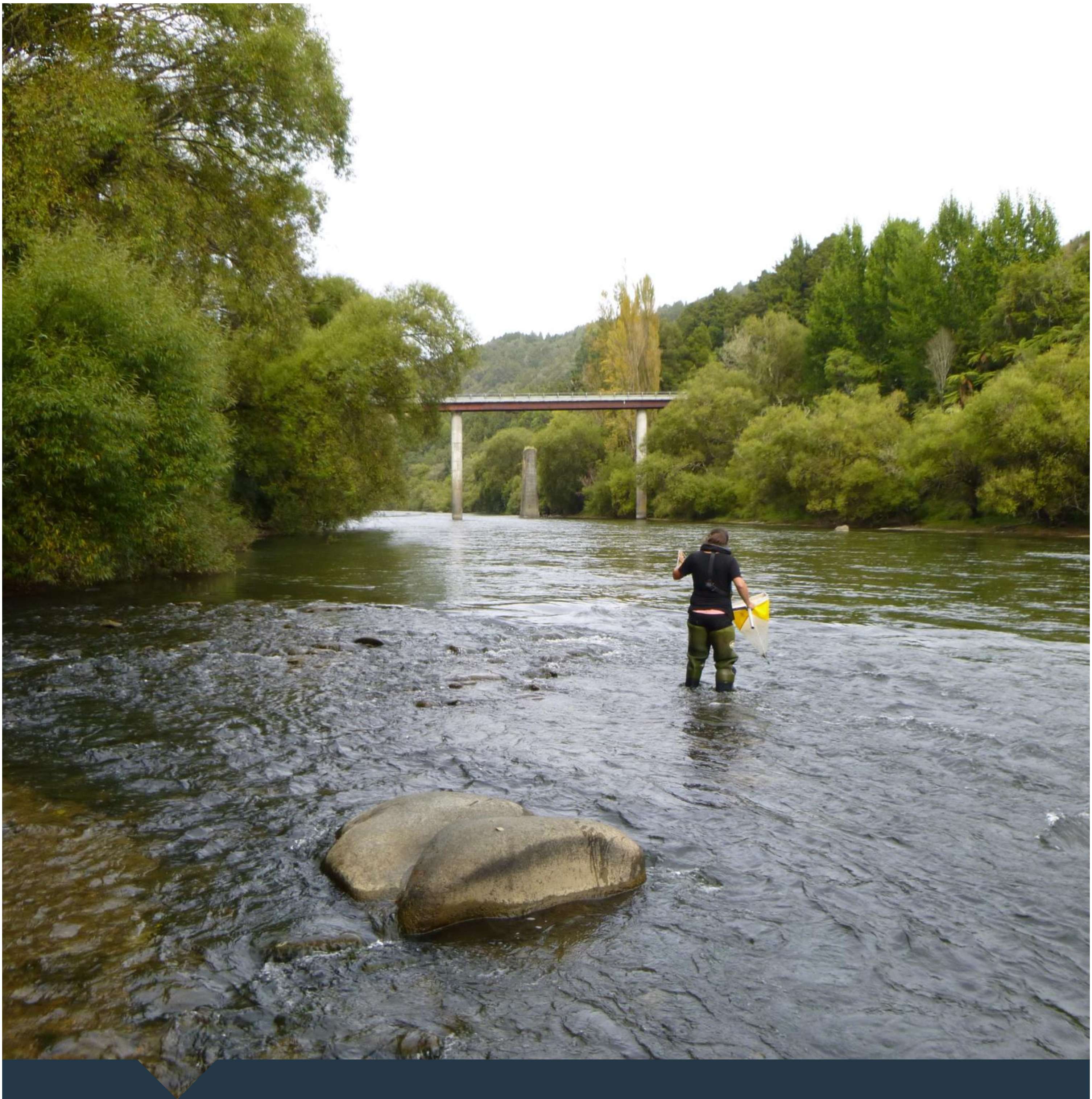


Manawatū-Whanganui Region Catchment Nutrient Models: Scenario Simulations

Supporting Regional Land and Water Management

November 2023

horizons
REGIONAL COUNCIL

Prepared for:

Maree Patterson
Acting Science Manager

November 2023
Report No. 2024/EXT1841
ISBN 978-1-99-106156-0

Prepared by:

Tim Cox
RMA Science Ltd

Tim Kerr
Ton Snelder
Caroline Fraser
LWP Ltd

CONTACT 24 hr freephone 0508 800 80 Help@horizons.govt.nz www.horizons.govt.nz

SERVICE CENTRES	Kairanga Cnr Rongotea and Kairanga-Bunnythorpe Roads Palmerston North Marton 19 Hammon Street Taumarunui 34 Maata Street	REGIONAL HOUSES	Palmerston North 11-15 Victoria Avenue Whanganui 181 Guyton Street	DEPOTS	Taihape 243 Wairanu Road Taihape Woodville 116 Vogel Street

POSTAL ADDRESS Horizons Regional Council, Private Bag 11025, Manawatū Mail Centre, Palmerston North 4442

F 06-952 2929

RMA Science
Good decisions, good science
Hamilton
New Zealand

LWP
landwaterpeople

Manawatū-Whanganui Region Catchment Nutrient Models: Scenario Simulations

Supporting Regional Land and Water Management

November 2023

Prepared By:

Tim Cox[1]

Tim Kerr[2]

Ton Snelder[2]

Caroline Fraser[2]

1. RMA Science Ltd
2. LWP 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

LWP Client Report Number:	2023-10
Report Date:	November 2023

Quality Assurance Statement

Version	Reviewed By	
Final	Oliver Floerl	

Table of Contents

Figures

Tables

Appended Tables

List of Abbreviations and Acronyms

Abbreviation	Full Name	Description
FMU	Freshwater Management Unit	As per National Policy Statement (2014), "A water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management."
WMSZ	Water Management Subzone	A sub-catchment delineated by Horizons Regional Council for planning, management, and monitoring purposes.
SCAMP	Simplified Contaminant Allocation Modelling Platform	Catchment modelling software
TN	Total Nitrogen	Includes both dissolved and particulate forms of nitrogen
TP	Total Phosphorus	Includes both dissolved and particulate form of phosphorus

Executive Summary

This report describes the application of previously developed catchment water quality models (Cox et al. 2022a, b) to simulate receiving water quality impacts of a suite of potential contaminant mitigation actions. In this study, five sets of simulation scenarios were used to explore mitigation strategies focused on pastoral farm management, horticulture farm management, and point source discharge load reduction. Four separate catchment models were used for the simulations, representing the region's four major river basins: the Manawatū (including the Horowhenua and Coastal Tararua catchments), the Rangitīkei, the Whanganui, and the Whangaehu (including the Turakina River catchment). The entire region is encompassed by the four models. In addition, a fifth model, focused only on the Waiopehu freshwater management unit (FMU) and Lake Horowhenua, was used to explore contaminant mitigation strategies specific to commercial vegetable growing. The models were updated, as part of this study, to more accurately represent current point source discharge loads, commercial vegetable growing nitrogen loss rates, and sources of nutrient load to Lake Horowhenua.

Simulation results demonstrate the potential for significant improvements in water quality throughout the region with the implementation of the simulated mitigation options. For example, full implementation of established and developing pastoral farm mitigation options, combined with planned point source discharge reductions, were projected to reduce total nitrogen and total phosphorus stream concentrations by approximately 20 – 30% on average throughout the region, and exceeded 40% at some sites. Targeted mitigation options associated with commercial vegetable growing (CVG) are projected to decrease Waiopehu FMU stream nutrient concentrations by between 40 and 60% and Lake Horowhenua phytoplankton levels by up to approximately 30%. Future applications of the model could involve investigation into mitigation requirements to achieve specific and spatially variable concentration targets that are associated with NPS-FM target attribute states.

1 Introduction

Horizons Regional Council (HRC) require appropriate scientific information to support planning and limit setting in the Manawatū-Whanganui region as part of its process to develop a new regional water plan that implements the National Policy Statement – Freshwater Management (NPS-FM; NZ Government, 2020). An important component of that information is how loss of contaminants from land in the Manawatū-Whanganui region can be managed to achieve target attribute states in freshwater and coastal receiving environments.

There are a wide range of potential management actions and limits that could help to achieve water quality target attribute states. Identifying which set of actions and limits is preferred requires analysis for at least two reasons. First, the impacts of actions and limits will not be evenly distributed across the region because land use and receiving environment sensitivity to contaminants is spatially variable. Second, there is environmentally mediated variation in both potential contaminant losses from land use and the processing of contaminants (attenuation) as they move through the drainage network. Because these two factors interact, the assessment of options requires iterative simulation modelling of the land-water systems being managed. The basis for such simulation is catchment water quality models. Catchment water quality models account for the relevant processes such as contaminant loss from land and attenuation as well as spatial variation in factors such as current and potential land use.

This report describes the application of previously developed catchment water quality models (Cox et al. 2022a, b) to simulate receiving water quality impacts of a suite of potential contaminant mitigation actions. In this study, five sets of simulation scenarios were used to explore mitigation strategies focused on pastoral farm management, horticulture farm management, and point source discharge load reduction. The primary objectives of these simulations were to a) quantify the water quality gains that could be achieved with future specific catchment mitigation actions, or bundles of actions, and b) assess the spatial distribution of those gains in the region. Key outputs from the simulations are total nitrogen (TN) and total phosphorus (TP) loads and concentrations for sites distributed throughout the region. Results are primarily expressed as changes relative to baseline (current) conditions.

Four separate catchment models were used for the simulations, representing the region's four major river basins: the Manawatū (including the Horowhenua and Coastal Tararua catchments), the Rangitīkei, the Whanganui, and the Whangaehu (including the Turakina River catchment). The entire region is encompassed by the four models. In addition, a fifth model, focused only on the Waiopehu freshwater management unit (FMU) and Lake Horowhenua, was used to explore contaminant mitigation strategies specific to commercial vegetable growing. This fifth model includes a higher spatial resolution than used in the larger Manawatū model.

The models were developed in a usable framework to allow for further application by a range of potential end users. Future applications of the model may focus on limit setting and the development of mitigation strategies to achieve specific target attribute states.

2 Methods

2.1 Original Model Construction

The catchment models were developed using RMA Science's (RMA) Simplified Contaminant Allocation and Modelling Platform (SCAMP) software. SCAMP is designed as a flexible, and usable, generalised modelling tool for simulating diffuse and point source contamination at a catchment scale. As noted above, the original model construction and parameterisation was undertaken as part of an earlier study (Cox et al. 2022a, b) and carried over into the present project for application to specific scenarios.

Each of the four river basin models (the Manawatū, Rangitīkei, Whanganui, and Whangaehu) is subdivided into sub-catchments based on HRC's Water Management Subzones (WMSZs). A total of 139 sub-catchments are represented in the four basin models. Additionally, the higher resolution Waiopehu model includes 9 sub-catchments. Each model sub-catchment is further subdivided into 14 land use classes: native bush, forestry, dairy farming, sheep and beef farming, other animals, horticulture, vegetable growing, urban, transport, water, lifestyle blocks (rural residential), arable land, unknown and other.

The main source of land use data was the primary classes (CLS_001) from the 2020 land use classification of Herzig *et al.* (2020). Each sub-catchment land use class was assigned a nutrient export coefficient to represent diffuse losses of nutrient (kg ha^{-1} $year^{-1}$) from the land surface or root zone. Export coefficients were assigned based on previous published studies and physiographic characteristics within each sub-catchment.

A total of 38 industrial and municipal point source discharges (> 20 m^3 d^{-1}) are also explicitly represented in the models. Point source discharge loads in the original models were quantified based on facility monitoring data collected for the period 2014-2018.

Sub-catchment attenuation coefficients were quantified in the models based on a rigorous model calibration process using measured water quality data that represent the baseline year 2018. Also quantified as part of the calibration process were observable sediment erosion phosphorus (OSEP) loads throughout the region. OSEP loads are associated with infrequent, but largescale, erosion events not captured by model export coefficients but reflected in the observed downstream loads used for model calibration. For some catchments, OSEP loads contribute to a substantial portion of the downstream observed P loads.

2.2 Model Updates

To better reflect current conditions, and based on new data and expert opinion, a small number of minor revisions were made to the original model construction and parameterisation for the simulations described here. These are briefly described below.

Firstly, model point source discharge loads were updated to reflect a more recent monitoring period, as compared to the original model construction. Facility mean annual TN and TP loads were updated in the model based on data from the period July 2017 to June 2022. These data were provided by HRC.

Secondly, model horticulture TN export coefficients were modified based on recommendations by Horticulture New Zealand (HortNZ) and a re-calibration process described below. The HortNZ recommended rates are summarised in Table These rates were translated into area-weighted model export coefficients for the general horticulture category, for each WMSZ, by HRC.

Thirdly, the modelled Ohakune commercial vegetable growing area was adjusted slightly to better reflect expert opinion on the extent of that area and in consideration of crop rotation cycles. This adjustment involved moving a small amount of land out of sheep and beef land and into the horticulture and vegetable growing category in the Whangaehu River basin model. The leaching values for this area were also increased (Table 1) based on the recommendations made by Horticulture NZ to reflect the fact that the land area included in the modelling did not incorporate all land in the full rotation. Rather, the model representation of this area only includes the land in vegetable growing in any one year. A summary of these changes, as provided by HRC, is included in Appendix A.

Fourthly, the Waikawa Stream WMSZ (West_9a) was sub-divided into two smaller sub-catchments in the Manawatu River basin model. This was done to more accurately represent the drainage area, and associated land use, above the Waikawa Stream water quality monitoring site at North Manakau Road.

Lastly, representation of the Lake Horowhenua catchment in the Waiopehu FMU model was refined to more accurately, and usefully, depict nutrient sources to the lake. To improve model calculations of surface nutrient loads to the lake, and to provide more flexibility for predictive simulations, the catchment was sub-divided into two smaller sub-catchments in the model: the Arawhata Stream catchment and the rest of the lake total catchment (including the Patiki Stream).

Table 1. Model horticulture total nitrogen export coefficients, as recommended by HortNZ.

Crop Type	Data Source	Loss Rate (kg ha^{-1} $year^{-1}$)
Horowhenua greens/brassica rotation	Bloomer et al. (2020)	84
Horowhenua potato/onion rotation	Bloomer et al. (2020)	31
Ohakune vegetable rotation	Drewry (2018)	53.9
Manawatū vegetable rotation	The Agribusiness Group (2014, 2017)	31
Orchards and vineyards	Drewry (2018)	9.9

Following the model updates described above, model performance was re-assessed with respect to reproducing observed current water quality conditions in the region. In other words, the model calibration was re-visited. As described in Cox et al. (2022a), the original model calibration involved adjustment of uncertain model parameters (primarily diffuse pathway attenuation coefficients) to reproduce observed conditions within an error tolerance threshold. That process used observed water quality data that approximately corresponds to a 2018 period, which aligns with the time periods associated with other input parameters, such as land use and point source loads.

It should be noted that the updates performed in this study have not significantly shifted the representative model simulation period. Horticulture export coefficient changes reflect an improved understanding of nutrient losses from this class of land use, rather than reflecting any changes in practices. Point source discharge load updates are based on monitoring data for the period 2017 to 2022, which is inclusive of the 2018 calibration period. Therefore, it was deemed appropriate to use the same observed water quality data used for the original calibration for the re-assessment performed here.

This reconfiguration of the Waikawa Stream catchment (West_9a in the Manawatu River basin) provided for a more accurate calibration of attenuation coefficients in the West_9a catchment (Manawatu River basin model). This recalibration exercise was performed as part of this study, resulting in revised TN and TP attenuation coefficients in that catchment.

As a consequence of the point source and horticulture input updates, minor adjustments to a small number of catchment TN attenuation coefficients in the Rangitīkei and Whangaehu river basins were justified. No adjustments to catchment TP attenuation coefficients were made in any of the major river basin models. Similarly, no adjustments to TN attenuation coefficients in the wider Manawatū River basin were justified. Model performance, with respect to reproducing observed conditions, is approximately equal to that achieved in the original model calibration (see Appendix B and Cox et al. 2022a).

For the Waiopehu FMU model, the disaggregation of the Lake Horowhenua catchment dictated the need for re-calibration of key lake catchment loading and water quality response parameters. As described in Cox et al. (2022b), the primary sources of uncertainty for this part of the model are the assumed groundwater loads to the lake and the surface diffuse pathway attenuation coefficients associated with the lake surface catchments. These inputs were the focus of the original model calibration and were re-visited as part of this study. A new lake nutrient budget study (Hydrosphere 2022) was used to guide the analysis.

As a first step in the Waiopehu model re-calibration, the Arawhata catchment TN attenuation coefficient was set to the minimum allowable (0.1), and dairy and horticulture export coefficients were increased, to achieve an acceptable agreement with the estimated mean annual load to the lake from the lake budget study (Hydrosphere 2022). Note that the Arawhata catchment portion of the lake budget is supported by long term monitoring data (Arawhata at Hokio Beach Road). The revised TN export coefficients are 60% higher than pre-calibration values (Table 2). In other words, the lake nutrient budget, supported by site specific observations, suggests significantly higher TN diffuse losses in the Arawhata catchment than those estimated from independent regional studies (see Cox et al. 2022a) and expert advice (Table). A similar exercise was performed for TP, resulting in a decrease in the model attenuation coefficient and a minor increase in the dairy export coefficient.

Table 2. Calibrated Arawhata catchment model parameters

Model Parameter	Original Value (Source)	Revised (Calibrated) Value
TN attenuation coefficient (unitless)	0.2 (2022 calibration, Hoki 1a)	0.1
TP attenuation coefficient (unitless)	0.7 (2022 calibration, Hoki 1a)	0.15
TN dairy export coefficient (kg ha^{-1} yr^{-1})	27 (2022 parameterisation, Hoki 1a)	45
TP dairy export coefficient (kg ha^{-1} yr^{-1})	1.3 (2022 parameterisation, Hoki 1a)	1.4
TN horticulture export coefficient (kg ha^{-1} yr^{-1})	71 (2022 parameterisation, Hoki 1a)	115
TP horticulture export coefficient (kg ha^{-1} yr^{-1})	1.6 (2022 parameterisation, Hoki 1a)	1.6

The second step in the Waiopehu model re-calibration involved parameterising groundwater nutrient loads to the lake. As described in Cox et al. (2022 b), these loads are simulated in the Waiopehu FMU model using a discrete catchment object representing the groundwater recharge zone. Parameterisation of this surrogate catchment object was based largely on a supporting groundwater model (Pattle Delamore Partners, personal communication) and a previous lake water quality study (Gibbs 2011). For the re-calibration, updated estimates of mean annual groundwater nutrient loads to the lake from the recent lake nutrient budget study (Hydrosphere 2022) were used to guide the process. More specifically, estimated annual groundwater loads were used as calibration targets with adjustments made to TN and TP groundwater catchment attenuation coefficients to achieve agreement between modelled and independently estimated loads.

Lastly, lake response output variables, in the form of modelled in-lake TN, TP, and phytoplankton concentrations, were reviewed and compared to measured lake water quality data (2013 – 2021). As a result of this exercise, small adjustments were made to the model's phytoplankton growth parameters to achieve an acceptable agreement between modelled and measured phytoplankton (as chlorophyll-a) concentrations. No adjustments to model in-lake nutrient concentration response parameters were required. Details of the SCAMP lake water quality calculations are provided in Cox et al. (2022 b).

2.3 Scenario Simulation Outputs

The key outputs for the scenario simulations described below are the *relative changes* in stream load and concentrations, of both TN and TP, at all existing water quality monitoring sites and assessment points. Assessment points are located at the downstream end of each of the region's 124 WMSZs. Some of these assessment points capture drainage from a single WMSZ, while others capture the aggregate drainage from multiple upstream WMSZs. Since monitoring sites were used as calibration points in the original model parameterisation, model confidence is higher at the monitoring locations as compared to unmonitored assessment points.

2.4 Scenario 1: Pastoral Farm Established Mitigations

Scenario 1 involved the simulation of instream TN and TP response to published pastoral (dairy and dry stock) mitigation actions using the four calibrated river basin models. For this scenario, a published set of "established" mitigation options, as of 2015, (Monaghan et al. 2021; McDowell et al. 2021) were used. The study described in those companion papers used farm scale modelling to quantify nutrient loss rates for pastoral agriculture throughout New Zealand as a function of a range of physiographic characteristics. The authors quantified loss rates for both current conditions, which includes partial uptake of established mitigation options (as of 2015), and for a hypothetical condition involving 100% uptake of the bundle of established mitigation options. The established mitigation options include specific actions associated with riparian protection, land retirement, improved management of fertiliser, irrigation water and effluent and off paddock grazing strategies. The published relative differences in loss rates between the two conditions (current and hypothetical 100% uptake) provided the inputs for this model scenario.

The published mitigation effectiveness values were translated into SCAMP model inputs as percent reductions in TN and TP losses from farms, as a function of both farm type and environmental typology. Model pre-processing for this scenario involved intersecting specific climate, topography, and soil drainage types for each WMSZ and using published mitigation reduction percentages for each intersection to calculate effective nutrient loss rate reductions for the two farm classes within each WMSZ. These loss rate reductions were then applied to the baseline model parameters for the simulation of this scenario. Loss rate reductions prescribed for this scenario are summarised, as river basin averages, in Table 3.

Table 3. Modelled areal average changes in pastoral farm nutrient loss rates, relative to baseline, for Scenario 1.

River Basin	% Change in Dairy N Loss Rate	% Change in Dairy P Loss Rate	% Change in Sheep and Beef N Loss Rate	% Change in Sheep and Beef P Loss Rate
Manawatū	-23%	-12%	-5%	-24%
Rangitīkei	-30%	-11%	-3%	-18%
Whanganui	-24%	-21%	-5%	-28%
Whangaehu	-23%	-12%	-4%	-25%

As noted above, this scenario simulation assumes 100% uptake of the published set of established mitigation options. Further, through the application of reduction rates to baseline model loss rates, the scenario construct assumes that uptake of the mitigation options to-date in the region, and reflected in the recent historical monitoring data, is approximately equal to the regional levels of "current" uptake assumed by McDowell et al. (2021).

2.5 Scenario 2: Pastoral Farm Established and Developing Mitigations

Scenario 2 involved the simulation of full implementation of both "established" (Scenario 1) and "developing" pastoral farm mitigation options, as described by McDowell et al. (2021). The set of developing mitigation options represent actions that are considered to still be in development or validation stages and not yet implemented on a large scale in New Zealand. The authors recognise that widespread adoption of such practices typically takes 15 to 20 years from inception. They therefore refer to a 2035 plausible planning horizon for the realisation of this hypothetical scenario. The bundle of developing mitigation options include specific actions associated with edge-of-field mitigation, instream sorbents, controlled drainage, management of critical source areas, and retention dams.

The published mitigation effectiveness values, representing the combined impacts of both established and developing options, were applied in the models following the same methods described above for Scenario 1. Loss rate reductions prescribed for this scenario are summarised, as river basin averages, in Table 4.

Table 4. Modelled areal average changes in pastoral farm nutrient loss rates, relative to baseline, for Scenario 2.

River Basin	% Change in Dairy N Loss Rate	% Change in Dairy P Loss Rate	% Change in Sheep and Beef N Loss Rate	% Change in Sheep and Beef P Loss Rate
Manawatū	-51%	-43%	-21%	-36%
Rangitīkei	-62%	-40%	-20%	-38%
Whanganui	-49%	-44%	-24%	-40%
Whangaehu	-51%	-39%	-23%	-38%

2.6 Scenario 3: Point Source Mitigations

Scenario 3 involved the simulation of a set of plausible potential mitigation actions to reduce point source discharge loads to receiving streams that were defined by HRC. These actions include revised consenting, facility closures, facility upgrades, and land disposal of facilities that currently have point source discharges. It was assumed that the full suite of these actions would be implemented by 2035 (per HRC). For each facility represented in the models, HRC projected a set of relative reductions (%) in the current point source discharge nutrient loads associated with the mitigation actions (revised consent, closure, upgrade, land disposal). These projections were directly used to modify model baseline point source mean annual loads for this scenario.

Detailed documentation of the assumed mitigation action, for each modelled facility, is provided in Appendix C.

2.7 Scenario 4: Pastoral Farm Mitigations + Point Source Reductions

Scenario 4 involved the combination of Scenario 2 (pastoral farm established and developing mitigations) and Scenario 3 (point source mitigations), as described above.

2.8 Scenarios 5a – 5e: Horticulture Mitigations

Scenario set 5 involved the simulation of five scenarios focused on horticulture mitigation using the Waiopehu FMU model. In a separate study (Jolly et al. 2023), specific commercial vegetable growing (CVG) mitigation actions were translated into corresponding reductions in nutrient exports from the model CVG land areas. The Waiopehu FMU catchment model was used to simulate the impacts of these mitigations on receiving water quality. Model outputs for these simulations included quantified responses of stream and lake nutrient concentrations, stream periphyton concentrations, and lake phytoplankton concentrations.

The scenarios are summarised below.

- Scenario 5a involved the adoption of best management practices (BMPs) and good management practices (GMPs) for CVG in the Hoki_1a and Hok WMSZs.
- Scenario 5b involved the adoption of BMPs and GMPs for CVG in the Hoki_1a and Hoki_1b WMSZs *and* the removal of all other agriculture in the catchment (conversion to native bush).
- Scenario 5c involved the removal of CVG from Hoki_1a and Hoki _1b WMSZs and replacement with sheep and beef, with new CVG in Mana_13e and Ohau_1b WMSZs.
- Scenario 5d involved the use of glass houses and in-field production.
- Scenario 5e involved the removal of the top 25% of nitrate leaching crops.
- Reductions in nutrient loss rates associated with the CVG mitigation actions outlined above are summarised in Table 5. Further details on these scenarios are provided in Jolly et al. (2023).

Table 5. Modelled changes to Waiopehu FMU commercial vegetable growing nutrient loss rates, relative to baseline, for horticulture mitigation scenarios, Scenarios 5a-5e (Jolly et al. 2023).

	% Change in N Loss Rate	% Change in P Loss Rate
Scenario 5a	-56%	-42%
Scenario 5b	-56%	-42%
Scenario 5c	NA*	NA*
Scenario 5d	-44%	-29%
Scenario 5e	-24%	0%

* = Not applicable. Scenario 5c involves land use change rather than change in loss rates.

3 Results

3.1 Scenario 1: Pastoral Farm Established Mitigations

The results of the Scenario 1 simulations for instream TN and TP are summarised in Table 6 and Figure 1. Further details are provided in Tables D-1 through D-8 in Appendix D. All results are compared to baseline model results to highlight predicted *relative* changes in water quality. Table 6 provides summary metrics for the modelled monitoring sites in each model basin. Figure 1 displays results for all WMSZs. Note that, in Figure 1, simulated relative changes are displayed uniformly for the entire catchment area of each WMSZ. In actuality, model calculations were only performed for the *bottom* of each WMSZ (i.e. assessment points). Concentration variability within each WMSZ is beyond the resolution of the constructed models.

The largest reductions in TN levels for this scenario are generally projected for the Manawatū River basin, while the largest reductions in projected TP levels are in the Whanganui and Manawatū basins. The maximum projected TN reduction in the Manawatū basin is 18%, at Kumeti at Te Rehunga The catchment upstream of this site is relatively small, dairy farming is the largest contributor to the TN load at this site, and the projected decrease in dairy nitrogen losses due to the simulated mitigation bundle is relatively high. The maximum projected TP reduction in the Manawatū basin is 28%, in the Mākuri River at Tuscan Hills. The maximum projected reduction in the Whanganui basin is 30%, in the Ōhura River at Tokorima. The catchments for both sites are dominated by sheep and beef farming with relatively high projected decreases in loss rates due to the simulated mitigations.

Table 6. Scenario 1 modelling results: statistical summaries of % differences, relative to baseline, aggregated across all monitoring sites. The reported mean values represent the average modelled change across all monitoring sites in the given model basin. The minimum, or maximum, values represent the minimum, or maximum, modelled change across the monitoring sites in the given model basin.

River Basin	Change in Total Nitrogen			Change in Total Phosphorus		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Manawatū	-9%	-1%	-18%	-14%	-3%	-28%
Rangitīkei	-5%	-3%	-12%	-9%	-6%	-16%
Whanganui	-4%	-1%	-6%	-17%	-9%	-30%
Whangaehu	-2%	-1%	-5%	-15%	-5%	-22%

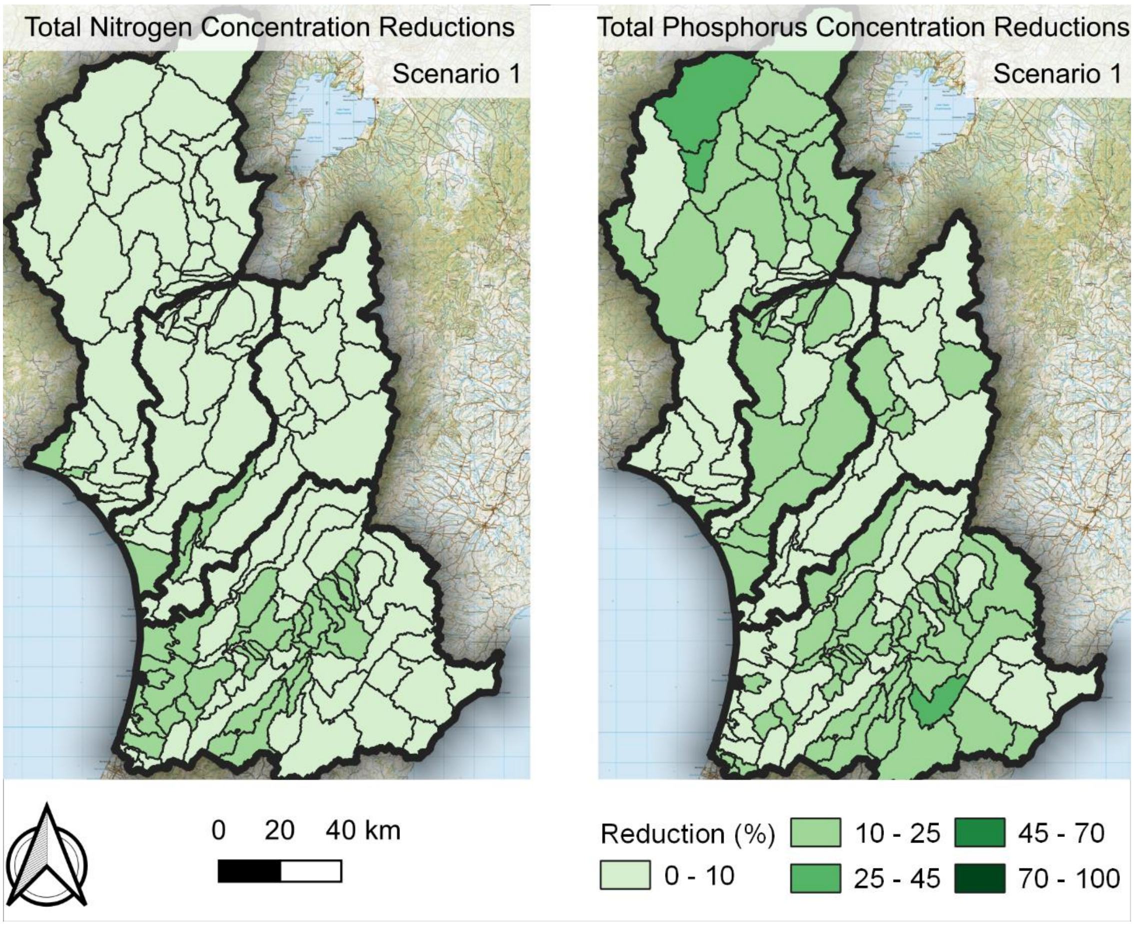


Figure 1. Scenario 1 modelling results: simulated changes in mean annual TN and TP concentrations for Manawatū-Whanganui Region Water Management Subzones.

3.2 Scenario 2: Pastoral Farm Established and Developing Mitigations

The results of the Scenario 2 simulations are summarised in Table 7 and Figure 2. Further details are provided in Tables E-1 through E-8 in Appendix E. All results are compared to baseline model results to highlight predicted *relative* changes in water quality.

The largest reductions in TN levels for this scenario are generally projected for the Manawatū River basin, while the largest reductions in projected TP levels are in the Whanganui and

Manawatū basins. The maximum projected TN reduction in the Manawatū basin is 42%, in the Ōruakeretaki Stream at S.H.2 Napier. The catchment upstream of this site is relatively small and dominated by dairy farming. The maximum projected TP reduction in the Manawatū basin is 42%, in the Mākuri River at Tuscan Hills. The maximum projected reduction in the Whanganui basin is 40%, in the Ōhura River at Tokorima. The catchments for both sites are dominated by sheep and beef farming with relatively high projected decreases in loss rates due to the simulated mitigation.

Table 7. Scenario 2 modelling results: statistical summaries of % differences, relative to baseline, aggregated across all monitoring sites. The reported mean values represent the average modelled change across all monitoring sites in the given model basin. The minimum, or maximum, values represent the minimum, or maximum, modelled change across the monitoring sites in the given model basin.

River Basin	Change in Total Nitrogen			Change in Total Phosphorus		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Manawatū	-26%	-8%	-42%	-24%	-5%	-42%
Rangitīkei	-22%	-15%	-37%	-20%	-11%	-34%
Whanganui	-21%	-18%	-25%	-24%	-12%	-40%
Whangaehu	-18%	-10%	-23%	-21%	-6%	-31%

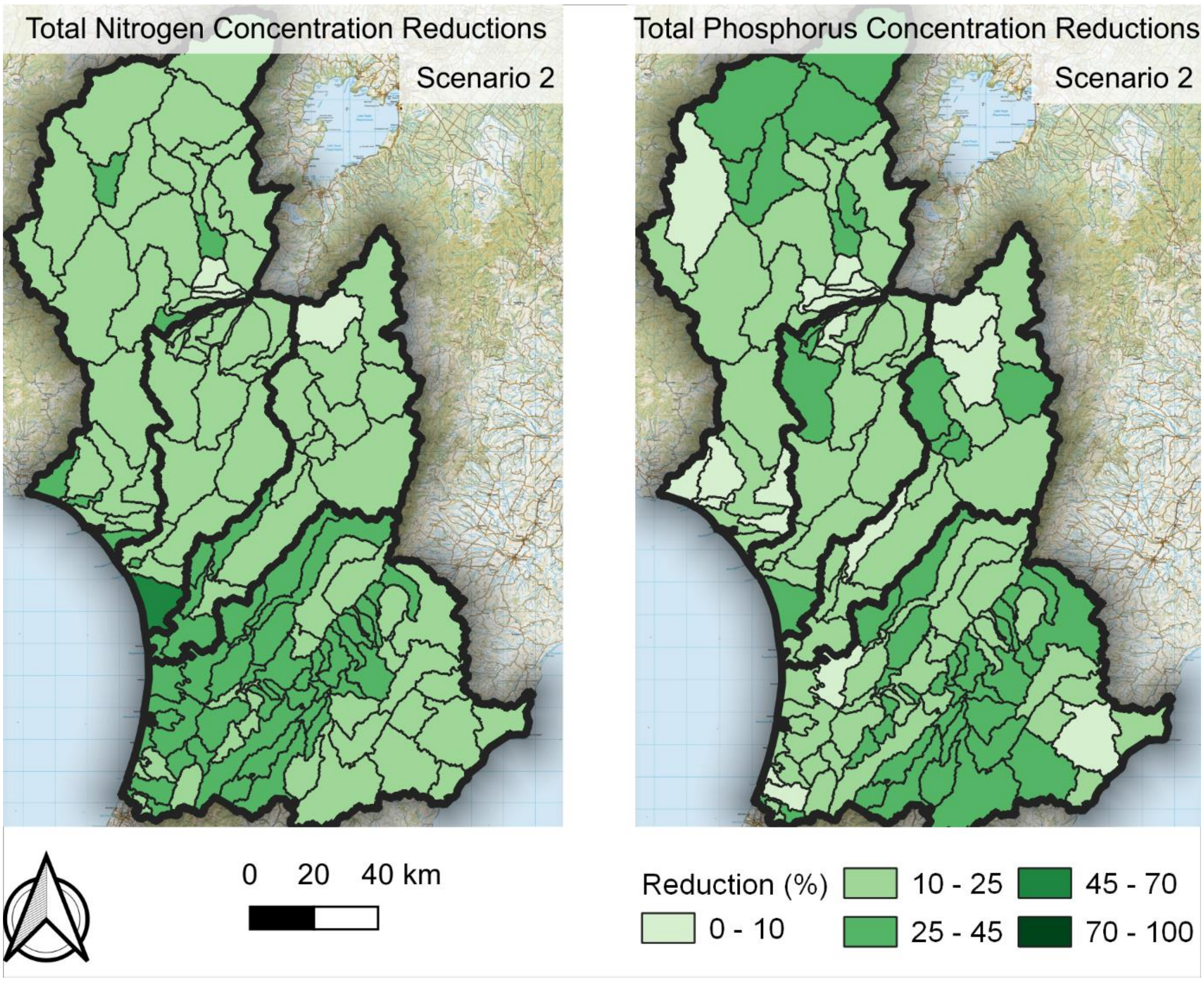


Figure 2. Scenario 2 modelling results: simulated changes in mean annual TN and TP concentrations for Manawatū-Whanganui Region Water Management Subzones.

3.3 Scenario 3: Point Source Mitigations

The results of the Scenario 3 simulations are summarised in **Error! Reference source not found.** and Figure 3. Further details are provided in Tables F-1 through F-8 in Appendix F. All results are compared to baseline model results to highlight predicted *relative* changes in water quality.

The largest reductions in TN levels for this scenario are generally projected for the Manawatū River basin, while the largest reductions in projected TP levels are in the Rangitīkei basin. The maximum projected TN reduction in the Manawatū basin is 26%, in the Ōroua River just downstream of the Feilding sewage treatment plant (STP). Over half of the total TN baseline load is attributable to point sources at this site. The maximum projected TP reduction in the Rangitīkei basin is 30%, in the Tūtaenui Stream just downstream of the Marton STP. Point sources contribute approximately 30% of the baseline TP load at this site.

Table 8. Scenario 3 modelling results: statistical summaries of % differences relative to baseline, aggregated across all monitoring sites. The reported mean values represent the average modelled change across all monitoring sites in the given model basin. The minimum, or maximum, values represent the minimum, or maximum, modelled change across the monitoring sites in the given model basin.

River Basin	Change in Total Nitrogen			Change in Total Phosphorus		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Manawatū	-3%	0%	-26%	-1%	0%	-3%
Rangitīkei	-2%	0%	-14%	-3%	0%	-30%
Whanganui	0%	0%	0%	0%	0%	0%
Whangaehu	0%	0%	0%	0%	0%	0%

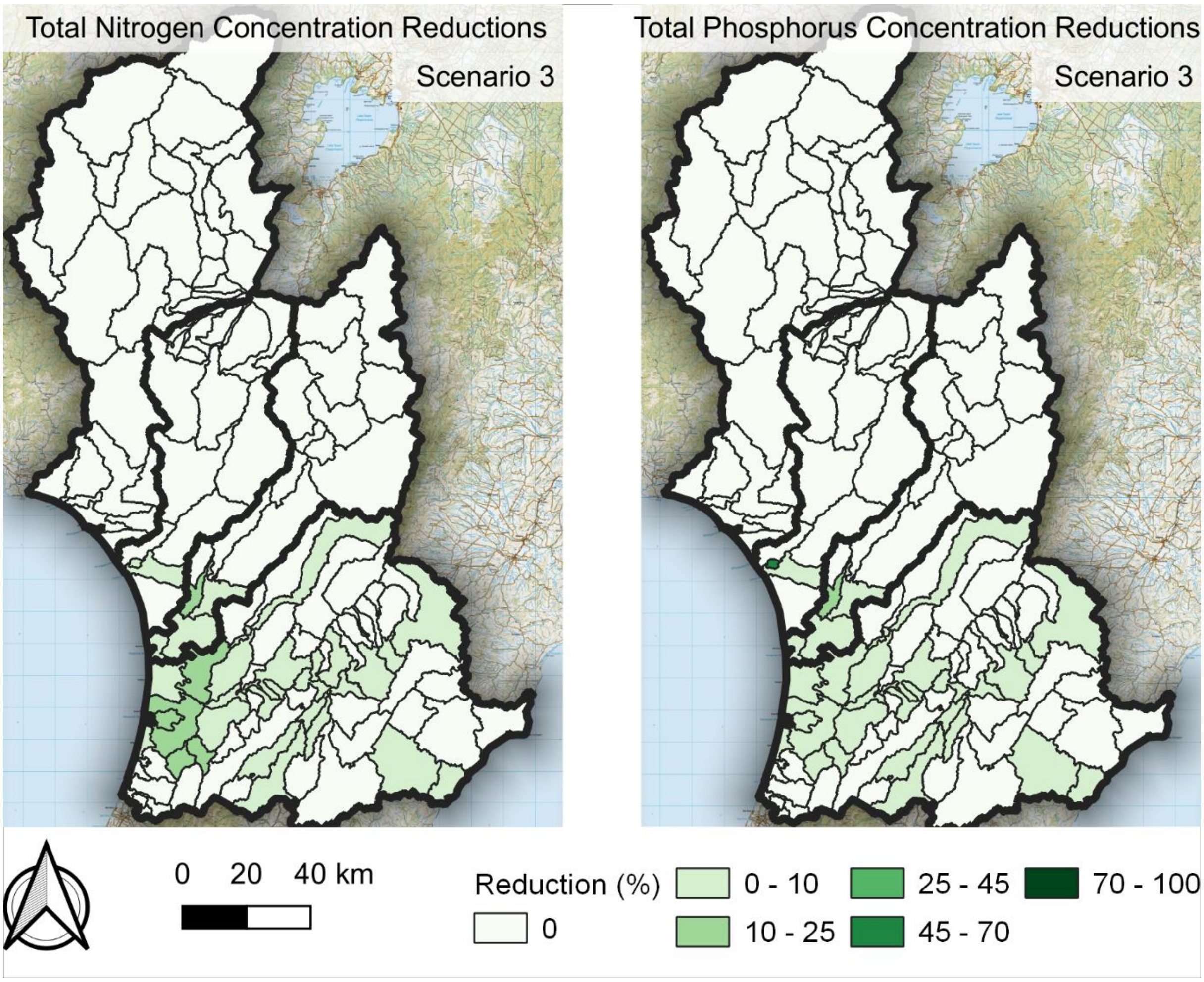


Figure 3. Scenario 3 modelling results: simulated changes in mean annual TN and TP concentrations for Manawatū-Whanganui Region Water Management Subzones.

3.4 Scenario 4: Pastoral Farm Mitigations + Point Source Reductions

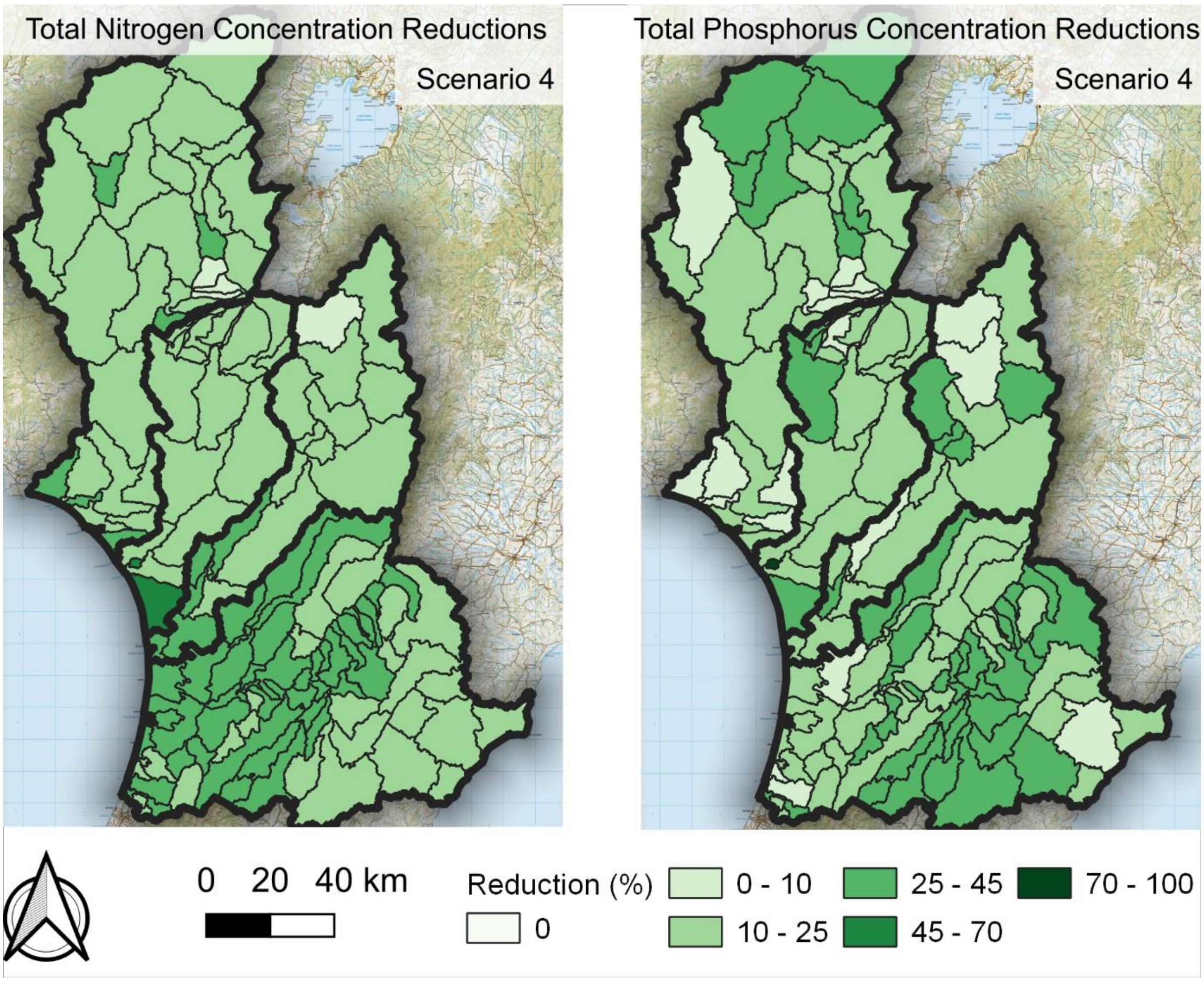
The results of the Scenario 4 simulations are summarised in Table 9 and Figure 4. Further details are provided in Tables G-1 through G-8 in Appendix G. All results are compared to baseline model results to highlight predicted *relative* changes in water quality.

The largest reductions in TN levels for this scenario are generally projected for the Manawatū River basin, while projected TP reductions are distributed fairly uniformly across the four basins. The maximum projected TN reduction in the Manawatū basin is 42%, in the Ōruakeretaki Stream at S.H.2 Napier. The catchment upstream of this site is relatively small and dominated by dairy farming. The maximum projected TP reduction in the Manawatū basin is 42%, in the Mākuri River at Tuscan Hills. The maximum projected TP reduction in the Whanganui basin is 40%, in the Ōhura River at Tokorima. The maximum projected TP reduction in the Whangaehu basin is 31% in the Mangawhero River Raupiu Road. The catchments for all three of these sites are dominated by sheep and beef farming with relatively high projected decreases in loss rates due to the simulated mitigation. The maximum projected TP reduction in the Rangitīkei basin is 41% in the Tūtaenui Stream just downstream of the Marton STP. Point sources contribute approximately 30% of the baseline TP load at this site.

Table 9. Scenario 4 modelling results: statistical summaries of % differences, relative to baseline, aggregated across all monitoring sites. The reported mean values represent the average modelled change across all monitoring sites in the given model basin. The minimum, or maximum, values represent the minimum, or maximum, modelled change across the monitoring sites in the given model basin.

River Basin	Change in Total Nitrogen			Change in Total Phosphorus		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Manawatū	-28%	-8%	-42%	-25%	-5%	-42%
Rangitīkei	-23%	-15%	-46%	-23%	-13%	-41%
Whanganui	-21%	-18%	-25%	-24%	-12%	-40%
Whangaehu	-18%	-10%	-23%	-21%	-6%	-31%

Figure 4. Scenario 4 modelling results*: simulated changes in mean annual TN and TP concentrations for Manawatū-Whanganui Region Water Management Subzones.*



3.5 Scenarios 5a to 5e: Horticulture Mitigations

Scenario 5 modelling results are summarised in Figure 5 and in Tables H-1 through H-15 in Appendix H. All results are compared to baseline model results to highlight predicted *relative* changes in water quality. In addition to river and stream nutrient concentrations, modelled Lake Horowhenua water quality response, in the form of in-lake nutrient and phytoplankton concentrations (as chlorophyll-a), is also presented. Lake concentration outputs represent annual mean values for an assumed well-mixed system. Lastly, modelled stream periphyton biomass concentrations are presented for each scenario, for both shaded and unshaded conditions. These outputs represent annual median levels.

Large reductions in Arawhata Stream nutrient concentrations, and total nutrient loads to the lake, are projected for scenarios involving large scale adoption of CVG best management practices and/or land use change (Scenarios 5a, 5b, and 5c). Lake modelling projects the largest improvement in lake water quality occurring as a result of the combination of CVG BMP and GMP adoption and conversion of pastoral agricultural land to native bush (Scenario 5b). For this scenario lake average TN, TP, and chlorophyll-a concentrations are projected to decrease by 18%, 46%, and 33%, respectively. Arawhata median stream periphyton concentrations are projected to decrease by approximately 30% for this scenario. Scenario 5c includes the simulation of new CVG in the lower Ohau River catchment (Ohau_1b) and in the lower Manawatu River basin (Mana_13e). Results of this simulation project increases in total instream TN and TP loads, at both locations, due to the introduction of new vegetable growing to the respective catchments. For the Ohau, increases of approximately 14% and 1%, for TN and TP respectively, are projected (pink shading, Figure 5). For the Manawatu the projected increases in instream load are less than 1% for both nutrients (results not shown).

Figure 5. Scenario Set 5 modelling results: simulated changes in mean annual TN and TP concentrations for the Waiopehu Water Management Subzone.

4 Summary and Conclusions

Previously constructed catchment water quality models were updated and used to simulate a range of plausible future water quality mitigation scenarios for the Manawatū-Whanganui region. Simulation results demonstrate the potential for significant improvements in water quality throughout the region with the implementation of mitigation options associated with pastoral farming, horticulture, and point source discharges. For example, full implementation of established and developing pastoral farm mitigation options, combined with planned point source discharge reductions, were projected to reduce TN and TP stream concentrations by approximately 20 – 30% on average throughout the region, and exceeded 40% at some sites. Targeted mitigation options associated with commercial vegetable growing (CVG) are projected to decrease Waiopehu FMU stream nutrient concentrations by between 40 and 60% and Lake Horowhenua phytoplankton levels by up to approximately 30% (Scenario 5b). Future applications of the model could involve investigation into mitigation requirements to achieve specific and spatially variable concentration targets that are associated with NPS-FM target attribute states.

5 Acknowledgements

We thank Maree Patterson of Horizons Regional Council for assistance with data and reviews of early versions of this report. We thank Dr Anne-Maree Jolly, Primary Industries Sustainability Consultant, for her timely horticulture mitigation loss rate modelling.

6 References

Agribusiness Group, 2014. Nutrient Performance and Financial Analysis of Horticultural Systems in the Horizons Region. Prepared for Horticulture NZ.

Agribusiness Group, 2017. Farm Scale Economic Impact Analysis of One Plan Intensive Land Use Provisions. Prepared for Horticulture NZ.

Bloomer, D., G. O'Brien, and L. Posthuma, 2020. Modelled Loss of Nutrients from Vegetable Growing Scenarios In Horowhenua. Page Bloomer Associates, New Zealand.

Cox, T.J., T. Snelder, T. Kerr, C. Fraser, 2022a. Manawatū-Whanganui Region Catchment Nutrient Models: Model Updates. RMA/LWP Client Report, RMA Science Ltd., Hamilton, New Zealand and LWP Ltd., Christchurch, New Zealand.

Cox, T.J., T. Snelder, T. Kerr, 2022b. The Waiopehu FMU Water Quality Model: At Tool for Simulating Catchment Nutrient Management Options. RMA/LWP Client Report, RMA Science Ltd., Hamilton, New Zealand and LWP Ltd., Christchurch, New Zealand.

Drewry J., 2018. Nitrogen and Phosphorus Loss Values for Selected Land Uses, Manaaki Whenua, Client Report Number LC3367

Gibbs, M., 2011. Lake Horowhenua Review. NIWA Client Report, NIWA, Hamilton, New Zealand.

Herzig, A., A. Manderson, B. Jolly, B. Barnes, and L. Baish, 2020. Opportunities and Constraints on Intensive Land-Use Expansion in the Horizons Region – Land-Use Mapping. MWLR Contract Report, Manaaki Whenua – Landcare Research, Palmerston North, New Zealand.

Hydrosphere, 2022. Phosphorus and Nitrogen Budgets for Lake Horowhenua. Report Prepared for Horizons Regional Council. September.

Jolly, A.M., L. Arnold, K. Wills, J. Bennett, 2023. Nutrient Losses from Commercial Vegetables in Horowhenua. WSP Client Report Prepared for Horizons Regional Council.

McDowell, R.W., R.M. Monaghan, C. Smith, A. Manderson, L. Basher, D.F. 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 64:390–410.

Monaghan, R., A. Manderson, L. Basher, R. Spiekermann, J. Dymond, C. Smith, R. Muirhead, D. Burger, 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.

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

Appendix A HRC Memorandum on Model Horticulture Input Refinements

Model changes N & P for commercial vegetable growing.

Initial calibration of the model utilized the area in vegetable growing identified by the primary classes (CLS_001) from the 2020 land use classification of Herzig et al. (2020) land use layer and a loss rate of 71 kg/ha/yr (Sourced from Bloomer et al 2020).

Conversations with Horticulture NZ about the loss rates raised concerns with the use of the loss rates identified from the Horowhenua growing by Bloomer as being representative of a more intensive production system than that of the rest of the Region. They were however satisfied these numbers represented the production in the Waiopehu FMU. Additional leaching numbers for the vegetable growing area in the rest of the Region were sought from Horticulture NZ. These numbers were provided to Horizons as well as recommended increase from the Bloomer et al. (2020) numbers for the Horowhenua area. (Appendix 1). Horticulture NZ also supplied the Horizons land use shape file back to Horizons with an identified rotation for each of the polygons identified as commercial vegetable growing.

Upon undertaking investigations for the loss rates Horticulture NZ checked whether the area identified as commercial vegetable growing was representative of farming in the catchments. Conversations between Horticulture NZ and growers in the Whangaehu catchments around Ohakune suggested this area had been underestimated by 458 ha. Whilst there was no shapefile agreement between council and Horticulture NZ experts, it was suggested that Horizons add this additional 458 ha across the sub-zones proportionally to what is there already, increasing the total area of vegetable cropping to 863 ha and removing it from the Sheep and/or Beef land use class.

In reviewing the provided references for leaching rates, it was discovered that the leaching rates provided were for a system that spent one in every seven years in vegetable production and the leaching rate provided was for the full rotation not just the time in vegetable production. This led Horizons to question the area of vegetable growing identified in the in the Ohakune catchments. It was the opinion of the Horticulture NZ experts that the 863 ha included all of the land in the full rotation not just the land that was in vegetable growing at any one time. (Michelle Sands pers comm. 19/04/2023). Following on from this meeting, Horizons staff found evidence from a grower in the Ohakune area suggesting 1200 ha was in vegetable production across the catchments although it was unclear whether this number was the area in any part of the rotation or the area growing vegetables at any one time. Horticulture NZ were approached for their input on this but to date we have not received a response.

To further understand the area of vegetable growing in the catchment, the consented water abstractions in the area were investigated. This found that 639-649 ha of land is consented to be irrigated for vegetable production in any one year in these sub-zones (Appendix 2). This is still likely an underestimate of the area in vegetables as there are additional farms with wash water consents that identify they are growing vegetables, but no spatial information is available. Additionally, the sub-zones in the land use layer identified to contain vegetable growing are areas where there are no consents (this may be due to the exact location of the vegetable growing vs the location of the take or proximity to sub-zone boundaries).

These values were forwarded to Horticulture NZ to ask for further information on this and how they wished to proceed. No response has been received to date and the need to continue the work to get the scenario modelling completed in time is pressing. Subsequently the following is proposed for the model for the Ohakune growing area.

The area of 649 ha is spread across the sub-zones in the quantities identified in the table below and removed from the sheep and beef land use category where there is more to be allocated to the sub-zone than is currently identified in this sub-zone. A nitrogen loss rate of 53.9 kg/ha/yr and a P loss rate of 0.3 kg/ha/yr (Table 1). These leaching values come from vegetable losses in Drewry (2018).

Table A-1. Ohakune growing area loss rates and spatial extent

Sub-zone	Area (ha)	N Loss kg/ha/yr	P Loss kg/ha/yr
Whau_1b	62	53.9	0.3
Whau_1c	359	53.9	0.3
Whau_3d	167	53.9	0.3
Whau_3c	61	53.9	0.3

For the remainder of the vegetable growing area the loss rates per the table from Horticulture NZ are utilized. These figures are outlined as an area weighted average in table 2 by sub-zone below. This was undertaken by multiplying the loss rate identified by horticulture NZ for a particular polygon by its area and then summing both the kg/yr of N lost and area of vegetable production by sub-zone. Finally, the total kg/yr for a sub-zone was divided by the total area of vegetable production to give a loss in kg/ha/yr for the sub-zone.

Table A-2. Area weighted loss rates for the remainder of the region.

Water Management sub-zone	Area (ha)	Sum of N Loss kg/yr	Area weighted N Loss Vegetables kg/ha
Hoki_1a	501.3330838	36253.57641	72
Mana_10a	483.2621963	14981.12809	31
Mana_10c	4.165795272	129.1396534	31
Mana_10d	28.62679617	887.4306814	31
Mana_10e	47.01367271	1457.423854	31
Mana_11a	54.59288229	1692.379351	31
Mana_11b	2.281599462	70.72958331	31
Mana_11c	2.137892725	66.27467448	31
Mana_11d	2.028390943	62.88011924	31
Mana_11e	5.669504587	175.7546422	31
Mana_11f	15.4210838	478.0535977	31
Mana_12a	18.46624136	572.4534822	31
Mana_12b	3.851956847	119.4106623	31
Mana_12c	55.68340863	1726.185668	31
Mana_12d	19.20117089	595.2362977	31
Mana_12e	18.48328075	572.9817032	31
Mana_13a	151.6574647	10638.99247	70
Mana_13c	390.097367	12093.01838	31
Mana_13d	31.46180407	975.3159263	31
Mana_13e	211.9477198	15941.18739	75
Mana_13f	38.11445287	1181.548039	31
Mana_2a	11.2239465	347.9423415	31
Mana_2b	5.703360717	176.8041822	31
Mana_8c	4.616679019	143.1170496	31
Mana_9b	31.61074369	979.9330544	31
Mana_9c	9.959608822	308.7478735	31
Ohau_1b	511.3014148	41538.31012	81
Rang_4a	76.53226439	2372.500196	31
Rang_4b	19.49046735	604.2044877	31
Rang_4c	7.497053857	232.4086696	31
Rang_4d	4.276974515	132.58621	31
Tura_1b	17.35296429	537.9418929	31
West_3	11.35713808	352.0712805	31
West_6	43.84542436	1359.208155	31
West_8	30.57490355	2571.349389	84
West_9a	34.30867104	2885.359234	84
West_9b	138.2814201	11629.46743	84
Whai_2a	1.919482919	59.5039705	31
Whai_4d	0.607182276	18.82265055	31
Whai_7a	22.08853915	684.7447135	31
Whai_7b	11.38545667	352.9491568	31
Whau_3a	19.19962368	595.188334	31
Whau_3c	20.55261432	719.3415012	35
Whau_3d	74.72583823	2615.404338	35

Table A-3. Proposed loss rates supplied by Horticulture NZ's expert

Rotation	**Location Description**	**Loss rate data source**	**Proposed N loss rate (kg N/ha/year)**	**Recommended area (at FMU scale)**
Horowhenua Greens/Brassica Vegetable Rotation	Waiopehu FMU largely in Hoki_1a and Hoki_1b WMSZs. Also in the Manawatu FMU south of the Manawatu river (Mana_13a and Mana_13e WMSZs).	Bloomer et al. (2020) – area weighted average of 'Brassica dominant vegetables' and 'Intensive fresh vegetables' rotations (see Appendix B)	84.1	1077 ha (89%) of VEG land in Waiopehu FMU. 288 ha (18%) of VEG land in Manawatū FMU.
Horowhenua Potato/Onion Vegetable Rotation	Largely within the Waiopehu FMU in Hoki_1a and Ohau_1b WMSZs, along Kimberley Road. Limited area in Manawatu FMU south of the Manawatu River in the Mana_13a and Mana_13e WMSZs.	Bloomer et al. (2020) 'Onion/Potato rotation'	31	139 ha (11%) of VEG land in Waiopehu FMU. 35 ha (2%) of VEG land in Manawatū.
Ohakune vegetable rotations	Ohakune area in Whangaehu FMU (not including Whau_3a and Whau_4 WMSZs).	Updated loss rate for 'Waimarino - Rotation 4' in The Agribusiness Group (2014) *	~~TBD~~ 35	~~405 ha (95%) of VEG land in Whangaehu FMU.~~ 863 ha apportioned across WMSZs according to existing 405 ha of Hort land in Ohakune area in SCAMP.
Manawatu vegetable rotations	Manawatu, Rangitikei-Turakina, Whanganui, and Whangaehu (Whau_3a and Whau_4 WMSZs) FMUs. Majority is located within the Mana_10a and Mana_13c WMSZs.	Updated loss rate for 'Cash cropping – Rotation 1' in The Agribusiness Group (2014, 2017) *	~~TBD~~ 31	1324 ha (80%) of VEG land in Manawatu FMU, 19 ha (5%) of VEG land in Whangaehu FMU, All VEG land in Rangitikei-Turakina, Kai Iwi, and Whanganui FMUs

Table A-4. Consented irrigation for horticulture in the Ohakune sub-zones with area irrigated per year.

Authorisation	Type	Ha irrigated	Crop	Sub-zone	Area data source	Volume m^3/day
ATH-2012014716.00	Horticultural irrigation	62.2	potato	Waitangi	Tech report for consent	3300
ATH-2008012090.01	Horticultural irrigation	86.4	potato's and other vegetable crops	Tokiahuru (Whau1c)	Volume divided by depth mm	4320
ATH-2008012128.02	Horticultural irrigation	79.48	potato's and other vegetable crops	Tokiahuru (Whau_1c)	Volume divided by depth mm	3974
ATH-2008012129.01	Horticultural irrigation	86.4	potato's and other vegetable crops	Tokiahuru (whau_1c)	Volume divided by depth mm	4320
ATH-2008012130.00	Horticultural irrigation	86.4	potato's and other vegetable crops	Tokiahuru	Volume divided by depth mm	4320
ATH-2009012661.02	Market Garden Irrigation	20	Potato Crops	Tokiahuru	Tech report for consent	1555
ATH-2013015000.00	Seasonal vegetable irrigation and wash water			Tokiahuru	only wash water no area available	400
ATH-2012014596.00	Washwater			Tokiahuru	only wash water no area available	423
ATH-2008012089.02	Horticultural irrigation	60.2	potato's and other vegetable crops	Upper Mangawhero	Volume divided by depth mm	3010
ATH-2015200530.01	Horticultural irrigation	10-20	Brussell sprouts	Upper Mangawhero	Application form	3001
ATH-2019202889.00	Horticultural irrigation	42		Upper Mangawhero	Application form	1014
ATH-2019202888.00	Horticultural irrigation	45		Upper Mangawhero	Application form	3360
ATH-2011013730.00	Washwater		Grow carrots parsnips and swedes	Upper Mangawhero	Application form	205
ATH-2012014610.00	Washwater			Upper Mangawhero	only wash water no area available	44
ATH-2013015086.02	Washwater		Potatoes	Upper Mangawhero	only wash water no area available	60
ATH-2014015146.00	Washwater – Same property as the proposal below		Carrots and Potatoes	Makara	only wash water no area available	450
APP-2019202663.00	Vegetable washing proposal		Carrots and Potatoes	Upper Makotuku	only wash water no area available	450
ATH-2013014806.00	Horticultural irrigation -	61	Carrots Onions and Brassicas	Lower Makotuku	Groundwater take harris road	1560

Appendix B Model Calibration Update Results

Table B-1. Manawatu River basin model calibration results: annual average TN concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Manawatu at Weber Road	1.40	1.37	570
Manawatu at Hopelands	1.19	1.19	1052
Manawatu at Ngawapurua Bridge	1.14	1.05	2307
Manawatu at Upper Gorge	1.05	1.09	2765
Manawatu at Teachers College	0.98	0.96	3181
Manawatu at u/s PNCC STP	0.99	1.22	3251
Manawatu at d/s PNCC STP	1.12	1.14	3733
Manawatu at us Fonterra Longburn	1.14	1.11	3897
Manawatu at ds Fonterra Longburn	1.14	1.06	3897
Manawatu at Opiki Br	1.16	1.09	3930
Mangatoro at Mangahei Road	1.08	1.11	133
Kumeti at Te Rehunga	1.66	1.79	21
Oruakeretaki at S.H.2 Napier	1.98	2.11	94
Oruakeretaki at d/s PPCS Oringi STP	1.98	1.87	94
Raparapawai at Jackson Rd	1.42	1.38	40
Makuri at Tuscan Hills	1.97	1.95	181
Tiraumea at Ngaturi	1.55	1.69	677
Mangatainoka at Larsons Road	0.35	0.37	35
Mangatainoka at Brewery - S.H.2 Bridge	1.23	1.34	530
Mangatainoka at d/s DB Breweries	1.24	1.34	530
Mangahao at Ballance	0.44	0.47	197
Mangapapa at Troup Rd	1.49	1.40	24
Mangaatua at u/s Woodville STP	0.89	1.21	48
Mangaatua at d/s Woodville STP	1.55	1.44	83
Pohangina at Mais Reach	0.38	0.38	177
Kahuterawa at Johnstons Rata	0.81	0.86	20
Oroua at Almadale Slackline	0.66	0.74	145
Oroua at U/S AFFCO Feilding	0.90	0.80	322
Oroua at d/s AFFCO Feilding	0.90	0.92	322
Oroua at U/S Feilding STP	0.96	1.31	343
Oroua at d/s Feilding STP	1.84	2.05	657
Oroua at Awahuri Bridge	1.71	1.37	680
Tokomaru River at Horseshoe bend	0.39	0.39	24
Manakau at S.H.1 Bridge	1.32	1.29	13
Waikawa at North Manakau Road	0.21	0.22	9
Owahanga at Branscombe Bridge	1.22	1.26	223
Ohau at Gladstone Reserve	0.24	0.26	43

Table B-2. Manawatu River basin model calibration results: annual average TP concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Manawatu at Weber Road	0.24	0.22	96
Manawatu at Hopelands	0.21	0.14	183
Manawatu at Ngawapurua Bridge	0.18	0.19	370
Manawatu at Upper Gorge	0.16	0.14	427
Manawatu at Teachers College	0.16	0.24	529
Manawatu at u/s PNCC STP	0.16	0.23	534
Manawatu at d/s PNCC STP	0.17	0.19	578
Manawatu at us Fonterra Longburn	0.18	0.20	626
Manawatu at ds Fonterra Longburn	0.18	0.21	626
Manawatu at Opiki Br	0.19	0.17	636
Mangatoro at Mangahei Road	0.34	0.37	42
Kumeti at Te Rehunga	0.06	0.07	1
Oruakeretaki at S.H.2 Napier	0.10	0.10	5
Oruakeretaki at d/s PPCS Oringi STP	0.10	0.10	5
Raparapawai at Jackson Rd	0.24	0.26	7
Makuri at Tuscan Hills	0.26	0.25	24
Tiraumea at Ngaturi	0.24	0.26	106
Mangatainoka at Larsons Road	0.04	0.04	4
Mangatainoka at Brewery - S.H.2 Bridge	0.09	0.08	37
Mangatainoka at d/s DB Breweries	0.09	0.09	37
Mangahao at Ballance	0.08	0.09	37
Mangapapa at Troup Rd	0.10	0.09	2
Mangaatua at u/s Woodville STP	0.08	0.11	4
Mangaatua at d/s Woodville STP	0.14	0.13	7
Pohangina at Mais Reach	0.10	0.09	45
Kahuterawa at Johnstons Rata	0.06	0.06	2
Oroua at Almadale Slackline	0.16	0.17	35
Oroua at d/s AFFCO Feilding	0.18	0.18	63
Oroua at U/S Feilding STP	0.18	0.17	63
Oroua at d/s Feilding STP	0.18	0.14	64
Oroua at Awahuri Bridge	0.17	0.16	69
Tokomaru River at Horseshoe bend	0.04	0.04	2
Manakau at S.H.1 Bridge	0.08	0.08	1
Waikawa at North Manakau Road	0.02	0.02	1
Owahanga at Branscombe Bridge	0.30	0.29	56
Ohau at Gladstone Reserve	0.03	0.03	6

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

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Rangitikei at Pukeokahu	0.21	0.21	158
Rangitikei at Mangaweka	0.38	0.38	825
Rangitikei at Onepuhi	0.41	0.39	1028
Rangitikei at u/s Bulls STP	0.56	0.59	1476
Rangitikei at us Riverlands STP	0.57	0.62	1508
Rangitikei at McKelvies	0.69	0.63	1894
Hautapu at Papakai Road Bridge	0.77	0.72	117
Hautapu at d/s Taihape STP	1.02	1.05	163
Hautapu at US Rangitikei River Conf	1.10	1.01	202
Tutaenui Stream at u/s Marton STP	3.50	3.69	111
Tutaenui Stream at d/s Marton STP	4.09	3.27	129

Table B-4. Rangitikei River basin model calibration results: annual average TP concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Rangitikei at Pukeokahu	0.03	0.03	25
Rangitikei at Mangaweka	0.11	0.11	223
Rangitikei at Onepuhi	0.14	0.14	344
Rangitikei at u/s Bulls STP	0.15	0.25	399
Rangitikei at us Riverlands STP	0.16	0.19	411
Rangitikei at McKelvies	0.17	0.18	477
Hautapu at Papakai Road Bridge	0.11	0.08	16
Hautapu at d/s Taihape STP	0.15	0.10	24
Hautapu at US Rangitikei River Conf	0.15	0.14	28
Tutaenui Stream at u/s Marton STP	0.39	0.13	12
Tutaenui Stream at d/s Marton STP	0.56	0.52	18

Table B-5. Whanganui River basin model calibration results: annual average TN concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Whanganui at Cherry Grove	0.33	0.35	440
Whanganui at u/s Taumarunui STP	0.49	0.35	1,206
Whanganui at d/s Taumarunui STP	0.49	0.39	1,225
Whanganui at Te Maire	0.56	0.61	1,414
Whanganui at Wades Landing	0.79	0.86	3,245
Whanganui at Pipiriki	0.67	0.69	4,370
Whanganui at Te Rewa	0.71	0.68	5,121
Whanganui at Paetawa	0.72	0.78	5,121
Whakapapa at Footbridge	0.05	0.05	18
Ongarue at Taringamotu	0.67	0.73	758
Ohura at Tokorima	0.97	0.98	732

Table B-6. Whanganui River basin model calibration results: annual average TP concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Whanganui at Cherry Grove	0.05	0.05	71
Whanganui at u/s Taumarunui STP	0.06	0.02	146
Whanganui at d/s Taumarunui STP	0.06	0.02	149
Whanganui at Te Maire	0.08	0.08	190
Whanganui at Wades Landing	0.11	0.10	446
Whanganui at Pipiriki	0.13	0.14	828
Whanganui at Te Rewa	0.14	0.19	1,007
Whanganui at Paetawa	0.14	0.24	1,007
Whakapapa at Footbridge	0.02	0.02	8
Ongarue at Taringamotu	0.07	0.06	74
Ohura at Tokorima	0.10	0.11	75

Table B-7. Whangaehu River basin model calibration results: annual average TN concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Whangaehu at Kauangaroa	0.77	0.78	1,104
Mangaehuehu at d/s Rangataua STP	0.29	0.30	7
Mangaehuehu at u/s Rangataua STP	0.30	0.29	8
Tokiahuru at Junction	0.21	0.20	54
Makotuku at SH49A	0.22	0.22	7
Makotuku at Raetihi	0.51	0.50	36
Makotuku at Above Sewage Plant	0.47	0.49	36
Makotuku at d/s Raetihi STP	0.51	0.51	39
Mangawhero at u/s Ohakune STP	0.49	0.49	45
Mangawhero at d/s Ohakune STP	0.82	0.54	75
Mangawhero at Pakihi Rd Bridge	0.54	0.53	87
Mangawhero at Raupiu Road	0.38	0.38	214
Turakina at ONeills Bridge	2.03	2.10	537

Table B-8. Whangaehu River basin model calibration results: annual average TP concentrations and load.

Water Quality Station	Modelled (mg/L)	Measured (mg/L)	Modelled Load (t/y)
Whangaehu at Kauangaroa	0.19	0.21	269
Mangaehuehu at d/s Rangataua STP	0.02	0.02	0.5
Mangaehuehu at u/s Rangataua STP	0.02	0.02	0.5
Tokiahuru at Junction	0.05	0.05	13
Makotuku at SH49A	0.01	0.01	0.3
Makotuku at Raetihi	0.02	0.02	1.5
Makotuku at Above Sewage Plant	0.02	0.02	1.5
Makotuku at d/s Raetihi STP	0.03	0.02	2.0
Mangawhero at u/s Ohakune STP	0.03	0.05	2.6
Mangawhero at d/s Ohakune STP	0.08	0.08	8
Mangawhero at Pakihi Rd Bridge	0.06	0.03	9
Mangawhero at Raupiu Road	0.05	0.05	28
Turakina at ONeills Bridge	0.50	0.51	133

Appendix C Point Source Mitigations (Scenario 3)

Table C-1. Assumed point source facility 2035 actions.

Facility Name	Projected 2035 Scenario Status	Projected change TN (%)	Projected change TP (%)
AFFCO Fielding at Industrial Wastewater	Status Quo	0.0%	0.0%
Aokautere Sewage	Closed	-100.0%	-100.0%
Ashhurst STP at Secondary oxpond waste	Closed	-100.0%	-100.0%
Bulls STP at Secondary oxpond waste	Status Quo	0.0%	0.0%
Bunnythorpe STP	Closed	-100.0%	-100.0%
Dannevirke STP at microfiltered oxpond	Status Quo	0.0%	0.0%
DB Breweries at Industrial wastewater	Closed	-100.0%	-100.0%
Eketahuna STP at Secondary oxpond waste	New Consent	-23.8%	-61.2%
Feilding STP at Secondary oxpond waste	Discharge to Land 6 months of the year	-50.0%	-50.0%
Fonterra Pahiatua wastewater	Closed	-100.0%	-100.0%
Foxton STP at Secondary oxpond waste	Closed	-100.0%	-100.0%
Halcombe at Secondary oxpond	Closed	-100.0%	-100.0%
Hunterville STP at Microfiltration Plant	Status Quo	0.0%	0.0%
Kimbolton STP at oxpond waste	Closed	-100.0%	-100.0%
Longburn STP at oxpond waste	Closed	-100.0%	-100.0%
Marton STP at Rock filtered oxpond waste	Closed	-100.0%	-100.0%
National Park STP at Secondary oxpond	Status Quo	0.0%	0.0%
Norsewood STP at oxpond waste	Upgrades	-17.8%	-85.8%
NZ Pharmaceuticals wastewater	Closed	-100.0%	-100.0%
Ohakea STP at Effluent outfall	Closed	-100.0%	-100.0%
Ohakune STP at Secondary oxpond waste	Status Quo	0.0%	0.0%
Ormondville STP at 2nd oxpond waste	Upgrades	-21.0%	-76.5%
Pahiatua STP at Tertiary oxpond waste	New Consent	-21.3%	0.0%
Pipiriki STP	Closed	-100.0%	-100.0%
PNCC STP at Tertiary Treated Effluent	New Application	-89.5%	-53.0%

Facility Name	Projected 2035 Scenario Status	Projected change TN (%)	Projected change TP (%)
Pongaroa STP at 2nd oxpond waste	Upgrades	-21.8%	-68.6%
PPCS Oringi STP at oxpond waste	Status Quo	0.0%	0.0%
PPCS Shannon at Clarifier Effluent	Closed	-100.0%	-100.0%
Raetihi STP at Secondary oxpond waste	Status Quo	0.0%	0.0%
Rangataua STP at Secondary oxpond waste	Status Quo	0.0%	0.0%
Ratana STP at Secondary oxpond waste	Closed	-100.0%	-100.0%
Riverlands at Industrial wastewater	Status Quo	0.0%	0.0%
Rongotea STP at Secondary oxpond waste	Closed	-100.0%	-100.0%
Sanson STP at Secondary oxpond waste	Closed	-100.0%	-100.0%
Shannon STP at oxpond waste	Closed	-100.0%	-100.0%
Taihape STP at oxpond waste	Status Quo	0.0%	0.0%
Taumarunui STP at Tertiary treated waste	Status Quo	0.0%	0.0%
Tokomaru at oxpond waste	Closed	-100.0%	-100.0%
Waiouru STP at oxpond waste	Status Quo	0.0%	0.0%
Winstone Pulp WWTP at oxpond waste	Status Quo	0.0%	0.0%
Woodville STP at Secondary oxpond waste	Upgrades	-21.5%	0.0%

Appendix D Scenario 1 Simulation Results

Table D-1. Scenario 1 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	1.40	1.29	-7.9%
Manawatū at Hopelands	1.19	1.05	-10.1%
Manawatū at Ngawapurua Bridge	1.14	1.01	-10.3%
Manawatū at Upper Gorge	1.05	0.93	-10.6%
Manawatū at Teachers College	0.98	0.87	-10.3%
Manawatū at u/s PNCC STP	0.99	0.88	-10.1%
Manawatū at d/s PNCC STP	1.12	1.01	-8.9%
Manawatū at us Fonterra Longburn	1.14	1.02	-9.2%
Manawatū at ds Fonterra Longburn	1.14	1.02	-9.2%
Manawatū at Opiki Br	1.16	1.04	-9.2%
Mangatoro at Mangahei Road	1.08	1.05	-3.0%
Kūmeti at Te Rehunga	1.66	1.36	-18.1%
Ōruakeretaki at S.H.2 Napier	1.98	1.64	-16.8%
Ōruakeretaki at d/s PPCS Oringi STP	1.98	1.65	-16.8%
Raparapawai at Jackson Rd	1.42	1.20	-15.8%
Mākuri at Tuscan Hills	1.97	1.88	-4.6%
Tīraumea at Ngaturi	1.55	1.47	-4.6%
Mangatainoka at Larsons Road	0.35	0.32	-10.3%
Mangatainoka at Brewery - S.H.2 Bridge	1.23	1.02	-17.9%
Mangatainoka at d/s DB Breweries	1.24	1.02	-17.9%
Mangahao at Ballance	0.44	0.41	-8.8%
Mangapapa at Troup Rd	1.49	1.28	-12.4%
Mangaatua at u/s Woodville STP	0.89	0.76	-14.9%
Mangaatua at d/s Woodville STP	1.55	1.33	-13.1%
Pohangina at Mais Reach	0.38	0.36	-3.8%
Kahuterawa at Johnstons Rata	0.81	0.79	-2.4%
Ōroua at Almadale Slackline	0.66	0.59	-11.6%
Ōroua at U/S AFFCO Feilding	0.90	0.80	-8.7%
Ōroua at d/s AFFCO Feilding	0.90	0.80	-8.7%
Ōroua at U/S Feilding STP	0.96	0.86	-8.5%
Ōroua at d/s Feilding STP	1.94	1.86	-4.1%
Ōroua at Awahuri Bridge	1.80	1.72	-4.2%
Tokomaru River at Horseshoe bend	0.39	0.39	-1.4%
Manakau at S.H.1 Bridge	1.32	1.30	-1.5%
Waikawa at North Manakau Road	0.21	0.21	-1.1%
Owahanga at Branscombe Bridge	1.22	1.17	-3.8%
Ōhau at Gladstone Reserve	0.24	0.23	-2.9%

Table D-2. Scenario 1 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	0.23	0.18	-21.1%
Manawatū at Hopelands	0.19	0.16	-18.4%
Manawatū at Ngawapurua Bridge	0.18	0.14	-21.2%
Manawatū at Upper Gorge	0.16	0.12	-20.1%
Manawatū at Teachers College	0.21	0.17	-13.7%
Manawatū at u/s PNCC STP	0.21	0.18	-13.0%
Manawatū at d/s PNCC STP	0.22	0.19	-12.4%
Manawatū at us Fonterra Longburn	0.22	0.19	-12.4%
Manawatū at ds Fonterra Longburn	0.22	0.19	-12.4%
Manawatū at Opiki Br	0.22	0.19	-12.3%
Mangatoro at Mangahei Road	0.37	0.30	-18.5%
Kūmeti at Te Rehunga	0.07	0.07	-6.3%
Ōruakeretaki at S.H.2 Napier	0.10	0.09	-10.5%
Ōruakeretaki at d/s PPCS Oringi STP	0.10	0.09	-10.5%
Raparapawai at Jackson Rd	0.27	0.25	-7.9%
Mākuri at Tuscan Hills	0.26	0.18	-28.1%
Tīraumea at Ngaturi	0.26	0.19	-24.5%
Mangatainoka at Larsons Road	0.04	0.03	-22.7%
Mangatainoka at Brewery - S.H.2 Bridge	0.09	0.07	-19.7%
Mangatainoka at d/s DB Breweries	0.09	0.07	-19.6%
Mangahao at Balance	0.09	0.08	-7.6%
Mangapapa at Troup Rd	0.10	0.08	-20.6%
Mangaatua at u/s Woodville STP	0.08	0.07	-21.8%
Mangaatua at d/s Woodville STP	0.14	0.11	-18.8%
Pohangina at Mais Reach	0.09	0.08	-9.9%
Kahuterawa at Johnstons Rata	0.06	0.05	-15.0%
Ōroua at Almadale Slackline	0.17	0.15	-7.0%
Ōroua at U/S AFFCO Feilding	0.18	0.16	-7.3%
Ōroua at d/s AFFCO Feilding	0.18	0.16	-7.3%
Ōroua at U/S Feilding STP	0.18	0.16	-7.3%
Ōroua at d/s Feilding STP	0.18	0.16	-7.1%
Ōroua at Awahuri Bridge	0.17	0.16	-7.5%
Tokomaru River at Horseshoe bend	0.04	0.04	-9.2%
Manakau at S.H.1 Bridge	0.08	0.07	-11.9%
Waikawa at North Manakau Road	0.02	0.02	-3.0%
Owahanga at Branscombe Bridge	0.29	0.22	-23.0%
Ōhau at Gladstone Reserve	0.03	0.03	-5.9%

Table D-3. Scenario 1 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.21	0.20	-2.8%
Rangitīkei at Mangaweka	0.39	0.38	-2.5%
Rangitīkei at Onepuhi	0.41	0.40	-3.1%
Rangitīkei at u/s Bulls STP	0.56	0.53	-5.6%
Rangitīkei at us Riverlands STP	0.57	0.54	-5.5%
Rangitīkei at McKelvies	0.69	0.64	-7.9%
Hautapu at Papakai Road Bridge	0.77	0.75	-2.6%
Hautapu at d/s Taihape STP	1.02	0.99	-2.6%
Hautapu at US Rangitīkei River Conf	1.10	1.07	-2.6%
Tūtaenui Stream at u/s Marton STP	3.50	3.07	-12.4%
Tūtaenui Stream at d/s Marton STP	4.08	3.65	-10.7%

Table D-4. Scenario 1 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.03	0.03	-14.8%
Rangitīkei at Mangaweka	0.11	0.11	-7.0%
Rangitīkei at Onepuhi	0.14	0.13	-6.7%
Rangitīkei at u/s Bulls STP	0.18	0.17	-5.8%
Rangitīkei at us Riverlands STP	0.18	0.17	-5.7%
Rangitīkei at McKelvies	0.19	0.18	-6.0%
Hautapu at Papakai Road Bridge	0.11	0.09	-16.1%
Hautapu at d/s Taihape STP	0.15	0.13	-12.8%
Hautapu at US Rangitīkei River Conf	0.14	0.12	-12.8%
Tūtaenui Stream at u/s Marton STP	0.37	0.34	-8.1%
Tūtaenui Stream at d/s Marton STP	0.53	0.50	-5.6%

Table D-5. Scenario 1 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whanganui at Cherry Grove	0.33	0.32	-4.0%
Whanganui at u/s Taumarunui STP	0.49	0.47	-3.8%
Whanganui at d/s Taumarunui STP	0.49	0.48	-3.7%
Whanganui at Te Maire	0.56	0.54	-4.1%
Whanganui at Wades Landing	0.79	0.75	-5.2%
Whanganui at Pipiriki	0.67	0.63	-5.1%
Whanganui at Te Rewa	0.71	0.68	-5.2%
Whanganui at Paetawa	0.72	0.68	-5.2%
Whakapapa at Footbridge	0.05	0.05	-0.9%
Ōngarue at Taringamotu	0.67	0.64	-3.6%
Ōhura at Tokorima	0.97	0.91	-6.4%

Table D-6. Scenario 1 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whanganui at Cherry Grove	0.05	0.04	-18.0%
Whanganui at u/s Taumarunui STP	0.06	0.05	-20.0%
Whanganui at d/s Taumarunui STP	0.06	0.05	-19.7%
Whanganui at Te Maire	0.08	0.07	-16.4%
Whanganui at Wades Landing	0.10	0.08	-19.9%
Whanganui at Pipiriki	0.14	0.12	-11.9%
Whanganui at Te Rewa	0.19	0.17	-8.7%
Whanganui at Paetawa	0.19	0.17	-8.7%
Whakapapa at Footbridge	0.02	0.02	-15.9%
Ōngarue at Taringamotu	0.07	0.05	-21.9%
Ōhura at Tokorima	0.10	0.07	-29.8%

Table D-7. Scenario 1 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whangaehu at Kauangaroa	0.77	0.74	-4.0%
Mangaehuehu at d/s Rangataua STP	0.29	0.29	-1.0%
Mangaehuehu at u/s Rangataua STP	0.30	0.30	-1.0%
Tokiahuru at Junction	0.21	0.21	-0.8%
Makotuku at SH49A	0.22	0.22	-1.1%
Makotuku at Raetihi	0.51	0.50	-2.7%
Makotuku at Above Sewage Plant	0.47	0.46	-2.7%
Makotuku at d/s Raetihi STP	0.51	0.50	-2.5%
Mangawhero at u/s Ohakune STP	0.49	0.48	-1.3%
Mangawhero at d/s Ohakune STP	0.82	0.82	-0.7%
Mangawhero at Pakihi Rd Bridge	0.54	0.53	-1.4%
Mangawhero at Raupiu Road	0.38	0.37	-2.9%
Turakina at ONeills Bridge	2.03	1.92	-5.2%

Table D-8. Scenario 1 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whangaehu at Kauangaroa	0.21	0.19	-10.3%
Mangaehuehu at d/s Rangataua STP	0.02	0.02	-17.0%
Mangaehuehu at u/s Rangataua STP	0.02	0.02	-15.8%
Tokiahuru at Junction	0.05	0.04	-16.8%
Makotuku at SH49A	0.01	0.01	-14.5%
Makotuku at Raetihi	0.02	0.02	-20.6%
Makotuku at Above Sewage Plant	0.02	0.02	-20.6%
Makotuku at d/s Raetihi STP	0.02	0.02	-16.9%
Mangawhero at u/s Ohakune STP	0.02	0.02	-17.6%
Mangawhero at d/s Ohakune STP	0.08	0.08	-4.5%
Mangawhero at Pakihi Rd Bridge	0.06	0.05	-7.2%
Mangawhero at Raupiu Road	0.05	0.04	-21.8%
Turakina at ONeills Bridge	0.50	0.45	-11.0%

Appendix E Scenario 2 Simulation Results

Table E-1. Scenario 2 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	1.40	1.07	-23.7%
Manawatū at Hopelands	1.19	0.84	-27.5%
Manawatū at Ngawapurua Bridge	1.14	0.82	-27.5%
Manawatū at Upper Gorge	1.05	0.75	-28.3%
Manawatū at Teachers College	0.98	0.70	-27.7%
Manawatū at u/s PNCC STP	0.99	0.71	-27.5%
Manawatū at d/s PNCC STP	1.12	0.84	-24.3%
Manawatū at us Fonterra Longburn	1.14	0.84	-24.8%
Manawatū at ds Fonterra Longburn	1.14	0.84	-24.8%
Manawatū at Opiki Br	1.16	0.86	-24.9%
Mangatoro at Mangahei Road	1.08	0.91	-16.1%
Kūmeti at Te Rehunga	1.66	1.02	-38.6%
Ōruakeretaki at S.H.2 Napier	1.98	1.14	-42.2%
Ōruakeretaki at d/s PPCS Oringi STP	1.98	1.15	-42.1%
Raparapawai at Jackson Rd	1.42	0.83	-41.4%
Mākuri at Tuscan Hills	1.97	1.58	-19.8%
Tīraumea at Ngaturi	1.55	1.24	-19.6%
Mangatainoka at Larsons Road	0.35	0.26	-25.7%
Mangatainoka at Brewery - S.H.2 Bridge	1.23	0.77	-37.5%
Mangatainoka at d/s DB Breweries	1.24	0.77	-37.5%
Mangahao at Ballance	0.44	0.33	-26.8%
Mangapapa at Troup Rd	1.49	0.98	-32.6%
Mangaatua at u/s Woodville STP	0.89	0.56	-36.8%
Mangaatua at d/s Woodville STP	1.55	1.03	-32.8%
Pohangina at Mais Reach	0.38	0.31	-17.3%
Kahuterawa at Johnstons Rata	0.81	0.66	-17.7%
Ōroua at Almadale Slackline	0.66	0.45	-32.4%
Ōroua at U/S AFFCO Feilding	0.90	0.64	-27.0%
Ōroua at d/s AFFCO Feilding	0.90	0.64	-27.0%
Ōroua at U/S Feilding STP	0.96	0.69	-26.9%
Ōroua at d/s Feilding STP	1.94	1.69	-13.0%
Ōroua at Awahuri Bridge	1.80	1.55	-13.5%
Tokomaru River at Horseshoe bend	0.39	0.34	-13.4%
Manakau at S.H.1 Bridge	1.32	1.09	-18.1%
Waikawa at North Manakau Road	0.21	0.20	-7.6%
Owahanga at Branscombe Bridge	1.22	1.00	-17.9%
Ōhau at Gladstone Reserve	0.24	0.20	-15.0%

Table E-2. Scenario 2 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	0.23	0.17	-28.4%
Manawatū at Hopelands	0.19	0.14	-26.4%
Manawatū at Ngawapurua Bridge	0.18	0.12	-31.3%
Manawatū at Upper Gorge	0.16	0.11	-29.8%
Manawatū at Teachers College	0.21	0.16	-21.0%
Manawatū at u/s PNCC STP	0.21	0.17	-20.0%
Manawatū at d/s PNCC STP	0.22	0.18	-19.1%
Manawatū at us Fonterra Longburn	0.22	0.17	-19.3%
Manawatū at ds Fonterra Longburn	0.22	0.17	-19.3%
Manawatū at Opiki Br	0.22	0.18	-19.3%
Mangatoro at Mangahei Road	0.37	0.28	-23.9%
Kūmeti at Te Rehunga	0.07	0.06	-14.5%
Ōruakeretaki at S.H.2 Napier	0.10	0.08	-22.9%
Ōruakeretaki at d/s PPCS Oringi STP	0.10	0.08	-22.9%
Raparapawai at Jackson Rd	0.27	0.23	-15.5%
Mākuri at Tuscan Hills	0.26	0.15	-41.8%
Tīraumea at Ngaturi	0.26	0.17	-34.7%
Mangatainoka at Larsons Road	0.04	0.03	-36.6%
Mangatainoka at Brewery - S.H.2 Bridge	0.09	0.08	-35.8%
Mangatainoka at d/s DB Breweries	0.09	0.09	-35.8%
Mangahao at Balance	0.09	0.09	-11.5%
Mangapapa at Troup Rd	0.10	0.09	-31.9%
Mangaatua at u/s Woodville STP	0.08	0.11	-36.7%
Mangaatua at d/s Woodville STP	0.14	0.13	-31.0%
Pohangina at Mais Reach	0.09	0.07	-21.8%
Kahuterawa at Johnstons Rata	0.06	0.04	-30.3%
Ōroua at Almadale Slackline	0.17	0.13	-18.1%
Ōroua at U/S AFFCO Feilding	0.18	0.14	-18.0%
Ōroua at d/s AFFCO Feilding	0.18	0.14	-18.0%
Ōroua at U/S Feilding STP	0.18	0.14	-18.0%
Ōroua at d/s Feilding STP	0.18	0.15	-17.4%
Ōroua at Awahuri Bridge	0.17	0.14	-18.1%
Tokomaru River at Horseshoe bend	0.04	0.03	-26.0%
Manakau at S.H.1 Bridge	0.08	0.06	-24.7%
Waikawa at North Manakau Road	0.02	0.02	-5.3%
Owahanga at Branscombe Bridge	0.29	0.20	-32.2%
Ōhau at Gladstone Reserve	0.03	0.03	-13.1%

Table E-3. Scenario 2 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TN concentrations.

Monitoring Site	**Baseline (mg L^{-1})**	**Scenario (mg L^{-1})**	**Difference (%)**
Rangitīkei at Pukeokahu	0.21	0.18	-15.2%
Rangitīkei at Mangaweka	0.39	0.33	-15.7%
Rangitīkei at Onepuhi	0.41	0.34	-17.1%
Rangitīkei at u/s Bulls STP	0.56	0.44	-22.1%
Rangitīkei at us Riverlands STP	0.57	0.45	-21.6%
Rangitīkei at McKelvies	0.69	0.52	-25.3%
Hautapu at Papakai Road Bridge	0.77	0.63	-18.1%
Hautapu at d/s Taihape STP	1.02	0.84	-17.6%
Hautapu at US Rangitīkei River Conf	1.10	0.91	-17.0%
Tūtaenui Stream at u/s Marton STP	3.50	2.22	-36.6%
Tūtaenui Stream at d/s Marton STP	4.08	2.80	-31.4%

Table E-4. Scenario 2 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TP concentrations.

Monitoring Site	**Baseline (mg L^{-1})**	**Scenario (mg L^{-1})**	**Difference (%)**
Rangitīkei at Pukeokahu	0.03	0.02	-32.7%
Rangitīkei at Mangaweka	0.11	0.09	-16.3%
Rangitīkei at Onepuhi	0.14	0.12	-15.4%
Rangitīkei at u/s Bulls STP	0.18	0.15	-13.3%
Rangitīkei at us Riverlands STP	0.18	0.16	-13.1%
Rangitīkei at McKelvies	0.19	0.16	-13.6%
Hautapu at Papakai Road Bridge	0.11	0.07	-33.8%
Hautapu at d/s Taihape STP	0.15	0.11	-27.2%
Hautapu at US Rangitīkei River Conf	0.14	0.10	-27.3%
Tūtaenui Stream at u/s Marton STP	0.37	0.31	-15.6%
Tūtaenui Stream at d/s Marton STP	0.53	0.47	-10.9%

Table E-5. Scenario 2 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TN concentrations.

Monitoring Site	**Baseline (mg L^{-1})**	**Scenario (mg L^{-1})**	**Difference (%)**
Whanganui at Cherry Grove	0.33	0.26	-20.5%
Whanganui at u/s Taumarunui STP	0.49	0.39	-20.0%
Whanganui at d/s Taumarunui STP	0.49	0.40	-19.6%
Whanganui at Te Maire	0.56	0.45	-20.4%
Whanganui at Wades Landing	0.79	0.61	-22.6%
Whanganui at Pipiriki	0.67	0.52	-21.6%
Whanganui at Te Rewa	0.71	0.56	-21.5%
Whanganui at Paetawa	0.72	0.56	-21.5%
Whakapapa at Footbridge	0.05	0.04	-17.6%
Ōngarue at Taringamotu	0.67	0.54	-19.7%
Ōhura at Tokorima	0.97	0.73	-24.8%

Table E-6. Scenario 2 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L-1)	Scenario (mg L-1)	Difference (%)
Whanganui at Cherry Grove	0.05	0.04	-24.6%
Whanganui at u/s Taumarunui STP	0.06	0.04	-27.3%
Whanganui at d/s Taumarunui STP	0.06	0.04	-26.8%
Whanganui at Te Maire	0.08	0.06	-22.3%
Whanganui at Wades Landing	0.10	0.07	-26.8%
Whanganui at Pipiriki	0.14	0.12	-16.3%
Whanganui at Te Rewa	0.19	0.17	-12.1%
Whanganui at Paetawa	0.19	0.17	-12.1%
Whakapapa at Footbridge	0.02	0.02	-21.7%
Ōngarue at Taringamotu	0.07	0.05	-29.8%
Ōhura at Tokorima	0.10	0.06	-39.7%

Table E-7. Scenario 2 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L-1)	Scenario (mg L-1)	Difference (%)
Whangaehu at Kauangaroa	0.77	0.63	-19.1%
Mangaehuehu at d/s Rangataua STP	0.29	0.24	-18.8%
Mangaehuehu at u/s Rangataua STP	0.30	0.25	-18.3%
Tokiahuru at Junction	0.21	0.18	-14.4%
Makotuku at SH49A	0.22	0.18	-16.6%
Makotuku at Raetihi	0.51	0.39	-23.2%
Makotuku at Above Sewage Plant	0.47	0.36	-23.2%
Makotuku at d/s Raetihi STP	0.51	0.40	-21.3%
Mangawhero at u/s Ohakune STP	0.49	0.41	-16.0%
Mangawhero at d/s Ohakune STP	0.82	0.75	-9.5%
Mangawhero at Pakihi Rd Bridge	0.54	0.48	-12.0%
Mangawhero at Raupiu Road	0.38	0.31	-18.5%
Turakina at ONeills Bridge	2.03	1.61	-20.5%

Table E-8. Scenario 2 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L-1)	Scenario (mg L-1)	Difference (%)
Whangaehu at Kauangaroa	0.21	0.18	-16.2%
Mangaehuehu at d/s Rangataua STP	0.02	0.01	-23.2%
Mangaehuehu at u/s Rangataua STP	0.02	0.02	-21.5%
Tokiahuru at Junction	0.05	0.04	-22.9%
Makotuku at SH49A	0.01	0.01	-19.8%
Makotuku at Raetihi	0.02	0.02	-28.2%
Makotuku at Above Sewage Plant	0.02	0.01	-28.2%
Makotuku at d/s Raetihi STP	0.02	0.02	-23.2%
Mangawhero at u/s Ohakune STP	0.02	0.02	-23.8%
Mangawhero at d/s Ohakune STP	0.08	0.08	-6.0%
Mangawhero at Pakihi Rd Bridge	0.06	0.05	-9.9%
Mangawhero at Raupiu Road	0.05	0.04	-31.1%
Turakina at ONeills Bridge	0.50	0.40	-21.1%

Appendix F Scenario 3 Simulation Results

Table F-1. Scenario 3 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	1.40	1.40	0.0%
Manawatū at Hopelands	1.19	1.17	0.0%
Manawatū at Ngawapurua Bridge	1.14	1.13	-0.1%
Manawatū at Upper Gorge	1.05	1.04	-0.1%
Manawatū at Teachers College	0.98	0.97	-0.1%
Manawatū at u/s PNCC STP	0.99	0.98	-0.1%
Manawatū at d/s PNCC STP	1.12	0.99	-10.2%
Manawatū at us Fonterra Longburn	1.14	1.01	-9.7%
Manawatū at ds Fonterra Longburn	1.14	1.01	-9.7%
Manawatū at Opiki Br	1.16	1.03	-9.7%
Mangatoro at Mangahei Road	1.08	1.08	0.0%
Kūmeti at Te Rehunga	1.66	1.66	0.0%
Ōruakeretaki at S.H.2 Napier	1.98	1.98	0.0%
Ōruakeretaki at d/s PPCS Oringi STP	1.98	1.98	0.0%
Raparapawai at Jackson Rd	1.42	1.42	0.0%
Mākuri at Tuscan Hills	1.97	1.97	0.0%
Tīraumea at Ngaturi	1.55	1.55	0.0%
Mangatainoka at Larsons Road	0.35	0.35	0.0%
Mangatainoka at Brewery - S.H.2 Bridge	1.23	1.23	-0.3%
Mangatainoka at d/s DB Breweries	1.24	1.23	-0.3%
Mangahao at Ballance	0.44	0.44	0.0%
Mangapapa at Troup Rd	1.49	1.46	0.0%
Mangaatua at u/s Woodville STP	0.89	0.89	0.0%
Mangaatua at d/s Woodville STP	1.55	1.51	-1.6%
Pohangina at Mais Reach	0.38	0.38	0.0%
Kahuterawa at Johnstons Rata	0.81	0.81	0.0%
Ōroua at Almadale Slackline	0.66	0.66	-0.9%
Ōroua at U/S AFFCO Feilding	0.90	0.88	-0.4%
Ōroua at d/s AFFCO Feilding	0.90	0.88	-0.4%
Ōroua at U/S Feilding STP	0.96	0.93	-0.4%
Ōroua at d/s Feilding STP	1.94	1.43	-26.0%
Ōroua at Awahuri Bridge	1.80	1.34	-25.2%
Tokomaru River at Horseshoe bend	0.39	0.39	0.0%
Manakau at S.H.1 Bridge	1.32	1.32	0.0%
Waikawa at North Manakau Road	0.20	0.20	0.0%
Owahanga at Branscombe Bridge	1.22	1.22	0.0%
Ōhau at Gladstone Reserve	0.24	0.24	0.0%

Table F-2. Scenario 3 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	0.23	0.23	-0.2%
Manawatū at Hopelands	0.19	0.19	-0.1%
Manawatū at Ngawapurua Bridge	0.18	0.17	-0.1%
Manawatū at Upper Gorge	0.16	0.16	-0.1%
Manawatū at Teachers College	0.21	0.20	-0.1%
Manawatū at u/s PNCC STP	0.21	0.21	-0.1%
Manawatū at d/s PNCC STP	0.22	0.21	-2.5%
Manawatū at us Fonterra Longburn	0.22	0.21	-2.4%
Manawatū at ds Fonterra Longburn	0.22	0.21	-2.4%
Manawatū at Opiki Br	0.22	0.21	-2.4%
Mangatoro at Mangahei Road	0.37	0.37	0.0%
Kūmeti at Te Rehunga	0.07	0.07	0.0%
Ōruakeretaki at S.H.2 Napier	0.10	0.10	0.0%
Ōruakeretaki at d/s PPCS Oringi STP	0.10	0.10	0.0%
Raparapawai at Jackson Rd	0.27	0.27	0.0%
Mākuri at Tuscan Hills	0.26	0.26	0.0%
Tīraumea at Ngaturi	0.26	0.26	0.0%
Mangatainoka at Larsons Road	0.04	0.04	0.0%
Mangatainoka at Brewery - S.H.2 Bridge	0.09	0.09	-0.6%
Mangatainoka at d/s DB Breweries	0.09	0.09	-0.7%
Mangahao at Balance	0.09	0.08	0.0%
Mangapapa at Troup Rd	0.10	0.10	0.0%
Mangaatua at u/s Woodville STP	0.08	0.08	0.0%
Mangaatua at d/s Woodville STP	0.14	0.14	0.0%
Pohangina at Mais Reach	0.09	0.09	0.0%
Kahuterawa at Johnstons Rata	0.06	0.06	0.0%
Ōroua at Almadale Slackline	0.17	0.16	-0.9%
Ōroua at U/S AFFCO Feilding	0.18	0.17	-0.5%
Ōroua at d/s AFFCO Feilding	0.18	0.17	-0.5%
Ōroua at U/S Feilding STP	0.18	0.17	-0.5%
Ōroua at d/s Feilding STP	0.18	0.17	-2.1%
Ōroua at Awahuri Bridge	0.17	0.17	-2.0%
Tokomaru River at Horseshoe bend	0.04	0.04	0.0%
Manakau at S.H.1 Bridge	0.08	0.08	0.0%
Waikawa at North Manakau Road	0.02	0.02	0.0%
Owahanga at Branscombe Bridge	0.29	0.29	-0.1%
Ōhau at Gladstone Reserve	0.03	0.03	0.0%

Table F-3. Scenario 3 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.21	0.21	0.0%
Rangitīkei at Mangaweka	0.39	0.39	0.0%
Rangitīkei at Onepuhi	0.41	0.41	0.0%
Rangitīkei at u/s Bulls STP	0.56	0.56	-0.1%
Rangitīkei at us Riverlands STP	0.57	0.57	-0.3%
Rangitīkei at McKelvies	0.69	0.68	-1.4%
Hautapu at Papakai Road Bridge	0.77	0.77	0.0%
Hautapu at d/s Taihape STP	1.02	1.02	0.0%
Hautapu at US Rangitīkei River Conf	1.10	1.10	0.0%
Tūtaenui Stream at u/s Marton STP	3.50	3.50	0.0%
Tūtaenui Stream at d/s Marton STP	4.08	3.50	-14.2%

Table F-4. Scenario 3 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.03	0.03	0.0%
Rangitīkei at Mangaweka	0.11	0.11	0.0%
Rangitīkei at Onepuhi	0.14	0.14	0.0%
Rangitīkei at u/s Bulls STP	0.18	0.18	0.0%
Rangitīkei at us Riverlands STP	0.18	0.18	-0.2%
Rangitīkei at McKelvies	0.19	0.18	-1.3%
Hautapu at Papakai Road Bridge	0.11	0.11	0.0%
Hautapu at d/s Taihape STP	0.15	0.15	0.0%
Hautapu at US Rangitīkei River Conf	0.14	0.14	0.0%
Tūtaenui Stream at u/s Marton STP	0.37	0.37	0.0%
Tūtaenui Stream at d/s Marton STP	0.53	0.37	-30.4%

Table F-5. Scenario 3 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whanganui at Cherry Grove	0.33	0.33	0.0%
Whanganui at u/s Taumarunui STP	0.49	0.49	0.0%
Whanganui at d/s Taumarunui STP	0.49	0.49	0.0%
Whanganui at Te Maire	0.56	0.56	0.0%
Whanganui at Wades Landing	0.79	0.79	0.0%
Whanganui at Pipiriki	0.67	0.67	0.0%
Whanganui at Te Rewa	0.71	0.71	0.0%
Whanganui at Paetawa	0.72	0.72	0.0%
Whakapapa at Footbridge	0.05	0.05	0.0%
Ōngarue at Taringamotu	0.67	0.67	0.0%
Ōhura at Tokorima	0.97	0.97	0.0%

Table F-6. Scenario 3 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline ($mg\ L^{-1}$)	Scenario ($mg\ L^{-1}$)	Difference (%)
Whanganui at Cherry Grove	0.05	0.05	0.0%
Whanganui at u/s Taumarunui STP	0.06	0.06	0.0%
Whanganui at d/s Taumarunui STP	0.06	0.06	0.0%
Whanganui at Te Maire	0.08	0.08	0.0%
Whanganui at Wades Landing	0.10	0.10	0.0%
Whanganui at Pipiriki	0.14	0.14	0.0%
Whanganui at Te Rewa	0.19	0.19	0.0%
Whanganui at Paetawa	0.19	0.19	0.0%
Whakapapa at Footbridge	0.02	0.02	0.0%
Ōngarue at Taringamotu	0.07	0.07	0.0%
Ōhura at Tokorima	0.10	0.10	0.0%

Table F-7. Scenario 3 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline ($mg\ L^{-1}$)	Scenario ($mg\ L^{-1}$)	Difference (%)
Whangaehu at Kauangaroa	0.77	0.77	0.0%
Mangaehuehu at d/s Rangataua STP	0.29	0.29	0.0%
Mangaehuehu at u/s Rangataua STP	0.30	0.30	0.0%
Tokiahuru at Junction	0.21	0.21	0.0%
Makotuku at SH49A	0.22	0.22	0.0%
Makotuku at Raetihi	0.51	0.51	0.0%
Makotuku at Above Sewage Plant	0.47	0.47	0.0%
Makotuku at d/s Raetihi STP	0.51	0.51	0.0%
Mangawhero at u/s Ohakune STP	0.49	0.49	0.0%
Mangawhero at d/s Ohakune STP	0.82	0.82	0.0%
Mangawhero at Pakihi Rd Bridge	0.54	0.54	0.0%
Mangawhero at Raupiu Road	0.38	0.38	0.0%
Turakina at ONeills Bridge	2.03	2.03	0.0%

Table F-8. Scenario 3 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline ($mg\ L^{-1}$)	Scenario ($mg\ L^{-1}$)	Difference (%)
Whangaehu at Kauangaroa	0.21	0.21	0.0%
Mangaehuehu at d/s Rangataua STP	0.02	0.02	0.0%
Mangaehuehu at u/s Rangataua STP	0.02	0.02	0.0%
Tokiahuru at Junction	0.05	0.05	0.0%
Makotuku at SH49A	0.01	0.01	0.0%
Makotuku at Raetihi	0.02	0.02	0.0%
Makotuku at Above Sewage Plant	0.02	0.02	0.0%
Makotuku at d/s Raetihi STP	0.02	0.02	0.0%
Mangawhero at u/s Ohakune STP	0.02	0.02	0.0%
Mangawhero at d/s Ohakune STP	0.08	0.08	0.0%
Mangawhero at Pakihi Rd Bridge	0.06	0.06	0.0%
Mangawhero at Raupiu Road	0.05	0.05	0.0%
Turakina at ONeills Bridge	0.50	0.50	0.0%

Appendix G Scenario 4 Simulation Results

Table G-1. Scenario 4 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	1.40	1.07	-23.7%
Manawatū at Hopelands	1.19	0.84	-27.5%
Manawatū at Ngawapurua Bridge	1.14	0.82	-27.6%
Manawatū at Upper Gorge	1.05	0.75	-28.4%
Manawatū at Teachers College	0.98	0.70	-27.8%
Manawatū at u/s PNCC STP	0.99	0.71	-27.6%
Manawatū at d/s PNCC STP	1.12	0.72	-34.5%
Manawatū at us Fonterra Longburn	1.14	0.73	-34.6%
Manawatū at ds Fonterra Longburn	1.14	0.73	-34.6%
Manawatū at Opiki Br	1.16	0.75	-34.6%
Mangatoro at Mangahei Road	1.08	0.91	-16.1%
Kūmeti at Te Rehunga	1.66	1.02	-38.6%
Ōruakeretaki at S.H.2 Napier	1.98	1.14	-42.2%
Ōruakeretaki at d/s PPCS Oringi STP	1.98	1.15	-42.1%
Raparapawai at Jackson Rd	1.42	0.83	-41.4%
Mākuri at Tuscan Hills	1.97	1.58	-19.8%
Tīraumea at Ngaturi	1.55	1.24	-19.6%
Mangatainoka at Larsons Road	0.35	0.26	-25.7%
Mangatainoka at Brewery - S.H.2 Bridge	1.23	0.77	-37.7%
Mangatainoka at d/s DB Breweries	1.24	0.77	-37.8%
Mangahao at Ballance	0.44	0.33	-26.8%
Mangapapa at Troup Rd	1.49	0.98	-32.6%
Mangaatua at u/s Woodville STP	0.89	0.56	-36.8%
Mangaatua at d/s Woodville STP	1.55	1.01	-34.4%
Pohangina at Mais Reach	0.38	0.31	-17.3%
Kahuterawa at Johnstons Rata	0.81	0.66	-17.7%
Ōroua at Almadale Slackline	0.66	0.44	-33.3%
Ōroua at U/S AFFCO Feilding	0.90	0.64	-27.5%
Ōroua at d/s AFFCO Feilding	0.90	0.64	-27.5%
Ōroua at U/S Feilding STP	0.96	0.68	-27.3%
Ōroua at d/s Feilding STP	1.94	1.18	-39.0%
Ōroua at Awahuri Bridge	1.80	1.10	-38.7%
Tokomaru River at Horseshoe bend	0.39	0.34	-13.4%
Manakau at S.H.1 Bridge	1.32	1.09	-18.1%
Waikawa at North Manakau Road	0.21	0.20	-7.6%
Owahanga at Branscombe Bridge	1.22	1.00	-17.9%
Ōhau at Gladstone Reserve	0.24	0.20	-15.0%

Table G-2. Scenario 4 modelling results: monitoring sites in the Manawatū River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Manawatū at Weber Road	0.23	0.17	-28.7%
Manawatū at Hopelands	0.19	0.14	-26.5%
Manawatū at Ngawapurua Bridge	0.18	0.12	-31.5%
Manawatū at Upper Gorge	0.16	0.11	-29.9%
Manawatū at Teachers College	0.21	0.16	-21.1%
Manawatū at u/s PNCC STP	0.21	0.17	-20.1%
Manawatū at d/s PNCC STP	0.22	0.17	-21.6%
Manawatū at us Fonterra Longburn	0.22	0.17	-21.7%
Manawatū at ds Fonterra Longburn	0.22	0.17	-21.7%
Manawatū at Opiki Br	0.22	0.17	-21.7%
Mangatoro at Mangahei Road	0.37	0.28	-23.9%
Kūmeti at Te Rehunga	0.07	0.06	-14.5%
Ōruakeretaki at S.H.2 Napier	0.10	0.08	-22.9%
Ōruakeretaki at d/s PPCS Oringi STP	0.10	0.08	-22.9%
Raparapawai at Jackson Rd	0.27	0.23	-15.5%
Mākuri at Tuscan Hills	0.26	0.15	-41.8%
Tīraumea at Ngaturi	0.26	0.17	-34.7%
Mangatainoka at Larsons Road	0.04	0.03	-36.6%
Mangatainoka at Brewery - S.H.2 Bridge	0.09	0.05	-36.4%
Mangatainoka at d/s DB Breweries	0.09	0.05	-36.5%
Mangahao at Balance	0.09	0.07	-11.5%
Mangapapa at Troup Rd	0.10	0.07	-31.9%
Mangaatua at u/s Woodville STP	0.08	0.05	-36.7%
Mangaatua at d/s Woodville STP	0.14	0.09	-31.0%
Pohangina at Mais Reach	0.09	0.07	-21.8%
Kahuterawa at Johnstons Rata	0.06	0.04	-30.3%
Ōroua at Almadale Slackline	0.17	0.13	-19.0%
Ōroua at U/S AFFCO Feilding	0.18	0.14	-18.6%
Ōroua at d/s AFFCO Feilding	0.18	0.14	-18.6%
Ōroua at U/S Feilding STP	0.18	0.14	-18.5%
Ōroua at d/s Feilding STP	0.18	0.14	-19.5%
Ōroua at Awahuri Bridge	0.17	0.14	-20.0%
Tokomaru River at Horseshoe bend	0.04	0.03	-26.0%
Manakau at S.H.1 Bridge	0.08	0.06	-24.7%
Waikawa at North Manakau Road	0.02	0.02	-5.3%
Owahanga at Branscombe Bridge	0.29	0.20	-32.3%
Ōhau at Gladstone Reserve	0.03	0.03	-13.1%

Table G-3. Scenario 4 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.21	0.18	-15.2%
Rangitīkei at Mangaweka	0.39	0.33	-15.7%
Rangitīkei at Onepuhi	0.41	0.34	-17.1%
Rangitīkei at u/s Bulls STP	0.56	0.44	-22.1%
Rangitīkei at us Riverlands STP	0.57	0.45	-21.9%
Rangitīkei at McKelvies	0.69	0.51	-26.7%
Hautapu at Papakai Road Bridge	0.77	0.63	-18.1%
Hautapu at d/s Taihape STP	1.02	0.84	-17.6%
Hautapu at US Rangitīkei River Conf	1.10	0.91	-17.0%
Tūtaenui Stream at u/s Marton STP	3.50	2.22	-36.6%
Tūtaenui Stream at d/s Marton STP	4.08	2.22	-45.6%

Table G-4. Scenario 4 modelling results: monitoring sites in the Rangitīkei River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Rangitīkei at Pukeokahu	0.03	0.02	-32.7%
Rangitīkei at Mangaweka	0.11	0.09	-16.3%
Rangitīkei at Onepuhi	0.14	0.12	-15.4%
Rangitīkei at u/s Bulls STP	0.18	0.15	-13.3%
Rangitīkei at us Riverlands STP	0.18	0.16	-13.2%
Rangitīkei at McKelvies	0.19	0.16	-14.9%
Hautapu at Papakai Road Bridge	0.11	0.07	-33.8%
Hautapu at d/s Taihape STP	0.15	0.11	-27.2%
Hautapu at US Rangitīkei River Conf	0.14	0.10	-27.3%
Tūtaenui Stream at u/s Marton STP	0.37	0.31	-15.6%
Tūtaenui Stream at d/s Marton STP	0.53	0.31	-41.3%

Table G-5. Scenario 4 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whanganui at Cherry Grove	0.33	0.26	-20.5%
Whanganui at u/s Taumarunui STP	0.49	0.39	-20.0%
Whanganui at d/s Taumarunui STP	0.49	0.40	-19.6%
Whanganui at Te Maire	0.56	0.45	-20.4%
Whanganui at Wades Landing	0.79	0.61	-22.6%
Whanganui at Pipiriki	0.67	0.52	-21.6%
Whanganui at Te Rewa	0.71	0.56	-21.5%
Whanganui at Paetawa	0.72	0.56	-21.5%
Whakapapa at Footbridge	0.05	0.04	-17.6%
Ōngarue at Taringamotu	0.67	0.54	-19.7%
Ōhura at Tokorima	0.97	0.73	-24.8%

Table G-6. Scenario 4 modelling results: monitoring sites in the Whanganui River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline (mg L^{-1})	Scenario (mg L^{-1})	Difference (%)
Whanganui at Cherry Grove	0.05	0.04	-24.6%
Whanganui at u/s Taumarunui STP	0.06	0.04	-27.3%
Whanganui at d/s Taumarunui STP	0.06	0.04	-26.8%
Whanganui at Te Maire	0.08	0.06	-22.3%
Whanganui at Wades Landing	0.10	0.07	-26.8%
Whanganui at Pipiriki	0.14	0.12	-16.3%
Whanganui at Te Rewa	0.19	0.17	-12.1%
Whanganui at Paetawa	0.19	0.17	-12.1%
Whakapapa at Footbridge	0.02	0.02	-21.7%
Ōngarue at Taringamotu	0.07	0.05	-29.8%
Ōhura at Tokorima	0.10	0.06	-39.7%

Table G-7. Scenario 4 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TN concentrations.

Monitoring Site	Baseline Modelled (mg L^{-1})	Scenario Modelled (mg L^{-1})	Difference (%)
Whangaehu at Kauangaroa	0.77	0.63	-19.1%
Mangaehuehu at d/s Rangataua STP	0.29	0.24	-18.8%
Mangaehuehu at u/s Rangataua STP	0.30	0.25	-18.3%
Tokiahuru at Junction	0.21	0.18	-14.4%
Makotuku at SH49A	0.22	0.18	-16.6%
Makotuku at Raetihi	0.51	0.39	-23.2%
Makotuku at Above Sewage Plant	0.47	0.36	-23.2%
Makotuku at d/s Raetihi STP	0.51	0.40	-21.3%
Mangawhero at u/s Ohakune STP	0.49	0.41	-16.0%
Mangawhero at d/s Ohakune STP	0.82	0.75	-9.5%
Mangawhero at Pakihi Rd Bridge	0.54	0.48	-12.0%
Mangawhero at Raupiu Road	0.38	0.31	-18.5%
Turakina at ONeills Bridge	2.03	1.61	-20.5%

Table G-8. Scenario 4 modelling results: monitoring sites in the Whangaehu River Basin, simulated mean annual TP concentrations.

Monitoring Site	Baseline Modelled (mg L^{-1})	Scenario Modelled (mg L^{-1})	Difference (%)
Whangaehu at Kauangaroa	0.21	0.18	-16.2%
Mangaehuehu at d/s Rangataua STP	0.02	0.01	-23.2%
Mangaehuehu at u/s Rangataua STP	0.02	0.02	-21.5%
Tokiahuru at Junction	0.05	0.04	-22.9%
Makotuku at SH49A	0.01	0.01	-19.8%
Makotuku at Raetihi	0.02	0.02	-28.2%
Makotuku at Above Sewage Plant	0.02	0.01	-28.2%
Makotuku at d/s Raetihi STP	0.02	0.02	-23.2%
Mangawhero at u/s Ohakune STP	0.02	0.02	-23.8%
Mangawhero at d/s Ohakune STP	0.08	0.08	-6.0%
Mangawhero at Pakihi Rd Bridge	0.06	0.05	-9.9%
Mangawhero at Raupiu Road	0.05	0.04	-31.1%
Turakina at ONeills Bridge	0.50	0.40	-21.1%

Appendix H Scenario Set 5 Simulation Results

Table H-1. Scenario 5a modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TN concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	1.32	1.32	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.20	0.20	0.0%
ŌhauŌhau at Gladstone Reserve (mg L^{-1})	0.24	0.24	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	9.81	5.86	-40.3%
Lake Horowhenua Total Input Load (tpy)	191	164	-14.0%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	3.3	3.1	-6.1%

Table H-2. Scenario 5a modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TP concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	0.08	0.08	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.02	0.02	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.03	0.03	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	0.21	0.18	-18.0%
Lake Horowhenua Total Input Load (tpy)	3.2	3.0	-8.2%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	0.28	0.26	-7.1%

Table H-3. Scenario 5a modelling results: monitoring sites in the Waiopehu FMU, simulated median annual periphyton and mean annual phytoplankton biomass.

Monitoring Site	Baseline	Scenario	Difference (%)
Arawhata at Hokio Beach Road Shaded Periphyton (mg m^{-2})	140	120	-14%
Arawhata at Hokio Beach Road Unshaded Periphyton (mg m^{-2})	180	150	-17%
Lake Horowhenua Phytoplankton (chl-a, ug L^{-1})	60	55	-8%

Table H-4. Scenario 5b modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TN concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	1.32	1.32	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.20	0.20	0.0%
Ōhauat Gladstone Reserve (mg L^{-1})	0.24	0.24	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	9.81	4.02	-59.1%
Lake Horowhenua Total Input Load (tpy)	191	129.8	-32.0%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	3.3	2.7	-18.2%

Table H-5. Scenario 5b modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TP concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	0.08	0.08	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.02	0.02	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.03	0.03	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	0.21	0.21	-39.1%
Lake Horowhenua Total Input Load (tpy)	3.2	1.9	-39.9%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	0.28	0.15	-46.4%

Table H-6. Scenario 5b modelling results: monitoring sites in the Waiopehu FMU, simulated median annual periphyton and mean annual phytoplankton biomass.

Monitoring Site	Baseline	Scenario	Difference (%)
Arawhata at Hokio Beach Road Shaded Periphyton (mg m^{-2})	140	100	-29%
Arawhata at Hokio Beach Road Unshaded Periphyton (mg m^{-2})	180	120	-33%
Lake Horowhenua Phytoplankton (chl-a, ug L^{-1})	60	40	-33%

Table H-7. Scenario 5c modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TN concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	1.32	1.32	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.20	0.20	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.24	0.24	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	9.81	3.76	-61.7%
Lake Horowhenua Total Input Load (tpy)	191	151	-21.1%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	3.3	3.0	-9.0%

Table H-8. Scenario 5c modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TP concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	0.08	0.08	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.02	0.02	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.03	0.03	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	0.21	0.18	-13.5%
Lake Horowhenua Total Input Load (tpy)	3.2	3.0	-6.3%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	0.28	0.26	-7.1%

Table H-9. Scenario 5c modelling results: monitoring sites in the Waiopehu FMU, simulated median annual periphyton and mean annual phytoplankton biomass.

Monitoring Site	Baseline	Scenario	Difference (%)
Arawhata at Hokio Beach Road Shaded Periphyton (mg m^{-2})	140	120	-14%
Arawhata at Hokio Beach Road Unshaded Periphyton (mg m^{-2})	180	160	-11%
Lake Horowhenua Phytoplankton (chl-a, ug L^{-1})	60	55	-8%

Table H-10. Scenario 5d modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TN concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	1.32	1.32	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.20	0.20	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.24	0.24	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	9.81	6.74	-31.4%
Lake Horowhenua Total Input Load (tpy)	191	170	-10.9%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	3.3	3.2	-3.0%

Table H-11. Scenario 5d modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TP concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	0.08	0.08	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.02	0.02	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.03	0.03	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	0.21	0.19	-12.6%
Lake Horowhenua Total Input Load (tpy)	3.2	3.0	-6.3%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	0.28	0.26	-7.1%

Table H-12. Scenario 5d modelling results: monitoring sites in the Waiopehu FMU, simulated median annual periphyton and mean annual phytoplankton biomass.

Monitoring Site	Baseline	Scenario	Difference (%)
Arawhata at Hokio Beach Road Shaded Periphyton (mg m^{-2})	140	120	-14%
Arawhata at Hokio Beach Road Unshaded Periphyton (mg m^{-2})	180	160	-11%
Lake Horowhenua Phytoplankton (ug L^{-1})	60	60	0.0%

Table H-13. Scenario 5e modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TN concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	1.32	1.32	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.20	0.20	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.24	0.24	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	9.81	8.13	-17.2%
Lake Horowhenua Total Input Load (tpy)	191	180	-5.9%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	3.3	3.3	-1.5%

Table H-14. Scenario 5e modelling results: monitoring sites in the Waiopehu FMU, simulated mean annual TP concentrations.

Monitoring Site	Baseline	Scenario	Difference (%)
Manakau at S.H.1 Bridge (mg L^{-1})	0.08	0.08	0.0%
Waikawa at North Manakau Road (mg L^{-1})	0.02	0.02	0.0%
Ōhau at Gladstone Reserve (mg L^{-1})	0.03	0.03	0.0%
Arawhata at Hokio Beach Road (mg L^{-1})	0.21	0.21	0.0%
Lake Horowhenua Total Input Load (tpy)	3.2	3.2	0.0%
Lake Horowhenua In-Lake Concentration (mg L^{-1})	0.28	0.28	0.0%

Table H-15. Scenario 5e modelling results: monitoring sites in the Waiopehu FMU, simulated median annual periphyton and mean annual phytoplankton biomass.

Monitoring Site	Baseline	Scenario	Difference (%)
Arawhata at Hokio Beach Road Shaded Periphyton (mg m^{-2})	140	140	0%
Arawhata at Hokio Beach Road Unshaded Periphyton (mg m^{-2})	180	180	0%
Lake Horowhenua Phytoplankton (ug L^{-1})	60	60	0%

horizons

REGIONAL COUNCIL

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