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

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The authors remain responsible for any opinions expressed and any errors and omissions.

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Abstract

The National Policy Statement for Freshwater Management (NPS-FM) establishes the need to set and manage water resources within limits. This report is the first national assessment of the indirect impacts of the NPS-FM on New Zealand's greenhouse gas emissions (GHGs). 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. 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. 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.

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. Key results are that without land use change, agricultural GHGs (primarily methane and nitrous oxide) could be reduced by 2.4% or 0.82 million metric tonnes of carbon-dioxide equivalent per annum (MtCO2e/yr) 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 MtCO2e/yr or 13%). If afforestation is perceived to be a feasible freshwater 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) MtCO2e/yr, primarily through reduction in stock numbers and increases in forest carbon sequestration. This option could reduce New Zealand's net land use emissions by nearly 80%, to about 2.0 MtCO2e/yr. The majority of the emissions impact occurs in the sheep and beef sector, with a gross (net) reduction of 0.61 (0.72) MtCO2e/yr. 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).

JEL codes

Q15, Q53, Q54, Q58

Keywords

Water quality, climate change, agriculture, emissions, New Zealand

Summary haiku

Clean water is good.

Does it reduce climate change?

Alas, not that much.

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Tables and Figures

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. Monaghan et al. 2007; McDowell & Nash, 2012; McDowell et al 2014). However, less research has been undertaken to assess the unintended impacts of the NPS-FM on New Zealand's greenhouse gas emissions (GHGs). 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

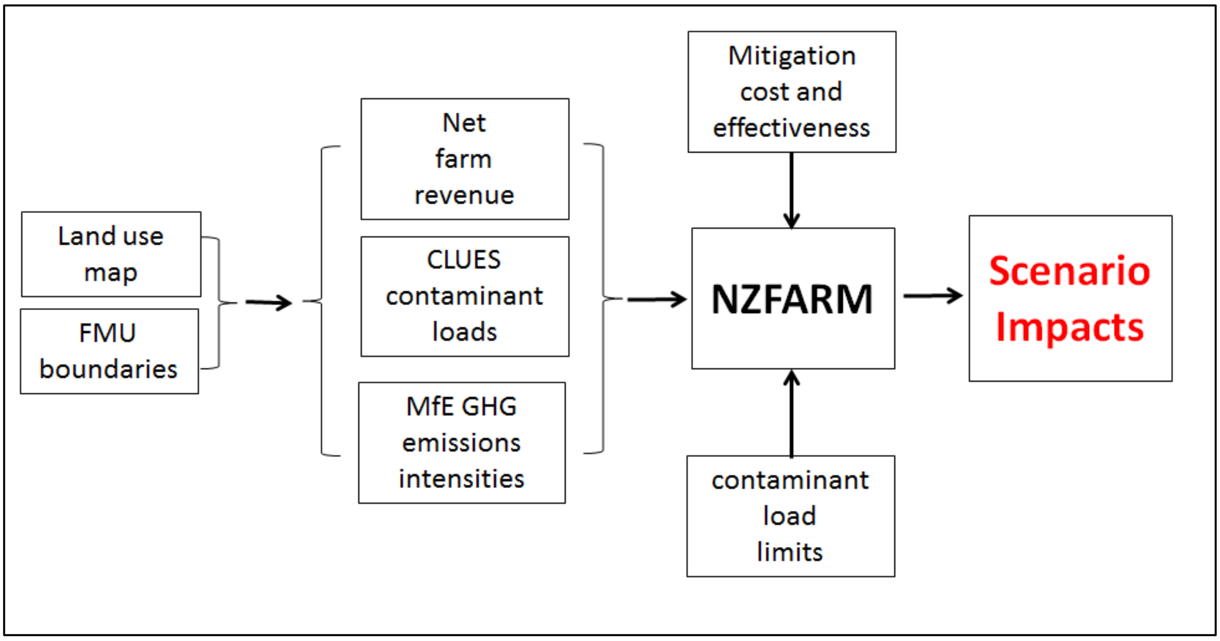
This report presents the assessment of the potential economic and environmental impacts of reducing N, P, sediment, and *E.coli* loads per targets specified under the NPS-FM. The modelling is conducted using the national-level NZFARM model (Daigneault et al. 2017). For this project, we:

- 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, 2017). 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 analysis 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)1 of agricultural production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs (e.g. sediment load limits) imposed on the catchment. Catchments can be disaggregated into sub-regions (i.e. zones) based on different criteria (e.g. land use capability, irrigation schemes) 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:

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

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.

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

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:

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

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:2

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

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:3

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

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 constraint4:

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

2 N.B. For this analysis, we assume there are no irrigated land uses
3 N.B. This analysis focused primarily 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.
4 N.B. This constraint can be placed on the farm, sub-catchment, or catchment level, depending on the focus of the policy or environmental target.

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

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

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

The main endogenous variable is the physical area for each of the feasible farm-based activities in a catchment ($X_{r,s,l,e,m}$). In the model, landowners have a degree of flexibility to adjust the share of the land use, enterprise, and land management components of their farm-based activities to meet an objective (e.g. achieve a nutrient reduction target at least cost). Commodity prices, environmental constraints (e.g. nutrient cap), water available for irrigation, and technological change are the important exogenous variables, and, unless specified, these exogenous variables are assumed to be constant across 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.[5] 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, a high-level modelling system for mathematical optimization. The baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the CONOPT solver (GAMS 2015).

2.1.1 Model Data and Parameterisation

NZFARM accounts for a variety of land use, enterprise, and land management options in a given area. The data required to parameterise each land use, enterprise, and land management combination include financial and budget data (e.g. inputs, costs, and prices), production data, and environmental outputs (e.g. 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 the figures in the

5 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.

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

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

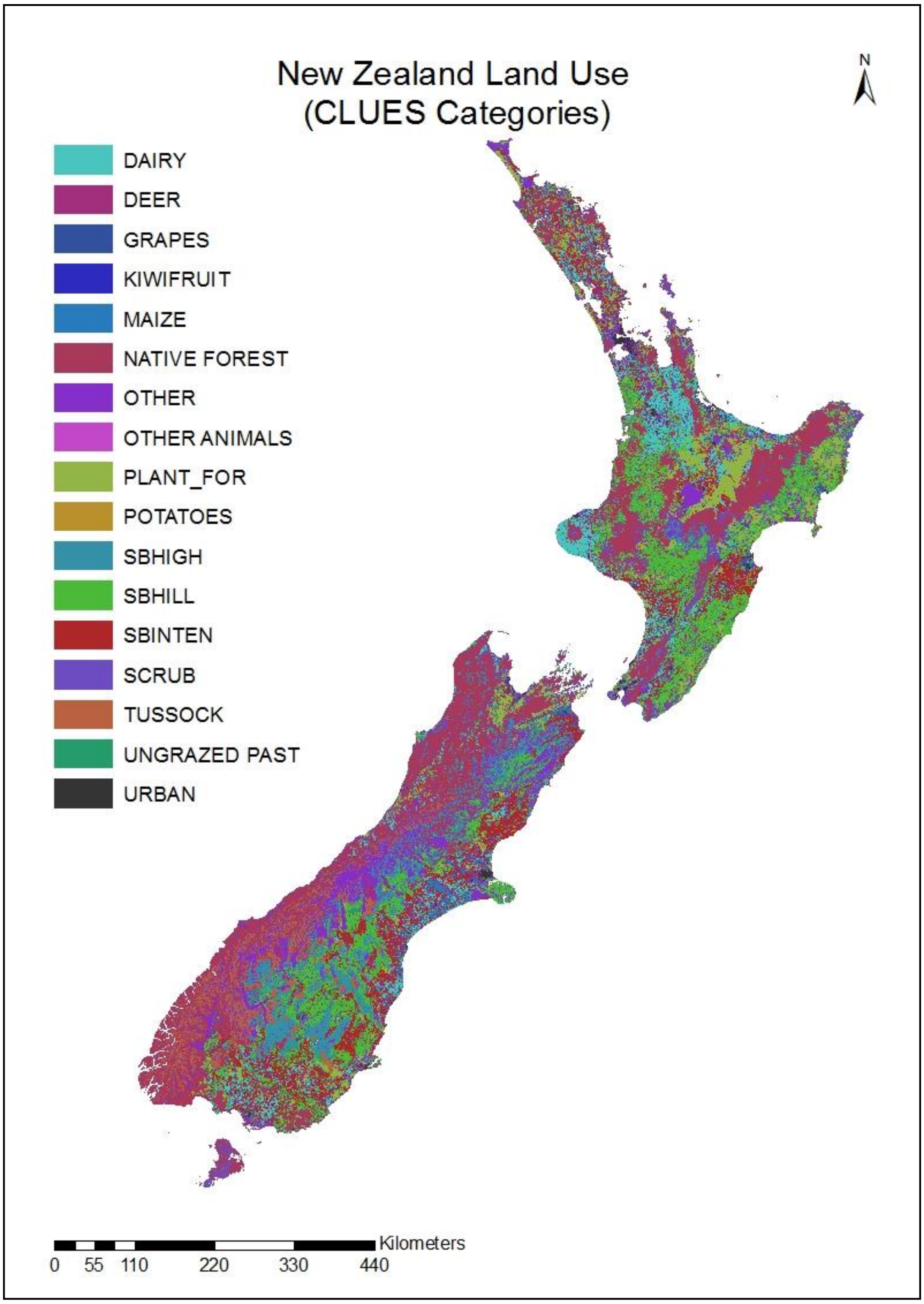
Table 2: List of key components of NZFARM-national

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

2.1.2 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. (2017).

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.6 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-FM7 (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 estimating 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

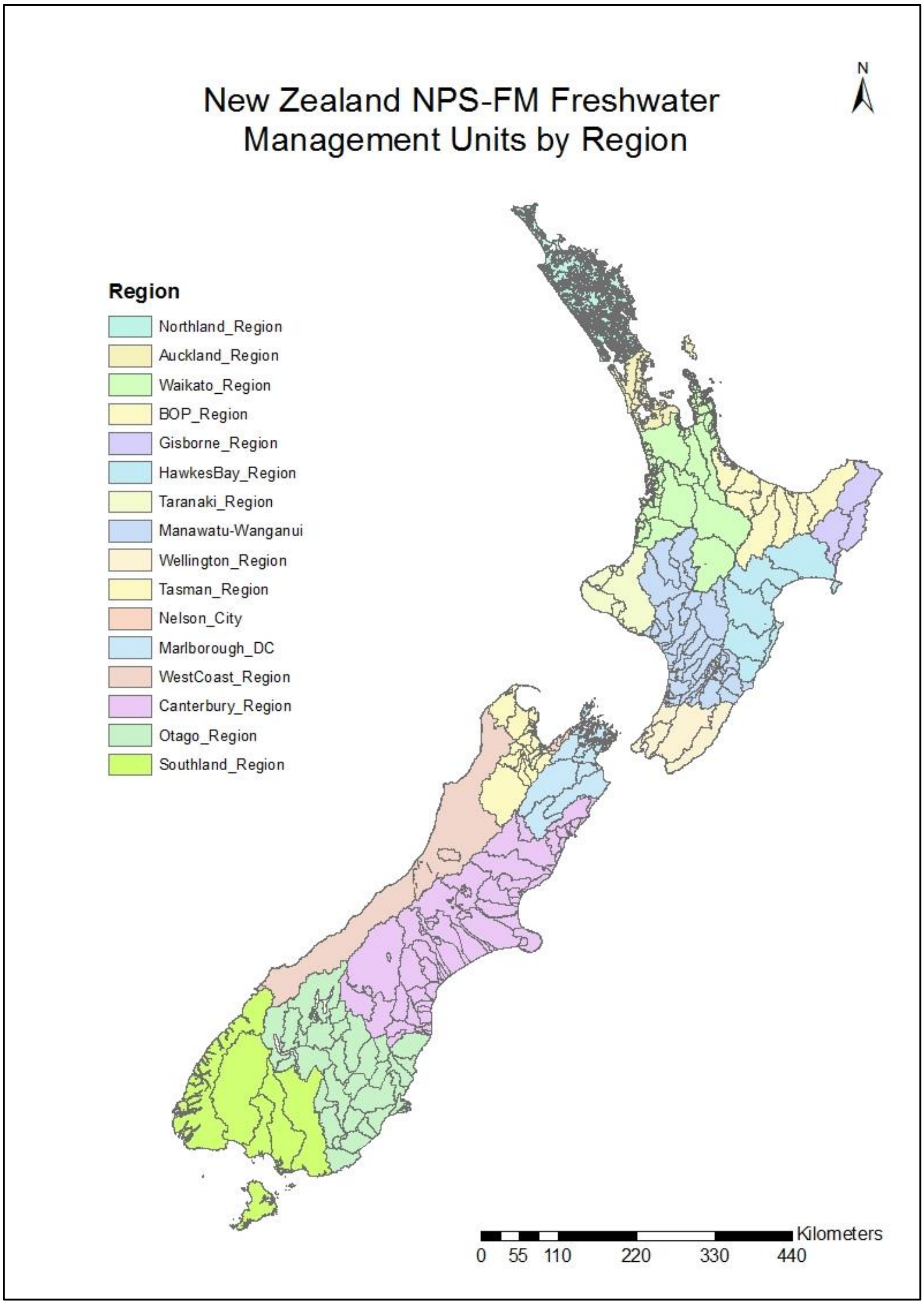
Information on FMU and reduction targets was collected by in-person meetings, email and phone calls with regional council representatives active in freshwater policy and the NPS-FM implementation process. The information collected from each council included:

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
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 one of the Technical Papers associated with this report "Freshwater Contaminant Limit Assessment of the Regions".

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

Figure 3: Freshwater Management Units (FMU) by region.



2.2.1 Freshwater Management Units

The national-level map of the FMUs is shown in Figure 2. 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.

2.2.2 Contaminant Load Reduction Targets

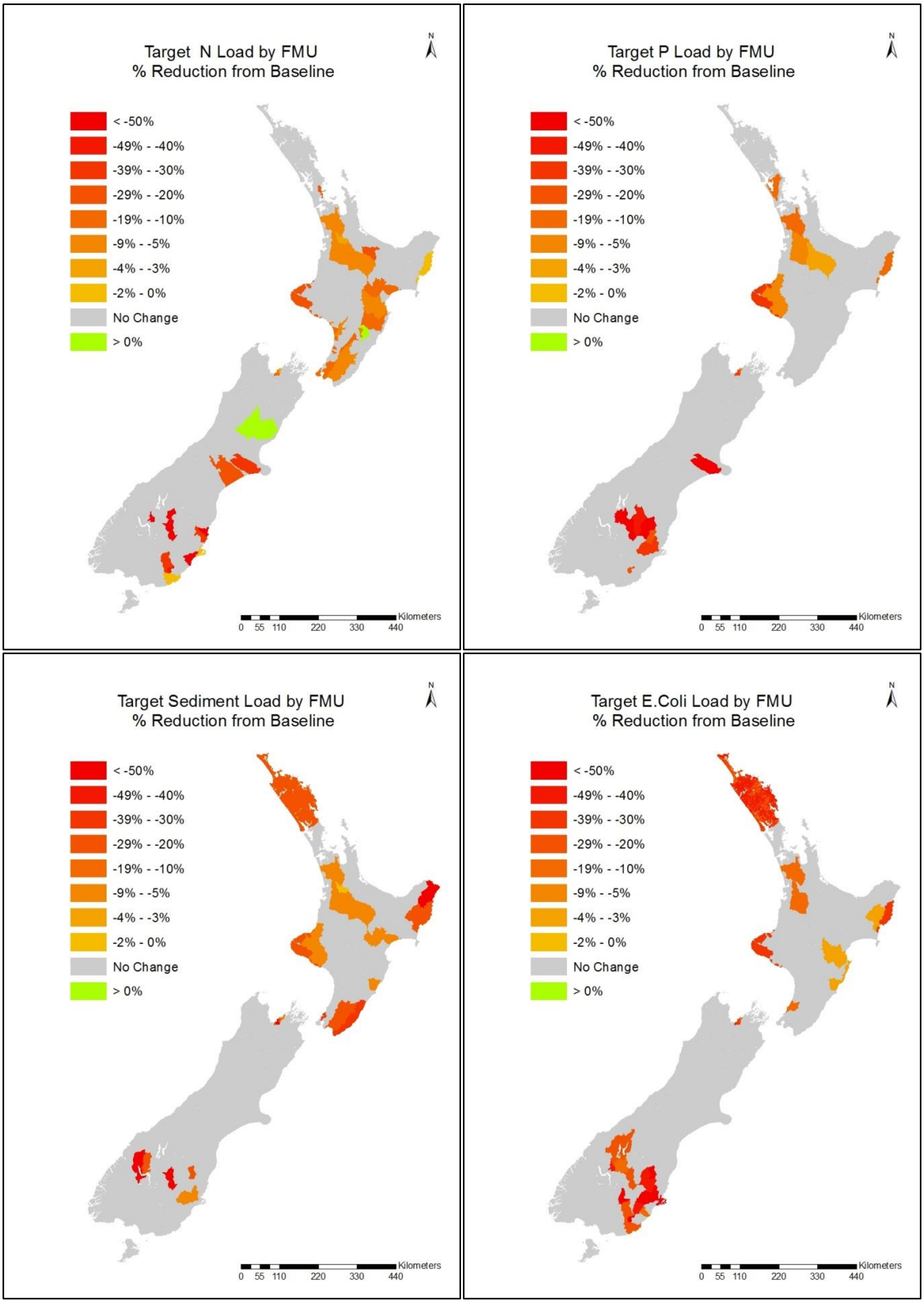
Specified targets to reduce diffuse source contaminants to waterways vary widely both across and within regions of New Zealand. A summary of the regional level targets (with range based on the spread across FMUs in the region) is listed in Table 3, while the spatial distribution is shown in Figure 3. 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.

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 sub-catchment-average slopes using a simplified version of the OVERSEER farm nutrient loss model (version 6.1).[8] 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 divided 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.

8 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 5-m 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 a Technical Paper associated with this paper: "Land-use Contaminant Loads and Mitigation Costs".

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 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 a Technical Paper associated with this paper: "Land-use Contaminant Loads and Mitigation Costs", 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%

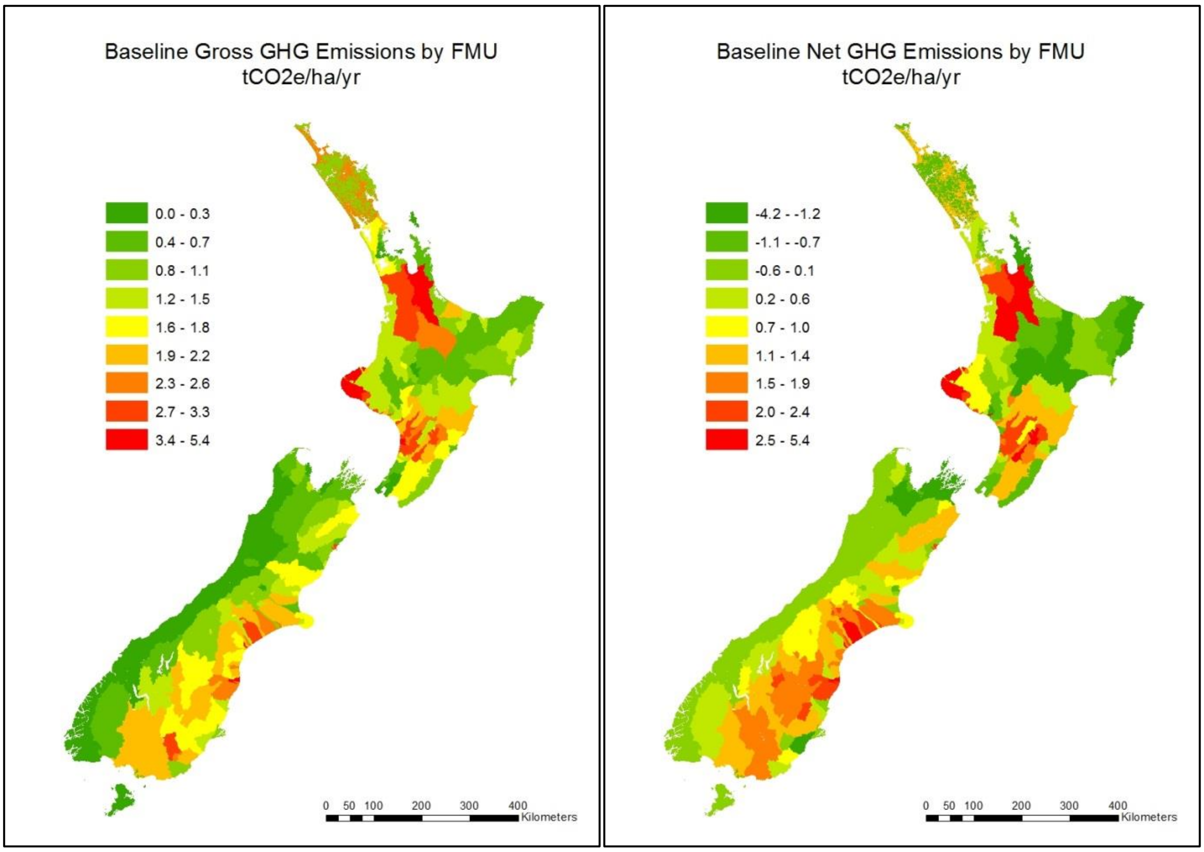
In addition to these mitigation practices, one policy scenario assumes that landowners can also afforest part of their land with exotic pine plantations. The relative costs of doing so will vary by land use and location, but mean annual returns from forestry are often similar to sheep & beef. The mean annual nutrient outputs per ha from an average NZ plantation are 4 kgN and 0 kgP. Sediment is assumed to be only 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 tCO_2/ha/yr, in addition to eliminating all 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 CO_2 equivalent (MtCO_2e) for New Zealand. The main emitters are sheep and beef and dairy farming, which together account for around 33 MtCO_2e annually. The forestry sector and native vegetation and scrub act as important carbon sinks, respectively sequestering 19 and 6 MtCO_2e annually. All these figures are similar to the recent estimates of NZ's GHG inventory (MfE 2016).

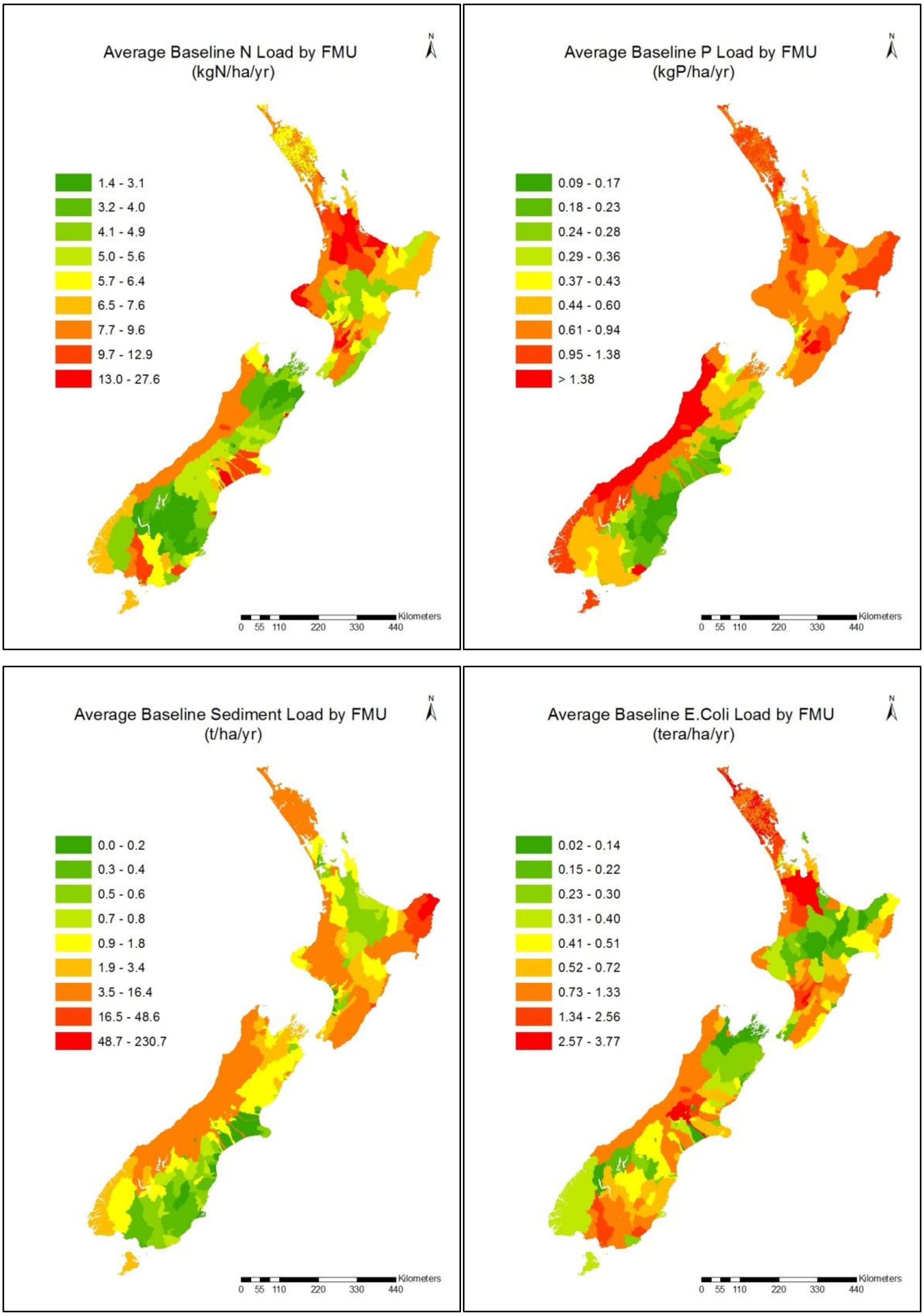
The spatial distribution of net emissions intensities are shown in Figure 5. Areas with a high proportion of pastoral enterprises have emissions intensities of 1 $MtCO_2e$/yr or more, while those with a high proportion of native bush and/or plantation forestry are estimated to sequester 1 $MtCO_2e$/yr or more and hence have negative net emissions.

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).



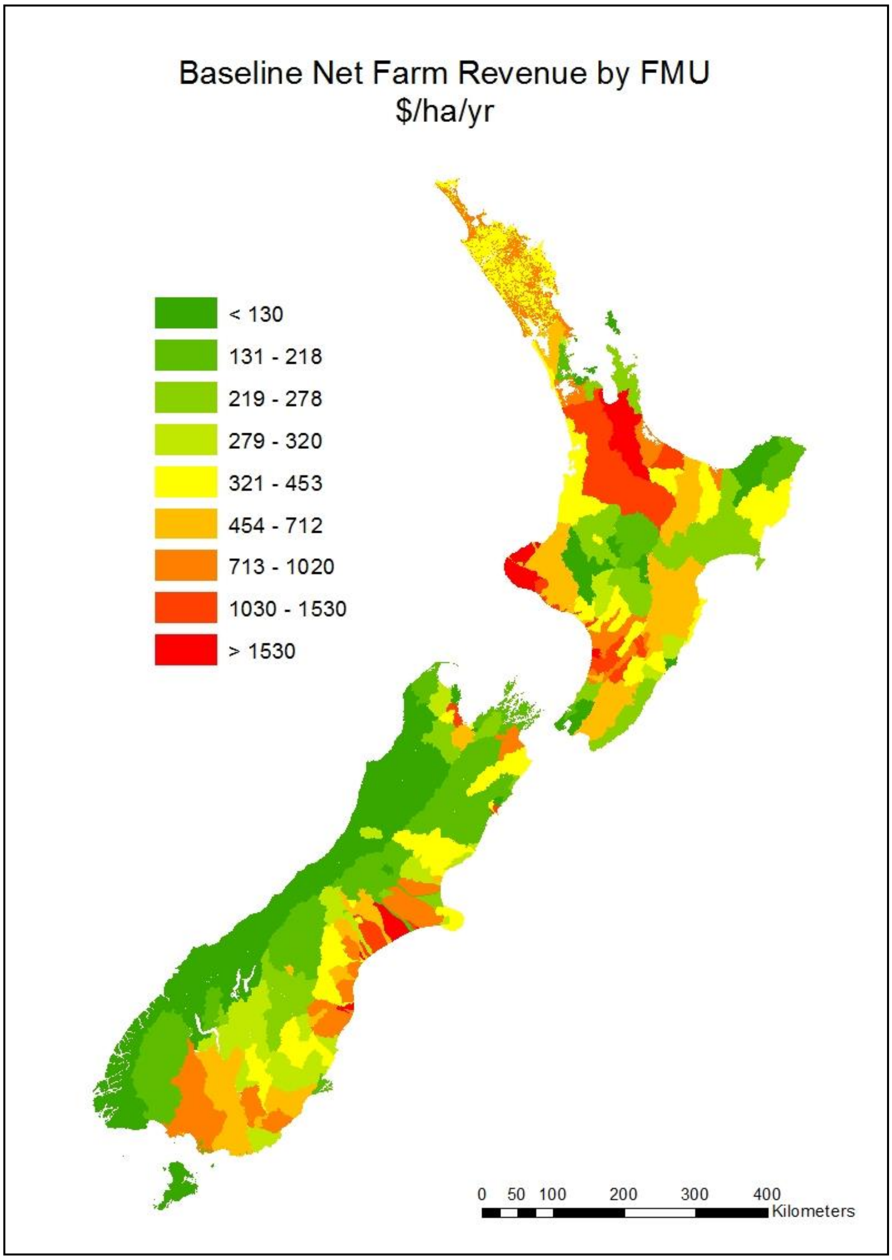
Baseline estimates for the New Zealand agriculture and forest sector economic and environmental output by aggregate enterprise are listed in Table 7. In total, the primary sectors produce more than NZ$11 billion in net farm revenue per annum. Dairy farms generate by far the highest net revenue (NZ$6.4 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	1695	12 750 260	12 750 259	43 612	2184	3866	5340	6 374 282
Sheep & Beef	8593	20 124 478	20 124 477	61 944	5131	35 026	14 161	3 007 499
Other Pasture	1,189	790 838	790 838	9287	1049	9244	2105	243 199
Arable & Hort	391	516 962	516 962	5722	77	173	9	1 197 945
Forestry	2127	0	–19 129 197	7979	564	21 594	36	832 768
Native	6303	0	–3 151 742	32 651	4014	28 777	422	6303
Scrub & Tussock	3603	0	–2 516 196	11 771	2621	22 964	328	51410
Other Land	2439	0	0	13 925	1893	28 917	291	2439
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 Figure 7. 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 to take a high-level approach to estimating the impact of the freshwater reforms on GHG emissions if the proposed targets for N, P, sediment, and *E. coli* were all met in 2030. For this analysis, we assumed reduction 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 also 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 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 the option of also planting trees on the farm (Table 8).

The reduction targets for the core policy scenario are based on the information obtained through the regional council surveys, as displayed in Figure 3. 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 Table 7. The key sensitivities are concerned with whether 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 further 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 for some regions will be more significant than for 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 Mt CO_2e 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).[9]

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. It is assumed all targets are met in every FMU; however, in some cases they will be overachieved. The aggregate reduction in all four contaminants is therefore 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* (tCO_2e)	Net GHG*,^ (tCO_2e)	N Leaching (t)	P Loss (t)	Sediment (Mt)	*E.coli* (peta)
Baseline	34 182 538	9 272 604	184 314	17 244	125 896	22 161
% Change From Baseline						
Aggregate Target	n/a	n/a	–2.5%	–1.3%	–16%	–6.3%
Core Policy	–2.4%	–13%	–6.4%	–5.1%	–18%	–9.9%

Table 10 presents 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 the GHG emissions reductions are attributed to pastoral enterprises; the majority of the impact occurs in the sheep and beef sector,

9 GHG emissions from energy use are excluded from this analysis.

which produces a gross net reduction of 0.61 (0.72) Mt CO_2e/yr. Emissions are estimated to increase slightly in the arable and horticultural crop sector, given that some of the more advanced bundles for mitigating contaminants are potentially more GHG intensive (Table 6).

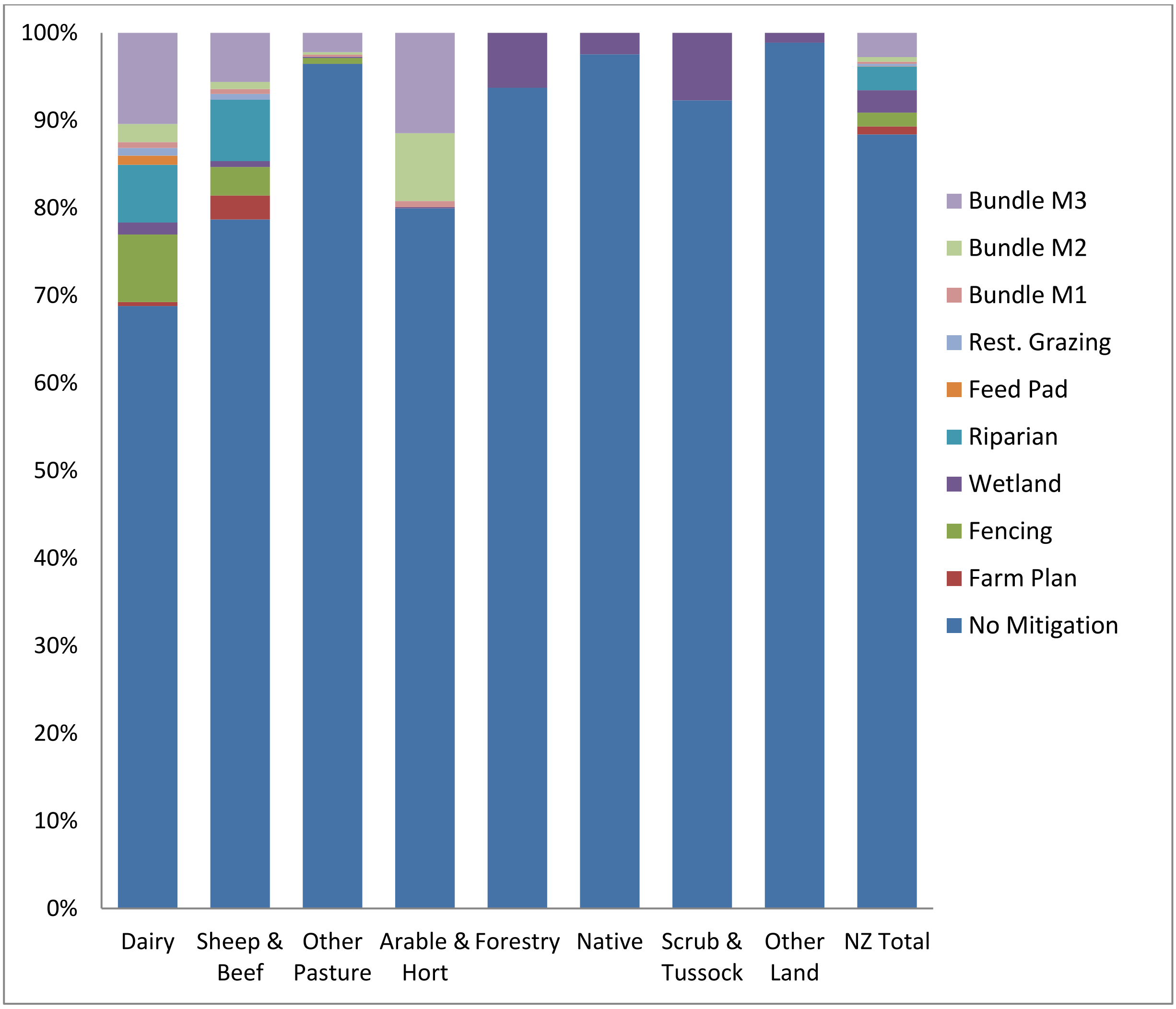
Table 10: Enterprise-level Core Policy Scenario Findings

Land Use	Gross GHG (tCO_2e)	Net GHG (tCO_2e)	N leaching (t)	P Loss (t)	Sediment (kt)	*E.coli* (peta)
			Absolute change from baseline			
Dairy	–216 362	–229 526	–5996	–204	–1715	–763
Sheep & Beef	–614 645	–719 190	–4625	–505	–11 086	–1453
Other Pasture	–3394	–3394	–78	–8	–28	–24
Arable & Hort	15 212	15 212	–421	–13	–43	–1
Forestry	0	0	58	0	–7602	-2
Native	0	1031	–76	–1	–978	–2
Scrub & Tussock	0	0	–130	–48	–4401	–7
Other Land	0	0	–258	–38	–755	–2
NZ Total	–819 188	–935 867	–11 642	–817	–26 608	–2254
			% 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 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 5-m riparian buffer planted adjacent to its streams; 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 (%).

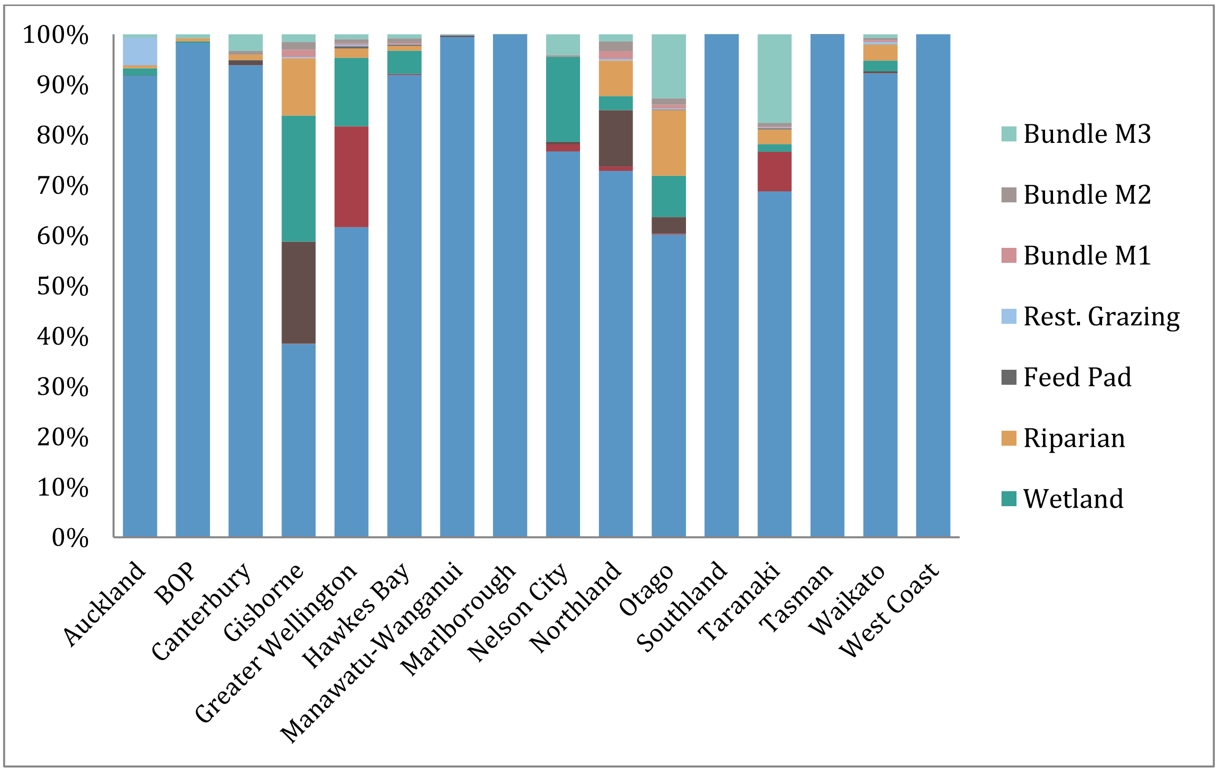


Figure 10 shows the spatial distribution of contaminant reductions across the FMUs. Comparing this with the distribution of targets specified by the council (Figure 3), we see that most FMUs that have a target of at least one contaminant result in an estimated decline in all four pollutants. This is because nearly all 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 intention of capturing up to 65% of the sediment runoff, they also has the ability to intercept 55% of *E.coli*, 45% of P loss, and 10% of N leaching. Rather, the same practice is not expected to have an impact on GHG emissions, as these wetlands are likely to be constructed on areas of farms 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.

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

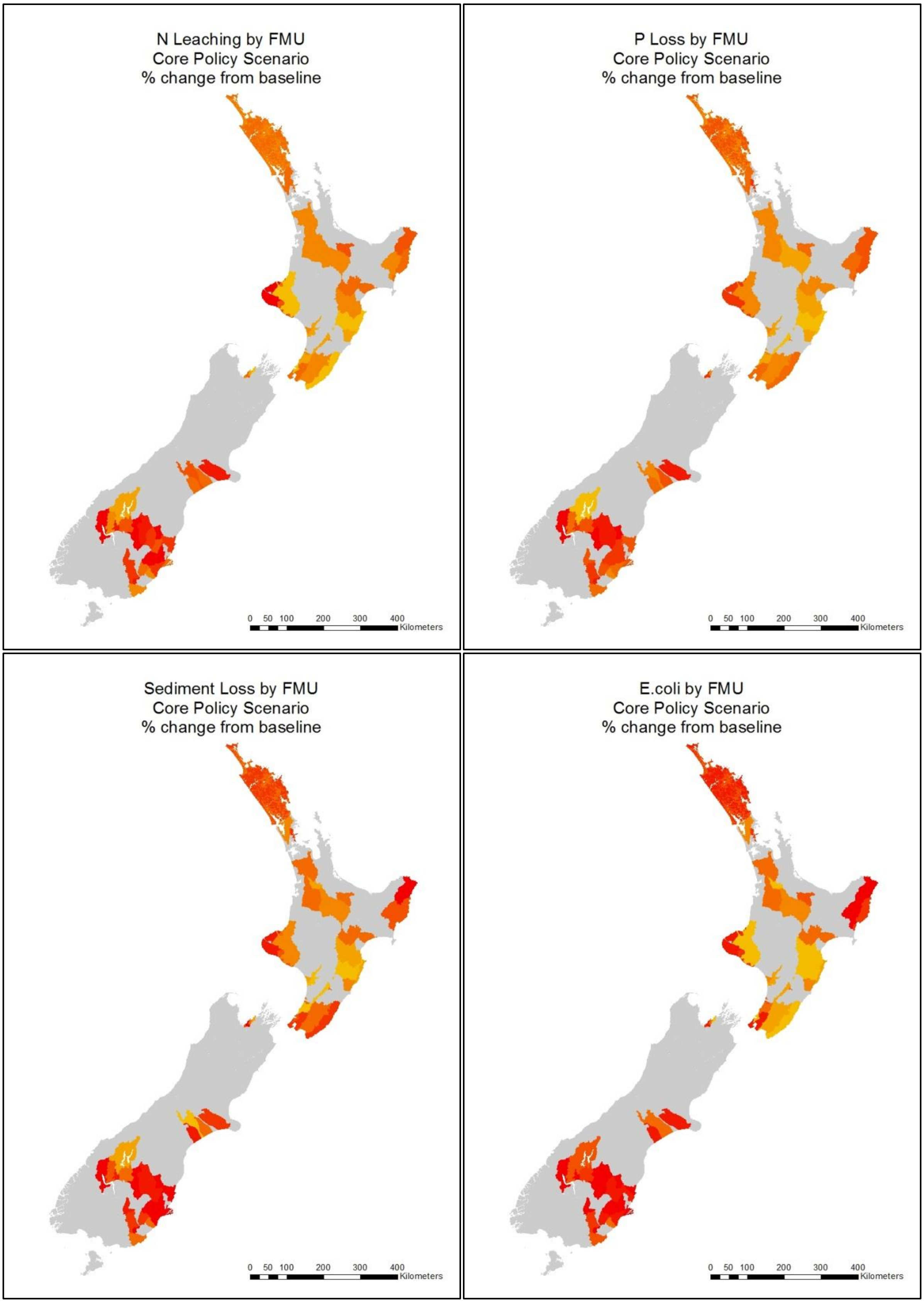


Figure 11 shows the spatial estimates of how mitigation implemented to achieve the freshwater reform targets could affect net GHG emissions at the FMU level. The figures highlight that emissions are expected to decline in all FMUs that have freshwater contaminant reduction targets as a result of the 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 (Figure 12). Interestingly, there are a few scattered FMUs where GHGs could actually increase over the baseline, albeit only 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 (%).

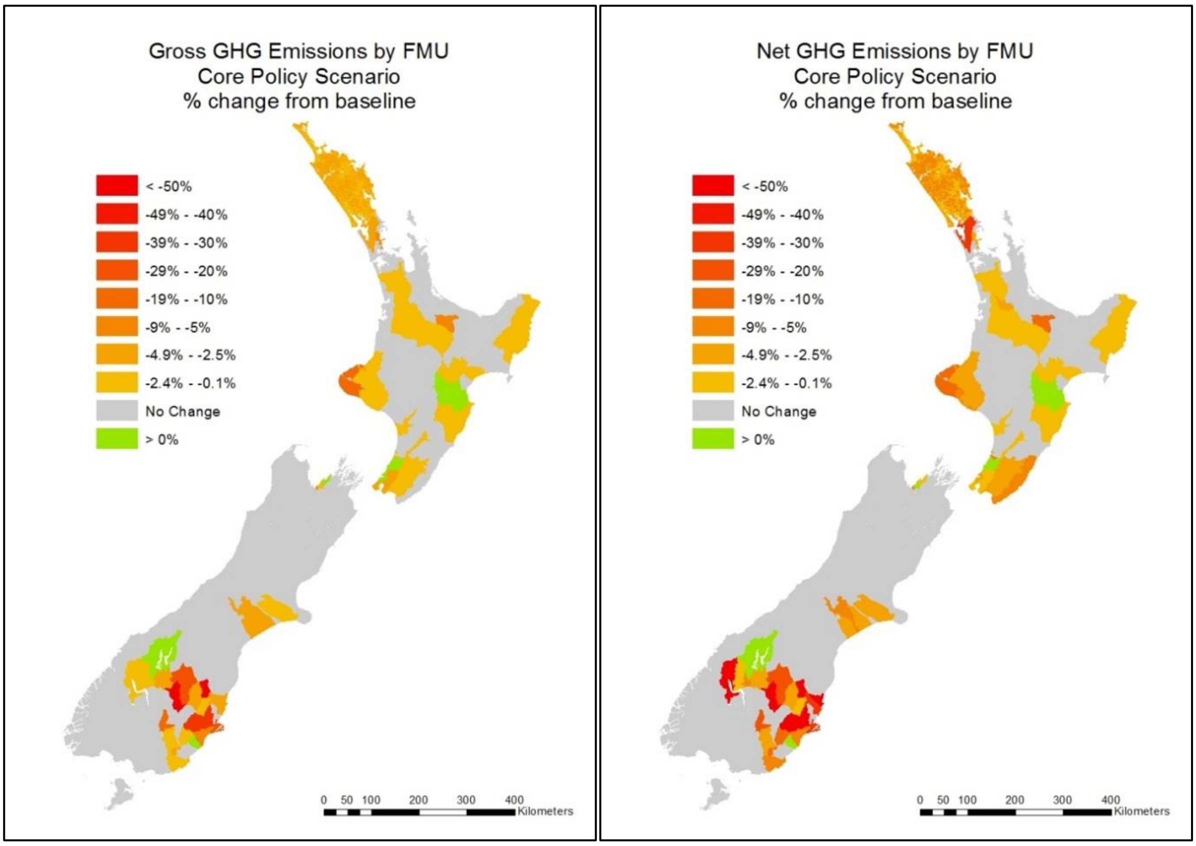
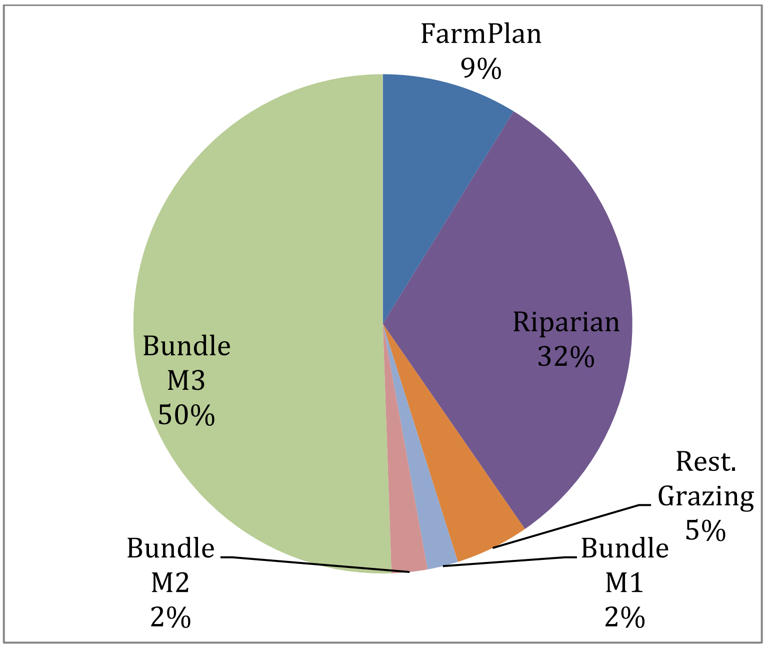


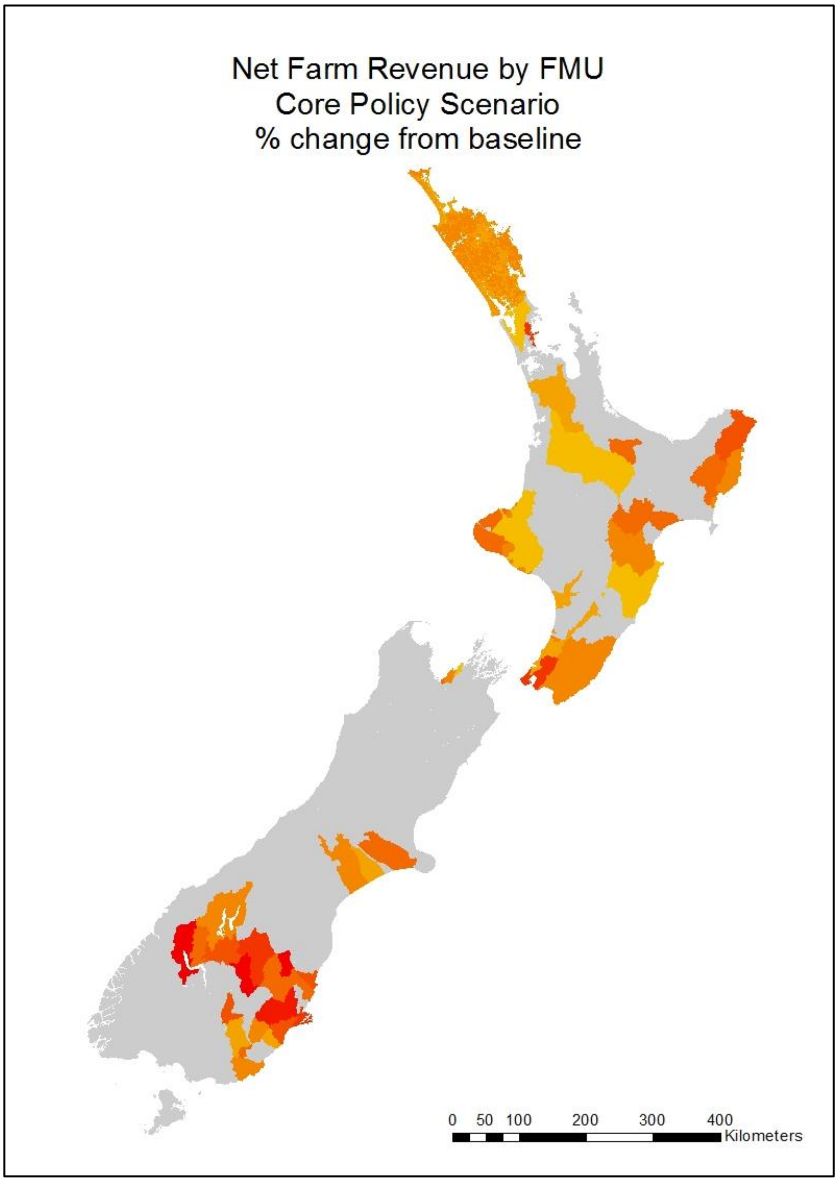
Figure 12 indicates the proportion of total net emissions reductions by mitigation option for the core policy scenario. It is apparent that the M3 mitigation bundle has the greatest impact, producing about half of the emissions reductions. These are reductions in gross emissions. Riparian planting and farm plans with pole planting also have a noticeable effect, as these two options reduce GHGs both by reducing stock and by 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* (tCO_2e)	Net GHG*,^ (tCO_2e)	N Leaching (t)	P Loss (t)	Sediment (Mt)	*E.coli* (peta)
Baseline	34 182 538	9 272 604	184 314	17 244	125 896	22 161
% Change From Baseline						
Aggregate Target	n/a	n/a	−2.5%	−1.3%	−16%	−6.3%
Core Policy	−2.4%	−13%	−6.4%	−5.1%	−18%	−9.9%
Core + Afforest	−8.4%	−79%	−6.8%	−5.5%	−17%	−9.9%
Min 10% Target	−4.3%	−19%	−16%	−12%	-30%	−27%
Min 20% Target	−4.9%	−23%	−23%	−17%	−37%	−37%

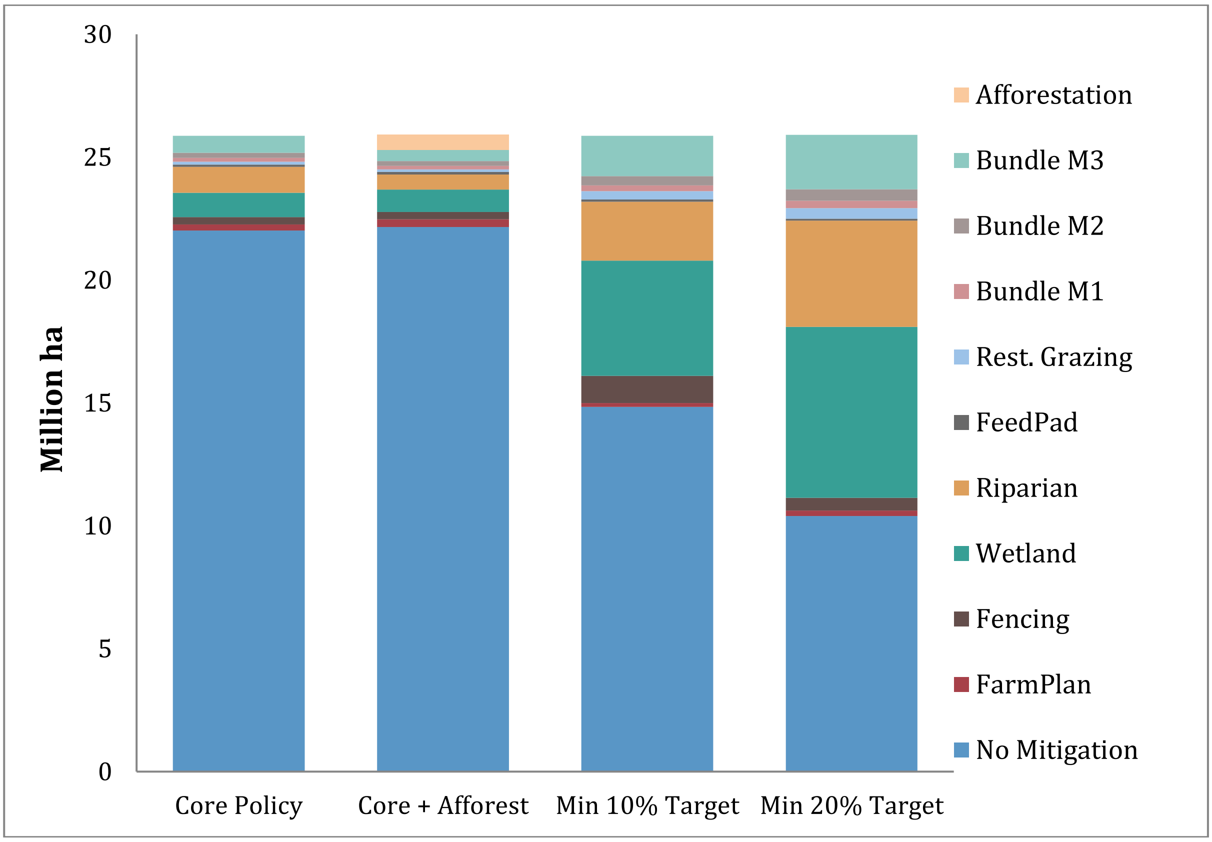
^ Energy GHGs are excluded from analysis.
* Includes gross biological emissions less forest carbon sequestration. Energy is excluded from this analysis.

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 $MtCO_2e$/yr, of which about 35% is attributed to reduced gross emissions from livestock farms while the remainder (5.4 $MtCO_2$-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 to 1.7 (1.7 to 2.1) $MtCO_2e$/yr. Most mitigation is estimated to occur through wetland construction/restoration, riparian planting, and implementation of mitigation bundle 3. Although two of these options 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 reduce N, P, sediment, and *E.coli* loads further 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 because of the different policy scenario assumptions is shown in Figure 15 and Figure 16. The figures highlight that in the afforestation case, the largest reductions in emissions are estimated to occur in dairy and sheep & 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 FMUs 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.

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

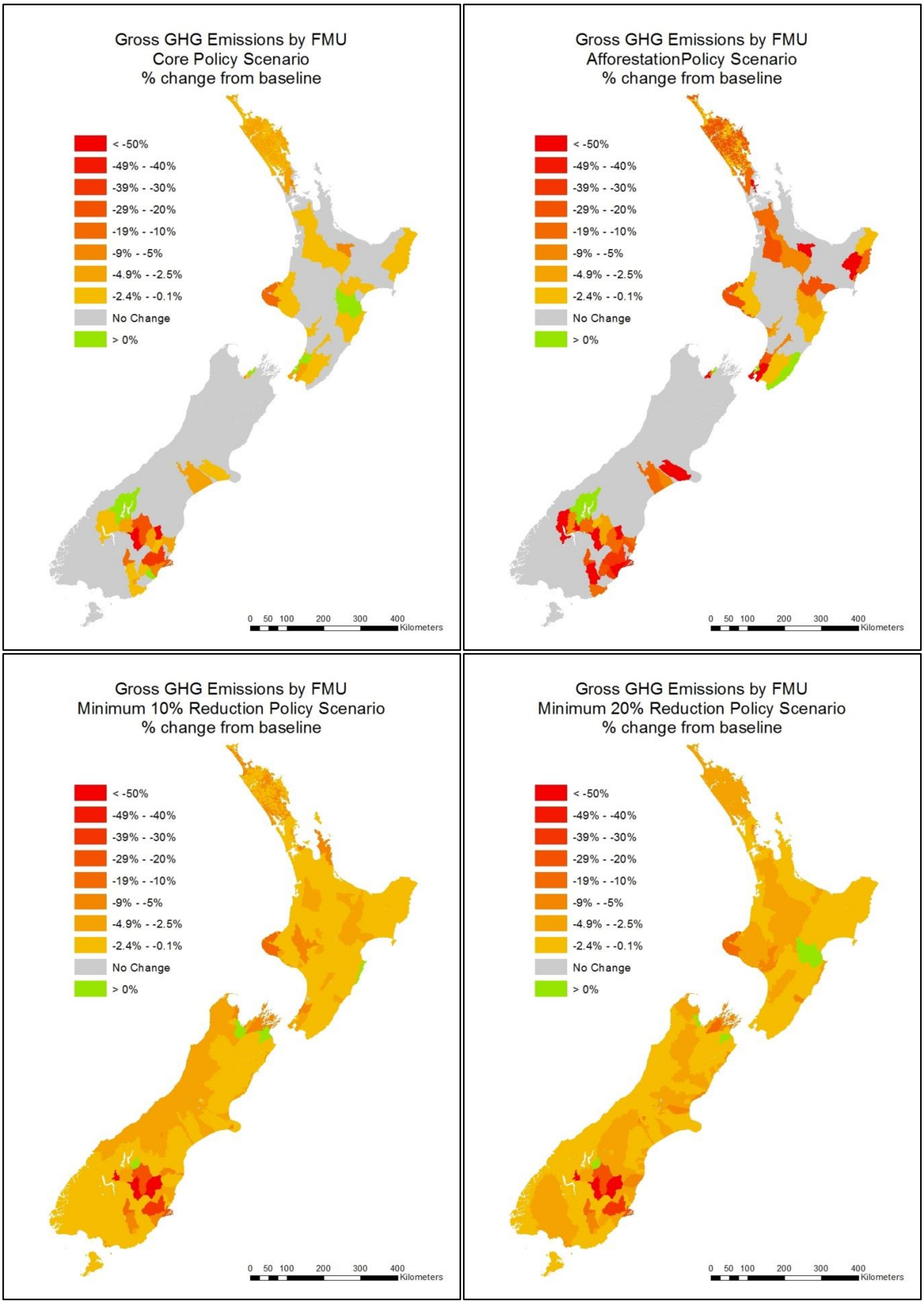
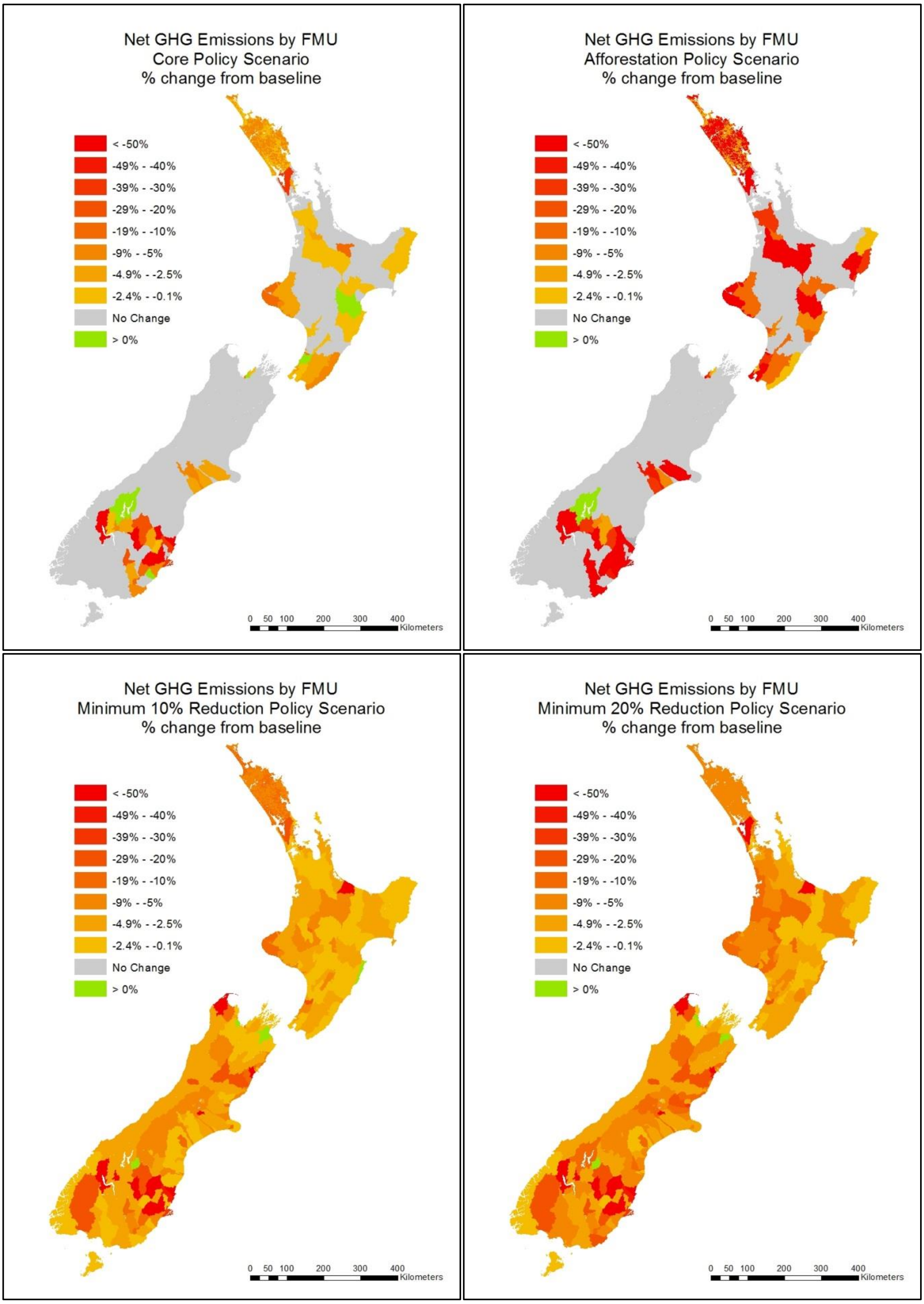


Figure 16: NZFARM estimated change in Net GHG Emissions by FMU (% below baseline loads) by policy scenario.



5 Summary

A summary of the key findings is as follows:

5.1 By 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 by 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 $MtCO_2e$ 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%).10 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 $MtCO_2$-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 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.

10 GHG emissions from energy use are also excluded from this analysis.

5.2 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.

5.3 How is mitigation achieved?

- Wide ranges of mitigation options are 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 and Samarasinghe. 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 by 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.

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