5 and Year 20.	Operative Year-20 Consented
Proposed Year-20 Pathway A	Year 20 implementation of PC2 discretionary pathways for non-consented/non-compliant IFU with 9kg/ha/yr reduction from basefile leaching rates.	Proposed Consented
Proposed Year-20 Pathway D	Year 20 implementation of PC2 discretionary pathways for non-consented/non-compliant IFU with 18kg/ha/yr reduction from basefile leaching rates.	Proposed year-20 pathway A
Proposed Year-20 Pathway GMP	Year 20 implementation of PC2 discretionary pathways for non-consented/non-compliant IFU with 18kg/ha/yr reduction from basefile leaching rates except for CVG for which a GMP reduction of 36% applies	Proposed Consented
Proposed Year-20 Pathway BMP	Year 20 implementation of PC2 discretionary pathways for non-consented/non-compliant IFU with 18kg/ha/yr reduction from basefile leaching rates except for CVG for which a MMP reduction of 55% applies	Proposed Consented
Proposed Year-20 Pathway GMP + point sources	Combination of Proposed Year-20 Pathway GMP and Point sources Scenario	Proposed Year-20 Pathway GMP Scenario
Proposed Year-20 Pathway BMP + point sources	Combination of Proposed Year-20 Pathway BMP and Point sources Scenario	Proposed Year-20 Pathway BMP Scenario

Proposed Year-5 Pathway A	Year 5 implementation PC2 discretionary pathways for non-consented/non-compliant IFLU with 9kg/ha/yr reduction from basefile leaching rates.	Proposed year-20 pathway A
Proposed Year-5 Pathway D	Year 5 implementation of PC2 discretionary pathways for non-consented/non-compliant IFLU with 18kg/ha/yr reduction from basefile leaching rates.	Proposed year-20 pathway D
Proposed Consented Strict	Year 20 implementation of PC2 with no provision for a discretionary activity pathway and adherence to consented rates where these are below Table 14.2 and reduction of N loss rates to Table 14.2 where consented rates are above Table 14.2.	Proposed Year-20 Consented
Natural state	Natural state (no land use or point sources of nitrogen)	Calibrated Model
Dairy Sector Pathway A	Alternative approach to restricting the leaching rates for the unconsented-IFLU applied only to the 70 Known-Unconsented dairy farms	Proposed Year-20 Consented
Dairy Sector Pathway A	Alternative approach to restricting the leaching rates for the unconsented-IFLU applied to all Unconsented dairy farms in the Target Catchments	Proposed Year-20 Consented
Horticulture Expansion A	Increasing vegetable growing on LUC class I- III land currently in a Dairy Farming or Sheep and Beef land use	Calibrated Model
Horticulture Expansion B	Increasing vegetable growing on LUC class I- III land currently in any land use	Calibrated Model
Potato Expansion A	Potato growing in a one in five year rotation on LUC class I- III land currently in a Dairy Farming or Sheep and Beef land use assuming a nitrogen leaching rate of 24 kg/ha/yr	
Potato Expansion B	Potato growing in a one in five year rotation on LUC class I- III land currently in a Dairy Farming or Sheep and Beef land use assuming a nitrogen leaching rate of 13 kg/ha/yr	
Potato Expansion C	Potato growing in a one in five year rotation on LUC class I- III land currently in a Dairy Farming or Sheep and Beef land use assuming a nitrogen leaching rate of 9 kg/ha/yr	

4 Results

4.1 Model uncertainty and interpretation of results

As described in the model calibration report (Snelder *et al.* 2020), the models are most reliably, and most appropriately, applied to predict *relative* changes in receiving water quality between scenarios. This is particularly true for unmonitored assessment points. The focus, therefore, of the presentation of results below is on predicted relative changes. The exception to this is where we make assessments with respect to compliance with One Plan targets (far right map shown in each section below), which must be based on estimated absolute concentration estimates. While we deem the compliance results useful, and the product of best available science, we acknowledge that these results are less certain than those summarising predicted relative changes in concentration only (centre maps). We encourage the reader to keep this in mind when considering the implications of the results presented below. A more detailed discussion of model uncertainty is provided in Snelder *et al.* (2020).

4.2 Historical simulations

4.2.1 Calibrated Model Simulation

The nitrogen export coefficients and resulting river SIN concentrations for the Calibrated Model Simulation are shown in Figure 5. Under the Calibrated Model Simulation, predicted concentrations of SIN do not comply with One Plan targets in 96 of the 124 assessment points (Figure 5). Predicted concentrations of SIN exceeded the target by more than 10%, 20% and 50% at 89, 77 and 48 assessment points respectively.

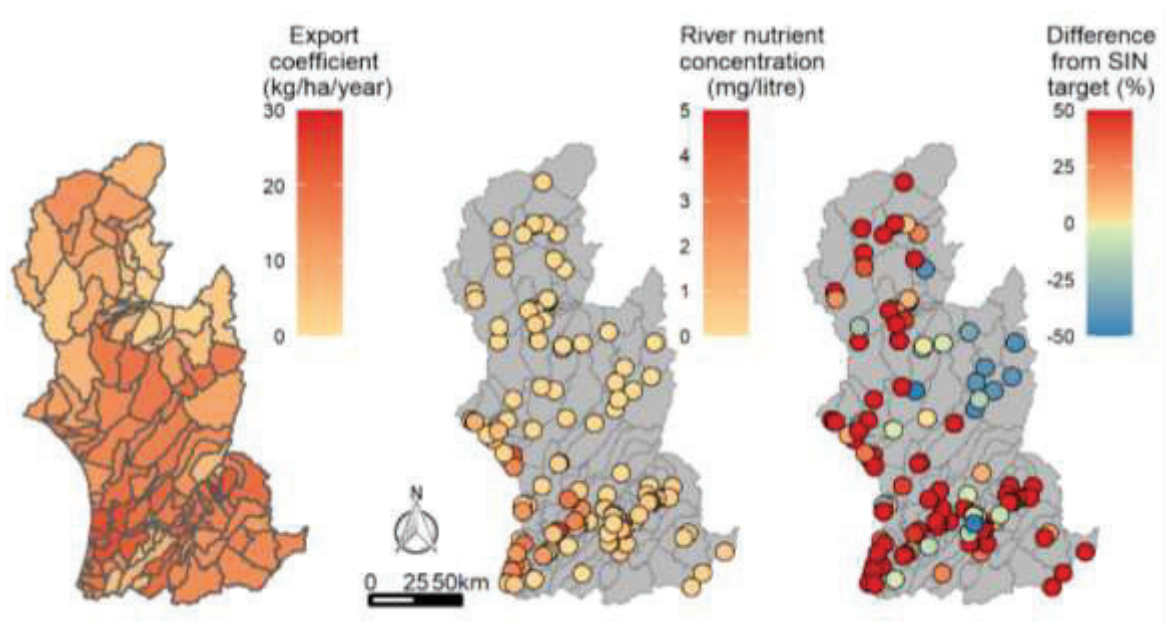


Figure 5. Nitrogen export coefficient and predicted river SIN concentrations for the Calibrated Model Simulation. The values shown on the left map are the mean nitrogen export coefficient in each WMSZ. The values shown on the centre map are the predicted SIN concentrations at each assessment point. The values shown on the right map indicate state in relative terms (i.e., SIN concentration divided by the SIN target) at each assessment point. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.2.2 Pre-regulation Simulation

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Pre-regulation Simulation compared to the Calibrated Model Simulation is shown in Figure 6. The Pre-regulation Simulation is similar to the Calibrated Model Simulation except that nitrogen leaching rates for consented-IFLU and unconsented-IFLU are set to their basefile rates rather than the export coefficients used in the calibration. TN export coefficients for WMSZs and SIN concentrations at assessment points under the Pre-regulation Simulation were variously lower or higher than the Calibrated Model Simulation (Figure 6).

There is a close match between the Calibrated Model Simulation and the Pre-regulation Simulation (i.e., differences in SIN concentration at assessment points between the Calibrated Model Simulation and the Pre-regulation Simulation are small). In addition, there is an absence of bias (i.e., differences in SIN concentration at assessment points between the Calibrated Model Simulation and the Pre-regulation Simulation are both positive and negative). This indicates that the calibration nitrogen export coefficients are reasonably consistent with the estimated leaching rates for the consented-IFLU and unconsented-IFLU. This observation is consistent with the comparisons of leaching rate estimates made by Snelder *et al.* (2020).

Under the Pre-regulation Simulation, predicted concentrations of SIN do not achieve One Plan targets in 97 of the 124 assessment points (Figure 6). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 88, 78 and 50 assessment points, respectively.

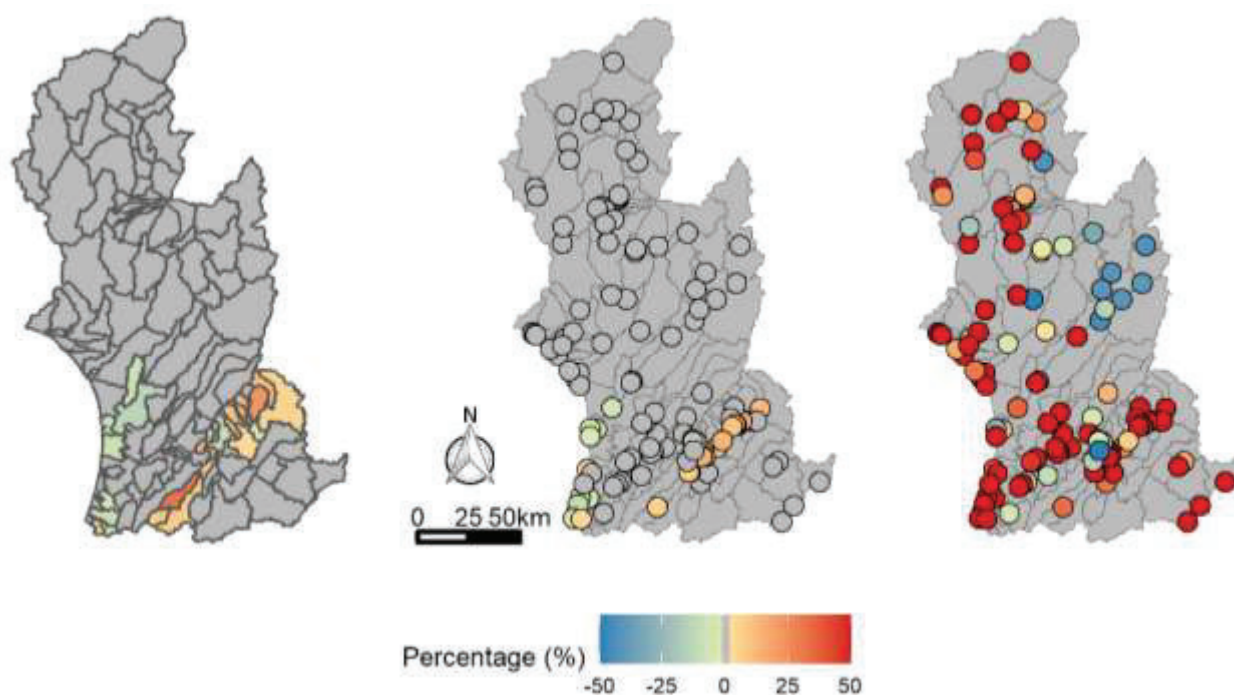


Figure 6. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Pre-regulation Simulation. The differences shown on the left and centre maps were derived by comparing the Pre-regulation Simulation with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.2.3 Point Sources Simulation

Nitrogen export coefficients under the Point Sources Scenario are unchanged compared to the modelling baseline simulation (Figure 7). However, of the 36 point sources that were common to both 2012 and 2017 simulation years, discharged nitrogen loads decreased at 25 locations and increased at 11 locations. Differences in river SIN concentrations between the Point Sources Scenario (representing point sources in 2017) and the Calibrated Model Simulation (representing point sources in 2012) are shown in Figure 7. Compared to the Calibrated Model Simulation, SIN concentrations under the Point Sources Scenario are predicted to be higher at 18 (i.e., 15%) assessment points and lower at 31 (i.e., 25%) assessment points.

Under the Point Sources Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 95 of the 124 assessment points (Figure 7). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 88, 76 and 47 assessment points, respectively.

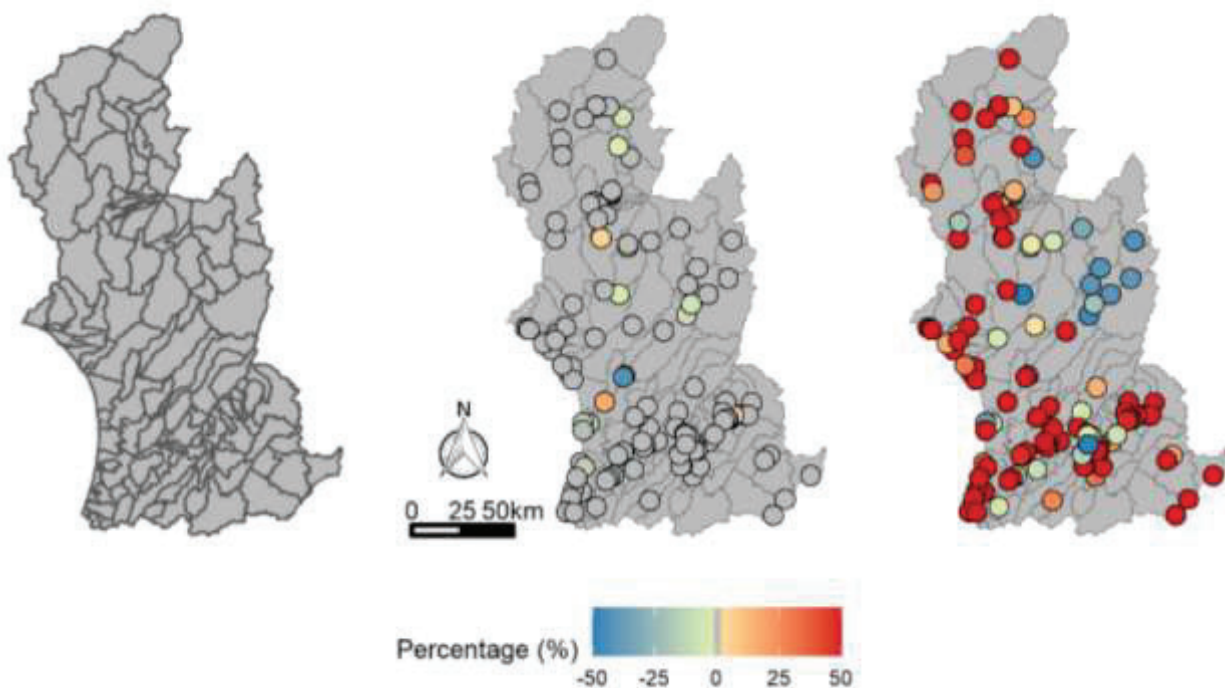


Figure 7. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Point Sources Scenario. The changes shown on the left and centre maps were derived by comparing the Point Sources Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.2.4 Post-regulation Simulations

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Post-regulation Simulation A compared to the Pre-regulation Simulation is shown in Figure 8. The Post-regulation Simulation A is similar to the Pre-regulation Simulation except that nitrogen leaching rates for Consented-IFLU are set to their consented rates. TN export

coefficients for WMSZs and SIN concentrations at assessment points under the Pre-regulation Simulation were the same or lower than the Pre-regulation Simulation (Figure 8).

The SIN concentrations at assessment points downstream of the Target Catchments were predicted to be lower for the Post-regulation Simulation compared to the Pre-regulation Simulation. This highlights the water quality impact of the consenting of the consented-IFLU (i.e., 213 consented dairy farms described by HRC database).

Under the Post-regulation A Simulation the predicted concentrations of SIN do not achieve One Plan targets in 97 of the 124 assessment points (Figure 8). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 88, 77 and 48 assessment points, respectively.

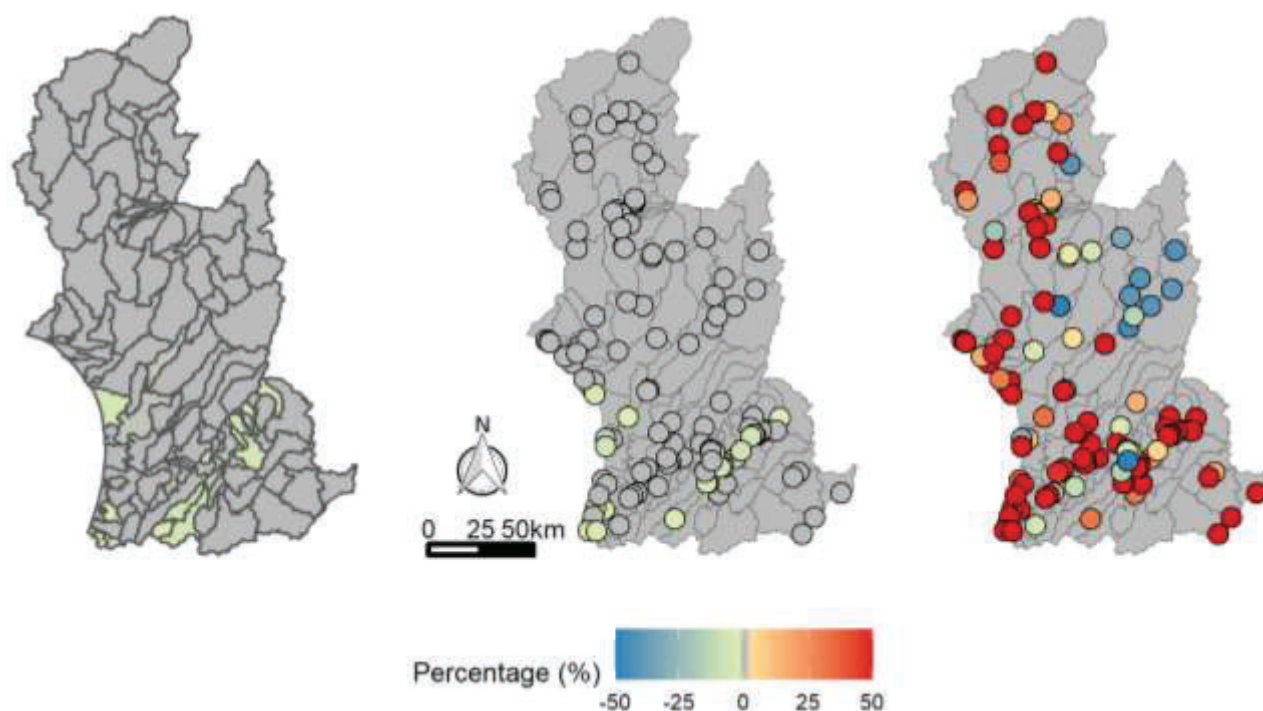


Figure 8. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Post-regulation A Simulation. The differences shown on the left and centre maps were derived by comparing the Post-regulation Simulation with the Pre-regulation Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

The SIN concentrations at assessment points were higher and lower for the Post-regulation B Simulation compared to the Pre-regulation Simulation (Figure 9). This highlights the combined water quality impact of the consenting of the consented-IFLU (i.e., 213 consented dairy farms described by HRC database, which uniformly decreased discharges) and the variable changes in nitrogen discharges (i.e., both increases and decreases) associated with point sources.

Under the Post-regulation B Simulation the predicted concentrations of SIN do not achieve One Plan targets in 96 of the 124 assessment points (Figure 9). Predicted concentrations of

SIN exceed the target by more than 10%, 20% and 50% at 88, 76 and 48 assessment points, respectively.

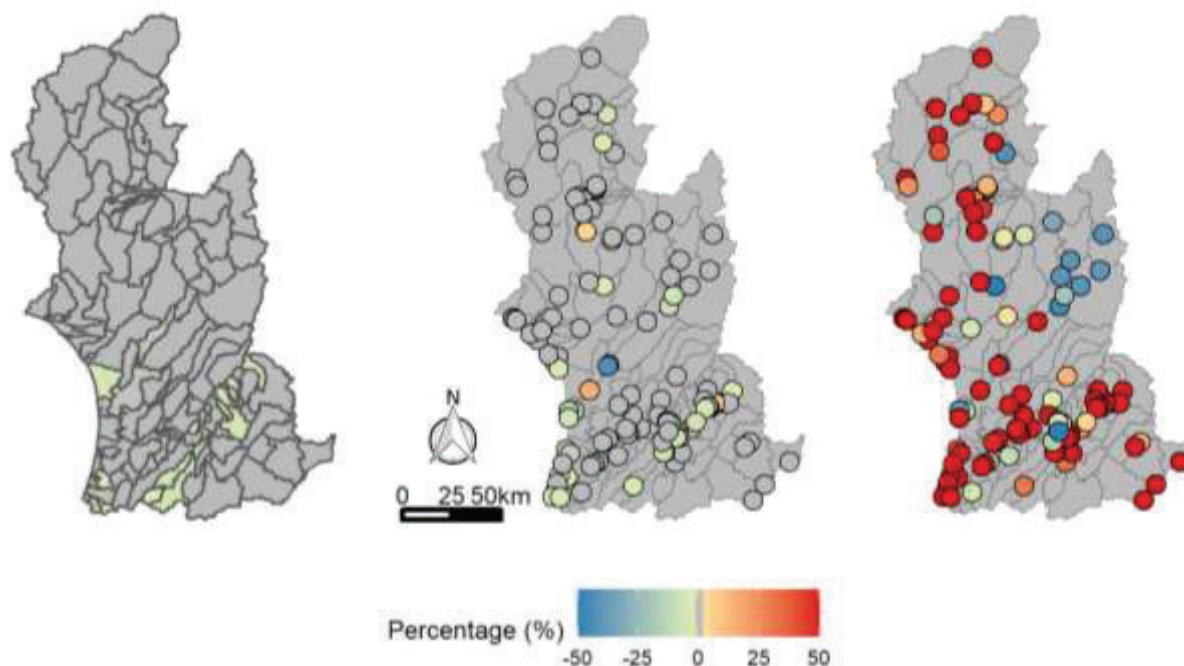


Figure 9. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Post-regulation B Simulation. The differences shown on the left and centre maps were derived by comparing the Post-regulation Simulation with the Pre-regulation Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.2.5 Horticulture Mitigation Scenarios

Nitrogen export coefficients under the Horticulture Mitigation A Scenario reduced slightly in WMSZs located in South West Coast climate zone (Horowhenua district) compared to the modelling baseline simulation (Figure 10). Differences in river SIN concentrations between the Horticulture Mitigation A Scenario and the Calibrated Model Simulation are shown in Figure 10. Compared to the Calibrated Model Simulation, SIN concentrations under the Horticulture Mitigation A Scenario are predicted to be lower at 29 (i.e., 23%) assessment points and were not predicted to be higher at any assessment points.

Under the Horticulture Mitigation A Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 96 of the 124 assessment points (Figure 10). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 77 and 48 assessment points, respectively. The mean relative difference indicates the mean amount by which the predicted concentration at assessment points deviate from the target. Positive values indicate the predicted SIN concentration exceeds the target (i.e., the objective is not achieved). The mean relative difference for the Horticulture Mitigation A Scenario indicated that, on average, predicted SIN concentrations at assessment points were 29.7% greater than the One Plan target. (Note that the percentage is given to one decimal place here in order to illustrate the very marginal difference to the results for the next scenario below).

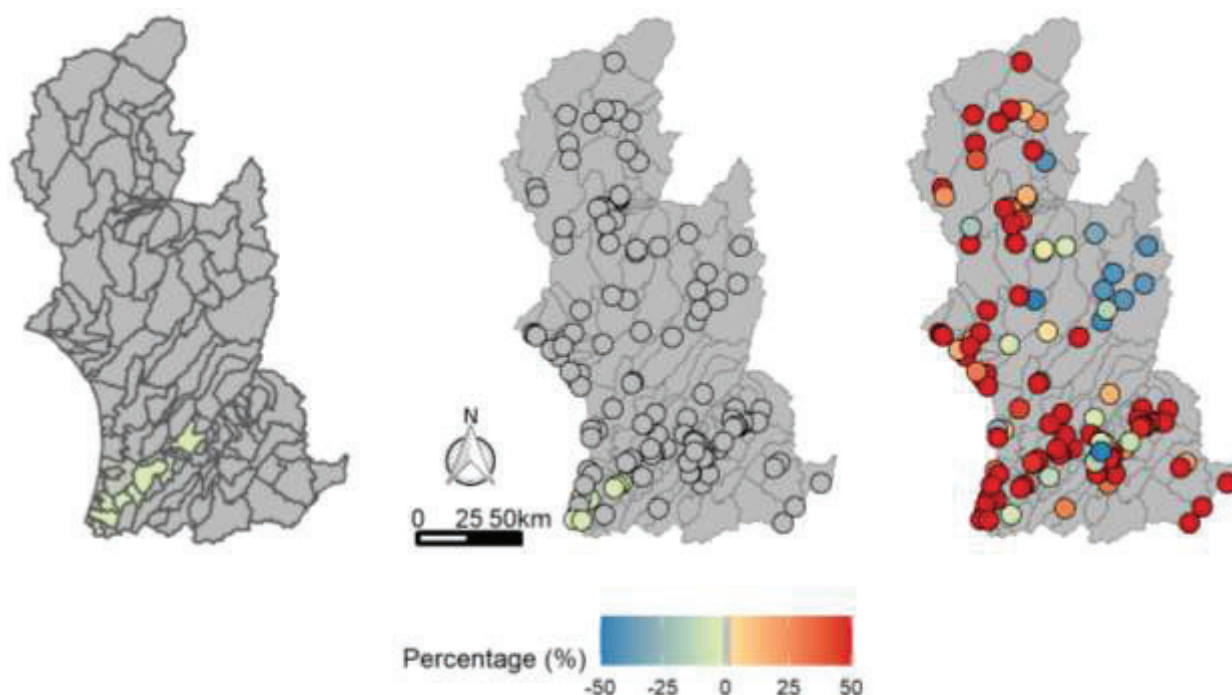


Figure 10. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Horticulture Mitigation A Scenario. The changes shown on the left and centre maps were derived by comparing the Horticulture Mitigation Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Differences in river SIN concentrations between the Horticulture Mitigation B Scenario and the Calibrated Model Simulation are shown in

Figure 11. Compared to the Calibrated Model Simulation, SIN concentrations under the Horticulture Mitigation B Scenario are predicted to be lower at 32 (i.e., 26%) assessment points and were not predicted to be higher at any assessment points. Under the Horticulture Mitigation B Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 96 of the 124 assessment points (Figure 11). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 77 and 48 assessment points, respectively. The mean relative difference for the Horticulture Mitigation B Scenario indicated that, on average, predicted SIN concentrations at assessment points were 29.6% greater than the One Plan target. There is therefore no significant difference between the A and B Scenarios in terms of the evaluated water quality outcomes.

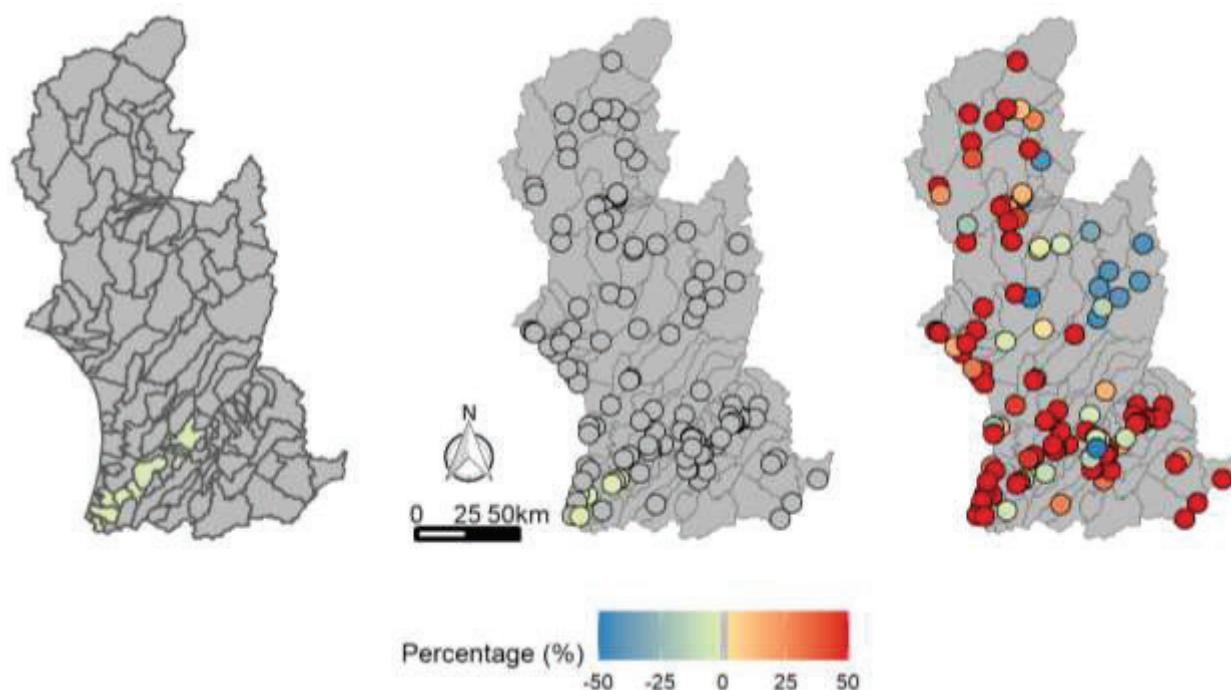


Figure 11. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Horticulture Mitigation B Scenario. The changes shown on the left and centre maps were derived by comparing the Horticulture Mitigation Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.3 Operative One Plan Scenarios

4.3.1 Operative Scenario

The differences in the nitrogen export coefficients and resulting river SIN concentrations under the Operative Scenario compared to the Calibrated Model Simulation are shown in Figure 12. The Operative Scenario represents the year 20 outcome of implementing the Operative Plan and assumes that all IFLU comply with the Operative Plan Table 14.2. TN export coefficients for WMSZs and SIN concentrations at assessment points under the Operative Year-20 Scenario were variously lower or higher than the Calibrated Model Simulation (Figure 12). Compared to the Calibrated Model Simulation, nitrogen export coefficients under the Operative Year-20 Scenario are higher in 2 (i.e., 2%) and lower in 85 (i.e., 69%) WMSZs. Compared to the Calibrated Model Simulation, SIN concentrations are predicted to be lower at 97 assessment points. Compared to the modelling baseline, SIN concentrations are predicted to be higher at six assessment points (Figure 12).

Under the Operative Scenario, predicted concentrations of SIN do not achieve One Plan targets in 91 of the 124 assessment points (Figure 12). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 81, 65 and 42 assessment points, respectively.

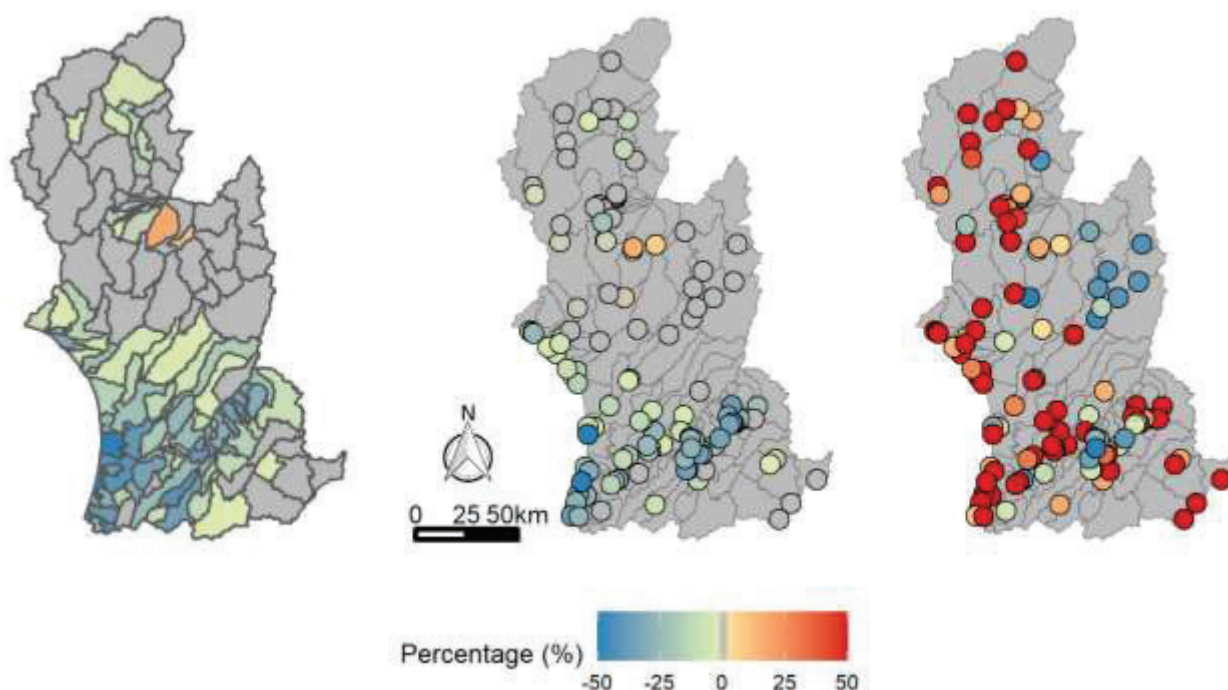


Figure 12. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Operative Scenario. The differences shown on the left and centre maps were derived by comparing the Operative Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.3.2 Operative Consented Scenario

The differences in the nitrogen export coefficients and resulting river SIN concentrations under the Operative Consented Year-20 Scenario compared to the Operative Scenario are shown in Figure 13. The Operative Consented Year-20 Scenario represents the year 20 outcome of implementation of the operative One Plan (note that the Operative Year-20 Consented A Scenario represents the year 5 outcome, but the results are not presented below). Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Operative Year-20 Consented B Scenario are the same or higher than the Operative Year-20 Scenario. Compared to the Operative Year-20 Scenario, nitrogen export coefficients under the Operative Year-20 Consented B Scenario are higher in 29 (i.e., 23%) of WMSZs. Compared to the Operative Year-20 Scenario, SIN concentrations under the Operative Year-20 Consented B Scenario are predicted to be higher at 36 (i.e., 29%) assessment points. These assessment points are all located downstream of target catchments where there are consented IFLU.

Under the Operative Consented Year-20 Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 96 of the 124 assessment points (Figure 13). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 87, 73 and 43 assessment points, respectively.

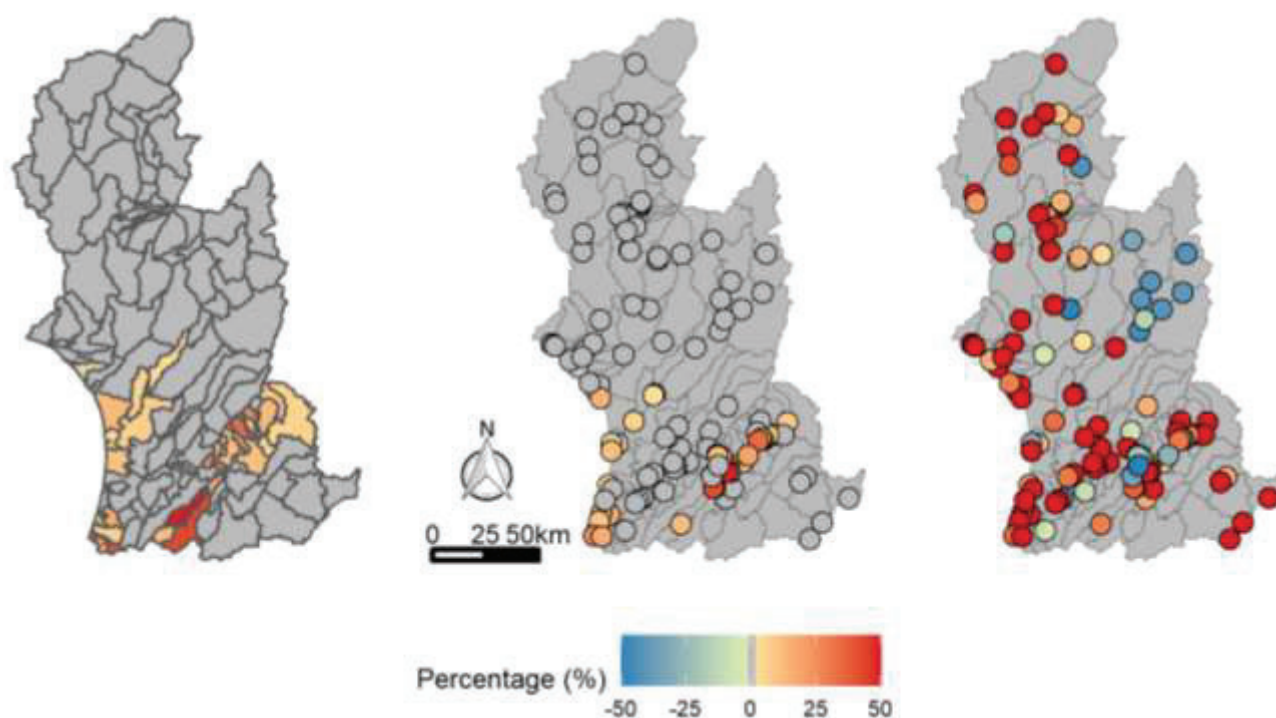


Figure 13. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Operative Consented Year-20 Scenario. The differences shown on the left and centre maps were derived by comparing the Operative Consented Year-20 Scenario with the Operative Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.3.3 Operative Dairy Expansion Scenario

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Operative Dairy Expansion Scenario compared to the Operative Scenario are shown in Figure 14. The Operative Dairy Expansion Scenario represents the year 20 outcome of the Operative Plan and the assumption that there is an 11% expansion of dairy farming that complies with Table 14.2.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Operative Dairy Expansion Scenario are the same or higher than the Operative Scenario. Compared to the Operative Scenario, SIN concentrations under the Operative Dairy Expansion Scenario are predicted to be higher at 76 (i.e., 62%) assessment points.

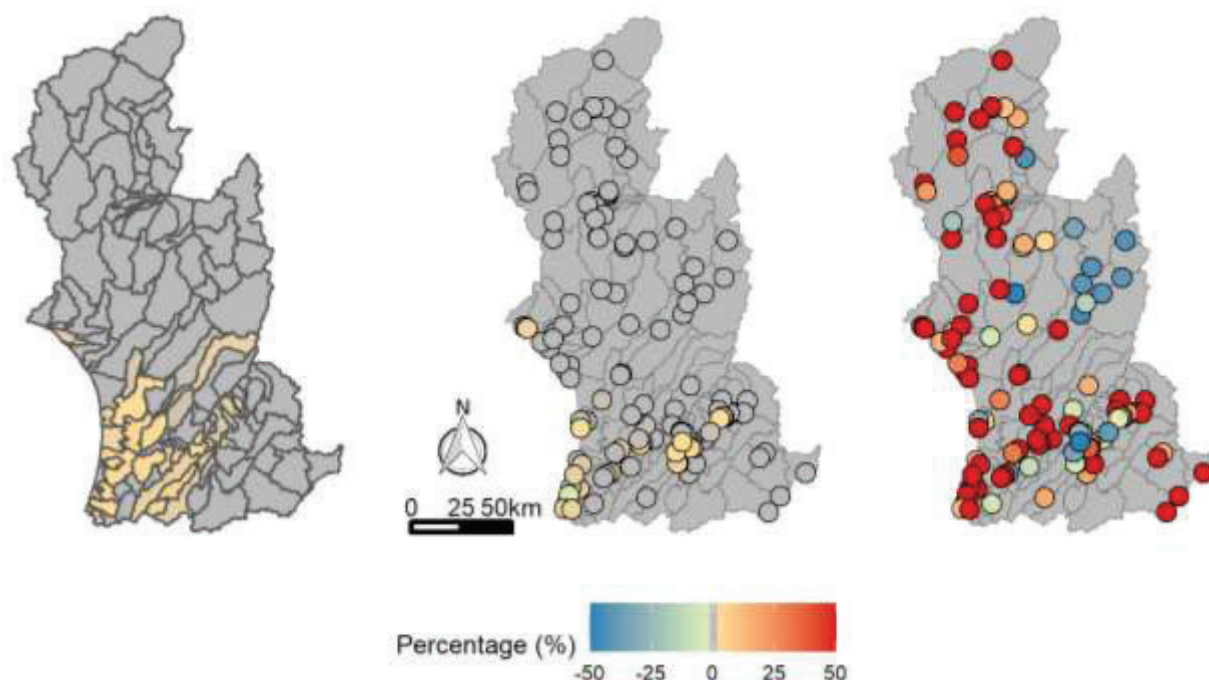


Figure 14. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Operative Dairy Expansion Scenario. The differences shown on the left and centre maps were derived by comparing the Operative Dairy Expansion Scenario with the Operative Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.4 Proposed Plan Changes

4.4.1 Proposed Consented Scenarios

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Consented Year-20 Scenario compared to Operative Consented Scenario are shown in Figure 15. The Proposed Consented Year-20 Scenario represents outcome of the Proposed Plan (i.e., PPC2 and new Table 14.2) for year 20 with no provision for a discretionary activity consent pathway. TN export coefficients in all WMSZs and SIN concentrations at all assessment points under the Proposed Consented Year-20 Scenario are the same or higher than the Operative Consented Scenario. Compared to the Operative Consented Scenario, nitrogen export coefficients under Proposed Consented Year-20 Scenario are higher in 86 (i.e., 69%) of WMSZs. Compared to the Operative Consented Scenario the SIN concentrations under Proposed Consented Year-20 Scenario are higher at 100 (i.e., 81%) assessment points (Figure 15).

Under the Proposed Consented Year-20 Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 98 of the 124 assessment points (Figure 15). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 77 and 47 assessment points, respectively.

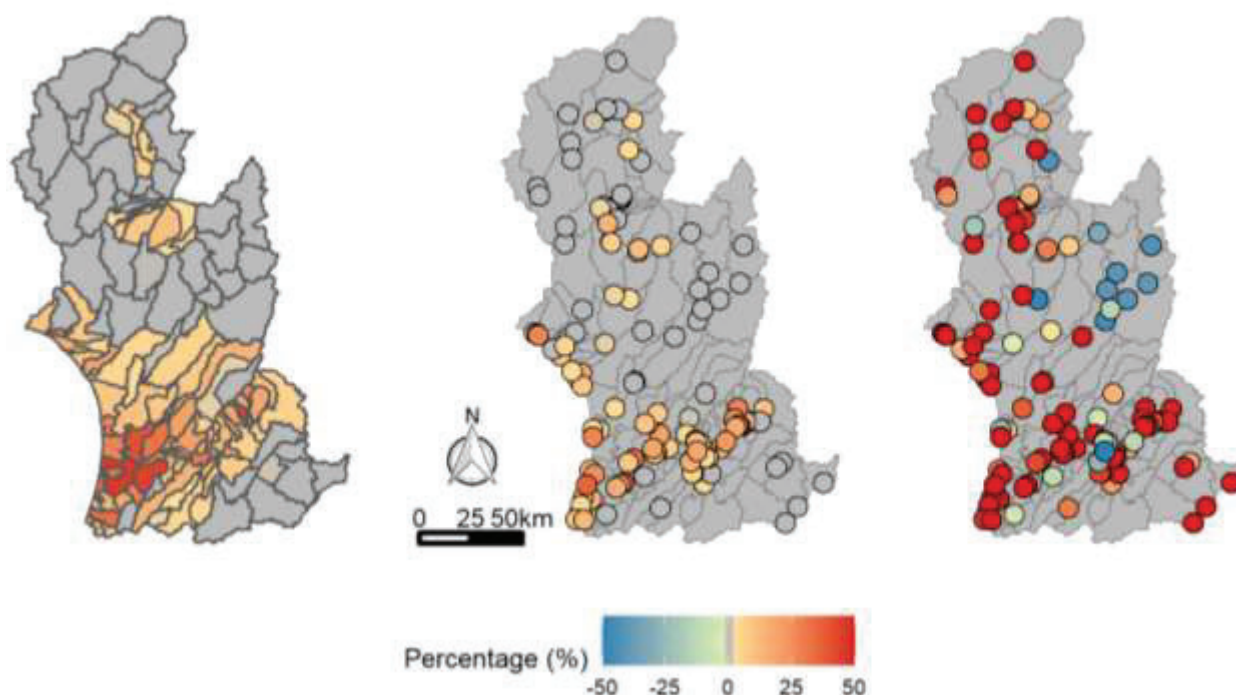


Figure 15. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Consented B Scenario. The differences shown on the left and centre maps were derived by comparing Proposed Consented Year-20 Scenario with the Operative Consented Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Compared to the Pre-regulation Scenario, SIN concentrations under Proposed Consented Year-20 Scenario were higher at 29 (i.e., 23%) assessment points and were lower at 81 (i.e., 65%) of assessment points (Figure 16). The assessment points where SIN concentrations were lower tended to be downstream of target catchments (Figure 16). The assessment points where SIN concentrations were higher tended to be downstream of non-target catchments (i.e., catchments where there was not consented IFLU) and where there was significant area of IFLU with export coefficients in the calibrated model that are below the cumulative leaching maximums set under the recalibrated Table 14.2 of PPC2 (see Figure 2). This indicates that under the Proposed Consented Year-20 Scenario, some existing IFLU is assumed to increase its nitrogen leaching rate to the limit specified in Table 14.2.

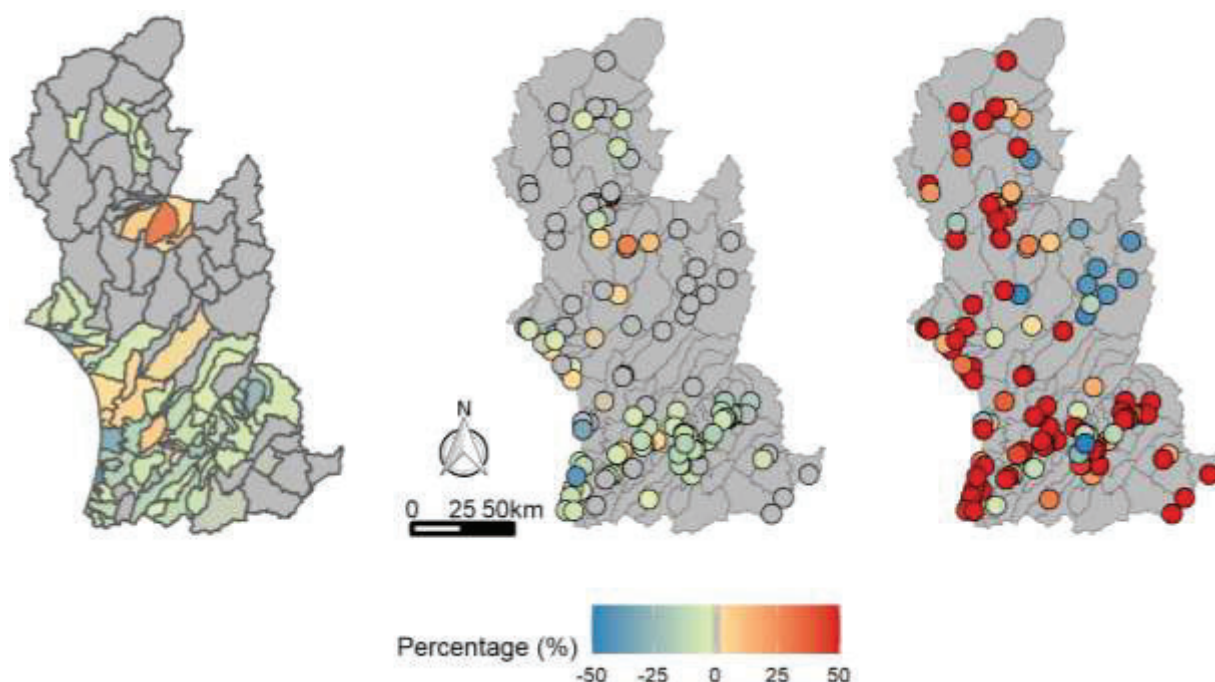


Figure 16. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Consented Scenario and the Pre-regulation Scenario.

4.4.2 Proposed Year-20 Pathway Scenarios

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Year-20 Pathway A Scenario compared to the Proposed Consented Year 20 Scenario are shown in Figure 17. The Proposed Year-20 Pathway A Scenario represents the year 20 outcome of implementing the Proposed Plan (i.e., as proposed by PPC2) with provision for discretionary pathways for non-consented and non-compliant dairy farms. The Proposed Year-20 Pathway A Scenario assumes that non-consented, non-compliant dairy farms reduce their loss rates by 9 kg/ha/yr. It is noted that farms pertaining to this scenario are limited to a sample of properties within the target water management sub zones as shown in Figure 2.

TN export coefficients in all WMSZs and SIN concentrations at all assessment points under the Proposed Year-20 Pathway A Scenario are the same or higher than the Proposed Consented Year-20 Scenario. Compared to the Proposed Consented Year-20 Scenario, nitrogen export coefficients were higher in 8 (i.e., 6%) of WMSZs (Figure 17). Compared to the Proposed Consented Year-20 Scenario, SIN concentrations under the Proposed Year-20 Pathway A Scenario were predicted to be higher at 14 assessment points in the Manawatu River Catchment (Figure 17).

Under the Proposed Year-20 Pathway A Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 99 of the 124 assessment points (Figure 17). Predicted concentrations of SIN exceeded the target by more than 10%, 20% and 50% at 89, 77 and 47 assessment points, respectively.

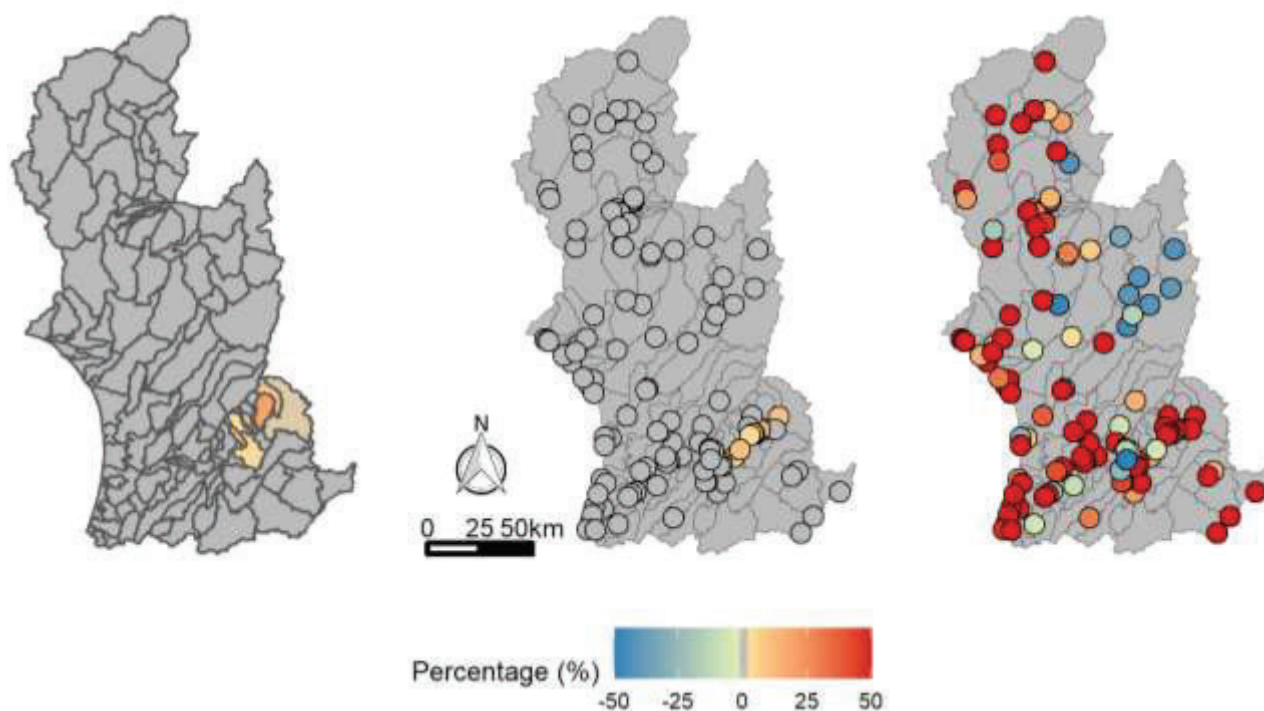


Figure 17. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Year-20 Pathway A Scenario. The differences shown on the left and centre maps were derived by comparing the Proposed Year-20 Pathway A Scenario with the Proposed Consented Year-20 Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Compared to the Pre-regulation Scenario, SIN concentrations under the Proposed Year-20 Pathway A Scenario were higher at 29 (i.e., 23%) assessment points and were lower at 81 (i.e., 65%) of assessment points (Figure 18). The assessment points where SIN concentrations were lower tended to be downstream of target catchments (Figure 18). The assessment points where SIN concentrations were higher tended to be downstream of non-target catchments (i.e., catchments where there was not consented IFLU) and where there was significant areas of IFLU with export coefficients in the calibrated model that are below the limits set by Table 14.2 of PPC2 (see Figure 2). This indicates that under the Proposed Year-20 Pathway A Scenario, some existing IFLU is assumed to increase its nitrogen leaching rate to the limit specified in Table 14.2.

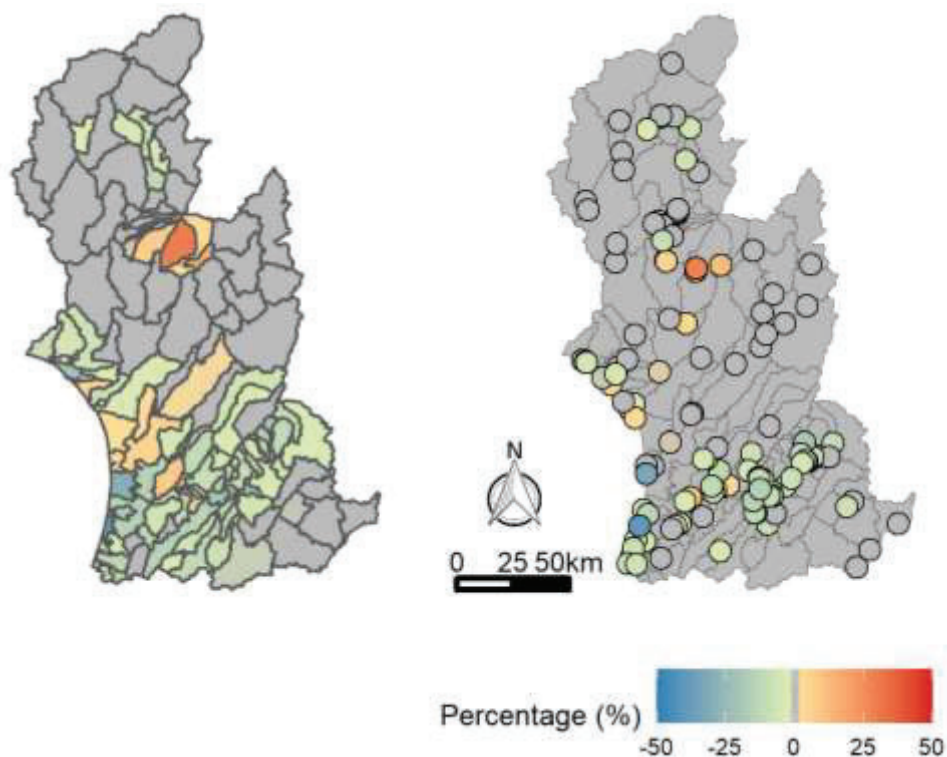


Figure 18. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway A Scenario and the Pre-regulation Scenario.

Compared to the Proposed Year-20 Consented Strict Scenario, SIN concentrations under the Proposed Year-20 Pathway A Scenario were higher at 32 (i.e., 26%) assessment points (Figure 19). The assessment points where SIN concentrations were higher tended to be downstream of target catchments. This indicates that the Proposed Year-20 Pathway A Scenario is less restrictive than the Proposed Consented Strict Scenario.

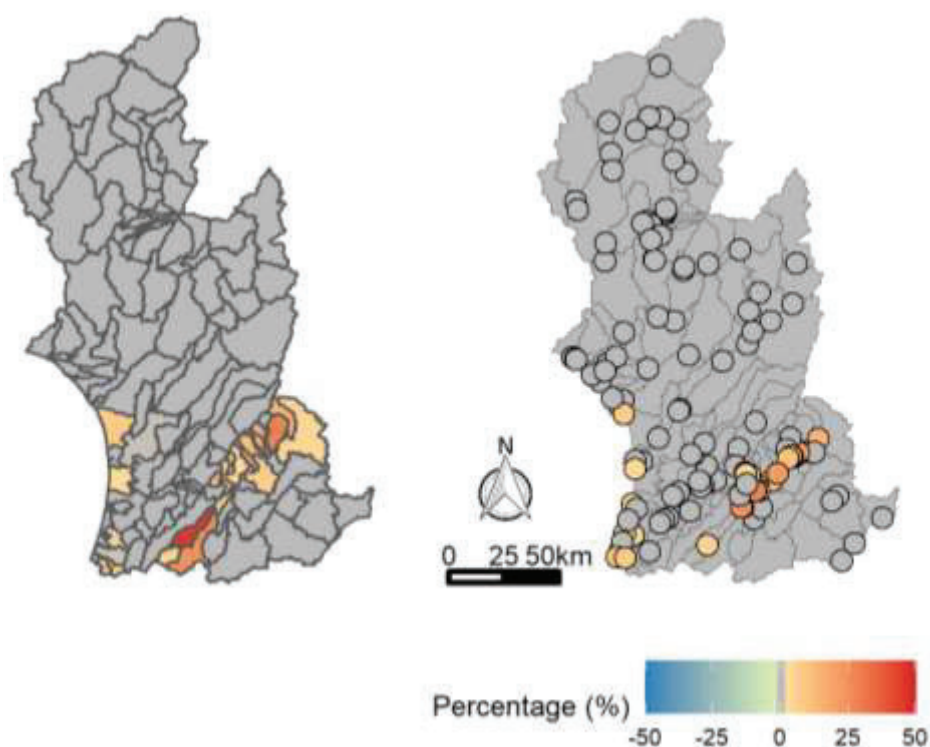


Figure 19. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway A Scenario and the Proposed Consented Strict Scenario.

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Year-20 Pathway D Scenario compared to the Proposed Year-20 Pathway A Scenario are shown in Figure 20. The Proposed Year-20 Pathway D Scenario assumes that non-consented, non-compliant dairy farms reduce their loss rates by 18 kg/ha/yr (whereas the Proposed Year-20 Pathway A Scenario assumes a reduction of 9 kg/ha/yr). Compared to the A Scenario, nitrogen export coefficients under the Proposed Year-20 Pathway D Scenario are lower in 8 (i.e., 6%) of WMSZs. Compared to the A Scenario, TN concentrations under the Proposed Year-20 Pathway D Scenario are predicted to be lower at 14 (i.e., 11%) assessment points.

Under the Proposed Year-20 Pathway D Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 99 of the 124 assessment points (Figure 20). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 77 and 47 assessment points, respectively.

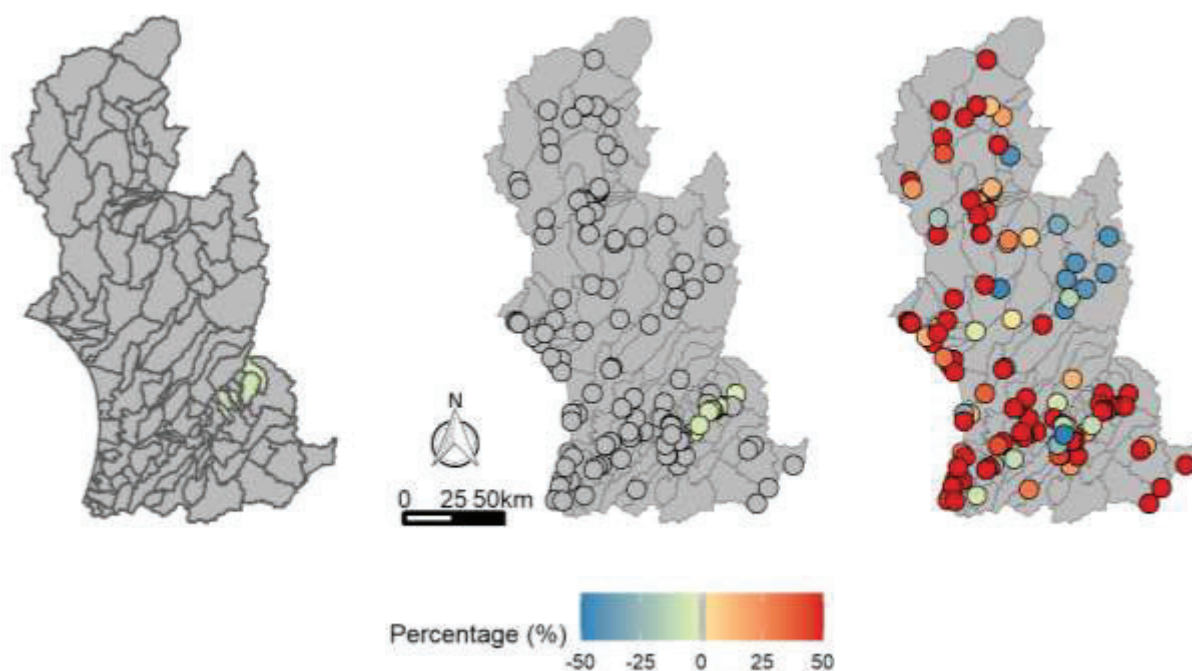


Figure 20. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Year-20 Pathway D Scenario. The changes shown on the left and centre maps were derived by comparing the Proposed Year-20 Pathway D Scenario with the Proposed Year-20 Pathway A Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Compared to the Pre-regulation Scenario, SIN concentrations under the Proposed Year-20 Pathway D Scenario were higher at 29 (i.e., 23%) assessment points and were lower at 81 (i.e., 65%) of assessment points (Figure 21). The assessment points where SIN concentrations were lower tended to be downstream of target catchments (Figure 21). The assessment points where SIN concentrations were higher tended to be downstream of non-target catchments (i.e., catchments where there was not consented IFLU) and where there was significant areas of IFLU with export coefficients in the calibrated model that are below that specified in Table 14.2 of PPC2 (see Figure 2). This indicates that under the Proposed Year-20 Pathway D Scenario, some existing IFLU (mainly outside of the target catchments) is assumed to increase its nitrogen leaching rate to the limit specified in Table 14.2.

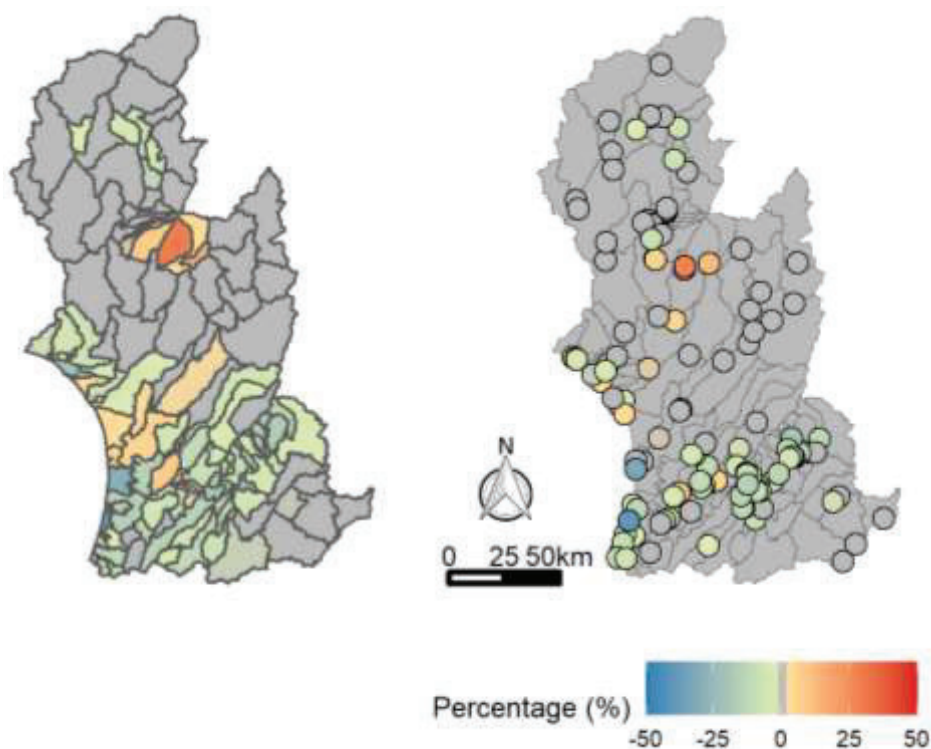


Figure 21. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations(right) between the Proposed Year-20 Pathway D Scenario and the Pre-regulation Scenario.

Compared to the Proposed Year-20 Consented Strict Scenario, SIN concentrations under the Proposed Year-20 Pathway D Scenario were higher at 32 (i.e., 26%) assessment points (Figure 22). The assessment points where SIN concentrations were higher tended to be downstream of target catchments. This indicates that the Proposed Year-20 Pathway D Scenario is less restrictive than the Proposed Year-20 Consented Strict Scenario.

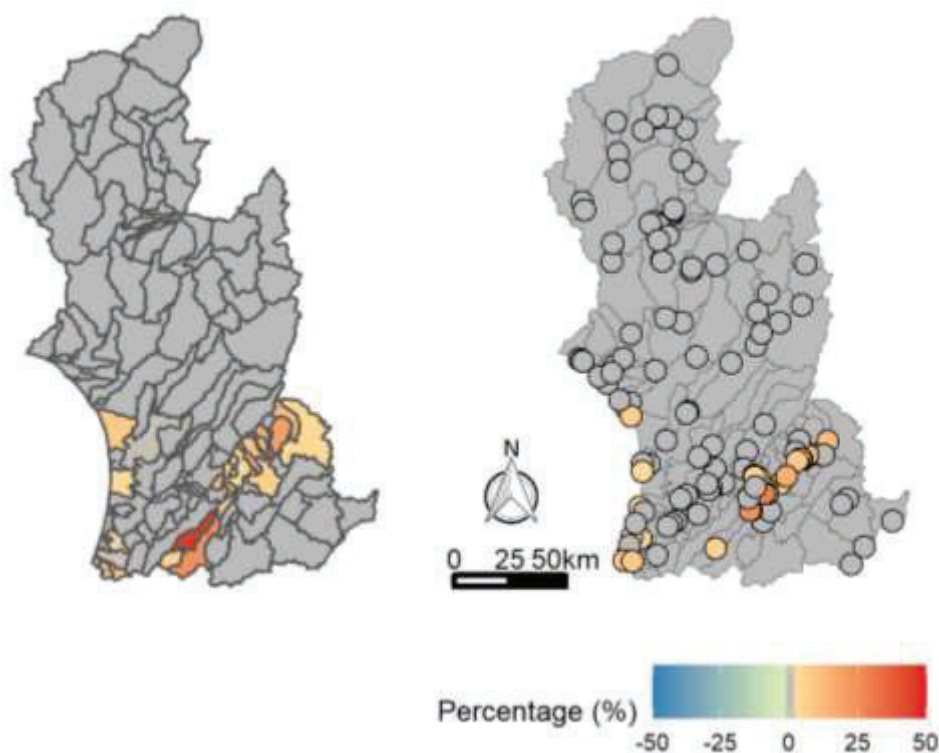


Figure 22. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway D Scenario and the Proposed Year-20 Consented Strict Scenario.

The Proposed Year-20 Pathway GMP Scenario and Proposed Year-20 Pathway BMP Scenarios simulate the impact at 20 years of implementing PPC2 with provision for discretionary consent pathways for both dairy farms and CVG. Comparison of these scenarios with the Operative Consented Scenario (Figure 23, Figure 24) indicates that WMSZ export coefficients and SIN concentrations at assessment points are higher than under the Operative Consented Scenario. This is an expected outcome because the recalibration of Table 14.2 for PC2 has increased allowable nitrogen leaching rates compared to the operative plan.

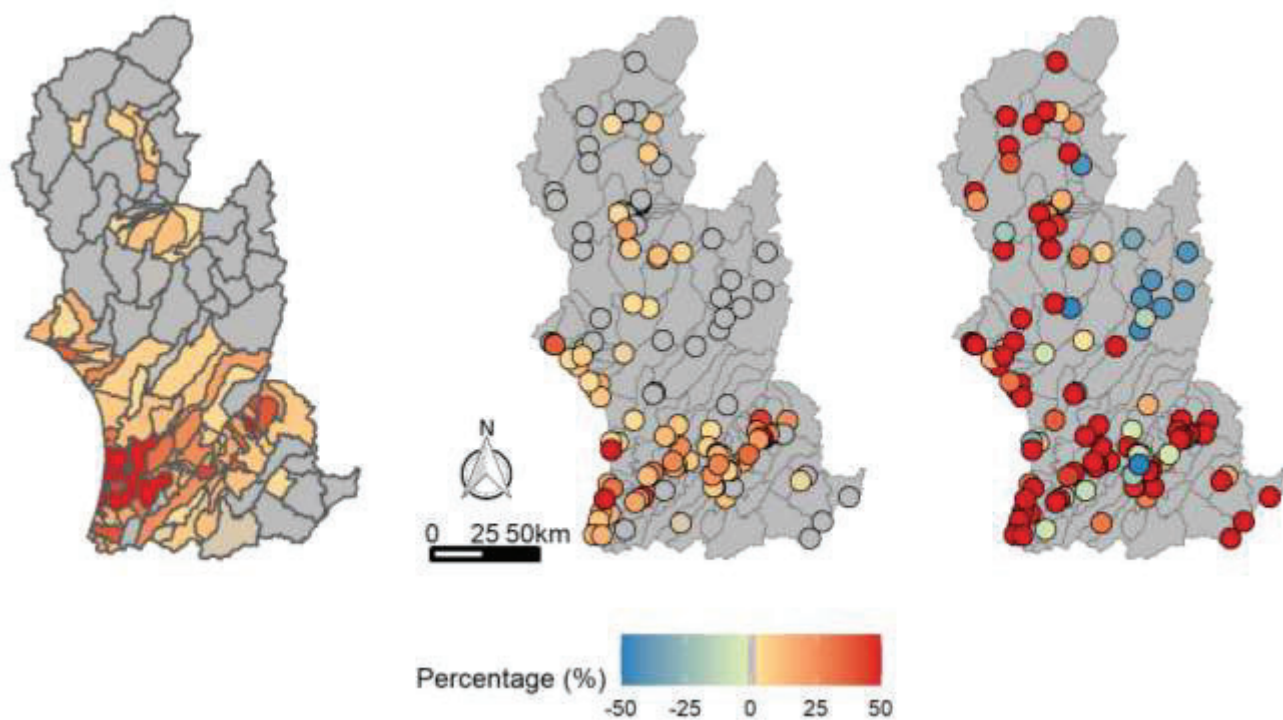


Figure 23. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway GMP Scenario and the Operative Consented Scenario.

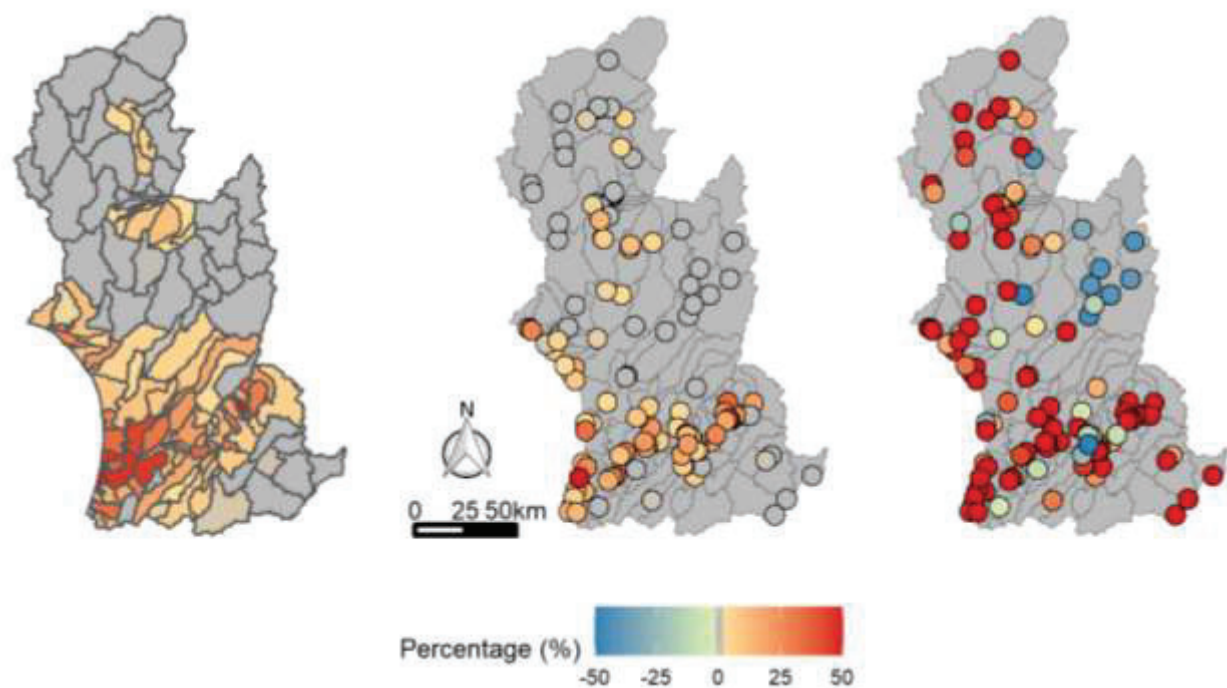


Figure 24. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway BMP Scenario and the Operative Consented Scenario.

Comparison of the Proposed Year-20 Pathway GMP Scenario and Proposed Year-20 Pathway BMP Scenarios with the Proposed Consented Scenario are shown on Figure 25 and Figure 26. The comparison indicates that WMSZ export coefficients and SIN concentrations at assessment points are slightly higher than under the Proposed Consented Scenario. This is an expected outcome because the consent pathway option under PPC2 allows higher nitrogen leaching rates than PPC2 Table 14.2.

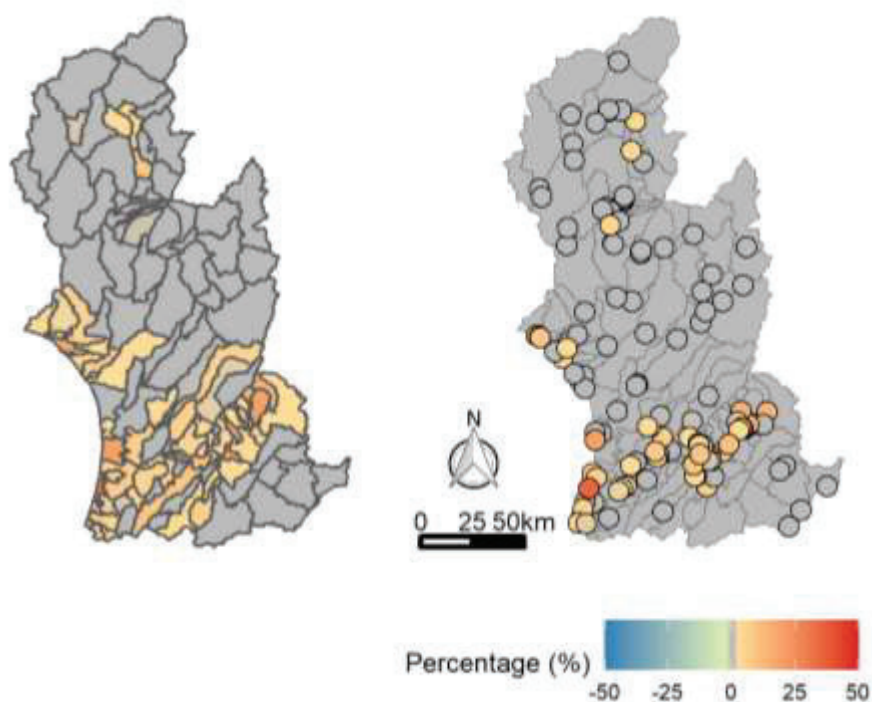


Figure 25. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway GMP Scenario and the Proposed Consented Scenario.

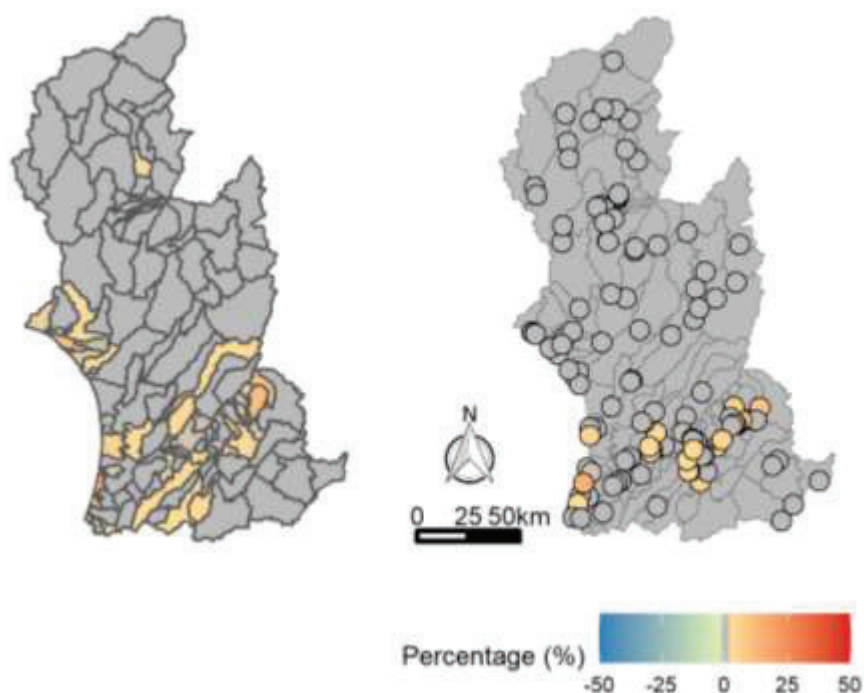


Figure 26. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway BMP Scenario and the Proposed Consented Scenario.

Comparison of the Proposed Year-20 Pathway GMP Scenario with the Proposed Year-20 Pathway A is shown in Figure 27 and comparison of the Proposed Year-20 Pathway BMP Scenario with the Proposed Year-20 Pathway D is shown in Figure 28. The comparisons indicate that WMSZ export coefficients and SIN concentrations at assessment points are slightly higher than under the GMP and BMP scenarios compared to their comparators. This is an expected outcome because the GMP and BMP scenarios allow higher nitrogen leaching rates for CVG to than the comparator scenarios.

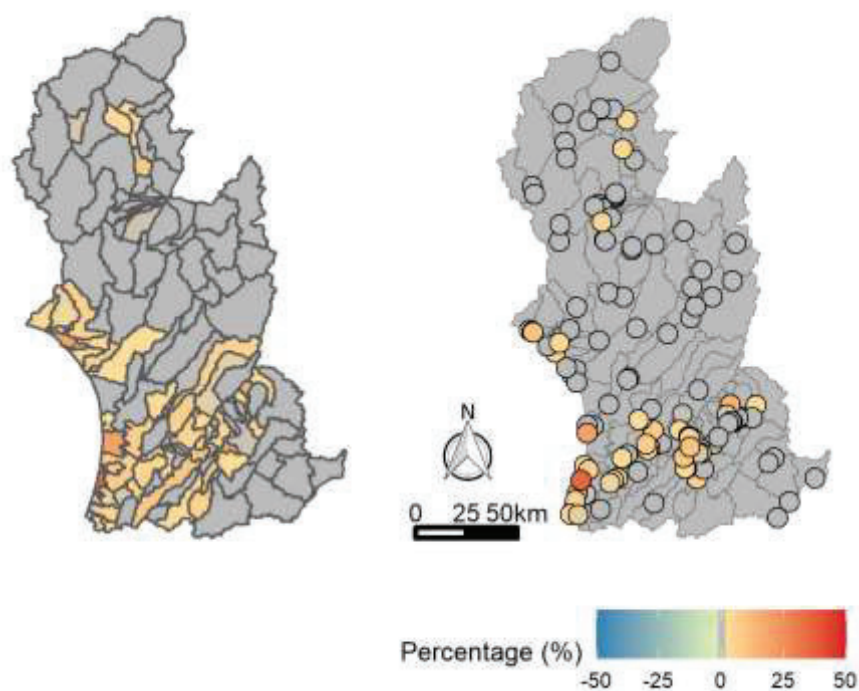


Figure 27. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway GMP Scenario and the Proposed Year-20 Pathway A Scenario.

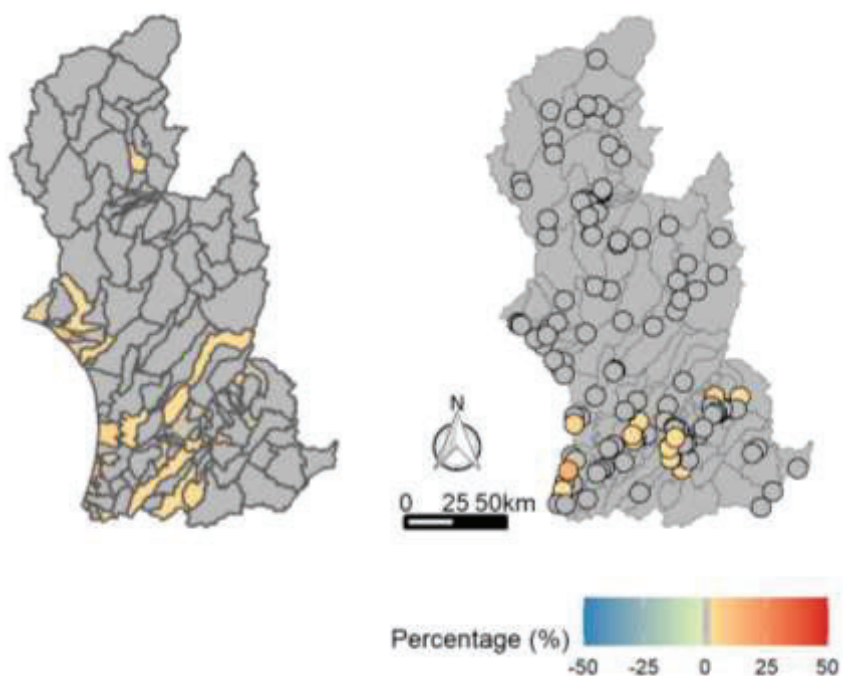


Figure 28. Percentage difference in nitrogen export coefficient (left) and percentage difference in river SIN concentrations (right) between the Proposed Year-20 Pathway BMP Scenario and the Proposed Year-20 Pathway D Scenario.

The results of the Proposed Year-20 Pathway GMP and Point Sources Scenario and the Proposed Year-20 Pathway BMP and Point Sources Scenario are not reported here but are summarised in the summary and conclusion section of this report. These scenarios represent the combination of implementation of PC2 with discretionary consent pathways (the scenarios described immediately above) with the changes to significant point source contributions of nitrogen across the Region between 2012 and 2017.

4.4.3 Proposed Year-5 Pathway Scenarios

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Year-5 Pathway A Scenario compared to Proposed Year-20 Pathway A Scenario are shown in Figure 29. The Proposed Year-5 Pathway A Scenario represents the year 5 outcome of implementing the Proposed Plan (i.e., as proposed by PPC2) with provision for discretionary consent pathways for non-consented and non-compliant dairy farms. The A Scenario assumes that non-consented, non-compliant properties reduce their loss rates by 9 kg/ha/yr. It is noted that farms pertaining to this scenario are limited to a sample of properties within the “target” water management sub zones as shown in Figure 4.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Proposed Year-5 Pathway A Scenario are the same or higher than the Proposed Year-20 Pathway A Scenario. Compared to the Proposed Year-20 Pathway A Scenario, nitrogen export coefficients under the Proposed Year-5 Pathway A Scenario are greater in 76 (i.e., 61%) of WMSZs. Compared to the Proposed Year-20 Pathway A Scenario, SIN concentrations under the Proposed Year-5 Pathway A Scenario were predicted to be higher at 98 (i.e., 79%) assessment points. In comparison to the Proposed Year-20 Pathway A Scenario, nitrogen export coefficients and predicted SIN concentrations are higher because the Proposed Year-5 Pathway A Scenario is based on the assumption of compliance with the year 5 nitrogen leaching rates in Table 14.2, which are higher than the rates for year 20.

Under the Proposed Year-5 Pathway A Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 100 of the 124 assessment points (Figure 29). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 76 and 47 assessment points, respectively.

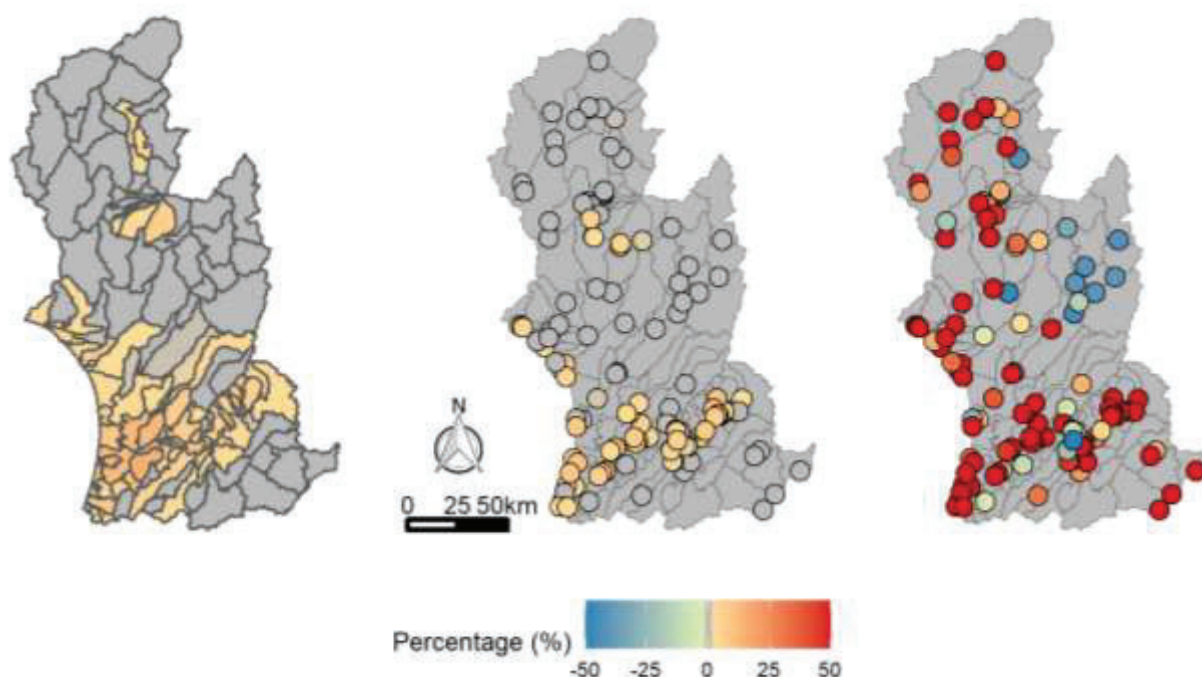


Figure 29. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Year-5 Pathway A Scenario. The differences shown on the left and centre maps were derived by comparing the Proposed Year-5 Pathway A Scenario with the Proposed Year-20 Pathway A Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Year-5 Pathway D Scenario compared to the Proposed Year-20 Pathway D Scenario are shown in Figure 30. The D Scenario is based on the assumption that non-consented, non-compliant properties reduce their estimated loss rates by 18 kg/ha/yr. It is noted that farms pertaining to this scenario are limited to a sample of properties within the “target” water management sub zones as shown in Figure 2.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Proposed Year-5 Pathway D Scenario are the same or higher than the Proposed Year-20 Pathway D Scenario (Figure 30). Compared to the Proposed Year-20 Pathway D Scenario, predicted SIN concentrations under the Proposed Year-5 Pathway D Scenario are higher at 98 (i.e., 79%) assessment points. This occurs because the Proposed Year-5 Pathway D Scenario is based on an assumption of compliance with the year 5 nitrogen leaching rates in Table 14.2, which are higher than the rates for year 20.

Under the Proposed Year-5 Pathway D Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 99 of the 124 assessment points (Figure 30). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 89, 76 and 46 assessment points, respectively.

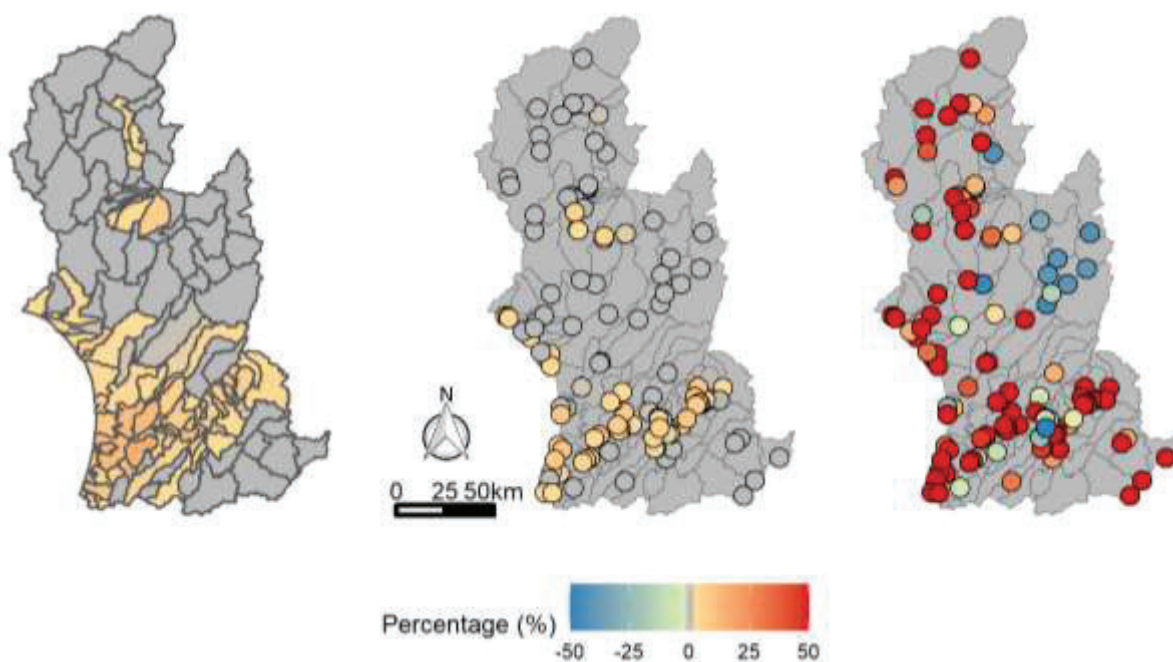


Figure 30. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Year-5 Pathway D Scenario. The differences shown on the left and centre maps were derived by comparing the Proposed Year-5 Pathway D Scenario with the Proposed Year-20 Pathway D Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.4.4 Proposed Consented Strict Scenario

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Proposed Consented Strict Scenario compared to the Proposed Consented Year-20 Scenario are shown in Figure 31. The Proposed Consented Strict Scenario represents the year 20 outcome of implementing the Proposed Plan (i.e., PPC2) Table 14.2 with no provision for a discretionary activity consent pathway and with strict adherence to the current consent where the consented nitrogen leaching rate is less than Table 14.2. Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Proposed Year-20 Consented Strict Scenario are the same or less than the Proposed Consented Year-20 Scenario (Figure 31). Compared to the Proposed Consented Year-20 Scenario, nitrogen export coefficients under the Proposed Consented Strict Scenario are lower in 24 (i.e., 19%) WMSZs. Compared to the Proposed Consented Year-20 Scenario, SIN concentrations under the Proposed Consented Strict Scenario are predicted to lower at 32 (i.e., 26%) assessment points.

Under the Proposed Consented Strict Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 97 of the 124 assessment points (Figure 31). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 86, 73 and 45 assessment points, respectively.

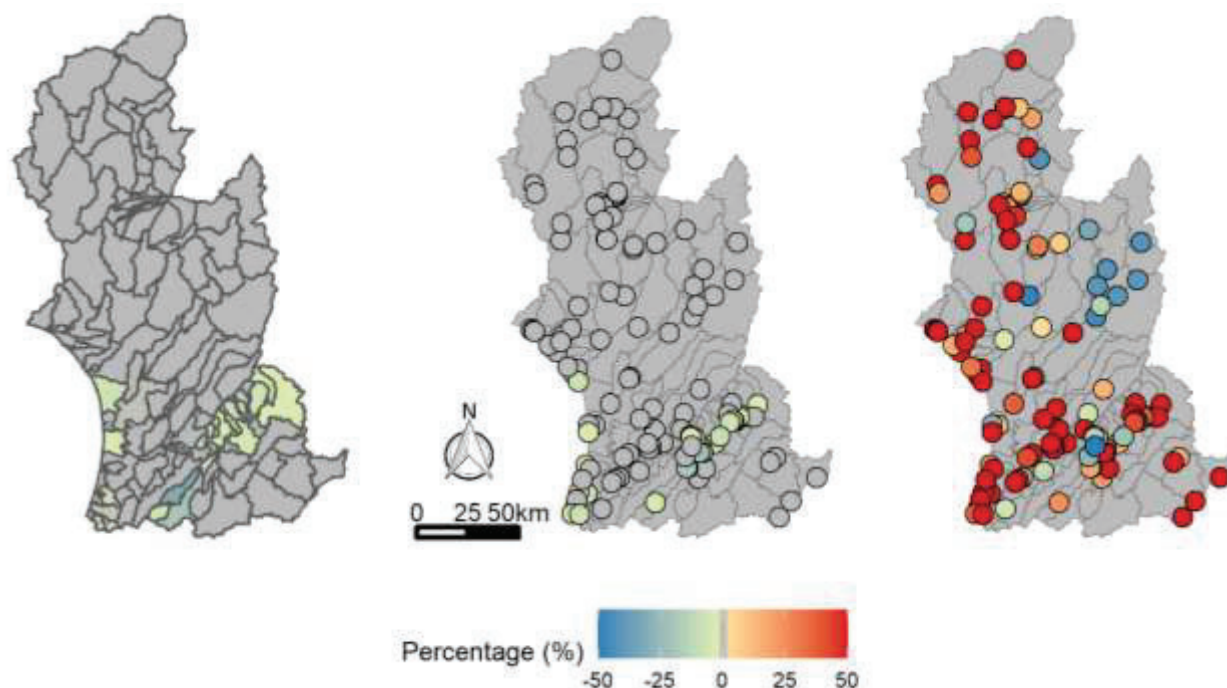


Figure 31. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Proposed Consented Strict Scenario. The changes shown on the left and centre maps were derived by comparing the Proposed Consented Strict Scenario with Proposed Consented Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.5 Additional scenarios

4.5.1 Natural State Scenario

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Natural State Scenario compared to the Calibrated Model Simulation are shown in Figure 32. the Natural State Scenario represents the outcome of removing all anthropogenic land use from the region and all point sources of nitrogen.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Natural State Scenario are the same or less than the Calibrated Model Simulation (Figure 32). Compared to the Calibrated Model Simulation, nitrogen export coefficients under the Natural State Scenario are predicted to be lower in 123 (i.e., 99%) WMSZs. Compared to the model baseline simulation, SIN concentrations under Scenario 7 are predicted to be lower or the same at 124 (i.e., 100%) assessment points.

Under the Natural State Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 13 of the 124 assessment points (Figure 32). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 12, 2 and zero assessment points, respectively.

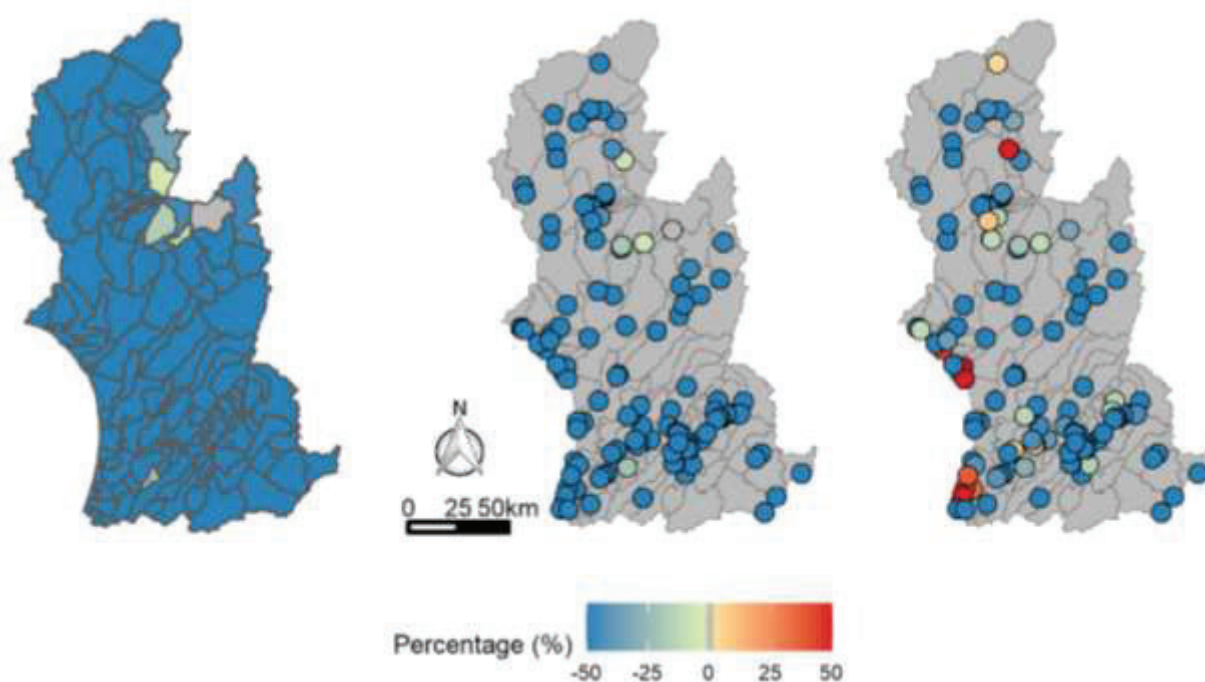


Figure 32. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Natural State Scenario. The differences shown on the left and centre maps were derived by comparing the Natural State Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.5.2 Dairy Sector Pathway Scenarios

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Dairy Sector Pathway A Scenario compared to the Proposed Consented Year-20 Scenario are shown in Figure 33. The Dairy Sector Pathway A Scenario represents an alternative approach to restricting the leaching rates for the 70 Known Unconsented-dairy farms that are represented in the HRC database.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Dairy Sector Pathway A Scenario are the same or greater than the Proposed Consented Year-20 Scenario (Figure 33). Compared to the Proposed Consented Scenario, nitrogen export coefficients under the Dairy Sector Pathway Scenario are predicted to be higher in 9 (i.e., 7%) WMSZs. This is an expected result because the Dairy Sector Pathway A Scenario is slightly less stringent than the PPC2 Table 14.2 requirements. Compared to the Proposed Consented Scenario, SIN concentrations under the Dairy Sector Pathway A Scenario are predicted to be greater at 17 (i.e., 11%) assessment points.

Under the Dairy Sector Pathway A Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 98 of the 124 assessment points (Figure 33). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 85, 72 and 34 assessment points, respectively.

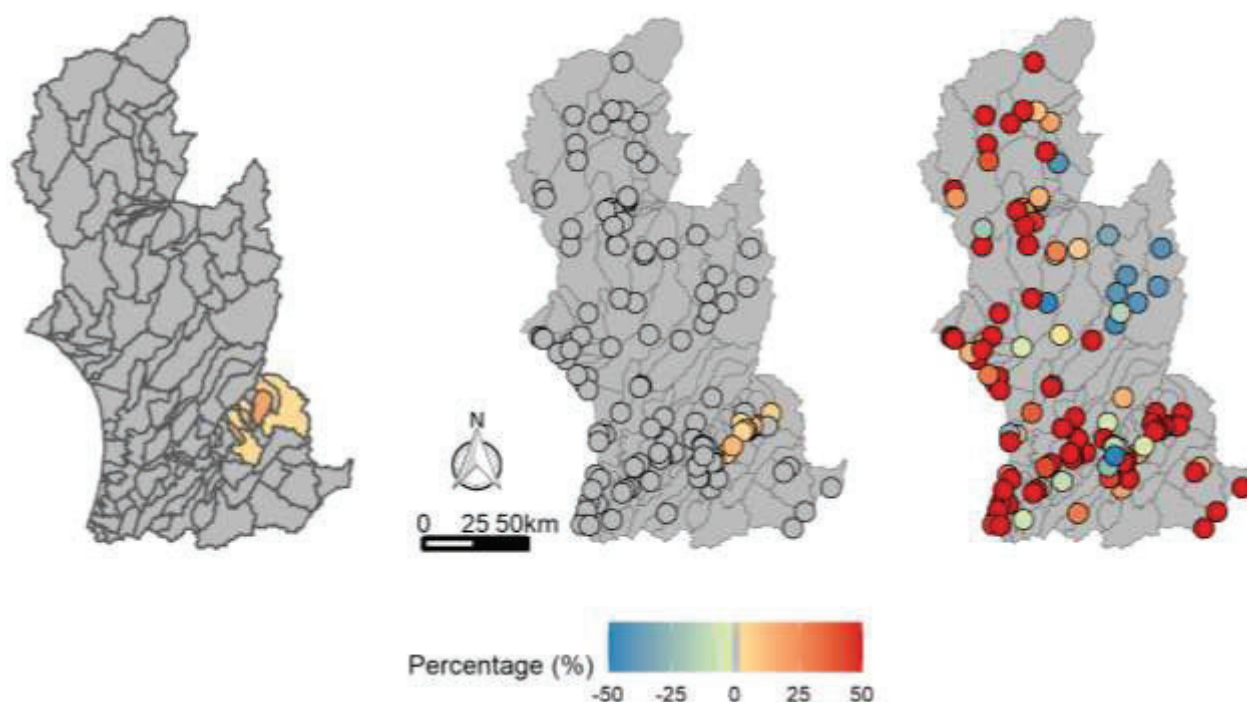


Figure 33. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Dairy Sector Pathway A Scenario. The differences shown on the left and centre maps were derived by comparing the Dairy Sector Pathway A Scenario with the Proposed Consented Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Compared to the Proposed Year-20 Pathway A Scenario, nitrogen export coefficients under the Dairy Sector Pathway A Scenario were higher in some WMSZs and lower in others (Figure 34). This outcome is due to the differences in leaching rate reduction requirements implied by the two pathways.

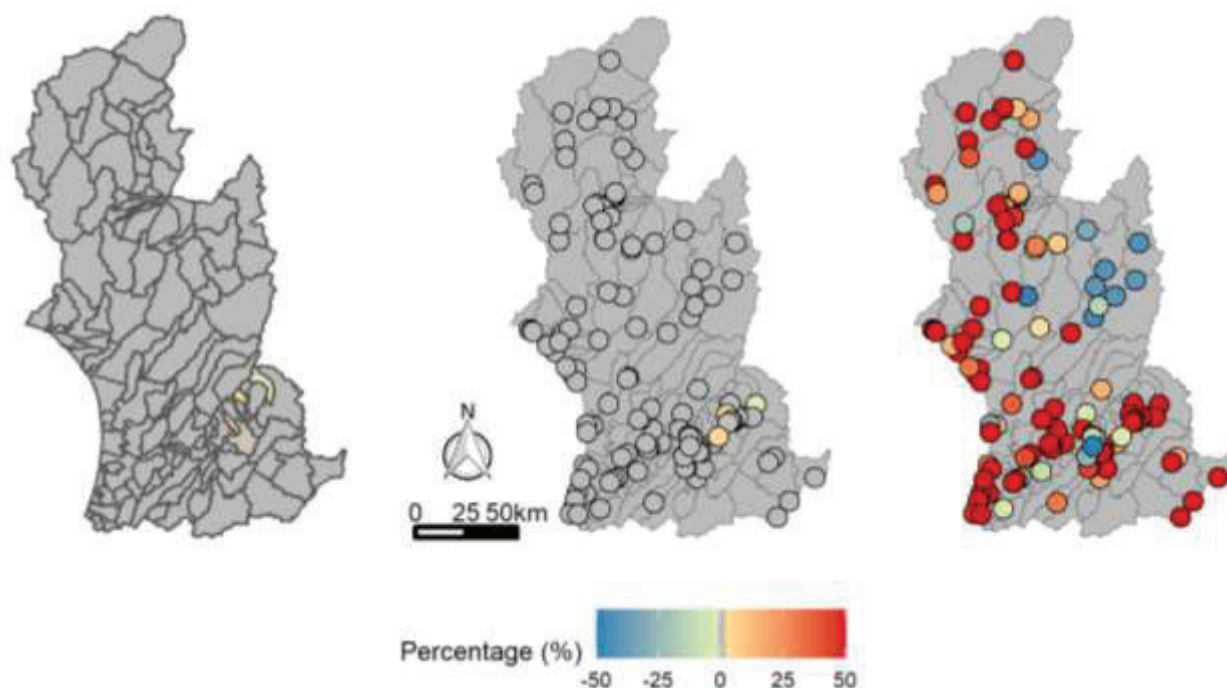


Figure 34. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Dairy Sector Pathway A Scenario. The differences shown on the left and centre maps were derived by comparing the Dairy Sector Pathway A Scenario with the Proposed Year-20 Pathway A Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

When the Dairy Sector Pathway Scenario was generalised to all dairy farms within water management zones that were represented by farms in the HRC database (i.e., the Dairy Sector Pathway B Scenario), one additional WMSZ (i.e., total of 10 WMSZ) had higher export coefficients than the Proposed Consented scenario (Figure 35). Compared to the Proposed Consented Scenario, SIN concentrations under the Dairy Sector Pathway B Scenario are predicted to be greater at 18 (i.e., 12%) assessment points.

Under the Dairy Sector Pathway B Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 99 of the 124 assessment points (Figure 35). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 85, 72 and 34 assessment points, respectively.

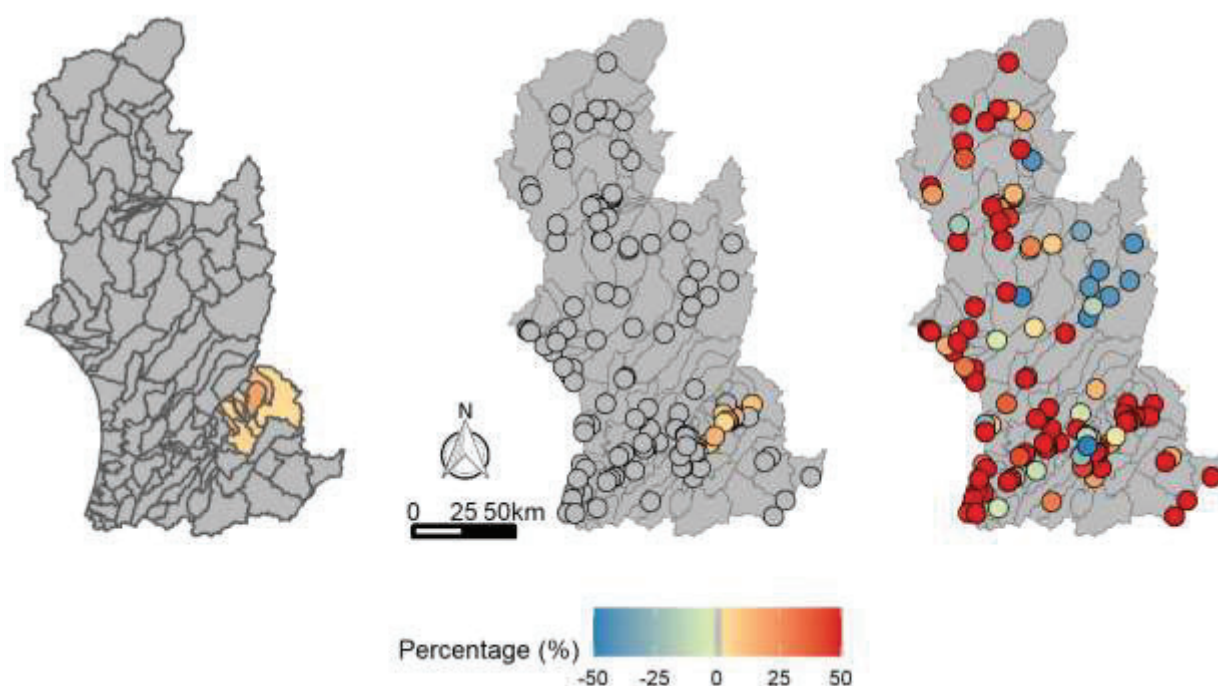


Figure 35. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Dairy Sector Pathway B Scenario. The differences shown on the left and centre maps were derived by comparing the Dairy Sector Pathway B Scenario with the Proposed Consented Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

Compared to the Proposed Year-20 Pathway D Scenario, nitrogen export coefficients under the Dairy Sector Pathway D Scenario were higher WMSZs (Figure 36). This outcome is due to the differences in leaching rate reduction requirements implied by the two pathways.

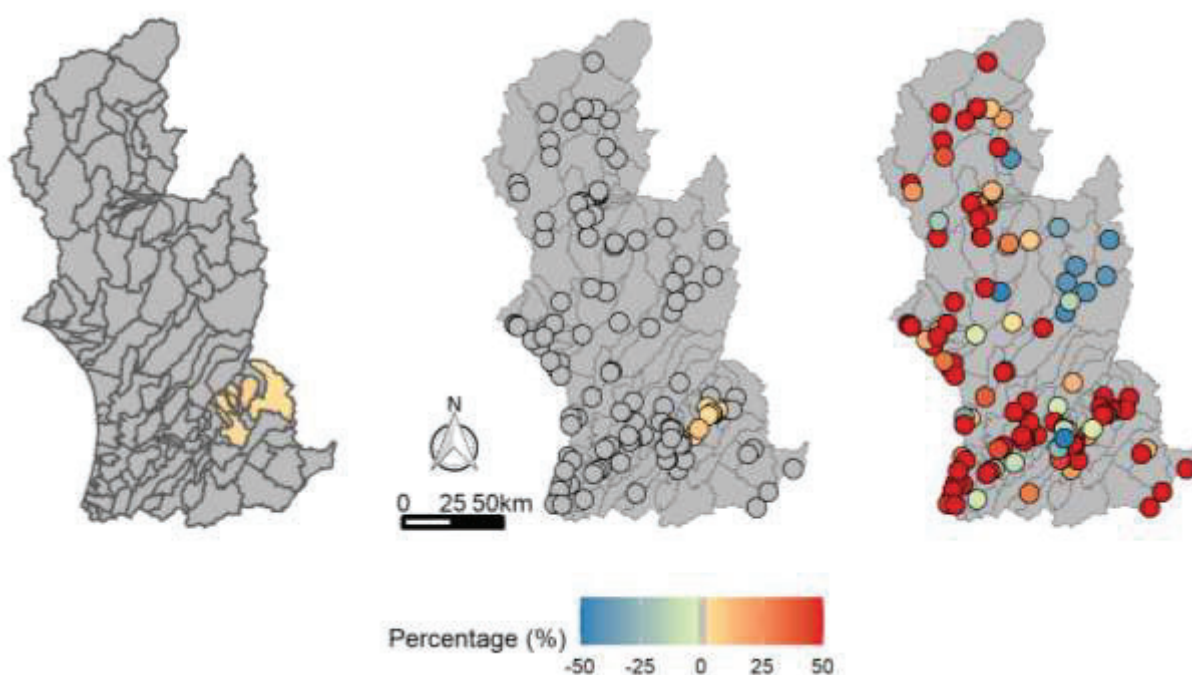


Figure 36. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Dairy Sector Pathway D Scenario. The differences shown on the left and centre maps were derived by comparing the Dairy Sector Pathway D Scenario with the Proposed Year-20 Pathway D Scenario. Negative percentages on the right map indicate achievement of the water quality state target and vice versa

4.5.3 Horticulture Expansion Scenarios

The change in the nitrogen export coefficients and resulting river SIN concentrations under the Horticulture Expansion A Scenario compared to the Calibrated Model Simulation are shown in Figure 37. The Horticulture Expansion Scenarios (comprising Scenario A and B) represent the water quality outcome of increasing commercial vegetable growing across the region.

Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Horticulture Expansion A Scenario are the same or greater than the Calibrated Model Simulation. Compared to the Calibrated Model Simulation, nitrogen export coefficients under the Horticulture Expansion A Scenario are predicted to increase in 113 (i.e., 91%) WMSZs. Compared to the Calibrated Model Simulation, SIN concentrations under the Horticulture Expansion A Scenario are predicted to be greater at 120 (i.e., 97%) assessment points.

Under the Horticulture Expansion A Scenario, predicted concentrations of SIN do not achieve the One Plan targets at 104 of the 124 assessment points (Figure 37). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 92, 79 and 49 assessment points, respectively.

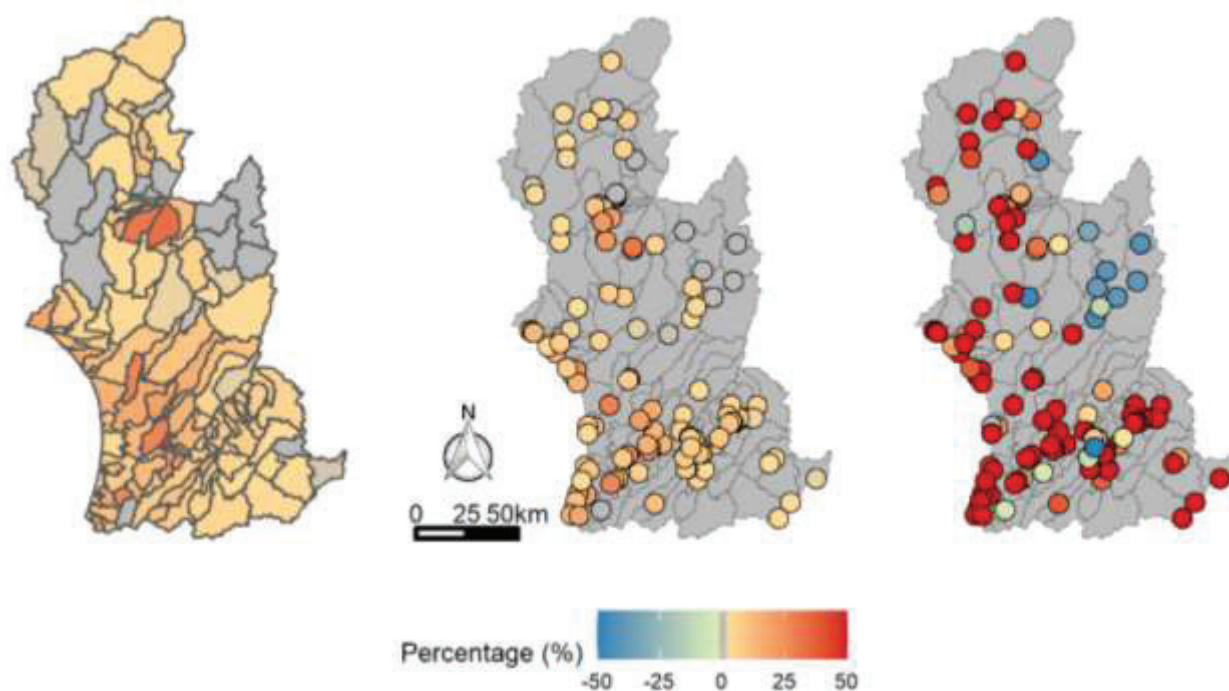


Figure 37. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Horticulture Expansion A Scenario. The differenced shown on the left and centre maps were derived by comparing the Horticulture Expansion A Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Horticulture Expansion B Scenario compared to the Calibrated Model Simulation are shown in Figure 38. Nitrogen export coefficients in all WMSZs and SIN concentrations at all assessment points under the Horticulture Expansion B Scenario are the same or greater than the Calibrated Model Simulation. Compared to the Calibrated Model Simulation, nitrogen export coefficients under the Horticulture Expansion B Scenario are predicted to increase in 116 (i.e., 94%) WMSZs. Compared to the Calibrated Model Simulation, SIN concentrations under the Horticulture Expansion B Scenario are predicted to be greater at 121 (i.e., 98%) assessment points.

Under the Horticulture Expansion B Scenario, predicted concentrations of SIN do not achieve the One Plan targets in 105 of the 124 assessment points (Figure 38). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 93, 81 and 50 assessment points, respectively.

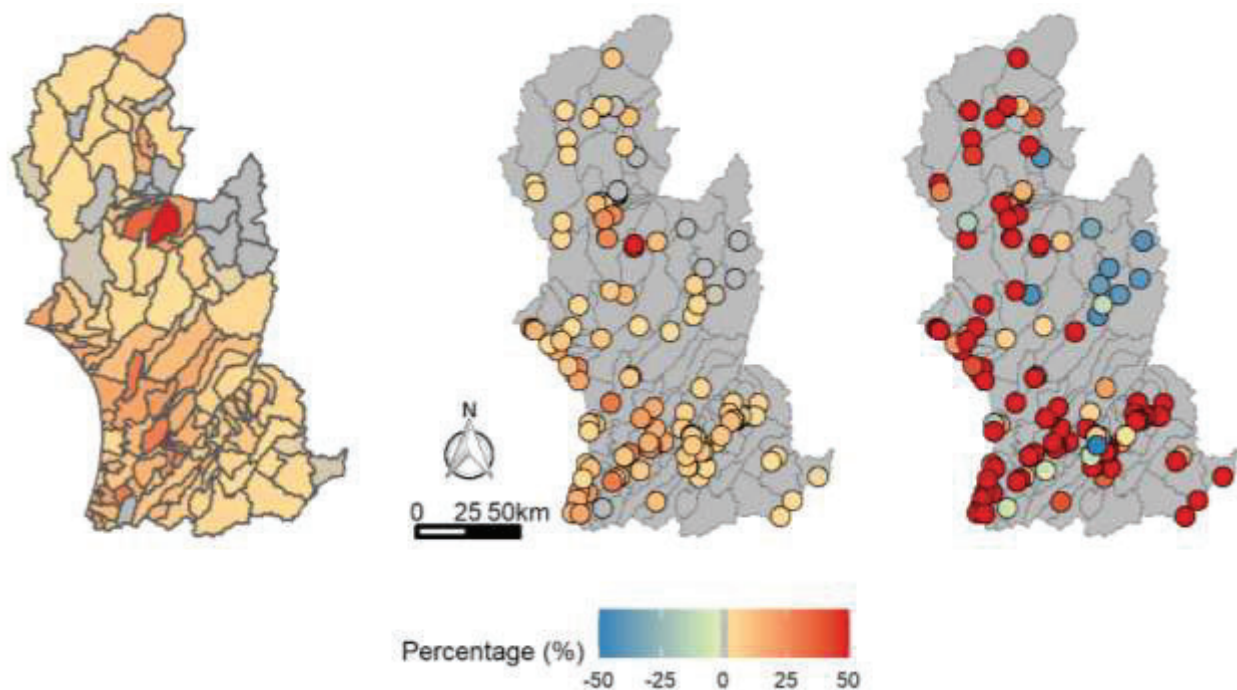


Figure 38. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Horticulture Expansion B Scenario. The differences shown on the left and centre maps were derived by comparing the Horticulture Expansion B Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

4.5.4 Potato Expansion Scenarios

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Potato Expansion A Scenario compared to the Calibrated Model Simulation are shown in Figure 39. The Potato Expansion Scenarios (comprising Scenario A, B and C) represent the water quality outcome of increasing commercial potato growing across the region.

Nitrogen export coefficients in WMSZs and SIN concentrations at assessment points variously increased and decreased under the Potato Expansion A Scenario compared to the Calibrated Model Simulation. Compared to the Calibrated Model Simulation, SIN concentrations under the Potato Expansion A Scenario are predicted to be higher at 102 (i.e., 82%) assessment points and lower at 10 (i.e., 15%) assessment points (Figure 39).

Under the Potato Expansion A Scenario, predicted concentrations of SIN do not achieve the One Plan targets at 98 of the 124 assessment points (Figure 39). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 79, 67 and 48 assessment points, respectively.

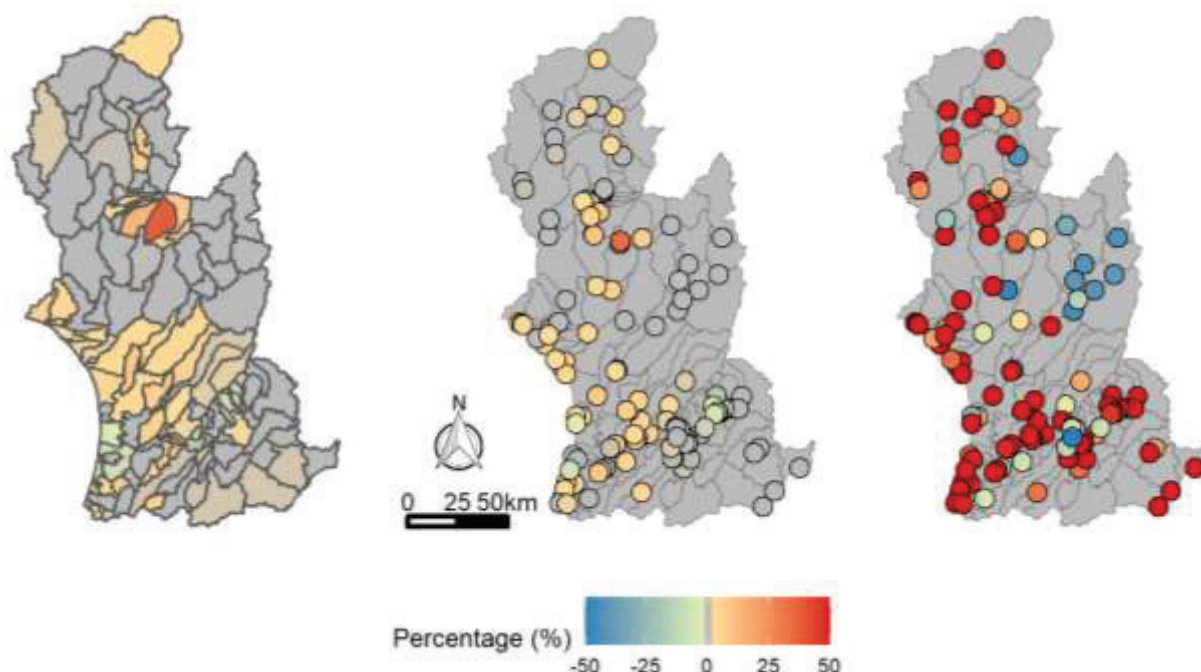


Figure 39. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Potato Expansion A Scenario. The differences shown on the left and centre maps were derived by comparing the Potato Expansion A Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Potato Expansion B Scenario compared to the Calibrated Model Simulation are shown in Figure 40. Nitrogen export coefficients in WMSZs and SIN concentrations at assessment points variously increased and decreased under the Potato Expansion B Scenario compared to the Calibrated Model Simulation. Compared to the Calibrated Model Simulation, SIN concentrations under the Potato Expansion B Scenario are predicted to be higher at 22 (i.e., 18%) assessment points and lower at 98 (i.e., 79%) of assessment points (Figure 40).

Under the Potato Expansion B Scenario, predicted concentrations of SIN do not achieve the One Plan targets at 95 of the 124 assessment points (Figure 40). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 88, 77 and 47 assessment points, respectively.

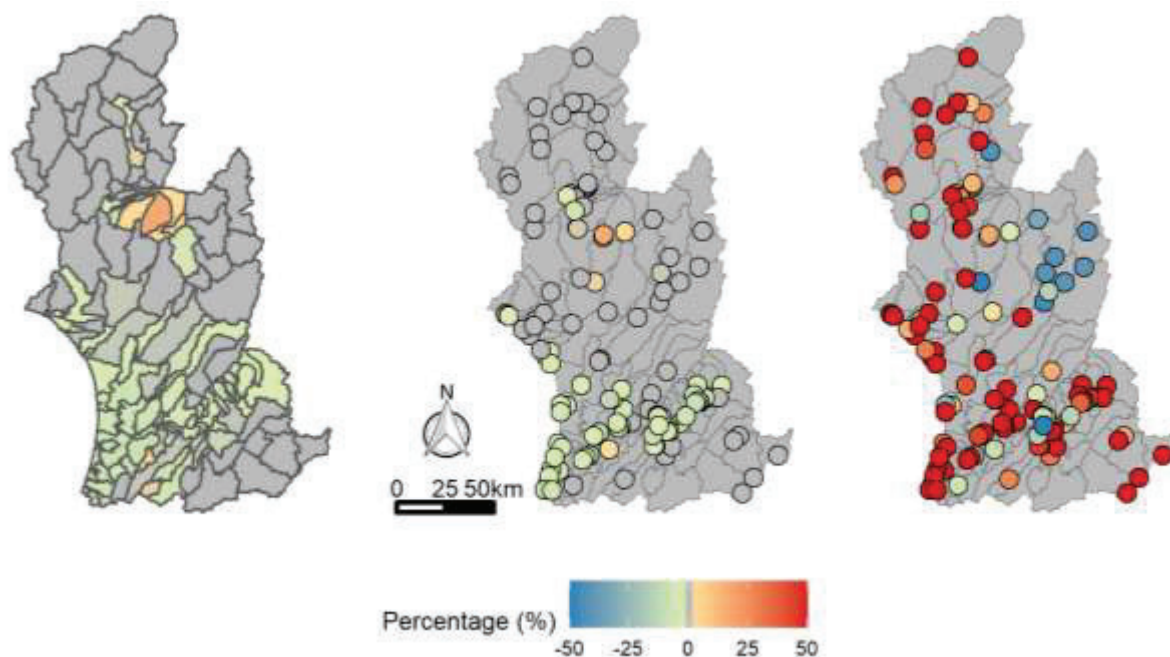


Figure 40. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Potato Expansion B Scenario. The differences shown on the left and centre maps were derived by comparing the Potato Expansion B Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

The difference in the nitrogen export coefficients and resulting river SIN concentrations under the Potato Expansion C Scenario compared to the Calibrated Model Simulation are shown in Figure 41. Nitrogen export coefficients in WMSZs and SIN concentrations at assessment points variously increased and decreased under the Potato Expansion C Scenario compared to the Calibrated Model Simulation. Compared to the Calibrated Model Simulation, SIN concentrations under the Potato Expansion C Scenario are predicted to be higher at 7 (i.e., 6%) assessment points and lower at 113 (i.e., 91%) of assessment points (Figure 41).

Under the Potato Expansion C Scenario, predicted concentrations of SIN do not achieve the One Plan targets at 95 of the 124 assessment points (Figure 41). Predicted concentrations of SIN exceed the target by more than 10%, 20% and 50% at 87, 76 and 46 assessment points, respectively.

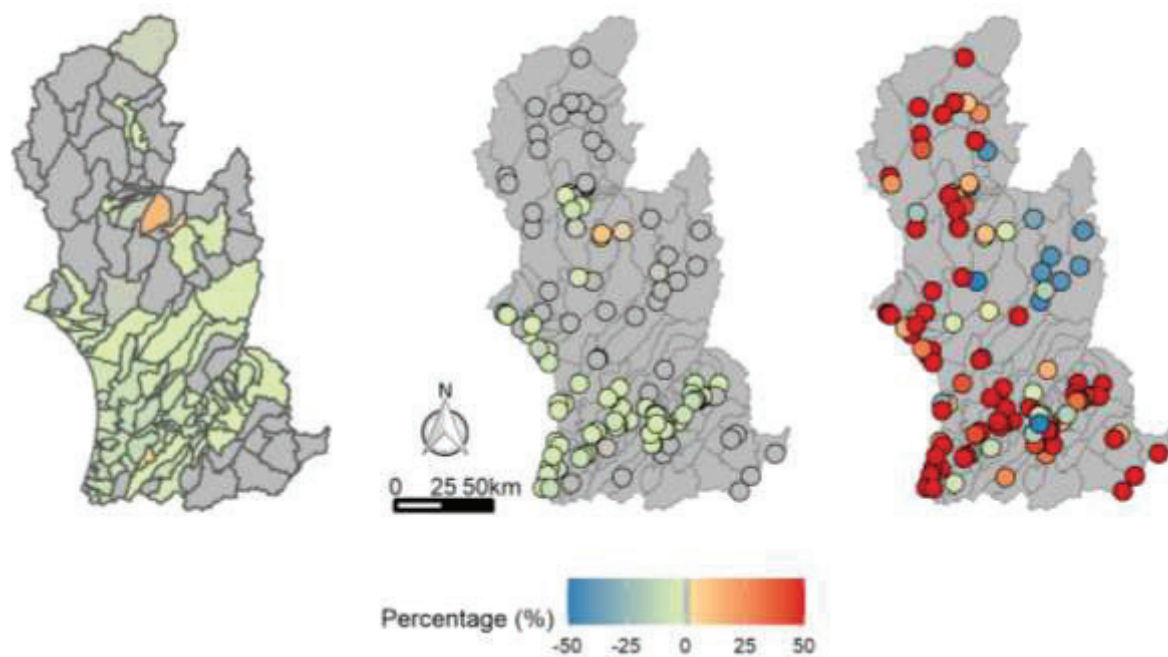


Figure 41. Percentage difference in nitrogen export coefficient (left), percentage difference in river SIN concentrations (centre) and percentage difference between predicted SIN concentration and SIN target (right) for the Potato Expansion C Scenario. The differences shown on the left and centre maps were derived by comparing the Potato Expansion C Scenario with the Calibrated Model Simulation. Negative percentages on the right map indicate achievement of the water quality state target and vice versa.

5 Summary and conclusions

The results of water quality impact simulations for all scenarios and all assessment points (i.e., region-wide) are summarised in Table 2 and are summarised for assessment points downstream of Target Catchments in Table 3.

Table 2 Summary of achievement of One Plan SIN targets at the 124 region-wide assessment points. The mean relative difference indicates the mean percentage amount by which the predicted concentration at assessment points deviate from the target. Positive values indicate the predicted SIN concentration exceeds the target (i.e., the objective is not achieved). The rows in the table are colour coded to reflect the four groups of scenarios: Historical Simulations, Operative Plan Scenarios, Proposed Plan Scenarios and Additional Scenarios.

Scenario	No. of points that do not achieve the target (% in brackets)	Mean relative difference (%)
Calibrated Model (2012)	96 (77%)	30
Pre-regulation (2012)	97 (78%)	31
Point Sources	95 (76%)	29
Post-regulation A	97 (78%)	30
Post-regulation B	96 (77%)	29
Horticulture Mitigation A	96 (77%)	30
Horticulture Mitigation B	96 (77%)	30
Operative Year-20	90 (73)	22
Operative Year-20 Consented	95 (76%)	24
Operative Year-20 Expansion	95 (76%)	22
Proposed Consented	97 (78%)	28
Proposed Year-20 Pathway A	98 (79%)	29
Proposed Year-20 Pathway D	98 (79%)	29
Proposed Year-20 Pathway GMP	98 (79%)	30
Proposed Year-20 Pathway BMP	98 (79%)	29
Proposed Year-20 Pathway GMP + point sources	96 (77%)	29
Proposed Year-20 Pathway BMP + point sources	96 (77%)	28
Proposed Year-5 Pathway A	100 (81%)	30
Proposed Year-5 Pathway D	99 (80%)	30
Proposed Consented Strict	97 (78%)	27
Natural State	13 (10%)	-294
Dairy Sector Pathway A	98 (79%)	23
Dairy Sector Pathway B	99 (80%)	23
Horticulture Expansion A	104 (84%)	33
Horticulture Expansion B	105 (85%)	34
Potato Expansion A	98 (79%)	31
Potato Expansion B	95 (76%)	29
Potato Expansion C	95 (76%)	28

The region-wide results indicate that the SIN concentrations predicted by the Calibrated Model Simulation and the Pre-regulation Simulation exceed the One Plan targets at a large majority of assessment points (i.e., $\geq 77\%$; Table 2). In addition, for these two simulations on average, assessment points have SIN concentrations that are 30% higher than the target (Table 2). These two historic simulations represent the estimated water quality conditions in 2012 prior to regulation of nitrogen leaching from IFLU.

The Calibrated Model and the Pre-regulation Simulations indicate that SIN concentrations at assessment points downstream of the Target Catchments exceed the One Plan targets at a large majority of assessment points (i.e., $\geq 89\%$; Table 3). In addition, in 2012, prior to regulation of nitrogen leaching from IFLU, assessment points downstream of the Target Catchments have SIN concentrations that are, on average, $\geq 42\%$ higher than One Plan targets.

Region-wide, the majority of scenarios produce only small changes in the water quality state Compared to the Calibrated Model Simulation. In general, the group of Operative One Plan scenarios produce the most notable improvements. All the Operative One Plan scenarios represent improvements to water quality outcomes; there are small improvements in the number of assessment points that exceed the One Plan targets, but significant improvements in the mean relative difference (i.e., the average amount by which SIN concentrations exceed the target at assessment sites).

Table 3. Summary of achievement of One Plan SIN targets at Target Catchment assessment points. Note that there are a total of 35 assessment points that are downstream of the Target Catchments. The details for this table are identical to Table 2 above.

Scenario	No. of points that do not achieve the target (% in brackets)	Mean relative difference (%)
Calibrated Model (2012)	31 (89%)	42
Pre-regulation (2012)	32 (91%)	45
Point Sources	30 (86%)	40
Post-regulation A	32 (91%)	43
Post-regulation B	31 (89%)	42
Horticulture Mitigation A	31 (89%)	42
Horticulture Mitigation B	31 (89%)	42
Operative Year-20	24 (69%)	24
Operative Year-20 Consented	29 (83%)	34
Operative Year-20 Expansion	29 (83%)	25
Proposed Consented	29 (83%)	40
Proposed Year-20 Pathway A	30 (86%)	41
Proposed Year-20 Pathway D	30 (86%)	40
Proposed Year-20 Pathway GMP	30 (86%)	42
Proposed Year-20 Pathway BMP	30 (86%)	41
Proposed Year-20 Pathway GMP + point sources	29 (83%)	40
Proposed Year-20 Pathway BMP + point sources	29 (83%)	39
Proposed Year-5 Pathway A	32 (91%)	43
Proposed Year-5 Pathway D	31 (89%)	42
Proposed Consented Strict	29 (83%)	35
Natural State	6 (17%)	-401
Dairy Sector Pathway A	30 (86%)	33
Dairy Sector Pathway B	31 (89%)	33
Horticulture Expansion A	33 (94%)	46
Horticulture Expansion B	34 (97%)	46
Potato Expansion A	30 (86%)	42
Potato Expansion B	29 (83%)	40
Potato Expansion C	29	38.7

Region-wide and downstream of the Target Catchments, compared to the Pre-regulation Scenario, the group of scenarios based on the Proposed Plan represent small improvements in mean relative difference and small improvements in the number of assessment points that do not achieve the target. This indicates that generally, the Proposed Plan, is anticipated to modestly improve water quality (i.e., reduce SIN concentrations) compared to 2012, but the improvement is less than with the Operative One plan scenarios.

Key general findings of the Proposed Plan Scenarios are:

1. Continued leaching from all IFLUs (consented and unconsented) at their pre-consented (2012 basefile) nitrogen leaching rates (the Pre-regulation Simulation) produced the worst water quality outcome (except for the two Horticulture Expansion scenarios). This is indicated by the highest mean relative difference and number of assessment points that do not achieve the target for the Pre-regulation Simulation in Tables 2 and 3.
2. There is a general improvement in water quality over the predicted 2012 (Pre-regulation) outcomes if all consented IFLUs operate at their consented N loss rates, and unconsented IFLUs operate at up to, but not exceed, the PPC2 Table 14.2 limits. This is indicated by comparing the Proposed Consented Scenario with the Pre-regulation Simulation in Tables 2 and 3.
3. The water quality outcome is improved over the Proposed Consented Scenario if IFLUs operate at their consented nitrogen leaching rates where those rates do not exceed PPC2 Table 14.2 limits, consented IFLU that have consented nitrogen leaching rates higher than PPC2 Table 14.2 are reduced to the Table 14.2 limits, and unconsented IFLUs operate at up to, but not exceeding, the PPC2 Table 14.2 limits. This is indicated by comparing the Proposed Consented Scenario with the Proposed Consented Strict Scenario in Tables 2 and 3.
4. The discretionary consent pathway options for unconsented farms (Proposed Year-20 Pathway) improves WQ relative to taking no action on unconsented farms (Scenario 12). This is indicated by comparing the Proposed Year-20 Pathway with the Post-regulation Scenario in Tables 2 and 3.
5. The impact on water quality of reducing the baseline nitrogen leaching rates from the Known Unconsented-IFLU is small at the regional level. This is indicated by comparing the Proposed Year-20 Pathway A Scenario with the Proposed Year-20 Pathway D Scenario in Tables 2 and 3.

The above key findings apply generally; however, under some of the Proposed Plan Scenarios there are increases in SIN concentrations at individual assessment points. For example, compared to the Pre-regulation Scenario, SIN concentrations were predicted to increase at some locations under the Proposed Consented Year-20 Scenario (see Figure 16). These increases occur because the calibrated model defined some areas of IFLU with export coefficients that are less than the nitrogen leaching rates specified in PPC2 Table 14.2, and under several scenarios these leaching rates are assumed to increase up to those specified in PPC2 Table 14.2. The areas where this can occur are shown in blue on Figure 2.

Areas with increased nitrogen leaching rates from IFLU land occur in some non-target catchments and therefore the overall export coefficients in the model and the predicted SIN concentrations increase under several of the Proposed Plan Scenarios. The conclusion is that the Proposed Plan will lead to modest water quality improvements in the Target Catchments but may allow some IFLU land to increase its nitrogen leaching rates up to levels specified in Table 14.2, and this will decrease water quality (i.e., increase SIN concentrations) in some locations.

The Natural State scenario indicates that some assessment points would not achieve the One Plan SIN target in the absence of any anthropogenic water quality pressure. This suggests that some of the One Plan SIN targets are too strict and should be reviewed in the future.

6 References

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Attachment B

Summary of achievement of SIN targets at assessment points downstream of Target catchment.

Summary of achievement of SIN targets at assessment points downstream of Target catchment. Note that there are 35 assessment points that are downstream of the Target catchments.

Simulation	Description¹	No. of points not achieving target	Mean relative difference (%)
Pre-regulation	Nitrogen leaching rates in 2012 prior to consenting.	32	44.6
Post-regulation A	N leaching rates for consented-IFLU are set to consented rates.	32	43.4
Proposed Consented	Implementation of PC2 with no provision for a discretionary activity pathway but existing consents at consented rates.	29	39.5
Proposed Pathway A	Implementation of PC2 discretionary pathway for non-consented/non-compliant IFU with 9kg/ha/yr reduction from current leaching rates.	30	40.8
Proposed Pathway B	As above but with 12 kg/ha/yr reduction.	30	40.7
Proposed Pathway C	As above but with 15 kg/ha/yr reduction.	30	40.5
Proposed Pathway D	As above but with 18 kg/ha/yr reduction.	30	40.2
Proposed Pathway E (GMP pathway)	Implementation of PC2 discretionary pathway for non-consented/non-compliant IFU with 9kg/ha/yr reduction from current leaching rates and 36 % reduction for CVG.	30	41.8
Proposed Pathway F (BMP pathway)	Implementation of PC2 discretionary pathway for non-consented/non-compliant IFU with 18kg/ha/yr reduction from current leaching rates and 55% reduction for CVG.	30	40.6
Proposed Consented Strict	Year 20 implementation of PC2 with no provision for a discretionary activity pathway and adherence to consented rates where these are below Table 14.2 and reduction of N loss rates to Table 14.2 where consented rates are above Table 14.2.	29	35.3
Dairy Sector Pathway A	Alternative approach to restricting the leaching rates for the unconsented-IFLU applied only to the 70 Known-Unconsented dairy farms	30	40.9
Dairy Sector Pathway B	Alternative approach to restricting the leaching rates for the unconsented-IFLU applied to all Unconsented dairy farms in the Target Catchments	31	41.3

¹ All results are for the Year 20 outcome.