
TECHNICAL MEMORANDUM

TO: THOMAS MCELROY (TARANAKI REGIONAL COUNCIL)

FROM: TIM COX (RMA SCIENCE), TON SNELDER (LWP), TIM KERR (LWP)

SUBJECT: CATCHMENT MITIGATION SIMULATIONS

DATE: 29/02/24

CC: ABBY MATTHEWS (TARANAKI REGIONAL COUNCIL)

Summary

Previously developed and calibrated Taranaki Region catchment water quality models (Cox et al. 2022) were used to simulate river and stream water quality response to a set of plausible farm mitigation options. These models simulate the fate and transport of total nitrogen (TN) and total phosphorus (TP) across four different stream and river basin aggregations in the Taranaki Region. Stream periphyton response, as a function of modelled nutrient concentrations, is also simulated. Four separate model predictive simulations (scenarios) are presented here.

The first two scenarios incorporate two sets of farm mitigation actions, respectively, as described by McDowell et al. (2021): one representing full implementation of “established” mitigation options, as of 2015; and a second representing full implementation of both established and “developing” options, anticipated for 2035. Within the catchment models, these scenarios were depicted with reductions in baseline (current) dairy and sheep/beef farm nutrient (TN and TP) export coefficients following the percent load reductions published in McDowell et al. (2021) and applied according to specific sub-catchments and a physiographic-based farm typology.

Scenarios 3 and 4 were based on the completion of existing TRC farm mitigation initiatives.

Scenario 3 specifically simulates the elimination of direct discharge of dairy shed effluent to waterways. Dairy shed discharges are represented as point sources in the catchment models. For the simulation of this scenario, all dairy shed point source loads were set to 0.

The fourth simulation is intended to represent full implementation of existing TRC farm mitigation initiatives. In addition to the removal direct dairy shed effluent discharges to waterways, this simulation incorporates both enhanced stock exclusion achieved through stream fencing initiatives and nutrient runoff load reductions achieved with riparian buffer zone (RBZ) planting along farm streams. For the simulation of both mitigation options, only the potential changes, from current condition to full implementation, were simulated. Existing programme implementation is assumed to be implicitly represented in the baseline model. Nutrient load reductions associated

with both enhanced stock exclusion and additional RBZ planting were derived from external studies (Monaghan et al. 2021; McKergow et al. 2022) and represented in the models with adjustments to baseline nutrient export coefficients.

Simulation results reveal the potential for significant water quality improvements from the implementation of known and projected on-farm management strategies and from the elimination of direct discharges of dairy shed effluent. Marginal gains have also been quantified for the completion of ongoing farm stream fencing and planting programmes. Total nitrogen concentration reductions of up to 50%, compared to baseline, have been simulated for some sites in the region. Maximum simulated total phosphorus concentration reductions were greater than 70% for some sites and maximum simulated periphyton biomass reductions were approximately 15%. Based on these results, the farm mitigation options simulated here will likely need to be a key feature of any comprehensive regional nutrient management strategy.

1. Methods

Catchment water quality models were developed for four stream and river basin aggregations in the Taranaki Region, labelled: the Northern basin, the Southern basin, the Ring Terraces North basin, and the Ring Terraces South basin (Cox et al. 2022). As part of the development process, the models were calibrated using available recent river monitoring data, thereby demonstrating the models' abilities to accurately simulate current river water quality. The calibrated models, hereafter referred to as "baseline" models, served as the starting point for the predictive simulations described here.

Note that, for the study presented here, six new calibration sites were added to the models using recently collected data at relatively recently activated monitoring sites. These sites were not included in the original model calibration described in Cox et al. (2022). However, the process of including these new sites in the calibration of the models is detailed in an addendum to that original report (Cox 2024). The six sites were deemed viable for inclusion in the models, as calibration targets, based on the following criteria: 1.) an adequate period of record (at least one year of recent monthly data), 2.) available observed flow data, and 3.) a location that is downstream of at least one simulated model catchment. Other active monitoring sites were excluded from the model calibration update because they lacked one, or more, of these three criteria.

Scenarios 1 and 2 incorporate two sets of farm mitigation actions, as described by Monaghan et al. (2021) and McDowell et al. (2021): one representing full implementation of "established" mitigation options, as of 2015; and a second representing full implementation of both established and "developing" options, anticipated for 2035. The published paper presents projected reductions in farm nutrient loss rates ("exports") for specific mitigation actions, as a function of both farm type and a physiographic-based typology. Typology characteristics include climate, topography, and soil type. For our analysis, pastoral farm (dairy and sheep/beef) export load reductions were assigned to model sub-catchments based on the intersection of physiographic and land use layers and the corresponding published mitigation impact estimates (Figures 1 and 2). All load reductions were applied as a percent reduction from baseline values for the dairy and sheep/beef land use categories in the models. No other diffuse source export

coefficients, or point source loads, were modified. The calibrated attenuation coefficients were retained in the models for these simulations.

In Scenario 3 we simulate the elimination of dairy shed direct discharge to waterways based on current TRC dairy effluent discharge consents. Existing dairy shed discharges are aggregated in the baseline model and represented as catchment-specific point source loads. For this scenario, we set all model dairy shed discharge nutrient loads to 0. No other changes to baseline model parameterisation are included in this simulation.

Scenario 4 involves the simulation of full implementation of existing TRC catchment mitigation strategies. These include the elimination of dairy shed discharges (Scenario 3) plus two additional components: 1. full stock exclusion (fencing), and 2. riparian buffer zone (RBZ) planting for all farm streams. Note that expanded stock exclusion is also part of the Scenario 1 established mitigation package and the Scenario 2 established + developing package¹. This mitigation work is largely already underway in the region, and existing fencing and RBZ projects are implicitly included in the baseline models. Scenario 4 therefore focuses on quantifying the expected gains in water quality due to full implementation of these strategies, as compared to the current levels of implementation represented in the baseline models.

¹ There are some key differences between the different fencing scenarios that require further explanation. The TRC riparian management programme (Scenario 4) does not cover the entire region, instead, it largely focuses on a targeted management zone where dairy farming is most concentrated. Therefore, this scenario does not simulate the effects of new fencing or planting outside of this zone, which generally excludes the eastern hill country area. In contrast, Scenarios 1 and 2 simulate a fencing scenario which broadly align with the Resource Management (Stock Exclusion) Regulations 2020, which require fencing throughout a greater proportion of the region (including some of the eastern hill country). However, the minimum stream size that must be fenced based on the stock exclusion regulations is greater than that required under the TRC riparian management programme. Therefore, the new fencing simulated under Scenarios 1 and 2 covers less total stream reach than Scenario 4 within the riparian management zone where the two scenarios overlap.

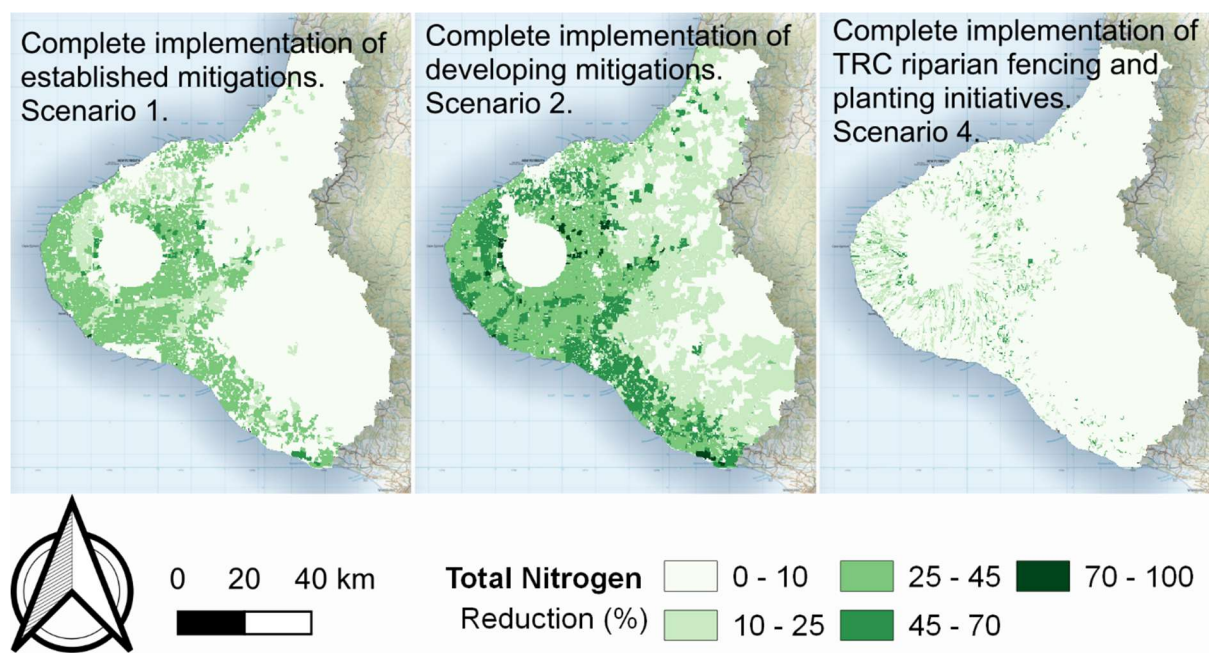


Figure 1. Percentage reduction in diffuse total nitrogen export loads associated with the mitigation actions compared to the baseline. Left hand image is for the 2015 established mitigations, middle is for the 2035 established + developing mitigations, right hand side is for the TRC riparian fencing and planting mitigations.

The impacts of the first mitigation component of Scenario 4, expanding farm stream fencing, were estimated using the data published in Monaghan et al. (2021) and the associated supplementary material. From these data, a nutrient loss reduction per percentage change in fencing was calculated. These values are different for each of the land use typologies. At the REC V2 Strahler order 1 watershed level, the percentage of fencing remaining to be completed was determined. These data were converted to a 250 m x 250 m grid, aligned to the existing land use typology data, and nutrient loss rate reductions were calculated. These reductions were subtracted from the baseline loss rates and aggregated into the SCAMP sub-catchments and land use types.

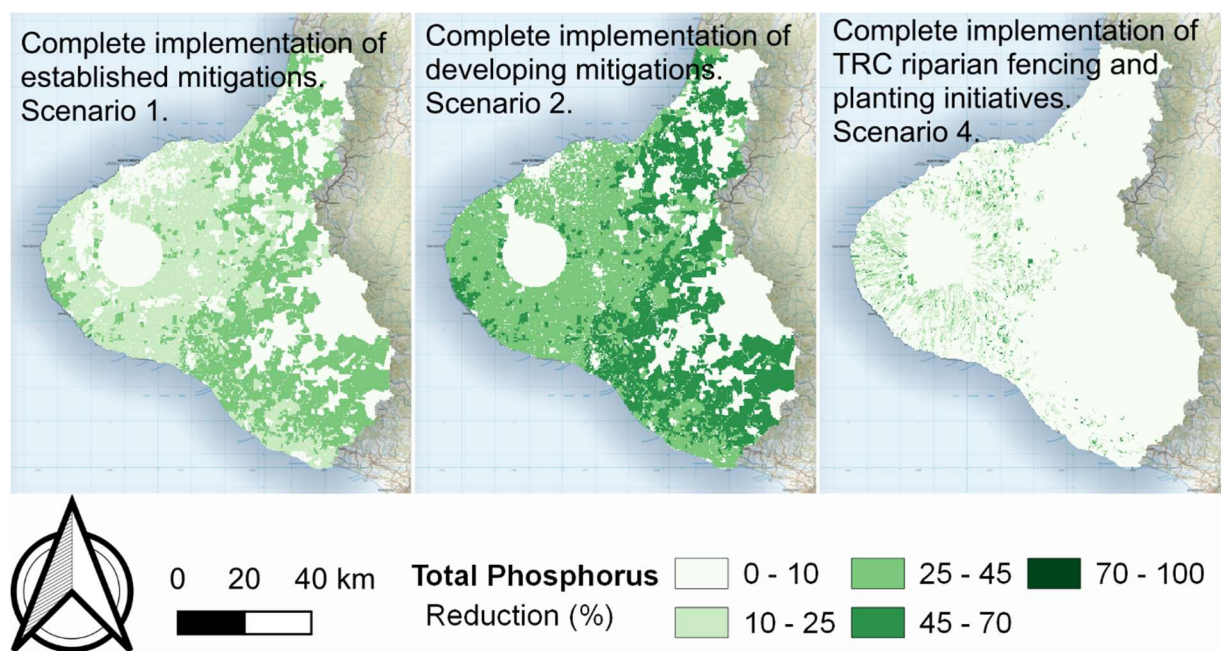


Figure 2. Percentage reduction in diffuse total phosphorus export loads associated with the mitigation actions compared to the baseline. Left hand image is for the 2015 established mitigations, middle is for the 2035 established + developing mitigations, right hand side is for the TRC riparian fencing and planting mitigations.

The second component of Scenario 4 is RBZ planting. The impact of riparian planting was estimated using data published in McKergow et al. (2022). In this study, nutrient loss rate reductions (mitigation rates) are presented as a function of the relative width of the riparian strip with respect to the length of the contributing hillslope. Therefore, for our study, characteristic values of the riparian-strip-to-hillslope-ratio for each stream Strahler order were determined from 100 representative site samples provided by TRC. At the REC V2 watershed level, mitigation rates were assigned based on these calculated ratios and the McKergow et al. (2022) data. Additionally, within each REC V2 watershed, the fraction of riparian planting yet to be completed was determined. This yet-to-be planted fraction was multiplied by the assigned mitigation rates (which assumed 100% planting) to estimate effective (scaled) mitigation rates for each watershed. Lastly, RBZs are known to only treat loads delivered via sheet flow (including shallow subsurface flow) (McKergow et al. 2022). Channelised and deeper subsurface flows are not impacted by RBZs. To account for this limitation, the scaled mitigation rates were assumed to impact only the diffuse nutrient loads generated by losses from land areas within 100 metres of the stream. In other words, mitigation rates were applied to only a portion of the total catchment diffuse nutrient losses. The 100-metre zone of impact was assumed based on professional judgement. These scaled nutrient reductions were added to those quantified for the fencing component to determine the total diffuse nutrient loss reductions associated with Scenario 4.

For all modelled scenarios, water quality outputs were summarised in multiple ways. Firstly, for 246 model assessment locations, results are reported as percent reductions in mean annual stream TN and TP concentration, as compared to baseline simulation results. These

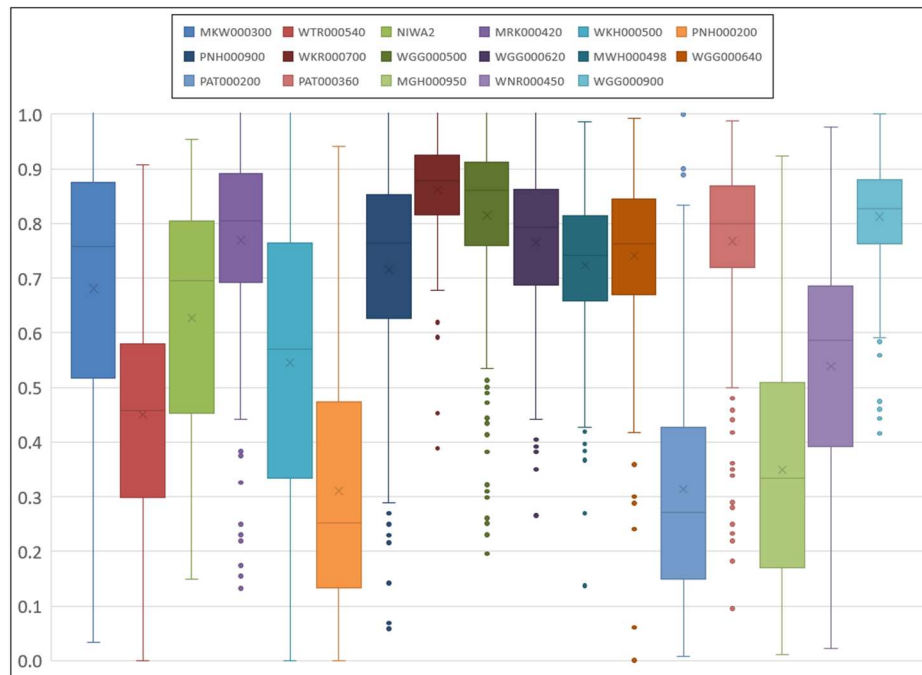
assessment locations correspond to locations where model sub-catchments drain to receiving streams, or to the Tasman Sea. These are typically unmonitored, and therefore uncalibrated, locations in the region. Consequently, output are most appropriately reported as relative changes (modelled vs. modelled percent reductions).

Additionally, twenty-two (22) water quality monitoring sites are included in the model output summaries. These sites were used as calibration points during the original model calibration (Cox et al. 2022) and, consequently, confidence in modelled concentrations at these locations is relatively high, as compared to the uncalibrated locations. For these sites, scenario simulation results are reported as both modelled flow-weighted mean concentrations and as percent changes relative to baseline.

Nitrate (NO_3^-) and dissolved reactive phosphorus (DRP) concentrations were also estimated for each model scenario and the baseline condition. These values were estimated in two different ways. For water quality stations, where model confidence is higher, modelled TN and TP concentrations were converted into nitrate and DRP concentrations, respectively, using site specific mass ratios observed in the monitoring data. Ratios of median and 95th percentile NO_3^- to median TN, and median and 95th percentile DRP to median TP, were calculated using a consistent extended recent monitoring period of record (2020 – 2023). These ratios were applied to the modelled median TN and TP concentrations to estimate median and 95th percentile nitrate and DRP concentrations, respectively. For reference, observed mass ratios for regional monitoring sites, using paired data, are summarized in Figure 3. Note that median TN and TP concentrations are calculated in the models as a linear function of the modelled flow weighted mean concentrations using site specific ratios (R factors) developed in national empirical studies (Oehler and Elliot 2011; Fraser and Snelder 2020). For assessment locations (lower confidence), previously published empirical regression modeling results (Snelder et. al 2023) were used to estimate baseline nitrate and DRP concentrations. The modelled TN and TP concentration relative changes (percent reductions), described above, were then applied to the baseline nitrate and DRP concentration estimates to generate estimates for each scenario presented here.

Periphyton predictions are reported both as the expected value of the 92nd percentile periphyton biomass concentration and as percent changes relative to baseline for the twenty-two water quality monitoring locations. The 92nd percentile of observed periphyton concentrations is used to assign a National Objective Framework (NOF) attribute band to a given stream reach. Periphyton calculations in the models are based on published relationships between stream nutrient concentrations and periphyton biomass exceedance probabilities (Snelder and Kilroy 2023). Modelled values are best interpreted as expected typical biomass values within an extended reach above and below a given monitoring site, given the assumed level of shading, rather than predictions for the site itself. Uncertainty in periphyton predictions is relatively high given the large number of confounding variables. In SCAMP, two sets of periphyton estimates are generated: one based on modeled TN and the published relationship between TN and periphyton; and a second based on modeled TP and the published relationship between TP and periphyton. For reporting purposes, the averages of the two sets of predictions are provided here for each simulation. Periphyton calculations are further detailed in Appendix A.

a.) ratios of nitrate to total nitrogen



b.) ratios of DRP to total phosphorus

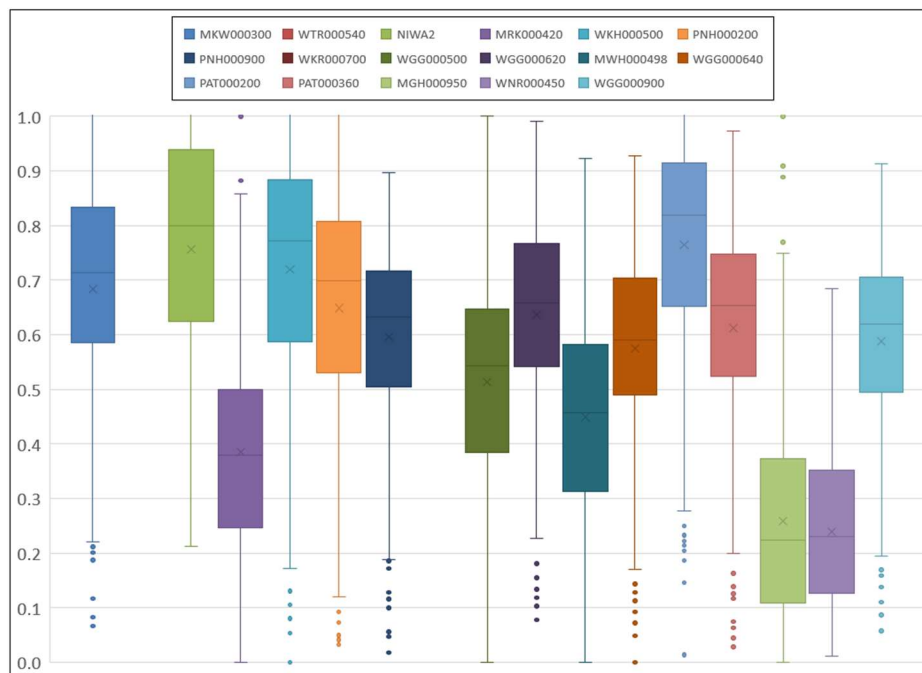


Figure 3. Mass ratios observed at monitoring sites, summarised for available periods of record. Box plots show median values (horizontal lines), mean values (x markers), inner quartile range (25th to 75th percentiles) (shaded rectangles), minimum and maximum values (whiskers), and outlier points (dots).

Lastly, Lake Rotorangi water quality response, in the form of in-lake TN, TP, and phytoplankton concentrations, is also reported for each modelled scenario, as compared to baseline. Lake Rotorangi is the only lake explicitly represented in the catchment models.

2. Results

Results of the scenario simulations, in the form of predicted percent nutrient load reductions, as compared to baseline, are available for 246 assessment locations, representing the bottom of each simulated catchment, throughout the modelled basins. These results are mapped in Figure 4 through Figure 7. Results of applying the modelled load reductions to previously estimated assessment point nitrate and DRP median and 95th percentile concentrations are mapped in Figure 8 through Figure 17.

Modelled flow weighted mean annual nutrient concentrations at active water quality monitoring stations (calibration points for the model) are summarised in Tables 1 and 2, while modelled median and 95th percentile nitrate and DRP concentrations are summarised in Table 3 through Table 6. Lastly, modelled expected value 92nd percentile periphyton concentrations at the water quality stations are summarised in Tables 7 and 8 (unshaded and shaded), and modelled relative changes in periphyton biomass are summarised in Tables 9 and 10. As noted above, for these tables, results of TN and TP-specific periphyton models have been averaged for reporting purposes. Detailed nutrient-specific periphyton output is provided in Appendix B.

Each of the simulated scenarios resulted in quantifiable reductions in total nitrogen (TN) and total phosphorus (TP) concentrations throughout the region. Region-wide reductions in TN concentrations of up to approximately 50%, as compared to baseline, are predicted for the full implementation of both established and developing pastoral farm mitigation options (Scenario 2). This farm mitigation scenario shows the greatest potential impacts, across the simulated scenarios, for TN. This is evident in both the mapping of model assessment point results (Figure 4) and the monitoring site tabulation (Table 1). More moderate, but just as widespread, impacts are predicted for TP for the same scenario (Scenario 2). TP impacts are moderated by the presence of relatively high naturally occurring phosphorus in the region, as captured in the models by the observable sediment erosion phosphorus (OSEP) (Cox et al. 2022). OSEP is assumed to be largely unmanageable and is unimpacted by the simulated mitigation actions in the models. The greatest intensity of TP impacts is predicted, for a small number of isolated sub-catchments, due to the elimination of dairy shed direct discharges (Scenario 3, Figure 5), with concentration reductions > 70% for some sub-catchments. Greater breadth of TP impacts is predicted for Scenario 2 (Figure 4), as compared to the elimination of dairy shed discharges (Scenario 3). Only marginal gains, for both TN and TP, are predicted for the completion of riparian fencing and buffer zone planting as part of the Full TRC intervention scenario (Scenario 4).

Nitrate simulation results at water quality stations (Tables 3 and 5) indicate that the greatest gains in water quality, with respect to nitrate toxicity, are predicted for Scenario 2, as compared to the other simulated scenarios. Scenario 2 involves the simulation of full implementation of both established and developing pastoral farm mitigation options, with a potential feasible time horizon of 2035. Large reductions in stream nitrate concentration are predicted for this scenario, as compared to baseline. For Scenario 2, all but two stations are predicted to achieve median nitrate concentrations lower than the A Band threshold specified in the National Policy Statement for

Freshwater Management (NPS-FM) (MFE 2020). For the baseline simulation, seven (out of seventeen) sites exceeded the A Band threshold, while no sites exceeded the B Band threshold.

DRP simulation results at water quality stations (Tables 4 and 6) indicate that the greatest gains in water quality, with respect to ecosystem health, are predicted for Scenario 4, as compared to the other scenarios. Scenario 4 involves the full implementation of planned TRC interventions, planned for a near-term time horizon. Significant reductions in stream DRP concentrations are predicted for many of the water quality stations due to this suite of mitigation actions. Even with these improvements, most sites are simulated at or above NPS-FM C Band thresholds. An exception is Site MWH000498 (Eltham Tributary), where simulation results indicate a move from C or D Band (baseline) to A Band with the full implementation of TRC interventions. This is a promising result.

Predicted periphyton biomass reductions are generally on the order of 10% or less throughout most of the region (Table 7 through Table 10). The largest impacts are predicted for the upper and lower Waingongoro River (WGG500 and NIWA3) and Eltham Tributary (MWH498), and for the Upper Patea River (PAT360) and Taiwhiti Stream (TWH435), with full implementation of both existing and developing pastoral farm mitigation options (Scenario 2). The catchments upstream of all of these sites are dominated by dairy farmland and, therefore, particularly responsive to dairy farm mitigations. For this scenario, and these sites, the model predicts 92nd percentile periphyton biomass reductions of approximately 10 to 15%.

Lake Rotorangi simulation results (Table 11) indicate moderate, but quantifiable, improvements in lake water quality due to the simulated lake catchment mitigations. The greatest gains are predicted for Scenario 2 (established and developing pastoral farm mitigations). For this scenario, TN and TP are predicted to decrease by 32% and 21%, respectively, as compared to baseline, and the trophic level index (TLI) is projected to decrease to a value (4.16) close to the mesotrophic threshold (4.0).

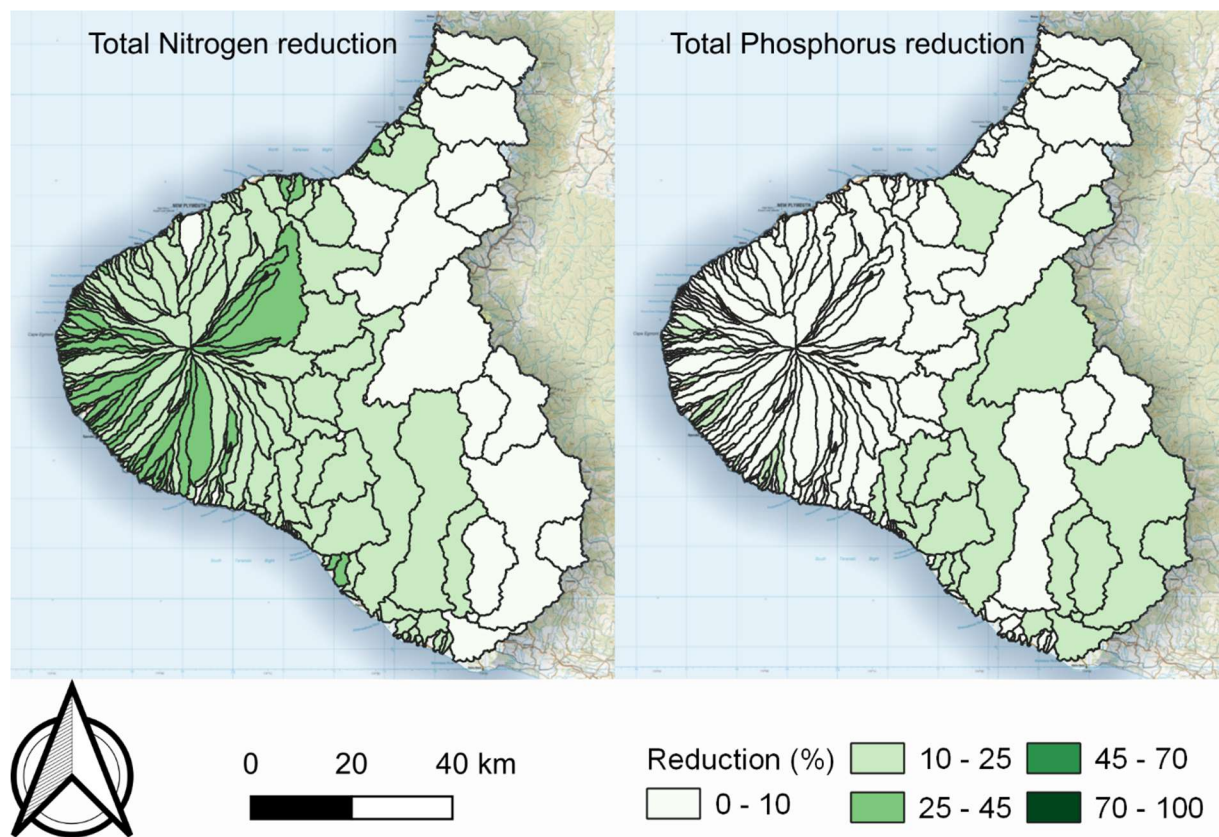


Figure 4. Percentage reduction in modelled instream loads associated with the mitigation actions compared to the baseline. Scenario 1, 2015 established farm mitigations.

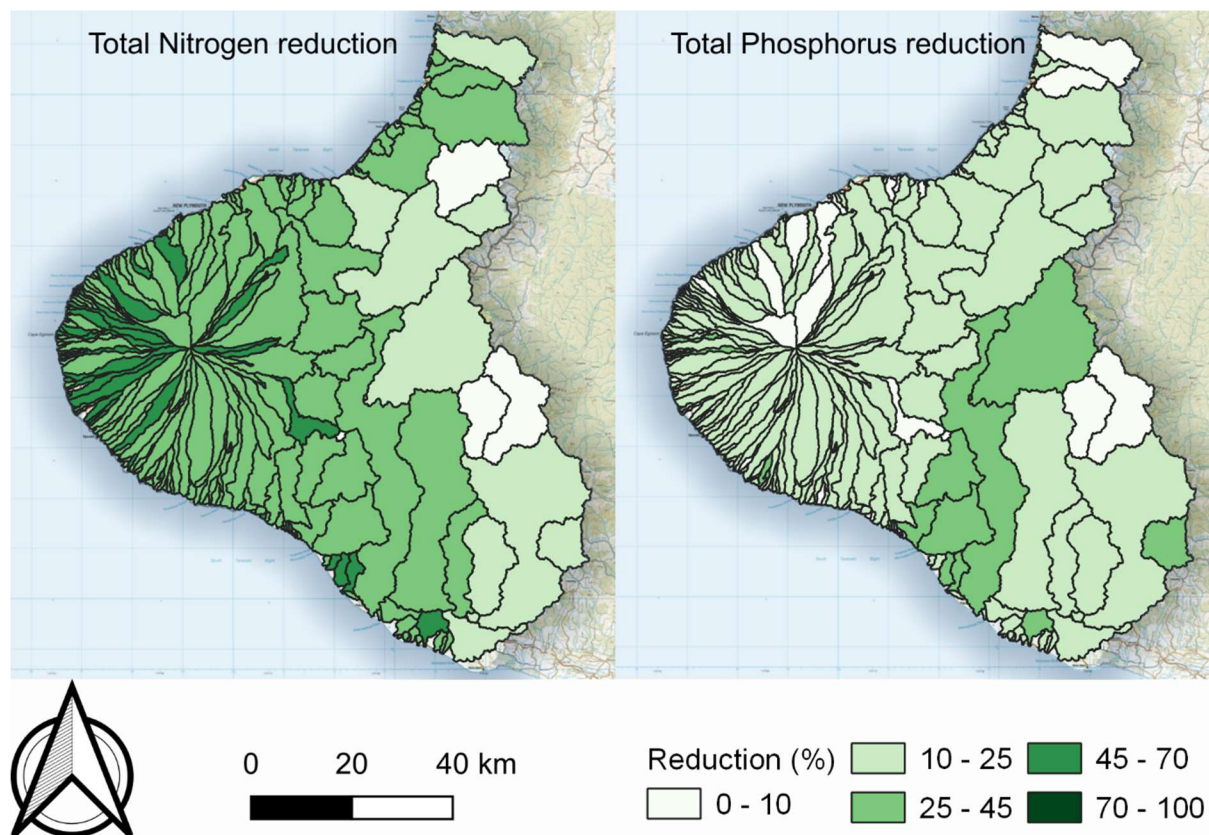


Figure 5. Percentage reduction in modelled instream loads associated with the mitigation actions compared to the baseline. Scenario 2, 2035 established + developing farm mitigations.

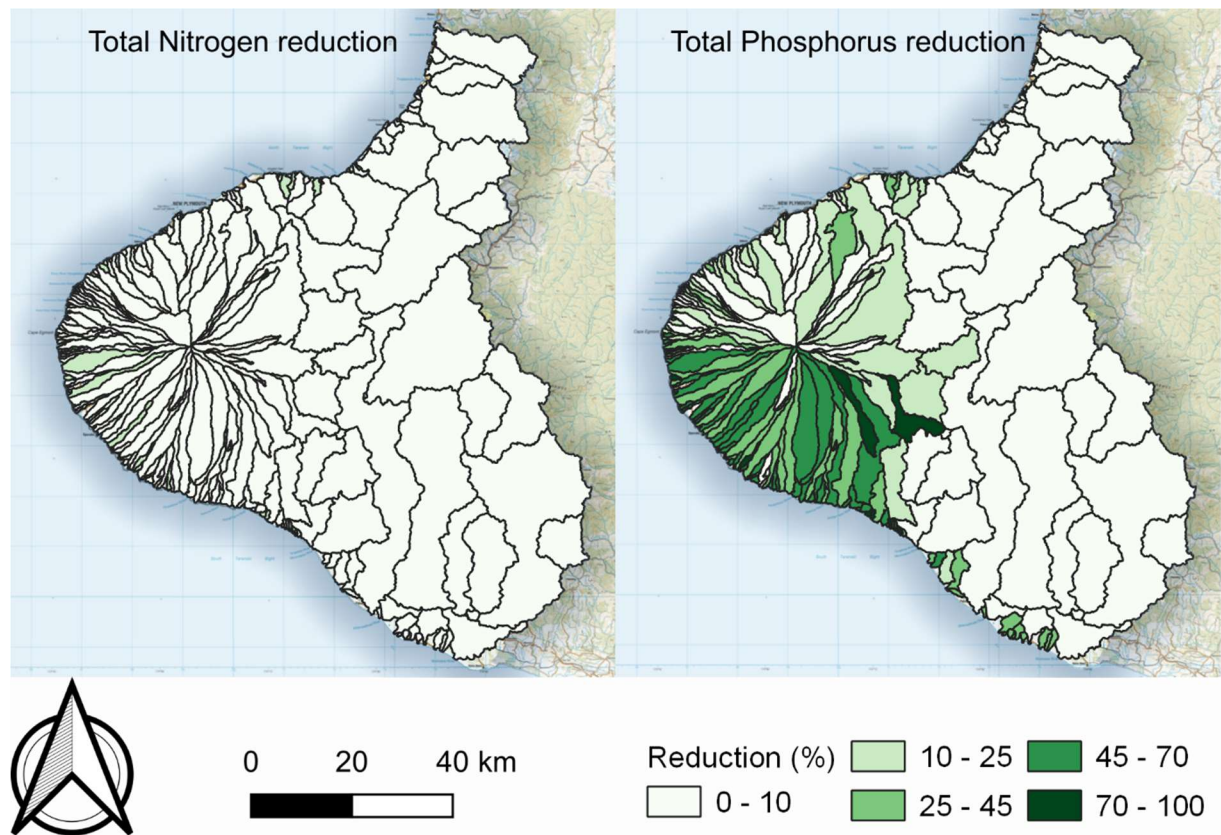


Figure 6. Percentage reduction in modelled instream loads associated with the mitigation actions compared to the baseline. Scenario 3, no dairy shed discharges.

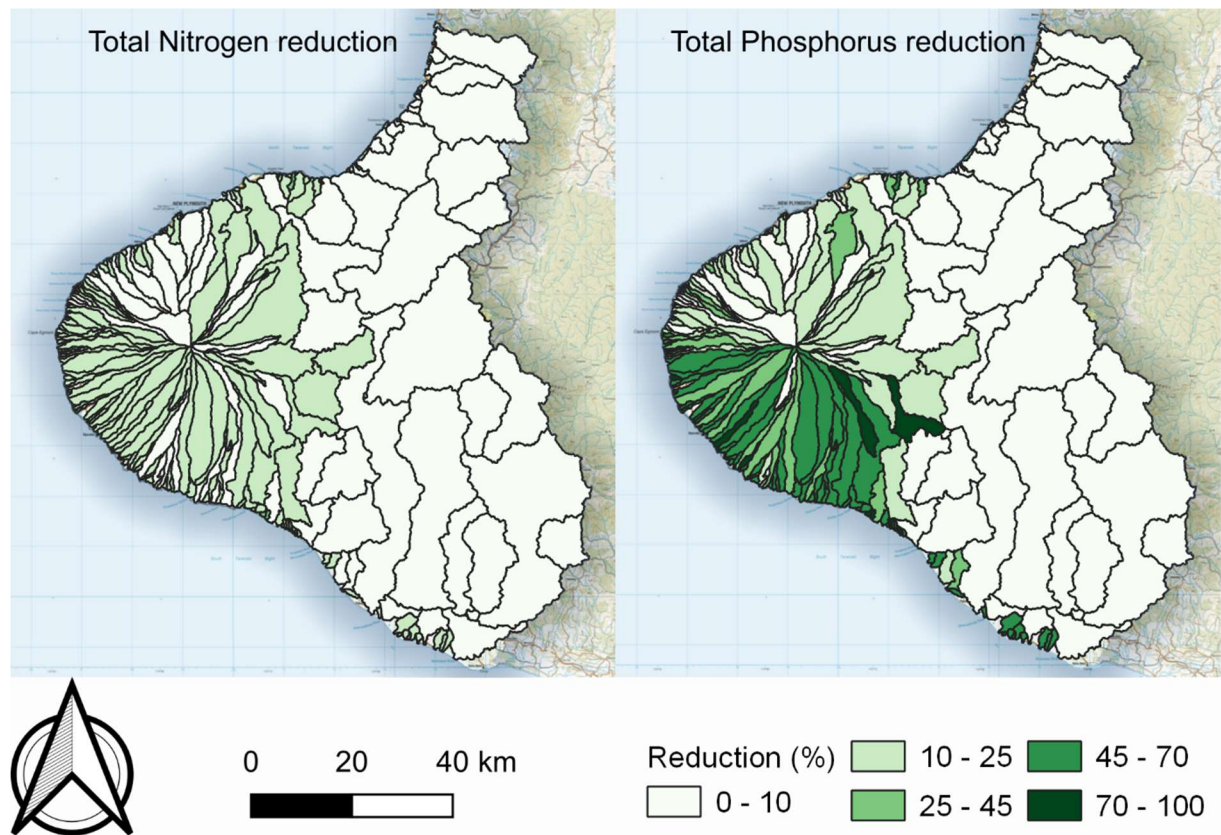


Figure 7. Percentage reduction in modelled instream loads associated with the mitigation actions compared to the baseline. Scenario 4, full implementation of TRC interventions.

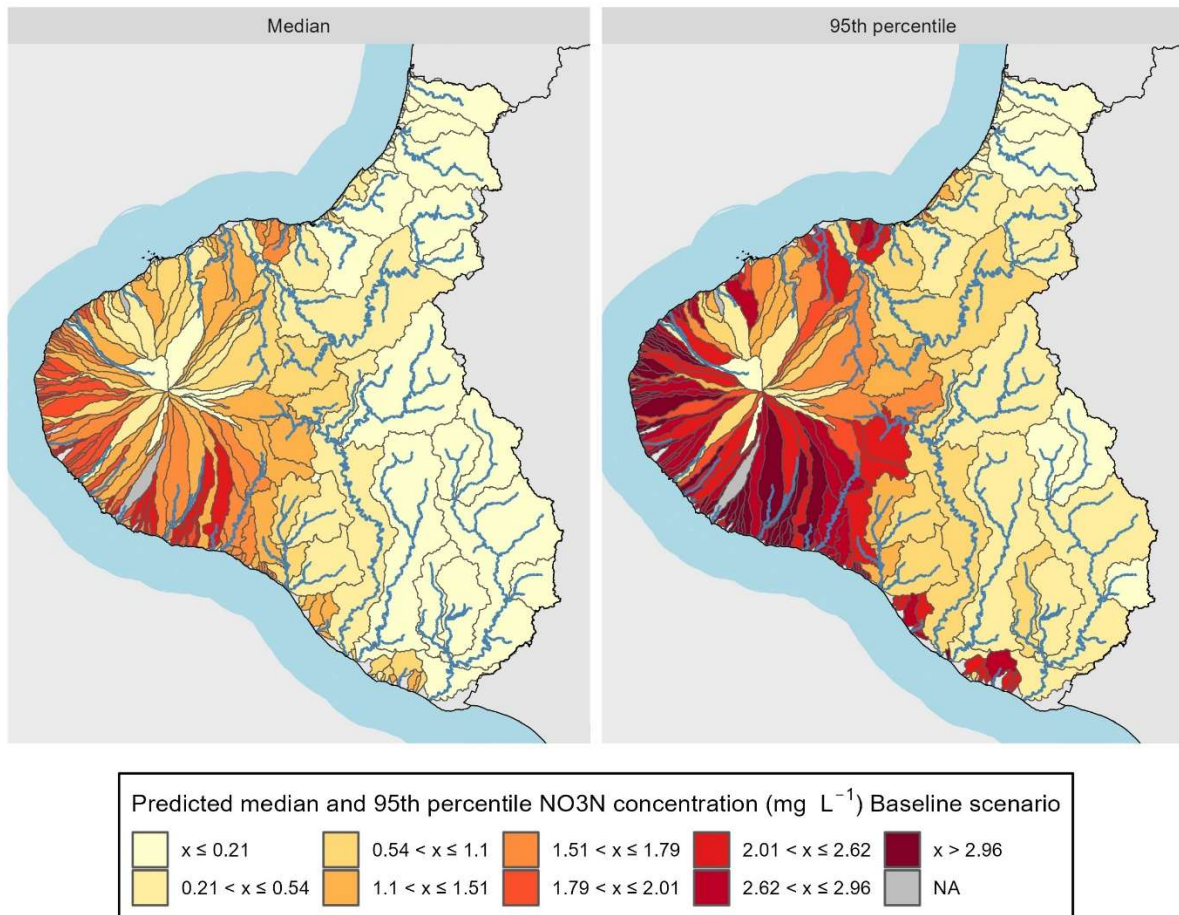


Figure 8. Modelled assessment point nitrate concentrations. Baseline simulation.

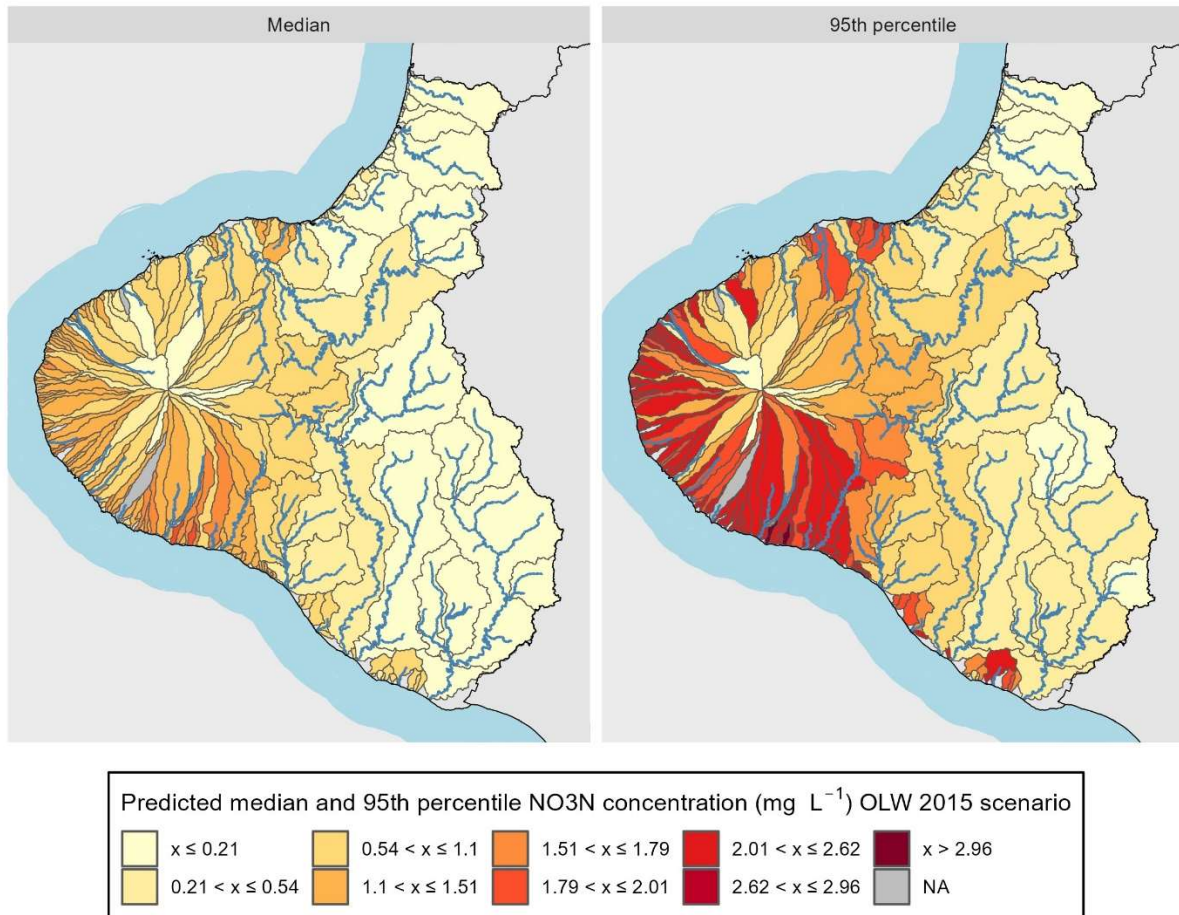


Figure 9. Modelled assessment point nitrate concentrations. Scenario 1, 2015 established farm mitigations.

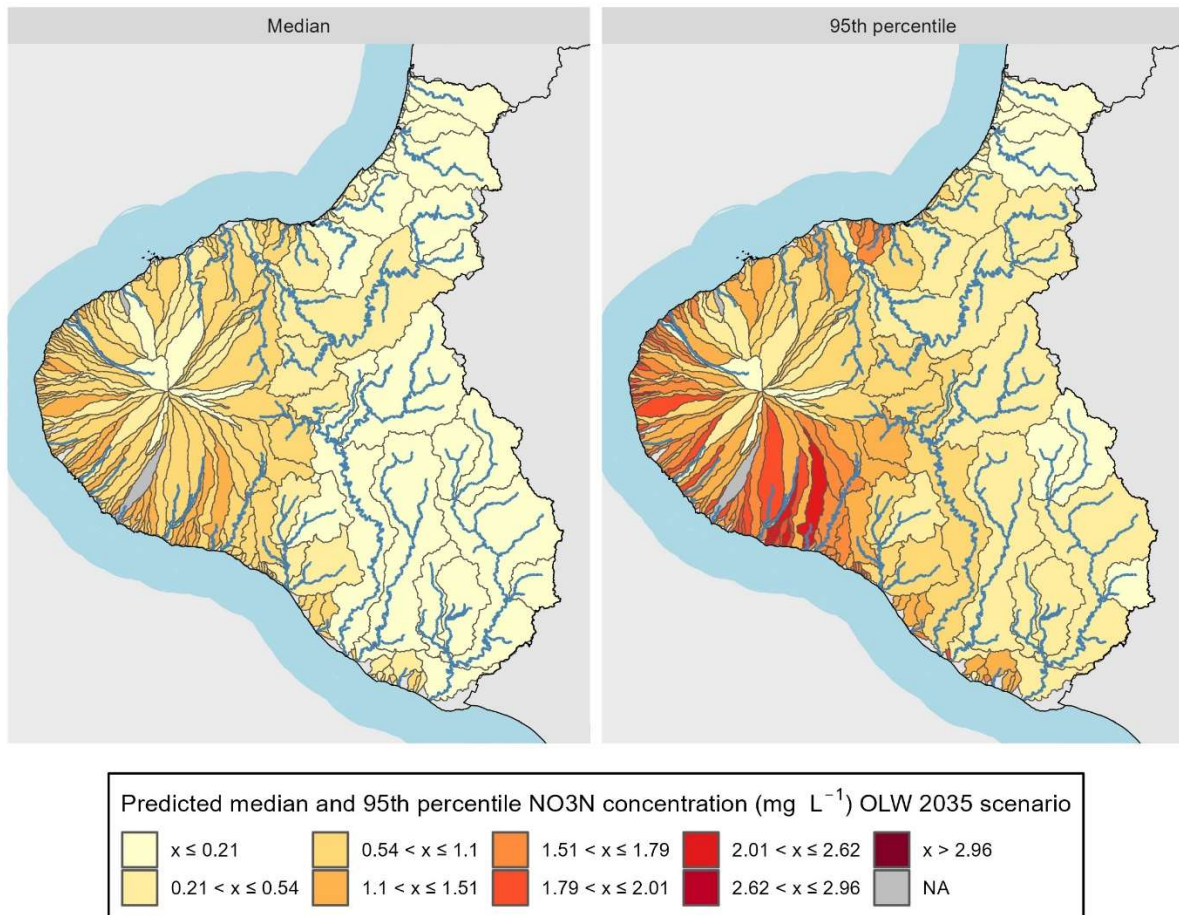


Figure 10. Modelled assessment point nitrate concentrations. Scenario 2, 2035 established + developing farm mitigations.

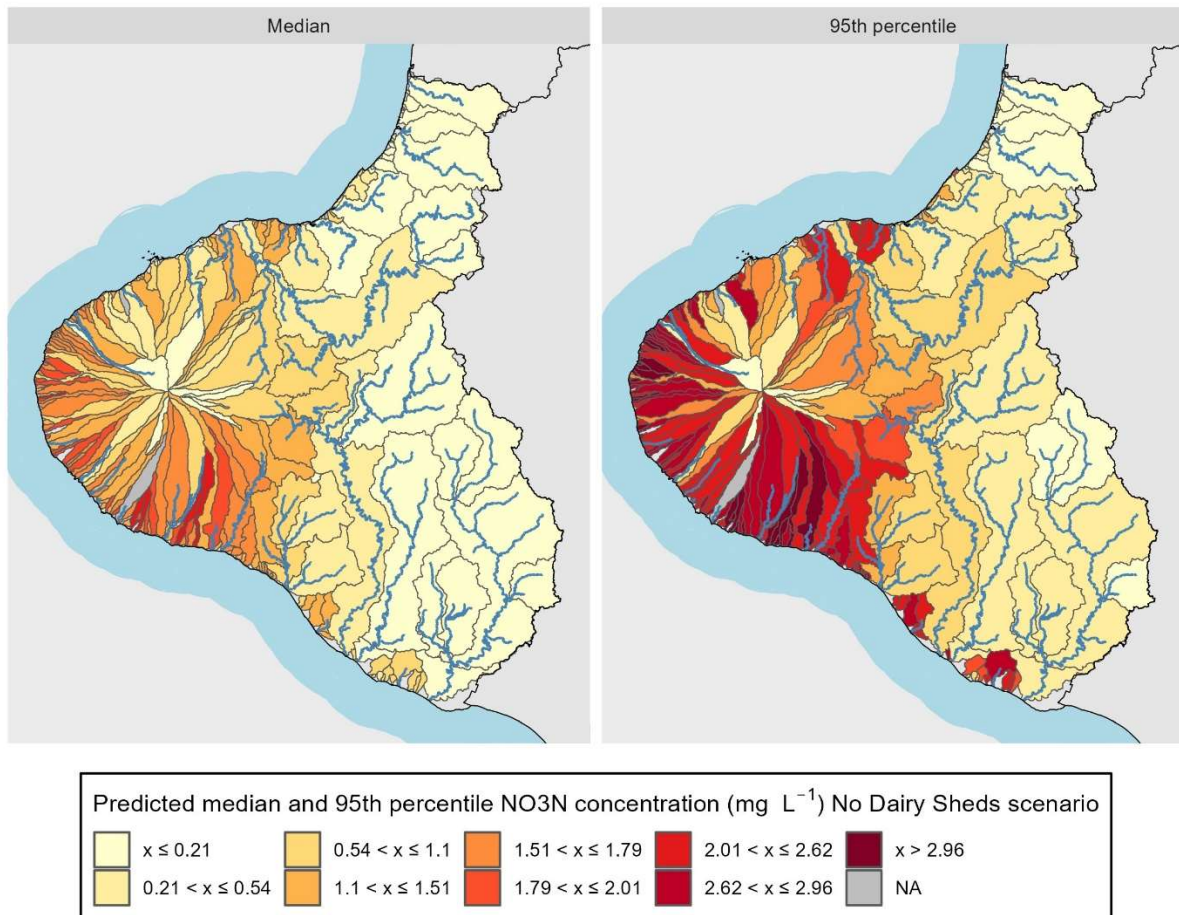


Figure 11. Modelled assessment point nitrate concentrations. Scenario 3, no dairy shed discharges.

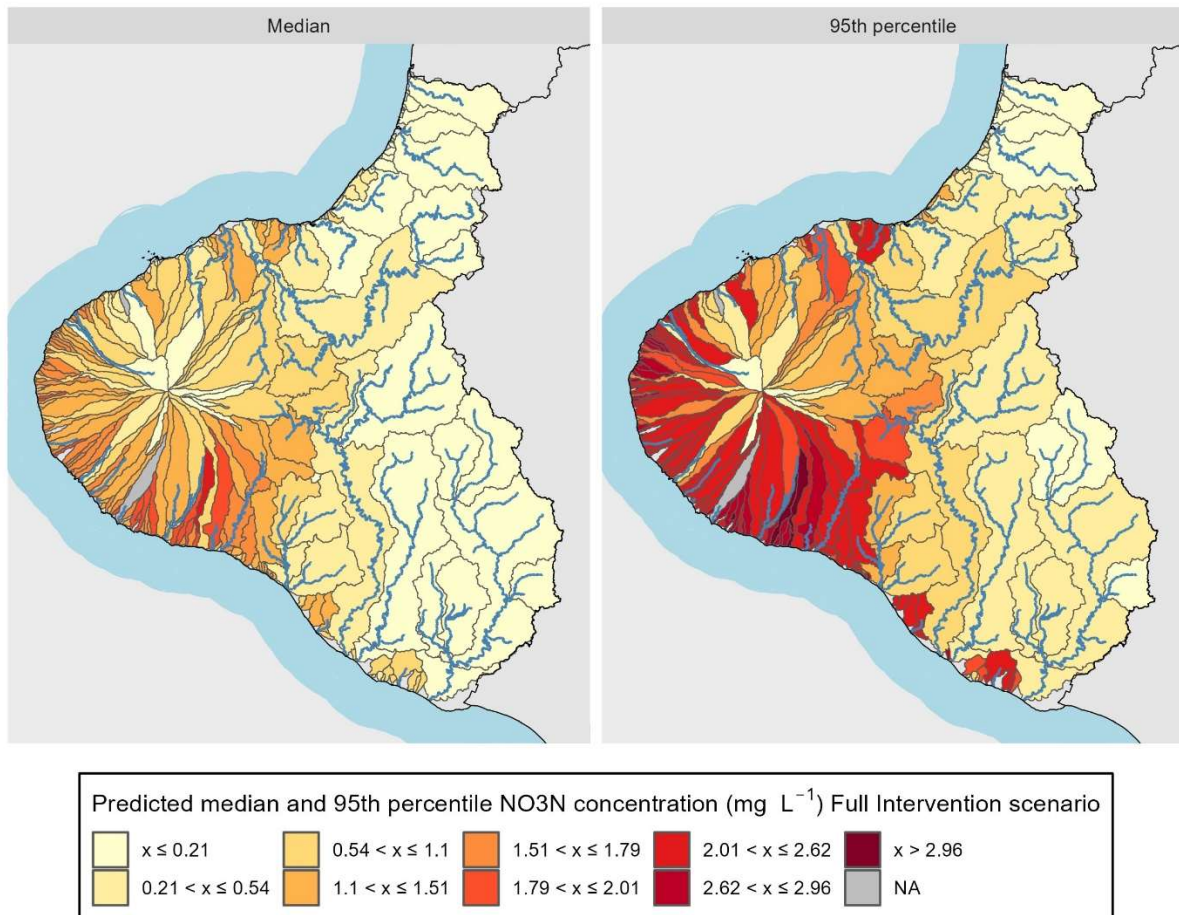


Figure 12. Modelled assessment point nitrate concentrations. Scenario 4, full implementation of TRC interventions.

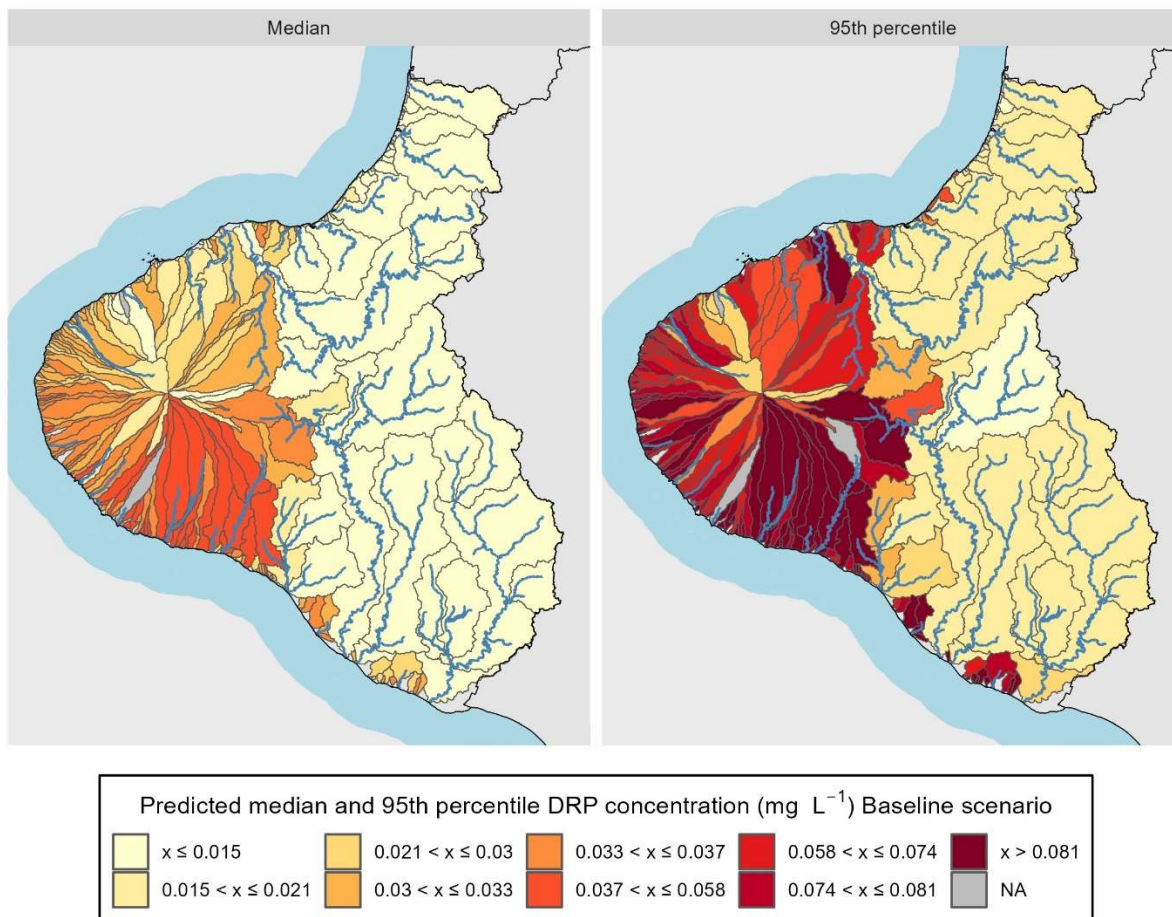


Figure 13. Modelled assessment point DRP concentrations. Baseline simulation.

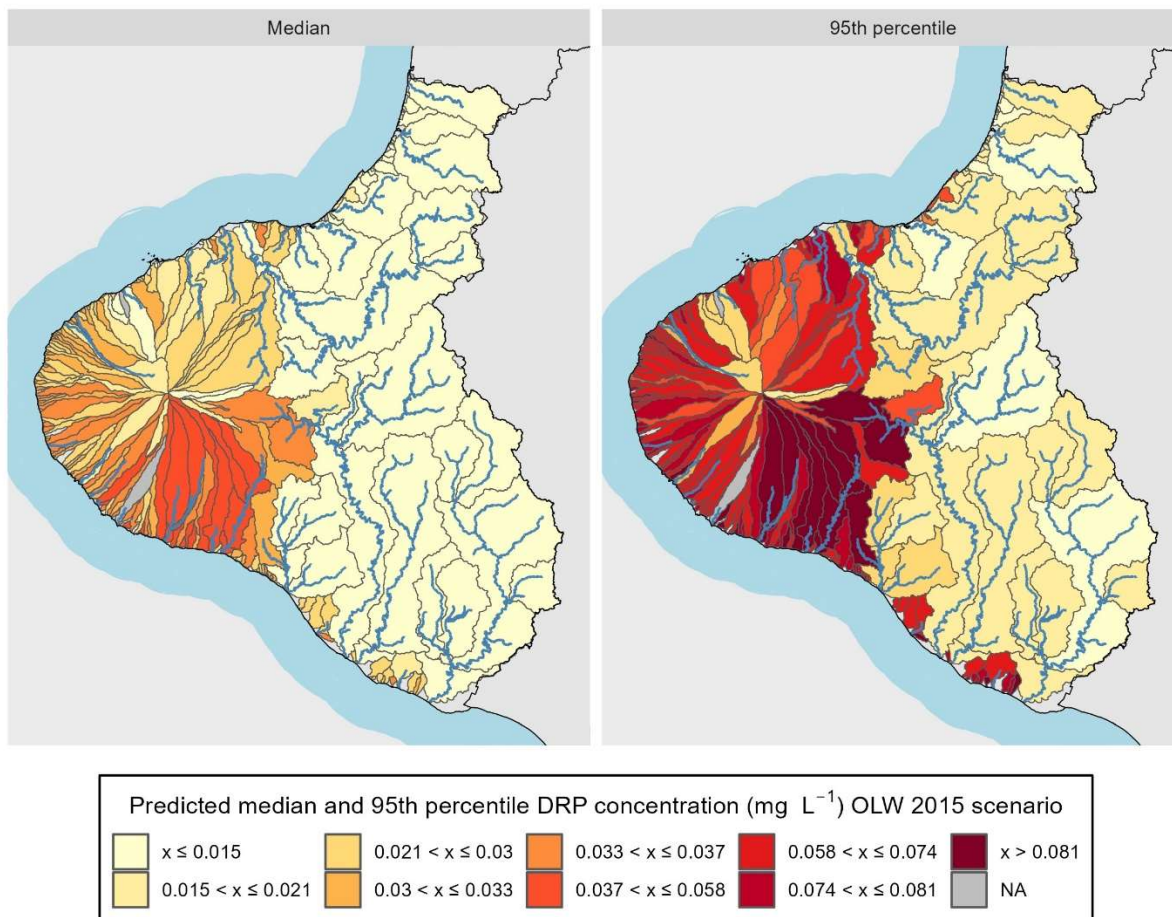


Figure 14. Modelled assessment point DRP concentrations. Scenario 1, 2015 established farm mitigations.

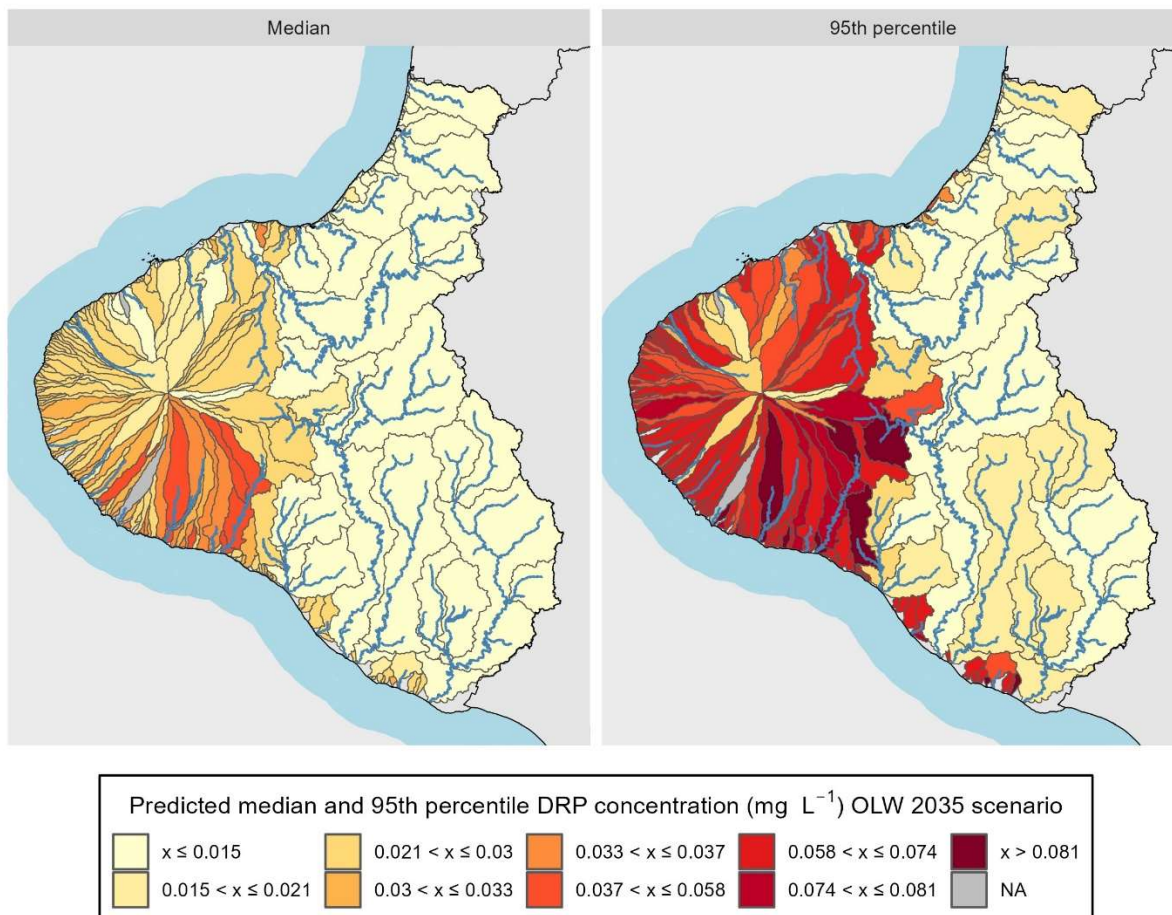


Figure 15. Modelled assessment point DRP concentrations. Scenario 2, 2035 established + developing farm mitigations.

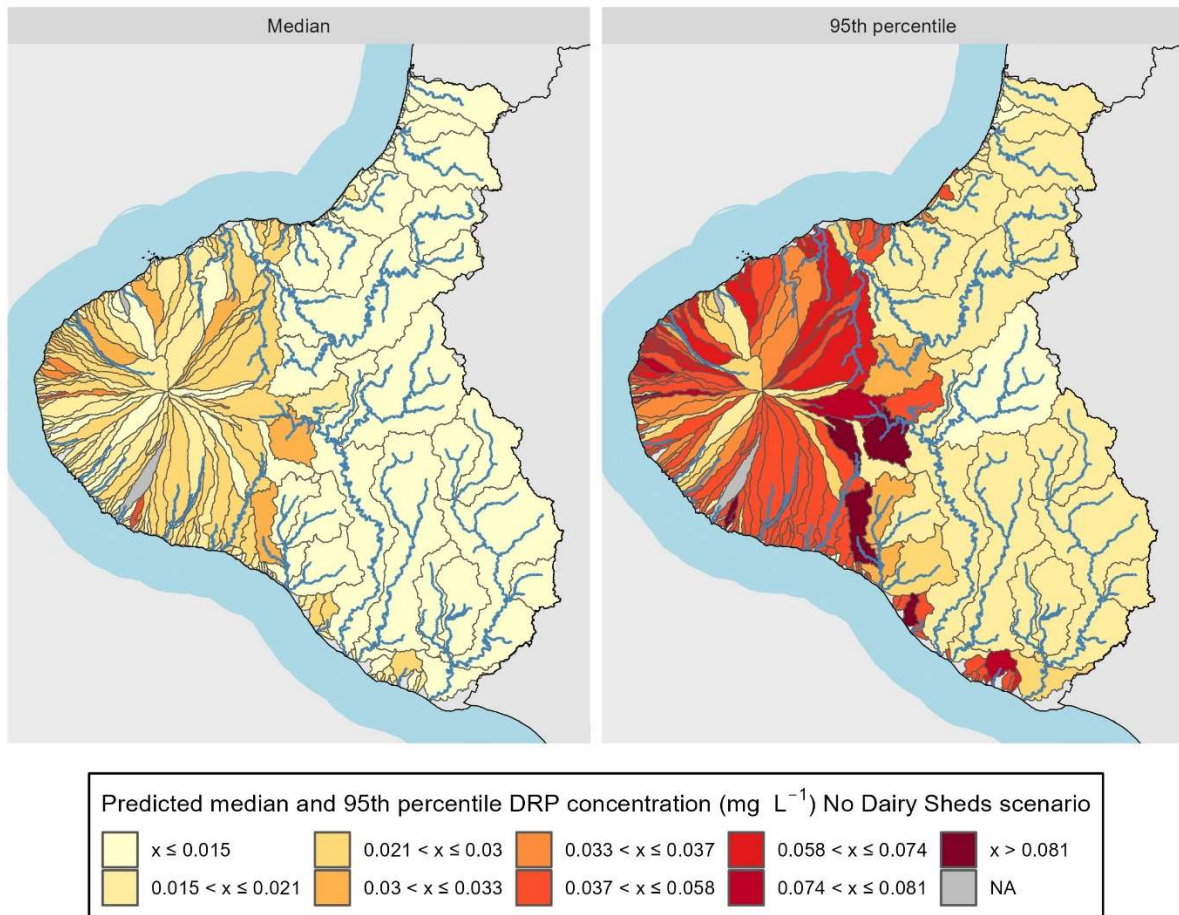


Figure 16. Modelled assessment point DRP concentrations. Scenario 3, no dairy shed discharges.

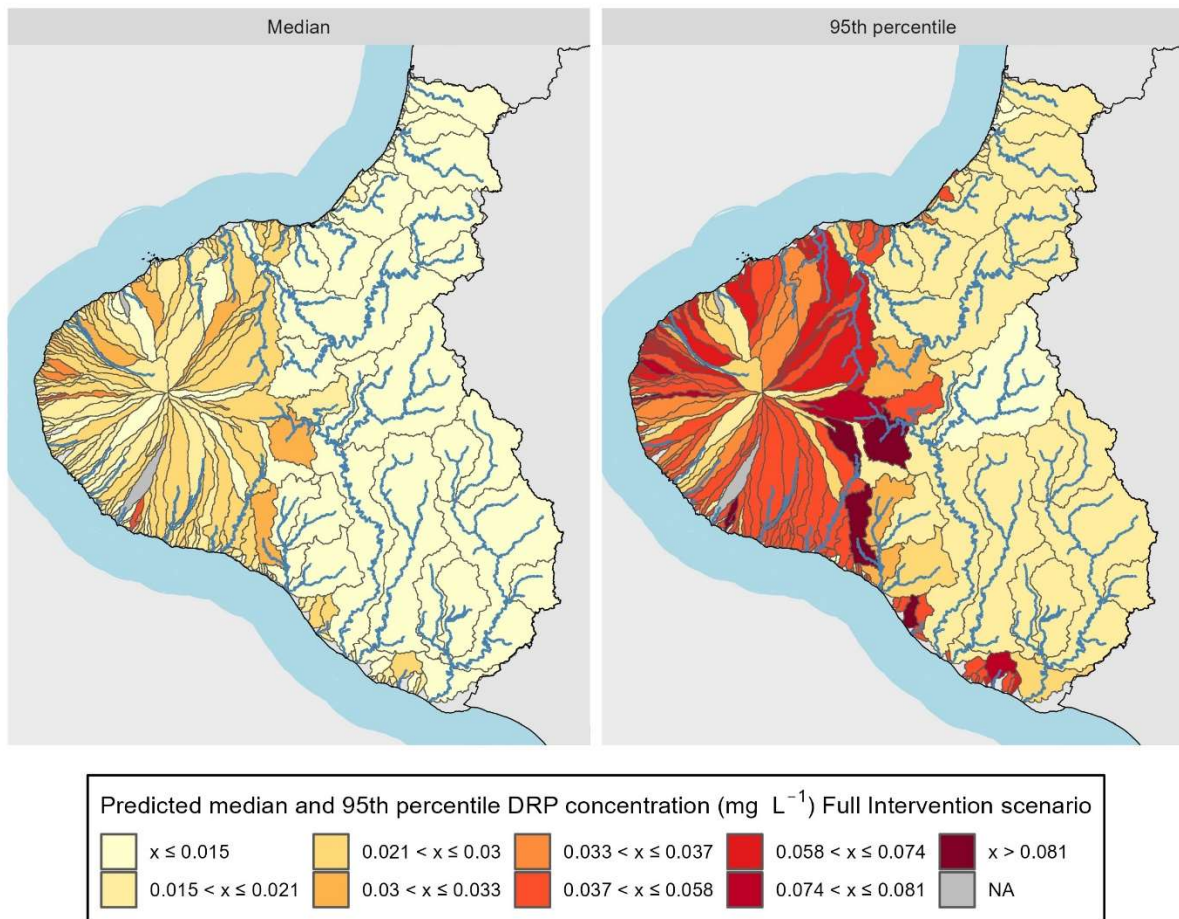


Figure 17. Modelled assessment point DRP concentrations. Scenario 4, full implementation of TRC interventions.

Table 1 Summary of Modelled Mean Annual Total Nitrogen Concentrations (g m^{-3}) at Water Quality Monitoring Stations (and % Reduction from Baseline).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.73	0.68 (7%)	0.58 (21%)	0.73 (0%)	0.72 (1%)
NIWA1 (WTR000800)	Waitara R.	0.85	0.68 (20%)	0.54 (36%)	0.83 (2%)	0.78 (8%)
MKW000300	Maketawa Str.	1.01	0.73 (28%)	0.57 (44%)	0.96 (5%)	0.90 (11%)
NIWA2 (MGN000195)	Manganui R.	0.31	0.19 (39%)	0.15 (52%)	0.29 (6%)	0.28 (10%)
WNR000450	Whenuakura R.	1.09	0.96 (12%)	0.76 (30%)	1.05 (4%)	1.03 (6%)
MGH000950	Mangaehu Str.	0.45	0.42 (7%)	0.36 (20%)	0.44 (2%)	0.44 (2%)
PAT000200	Patea R.	0.17	0.13 (24%)	0.11 (35%)	0.17 (0%)	0.17 (0%)
PAT000360	Patea R.	1.48	1.15 (22%)	0.92 (38%)	1.40 (6%)	1.32 (11%)
TWH000435	Tawhiti Stream	2.88	2.25 (22%)	1.68 (42%)	2.69 (7%)	2.50 (13%)
MRK000420	Mangaoraka R.	1.16	0.98 (16%)	0.68 (41%)	1.10 (5%)	1.01 (13%)
KPA000950	Kapoaiaia Stream	0.75	0.56 (25%)	0.41 (45%)	0.71 (5%)	0.64 (14%)
STY000300	Stony River (Hangatahua)	0.09	0.07 (21%)	0.05 (44%)	0.09 (0%)	0.09 (1%)
OKR000475	Oakura River	0.40	0.33 (18%)	0.25 (38%)	0.37 (8%)	0.36 (10%)
WKH000500	Waiwhakaiho R.	0.52	0.41 (21%)	0.33 (37%)	0.49 (6%)	0.47 (10%)
WGG000500	Waingongoro R.	1.70	1.33 (22%)	1.02 (40%)	1.59 (6%)	1.53 (10%)
WGG000620	Waingongoro R.	1.92	1.54 (20%)	1.23 (36%)	1.81 (6%)	1.74 (9%)
WGG000640	Waingongoro R.	1.99	1.59 (20%)	1.21 (39%)	1.86 (7%)	1.80 (10%)
NIWA3 (WGG000900)	Waingongoro R.	2.68	2.14 (20%)	1.59 (41%)	2.49 (7%)	2.36 (12%)
MWH000498	Eltham Trib.	2.13	1.69 (21%)	1.16 (46%)	1.97 (8%)	1.90 (11%)
PNH000200	Punehu Str.	0.23	0.18 (22%)	0.14 (39%)	0.23 (0%)	0.20 (13%)
PNH000900	Punehu Str.	1.63	1.27 (22%)	0.90 (45%)	1.52 (7%)	1.41 (13%)
KPK000920	Kaupokonui Stream	1.52	1.16 (24%)	0.91 (40%)	1.38 (9%)	1.28 (16%)

Table 2 Summary of Modelled Mean Annual Total Phosphorus Concentrations (g m⁻³) at Water Quality Monitoring Stations (and % Reduction from Baseline).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.32	0.29 (9%)	0.26 (19%)	0.32 (0%)	0.32 (0%)
NIWA1 (WTR000800)	Waitara R.	0.19	0.17 (11%)	0.15 (21%)	0.18 (5%)	0.18 (5%)
MKW000300	Maketawa Str.	0.079	0.075 (5%)	0.067 (15%)	0.067 (15%)	0.063 (20%)
NIWA2 (MGN000195)	Manganui R.	0.043	0.041 (5%)	0.038 (12%)	0.039 (9%)	0.038 (12%)
WNR000450	Whenuakura R.	0.30	0.27 (10%)	0.25 (17%)	0.29 (3%)	0.29 (3%)
MGH000950	Mangaehu Str.	0.10	0.079 (21%)	0.060 (40%)	0.10 (0%)	0.10 (0%)
PAT000200	Patea R.	0.030	0.030 (0%)	0.029 (0%)	0.030 (0%)	0.030 (0%)
PAT000360	Patea R.	0.11	0.102 (7%)	0.089 (19%)	0.091 (17%)	0.084 (24%)
TWH000435	Tawhiti Stream	0.12	0.10 (17%)	0.092 (23%)	0.075 (38%)	0.066 (46%)
MRK000420	Mangaoraka R.	0.060	0.057 (5%)	0.046 (23%)	0.043 (28%)	0.040 (33%)
KPA000950	Kapoaiaia Stream	0.060	0.060 (0%)	0.052 (13%)	0.055 (8%)	0.049 (25%)
STY000300	Stony River (Hangatahua)	0.048	0.048 (0%)	0.048 (0%)	0.048 (0%)	0.048 (0%)
OKR000475	Oakura River	0.022	0.020 (9%)	0.018 (18%)	0.015 (32%)	0.014 (37%)
WKH000500	Waiwhakaiho R.	0.080	0.078 (3%)	0.074 (8%)	0.072 (10%)	0.070 (13%)
WGG000500	Waingongoro R.	0.10	0.091 (9%)	0.074 (26%)	0.072 (28%)	0.065 (35%)
WGG000620	Waingongoro R.	0.14	0.13 (7%)	0.12 (14%)	0.12 (14%)	0.11 (21%)
WGG000640	Waingongoro R.	0.11	0.11 (0%)	0.10 (9%)	0.083 (25%)	0.078 (29%)
NIWA3 (WGG000900)	Waingongoro R.	0.10	0.099 (1%)	0.090 (10%)	0.055 (45%)	0.052 (48%)
MWH000498	Eltham Trib.	0.056	0.053 (5%)	0.050 (11%)	0.015 (73%)	0.015 (73%)
PNH000200	Punehu Str.	0.040	0.038 (5%)	0.034 (15%)	0.040 (0%)	0.037 (8%)
PNH000900	Punehu Str.	0.064	0.061 (5%)	0.056 (13%)	0.037 (42%)	0.033 (48%)
KPK000920	Kaupokonui Stream	0.073	0.071 (3%)	0.063 (14%)	0.037 (55%)	0.035 (53%)

Table 3 Summary of Modelled Median Nitrate Concentrations (g m^{-3}) at Water Quality Monitoring Stations (note: % reductions from baseline are equivalent to those in Table 1).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.23	0.22	0.18	0.23	0.23
NIWA1 (WTR000800)	Waitara R.	0.34	0.27	0.22	0.33	0.31
MKW000300	Maketawa Str.	0.51	0.37	0.29	0.49	0.45
NIWA2 (MGN000195)	Manganui R.	0.14	0.09	0.07	0.13	0.13
WNR000450	Whenuakura R.	0.40	0.36	0.28	0.39	0.38
MGH000950	Mangaehu Str.	0.10	0.09	0.08	0.10	0.10
PAT000200	Patea R.	0.03	0.02	0.02	0.03	0.03
PAT000360	Patea R.	0.99	0.77	0.61	0.94	0.88
TWH000435	Tawhiti Stream	1.95	1.52	1.14	1.82	1.69
MRK000420	Mangaoraka R.	0.77	0.65	0.45	0.73	0.67
KPA000950	Kapoaiaia Stream	0.37	0.28	0.20	0.35	0.32
STY000300	Stony River (Hangatahua)	0.02	0.02	0.01	0.02	0.02
OKR000475	Oakura River	0.17	0.14	0.10	0.16	0.15
WKH000500	Waiwhakaiho R.	0.19	0.15	0.12	0.18	0.17
WGG000500	Waingongoro R.	1.31	1.02	0.78	1.22	1.17
WGG000620	Waingongoro R.	1.45	1.17	0.93	1.37	1.32
WGG000640	Waingongoro R.	1.39	1.12	0.85	1.31	1.26
NIWA3 (WGG000900)	Waingongoro R.	1.85	1.47	1.09	1.71	1.63
MWH000498	Eltham Trib.	1.45	1.15	0.79	1.34	1.29
PNH000200	Punehu Str.	0.05	0.04	0.03	0.05	0.05
PNH000900	Punehu Str.	0.85	0.66	0.47	0.79	0.73
KPK000920	Kaupokonui Stream	0.94	0.72	0.56	0.85	0.79

Table 4 Summary of Modelled Median DRP Concentrations (g m^{-3}) at Water Quality Monitoring Stations (note: % reductions from baseline are equivalent to those in Table 2).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.014	0.012	0.011	0.014	0.014
NIWA1 (WTR000800)	Waitara R.	0.006	0.006	0.005	0.006	0.006
MKW000300	Maketawa Str.	0.038	0.037	0.033	0.033	0.031
NIWA2 (MGN000195)	Manganui R.	0.016	0.015	0.014	0.014	0.014
WNR000450	Whenuakura R.	0.021	0.019	0.017	0.020	0.020
MGH000950	Mangaehu Str.	0.005	0.004	0.003	0.005	0.005
PAT000200	Patea R.	0.026	0.025	0.024	0.026	0.026
PAT000360	Patea R.	0.050	0.047	0.041	0.041	0.038
TWH000435	Tawhiti Stream	0.025	0.021	0.019	0.015	0.014
MRK000420	Mangaoraka R.	0.014	0.013	0.011	0.010	0.009
KPA000950	Kapoiaia Stream	0.026	0.024	0.021	0.022	0.019
STY000300	Stony River (Hangatahua)	0.011	0.011	0.011	0.011	0.011
OKR000475	Oakura River	0.004	0.004	0.003	0.003	0.002
WKH000500	Waiwhakaiho R.	0.048	0.047	0.044	0.043	0.042
WGG000500	Waingongoro R.	0.038	0.035	0.029	0.028	0.025
WGG000620	Waingongoro R.	0.058	0.055	0.048	0.048	0.044
WGG000640	Waingongoro R.	0.045	0.042	0.038	0.033	0.031
NIWA3 (WGG000900)	Waingongoro R.	0.038	0.036	0.033	0.020	0.019
MWH000498	Eltham Trib.	0.013	0.012	0.011	0.003	0.003
PNH000200	Punehu Str.	0.019	0.018	0.016	0.019	0.017
PNH000900	Punehu Str.	0.028	0.026	0.024	0.016	0.014
KPK000920	Kaupokonui Stream	0.028	0.028	0.024	0.014	0.013

Table 5 Summary of Modelled 95th Percentile Nitrate Concentrations (g m^{-3}) at Water Quality Monitoring Stations (note: % reductions from baseline are equivalent to those in Table 1).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.40	0.37	0.31	0.40	0.39
NIWA1 (WTR000800)	Waitara R.	0.78	0.63	0.50	0.76	0.72
MKW000300	Maketawa Str.	1.06	0.77	0.60	1.02	0.95
NIWA2 (MGN000195)	Manganui R.	0.38	0.24	0.19	0.36	0.34
WNR000450	Whenuakura R.	0.65	0.57	0.45	0.63	0.62
MGH000950	Mangaehu Str.	0.22	0.21	0.17	0.22	0.21
PAT000200	Patea R.	0.06	0.05	0.04	0.06	0.06
PAT000360	Patea R.	1.27	0.99	0.79	1.20	1.13
TWH000435	Tawhiti Stream	2.59	2.02	1.51	2.42	2.24
MRK000420	Mangaoraka R.	1.00	0.84	0.59	0.94	0.87
KPA000950	Kapoaiaia Stream	1.13	0.85	0.62	1.07	0.97
STY000300	Stony River (Hangatahua)	0.06	0.05	0.04	0.06	0.06
OKR000475	Oakura River	0.29	0.23	0.18	0.27	0.26
WKH000500	Waiwhakaiho R.	0.41	0.33	0.26	0.39	0.37
WGG000500	Waingongoro R.	1.86	1.46	1.12	1.75	1.67
WGG000620	Waingongoro R.	2.18	1.75	1.40	2.06	1.98
WGG000640	Waingongoro R.	2.11	1.69	1.29	1.98	1.91
NIWA3 (WGG000900)	Waingongoro R.	2.63	2.09	1.55	2.44	2.31
MWH000498	Eltham Trib.	1.80	1.43	0.98	1.66	1.60
PNH000200	Punehu Str.	0.11	0.09	0.07	0.11	0.10
PNH000900	Punehu Str.	1.61	1.26	0.89	1.50	1.39
KPK000920	Kaupokonui Stream	1.50	1.14	0.90	1.35	1.26

Table 6 Summary of Modelled 95th Percentile DRP Concentrations (g m^{-3}) at Water Quality Monitoring Stations (note: % reductions from baseline are equivalent to those in Table 2).

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	0.025	0.023	0.021	0.025	0.025
NIWA1 (WTR000800)	Waitara R.	0.020	0.018	0.017	0.019	0.019
MKW000300	Maketawa Str.	0.070	0.066	0.060	0.059	0.056
NIWA2 (MGN000195)	Manganui R.	0.025	0.024	0.022	0.023	0.022
WNR000450	Whenuakura R.	0.031	0.028	0.026	0.030	0.030
MGH000950	Mangaehu Str.	0.009	0.007	0.005	0.009	0.009
PAT000200	Patea R.	0.045	0.044	0.042	0.045	0.045
PAT000360	Patea R.	0.100	0.093	0.081	0.083	0.077
TWH000435	Tawhiti Stream	0.041	0.034	0.031	0.025	0.022
MRK000420	Mangaoraka R.	0.035	0.033	0.027	0.025	0.023
KPA000950	Kapoaiaia Stream	0.054	0.050	0.044	0.046	0.041
STY000300	Stony River (Hangatahua)	0.014	0.014	0.014	0.014	0.014
OKR000475	Oakura River	0.023	0.021	0.019	0.016	0.014
WKH000500	Waiwhakaiho R.	0.082	0.079	0.075	0.073	0.071
WGG000500	Waingongoro R.	0.063	0.058	0.047	0.046	0.041
WGG000620	Waingongoro R.	0.379	0.356	0.312	0.309	0.289
WGG000640	Waingongoro R.	0.210	0.198	0.175	0.153	0.144
NIWA3 (WGG000900)	Waingongoro R.	0.063	0.060	0.055	0.033	0.032
MWH000498	Eltham Trib.	0.031	0.029	0.028	0.008	0.008
PNH000200	Punehu Str.	0.036	0.035	0.031	0.036	0.034
PNH000900	Punehu Str.	0.053	0.050	0.046	0.030	0.027
KPK000920	Kaupokonui Stream	0.061	0.059	0.052	0.030	0.029

Table 7 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) (and % Reduction from Baseline) at Water Quality Monitoring Stations, Unshaded.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	114	111 (2%)	108 (5%)	114 (0%)	113 (0%)
NIWA1 (WTR000800)	Waitara R.	83	81 (2%)	79 (4%)	82 (1%)	82 (1%)
MKW000300	Maketawa Str.	73	70 (3%)	68 (6%)	72 (1%)	71 (2%)
NIWA2 (MGN000195)	Manganui R.	59	56 (4%)	56 (5%)	58 (1%)	58 (2%)
WNR000450	Whenuakura R.	117	114 (2%)	110 (6%)	116 (1%)	116 (1%)
MGH000950	Mangaehu Str.	92	88 (4%)	84 (8%)	92 (0%)	92 (0%)
PAT000200	Patea R.	59	59 (1%)	59 (2%)	59 (0%)	59 (0%)
PAT000360	Patea R.	123	119 (3%)	115 (7%)	120 (3%)	118 (4%)
TWH000435	Tawhiti Stream	131	123 (6%)	118 (10%)	123 (6%)	120 (8%)
MRK000420	Mangaoraka R.	107	104 (2%)	97 (9%)	102 (5%)	100 (6%)
KPA000950	Kapoaiaia Stream	67	65 (4%)	62 (8%)	66 (2%)	64 (5%)
STY000300	Stony River (Hangatahua)	53	52 (1%)	52 (2%)	53 (0%)	53 (0%)
OKR000475	Oakura River	57	56 (2%)	55 (4%)	55 (4%)	54 (5%)
WKH000500	Waiwhakaiho R.	68	66 (2%)	65 (3%)	67 (1%)	66 (2%)
WGG000500	Waingongoro R.	122	118 (4%)	112 (8%)	117 (4%)	115 (6%)
WGG000620	Waingongoro R.	130	126 (3%)	121 (7%)	125 (3%)	124 (5%)
WGG000640	Waingongoro R.	127	123 (3%)	117 (7%)	121 (4%)	120 (6%)
NIWA3 (WGG000900)	Waingongoro R.	130	125 (4%)	119 (8%)	120 (8%)	118 (9%)
MWH000498	Eltham Trib.	116	113 (3%)	107 (8%)	100 (14%)	100 (14%)
PNH000200	Punehu Str.	88	86 (2%)	84 (4%)	88 (0%)	86 (2%)
PNH000900	Punehu Str.	114	110 (3%)	106 (7%)	105 (8%)	103 (9%)
KPK000920	Kaupokonui Stream	115	111 (3%)	108 (6%)	104 (9%)	103 (10%)

Table 8 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) at Water Quality Monitoring Stations, Shaded.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	91	89 (2%)	87 (5%)	91 (0%)	91 (0%)
NIWA1 (WTR000800)	Waitara R.	68	66 (3%)	65 (5%)	68 (1%)	67 (1%)
MKW000300	Maketawa Str.	59	57 (3%)	56 (5%)	58 (2%)	56 (5%)
NIWA2 (MGN000195)	Manganui R.	50	49 (2%)	48 (4%)	50 (0%)	49 (1%)
WNR000450	Whenuakura R.	91	89 (2%)	87 (5%)	90 (1%)	90 (1%)
MGH000950	Mangaehu Str.	73	71 (2%)	69 (6%)	73 (0%)	73 (0%)
PAT000200	Patea R.	51	50 (1%)	50 (2%)	51 (0%)	51 (0%)
PAT000360	Patea R.	98	94 (4%)	88 (10%)	94 (4%)	92 (6%)
TWH000435	Tawhiti Stream	105	97 (8%)	92 (12%)	97 (8%)	94 (10%)
MRK000420	Mangaoraka R.	81	78 (4%)	75 (7%)	77 (5%)	76 (6%)
KPA000950	Kapoiaia Stream	54	54 (1%)	53 (3%)	53 (1%)	53 (2%)
STY000300	Stony River (Hangatahua)	46	45 (1%)	45 (2%)	46 (0%)	46 (0%)
OKR000475	Oakura River	49	49 (1%)	48 (3%)	48 (2%)	48 (3%)
WKH000500	Waiwhakaiho R.	57	56 (2%)	55 (3%)	56 (2%)	56 (2%)
WGG000500	Waingongoro R.	96	92 (4%)	85 (11%)	91 (5%)	89 (7%)
WGG000620	Waingongoro R.	104	100 (4%)	95 (8%)	100 (4%)	98 (6%)
WGG000640	Waingongoro R.	101	97 (4%)	92 (9%)	95 (6%)	94 (7%)
NIWA3 (WGG000900)	Waingongoro R.	104	99 (5%)	93 (10%)	94 (9%)	93 (10%)
MWH000498	Eltham Trib.	91	87 (4%)	83 (9%)	80 (12%)	79 (13%)
PNH000200	Punehu Str.	69	68 (2%)	66 (5%)	69 (0%)	68 (2%)
PNH000900	Punehu Str.	88	85 (3%)	80 (9%)	81 (8%)	80 (9%)
KPK000920	Kaupokonui Stream	89	86 (3%)	81 (8%)	81 (9%)	80 (10%)

Table 9 Summary of Modelled Lake Rotorangi Water Quality (and % Reduction from Baseline).

Lake Water Quality Parameter	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
TN (g m ⁻³)	0.73	0.66 (10%)	0.50 (32%)	0.72 (1%)	0.7 (4%)
TP (g m ⁻³)	0.038	0.034 (11%)	0.030 (21%)	0.037 (3%)	0.036 (5%)
phytoplankton, as chl-a (mg m ⁻³)	4.4	3.9 (11%)	3.4 (23%)	4.3 (2%)	4.2 (5%)
trophic level index (TLI)	4.53	4.44	4.16	4.51	4.49
trophic status	eutrophic	eutrophic	eutrophic	eutrophic	eutrophic

3. Conclusions

Model simulations of a suite of farm nutrient mitigation options reveal the potential for significant water quality gains from the implementation of known and projected on-farm developing management strategies and from the elimination of direct discharges of dairy shed effluent. Marginal gains have also been quantified for the completion of ongoing farm stream fencing and planting programmes. Total nitrogen concentration reductions of up to 50%, compared to current conditions, have been simulated for some sites in the region. Maximum simulated total phosphorus concentration reductions were greater than 70% for some sites, and maximum simulated periphyton biomass reductions were approximately 15%. Based on these results, the farm mitigation options simulated here will likely need to be a key feature of any comprehensive regional nutrient management strategy.

References

Cox, T., T. Kerr, T. Snelder, and C. Fraser, 2022. Taranaki region catchment nutrient models: supporting regional land and water management. Technical Report, Taranaki Regional Council, Stratford, New Zealand.

Fraser, C., and T. Snelder, 2020. Relationships between instream concentrations and river nutrient loads. Technical Report prepared for Dairy New Zealand and Horizons Regional Council.

McDowell, R. W., R. Monaghan, C. Smith, A. Manderson, L. Basher, D. Burger, S. Laurenson, P. Pletnyakov, R. Spiekermann and C. Depree, 2021. Quantifying contaminant losses to water from pastoral land uses in New Zealand III. What could be achieved by 2035? New Zealand Journal of Agricultural Research, DOI: 10.1080/00288233.2020.1844763.

McKergow, L., F. Matheson, B. Moore, and B. Woodward, 2022. Riparian buffer design guide, water quality design and performance estimates. (No. NIWA Information Series 103). NIWA, Hamilton.

Monaghan, R., A. Manderson, L. Basher, R. Spiekermann, J. Dymond, C. Smith, R. Muirhead, D. Burger, and R. McDowell, 2021. Quantifying contaminant losses to water from pastoral landuses in New Zealand II. The effects of some farm mitigation actions over the past two decades. New Zealand Journal of Agricultural Research 64, 365–389.
<https://doi.org/10.1080/00288233.2021.1876741>

New Zealand Ministry for the Environment (MFE). 2020. National Policy Statement for Freshwater Management.

Oehler, F. and A.H. Elliott, 2011. Predicting stream N and P concentrations from loads and catchment characteristics at regional scale: a concentration ratio method. Science of the Total Environment 409: 5392–5402.

Snelder, T. and C. Kilroy, 2023. Revised nutrient criteria for periphyton biomass objectives. Updating criteria referred to in Ministry for Environment 2022 guidance. LWP Client Report, LWP and NIWA Ltd, Christchurch, New Zealand.

Snelder, T, H. Smith, D. Plew, and C. Fraser (2023). Nitrogen, phosphorus, sediment and Escherichia coli in New Zealand's aquatic receiving environments: Comparison of current state to national bottom lines. LWP Client Report 2023–06. LWP Ltd, Christchurch, New Zealand.

Appendix A. Stream Periphyton Calculations

The SCAMP periphyton module is based on nutrient criteria to achieve periphyton biomass objectives described by Snelder *et al.* (2023). The criteria are presented as look-up tables for stream nutrient (TN and TP) concentrations thresholds, defined as median concentrations, to achieve National Objective Framework (NOF) periphyton attribute bands. The criteria are defined for each of 21 River Environment Classification (REC) Source-of-Flow (SOF) classes (Snelder and Biggs, 2002) and for designated stream shade status (shaded or unshaded). The look-up tables are based on statistical analysis of data collected at 251 monitoring sites across New Zealand. SOF class designations are available for all New Zealand rivers based on the REC. SOF classes account for differences between rivers in the drivers of periphyton biomass to nutrient concentration that are attributable to differences in factors such as flow regime, temperature and light. Snelder *et al.* (2023) recommend that the criteria are applied to third order rivers or higher because few of the 251 sites in the dataset were located on streams of order less than three.

Each NOF attribute band is associated with thresholds defined by periphyton biomass concentration (g m^{-2}) (Table). These thresholds are applied to the 92nd percentile of observed periphyton concentrations. In other words, for regulatory purposes, if the 92nd percentile of observed periphyton concentrations lies between the thresholds shown in Table A-1, then the site is assigned to the associated NOF band. Snelder *et al.* (2023) provide nutrient concentration criteria for a range of levels of “under-protection risk”. The under-protection risk can be interpreted as the probability of exceeding a given periphyton band threshold despite being compliant with the nutrient concentration criteria. These risks were derived by Snelder *et al.* (2023) and reflect the quantified uncertainty associated with the underlying statistical models.

In SCAMP, the Snelder *et al.* (2023) criteria are implemented with separate look up tables for modelled TN and TP concentrations, as shown by the example in A-2. For each location of interest, defined by the user, the modelled instream median nutrient concentration is translated into an estimated probability of membership of each of the NOF periphyton attribute states (i.e., probability the state is A, B, C or D band. Linear interpolation of the lookup tables is used to calculate the probability that each of the NOF band’s upper thresholds are exceeded, given the modelled nutrient concentration. Model output is expressed as exceedance percentages for each NOF periphyton attribute band. In other words, the model estimates the likelihood (as a percentage) that the 92nd percentile periphyton concentration will exceed each upper threshold for each NOF band periphyton based on the modelled nutrient concentration.

As a second set of periphyton output, the model estimates the “expected value” of the 92nd percentile periphyton concentration (mg m^{-2}). Expected value is, conceptually, defined as the most likely observed value (in this case the most likely 92nd percentile value) given the calculated probabilities. Mathematically, the expected value is the weighted average of the possible outcomes, with the weightings equal to assigned probabilities associated with each outcome. For discrete random variables, the calculation can be written as:

$$E(X) = \sum_{i=1}^n x_i p_i, \quad \text{Equation A-1}$$

Where $E(X)$ = the expected value of the random variable, x_i = value of random value (in this case, 92nd percentile periphyton concentration), p_i = probability associated with given random variable value (x_i). In SCAMP, Equation A-1 is solved using the three quantified exceedance percentages. Since exceedance percentages represent *cumulative* probabilities, they are firstly translated into

discrete probabilities (p_i) in the model, before applying Equation A-1, by disaggregating the implied cumulative distribution function using incremental changes in the calculated exceedance percentages.

All model outputs are provided for each assessment point and assuming both shaded and unshaded reach conditions (i.e., two sets of probabilities).

Note that stream periphyton calculations in SCAMP are performed for TN and TP separately. The utilised look up tables are specific to TN and TP independently. Dual nutrient periphyton models are not available in SCAMP currently. Consequently, periphyton output can be generated for one, or both (separately), of the modelled nutrients. No interpretation is provided for inconsistent results (TN-based vs. TP-based). For the TRC scenario simulations described here, the average of the two periphyton output sets is presented, to include the influence of both nutrients and, importantly, the modelled changes in each nutrient.

Table A-1. NOF periphyton attribute band thresholds (mg m⁻²). The thresholds are applied to the 92nd percentile of monthly periphyton (represented by x).

Band A	Band B	Band C	Band D
$x \leq 50$	$50 < x \leq 120$	$120 < x \leq 200$	$x > 200$

Table A-2. Example SCAMP periphyton – TN look up table (partial).

SOF Class	Exceedance Probability	Median TN Threshold (mg L⁻¹)					
		Unshaded Band A	Unshaded Band B	Unshaded Band C	Shaded Band A	Shaded Band B	Shaded Band C
CD/H	5	0.001	0.057	0.91	0.003	0.258	2.32
CD/H	10	0.003	0.223	2.16	0.012	0.787	3.58
CD/H	15	0.006	0.497	3.05	0.030	1.49	4.13
CD/H	20	0.013	0.858	3.67	0.063	2.24	4.37
CD/H	30	0.045	1.88	4.28	0.206	3.36	4.48
CD/H	50	0.305	3.69	4.50	0.998	4.37	4.50
CD/H	70	1.33	4.43	4.50	2.87	4.50	4.50
CD/H	80	2.52	4.50	4.50	3.83	4.50	4.50
CD/H	90	3.88	4.50	4.50	4.42	4.50	4.50
CD/H	95	4.39	4.50	4.50	4.50	4.50	4.50
CD/L	5	0.001	0.007	0.182	0.001	0.036	0.806
CD/L	10	0.001	0.031	0.694	0.002	0.147	2.14
CD/L	15	0.001	0.079	1.48	0.004	0.368	2.96
CD/L	20	0.002	0.164	2.25	0.008	0.744	3.53
CD/L	30	0.006	0.533	3.27	0.028	1.85	4.16
CD/L	50	0.042	2.28	4.30	0.200	3.56	4.49
CD/L	70	0.3	3.81	4.50	1.26	4.38	4.50
CD/L	80	0.929	4.31	4.50	2.48	4.49	4.50
CD/L	90	2.55	4.50	4.50	3.76	4.50	4.50
CD/L	95	3.62	4.50	4.50	4.33	4.50	4.50

Appendix B. Modeled Periphyton Biomass Expected Value: Detailed Output

Table B-1 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) at Water Quality Monitoring Stations, Unshaded, TP Model only.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	119	116	114	119	119
NIWA1 (WTR000800)	Waitara R.	86	85	83	86	85
MKW000300	Maketawa Str.	75	74	73	73	73
NIWA2 (MGN000195)	Manganui R.	62	61	60	60	60
WNR000450	Whenuakura R.	127	124	122	126	126
MGH000950	Mangaehu Str.	97	91	85	97	97
PAT000200	Patea R.	67	67	66	67	67
PAT000360	Patea R.	127	124	120	121	119
TWH000435	Tawhiti Stream	124	118	116	111	108
MRK000420	Mangaoraka R.	102	100	95	93	91
KPA000950	Kapoaiaia Stream	67	66	64	65	63
STY000300	Stony River (Hangatahua)	56	56	56	56	56
OKR000475	Oakura River	56	55	54	52	51
WKH000500	Waiwhakaiho R.	75	75	74	74	74
WGG000500	Waingongoro R.	121	118	113	112	110
WGG000620	Waingongoro R.	133	131	127	126	124
WGG000640	Waingongoro R.	126	124	120	116	115
NIWA3 (WGG000900)	Waingongoro R.	121	120	117	105	103
MWH000498	Eltham Trib.	105	104	102	75	75
PNH000200	Punehu Str.	98	97	94	98	97
PNH000900	Punehu Str.	109	107	105	94	91
KPK000920	Kaupokonui Stream	111	111	107	93	92

Table B-2 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) at Water Quality Monitoring Stations, Unshaded, TN Model only.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	89	87	85	88	88
NIWA1 (WTR000800)	Waitara R.	79	77	75	79	78
MKW000300	Maketawa Str.	70	66	63	70	69
NIWA2 (MGN000195)	Manganui R.	56	52	51	56	55
WNR000450	Whenuakura R.	107	104	98	107	106
MGH000950	Mangaehu Str.	86	86	83	86	86
PAT000200	Patea R.	52	51	51	52	52
PAT000360	Patea R.	120	114	110	119	117
TWH000435	Tawhiti Stream	139	129	120	136	132
MRK000420	Mangaoraka R.	111	108	100	110	109
KPA000950	Kapoaiaia Stream	67	64	60	67	65
STY000300	Stony River (Hangatahua)	49	48	47	49	49
OKR000475	Oakura River	58	57	55	58	58
WKH000500	Waiwhakaiho R.	60	58	56	59	59
WGG000500	Waingongoro R.	123	117	111	121	120
WGG000620	Waingongoro R.	126	120	115	124	123
WGG000640	Waingongoro R.	127	121	114	126	124
NIWA3 (WGG000900)	Waingongoro R.	138	129	121	135	133
MWH000498	Eltham Trib.	128	121	112	125	124
PNH000200	Punehu Str.	77	75	73	77	76
PNH000900	Punehu Str.	118	113	107	116	115
KPK000920	Kaupokonui Stream	118	112	108	115	114

Table B-3 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) at Water Quality Monitoring Stations, Shaded, TP Model only.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	96	94	91	96	96
NIWA1 (WTR000800)	Waitara R.	72	71	70	71	71
MKW000300	Maketawa Str.	63	62	60	60	60
NIWA2 (MGN000195)	Manganui R.	52	52	51	51	51
WNR000450	Whenuakura R.	105	102	99	104	104
MGH000950	Mangaehu Str.	76	74	71	76	76
PAT000200	Patea R.	56	56	55	56	56
PAT000360	Patea R.	105	103	98	99	96
TWH000435	Tawhiti Stream	102	95	93	88	86
MRK000420	Mangaoraka R.	82	77	75	75	74
KPA000950	Kapoiaia Stream	56	56	55	55	54
STY000300	Stony River (Hangatahua)	49	49	49	49	49
OKR000475	Oakura River	49	49	48	47	47
WKH000500	Waiwhakaiho R.	63	63	62	62	61
WGG000500	Waingongoro R.	99	96	91	90	87
WGG000620	Waingongoro R.	112	110	105	105	102
WGG000640	Waingongoro R.	104	102	98	94	92
NIWA3 (WGG000900)	Waingongoro R.	99	98	95	84	83
MWH000498	Eltham Trib.	84	83	82	64	64
PNH000200	Punehu Str.	77	76	75	77	76
PNH000900	Punehu Str.	87	86	84	75	74
KPK000920	Kaupokonui Stream	89	88	86	75	74

Table B-4 Summary of Modelled 92nd Percentile Periphyton Biomass Expected Value (mg m⁻²) at Water Quality Monitoring Stations, Shaded, TN Model only.

Station Name	Stream Name	Baseline	Scenario 1: 2015 Established Farm Mitigations	Scenario 2: 2035 Established+ Developing Farm Mitigations	Scenario 3: No Dairy Shed Discharges	Scenario 4: Full TRC Interventions
WTR000540	Waitara R.	70	70	68	70	70
NIWA1 (WTR000800)	Waitara R.	65	62	59	64	63
MKW000300	Maketawa Str.	55	52	51	55	53
NIWA2 (MGN000195)	Manganui R.	48	46	45	48	48
WNR000450	Whenuakura R.	77	76	74	77	77
MGH000950	Mangaehu Str.	69	69	66	69	69
PAT000200	Patea R.	46	45	44	46	46
PAT000360	Patea R.	90	85	79	89	88
TWH000435	Tawhiti Stream	108	99	90	105	102
MRK000420	Mangaoraka R.	80	78	75	79	78
KPA000950	Kapoiaia Stream	52	51	51	52	52
STY000300	Stony River (Hangatahua)	42	41	40	42	42
OKR000475	Oakura River	50	49	47	49	49
WKH000500	Waiwhakaiho R.	50	49	48	50	50
WGG000500	Waingongoro R.	93	88	80	92	91
WGG000620	Waingongoro R.	96	91	86	95	94
WGG000640	Waingongoro R.	98	92	86	96	95
NIWA3 (WGG000900)	Waingongoro R.	108	99	91	105	103
MWH000498	Eltham Trib.	98	92	84	96	95
PNH000200	Punehu Str.	62	60	57	62	61
PNH000900	Punehu Str.	89	84	77	88	86
KPK000920	Kaupokonui Stream	89	84	77	87	85