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Ruamahanga Catchment Economic Model:

Draft Baseline and Test Policy Scenarios

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June 2016

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Glossary

Attribute: A measurable characteristic of fresh water, including physical, chemical and biological properties, which supports particular values.

Attribute state: The level to which an attribute is to be managed, for attributes specified.

Baseline: The economic and environmental state of the catchment before the implementation of any practice or policy intended to reduce sediment or *E. coli* in the catchment.

Concentration: The amount of a particular substance per unit of another substance (e.g. grams sediment per cubic metre of water).

Contaminant: Biological (e.g. bacterial and viral pathogens) or chemical (e.g. toxicants) introductions capable of producing an adverse effect in a waterbody.

Discharge: The release of contaminants into the environment either directly into water, or onto (or into) land.

Diffuse source discharge: Pollutants sourced from widespread or dispersed sources (e.g. from pasture runoff of animal wastes, fertiliser and sediments, as well as runoff of pollutants from paved surfaces in urban areas). Also called non-point source discharges.

Earnings before Interest and Tax (EBIT): Farm profits that excludes interests and taxes. Used interchangeably with net farm revenue.

***E. coli*:** Bacteria that live in the intestines of people and animals. A primary indicator of pathogenic micro-organisms that can impact human health.

Erosion: The group of processes, including weathering, dissolution, abrasion, corrosion, and transportation, by which material is worn away from the Earth's surface.

Load: The flux of a contaminant passing a point of interest. Generally measured as mass (sediment) or number of individual organisms (*E. coli*) per unit area and per unit time (e.g. kg/ha/year). In this study typically presented as annual estimates at a catchment or sub-catchment scale.

Mitigation: The moderation of the intensity of one or more environmental contaminants through implementing changes in resource or land management.

Mitigation Cost: The annual cost of implementing a specific mitigation practice. Includes capital and implementation costs, annual operating and maintenance costs, and opportunity costs of removing land and/or stock from production.

Net Farm Revenue: The key measurement of economic output from land-based activities at the catchment scale incorporated in NZFARM. Based on farm earnings before interest and tax (EBIT). Includes wages for management and capital and implementation costs for mitigation practices.

New Zealand Forest and Agriculture Regional Model (NZFARM): A subcatchment-scale economic land use model, that optimises total net farm revenue subject to economic, environmental, and resource constraints. The model estimates the economic and environmental impacts of policy and management scenarios relative to a baseline (i.e., no policy or mitigation).

Nodes of importance: Sites within the Ruamahanga catchment of particular interest to the Greater Wellington Regional Council and Whaitua Committee. They are typically located near environmental monitoring stations and/or popular recreation sites.

Point source discharge: Discharge of contaminants into a waterbody from a single fixed point, such as a pipe or drain (e.g. from the likes of sewerage, factory and dairy shed outfalls).

Primary contact recreation: Activities likely to involve full immersion in water (e.g. swimming).

Secondary contact recreation: Activities with occasional immersion in water and some ingestion of water (e.g. wading and boating).

Suspended sediment: The ratio of the mass of dry sediment in a water-sediment mixture to the volume of the mixture.

Sediment: Geological material, such as silt, sand, rocks, and fossils that has been transported and deposited by water or wind.

Target: Limit which must be met at a defined time in the future. Often expressed as a percent change from a baseline.

Turbidity: The cloudiness of water caused by scattering of light from suspended particles.

Water Clarity: The distance of water through which an object can be clearly seen. A direct measure of the immediate foraging range of fish.

Executive 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 the Ruamahanga catchment in particular. As a result, GWRC and the Ministry for Primary Industries (MPI) have contracted Landcare Research to create the Ruamahanga catchment economic model. This work is just one component of the greater Whaitua Collaborative Modelling Project (WCMP).

Objectives

The aim of this project is to develop a model that will integrate science and economics to assess the potential economic costs of meeting a range of contaminant loads and attribute states for N, P, sediment and *E. coli* in the Ruamahanga. This is the first stage of the model development, where the focus is primarily on parameterising and calibrating the baseline as well as developing some ‘test’ policy scenarios to determine that the model is operating logically. A second stage will produce a more robust set of policy scenarios based on input from the Ruamahanga Whaitua Committee (RWC). It will also further develop the hydrological component of the model with input from other researchers working on the WCMP.

Methods

The integrated catchment economic modelling of the Ruamahanga catchment (RC) was completed using the New Zealand Forest and Agriculture Regional Model (NZFARM), Landcare Research’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 and *E.coli* loads from various land uses in the RC were estimated using the SedNet model, while *E. coli* loads and resulting concentrations were estimated using the CLUES model (Jacobs 2016). 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 mitigation bundles (Muirhead 2016). In addition, it could be updated to include mitigation on non-pastoral land uses, including wetland construction or afforestation and other types of land use change .

Illustrative model scenarios were conducted to test the utility of NZFARM and assess the possible impacts for a range of management and mitigation approaches to reduce contaminant loads in the RC (Table ES.1). These include both practice-based approaches such as having all dairy farms implement a given mitigation bundle, and outcome-based approaches that include meeting contaminant reduction targets for the entire catchment or at a Freshwater Management Unit (FMU) level, as defined by Snelder and Fraser (2016). We also modelled a large afforestation scenario to establish the minimum feasible loads that could be achieved in the RC. In all scenarios, mitigation costs estimates are annualised and assumed to be accrued for 25 years.

Table ES.1: NZFARM scenarios for the Ruamāhanga catchment

Scenario Name	Description	N Leach Target	P Loss Target	Sediment Target	*E. coli* Target
	Management Actions				
All Farms M1	All dairy, sheep & beef, and dairy support farms implement M1 mitigation bundle	n/a	n/a	n/a	n/a
All Farms M2	All dairy, sheep & beef, and dairy support farms implement M2 mitigation bundle	n/a	n/a	n/a	n/a
All Farms M3	All dairy, sheep & beef, and dairy support farms implement M3 mitigation bundle	n/a	n/a	n/a	n/a
	Minimum Feasible Loads				
Convert All to Forest	Afforestation of all non-native land in the catchment to estimate the minimum loads possible	n/a	n/a	n/a	n/a
	Contaminant load reduction targets				
10% catchment	10% reduction in N, P, and sediment for entire Ruamahanga catchment	10%	10%	10%	0%
10% FMU	10% reduction in N, P, and sediment for each FMU in the Ruamahanga catchment	10%	10%	10%	0%

Results

The calibrated baseline estimated that the nearly 360,000 ha of the Ruamāhanga catchment produced an annual net farm revenue of $200 million (M). Key land uses contributing to this figure include sheep and beef ($72M), dairy ($66M) and mixed cropping ($27M). Total N and P loads in the catchment were estimated to be 5,284 tN/yr and 209 tP/yr. Approximately 814 kt of sediment was estimated to reach waterways each year, while the total *E.coli* in the catchment was estimated to be nearly 135 peta *E.coli* per annum. A summary of the key baseline and economic outputs at the catchment model are listed in Table ES.2.

Table ES.2: Key Ruamāhanga catchment economic model baseline estimates by land use

Aggregated Land Use	Area (ha)	Net Farm Revenue ($)	N leaching (t)	P loss (t)	Sediment (kt)	*E.coli* (peta)
Dairy	35,739	66,499,471	1,045	33	10	28
Dairy Support	14,880	13,066,002	965	16	16	9
Sheep & Beef	154,276	72,496,361	2,045	136	378	74
Other Pasture	2,750	2,354,785	52	1	5	1
Forestry	11,306	5,174,823	34	2	23	3
Mixed (Arable)	16,742	27,623,821	653	7	7	4
Horticulture	2,352	13,202,910	20	0	0	1
Native Bush	85,843	0	86	9	365	4

Lifestyle	12,207	0	330	5	4	7
Other	22,898	0	56	0	4	3
Ruamahanga Total	358,993	$200,417,788	5285	209	813	135

The 6 modelled 'test' scenarios produced a wide range of economic and environmental impacts. A summary of the catchment-wide impacts is listed in Table ES.3.

The study showed that, given current land use, the Regional Council needs to be realistic about the possible outcomes that can be achieved. The RC has a great deal of area classified as forestry or native, which is managed differently from the productive land uses covered by the MPI representative farms (e.g.,dairy, sheep and beef, and dairy support). In fact, only 60% of the area in the Ruamahanga catchment is covered by the representative farms, so the management options (i.e. mitigation bundles) that only target pastoral enterprises may not be sufficient to achieve large reductions in environmental contaminants.

In considering each mitigation bundle on its own, the M1 bundle is relatively costless, but also has a minimal effect on contaminant loads in the catchment. According to the model, it leads to less than 1% reduction in N, P, and sediment and reduces E.coli by about 3.7% below the baseline. This is because the effectiveness estimated by Muirhead et al (2016). Implementing M2 on all eligible farms reduces N, P, and sediment loads by almost 10% percent below the baseline. If all the representative farms implemented M3-level mitigation, the most stringent set of management options, then N would be reduced by 10%, P by 48%, sediment by 25% and E.coli by 4%. This of course, would come at a cost to pastoral farmers in the catchment of about $28M per annum or about $137/ha/yr. These figures signal that the degree of mitigation currently included in the model may not be large enough to meet Whaitua Committee aspirations, particularly for N and *E.coli*-based attributes.

Table ES.3: Key 'test' model scenario estimates

Scenario	Total Annual Cost ($/yr)	Net Revenue ($)	N Leach (t)	P Loss (t)	Sediment (kt)	E.coli (peta)
Baseline	$0	$200,679,150	5,285	209	814	134.7
% Change from no mitigation baseline						
All Farms M1	$583,436	0%	0%	0%	0%	-4%
All Farms M2	$18,270,930	-9%	-10%	-7%	-9%	-4%
All Farms M3	$27,926,712	-14%	-10%	-48%	-25%	-4%
Convert All to Forest	$108,954,857	-54%	-82%	-82%	-41%	-84%
10% catchment	$12,193,487	-6%	-10%	-15%	-10%	-3.7%
10% FMU	$15,713,580	-8%	-10%	-28%	-10%	-3.0%

A less realistic but useful scenario is to estimate the impact of afforesting all productive land with pine plantations. In this case, sediment could be reduced by 40% while, N, P, and E.coli could be reduced by up to 80%. These are likely to be the maximum reductions achievable in the Ruamahanga catchment, although at a potential cost of $109M/yr, it is not likely that a massive afforestation programme would be considered a feasible option.

In the event that the policy focuses on outcome-based scenarios rather than practice-based ones, we estimate that a catchment-wide 10% reduction in N, P, and sediment would be achievable through a mix of M1-M3 mitigation being implemented on different farms at a cost of $12M/yr. If the reduction targets were imposed on each of the 6 draft FMUs rather than the catchment as a whole, then the total cost would be about $16M/yr. Note that in both cases, the reduction target for P is over-achieved because types of mitigation being applied results in a greater reduction of that contaminant than required.

1 Introduction

This report has been prepared for the Ministry for Primary Industries (MPI) as a component of the larger Ruamahanga Whaitua Collaborative Modelling Project. The Ruamahanga Whaitua Collaborative Modelling Project (RWCMP) is led by Greater Wellington Regional Council (GWRC) with the aim of providing the community based Ruamahanga Whaitua with information about water and contaminant flows through the Ruamāhanga catchment (RC) to support the limit setting process. MPI has a joint venture with GWRC to provide an Economic Modelling component to potential scenario analyses through a 3 stage process, of which this report describes step 2. Step 1 was the development of 16 base- or representative farms that are described in the MPI report by Parminter and Grinter (2016). The second step was for AgResearch to develop of a series of cost-abatment curves for each farm describing the relative cost and potential reduction of nitrogen (N), Phosphorus (P), sediment, and E. coli losses (Muirhead et al 2016). The third step is for Landcare Research to develop a catchment-scale economic model that not only incorporates the information from the previous but also integrates contaminant load and hydrological modelling aspects undertaken by others involved in the RWCMP. This report focuses on the third step and should be read in conjunction with the other reports.

This report focuses on the development from the spatially distributed catchment economic model. The integrated model of the RC consists of two key components: (1) baseline contaminant losses for each hectare of land in the study area; and (2) how these loads are modified with the use of on-farm mitigations and possibly land use change such as afforestation. 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 changes in contaminant loads.

The RC model is based on the New Zealand Forest and Agriculture Regional Model (NZFARM), 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 policy scenarios by estimating and comparing the relative changes in economic and environmental outputs. The RC version of NZFARM includes several farm- or parcel-level management options for managing N, P, sediment and *E. coli* loads: implementing farm plans, fencing streams, and constructing wetlands. 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.

This report presents estimates from a calibrated baseline and results from six 'test' scenarios to illustrate how the model could be applied for policy analysis. These include both practice-based approaches such as having all eligible farms implement a specific mitigation bundle (e.g., M2), and outcome-based approaches that include reducing N, P, sediment and E.coli to reach catchment-wide or specific freshwater management unit (FMU) targets.

The focus of this portion of the RWCMP is to develop and test an economic catchment model that looks at N, P, sediment and *E. coli* management in an integrated framework. It is not intended to define or analyse any specific policy or reduction target. Thus, the scenarios presented here should be taken as illustrative examples of how the model works and can be utilised in future analyses, as opposed to a rigorous analysis of a proposed policy or rule change. It is anticipated that more realistic policy scenarios will be defined with input by the Whaitua Committee in stage 2 of model development.

2 Methodology

This report presents the assessment of the potential economic and environmental impacts of reducing N, P, sediment and *E. coli* in the Ruamahanga catchment (RC) in the Greater Wellington region. The economic analysis is conducted using the NZFARM model. Farm level N and P losses for 16 representative dairy, sheep & beef (S&B), and dairy support farms were estimated by Parminter and Grinter (2016), while loss figures for other land uses were defined by Jacobs New Zealand Limited (hereafter 'Jacobs). Baseline estimates of sediment and *E.coli* were obtained, respectively, by Jacobs (2016) through the use of the SedNetNZ and CLUES models. The cost and effectiveness of mitigating the 4 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 (base) management practices. Environmental impacts are measured as changes in N, P, sediment and *E. coli* loads and related attributes relative to a no mitigation baseline. A more detailed description of the integrated economic model is presented below.

2.1 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 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 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 RC 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 a 10-year period.

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 RC 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[1] 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 freshwater management units (FMUs), as described in Snelder and Fraser (2016).

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

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

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:[2]

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

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

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

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[1] 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.

[2] N.B. For this analysis, we assume there are no irrigated land uses

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

$$L_{r,s,l} \leq L_{r,s,l}^{init} + Z_{r,s,l} \tag{5}$$

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:

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

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:

$$L_{r,s,fixed} = L_{r,s,fixed}^{init} \tag{7}$$

The model also includes a constraint on changes to enterprise area (E), if desired[3]:

$$E_{r,s,l,fixed} = E_{r,s,l,fixed}^{init} \tag{8}$$

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 focus on 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[4]:

$$\sum_{s,l,e,m} \gamma_{r,s,l,e,m}^{env} X_{r,s,l,e,m} \leq ENV_r \tag{9}$$

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:

$$Y, X, L \geq 0 \tag{10}$$

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.

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[3] N.B. The RC 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.

[4] 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.

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 policy 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 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, 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 employ the most cost-effective practices 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 & 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).

2.2 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 ha figures for the mitigation practices are discussed in Muirhead (2016). Estimates for other land uses not covered by the representative farms were specified by Jacobs (2016) with insight from other stakeholders participating in the RWCMP.

2.3 Sediment Modelling

Jacobs was contracted by GWRC to undertake an analysis of baseline erosion rates and sediment yields in the RC 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 RC 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 available in Jacobs (2016).

2.4 E.coli Modelling

Jacobs (2016) used the CLUES model to estimate baseline annual-average *E. coli* loads in the RC. 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 Ruamahanga. It is believed that attenuation rates throughout the flow network were also estimated as part of this work, and that estimates were broken out by land cover and point-sources, although Jacobs did not provide that information at the time of publication.

The REC1 sub-catchments are displayed in Figure 1. NZFARM has incorporated the *E. coli* estimates by intersecting the GIS layer of E.coli loads provided by Jacobs with the RC land use map (more below). It is envisioned that the figures will be updated in the catchment economic model after additional information on attenuation coefficients and yields by land use is supplied by Jacobs.

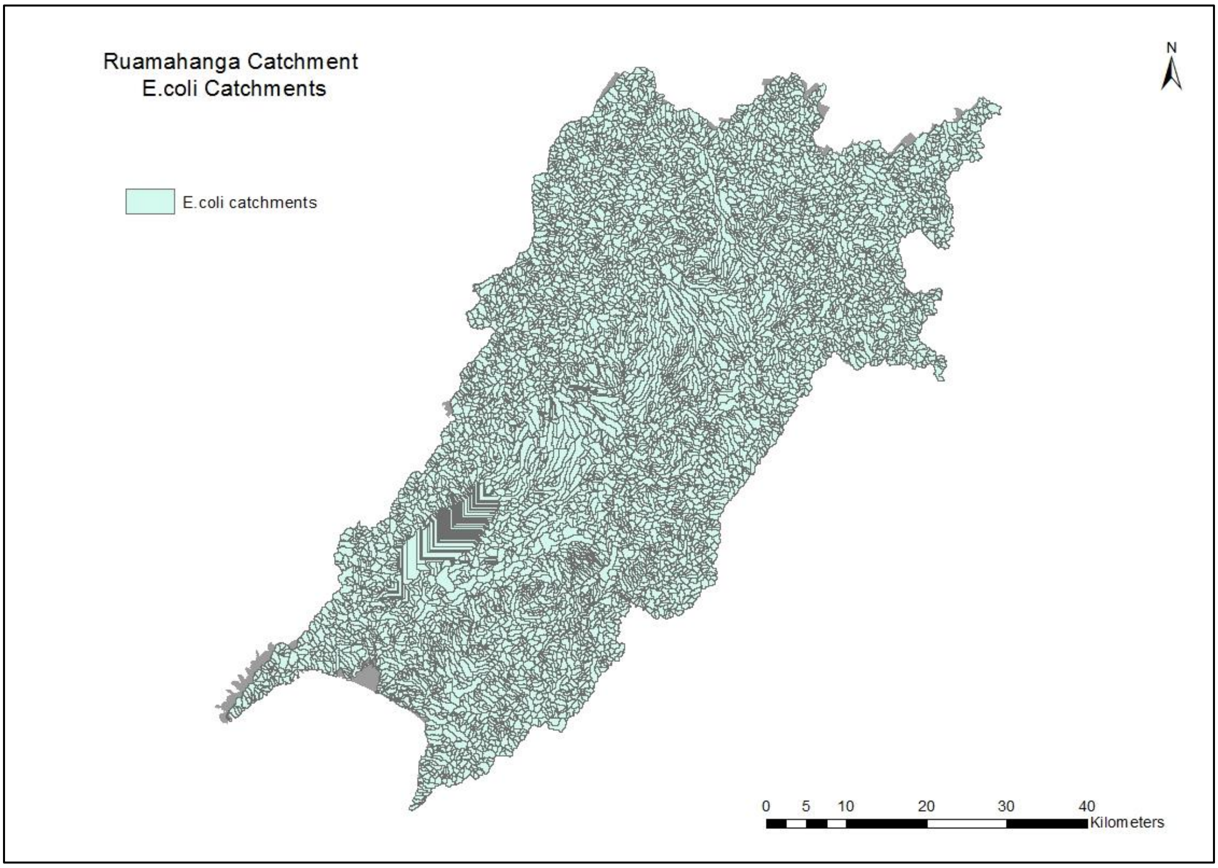

Figure 1: Ruamahanga REC2 sub-catchments.

2.5 Water quality attributes

This current version of the model only accounts for N, P, sediment, and *E.coli* loads but not attributes (e.g., *E.coli concentrations*) associated with these loads. It is envisioned that attributes at given nodes of interest will be included in the next stage of the model, once this information is provided by other participants in the RWCMP

2.6 Mitigation practices

MPI contracted AgResearch to model up to 3 set of mitigation bundles for each of the 16 representative farms (Muirhead et al 2016). The three bundles are grouped base on how easy (M1), medium (M2), and difficult (M3) 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, S&B, and dairy support farms are listed in Table 1 to 3.

Table 1: Potential Good Management Practices (GMPs) that could be applied to 16 MPI representative farms. The data indicates the key contaminants that the migitation 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) that the specific mitigation would be applied in.

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	L-H	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 & 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

2.7 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. sediment loads, *E. coli* loads, etc).

Table 2 lists the key variables and data requirements used to parameterise NZFARM, while Table 3 provides specific elements of the model. More details on the data and parameter assumptions used to populate the RC version of the model are provided below. All of the figures in the NZFARM are converted to per ha values and 2015 NZD so that they are consistent across sources and scenarios.

Table 2: Data sources for NZFARM's modelling of Whangarei Harbour 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
Land cover and enterprise mix	GIS data file(s) of current land use with the catchment Key enterprises (e.g., dairy).	Regional land use map broken out by key land uses	Provided by GWRC and Jacobs
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 (2016)	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 Ruamahanga 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*	N and P: Parminter & Grinter (2016) Sediment and *E. coli*: Jacobs (2016)	Data supplied by project partners

Table 3: List of key components of NZFARM Ruamahanga Catchment

Enterprise (E)	Mitigation Practice (M)	Soil/Rainfall (S)	Freshwater Management Units (R)	Environmental Indicators (ENV)
Dairy_FD_LRHP	None	BROWN_1050to1250mm	D_HS_Zone	N leaching
Dairy_FD_LRMP	M1	BROWN_1250to1650mm	D_SS_Zone	P loss
Dairy_FD_MR	M2	BROWN_1650to2050mm	MS_Zone	Sediment
Dairy_FD_HR	M3	BROWN_2050to2450mm	W_HS_Hill_Zone	*E.coli*
Dairy_Irrigated		BROWN_750to850mm	W_HS_Low_Zone	
Dairy_Organic		BROWN_850to1050mm	W_SS_Zone	
SNB_Finish_SD		BROWN_850to1250mm	None	
SNB_Breed_SW		BROWN_gt2450mm		
SNB_Finish_SW		GLEY_1050to1250mm		
SNB_Finish		GLEY_1250to1650mm		
SNB_Irrigated		GLEY_1650to2050mm		
SNB_trade_20crop		GLEY_2050to2450mm		
SNB_Breed_SD		GLEY_750to850mm		
SNB_Finish_65crop		GLEY_850to1050mm		
DairySupport_SD		GLEY_lt750mm		
DairySupport_SW		lake_1050to1250mm		
Deer_Farming		lake_1250to1650mm		
Forestry		lake_850to1050mm		
Horticulture		MELANIC_1050to1250mm		
Lifestyle		MELANIC_1250to1650mm		
Mixed (Arable)		MELANIC_750to850mm		
Native_Bush		MELANIC_850to1050mm		
Urban		None_None		
Utility		ORGANIC_1650to2050mm		
Equine		ORGANIC_750to850mm		
Viticulture		ORGANIC_850to1050mm		
		PALLIC_1050to1250mm		
		PALLIC_1250to1650mm		
		PALLIC_1650to2050mm		
		PALLIC_750to850mm		
		PALLIC_850to1050mm		
		PALLIC_lt750mm		
		RAW_1050to1250mm		
		RAW_1250to1650mm		
		RAW_1650to2050mm		
		RAW_2050to2450mm		
		RAW_750to850mm		
		RAW_850to1050mm		
		RAW_lt750mm		
		RECENT_1050to1250mm		
		RECENT_1250to1650mm		
		RECENT_1650to2050mm		
		RECENT_2050to2450mm		
		RECENT_750to850mm		
		RECENT_850to1050mm		
		RECENT_gt2450mm		
		RECENT_lt750mm		
		river_1050to1250mm		
		river_1250to1650mm		
		river_1650to2050mm		
		river_850to1050mm		
		town_1050to1250mm		
		town_1250to1650mm		
		town_850to1050mm		
		ULTIC_1050to1250mm		
		ULTIC_1250to1650mm		

2.7.1 Freshwater management units

Draft freshwater management units (FMUs) were specified by Snelder and Fraser (2016). For this version of the catchment economic model, we used the six 'management zone' delineation (). Alternative delineations may be used in a future update, including the possibility of having different zones for water quality and water quantity-based scenarios, per discussion with the RWC and other researchers in the RWCMP.

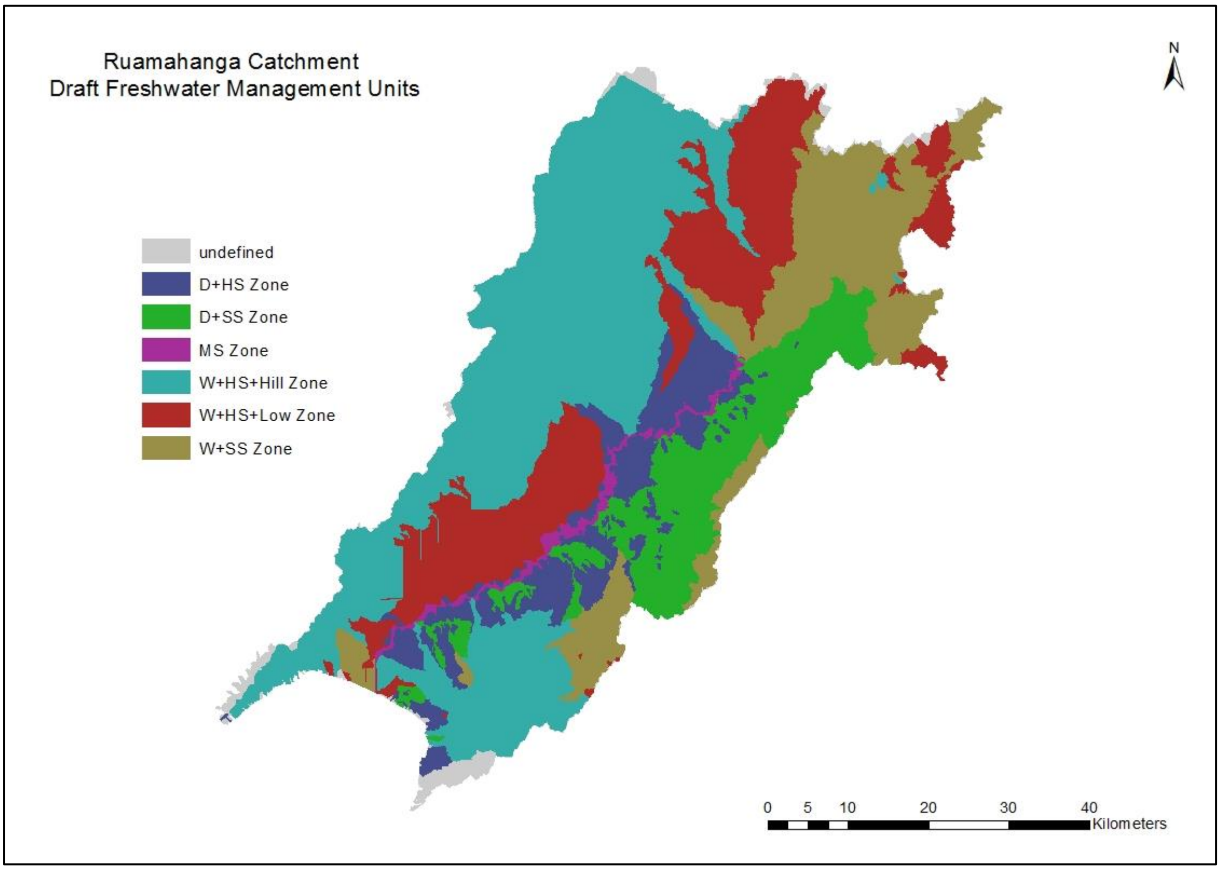

Figure 2: Ruamāhanga Catchment FMUs

2.7.2 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 Consulting (Fig. 4). The catchment is approximately 358 000 ha in size, and key land uses include sheep & beef (45%), native (25%), dairy (10%), and mixed cropping (5%). Note that because only 60% of the total catchment area is covered by the 16 representative farm types, the remain-based mitigation options explored in this study may not have a large effect compared to other rural catchment studies that included mitigation options for other land uses as well. This is the case for the RC, where 50% of sediment are estimated to come from land uses not covered under the representative farm mitigation bundles (more below).

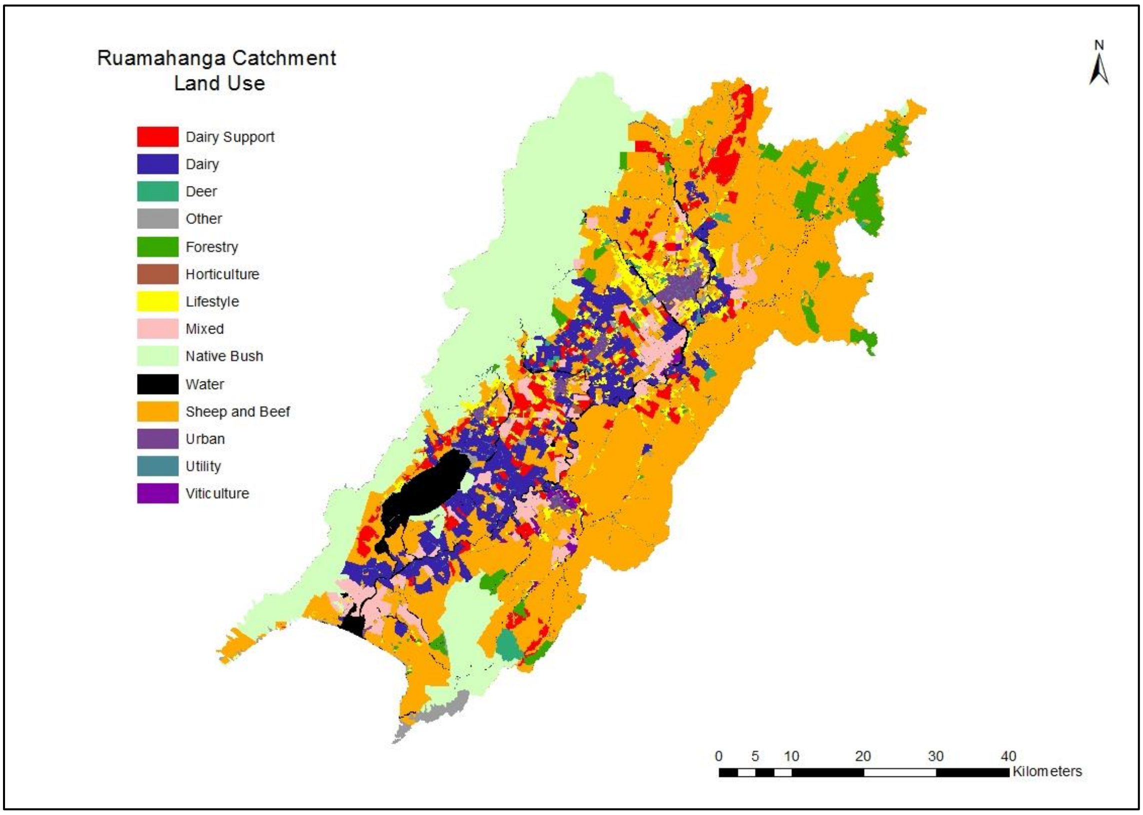

Figure 3: Ruamāhanga Catchment land use based on map from GWRC.

The map provided by GWRC did distinguish between some sheep and beef systems, but it did not break out dairy or dairy support to any degree. Parminter and Grinter (2016), however, estimated farm and nutrient budgets for 6 dairy, 8 S&B, and 2 dairy support systems, which then had to be assigned to the land use map by Jacobs. As a result, NZFARM was also parameterised based on this characterisation. The name and description of each of the 16 MPI representative farm categories are listed in Table 4, while the spatial distribution is shown in Figure 4.

Table 4: Details of representative farm types in Parminter and Grinter (2016)

Scenario	*MPI Scenario*	*NZFARM Name*
4.1 Dry flat dairy (low rainfall and high prod)	1b	Dairy_FD_LRHP
4.2 Dry flat dairy (low rainfall and mod prod)	1b2	Dairy_FD_LRMP
4.3 Dry flat dairy (moderate rainfall)	1a	Dairy_FD_MR
4.4 Dry flat dairy (high rainfall)	3	Dairy_FD_HR
4.5 Irrigated flat dairy	2	Dairy_Irrigated
4.6 Organic dairy	4	Dairy_Organic
4.7 Sheep and beef finishing, summer dry	5	SNB_Finish_SD
4.8 Sheep and beef breeding, summer wet	6a	SNB_Breed_SW
4.9 Sheep and beef finishing, summer wet	6b	SNB_Finish_SW
4.10 Sheep and bull finishing	7	SNB_Finish
4.11 Irrigated sheep and beef trading	8a	SNB_Irrigated

4.12 Lamb and bull trading, 20% cropping	8b	SNB_trade_20crop
4.13 Sheep and beef breeding, summer dry	9	SNB_Breed_SD
4.14 Finishing beef, 65% cropping	10	SNB_Finish_65crop
4.15 Dairy support, 15% cropping, summer dry	11b	DairySupport_SD
4.16 Dairy support, 48% cropping, summer wet	11a	DairySupport_SW

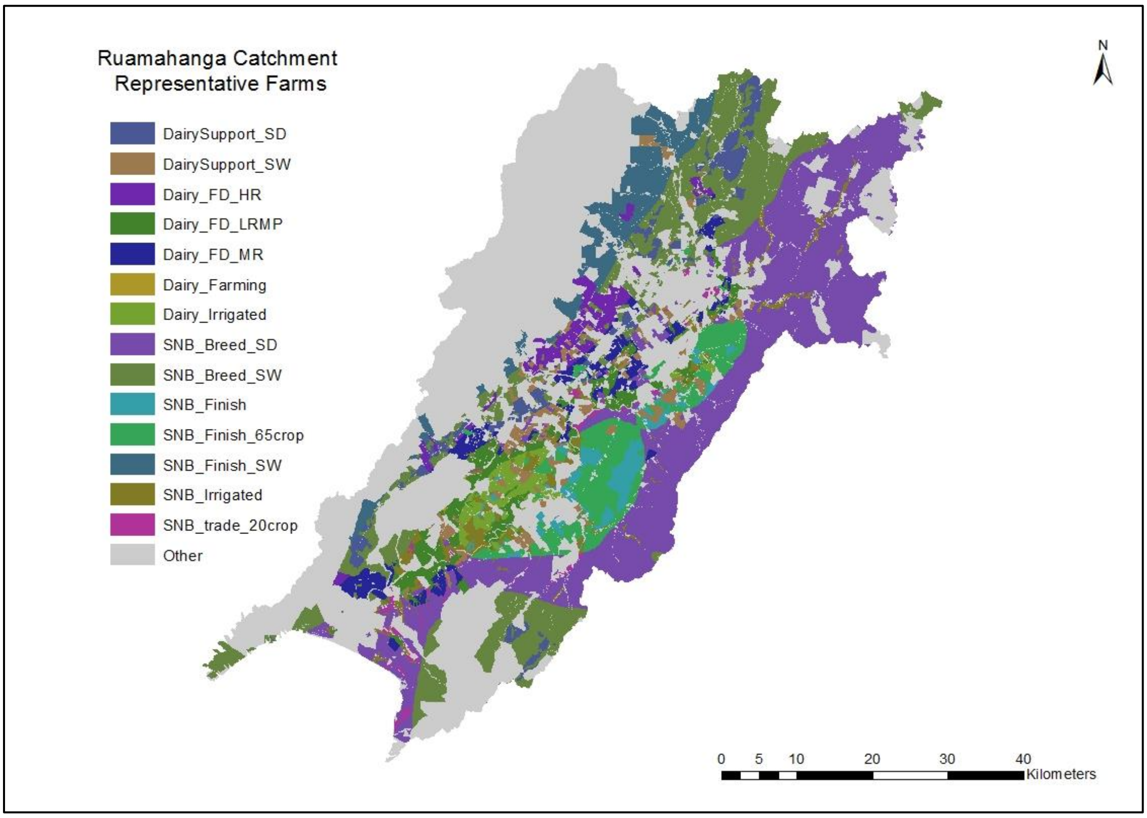

Figure 4: Spatial distribution of MPI representative farms in Ruamahanga catchment

2.7.3 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 are 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 constructing wetlands (more below). The figures have been verified with agricultural consultants and enterprise experts, and documented in Daigneault et al. (2016). In addition, the RC-level figures have been shared with members of the RWC and agricultural consultants working in the catchment.

The distribution of net farm revenue across the catchment is shown in Figure 5. S&B farming is estimated to produce the greatest proportion of net farm revenue in the catchment (36%), followed by dairy (33%), mixed arable (14%), horticulture (7%), and dairy support (7%).

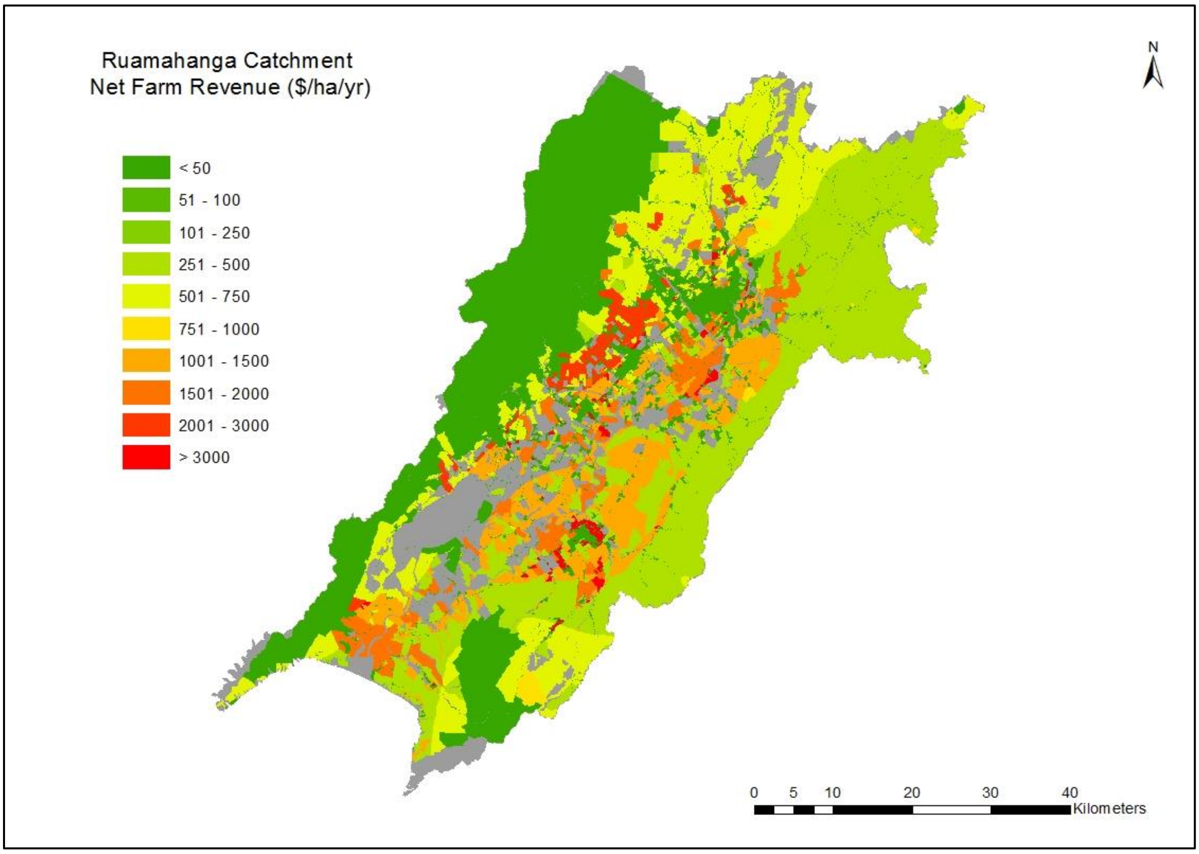

Figure 5: Baseline net farm revenue ($/ha/yr).

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 RC version of the model is currently focused on the impacts of management change within the current land use as opposed to land use change.[5] 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 NPS-FM[6] (e.g. nutrients reduction targets in Daigneault et al. 2013).

2.7.4 Nodes of Importance

GWRC did not provide any specifics on specific areas or sites that have been classified as nodes of importance. These sites are typically chosen because they are located near environmental monitoring stations and/or popular recreation sites. It is envisioned that the next iteration of the catchment economic model will include some of these nodes.

[5] N.B. We do have an afforestation scenarios to assess the possible lower bound of N, P, sediment and *E.coli* loads that could occur in the catchment. All the other scenarios assume no land use change.

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

2.7.5 N leaching and P Loss

Baseline N leaching and P loss by land use were estimated by Parminter and Grinter (2016) and Jacobs (2016). A total of 5,285 tN/yr of N are estimated to come primarily from S&B (39%), dairy (20%), and dairy support (18%). Total P loss is estimated to be 209 tP/yr, of which the major land use contributors are S&B (65%), dairy (16%), and dairy support (7%). All of the other land uses produce less than 6% of the total N and P loads in the catchment.

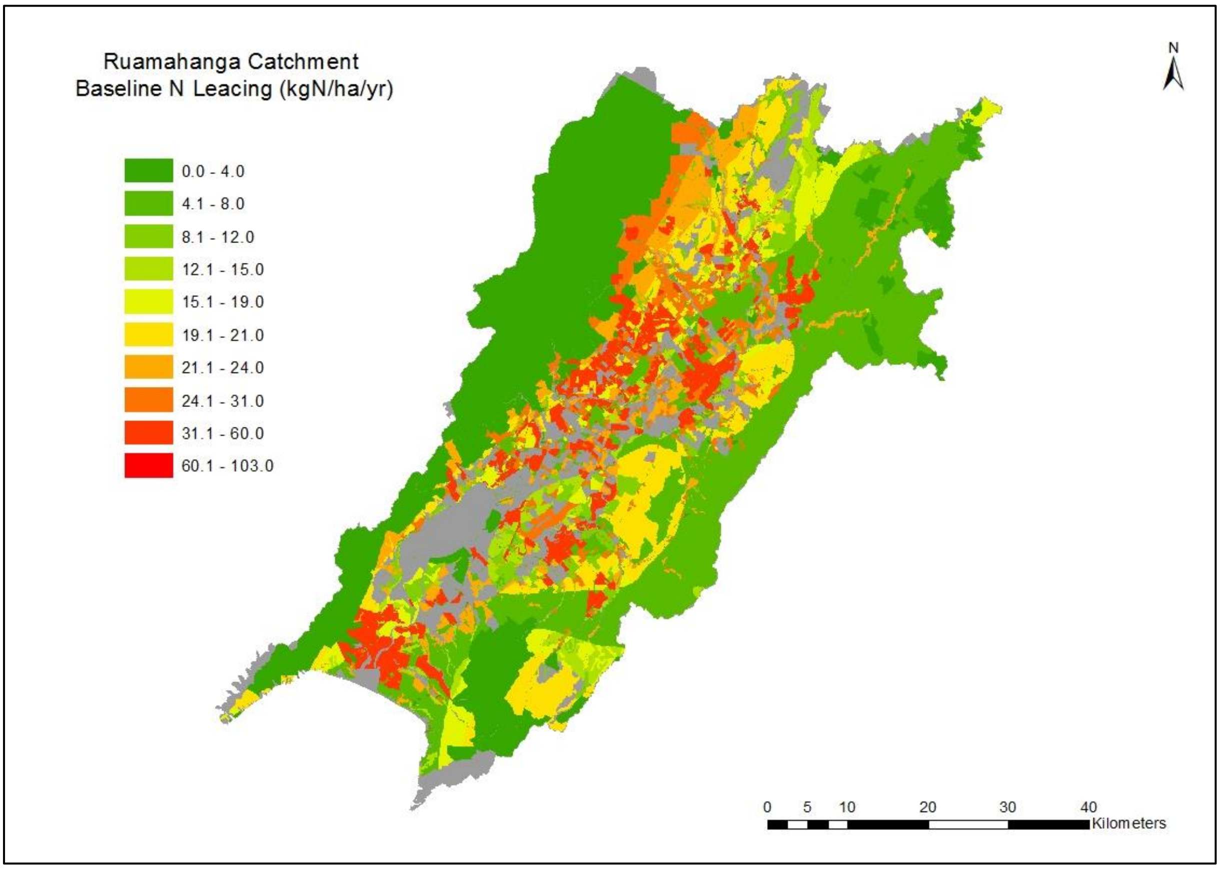

Figure 6: Baseline nitrogen loads in the Ruamahanga Catchment.

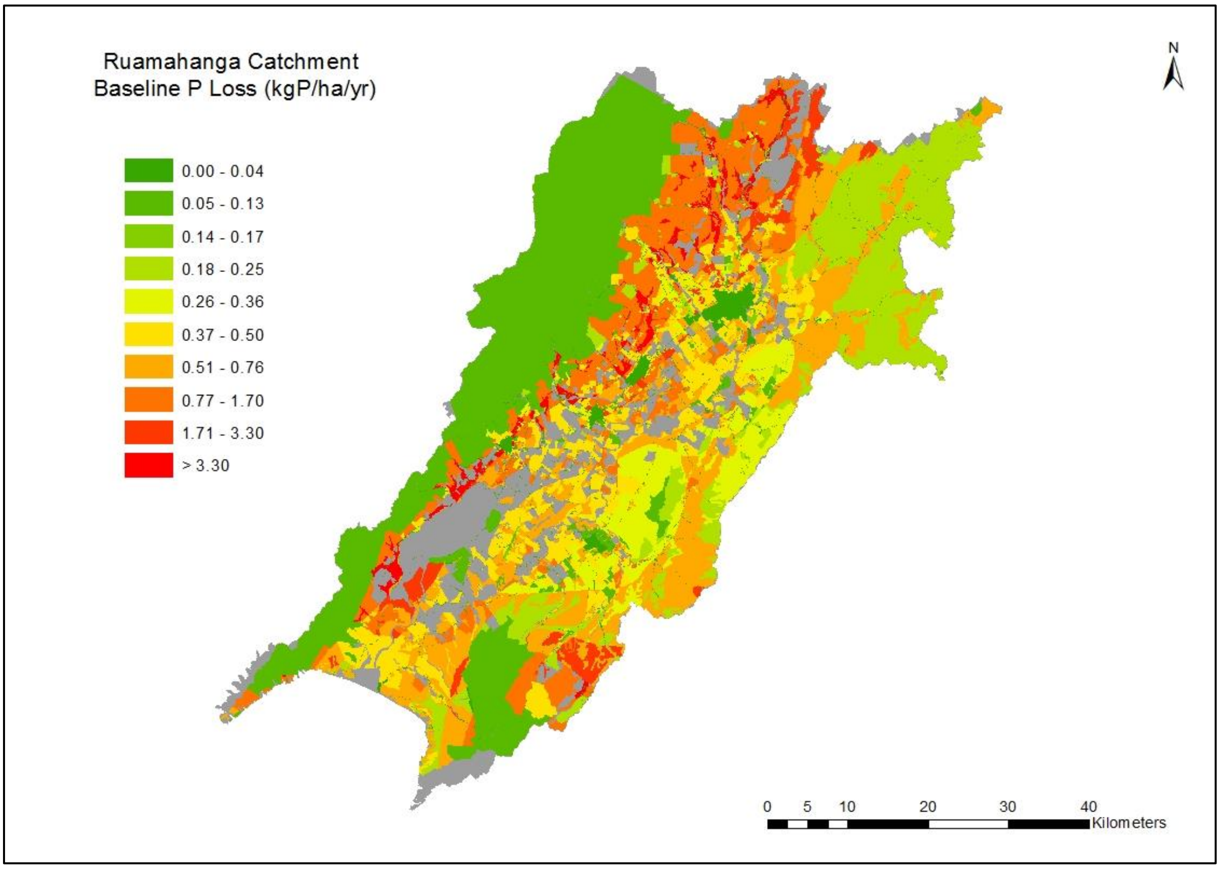

Figure 7: Baseline phosphorus loss in the Ruamahanga Catchment.

2.7.6 Sediment Loads

Sediment load estimates were provided as a raster GIS layer by Jacobs (2016) using the SedNetNZ model. The land use contributions to sediment are estimated for hill, landmass and streambank erosion. The sum of erosion processes are then aggregated to estimate total erosion for each NZFARM combination of land-use/soil/rainfall/FMU, so that aggregated loads are consistent with the resolution of the other contaminant load modelling.

It is estimated that the total load in the catchment is more than 813 000 tonnes of sediment per year. (Figure 8). A bulk of the sediment is estimated to come from sheep and beef (47%), native land (45%), and pine plantations (3%). A large amount of sediment comes from forested areas because they are generally located on less productive areas with steeper slopes relative to the rest of the catchment[7]. Note that if any of the forested area were converted to pasture, the level of erosion could increase by up to a factor of 10 (Dymond et al. 2010).

[7] This findings has implications for sediment mitigation, as only 50% of total sediment is accounted for in the 16 representative farm types

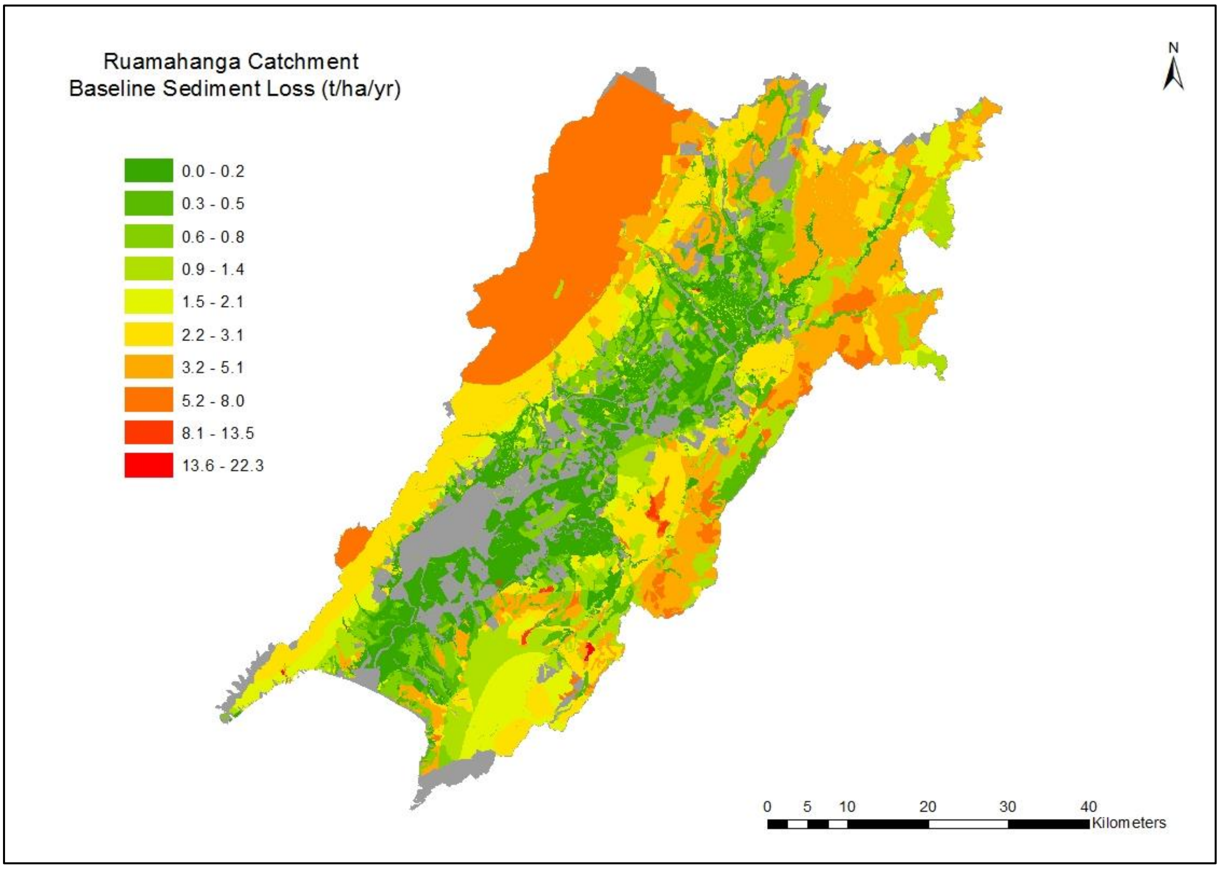

Figure 8: Total sediment load in the Ruamahanga Catchment.

2.7.7 *E. coli* Loads

E. coli loads for the RC are estimated by Jacobs (2016) using the CLUES model version 10.3 (Elliott et al. 2005; Semadeni-Davies et al. 2011). The loads were calculated for catchments defined according to the REC1 sub-catchment classification. There were more than 7,000 of these sub-catchments within the RC.

The CLUES model determines mean annual loads of *E. coli* (Fig. 9). The catchment of interest is broken into REC1 sub-catchments, and each sub-catchment has a number of land uses with associated yields, which are modified according to environmental factors such as rainfall. These sources are accumulated and attenuated down the stream network, with the addition of point source loadings[8]. This gives estimated loads (measured in peta *E. coli*/yr) for each REC1 sub-catchment.

It is estimated that the total load in the catchment is more than 134 peta *E.coli* per year.. A majority of the *E.coli* is estimated to come from sheep and beef (55%), followed by dairy (21%), and dairy support (7%). All other land uses tracked in the model contribute less than 5% of the total load in the catchment.

[8] N.B. these attenuation rates were not supplied by Jacobs at the time of this report

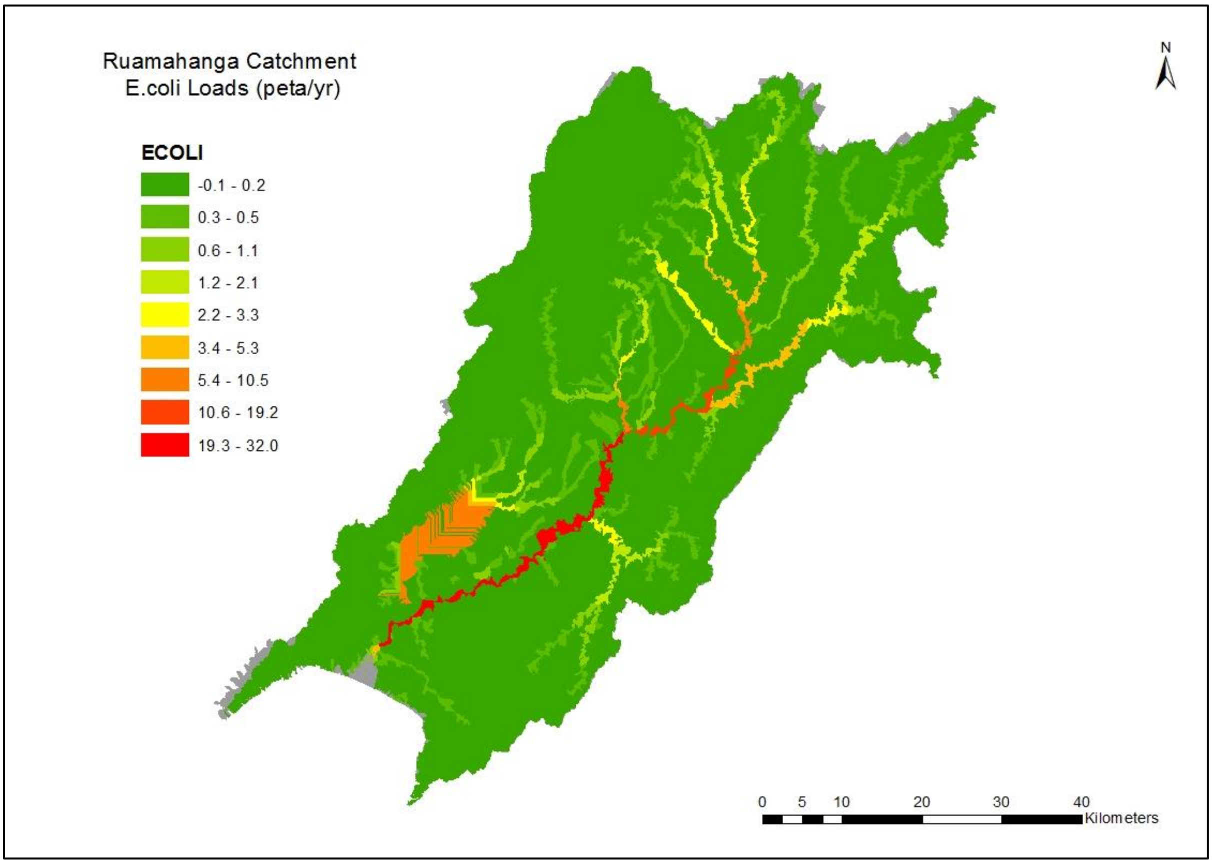

Figure 9: CLUES estimates of annual ***E. coli*** loads (peta ***E. coli***) for Ruamāhanga catchment.

2.7.8 Mitigation Costs and Effectiveness

Assumptions about mitigation costs and effectiveness in reducing N, P, sediment and *E. coli* loads were estimated by AgResearch (Muirhead et al 2016). The costs were broken out 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 5. Note that they only apply to the 16 dairy, sheep & beef, and dairy support representative farm scenarios developed for MPI by Parminter and Grinter (2016). A future update to the model may include mitigation from other land uses such as horticulture, forestry, or urban and point sources

The 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 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.

More details are provided in the Muirhead et al (2016) report.

Table 5: Ruamāhanga catchment mitigation cost and effectiveness assumptions for MPI representative farms

Mitigation Bundle	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
		MPI Representative Farm Scenario															
M1	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%
M2	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%
M3	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%

3 Baseline

NZFARM must establish a baseline for the RC before conducting any scenario analysis. Here we specify that the distribution of enterprise area in the model match the land use map. The baseline also assumes no N, P, sediment or *E. coli* mitigation bundles or policies have been implemented. Thus, the model's aggregate reduction results may be an overestimate of the actual reduction that could occur under the different model scenarios.

A summary of the key economic and environmental outputs for the aggregate land use categories tracked in the model is listed in Table 6. Results that are broken out by the 16 representative farms are included in the Appendix. Total net farm income from land-based operations with the current land use mix is estimated at $200.4 million/yr or $558/ha for all land and $842/ha for land that is currently earning revenue from farming and forestry. Total N and P are 5,285 and 209 t/yr respectively. The total sediment load is about 813,000 tonnes, of which more than 50% comes from not pastoral land uses. The total stream *E. coli* loads are estimated to be 134.7 peta *E. coli*/yr, of which 82% is accounted for in the 16 representative farm types.

Table 6: Total baseline area, farm earnings, and environmental outputs by aggregated land use

Aggregate Land Use	*Area (ha)*	*Net Farm Revenue ($)*	*N leaching (tN)*	*P loss (tP)*	*Sediment (kt)*	*E.coli (peta)*
Dairy	35,739	$66,499,471	1,045	33.5	9.7	27.8
Dairy Support	14,880	$13,066,002	965	15.5	16.4	8.9
Sheep & Beef	154,276	$72,496,361	2,045	136.2	378.2	74.2
Other Pasture	2,750	$2,354,401	52	1.2	4.9	1.2
Forestry	11,306	$5,174,823	34	2.3	23.0	2.6
Mixed (Arable)	16,742	$27,623,821	653	6.7	7.2	4.4
Horticulture	2,352	$13,202,910	20	0.2	0.1	0.9
Native Bush	85,843	$0	86	8.6	365.4	4.4
Lifestyle	12,207	$0	330	5.1	4.0	7.3
Other	22,898	$0	56	0.0	4.5	3.0
Ruamahanga Total	358,993	$200,417,788	5285	209.4	813.3	134.7

The per hectare baseline estimates for each aggregate land use is listed in Table 7. These figures indicate that there is a wide distribution in per ha values across the various land uses, as expected. Table A2 in the appendix also shows 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 farms is likely to lead to a wide range of reductions.

Table 7: Per hectare farm earnings, and environmental outputs by aggregated land use

Aggregate Land Use	*Net Farm Revenue ($)*	*N leaching (kgN)*	*P loss (kgP)*	*Sediment (t)*	*E.coli (tera)*
Dairy	$1,861	29	0.9	0.3	0.8
Dairy Support	$878	65	1.0	1.1	0.6
Sheep & Beef	$470	13	0.9	2.5	0.5
Other Pasture	$856	19	0.4	1.8	0.4
Forestry	$458	3	0.2	2.0	0.2
Mixed (Arable)	$1,650	39	0.4	0.4	0.3
Horticulture	$5,614	8	0.1	0.0	0.4
Native Bush	$0	1	0.1	4.3	0.1
Lifestyle	$0	27	0.4	0.3	0.6
Other	$0	2	0.0	0.2	0.1
Ruamahanga Total	$558	15	0.6	2.3	0.4

4 Scenario Analysis

Landcare Research, has specified 6 'test' mitigation scenarios to illustrate the utility of the catchment economic model (Table 8). These include (1) practice-based (management action) approaches such as fencing streams for stock exclusion, and (2) target-based (environmental outcome) approaches that focus on the impacts of collectively reducing all four contaminants at the catchment of FMU-level. In addition, we include an extreme scenario where all non-forested land in the catchment is converted to pine plantations to estimate the minimum loads possible in the RC.

The management action scenarios investigate the maximum amount of reductions that could be achieved when implementing certain mitigation options. The environmental outcome scenarios investigate the impact of setting a specific reduction target but then allowing landowners to collectively select the set of mitigation options that will meet the target.

The key results reported for each policy scenario include total annual cost, and change in net farm revenue and contaminant loads. The estimates in this section compare the 'no policy' baseline to the policy scenario after it has been fully implemented.[9] Spatial impacts are shown in the Appendix (Figures A1 – A10)

[9] For this analysis, we assume that the policy is fully implemented over a relatively long timeframe of 10 years or more to allow landowners adequate time to adopt new mitigation practices

Table 8: Ruamāhanga catchment economic model scenarios

Scenario Name	Description	N Leach Target	P Loss Target	Sediment Target	*E. coli* Target
	Management Actions				
All Farms M1	All dairy, sheep & beef, and dairy support farms implement M1 mitigation bundle	n/a	n/a	n/a	n/a
All Farms M2	All dairy, sheep & beef, and dairy support farms implement M2 mitigation bundle	n/a	n/a	n/a	n/a
All Farms M3	All dairy, sheep & beef, and dairy support farms implement M3 mitigation bundle	n/a	n/a	n/a	n/a
	Minimum Feasible Loads				
Convert All to Forest	Afforestation of all non-forest land in the catchment to estimate the minimum loads possible	n/a	n/a	n/a	n/a
	Environmental Outcomes				
10% catchment	10% reduction in N, P, and sediment for entire Ruamahanga catchment	10%	10%	10%	0%
10% FMU	10% reduction in N, P, and sediment for each FMU in the Ruamahanga catchment	10%	10%	10%	0%

The total estimated impacts for the entire RC are listed in Table 9. The table indicates that the impacts vary widely across scenarios. More insight on each scenario is provided below.

Table 9: Key model 'test' scenario estimates, Ruamāhanga catchment

Scenario	Total Annual Cost ($/yr)	Net Revenue ($)	N Leach (t)	P Loss (t)	Sediment (kt)	E.coli (peta)
Baseline	$0	$200,679,150	5,285	209	814	134.7
		% Change from no mitigation baseline				
All Farms M1	$583,436	0%	0%	0%	0%	-4%
All Farms M2	$18,270,930	-9%	-10%	-7%	-9%	-4%
All Farms M3	$27,926,712	-14%	-10%	-48%	-25%	-4%
Convert All to Forest	$108,954,857	-54%	-82%	-82%	-41%	-84%
10% catchment	$12,193,487	-6%	-10%	-15%	-10%	-3.7%
10% FMU	$15,713,580	-8%	-10%	-28%	-10%	-3.0%

In considering each mitigation bundle on its own, the M1 bundle is relatively costless, but also has a minimal effect on contaminant loads in the catchment. According to the model, it leads to less than 1% reduction in N, P, and sediment and reduces E.coli by about 3.7% below the baseline. This is because the effectiveness estimated by Muirhead et al (2016). Implementing M2 on all eligible farms reduces N, P, and sediment loads by almost 10% percent below the baseline. If all the representative farms implemented M3-level mitigation, the most stringent set of management options, then N would be reduced by 10%, P by 48%, sediment by 25% and E.coli by 4%. This of course, would come at a cost to pastoral farmers in the catchment of about $28M per annum or about $137/ha/yr. These figures signal that the degree of mitigation currently included in the model may not be large enough to meet Whaitua Committee aspirations, particularly for N and *E.coli*-based attributes.

A less realistic but useful scenario is to estimate the impact of afforesting all productive land with pine plantations. In this case, sediment could be reduced by 40% while, N, P, and E.coli could be reduced by up to 80%. These are likely to be the maximum reductions achievable in the Ruamahanga catchment, although at a potential cost of $109M/yr, it is not likely that a massive afforestation programme would be considered a feasible option.

In the event that the policy focuses on outcome-based scenarios rather than practice-based ones, we estimate that a catchment-wide 10% reduction in N, P, and sediment would be achievable through a mix of M1-M3 mitigation being implemented on different farms at a cost of $12M/yr. If the reduction targets were imposed on each of the 6 draft FMUs rather than the catchment as a whole, then the total cost would be about $16M/yr. Note that in both cases, the reduction target for P is over-achieved because types of mitigation being applied results in a greater reduction of that contaminant than required.

The distribution of mitigation practices is quite varied (Figure 10). For the practice-based scenarios, the mitigation is prescribed. For the outcome-based scenarios, mitigation is selected within NZFARM to achieve the specified target at least total aggregate cost to the catchment. As a result, landowners implement a mix M2 and M3 for the scenarios that focus reducing N, P, and sediment by 10% below baseline levels. Note that when targets are set at the FMU-level, more landowners have to implement the most costly M3 bundle. This makes sense because targets have to be met in 6 different FMUs as opposed to a single catchment and hence it’s likely that more costly (and effective) mitigation will have to be implemented, particularly in specific FMUs within the catchment due to the nature of the current land use operating there.

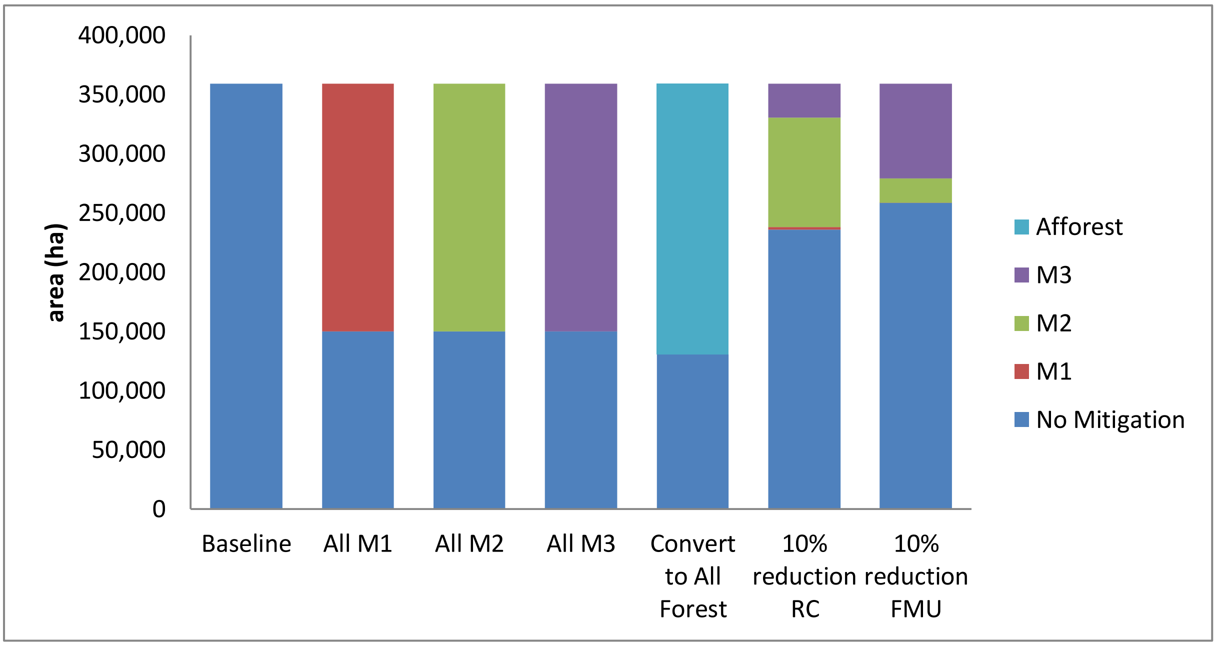

Figure 10: Area (ha) of implemented mitigation option by scenario.

The total costs for the non-afforestation scenarios range from $20,000/yr for achieving the secondary contact target, to about $1.9 million/yr for implementing the maximum amount of mitigation on all land in the catchment (Figure 11). Sheep & beef farms face the largest total and per hectare costs for nearly all scenarios. This is to be expected as this enterprise comprises the largest area of productive land and pasture in the catchment, is often located on land with high erosion rates, and have the greatest length of streams running through them. Note that the total costs for scenarios that include fencing as a mitigation options may be overstated by as much as $107,000/yr as some dairy and sheep & beef farmers have already fenced some or all of their streams (see current fencing scenario).

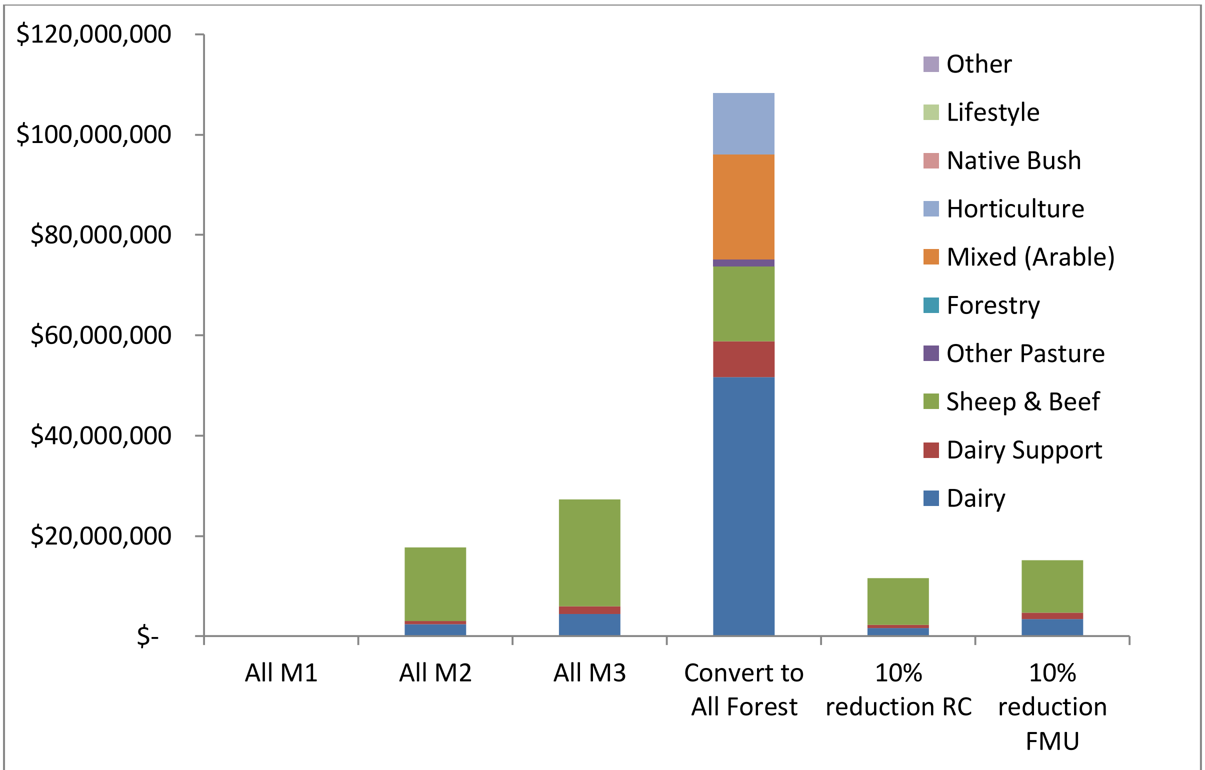

Figure 11: Total annual cost ($/yr), by land uses.

The mean annual mitigation costs figures for each scenario are broken out into per hectare values in Table 10. It is apparent from these figures that there is a wide distribution of impacts across both land use and scenario. Per hectare costs are generally higher for the scenarios that have a greater proportion of M3 implemented because they are the most costly, by definitoin. Many of the estimates from the outcome-based scenarios appear relatively cheaper than the practice-based scenarios because mitigation is not necessarily implemented on every parcel of land in the catchment.

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

Land Use	*All M1*	*All M2*	*All M3*	*Convert to All Forest*	*10% reduction RC*	*10% reduction FMU*
Dairy	$0	$69	$125	$1,444	$47	$96
Dairy Support	$0	$42	$97	$478	$42	$86
Sheep & Beef	$0	$95	$139	$97	$60	$67
Other Pasture	$0	$0	$0	$595	$0	$0
Forestry	$0	$0	$0	$0	$0	$0
Mixed (Arable)	$0	$0	$0	$1,250	$0	$0
Horticulture	$0	$0	$0	$5,214	$0	$0
Other	$0	$0	$0	$0	$0	$0
RC Total	$0	$50	$78	$309	$33	$43

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

5 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. The economic land use model should be used to provide insight on the relative impacts and trade-offs across a range of policy scenarios (e.g. practice v. outcome-based targets), rather than for explicitly modelling the absolute impacts of a single policy scenario, and thus 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 RC. Some of the modelling limitations from the current versoin 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 like SedNetNZ and CLUES, 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 RC 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 what 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 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. Assumption number three is likely to have the greatest impact on model estimates, as some farms in the catchment have already implemented practices that are included in M1-M3. 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 mitigation options that might be developed in the future as a result of incentives created under the policy. Although not all possible mitigation 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 M3 practices, thereby limiting the feasibility to achieve stringent reduction targets. In addition, as mitigation options were only estimated for the 16 MPI representative farms, adding mitigation practices 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 sediment and *E. coli* loads (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 select the 'optimal' combination of management practices required to achieve specific outcomes related to managing contaminants in the RC. This is assumed to occur over a period of at least 10 years, as landowners typically need adequate time to make significant changes to their operation. In reality, not all landowners will necessarily select the option that is considered most optimal, and thus the actual effectiveness of the policy may be overstated.

7. **Regional economic impacts** – NZFARM does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the scenarios investigated in this report could produce some change in regional employment and GDP due to reductions in farm outputs for taking land out of production (e.g. in the case of afforestation with native bush or constructing wetlands). There could also be social and cultural impacts. The estimates produced by NZFARM provide just a subset of possible metrics that could be used to determine the 'best' option to manage sediment and *E. coli* at the catchment-level.

We have also identified several specific limitations of the current version of the catchment economic model due the lack of information provided (or even available) by GWRC, RWC, and/or other participants of the RWCMP. These include:

- This version of the model only tracks contaminant loads. It does not yet relate these loads to attributes (e.g., E.coli concentration).
- There are currently no 'nodes of importance' tracked in the model (e.g, popular swimming sites).
- Attenuation rates not explicitly accounted for. That is, we know the per hectare load levels for each farm in the catchment, but we do not know how much of that load will flow downstream to key areas of the Ruamahanga catchment.
- The model has yet to include input from the hydrological models, as information was not made available at time of publication. We have discussed with the other modellers how to incorporate this into the next stage of the model.

It is anticipated that many if not all of these limitations will be addressed in the second stage of the catchment economic model development.

6 Acknowledgements

We would like thank the following for contributing to this report:

TO BE COMPLETED AFTER REVIEW

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Appendix 1 – Detailed Results

Table A1: Total baseline area, farm earnings, and environmental outputs by disaggregated land use

Land use	*Area(ha)*	*Net Farm Revenue($)*	*N leaching (tN)*	*P loss (tP)*	*Sediment (kt)*	*E.coli (peta)*
Dairy_FD_HR	6,391	$15,421,845	252	13	4	4.6
Dairy_FD_LRHP	10,399	$21,932,351	311	7	1	7.7
Dairy_FD_MR	5,600	$8,070,288	152	5	0	4.7
Dairy_Irrigated	7,976	$11,900,873	197	5	3	6.4
Dairy_Organic	5,371	$9,174,115	132	3	1	4.4
DairySupport_SD	5,976	$3,209,199	98	1	2	3.9
DairySupport_SW	8,904	$9,856,802	868	14	14	5.0
Deer_Farming	2,366	$2,354,401	50	1	5	0.9
Forestry	11,306	$5,174,823	34	2	23	2.6
Horticulture	732	$5,418,453	5	0	0	0.4
Lifestyle	12,207	$0	330	5	4	7.3
Mixed (Arable)	16,742	$27,623,821	653	7	7	4.4
Native_Bush	85,843	$0	86	9	365	4.4
SNB_Breed_SD	71,328	$24,608,307	558	30	205	33.4
SNB_Breed_SW	39,140	$22,975,254	682	60	84	13.9
SNB_Finish	12,888	$5,915,472	143	11	32	7.1
SNB_Finish_65crop	3,042	$3,303,252	72	1	5	1.7
SNB_Finish_SD	3,561	$2,289,636	66	2	7	2.3
SNB_Finish_SW	15,324	$7,999,326	361	27	43	10.3
SNB_Irrigated	7,203	$3,205,366	139	5	1	4.7
SNB_trade_20crop	1,790	$2,199,747	25	1	1	0.7
Urban	3,179	$0	22	0	0	0.3
Utility	4,825	$0	34	0	4	2.7
Equine	384	$0	3	0	0	0.2
Viticulture	1,620	$7,784,457	15	0	0	0.6
Other	14,894	$0	0	0	0	0.0
Ruamahanga Total	**358,993**	**$200,417,788**	**5,285**	**209**	**813**	**134.7**

Table A2: Per hectare farm earnings, and environmental outputs by disaggregated land use

Land use	*Net Farm Revenue($)*	*N leaching (kgN)*	*P loss (kgP)*	*Sediment (t)*	*E.coli (tera)*
Dairy_FD_HR	$2,413	40	2.1	0.7	0.7
Dairy_FD_LRHP	$2,109	30	0.6	0.1	0.7
Dairy_FD_MR	$1,441	27	1.0	0.1	0.8
Dairy_Irrigated	$1,492	25	0.7	0.4	0.8
Dairy_Organic	$1,708	25	0.5	0.2	0.8
DairySupport_SD	$537	16	0.2	0.4	0.6
DairySupport_SW	$1,107	97	1.6	1.6	0.6
Deer_Farming	$995	21	0.5	2.0	0.4
Forestry	$458	3	0.2	2.0	0.2
Horticulture	$7,406	7	0.1	0.0	0.5
Lifestyle	$0	27	0.4	0.3	0.6
Mixed (Arable)	$1,650	39	0.4	0.4	0.3
Native_Bush	$0	1	0.1	4.3	0.1
SNB_Breed_SD	$345	8	0.4	2.9	0.5
SNB_Breed_SW	$587	17	1.5	2.1	0.4
SNB_Finish	$459	11	0.8	2.5	0.6
SNB_Finish_65crop	$1,086	24	0.4	1.6	0.6
SNB_Finish_SD	$643	18	0.5	2.1	0.6
SNB_Finish_SW	$522	24	1.7	2.8	0.7
SNB_Irrigated	$445	19	0.7	0.1	0.7
SNB_trade_20crop	$1,229	14	0.4	0.7	0.4
Urban	$0	7	0.0	0.1	0.1
Utility	$0	7	0.0	0.9	0.5
Equine	$0	7	0.4	0.2	0.6
Viticulture	$4,805	9	0.1	0.0	0.4
Other	$0	0	0.0	0.0	0.0
Ruamahanga Total	**$558**	**15**	**0.6**	**2.3**	**0.4**

Table A3 Total cost ($/yr) of modelled 'test' scenarios by disaggregated land use

Land Use	*All M1*	*All M2*	*All M3*	*Convert to All Forest*	*10% reduction RC*	*10% reduction FMU*
Dairy_FD_HR	$0	$2,390,291	$3,131,662	$12,609,744	$1,596,391	$2,940,863
Dairy_FD_LRHP	$0	$0	$0	$17,772,588	$0	$0
Dairy_FD_MR	$0	$212,818	$800,867	$5,656,483	$211,735	$522,661
Dairy_Irrigated	$0	-$566,328	$0	$8,638,502	-$564,248	-$346,060
Dairy_Organic	$0	$424,330	$547,868	$6,945,042	$424,219	$321,961
DairySupport_SD	$0	$0	$0	$818,734	$0	$0
DairySupport_SW	$0	$623,285	$1,442,458	$6,295,177	$622,001	$1,284,421
Deer_Farming	$0	$0	$0	$1,407,908	$0	$0
Forestry	$0	$0	$0	$0	$0	$0
Horticulture	$0	$0	$0	$5,125,801	$0	$0
Lifestyle	$0	$0	$0	$0	$0	$0
Mixed	$0	$0	$0	$20,927,137	$0	$0
Native_Bush	$0	$0	$0	$0	$0	$0
SNB_Breed_SD	$0	$4,992,992	$7,703,466	$246,083	$799,210	$979,281
SNB_Breed_SW	$0	$3,953,154	$5,675,315	$7,319,207	$3,904,282	$3,296,348
SNB_Finish	$0	$1,855,836	$2,809,526	$760,377	$1,550,788	$2,059,568
SNB_Finish_65crop	$0	$1,128,460	$1,514,751	$2,086,587	$0	$1,366,081
SNB_Finish_SD	$0	$359,648	$573,299	$865,291	$359,648	$344,717
SNB_Finish_SW	$0	$1,563,087	$2,007,493	$1,869,575	$1,972,661	$1,614,962
SNB_Irrigated	$0	$590,652	$849,962	$324,138	$590,202	$566,822
SNB_trade_20crop	$0	$144,979	$263,110	$1,483,800	$144,979	$180,338
Viticulture	$0	$0	$0	$7,136,427	$0	$0
RC Total	**$0**	**$17,673,205**	**$27,319,777**	**$108,288,601**	**$11,611,869**	**$15,131,962**

Table A4 Per ha cost ($/ha/yr) of modelled 'test' scenarios by disaggregated land use

Land Use	*All M1*	*All M2*	*All M3*	*Convert to All Forest*	*10% reduction RC*	*10% reduction FMU*
Dairy_FD_HR	$0	$374	$490	$1,973	$250	$460
Dairy_FD_LRHP	$0	$0	$0	$1,709	$0	$0
Dairy_FD_MR	$0	$38	$143	$1,010	$38	$93
Dairy_Irrigated	$0	-$71	$0	$1,083	-$71	-$43
Dairy_Organic	$0	$79	$102	$1,293	$79	$60
DairySupport_SD	$0	$0	$0	$137	$0	$0
DairySupport_SW	$0	$70	$162	$707	$70	$144
Deer_Farming	$0	$0	$0	$595	$0	$0
Forestry	$0	$0	$0	$0	$0	$0
Horticulture	$0	$0	$0	$7,006	$0	$0
Lifestyle	$0	$0	$0	$0	$0	$0
Mixed	$0	$0	$0	$1,250	$0	$0
Native_Bush	$0	$0	$0	$0	$0	$0
SNB_Breed_SD	$0	$70	$108	$3	$11	$14
SNB_Breed_SW	$0	$101	$145	$187	$100	$84
SNB_Finish	$0	$144	$218	$59	$120	$160
SNB_Finish_65crop	$0	$371	$498	$686	$0	$449
SNB_Finish_SD	$0	$101	$161	$243	$101	$97
SNB_Finish_SW	$0	$102	$131	$122	$129	$105
SNB_Irrigated	$0	$82	$118	$45	$82	$79
SNB_trade_20crop	$0	$81	$147	$829	$81	$101
Viticulture	$0	$0	$0	$4,405	$0	$0
RC Total	**$0**	**$53**	**$81**	**$323**	**$35**	**$45**

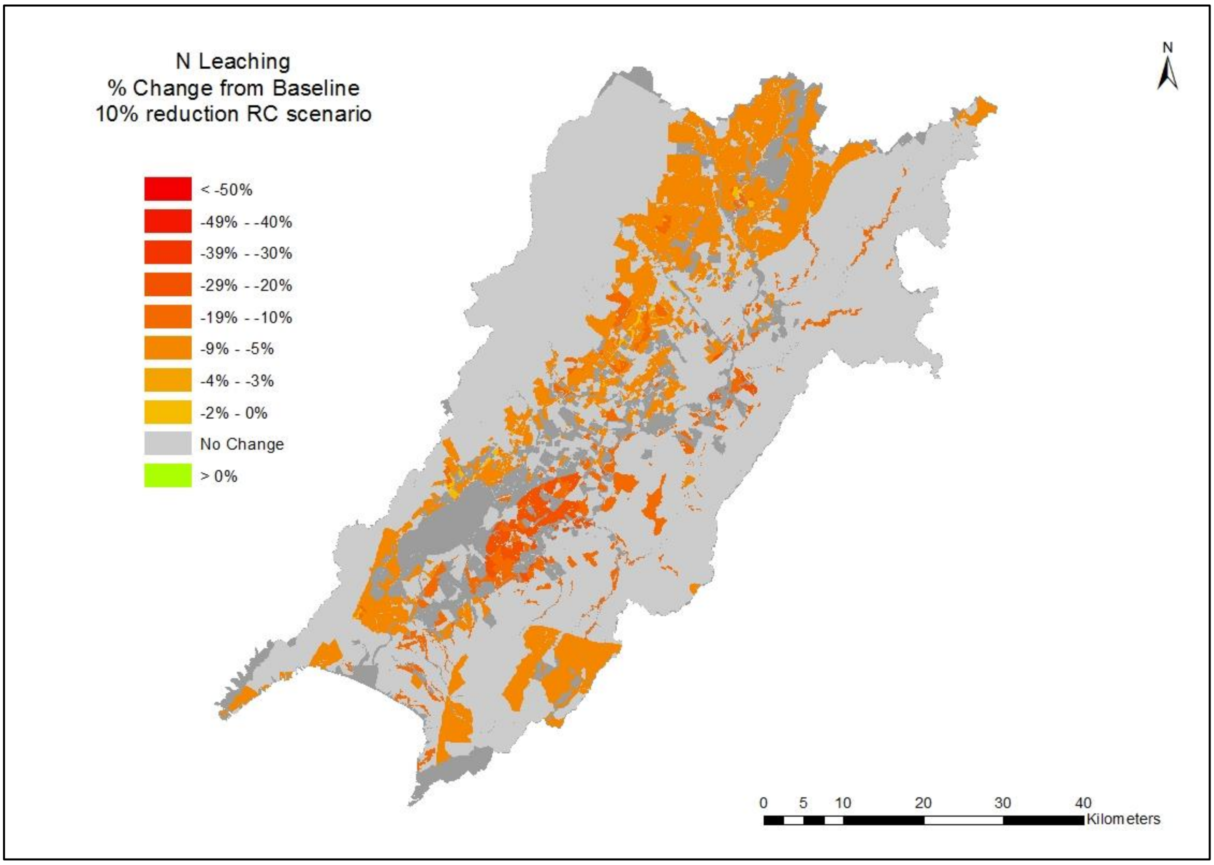
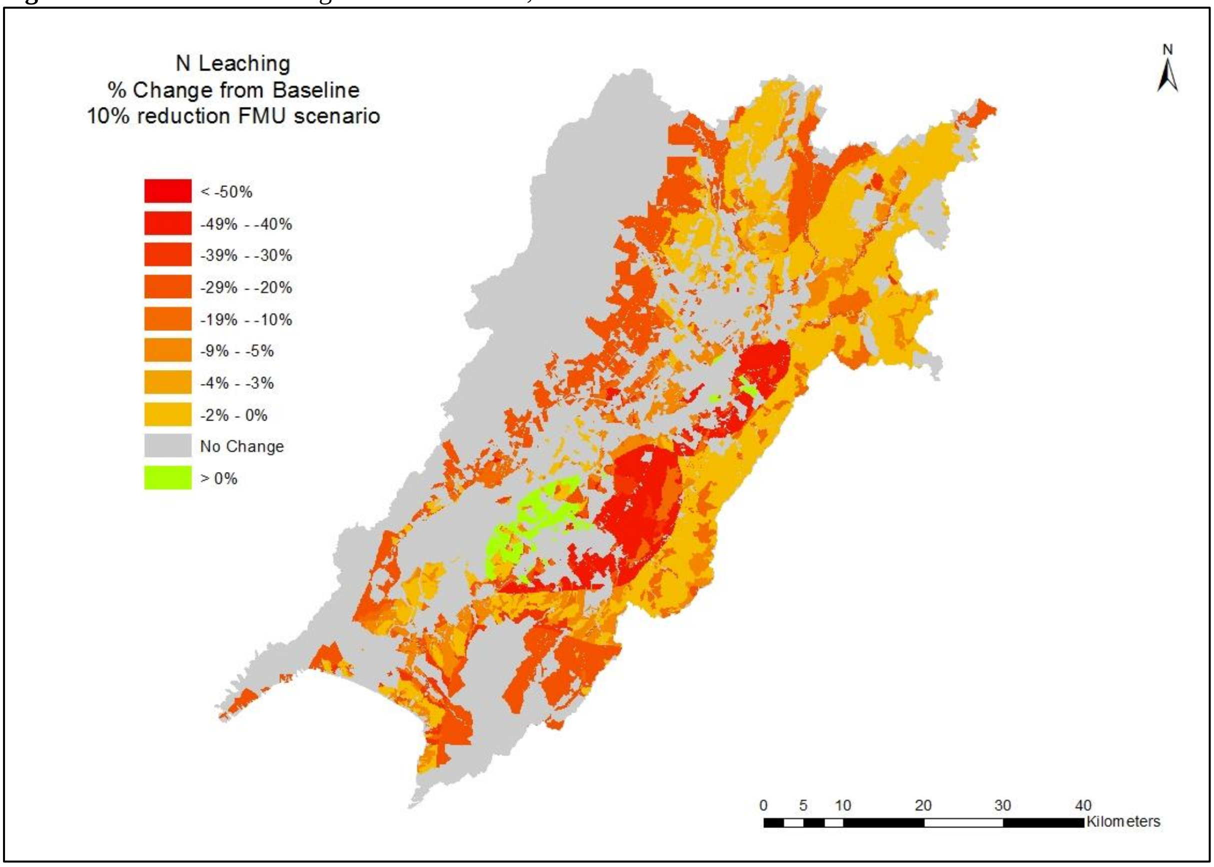


Figure A1: Net revenue change – 10% reduction, RC-wide scenario



FigureA2: Net revenue change – 10% reduction, FMU scenario

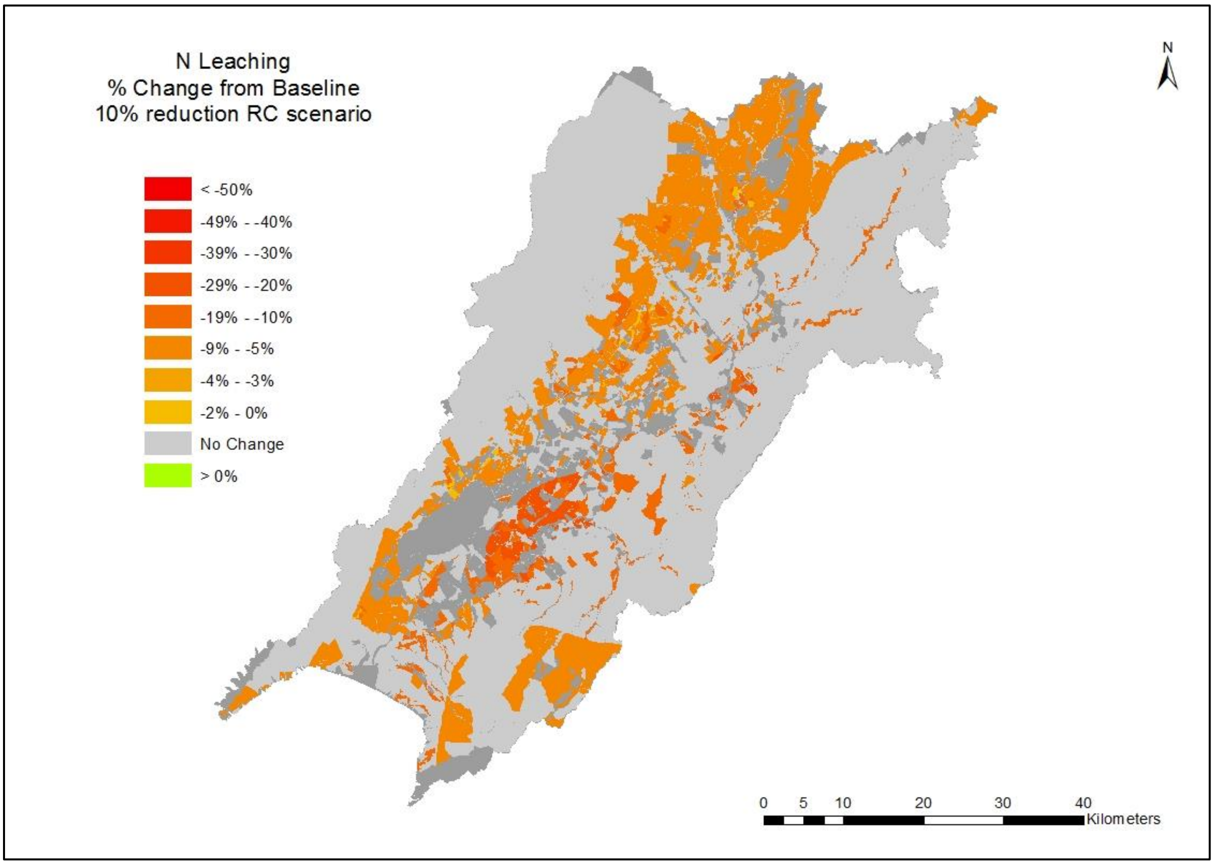


Figure A3: N leaching change – 10% reduction, RC-wide scenario

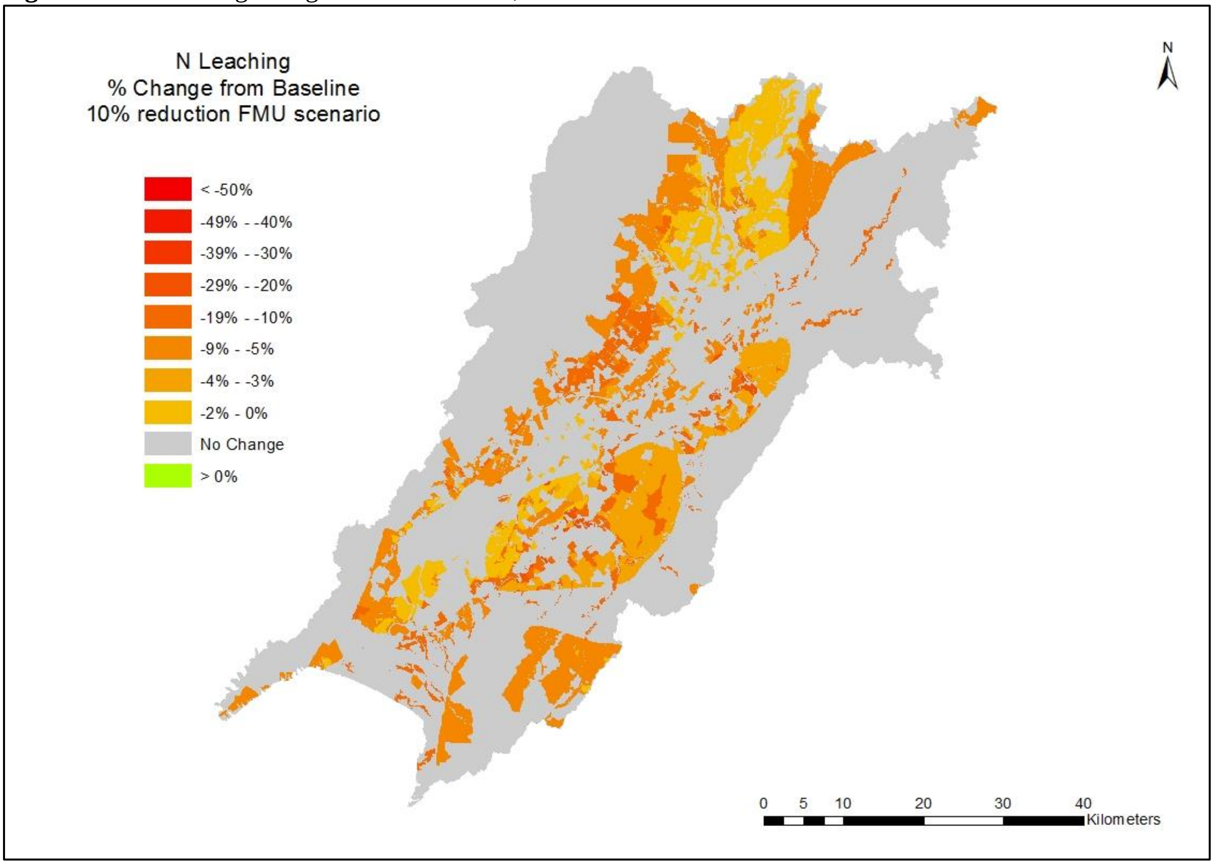


Figure A4: N leaching change – 10% reduction, FMU scenario

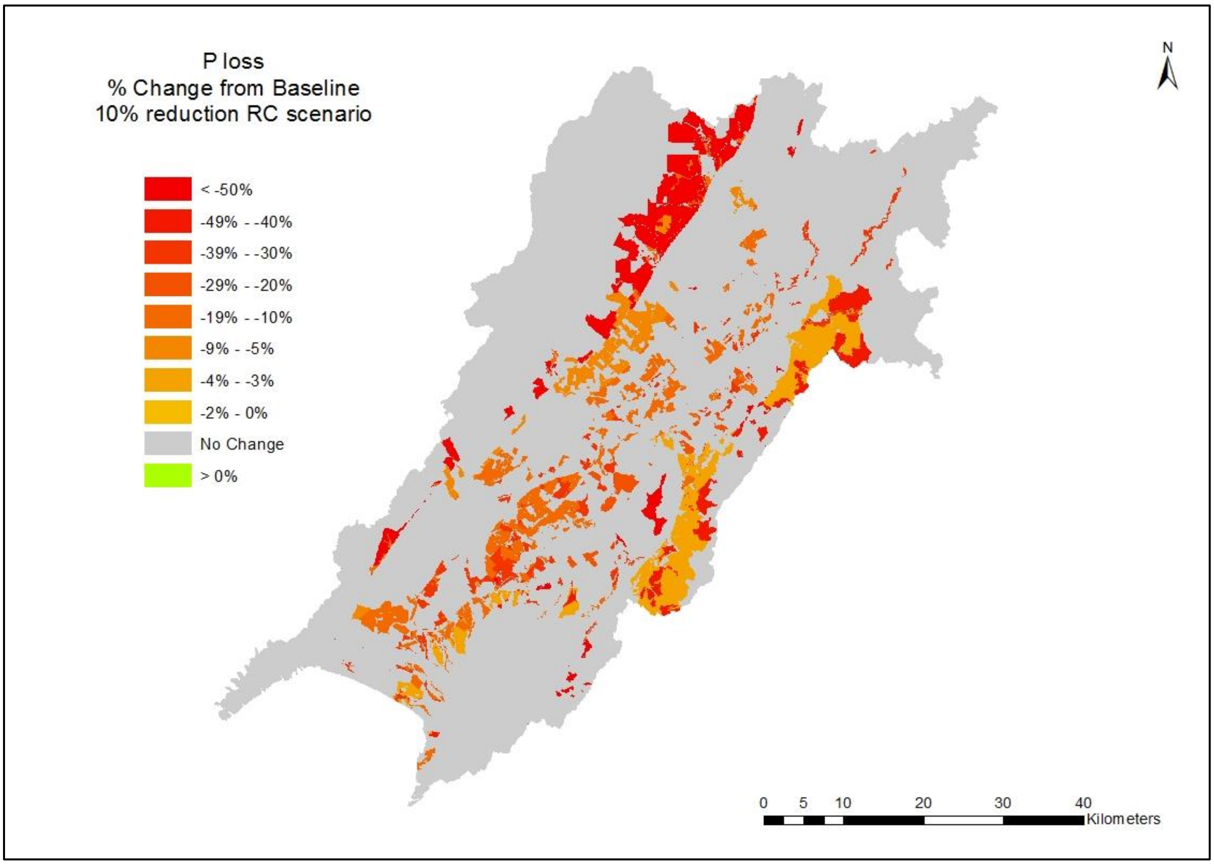


Figure A5: P loss change – 10% reduction, RC-wide scenario

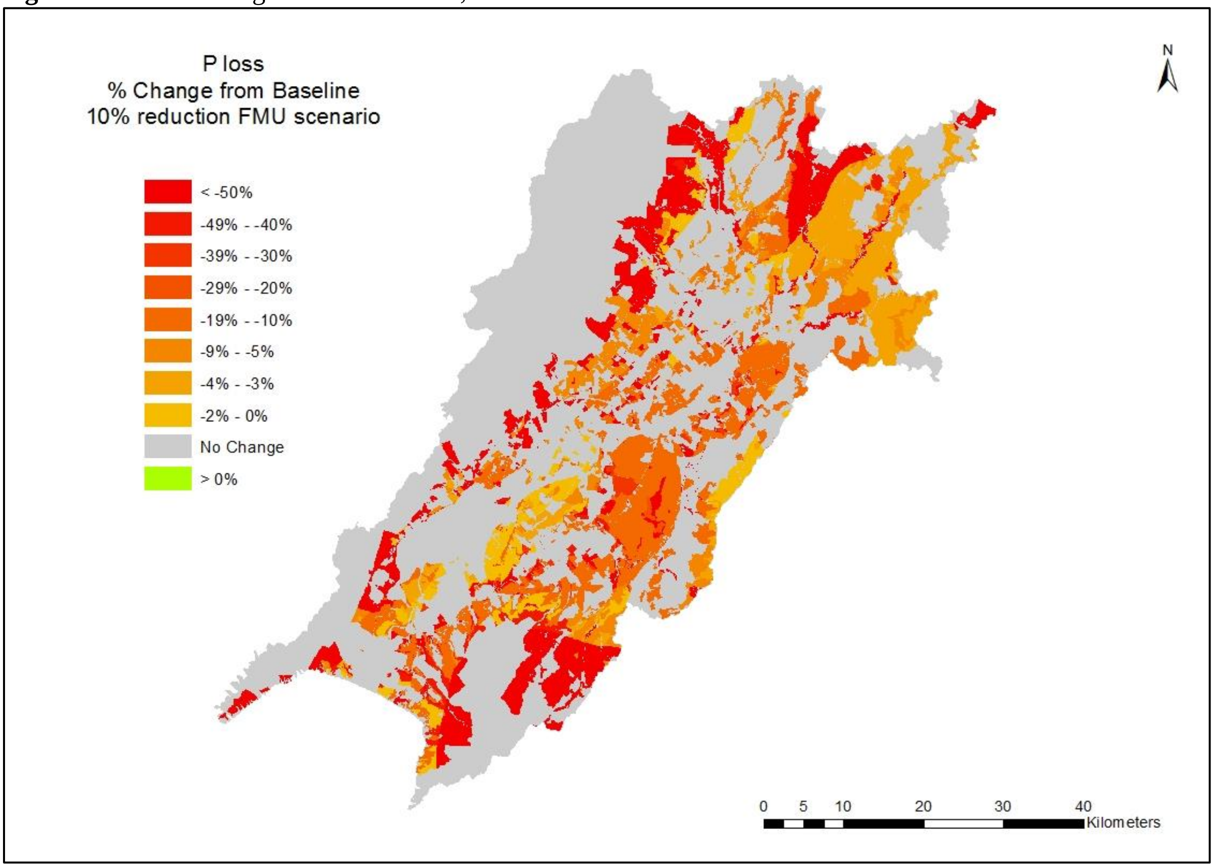


Figure A6: P loss change – 10% reduction, FMU scenario

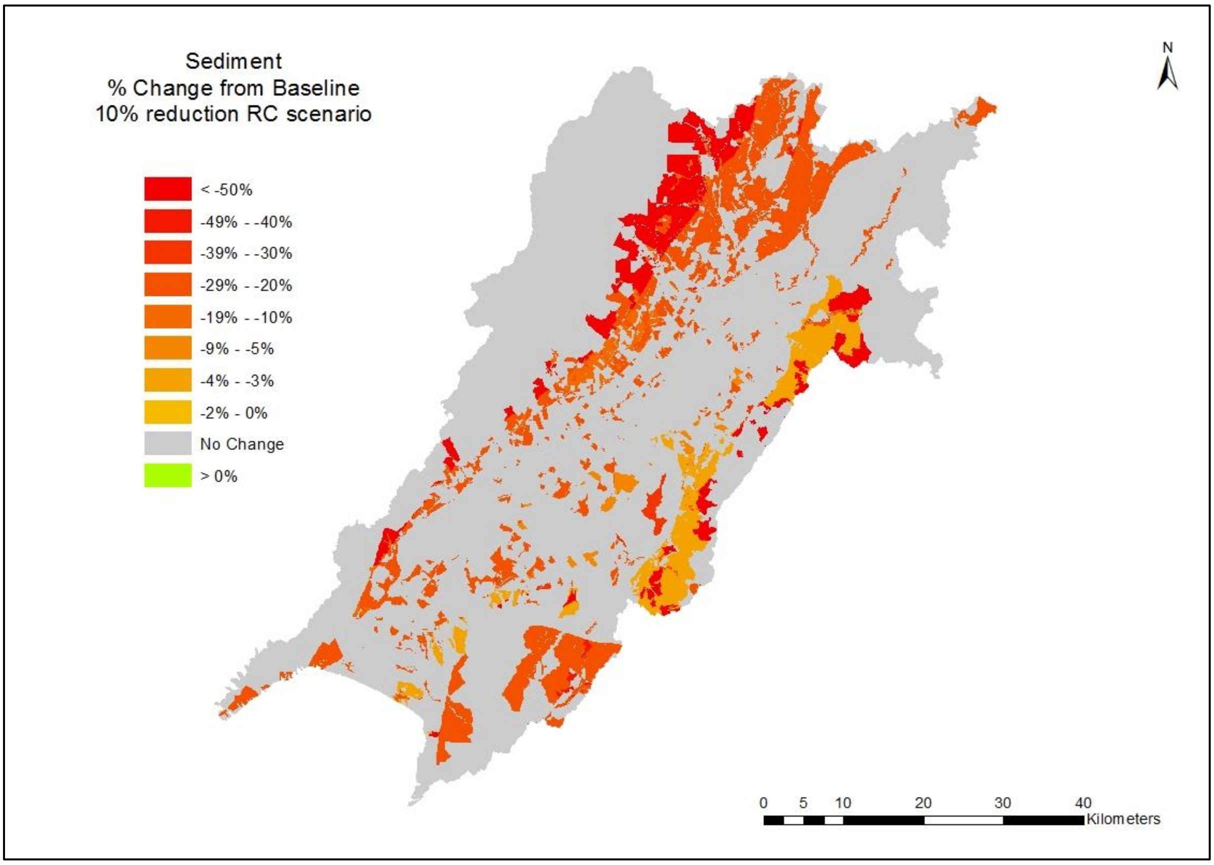


Figure A7: Sediment change – 10% reduction, RC-wide scenario

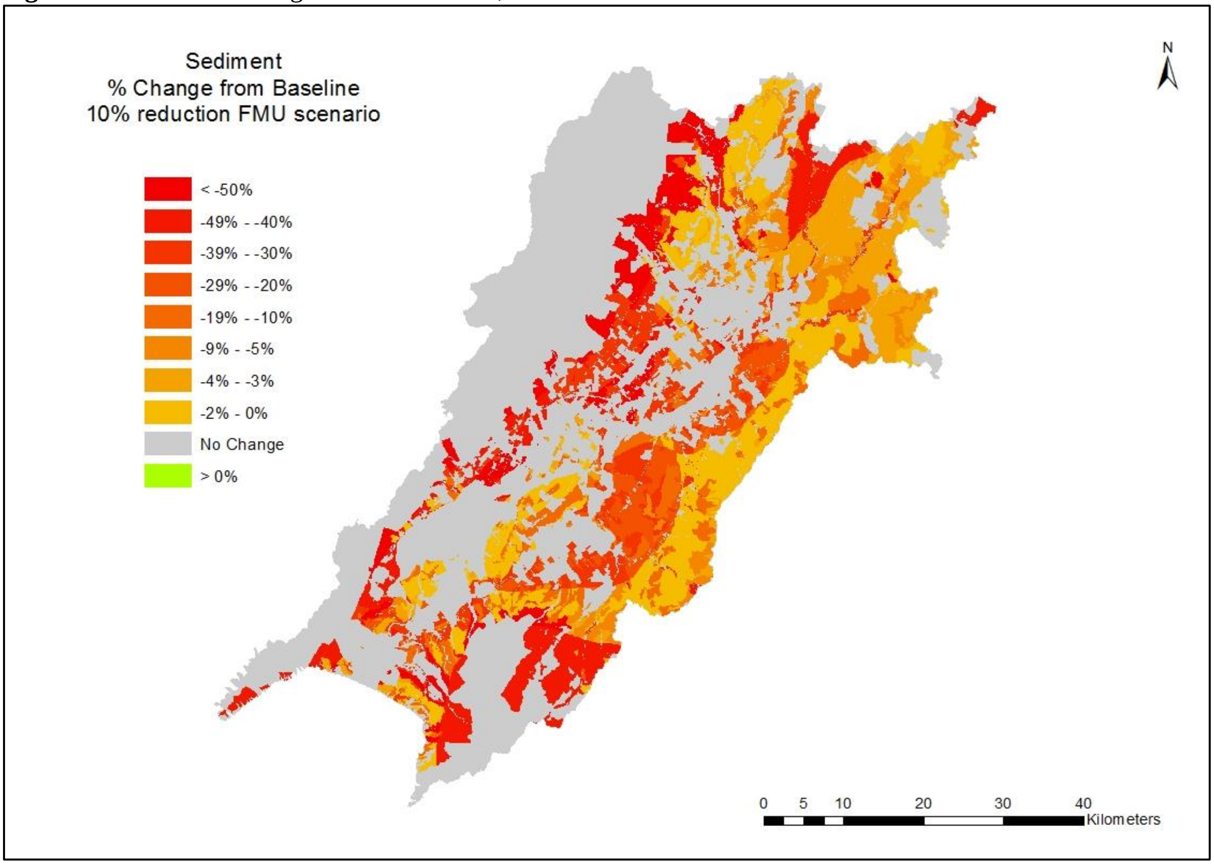


Figure A8: Sediment change – 10% reduction, FMU scenario

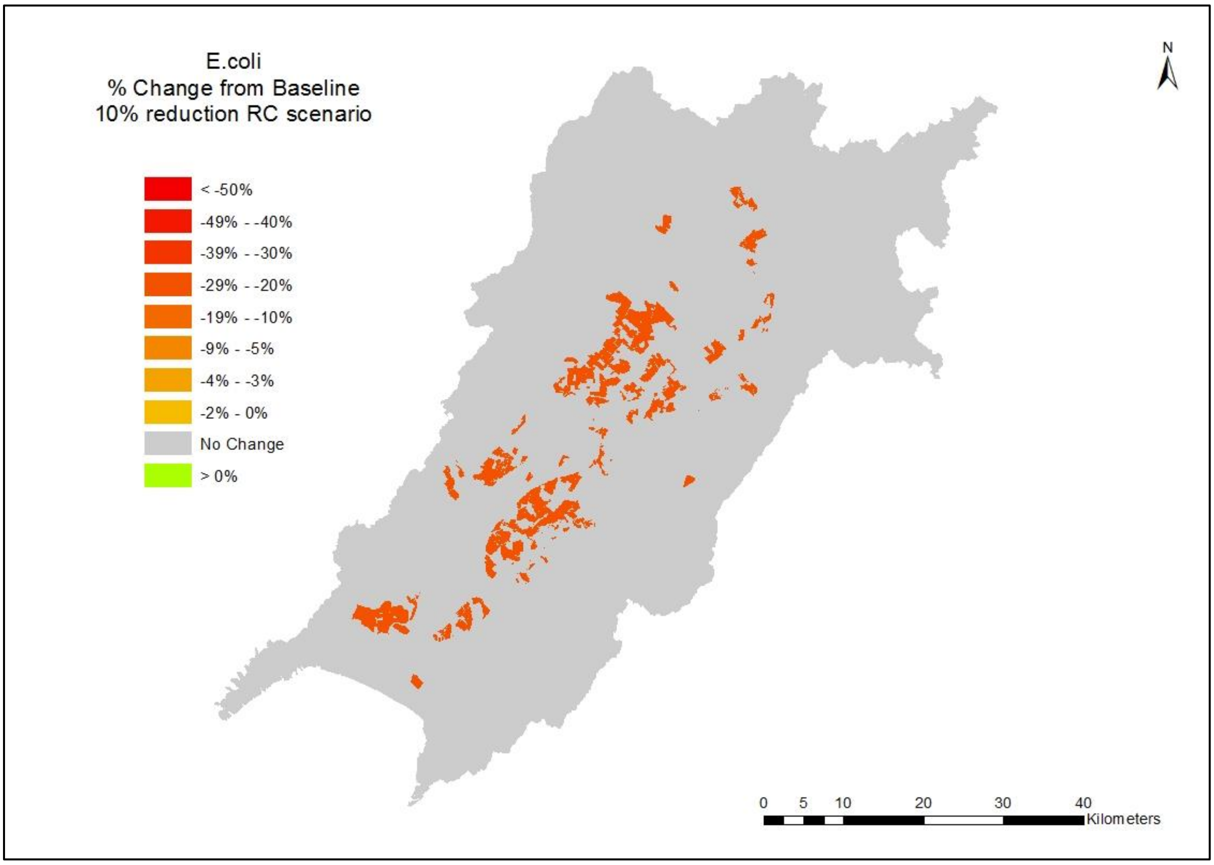


Figure A9: *E.coli* change – 10% reduction, RC-wide scenario

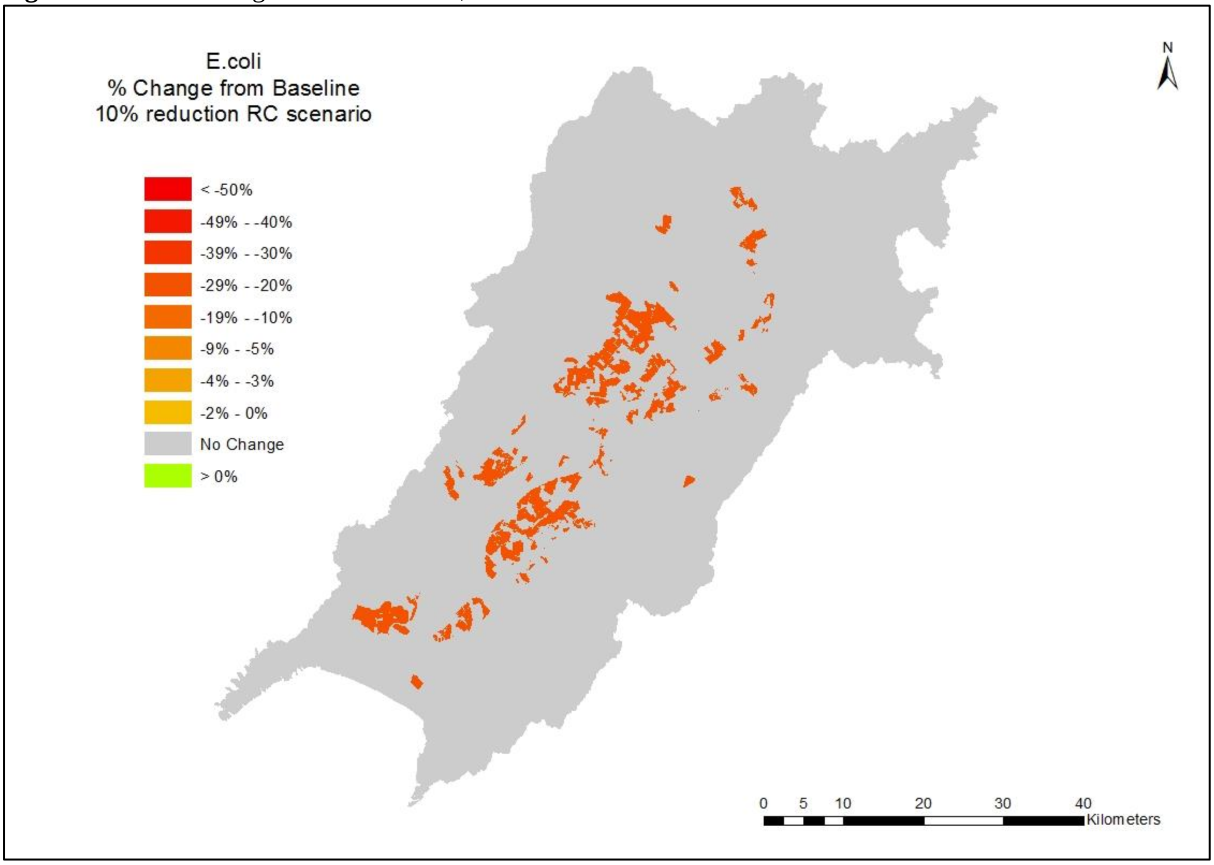


Figure A10: *E.coli* change – 10% reduction, FMU scenario