Manaaki Whenua
Landcare Research

Economic assessment of scenarios for the Ruamāhanga Whaitua Collaborative Modelling Project

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Economic assessment of scenarios for the Ruamāhanga Whaitua Collaborative Modelling Project

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Summary

Project and Client

- Greater Wellington Regional Council (GWRC) has identified that freshwater contaminants such as nitrogen (N), phosphorus (P), sediment, and *E. coli* are key water quality challenges in the region, and in the Ruamāhanga catchment in particular. As a result, GWRC contracted Manaaki Whenua – Landcare Research to create the Ruamāhanga catchment economic model. This work is just one component of the Ruamāhanga Whaitua Collaborative Modelling Project (RWCMP).

Objective

- The aim of this project is to develop a model that will integrate science and economics to assess the potential economic impacts of meeting a range of contaminant loads and attribute states for N, P, sediment, and *E. coli* in the Ruamāhanga. The integrated model will estimate a calibrated baseline and results from scenarios (over 3 time periods – 2025, 2040, and 2080) created for the RWCMP.

Methods

- The integrated catchment economic modelling of the Ruamāhanga catchment was completed using the New Zealand Forest and Agriculture Regional Model (NZFARM), Manaaki Whenua's economic land use model. The model incorporated data and estimates from economic and land use databases and biophysical models. N and P loads from representative dairy, sheep and beef, and dairy support farms were estimated using Overseer (MPI 2016). Annual sediment loads from various land uses in the Ruamāhanga catchment were estimated using the SedNet model, while *E. coli* loads and resulting concentrations were estimated using the CLUES model (Jacobs 2018). Land-based mitigation costs and effectiveness in reducing each of these 4 contaminants were estimated by AgResearch (Muirhead 2016).
- NZFARM includes several options for managing N, P, sediment and *E. coli* loads from the MPIs representative farms, which include 3 sets of on-farm mitigation bundles (Muirhead 2016), land retirement, space/pole planting, upgrading wastewater treatment plants (WWTP) and also changes in irrigation reliability. Land retirement and space/pole planting target sediment management while on-farm mitigation bundles target nutrient management.
- The exact set of scenarios as well as mitigation that should be imposed on each land use within the Ruamāhanga catchment was specified by Ruamāhanga Whaitua Committee (Table ES1). No other analyses were undertaken outside of those specified by the Ruamāhanga Whaitua Committee.

Table ES1: Summary of scenarios

Mitigation option	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080[a]
Retirement of steep slopes	Retirement rate specified	No	Yes	Yes	Yes	Yes	Yes
Space planting on steep slopes	Planting rate specified	Yes	Yes	Yes	Yes	Yes	Yes
Additional riparian planting (+5m)	No	No	No	No	Yes	Yes	Yes
Stock exclusion	Yes	Yes	Yes	Yes	Yes	Yes	Yes
WWTP discharge to land	Staggered	60%	100%	100%	100%	100%	100%
Minimum flow and allocation set	Yes	Yes	Yes	Yes	Yes	Yes	Yes
On-farm mitigation options	Tier 1	Tier 1	Tier 2	Tier 3	Tier 2	Tier 3	Tier 3

a: There are no differences between the mitigation options included in Gold 2040 and Gold 2080 scenarios. Both are presented to enable a comparison between the Silver and Gold scenarios at each time period.

Results

When interpreting the economic impacts, it should be noted that by 2080 there is little difference between the Silver and Gold scenarios in terms of environmental responses[1] (i.e. sediment, N and P losses). The Gold scenario, however, has a larger reduction in P losses in 2025 and 2040 than the Silver scenario. For sediment and N losses, both scenarios achieve similar reductions in 2025 and 2040 (Table ES2).

Summarising across our analysis of on-farm mitigation and sediment management, WWTP upgrades, changes in water reliability, and the flow-on effects to the wider regional economy, we estimate the following economic impacts[2] to the Ruamāhanga Catchment:

- *On-farm mitigation and sediment management* is estimated to cost between $20.5 and $46.8 million per year for the Silver and Gold scenarios, respectively. This is equivalent to an 11–24% reduction from baseline net farm revenue.
- The impact on net farm revenue is greater under the Gold scenario than the Silver scenario and increasing over time as more management options are implemented (Table ES3).
- The sheep and beef industry has the largest reduction (percent and absolute) in net revenue and bares the largest total mitigation cost in the agricultural sector. Dairy farms typically face the largest per hectare mitigation cost.
- Wider economic impacts of on-farm mitigation and sediment management options are estimated to reduce regional output by $19.0 to $44.6 million (table ES3) and regional employment by 88 to 206 full-time equivalents (FTE), per year (Table ES4). This is equivalent to a 4–8% reduction from both baseline regional economic output and employment. Wider regional impacts capture the flow on

[1] N.B. Jacobs (2018) estimated scenario impacts on physical *E.coli* loads, but they did not provide the data for the economic analysis. This omission has no impact on the economic impact estimates as we account for the cost of mitigation practices intended to reduce *E.coli* loads in each scenario.

[2] This includes the costs associated with the mitigation and management options as well as any corresponding impacts on production.

effects of agricultural farm-gate revenue reductions in the catchment as a result of the scenarios assessed.

- *Wastewater treatment plant upgrades* are estimated to have an annualized cost of $10.4 to $14.8 million/yr depending on the scenario (Table ES3). More than half the total costs (55–64%) are incurred in the Masterton District, depending on the population at the time of upgrades.
- *Changes in irrigation reliability* because of the changes in minimum flows in the sub-catchments of particular concern (Waipoua and Upper Ruamāhanga) are estimated to reduce farm-gate revenue by $0.32 to $2.25 million (0.2%–1.2% reduction from baseline farm-gate revenue) per year, depending on level of reliability and which farm systems are irrigated[3]. These impacts only relate to the new minimum flow requirements and are in addition to the current reliability impacts that are being experienced. Table ES3 shows that there is an estimated $0.7 million reduction in net farm revenue per year related to average summer reliability on the average farm system.
- Wider regional impacts of change in irrigation reliability include future regional economic output reductions between $0.5 and $3.5 million per year, and future regional employment reductions between 3.9 and 27.5 FTEs, depending on farm system and reliability level. Tables ES3 and ES4 show that there is an estimated reduction in wider regional economic impacts for average summer reliability on the average farm system of $1.2 million per year and reduction in regional employment of 9 FTEs per year.
- *Total regional economic impacts* of the mitigation options analysed in this report range between $52 and 108 million per year for the Silver and Gold scenarios, respectively (10%–20% reduction from baseline regional economic output) (Table ES3). This includes the on-farm impacts, mitigation costs and the wider regional economic impacts. Total regional employment levels are reduced by 97 to 215 FTEs (Table ES4). This is equivalent to a 4–9% reduction from baseline regional employment.

[3] No additional storage is assumed.

Table ES2: Summary of environmental response to the scenarios

	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
			Environmental parameters (% change)					
Sediment loss[4]	−9.3%	−15.3%	N/A	−26.9%	−36.8%[5]	N/A	−30.1%	−32.9%
N losses	0%	0%	−8.1%	−8.7%	−8.7%	−9.0%	−9.1%	−9.1%
P losses	0%	0%	−18.1%	−43.4%	−52.1%	−32.4%	−52.6%	−52.6%

Table ES3: On-farm impacts and wider regional economic impacts of mitigation options

Mitigation Option	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Change in net farm revenue and mitigation costs from baseline (Mil $/yr)							
On-farm mitigation and sediment management	-1.1	-20.5	-39.8	-42.9	-36.2	-46.8	-46.8
Changes in irrigation reliability - average summer reliability[a]	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Wastewater treatment plant (WWTP) mitigation	-12.8	-10.4	-14.8	-14.8	-14.5	-14.8	-14.8
Total net farm revenue + WWTP mitigation costs	*-14.6*	*-31.7*	*-55.4*	*-58.4*	*-51.4*	*-62.3*	*-62.3*
Change in wider regional economic impacts (Mil $/yr)							
On-farm mitigation and sediment management	-1.3	-19.0	-35.6	-37.9	-38.4	-44.6	-44.6
Changes in irrigation reliability - average summer reliability[a]	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2
Total wider regional impacts	*-2.5*	*-20.2*	*-36.7*	*-39.1*	*-39.5*	*-45.8*	*-45.8*
Total impact – Change in net farm revenue, WWTP mitigation costs & wider regional economic output (Mil $/yr)							
Total regional impacts	*-17.1*	*-51.9*	*-92.1*	*-97.5*	*-90.9*	*-108.1*	*-108.1*

a: average farm systems under average summer reliability only. See section 5.4 for estimated impacts for a full range of reliability levels and farm systems.

[4] No information on sediment loss was provided for 2025 as sediment management options take over 10-15 years to show any significant reductions in sediment loss (Jacobs 2017).

[5] Note that the reduction in sediment losses under the Silver scenario was greater than under the Gold scenario. This may have been due to rounding errors when the raster GIS layer provided by Jacobs was converted to a shapefile or it may also be due to differences in the actual layers provided by Jacobs.

Table ES4: Wider regional employment impacts of mitigation options

Mitigation Option	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Change in regional employment impacts (FTE)							
On-farm mitigation and sediment management	-6	-88	-164	-174	-177	-206	-206
Changes in irrigation reliability - average summer reliability[a]	-9	-9	-9	-9	-9	-9	-9
Total regional impact on employment	*-15*	*-97*	*-172*	*-183*	*-185*	*-215*	*-215*

a: average farm systems under average summer reliability only. See section 5.4 for estimates for a range of reliability levels and farm systems.

1 Introduction

This report provides an assessment of the economic impacts of the scenarios proposed by the Ruamāhanga Whaitua Committee. It is prepared for the Greater Wellington Regional Council (GWRC) and Ruamāhanga Whaitua Committee as a component of the larger Ruamāhanga Whaitua Collaborative Modelling Project (RWCMP). The purpose of RWCMP is providing the community based Ruamāhanga Whaitua Committee with information about water and contaminant flows through the Ruamāhanga catchment to support the limit setting process.

To assess the economic impacts the following process was followed:

1 Parminter and Grinter (2016) developed 16 base or representative farms that are described in the MPI report.

2 AgResearch (Muirhead et al. 2016) developed a series of cost-abatement curves for each farm describing the relative cost and potential reduction of nitrogen (N), Phosphorus (P), sediment, and *E. coli* losses.

3 GWRC and Ruamāhanga Whaitua Committee identified other mitigation that could be implemented in the catchment such as space/pole planting and upgrading wastewater treatment plants.

4 Ruamāhanga Whaitua Committee specified a set of scenarios to consider in economic modelling.

5 Jacobs New Zealand Limited (hereafter 'Jacobs') brought all the information together to estimate the environmental impacts on all land uses in the catchment.

6 Manaaki Whenua – Landcare Research developed a catchment-scale economic model that incorporates the information from the previous steps undertaken in the RWCMP and estimated the on-farm and wider regional economic impacts for a range of specified scenarios in the Ruamāhanga catchment.

This report presents the results of the economic modelling component of the project and should be read in conjunction with the other reports. Focus of this report is on the development of the spatially distributed catchment economic model. The integrated model of the Ruamāhanga catchment consists of two key components: (1) baseline contaminant losses for each hectare of land in the study area; and (2) analysis showing how these loads are changed with the use of on-farm mitigations. The model allows for any combination of mitigation measures to be applied at farm, sub-catchment, and catchment levels to achieve spatially distributed environmental objectives, which in this case are represented as percentage changes in contaminant loads and their related attributes.

The Ruamāhanga catchment economic model is based on the New Zealand Forest and Agriculture Regional Model (NZFARM), Manaaki Whenua - Landcare Research's economic land use model. NZFARM is designed for detailed modelling of land uses at a catchment scale. It enables the consistent assessment of multiple scenarios by estimating and comparing the relative changes in economic and environmental outputs. The Ruamāhanga catchment version of NZFARM includes several farm- or parcel-level management options for managing N, P, sediment and *E. coli* loads: implementing farm soil management plans, fencing streams, riparian planting, and more. While the list of feasible farm management options for the representative pastoral farms is considered extensive, we do not necessarily include all possible options to mitigate losses from diffuse sources into waterways. The results from NZFARM are reliant on input data (e.g. farm budgets, mitigation costs, and contaminant loss rates) from external sources and may vary if alternative data are utilised. NZFARM also does not account for the broader impacts of changes in land use and land management beyond the farm-gate. Instead, the broader economic impacts of the scenarios are estimated using a multiplier approach (see section 2.2.5).

This report presents estimates from a calibrated baseline and results from scenarios (over 3 time periods – 2025, 2040, and 2080) created for the RWCMP. These include both practice-based approaches, such as having all eligible farms implement a specific on-farm mitigation bundle, to undertaking space/pole planting or land retirement from steep sloping land with high sediment rates to achieve the Ruamāhanga Whaitua Committee's specific environmental objectives in the Ruamāhanga catchment. This report only analysed those scenarios specified by the Ruamāhanga Whaitua Committee (see section 4 and Appendix 2 for scenario descriptions).

A list of key caveats, assumptions, and limitations for this analysis is included in Box 1. A comprehensive list of caveats, assumptions and limitations is included in section 3 and at the beginning of sections 5.2, 5.3, 5.4.

Box 1: key caveats, assumptions, and limitations for this analysis

- For this analysis, NZFARM has been programmed such that all landowners are assumed to collectively implement the exact set of practices specified by the scenarios. Thus NZFARM is not utilised as an 'optimisation' model that takes into account land use and land management change. This did not capitalise on the flexibility of the model to explore other policy options or mix of mitigation options to potentially achieve the same objective. In reality, it is likely to be more cost effective if the landowner has a greater degree of flexibility to choose from a range of management practices to improve water quality.
- The results of this analysis should not be interpreted as the actual impacts on individual farms. Rather it is an estimation of the catchment-wide economic impacts of the scenarios using representative farm responses to the specified mitigation and management options in each scenario and the reduction requirements for waste water treatment plants in the catchment
- Our economic analysis largely depends on the datasets and estimates provided by GWRC and RWCMP partners. Estimates derived from other data sources may provide different results for the same catchment. Thus, the tools and analysis presented here should be used in conjunction with other information during the decision making process.
- This analysis includes an extensive list of N, P, sediment, and *E. coli* mitigation strategies that could be implemented in the Ruamāhanga catchment. However, including additional mitigation options could lower both the overall cost of the policy and the cost to individual landowners.
- This analysis does not explicitly account for all administrative and transaction costs of the various scenarios. Doing so could alter both the estimates for the distributional impacts to landowners and water treatment plant facilities, as well as the overall cost of the different policies.
- The modelling exercise assumes that technology, climate, input costs, and output prices are all constant for the duration of the policy, since the aim of this modelling exercise is to focus on comparing a range of scenarios at specific points in time.

2 Methodology

This report presents the assessment of the potential economic and environmental impacts of reducing N, P, sediment, and *E. coli* in the Ruamāhanga catchment. The economic analysis is conducted using the NZFARM model. NZFARM is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale (Daigneault et al. 2012, 2013). Farm level N and P losses for 16 representative dairy, sheep and beef, and dairy support farms were estimated by Parminter and Grinter (2016), while loss figures for other land uses were defined by Jacobs (2017, 2018). Baseline estimates of sediment and *E. coli* were obtained by Jacobs (2018) through the use of the SedNetNZ and CLUES models, respectively. The cost and effectiveness of mitigating the four contaminants from the representative farms were estimated by AgResearch (Muirhead et al. 2016). Economic impacts are estimated as the cost to landowners of implementing mitigation options relative to their current (baseline) management practices. Environmental impacts are measured as percent changes in N, P and sediment loads and related attributes relative to a no mitigation baseline. Note that impacts of mitigation options on *E. coli* loads were not provided by Jacobs for this analysis. Figure 1 shows how the components of the integrated economic analysis are linked within NZFARM. Key components of the analysis are presented in the following subsections, while a more detailed description of the model is presented in Appendix 1.

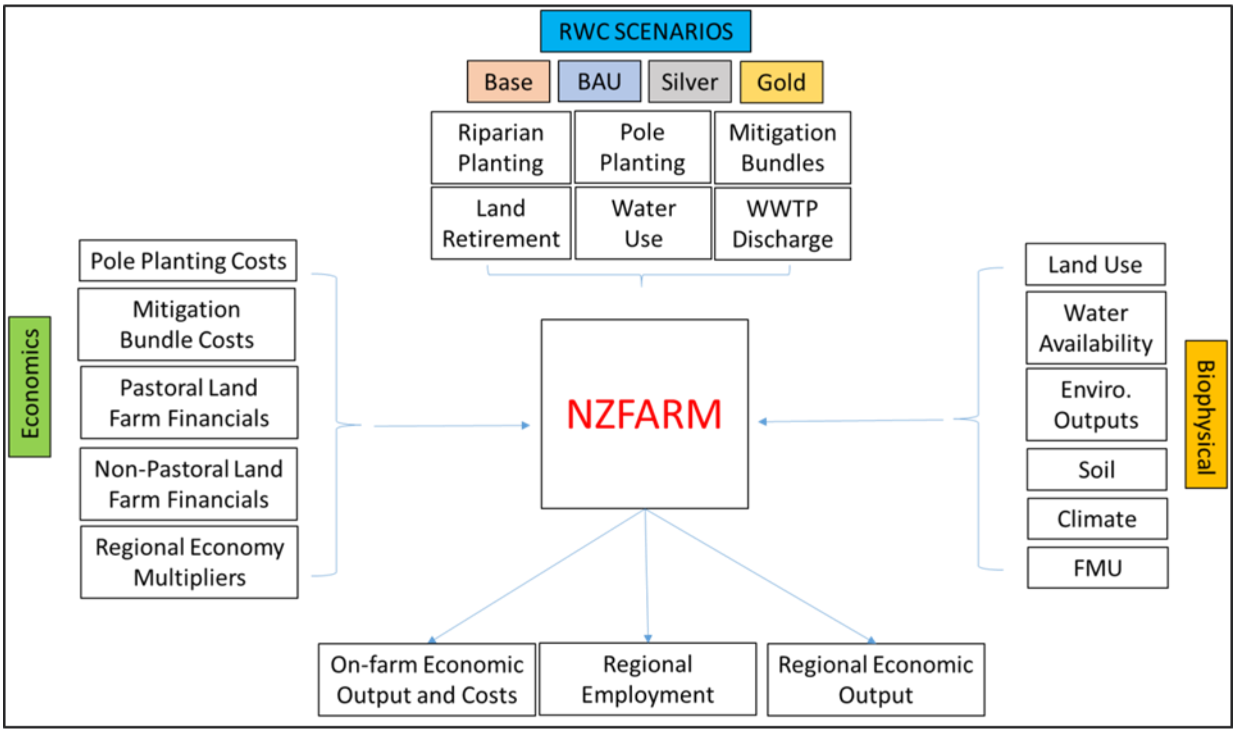

Figure 1: Flow Diagram of Integrated Economic Modelling

2.1 Model Data and Parameterisation

NZFARM accounts for a variety of land use, enterprise, and land management options in a given area. The data required to parameterise each land use, enterprise, and land management combination include financial and budget data (e.g. inputs, costs, and prices), production data, and environmental outputs (e.g. nutrient loads, sediment loads, *E. coli* loads, etc.). Table 1 lists the key variables and data requirements used to parameterise NZFARM. More details on the key data and assumptions used to populate the Ruamāhanga catchment version of the model are provided below. All of the figures in the NZFARM are converted to per hectare values and 2015 NZD so that they are consistent across sources and scenarios.

Table 1: Data sources for NZFARM's modelling of Ruamāhanga Catchment

Variable	Data requirement	Source	Comments
Geographic area	GIS data identifying the catchment area	Catchment and sub-catchments based on REC	Provided by GWRC and Jacobs [a]
Land cover and enterprise mix	GIS data file(s) of current land use within the catchment Key enterprises (e.g., dairy).	Regional land use map broken out by key land uses	Provided by GWRC and Jacobs [a]
Management practices	Distribution of feasible management practices (e.g., stream fencing, farm, management plan, etc.)	Muirhead et al. (2016)	Data and assumptions verified by project partners
Climate	Temperature and precipitation	Jacobs (2016)	Analysis assumes constant climate and production
Soil type	Soil maps used to divide area into dominant soil types	Jacobs (2018)	Used for distribution of representative farms and nutrient losses
Input costs	Stock purchases, electricity and fuel use, fertiliser, labour, supplementary feed, grazing fees, etc.	MPI representative farms: Parminter & Grinter (2016) Other Land Uses: A mix of: pers. comm. with farm consultants and regional experts, MPI farm monitoring report, Lincoln Financial Budget Manual	Verified with Whaitua committee and industry consultants
Product outputs	Milk solids, Dairy calves, Lambs, Mutton, Beef, Venison, Grains, Fruits, Vegetables, Timber, etc.	MPI representative farms: Parminter & Grinter (2016) Other land uses: Used yields for Greater Wellington Region, but nothing specific to Ruamāhanga Catchment	Verified with Whaitua committee and industry consultants
Commodity Prices	Same as outputs, but in \$/kg or \$/m3	MPI representative farms: Parminter & Grinter (2016) Other land uses: MPI (2015) and other sources	Other land uses assume 5-year average
Environmental indicators	N leaching P loss Soil Erosion/Sediment Stream *E. coli*[b]	N and P: Parminter & Grinter (2016) Sediment and *E. coli*: Jacobs (2018)	Data supplied by project partners.
Regional Economic Multipliers	Regional employment Regional economic output	Butcher Partners Ltd (2017)	Data supplied by project partners

a: the data are provided by GWRC and Jacobs as GIS maps

b: Jacobs (2018) estimated scenario impacts on physical *E.coli* loads, but they did not provide the data for the economic analysis. This omission has no impact on the economic impact estimates.

2.2 Land use

Observed baseline land-use information is required to fit the model to an empirical baseline. Baseline land use areas for this catchment model are based on a GIS-based land-use map created by GWRC and updated by Jacobs (Figure 2). The catchment is approximately 359 000 ha in size, and key land uses by percent of total area include sheep and beef (46%), native bush (24%), dairy (8%), mixed cropping (5%), dairy support (3%), and forestry (3%).

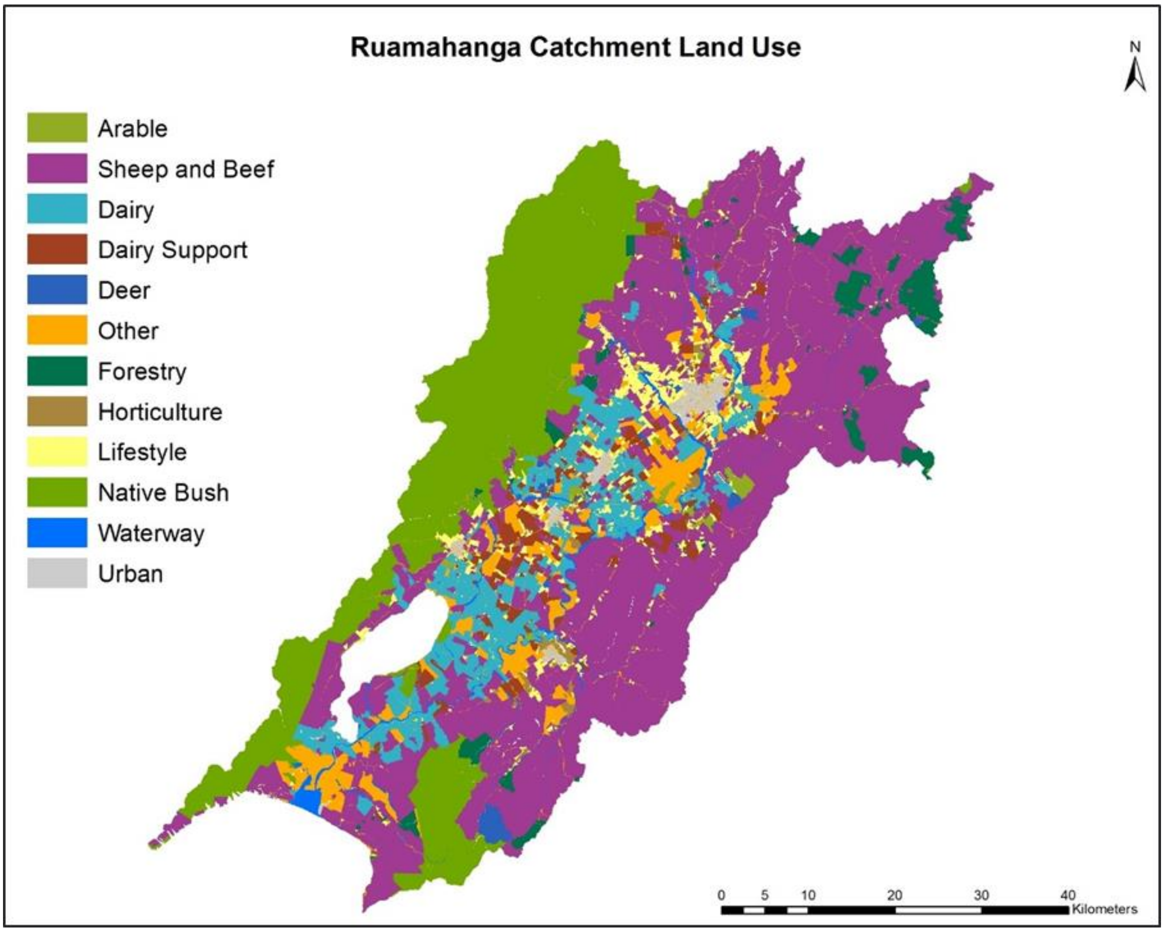

Figure 2: Ruamāhanga Catchment land use based on map from GWRC.

The map provided by GWRC did distinguish between some sheep and beef systems, but it did not differentiate dairy or dairy-support systems. Parminter and Grinter (2016) and KapAg (2016), however, estimated farm and nutrient budgets for 6 dairy, 8 sheep and beef, and 2 dairy-support systems, which then had to be assigned to the land-use map by Jacobs. As a result, NZFARM is also parameterised based on this characterisation. The name and description of each of the 16 MPI representative farm categories are listed in Table 2, while the spatial distribution is shown in Figure 3. About 58% of the total catchment area, or 207 000 ha, is covered by the 16 representative farm types.

Table 2: Details of representative farm types in Parminter and Grinter (2016) and KapAg (2016)

Farm system	MPI Farm type
4.1 Dry flat dairy (low rainfall and high prod)	1b
4.2 Dry flat dairy (low rainfall and mod prod)	1b2
4.3 Dry flat dairy (moderate rainfall)	1a
4.4 Dry flat dairy (high rainfall)	3
4.5 Irrigated flat dairy	2
4.6 Organic dairy	4
4.7 Sheep and beef finishing, summer dry	5
4.8 Sheep and beef breeding, summer wet	6a
4.9 Sheep and beef finishing, summer wet	6b
4.10 Sheep and bull finishing	7
4.11 Irrigated sheep and beef trading	8a
4.12 Lamb and bull trading, 20% cropping	8b
4.13 Sheep and beef breeding, summer dry	9
4.14 Finishing beef, 65% cropping	10
4.15 Dairy support, 15% cropping, summer dry	11b
4.16 Dairy support, 48% cropping, summer wet	11a

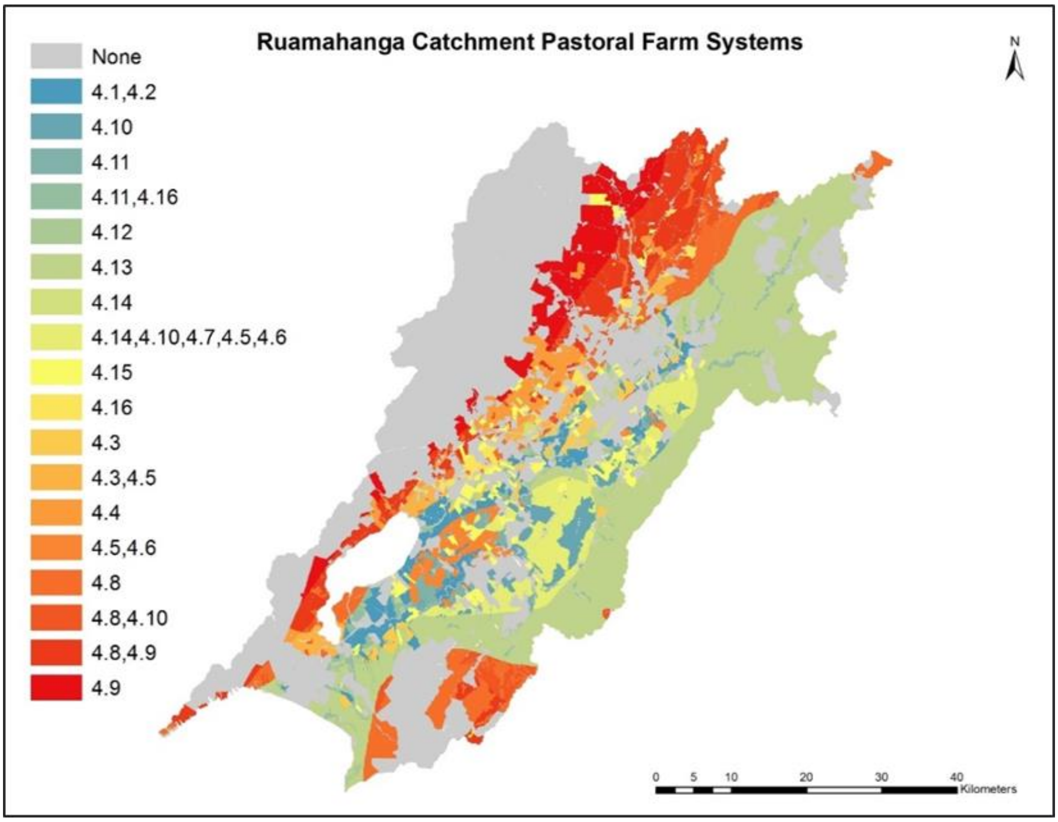

Figure 3: Spatial distribution of MPI representative farms in Ruamāhanga catchment.

2.2.1 Farm Financial Budgets

The farm financial budgets for the 16 representative pastoral farms were estimated by Parminter and Grinter (2016) and Muirhead et al. (2016). Farm financial budgets for the other land uses in the catchment were based on estimates for production yields, input costs, and output prices that come from a wide range of literature and national-level databases (e.g. MPI SOPI 2013a; MPI Farm Monitoring 2013b; Lincoln University Budget Manual 2013). These farm budgets form the foundation of the baseline net revenues earned by landowners and are specified as earnings before interest and taxes (EBIT). These figures assume that landowners currently face no mitigation costs such as fencing streams or retiring steep land (more below). The figures have been verified with agricultural consultants and enterprise experts, and have been documented in Daigneault et al. (2018). In addition, the Ruamāhanga catchment-level figures have been shared with members of the Ruamāhanga Whaitua Committee and agricultural consultants working in the catchment.

The distribution of net farm revenue across the catchment is shown in Figure 4. Sheep and beef farming is estimated to produce the greatest proportion of net farm revenue in the catchment (39%), followed by dairy (31%), mixed and arable (15%), horticulture (7%), and dairy support (3%).

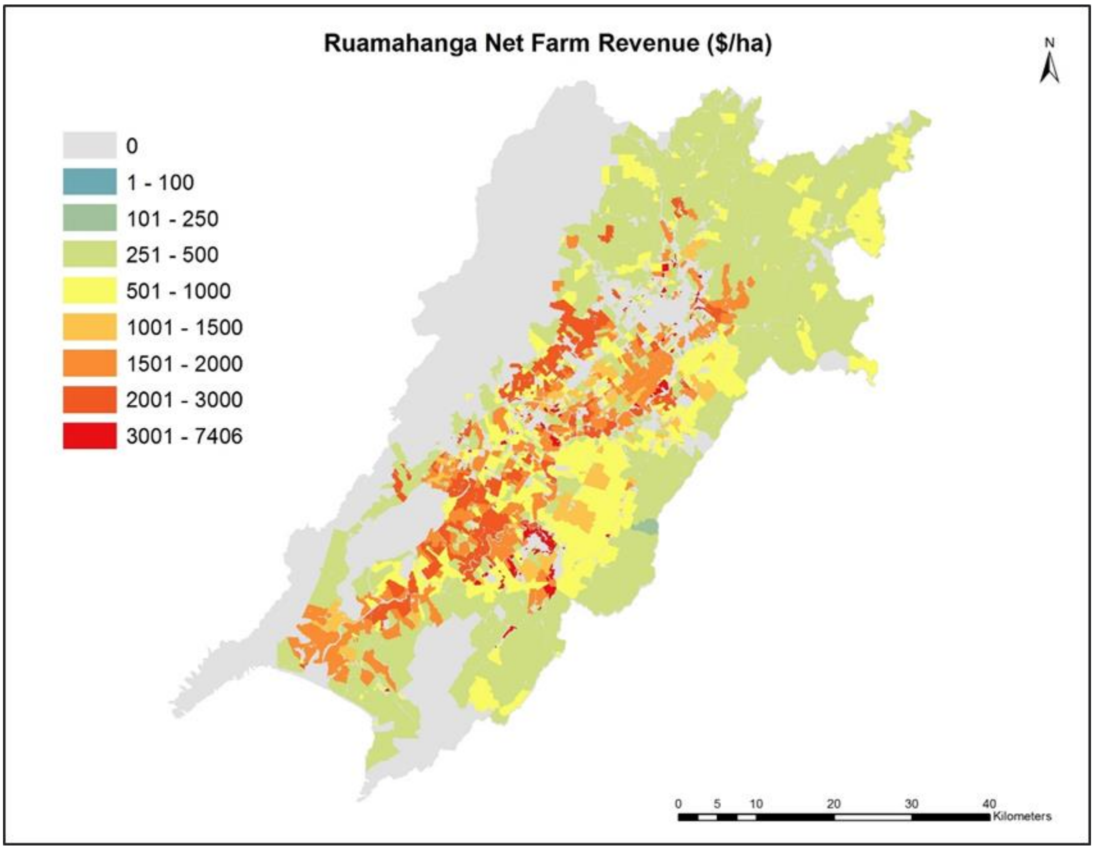

Figure 4: Baseline net farm revenue ($/ha/yr).

For this study, the net farm revenue figures are used to estimate the cost of implementing the different mitigation bundles relative to a no policy baseline (see Muirhead et al. 2016).

Many of the pasture-based mitigation options estimate an increase in capital and maintenance expenses relative to the baseline but not necessarily opportunity costs for production losses. In addition, the Ruamāhanga catchment version of the model is currently focused on the impacts of management change within the current land use as opposed to land use change. Thus, the net farm revenue figures for this analysis are not as crucial as other catchment-level studies recently conducted to look impacts of the National Policy Statement for Freshwater Management (NPS-FM)[6] (e.g. nutrients reduction targets in Daigneault et al. 2013).

2.2.2 On-Farm Mitigation Options

Assumptions about mitigation costs and effectiveness in reducing N, P, sediment and *E. coli* loads from implementing bundles of mitigation practices in three 'tiers' are estimated by AgResearch (Muirhead et al. 2016). The tiers represent bundles of mitigation options based on cost and difficulty of implementation. These were developed in collaboration with the Ruamāhanga Whaitua committee.

The costs are separated by initial capital, ongoing and periodic maintenance, and opportunity costs from taking land out of production. A summary of these costs and effectiveness are outlined in Table 3. Note that they only apply to the 16 dairy, sheep and beef, and dairy-support representative farm scenarios developed for MPI by Parminter and Grinter (2016). The Ruamāhanga Whaitua committee did not specify any scenarios where other land uses such as horticulture, or forestry implemented any mitigation bundles. More details on the mitigation bundles are provided in the Muirhead et al (2016) report.

In addition to the tiers of mitigation bundles, the analysis also considered the following on-farm mitigation options, all of which are specified by the Ruamāhanga Whaitua committee:

- **Retiring land on steep slopes**. The cost of retirement is assumed to be a complete loss in net revenue earned on the area that is taken out of production, while the level of effectiveness is specified in Jacobs (2017).
- **Pole planting on steep slopes**. Cost data of space/pole planting ($1500/ha) is obtained from Fernandez and Daigneault (2017) and confirmed with GWRC. The level of effectiveness is specified in Jacobs (2017).
- **Extending the width of riparian planting** in Tier 3 bundles from 5 to 10m. Costs are assumed to follow the 'medium-cost' scenario assumptions in Daigneault et al. (2017), and varied by land use type and stream length. The level of effectiveness is specified in Jacobs (2017).

All mitigation costs are converted to an annual figure so that they can be directly comparable to the costs already included in the baseline net farm revenue calculation. Initial capital and periodic maintenance costs are annualised over 25 years using a

[6] http://www.mfe.govt.nz/fresh-water/national-policy-statement/supporting-impact-papers-nps

discount rate of 8%. Annual maintenance and opportunity costs are assumed to accrue on a yearly basis and thus are directly subtracted from the base net farm revenue figure.

Table 3: Ruamāhanga catchment on-farm mitigation bundle effectiveness assumptions for MPI representative farms

		MPI Representative Farm Scenario															
Mitigation Bundle[7]	Metric	Dairy_FD_LRHP 1b	Dairy_FD_LRMP 1b2	Dairy_FD_MR 1a	Dairy_FD_HR 3	Dairy_Irrigated 2	Dairy_Organic 4	SNB_Finish_SD 5	SNB_Breed_SW 6a	SNB_Finish_SW 6b	SNB_Finish 7	SNB_Irrigated 8a	SNB_trade_20crop 8b	SNB_Breed_SD 9	SNB_Finish_65crop 10	DairySupport_SD 11b	DairySupport_SW 11a
Tier 1	Net Revenue	1%	2%	2%	2%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	N leaching	-2%	6%	0%	2%	0%	-3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	P loss	-10%	13%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Sediment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	E. coli	28%	28%	28%	21%	28%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tier 2	Net Revenue	18%	21%	5%	17%	-4%	6%	16%	17%	20%	31%	18%	7%	20%	34%	0%	6%
	N leaching	45%	24%	8%	11%	21%	51%	10%	9%	10%	11%	20%	20%	0%	5%	7%	27%
	P loss	10%	7%	17%	6%	11%	38%	0%	0%	20%	22%	33%	17%	0%	0%	0%	10%
	Sediment	0%	19%	0%	22%	0%	0%	18%	27%	13%	10%	21%	0%	19%	0%	0%	17%
	E. coli	28%	28%	28%	21%	28%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tier 3	Net Revenue	24%	24%	12%	22%	1%	7%	25%	25%	25%	47%	27%	12%	31%	46%	0%	15%
	N leaching	43%	24%	8%	11%	17%	51%	0%	9%	10%	11%	20%	20%	0%	5%	7%	27%
	P loss	20%	7%	17%	6%	11%	38%	50%	78%	82%	56%	56%	17%	50%	20%	0%	30%
	Sediment	8%	72%	65%	39%	65%	22%	52%	50%	54%	38%	33%	0%	52%	33%	0%	44%
	E. coli	28%	28%	28%	21%	28%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

[7] N.B., these are referred to as M1, M2, and M3 bundles in Muirhead et al. (2016).

2.2.3 Wastewater Treatment Plant Mitigation

In addition to on-farm mitigation, the Ruamāhanga Whaitua committee also considered the cost of upgrading 5 wastewater treatment plants in the catchment. Data and information on these upgrades are very limited, so as a result we based all upgrades from estimates provided by the Carterton District Council (CDC).[8] These estimates include cost components of treatment plant construction and upgrade as well as irrigation and storage (including the costs of land purchase). Costs for WWTP mitigation in other districts are estimated by scaling the CDC estimates based on the relative population that the district served. The projected population for each district[9] was used to estimate WWTP mitigation costs in 2025, 2040, and 2080 for each scenario. All costs are assumed constant and annualized over 25 years at a rate of 8% so that estimates are consistent with on-farm mitigation costs.

2.2.4 Change in Water Availability

The Ruamāhanga Whaitua committee also identified that some of the proposed scenarios would have an impact on water availability for irrigation use in certain areas of the Ruamāhanga catchment. The two sub-catchments of particular concern specified by the Ruamāhanga Whaitua committee are the Upper Ruamāhanga and Waipoua, located in the northwest area of the Ruamāhanga (Figure 5).

The estimated impacts of changes in water availability are estimated using the following set of assumptions:

- **Changes in water availability**: based on three different reliability scenarios: average annual, average summer, and 90th percentile summer. Data are provided by GWRC (GWRC 2017).
- **Baseline (current) irrigated area**: based on consented irrigation area by land use and sub-catchment (Table 4). Data are provided by GWRC (GWRC 2017).
- **Net farm revenue (i.e., profit) under alternative water availability**: estimated using dairy, arable, and sheep and beef profit curves (Figure 6) (John Bright, pers. comm., September 2017).
- **Farm systems**: Due to the lack of information on the spatial distribution of different irrigated farm systems in the two sub-catchments this analysis was undertaken using two types of farm systems. One analysis assumed only the most intensive farm systems were irrigated and the other assumed the average farm system was irrigated in each sub-catchment (see Figure 3, Figure 4, and Table 2).

A summary of the farm revenue and irrigated areas for each sub-catchment is listed in Table 4. More details on this methodology are provided in Appendix 1.

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[8] GWRC was unable to obtain information from the other 4 districts in the catchment.

[9] Population projections obtained from Statistics NZ subnational population projection tables http://nzdotstat.stats.govt.nz/WBOS/Index.aspx?DataSetCode=TABLECODE7545#

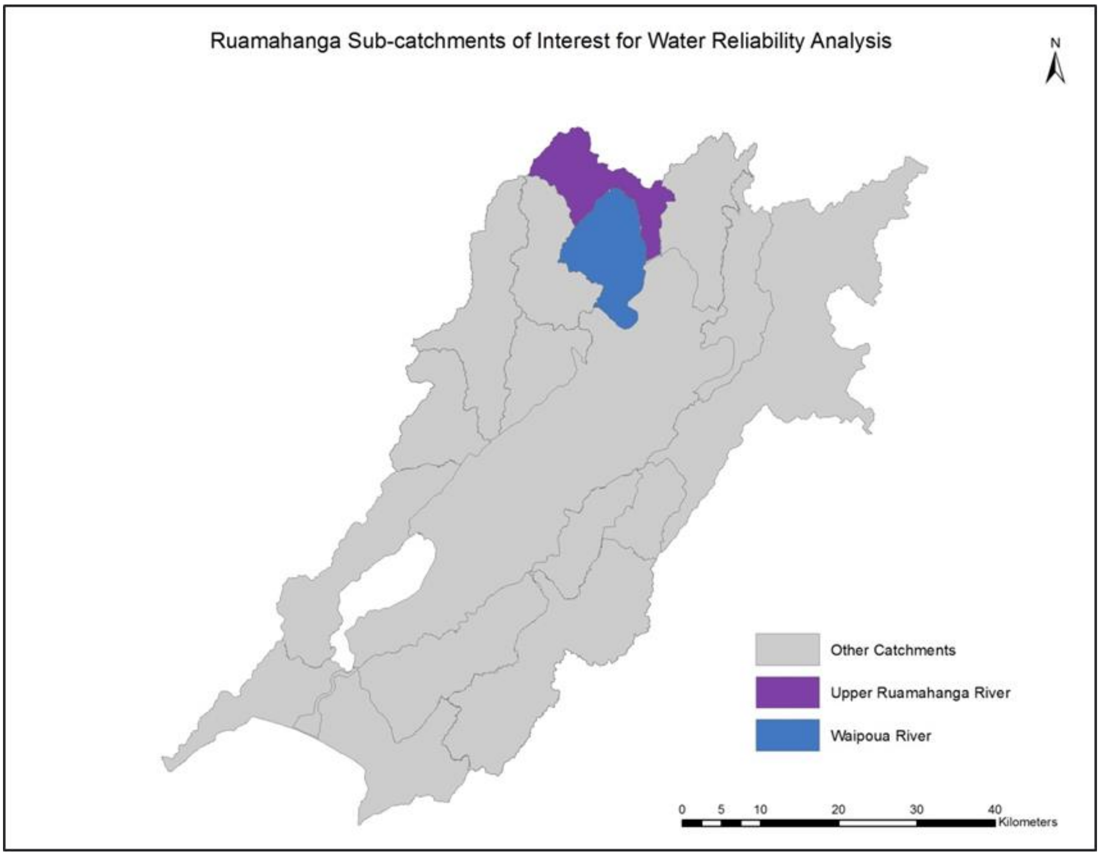

Figure 5: Ruamāhanga sub-catchments of particular concern for possible changes in water availability.

Table 4: Baseline assumptions for estimating Ruamāhanga water availability impacts

Land Use	**Farm-Gate Revenue ($/ha/yr)**		**Irrigated Area (ha)**	
	Most Intensive Farm System	***Average Farm System***	***Waipoua***	***Upper Ruamāhanga***
Dairy	$6,525	$5,005	0.0	1951.0
Arable	$2,410	$2,410	20.0	80.0
Sheep, Beef & Dairy Support	$2,973	$1,180	61.0	799.2
Other[a]	N/A	N/A	105.0	251.8
Total	**N/A**	**N/A**	**186.0**	**3082.0**

a: include horticulture and viticulture

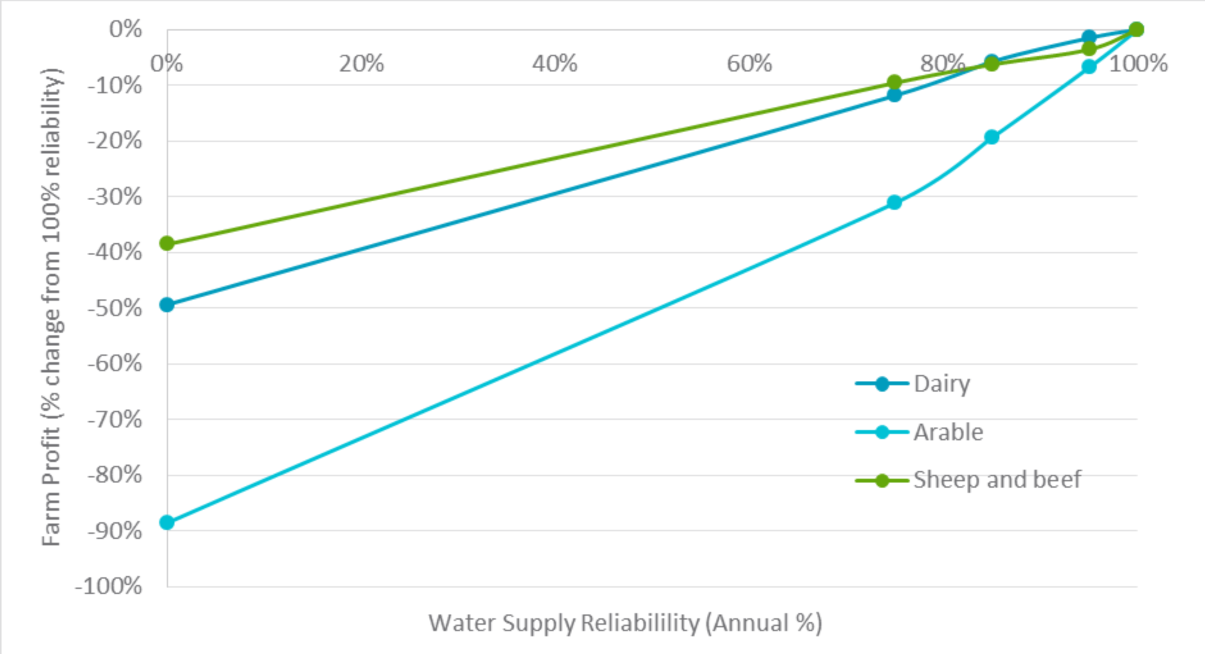

Figure 6: Assumed change in farm profit relative to a reduction in water supply available for irrigation. Estimates based on figures provided by John Bright, Aqualinc (2018).

2.2.5 Wider Regional Economic Impacts

Wider economic impacts of the proposed scenarios are estimated using regional multipliers. Multipliers for the Wellington Region are obtained from Butcher Partners Ltd. For this report, we estimated the wider regional impacts on the economic output (i.e. revenue) and employment, which include direct, indirect and induced impacts. Direct impacts are the impacts on the revenue of Ruamāhanga catchment farmers estimated from the NZFARM economic modelling analysis.[10] Indirect impacts are the impacts on the suppliers of the Ruamāhanga catchment farmers, where the farmers themselves obtain their goods and services. Finally, the induced impacts are further household impacts of the direct and indirect impacts. Table 5 shows the multipliers used for this analysis. For example, for dairy farming the multiplier for economic output means that the regional output is 1.6 times of every dollar of revenue generated at the farm-gate. For every one-million dollar of farm-gate revenue generated, 7.8 full time equivalent (FTE) jobs are created at the regional level, based on the employment multiplier for this industry. As a result, a collection of dairy farms that produces $100 million in annual farm-gate revenues is estimated to create $160 million of total regional economic output and 780 FTEs (including the direct revenue earned and jobs created on the farms). We refer to these impacts as wider regional economic impacts throughout the document.

[10] Note that this revenue is referred to as 'farm-gate' revenue in later tables.

Table 5: Regional multipliers obtained from Butcher Partners Ltd

Industry	Regional Economic Multiplier (Total $ per revenue earned on farm)	Regional Employment Multiplier (FTEs per $1 million in farm-gate revenue)
Horticulture and fruit growing	1.71	11.3
Sheep, beef cattle, and grain farming	1.56	7.0
Dairy cattle farming	1.60	7.8

3 Model Limitations

NZFARM has been developed to assess economic and environmental impacts over a wide range of land uses, but it does not account for all sectors of the economy. NZFARM should be used to provide insight on the relative impacts and trade-offs across a range of scenarios (e.g. practice v. outcome-based targets), rather than explicitly modelling the absolute impacts of a single scenario. It should be used to compare impacts across a range of scenarios or policy options. The parameterisation of the model relies on biophysical and economic input data from several different sources. Therefore, the estimated impacts produced by NZFARM should be used in conjunction with other decision support tools and information not necessarily included in the model to evaluate the 'best' approach to manage N, P, sediment, and *E. coli* in the Ruamāhanga catchment. Some of the modelling limitations from the current version of the model include:

1 **Input data** – The quality and depth of the economic analysis depends on the datasets and estimates provided by biophysical models, farm budgeting data based on information published by MPI and industry groups, and spatial datasets such as maps depicting current land use and sub-catchments. Estimates derived from other data sources or models not included in this analysis may provide different results for the same catchment. Thus, analysis presented here should be used in conjunction with other information (e.g. input from key stakeholders affected by policy, study of health and recreational benefits from water quality improvements) during any decision making process.

2 **Representative farms** – The model includes detailed financial and mitigation practices for representative farms for the Ruamāhanga catchment that were parameterised based on their physical characteristics (e.g. land use capability, slope, etc.) and annual financial returns. It does not explicitly model the economic impacts for specific farms in the catchment. As a result, some landowners in the catchment may actually face higher or lower costs than are modelled using this representative farm approach.

3 **Baseline conditions** – The NZFARM baseline assumed that (1) land use in the catchment was the same as the year the GWRC land use map was produced, and (2) that net farm revenue for non-representative farms (i.e., non-pastoral land uses) was based on a 5-year average of input costs and output prices, and (3) that all landowners were implementing the same set of baseline management practices in the catchment. The third assumption is likely to have the greatest impact on model

estimates, as some farms in the catchment are likely to have already implemented practices that are included in the Tier 1–3 mitigation bundles as well as space/pole planting on steep slopes. However, the number of farms that have implemented these management options to their maximum effectiveness is uncertain and likely to be relatively small.

4 **Management practices** – The model only includes some management practices deemed feasible and likely to be implemented on the 16 representative farm types, given the current state of knowledge and technology available. It does not necessarily account for new and innovative management options that might be developed in the future as a result of incentives created through policy. Although not all possible management options may be included in the model, the suite of management practices should be large enough to account for a wide-range of mitigation costs (e.g. change in farm profit) and total effectiveness (e.g. change in sediment or *E. coli* loads). In this case, N and *E. coli* reductions were relatively small even if all farms implemented Tier 3 practices, thereby limiting the feasibility to achieve stringent reduction targets. In addition, bundled mitigation options were only estimated for the 16 MPI representative farms. Adding additional mitigation practices beyond space/pole planting and land retirement to other land uses is likely to lower the cost of reducing contaminant loads.

5 **Mitigation effectiveness** – Each management practice included in the model is assumed to have a fixed relative rate of effectiveness for reducing environmental outputs at a given point in time (e.g. 25% of baseline loads). In reality, the actual impact of a given practice is likely to vary depending on where, when, and how well the practice is implemented.

6 **'Optimisation' routine** – For this analysis, NZFARM has been programmed such that all landowners are assumed to collectively implement the exact set of practices chosen by the Ruamāhanga Whaitua committee by a specific scenario and date (e.g. Gold 2040). In reality, it is likely to be more cost effective if the landowner has a greater degree of flexibility to choose from a range of management practices. While it is possible that not all landowners will necessarily select the option that is considered most cost-effective, other farmers may find ways to meet the environmental objectives in the Ruamāhanga catchment at a lower cost than what was directly imposed on them in this modelling exercise.

7 **Wider regional economic impacts** – This analysis took a regional multiplier approach to account for the broader impacts of changes in land use and land management beyond the farm-gate. These wider impacts were estimated using a 'regional multiplier' approach, with the multipliers provided by Butcher Partners Ltd (2017) for the Wellington region. These multipliers allow us to roughly estimate changes in regional economic output (revenue) and employment based on historical data for pastoral and arable farming sectors. It did not take into account the flow-on effects that the labour-generating mitigation practices such as space/pole planting and riparian planting could have on regional employment and GDP. In addition, this analysis did not account for any of the other social and cultural impacts of these scenarios. The estimates produced by NZFARM and multiplier analysis provide a subset of possible metrics that could be used to determine the 'best' option to manage environmental outputs at the catchment-level.

8 **Administrative and transaction costs** – This analysis does not explicitly account for all administrative and transaction costs of the various scenarios. Doing so could alter the estimates for the distributional impacts to landowners and water treatment plant facilities, as well as the overall cost of the different policies.

4 Scenarios

The Ruamāhanga Whaitua Committee provided a set of scenarios to be tested by the RWCMP over 3 time periods. These scenarios contain a range of management options and are presented as packages. A summary of these scenarios are presented in Table 6, while more detailed descriptions of the scenarios are included in Appendix 2 and on the Ruamāhanga Whaitua Committee website.[11] The scenarios assessed in this report are as follows:

- Baseline – no existing mitigation options or policies. Estimates based on 2015 land use, farm financials, and practices
- Business as usual (BAU) – represents future pathways based on existing policy, practice and investment
- Silver – The management options in this scenario correspond to a moderate effort for making water quality improvements across the Ruamāhanga catchment, for 2025, 2040, and 2080
- Gold – represents the highest and most aspirational effort for making water quality improvements across a broad range of activities and issues in the Ruamāhanga catchment, for 2025, 2040, and 2080.

In the case of land retirement or space/pole planting on steep slopes, the rate of implementation is specified to vary across time (see Appendix 2 for a description of the implementation rates). Note, however, that exact scenario specifications provided by RWCMP do not include any additional on-farm mitigation and management efforts between Gold 2040 and Gold 2080 scenarios.

[11] http://www.gw.govt.nz/ruamahanga-whaitua-process/

Table 6 : Summary of scenarios

Mitigation option	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080[a]
Retirement of steep slopes	Retirement rate specified	No	Yes	Yes	Yes	Yes	Yes
Space planting on steep slopes	Planting rate specified	Yes	Yes	Yes	Yes	Yes	Yes
Additional riparian planting (+5m)	No	No	No	No	Yes	Yes	Yes
Stock exclusion	Yes	Yes	Yes	Yes	Yes	Yes	Yes
WWTP discharge to land	Staggered	60%	100%	100%	100%	100%	100%
Minimum flow and allocation set	Yes	Yes	Yes	Yes	Yes	Yes	Yes
On-farm mitigation options	Tier 1	Tier 1	Tier 2	Tier 3	Tier 2	Tier 3	Tier 3

a: There are no differences between the mitigation options included in Gold 2040 and Gold 2080 scenarios.

5 Scenario Analysis

To be consistent with other RWCMP reports, the estimates in this section compare the 'no policy' baseline to each scenario after they have been fully implemented for each time period.[12] Although there are no additional on-farm mitigation and management efforts between Gold 2040 and Gold 2080 scenarios, Gold 2080 estimates are presented to enable comparison between the Silver 2080 scenario estimates. Spatial impacts are shown in the Appendix 3.

5.1 Baseline

Before conducting any scenario analysis in NZFARM a baseline needs to be estimated for the Ruamāhanga catchment. When the baseline has been generated the distribution of enterprise area in NZFARM matches the land use map. The baseline also assumes no N, P, sediment or *E. coli* on-farm mitigation bundles (e.g. Tier 1) or policies have been implemented (Jacobs 2018)[13]. This may mean the model's aggregate reduction results may be an overestimate of the actual reduction that could occur under the different modelled scenarios.

A summary of the main economic outputs for the aggregate land use categories tracked in NZFARM is listed in Table 7. Total net farm revenue from land-based operations with the current land use mix is estimated at $192.5 million/yr or $536/ha for all land and $801/ha for land that is currently earning revenue from farming and forestry. Total N leaching and P loss are 4,843 and 263 t/yr respectively. The total sediment load is about 1,061,000 tonnes, of which around 40% comes from not pastoral land uses. At the

[12] For this analysis, we assume that the policy is fully implemented at the specified timeframe (i.e. 2025, 2040, 2080).

[13] N.B. Jacobs (2018) estimated scenario impacts on physical *E.coli* loads, but they did not provide the data for the economic analysis. This omission has no impact on the economic impact estimates as we account for the cost of mitigation practices intended to reduce *E.coli* loads in each scenario.

Ruamāhanga catchment level the sheep and beef sector is the largest land use in the catchment. As a consequence sheep and beef sector is estimated to earn the highest total net revenue and also to produce the highest environmental outputs.

Table 7: Total baseline area, farm earnings, and environmental outputs by aggregated land use

Land Use	Area (ha)	Net Farm Revenue ($)	N leaching (kg)	P loss (kg)	Sediment (t)
Dairy	30,090	$59,452,530	900,217	28,708	8,048
Dairy Support	10,008	$6,151,398	368,101	2,634	4,762
Sheep and Beef	165,132	$74,721,075	2,282,425	170,481	614,433
Other Animal	2,762	$2,354,707	49,697	329	7,115
Arable	1,658	$1,904,611	46,598	610	1,757
Mixed	16,744	$27,626,885	652,980	6,865	6,205
Horticulture	2,352	$13,204,986	19,705	94	114
Forestry	11,310	$7,087,498	33,931	1,470	24,065
Native Bush	85,853	$0	85,853	15,453	381,679
Water	12,223	$0	0	0	0
Other	20,972	$0	403,795	35,229	10,873
Total	**359,103**	**$192,503,691**	**4,843,302**	**262,726**	**1,060,591**

Per hectare estimates are presented in Table 8. As expected, there is a wide distribution in per hectare values across the various land uses. Highest net revenue is estimated to come from horticulture, followed by dairy while the lowest net revenue is estimated for sheep and beef. Mixed, dairy support, and dairy land uses have the highest N leaching while dairy and sheep and beef have the highest P losses, of the pastoral uses. Sheep and beef sector is estimated to be the highest contributor of sediment loss. Estimated scenario results by disaggregated land uses (see tables and figures in Appendix 3 sections 3.1–3.2) also show how there is a wide distribution across the different farm systems, particularly for N, P, and sediment, and thus applying the same mitigation practices on different farm systems is likely to lead to a wide range of reductions.

Table 8: Per hectare baseline annual farm earnings and environmental outputs by aggregated land use

Land Use	Net Farm Revenue ($/ha)	N leaching (kg/ha)	P loss (kg/ha)	Sediment (t/ha)
Dairy	$1,976	29.9	1.0	0.3
Dairy Support	$615	36.8	0.3	0.5
Sheep and Beef	$452	13.8	1.0	3.7
Other Animal	$853	18.0	0.1	2.6
Arable	$1,149	28.1	0.4	1.1
Mixed	$1,650	39.0	0.4	0.4
Horticulture	$5,614	8.4	0.0	0.0
Forestry	$627	3.0	0.1	2.1
Native Bush	$0	1.0	0.2	4.4
Water	$0	0.0	0.0	0.0
Other	$0	13.8	1.2	0.4
Total	**$536**	**13.5**	**0.7**	**3.0**

5.2 On-farm Mitigation and sediment management options

Assumptions and caveats for on-farm mitigation and sediment management options

- Mitigation options and areas for each scenario are specified by Ruamāhanga Whaitua Committee. The economic model is therefore parameterised to estimate the impacts of imposing these practices on particular farms in the catchment rather than estimating the most cost-effective way to achieve an outcome (e.g. reduce nutrient leaching by 20%).
- Farm financials, land use, climate and other environmental or policy factors beyond those explicitly stated in this analysis are assumed fixed for all scenarios. Thus, a specific farm system is assumed to produce the same level of agricultural output and receive the same price for their commodities in each time period.
- The key impact to the model's farm financials are the changes in input costs or level of production associated with having to implement a given on-farm mitigation practice.
- The current subsidy provided by GWRC for space/pole planting is not included in this analysis. Thus, the average cost of space/pole planting ($1500/ha) estimated in this analysis may over-estimate the cost farmers would currently pay. How long the subsidy may remain in place is uncertain.
- Wider regional impact estimates are based on multipliers obtained from Butcher Partners Ltd. Any employment opportunities created through the implementation of mitigation practices such as space/pole and riparian planting may not be fully captured by the regional multipliers.

The estimated economic impacts of the on-farm mitigation and sediment management options for the various scenarios for the entire Ruamāhanga catchment are listed in Table

9. The impacts vary widely across scenarios and across land uses. Other framings of the results, e.g. impacts by Freshwater Management Unit (FMU), are listed in Appendix 3.

Table 9: Summary of the economic analysis of the on-farm mitigation and sediment management options for each scenario

Parameter	Base	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
			Net agricultural farm revenue (% change)					
Total agricultural net farm revenue	$192,504,691	–0.6%	–11%	–21%	–22%	–19%	–24%	–24%
Total dairy net farm revenue	$59,452,530	–1.3%	–13%	–15%	–16%	–16%	–18%	–18%
Total sheep and Beef net farm revenue	$74,721,075	–0.4%	–16%	–39%	–43%	–34%	–46%	–46%
Total other land use net farm revenue	$58,330,085	0.0%	–2%	–3%	–3%	–2%	–3%	–3%
			Mitigation costs by mitigation option ('000 $/yr)					
Total mitigation cost		1,516	20,528	39,848	42,971	36,188	46,806	46,806
Cost of on-farm mitigation bundles		863	15,732	29,359	32,483	27,231	32,267	32,267
Cost of 10m riparian planting		0	0	0	0	1,546	4,051	4,051
Cost of space/pole planting		588	1,976	5,054	5,054	1,977	5,054	5,054
Cost of retirement		65	2,820	5,434	5,434	5,434	5,434	5,434
			Mitigation costs by aggregated land use ('000 $/yr)					
Dairy mitigation costs		799	7,488	9,136	9,382	9,505	10,506	10,506
Sheep and beef mitigation costs		715	12,196	29,191	32,065	25,608	34,735	34,735
Other land use mitigation costs		2	844	1,521	1,524	1,075	1,565	1,565

The impact on net agricultural revenue is greater under the Gold scenario than under the Silver scenario. This negative impact is increasing over time as more management options are implemented. The sheep and beef sector experiences a greater reduction in revenue (both percent and absolute) than dairy in both the Silver and Gold scenarios. Other land uses do not face significant net revenue reductions as they are not required to implement on-farm mitigation and sediment management options under these scenarios.

The mitigation and management costs are also higher for the Gold scenario than the Silver scenario. The total cost for the on-farm mitigation and sediment management options are estimated at between $20.5 and $46.8 million per year for the Silver and Gold scenarios. This leads to an 11–24% reduction in net agricultural farm revenue compared to the baseline. In considering each management option on its own, the on-farm mitigation bundles have the highest cost followed by land retirement (Figure 7). Sheep and beef farms have the highest total costs for implementing the on-farm mitigation and sediment management practices with dairy costs being less than half those of sheep and beef farms for nearly all scenarios (Figure 8). This is to be expected as sheep and beef farms comprise the largest area of productive land and pasture in the Ruamāhanga catchment, and much of this land has high erosion rates and the greatest length of streams running through them.

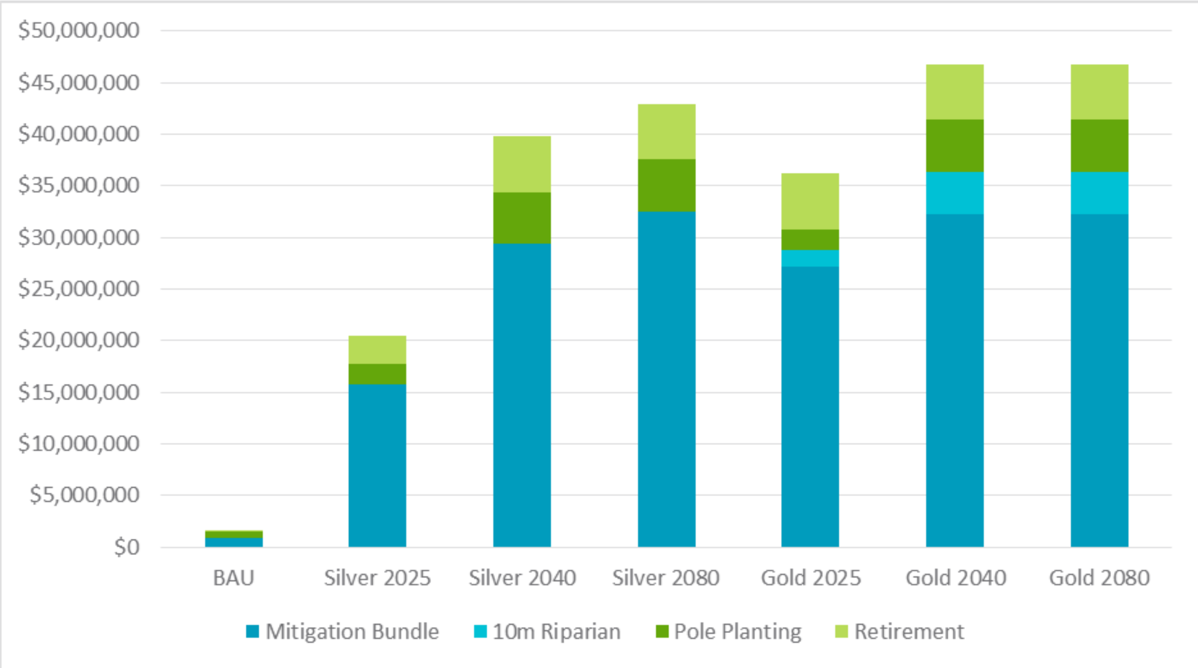

Figure 7: Total annual cost ($/yr), by mitigation type.

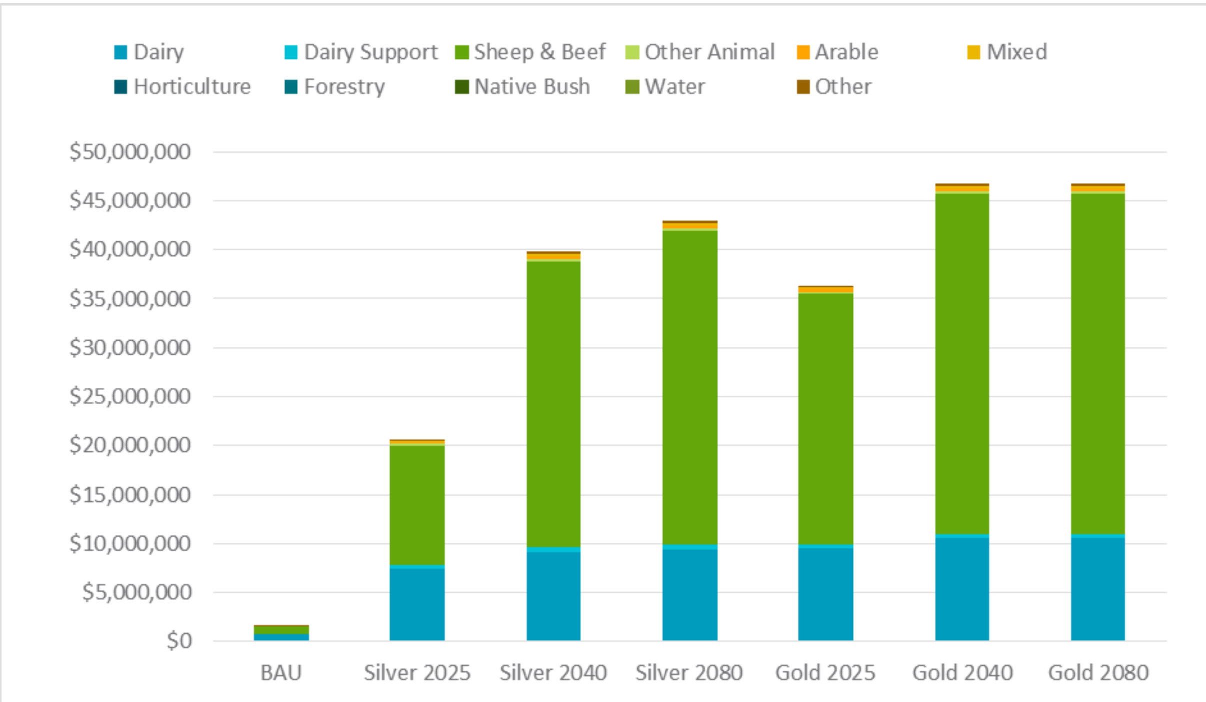

Figure 8: Total annual cost ($/yr), by aggregated land uses.

The mean annual costs for implementing the on-farm mitigation and sediment management practices in each scenario are presented as per hectare values in Table 10. It is apparent that there is a wide distribution of impacts across both land use and scenario. On a per hectare basis, dairy has the highest costs across all scenarios followed by sheep and beef and arable. Most of these costs relate to the requirement in the scenarios that all pastoral land uses must implement tier 2 and 3 mitigation bundles, which can be relatively costly.

Table 10: Mean annual mitigation cost ($/ha/yr)*

	BAU	***Silver 2025***	***Silver 2040***	***Silver 2080***	***Gold 2025***	***Gold 2040 and 2080***
Dairy	$27	$249	$304	$312	$316	$349
Dairy Support	$0	$35	$46	$47	$37	$47
Sheep and Beef	$4	$74	$177	$194	$155	$210
Other Animal	$0	$79	$88	$88	$81	$88
Arable	$0	$102	$177	$176	$178	$201
Mixed	$0	$4	$15	$15	$9	$15
Horticulture	$0	$0	$4	$4	$0	$4
Forestry	$0	$0	$0	$0	$0	$0
Native Bush	$0	$0	$0	$0	$0	$0
Water	$0	$0	$0	$0	$0	$0
Other	$0	$1	$9	$9	$1	$9
Total	$4	$57	$111	$120	$101	$130

* Estimated as total mitigation cost divided by total area for each land use

Based on the maps provided by Jacobs (2016) that outlined where the on-farm mitigation and sediment management options were implemented, Figure 9–Figure 11 list the area of each option that was implemented. For all the farm management options (e.g. mitigation bundles, space/pole planting, land retirement, etc.) the rate of uptake was prescribed by the Ruamāhanga Whaitua Committee. Thus, NZFARM was programmed to take the areas as given and estimate the costs to the landowner from implementing the management options. A majority of space/pole planting is undertaken on sheep and beef farms (up to 29,495 ha) followed by dairy (up to 2,208 ha). Similarly, most of the land that is retired is on sheep and beef farms (up to 11,000 ha).

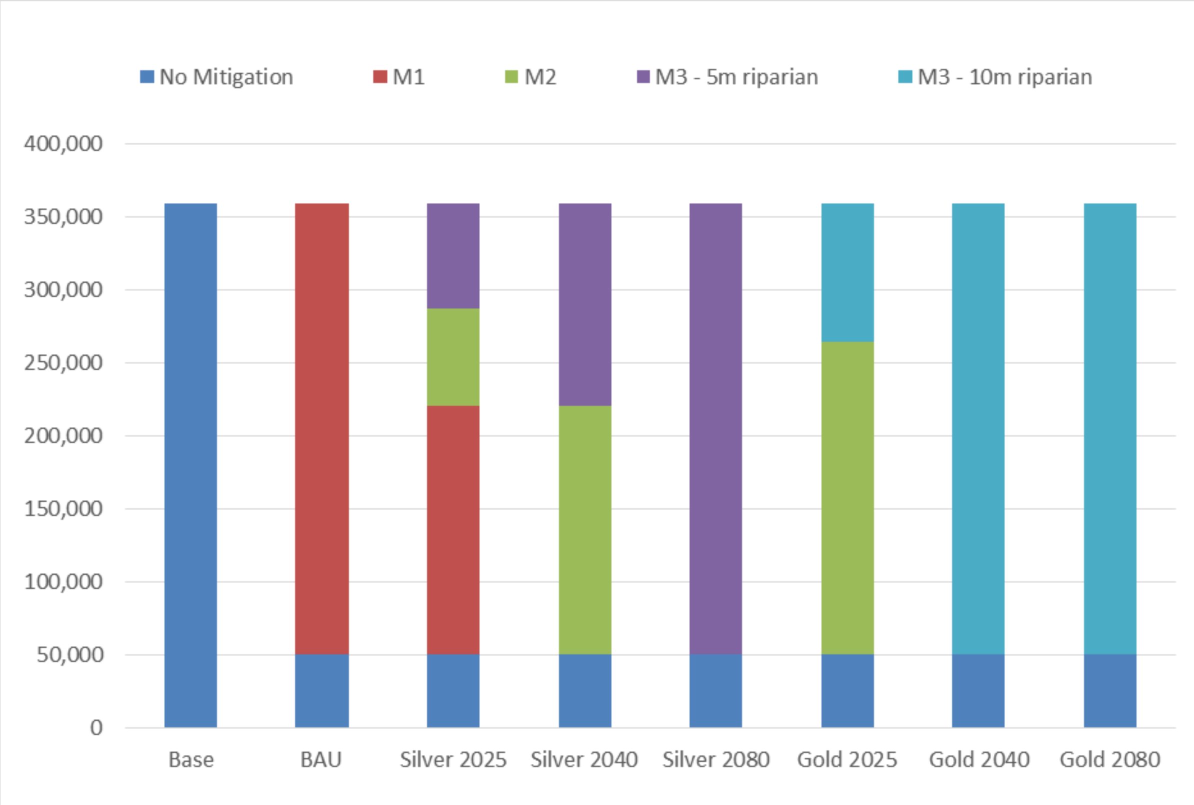

Figure 9: Area (ha) of implemented on-farm mitigation option by scenario.

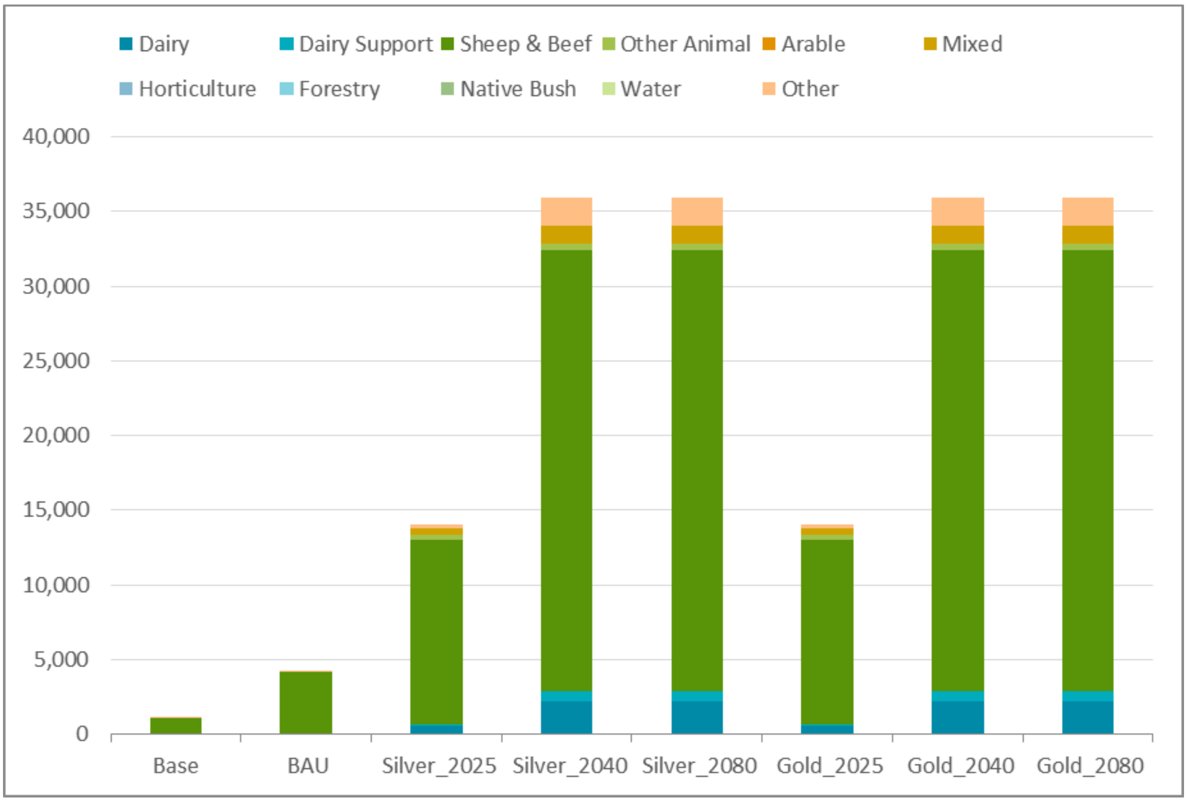

Figure 10: Area (ha) of space/pole planting by aggregated land use.

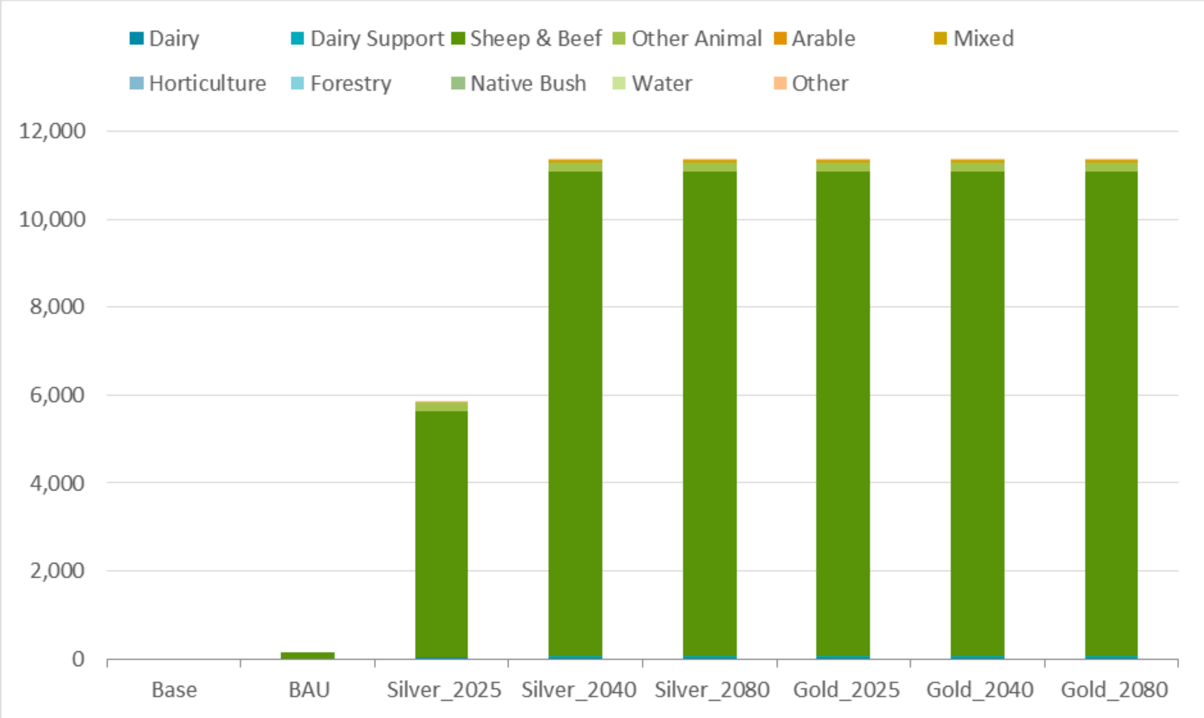

Figure 11: Area (ha) of retired land by aggregated land use.

The environmental response is estimated for each scenario (Table 11). There are marked reductions in sediment losses in the Silver (~37%) and Gold (~33%) scenarios by 2080. The biggest reductions are on sheep and beef farms, which are to be expected, given these farms are in steeper areas and a number of the management options target sediment losses. There is an even larger percent reduction in P losses with reductions of just over 50% for the Silver and Gold scenarios by 2080. Again most reductions are associated with sheep and beef farming areas. There are only modest decreases of about 9 % in N losses with both Silver and Gold scenarios. The disaggregated environmental responses at land use level are shown in Appendix 3.

Table 11: Summary of environmental response to the scenarios

	BAU 2040	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
				Environmental parameters (% change)				
Sediment loss[14]	–9.3%	–15.3%	N/A	–26.9%	–36.8%[15]	N/A	–30.1%	–32.9%
N losses	0%	0%	–8.1%	–8.7%	–8.7%	–9.0%	–9.1%	–9.1%
P losses	0%	0%	–18.1%	–43.4%	–52.1%	–32.4%	–52.6%	–52.6%

[14] No information on sediment loss was provided for 2025 as sediment management options take over 10-15 years to show any significant reductions in sediment loss (Jacobs 2017).

[15] Note that the reduction in sediment losses under the Silver scenario was greater than under the Gold scenario. This may have been due to rounding errors when the raster GIS layer provided by Jacobs was converted to a shapefile or it may also be due to differences in the actual layers provided by Jacobs.

5.2.1 Wider regional impacts of the farm management options

We use a multiplier approach to estimate the wider economic impacts of the scenarios at the regional level (Table 12 and Table 13). Total regional economic output could be reduced by $19.0 to $44.6 million per year while regional employment could be reduced by 88 to 206 full time equivalents (FTE), for Silver and Gold scenarios. The changes in farm-gate revenue for the sheep and beef and dairy support land uses have a larger impact on the regional economy than the revenue changes for dairy.

Table 12: Summary of wider regional economic impacts due to on-farm mitigation and sediment management options for each scenario

Land Use	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Change in Farm-Gate Revenue from Baseline (mil $/yr)							
Dairy	$0.00	–$4.25	–$6.67	–$7.36	–$7.54	–$9.56	–$9.56
Sheep and Beef, and Dairy Support	–$0.84	–$7.82	–$15.97	–$16.75	–$16.85	–$18.81	–$18.81
Total	**–$0.85**	**–$12.08**	**–$22.64**	**–$24.11**	**–$24.39**	**–$28.37**	**–$28.37**
Change in Wider Regional Economic Output from Baseline (mil $/yr)							
Dairy	–$0.01	–$6.80	–$10.65	–$11.75	–$12.04	–$15.27	–$15.27
Sheep and Beef, and Dairy Support	–$1.32	–$12.21	–$24.93	–$26.16	–$26.31	–$29.38	–$29.38
Total	**–$1.32**	**-$19.01**	**–$35.58**	**–$37.91**	**–$38.36**	**–$44.64**	**–$44.64**
Change in Regional Employment from Baseline (FTE)							
Dairy	0.0	–33.0	–51.6	–56.9	–58.4	–74.0	–74.0
Sheep and Beef, and Dairy Support	–5.9	–54.8	–111.9	–117.5	–118.1	–132.0	–132.0
Total	**–5.9**	**–87.8**	**–163.5**	**–174.4**	**–176.5**	**–206.0**	**–206.0**

The on-farm revenues from which the wider regional economic impacts are estimated are affected by the implementation of on-farm mitigation bundles and land retirement (Table 13). Space/pole planting and riparian planting are assumed to affect farm costs but not production and on-farm revenue. Sheep and beef, and dairy-support farm revenues are affected more by land retirement where most of the land retirement is implemented. Dairy farm revenue, on the other hand, is more affected by the implementation of on-farm mitigation bundles as these effects their productivity.

Table 13: Summary of the lost farm-gate revenue from implementing on-farm mitigation bundles and retiring land for each scenario

Land Use	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Change in Farm-Gate Revenue From Baseline due to on-farm Mitigation Bundles (Mil $/yr)							
Dairy	$0.00	–$3.57	–$5.37	–$6.07	–$6.24	–$8.27	–$8.27
Sheep and Beef, and Dairy Support	$0.00	–$3.00	–$6.57	–$7.35	–$7.46	–$9.42	–$9.42
Total	**$0.00**	**–$6.57**	**–$11.94**	**–$13.42**	**–$13.70**	**–$17.68**	**–$17.68**
Change in Farm-Gate Revenue From Baseline due to Retired Land (Mil $/yr)							
Dairy	$0.00	–$0.69	–$1.30	–$1.30	–$1.30	–$1.30	–$1.30
Sheep and Beef, and Dairy Support	–$0.84	–$4.82	–$9.40	–$9.40	–$9.40	–$9.40	–$9.40
Total	**–$0.85**	**–$5.51**	**–$10.69**	**–$10.69**	**–$10.69**	**–$10.69**	**–$10.69**

5.3 Wastewater treatment plant (WWTP) upgrades

Assumptions and caveats for WWTP upgrade impacts

- Estimates are based on costs provided by Carterton District Council (CDC). Thus, the costs for the other districts may differ from the estimates provided by this analysis. For example, the land price in Masterton may be markedly different from that in Carterton. Land is required for the storage and irrigation of waste to land.
- Population growth rates are based on projections obtained from Statistics NZ subnational population projection tables. Martinborough, Greytown, and Featherston populations are assumed to grow at the same rate as South Wairarapa district.
- There are no assumed impacts to wider regional economic output as WWTP upgrade impacts would affect the cost of operation but not revenue.

Discharges from WWTPs are progressively moving to discharge to land. There are existing investments and resource consent conditions that require the Masterton and Carterton WWTPs to discharge partially to land; Martinborough and Greytown WWTPs will discharge to land fully by 2035 and 2039 respectively; Featherston discharges entirely to water.[16]

We estimate the impacts of WWTP upgrades based on cost estimates provided by Carterton District Council (CDC), annualized over 25 years at rate of 8% (Table 14). WWTP upgrades are estimated to have a total annualized cost of $10.4 to $14.8 million/yr depending on the scenario. More than half of the total costs (55-64%) are incurred in the Masterton District, which has the largest number of residents, businesses, and households. Approximately 20% of the costs are estimated to be in Carterton, the next most populated district in the Ruamāhanga catchment.

The estimates for WWTP mitigation costs equate to $230–319 per person per year for the Gold and Silver scenarios respectively (based on estimated WWTP costs and projected population growth for each district).

Table 14: Summary of wastewater treatment plant mitigation costs (‘000 $/yr)

District	BAU 2080	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Masterton	8,178	5,873	8,241	8,178	8,146	8,241	8,178
Carterton	2,243	2,149	3,105	3,111	2,980	3,105	3,111
Martinborough	1,202	839	1,202	1,202	1,164	1,202	1,202
Greytown	1,181	824	1,181	1,181	1,143	1,181	1,181
Featherston	0	758	1,086	1,086	1,051	1,086	1,086
Total	**12,805**	**10,443**	**14,816**	**14,758**	**14,483**	**14,816**	**14,758**

[16] http://www.gw.govt.nz/assets/Ruamahanga-Whaitua/Presentation-on-scenario-1-BAU-Management-options-example-05.09.16.pdf

5.4 Change in irrigation reliability

Assumptions and caveats for the impacts of changes in irrigation reliability

- This analysis assumes no land use changes occur in response to changes in irrigation reliability. It also assumes that there are no changes in water availability due to climate change or other environmental or policy factors.
- It is uncertain how much irrigation reliability will change. Thus, we estimate potential impacts for three different reliabilities under current and future conditions.
- The Ruamāhanga Whaitua Committee was interested in estimating impacts in two particular sub-catchments, the Upper Ruamāhanga and Waipoua. Changes in reliability could also impact other areas of the catchment, but these are not modelled for this project.
- Irrigated area for each sub-catchment is estimated using consent data from GWRC. The consent data did not have information on the spatial distribution of different irrigated farm systems. Therefore, we estimate impacts using 'most intensive' and 'average' farm systems based on what farm systems Jacobs identified were present in each sub-catchment.
- Differences in water availability are assumed to have an impact on farm revenue, which could also result in changes in wider regional economic output and employment.
- Impacts to farm-gate revenue under different water reliability conditions are available for pastoral and arable farming systems.
- Impacts to wider regional economic output and employment are estimated using a regional multiplier approach.
- Costs of additional water storage, efficient irrigation methods, use of different crops etc. are not included in this analysis.

The Ruamāhanga Whaitua Committee identified the Upper Ruamāhanga and Waipoua sub-catchments as areas of most concern. It was to these catchments that changes to the minimum flows were proposed (for consented Category A groundwater and consented surface water takes). Collectively, these sub-catchments currently have 3,268 ha of irrigated land, mostly in dairy (60%) and sheep and beef (26%). As we do not know what type of farms (i.e. intensive or average farm systems) are being irrigated we have estimated the impacts based on those farms being 'average' farm systems (which is an average of all farm systems within a given sector based on Muirhead et al. (2016)) and also the 'most intensive' farm system. Note that the proposed minimum flow limits are the same across all modelled scenarios (see Appendix 2).

Impacts to irrigation reliability because of the changes in minimum flows in the sub-catchments of concern are estimated to reduce catchment farm revenue by $0.46 to $2.25 million per year (Table 15) if the irrigated farm system is "most intensive" (based on the projected future reliability). If "average" farm systems are irrigated farm revenue reductions range between 0.32 and 1.63 million per year (Table 16). Dairy farms are estimated to face the highest revenue reductions followed by sheep and beef and dairy support farms. Approximately 97% of the impacts of changes in irrigation reliability are expected to occur in the Upper Ruamāhanga sub-catchment, which has 94% of the irrigated land in the area of concern. The greatest impacts are estimated to occur if the farm systems are 'most intensive' (which have the highest revenue potential) and reliability is reduced to 90th percentile of summer annual estimates.

Table 15: Estimated impacts on farm-gate revenue from changes in irrigation reliability in Waipoua and Upper Ruamāhanga sub-catchments, if irrigated farm system is "intensive"

	Waipoua (186 ha)		Upper Ruamāhanga (3082 ha)	
Reliability	***Now*[a]**	***Future*[b]**	***Now*[a]**	***Future*[b]**
Dairy (Total Farm-Gate Revenue Change)				
Average Annual Reliability	$0	$0	–$39,466	–$332,276
Average Summer Reliability	$0	$0	–$215,152	–$800,773
90th Percentile Summer Reliability	$0	$0	–$625,087	–$1,854,891
Arable (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$3,456	–$5,163	–$6,999	–$18,376
Average Summer Reliability	–$6,869	–$9,713	–$13,825	–$36,578
90th Percentile Summer Reliability	–$15,098	–$17,441	–$29,753	–$67,681
Sheep and Beef & Dairy Support (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$6,153	–$7,843	–$58,474	-$95,371
Average Summer Reliability	–$9,532	–$12,349	–$80,613	–$154,406
90th Percentile Summer Reliability	–$17,981	–$23,050	–$132,268	–$287,235
All Land Uses (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$9,609	–$13,005	–$104,940	-$446,024
Average Summer Reliability	–$16,402	–$22,062	–$309,590	–$991,758
90th Percentile Summer Reliability	–$33,079	–$40,491	–$787,108	–$2,209,807

a: Under existing minimum flow

b: Under fully implemented new minimum flow recommended by Ruamāhanga Whaitua Committee

Table 16: Estimated impacts on farm-gate revenue from changes in irrigation reliability in Waipoua and Upper Ruamāhanga sub-catchments, if irrigated farm system is "average".

	Waipoua (186 ha)		**Upper Ruamāhanga (3082 ha)**	
Reliability	***Now*[a]**	***Future*[b]**	***Now*[a]**	***Future*[b]**
Dairy (Total Farm-Gate Revenue Change)				
Average Annual Reliability	$0	$0	-$30,271	–$254,858
Average Summer Reliability	$0	$0	-$165,023	–$614,198
90th Percentile Summer Reliability	$0	$0	-$479,446	–$1,422,714
Arable (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$3,456	–$5,163	–$6,999	–$18,376
Average Summer Reliability	–$6,869	–$9,713	–$13,825	–$36,578
90th Percentile Summer Reliability	–$15,098	–$17,441	–$29,753	–$67,681
Sheep and Beef & Dairy Support (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$2,442	–$3,113	–$23,210	–$37,855
Average Summer Reliability	–$3,784	–$4,901	–$31,997	–$61,287
90th Percentile Summer Reliability	–$7,137	–$9,149	–$52,500	–$114,009
All Land Uses (Total Farm-Gate Revenue Change)				
Average Annual Reliability	–$5,899	–$8,276	–$60,480	–$311,089
Average Summer Reliability	–$10,653	–$14,615	–$210,845	–$712,064
90th Percentile Summer Reliability	–$22,235	–$26,590	–$561,698	–$1,604,404

a: Under existing minimum flow

b: Under fully implemented new minimum flow recommended by Ruamāhanga Whaitua Committee

The impacts of increased minimum flows in these two sub-catchments on irrigation reliability are estimated to reduce wider regional economic output by $0.5 to $3.6 million per year (depending on farm system) (Table 17), and reduce employment by 3.9 to 27.5 FTEs (based on the projected future reliability) (Table 18). These farm revenue changes and wider regional economic impacts are above and beyond any irrigation reliability impacts that are currently being experienced in these changes. For example, if farm-gate revenue in a sub-catchment is currently $50,000 lower due to current minimum flows and the additional impact of the new minimum flows is $57,000, then the total reduction in farm revenue for the new minimum flow is $107,000.

Table 17: Estimated impacts on wider regional economic output from changes in irrigation reliability in Waipoua and Upper Ruamāhanga sub-catchments

Reliability	Waipoua (186 ha)		Upper Ruamāhanga (3082 ha)	
	Now[a]	*Future*[b]	*Now*[a]	*Future*[b]
Change in Wider Regional Economic Output from Baseline - Most Intensive Systems Irrigated				
Average Annual Reliability	–$14,990	–$20,288	–$165,280	–$709,080
Average Summer Reliability	-$25,587	–$34,417	–$491,560	–$1,579,161
90th Percentile Summer Reliability	–$51,603	–$63,166	–$1,252,881	–$3,521,472
Change in Wider Regional Economic Output from Baseline - Average System Irrigated				
Average Annual Reliability	–$9,202	-$12,910	–$95,557	–$495,490
Average Summer Reliability	-$16,618	-$22,799	–$335,517	–$1,135,382
90th Percentile Summer Reliability	–$34,687	–$41,480	–$895,423	–$2,559,769

a: Under existing minimum flow

b: Under fully implemented new minimum flow recommended by Ruamāhanga Whaitua Committee

Table 18: Estimated impacts on regional employment from changes in irrigation reliability in Waiapoua and Upper Ruamāhanga sub-catchments

Reliability	Waipoua (186 ha)		Upper Ruamāhanga (3082 ha)	
	Now[a]	*Future*[b]	*Now*[a]	*Future*[b]
Change in Regional Employment from Baseline (FTE) – Most Intensive Systems Irrigated				
Average Annual Reliability	–0.1	–0.1	–1.2	–5.4
Average Summer Reliability	–0.2	–0.2	–3.7	-12.1
90th Percentile Summer Reliability	–0.4	–0.4	–9.6	–27.0
Change in Regional Employment from Baseline (FTE) – Average System Irrigated				
Average Annual Reliability	-0.1	–0.1	–0.7	-3.8
Average Summer Reliability	0.1	–0.2	–2.6	–8.7
90th Percentile Summer Reliability	–0.2	–0.3	–6.9	–19.8

a: Under existing minimum flow

b: Under fully implemented new minimum flow recommended by Ruamāhanga Whaitua Committee

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Appendix 1 – Detailed Methods

A1.1: New Zealand Forest and Agriculture Regional Model (NZFARM)

NZFARM is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale developed by Manaaki Whenua – Landcare Research (Daigneault et al. 2012, 2013). Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as how a policy aimed at one environmental issue could affect other environmental factors. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or in farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners. The version of the model used for the Ruamāhanga catchment analysis can track changes in land use, land management, agricultural production, and N, P, sediment and *E. coli* loads by imposing policy options that range from having landowners implement specific mitigation practices to identifying the optimal mix of land management to meet a particular target. The model is parameterised such that responses to policy are not instantaneous but instead assume a response that landowners are likely to take over the specified period (i.e., full implementation by 2025, 2040, and 2080).

Simulating endogenous land management is an integral part of the model, which can differentiate between 'business as usual' (BAU) farm practices and less-typical options that can change levels of environmental and agricultural outputs. Key land management options in the NZFARM version used for the Ruamāhanga catchment include three mitigation bundles that include fencing streams, constructing wetlands, enlarging effluent area, and adjusting fertiliser and stocking rates. Including a range of management options allows us to assess what levels of regulation might be needed to bring new technologies into general practice. Landowner responses to N, P, sediment, and *E. coli* load restrictions in NZFARM are parameterised using estimates from biophysical and farm budgeting models.

The model's objective function maximizes the net revenue[17] of agricultural production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs (e.g. sediment load limits) imposed on the catchment. Catchments can be disaggregated into sub-regions (i.e. zones) based on different criteria (e.g. land use capability, irrigation schemes), and in this case are divided into FMUs (see Fig. A1.1), as described in Snelder and Fraser (2016) and Thompson et al. (2018).

The objective function, total catchment net revenue (π), is specified as:

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[17] Net revenue (farm profit) is measured as annual earnings before interest and taxes (EBIT), or the net revenue earned from output sales less fixed and variable farm expenses. It also includes the additional capital costs of implementing new land management practices.

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{array}{c} PA_{r,s,l,e,m} + Y_{r,s,l,e,m} - \\ X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Z_{r,s,l} \end{array} \right\} \quad (1)$$

where P is the product output price, A is the product output, Y is other gross income earned by landowners (e.g. grazing leases), X is area of the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs, τ is an environmental tax (if applicable), γ^{env} is an environmental output coefficient, ω^{land} is a land use conversion cost, and Z is the area of land use change from the initial (baseline) allocation. Summing the revenue and costs of production across all reporting zones (r), soil/rainfall combinations (s), land covers (l), enterprises (e), and management options (m) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production but also by a number of production, land, technology, and environmental constraints.

The production in the catchment is constrained by the product balance equation and a processing coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

$$A_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \quad (2)$$

Landowners are allocated a certain amount of irrigation (γ^{water}) for their farming activities, provided that there is sufficient water (W) available in the catchment:

$$\sum_{s,l,e,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq W_r \quad (3)$$

Land cover in the catchment is constrained by the amount of land available (L) on a particular soil type in a given zone:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \quad (4)$$

and landowners are constrained by their initial land allocation (L^{init}) and the area of land that they can feasibly change:

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Z_{r,s,l} \quad (5)$$

The level of land cover change in a given zone and sub-catchment is constrained to be the difference in the area of the initial land-based activity (X^{init}) and the new activity:

$$Z_{r,s,l} \leq \sum_{e,m}\left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m}\right) \quad (6)$$

and we can also assume that it is feasible for all managed land cover to change (e.g., convert from pasture to forest). Exceptions include urban, native bush and tussock grassland under conservation land protection, which are fixed across all model scenarios:

$$L_{r,s,fixed} = L^{init}_{r,s,fixed} \quad (7)$$

The model also includes a constraint on changes to enterprise area (*E*), if desired:[18]

$$E_{r,s,l,fixed} = E^{init}_{r,s,l,fixed} \quad (8)$$

In addition to estimating economic output from the agriculture and forest sectors, the model also tracks a series of environmental factors, and in this study focuses on N, P, sediment and *E. coli* loads. In the case where farm-based loads (γ^{env}) are regulated by placing a cap on a given environmental output from land-based activities (*ENV*), landowners could also face an environmental constraint[19]:

$$\sum_{s,l,e,m} \gamma^{env}_{r,s,l,e,m} X_{r,s,l,e,m} \leq ENV_r \quad (9)$$

Finally, the variables in the model are constrained to be greater or equal to zero such that landowners cannot feasibly use negative inputs such as land and fertiliser to produce negative levels of goods:

$$Y, X, L \geq 0 \quad (10)$$

The 'optimal' distribution of land-based activities based on soil/rainfall type $s_{1\ldots i}$, land cover $l_{1\ldots j}$, enterprise $e_{1\ldots k}$, land management $m_{1\ldots l}$, and agricultural output $a_{1\ldots m}$ are simultaneously determined in a nested framework that is calibrated based on the shares of initial enterprise areas for each of the zones. Detailed land use maps of the catchment are used to derive the initial (baseline) enterprise areas and a mix of farm surveys and expert opinion is used to generate the share of specific management systems within these broad sectoral allocations.

The main endogenous variable is the physical area for each of the feasible farm-based activities in a catchment ($X_{r,s,l,e,m}$). In the model, landowners have a degree of flexibility to adjust the share of the land use, enterprise, and land management components of their farm-based activities to meet an objective (e.g. achieve a nutrient reduction target at least cost). Commodity prices, environmental constraints (e.g. nutrient cap), water available for irrigation, and technological change are the important exogenous variables, and, unless specified, these exogenous variables are assumed to be constant across scenarios.

NZFARM has been programmed to simulate the allocation of farm activity area through constant elasticity of transformation (CET) functions. The CET function specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. This approach is well suited for models that impose resource and policy constraints as it allows the representation of a 'smooth' transition

[18] N.B. the Ruamāhanga catchment analysis was primarily focused on the effects of land management on N, P, sediment, and *E. coli* loads. As a result, all the scenarios in this report assume all enterprises areas are fixed at baseline levels with exception of the scenarios that estimate the impacts of including afforestation as a management option.

[19] N.B. this constraint can be placed on the farm, sub-catchment, or catchment level, depending on the focus of the policy or environmental target.

across production activities while avoiding unrealistic discontinuities and corner solutions in the simulation solutions (de Frahan et al. 2007).

At the highest levels of the CET nest, land use is distributed over the zone based on the fixed area of various soil types. Land cover is then allocated between several enterprises such as arable crops (e.g. process crops or small seeds), livestock (e.g. dairy or sheep and beef), or forestry plantations that will yield the maximum net return. A set of land management options (e.g. fencing streams, reduced fertiliser regime) are then applied to an enterprise which then determines the level of agricultural outputs produced in the final nest.

The CET functions are calibrated using the share of total baseline area for each element of the nest and a CET elasticity parameter, σ_i, where $i \in \{s, l, e, m, a\}$ for the respective soil/rainfall type, land cover, enterprise, land management, and agricultural output. These CET elasticity parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes (i.e. no implicit cost from switching from one land use or enterprise activity to another).

The CET elasticity parameters in NZFARM typically ascend with each level of the nest between land cover, enterprise, and land management. This is because landowners have more flexibility to change their mix of management and enterprise activities than to alter their share of land cover. For this analysis the CET elasticities are specified **to focus specifically on the impact of holding land cover and enterprise area fixed**, as requested by the RWCMP, which allows us to focus on the impacts of imposing mitigation practices on existing farms. Thus, the elasticities are as follows: land cover ($\sigma_L = 0$), enterprise ($\sigma_E = 0$), and land management ($\sigma_M = \infty$). An infinite CET elasticity value was used in the land-management nest to simulate that landowners are 100% likely over the long-run to **exactly employ mitigation practices that were specified in each scenario developed by the RWCMP**[20] on their existing farm to meet environmental constraints rather than change land use. The CET elasticity parameter for each soil/rainfall combination (σ_S) is set to be 0, as that area is fixed. In addition, the parameter for agricultural production (σ_A) is also assumed to be 0, implying that a given activity produces a fixed set of outputs.

We note that this specification, along with equation (7), essentially re-specifies NZFARM to solve without needing to use the PMP-like formulation because it now includes additional levels of constraints. In this case, the only thing that is allowed to change is land-management, which is now assumed to be completely substitutable over the long run. That is, the landowner will choose whatever land management option is most profitable for the farm without any reservation. However, this approach also constrains changes in land use, and thus although a farm may be more profitable if it switches from sheep and

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[20] N.B. this approach is different from all prior analyses conducted using NZFARM (e.g. Daigneault et al. 2013; Daigneault & Samarasinghe 2015), where at least some of the scenarios set an environmental target but then ran the 'optimization' routine of the economic land use model to estimate the most cost-effective option for landowners to achieve a given objective. In the case of the RWCMP, all scenarios assumed a fix set of practices were imposed in each parcel of land, which eliminated the flexibility of the model to explore other policy options or mix of mitigation options to potentially achieve the same objective.

beef to forestry, this specification prohibits it from doing so. As a result, the simulated costs of the policy are the same as those estimated using catchment economic modelling methods discussed in Doole (2015).

The economic land use model is programmed in the modelling General Algebraic Modelling System (GAMS) software package. The baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the CONOPT solver (GAMS 2015).

Table A1.1 shows the key components of NZFARM specific to Ruamāhanga catchment.

Table A1.1: List of key components of NZFARM Ruamāhanga Catchment

Enterprise (E)	Mitigation Practice (M)	Soil/Rainfall (S) mm	Freshwater Management Units (R)	Environmental Indicators (ENV)
Arable_4.14	None	BROWN_>2450	Eastern Hill streams	N leaching
Beef Farming_4.10	Tier 1	BROWN_1050-1250	Eastern hill rivers	P loss
Beef Farming_4.11	Tier 2	BROWN_1250-1650	Valley floor streams	Sediment
Beef Farming_4.11,4.16	Tier 3	BROWN_1650-2050	Main stem Ruamāhanga River	*E. coli*
Beef Farming_4.12		BROWN_2050-2450	Lake Onoke	
Beef Farming_4.13		BROWN_750-850	Western hill rivers	
Beef Farming_4.16		BROWN_850-1050	Northern rivers	
Beef Farming_4.8		BROWN_850-1250	None	
Beef Farming_4.8,4.10		GLEY_<750		
Beef Farming_4.8,4.9		GLEY_1050-1250		
Beef Farming_4.9		GLEY_1250-1650		
Dairy Farming_4.1,4.2		GLEY_1650-2050		
Dairy Farming_4.3		GLEY_2050-2450		
Dairy Farming_4.3,4.5		GLEY_750-850		
Dairy Farming_4.4		GLEY_850-1050		
Dairy Farming_4.5,4.6		lake_1050-1250		
Dairy Support_4.15		lake_1250-1650		
Dairy Support_4.16		lake_850-1050		
Finishing_4.10		MELANIC_1050-1250		
Finishing_4.11		MELANIC_1250-1650		
Finishing_4.11,4.16		MELANIC_750-850		
Finishing_4.12		MELANIC_850-1050		
Finishing_4.13		ORGANIC_1650-2050		
Finishing_4.8		ORGANIC_750-850		
Finishing_4.8,4.10		ORGANIC_850-1050		
Finishing_4.8,4.9		PALLIC_<750		
Finishing_4.9		PALLIC_1050-1250		
Sheep and Beef Farming South-East_4.8		PALLIC_1250-1650		
Sheep and Beef Farming_4.10		PALLIC_1650-2050		
Sheep and Beef		PALLIC_750-850		
		PALLIC_850-1050		
		RAW_<750		

Farming_4.11	RAW_1050-1250
Sheep and Beef Farming_4.11,4.16	RAW_1250-1650
Sheep and Beef Farming_4.12	RAW_1650-2050
Sheep and Beef Farming_4.13	RAW_2050-2450
Sheep and Beef Farming_4.14,4.10,4.7,4.5,4.6	RAW_750-850
Sheep and Beef Farming_4.8	RAW_850-1050
Sheep and Beef Farming_4.8,4.10	RECENT_<750
Sheep and Beef Farming_4.8,4.9	RECENT_>2450
Sheep and Beef Farming_4.9	RECENT_1050-1250
Sheep and Beef	RECENT_1250-1650
Sheep Farming_4.10	RECENT_1650-2050
Sheep Farming_4.11	RECENT_2050-2450
Sheep Farming_4.11,4.16	RECENT_750-850
Sheep Farming_4.12	RECENT_850-1050
Sheep Farming_4.13	river_1050-1250
Sheep Farming_4.16	river_1250-1650
Sheep Farming_4.8	river_1650-2050
Sheep Farming_4.8,4.10	river_850-1050
Sheep Farming_4.8,4.9	town_1050-1250
Sheep Farming_4.9	town_1250-1650
Horticulture	town_850-1050
Lifestyle	ULTIC_1050-1250
Native Bush	ULTIC_1250-1650
Urban	
Utility	
Equine	
Viticulture	
Recreation	
Mixed	
Poultry	
Waterway	
River	

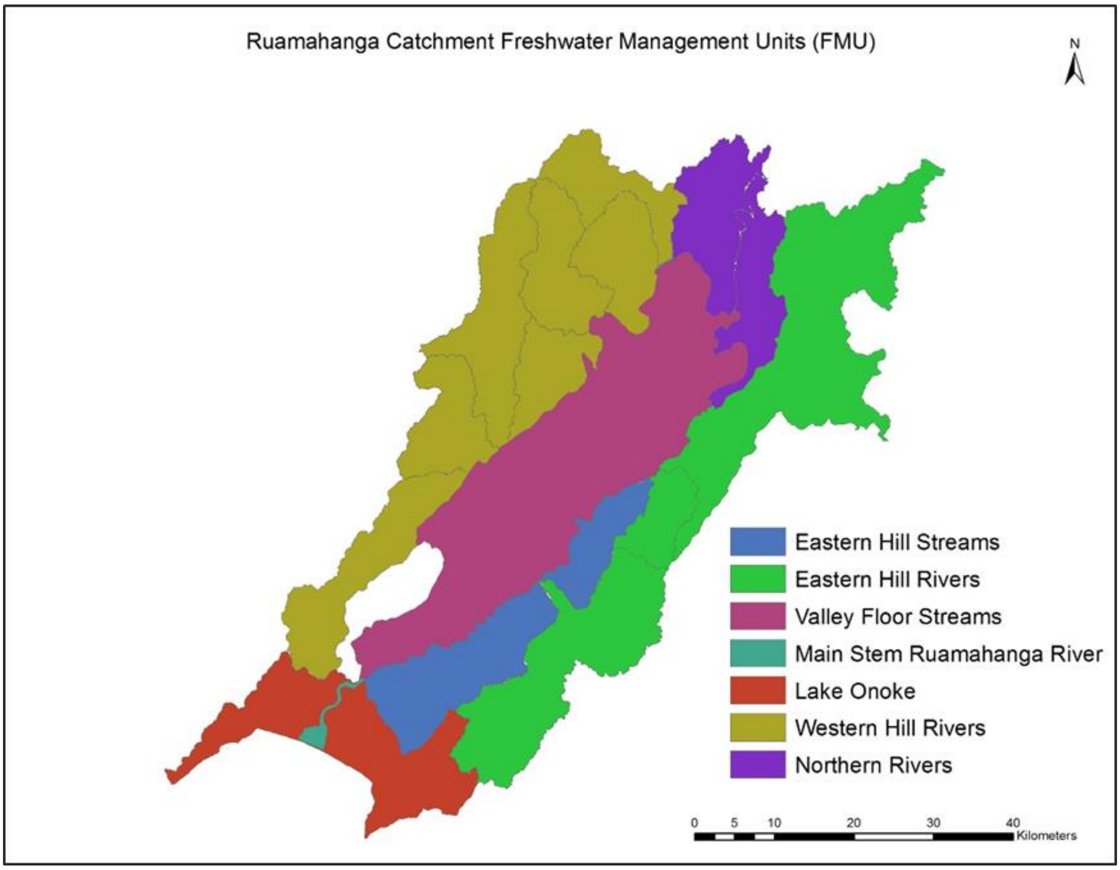


Figure A1.1: Ruamāhanga Catchment FMUs.

A1.2: Nutrient Modelling

Nutrient modelling was conducted in Overseer. Methods for estimating baseline figures for the 16 representative farms were presented in Parminter and Grinter (2016), while methods for estimating per hectare figures for the mitigation practices are discussed in Muirhead (2016). Estimates for other land uses not covered by the representative farms, as well as adjustments to nutrient losses provided by the other two sources were specified by Jacobs (2018) along with insight from other stakeholders participating in the RWCMP.

A1.3: Sediment Modelling

Jacobs was contracted by GWRC to undertake an analysis of baseline erosion rates and sediment yields in the Ruamāhanga catchment using the SedNetNZ model. The catchment erosion and sediment model simulates several erosion processes, sediment storages, and transfers. For this analysis, SedNetNZ has been calibrated for the Ruamāhanga catchment and downscaled to a grid scale. Sediment is estimated as total sediment and thus expected to come from a range of sources that include landslide, earthflow, gully, and surficial erosion, as well as floodplain deposition and streambank erosion. More details on how sediment was modelled are available in Jacobs (2018).

A1.4: *E. coli* Modelling

Jacobs (2018) used the CLUES model to estimate baseline annual-average *E. coli* loads in the Ruamāhanga catchment. The estimated loads are broken down to river environment classification level 1 (REC1) sub-catchment scale, of which there are more than 7,000 in the Ruamāhanga. NZFARM has incorporated the baseline *E. coli* estimates by intersecting the GIS layer of *E. coli* loads provided by Jacobs with the Ruamāhanga catchment land use map. Note that the impacts of modelled scenarios on *E. coli* loads were not provided by Jacobs for this analysis. However, while the *E. coli* impacts are not included in this report the mitigation options and costs to reduce *E. coli* loads have been included in the economic analysis. More details on how *E. coli* was modelled available in Jacobs (2018).

A1.5: Mitigation practices

AgResearch was contracted to model up to 3 set of mitigation bundles for each of the 16 representative farms for the RWCMP (Muirhead et al. 2016). The three bundles are grouped base on how easy (Tier 1), medium (Tier 2), and difficult (Tier 3) they are to implement on farm, both in terms of financial cost and technical expertise (Monaghan 2009). The N and P mitigation options were modelled using Overseer, while the losses of sediment and *E. coli* were estimated using the best available data on farm-scale losses of these contaminants. The financial implications were modelled using Farmax. A summary of the mitigation options considered for dairy, sheep and beef, and dairy support farms are listed in Table A1.2.

Table A1.2: Potential Good Management Practices (GMPs) that could be applied to 16 MPI representative farms. The data indicates the key contaminants that the mitigation targets as well as an estimate of the effectiveness rated as low (L), medium (M), high (H) or unsure (?). The Bundle refers to the mitigation bundle (1, 2 or 3) in which the specific mitigation would be applied

GMP	***Target***	***Effectiveness***	***Bundle***
	Dairy		
Stock exclusion from streams, wetlands	P, *E. coli*, NH_4-N, sediment	High for *E. coli*	1
Deferred and/or low rate effluent irrigation	*E. coli*, P	?	1
Efficient water irrigation	N	L	2
Optimal P fertility & fert form	P	?	2
Enlarged effluent area	N	L	2
Early re-establishment of summer crops	N	L	2
Diverting laneway runoff	*E. coli*, P, NH_4	LH	2
Reduced use of fertiliser N	N	M	2
Facilitated or constructed wetlands	N, sediment, *E. coli*	L–M	2
Autumn substitution of N-fertilised pasture with low N feeds	N	L	2
Split grass/clover swards	P	L–M	3
	Sheep and Beef		
Cattle exclusion from streams, wetlands	P, *E. coli*, NH_4-N, sediment	High for *E. coli*	1
Protection of CSAs on grazed forage crops	Sediment, P E. coli	H	2
Efficient water irrigation	N	L	2
Low solubility P fertiliser to sloping land	P	L	2
Early re-establishm. of summer crops	N	L	2
Facilitated or constructed wetlands	N, sediment, *E. coli*	L–M	2
Catch crops following winter crops	N	L	2
Planted buffer strips	Sediment, P	M	3
Sediment traps	Sediment, P	?	3
	Dairy Support		
Stock exclusion from streams, wetlands	P, *E. coli*, NH_4-N, sediment	High for *E. coli*	1
Protection of CSAs on grazed forage crops	Sediment, P, *E. coli*	H	2
Optimal P fertility & fert form	P	?	2
Early re-establishm. of cropped land	N	L	2
Catch crops following winter crops?	N	L	2
Reduced use of fertiliser N	N	L	2
Facilitated or constructed wetlands	N, sediment, *E. coli*	L–M	2
Reduce % as cattle Sus	N	M	2
Duration-controlled crop grazing	N, sediment	L	3
Off-paddock wintering	N, sediment	H	3
Sediment traps	Sediment, P	L	3
Planted buffer strips	Sediment, P	L	3

A1.6: Reliability numbers for economics modelling

Percentages below are calculated from the number of days that water takes would be fully suspended (i.e. no water available) under the minimum flows recommended by the GWRC, and based on the past 20 years of flow data.

Table A1.3: Water reliability figures for economic analysis scenarios

Reliability Band	Waipoua		Upper Ruamāhanga	
	Now[1]	Future[2]	Now[1]	Future[2]
Average Annual Reliability[3]	95%	92%	98%	93%
Average Summer Reliability[4]	89%	84%	95%	85%
90th Percentile Summer Reliability	74%	65%	88%	67%

[1]Under existing minimum flow

[2]Under fully implemented new minimum flow recommended by committee. Phase in time for full implementation has not been decided but assumption needed for economic analysis

[3]Average annual reliability calculated as number of days per year of record under full suspension divided by 365

[4]Average summer reliability calculated as number of days per year of record under full suspension divided by 180

Appendix 2 – Scenario Description

Table A2.1: Business as usual (BAU) scenario description

Management option	Description
Land retirement	Retirement of very steep slopes and afforestation/ reversion to bush on Class 8 and 7e land Retire at the rate of 18 ha per year
Space/pole planting	Space planting on steep slopes (Class 7 land and above) Plant at the rate of 135 ha per year
Stock exclusion from water ways	All Category 1 and 2 water bodies as defined in the PNRP (includes wetlands, estuaries, lakes, water races and large drains – see page 19 of PNRP)
Wastewater treatment	Wastewater treatment plant are discharging partially to land % volume of discharge to land: Masterton: • 60% (summer) and 5% (winter) by 2025, • 100% (summer) and 80% (winter) by 2040 • 100% (summer) and 97% (winter) by 2080 Carterton: • 35% by 2025 • 60% by 2080 Martinborough: • 24% by 2025 • 100% by 2040 Greytown: • 20% by 2025 • 100% by 2040 Featherston: • 0% (full course of model)
Minimum flows	Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP) on all rivers and streams and groundwater Minimum flows are identified in Tables 7.1 and 7.2 of the PNRP
On-farm mitigation	Mitigation practices from Tiers 1, 2, and 3 good management practices applied to all dairy, dairy support and sheep and beef farms. Tier 1 is applied immediately

Table A2.2: Gold scenario description

Management option	Description
Land retirement	Retirement of very steep slopes and afforestation/ reversion to bush on very steep land in Eastern Hill country (the top ~5% of sediment load in source model) Retire land by 2025, woody vegetation cover achieved by 2040
Space/pole planting	Space planting on steep slopes - on all land of LUC class 6e and above (less top 5%, as above) All trees planted by 2040
Riparian planting	Riparian planting (10m wide, in native tree species) on all streams ,all trees planted by 2040
Stock exclusion from water ways	All Category 1 and 2 water bodies as defined in the PNRP (includes wetlands, estuaries, lakes, water races and large drains – see page 19 of PNRP) Exclusion complete by 2025
Wastewater treatment	Wastewater treatment plant are discharging fully to land % volume of discharge to land: Masterton: • 100% by 2025 Carterton: • 100% by 2025 Martinborough: • 100% by 2025 Greytown: • 100% by 2025
Minimum flows	Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP) on all rivers and streams Minimum flows are identified in Tables 7.1 and 7.2 of the PNRP
On-farm mitigation	Mitigation practices from Tiers 1, 2, and 3 good management practices applied to all dairy, dairy support and sheep and beef farms. Tier 1 mitigations immediately (as BAU) Tier 2 mitigations by 2025 Tier 3 mitigations by 2040

Table A2.3: Silver Scenario description

Management option	Description
Land retirement	Retirement of very steep slopes and afforestation/ reversion to bush on very steep land in Eastern Hill country (the top ~5% of sediment load in source model) Retire land by 2040, woody vegetation cover achieved by 2080
Space/pole planting	Space planting on steep slopes – on all land of LUC class 6e and 7 All trees planted by 2040
Riparian planting	Riparian planting (5m wide) on all streams, all trees planted by 2080
Stock exclusion from water ways	All Category 1 and 2 water bodies as defined in the PNRP (includes wetlands, estuaries, lakes, water races and large drains – see page 19 of PNRP) Exclusion complete by 2025
Wastewater treatment	Wastewater treatment plant are discharging fully to land % volume of discharge to land: Masterton: • 60% by 2025, • 100% by 2040 Carterton: • 60% by 2025 • 100% by 2040 Martinborough: • 60% by 2025 • 100% by 2040 Greytown: • 60% by 2025 • 100% by 2040
Minimum flows	Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP) on all rivers and streams Minimum flows are identified in Tables 7.1 and 7.2 of the PNRP
On-farm mitigation	Mitigation practices from Tiers 1, 2 and 3 good management practices applied to all dairy, dairy support and sheep and beef farms. Tier 1 mitigations immediately (as BAU) Tier 2 mitigations by 2040 Tier 3 mitigations by 2080

Appendix 3 – Detailed Scenario Results

A3.1: Scenario results by disaggregated land use

Table A3.1: Total baseline area, net farm revenue, and environmental outputs by disaggregated land use

	Area (ha)	Net Farm Revenue ($)	N leaching (kg)	P Loss (kg)	Sediment (t)
Arable	1,658	$1,904,611	46,598	610	1,757
Beef Farming	9,505	$3,832,390	168,630	11,509	27,819
Dairy Farming	30,090	$59,452,530	900,217	28,708	8,048
Dairy Support	10,008	$6,151,398	368,101	2,634	4,762
Deer Farming	2,367	$2,354,707	49,697	237	7,053
Equine	384	$0	0	92	62
Finishing	1,915	$763,742	29,511	2,638	1,323
Forestry	11,310	$7,087,498	33,931	1,470	24,065
Horticulture	732	$5,419,367	5,122	29	14
Other Land use	60	$0	0	0	0
Lifestyle	12,210	$0	329,659	16,361	4,778
Mixed	16,744	$27,626,885	652,980	6,865	6,205
Native Bush	85,853	$0	85,853	15,453	381,679
Poultry	11	$0	0	0	0
Recreation	695	$0	18,076	56	1,542
River	3,876	$0	0	0	0
Sheep and Beef Farming	142,078	$65,285,066	1,880,983	145,234	541,570
Sheep and Beef Farming South-East	7,137	$3,126,016	138,756	7,087	35,174
Sheep Farming	4,498	$1,713,861	64,544	4,013	8,547
Urban	3,182	$0	22,274	6,746	249
Utility	4,826	$0	33,782	10,231	4,109
Viticulture	1,620	$7,785,619	14,583	65	100
Waterway	8,346	$0	0	0	0
Total	**359,103**	**$192,503,691**	**4,843,302**	**262,726**	**1,060,591**

Table A3.2: Per hectare baseline net farm revenue, and environmental outputs by disaggregated land use

	Area (ha)	Net Farm Revenue ($/ha)	N leaching (kg/ha)	P Loss (kg/ha)	Sediment (t/ha)
Arable	1,658	$1,149	28	0.4	1.1
Beef Farming	9,505	$403	18	1.2	2.9
Dairy Farming	30,090	$1,976	30	1.0	0.3
Dairy Support	10,008	$615	37	0.3	0.5
Deer Farming	2,367	$995	21	0.1	3.0
Equine	384	$0	0	0.2	0.2
Finishing	1,915	$399	15	1.4	0.7
Forestry	11,310	$627	3	0.1	2.1
Horticulture	732	$7,404	7	0.0	0.0
Other Land use	60	$0	0	0.0	0.0
Lifestyle	12,210	$0	27	1.3	0.4
Mixed	16,744	$1,650	39	0.4	0.4
Native Bush	85,853	$0	1	0.2	4.4
Poultry	11	$0	0	0.0	0.0
Recreation	695	$0	26	0.1	2.2
River	3,876	$0	0	0.0	0.0
Sheep and Beef Farming	142,078	$460	13	1.0	3.8
Sheep and Beef Farming South-East	7,137	$438	19	1.0	4.9
Sheep Farming	4,498	$381	14	0.9	1.9
Urban	3,182	$0	7	2.1	0.1
Utility	4,826	$0	7	2.1	0.9
Viticulture	1,620	$4,806	9	0.0	0.1
Waterway	8,346	$0	0	0.0	0.0
Total	**359,103**	**$536**	**13**	**0.7**	**3.0**

Table A3.3: Total cost ($/yr) of modelled scenarios by disaggregated land use

Disaggregated land use	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Arable	$0	$168,540	$293,400	$292,126	$295,088	$333,647	$333,647
Beef Farming	$6,383	$1,021,986	$1,707,774	$1,610,338	$1,460,383	$1,744,188	$1,744,188
Dairy Farming	$798,924	$7,488,039	$9,136,179	$9,382,477	$9,504,781	$10,505,893	$10,505,893
Dairy Support	$0	$349,266	$463,547	$467,974	$366,905	$467,974	$467,974
Deer Farming	$0	$217,329	$242,130	$242,130	$224,028	$242,130	$242,130
Equine	$0	$967	$1,889	$1,889	$967	$1,889	$1,889
Finishing	$0	$266,150	$322,947	$320,176	$324,654	$351,684	$351,684
Forestry	$227	$105	$106	$106	$105	$106	$106
Horticulture	$0	$0	$5,592	$5,592	$0	$5,592	$5,592
Other Land use	$0	$0	$0	$0	$0	$0	$0
Lifestyle	$843	$33,680	$264,800	$264,800	$33,673	$264,800	$264,800
Mixed	$386	$73,930	$244,563	$244,563	$153,928	$244,563	$244,563
Native Bush	$0	$0	$0	$0	$0	$0	$0
Poultry	$0	$0	$0	$0	$0	$0	$0
Recreation	$0	$0	$0	$0	$0	$0	$0
River	$0	$0	$0	$0	$0	$0	$0
Sheep and Beef Farming	$604,824	$9,753,158	$24,674,607	$27,322,641	$21,550,399	$29,647,395	$29,647,395
Sheep and Beef Farming South-East	$90,331	$587,531	$1,630,863	$1,892,877	$1,480,434	$2,000,917	$2,000,917
Sheep Farming	$13,678	$567,639	$854,566	$918,638	$792,518	$990,993	$990,993
Urban	$0	$0	$0	$0	$0	$0	$0
Utility	$58	$29	$40	$40	$29	$40	$40
Viticulture	$0	$0	$4,596	$4,596	$194	$4,596	$4,596
Waterway	$0	$0	$0	$0	$0	$0	$0
Grand Total	**$1,515,654**	**$20,528,348**	**$39,847,600**	**$42,970,964**	**$36,188,085**	**$46,806,409**	**$46,806,409**

Table A3.4 Per hectare cost ($/ha/yr) of modelled scenarios by disaggregated land use

	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Arable	$0	$102	$177	$176	$178	$201	$201
Beef Farming	$1	$108	$180	$169	$154	$184	$184
Dairy Farming	$27	$249	$304	$312	$316	$349	$349
Dairy Support	$0	$35	$46	$47	$37	$47	$47
Deer Farming	$0	$92	$102	$102	$95	$102	$102
Equine	$0	$3	$5	$5	$3	$5	$5
Finishing	$0	$139	$169	$167	$170	$184	$184
Forestry	$0	$0	$0	$0	$0	$0	$0
Horticulture	$0	$0	$8	$8	$0	$8	$8
Other Land use	$0	$0	$0	$0	$0	$0	$0
Lifestyle	$0	$3	$22	$22	$3	$22	$22
Mixed	$0	$4	$15	$15	$9	$15	$15
Native Bush	$0	$0	$0	$0	$0	$0	$0
Poultry	$0	$0	$0	$0	$0	$0	$0
Recreation	$0	$0	$0	$0	$0	$0	$0
River	$0	$0	$0	$0	$0	$0	$0
Sheep and Beef Farming	$4	$69	$174	$192	$152	$209	$209
Sheep and Beef Farming South-East	$13	$82	$229	$265	$207	$280	$280
Sheep Farming	$3	$126	$190	$204	$176	$220	$220
Urban	$0	$0	$0	$0	$0	$0	$0
Utility	$0	$0	$0	$0	$0	$0	$0
Viticulture	$0	$0	$3	$3	$0	$3	$3
Waterway	$0	$0	$0	$0	$0	$0	$0
Grand Total	$4	$57	$111	$120	$101	$130	$130

A3.2: Environmental responses at disaggregated land use level

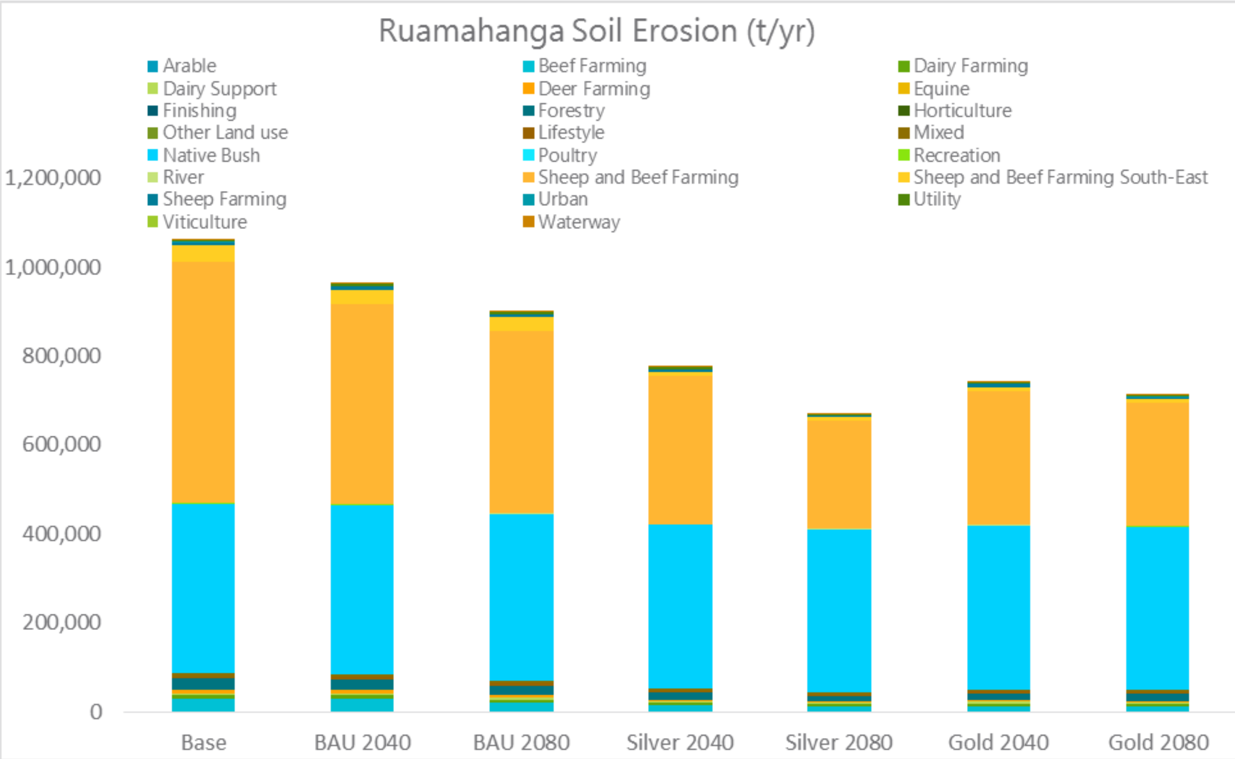


Figure A3.1: Sediment loss (t/yr) for disaggregated land use, by scenario.

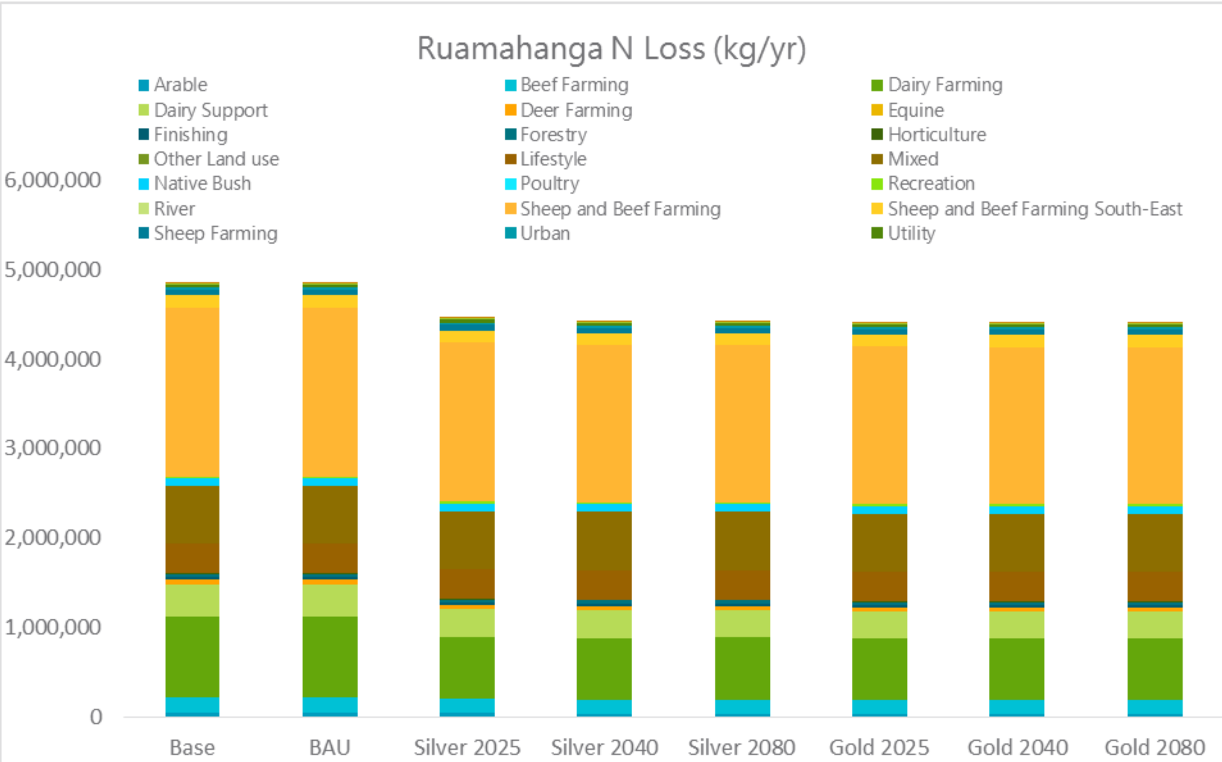


Figure A3.2: N leaching loss (kg/yr) for disaggregated land use, by scenario.

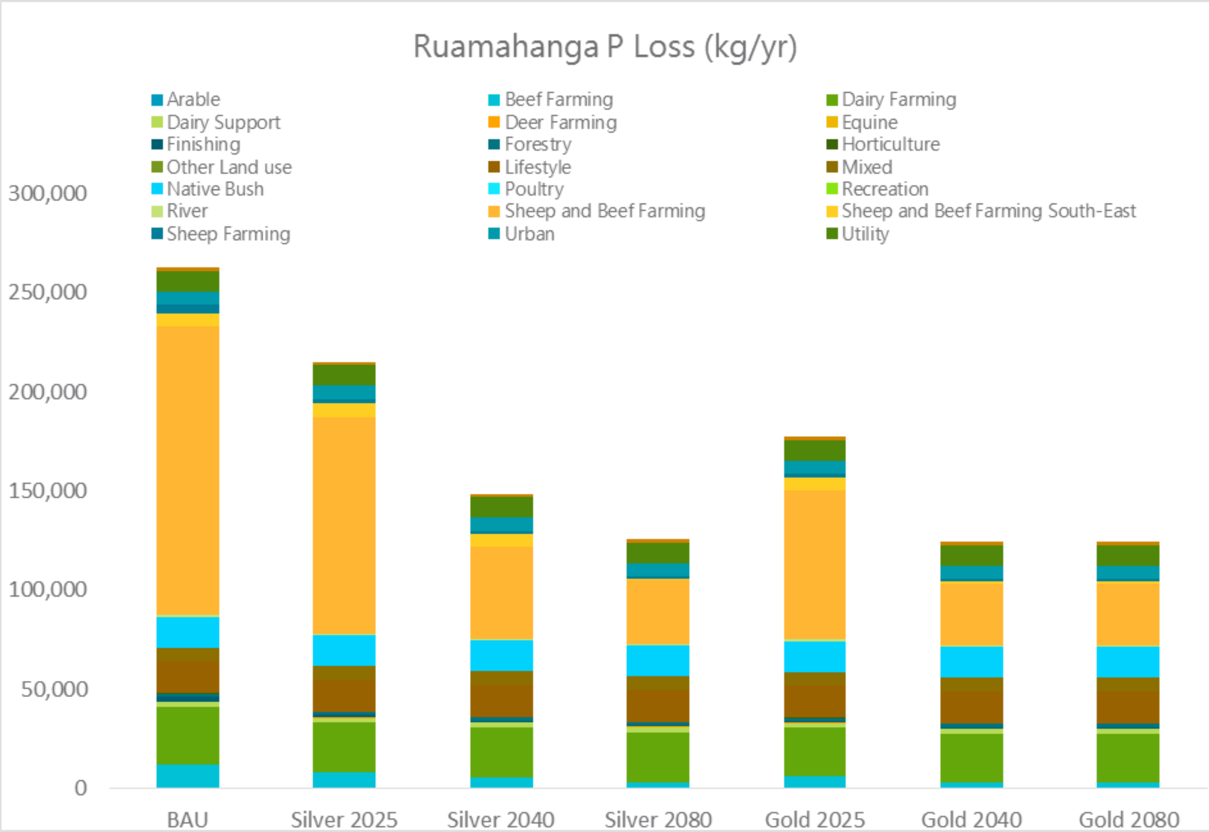
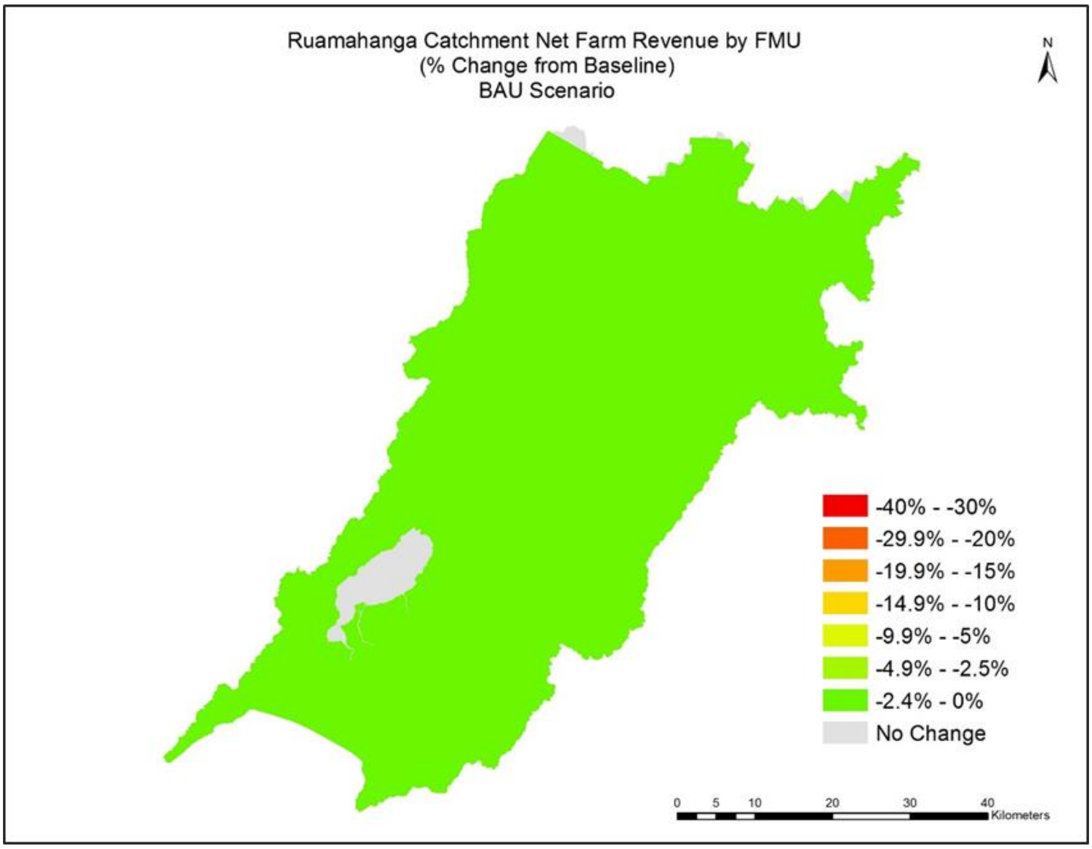


Figure A3.3: P loss (kg/yr) for disaggregated land use, by scenario.

A3.3: Scenario results by Freshwater Management Unit (FMU)

Table A3.5: Change in net Farm revenue from Baseline for each scenario, by FMU

FMU	Area (ha)	Base ($ Mil)	BAU	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040	Gold 2080
Eastern Hill streams	20,395	$17.76	0%	–7%	–16%	–17%	–14%	–19%	–19%
Eastern hill rivers	86,490	$43.49	–1%	–11%	–29%	–33%	–25%	–35%	–35%
Valley floor streams	46,034	$44.30	–1%	–11%	-13%	–13%	–13%	-14%	–14%
Main stem Ruamāhanga River	16,945	$19.15	–1%	–9%	–13%	–13%	–12%	–15%	–15%
Lake Onoke	23,824	$9.99	–1%	–10%	–21%	–20%	–18%	–22%	–22%
Western hill rivers	127,647	$39.05	–1%	–12%	–21%	-23%	–20%	–25%	–25%
Northern rivers	35,146	$18.42	0%	–13%	–31%	-34%	–28%	-36%	–36%
Not Specified	2,623	$0.34	–1%	–12%	–48%	–37%	–15%	-39%	–39%
Entire Catchment	**359,103**	**$192.50**	**–1%**	**–11%**	**–21%**	**-–22%**	**–19%**	**-24%**	**–24%**



FigureA3.4. Change in net farm revenue by FMU – BAU Scenario.

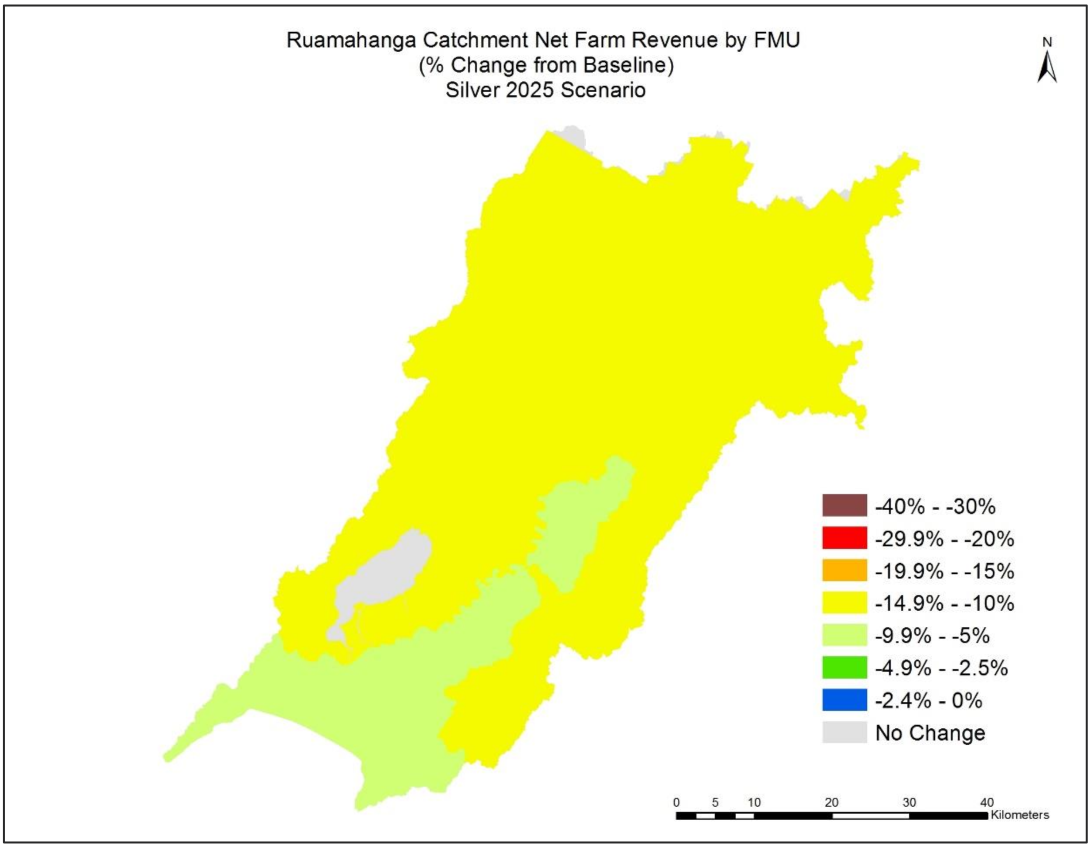


Figure A3.5: Change in net farm revenue by FMU – Silver 2025 scenario.

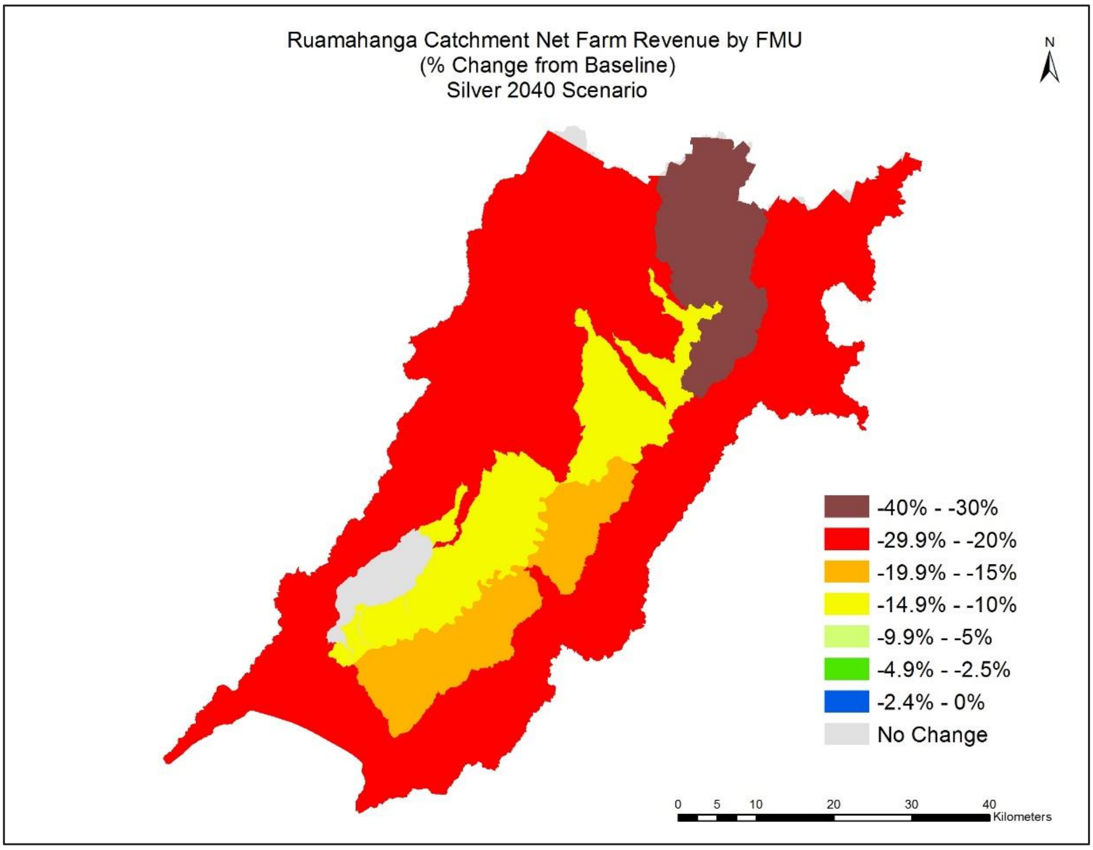


Figure A3.6: Change in net farm revenue by FMU – Silver 2040 scenario.

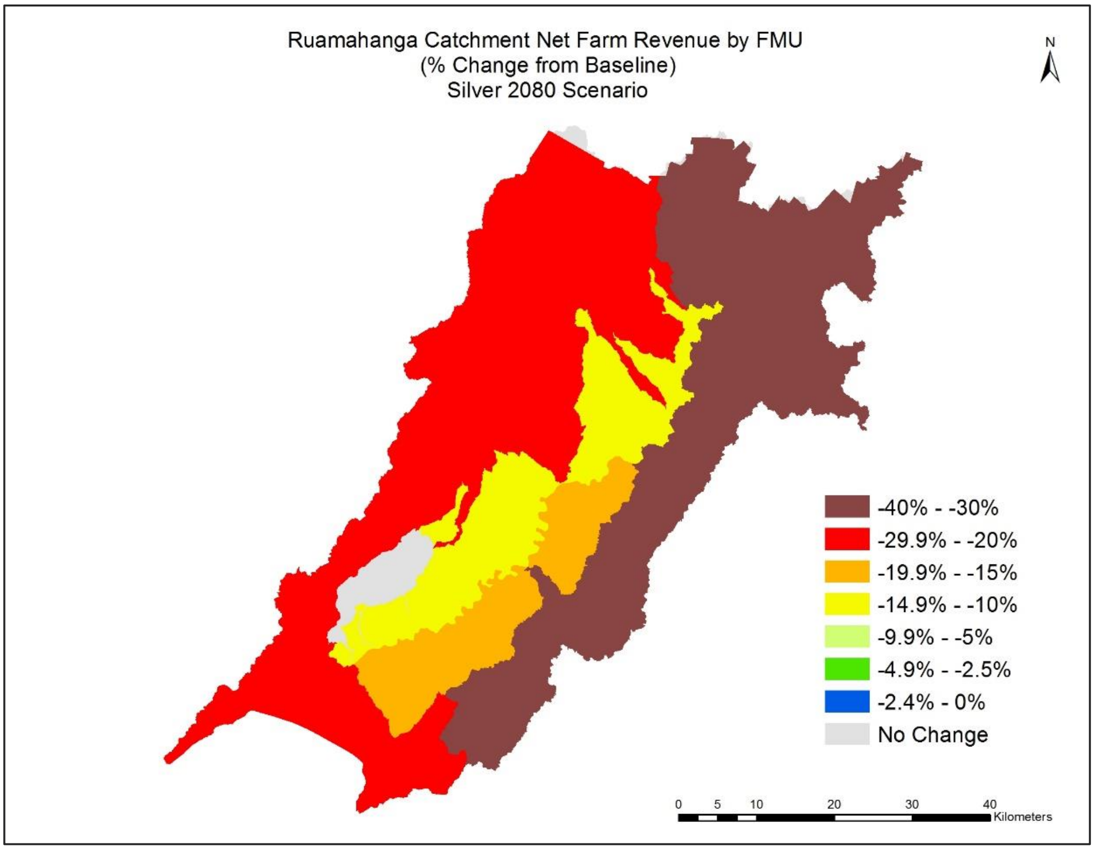


Figure A3.7: Change in net farm revenue by FMU – Silver 2080 scenario.

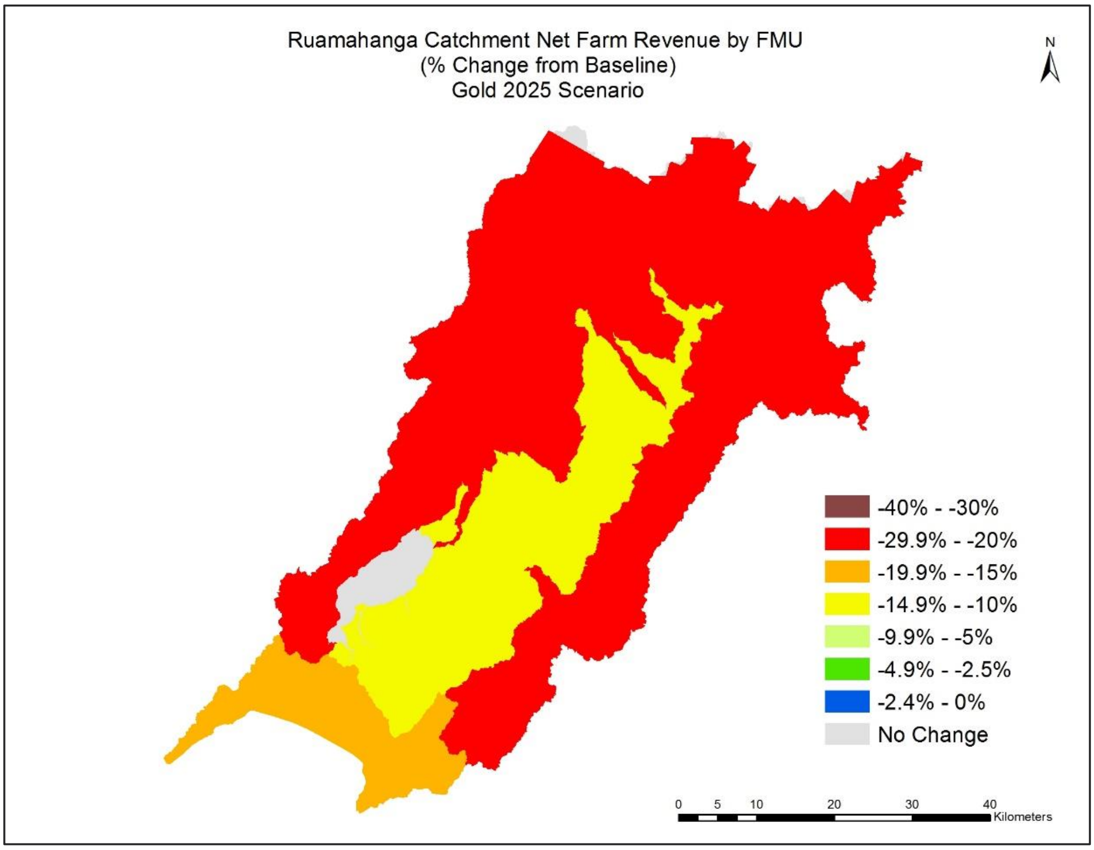


Figure A3.8: Change in net farm revenue by FMU – Gold 2025 scenario.

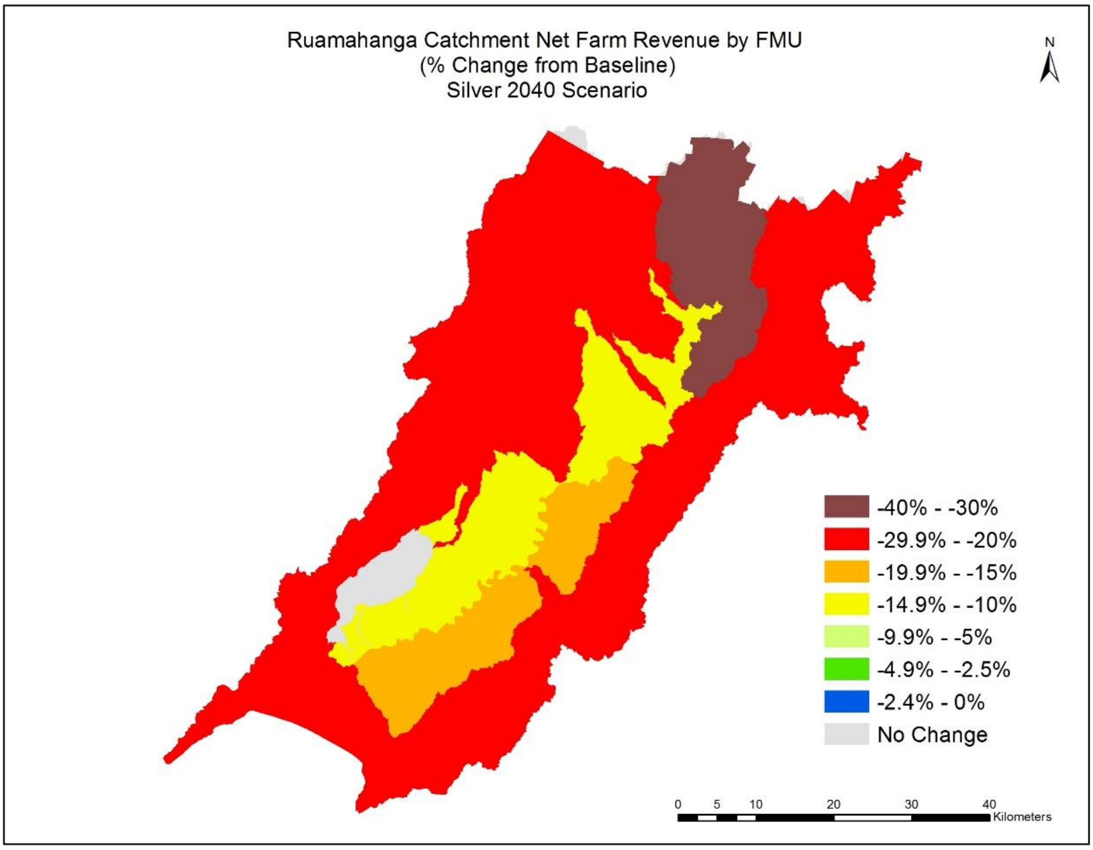


Figure A3.9: Change in net farm revenue by FMU – Gold 2040 scenario.

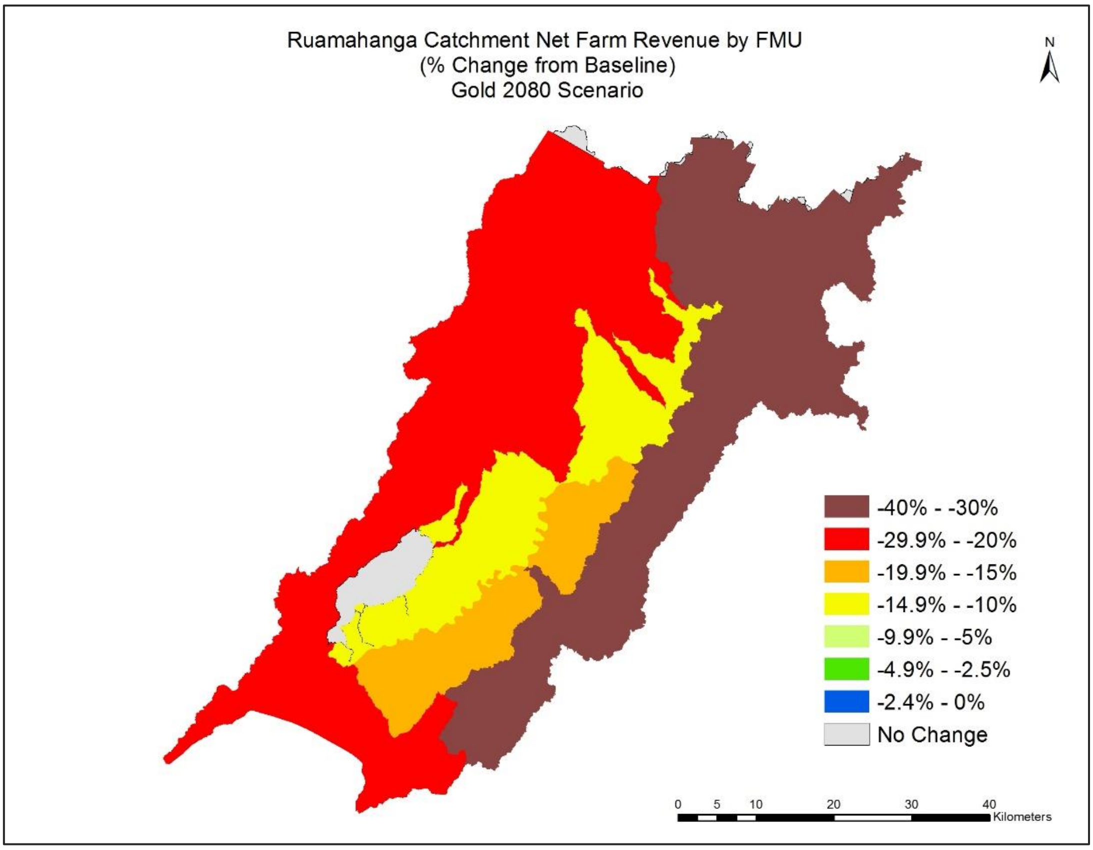


Figure A3.10: Change in net farm revenue by FMU – Gold 2080 scenario.