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Manatū Ahu Matua

Modelling the potential impact of New Zealand's freshwater reforms on land-based Greenhouse Gas emissions

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Prepared for MPI SLMACC

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Executive Summary

The National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2014a) establishes the need to set and manage water resources within limits. A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water, as well as to identify strategies to mitigate contaminant losses to fresh water (e.g. McDowell and Nash, 2012; Monaghan et al., 2007; McDowell et al 2014). However, no national level research has been undertaken to assess the indirect impacts of the water quality component of the NPS-FM on New Zealand's greenhouse gas (GHG) emissions. As a result, MPI SLMACC has contracted Motu with Landcare Research, and assistance from NIWA and AgResearch, to use a national-level economic land use model, NZFARM, to assess the possible impacts of freshwater reforms on NZ's land-based GHG emissions. This report presents the key findings of that analysis.

For this project, we reviewed and collected information on (a) the current level of develoment for reduction targets that are intended or likely to be applied to four key freshwater contaminants: nitrogen (N), phosphorus (P), sediment, *E.coli*; (b) the freshwater management units (FMU) that these targets will be set at; (c) the range of policy options that may be used to meet these targets; (d) the cost and effectiveness for a wide-range of options to mitigate the four contaminants as well as GHG emissions; (e) the distribution of management practices that are likely to be implemented based on a least-cost criteria; and (f) the change in land-based GHG as a result of these policy approaches.

The modelling analysis is based on the following methodology:

- NZ is broken out into 225 FMUs, as defined by each regional council (RC) in the country. Note that some of the areas that we refer to as FMUs are currently draft FMUs and/or referred to in regional plans as other geographical features such as water management zones or catchments.

- Limits are set for each FMU and contaminant based on published targets and interviews with the Regional Councils responsible for implementing them (see Appendix A for details), and on modelling scenarios. The specific limits for N, P, sediment and *E.coli* are modelled in our 'core' policy scenario.

- We model the impact of FMU-level reduction targets for 4 contaminants: N leaching, P loss, sediment, and *E.coli*. Although sediment is not currently in NPS-FM, it is expected to be added in a future iteration. Targets are for 2030 and based on a change from baseline (2012) loads.

- The baseline assumes 2012 land use, commodity prices, and carbon price. The model incorporates a land-use map developed for this project (see Appendix B for details) and contaminant loads measured by NIWA's CLUES model (see Appendix C for details). We

assume that these figures remain the same in the future, i.e. land use, farm profits, and load intensities are assumed to remain constant through 2030 for the no policy baseline.[1]

- The policy impacts are modelled using the economic land use model New Zealand Forest and Agricultural 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 (Daigneault et al. 2012, 2016). Its primary use is to provide decision-makers with information on the economic impacts of agri-environmental policy.

- The policy scenario is assumed to be fully implemented by 2030.

- As the model is comparative static, it is progressed to estimate outputs under a new steady state as a result of the policy. Thus, outputs are measured as policy impacts in 2030 under the assumption that the policy scenario is fully implemented and landowners are collectively in compliance.

- We run a ‘core’ policy scenario and a number of sensitivity cases that adjust assumptions about the stringency of the targets and mitigation options available.[2] All cases assume full compliance in each FMU.

- Unless specified, all policies assume that each FMU meets the target at the least aggregate cost to landowners operating in that geographical area (i.e. model run as an optimisation problem with the least cost combination of mitigation options available). We focus on on-farm mitigation. These mitigation options were reassessed and validated against new empirical evidence (see Appendix D for details). Land-use change is mostly limited to among pastoral uses; in some scenarios afforestation is allowed. FMUs that listed specific policies or allocation options (e.g., natural capital in Manawatu-Wanganui regions) were also accounted for in the model.

A summary of the policy scenario assumptions are listed in Table E1.

Table E1: Policy scenario overview

Scenario	*Mitigation Options Available*	*2030 Reduction Targets**
Baseline	None. Assume all landowners implement current/baseline practices	None. Assume current loads are maintained through 2030
Core Policy	Individual practices & mitigation bundles	Regional Council (RC) interview info only (non-reported FMUs assume no change)
Core + Afforestation	Individual practices, mitigation bundles, and afforestation	Regional Council (RC) interview info only (non-reported FMUs assume no change)
Min 10% Target	Individual practices & mitigation	All FMUs at least a 10% reduction in N, P, E, and S from

[1] Given low current price forecasts for dairy, this may not be a very strong assumption. LURNZ forecasts relatively little change in dairy land compared with changes experienced over the last 15 years. Land is projected to continue to transition from sheep/beef toward forestry and scrub.

[2] Incomplete implementation or compliance could be considered as a change in stringency of target.

	bundles	baseline. RC reported targets greater than 10% continue to be implemented
Min 20% Target	Individual practices & mitigation bundles	All FMUs at least a 20% reduction from baseline. RC reported targets greater than 20% continue to be implemented

* from 2012 contaminant levels

A summary of the key findings is as follows:

(i) How much might contaminants and GHG emissions fall?

- Based on the information provided by regional councils on the level of freshwater contaminant targets, the aggregate reductions in N, P, sediment, and *E.coli* are relatively small and range from -1% for P to -16% for sediment. Regional councils indicated that (a) most FMUs have a target of maintaining current water quality or (b) they are not at the point where they can indicate/determine what the reduction targets may be. For those who answered (b), we assumed that the FMUs would maintain current loads.

- The aggregate (i.e. NZ-wide) reductions in N, P, and E.coli are greater than the targets intended by the regional councils. This is because actions taken to meet one contaminant's target will often further reduce other contaminants for which the target has already been met. We find that sediment reductions are typically close to the intended target.

- **On-farm:** Agricultural GHGs (primarily methane and nitrous oxide) could be reduced 2.4% or 0.82 million metric tonnes of carbon-dioxide equivalent per annum ($MtCO_2e/yr$) under the core policy assumptions, along with an additional 0.11 MtCO2e of forest carbon sequestration as a result of planting riparian buffers and pole planting for erosion control (for a net reduction of 0.92 $MtCO_2e/yr$ or 13%).[3] In a more extreme case where targets were increased to a minimum of 20% below baseline loads for all four contaminants, gross (net) GHGs could be reduced by about 1.7 (2.2) $MtCO_2e/yr$ or 5 (23) %.

- **Afforestation:** If afforestation is perceived to be a feasible mitigation option, up to 800,000 ha of additional trees could be planted, thereby increasing carbon sequestration by 5.4 MtCO2-e/yr. In this case gross (net) GHGs could be reduced by 2.9 (8.2) $MtCO_2e/yr$, primarily through reduction in stock numbers and increases in forest carbon sequestration. This option could reduce net emissions by nearly 80%.

- **Stricter Targets:** Increasing the stringency of the contaminant load target may have a relatively marginal effect on reducing GHG emissions. That is, a scenario where all FMUs are required to reduce contaminant loads by a minimum of 10% below the baseline results in a -4.3% (-19%) gross (net) reduction in GHGs, while a minimum load reduction of 20% scenario results in a 4.9% (23%) reduction in emissions. This suggests

[3] GHG emissions from energy use are also excluded from this analysis.

that the extra mitigation put in place to further reduce N, P, sediment, and *E.coli* loads may not have an equivalent impact on the relative reductions in GHGs.

Table E2: Summary of key scenario outputs, New Zealand aggregate output per annum in 2030

Scenario	Gross GHG* (tCO2e)	Net GHG*,^ (tCO2e)	N Leaching (t)	P Loss (t)	Sediment (Mt)	*E.coli* (peta)	Net Revenue (Bil $)
Baseline	34,182,538	9,272,604	184,314	17,244	125,896	22,161	$11.639
% Change From Baseline							
Aggregate Target	n/a	n/a	-2.5%	-1.3%	-16%	-6.3%	n/a
Core Policy	-2.4%	-13%	-6.4%	-5.1%	-18%	-9.9%	-3.8%
Core + Afforest	-8.4%	-79%	-6.8%	-5.5%	-17%	-9.9%	-9.4%
Min 10% Target	-4.3%	-19%	-16%	-12%	-30%	-27%	-9.0%
Min 20% Target	-4.9%	-23%	-23%	-17%	-37%	-37%	-12%

^ Energy GHGs are excluded from analysis

* Includes gross biological emissions less forest carbon sequestration. Energy is excluded from this analysis.

(ii) Where might mitigation of contaminants and GHGs occur?

- Spatially, areas with high dairy require the greatest reductions in N and P. Regions with high slopes and rainfall require significant mitigation of sediment.

- For the core policy, where all of the GHG emissions reductions are attributed to pastoral enterprises, a majority of the impact occurs in the sheep and beef sector, with a gross (net) reduction of 0.61 (0.72) MtCO2e/yr.

Figure E1 shows the proportion of abatement at the aggregate land use level for the core policy scenario. The figure indicates that a majority of the abatement is estimated to occur on dairy and sheep & beef farms, with the exception being sediment, which requires placing mitigation measures such as wetlands and sediment traps on the edge of vegetated land.

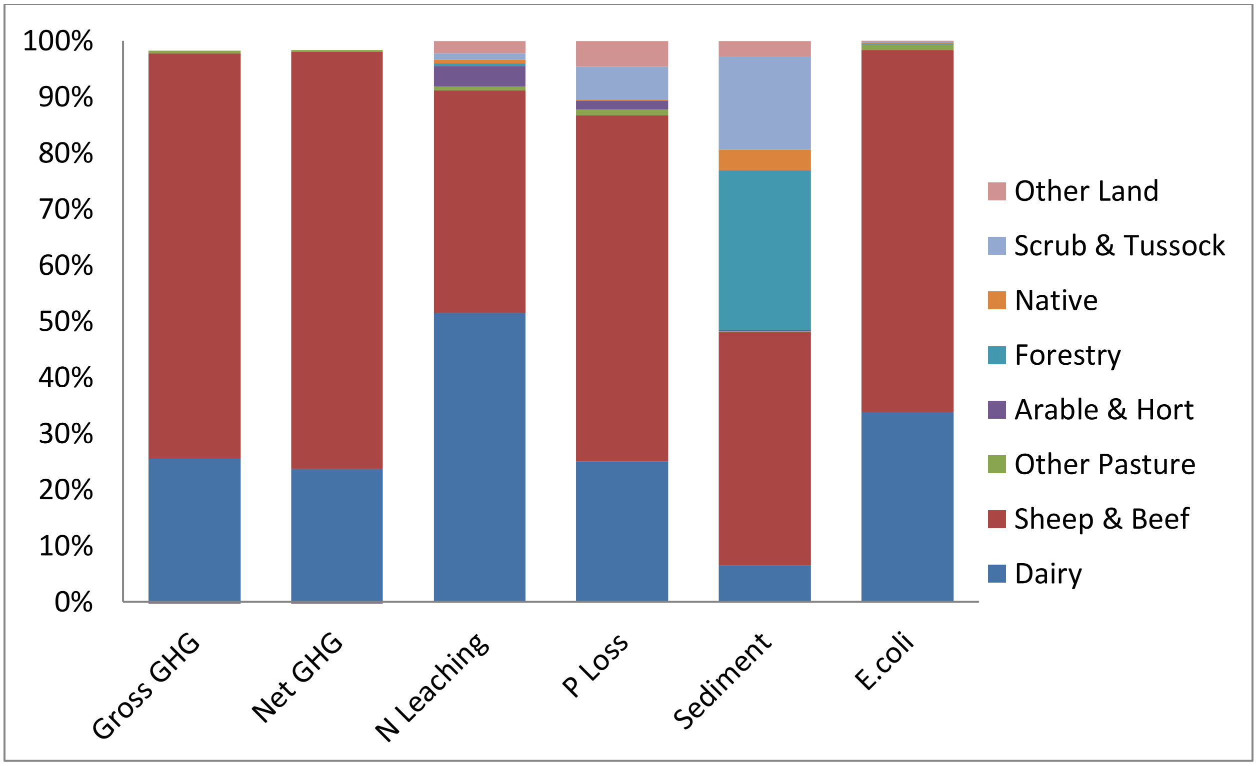

Figure E1. NZFARM estimated proportion of abatement by aggregate land use (core policy scenario)

(iii) How is mitigation achieved?

- A wide range of mitigation options are found to be implemented to meet the various targets. These include riparian buffers, fencing streams, constructing wetlands, and implementing bundles of mitigation practices.

- Nitrogen targets most strongly drive on-farm GHG reductions for all the modelled scenarios that limit mitigation to on-farm changes. This is primarily because actions to mitigate N are most closely related to practices that can also mitigate GHGs (e.g., stock management).

- GHG emissions reductions are a combination of reduced emissions through changes in management and de-stocking and increased carbon sequestration associated with planting riparian buffers or afforesting part of the farm. Some of the sequestration may be in relatively small areas and hence may not be recognised in New Zealand's National GHG Inventory using current methodology.

- In some FMUs, when 10 or 20% minimum mitigation targets are applied, mitigation in the form of wetland construction/restoration adjacent to 'non-traditional' agricultural land uses such as exotic forest plantations and native bush, and to other classifications (e.g., lifestyle) are needed to meet targets. This is because of the composition of land use in the FMU and loads associated with each use, particularly those with high sediment reduction targets. Note that this finding is consistent with recent mitigation analyses that have focused on the feasibility of wetlands to achieve sub-catchment level objectives (e.g., Daigneault et al 2015).

The distribution of mitigation practices for the core and sensitivity analysis scenarios is presented in Figure E2. This figure indicates that the total area of mitigation is relatively consistent for the 'core' and 'core+afforestation' case, but the distribution of practices implemented can shift from riparian and bundle M3 (i.e., systems change) to afforested blocks. For the two scenarios with at least 10% reduction targets for all of the contaminants, the total area of mitigation requires increases significantly. This is particularly the case for land where riparian buffers and wetlands are constructed at the edge of the fields or forests.

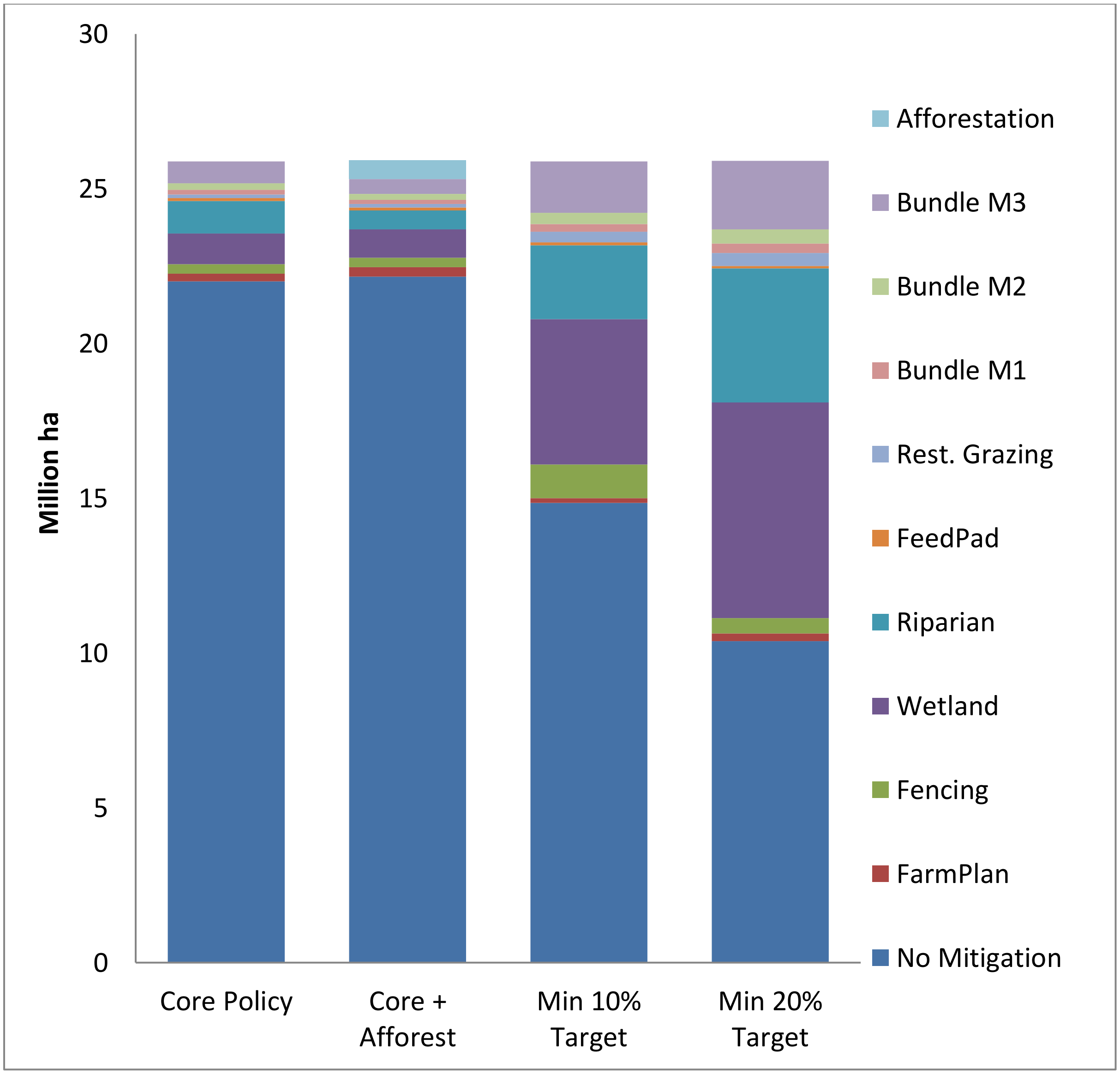

Figure E2. NZFARM estimated distribution of total area by mitigation practice by scenario

Figure E3 highlights the proportion of total net emissions reductions by mitigation option for the core policy scenario. It is apparent that the M3 mitigation bundle has the greatest impact, producing about half of the emissions reductions. These are reductions in gross emissions. Riparian planting and farm plans with pole planting also have a noticeable effect. These two options reduce GHGs both by reducing stock and increasing forest carbon sequestration associated with planting vegetation so affect gross and net emissions. In the policy scenario that allows afforestation, land-use change into forestry drives most changes in both gross and net emissions.

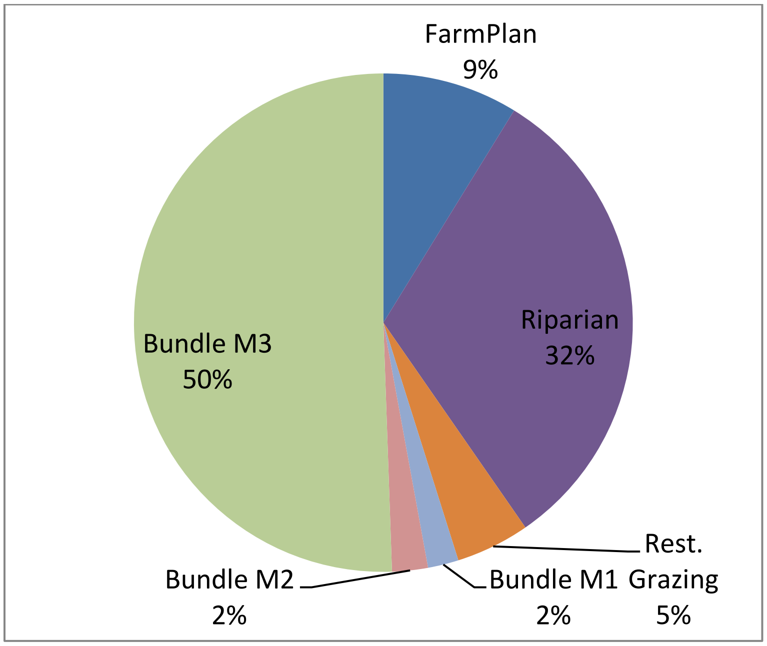

Figure E3 NZFARM estimated % of total net GHG reductions by mitigation option in core scenario (no afforestation)

1 Introduction

The National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2014a) establishes the need to set and manage water resources within limits. A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water, as well as to identify strategies to mitigate contaminant losses to freshwater (e.g. McDowell and Nash, 2012; Monaghan et al., 2007; McDowell et al 2014). However, less reseach has been undertaken to assess the unintended impacts of the NPS-FM on New Zealand's greenhouse gas emissions (GHG) Emissions. As a result, MPI SLMACC has contracted Motu with Landcare Research, and with assistance from NIWA and AgResearch, to assess the possible impacts of freshwater reforms on NZ's land-based GHG emissions.

The water quality improvement aspect of New Zealand's freshwater reforms are expected to drive significant changes in land and water management across the country. These changes could have positive and negative implications for our GHG profile. Emissions benefits through the freshwater reforms could potentially result in significant savings for New Zealand by starting the transition to low emissions in the agricultural sector and helping to achieve New Zealand's overall climate goals (e.g. as expressed in our Nationally Determined Contribution). For farmers, changes in land use and management to meet water quality targets will reduce their potential future exposure to needs to reduce GHG emissions. Wise on-farm and catchment-scale investment now through the freshwater reforms could potentially lead to more cost-effective solutions for managing the land for water and climate outcomes. This analysis attempts to quantify the likely magnitude of GHG reductions and which mitigation options might play the most significant roles.

2 Methodology

This report presents the assessment of the potential economic and environmental impacts of reducing N, P, sediment, and *E.coli* loads per targets specified under the NPS-FM. The modelling is conducted using the national-level NZFARM model (Daigneault et al 2016).

For this project, we:

- developed a new map of land use in 2012;
- reviewed and collected data on (a) the current level of development for reduction targets applied to four key freshwater contaminants: nitrogen (N), phosphorus (P), sediment, *E.coli*; the freshwater management units (FMU) that these targets will be set at; and the range of policy options that may be used to meet these targets;
- collected evidence on the cost and effectiveness for a wide-range of options to mitigate the four contaminants;
- generated new evidence on variation in nitrogen leaching and phosphorus loss and the relationship between that variation and greenhouse gases (methane, nitrous oxide and CO_2); and
- used NZFARM to model the distribution of management practices that are likely to be implemented based on a least-cost criteria; and

- assessed the change in land-based GHGs as a result of these reduction targets and policy approaches.

Figure 1 Illustrates the flow of each key component of the study from generating the land use map to using NZFARM to assess the policy scenario impacts.

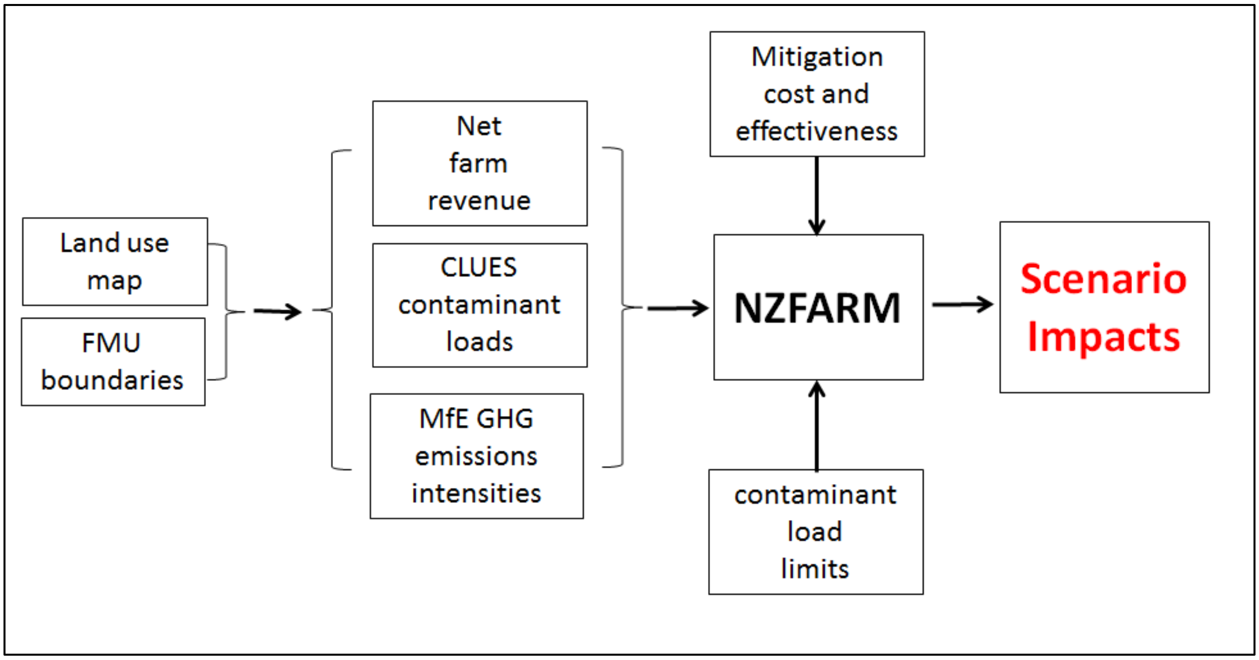

Figure 1. Flow diagram of study methodology

A more detailed description of the integrated economic model is presented below. Details on each new piece of research that fed into this updated model are given in the Appendices.

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, 2016). Its primary use is to provide decision-makers with estimates of 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, input and output prices, resource constraints, or farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decision-makers and rural landowners. The version of the model used for this analysis can track changes in land use, land management, agricultural production, freshwater contaminant loads and GHG emissions by imposing policy options that identify the optimal mix of land use and management to meet a particular target.

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 this anlaysis include implementing farm plans, fencing streams, constructing wetlands, implementing bundles of mitigation practices, and more. 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 (or minimize cost)[4] 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) such that all land in the same zone will yield similar levels of productivity for a given enterprise and land management option.

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

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

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 or regions (r), sub-catchments or FMUs (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 (i.e., yield) coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

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[4] 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.

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

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:[5]

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

Land cover in the catchment is constrained by the amount of land available (L) in an FMU in a given zone:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \tag{4}$$

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

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

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:

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

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:

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

The model also includes a constraint on changes to enterprise area (E), if desired[6]:

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

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 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) at the FMU level, landowners could also face an environmental constraint[7]:

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

[6] N.B. This analysis was primarily focused on the effects of land management on freshwater contaminant loads. As a result, most of the scenarios in this report assume all enterprises are fixed at baseline levels with exception of one that estimates the impacts of also allowing afforestation.

[7] 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.

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

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 sub-catchment $s_{1...i}$, land cover $l_{1...j}$, enterprise $e_{1...k}$, land management $m_{1...l}$, and agricultural output $a_{1...m}$ 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 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 sub-catchments or FMUs. 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 sub-catchment, 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 sub-catchment (σ_S) is set to be 0, as the area of a particular sub-catchment in a zone is fixed.[8] 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).

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 1 lists the key variables and data requirements used to parameterise NZFARM, while Table 2 provides specific elements of the model. More details on the data and parameter assumptions used to populate this version of the model are provided below. All of the figures in the NZFARM are converted to per ha values and 2012 NZD so that they are consistent across sources and scenarios.

Table 1: **Data sources for NZFARM's modelling of national freshwater reforms**

[8] Recall that other NZFARM-based catchment models specify *S* as soil type and *R* as the zone or sub-catchment. In this study, we assume that there is just a single soil type and many reporting zones and sub-catchments. As both *R* and *S* are fixed in area, we can keep the same structure and simply replace soil-type with FMU.

Variable	Data requirement	Source	Comments
Geographic area	GIS data identifying the FMU areas	Regional councils	Subject to change as many regions still drafting FMU boundaries
Land cover and enterprise mix	GIS data file(s) of current land use with the catchment Key enterprises (e.g., dairy).	Estimated using national land use map based on AgriBase and LCDBv4	Land use map verified by project partners.
Management practices	Distribution of feasible management practices (e.g., stream fencing, farm, management plan, etc.)	List developed for April 2016 milestone report	Data and assumptions verified by project partners
Climate	Temperature and precipitation	Historical data Future climate projections being developed in alternative project	Analysis assumes constant climate and production
Soil type	Soil maps used to divide area into dominant soil types	S-map (partial coverage only), Fundamental Soil Layer and the NZ Land Resource Inventory (NZLRI)	Not necessary for this project, so assumed a single, generic soil type
Stocking rates	Based on animal productivity model estimates or carrying capacity map	Average land carrying capacity from NZLRI and detailed 'stocking budgets' for various pastoral enterprise systems	Used to estimate production and net farm revenue for dairy, sheep & beef, and deer enterprises
Input costs	Stock purchases, electricity and fuel use, fertiliser, labour, supplementary feed, grazing fees, etc.	Obtained using a mix of: pers. comm. with farm consultants and regional experts, MPI farm monitoring report, Lincoln Financial Budget Manual	Verified with local land managers and industry consultants
Product outputs	Milk solids, Dairy calves, Lambs, Mutton, Beef, Venison, Grains, Fruits, Vegetables, Timber, etc.	Used yields based on biophysical models (e.g. CenW) and regional production reports	Verified with local land managers and industry consultants
Commodity Prices	Same as outputs, but in \$/kg or \$/m3	Obtained from MPI and other sources	Assume 5-year average
Environmental indicators	GHG emissions Nitrate leaching Phosphorous loss Soil Erosion/Sediment Stream *E. coli*	GHGs modelled following MfE inventory methods Freshwater contaminant loads estimated with CLUES	Baseline estimates reviewed by project partners

Table 2: **List of key components of NZFARM-national**

Enterprise (E)	Mitigation Practice (M)	Sub-catchment (S)	Reporting Zone (R)	Environmental Indicators (ENV)
Dairy Sheep & Beef Deer Forestry Grapes Horticultural crops Arable crops Scrub Native Urban Other	Stream bank Fencing Riparian buffers Wetland Construction Alum application Low Solubility P Sediment Traps Variable Rate Irrigation Feed Pads Restrictive Grazing Nitrification Inhibitors Space-Planted Trees Reduce Fertiliser Reduced Tillage Zero Tillage Cover Crops Forestry blocks Mitigation Bundle	225 Freshwater Management units	16 regional councils	Total N leaching Total P loss Total sediment Stream E. *coli* loads GHG emissions Forest carbon sequestration Net GHG emissions

Land use and net farm revenue

Baseline land use areas for this catchment model are based on a 2012 GIS-based land use map using information from Agribase and the NZ Land Cover Database version 4 (LCDBv4) (Figure 2). New Zealand has a land area of approximately 27 Million hectares (Mha), which comprises mainly sheep and beef farms (8.6 Mha) and unproductive native bush, scrub and tussock (9.9 Mha). The 1.7 Mha of Dairy farms are primarily located in the Waikato, Taranaki, and Canterbury regions, while the 2.1 Mha of pine plantations are concentrated in the central North Island.

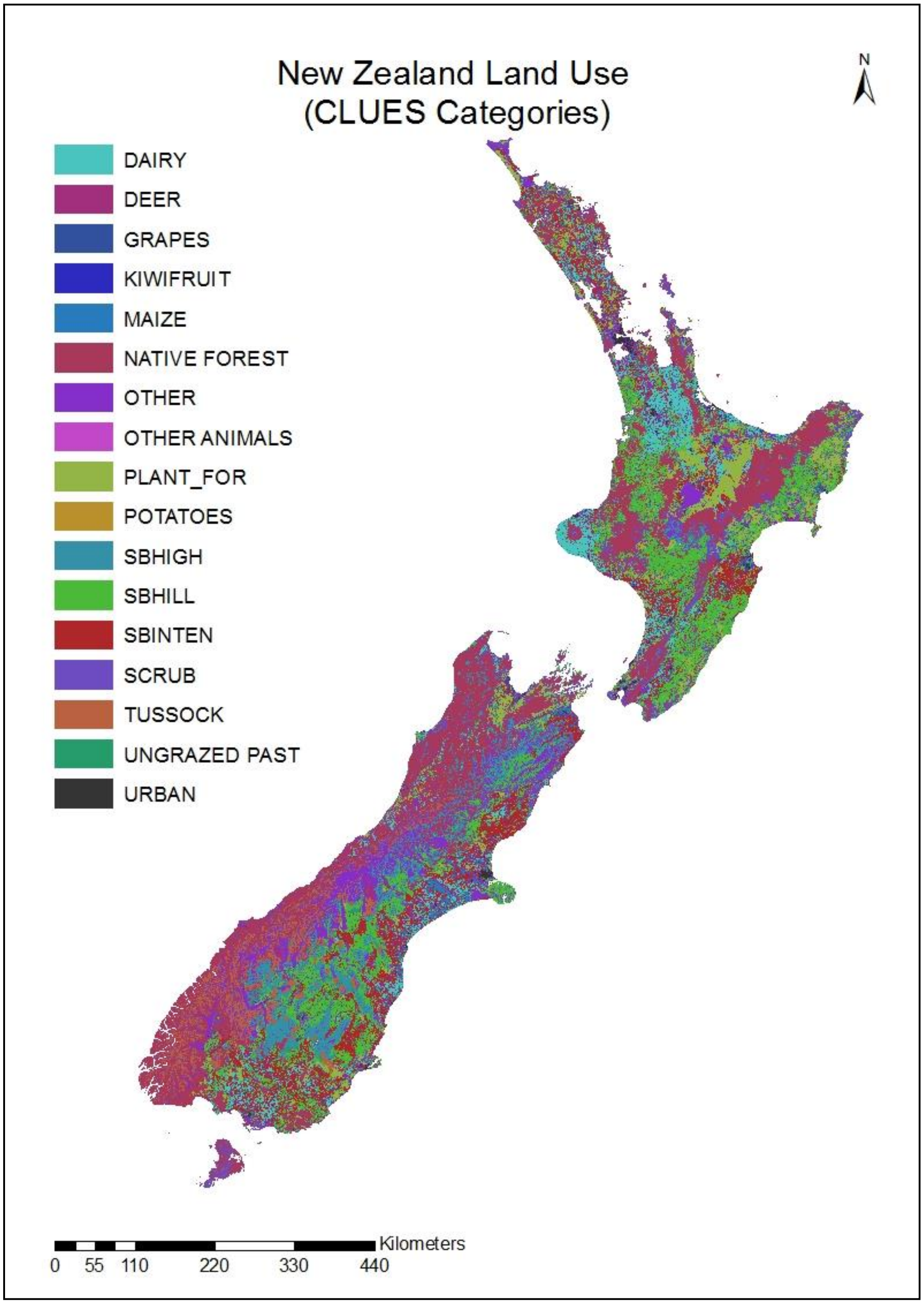


Figure 2: New Zealand land use.

The baseline farm financial budgets for 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 national-level figures have been verified with agricultural consultants and enterprise experts, and documented in Daigneault et al. (2016).

For this study, the net farm revenue figures are used to estimate the opportunity costs of taking land out of production in order to implement certain mitigation options. A good example of this is wetland construction or riparian planting, which both occur at the edge of field and can take up to 5% of the area the mitigation covers out of production. Most of the other pasture-based mitigation options assume an increase in capital and maintenance expenses but no opportunity costs for production losses and hence do not take net revenues into account. In addition, the study is focused on management change within the current land use as opposed to land use change.[9] Thus, the net farm revenue figures for this analysis are not as crucial as other catchment-level studies recently conducted to look at other impacts of the NPS-FM[10] (e.g. nutrients reduction targets in Daigneault et al. 2013).

Baseline freshwater contaminant loads were based on embedding the land use map in the CLUES model and esimating enterprise-level outputs for each FMU (more below). GHG emissions were estimated using national GHG inventory methods (MfE 2014b).

2.2 Freshwater Management Units and Reduction Targets

Information on FMU and reduction targets was collected by in-person meetings, email and phone calls with regional council representatives active in freshwater policy and the NPS-FM implementation process. The information that collected from each council included:

1. A map of regional catchments and/or freshwater management units (FMU),
2. Any relevant water policy documentation/plans.
3. Concerns about contamination from N,P, sediment and *E. coli* in the region.
4. A list of priority catchments/FMUs where these contaminants are being actively managed
5. Specific reductions targets (i.e. limits) or headroom that have been proposed or agreed on for each FMU
6. In the event that limits have not been established in the region yet, the range of targets for each FMU (e.g., 5-10% reduction in N, keep P at current levels, 20% increase in *E.coli*, etc.)
7. The timeframe in each FMU to achieve these limits

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

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

8. Mandatory practices that landowners must undertake as a result (e.g., stock exclusion)
9. Additional practices landowners are undertaking to reduce the different contaminant loads in each FMU (e.g. farm plans for erosion control).

More details on the methodology and responses from each region is included in Appendix B "Freshwater Contaminant Limit Assessment of the Regions".

Freshwater Management Units

The national-level map of the FMUs is shown in Figure 3. These 225 FMUs are primarily based on GIS shapefiles provided by the Regional Councils, In the event that files were not available, FMUs boundaries were drawn in ArcGIS based on maps published online and/or descriptions provided by the council. Note that many of the regional FMU maps are still in draft form and subject to change. In addition, some regions use alternative nomenclature to define their FMUs, such as Water Management Zones. In this report, we refer to all units as FMUs to for consistency.

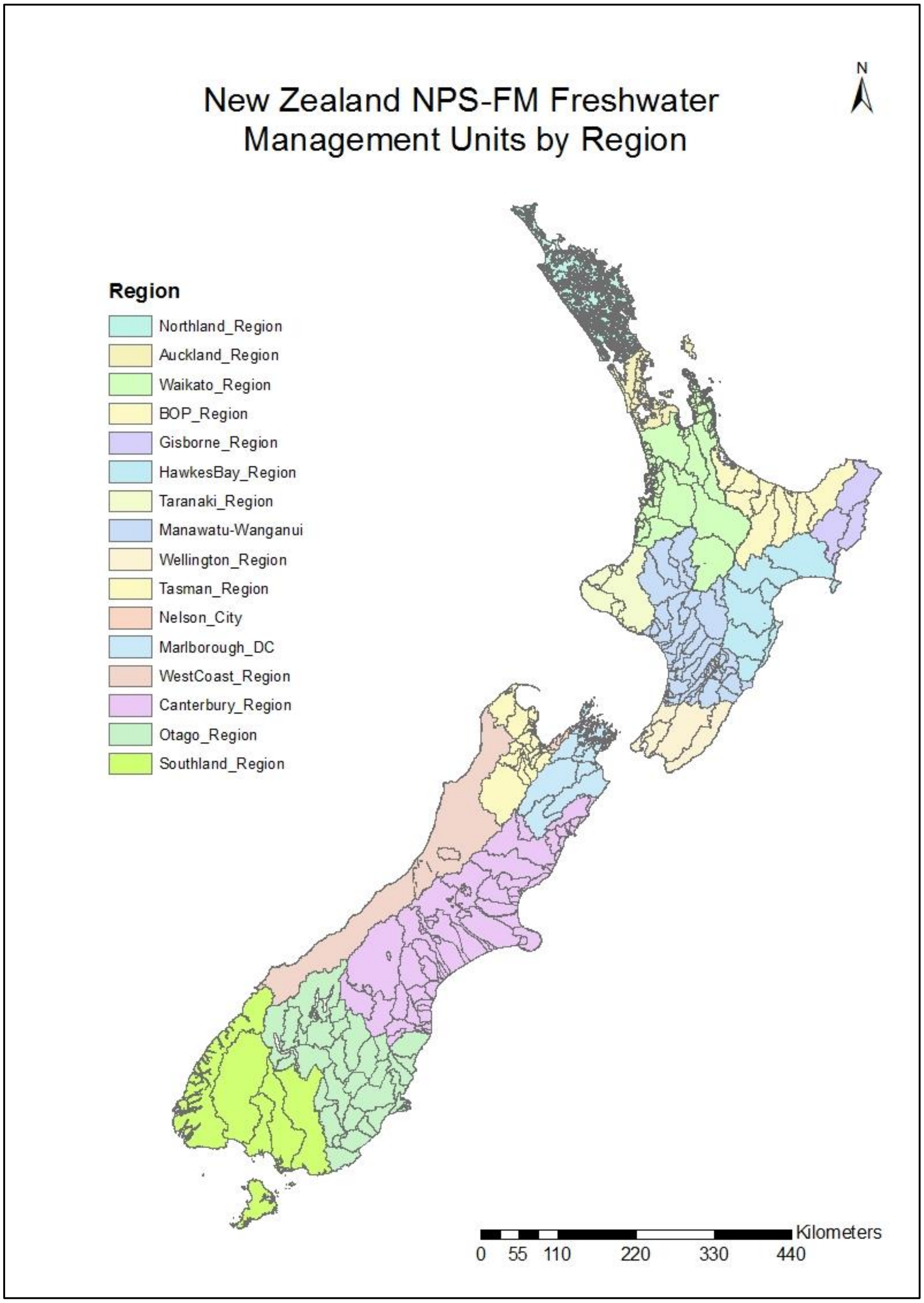


Figure 3. Freshwater Management Units (FMU) by region

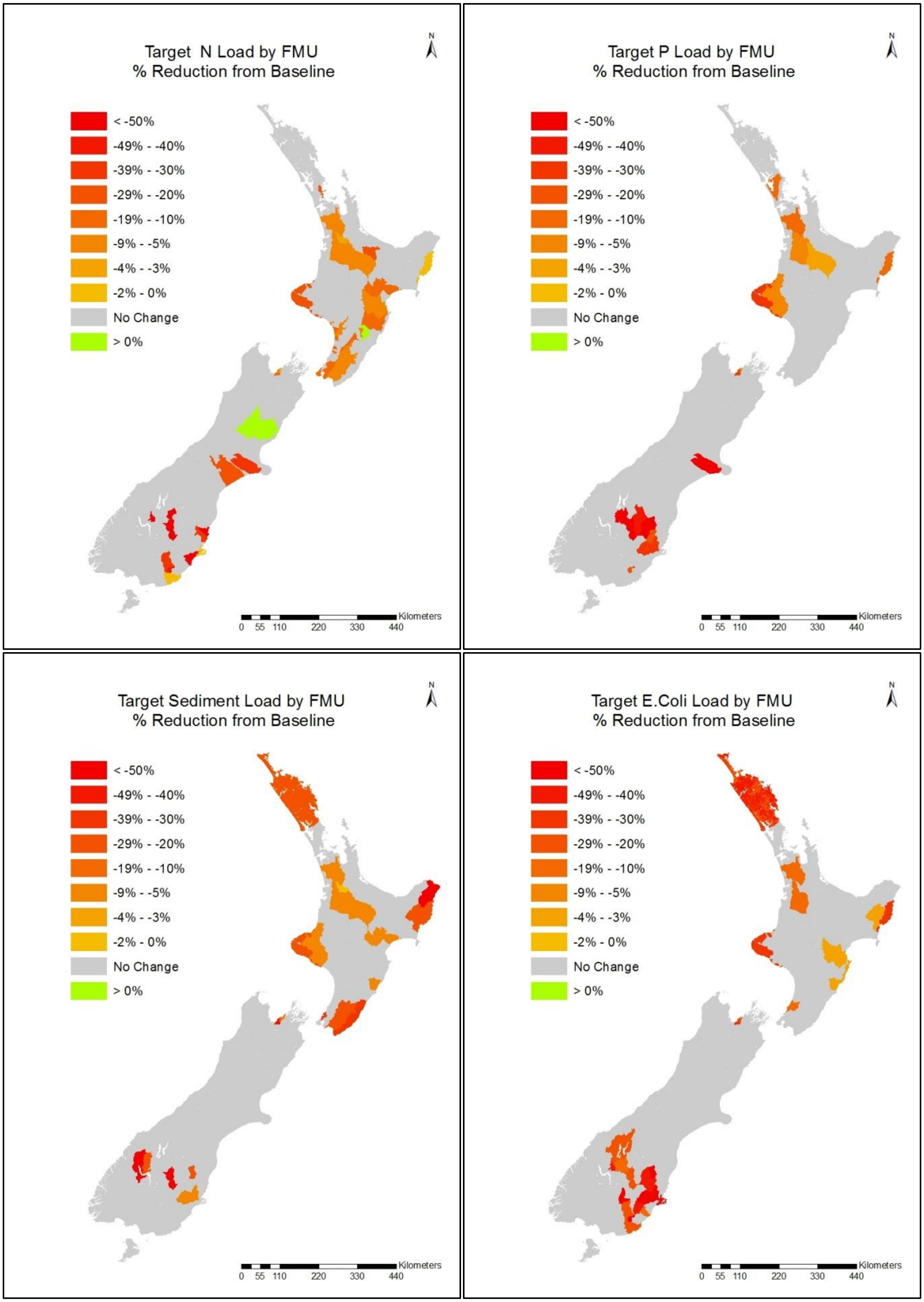
Contaminant Load Reduction Targets

Specified targets to reduce diffuse source contaminants to waterways vary widely both across and within regions of New Zealand. A summary of the regional level targets (with range based on the spread across FMUs in the region) is listed in Table 3, while the spatial distribution is shown in Figure 4. Note that for most of these regions, the targets are still in draft form and/or still under discussion by stakeholders working through collaborative processes and hence could change in the future. For the regions where FMUs and/or targets are undefined, we assume no change from the 2015 baseline contaminant loads estimated in CLUES.

Table 3. Summary of regional level contaminant targets (% from baseline)

Region	# of FMUs	Contaminant Reduction Targets (% from 2015 baseline)			
		Nitrogen	Phosphorus	Sediment	*E. coli*
Northland	2	undefined	undefined	undefined	undefined
Auckland	9	0-50% decrease	0-20% reduction	0-10% increase	0% change
Waikato	8	0-7% decrease	0-10% decrease	0-6% decrease	0-15% decrease
Bay of Plenty	9	0-27% decrease	0% change	0% change	0% change
Gisborne	3	0-12% decrease	0-50% decrease	0-65% decrease	0-94% decrease
Hawke's Bay	15	0-30% decrease	0-10% decrease	0-10% decrease	0-10% decrease
Taranaki	4	0-10% decrease	0-30% decrease	0-30% decrease	0-30% decrease
Horizons#	43	Undefined#	undefined	undefined	undefined
Greater Wellington	5	0-15% decrease	0% change	0-40% decrease	0-10% decrease
Nelson	5	0-50% decrease	0-50% decrease	0-50% decrease	0-50% decrease
Tasman	6	0% change	0% change	0% change	0% change
Marlborough	7	undefined	undefined	undefined	undefined
Canterbury	10	0-30% decrease	0-50% decrease	0% change	0% change
Otago	29	0-80% decrease	0-78% decrease	0-94% decrease	0-66% decrease
West Coast	2	0% change	0% change	0% change	0% change
Southland	5	0% change	0% change	0% change	0% change

with exception of N in priority catchments, in which limits are set based on per ha leaching rates allocated using a natural capital approach.



Target N Load by FMU
% Reduction from Baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4% - -3%
-2% - 0%
No Change
> 0%
Kilometers
0 55 110 220 330 440
Target P Load by FMU
% Reduction from Baseline
Target Sediment Load by FMU
% Reduction from Baseline
Target E.Coli Load by FMU
% Reduction from Baseline

Figure 4: Contaminant reduction targets by FMU (% below baseline loads)

2.3 CLUES Model

CLUES determines mean annual loads of total nitrogen (TN), total phosphorus (TP), suspended sediment, and *E. coli* for each stream in the national REC (River Ecosystem Classification) stream network (Snelder et al. 2010). For pastoral land-uses, the 'generated' load of TN and TP are determined as a function of broad enterprise type (e.g. Dairy) and other catchment attributes such as rainfall and subcatchment-average slopes using a simplified version of the OVERSEER farm nutrient loss model (version 6.1)[11]. TN loads from horticulture and cropping are determined from equations summarising results of SPASMO model runs for selected enterprise types, as described in Woods et al. (2006). Nutrient loading for other land-use types is determined by calibrating yields to measured loads using the SPARROW catchment model software (Elliott et al. 2005) which includes factors for drivers such as rainfall and soil drainage. For TP, a further source proportional to the estimated sediment generation is added, to account for TP associated with mass erosion (Elliott et al. 2005). Sediment sources are determined according to erosion terrain classification and land cover, and drivers of slope and rainfall (Elliott et al. 2008). Sources of *E. coli* are based on source coefficients for pasture and non-pasture, adjusted for rainfall and soil drainage, and calibrated to measured loads. Point sources of TN, TP and *E. coli* are also incorporated into the model.

This study was based on the most recent version of CLUES (Version 10.1), which incorporates updates in parameter values from model-recalibration. CLUES also accumulates contaminants down the stream network including accounting for loss of contaminants (for example, by settling in lakes), and also includes methods for determining concentrations. Those aspects of CLUES are not relevant to the current study, which only addresses contaminant generation rather the loading in streams or concentrations.

2.4 Mitigation practices

We estimated the cost and effectiveness for several mitigation options to reduce N, P, sediment and *E. coli* loads for a range of land uses as well as the resulting impact on GHG emissions. These are broken out into individual options, such as fencing or restricted grazing and as well as aggregated up into mitigation 'bundles' that can be implemented simultaneously. Descriptions of each option are listed in Table 4. Costs and effectiveness for the various practices are listed in Table 5 and Table 6.

[11] http://www.Overseer.org.nz

Table 4: Summary of individual mitigation options

Option	Description	Cost Component		
		Opportunity	Capital	Maint
Stream bank Fencing	Construct fences to exclude stock from permanent waterways		X	X
Riparian buffers	Fence streams with 5m buffer that is planted with grass and native vegetation.	X	X	X
Wetland Construction	Modification of landscape features such as depressions and gullies to form wetlands and retention bunds	X	X	X
Alum	Apply to pasture and cropland to decrease P loss in runoff			X
Low Solubility P	Apply low water soluble fertiliser to reduce P loss in runoff			X
Sediment Traps	Stock pond or earth reservoir constructed at natural outlet of zero-order catchment	X	X	X
Variable Rate Irrigation	Optimise water and nutrient application according to local pasture and crop requirements		X	X
Feed Pads	Constructed area to keep animals off paddock for specified time	X	X	X
Restrictive Grazing	Remove animals from pasture at certain times and/or extend housing period.	X	X	X
Nitrification Inhibitors	Apply dicyandiamide (DCD) or alternative inhibitor to reduce nitrate		X	X
Space-Planted Trees (farm plan)	Trees planted on slopes to retain soil and prevent erosion via a whole farm plan	X	X	
Reduce Fertiliser	Lower fertiliser application rates and/or adjust timing	X		
Reduced Tillage	Adjust tilling practices and timing to reduce the time land is bare during the growing cycle.	X		
Zero Tillage	Eliminate crop disturbance from tilling	X		
Cover Crops	Plough crops into soil between harvest and sowing periods		X	X
Full afforestation	Convert part or all of farm to pine plantation or native bush	X	X	X
Mitigation Bundle	Includes a combination of the practices listed above. Often more effective, albeit at a higher cost	X	X	X

Mitigation options were quantified as an individual practice or technology, or as a set of options referred to as mitigation bundles. Cost figures are reported as both annualized costs ($/ha/yr) as well as relative change in net farm returns, while reductions in the contaminants/emissions are listed in relative terms due to the wide variance in baseline rates that can vary through factors such as stocking rate, slope, rainfall, fertiliser rate, etc.

We have typically focused on mitigation estimates that came from models, literature, or research programmes that originated in New Zealand. The relative effectiveness of N and P mitigation options were often reported in the literature as being estimated using the OVERSEER model, while sediment, *E. coli* , and GHG mitigation estimates were reported as using a variety of methods.

More details on how these were derived are available in Appendix D.

Table 5: Cost and effectiveness of individual mitigation options

Option	Annual Cost ($/ha/yr)	Net Revenue	N Leach	P Loss	Sediment	*E. coli*	Net GHG	Gross GHG
		% Change From No Mitigation Management Option						
Dairy								
Effluent	24	-1%	-4%	-30%	0%	0%	0%	0%
Riparian	71	-2%	-56%	-66%	-75%	-60%	-2%	-3%
Fencing	137	-4%	-13%	-15%	-70%	-60%	0%	0%
Wetland	68	-2%	-10%	-45%	-65%	-55%	0%	0%
Alum	34	-1%	0%	-26%	0%	0%	0%	0%
Low P	48	-1%	0%	-10%	0%	0%	0%	0%
VRI	58	-2%	-10%	0%	0%	0%	0%	0%
Feed Pad	171	-5%	-15%	-15%	0%	-10%	0%	0%
Res Graz	513	-15%	-36%	-30%	-40%	-10%	-10%	-10%
Space planting	34	-1%	0%	-20%	-70%	0%	-5%	0%
Sheep and Beef								
Riparian	26	-21%	-56%	-50%	-75%	-60%	-2%	-7%
Fencing	32	-25%	-13%	-15%	-70%	-60%	0%	0%
Wetland	25	-20%	-10%	-45%	-65%	-55%	0%	0%
Alum	64	-50%	0%	-26%	0%	0%	0%	0%
Low P	25	-19%	0%	-10%	0%	0%	0%	0%
Res Graz	14	-11%	-16%	-20%	-10%	-10%	-6%	-6%
Space planting	6	-5%	0%	-20%	-70%	0%	-6%	0%
Deer								
Riparian	37	-4%	-51%	-50%	-82%	-60%	-2%	-13%
Fencing	40	-4%	-13%	-15%	-70%	-60%	0%	0%
Wetland	30	-3%	-10%	-45%	-65%	-55%	0%	0%
Space planting	20	-2%	0%	-20%	-70%	0%	-6%	0%
Arable Crops								
Riparian	11	-1%	-51%	-50%	-75%	-60%	-1%	-4%
Wetland	50	-4%	-10%	-45%	-65%	-55%	0%	0%
Red Fert	22	-1%	-7%	0%	0%	0%	-5%	-5%
Red Till	141	-9%	-2%	-25%	-25%	0%	-4%	0%
Zero Till	171	-10%	-10%	-50%	-25%	0%	-20%	0%
Cover crop	409	-25%	-60%	-25%	-10%	0%	-20%	0%
Horticulture								
Riparian	62	-4%	-51%	-50%	-75%	-60%	-1%	-5%
Wetland	50	-3%	-10%	-45%	-65%	-55%	0%	0%
Limit N App	90	-2%	-4%	0%	0%	0%	0%	0%
Red Fert	1679	-30%	-10%	0%	0%	0%	-3%	-3%
Cover crop	347	-6%	-5%	-25%	-25%	0%	-10%	0%
Red Till	0	0%	-5%	-25%	-25%	0%	-4%	0%
Pine								
Wetland	50	10%	10%	0%	65%	55%	0%	0%
Native and Scrub								
Wetland	50	n/a	10%	0%	65%	55%	0%	0%
Wetland	50	n/a	10%	0%	65%	55%	0%	0%

In recent catchment-scale modelling the effect of management practices to reduce diffuse-source pollution has focused on including a set of mitigation that are packaged as a ‘bundle’ of options that would likely be introduced on the farm at the same time (e.g., Everest 2014; Vibart et al 2015) . These bundles are typically defined as:

- M1: relatively cost-effective measures with minimal complexity to existing farm systems & management

- M2: mitigation that is less cost-effective than M1, and require limited capital costs or systems change

- M3: management options with large capital costs and/or are relatively unproven

These bundles are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes practices from M1 and M2. Table 6 shows the mean cost and effectiveness of each mitigation bundle for pastoral, arable, and horticultural enterprises. Note that a bundle will not necessarily include all of these practices, but rather a mix that achieves a similar reduction in contaminants for a given annualized cost per ha. In addition, adjusting the set of mitigation included in each bundle could have an effect on the effectiveness of both freshwater contaminant load and GHG emissions.

In new analysis presented in Appendix E where only currently used practices are used, and production levels are sustained, our 'ambitious' scenario where those farmers who produce lower levels of product for given levels of leaching are brought half way up to the 85th percentile of product per unit of pollution could be considered to be similar to modelling M1. In that scenario we find that dairy farms reduce N leaching by around 23% and GHGs by 2.6%; and that sheep/beef farms reduce N leaching by 12% and GHGs by 1.23%. This analysis with a completely different methodology validates the general scale of mitigation and co-benefits from N mitigation in our scenario modelling.

Table 6: Mean cost and effectiveness of mitigation bundles

Enterprise	Bundle	Annual Cost	Net Revenue	N Leach	P Loss	Sediment	*E. coli*	Net GHG
			% Change From No Mitigation Management Option					
Dairy	M1	$10	0%	-23%	-14%	-58%	-51%	-8%
Dairy	M2	$41	-1%	-38%	-30%	-60%	-51%	-8%
Dairy	M3	$652	-22%	-60%	-34%	-62%	-51%	-12%
Sheep & Beef	M1	$18	-9%	-19%	-35%	-43%	-49%	0%
Sheep & Beef	M2	$24	-12%	-25%	-48%	-60%	-50%	1%
Sheep & Beef	M3	$41	-21%	-40%	-58%	-52%	-50%	-4%
Deer	M1	$71	-9%	-19%	-35%	-43%	-49%	0%
Deer	M2	$95	-12%	-25%	-48%	-60%	-50%	1%
Deer	M3	$166	-21%	-40%	-58%	-52%	-50%	-4%
Crops & Horticulture	M1	$158	-11%	-34%	-56%	-58%	-50%	-13%
Crops & Horticulture	M2	$375	-25%	-37%	-88%	-60%	-50%	24%
Crops & Horticulture	M3	$446	-30%	-41%	-88%	-62%	-50%	10%

In addition to these mitigation practices, one policy scenario assumes that landowners can also afforest part of their land with exotic pine plantations. The relative costs of doing so will vary by land use and location, but mean annual returns from forestry are often similar to sheep & beef. The mean annual nutrient outputs per ha from an average NZ plantation are 4 kgN and 0 kgP. Sediment is assumed to be just 20% of the load from pastoral use on the same parcel of land, while *E. coli* is highly variable but often significantly less than livestock based enterprises operating in the vicinity. In terms of GHG emissions, plantations forests can on average sequester about -9 tCO2/ha/yr in addition to eliminating all the emissions from the afforested area.

3 Model Baseline

In the baseline we assume that current loads are maintained through 2030 and that all landowners implement current/baseline practices. The total net GHG emissions produced by the agricultural sectors are 9.2 million tonnes of CO2 equivalent (MtCO2e) for New Zealand. The main emitters are sheep and beef and dairy farming, which together account for around 33 MtCO2e annually. The forestry sector and native vegetation and scrub act as important carbon sinks, respectively sequestering 19 and 6 MtCO2e annually. All of these figures are simlar to the recent estimates of NZ's GHG inventory (MfE, 2016).

The spatial distribution of net emissions intensities are shown in Figure 5. Areas with a high proportion of pastoral enterprises have emissions intensities of 1 MtCO2e/yr or more, while those with a high proportion of native bush and/or plantation forestry are estimated to sequester 1 MtCO2e/yr or more and hence have negative net emissions[12].

[12] N.B, an update of this analysis will break out net emissions by gross emissions and forest carbon sequestration.

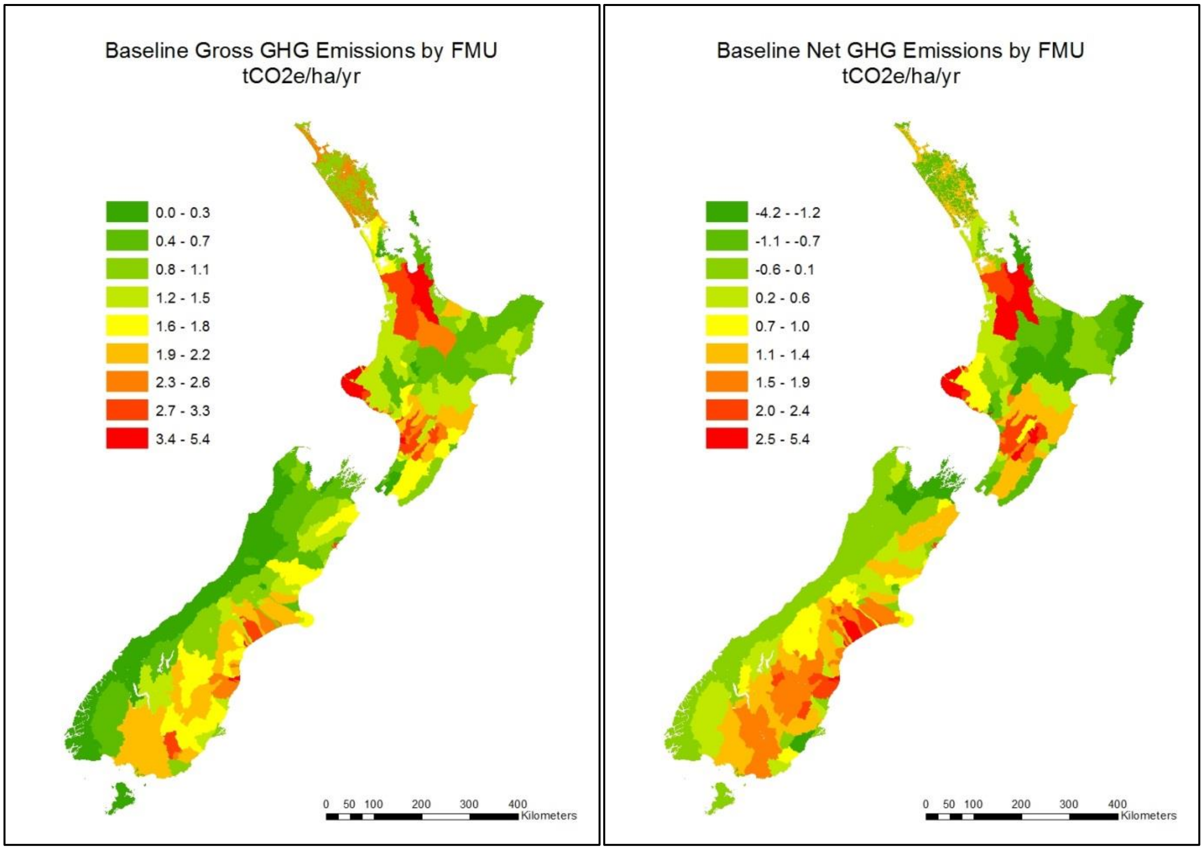


Figure 5. NZFARM estimated baseline gross and net GHG intensities by FMU (per hectare per annum)

Mean freshwater contaminant load estimates by FMU are displayed in Figure 6, and consistent with prior research (e.g, Parfitt et al. 2012; Dymond et al. 2010, 2013; Ausseil et al 2013). The sheep and beef and dairy sectors are the major sources of N and P, leaching 103 kilotonnes (Kt) from a total of 184 Kt of N, and losing 7.1 Kt out of 17.3 Kt of P annually to streams. With an annual sediment loss of 33.4 million tonnes (Mt), sheep and beef farms are also the main contributor to the 148.3 Mt total annual sediment loss. These farms are generally large and located in hilly country, which makes pastures particularly susceptible to soil loss. Forestry is another significant contributor to sediment loss (21 Mt), as wind and rain wash away the bare soil that remains after plantation forest is harvested, particularly from stands located on steep slopes. Native vegetation is generally located on very steep land with high rainfall, which explains the relatively high sediment loss from this land cover class. In terms of *E.coli*, pastoral enterprises contribute about 95% of the total load in New Zealand due to stock waste getting in the waterways via direct defecation or runoff. The totals of N leaching, P, and sediment loss estimated by our model are in range of other national-level studies (Parfitt et al. 2012; Dymond et al. 2010, 2013; Ausseil et al 2013), while *E.coli* is simlar to previous studies based on CLUES.

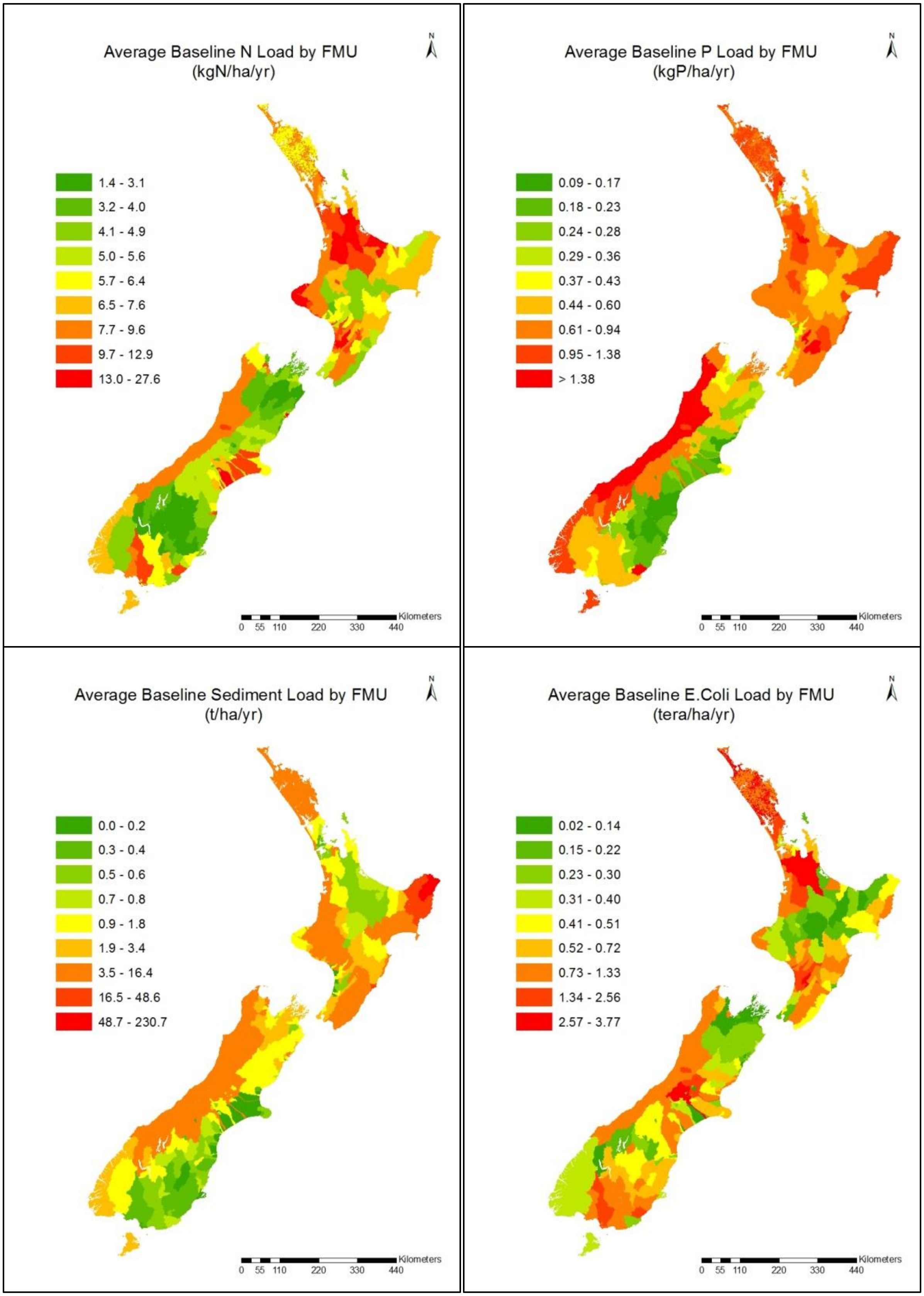


Figure 6: Baseline freshwater contaminant load estimates by FMU (per hectare per annum)

Baseline estimates for the New Zealand agriculture and forest sector economic and environmental output by aggregate enterprise are listed in **Error! Reference source not found.**. n total, the primary sectors produce more than NZ$11 billion in net farm revenue per annum. Dairy farms generate by far the highest net revenue (NZ$6.4 billion), which is approximately twice the revenue from the next-largest sector in terms of total net revenue, sheep and beef farming. Arable and horticultural crops are comparatively profitable, contributing NZ$1.2 billion from about 391,000 ha of land.

Table 7 Baseline NZFARM estimates for all of New Zealand

Land Use	Area (Kha)	Gross GHG ($MtCO_2e$)	Net GHG ($MtCO_2e$)	N Leach (Kt)	P Loss (Kt)	Sediment (Mt)	*E. coli (peta)*	Net Farm Revenue (mil NZ$)
Dairy	1,695	12,750,260	12,750,259	43,612	2,184	3,866	5,340	6,374,282
Sheep & Beef	8,593	20,124,478	20,124,477	61,944	5,131	35,026	14,161	3,007,499
Other Pasture	1,189	790,838	790,838	9,287	1,049	9,244	2,105	243,199
Arable & Hort	391	516,962	516,962	5,722	77	173	9	1,197,945
Forestry	2,127	0	-19,129,197	7,979	564	21,594	36	832,768
Native	6,303	0	-3,151,742	32,651	4,014	28,777	422	6,303
Scrub & Tussock	3,603	0	-2,516,196	11,771	2,621	22,964	328	51,410
Other Land	2,439	0	0	13,925	1,893	28,917	291	2,439
NZ Total	26,340	34,182,538	9,385,400	186,890	17,534	150,562	22,692	11,715,846

The distribution of net farm revenue across the country is shown in Error! Reference source not ound.. Net farm revenue ranges from less than $100/ha/yr for some FMUs that have a large proportion of native bush, scrub, and sheep & beef farms to more than $1500/ha/yr in areas with significant dairy and horticulture.

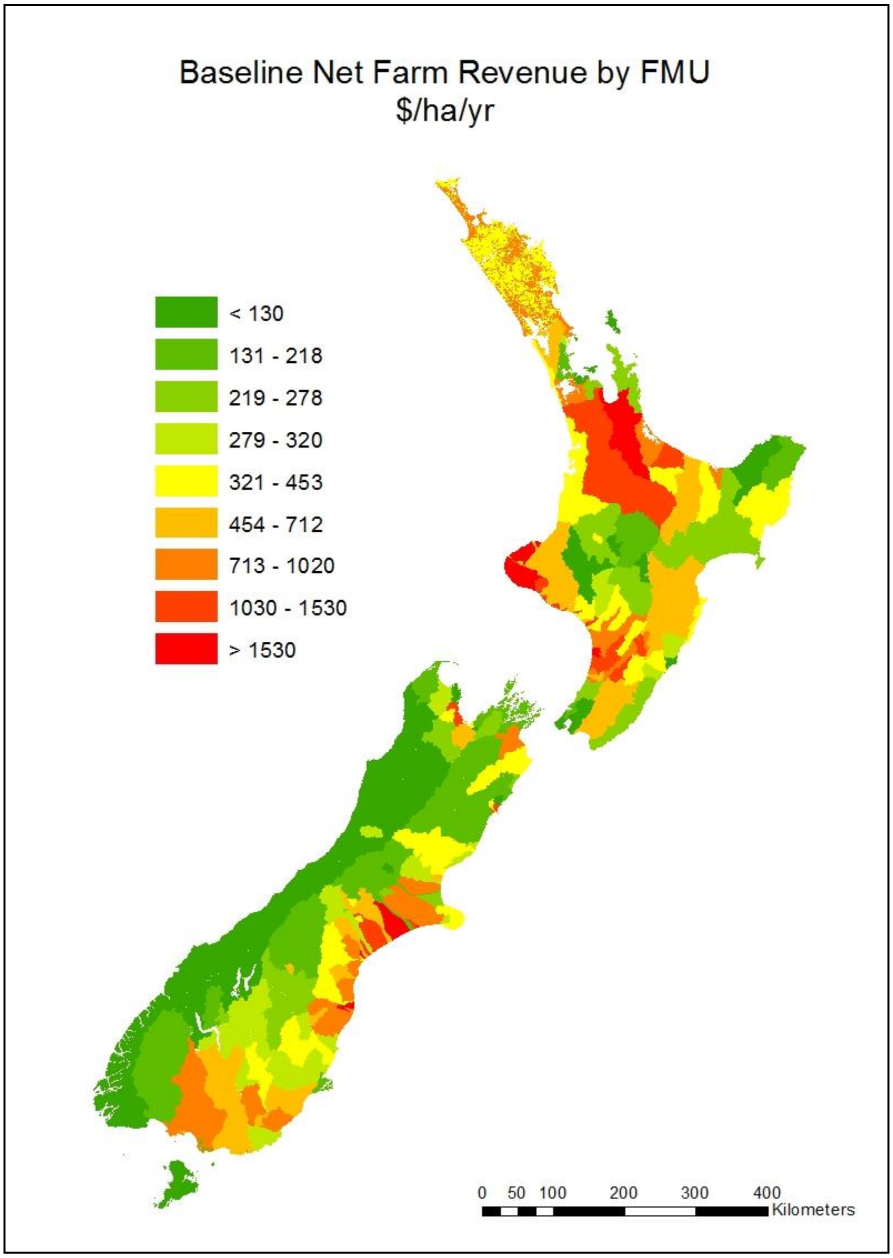


Figure 7: Baseline net farm revenue ($,000/ha/yr).

4 Policy Analysis

Policy scenarios were developed with the intent to take a high-level approach to estimating the impact of the freshwater reforms to GHG emissions if the proposed targets for N, P, sediment and *E. coli* were all met in 2030. For this analysis, we assumed that reductions targets specified for each FMU would be met using a least-cost approach. Thus, the model takes the approach that landowners in each FMU collectively implement the set of mitigation options that allows them to achieve the specified target while achieving the highest net farm revenue possible for the catchment. The core policy scenario assumes that landowners will maintain their current land use (e.g., dairy) but they can choose to implement any of the individual or mitigation bundles. We relax the mitigation assumption for one of the sensitivity cases to assess the possible effect of having the option to plant trees on the farm as well (**Error! Reference source not found.**).

The reduction targets for the core policy scenario are based on the information obtained through the regional council surveys, as displayed in Figure 4. As these targets result in relatively small reductions in New Zealand's freshwater contaminants in aggregate, we conduct two sensitivity cases that assume each FMU must reduce each contaminant by at least 10% or 20% below the baseline. Thus, a FMU that was initially constrained to a 5% reduction in only N based on input from the regional council would instead have to reduce N, P, sediment and *E. coli* by 10%. Running these scenarios allows us to assess what could occur should councils and stakeholders revise their water quality objectives in the future as the freshwater reforms evolve and also receive feedback about whether the initial targets are indeed meeting the objectives of the community.

Table 8. Policy scenario assumptions

Scenario	*Mitigation Options Available*	*2030 Reduction Targets**
Baseline	None. Assume all landowners implement current/baseline practices	None. Assume current loads are maintained through 2030
Core Policy	Individual practices & mitigation bundles	Regional Council (RC) interview info only (non-reported FMUs assume no change)
Core + Afforestation	Individual practices, mitigation bundles, and afforestation	Regional Council (RC) interview info only (non-reported FMUs assume no change)
Min 10% Target	Individual practices & mitigation bundles	All FMUs at least a 10% reduction in N, P, *E. coli*, and sediment from baseline. RC reported targets greater than 10% continue to be implemented
Min 20% Target	Individual practices & mitigation bundles	All FMUs at least a 20% reduction from baseline. RC reported targets greater than 20% continue to be implemented

* from 2015 contaminant levels

An overview of the key assumptions for the freshwater reform policy scenarios modelled in NZFARM is provided in **Error! Reference source not found.**. The key sensitivities are around hether afforestation is a possible option for landowners to mitigate N, P, sediment, and *E.coli*, and the stringency of the FMU-level reduction targets for all 4 contaminants. Detailed results for the 'core' policy scenario are presented and discussed below, followed by some more aggregate results of the sensitivity analysis.

4.1 Core Policy Scenario

A summary of the key policy scenario outputs for New Zealand is listed in Table 9. Based on the information provided by regional councils, the aggregate reductions in N, P, sediment, and *E.coli* are relatively small and range from -1% for P to -16% for sediment. Note also that the targets are only applied in particular FMUs, and thus the impacts in some regions will be more significant than others. Gross agricultural GHGs (primarily methane and nitrous oxide) could be reduced by 0.82 million $MtCO_2e$/yr under the core policy assumptions, along with an additional 0.11 MtCO2e of forest carbon sequestration as a result of planting riparian buffers and pole planting for erosion control (for a net reduction of 0.94 $MtCO_2e$/yr).[13]. As a result of landowners applying mitigation to achieve these targets, net farm revenue declines by 4%, or about $18/ha/yr on average.

Some of the most cost-effective mitigation practices implemented have an effect on more than one contaminant and hence efforts to achieve one more challenging contaminant target will lead to over-achievement of other contaminant targets in the same FMU. By assumption all targets are at met in every FMU; in some cases they will be overachieved. Thus the aggregate reduction in all four contaminants is larger than the aggregate target. Further investigation indicates that sediment reductions are typically close to the intended target at both the national-level aggregate and for many of the FMUs where sediment has an explicit reduction target.

Table 9. NZ Level Core Policy Scenario Estimates

Scenario	Gross GHG* (tCO2e)	Net GHG*,^ (tCO2e)	N Leaching (t)	P Loss (t)	Sediment (Mt)	*E.coli* (peta)	Net Revenue (Bil $)
Baseline	34,182,538	9,272,604	184,314	17,244	125,896	22,161	$11.639
			% Change From Baseline				
Aggregate Target	n/a	n/a	-2.5%	-1.3%	-16%	-6.3%	n/a
Core Policy	-2.4%	-13%	-6.4%	-5.1%	-18%	-9.9%	-3.8%

Table 10 breaks out the key estimates by major land use. Most N leaching, P loss, and *E.coli* reductions occur through mitigation on dairy, sheep & beef farms. The distribution of sediment reduction is spread over a greater number of land uses including land that is already planted with exotic and native trees as well as scrub and tussock. All of the GHG emissions reductions are attributed to pastoral enterprises, with a majority of the impact occurring in the sheep and beef sector, with a gross net reduction of 0.61 (0.72) MtCO2e/yr. Emissions are estimated to increase slightly in the arable and horticultural crop sector as some of the more advanced bundles for mitigating contaminants are potentially more GHG intensive (Table 6).

Table 10. Enterprise-level Core Policy Scenario Findings

Land Use	Gross GHG (tCO2-e)	Net GHG (tCO2-e)	N leaching (t)	P Loss (t)	Sediment (kt)	E.coli (peta)
			Absolute change from baseline			
Dairy	-216,362	-229,526	-5,996	-204	-1,715	-763
Sheep & Beef	-614,645	-719,190	-4,625	-505	-11,086	-1,453
Other Pasture	-3,394	-3,394	-78	-8	-28	-24

[13] GHG emissions from energy use are excluded from this analysis.

Arable & Hort	15,212	15,212	-421	-13	-43	-1
Forestry	0	0	-58	0	-7,602	-2
Native	0	1,031	-76	-1	-978	-2
Scrub & Tussock	0	0	-130	-48	-4,401	-7
Other Land	0	0	-258	-38	-755	-2
NZ Total	-819,188	-935,867	-11,642	-817	-26,608	-2,254
			% Change from baseline			
Dairy	-2%	-2%	-14%	-9%	-44%	-14%
Sheep & Beef	-3%	-4%	-7%	-10%	-32%	-10%
Other Pasture	0%	0%	-1%	-1%	0%	-1%
Arable & Hort	3%	3%	-7%	-17%	-25%	-10%
Forestry	0%	0%	-1%	0%	-35%	-4%
Native	0%	0%	0%	0%	-3%	-1%
Scrub & Tussock	0%	0%	-1%	-2%	-19%	-2%
Other Land	0%	0%	-2%	-2%	-3%	-1%
NZ Total	-2%	-10%	-6%	-5%	-18%	-10%

The mitigation applied to achieve the reduction targets varies across the land uses (

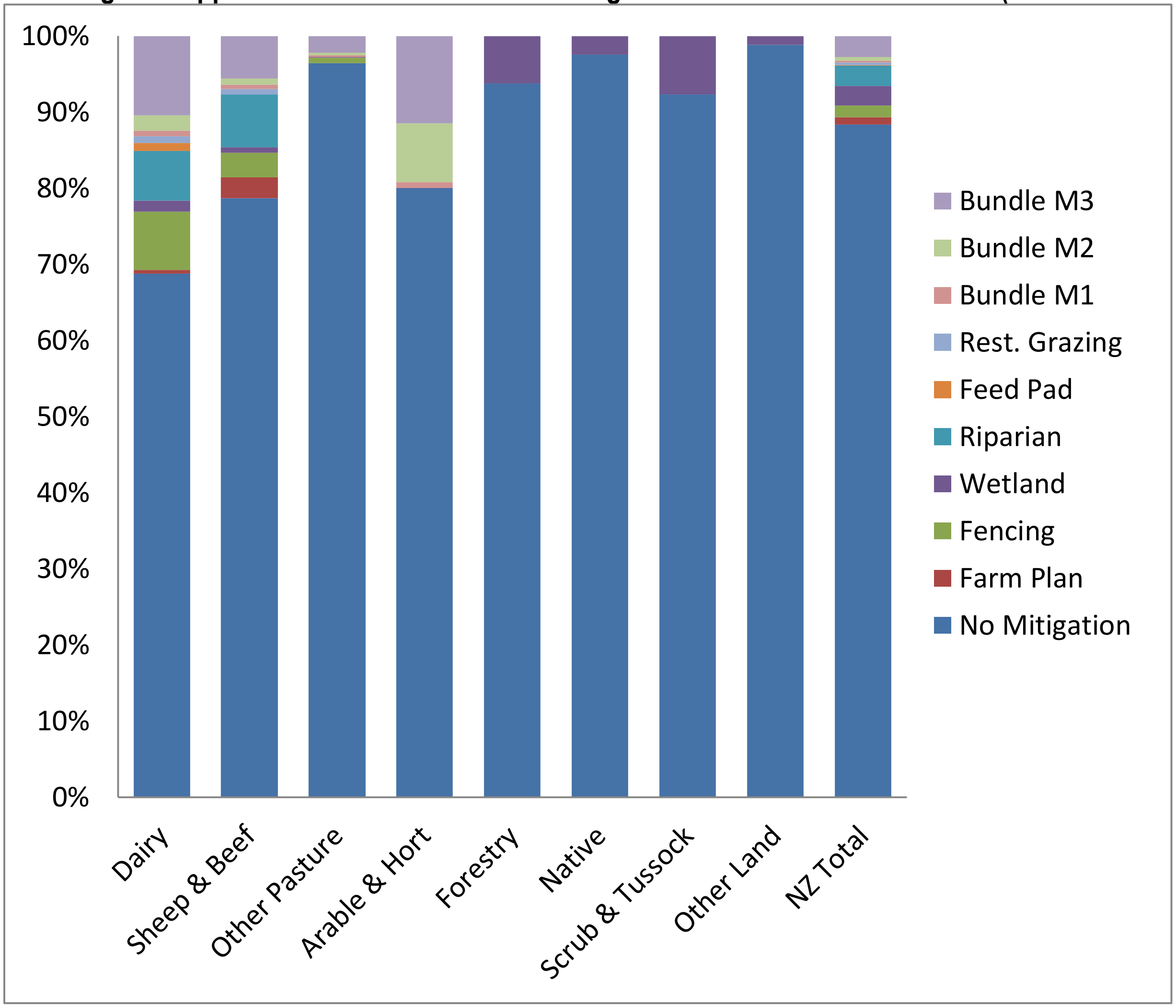


Figure 8), of which about 12% of the total area of NZ (3.0 Mha) is estimated to implement a mitigation practice. NZFARM estimates that there could be a wide mix of mitigation practices implemented on the various land uses. Almost 700,000 ha of productive land are estimated to have a 5m riparian buffer planted adjacent to its streams, while about 667,000 ha of farms and forests could construct wetlands on part of their land to help mitigate freshwater contaminants. The former has an effect on GHGs through both a reduction in area grazed by livestock and an increase in carbon sequestration from planted vegetation, while the latter has no assumed effect on emissions.

Dairy farmers are estimated to implement the greatest amount of mitigation by percent of total area (31%), while sheep and beef farmers are expected to implement the most mitigation on a total area basis (1.8 Mha). Nearly 90% of the land estimated to add or restore wetlands is assumed to occur on already vegetated areas (e.g., forestry, scrub), as this is the only assumed mitigation option for those land uses included in the model.

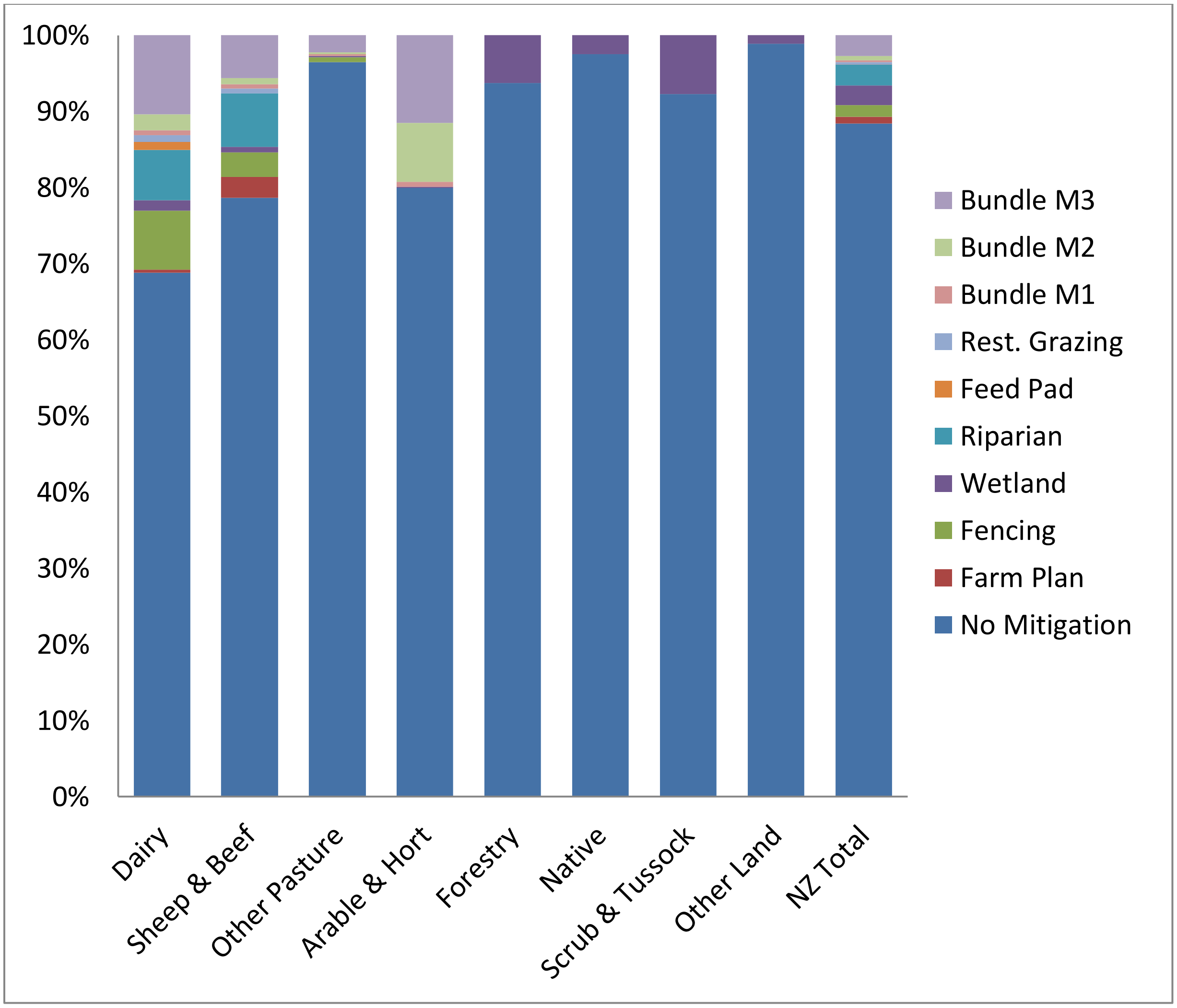


Figure 8: Percent of area for each mitigation option by land use

The source of mitigation in terms of proportion of total area in each region can vary significantly depending on the stringency of the location targets and distribution of land use (Figure 9). Regions with relatively high reduction targets such as Otago, Gisborne, and Taranaki (see Table 3) are expected to implement mitigation on a greater area of total land.

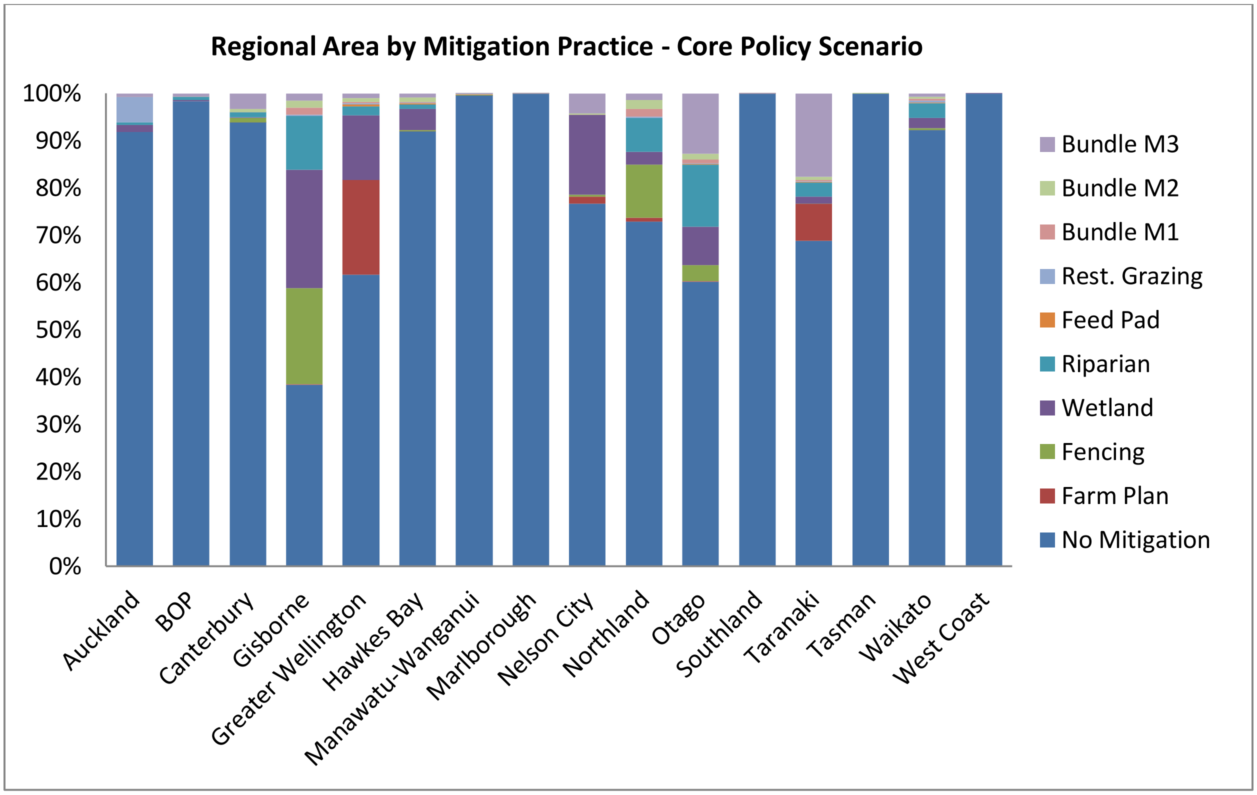


Figure 9. Proportion of mitigation area by region (%)

Figure 10 shows the spatial distribution of contaminant reductions across the FMUs. Comparing this with the distribution of targets specified by the council (Figure 4), we see that in most FMUs that have a target on at least one contaminant results in an estimated decline in all four pollutants. This is because nearly all of the mitigation options have an effect on more than one contaminant. For example while wetlands may be constructed at the edge of a paddock or forest with the primary intent to capture up to 65% of the sediment runoff, it also has the ability to intercept 55% of *E.coli*, 45% of P loss, and 10% of N leaching. On the contrary, the same practice is not expected to have an impact on GHG emissions, as these wetlands are likely to be constructed on areas of farm that have already have low to no productivity and hence will not result in the reduction of livestock or displacement of vegetated land with high carbon sequestration rates.

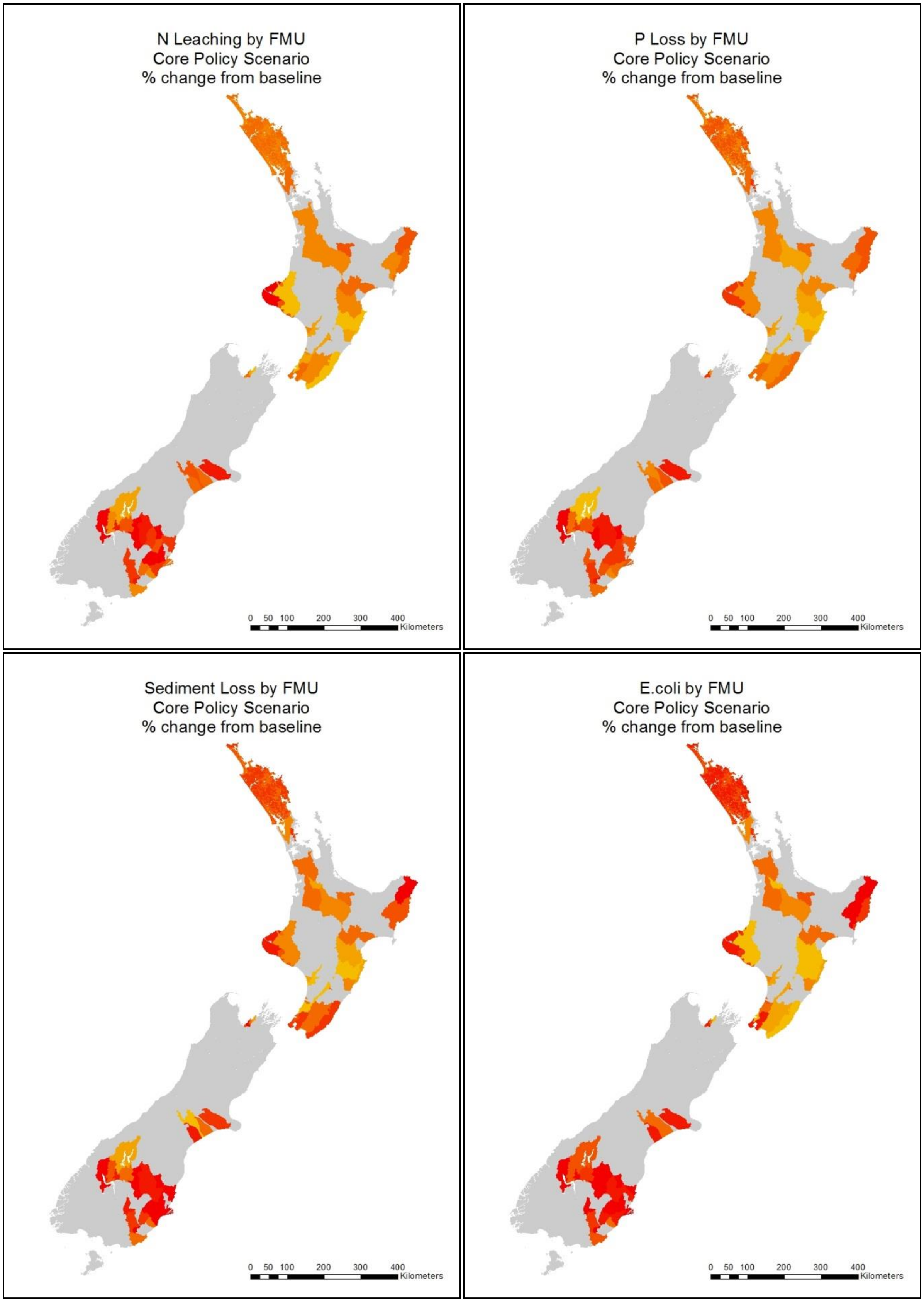

N Leaching by FMU
Core Policy Scenario
% change from baseline
0 50 100 200 300 400
Kilometers
P Loss by FMU
Core Policy Scenario
% change from baseline
0 50 100 200 300 400
Kilometers
Sediment Loss by FMU
Core Policy Scenario
% change from baseline
0 50 100 200 300 400
Kilometers
E.coli by FMU
Core Policy Scenario
% change from baseline
0 50 100 200 300 400
Kilometers

Figure 10. NZFARM estimated contaminant reduction targets by FMU (% below baseline loads)

Figure 11 shows the spatial estimates of how mitigation implemented to achieve the freshwater reform targets could impact net GHG emissions at the FMU level. The figures highlight that emissions are expected to decline in all FMUs that have freshwater contaminant reduction targets due to the types of mitigation that are expected to be implemented. For example, Otago faces large reduction targets for a number of contaminants and hence will have to implement more mitigation bundles and riparian planting, which is estimated to have a large effect on GHGs (**Error! Reference source not found.**). Interestingly, there are a few scattered FMUs where HGs could actually increase over the baseline, albeit just by a couple of percentage points at most. This is because some of the mitigation bundles, particularly the ones for arable and horticultural crops as well as the sheep & beef M2 bundle are estimated to have a positive effect on GHG emissions (see Table 6).

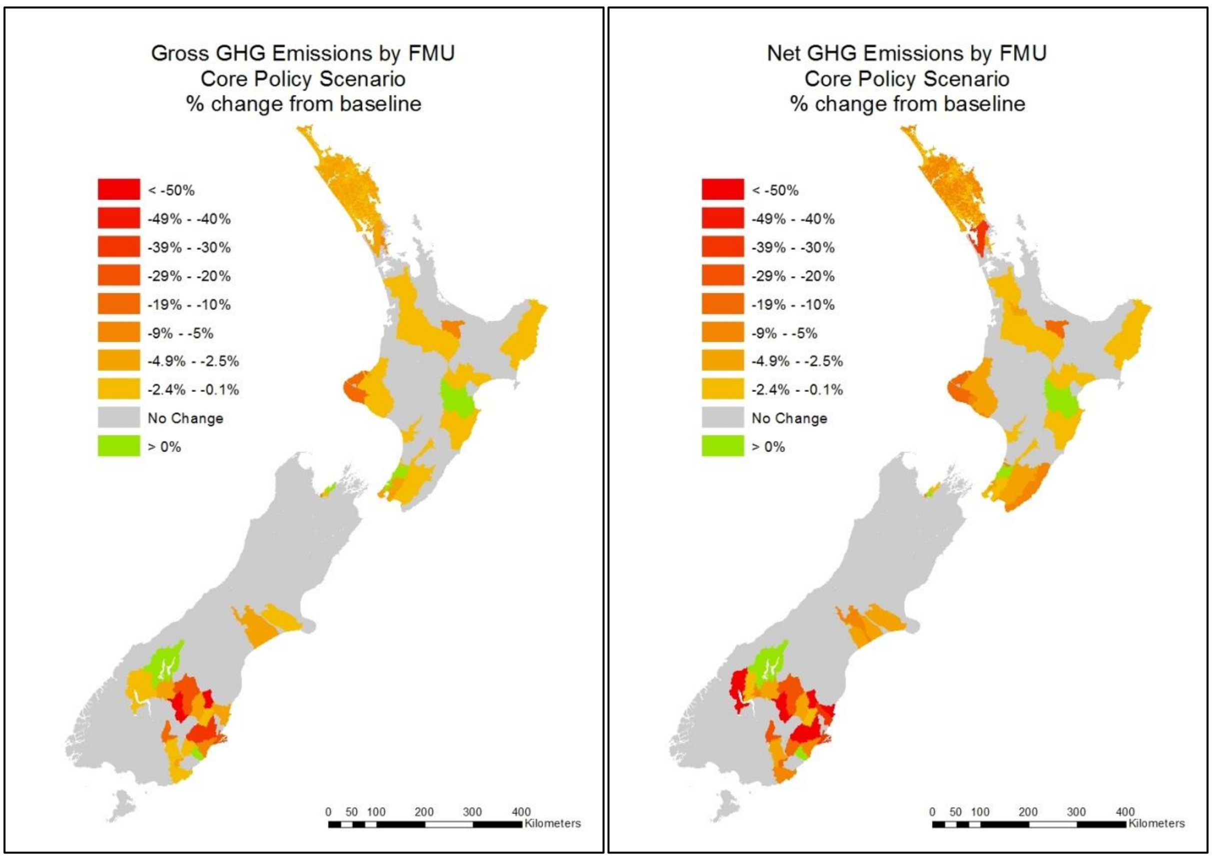


Figure 11. NZFARM estimated net GHG reduction below baseline by FMU (%)

Figure 12 indicates the proportion of total net emissions reductions by mitigation option for the core policy scenario. It is apparent that the M3 mitigation bundle has the greatest impact, producing about half of the emissions reductions. These are reductions in gross emissions. Riparian planting and farm plans with pole planting also have a noticeable effect. These two options reduce GHGs both by reducing stock and increasing forest carbon sequestration associated with planting vegetation so affect gross and net emissions. In the policy scenario that allows afforestation, land-use change into forestry drives most changes in both gross and net emissions.

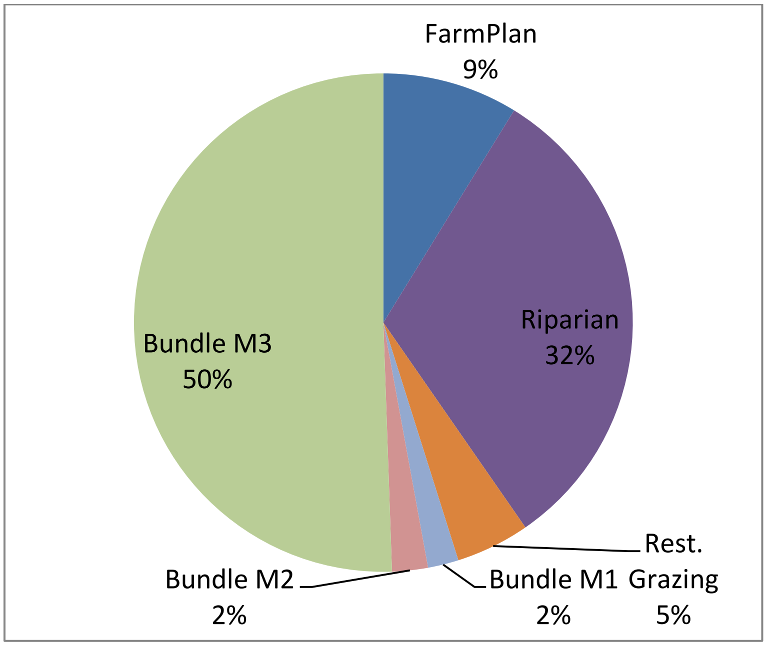


Figure 12. Estimated % of total net GHG reductions by mitigation option in core scenario

There is a large range of estimated changes in net farm revenue for the core scenario (Figure 13). The reductions are mostly correlated with the stringency of the reduction targets, and while 11% of all FMU's are estimated to see a reduction greater than 10% below baseline, about 75% of the FMUs are estimated to experience less than 2% reduction in net farm revenue.

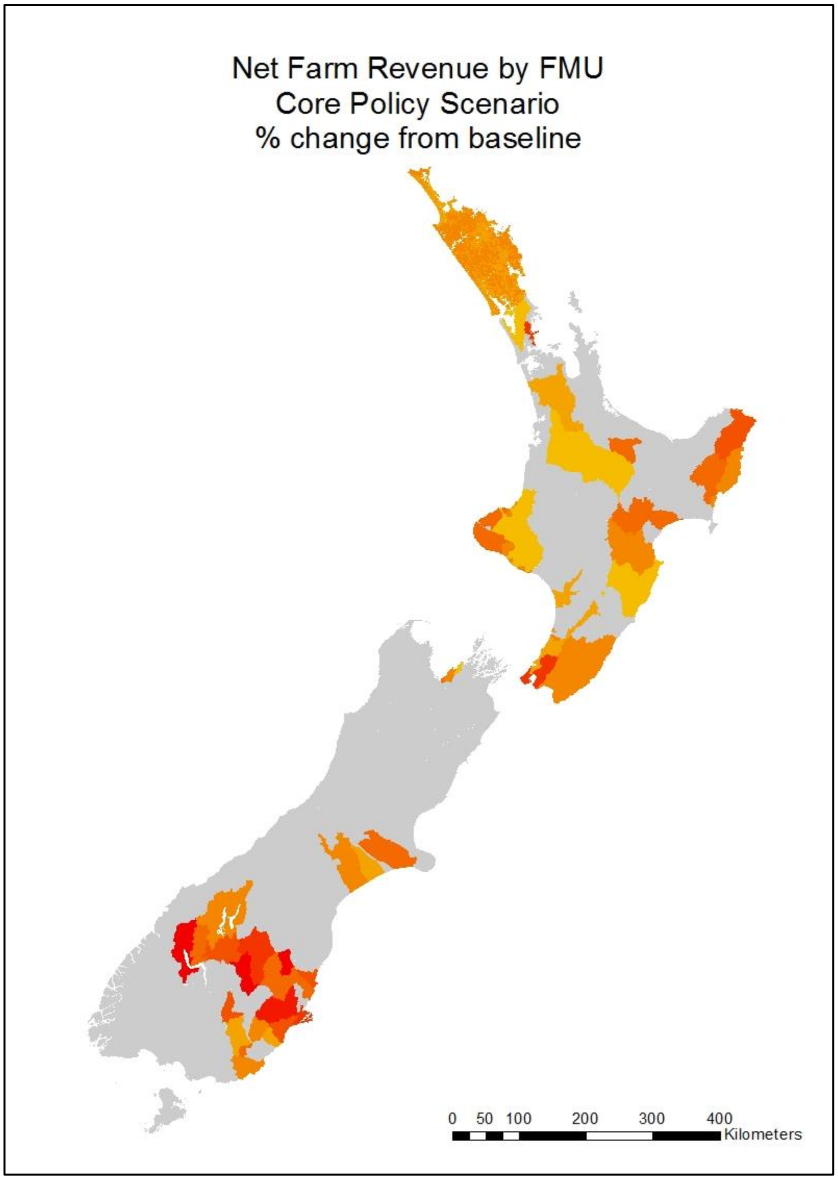


Figure 13. NZFARM estimated net revenue reduction below baseline by FMU (%)

4.2 Sensitivity Analysis

A summary of the key scenario findings at the national-level is listed in Table 11.

Table 11: Summary of key scenario outputs, New Zealand aggregate

Scenario	Gross GHG* (tCO2e)	Net GHG*,^ (tCO2e)	N Leaching (t)	P Loss (t)	Sediment (Mt)	*E.coli* (peta)	Net Revenue (Bil $)
Baseline	34,182,538	9,272,604	184,314	17,244	125,896	22,161	$11.639
			% Change From Baseline				
Aggregate Target	n/a	n/a	-2.5%	-1.3%	-16%	-6.3%	n/a
Core Policy	-2.4%	-13%	-6.4%	-5.1%	-18%	-9.9%	-3.8%

Core + Afforest	-8.4%	-79%	-6.8%	-5.5%	-17%	-9.9%	-9.4%
Min 10% Target	-4.3%	-19%	-16%	-12%	-30%	-27%	-9.0%
Min 20% Target	-4.9%	-23%	-23%	-17%	-37%	-37%	-12%

^ Energy GHGs are excluded from analysis

* Includes gross biological emissions less forest carbon sequestration. Energy is excluded from this analysis.

Figure 14 shows the distribution of mitigation implemented at the aggregate land use level for the full range of policy scenario sensitivities. In the case where an afforestation option is available, some landowners opt to plant trees on approx. 830,000 ha of land in lieu of creating riparian buffers or implementing some of the mitigation bundles. This potentially increases the net reduction in GHG emissions from the agricultural and forestry sector by about 7.3 MtCO2e/yr, of which about 35% is attributed to reduced gross emissions from livestock farms while the remainder (5.4 MtCO2-e/yr) is from additional forest carbon sequestration.

Making the targets for all four contaminants more stringent but holding the original set of mitigation options (i.e. the 10 and 20% minimum reduction target scenarios) constant could reduce gross (net) GHGs by 1.5-1.7 (1.7 to 2.1) MtCO2e/yr. Most mitigation is estimated to occur through wetland construction/restoration, riparian planting, and implementation of mitigation bundle 3. Although two of these options do have the ability to abate GHGs, the effect is at most a 2% (13%) reduction in gross (net) emissions relative to baseline practices (for riparian on deer farms).

Interestingly, we find the effects of moving from a minimum 10 and 20% contaminant load target to be relatively marginal in terms of reducing GHG emissions. That is the 10% target results in a -4.3% (-19%) gross (net) reduction in GHGs, while at 20% case results in a 4.9% (23%) reduction. This suggests that the extra mitigation put in place to further reduce N, P, sediment, and *E.coli* loads may not have an equivalent effect on the relative reductions in GHGs.

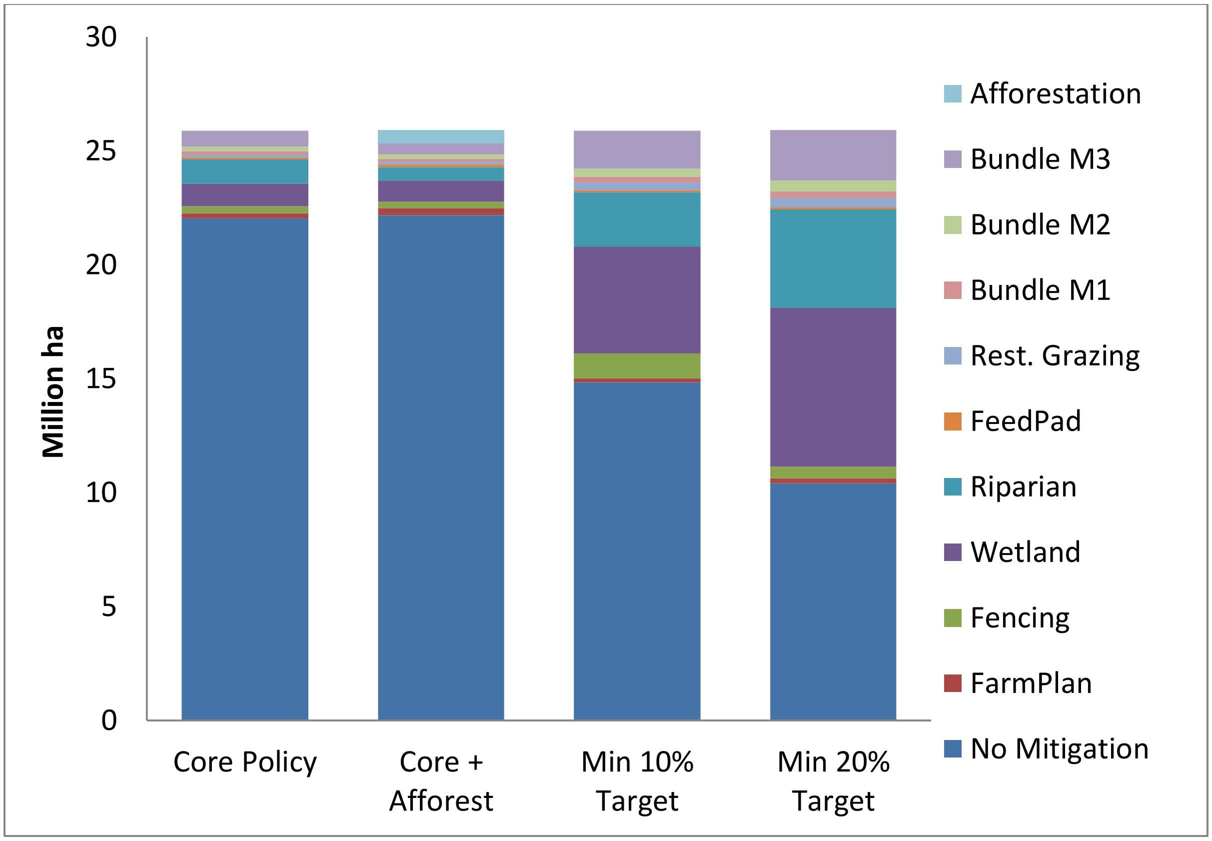
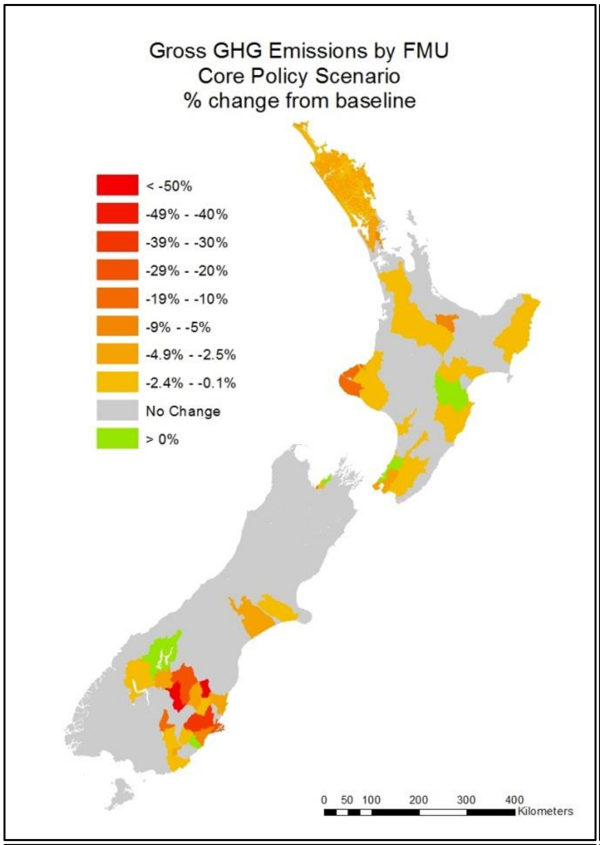
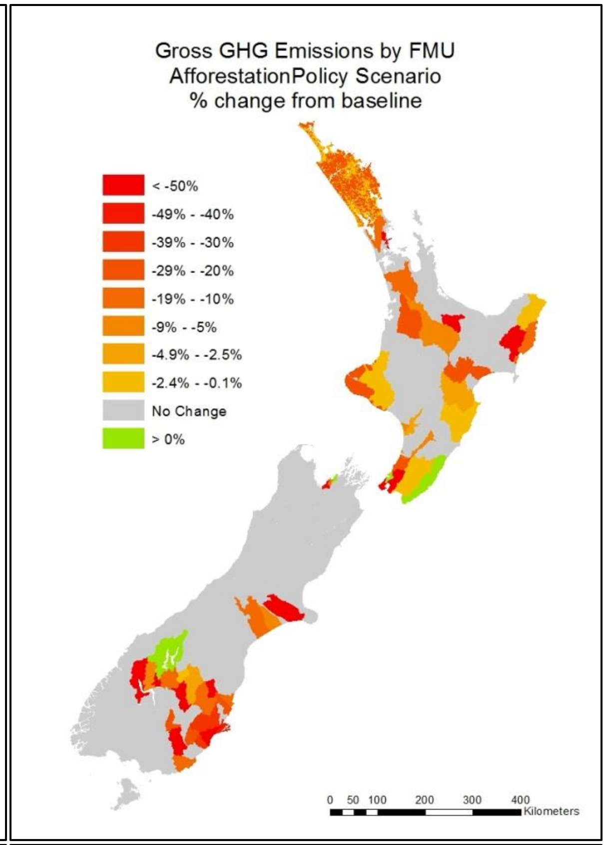
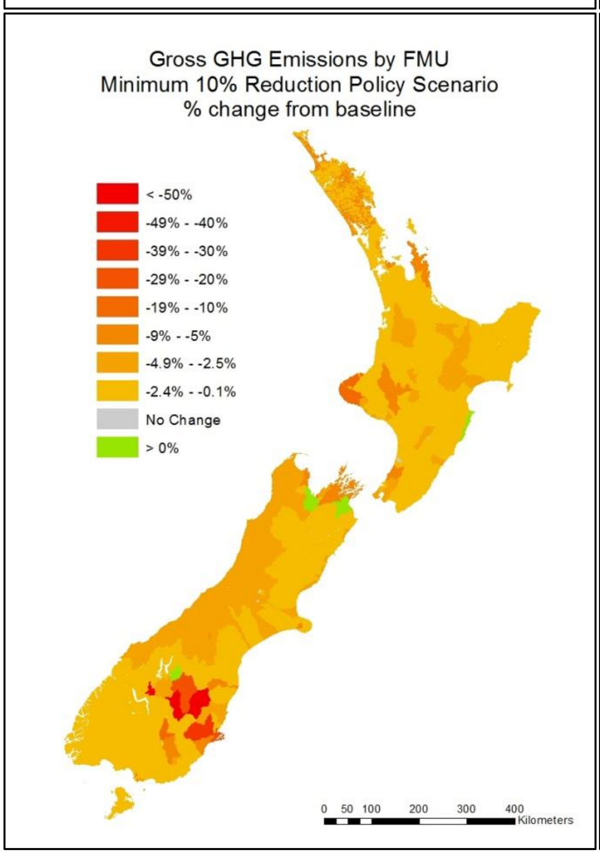


Figure 14: Estimated distribution of total area by mitigation practice

The FMU-level change in gross and net GHG emissions as a result of the different policy scenario assumptions is shown in Figure 15Figure 16 and Figure 16. The figures highlight that in the afforestation case, the largest reductions in emissions are estimated to occur in dairy and sheep and beef-intensive FMUs. In terms of the 10% and 20% minimum reduction scenarios, there is a greater spread in the distribution of emissions reductions, and every GHG emissions are estimated to decline in every FMU. Many of the FMU's are estimated to see emissions abatement of less than 10% relative to the because of the types of cost-effective mitigation practices that are being implemented on the dominant land uses in the region, as discussed above, for which many have a limited impact on GHGs.


Gross GHG Emissions by FMU
Core Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers


Gross GHG Emissions by FMU
AfforestationPolicy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers


Gross GHG Emissions by FMU
Minimum 10% Reduction Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers

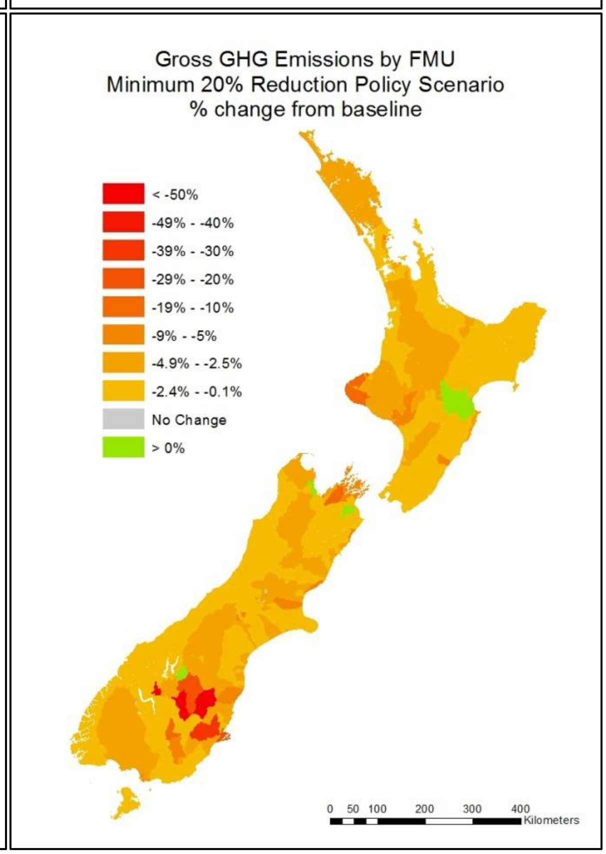
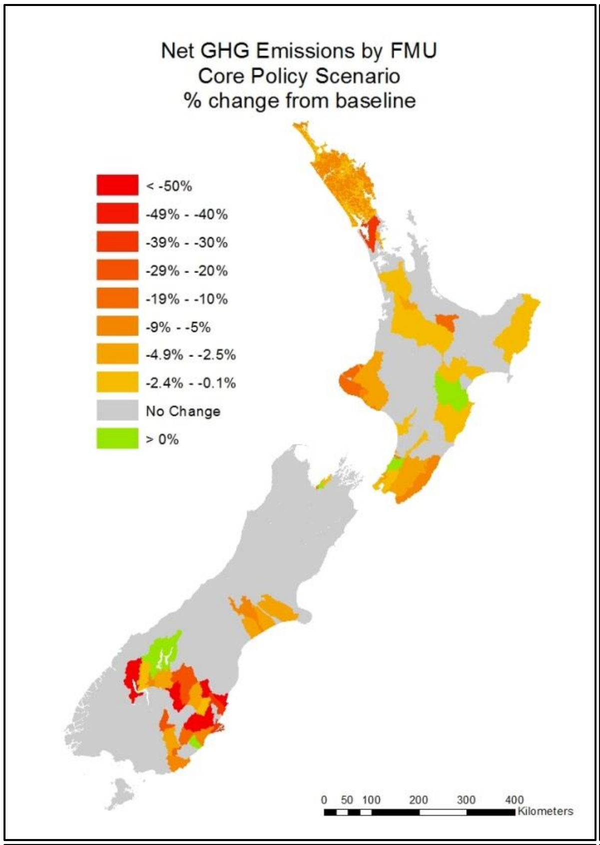
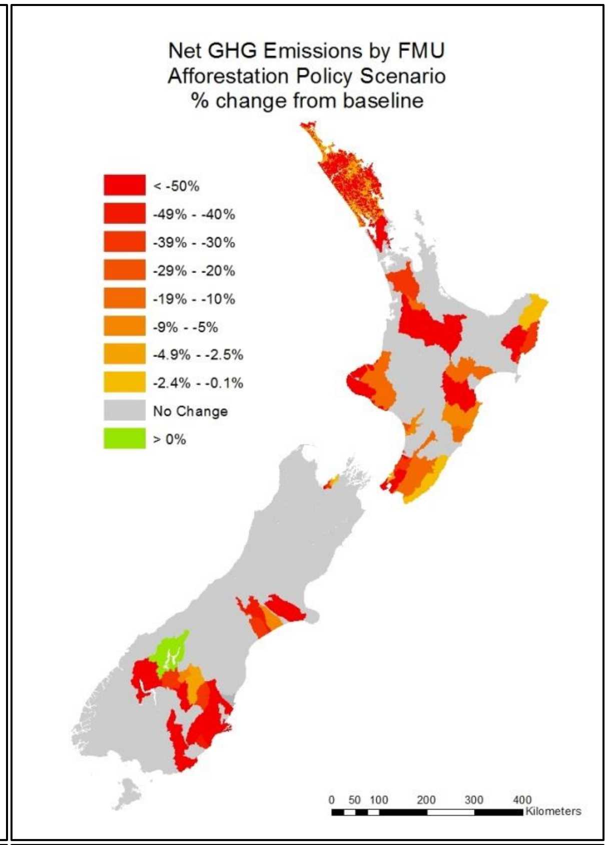
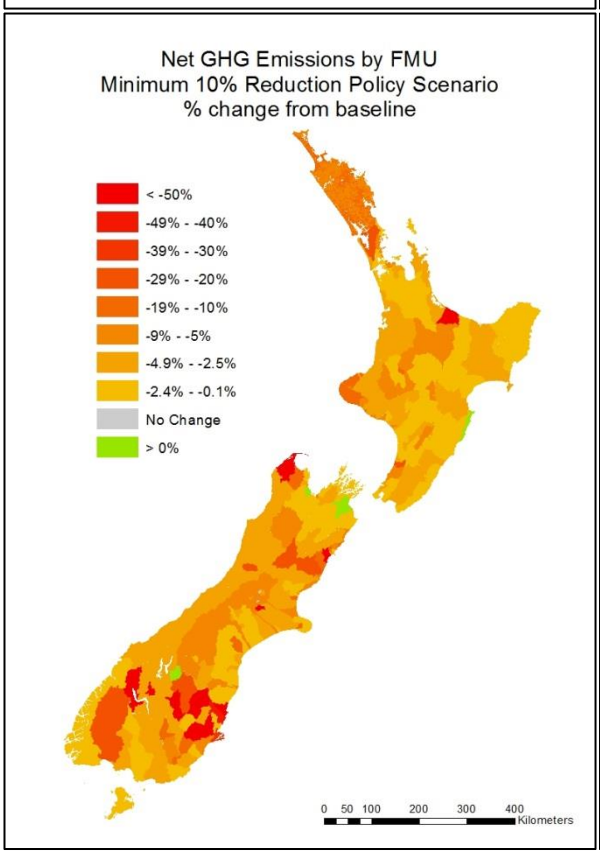

Gross GHG Emissions by FMU
Minimum 20% Reduction Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers

Figure 15. NZFARM estimated change in Gross GHG Emissions by FMU (% below baseline loads) by policy scenario


Net GHG Emissions by FMU
Core Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers


Net GHG Emissions by FMU
Afforestation Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers


Net GHG Emissions by FMU
Minimum 10% Reduction Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers

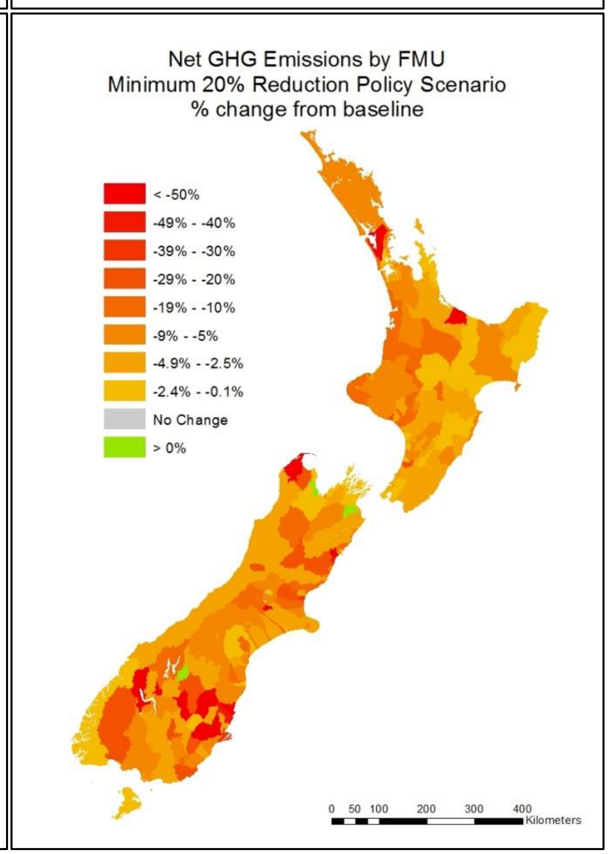

Net GHG Emissions by FMU
Minimum 20% Reduction Policy Scenario
% change from baseline
< -50%
-49% - -40%
-39% - -30%
-29% - -20%
-19% - -10%
-9% - -5%
-4.9% - -2.5%
-2.4% - -0.1%
No Change
> 0%
0 50 100 200 300 400
Kilometers

Figure 16. NZFARM estimated change in Net GHG Emissions by FMU (% below baseline loads) by policy scenario

5 Summary

A summary of the key findings is as follows:

(i) How much might contaminants and GHG emissions fall?

- Based on the information provided by regional councils on the level of freshwater contaminant targets, the aggregate reductions in N, P, sediment, and *E.coli* are relatively small and range from -1% for P to -16% for sediment. Regional councils indicated that (a) most FMUs have a target of maintaining current water quality or (b) they are not at the point where they can indicate/determine what the reduction targets may be. For those who answered (b), we assumed that the FMUs would maintain current loads.

- The aggregate (i.e. NZ-wide) reductions in N, P, and E.coli are greater than the targets intended by the regional councils. This is because actions taken to meet one contaminant's target will often further reduce other contaminants for which the target has already been met. We find that sediment reductions are typically close to the intended target.

- **On-farm:** Agricultural GHGs (primarily methane and nitrous oxide) could be reduced 2.4% or 0.82 million metric tonnes of carbon-dioxide equivalent per annum ($MtCO_2e/yr$) under the core policy assumptions, along with an additional 0.11 MtCO2e of forest carbon sequestration as a result of planting riparian buffers and pole planting for erosion control (for a net reduction of 0.92 $MtCO_2e/yr$ or 13%).[14] In a more extreme case where targets were increased to a minimum of 20% below baseline loads for all four contaminants, gross (net) GHGs could be reduced by about 1.7 (2.2) $MtCO_2e/yr$ or 5 (23) %.

- **Afforestation:** If afforestation is perceived to be a feasible mitigation option, up to 800,000 ha of additional trees could be planted, thereby increasing carbon sequestration by 5.4 MtCO2-e/yr. In this case gross (net) GHGs could be reduced by 2.9 (8.2) $MtCO_2e/yr$, primarily through reduction in stock numbers and increases in forest carbon sequestration. This option could reduce net emissions by nearly 80%.

- Increasing the stringency of the contaminant load target may have a relatively marginal effect on reducing GHG emissions. That is, a scenario where all FMUs are required to reduce contaminant loads by a minimum of 10% below the baseline results in a -4.3% (-19%) gross (net) reduction in GHGs, while a minimum load reduction of 20% scenario results in a 4.9% (23%) reduction in emissions. This suggests that the extra mitigation put

[14] GHG emissions from energy use are also excluded from this analysis.

in place to further reduce N, P, sediment, and *E.coli* loads may not have an equivalent impact on the relative reductions in GHGs.

(ii) Where might mitigation of contaminants and GHGs occur?

- Spatially, areas with high dairy require the greatest reductions in N and P. Regions with high slopes and rainfall require significant mitigation of sediment.

- For the core policy, where all of the GHG emissions reductions are attributed to pastoral enterprises, a majority of the impact occurs in the sheep and beef sector, with a gross (net) reduction of 0.61 (0.72) $MtCO_2e/yr$.

- A majority of the abatement is estimated to occur on dairy and sheep & beef farms, often with a combination of practices that result in stock change. Net GHGs also decrease through mitigation measures such as riparian buffers and pole planting for erosion control.

(iii) How is mitigation achieved?

- A wide range of mitigation options are found to be implemented to meet the various targets. These include riparian buffers, fencing streams, constructing wetlands, and implementing bundles of mitigation practices.

- Nitrogen targets most strongly drive on-farm GHG reductions for all the modelled scenarios that limit mitigation to on-farm changes. This is primarily because actions to mitigate N are most closely related to practices that can also mitigate GHGs (e.g., stock management).

- GHG emissions reductions are a combination of reduced emissions through changes in management and de-stocking and increased carbon sequestration associated with planting riparian buffers or afforesting part of the farm. Some of the sequestration may be in relatively small areas and hence may not be recognised in New Zealand's National GHG Inventory using current methodology.

- In some FMUs, when 10 or 20% minimum mitigation targets are applied, mitigation in the form of wetland construction/restoration adjacent to 'non-traditional' agricultural land uses such as exotic forest plantations and native bush, and to other classifications (e.g., lifestyle) are needed to meet targets. This is because of the composition of land use in the FMU and loads associated with each use, particularly those with high sediment reduction targets. Note that this finding is consistent with recent mitigation analyses that have focused on the feasibility of wetlands to achieve sub-catchment level objectives (e.g., Daigneault et al 2015).

- the total area of mitigation is relatively consistent for the 'core' and 'core+afforestation' case, but the distribution of practices implemented can shift from riparian and bundle M3 (i.e., systems change) to afforested blocks. For the two scenarios with at least 10% reduction targets for all of the contaminants, the total area of mitigation requires increases significantly. This is particularly the case for land where riparian buffers and wetlands are constructed at the edge of the fields or forests.

- The M3 mitigation bundle has the greatest impact on GHG reductions, producing about half of the emissions reductions (all contributed to gross emissions change). Riparian planting and farm plans with pole planting also have a noticeable effect on emissions. These two options reduce GHGs both by reducing stock and increasing forest carbon sequestration associated with planting vegetation so affect gross and net emissions. In the policy scenario that allows afforestation, land-use change into forestry drives most changes in both gross and net emissions.

6 References

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Appendix A - Freshwater Contaminant Limit Assessment of the Regions

1 Introduction

This report provides freshwater contaminant limit assessments for the regions for phosphorus, nitrogen, *E. coli*, and sediment. The assessments will be used for a national modelling exercise using New Zealand Forestry and Agricultural Regional Model (NZFARM) to help estimate impact of the implementation of the National Policy Statement for Freshwater Management (NPS-FM) 2014 on New Zealand's greenhouse gas emissions.

Information about freshwater management areas (including, where available freshwater management units (FMUs)), priority catchments, relevant mandatory requirements, other practices, and non-regulatory policies that reduce contaminant loads, and limit setting in the regions are covered in the report. This information is used to estimate high and low scenarios for the expected change in levels of phosphorus (P), nitrogen (N), *E. coli*, and sediment in the freshwater of each region between 2015 and a future date such as 2030.

The report also includes information on baseline loads created by NIWA from the CLUES model.

This report fulfils Milestone 5, Limit Assessment, of the study entitled: Climate Change Co-benefits of the Freshwater Reforms. This report was revised in June 2016 but did not include any new information on FMU delineation or limits that may have been finalised between March and June 2016. This is primarily due to the modelling analysis in the final report being based on the available information in March 2016.

2 Methodology

Motu Public Policy and Research (Motu), Landcare Research and AgResearch worked together to gather this information from Regional Councils. AgResearch approached the six councils they were already liaising with for its deliverables under a complementary project. Motu and Landcare Research collected the data for the remaining councils. Information was collected through in-person meetings, email and phone calls. The information we attempted to collect from each council included:

1. A map of regional catchments and/or agreed or proposed freshwater management areas. While all Regional and Unitary Councils will eventually have NPS-FM FMUs delineated for their regions, not all councils have completed that process. Therefore, the map delineates a mix of management zones, FMUs, priority catchments and other types of catchment delineations as noted by the individual councils.
2. Any relevant water policy documentation/plans.
3. Any concerns about contamination from nitrogen, phosphorous, sediment and *E. coli* in the region.
4. A list of priority catchments/FMUs where these contaminants are being actively managed
5. Specific reduction targets or limits that have been proposed or agreed for each water management zone. In this report we will use the limits and target terminology used in each region. Where this is unclear or where we have manipulated the data for use in our modelling we will use the term limits to refer to both where existing water quality is better or worse than the desired state (we acknowledge that many regions use the term target as the limit they are wanting to reach where water quality is worse than the desired state).
6. In the event that water quality limits or targets are not yet established, a range for the potential limits/targets for each water management zone (e.g. 5–10% decrease in nitrogen, no change in phosphorous, 20% increase in *E. coli*, etc.) was specified. This range for the potential limits is based on a percentage change in the estimated current load (or baseline). This percentage change is either a reduction in contaminant loads or no change in load. The current load is estimated based on 2012 land use. This is the most current national land use

map that was available. This map had previously been generated for other national level economic analyses (Daigneault et al. in review).

7. The timeframe to achieve any limit for each water management zone.
8. Mandatory practices that landowners must undertake in any region (e.g. stock exclusion[15]) as part of any regional plan or proposed regional plan.
9. Additional practices landowners are currently undertaking to reduce the different contaminant loads in each water management zone (e.g. farm plans for erosion control).

More details on the questions asked to each regional council are provided in Appendix 1.

3 Northland

Freshwater Management Units

The FMUs for Northland are being finalised in March 2016. For the purposes of managing river water quality, Northland Regional Council (NRC) have divided rivers into lowland rivers and hill country rivers based on catchment slope, which appears to be the best explanatory variable for most but not all water quality parameters. With regard to managing river water quantity, NRC has divided the region's rivers into four classes based on river size, climate, and proximity to coast: coastal streams, small rivers, large rivers, and warm extremely wet rivers. For lakes, NRC has divided natural lakes into four classes: shallow (<10 m) perched, deep (>10 m) perched, shallow window, deep window. NRC has also divided aquifers into four classes: shallow coastal, deep coastal, other mapped, and unmapped. In addition, NRC has specified that there will be catchment (i.e. water body) specific FMU's across all water body types. They define catchment-specific FMU's as catchments where good information is available on current state and resource use capacity with respect to local values. The council has stated that lake and aquifer FMUs will correspond with natural catchment boundaries, but the river FMUs are based on other variables.

The situation with N, P, sediment, E. coli contamination in Northland and priority catchments

The main contaminants of concern in Northland's rivers are sediment and faecal microbes (e.g. *E. coli*). Nutrients are more of an issue in NRC's dune lakes.

NRC has identified six priority catchments (Whāngārei Harbour, Mangere, Waitangi, Poutō Peninsula, Doubtless Bay, and Ngunguru). All are considered relatively small catchments and were selected for various reasons, however NRC has indicated that the Whāngārei Harbour and

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[15] Note: stock exclusion is being proposed as a national requirement under the 2016 Next steps for fresh water consultation document (http://www.mfe.govt.nz/fresh-water/reform-programme/freshwater-reforms-2016P

Poutō Peninsula are the only areas with significant water quality or quantity related issues. Catchment groups in Mangere, Waitangi, Doubtless Bay, Whāngārei, and Poutō are currently working on catchment plans (with voluntary and regulatory elements) with a goal to have these draft catchment plans ready by mid-2016. The Ngunguru catchment group started in November 2015 and is focused on developing an erosion and sediment management plan that is due for completion by November 2018.

Freshwater quality limits in Northland

NRC intends to set concentration limits for the compulsory attributes in the NPS-FM. They have no intention in the near future to set contaminant load or property scale loss limits, given the costs and practicalities (and the lack of intervention logic) to do so.

The council anticipates that the key policies targeting improvements in river and lake water quality are compulsory stock exclusion, slightly tighter controls on farm dairy effluent discharges and land disturbance activities, and outreach and support for good management practices (GMPs). Stock exclusion requirements are likely to be similar to the recent recommendations of the Land and Water Forum. NRC does not anticipate that their existing or new water quality controls will cause any substantial land use change. The latest Regional Water and Soil and Coastal plans provide details on current controls that have already been implemented in the region.

4 Auckland

Freshwater Water Management Units

Auckland Council has defined nine water management areas. These include: Manukau Harbour (includes Mangere, Drury, Pukekohe area), Wairoa (includes Hunua Ranges), West Coast, Waitemata, Greater Tamaki, Hibiscus coast, Maharangi, Northeast coast, and the South Kaipara Harbour. FMUs within each water management area have not yet been defined.

Nitrogen, phosphorous, sediment, and E. coli contamination in Auckland Region

Nitrogen is believed to be an issue in the Manukau Harbour, and it is likely that a substantial reduction will be required to meet the NPS-FM attribute bottom lines. Sediment is the most pressing issue in the Kaipara Harbour, as is *E. coli* (which is likely to be dealt with through addressing the sediment loss). Phosphorous is generally not believed to currently be an issue in the region.

Mandatory requirements

Auckland Council has not specified any mandatory requirements for landowners in the region beyond what is already included in the Regional Plan. They are exploring economically feasible options to reduce nitrogen in the Manukau Harbour, which could be partially achieved through best management practices.

Other practices and non-regulatory policies of note that reduce contaminant loads

The council did not specify any other policies of note that could help reduce contaminant loads.

Freshwater quality limits in the Auckland Region

Potential limits for each water management area in the Auckland Region were developed in consultation AC staff involved with NPS-FM implementation (Table 1). This limit range is expressed as a percentage change from current loads. Note that these limits are only for changes in agricultural and forestry sector contaminants as urban pollutants were not discussed. The limits are also not the definitive limits for the region and are subject to change based on additional science, council investigations and outcomes of limit setting processes.

Table 1. Potential limit ranges for Auckland Council (% change from baseline), by water management area

Water Management Area	Nitrogen	Phosphorous	Sediment	*E. coli*	Comments/notes
Manukau Harbour	model best practice, 20, 30, 40, 50 % decrease	No change	No change	No change	Some mangrove clearance in the Puhiri & Mangere areas; *E.coli* is naturally high; lots of houses going in (likely to reduce sediment and N); N is the big problem (likely need large reduction to meet National Objectives Framework) but not sure how far they can actually reduce or is economically feasible to reduce (fertiliser is the issue); best thing to do is to model best practice
Wairoa	No change	No change	0%, 10% increase	No change	Forestry operations are big in area; one issue is going to be that the new Forestry National Environmental Standard is weaker than Auckland Council rules so could be an increase in sediment as a result
West Coast	No change	No change	No change	No change	Mostly forestry
Waitemata	No change	No change	No change	No change	Urban
Greater Tamaki	No change	No change	No change	No change	Urban
Hibiscus coast	No change	No change	No change	No change	Mostly urban with a little forestry inland

Maharangi	No change	No change	No change	No change	Significant investment in this catchment already on improving ag practices but don't know if they have really made a difference
Northeast coast	No change	No change	No change	No change	Mostly lifestyle blocks with some sheep and beef, maybe some wetlands going in
South Kaipara Harbour	No change	10-20% decrease	No change	No change	Sediment is the big issue, mostly related to sheep and beef. *E. coli* is natural (some sheep and beef *E.coli* but likely this will be dealt with when address sediment loss)

5 Waikato

The Waikato Regional Council has only established limits and a policy to achieve these limits for the Lake Taupo catchment. It is still undergoing the process of defining limits for the other catchments in the region. The Healthy Rivers Wai Ora process will be defining limits for the Waikato/Waipa catchments in May 2016. There are eight FMUs for these catchments (Healthy Rivers 2016). As a result, this section only discusses the limits for the Lake Taupo catchment.

Freshwater Water Management Units

Lake Taupo is New Zealand's largest lake and has very high water quality. The lake and its catchment are within the rohe of Ngati Tuwharetoa, who own much of the land in the catchment, including the bed of the lake. Variation 5 to the Waikato Regional Plan is focused on protecting the existing high water clarity in Lake Taupo. It became operative in July 2011.

Nitrogen, phosphorous, sediment and E. coli contamination in Waikato Region

The contaminant discharge of concern in Lake Taupo is nitrogen. Sources of nitrogen that can be reduced through management are relatively limited, and primarily include human wastewater and pastoral farming. Pastoral farming represents around 40 percent of the total load of nitrogen to the lake, and 93 percent of the manageable load.

Mandatory requirements

Around Lake Taupo, farmers are required to prepare a Nitrogen Management Plan that describes how the farm will be managed over the farming year within the nitrogen limit for the property or properties, including livestock levels, nutrient applications, and feed regimes.

Freshwater quality limits in the Waikato

In 2011, Waikato Regional Plan Variation 5 – Lake Taupo Catchment became operative, and was inserted as Chapter 3.10 of the Waikato Regional Plan.[16] In the Taupo cap-and-trade scheme, the cap restricts nitrogen use through the resource consenting process. A resource consent, applied for by a farmer, sets the property-level nitrogen limit expressed both as a nitrogen discharge allowance (NDA – kg/ha/yr) and total annual discharge allowance (TAND – kg/yr). The nitrogen limit is a right to discharge diffuse nitrogen emissions, and is held by farmers to enable them to continue farming activities. Nitrogen can be traded permanently or through a temporary lease agreement. Trading involves formal (via the resource consent processes) adjustments to the resource consents held by the purchaser and the seller. All resource consents have a common expiry date of 2036, and are subject to changes that may occur as a result of reviews of the nitrogen removal target and its method of achievement.

A 20 percent reduction of nitrogen from municipal sewage schemes and pastoral land is signalled in objectives and policies of the Waikato Regional Plan. This will be achieved through Taupo District Council's ongoing upgrades to sewage treatment, and public funded buy-back of nitrogen through a specially formed charitable trust (Lake Taupo Protection Trust) respectively.

As of early 2014:

- All farms in the catchment have been benchmarked, nitrogen limits have been set, and farms are now under a resource consenting system.
- The 20 percent reduction target has been met by the Lake Taupo Protection Trust (the Trust) – on budget and within the time limit specified.
- The policy is on-track to achieve the environmental target of 2001 levels of water quality and clarity by 2080.
- The market appears to be operating efficiently (Barnes & Young 2013; Duhon et al. 2015; Kerr et al. 2015). Private trades still occurred during the time the Trust was dominant in the market, and are expected to continue to do so.
- The monitoring regime has been established, using desk top audits of farmer-supplied financial information, as a first filter of compliance, and a risk-based approach to the frequency of audits and need for on farm monitoring inspections.

[16] Information about the Lake Taupo nitrogen cap and trade scheme has been adapted from: Waikato Regional Council, *Case Study I: Lake Taupo catchment property-level nitrogen discharge limits*, 2014

6 Bay of Plenty

Freshwater Water Management Units

The Bay of Plenty (BOP) Regional Council has specified nine water management zones for the region. These include: Kaituna, Maketu and Pongakawa; Ohiwa Harbour and Waiotahi; Rotorua Lakes; Tarawera; Tauranga Harbour; East Coast; Waioeka and Otara Whakatane and Waiman;, and Rangitaiki.

Nitrogen, phosphorous, sediment and E. coli contamination in Bay of Plenty Region

Waterbodies in the BOP are mostly affected by nitrogen and phosphorous. The Rotorua Lakes area is particularly affected by nutrient discharges from diffuse sources, although there are also some issues with sediment.

Mandatory requirements

Rules of the Rotorua Te Arawa Lakes Programme are based on the Lake Rotorua groundwater catchment. The goal is to reduce the nitrogen load to Lake Rotorua by 320 tonnes to achieve an annual nitrogen load to the lake of 435 tonnes by 2032 (from current load of 755 t N/y), with 70 percent of this load reduction to be reached by 2022.

The strategy to achieve this reduction target is to remove 50 t N/y through "engineering solutions" (to remove geothermal sources of N) and 30 t N/ha through gorse removal. A further 96 t N/y from dairy and 44 t N/y from drystock will be removed through Nitrogen Discharge Allowances (NDAs), and the remaining 100 t N/y through an incentives scheme to further incentivise nitrogen reduction actions.

Part of an individual farm property or a farming enterprise's nitrogen management plan shall identify the risks of sediment and phosphorous loss and best practices to reduce those losses shall be implemented.

Conditions set on forestry enterprises are that there is no grazing on the land, no transfer of NDAs and the period between harvesting and replanting is less than two years.

Freshwater quality limits

The BOPRC has only set limits for the Rotorua lakes (Table 2). The nitrogen limit is to be met through reductions from the land-based sectors (such as dairy and drystock), engineering solutions, and gorse removal. Approximately 53 percent of the total nitrogen reduction target is expected to come directly from changes to dairy and drystock farming (a 27percent reduction from their baseline N loads). Phosphorus limits are not specifically set, but are typically based on a lake's target trophic level index.

The council is currently rolling out the Water Project, which will be setting the limits for the remaining water management zones.

Table 2. Agreed limit or potential limit range in Bay of Plenty Region (% change from baseline), by water management zone

Water Management Zone	Nitrogen	Phosphorous	Sediment	*E. coli*	Notes/Comments
Kaituna, Maketu and Pongakawa	n/a	n/a	n/a	n/a	n/a
Ohiwa Harbour and Waiotahi	n/a	n/a	n/a	n/a	n/a
Rotorua Lakes	42% decrease	co-benefit of N decrease	No change	No change	27% N decrease from drystock and dairy
Tarawera	n/a	n/a	n/a	n/a	n/a
Tauranga Harbour	n/a	n/a	n/a	n/a	n/a
East Coast	n/a	n/a	n/a	n/a	n/a
Waioeka and Otara	n/a	n/a	n/a	n/a	n/a
Whakatane and Waimana	n/a	n/a	n/a	n/a	n/a
Rangitaiki	n/a	n/a	n/a	n/a	n/a

n/a indicates there are no limits in place for these water management zones

7 Gisborne

Freshwater Water Management Units

The proposed Gisborne Regional Freshwater Plan, published in October 2015, has only established FMUs in the Waipaoa Catchment Plan.[17] There are three FMUs proposed for this catchment: Waipaoa Hill Country; Gisborne Urban; and Poverty Bay Flats. The largest FMU, Waipaoa Hill Country, is largely rural and is rolling to steep hill country composed mainly of soft sedimentary materials. Land use is predominantly pastoral grassland with scattered blocks of exotic forestry in the upper catchment areas. Farming is a major land use activity. Hill Country water bodies are also significant for their ecosystem health and natural character. Water quality across this management unit is generally good although some localised water quality issues exist and relate to specific water bodies.

[17] http://consult-gdc.objective.com/portal/plans/pfwp15?pointId=s1442642545186#section-s1442642545186

Gisborne is located near the convergence of three different rivers. With the majority of the region's population living and working in the urban environment, the centrality of the city's waterways and people's exposure to them make water quality a critical issue. The two prominent freshwater bodies in the Gisborne Urban unit are the Taruheru River and the Waikanae Stream. These waterways are identified as having important in-stream and indirect amenity values including swimming, boating, and fishing. The establishment of an Urban FMU provides a spatial context for dealing with urban challenges, such as the high proportion of hard surfacing and the stormwater network.

The Poverty Bay Flats cover over 20,000 hectares of land around the lower Waipaoa River valley.[18] The area receives an annual rainfall of between 650 mm and 1640 mm and often experiences drought conditions. The management unit is used intensively for arable farming, market gardening, horticulture and viticulture. Groundwater is important to irrigation on the Poverty Bay Flats as the Waipaoa River is often subject to low flows during summer months as well as high sediment loading following storm events.

Nitrogen, phosphorous, sediment, and E. coli contamination in Gisborne District

The overall purpose of the Proposed Gisborne Freshwater Plan is to guide the sustainable management of the region's rivers, streams, lakes, wetlands, and groundwater. *E. coli* and sediment have been prioritised in the region.[19] Improving water quality in this region is strongly tied to reducing erosion and reducing opportunities for faecal contamination of waterways. River water quality is generally good in that it does not indicate high levels of nutrients, and biological indicators are generally good.

Reducing erosion rates and the effects erosion has on waterways has long been a key issue for Gisborne.[20] Soft sedimentary rocks dominate the region. Council's soil conservation activities seek to mitigate or prevent soil erosion caused by historical bush clearance for pastoral farming as well as more recent tree removal and earthworks.

Mandatory requirements

The Sustainable Hill Country Project established the requirement for tree planting or maintaining tree cover on the most erosion-prone land. Works are to be completed and effective tree cover established by 2021. By mid-2012, 61 percent of properties and 90 percent of the most erosion-prone land had Works Plans completed or being progressed. The Combined Regional Land and

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[18] Adapted from the proposed Gisborne Regional Freshwater Management Plan

[19] The summary of the situation in the region regarding contaminants has been adapted from the proposed Gisborne Regional Freshwater Management Plan

[20] Adapted from: AgResearch, *Climate mitigation co-benefits arising from the Freshwater Reforms: Summary of policy and agricultural landscape: Report prepared for MPI (Milestone Report 1)*, 2015

District Plan requires that the most erosion-prone be treated with effective tree planting or reserve fencing.

There are existing rules for riparian areas that control earthworks, vegetation clearance and structures. There is no regulation of stock access to waterways, and current rules allow stock entry to waterways. In comparison with other regions, the intensity of most farming operations would not warrant a blanket stock exclusion rule in this region.

There is also a requirement for intensive land users to have farm environmental plans.[21] The main activities that are expected to result from the farm plans in each FMU are listed in the table below.

Table 3. Key activities as a result of farm plans in Gisborne District

FMU	Main activities in farm environmental plans that affect nitrogen, phosphorous, *E. coli*, and sediment
Waipaoa Hill Country	Install stock crossings and stock exclusion for intensively stocked locations Move or bund and treat runoff from woolsheds Willow and native riparian planting Slope erosion planting of poplars Move silage pits/offal pits to better locations Install water reticulation systems for stock water
Gisborne Urban	n/a
Poverty Bay Flats	Install stock crossings and stock exclusion for intensively stocked locations Willow and native riparian planting Constructed wetlands Various horticultural practices (earthworks, harvesting methods, fertiliser use) changes in accordance with Code of Practice for Vegetable Growing Growing green crops over winter rather than leaving fallow, etc., practices for maize

Freshwater quality limits in Gisborne

The Gisborne District Council has proposed freshwater concentration limits for the Waipaoa Catchment and is setting these limits through the development of catchment management plans. The plans are set out in the proposed Gisborne Regional Freshwater Plan. The council wishes to balance the limit-setting process with the NPS-FM requirement to maintain or improve the overall quality of water within the region. Therefore the council's approach to maintaining water

[21] Information provided by Lois Easton by email in February 2016

quality through the National Objectives Framework is to maintain the current state of the attribute being measured. Improving water quality is proposed where an attribute is below a national bottom line or where the current state does not provide for the priority values. The freshwater targets have been defined which describe the specific changes they are aiming to achieve and relate to the freshwater objectives that have been defined for the catchment. These targets are set with the aim of maintaining or improving nitrate, ammonia, dissolved oxygen, temperature, pH, sediment, dissolved reactive phosphorus (DRP), *E. coli* in rivers. They are not yet linked to farming activities. Specific Freshwater Targets have been proposed for the three Waipaoa catchment FMUs. Most of the targets are aimed at increasing dissolved oxygen levels, decreasing water temperature, and reducing *E. coli* levels and sediment loads. In the Poverty Bay Flats FMU, there are also targets to reduce N and DRP concentrations.

The proposed Gisborne Regional Freshwater Plan outlines the current state in a number of sites in each FMU. The council intends to maintain the water quality of those that do not need targets because they already meet acceptable water quality levels. When asked about the change in expected between 2015 and 2030 for *E. coli*, the council provided information in Table 4.

Table 4. *E. coli* limits for Gisborne District

FMU	Proposed Gisborne Regional Freshwater plan – Freshwater targets (Gisborne District Council, 2015).	Other comments about land use, mandatory or other activities to improve *E. coli*	Estimated change in *E. coli* between 2015 and 2030 (example numbers only)
Wharekopae River (in Waipaoa Hill Country FMU)	Reduce median *E.coli* levels to 260 cfus/100 ml or below and 95th percentiles to 1000 cfus/100 ml or below by 2030	Farm Environment Plans, fencing subsidies.	3% decrease on median, 70% decrease on 95th percentiles
Waipaoa Hill Country excluding Wharekopae River	n/a	Farm Environment Plans for intensive land uses.	Maintain
Waikanae Stream at Stanley Road (in Gisborne Urban FMU)	Reduce median *E.coli* levels to 540 cfus/100 ml or below for Waikanae Stream at Stanley Road	Stormwater quality project – urban sources	34% decrease
Gisborne Urban excluding Waikanae Stream at Stanley Road	Reduce 95th percentiles for *E. coli* levels to 1000 cfus/100 ml or below by 2030 for all water bodies	Stormwater quality project – urban sources	95% decrease

When asked about the change in expected between 2015 and 2030 for sediment, the council provided the sedimentation information that is outlined in Table 5.

Table 5. Sediment limits for Gisborne District

FMU	Proposed Gisborne Regional Freshwater plan – Freshwater targets (Gisborne District Council, 2015).	Other comments about land use, mandatory or other activities to improve Sediment	Estimated change in sediment between 2015 and 2030 (example numbers only)
Waipaoa Hill Country (sheep and beef and forestry land uses)	target <10 g/m^3 sediment for those rivers without major gullies in headwaters	No comments made	a 41% reduction by 2030 in some rivers, and for those rivers with major erosion features we are targeting <50 g/m^3 – will represent a 66% reduction in sediment if we achieved that by 2030 (unlikely)

When asked about the change expected between 2015 and 2030 for phosphorous, the council provided the phosphorus information in Table 6.[22]

Table 6. Phosphorus limits for Gisborne District

FMU	Proposed Gisborne Regional Freshwater plan – Freshwater targets (Gisborne District Council, 2015).	Other comments about land use, mandatory or other activities to improve P	Estimated change in P between 2015 and 2030 (example numbers only)
Poverty Bay Flats	Reduce dissolved reactive phosphorus levels to 0.03 g/m^3 or below by 2035 for Taruheru River at Tuckers Road;	Farm Environment Plans required for all intensive horticultural uses by 2021. Council action on own land in flood control scheme (riparian management, wetland development)	62% decrease

[22] Email from Lois Easton (Gisborne Regional Council) to Tracy Nelson (AgResearch), 2015

Poverty Bay FMU is the only FMU where the council is focussing on decreasing phosphorous as parts of the FMU currently lie in D band.

When asked if the council was able to estimate reductions or to state no change for other catchments and for other contaminants not mentioned above, the council noted that[23] in many locations communities will expect the council to improve water quality in relation to faecal pathogens and sediment, similar to the Waipaoa Catchment situation. Swimmable streams will be the focus of community expectations. Therefore it could be estimated to meet these expectations targets of a 5–10 percent improvement in median bacteria levels could be set. For nitrate and phosphorus the council is likely to seek to maintain the current states in all locations *except* the Motu River catchment. In the Motu catchment, the community is likely to expect improvements in the order of 30 percent decrease in phosphorous by 2035 and perhaps 10 percent reduction in nitrogen.

8 Taranaki

Freshwater Water Management Units

The Taranaki does not have finalised Freshwater Management Units. However, in April 2015, the council released a draft Freshwater and Land Management Plan for Taranaki[24] which proposed four FMU – A, B C and D. Each FMU has similar physical and hydrological characteristics as well as land use and community values.[25] Each FMU is briefly described below.[26]

FMU A – outstanding freshwater bodies

This FMU includes the Hangatahua (Stony) River, the Maketawa catchment immediately upstream of but excluding the Ngatoro Stream catchment and Lake Rotokare Scenic Reserve. These freshwater bodies mostly protected, have valuable, or increasingly valuable, habitat for indigenous flora and fauna and many have high cultural significance.

FMU B – waterways on Mount Taranaki and the ring plain

The main land use in this FMU is dairying. It also includes New Plymouth and other urban areas. High consumption and waste discharge are common in these smaller waterways.

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[23] Email from Lois Easton (Gisborne Regional Council) to Tracy Nelson (AgResearch), 2015

[24] http://www.trc.govt.nz/freshwater-and-land-management/

[25] http://www.trc.govt.nz/assets/taranaki/environment/water/DraftPlan2015/DraftPlan-April2015W.pdf

[26] Information adopted from http://www.trc.govt.nz/assets/taranaki/environment/water/DraftPlan2015/1FMU.pdf

FMU C – waterways on the northern and southern coastal terraces

There is intensive farming and irrigation in this FMU. In the southern coastal terraces there are mostly short, spring-fed streams that discharge as waterfalls into the ocean. In the northers coastal terraces there are longer rivers that are subject to large tidal ranges and naturally high sediment loads.

FMU D – waterways in the eastern hill country

A large area of this FMU is in natural land cover, there is also some drystock farming and plantation forestry. The rivers tend to carry a high sediment load as a result of the steep, easily erodible geology.

Nitrogen, phosphorous, sediment, and E. coli contamination in Taranaki[27] Region

While nitrogen, phosphorous, sediment, and *E. coli* all have an impact on water quality in Taranaki, phosphorous is the contaminant of most concern, particularly where there is intensive farming in the ring plain and the coastal terraces.

State of the Environment monitoring confirms improvement in the management of the region's waterways over the past 40 years. Over the past 18 years the ecological health has improved at a number of sites, and at least 14 sites significant improvements have occurred since 2007.

Mandatory requirements

The draft Freshwater and Land Management Plan for Taranaki proposes to require riparian fencing and planting on intensively farmed properties (over 20 hectares) on the ring plain and coastal terraces by 2020. Those who have not done so by mid-2020 will need a resource consent requiring stock exclusion from waterways and completion of riparian planting. Policies and rules are also proposed to require animal effluent to be discharged to land as a general rule.

Other practices and non-regulatory policies of note that reduce contaminant loads

The council has two key non-regulatory programmes. First is the Taranaki Riparian Management Programme in the ring plain and coastal terraces. It is the largest environmental enhancement planting scheme on privately owned land in New Zealand. It has resulted in 99.5 percent of dairy farms with riparian plans and 14 000 kilometres of streambank is covered by fencing and planting plans, and of these, 80 percent of streambanks are fenced, and 65 percent of streambanks recommended for vegetation are protected by both established and more recent plantings. Second, in the hill country, the council is working with farmers to promote sustainable

[27] Email from Chris Spurdle (Taranaki Regional Council) to Leah Murphy (Motu), 2015

land management practices, with a focus on soil conservation and sedimentation on erosion prone land. In addition, there is an industry lead initiative to promote nutrient budgeting.

Freshwater quality limits in Taranaki

Water quality limits have not been formally set in Taranaki. The Regional Fresh Water Plan for Taranaki is currently under review. The draft Freshwater and Land Management Plan proposes to manage freshwater contamination through a combination of the new discharge policies and rules plus the plan sets out boundaries for the region's waterways using the National Objectives Framework.[28]

The water quality limits listed in Table 7 are council estimates based on their anticipated water quality trends by 2025. These limits take into account substantial but not complete implementation of riparian management recommendations and diversion of ponds from streams to land over the next 10 years. The predictions are also based on State of the Environment monitoring trends. Findings are extrapolated from the Best Practice Dairy Catchment Study on the Waiokura[29] and applied to other ring plain streams.

Table 7: Estimated limit ranges for Taranaki Region (% change from baseline)

FMU	Nitrogen	Phosphorous	Sediment	*E. coli*	Comments/notes
Outstanding freshwater body	No change	No change	No change	No change	Pristine catchments. Management response aims to maintain/protect outstanding natural character and already excellent to very good water quality
Ring plain	10–30% decrease	20–40% decrease	10–30% decrease	20–40% decrease	Intensively farmed catchments. Management response aims to maintain and enhance already good water quality through rules diverting farm effluent to land and riparian management
Coastal terraces	10–30% decrease	20–40% decrease	10–30% decrease	20–40% decrease	Intensively farmed catchments. Comments as above.
Eastern hill country	No change	5–10% decrease	5–10% decrease	No change	Extensively farmed catchments on erosion prone land. Relatively good water quality but with sedimentation

[28] http://www.trc.govt.nz/assets/taranaki/environment/water/DraftPlan2015/2NOF.pdf

[29] http://maxa.maf.govt.nz/sff/about-projects/search/06-029/best-practice-dairy-catchment-study.pdf

issues. Largely non regulatory responses to avoid erosion and maintain good water quality.

9 Manawatu–Wanganui (Horizons)

Freshwater Water Management Units

The One Plan outlines many water management zones within the Manawatu-Wanganui region (Fig. 1). The council has also listed several water management sub-zones, or priority catchments, that are most affected by nutrient enrichment and/or bacterial contamination. Agricultural run-off in these sub-zones is managed using a mixture of persuasion, advice and rules.[30] These water management zones predate the NPS-FM and the council will have to go through the process of identifying FMUs for the region to meet the requirements of the NPS-FM.

[30] http://www.horizons.govt.nz/assets/publications/about-us-publications/one-plan/Chapter-1-Setting-the-Scene.pdf#pagemode=thumbs

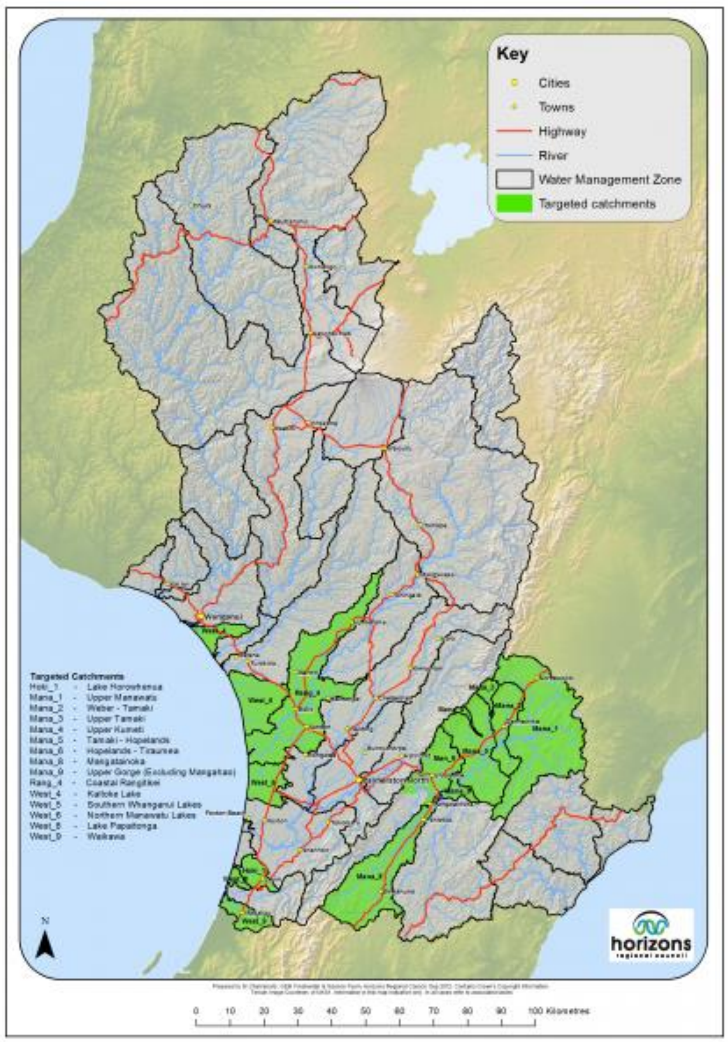

Figure 1. Manawatu-Wanganui water management zones and targeted catchments.

Nitrogen, phosphorous, sediment, and E. coli contamination in Manawatu–Wanganui Region

Key issues for water quality in the region include: nutrient levels, algae growth and sediment. Around 75 percent of this region is classified as hill country and 40 percent of this land has potential for moderate to severe erosion. There is a need to mitigate this risk to preserve this productive land.

The growing concern around the intensification of land use (e.g. dairy) in the region and the effect of increased nutrient and bacterial runoff on water quality was tackled in Horizons' regional policy document, the One Plan. For example, in the Upper Manawatu, one of the priority catchments (Mangatainoka), the amount of nitrogen in the river is 2.5 times the ecological limit, with 50 percent coming from dairy occupying less than 25 percent of the catchment. Cyanobacteria (often referred to as blue-green-algae) have also been identified as an emerging issue affecting rivers and lakes in the region.

Mandatory requirements

The One Plan is an integrated plan which guides the management of natural resources in the Horizons Region. It weaves together the previous six separate plans and Regional Policy Statement into one document. The One Plan provides an environmental roadmap directing how the Council manages the Region's resources.

The One Plan focuses on intensive farming in priority catchments and aims to manage the effects those activities have on water quality, including as a major source of nutrients that can cause increased levels of periphyton. New regulations require intensive farmers to apply for consent around nutrient management.

The rules apply to various coastal catchments between Otaki and Wanganui and most of the dairying area of the Tararua, excluding farms in the upper Mangahao and the Tiraumea catchments, the lower section of the Rangitikei River, and Waikawa and Manakau Rivers (see Fig. 1).

Other practices and non-regulatory policies of note that reduce contaminant loads

The Sustainable Land Use Initiative (SLUI), a non-regulatory approach, that is backed up by regulations covering vegetation clearing and tracking, takes a 'mountains to the sea' approach to prevent accelerated erosion in hill country. The initiative is underpinned by the development of voluntary management plans. These voluntary plans provide paddock-scale best land management advice while optimising economic return to the landowner. The first voluntary management plan was piloted on a farm in the Pohangina Valley in 2005 and the programme is currently being rolled out in priority areas.

SLUI is the key instrument being used in the region to reduce sediment and associated phosphorus losses to waterways.

Freshwater quality limits

The Horizons Regional Council has set maximum cumulative nitrogen leaching losses for priority catchments (Table 8)[31] in the One Plan. These losses vary by land use capability (LUC) class and are imposed on the intensive land uses of dairy, horticulture, cropping, and intensive sheep and beef. The maximum nitrogen leaching losses are intended to become gradually more stringent over a 20-year timeframe.

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[31] http://www.horizons.govt.nz/assets/publications/about-us-publications/one-plan/Chapter-14-Discharges.pdf

There are no mandatory requirements around phosphorous, sediment or *E. coli*. Phosphorous and sediment are being managed through SLUI programme.

Table 8: Horizons One Plan maximum cumulative nitrogen leaching losses (kgN/ha/yr) by Land Use Capability (LUC) class

Year	LUC1	LUC2	LUC3	LUC4	LUC5	LUC6	LUC7	LUC8
1	30	27	24	18	16	15	8	2
5	27	25	21	16	13	10	6	2
10	26	22	19	14	13	10	6	2
20	25	21	18	13	12	10	6	2

10 Hawke's Bay

Freshwater Water Management Units

The Hawke's Bay Region has seven major river catchments. In terms of water management these catchments are further divided into 15 possible management areas (note the FMUs are still not defined). The management areas include: Wairoa, Mohaka (upper, middle, and lower), Waikere, Waihua, Esk, Tutira, Ngaruroro, Tutaekuri, Karamu, Ahuriri, Tukituki, Porangahau, and the Southern Coast.

Nitrogen, phosphorous, sediment and E. coli contamination in Hawke's Bay Region

Hawke's Bay Regional Council (HBRC) has indicated that there are issues with all four contaminants and that the severity of the effects varies across the region. Most areas that have an issue with nitrogen are also likely to need to manage phosphorous. Sediment is a bigger issue in the hillier areas of the catchment.

Mandatory requirements

The Tukituki River Catchment Plan Change 6 (hereafter Change 6) is a catchment-specific change to the Hawke's Bay Regional Resource Management Plan that became operative in

October 2015.[32] It adds new chapters specifically for the Tukituki River Catchment, and at the same time, a number of existing chapters will no longer apply to the Tukituki River Catchment. Among its proposals, Change 6 seeks to address specific water allocation and water quality issues in the catchment.

Five key programmes are being developed to support the implementation of Change 6:[33]

1. Stock Exclusion
2. Nutrient Budgeting, phosphorus management planning and farm environmental management plans
3. Monitoring, evaluation, reporting and improvement (MERI) Plan
4. Sub-catchment over-allocation mitigation
5. The adoption of Industry Good Practice

These programmes are based around the short term need to provide transitional support to landholders adapting to the new policies and rules contained within Change 6 and the medium-term programmes to target a coordinated and collaborative approach to driving the adoption of Industry Good Practice throughout the Tukituki Catchment. An additional programme will focus on targeting priority sub-catchments where existing nutrient losses are beyond the proposed targets within Change 6.

Freshwater quality limits

HBRC is in the process of setting limits for most management areas in the region. Potential limit ranges were developed with policy staff at the councils (Table 9). These limit ranges are expressed as a percentage change from current loads.

The priority catchments in the Tukituki catchment have set limits and targets[34] and these are listed in the Tukituki River Catchment Plan Change 6. In the priority catchments, maximum nitrogen leaching rates are set to vary by land use capability (LUC) class (Table 10),[35] which is similar to the approach taken by the Horizons Regional Council in the Manawatu-Wanganui

[32] http://www.hbrc.govt.nz/About-your-Council/Plans-Strategies/RRMP/Pages/tukituki-plan-change-6.aspx

[33] http://www.hbrc.govt.nz/HBRC-Documents/HBRC%20Document%20Library/Heath%20N%202013%20-%20Draft%20Tukituki%20Catchment%20Implementation%20Plan.pdf

[34] Limits refer to where existing water quality is better than the desired numerical value and targets refer to where the existing water quality is worse than the desired numerical value

[35] http://www.hbrc.govt.nz/HBRC-Documents/HBRC%20Document%20Library/Regional%20Plan%20Change%206%20-%20Tukituki%20River%20Catchment%20(Operative%201%20October%202015)%20excl%20planning%20maps.pdf

region. The limits are not the definitive limits for the region with most subject to change based on additional science, council investigations and outcomes of limit setting processes.

Table 9. Potential limit ranges for catchments in Hawkes Bay (% change from baseline)

Catchment	Nitrogen	Phosphorous	Sediment	*E. coli*
Wairoa	No change	No change	5–10% decrease	No change
Mohaka - upper	10–30% decrease	No change	No change	No change
Mohaka - middle	No change	No change	No change	No change
Mohaka - lower	No change	No change	5–10% decrease	No change
Waikere	0–5% decrease	0–5% decrease	No change	No change
Waihua	0–5% decrease	0–5% decrease	No change	No change
Esk	No change	No change	No change	No change
Tutira	5–15% decrease	5–15% decrease	5–15% decrease	5–15% decrease
Ngaruroro	No change	No change	No change	No change
Tutaekuri	0–10% decrease	No change	No change	No change
Karamu	No change	0–5% decrease	0–5% decrease	No change
Ahuriri	No change	No change	No change	0–5% decrease
Tukituki	See plan (Table 10)	See plan (Table 10)	See plan (Table 10)	See plan (Table 10)
Porangahau	No change	No change	5–10% decrease	0–5% decrease
Southern Coast	No change	No change	No change	0–5% decrease

Table 10. Tukituki catchment nitrogen leaching rate by Land Use Capability (LUC) class (to be calculated on a whole of farm property or whole of farming enterprise basis)

Land Use Class	LUC1	LUC2	LUC3	LUC4	LUC5	LUC6	LUC7	LUC8
Rate (kgN/ha/yr)	30.1	27.1	24.8	20.7	20	17	11.6	3

11 Greater Wellington

Freshwater Water Management Units

The Greater Wellington Regional Council (GWRC) has divided up the region into 5 catchments, referred to a Whaituas.[36] These include: Ruamahanga, Wairarapa Coast, Kapiti Coast, Te Awarua o Porirua, and the Wellington Harbour and Hutt Valley (Fig. 2). The council has identified that these five areas place different demands on land and water resources and is enlisting the support of local people to help understand local needs and make recommendations on how they will be managed through Whaitua Committees. The first committee established in December 2013 was the Ruamāhanga Whaitua Committee, followed by the establishment of the Te Awarua o Porirua Whaitua Committee in December 2014. Both committees are still in the process of determining the water quality limits required to meet their community values.

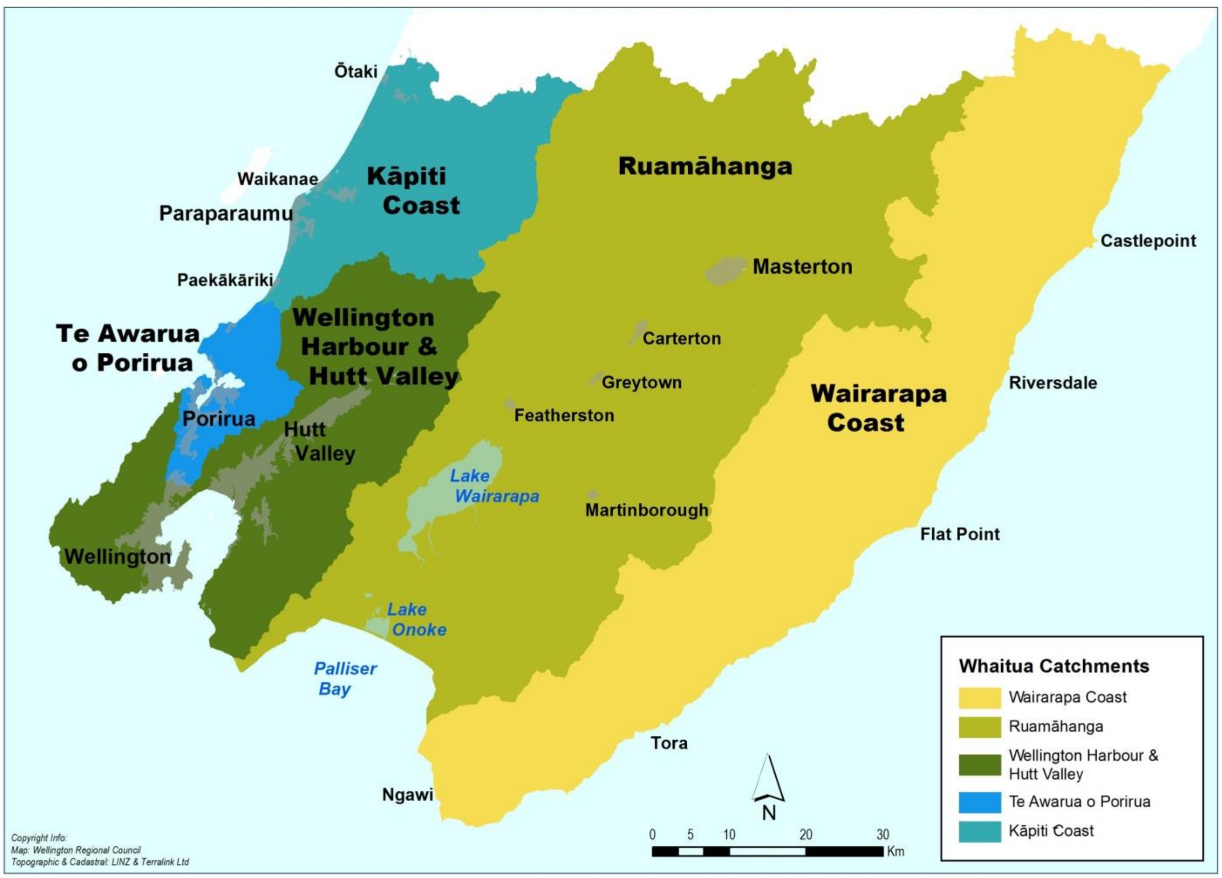

Figure 2. Greater Wellington whaitua catchments.

[36] http://www.gw.govt.nz/whaitua-committees/

Nitrogen, phosphorous, sediment, and E. coli contamination in Hawke's Bay Region

Sediment is perhaps the largest issue in most of the region. Nitrogen and phosphorous are of some concern, although nutrient-related water quality is generally good in most water bodies. *E. coli* appears to be only a concern in the Kapiti Coast. Heavy metals such as zinc and copper contamination from industry are an issue in areas close to Wellington City.

Mandatory requirements

GWRC has not specified any mandatory requirements for landowners in the region beyond what is already included in the Regional Plan. They have recently drafted a Proposed Natural Resources Plan that is currently undergoing public consultation. One of the proposed activities is stock exclusion from permanent streams, which should have a noticeable impact on water quality.[37]

Freshwater quality limits

GWRC is still in the process of setting limits for each whaitua in the region. Table 11 lists a draft of possible limits for each whaitua based on discussions with a member of the Science team. The limits are not the definitive limits for the region and are subject to change based on additional science, council investigations, and outcomes of limit setting processes.

Table 11: Potential limit ranges in the Greater Wellington Region (% change from baseline), by catchment

Whaitua Catchments	Nitrogen	Phosphorous	Sediment	*E. coli*	Heavy metals	Comments/notes
Ruamahanga	5–10% decrease	hopefully dealt with through sediment goals	15–25% decrease	No change	n/a	Most sediment coming from forestry and sheep and beef on highly erodible land; forestry rules. Should be able to deal with *E.coli* by keeping stock out of streams, moving wastewater treatment plant discharge to land (rather than water; currently 3 out of 6 wastewater treatment plants discharge to water). For water allocation, want to get rid of the water races
Wairarapa Coast	No change	No change	25–35% decrease	No change	n/a	Any ag is low intensity, most area is in forestry, typically erosion is into the sea; use of fertiliser rules - don't use fertiliser unless you can grow something; *E. coli* is a public perception problem but not really expected to be an issue

[37] http://www.gw.govt.nz/assets/Plans--Publications/Regional-Plan-Review/Proposed-Plan/Chapter-5-Rules.pdf

Kapiti Coast	No change	No change	No change	5–15% decrease	n/a	Land use mainly gardens; iwi very active in this catchment limit setting process; *E. coli* mostly from sheep and beef and pigs through overland flows; will address by managing the wetland streams complex; current loads are not high though but likely public perception indicates they will want some sort of improvement.
Te Awarua o Porirua	No change	No change	30–40% decrease	No change	20–30% decrease (Zn & Cu)	Land use mostly low intensity sheep and beef; farmland not used so much; *E.coli* issue is not ag related, mostly stormwater issue from dogs, etc. (should be able to deal with through stormwater infrastructure & restoring habitat in streams
Wellington Harbour & Hutt Valley	10–15% decrease	low P levels; N:P ratio causes an issue	No change	No change	20–30% decrease (Zn & Cu)	N management will be a challenge as most discharge comes from market gardens, golf courses, etc.

12 Marlborough

Freshwater Water Management Units

FMUs have not been formally set in Marlborough. However, they use the following catchments for State of the Environment Reporting:[38] Marlborough Sounds, Rai/Pelorus, Upper and Mid Wairau, Lower Wairau, Opawa and South Marlborough. We use these catchments as the basis for estimating limits in the region.

Nitrogen, phosphorous, sediment and E. coli contamination in Marlborough District[39]

Catchments are prioritised based on the annual State of the Environment monitoring report which categorizes waterways into water quality classes (A–D). The aim is to improve (where possible) water quality of currently marginal classed waterways to a fair class. The process begins with a catchment-wide investigation of water quality in order to identify problem areas and the sources of contamination. The next step for the council is to work with land-owners on improving the water quality through targeted management.

Phosphorous and sediment issues are dealt with on an individual catchment basis with management initiatives being based on catchment investigations. For example, the catchment study for Doctors Creek showed that drainage-works and bank management (including stock access) are the main contributors to increased levels of sediment and phosphorous. The council will work with the land-owners on addressing these problems, initially on a voluntarily basis. It is difficult to assess the possible reduction that can be achieved without mandatory requirements.

Another catchment where sediment is a recognized problem is the Tuamarina River (with follow-on effects on the Wairau Diversion). Investigations are currently being conducted, but it is still unclear, what the main sources are and if and to what extend they can be managed. Therefore the council aims for an improvement in regard to sediment load, but are currently unable to quantify what can be achieved with the current regulatory tools.

Mandatory requirements[40]

Marlborough regional rules are currently under review and were due to be notified for submission by the end of 2015, but this has still not occurred. There are some fencing requirements, but these may change as a result of the submission process. There are no other

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[38] Phone discussion with Peter Hamil, December 2015

[39] Excerpts from email exchanges between Steffi Henkel (NCC) and Leah Murphy (Motu), December 2015

[40] Phone call with Steffi Henkel, December 2015

relevant mandatory requirements in Marlborough, broadly the council works on an issue by issue basis with individual landowners.

Freshwater quality limits in the Marlborough

There are no freshwater quality limits in place at present. Limit setting for the individual FMUs will be done through a community consultation process.

13 Nelson

Freshwater Water Management Units

Nelson has publically notified its Progressive Implementation Programme for freshwater.[41] Regional policy statement provisions will be publically consulted on during 2016 and the freshwater provisions will be publically consulted on during 2017.

Nelson City has 5 Proposed FMUs: Stoke Streams, Mahitahi/Maitai, Wakapuaka, Whangamoa, and Roding.

In the case of the North Nelson FMUs (Whangamoa and Wakapuaka) the FMUs are catchment based. The Mahitahi/Maitai FMU is the largest in Nelson and comprises the catchments of the Mahitahi/Maitai, York Stream, Oldham Creek Todd Valley and Hillwood Streams. The Stoke Streams FMU comprises the catchment areas of five streams, although part of the Saxton Stream is within the Tasman District Council area. The final FMU is the Roding. This FMU comprises only the upper portion of the catchment, which is a tributary of the Waimea River. The lower catchment is also within the Tasman District.

Nitrogen, phosphorous, sediment, and E. coli contamination for Nelson City[42] and priority catchments[43]

Water quality and ecosystem health are generally good in the upper reaches of most catchments in Nelson and in areas with little resource pressure like the Whangamoa River in North Nelson. However, the impacts of urban, pastoral and production forestry land uses are apparent across different waterways and declines in water quality and ecosystem health at lower catchment sites are common. Specific water quality issues include:

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[41] http://nelson.govt.nz/environment/water-3/freshwater-2/freshwater-management/freshwater-implementation-programme/

[42] Email from Chris Spurdle (Taranaki Regional Council) to Leah Murphy (Motu), 2015

[43] Information provided by Kate McArthur (on behalf of NCC) in emails to Leah Murphy (Motu), December 2015

Stoke Streams FMU

The Saxton Stream has some of the worst water quality of all sites in Nelson. Elevated nitrogen, phosphorus, faecal contaminants, and sediment are indicative of pastoral land use with unmanaged or unmitigated contaminant losses.

Roding FMU

Little water quality monitoring has been undertaken in the Roding. Biomonitoring of the water take consent shows significant increasing trends in ecosystem health downstream of the water take since 2002.

Mahitahi/Maitai FMU

The Groom and Sharland tributaries contribute significantly to water quality decline in the lower Mahitahi/Maitai and potentially contribute to cyanobacterial blooms there. Sources of fine sediment and nitrogen from forestry and pastoral land uses require careful management in the Mahitahi/Maitai. York, Hillwood, and Todd Streams have poor water quality. This is a result of the impacts of urban land use and landfills in the York, and pastoral land use in the Todd and Hillwood Streams.

Wakapuaka FMU

Water quality issues including elevated faecal contaminants, soluble nitrogen and sediment that increases between the upstream and downstream sites on the Lud indicates contaminant losses characteristic of unmanaged pastoral land use.

Whangamoa FMU

Water quality and ecological health is very good in the Whangamoa FMU most likely the result of a high proportion of native forest in the catchment. Maintenance of water quality will be an important consideration, particularly if there is any risk of land use change or intensification, and when exotic forest harvesting begins in the tributaries. Little is known about the ecosystem health or water quality of the Māori Pa Stream.

Priority catchments have not been determined yet, but as Nelson is a small region a priority catchment approach is unlikely to be needed. However, there is strong community interest around the Mahitahi/Maitai catchment as it is a focal point of Nelson City and non-regulatory restoration and science has already begun in that catchment through Project Mahitahi/Maitai.[44] The poorest water quality is found in the Saxton, York, and to a lesser extent the Todd, Hillwood, and Ludd. Additionally, the Stoke Streams provide the highest biodiversity potential with respect to migratory native fish, given their proximity to the Waimea Inlet and the coastal

[44] http://nelson.govt.nz/environment/water-3/projectmaitai/

environment. Water quality in the Whangamoa catchment is very good and requires maintenance rather than improvement based on current monitoring data.

There are insights available about trends in the region due to an independent review of Nelson's freshwater quality classification and river health monitoring information.[45] The review provides a stock take of Nelsons freshwater quality and the significant freshwater trends from 10 years of monitoring. Overall, there has been a slight improvement in water quality at monitoring sites. The recommendations in the report include investigations to identify pollution sources in the York and Poorman Valley streams and Maitai catchment, which will be part of the environmental monitoring work programme over the next year.

Mandatory requirements[46]

There are no mandatory requirements other than the consent process for new activities. However there is a lot of non-regularity activity in Nelson. Of particular note is the council's offer to cover 50 percent of the costs of fencing or planting around waterways. There has been good uptake of this programme but no statistics are available.

It is likely that impervious surfaces and production forestry have significant land use influences on water quality in Nelson, with some minor exceptions. Methods around these issues have yet to be developed through the community and iwi engagement process.

Other practices and non-regulatory policies of note that reduce contaminant loads[47]

There are a range of non-regulatory activities in Nelson City that are expected to have an impact on nitrogen, phosphorous, sediment and *E. coli*.

Working with land owners

Nelson City Council provides free advice for land owners and financial assistance (50 percent) toward fencing livestock out from waterways and native plants for riparian planting and

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[45] Download the Updated Freshwater Classification for Nelson, 2013 Report (2.4MB PDF)

[46] Information about mandatory requirements and the fending/planting regime obtained from Sharon Flood of NCC in December 2015. Information about impervious surfaces and projection forestry obtained from Kate McArthur on behalf of NCC, by email in December 2015

[47] The information in this section is adapted from the NCC webpage on freshwater management: http://nelson.govt.nz/environment/water-3/freshwater-2/freshwater-management

biodiversity enhancement. Several residents have taken up the offer of Council assistance to fence and plant along the Lud and Wakapuaka River, and Stoke stream.

***Project Maitai/Mahitahi*[48]**

Project Maitai/Mahitahi was launched in July 2014. NCC is working in partnership with iwi, the community, and key agencies in the region, on a 5-year project to improve the water quality of the Maitai/Mahitahi River. The project's goal is to create a river that is safe to swim in and take *kai* from. The integrated projects are addressing a range of issues affecting water quality.

There have been a number of projects over the past year. Six community group projects in and around the Maitai have been set up with support (grants) from the Council. These included planting, monitoring, research and beautification projects. Major riverside planting events have resulted in a total of 6500 plants being put into the ground.

The Maitai and its tributaries run through densely populated areas so there have been several initiatives to reduce urban impacts on water quality, with more planned next year. These have involved locating and fixing three large wastewater leaks, rubbish clean up in Saltwater Creek, and signs and bollards being placed near the Almond Tree Flats ford to prevent inappropriate use of the ford. Other activities have been carried out to help improve in-stream biodiversity.

A variety of other work has also been carried out including fencing stock out of waterways, meetings with forestry representatives, research into gravel movement throughout the catchment and a study of river flows. Operations at the Maitai Dam were changed to improve the quality of water discharged from the reservoir into the Maitai south branch, and options for aeration of the reservoir to improve water quality have been investigated, with further work planned in this area.

***Other relevant ongoing work by NCC*[49]**

The council is enhancing riparian margins and instream habitat for wildlife in urban streams, as part of the flood recovery remediation work.

Freshwater quality limits in Nelson City[50]

Limits have not been formally set for the proposed FMUs in Nelson City. A process to determine the values for each FMU has been completed through community engagement groups and alongside the iwi freshwater working group for Te Tau Ihu o Whakatū. Work to define the attributes relevant to these values has begun and will also involve further stakeholder

[48] This section has been adapted from the NCC webpage about Project Maitai/Mahitahi: http://nelson.govt.nz/environment/water-3/projectmaitai/

[49] http://nelson.govt.nz/environment/water-3/freshwater-2/river-and-stream-health/

[50] Information provided by email by Kate McArthur on behalf of NCC, December 2015

engagement through 2016. The process of developing freshwater objectives and limits to support the values through each of the attributes will then be undertaken. These objectives and limits will then be tested against the current state of the values. Where resources are over-allocated targets will need to be set to achieve the objectives and limit over time. Rationalisation of the costs and benefits of various management approaches (methods) to achieve outcome for water quality and aquatic biodiversity will be undertaken in conjunction with the iwi and community FMU groups, within the bounds of the bottom lines set through the purpose of the Act and the NPS-FM (2014), including life-supporting capacity, requirements to maintain or improve water quality through the NPS-FM and s30 of the Act and the compulsory ecosystem health value and bottom lines within the National Objectives Framework of the NPS-FM (2014).

The estimated change in N, P, Sediment and *E. coli* in the district are noted in the table below. No date has been provided for these estimated targets.

Table 12. Potential limit ranges in Nelson City (% change from baseline), by FMU

FMU	Nitrogen	Phosphorous	Sediment+	*E. coli*
Stoke Streams#	50% decrease for Saxton Stream, other three streams require 5% decrease or no change	25–50% decrease for two streams, 5% decrease or no change for others	25–50% decrease for two streams, 5% decrease or no change for others	50% decrease for 3 or the 4 monitored streams, no change needed for the fourth
Mahitahi/Maitai	50% decrease for York Stream, other three streams require 5% decrease or no change	Brook, Hillwood and Todd catchments: 60–40% decrease. 5% decrease or no change required in all other streams	>50% decrease needed	50% decrease for York Creek, 25% decrease in Todd, Hillwood and lower Mahitahi/Maitai
Whangamoa	No change	No change	10–20% decrease in the Collins and Dencker tributaries, no change needed elsewhere	No change
Wakapuaka	5% decrease in the Lud, no change needed elsewhere	20% decrease in the Lud, 5% decrease or no change needed elsewhere	20–40% decrease needed in the Lud, 5% decrease to no change needed elsewhere	40% decrease in the Lud. 5% decrease or no change everywhere else
Roding*	No change	No change	No change	No change

+ Historic NCC data on sediment is limited to baseflow conditions – reliable inferences cannot be drawn from this dataset

One stream out of the five in the FMU is not currently monitored

* There is no current reliable water quality information available for the Roding upper catchment FMU. Lack of requirement for change is based on MCI and Ecosystem health monitoring at the water supply weir for consent monitoring purposes. Given the land use in the FMU, it is unlikely reductions will be needed at this stage

Although many freshwater objectives and limits will be met already (see table above where no change is stated), others will require targets and management actions over time – this will depend on the nature of the cause and how easily impacts are managed. As yet, no time frames have been explored.

14 Tasman District

Freshwater Water Management Units

There are six water management areas defined in the Tasman District: Oerere/West Coast, Takaka, Upper Buller, Motueka (consists of Upper Motueka, Middle Motueka, Motuek/Riwaka Plains, Abel Tasman), Moutere, and the Waimea.

Nitrogen, phosphorous, sediment, and E. coli contamination in Tasmin District

There are few issues with contaminants in the district. The Waimea has issues with legacy nitrogen in groundwater from a piggery and intensive market gardens, but this is not expected to be a major concern as long as the land use does not change much in the future. *E. coli* used to be an issue in the Oerere/West Coast water management area, but this has since been resolved. There are no known concerns about P and sediment.

Mandatory requirements

Tasman District Council (TDC) has not specified any mandatory requirements for landowners in the region beyond what is already included in the Regional Plan.

Other practices and non-regulatory policies of note that reduce contaminant loads

The council did not specify any other policies of note that could help reduce contaminant loads.

Freshwater quality limits

A draft list of possible limits for each water management areas in the Tasman District was based on discussions with planning staff (Table 13). There are not expected to be any water management areas that require reductions in contaminants from current discharge levels. The limits, however, are not the definitive limits for the region and are subject to change based on additional science, council investigations and outcomes of limit setting processes.

Table 13. Potential limit ranges for Tasman District (% change from baseline), by water management area

Water management area	Nitrogen	Phosphorous	Sediment	*E. coli*	Comments/notes
Oerere/West Coast	No change	No change	No change	No change	*E. coli* was an issue but it is mostly resolved now
Takaka	No change	No change	No change	No change	Maybe more irrigation going into catchment to feed cows in summer (some soils may need more water); significant springs in catchment--Te Waikoropupu; going to implement farm plans
Upper Buller	No change	No change	No change	No change	Water Conservation Order in place; ecosystem health is key; expect a little more dairying; will need better land use practice than currently have; more stock access & fencing
Motueka	No change	No change	No change	No change	Water Conservation Order in place in the Upper Motueka; some risk of dairy but not a large risk
Moutere	No change	No change	No change	No change	Very dry and hilly; not suitable for dairy; lots of forestry; follow good practice and should be okay
Waimea	No change	No change	No change	No change	Legacy N (in groundwater) from piggery and intensive market gardens; if dam, then more horticulture (if livestock decreases and goes to apples it should be okay but if land goes into market gardens then water quality problems could arise; will use farm plans and track market garden conversion; there are 3 dairy farms, all small titles and won't be able to amalgamate titles to convert to dairy; mostly a groundwater system (not much surface water)

15 Canterbury

Freshwater Management Zones

There are 13 freshwater management zones in Canterbury:[51] Kaikoura, Conwway, Hurunui-Waiau, Waipawa, Ashley and Waimakariri, Christchurch-West Melton, Selwyn-Waihora, Waiwera-Lake Forsyth, Ashburton to Rakaia, Hinds Plain, Orari-Opihi-Pareora, Waitaki, and South Coastal Canterbury. Each of these zones consists of multiple FMUs.

[51] http://ecan.govt.nz/publications/Reports/targets-report-cwms-2015.pdf

Nitrogen, phosphorous, sediment, and E. coli contamination in Canterbury Region

Nitrogen is the contaminant of most concern in the region. There are also some concerns about phosphorous, faecal indicator organisms (FIOs), and occasionally metals.

Mandatory requirements

There are a range of mandatory requirements in place that relate to the management of freshwater contaminants in Canterbury, some highlighted requirements are:[52]

- Farm Environment Plans (FEPs) and nutrient budgets are required. The plan sets limits on the amounts of nutrients such as nitrogen that can be leached into the environment especially in zones where current water quality objectives are not being met — the 'red' Nutrient Allocation Zones.
- Depending on the farm risk profile, the FEP will need to be audited regularly to monitor improvement in on-farm management practice.

Other practices and non-regulatory policies of note that reduce contaminant loads

There are a range of activities underway that relate to the management of contaminants in Canterbury:[53]

- The council is actively encouraging all farmers to collect their nitrogen loss data and to use Overseer™ to prepare nutrient budgets.
- Since 2009, ten catchment-based zone committees have been established as joint committees of the district or city councils and Environment Canterbury with membership from local rūnanga and appointed community members. More than 950 recommendations have been made by the Zone Committees and include setting catchment load limits and improving nutrient management. Annually updated zone-based work programmes are in place for each Zone Committee, with clear projects and milestones tailored to meet the Zone Committees' 5-year outcomes. Currently, there are more than 90 projects underway in partnership with industry and community groups, involving more than 3400 stakeholders.
- The types of work programmes by catchment zone committees include: scheme support, farm environmental plans, planting, education, partnerships, catchment groups, field days, and awareness raising.
- Matrix of Good Management project aims to identify expected nitrogen and phosphorous losses under Good Management Practice across the range of farming systems, soils and climates within

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[52] Adapted from: http://ecan.govt.nz/publications/Reports/targets-report-cwms-2015.pdf

[53] Adapted from: http://ecan.govt.nz/publications/Reports/targets-report-cwms-2015.pdf

the Canterbury region. This will be achieved through collaborative research and stakeholder engagement involving the primary industries, researchers and Environment Canterbury.

Freshwater Quality Limits in Canterbury

Environment Canterbury has developed and started on a schedule of notified RMA Plans to set water quality limits.[54] The Land and Water Regional Plan (LWRP), effective from January 2014, sets the framework to implement community aspirations for water through the Canterbury Water Management Strategy. The plan includes region-wide limits that apply across most of Canterbury. These limits apply now and are based on the Nutrient Allocation Zones (NAZ) around Canterbury.[55] The more serious the water quality issues in a NAZ the stronger the rules. By 2017 the LWRP will be updated to reference the Matrix of Good Management that specifies numbers for nitrate and phosphorus losses and sets out good management practices across a range of land types, climates, and land uses.

Catchment load limits are in the process of being set for each of 13 water management zones through Regional Catchment Plans and sub-catchment.[56] The council's target is that by 2020, a programme will have been implemented to review existing consents where such reviews are necessary in order to achieve catchment load limits.

Many of the water management zones have been assessed and categorised as either Red (water quality not met) or as Orange (water quality at risk). Progress on limit setting is variable with the four zones most advanced in the process (submission of plan and/or decisions reached): Hurunui/ Waiau River; Hinds Plain; Selwyn-Waihora; and South Coastal Canterbury.[57] Details on the three zones where limits have been set are listed in Table 14.

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[54] Adapted from: http://ecan.govt.nz/publications/Reports/targets-report-cwms-2015.pdf

[55] Please note it is not clear how these 'limits' relate to those being set for each catchment and described below

[56] Adapted from AgResearch, *Climate mitigation co-benefits arising from the Freshwater Reforms: Summary of policy and agricultural landscape: Report prepared for MPI (Milestone Report 1),* 2015

[57] Comments about these zones have been adapted from AgResearch, *Climate mitigation co-benefits arising from the Freshwater Reforms: Summary of policy and agricultural landscape: Report prepared for MPI (Milestone Report 1),* 2015 and email information provided by Environment Canterbury staff to AgResearch

Table 14. Limits for water management zones in Canterbury (% change from baseline)

Water management zone	Nitrogen	Phosphorous	Sediment	*E. Coli*	Comments/notes
Hurunui/ Waiau River	20% permissible increase in N loads at the river level.	No change	n/a	n/a	Phosphorus is the main contaminant of concern in this zone. Phosphorus limits are set at the 2005–10 catchment average (i.e. set for the receiving environment) and are therefore at or around current values. There is some headroom for intensification, in terms of limits on N. No farm limits have been set.
Selwyn-Waihora	See comments section for limits – equates to about 30% reduction	Reduce the receiving environment phosphorus load by 50%	n/a	n/a	Similar to Hurunui/ Waiau, this zone is considered to be P-limited. Approximately half of the reduction is expected to be achieved by targeting the receiving waters (e.g., alum dosing). Although the remaining half will need to be achieved by reducing the catchment load, no specific P discharge allowances have been set because it is technically too difficult to set farm specific limits. From 2017, if nitrogen loss >15 kg N/ha/year (OVERSEER® estimates), farmers will need to achieve good management practice N loss rates for their existing (2009–13) land use. For nitrogen loss <15 kg N/ha/year, land use change is allowed, provided farmers operate at good management practice and loss rates do not exceed 15 kg N/ha/year. From 2022: all farms with losses of more than 15 kg N/ha/year will need to further reduce nitrogen losses (ranging from 30% for dairy to 7% for arable; see Table 7 on page 18 of the AgResearch 2015 report for details for each sector).
Hinds/ Hekeao Plains	Estimate 15–20% by 2035 across the catchment[58]				The main issue in this zone relates to dairy and dairy support. The council has agreed to reductions of 15% by 2025, 25% by 2030 and 36% by 2035 or down to 20 kgN/ha (whichever is greater) for land uses leaching >20 kgN/ha in 2015. There are flexibility allowances for lower emitters to increase to 15 and 20 kgN/ha, so the overall catchment scale reductions are lower than the percentage reductions for

[58] Information provided by Lisa Scott (ECAN) in an email to Melissa Robson (AgResearch), February 2016

higher emitters. (See table 8 on page 19 of the AgResearch 2015 report for details for each sector).

In recent council decisions about the Hinds, there are some values for other contaminants that could be considered limits[59]. These could be further investigated but are not provided here.

[59] Information provided by Robert Bower (on behalf of ECAN) by email to Melissa Robson (AgResearch), February 2016

16 Otago

Freshwater Water Management Units

Otago has the following main water catchment areas:[60] Kawarau, Upper Clutha, Lower Clutha, North Otago, Taieri, and Dunedin. Within these catchment areas, there are 29 defined FMUs (Fig. 3).

[60] http://water.orc.govt.nz/WaterInfo/Default.aspx

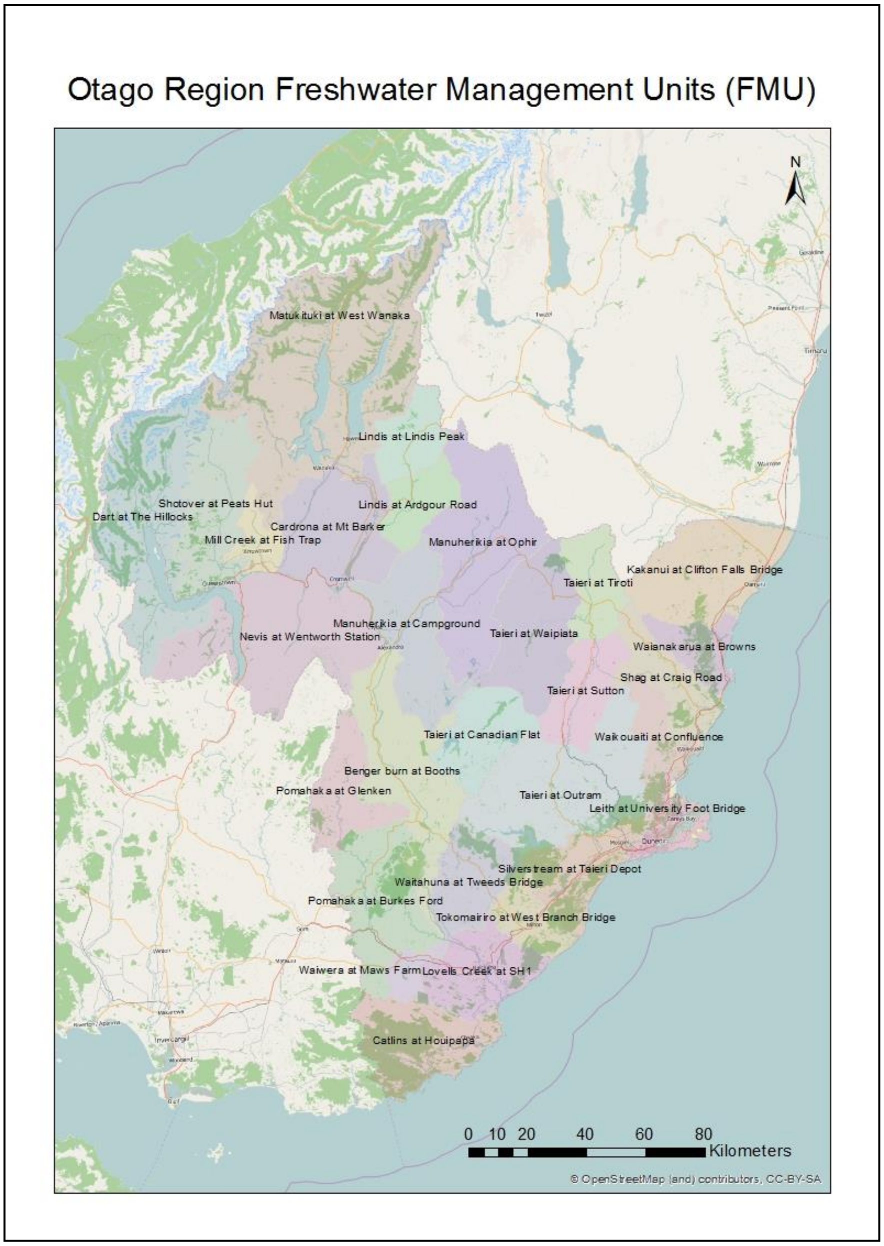

Figure 3 Otago FMUs

Nitrogen, phosphorous, sediment, and E. coli contamination in Otago Region

Otago Regional council has set targets and limits for its freshwater bodies and have supplied the percentage change from the current levels to 2025. More is discussed below.

Mandatory requirements[61]

The Otago Water Plan includes a suite of water quality rules to ensure good quality water in Otago's waterways. These rules control contaminants and sediment from non-point sources, mainly rural farming.

Otago Regional Councils Plan Change 6A is an effects-based, permitted activity approach to managing contaminants which may affect the water quality of waterways. Where an activity has a minimal effect on a waterway, resource consents are not needed as long as certain conditions are met. However, gross discharges and objectionable activities that degrade water quality are prohibited.

The rules provide for permitted activities, prohibited activities and a set of limits, targets and thresholds.

Permitted Activities

Permitted activities include contaminant discharges including surface runoff, groundwater seepage, or discharges from drains and races if:

- they comply with conditions controlling the effects of sediment runoff
- after 2020 they comply with the Otago Water Plan Schedule 16 thresholds set for nitrogen, phosphorus, and *E. coli*
- they comply with rules on nitrogen loss to groundwater as calculated using OVERSEER (Version 6).

There are specific conditions that must be met for each of these types of discharges set out in the rules:

- Discharges of water or contaminants
- Sediment discharge to waterways
- Discharges from water races
- Discharges from small dams
- Discharges to and from drains
- Construction work that disturbs the bed of a waterway
- Building a single span bridge
- Building a crossing
- Driving stock through waterways.

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[61] Information adapted from ORC website on the Water Quality Rules Plan Change 6A: http://www.orc.govt.nz/Publications-and-Reports/Regional-Policies-and-Plans/Regional-Plan-Water/Water-Quality-Rules-Plan-Change-6A/

Prohibited Activities

Landowners in Otago are not permitted to discharge:

- any contaminant to water that produces a nasty odour, or an obvious oil or grease film, scum, or foam
- any contaminant from an effluent pond or any other animal waste collection or storage system, silage pit, or composting
- sediment from disturbed land to water in any lake, river, or Regionally Significant Wetland, or to any drain or water race that flows to them or to coastal waters if nothing has been done to control sediment runoff.

Limits, Targets and Thresholds

Schedule 15 of the Otago Water Plan[62] describes and sets out the characteristics, contaminant concentration limits, and targets for good quality surface water in Otago rivers and lakes, as required by the National Policy Statement for Freshwater Management. These are discussed in the section below.

Schedule 16 thresholds[63] set the maximum concentration of contaminants that can come off any property, or from drains and irrigation races, and pass into waterways, without a consent. The thresholds come into effect from April 2020 and only apply when the representative flow site is at or below median flow. The sediment rules apply now.

Other practices and non-regulatory policies of note that reduce contaminant loads

Landholders are responsible for choosing methods of managing contaminant discharge to waterways that ensure that their property complies with the rules. Otago Regional Council provides some information about what landowners can do. For example, it has provided the following guidance about what activities will help landowners to comply with the rules in areas where water quality is deteriorating:

- Improved effluent management
- Stock exclusion from streams and wetlands
- Nutrient management planning
- Wintering cows in herd shelters with restricted autumn grazing
- Uncultivated grass riparian strips
- Stock tracks and lanes located away from streams
- Limiting fertiliser use or using nitrification inhibitors

[62] http://www.orc.govt.nz/Documents/Publications/Regional/Water/Plan%20Change%206A/2015/Schedule%2015.pdf

[63] http://www.orc.govt.nz/Documents/Publications/Regional/Water/Plan%20Change%206A/2015/Schedule%2016.pdf

- Quickly removing dead animals from waterways.

The council commissioned AgResearch to study water quality in the Pomahaka catchment in South Otago and the effects of farming on it. The report[64] identifies the cost-effective means available to farmers to reduce stream contamination (see page 34, section 3.5.2: The cost and effectiveness of mitigation strategies for decreasing contaminant losses from dairy and sheep farms).

The council provides a phone line for information on farm discharge management practices that will help meet discharge limits.

Freshwater quality limits in the Otago Region

The contaminant concentration limits and targets for nitrogen, phosphorus, *E. coli*, and turbidity (sediment) in Otago are listed in Schedule 15 of the Otago Water Plan (Table 15). These must be met by 31 March 2025, if they have not been met already. Schedule 16[65] sets the maximum concentration of contaminants resulting from discharges that can come off any property, or from drains and irrigation races, and pass into waterways, without a consent. Schedule 16 sets thresholds for *E. coli*, phosphorus, and nitrogen. The thresholds come into effect from April 2020.

Table 15. Estimated limits based on Schedule 15 for the Otago Region (% from baseline) between 2015 and 2025

Receiving water	Nitrogen	Phosphorus	Sediment	*E. coli*
Catlins at Houipapa	1% decrease	No change	No change	26% decrease
Leith at University Foot Bridge	1% decrease	No change	No change	63% decrease
Lovells Creek at SH1	No change	No change	No change	No change
Pomahaka at Burkes Ford	37% decrease	No change	No change	24% decrease
Tokomairiro at West Branch Bridge	No change	No change	No change	19% decrease
Waitahuna at Tweeds Bridge	No change	No change	No change	41% decrease
Waiwera at Maws Farm	50% decrease	24% decrease	No change	65% decrease

[64] http://www.orc.govt.nz/Documents/Publications/Regional/RWQS/AgResearch%20-%20WQ%20of%20the%20Pomahaka%20River%20-%20scope%20for%20improvement.pdf

[65] http://www.orc.govt.nz/Documents/Publications/Regional/Water/Plan%20Change%206A/2015/Schedule%2016.pdf

Benger burn at Booths	No change	No change	No change	No change
Cardrona at Mt Barker	No change	76% decrease	No change	18% decrease
Kakanui at Clifton Falls Bridge	No change	No change	No change	No change
Lindis at Ardgour Road	59% decrease	No change	No change	No change
Lindis at Lindis Peak	No change	No change	No change	No change
Manuherikia at Campground	80% decrease	65% decrease	60% decrease	20% decrease
Manuherikia at Ophir	No change	40% decrease	No change	No change
Mill Creek at Fish Trap	82% decrease	No change	No change	42% decrease
Pomahaka at Glenken	No change	No change	No change	54% decrease
Shag at Craig Road	32% decrease	No change	No change	No change
Silverstream at Taieri Depot	80% decrease	No change	No change	No change
Taieri at Sutton	No change	29% decrease	No change	41% decrease
Taieri at Waipiata	No change	78% decrease	No change	46% decrease
Waianakarua at Browns	70% decrease	No change	No change	No change
Waikouaiti at Confluence	No change	No change	No change	No change
Taieri at Outram	No change	38% decrease	7% decrease	66% decrease
Shotover at Peats Hut	No change	No change	26% decrease	No change
Taieri at Tiroti	No change	71% decrease	28% decrease	86% decrease
Dart at The Hillocks	No change	No change	94% decrease	No change
Matukituki at West Wanaka	No change	No change	No change	26% decrease
Nevis at Wentworth Station	No change	No change	No change	No change
Taieri at Canadian Flat	No change	No change	No change	No change

17 West Coast

Freshwater Water Management Units

Two management areas have been set for the West Coast, one contains catchments for Lake Brunner and the other is entitled ‘West Coast Excluding Brunner’. Most of the West Coast

Excluding Brunner management area is in the Department of Conservation (DOC) estate, in the order of 86 percent of the region.

Nitrogen, phosphorous, sediment, and E. coli contamination in West Coast Region[66]

In general water quality in the region is either excellent or at acceptable levels. Three catchments have had quality issues. Phosphorus is the most problematic contaminant in the region. In Lake Brunner, Orawaiti, and Harris Creek the issue has been identified through monitoring and a set of management activities put in place. In each case water quality has returned to acceptable levels, most notably and recently in Lake Brunner. The statement below was made by the West Coast Regional Council in 2015:[67]

> *As of January 2015 lake water monitoring data shows the rolling 5 year mean of the Tropic Level Index (TLI) for the lake dropped below the target level of 2.8. This means that all the hard work by landowners and others in the catchment in recent years has paid off. The TLI target has been met five years earlier than was anticipated in the Regional Council's Land and Water Plan.*

Lake Brunner will require ongoing management through the rules that have already been established (dedicated policy chapter in the regional plan). Other catchments where there have been issues include Orawaiti and Harris Creek.

The catchments in the DOC estate are not considered to be a problem.

Mandatory requirements

The Land and Water plan became operative in 2014.[68] Its goal is to reduce the loss of phosphorus to water in the Lake Brunner catchment. It notes that phosphorus is the limiting nutrient in Lake Brunner and that discharges of phosphorus can result from discharges of dairy effluent, the use of phosphorus-based fertiliser, and stock access to waterways.

The plan sets out to:

- require discharges of dairy effluent in the Lake Brunner catchment to be to land, rather than directly to water
- prevent stock access to waterways

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[66] Phone call with Lillie Sadler, November 2015

[67] http://www.wcrc.govt.nz/Documents/Newsletters/2015%20September%20Newsletter.pdf

[68] http://www.wcrc.govt.nz/our-services/resource-management-planning/Pages/Land-and-Water-Plan.aspx

- reduce the loss of phosphorus to Lake Brunner associated with the development of land, by managing phosphate fertiliser use in the catchment so that no net increases in annual loss occurs per property, and
- encourage methods of wintering of stock that will reduce the risk of phosphorus loss in the Lake Brunner catchment, including the management of effluent that results from wintering methods.

One of the many methods listed in the plan is to encourage the implementation of Nutrient Management Plans and Farm Plans to address best practice on individual farms to reduce effects on Lake Brunner.

The plan contains specific rules relating to:

- grazing and livestock access to riparian margins (permitted with requirements)
- any humping and hollowing, flipping, v-blading, or contouring in the Lake Brunner catchment (discretionary activity)
- stock crossings through waterways in the Lake Brunner catchment (discretionary activity)
- discharge of fertiliser, into or onto land (permitted with conditions)
- phosphorous fertiliser shall not be discharged in the Lake Brunner catchment to land that is developed under Rule 15 unless it has a water solubility of less than 10 percent
- discharge of phosphorus fertiliser into or onto land in the Lake Brunner Catchment associated with land development requires a consent (controlled activity)
- discharge of agricultural effluent into or onto land, in the Lake Brunner catchment, requires a consent (controlled activity).

Other practices and non-regulatory policies of note that reduce contaminant loads

Non-regulatory activities include riparian planting, fencing and farm plans with funding from the Ministry for the Environment. The West Coast Regional Council News[69] reports that:

> *In 2003/4 Council received funding through the Ministry for the Environment to undertake farm planning work in the catchment. The farm plan work was coordinated by Landcare Trust and was a voluntary process, where each participating landowner worked through a list of water quality issues identified on their property. These were prioritised and compiled into a three year plan for the farm, fitting within the farm budget. The voluntary farm plan work received a high uptake from the farming community and resulted in many improved practices. It identified high priority actions, which were completed by farmers at their own cost. In 2013 Council and Westland Milk*

[69] http://www.wcrc.govt.nz/Documents/Newsletters/2015%20September%20Newsletter.pdf

Products funded further farm planning work in the catchment to assist landowners in meeting the new rules. This was again a voluntary process with a high level of uptake.

In 2013 Council was successful in an application to the Ministry for the Environment Fresh Start to Freshwater Fund. This resulted in $200,000 being allocated towards riparian planting and fencing work within the catchment. $20,000 of the funding was allocated towards the newly formed Lake Brunner Catchment Care Group who used the funding to plant and fence four community sites. $180,000 was allocated towards works landowners identified in their farm plan, which related to improving water quality. This project is set for completion in October 2015.

Freshwater quality limits in the West Coast

The Land and Water Plan Objective for Lake Brunner/ Kotuku-Whakaoho Catchment is:[70] "To improve the water quality of Lake Brunner by managing the adverse effects of activities in the catchment to reach an average trophic level index of 2.8 by 2020, and then maintain or enhance the trophic level index." This trophic level index was achieved in 2015 which is 5 years earlier than required.

This means that no change in contaminant levels is needed between 2015 and 2020 (or later) for both management areas. In Lake Brunner, however, there will be ongoing management activities to ensure the water quality remains as good as it is today. In most other areas the land use and associated waterways are pristine.

18 Southland

Freshwater Water Management Units

Southland is drained by four major river catchments: Waiau, Mataura, Oreti, and Aparima Rivers. Combined, these cover 54 percent of the region. Southland has aggregated the remaining land into a fifth area called Fiordland and Stewart Island.

Nitrogen, phosphorous, sediment, and E. coli contamination in Southland Region

Pressures on water quality in Southland are mainly due to agricultural intensification, and industrial and urban waste water discharges (Environment Southland 2015). While water quality is generally excellent in natural state areas such as Fiordland, many lowland rivers and streams show elevated levels of nutrients. Water quality issues across the region vary but include

[70] West Coast Regional Council Rates

sediment, nitrogen, phosphorous and bacteria contamination. Water quality is good in conservation areas (Fiordland and Stewart Island) and in 'low intensity' (hill and high country) areas. In contrast, the Mataura and Oreti Rivers are polluted, which is often associated with the increasing pressure that growth in farming and urban communities has placed on the region's waterways.

Mandatory requirements and other practices and policies of note that reduce contaminant loads

A two-pronged approach to managing water quality is currently being pursued. The first involves the development of a set of 'Interim Measures' intended to 'hold the line' in terms of stopping any further decline in water quality, against the backdrop of continuing changes in land use patterns and intensity. These on-farm measures are proposed as the minimum standard for operations in Southland and are being put forward to ensure that stakeholders are in the best possible position when catchment limits will have to be set. The measures currently being considered include:

- Managing critical source areas of runoff
- Hill country development and cultivation of steep land
- Stock access to waterways
- Nutrient management
- Riparian management, and
- Managing intensive winter grazing operations.

The second approach to guide limit setting is categorizing the region into different physiographic zones. The science team at Environment Southland has identified how these zones vary according to factors such as water origin, soil type, geology, and topography. Each zone is different in the way contaminants build up and move through the soil and aquifers, and into streams and rivers. This approach has provided a framework from which the council has been able to develop proposed policies and rules based on the particular issues for each zone. For example, in a zone where groundwater nitrate is the main issue, there may be more requirements for managing nitrate than in zones where nitrate is not the main issue (AgResearch 2015).

Freshwater quality limits

In terms of limit setting, Environment Southland is establishing a new Water and Land Plan under a new project called: Water and Land 2020 and Beyond. The timetable for development of catchment plans varies, but all 5 are expected to be started by 2018 (AgResearch 2015). As a result, there are no defined limits for Southland at the time of this report.

19 Summary

As discussed in this report, specified targets to reduce diffuse source contaminants to waterways vary widely both across and within regions of New Zealand. A summary of the regional level targets (with range based on the spread across water management areas in the region) is listed in Table 16. Note that for most of these regions, the limits/targets are still in draft form and/or still under discussion with stakeholders working through collaborative processes and hence could change in the future. For the regions where limits are currently undefined and there are no potential limits specified, we will use NIWA's CLUES model to estimate the current baseline loads (based on 2012 land use). We then use these baseline loads as the limit for that water management area.

The national-level map of the different types of water management areas is shown in Figure 4. These areas are primarily based on a GIS shapefiles files provided by the Regional Councils. Where GIS files were not available, the management area boundaries were drawn in ArcGIS based on maps published online and/or descriptions provided by the council.

Table 16. Summary for the range of potential or actual regional level limits (% change from baseline)

Region	FMUs	Contaminant Limits (% change from 2012 baseline)			
		Nitrogen	Phosphorous	Sediment	*E. coli*
Northland	n/a	undefined	Undefined	undefined	undefined
Auckland	9	0–50% decrease	0–20% decrease	0–10% increase	No change
Waikato	8	undefined*	Undefined	undefined	undefined
Bay of Plenty	9	undefined^	Undefined	undefined	undefined
Gisborne	3	0–12% decrease	0–50% decrease	0–65% decrease	0–94% decrease
Hawkes Bay	15	0–30% decrease	0–10% decrease	0–10% decrease	0–10% decrease
Taranaki	4	0–10% decrease	0–30% decrease	0–30% decrease	0–30% decrease
Horizons	43	undefined	Undefined	undefined	undefined
Greater Wellington	5	0–15% decrease	No change	0-40% decrease	0–10% decrease
Nelson	5	0–50% decrease	0–50% decrease	0-50% decrease	0–50% decrease
Tasman	6	No change	No change	No change	No change
Marlborough	n/a	undefined	undefined	undefined	undefined
Canterbury	10	0-30% decrease	0-50% decrease	No change	No change

Otago	29	0–80% decrease	0–78% decrease	0–94% decrease	0–66% decrease
West Coast	2	No change	No change	No change	No change
Southland	5	undefined	undefined	undefined	undefined

* with exception of Lake Taupo catchment

^ with exception of Lake Rotorua catchment

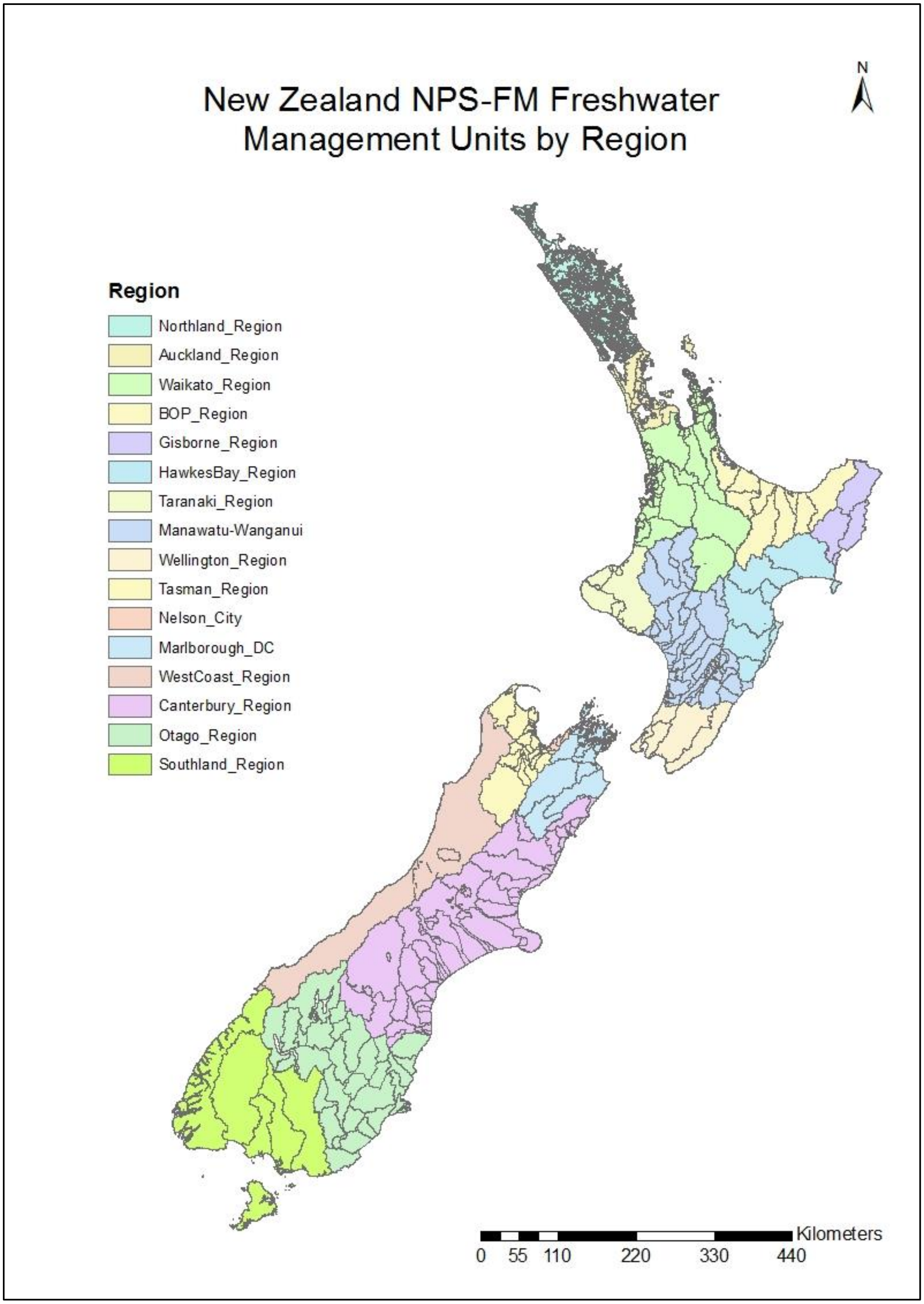
New Zealand NPS-FM Freshwater
Management Units by Region
N
Region
Northland_Region
Auckland_Region
Waikato_Region
BOP_Region
Gisborne_Region
HawkesBay_Region
Taranaki_Region
Manawatu-Wanganui
Wellington_Region
Tasman_Region
Nelson_City
Marlborough_DC
WestCoast_Region
Canterbury_Region
Otago_Region
Southland_Region
Kilometers
0 55 110 220 330 440

Figure 4. Freshwater management areas used for the purposes of this analysis (Note: FMU is used to refer to the range of different management areas across the country).

Appendix A1: Approach to determining the limits for the catchments in each region

Objective: to obtain information on possible contaminant reduction levels for all freshwater management units (FMUs) of New Zealand (note not all regions have identified FMU as yet so other types of management units have been used in some regions).

1. Get a map of regions catchments and any relevant water policy documentation/plans.
2. Contact a senior planner or other appropriate personnel
3. Find out: limits by catchment for nitrogen, phosphorous, sediment and *E. coli* by asking the following questions:

3.1 Have the FMUs for the region been finalised?

   a. If so, what are they and is there a GIS layer available for them?
   b. If so, how well do they correspond to catchment boundaries?

3.2 For each FMU, are their concerns about nitrogen, phosphorous, sediment, *E. coli*?

   a. If so, have reductions levels (or limits) been proposed or agreed and what are they?
   b. If status quo, what does this mean – no change, business as usual (so some change probably for the worst but it can handle it??), no new regulation? To confirm approach to be used for all.
   c. If no reduction levels (or limits) have been proposed or agreed, what does the council think the possible range of reductions (limits) might be, e.g. 5–10 percent reduction, 30–40 percent reduction, keep at current levels? i.e. Is there a possible plausible scenario (try to make consistent between regions)?

3.3 Which are the priority catchments? Do some catchments affect others? Are some catchments not considered to be a problem?

3.4 In the region are there any mandatory requirements on landowners that may affect nitrogen, phosphorous, sediment and *E. coli* levels and what are they? e.g. streambank fencing is required on all streams with slope < x percent.

3.5 What kinds of practices are landowners undertaking to reduce the different contaminant loads in the region/FMU?

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Appendix B – 2012 Land-use Map

A national-scale map of New Zealand was initially developed by Landcare Research in the mid-2000s for a project featuring the 'CLUES' model. This layer used an intersection between land-cover from the NZ Land-cover Database version 2 (LCDB2) and a 2003 version of land uses from AgriQuality's Agribase™ dataset. Once intersected, decision rules were made to create a land-use map based on the classification developed for the project (Woods, Elliott et al. 2006). This map was recently updated using an intersection of LCDB2[71] (Ministry for the Environment, 2004) and Agribase™ version from March 2011. More details on these two databases are provided in Appendix 1.

The land-use classification used a tiered approach from broad categories (e.g. pastoral, arable, horticultural, etc) to more detailed categories (e.g. dairy, maize, kiwifruit). The latest version of the land use map was re-created down to an additional tier 2 based on the most detailed information available in Agribase™. Other national-level data sets such as the Land Environments of New Zealand (Leathwick et al, 2003), and the Agricultural Census (StatsNZ, 2008) were used to further distinguish between intensive and extensive livestock farming depending on the topography of the landscape and number of animals in a given territorial authority. The high-level steps for creating the various tiers of the map are as follows:

- **Step 1:** Define the unified, virtualized geometries for each land parcel and territorial authority in New Zealand (TA) in New Zealand. Individual land parcels are initially defined using LCDB2.

- **Step 2 (Tier I):** Specify the high level land uses for each land parcel defined in Step 1 using both Agribase™ and LCDB2. This establishes whether each farm is pastoral, arable, horticultural, forestry, etc., but does not assign specific stock types or crops to the land.

- **Step 3 (Tier II):** Refine Tier I to provide additional spatial and descriptive detail by specifying the livestock and crop types for each land parcel. The first stage is to assign the most specific land uses (e.g., dairy, sheep & beef, kiwifruit, etc.) based on the Agribase™ classification. For parcels not included in Agribase™, first use LENZ to distribute the different land uses in relation to the land form (e.g., flat, rolling, etc.) and then assign the most profitable land uses to the flatter areas. Aggregate arable and horticultural crops (e.g., vegetables, viticulture) are further refined based on the relative area of each crop for a given TA using the Agricultural Production Survey.

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[71] At the time that the 2011 land use map was created, LCDBv3 had not been released yet (available from 2012). Although there was been notable *land use* change (e.g., sheep and beef to dairy) in some areas of New Zealand between 2002 and 2011, the *land cover* change (e.g., exotic forestry to high exotic productive grassland) over that same time period is relatively small. Landcare Research is in the process of updating this land use map with the latest version of Agribase™ and LCDBv4, but this will not be completed until at least June 2016.

- **Step 4 (Tier III):** Further refine Tier II to provide additional regional detail using information about MAF monitor farms (MAF, 2011) and the regional statistics from the Agricultural Production Survey (see Appendix B1 for more details on this database). Note that this step is not utilised in the 2015 SLMACC modelling project.

- **Step 5 (Tier IV):** Refine further to give the highest classification of land use. This uses additional information from Agribase™ to assign other livestock (e.g., alpaca, goats, etc.) and crops (e.g., potatoes, wheat, etc.) to each parcel. This assignment is refined in each TA based on the relative area of each crop in the Agricultural Production Survey.

A schematic of how the classification was defined is shown in Figure 1. The full list of land uses included in the map is shown in Appendix 2.

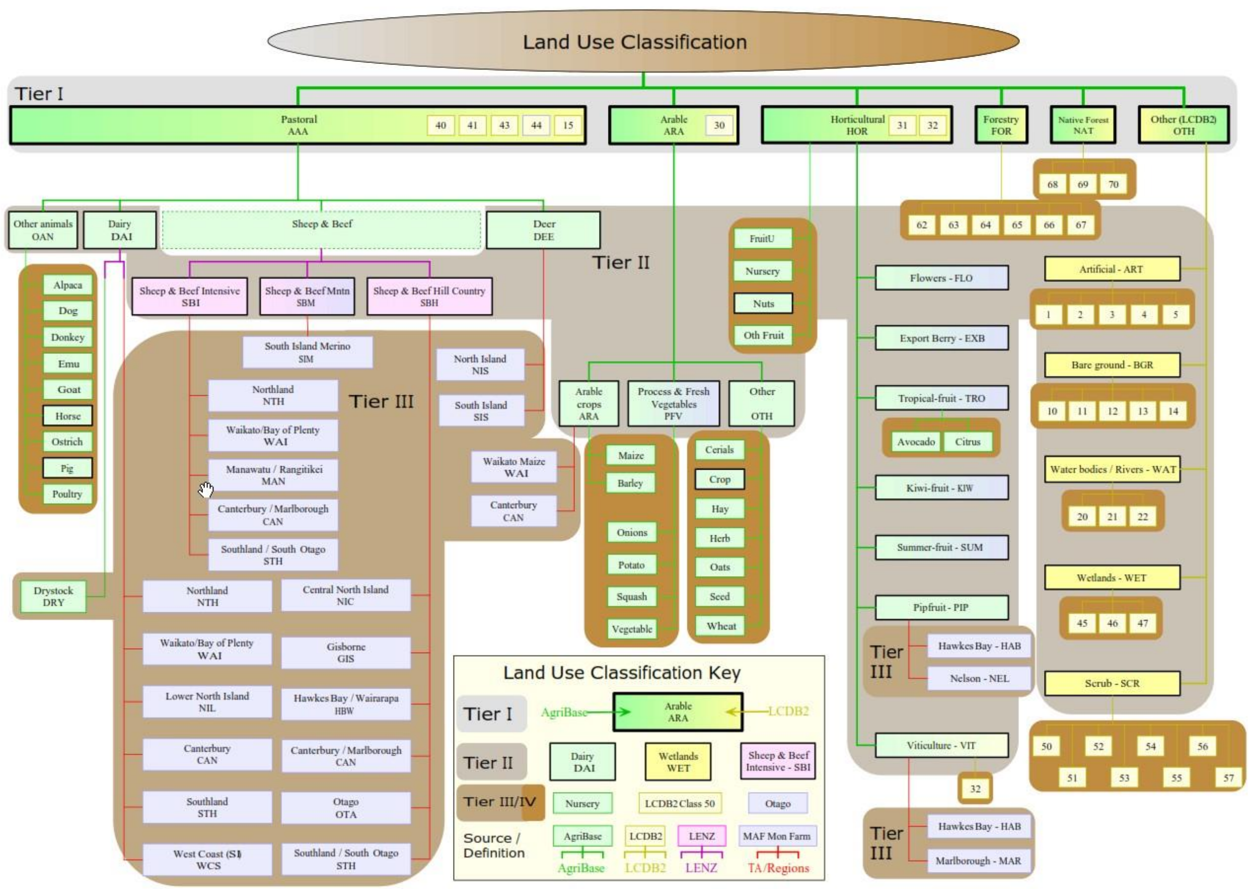
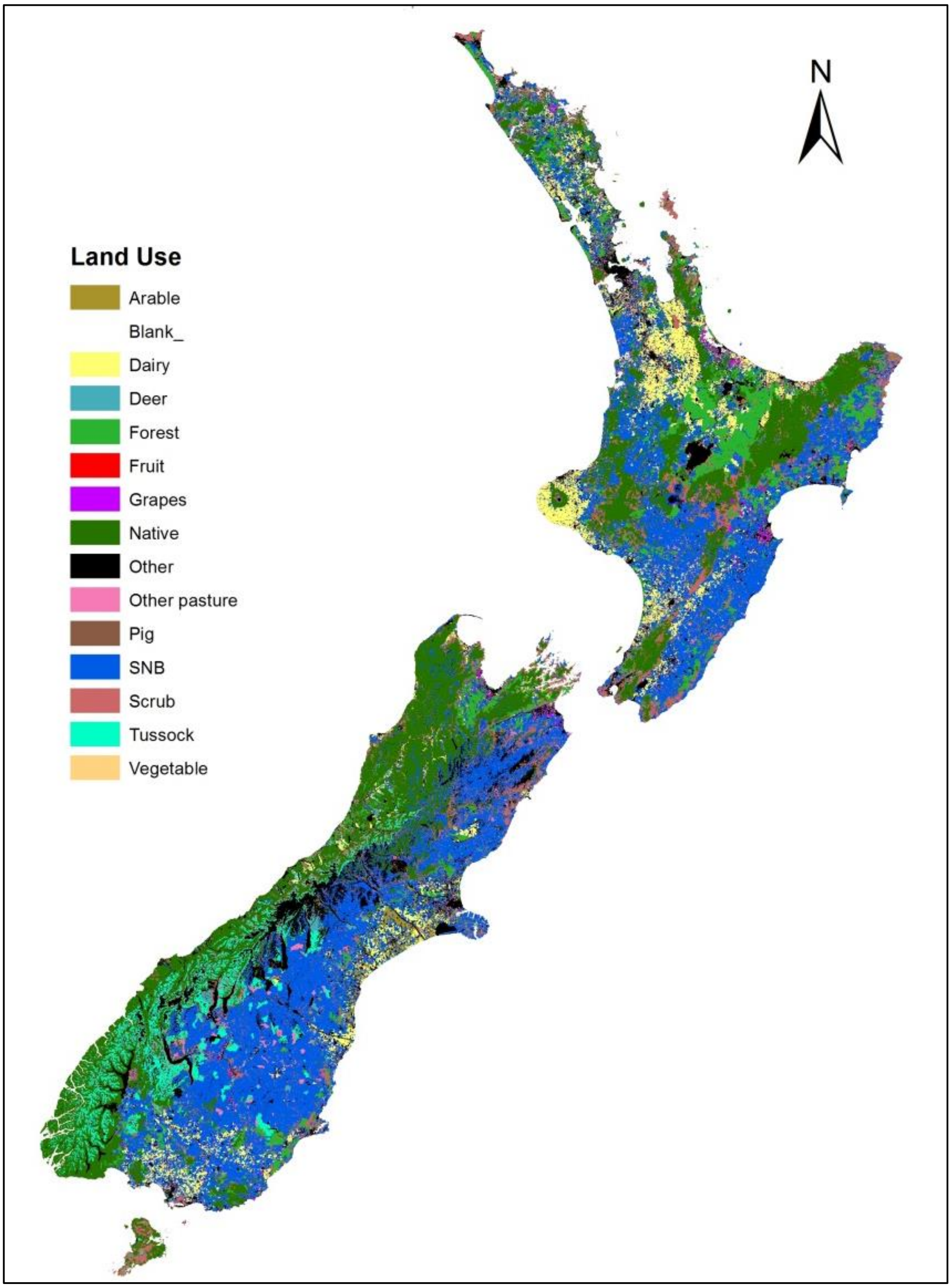


Figure B1: New Zealand land use map tier system

The land use map output is a shapefile with attributes from both LCDB2 and Agribase™, with inferences on dominant land use. We decided to use the land cover as the primary attribute. Where the land cover is grassland (high-producing or low-producing), we used the information on the dominant land use from Agribase™. Where there was no additional information from Agribase™, the classification stayed as “land area devoted to livestock” (coded “AAA”). **Error! Reference source not found.** shows how some land uses included n this map were aggregated to establish a smaller classification of land uses that will be modelled in NZFARM and LURNZ for this research project. This is due to (a) the lack of nationally-comprehensive economic data available for some of the land uses, and (b) the assumption that the NPS-FM will not have a noticeable impact on some of these land uses, and therefore also not have an impact on GHG emissions. A draft map indicating the spatial distribution of 14 different land uses across New Zealand is shown in Figure 2. This map has already been incorporated into NZFARM. It has also been formatted into 1ha and 25ha grid cells so that it can be added to LURNZ.

Figure B2: New Zealand land use, 2011



Appendix B1 – Description of key datasets for land use map

AgriBase™

AgriBase™ is a spatial dataset originally developed by the Ministry for Agriculture (MAF) in 1993, and is now curated by AgriQuality Limited. AgriBase™ provides rich detail about on-farm crops, horticultural species and animal numbers for many stock types (Sanson, 2005).

Farmers are encouraged enter information on their farm on a voluntary basis (AgriQuality New Zealand, 2011), meaning that the database is incomplete both in spatial coverage (not all farms are present) and in the data-fields farm owners have chosen to fill in. Furthermore its spatial detail is limited to whole farm enterprises. This has four types of consequences a number of which may coincide for a single farm:

1. Where a farm has more than one activity, AgriBase records what the activities are but doesn't record where they take place within the farm.

2. Where a farm uses both land owned by the enterprise and leased from other owners, the AgriBase record may contain conflicting information – such as: the sum of the areas occupied by all the plant types may differ significantly from the recorded total spatial extent of the farm.

3. Where a farmer has not filled in all the data-fields that are relevant to their farm, there will obviously be data gaps leading to uncertainty in the interpretation.

4. Where a farmer has misinterpreted the meaning of one or more data-fields, the data will appear to be inconsistent.

Land Cover Database 2 (LCDB2)

Land Cover Database 2 (LCDB2) is a thematic classification of 43 land cover and land use classes covering mainland New Zealand, near shore islands and the Chatham Islands. The first Land Cover Database (LCDB1) was completed in 2000 using SPOT satellite imagery acquired over the summer of 1996/97. LCDB2 was released in July 2004 and used Landsat 7 ETM+ satellite imagery acquired over the summer of 2001/02. This release also reports land cover/land use changes for the five-year period between the two acquisitions of satellite imagery.

LCDB2 provides complete, internally consistent national coverage with a nominal spatial resolution of 1ha, but gives no indication of what stock are present on pasture or of crop types or (with a couple of exceptions) of horticultural species.

Agricultural Production Survey (APS)

The Agricultural Production Survey is a collective term that describes both the Agricultural Production Census and the Agricultural Production Survey. The Census is undertaken every 5 years from a population of approximately 80,000 farm businesses, while the Survey is undertaken annually between Census years using a representative stratified sample of approximately 30 000 farm businesses. Statistics NZ collects and maintains APS data on behalf of MPI.

"Farm businesses" include all units identified on Statistics New Zealand's Business Frame as having agricultural activity (Statistics New Zealand 2015). This includes individuals or farming enterprises involved in livestock farming, arable farming, horticulture or forestry. The Business Frame is a list of businesses in New Zealand, based on their registration for goods and services tax (GST) with Inland Revenue. Since the compulsory registration level for GST is $60,000, there is an unknown proportion of units below this level that are excluded from the APS population (e.g. lifestyle blocks and other small farming endeavours paying <$60,000 in GST per year).

Table B2 - Land use classification description

Field Name (class)	Description	SLMACC 2015 Land Use Classification
AAA	Land area devoted to livestock	Sheep & Beef (SNB)
AVOC	Avocado	Fruit
BARL	Barley (grain)	Arable
CERU	Undefined Cereals	Arable
CROU	Undefined Cropping	Arable
MAIZ	Maize (grain)	Arable
OATS	Oats (grain)	Arable
OPLA	Other Planted Types	Arable
SEED	Seed Crops (e.g. Herbage / Cereal)	Arable
WHEA	Wheat (grain)	Arable
BEF	Beef cattle numbers	Sheep & Beef
BERR	Berry fruit	Fruit
BISO	Bison numbers	Other pasture
CAM	Camelids (Alpacas and Llamas)	Other pasture
CITR	Citrus fruit	Fruit
DAI	Dairy Cattle numbers	Dairy
DEE	Deer numbers	Deer
DOG	Dogs	Other
DONK	Donkeys	Other pasture
DUCK	Ducks	Other
EMU	Emus	Other pasture
FLOW	Flowers	Vegetables
FODD	Fodder	Other pasture
HAYF	Fodder (eg. Lucerne / green maize / hay)	Other pasture
FOR	Forestry	Forestry
FRUU	Undefined Fruit	Fruit
GOAT	Goats farmed	Other pasture
GRAZ	Grazing Other Peoples Stock	Sheep & Beef
HERB	Herbs/Medicinal Plants	Other
HORS	Horse numbers	Other pasture
KIWF	Kiwifruit Orchards	Fruit
MAN	Manuka-Kanuka	Scrub
NAT	Native Bush	Native
NURS	Nursery	Other
NUTS	Nuts	Fruit
OANM	Other Animals	Other
OFRU	Other Fruit	Fruit
OLAN	Other Land Use	Other
OSTR	Ostrich numbers	Other pasture
OTH	Idle land or planned for redevelopment	Other
PIGS	Pig numbers	Pig
PIPF	Pipfruit	Fruit
POU	Poultry birds	Other
SCR	Scrub	Scrub
SHP	Sheep	Sheep & Beef
STON	Stone Fruit	Fruit
TUSS	Tussock grassland	Tussock
ONIO	Onions (vegetables)	Vegetables
POTA	Potato (vegetables)	Vegetables
SQUA	Squash (vegetables) for export	Vegetables

VITI	Viticulture	Grapes

Appendix B2 – Updating LU Map to 2012 for NZFARM

In constructing a 2012 land-use basemap for NZFARM, land-cover data from the 2012 Land Cover Database 4 (LCDB4) is combined with land-use data from the most current Land Use in New Zealand (LUNZ) map. LUNZ itself combines information from the 2011 Agribase with a previous version of the LCDB.

In general, the land-use classification in the new basemap is primarily determined by LCDB4 where land cover is expected to accurately reflect land use, and it is mainly based on LUNZ use where land cover is expected to be a poor proxy for land use (for example, in the identification of sheep-beef and dairy pasture). A map of land ownership is also used in the process: the classification differs slightly on private and public land.

We first reclassify the LCDB4 land cover categories into simplified land cover classes as shown in the table below. This reclassification is consistent with the one used to form the land cover classes for the Land Use in Rural New Zealand (LURNZ) model (Anastasiadis et al., 2014).

Table 1. The construction of simplified land cover classes based on the original LCDB4 classification

LCDB4 classification	LCDB4 simplified
High producing exotic grassland	Pasture
Low producing grassland	Pasture
Tall tussock grassland	Pasture
Depleted tussock grassland	Pasture
Exotic Forest	Forestry
Forest harvested	Forestry
Deciduous hardwoods	Forestry
Flaxland	Scrub
Fernland	Scrub
Gorse and/or Broom	Scrub
Manuka and/or Kanuka	Scrub
Matagouri or Grey Scrub	Scrub
Broadleaved indigenous hardwoods	Scrub
Sub-alpine scrubland	Scrub
Mixed exotic scrubland	Scrub
Short-rotation cropland	Horticulture
Orchard, vineyard and other perennial crops	Horticulture
Surface mines and Dumps	Non-productive
Sand and gravel	Non-productive
Alpine grass / herb field	Non-productive
Gravel and rock	Non-productive
Land slide	Non-productive
Permanent ice and snow	Non-productive
Lake and pond	Non-productive
River	Non-productive
Estuarine open water	Non-productive
Herbaceous freshwater vegetation	Non-productive

Herbaeceous saline vegetation	Non-productive
Mangrove	Non-productive
Built-up area	Urban
Urban parkland / openspace	Urban
Transport infrastructure	Urban
Indigenous forest	Indigenous forest

A three-way intersection of the maps representing simplified LCDB4 classes, LUNZ land uses and land ownership is then taken. The analysis is performed with 1-hectare resolution versions of each map. The top panels in tables 2 and 3 show the land areas associated with every combination of LUNZ and simplified LCDB4 classes on private and public land, respectively. The bottom panels of each table displays the land use into which each cell from the top panel is reclassified in the NZFARM basemap. The NZFARM target land uses are colour coded.

Finally, table 4 summarises land-use areas by ownership type in the NZFARM basemap. The final land-use areas were checked for approximate consistency with other data sources, including land area data from DairyNZ and the National Exotic Forestry Description (NEFD).

Table 2. The top panel shows the intersection of LUNZ with the LCDB4 simplified land cover layer on private land. Land areas shown are in hectares. The bottom panel represents the same intersection displaying the (color-coded) target land use for the NZFARM basemap.

	LCDB4 simplified							
LUNZ use	Pasture	Forestry	Scrub	Horticulture	Non-productive	Urban	Indigenous forest	**Private area**
Missing	95	15	9	10	8	1	11	149
Arable	42,801	503	110	153,197	179	462	36	197,288
Blank (sea)	3,159	276	1,697	54	2,901	366	677	9,130
Dairy	1,652,404	7,566	6,310	31,147	2,302	763	3,057	1,703,549
Deer	173,577	1,390	2,049	5,096	124	39	320	182,595
Plantation Forest	166,325	1,260,773	36,198	2,403	2,269	1,843	16,237	1,486,048
Fruit	9,309	199	165	6,742	38	122	32	16,607
Grapes	42,640	991	1,124	51,203	221	1,203	184	97,566
Native Bush	74,626	68,265	47,726	820	24,291	1,017	1,006,433	1,223,178
Other Land Use	577,109	11,492	15,419	67,122	412,439	172,303	2,684	1,258,568
Other Pasture	774,485	20,681	15,463	14,857	4,949	10,899	2,231	843,565
Pig	7,331	62	35	2,202	10	29	6	9,675
Scrub	110,962	51,609	1,086,491	648	8,185	1,090	16,640	1,275,625
Sheep & Beef	5,895,529	81,460	97,134	115,044	15,452	1,644	12,391	6,218,654
Tussock	60,688	2,719	602	127	1,270	11	235	65,652
Vegetable	6,623	69	23	10,259	4	120	13	17,111
Private area	9,597,663	1,508,070	1,310,555	460,931	474,642	191,912	1,061,187	14,604,960

	LCDB4 simplified							
LUNZ use	Pasture	Forestry	Scrub	Horticulture	Non-productive	Urban	Indigenous forest	**Private area**
Missing	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	149
Arable	Arable	Plantation Forest	Arable	Arable	Other Land Use	Other Land Use	Native Bush	197,288
Blank (sea)	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	9,130
Dairy	Dairy	Plantation Forest	Dairy	Dairy	Dairy	Other Land Use	Native Bush	1,703,549
Deer	Deer	Plantation Forest	Deer	Deer	Deer	Other Land Use	Native Bush	182,595
Plantation Forest	Sheep & Beef	Plantation Forest	Plantation Forest	Arable	Other Land Use	Other Land Use	Native Bush	1,486,048
Fruit	Fruit	Plantation Forest	Fruit	Fruit	Other Land Use	Other Land Use	Native Bush	16,607
Grapes	Grapes	Plantation Forest	Grapes	Grapes	Other Land Use	Other Land Use	Native Bush	97,566
Native Bush	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	1,223,178
Other Land Use	Other Land Use	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	1,258,568
Other Pasture	Other Pasture	Plantation Forest	Other Pasture	Other Pasture	Other Pasture	Other Land Use	Native Bush	843,565

Pig	Pig	Plantation Forest	Pig	Pig	Pig	Other Land Use	Native Bush	9,675
Scrub	Scrub	Plantation Forest	Scrub	Scrub	Scrub	Other Land Use	Native Bush	1,275,625
Sheep & Beef	Sheep & Beef	Plantation Forest	Sheep & Beef	Sheep & Beef	Sheep & Beef	Other Land Use	Native Bush	6,218,654
Tussock	Tussock	Plantation Forest	Tussock	Tussock	Tussock	Other Land Use	Native Bush	65,652
Vegetable	Vegetable	Plantation Forest	Vegetable	Vegetable	Other Land Use	Other Land Use	Native Bush	17,111
Private area	9,597,663	1,508,070	1,310,555	460,931	474,642	191,912	1,061,187	14,604,960

Table 3. The top panel shows the intersection of LUNZ with the LCDB4 simplified land cover layer on public land. Land areas shown are in hectares. The bottom panel represents the same intersection displaying the (color-coded) target land use for the NZFARM basemap.

				LCDB4 simplified				
LUNZ use	Pasture	Forestry	Scrub	Horticulture	Non-productive	Urban	Indigenous forest	**Public area**
Missing	14	1	14	1	8	1	8	47
Arable	2,743	162	15	3,350	71	134	1	6,476
Blank (sea)	671	131	996	3	1,354	196	2,229	5,580
Dairy	36,620	346	280	573	305	176	278	38,578
Deer	55,283	70	746	127	2,346	3	149	58,724
Plantation Forest	15,802	550,805	12,544	125	1,366	618	10,743	592,003
Fruit	252	3	16	88	2	21	2	384
Grapes	15,775	212	975	1,208	207	239	416	19,032
Native Bush	46,035	29,173	66,256	150	19,331	354	5,265,550	5,426,849
Other Land Use	102,211	3,765	16,827	1,491	1,230,302	35,230	6,094	1,395,920
Other Pasture	149,456	2,392	3,587	647	3,579	3,287	565	163,513
Pig	186	11	0	52	0	0	1	250
Scrub	52,128	8,585	1,145,255	134	28,670	387	23,806	1,258,965
Sheep & Beef	2,053,582	5,599	41,290	3,759	102,561	389	6,413	2,213,593
Tussock	874,908	397	16,367	106	135,936	30	6,129	1,033,873
Vegetable	727	7	53	345	46	13	21	1,212
Public area	3,406,393	601,659	1,305,221	12,159	1,526,084	41,078	5,322,405	12,214,999

				LCDB4 simplified				
LUNZ use	Pasture	Forestry	Scrub	Horticulture	Non-productive	Urban	Indigenous forest	**Public area**
Missing	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	47
Arable	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	6,476
Blank (sea)	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	5,580
Dairy	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	38,578
Deer	Deer	Plantation Forest	Deer	Deer	Deer	Other Land Use	Native Bush	58,724
Plantation Forest	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	592,003
Fruit	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	384
Grapes	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	19,032
Native Bush	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	5,426,849
Other Land Use	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	1,395,920

Other Pasture	Other Pasture	Plantation Forest	Other Pasture	Other Pasture	Other Pasture	Other Land Use	Native Bush	163,513
Pig	Pig	Plantation Forest	Pig	Pig	Pig	Other Land Use	Native Bush	250
Scrub	Scrub	Plantation Forest	Scrub	Scrub	Scrub	Other Land Use	Native Bush	1,258,965
Sheep & Beef	Sheep & Beef	Plantation Forest	Sheep & Beef	Sheep & Beef	Sheep & Beef	Other Land Use	Native Bush	2,213,593
Tussock	Tussock	Plantation Forest	Tussock	Tussock	Tussock	Other Land Use	Native Bush	1,033,873
Vegetable	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	1,212
Public area	3,406,393	601,659	1,305,221	12,159	1,526,084	41,078	5,322,405	12,214,999

Table 4. Land-use areas by land ownership in the 2012 NZFARM basemap. The colour coding corresponds to that used in the bottom panels of tables 2 and 3.

NZFARM land use	Private area	Public area	Total area
Dairy	1,692,163	0	1,692,163
Sheep & Beef	6,367,364	2,303,077	8,670,441
Other Pasture	809,754	157,269	967,023
Deer	180,846	58,502	239,348
Pig	9,578	238	9,816
Plantation Forest	1,544,268	601,659	2,145,927
Scrub	1,271,137	1,324,163	2,595,300
Tussock	62,687	1,027,317	1,090,004
Arable	266,517	0	266,517
Fruit	16,216	0	16,216
Grapes	94,967	0	94,967
Vegetable	16,905	0	16,905
Native Bush	1,061,187	5,322,405	6,383,592
Other Land Use	1,211,371	1,420,369	2,631,740
Total	14,604,960	12,214,999	26,819,959

Appendix B References

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Appendix C - CLUES-based determination of contaminant loads

The aim of this component of the study was to use the existing catchment model CLUES[72] (Catchment Model for Land use and Environmental Sustainability) (Woods et al. 2006; Semadeni-Davies et al. 2011, 2012) (to assess the loads of contaminants entering streams, summarised by Freshwater Management Unit (FMU). This involved running CLUES for a 'current' land use, extracting loads for each land-use by REC subcatchment, and then summarising the results by the larger FMU polygons.

Brief description of CLUES

CLUES determines mean annual loads of total nitrogen (TN), total phosphorus (TP), suspended sediment, and *E. coli* for each stream in the national REC (River Ecosystem Classification) stream network (Snelder et al. 2010). For pastoral land-uses, the 'generated' load of TN and TP are determined as a function of broad enterprise type (e.g. Dairy) and other catchment attributes such as rainfall and subcatchment-average slopes using a simplified version of the OVERSEER farm nutrient loss model (version 6.1, http://www.Overseer.org.nz). TN loads from horticulture and cropping are determined from equations summarising results of SPASMO model runs for selected enterprise types, as described in Woods et al. (2006). Nutrient loading for other land-use types is determined by calibrating yields to measured loads using the SPARROW catchment model software (Elliott et al. 2005) (http://water.usgs.gov/nawqa/sparrow), which includes factors for drivers such as rainfall and soil drainage. For TP, a further source proportional to the estimated sediment generation is added, to account for TP associated with mass erosion (Elliott et al. 2005). Sediment sources are determined according to erosion terrain classification and land cover, and drivers of slope and rainfall ((Elliott et al. 2008). Sources of *E. coli* are based on source coefficients for pasture and non-pasture, adjusted for rainfall and soil drainage, and calibrated to measured loads. Point sources of TN, TP, and *E. coli* are also incorporated into the model.

CLUES also accumulates contaminants down the stream network including accounting for loss of contaminants (for example, by settling in lakes), and also includes methods for determining concentrations. Those aspects of CLUES are not relevant to the current study, which only addresses contaminant generation rather the loading in streams or concentrations.

This study was based on the most recent version of CLUES (Version 10.1), which incorporates updates in parameter values from model-recalibration.

Application for the current study

Land use for the current study was based on NZFARM land-use layers provided by Landcare Research (described elsewhere in the report). The mapping NZFARM to CLUES land use classes are shown in Table C1. NZFARM Sheep & Beef was split into three CLUES classes (SBINTEN, SBHILL, SBHIGH) as described in Woods et al. (2006)

[72] https://www.niwa.co.nz/freshwater-and-estuaries/our-services/catchment-modelling/clues-%E2%80%93-catchment-land-use-for-environmental-sustainability-model

Table C1. Mapping from NZFARM land use classes to CLUES representative classes

NZFARM land use class	CLUES land use class
Arable	MAIZE
Dairy	DAIRY
Deer	DEER
Plantation Forest	PLANT_FOR
Fruit	KIWIFRUIT
Grapes	GRAPES
Native Bush	NAT_FOR
Other Land Use	OTHER
Other Pasture	UNGR_PAST
Pig	OTHER_ANIM
Scrub	SCRUB
Sheep & Beef	SBINTEN,SBHILL,SBHIGH
Tussock	TUSSOCK
Vegetable	POTATOES

Slope, rainfall, soil drainage, soil order, and point sources were taken from CLUES default values.

In the standard CLUES model, the component of P associated with mass erosion is considered as a separate source term not associated with a particular land use. For the current study, this source was apportioned to forested (including scrub) and non-forested areas assuming a 5.1-fold greater loss per unit area for non-forested areas for this term. This ratio is consistent with the CLUES erosion model.

The load for each land-use and REC subcatchment was extracted from CLUES model outputs (using an in-house version of CLUES to enable separation by land-use). The load for each land use within each Freshwater Management Unit (FMU, as supplied by Landcare Research) was then determined by summing the loads from the subcatchments within the FMU. If an REC subcatchment was split by and FMU boundary, the loads from the REC subcatchment were apportioned to the relevant FMUs according to the proportions of the REC subcatchment. In some cases, such as areas abutting the coast, the FMU has no REC subcatchment, so the above method would give zero load. To account for this, we determined the yield (load per unit area) for those parts of the FMU that are covered by the FMU, and this yield could be used to approximate the load for the full FMU assuming that the same yield applies.

Tables of yield and load by land use (along with point sources) for each FMU are provided in a separate excel file. These are mapped in Figures C1–C4.

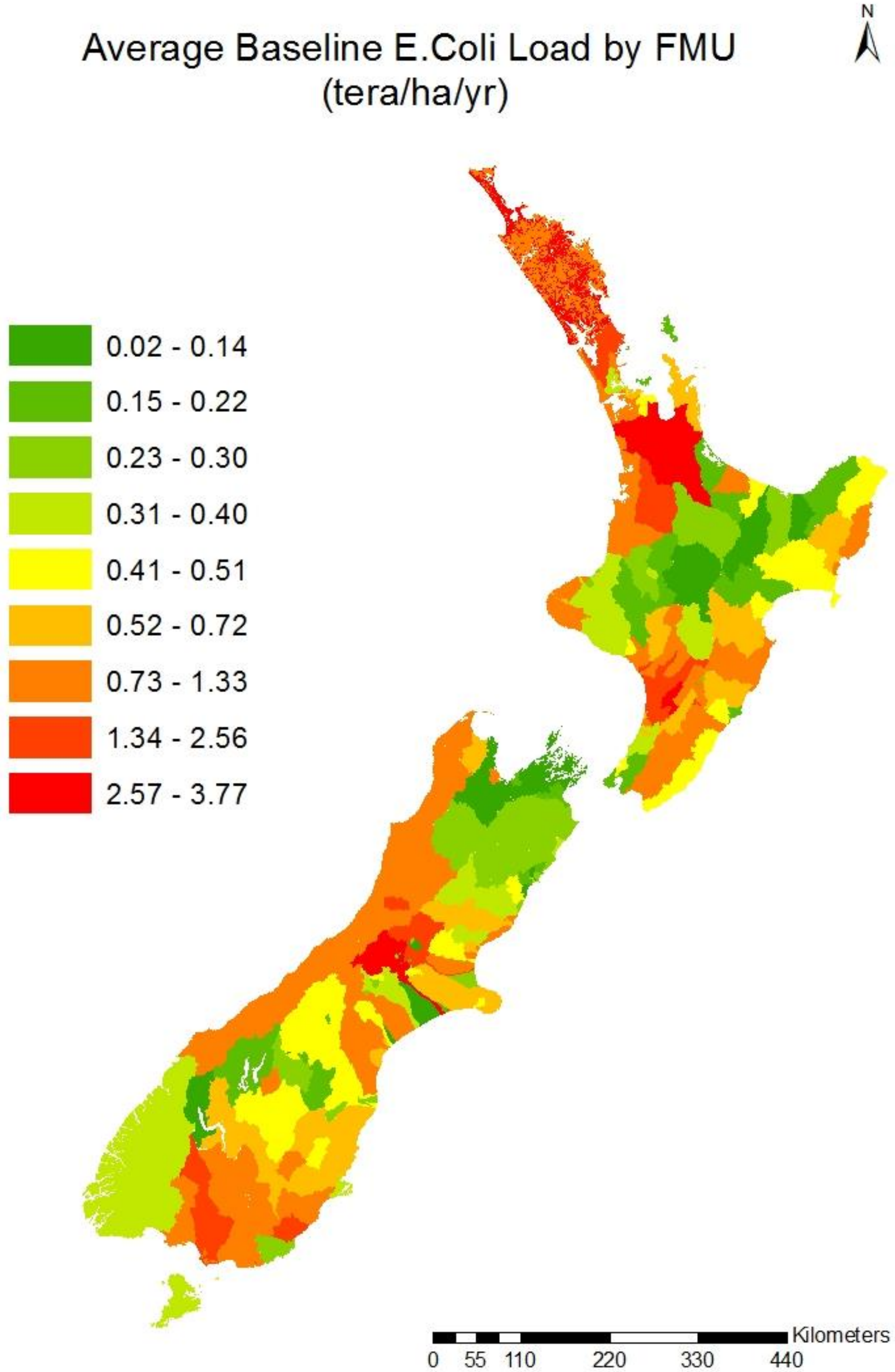

Figure C1. ***E. coli*** **baseline loads (tera/ha/yr) for each water management area (Note: FMU is used to refer to the range of different management areas across the country).**

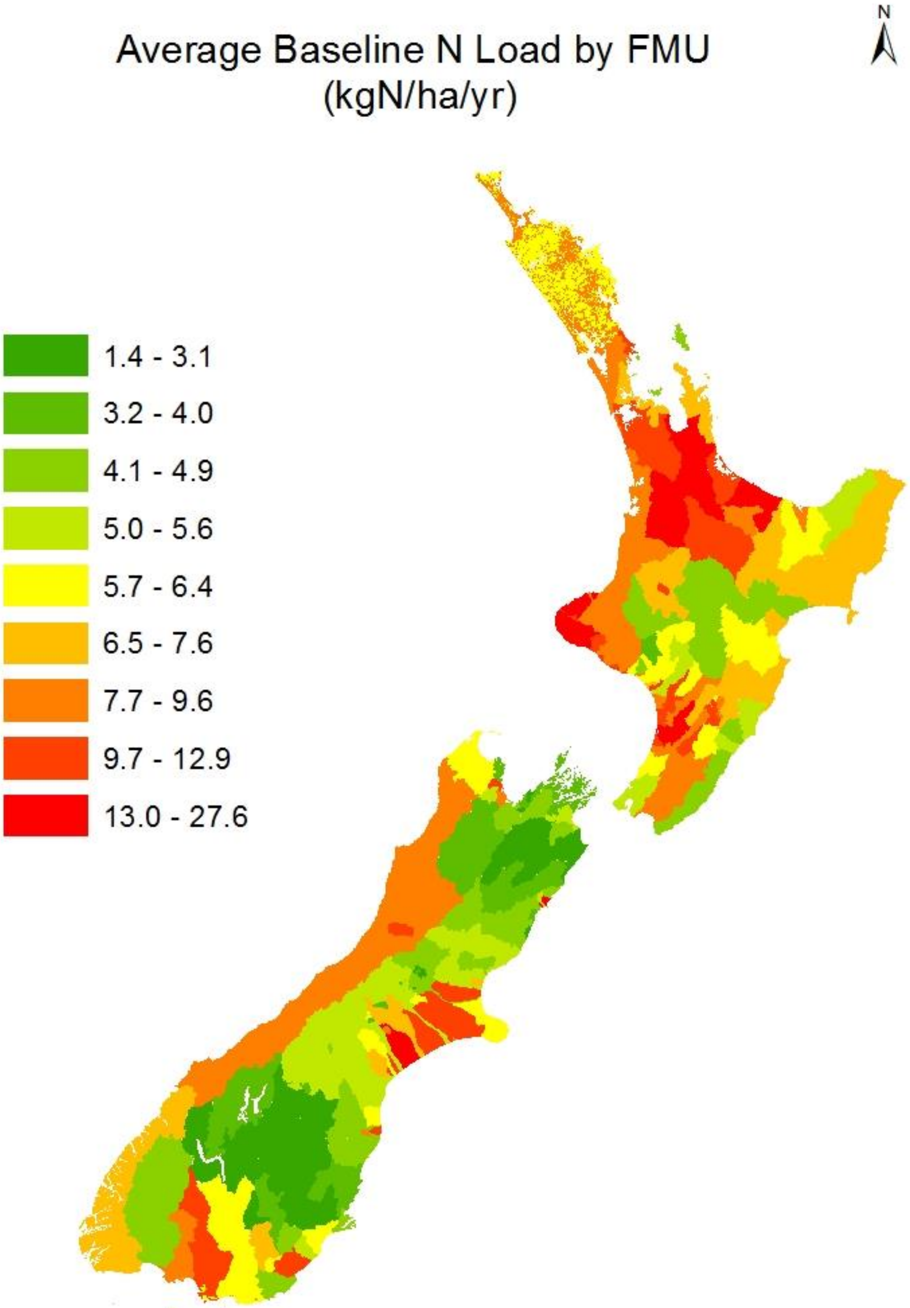

Figure C2. Nitrogen baseline loads (kgN/ha/yr) by water management area (Note: FMU is used to refer to the range of different management areas across the country).

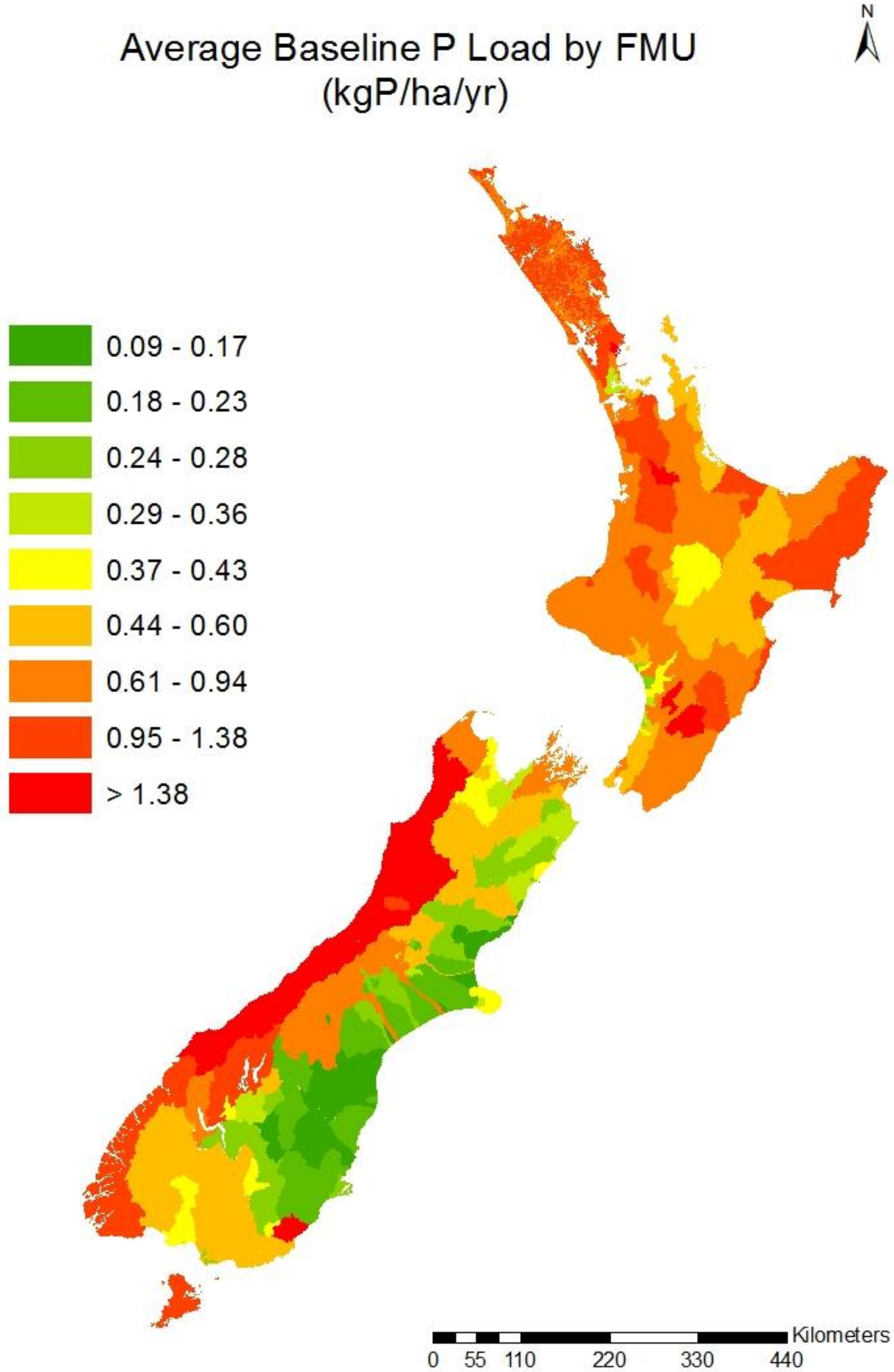

Figure C3. Phosphorus baseline loads (kgP/ha/yr) by water management area (Note: FMU is used to refer to the range of different management areas across the country).

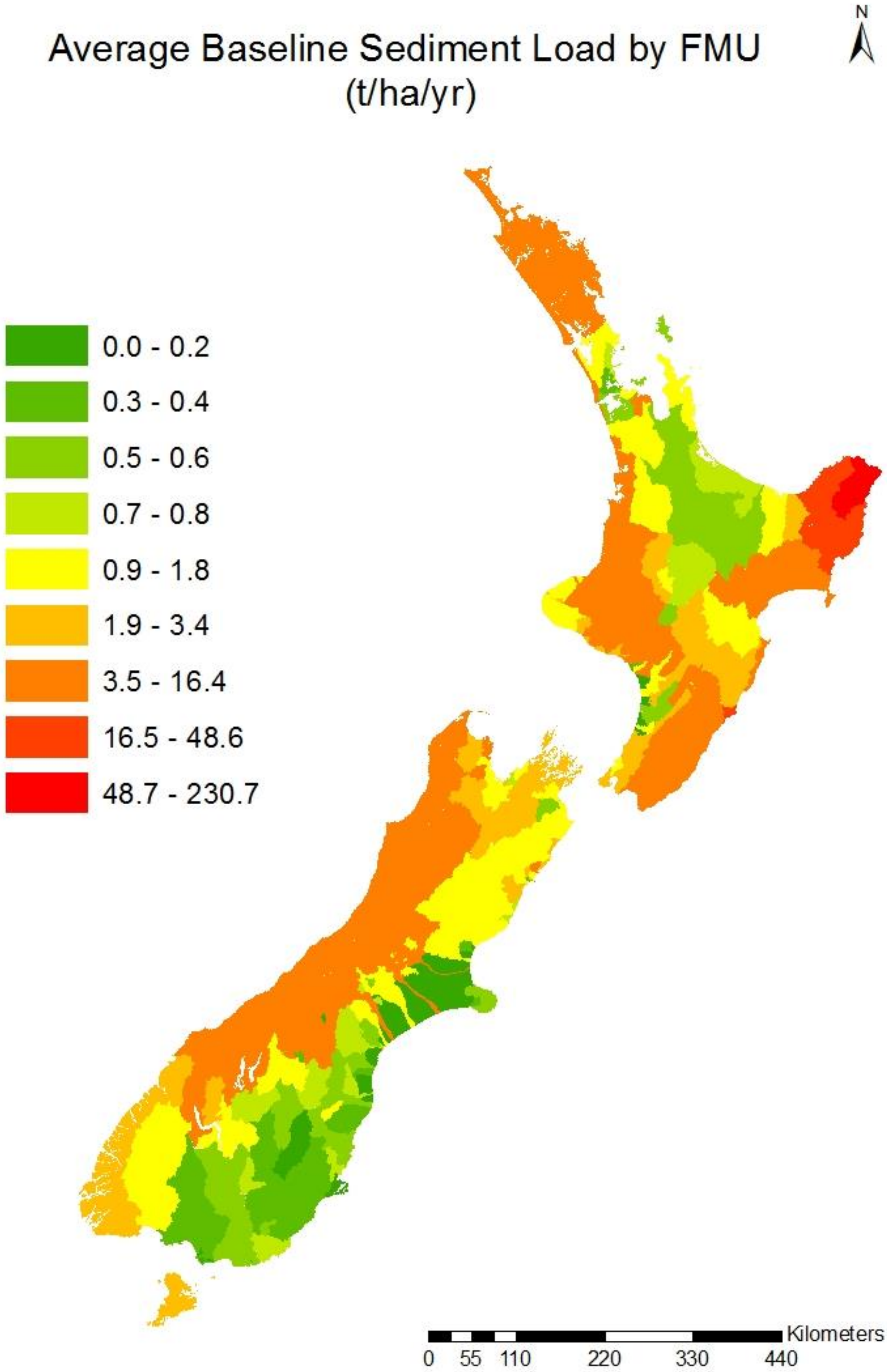

Figure C4. Sediment baseline loads (t/ha/yr) by water management area (Note: FMU is used to refer to the range of different management areas across the country).

Appendix C References

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Appendix D – Details on Mitigation Cost Estimates

1. Overview

The National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2014a) establishes the need to set and manage water resources within limits. A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water, as well as to identify strategies to mitigate contaminant losses to fresh water (e.g. McDowell and Nash, 2012; Monaghan et al., 2007; McDowell et al 2014). This research has focused on mitigation from implementing technology (e.g., feed pads) as well as conducting better management practices (e.g., reduced fertiliser application).

For this project, we reviewed and collected data on the cost and effectiveness for a wide-range of options to mitigate nitrogen (N), phosphorus (P), sediment (S), *E.coli* (E) and greenhouse gas emission (GHG) from a range of land uses. These include dairy, sheep & beef (S&B), deer, arable cropping, and horticulture. Mitigation options were quantified as an individual practice or technology, or as a set of options referred to as mitigation bundles. Cost figures are reported as both annualized costs ($/ha/yr) as well as relative change in net farm returns, while reductions in diffuse pollution from the contaminants/emissions are listed in relative terms due to the wide variance in baseline rates that can vary through factors such as stocking rate, soil type, slope, fertiliser rate, etc.

We have typically focused on mitigation estimates that came from models, literature, or research programmes that originated in New Zealand. The relative effectiveness of N and P mitigation options were often reported in the literature as being estimated using the OVERSEER model, while S, E, and GHG mitigation estimates were reported as using a variety of methods.

2. Methods

In this report, we construct mitigation cost figures to help estimate the impacts that implementing the NPS-FM nationally will have on New Zealand's GHG emissions. These curves will be incorporated in to spatial economic land use model that have been designed to estimate the effects of potential policies and pathways to meeting an agri-environmental policy objective by estimating cost-effective ways to implement land use and land management change (Daigneault et al 2015). The model is parameterised to track GHG emissions and several contaminants that can affect the quality of freshwater from a wide-range of land uses as well as a few land management options such as fencing streams, planting riparian buffers, and reducing stock. The key addition from this project will be to update and improve the cost and effectiveness figures for mitigation options that can be tracked in the model.

We collected several mitigation options for reducing nitrogen, phosphorus sediment and *E. coli* loads in the New Zealand. Additional details on some of the wetland mitigation were provided by expert option (e.g., Chris Tanner of NIWA was consulted about the wetland mitigation options). The costs are broken out by initial capital, ongoing and periodic maintenance, and opportunity costs from taking land out of production. An overview of the individual mitigation options considered is listed in Table 4. See McDowell et al (2013) for more details on each option, including factors limiting uptake and co-benefits.

Table 12: Summary of individual mitigation options

Option	Description	Cost Component		
		Opp	Capital	Maint
Stream bank Fencing	Construct fences to exclude stock from permanent waterways		X	X
Riparian buffers	Fence streams with 5m buffer that is planted with grass and native vegetation.	X	X	X
Wetland Construction	Modification of landscape features such as depressions and gullies to form wetlands and retention bunds	X	X	X
Alum	Apply to pasture and cropland to decrease P loss in runoff			X
Low Solubility P	Apply low water soluble fertiliser to reduce P loss in runoff			X
Sediment Traps	Stock pond or earth reservoir constructed at natural outlet of zero-order catchment	X	X	X
Variable Rate Irrigation	Optimise water and nutrient application according to local pasture and crop requirements		X	X
Feed Pads	Constructed area to keep animals off paddock for specified time	X	X	X
Restrictive Grazing	Remove animals from pasture at certain times and/or extend housing period.	X	X	X
Nitrification Inhibitors	Apply dicyandiamide (DCD) or alternative inhibitor to reduce nitrate		X	X
Space-Planted Trees	Trees planted on slopes to retain soil and prevent erosion	X	X	
Reduce Fertiliser	Lower fertiliser application rates and/or adjust timing	X		
Reduced Tillage	Adjust tilling practices and timing to reduce the time land is bare during the growing cycle.	X		
Zero Tillage	Eliminate crop disturbance from tilling	X		
Cover Crops	Plough crops into soil between harvest and sowing periods		X	X
Full afforestation	Convert part or all of farm to pine plantation or native bush	X	X	X
Mitigation Bundle	Includes a combination of the practices listed above. Often more effective, albeit at a higher cost	X	X	X

Costs are likely to vary over time and practice, particularly for mitigation options that include high capital costs. Thus, we converted these costs 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. These base figures are discussed in the next section.

For the NZFARM baseline, production yields, input costs, and output prices come from several sources (MPI SOPI 2013a; MPI Farm Monitoring 2013b; Lincoln University Budget Manual 2013), and have been verified with agricultural consultants and enterprise experts. All figures are listed in 2012 New Zealand Dollars (NZD). Nutrient losses for pastoral enterprises are estimated using the OVERSEERv6 nutrient budgeting tool, while estimates for other enterprises are derived from the literature (e.g. Lilburne et al. 2010; Parfitt et al 1997). GHG emissions are derived using national GHG inventory methodologies (MfE 2014b). Erosion figures are based on methods from Ausseil et al. (2013), while E.coli figures were estimated using the CLUES model (Elliot et al 2005). Note that many of the figures for the freshwater contaminants will change once we update the model with new load estimates from the CLUES model, which is currently being updated with a land use map that was developed as part of this project.

3. Baseline practices

We use baseline or no mitigation estimates from the national-level NZFARM model as a basis for which to estimate opportunity costs and relative impacts of each mitigation practice[73]. These baseline practices assume 'typical' management practices for a given land use (e.g,. Dairy farms already have a nutrient management plan). The mean estimates for each major land use is reported in Table 13. As these are listed as national averages, each figure actually has a distribution around it due to variances in factors such production, financial returns, land use capability class, climate, region and more.

Table 13. Mean New Zealand net farm revenue and contaminant losses by land use (per ha per yr)

Land Use	Net Farm Revenue ($)	GHG (kg)	Nitrogen (kg)	Phosphorus (kg)	Sediment (t)	*E.Coli* (tera)
Dairy	3418	6.4	38.0	0.8	4.2	4.1
Sheep & Beef	127	2.0	10.2	0.5	12.4	4.0
Deer	995	0.8	2.3	0.5	6.2	0.6
Other Pasture	96	1.5	7.5	0.4	8.9	2.9
Arable	1650	1.0	20.0	0.4	0.9	0.2
Horticulture	5597	1.5	12.7	0.1	2.6	1.6
Forestry	514	-11.3	2.0	0.2	3.2	0.4
Other	3	-0.5	1.4	0.1	2.7	2.0
All land	431	0.4	8.7	0.4	7.3	2.8

4. Individual Mitigation Options

In this section, we report the findings from the main set of individual mitigation options reported in the literature. These are broken out by key land use: dairy, S&B, deer, arable cropping, and horticulture. A list of the sources consulted to develop these estimates is listed in Appendix 1.

Table 14. Individual mitigation options cost and effectiveness (% from no baseline)

Mitigation Option	Annualised Cost ($/ha/yr)	EBIT	N Loss	P Loss	Sediment	*E.Coli*	GHG
Dairy							
Effluent Management	$24	-0.7%	-4%	-30%	0%	0%	0%

[73] N.B., these estimates are based on a 2012 land use map that is in the process of being updated for this project. Thus, some of the figures may change between now and when the project is finalised.

Riparian Planting	$71	-2.1%	-56%	-66%	-75%	-60%	-3%
Fencing Streams	$137	-4.0%	-13%	-15%	-70%	-60%	0%
Wetlands	$68	-2.0%	-10%	-45%	-65%	-55%	0%
Alum	$34	-1.0%	0%	-26%	0%	0%	0%
Low Solubility P	$48	-1.4%	0%	-10%	0%	0%	0%
Sediment Traps	$68	-2.0%	0%	-15%	-80%	-50%	0%
Variable Rate Irrigation	$58	-1.7%	-10%	0%	0%	0%	0%
Feed Pads	$171	-5.0%	-15%	-15%	0%	-10%	0%
Restrictive Grazing	$513	-15%	-36%	-30%	-40%	-10%	-10%
Nitrification Inhibitors	$137	-4.0%	-25%	0%	0%	0%	-17%
Space-Planted Trees	$34	-1.0%	0%	-20%	-70%	0%	-5%
Sheep & Beef							
Riparian Planting	$26	-21%	-56%	-50%	-75%	-60%	-10%
Fencing Streams	$32	-25%	-13%	-15%	-70%	-60%	0%
Wetlands	$25	-20%	-10%	-45%	-65%	-55%	0%
Alum	$64	-50%	0%	-26%	0%	0%	0%
Sediment Traps	$25	-20%	0%	-15%	-80%	-50%	0%
Low Solubility P	$25	-19.4%	0%	-10%	0%	0%	0%
Nitrification Inhibitors	$0	0.0%	-25%	0%	0%	0%	-15%
Restrictive Grazing	$14	-11%	-16%	-20%	-10%	-10%	-6%
Space-Planted Trees	$6	-5%	0%	-20%	-70%	0%	-6%
Deer							
Riparian Planting	$37	-3.7%	-51%	-50%	-82%	-60%	-13%
Fencing Streams	$40	-4.0%	-13%	-15%	-70%	-60%	0%
Wetlands	$30	-3.0%	-10%	-45%	-65%	-55%	0%
Space-Planted Trees	$20	-2.0%	0%	-20%	-70%	0%	-6%
Nitrification Inhibitors	$0	0.0%	-7%	-9%	0%	0%	-3%
Arable Cropping							
Riparian Planting	$11	-0.7%	-51%	-50%	-75%	-60%	-4%
Reduce Fertiliser by 15%	$22	-1.3%	-7%	0%	0%	0%	-5%
Reduced Tillage	$141	-8.6%	-2%	-25%	-25%	0%	-4%
Zero Tillage	$171	-10%	-10%	-50%	-25%	0%	-20%
Cover Crops	$409	-25%	-60%	-25%	-10%	0%	-20%
Horticulture							
Riparian Planting	$62	-1.1%	-51%	-50%	-75%	-60%	-4%
Limit N per application	$90	-1.6%	-4%	0%	0%	0%	0%
10% reduction in N	$1,679	-30%	-10%	0%	0%	0%	-3%
Cover crops	$347	-6.2%	-5%	-25%	-25%	0%	-10%
Altering tillage practice	$0	0.0%	-5%	-25%	-25%	0%	-4%

5. Mitigation Bundles

In recent years, catchment-scale modelling the effect of management practices to reduce diffuse-source pollution has focused on including a set of mitigation that are packaged as a 'bundle' of options that would likely be introduced on the farm at the same time (e.g., Everest 2014; Vibart et al 2015) . These bundles are typically defined as:

- M1: relatively cost-effective measures with minimal complexity to existing farm systems & management
- M2: mitigation that is less cost-effective than M1, but little capital costs and/or large system change
- M3: management options with large capital costs and/or are relatively unproven

These bundles are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes practices from M1 and M2. Examples of practices that are included in each of these bundles are listed in Table 15. Note that a bundle will not necessarily include all of these practices, but rather a mix that achieves a similar reduction in contaminants for a given annualized cost per ha.

Table 15. Mitigation bundle practices

Mitigation Bundle	Management Option
M1	Installation of soil moisture monitoring gear and VRI on existing centre pivots.
	Adjust cropping fertiliser rates and types to best suit plant requirements and timings.
	Limit each urea application
	Variable Rate Fertiliser.
	Gibberellic Acid to substitute some spring and autumn nitrogen on pastures.
	Apply nitrate inhibitors
	Optimise Stocking Rates
	Implement best management practices for infrastructure use and maintenance
	Optimum Olsen P
	Low solubility P fertiliser
	Laneway runoff diversion
	Effluent management
	Stock exclusion/fencing
M2	Modify irrigated area to include centre pivots/laterals fitted with Variable Rate Irrigation technology.
	Variable Rate application of liquid urea.
	Wetlands and/or sediment traps
	Tile drain amendments
	Reduce nitrogen fertiliser applications
	Riparian planting
	Enhance animal productivity via introducing cows with greater genetic merit
	Dairy farms to install covered feed pads and required effluent systems.
M3	Further reduce nitrogen fertiliser applications
	Reduce stocking rates
	All cows wintered off paddock, possibly in barns
	Restricted grazing of pasture and cropland
	Apply alum to pastures and crops
	Increase effluent area
	No winter feed crop yields over 14t/ha.

Figure 17 shows scatter plots indicating the relative cost and effectiveness of mitigation bundles taken from the following studies:

- Parsons et al (2015): Rotorua Lakes catchment, Bay of Plenty
- Everest (2014): Hinds catchment, Canterbury
- Vibart et al (2015): Southland region
- Monaghan et al (2016): New Zealand

In all cases, the effectiveness of each bundle was tracked for most, but not all of the 5 types of contaminants/emissions (N, P, S, E, GHG) that we are interested in. As a result, we estimated the relative effectiveness for the ‘missing’ contaminants by using the figures from the individual practices discussed in the previous section of this report. For example, Vibart et al (2015) did not estimate the effects of practices on mitigating S and E, but as their bundles included options such as stock exclusion and constructing wetlands, we were able to use that information to fill in the blanks. To the best of our knowledge, no studies have been conducted to develop mitigation bundles for horticultural crops (see Agribusiness 2014a,b).

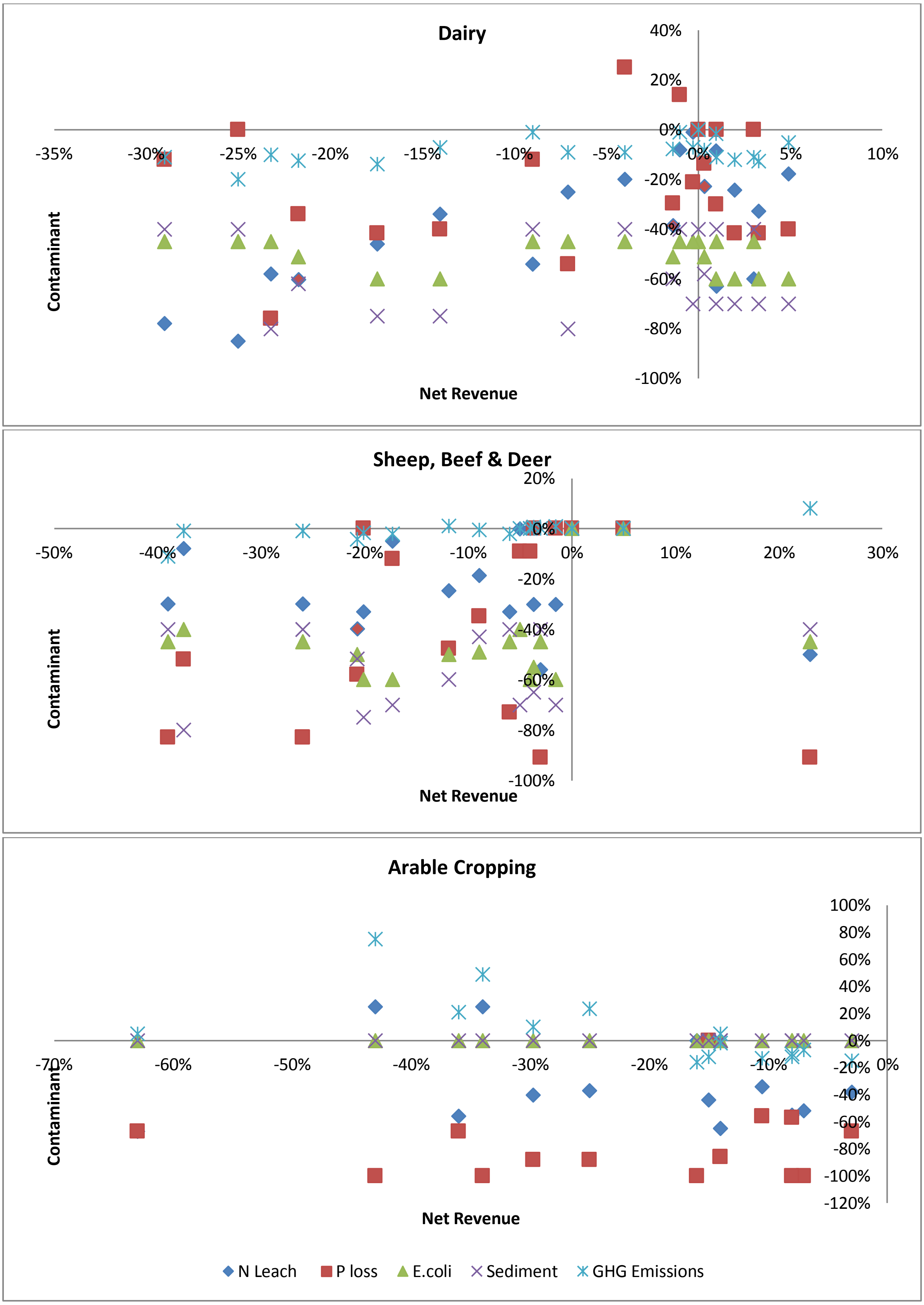

Figure 17. Relative change in net revenue v. contaminant (% change from baseline) for modelled mitigation bundles

The mean, max, and min values for impacts to net revenue and the different contaminants and emissions of the mitigation bundles for each land use is listed in Table 16. The mean values are the figures that we will initially include in economic land use model that will be used in the next stage of the SLMACC project to estimate the possible effects of the NPS-FM on GHG emissions.

A few things to note from the mitigation bundle figures:

- The M1 bundles are indeed relatively low-cost (mean of 0 to 11% reduction in net farm revenue) but present a wide range of effectiveness for the different contaminants.
- The arable cropping bundles did not include any mitigation that could reduce S or E. This may not be huge issue for this land use, but we will have to wait for the updated CLUES modelling to confirm.
- As many of these mitigation bundles were developed to just focus on N and/or P, they often do not have a large effect on GHG emissions
- The figures that do have a larger effect on GHGs include de-stocking, DCDs, or additional trees or vegetation
- Implementing some mitigation bundles could actually lead to an increase in GHGs. This is particularly the case for more advanced mitigation for sheep, beef, & deer, and arable cropping.

Table 16. Cost and effectiveness of mitigation bundles by land use

		Dairy			**Sheep, Beef, & Deer**			**Arable Cropping**		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
Net Revenue	Min	-4%	-9%	-29%	-26%	-38%	-39%	-16%	-43%	-63%
	Mean	0%	-1%	-22%	-9%	-12%	-21%	-11%	-25%	-30%
	Max	3%	5%	-14%	-4%	23%	-3%	-3%	-7%	-8%
Nitrogen	Min	-60%	-63%	-85%	-33%	-50%	-56%	-55%	-65%	-67%
	Mean	-23%	-38%	-60%	-19%	-25%	-40%	-34%	-37%	-41%
	Max	-1%	-18%	-34%	0%	-5%	-30%	0%	25%	25%
Phosph	Min	-42%	-54%	-76%	-83%	-91%	-91%	-100%	-100%	-100%
	Mean	-14%	-30%	-34%	-35%	-48%	-58%	-56%	-88%	-88%
	Max	25%	0%	0%	0%	0%	0%	0%	-67%	-67%
E.coli	Min	-60%	-60%	-60%	-60%	-60%	-60%	0%	0%	0%
	Mean	-51%	-51%	-51%	-49%	-50%	-50%	0%	0%	0%
	Max	-45%	-45%	-45%	-40%	-40%	-45%	0%	0%	0%
Sediment	Min	-70%	-80%	-80%	-70%	-80%	-75%	0%	0%	0%
	Mean	-58%	-60%	-62%	-43%	-60%	-52%	0%	0%	0%
	Max	-40%	-40%	-40%	0%	-40%	-40%	0%	0%	0%
GHG	Min	-12%	-13%	-20%	-2%	-2%	-11%	-16%	-7%	-12%
	Mean	-8%	-8%	-12%	0%	1%	-4%	-13%	24%	10%
	Max	-2%	-1%	-7%	1%	8%	0%	-10%	75%	49%

6. References

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Appendix D1. Sources for individual mitigation cost and effectiveness estimates

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Appendix E – Empirical evidence on mitigation and co-benefit potential on dairy and sheep-beef farms with currently used farm practices.

Contents

Tables

Figures

1. Introduction

The agricultural sector in New Zealand is a major source of both nutrient leaching (nitrogen (N) and phosphorus (P)) and greenhouse gas (GHG) emissions. The amount of N leached from agricultural activities, according to Environment Aotearoa 2015, increased by 28.6% over the 1990-2012 period (Ministry for the Environment and Statistics New Zealand, 2015). During the same time, agricultural GHG emissions contributed approximately 48 percent of New Zealand's total emissions (Ministry of the Environment, 2015).

The New Zealand government released in 2014 the National Policy Statement for Freshwater Management, largely aiming at controlling nutrient leaching across the country. What effects will this reform be likely to have on greenhouse gases? This report is part of a study (Daigneault et al. 2016) to estimate this. Our results will help to validate nutrient abatement cost curves used in a national model NZFarm.

Mitigation of agricultural GHGs plays a critical role in climate mitigation (McCarl and Schneider 2001; Maraseni, 2009). Research has also found that, in the United States, change in agricultural activities can have significant benefits for both GHG mitigation and water quality (e.g., Pattanayak et al. 2005; Boehlert et al. 2015). For example, improved efficiency of nitrogen usage in fertilisers or manure management can reduce the emissions of nitrous oxide (N_2O) via the nitrification process while controlling nitrogen loss into rivers and lakes through surface runoff or groundwater. Faeth and Greenhalgh (2000, 2002) have explored how water quality and GHG policy could interact. Early New Zealand work on this issue includes (Kerr and Kennedy 2009), Daigneault et al (2012), (Yeo et al. 2014), Coleman and Yeo (2014), and Kerr (2013).

In this report, we use historical data to estimate dairy and sheep/beef farmers' nitrogen and phosphorus management efforts. That is, the amount of nutrient leached or lost per unit of output (or stock unit) after controlling for factors that affect nutrient leaching and loss but that are outside the farmer's control (e.g. climate, soil, slope). Since nutrient leaching is a function of the interaction of many variables, a generalised version of a Cobb-Douglas function is used. Farmers' nutrient management efforts are estimated as the residuals from a multivariate regression. For dairy farms, consistent with the Cobb-Douglas function, we use a logarithmic specification. We assume that when nutrients are regulated through the Freshwater Reforms farmers' practices will tend to become more like what the currently efficient farmers are doing. Thus we use the nutrient management effort measure as a proxy for the pressure that will be imposed by the Freshwater Reform.

Having established a proxy for effort to reduce nutrients, we estimate how much agricultural GHGs might be mitigated if all farmers face pressure to change practices to reduce nutrient leaching. We find modest co-benefits from control of nitrogen leaching for reductions in greenhouse gases through changes to reduce nitrogen leaching per unit of product produced within current farm management practices. A one percent reduction in nitrogen leaching leads to around a quarter of a percent reduction in nitrous oxide and a tiny reduction in methane. Our 'ambitious' scenario suggests that dairy (sheep/beef) farmers might reduce nitrogen leaching by 23.5% (12%) and total greenhouse gases by 2.6% (1.2%) without changing production levels.

The rest of this report proceeds as follows. In Section 2, we discuss the conceptual logic behind our modelling approach. We describe our data and present our empirical strategy in Section 3. Section 4 shows the results and Section 5 concludes.

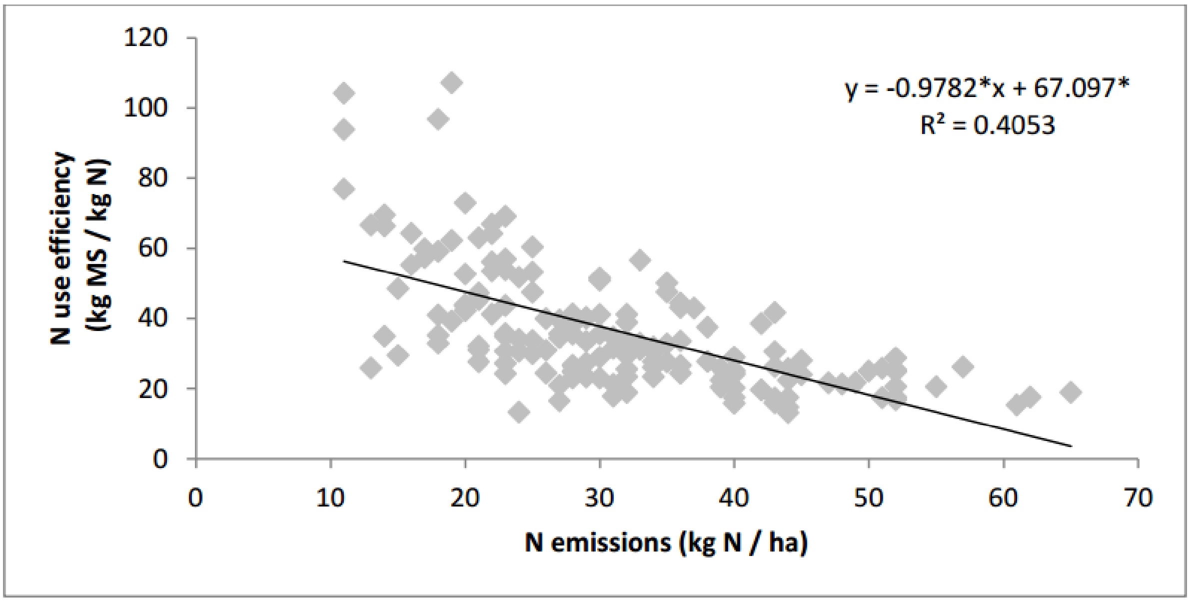
2. Conceptual approach

When farmers face pressure to reduce nitrogen leaching and phosphorus loss as part of efforts to improve freshwater quality, they will need to change their farm practices. Those changes in behaviour will have implications for greenhouse gas emissions. Others have modelled behaviour changes that they think are likely using simulation models ((Doole, Marsh, and Ramilan 2012) (Ridler, Anderson, and Fraser 2010) and (Daigneault et al. 2012). We take a different approach. We assume that when farmers face pressure to reduce nutrients they will tend to behave more like those who are already running nutrient efficient farms and use data from actual farms and farmer decisions to predict those shifts in behaviour and their implications.

This seems plausible but is only an assumption. We do not know why the farmers in our sample are behaving differently without regulation and therefore cannot confidently predict the effect regulation will have on those behavioural differences. We are using statistical relationships but not identifying a causal model. Implicitly we are assuming that the more nutrient efficient farmers are actively trying to reduce nutrients. This could be because they feel a sense of personal responsibility for water ways or because they experience some social pressure. If this is true, their responses may be similar to those they and others would make when faced with regulatory pressure.

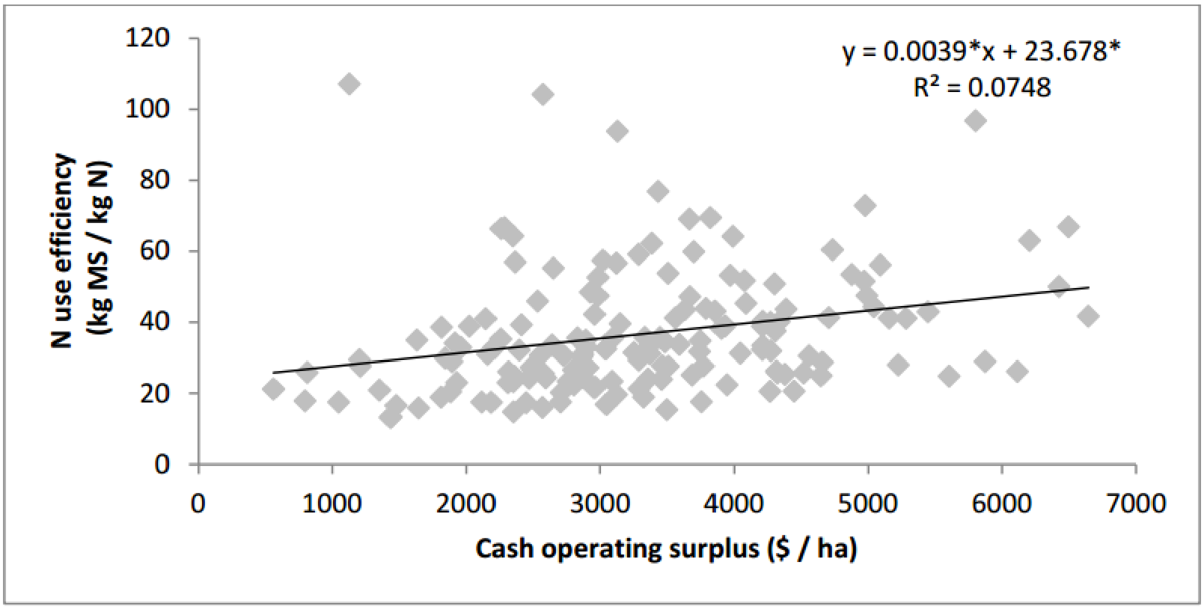
An alternative plausible explanation is that high levels of production per unit of nutrient leaching is associated with higher profitability and what we are observing is differences in farmers' capability to maximise profit. Previous research (Anastasiadis and Kerr 2013) found that those who produced more milk solids per unit of N leached also leached less in total between 2008 and 2010 (**Figure** 1) while having higher operating surplus in 2010 (Figure 19). This supports the alternative hypothesis that actions to improve production per unit of N leaching might be motivated by improved profitability instead of, or as well as, improved environmental performance. We cannot distinguish these motivations and results should be interpreted with this caveat. Our simulation results would hence provide an upper bound on the level of response that might be expected.

Figure 18: N leaching and production per unit of N leached – Dairy farms: 2008 – 11



Source: (Anastasiadis and Kerr 2013) Figure 21

Figure 19: Production per unit of N leaching and cash operating surplus – Dairy farms, 2010



Source: (Anastasiadis and Kerr 2013) Figure 28

To model the effect of freshwater reforms we first try to identify farmers who are running nutrient efficient farms. We want to separate out the farms that have geophysical characteristics that make their nutrient leaching lower from the farmer actions that affect leaching. Thus we control for observable geophysical variables and identify farms that still have surprising low nutrient loss.

Second, we estimate the extent to which these same farms also have surprisingly low greenhouse gases. We then run scenarios to explore how changes in nutrient leaching behaviour could affect greenhouse gases in the sample as a whole. For our scenarios, we consider three levels of farmer response; responses will vary with the intensity of the freshwater regulation and with the extent to which the variation we identify is driven by effort rather than capability.

3. Data

We use unit record annual farm level data collected as part of the Ministry of Agriculture and Forestry (MAF) monitor farm reporting, from 2008 to 2010 (Ministry of Agriculture and Forestry, dataset, 2010).[74] MAF combined these data by region and farm type to construct representative model farms, which were the focus of their monitor farm reports (see, for example, Ministry of Agriculture and Forestry (2011)). The farms in the dataset are not randomly selected, but are chosen in an attempt to create a representative sample.[75]

Estimates of *Nitrogen leaching* (kg N/ha), *Phosphorus loss* (kg P/ha) and *GHG emissions* (methane, nitrous oxide and total: T CO2-eq/ha) for the farms in the dataset were calculated from reported farm characteristics and management practices using the OVERSEER© (version 6.2.1) developed by AgResearch. The original OVERSEER files were run through this more recent version of OVERSEER by AgResearch to be more consistent with current scientific understanding and other recent modelling. Some of the inputs have been set to default values because they were not used in earlier OVERSEER versions and hence were not part of our data. The use of a model means that some variability in N leaching and greenhouse gas emissions is not captured.

Our dataset is an unbalanced panel of 384 dairy farms and 404 sheep/beef farms over four years.[76] Out of a total of 384 dairy farm observations, 150 farms were observed in only one year, 41 farms were observed in two years, 23 farms were observed in three years, and 18 farms were observed in all four years. The number of dairy farm observations in each year also varied: 138

[74] MAF is now part of the Ministry of Primary Industries.

[75] These farms may on average be more efficiently run than the true population, simply on the basis that they agreed to participate in this programme. Farms in the lower 'tail' of the productivity distribution are unlikely to be included.

[76] Deer farms are included in the sheep/beef category.

farms were observed in 2008, 63 observed in 2009, 86 observed in 2010, and 97 observed in 2011. Among the total 404 sheep/beef farm observations, 141 farms were observed in one year, 44 in two years, 57 in three years, and only 1 in four years. In the sheep/beef panel, 103 farms were observed in 2008, 94 observed in 2009, 103 observed in 2010, and 104 observed in 2011.

The dairy farms are well distributed across regions, with 2.9% of our observations in Bay of Islands, 18.2% in Canterbury, 2.3% in the Central Plateau, 7.8% in the East Coast of North Island, 0.5% in King Country/Taihape, 8.3% in Manawatu/Wanganui, 7.0% in Northland, 1.0% in Otago, 17.7% in Southland, 14.8% in Taranaki, 19.0% in Waikato/Coromandel, and 0.3% in Wellington. Our sheep/beef farm observations are also widely distributed: 2.5% in Auckland, 1.2% in Bay of Islands, 11.6% in Canterbury, 3.2% in the Central Plateau, 20.8% in the East Coast of North Island, 5.2% in the South Island High Country, 4.2% in King Country/Taihape, 7.3% in Manawatu/Wanganui, 2.5% in Marlborough, 8.4% in Northland, 13.4% in Otago, 14.6% in Southland, 0.5% in Taranaki, and 4.5% in Waikato/Coromandel.

For each farm in each year we observe *Total effective area*. For dairy farms we observe the area used for milking and grazing the dairy herd (ha), and *Milk solids*, total milk solid production for the farm (kg MS). For sheep/beef farms we observe separate stocking rates for sheep, beef and deer. We use *revised stock units* as defined by (Nicol and Brookes 2007).[77]

Figures 4 – 6 give the distributions for product per unit N, P and GHG pollution (PPP hereafter) on dairy farms. They have been constructed such that the more efficient farms are to the right and the less efficient farms are to the left. For both figures we observe a skewed distribution with a large number of relatively less efficient farms and a long tail of farms that are more efficient.[78]

[77] The original stock units were defined by (Coop 1965).

[78] It seems likely that some of the farm observations in the tail of the Nitrogen and GHG PPP distributions may involve either data error or extremely unusual circumstances. Their existence does not affect our results.

Figure 20: Distribution of Nitrogen PPP on dairy farms

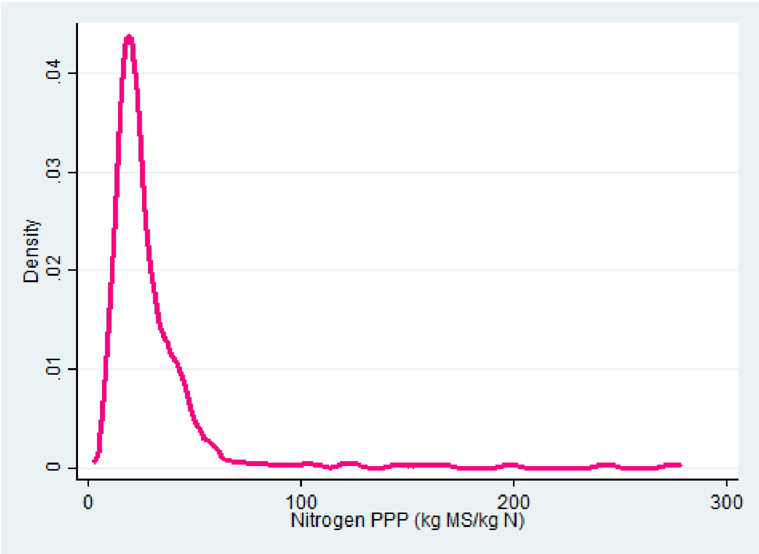


Figure 21: Distribution of Phosphorus PPP on dairy farms

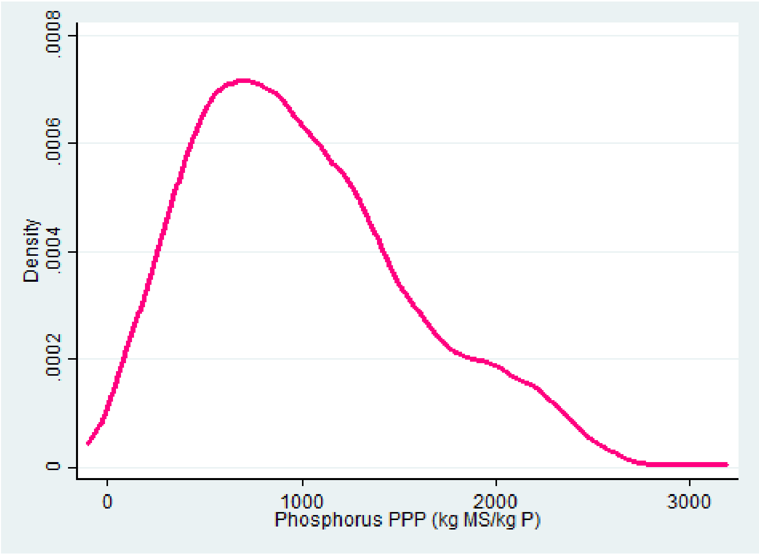
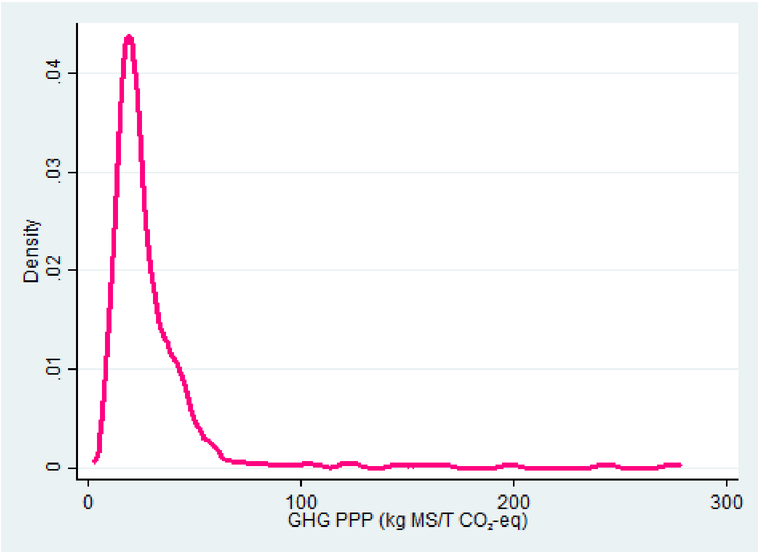


Figure 22: Distribution of GHG PPP on dairy farms



There is significant variation in PPP among dairy farms. The most N efficient farms produce more than twice the amount of milk solids per kg N relative to the farms with median N efficiency. The most GHG efficient dairy farms produce 25% more milk solids per T GHG than the least efficient dairy farms. Results for sheep/beef farms are similar (though the GHG variation is even greater). The distributions are given in Appendix A.

How much of this variation in N leaching is due to factors that can be managed on existing farms and could respond to regulation as a part of the Freshwater reforms is our first question. How those regulation-driven responses could affect the distribution of GHG PPP is our second question.

We now describe the farm characteristics included in the monitor farm data that are used for our analysis. We group the farm characteristics into two categories: exogenous characteristics of the land and farming practices. Some descriptive statistics are reported in Tables 1 and 2.

Table 17: Summary table of variables: Dairy farms

Variable	Mean	Std. Dev.	Min	Median	Max
Rainfall (mm)	1162.4	386.0	425.0	1200.0	3000.0
Temperature (°C)	13.0	1.7	8.1	13.0	18.0
Total effective area (ha)	166.0	88.8	40.0	145.0	527.0
Production (T MS)	179.9	115.0	29.6	148.0	815.8
N leaching (kg N/ha)	48.4	24.4	6.0	44.5	160.0
P loss (kg P/ha)	1.5	1.3	0.3	1.2	9.8
GHG emissions (T CO_2-eq/ha)	12.2	3.2	3.4	12.0	22.3
Methane (T CO_2-eq/ha)	7.6	1.8	2.0	7.5	12.7
Nitrous oxide (T CO_2-eq/ha)	2.9	1.0	1.0	2.8	6.2
N PPP (kg MS/kg N)	29.4	26.9	5.7	22.0	274.5
P PPP (kg MS/kg P)	1003.8	565.7	54.2	926.5	3037.5
GHG PPP (kg MS/T CO_2-eq)	89.8	19.0	30.6	87.4	225.4
Stocking rate (cows/ha)	2.8	0.7	0.9	2.8	4.9
Production per animal (MS/cow)	364.7	63.3	171.4	363.0	763.6

Table 18: Summary table of variables: Sheep and beef farms

Variable	Mean	Std. Dev.	Min	Median	Max
Rainfall (mm)	1131.5	355.8	373.6	1100.0	2000.0
Temperature (°C)	12.0	2.2	7.0	12.0	17.0
Total effective area (ha)	1161.3	2332.3	58.0	493.0	21910.0
N leaching (kg N/ha)	12.4	7.0	2.0	12.0	40.0
P loss (kg P/ha)	0.9	1.0	0.0	0.6	6.7
GHG emissions (T CO_2-eq/ha)	3.7	1.7	0.2	3.7	14.1
Methane (T CO_2-eq/ha)	2.7	1.3	0.1	2.7	10.7
Nitrous oxide (T CO_2-eq/ha)	0.8	0.4	0.1	0.8	3.1
Revised stock unit: sheep (sheep/ha)	5.5	4.1	0.0	4.9	24.5
Revised stock unit: beef (beef/ha)	2.9	3.1	0.0	2.3	25.6
Revised stock unit: deer (deer/ha)	0.9	3.2	0.0	0.0	21.6

Some characteristics are out of the control of an existing farm. We observe mean annual *Rainfall* (mm); mean annual *Temperature* (°C); *Topography*, classified as flat land (80.2% for dairy and 54.0% for sheep/beef)[79], and non-flat hill (19.8% and 46%); and *Soil group*, classified as peat (1.3% and 0.3%), podzol (2.6% and 0.0%), pumice (3.1% and 6.9%), recent yellow-grey earth (YGE)

[79] For each of the following variables, the first percentage is for dairy farms and the second for sheep/beef farms.

(15.1% and 23.0%), sands (2.9% and 1.7%), sedimentary (46.6% and 58.2%) and volcanic soil (30% and 9.9%).[80] We create a binary variable, *South Island.*

Other characteristics are within the control of an existing farm. For both dairy and sheep/beef farms we include measures of output (*milksolids* and *stocking rate*[81]) because our focus is on reductions in pollution per unit of output. Farmers do have control over the intensity of their production per hectare and reducing production intensity is one potential mitigation option. Stocking rate is a coarse measure of production but no other measure is available in our data. Previous work has found that sheep-beef stocking rates are strongly driven by geophysical characteristics at least at a high level of aggregation (Figure 2.1 in Timar and Kerr 2014) so farmers' key decision may be whether to keep land in pasture.

Other characteristics are included as controls for activity and hence pollutants that have been moved from one farm to another during the year, for infrastructure that is unlikely to be changed (e.g. irrigation) and for a specific mitigation (DCD) which is not currently available. The movement of activity does not constitute on-farm mitigation although for freshwater, if activity is moved outside of the catchments of greatest concern it may still have value. For dairy farms, we observe; *Dairy replacements*, the number of replacement heifers per hectare; *Cows wintered off*, the number of animals wintered off per hectare; *Irrigated*, showing whether a farm is irrigated; and *DCD used*, the application of nitrification inhibitor DCD.

4.1 Empirical Strategy: the two-step model

We introduce first in this section a two-step regression model for dairy farms. The first (or step-one) regression equation takes the following form:

$$n_{it} = \alpha_0 + \alpha_1 m_{it} + \alpha_2 c'_{it} + \alpha_3 p'_{it} + \varepsilon_{it}. \quad (1)$$

The subscript i indexes the individual farm and t the year. The dependent variable n_{it} is the logarithmic scale of N leaching (or P loss) of farm i during year t. The independent variable m_{it} is the amount of milk solids produced in logarithm; c_{it} is a vector of variables that describe the controls for stock movement; and p_{it} is a vector of geophysical variables. All logarithmically transformed variables are mutually interactive. However, since some variables are binary we could not take logarithms, for the dairy farms we include interactions of some key variables with

[80] These are the soil types available in the OVERSEER datafiles we have. AgResearch staff confirmed that these are the best we can use for this project.

[81] We combine sheep, beef and deer stock units. The type of stock is within the farmer's control. Implicitly we are treating the output from farming different ruminants as socially equivalent.

production levels. The error term ϵ_{it} in Equation (1) is associated with the nutrient management effort (in logarithmic scale) that stems from the farmer's set of management practices but also reflects all other unexplained variability. It is adjusted by the shift parameter α_0 to have a zero mean.

For readers familiar with the theory of productivity growth, this regression specification can be viewed as coming from a Cobb-Douglas-type function, where nutrient leaching is "produced" by the interactions among all the "input" variables.[82] The error term coupled with α_0 is an analogue of the Solow residual.[83] Therefore we extract the residual $\hat{\varepsilon}_{it}$ and define $\hat{\epsilon}_{it} = -\hat{\varepsilon}_{it}$ as a proxy for the total nutrient management effort for each monitored farm in a given year. Any increase in the value of this proxy is assumed to reflect an increase in effort to control nutrients.

The second (or step-two) regression equation explores how much GHGs can be potentially mitigated if farmers increase their nutrient management effort, controlling for other non-management variables listed in Equation (1):

$$g_{it} = \beta_0 + \beta_1 m_{it} + \beta_2 c'_{it} + \beta_3 p'_{it} + \gamma \hat{\epsilon}_{it} + \mu_{it}. \qquad (2)$$

Throughout this report, we only concentrate on nutrient management effort on the main contributing GHGs from pastoral farming; that is, the GHG measure is the sum of emissions of methane and nitrous oxide.

The two-step model for sheep/beef farms follows the same structure discussed above but is with m_{it} replaced by a quadratic function of stock unit and without taking logarithms of n_{it} and g_{it}.

4. Results

Here we present the results for nitrogen in some detail. Similar analysis for Phosphorus loss is given in the Appendix.

4.1. Estimates of N management effort

Table 3 and Table 4 show a set of core results of the two-step regression approach. In the step-one regression for dairy farms all coefficients are consistent with expectations except rainfall, which is expected to have a positive effect on nitrogen leaching. Farms that produce more milk solids or carry more replacement heifers per hectare leach more. Farms in the South Island

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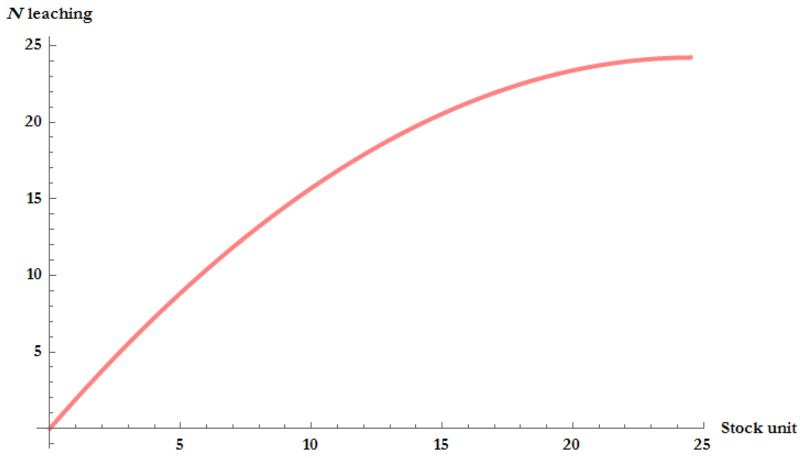
82 Here we sacrifice the "meaningfulness" of unit (or dimension) to derive a specification from the Cobb-Douglas-type production function, in which the product is a product of all the input variables.

83 Any interested reader is referred to Chapter 10 of Barro and Sala-i-Martin (2004).

generally have relatively newer equipment; this may be why they leach less. Utilising nitrification inhibitors (DCDs) does lower leaching.[84]

In the step-one regression for sheep/beef farms, N leaching is associated with a concave function of stock unit per hectare controlling for all other variables (see Figure 7).[85] It says that a farm having more stock units leaches more but at a decreasing rate.

Figure 23: Concave function of stock units per hectare



4.2. Negative impact on GHGs of N management effort

We find that the impact of N management effort on GHG emissions is negative and highly significant for dairy farms. In other words, any incentive that stimulates more effort in nutrient control is likely to have the expected negative effect on GHG emissions, especially on nitrous oxide. The N management effort effect is still negative for sheep/beef farms but is insignificant for methane. The R^2 in our step 2 sheep/beef farms is suspiciously high which makes us suspect that the algorithm used to calculate methane and nitrous oxide is not very sensitive to farm characteristics other than stocking rates. This leaves little room for the influence of management effort. This may reflect a lack of mitigation options without changing stocking rates on sheep/beef land.

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[84] DCDs are not currently used in New Zealand.

[85] Stock unit per hectare is less than 24.58, the maximum for the concave function, for all sheep/beef observations except one farm, which has stock unit/ha 39.01.

Table 19: Regression results for dairy farms using the two-step model

	Step 1	Step 2		
	log(N leaching)	log(GHG)	log(CH_4)	log(N_2O)
log(milk solids)	0.675***	0.727***	0.728***	0.726***
	(0.0981)	(0.0258)	(0.0280)	(0.0345)
log(rainfall)	-0.298*	-0.0602	-0.0632	-0.0732
	(0.129)	(0.0338)	(0.0367)	(0.0452)
log(temperature)	-0.0736	-0.0511	-0.0132	-0.140
	(0.268)	(0.0703)	(0.0763)	(0.0941)
topography = non-flat hill	-0.0856	0.000766	0.00111	-0.00324
	(0.0669)	(0.0176)	(0.0191)	(0.0235)
soil = peat	0.177	0.0629	0.0619	0.0568
	(0.228)	(0.0600)	(0.0651)	(0.0803)
soil = podzol	0.125	0.0773	0.0863	0.0496
	(0.167)	(0.0438)	(0.0476)	(0.0587)
soil = pumice	0.168	0.0780	0.0825	0.0747
	(0.153)	(0.0403)	(0.0437)	(0.0539)
soil = recent YGE	0.0749	0.0560**	0.0498*	0.0778**
	(0.0809)	(0.0212)	(0.0231)	(0.0284)
soil = sands	0.131	0.0805*	0.0342	0.174**
	(0.156)	(0.0409)	(0.0444)	(0.0547)
soil = volcanic	-0.0248	0.0719***	0.0754***	0.0660**
	(0.0711)	(0.0187)	(0.0203)	(0.0250)
log(cows wintered off)	-0.0238	-0.0109**	-0.00805*	-0.0174***
	(0.0127)	(0.00334)	(0.00362)	(0.00447)
log(dairy replacements)	0.0831**	0.0731***	0.0770***	0.0677***
	(0.0299)	(0.00786)	(0.00853)	(0.0105)
year = 2009-10	-0.00514	-0.0119	-0.0126	-0.0127
	(0.0761)	(0.0200)	(0.0217)	(0.0268)
year = 2010-11	-0.0600	-0.0491**	-0.0486*	-0.0469
	(0.0689)	(0.0181)	(0.0197)	(0.0242)
year = 2011-12	-0.135*	-0.0581**	-0.0489*	-0.0813***
	(0.0675)	(0.0177)	(0.0193)	(0.0238)
south island	-0.293***	-0.0333	-0.0410	-0.0236
	(0.0801)	(0.0210)	(0.0228)	(0.0282)
DCD used	-0.327**	-0.0957***	-0.0267	-0.302***
	(0.0999)	(0.0268)	(0.0291)	(0.0361)
irrigated	-0.0273	0.0560*	0.00464	0.178***
	(0.104)	(0.0273)	(0.0297)	(0.0366)
N residual		-0.111***	-0.0516***	-0.266***
		(0.0137)	(0.0149)	(0.0184)
constant	6.175***	9.776***	9.395***	8.753***
	(0.927)	(0.244)	(0.264)	(0.326)
No. observations	384	384	384	384
R-squared	0.215	0.780	0.730	0.756
adjusted R-squared	0.176	0.768	0.716	0.743

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Here GHG = methane + nitrous oxide, measured in T CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

Table 20: Regression results for sheep/beef farms using the two-step model

	Step 1	Step 2		
	N leaching	GHG	CH_4	N_2O
stock units	1.971***	379.8***	287.3***	92.48***
	(0.135)	(4.295)	(2.520)	(3.332)
stock units squared	-0.0401***	-0.726***	-0.347***	-0.379**
	(0.00531)	(0.169)	(0.0992)	(0.131)
rainfall	-0.00162	-0.0775**	-0.0167	-0.0608**
	(0.000921)	(0.0294)	(0.0172)	(0.0228)
temperature	0.164	26.30***	9.980***	16.32***
	(0.148)	(4.713)	(2.765)	(3.656)
topography = non-flat hill	-0.177	-25.70	-20.93*	-4.763
	(0.520)	(16.57)	(9.724)	(12.86)
soil = peat	0.896	-33.41	-24.85	-8.564
	(4.953)	(157.9)	(92.62)	(122.5)
soil = pumice	1.359	0.970	12.67	-11.70
	(1.078)	(34.36)	(20.16)	(26.66)
soil = recent YGE	0.342	-7.997	-2.395	-5.602
	(0.614)	(19.56)	(11.47)	(15.17)
soil = sands	-3.209	-81.70	-26.97	-54.72
	(1.926)	(61.39)	(36.02)	(47.63)
soil = volcanic	1.818	100.6***	30.20	70.37**
	(0.934)	(29.77)	(17.47)	(23.10)
south island	2.463***	25.93	-21.35	47.28**
	(0.638)	(20.33)	(11.93)	(15.77)
year = 2009-10	3.472***	17.89	15.32	2.571
	(0.733)	(23.35)	(13.70)	(18.11)
year = 2010-11	3.793***	35.46	25.95	9.510
	(0.713)	(22.73)	(13.34)	(17.63)
year = 2011-12	3.844***	56.38*	38.77**	17.61
	(0.711)	(22.66)	(13.29)	(17.58)
N residual		-18.27***	-0.861	-17.41***
		(1.616)	(0.948)	(1.254)
constant	-5.919**	-239.5***	-75.65	-163.8**
	(2.191)	(69.84)	(40.98)	(54.18)
No. observations	404	404	404	404
R-squared	0.532	0.991	0.995	0.914
adjusted R-squared	0.515	0.991	0.995	0.911

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Here GHG = methane + nitrous oxide, measured in T CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

5. Scenario analysis

The analysis so far gives direction and significance of the likely effect of nutrient leaching management effort on greenhouse gases but does not tell us the scale of the effect. To explore this we run several scenarios.

First we transform $\hat{\epsilon}_{it}$ according to a monotone transformation:

$$e_{it} = 100 \times (\hat{\epsilon}_{it} - min(\hat{\epsilon}_{it})). \quad (3)$$

This transformation gives nothing but a more sensible scale of the measure of nutrient management effort. Farms with the lowest estimated N management effort are defined as having effort of zero. The variable provides a ranking of farms but the numerical value does not have an intuitive interpretation.

Next we consider three following scenarios.[86]

1. Conservative: every farmer with current nutrient management effort below the median (50th percentile) increases his level of effort by half of the difference between the median and the current level.
2. Ambitious: every farmer with current nutrient management effort below the 85th percentile increases his effort level by half of the difference between the 85th percentile and his current effort level.
3. Extreme: every farmer with current nutrient management effort below the 85th percentile increases his effort level to the 85th percentile.

Table 21 summarises the mean N management effort for dairy farms and its implied mean GHG mitigation for each scenario.

Table 22 does the same thing for sheep/beef farms. Figures 8 and 9 depict the shifts of N management effort distributions under each scenario.

For dairy farms we simulate that for each one percent reduction in nitrogen leaching farmers are likely to reduce greenhouse gases by around 0.11%. Nitrous oxide falls by more than methane; 0.26 relative to 0.05. These levels of greenhouse gas co-benefits are stable across scenarios.

Preliminary results on sheep-beef farms suggest very similar GHG co-benefits: around 0.10% overall for each one percent reduction in nitrate leaching, almost zero for methane and 0.41% for nitrous oxide. These results are similarly stable across scenarios.

Table 21: Scenario analysis of N management effort for dairy farms

Scenario	Mean N mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-7.30%	-0.81%	-0.38%	-1.94%
Ambitious	-23.47%	-2.61%	-1.21%	-6.23%
Extreme	-46.93%	-5.22%	-2.42%	-12.47%

86 These are the same as the three scenarios used in Anastasiadis and Kerr (2013).

Note: GHG = $CH_4 + N_2O$ in T CO_2-equivalent measure.

Figure 24: Shift of N management effort distribution for dairy farms

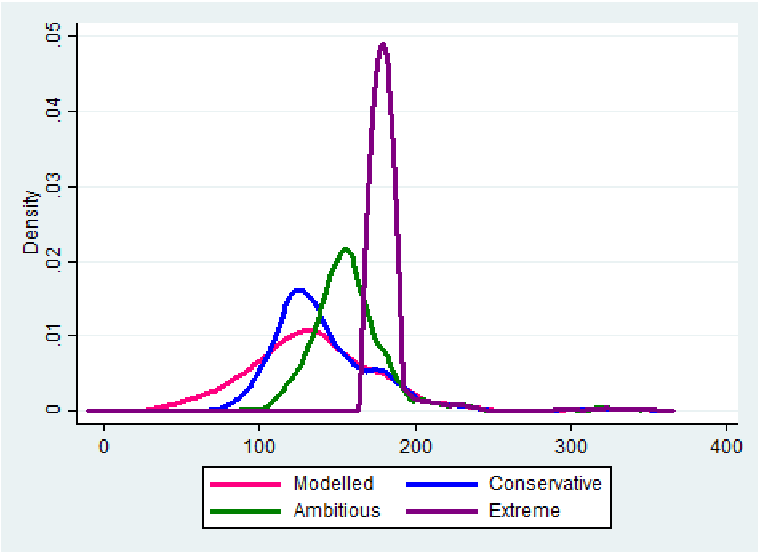
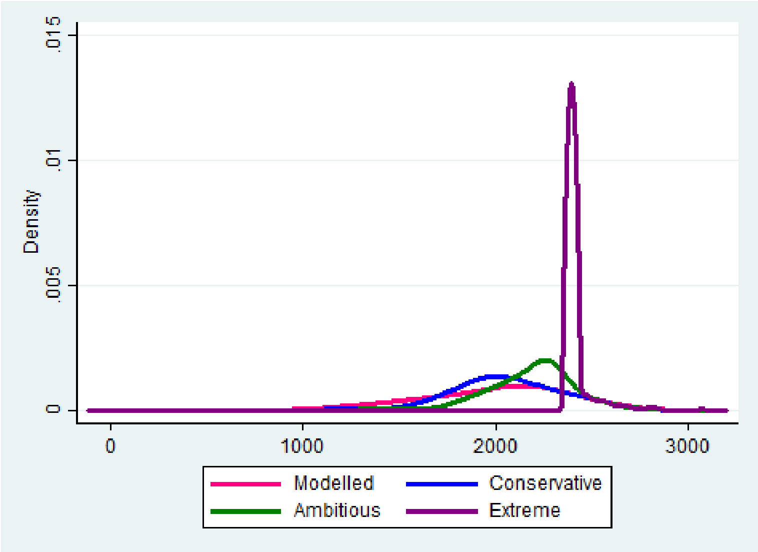


Table 22: Scenario analysis of N management effort for sheep/beef farms

Scenario	Mean N mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-5.79%	-0.59%	-0.04%	-2.41%
Ambitious	-12.03%	-1.23%	-0.08%	-5.01%
Extreme	-24.06%	-2.46%	-0.15%	-10.02%

Note: GHG = $CH_4 + N_2O$ in T CO_2-equivalent measure.

Figure 25: Shift of N management effort distribution for sheep/beef farms



6. Conclusion

In this paper we use a new dataset and a data driven approach as an alternative method to consider the potential for on-farm mitigation of nitrate leaching and phosphorus loss through use of existing practices, without changes in levels of production. We find estimates of nitrogen mitigation potential on dairy farms under conservative, ambitious and extreme scenarios that are very similar to those in (Anastasiadis and Kerr 2013). For sheep/beef farms we find nitrogen mitigation potential that is around half that on dairy farms. We are less confident about our estimates for potential mitigation of P-loss but they suggest similar potential for mitigation on dairy (around 30% in the 'ambitious' scenario) and half on sheep/beef farms (6% in the 'ambitious' scenario). These P results may however be heavily driven by correlations between unexplained low levels of N and P.

We find modest co-benefits from control of nitrogen leaching for reductions in greenhouse gases through changes to reduce nitrogen leaching per unit of product produced within current farm management practices. A one percent reduction in nitrogen leaching leads to around a quarter of a percent reduction in nitrous oxide and a tiny reduction in methane. Our 'ambitious' scenario suggests that dairy (sheep/beef) farmers might reduce nitrogen leaching by 23.5% (12%) and total greenhouse gases by 2.6% (1.2%) without changing production levels.

These reductions represent only one channel of effect of freshwater policy, but do suggest that freshwater policy that primarily focuses on changes in management within existing pastoral land use and currently used practices may have very limited effects on greenhouse gases.

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Appendix

7.1. Distributions of Product Per unit Pollution for Sheep/Beef farms

Figure 26: Distribution of Stock units per unit of Nitrogen leached on sheep/beef farms

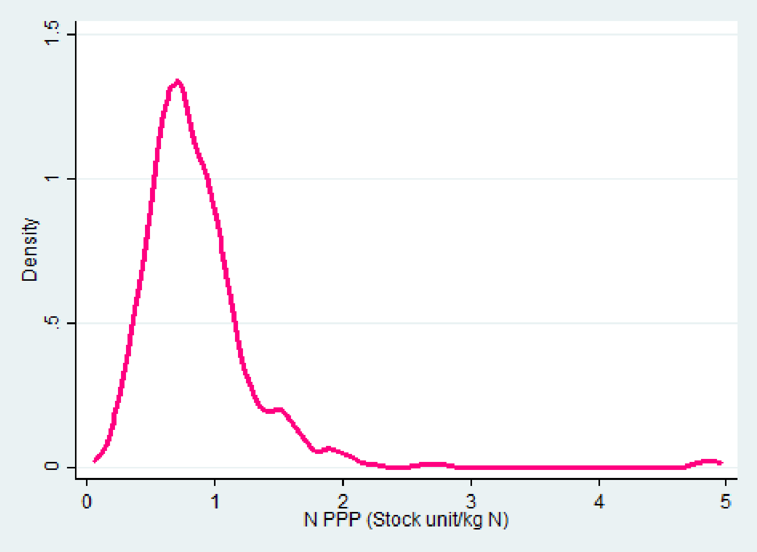
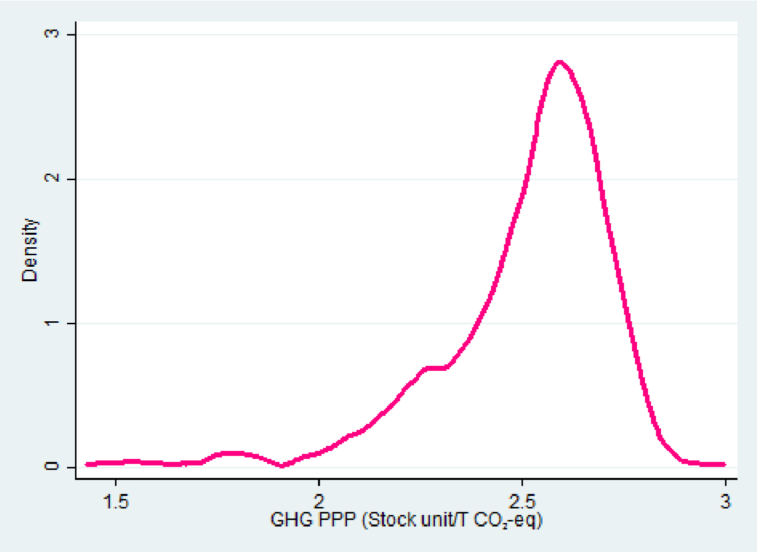


Figure 27: Distribution of stock units per unit of GHGs on sheep/beef farms



8.1 Direct P analysis for dairy farms

Table 23: P regression results for dairy farms

	Step 1	Step 2		
	log(P loss)	log(GHG)	log(CH_4)	log(N_2O)

log(milk solids)	-0.0384 (0.111)	0.727*** (0.0274)	0.728*** (0.0282)	0.726*** (0.0420)
log(rainfall)	-0.139 (0.146)	-0.0602 (0.0359)	-0.0632 (0.0369)	-0.0732 (0.0550)
log(temperature)	0.769* (0.303)	-0.0511 (0.0747)	-0.0132 (0.0768)	-0.140 (0.114)
topography = non-flat hill	-0.0690 (0.0758)	0.000766 (0.0187)	0.00111 (0.0192)	-0.00324 (0.0286)
soil = peat	0.0727 (0.259)	0.0629 (0.0638)	0.0619 (0.0655)	0.0568 (0.0977)
soil = podzol	0.461* (0.189)	0.0773 (0.0466)	0.0863 (0.0479)	0.0496 (0.0714)
soil = pumice	0.360* (0.174)	0.0780 (0.0428)	0.0825 (0.0440)	0.0747 (0.0656)
soil = recent YGE	0.165 (0.0916)	0.0560* (0.0226)	0.0498* (0.0232)	0.0778* (0.0346)
soil = sands	-0.120 (0.176)	0.0805 (0.0435)	0.0342 (0.0447)	0.174** (0.0666)
soil = volcanic	0.221** (0.0806)	0.0719*** (0.0199)	0.0754*** (0.0204)	0.0660* (0.0304)
log(cows wintered off)	0.00372 (0.0144)	-0.0109** (0.00355)	-0.00805* (0.00365)	-0.0174** (0.00544)
log(dairy replacements)	-0.0107 (0.0339)	0.0731*** (0.00836)	0.0770*** (0.00859)	0.0677*** (0.0128)
year = 2009-10	-0.113 (0.0862)	-0.0119 (0.0212)	-0.0126 (0.0218)	-0.0127 (0.0326)
year = 2010-11	-0.0761 (0.0781)	-0.0491* (0.0193)	-0.0486* (0.0198)	-0.0469 (0.0295)
year = 2011-12	-0.0225 (0.0765)	-0.0581** (0.0189)	-0.0489* (0.0194)	-0.0813** (0.0289)
south island	-0.292** (0.0907)	-0.0333 (0.0224)	-0.0410 (0.0230)	-0.0236 (0.0343)
DCD used	-0.127 (0.111)	-0.0897** (0.0274)	-0.0198 (0.0281)	-0.297*** (0.0419)
Irrigated	0.579*** (0.118)	0.0560 (0.0291)	0.00464 (0.0299)	0.178*** (0.0446)
P residual		-0.0512*** (0.0129)	-0.0353** (0.0133)	-0.0940*** (0.0198)
constant	-0.817 (1.050)	9.776*** (0.259)	9.395*** (0.266)	8.753*** (0.397)
No. observations	384	384	384	384
R-squared	0.237	0.751	0.727	0.638
adjusted R-squared	0.199	0.738	0.713	0.619

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. GHG = methane + nitrous oxide, measured in T CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

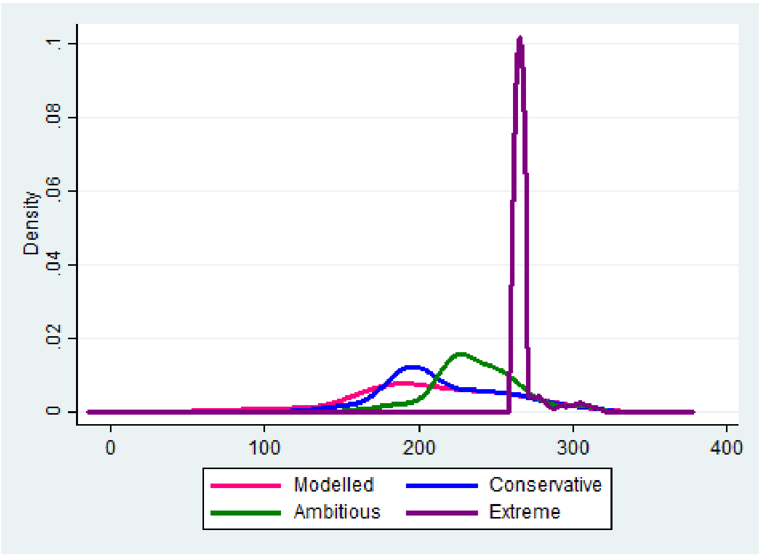
Table 24: Scenario analysis of P management effort for dairy farms

Scenario	Mean P mitigation	Implied mean GHG mitigation

		GHG	CH_4	N_2O
Conservative	-10.20%	-0.52%	-0.36%	-0.96%
Ambitious	-30.42%	-1.56%	-1.07%	-2.86%
Extreme	-60.84%	-3.11%	-2.15%	-5.72%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

Figure 28: Shift of P residual distribution for dairy farms



8.2 Direct P analysis for sheep/beef farms

Table 25: P regression results for sheep/beef farms

	Step 1	Step 2		
	P loss	GHG	CH_4	N_2O
stock units	0.0510*	379.8***	287.3***	92.48***
	(0.0240)	(4.817)	(2.500)	(3.996)
stock units squared	-0.00126	-0.726***	-0.347***	-0.379*
	(0.000945)	(0.190)	(0.0984)	(0.157)
rainfall	0.000435**	-0.0775*	-0.0167	-0.0608*
	(0.000164)	(0.0329)	(0.0171)	(0.0273)
temperature	-0.0187	26.30***	9.980***	16.32***
	(0.0263)	(5.285)	(2.743)	(4.384)
topography = non-flat hill	0.0311	-25.70	-20.93*	-4.763
	(0.0926)	(18.59)	(9.646)	(15.42)
soil = peat	-0.569	-33.41	-24.85	-8.564
	(0.882)	(177.0)	(91.87)	(146.8)
soil = pumice	-0.265	0.970	12.67	-11.70
	(0.192)	(38.53)	(20.00)	(31.96)
soil = recent YGE	-0.153	-7.997	-2.395	-5.602
	(0.109)	(21.93)	(11.38)	(18.19)
soil = sands	0.136	-81.70	-26.97	-54.72
	(0.343)	(68.84)	(35.73)	(57.11)
soil = volcanic	-0.226	100.6**	30.20	70.37*
	(0.166)	(33.39)	(17.33)	(27.69)
south island	-0.748***	25.93	-21.35	47.28*
	(0.114)	(22.79)	(11.83)	(18.91)
year = 2009-10	0.0791	17.89	15.32	2.571
	(0.131)	(26.19)	(13.59)	(21.72)
year = 2010-11	0.187	35.46	25.95	9.510
	(0.127)	(25.49)	(13.23)	(21.14)
year = 2011-12	0.289*	56.38*	38.77**	17.61
	(0.127)	(25.41)	(13.18)	(21.07)
P residual		-47.95***	-14.17**	-33.78***
		(10.17)	(5.279)	(8.438)
constant	0.565	-239.5**	-75.65	-163.8*
	(0.390)	(78.32)	(40.64)	(64.96)
No. observations	404	404	404	404
R-squared	0.233	0.989	0.995	0.876
adjusted R-squared	0.205	0.989	0.995	0.871

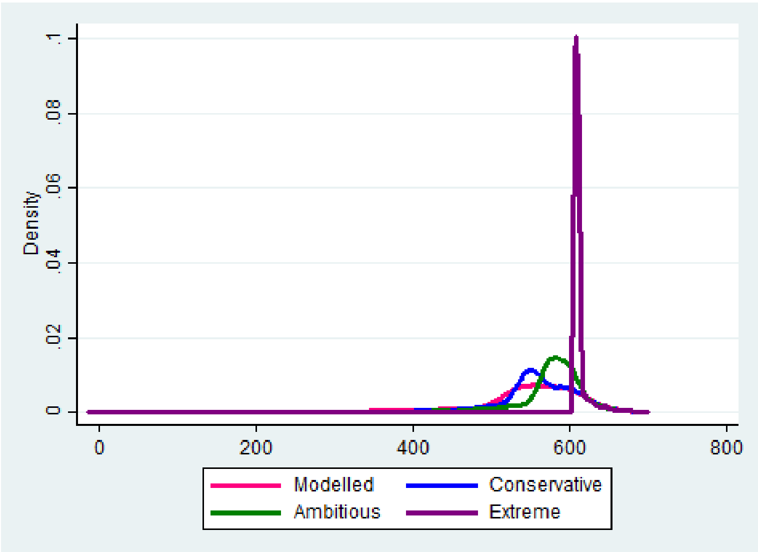
Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Here GHG = methane + nitrous oxide, measured in T CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

Table 26: Scenario analysis of P management effort for sheep/beef farms

Scenario	Mean P mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-3.24%	-0.24%	-0.09%	-0.73%
Ambitious	-6.37%	-0.47%	-0.18%	-1.43%
Extreme	-12.74%	-0.95%	-0.37%	-2.86%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

Figure 29: Shift of P residual distribution for sheep/beef farms



8.3 Indirect N analysis for dairy farms

To test for robustness and explore further we test the P-loss management effort proxy as an explanator in the N leaching equation. This is an attempt to isolate co-benefits driven solely by differences in N management. We find that those with unexplained low P loss also have lower nitrogen leaching but the impacts on GHGs are unaffected. These results hold for both dairy and sheep/beef farms.

Table 27: Repeated two-step N regression results for dairy farms

	Step 1	Step 2			
		Step 1	Step 2		
	log(P loss)	log(N leaching)	log(GHG)	log(CH_4)	log(N_2O)
log(milk solids)	-0.0384	0.675***	0.727***	0.728***	0.726***
	(0.111)	(0.0954)	(0.0262)	(0.0281)	(0.0358)
log(rainfall)	-0.139	-0.298*	-0.0602	-0.0632	-0.0732
	(0.146)	(0.125)	(0.0343)	(0.0368)	(0.0469)
log(temperature)	0.769*	-0.0736	-0.0511	-0.0132	-0.140
	(0.303)	(0.260)	(0.0714)	(0.0767)	(0.0976)
topography = non-flat hill	-0.0690	-0.0856	0.000766	0.00111	-0.00324
	(0.0758)	(0.0651)	(0.0179)	(0.0192)	(0.0244)
soil = peat	0.0727	0.177	0.0629	0.0619	0.0568
	(0.259)	(0.222)	(0.0610)	(0.0654)	(0.0833)
soil = podzol	0.461*	0.125	0.0773	0.0863	0.0496
	(0.189)	(0.162)	(0.0446)	(0.0478)	(0.0609)
soil = pumice	0.360*	0.168	0.0780	0.0825	0.0747
	(0.174)	(0.149)	(0.0409)	(0.0439)	(0.0559)
soil = recent YGE	0.165	0.0749	0.0560**	0.0498*	0.0778**
	(0.0916)	(0.0787)	(0.0216)	(0.0232)	(0.0295)
soil = sands	-0.120	0.131	0.0805	0.0342	0.174**
	(0.176)	(0.151)	(0.0416)	(0.0446)	(0.0568)
soil = volcanic	0.221**	-0.0248	0.0719***	0.0754***	0.0660*
	(0.0806)	(0.0692)	(0.0190)	(0.0204)	(0.0259)
log(cows wintered off)	0.00372	-0.0238	-0.0109**	-0.00805*	-0.0174***
	(0.0144)	(0.0124)	(0.00339)	(0.00364)	(0.00464)
log(dairy replacements)	-0.0107	0.0831**	0.0731***	0.0770***	0.0677***
	(0.0339)	(0.0291)	(0.00799)	(0.00857)	(0.0109)
year = 2009-10	-0.113	-0.00514	-0.0119	-0.0126	-0.0127
	(0.0862)	(0.0740)	(0.0203)	(0.0218)	(0.0277)
year = 2010-11	-0.0761	-0.0600	-0.0491**	-0.0486*	-0.0469
	(0.0781)	(0.0671)	(0.0184)	(0.0198)	(0.0251)
year = 2011-12	-0.0225	-0.135*	-0.0581**	-0.0489*	-0.0813**
	(0.0765)	(0.0657)	(0.0180)	(0.0194)	(0.0246)
south island	-0.292**	-0.293***	-0.0333	-0.0410	-0.0236
	(0.0907)	(0.0779)	(0.0214)	(0.0230)	(0.0292)
DCD used	-0.327**	-0.138	-0.0957**	-0.0267	-0.302***
	(0.0999)	(0.112)	(0.0289)	(0.0296)	(0.0437)
irrigated	0.579***	-0.0273	0.0560*	0.00464	0.178***
	(0.118)	(0.101)	(0.0278)	(0.0298)	(0.0380)

P residual		-0.209*** (0.0450)			
N residual			-0.103*** (0.0144)	-0.0447** (0.0154)	-0.255*** (0.0196)
constant	-0.817 (1.050)	6.175*** (0.902)	9.776*** (0.248)	9.395*** (0.266)	8.753*** (0.338)
N	384	384	384	384	384
R-squared	0.237	0.259	0.773	0.728	0.737
adjusted R-squared	0.199	0.220	0.761	0.714	0.723

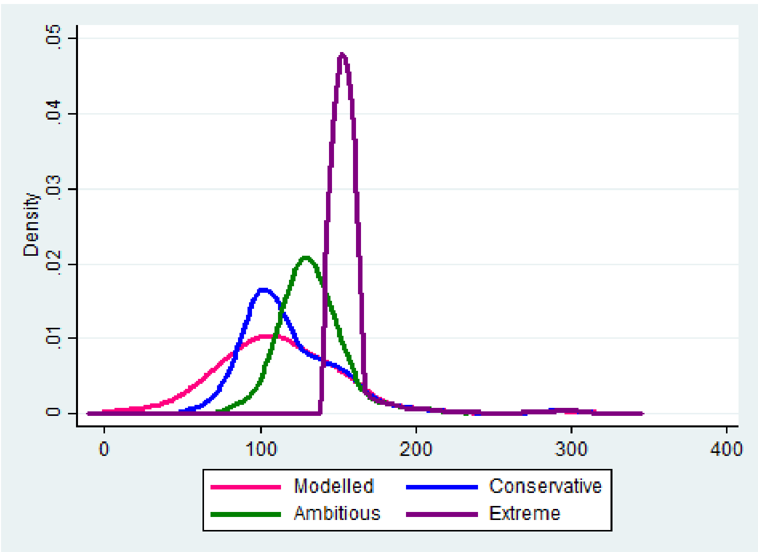
Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. GHG = methane + nitrous oxide, measured in ton CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

Table 28: Scenario analysis of N management effort for dairy farms

Scenario	Mean N mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-7.13%	-0.74%	-0.32%	-1.82%
Ambitious	-21.72%	-2.24%	-0.97%	-5.53%
Extreme	-43.43%	-4.48%	-1.94%	-11.06%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

1. **Figure 30: Shift of N residual distribution for dairy farms**



8.4 Indirect N analysis for sheep/beef farms

Table 29: Repeated two-step N regression results for sheep/beef farms

	Step 1	Step 2			
		Step 1	Step 2		
	P loss	N leaching	GHG	CH_4	N_2O
stock unit	0.0510* (0.0240)	1.971*** (0.133)	379.8*** (4.389)	287.3*** (2.522)	92.48*** (3.407)
stock unit squared	-0.00126 (0.000945)	-0.0401*** (0.00523)	-0.726*** (0.173)	-0.347*** (0.0993)	-0.379** (0.134)
rainfall	0.000435** (0.000164)	-0.00162 (0.000907)	-0.0775* (0.0300)	-0.0167 (0.0172)	-0.0608** (0.0233)
temperature	-0.0187 (0.0263)	0.164 (0.146)	26.30*** (4.815)	9.980*** (2.767)	16.32*** (3.738)
topography = non-flat hill	0.0311 (0.0926)	-0.177 (0.512)	-25.70 (16.93)	-20.93* (9.732)	-4.763 (13.15)
soil = peat	-0.569 (0.882)	0.896 (4.878)	-33.41 (161.3)	-24.85 (92.69)	-8.564 (125.2)
soil = pumice	-0.265 (0.192)	1.359 (1.062)	0.970 (35.11)	12.67 (20.18)	-11.70 (27.25)
soil = recent YGE	-0.153 (0.109)	0.342 (0.604)	-7.997 (19.98)	-2.395 (11.48)	-5.602 (15.51)
soil = sands	0.136 (0.343)	-3.209 (1.897)	-81.70 (62.72)	-26.97 (36.05)	-54.72 (48.69)
soil = volcanic	-0.226 (0.166)	1.818* (0.920)	100.6** (30.42)	30.20 (17.48)	70.37** (23.61)
year = 2009-10	0.0791 (0.131)	3.472*** (0.722)	17.89 (23.86)	15.32 (13.71)	2.571 (18.52)
year = 2010-11	0.187 (0.127)	3.793*** (0.702)	35.46 (23.22)	25.95 (13.35)	9.510 (18.03)
year = 2011-12	0.289* (0.127)	3.844*** (0.700)	56.38* (23.15)	38.77** (13.30)	17.61 (17.97)
south island	-0.748*** (0.114)	2.463*** (0.628)	25.93 (20.77)	-21.35 (11.94)	47.28** (16.12)
P residual		-1.012*** (0.280)			
N residual			-17.29*** (1.678)	-0.420 (0.965)	-16.87*** (1.303)
constant	0.565 (0.390)	-5.919** (2.158)	-239.5*** (71.35)	-75.65 (41.01)	-163.8** (55.39)
N	404	404	404	404	404
R-squared	0.233	0.547	0.991	0.995	0.910
adjusted R-squared	0.205	0.529	0.990	0.995	0.906

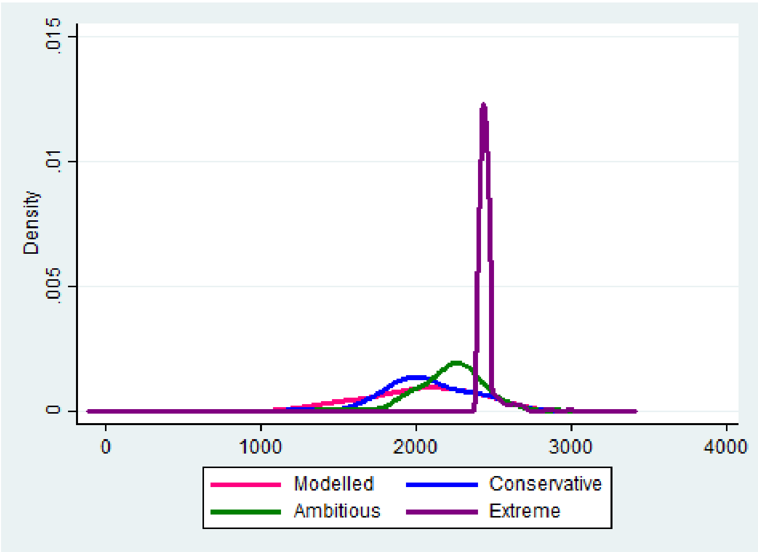
Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Here GHG = methane + nitrous oxide, measured in ton CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

Table 30: Scenario analysis of N management effort for sheep/beef farms

Scenario	Mean N mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-5.22%	-0.51%	-0.02%	-2.14%
Ambitious	-11.97%	-1.18%	-0.04%	-4.91%
Extreme	-23.94%	-2.35%	-0.07%	-9.82%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

Figure 31: Shift of N residual distribution for sheep/beef farms



8.5 Indirect P analysis for dairy farms

Similarly to sections 8.3 and 8.4, we include the N management effort residual in the P-loss equation in an attempt to isolate the effect of differences in P-loss management on GHGs. We find that the effect of changes in P-loss management on GHGs seems slightly smaller than our main estimates. In particular the effect on nitrous oxide reduces to around half of the previous estimate.

Table 31: Repeated two-step P regression results for dairy farms

	Step 1	Step 2			
		Step 1	Step 2		
	log(N leaching)	log(P loss)	log(GHG)	log(CH_4)	log(N_2O)
log(milk solids)	0.675***	-0.0384	0.727***	0.728***	0.726***
	(0.0981)	(0.108)	(0.0278)	(0.0283)	(0.0430)
log(rainfall)	-0.298*	-0.139	-0.0602	-0.0632	-0.0732
	(0.129)	(0.142)	(0.0364)	(0.0371)	(0.0564)
log(temperature)	-0.0736	0.769**	-0.0511	-0.0132	-0.140
	(0.268)	(0.295)	(0.0758)	(0.0772)	(0.117)
topography = non-flat hill	-0.0856	-0.0690	0.000766	0.00111	-0.00324
	(0.0669)	(0.0737)	(0.0190)	(0.0193)	(0.0293)
soil = peat	0.177	0.0727	0.0629	0.0619	0.0568
	(0.228)	(0.252)	(0.0647)	(0.0658)	(0.100)
soil = podzol	0.125	0.461*	0.0773	0.0863	0.0496
	(0.167)	(0.184)	(0.0473)	(0.0481)	(0.0732)
soil = pumice	0.168	0.360*	0.0780	0.0825	0.0747
	(0.153)	(0.169)	(0.0434)	(0.0442)	(0.0672)
soil = recent YGE	0.0749	0.165	0.0560*	0.0498*	0.0778*
	(0.0809)	(0.0891)	(0.0229)	(0.0233)	(0.0355)
soil = sands	0.131	-0.120	0.0805	0.0342	0.174*
	(0.156)	(0.172)	(0.0441)	(0.0449)	(0.0683)
soil = volcanic	-0.0248	0.221**	0.0719***	0.0754***	0.0660*
	(0.0711)	(0.0784)	(0.0202)	(0.0205)	(0.0312)
log(cows wintered off)	-0.0238	0.00372	-0.0109**	-0.00805*	-0.0174**
	(0.0127)	(0.0140)	(0.00360)	(0.00367)	(0.00558)
log(dairy replacements)	0.0831**	-0.0107	0.0731***	0.0770***	0.0677***
	(0.0299)	(0.0330)	(0.00848)	(0.00863)	(0.0131)
year = 2009-10	-0.00514	-0.113	-0.0119	-0.0126	-0.0127
	(0.0761)	(0.0838)	(0.0216)	(0.0219)	(0.0334)
year = 2010-11	-0.0600	-0.0761	-0.0491*	-0.0486*	-0.0469
	(0.0689)	(0.0760)	(0.0195)	(0.0199)	(0.0302)
year = 2011-12	-0.135*	-0.0225	-0.0581**	-0.0489*	-0.0813**
	(0.0675)	(0.0744)	(0.0191)	(0.0195)	(0.0296)
south island	-0.293***	-0.292**	-0.0333	-0.0410	-0.0236
	(0.0801)	(0.0883)	(0.0227)	(0.0231)	(0.0351)
DCD used	-0.295**	-0.127	-0.0897**	-0.0198	-0.297***
	(0.0980)	(0.108)	(0.0278)	(0.0283)	(0.0430)

irrigated	-0.0273 (0.104)	0.579*** (0.115)	0.0560 (0.0295)	0.00464 (0.0300)	0.178*** (0.0457)
N residual		-0.268*** (0.0577)			
P residual			-0.0296* (0.0135)	-0.0260 (0.0137)	-0.0409 (0.0209)
constant	6.175*** (0.927)	-0.817 (1.022)	9.776*** (0.263)	9.395*** (0.267)	8.753*** (0.407)
N	384	384	384	384	384
R-squared	0.215	0.279	0.744	0.724	0.620
adjusted R-squared	0.176	0.242	0.730	0.710	0.600

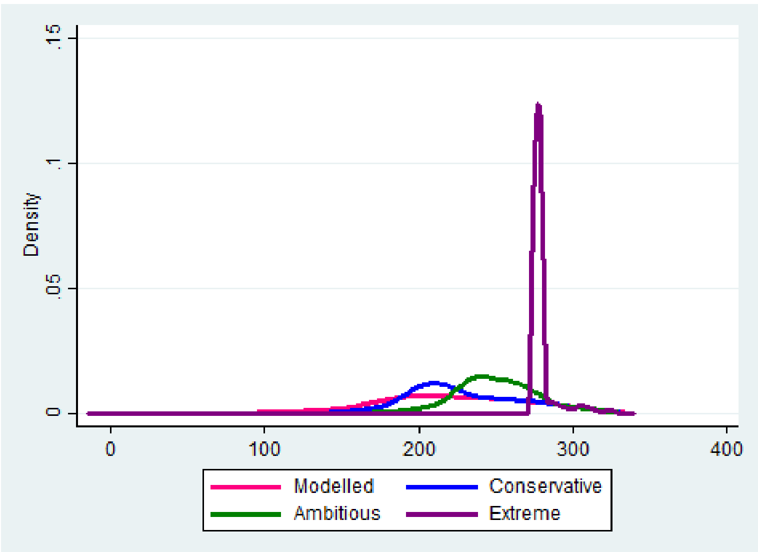
Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Here GHG = methane + nitrous oxide, measured in ton CO_2-equivalent.
Controls: topography = flat, soil = sedimentary.

Table 32: Scenario analysis of indirect P management effort for dairy farms

Scenario	Mean P mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-10.46%	-0.31%	-0.27%	-0.43%
Ambitious	-29.88%	-0.89%	-0.78%	-1.22%
Extreme	-59.76%	-1.77%	-1.55%	-2.44%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

Figure 32: **Shift of P residual distribution for dairy farms**



8.6 Indirect P analysis for sheep/beef farms

Table 33: Repeated two-step P regression results for sheep/beef farms

	Step 1	Step 2			
		Step 1	Step 2		
	N leaching	P loss	GHG	CH_4	N_2O
stock unit	1.971***	0.0510*	379.8***	287.3***	92.48***
	(0.135)	(0.0236)	(4.900)	(2.502)	(4.058)
stock unit squared	-0.0401***	-0.00126	-0.726***	-0.347***	-0.379*
	(0.00531)	(0.000931)	(0.193)	(0.0985)	(0.160)
rainfall	-0.00162	0.000435**	-0.0775*	-0.0167	-0.0608*
	(0.000921)	(0.000162)	(0.0335)	(0.0171)	(0.0277)
temperature	0.164	-0.0187	26.30***	9.980***	16.32***
	(0.148)	(0.0259)	(5.376)	(2.745)	(4.452)
topography = non-flat hill	-0.177	0.0311	-25.70	-20.93*	-4.763
	(0.520)	(0.0912)	(18.91)	(9.654)	(15.66)
soil = peat	0.896	-0.569	-33.41	-24.85	-8.564
	(4.953)	(0.869)	(180.1)	(91.94)	(149.1)
soil = pumice	1.359	-0.265	0.970	12.67	-11.70
	(1.078)	(0.189)	(39.20)	(20.01)	(32.46)
soil = recent YGE	0.342	-0.153	-7.997	-2.395	-5.602
	(0.614)	(0.108)	(22.31)	(11.39)	(18.48)
soil = sands	-3.209	0.136	-81.70	-26.97	-54.72
	(1.926)	(0.338)	(70.04)	(35.76)	(58.00)
soil = volcanic	1.818	-0.226	100.6**	30.20	70.37*
	(0.934)	(0.164)	(33.96)	(17.34)	(28.13)
year = 2009-10	3.472***	0.0791	17.89	15.32	2.571
	(0.733)	(0.129)	(26.64)	(13.60)	(22.06)
year = 2010-11	3.793***	0.187	35.46	25.95	9.510
	(0.713)	(0.125)	(25.93)	(13.24)	(21.47)
year = 2011-12	3.844***	0.289*	56.38*	38.77**	17.61
	(0.711)	(0.125)	(25.85)	(13.20)	(21.40)
south island	2.463***	-0.748***	25.93	-21.35	47.28*
	(0.638)	(0.112)	(23.19)	(11.84)	(19.20)
N residual		-0.0321***			
		(0.00889)			
P residual			-30.45**	-13.75*	-16.70
			(10.52)	(5.372)	(8.713)
constant	-5.919**	0.565	-239.5**	-75.65	-163.8*
	(2.191)	(0.384)	(79.67)	(40.68)	(65.98)
N	404	404	404	404	404
R-squared	0.532	0.258	0.989	0.995	0.872
adjusted R-squared	0.515	0.229	0.988	0.995	0.867

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. GHG = methane + nitrous oxide, measured in ton CO_2-equivalent.
Controls: topography = flat, soil = sedimentary

Table 34: Scenario analysis of indirect P management effort for sheep/beef farms

Scenario	Mean P mitigation	Implied mean GHG mitigation		
		GHG	CH_4	N_2O
Conservative	-3.08%	-0.15%	-0.09%	-0.35%
Ambitious	-6.23%	-0.30%	-0.18%	-0.71%
Extreme	-12.46%	-0.61%	-0.36%	-1.42%

Note: GHG = CH_4 + N_2O in T CO_2-equivalent measure.

Figure 33**: Shift of P residual distribution for sheep/beef farms**