Impacts of Farmer Attitude on the Design of a Nutrient Reduction Policy – a New Zealand Catchment Case Study[1]

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ABSTRACT

This paper uses responses from a regional farmer survey that identify farmers' perceptions of environmental policies to calibrate a catchment-level environmental economic model (NZ-FARM) to estimate the impacts of a nutrient reduction policy in North Canterbury, New Zealand. The model maximizes farm income across a catchment, accounting for changes in land use, farm output, nutrient leaching, and GHG emissions. Simulations estimate that reducing nutrient loads by 15–30% can be achieved with economic impacts ranging between 1 and 10%, based on how willing landowners are to change how they manage their farm. Farmers are often hesitant to implement certain mitigation options, however, which results in higher economic costs than the 'optimal' estimates. Farm-level impacts will likely vary through the current farm practice, the farmers' attitude towards the regulation, and the ability of policymakers to educate and incentivise landowners to adopt a variety of land management options.

KEYWORDS: Agriculture and forestry modelling, land use, nutrient budgeting, water quality, greenhouse gas emissions, farmer perception towards policy

Paper prepared for the 56th Annual Australian Agricultural and Resource Economics Society Annual Meeting, Fremantle, Western Australia, 8-10 February, 2012

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[1] This research was made possible by generous funding from NZ Ministry of Agriculture and Forestry (MAF) and the NZ Ministry of Science and Innovation (MSI). Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of MAF or MSI. The authors also wish to acknowledge the assistance of Stuart Ford and Steve Green for their tireless effort in helping collect the data for this paper, and Elizabeth Marshall of USDA Economic Research Service for her significant contribution to model development.

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INTRODUCTION

Agriculture is an important part of New Zealand's economy, but the sector faces several challenges as it strives to maintain and enhance output levels, while at the same time limiting resource use and achieving environmental integrity. Agricultural production in most parts of the country has increased significantly in recent decades through the use of additional inputs, including fertilizer, irrigation, and supplemental feeds. Intensifying agricultural inputs has increased nutrient levels and sediment runoff to lakes and streams, putting additional strain on the country's freshwater resources. In response, environmental policy for agricultural land management in New Zealand has undergone considerable change over the last two decades with the introduction of the Resource Management Act (RMA) (Bewsell and Brown 2011). More recently the New Zealand government announced plans to increase funding for efforts to clean up waterways, as specified in the National Policy Statement for Freshwater Management (NZ Government 2011). Nutrient reduction policies are increasingly being considered in several regions to achieve these environmental targets (Environment Bay of Plenty *et al*. 2009; Environment Waikato 2009; Horizons Regional Council 2010; Canterbury Water Management Strategy 2011). Adoption of such policies however may depend on farmers' attitudes towards and perceptions of regulation and also on current land management practices. Moreover, debate exists as to whether water quality policies such as limiting nutrient leaching levels can be feasibly met while maintaining economic viability and anticipated gains in agricultural productivity.

This paper uses NZ Forest and Agricultural Regional Model (NZ-FARM), a catchment-level agro-environmental economic model to assess the potential economic and environmental impacts of a nutrient reduction policy on land-based production in the Hurunui and Waiau catchments, a major farming region in Canterbury. Catchment models are important for appropriately addressing water-related impacts and identifying the synergies between climate change and water quality. Partial equilibrium models are often preferred for catchment-level analyses as they detail quality representation of practices, economics and environmental impacts for the sectors being modelled, in this case the agricultural and forestry sectors (Johanssen *et al.* 2007; Adams *et al.* 1996).

In this study we simulate the potential impacts of introducing a nutrient reduction policy on the Hurunui/Waiau catchment by investigating scenarios that impose two caps on nitrogen (N) leaching from land-based enterprises at the catchment-level. Targets of 15% and 30% below total baseline leaching levels are selected as they are in the range of the nutrient reduction plans being discussed in the region (Canterbury Water Management Strategy 2011). These reductions also correspond with limits that are already operational for other waterways in New Zealand, including a 20% N reduction target as part of the nutrient trading system within the Lake Taupo catchment (Environment Waikato 2009), and the 22–56% N reduction target in place for Lake Rotorua (Environment Bay of Plenty *et al.* 2009). Additionally, we assess the potential range of estimated impacts of nutrient reduction policy when uptake of possible land management options to meet policy targets differ. Indication of land management adoption probabilities are obtained from a series of face-to-face interviews with farmers in the Hurunui/Waiau region that identify their perceptions of environmental policies.

Using NZ-FARM to model the impact of nutrient reduction policies on farm management and land use also allows us to assess potential co-benefits for environmental factors such as reductions in greenhouse gas (GHG) emissions. These findings can be used to assess where additional land-use regulations may be needed to achieve environmental targets (e.g., GHG emission reductions) or whether a stand-alone nutrient policy could be used achieve multiple environmental goals. For example, agriculture is scheduled to enter the New Zealand Emissions Trading Scheme (ETS) in 2015, but bringing the agricultural sector into the ETS without placing a large burden on its stakeholders is a high priority for both the New Zealand government and the agricultural sector. Additionally, regional councils beyond Canterbury are considering and introducing water quality improvement plans that could also affect farm activities. NZ-FARM enables analysis of the potential GHG emissions reductions associated with nutrient reduction policies. Having a better understanding of the impacts of regional level policies provides valuable insight for the formulation of national level climate policy. The estimated impacts on the Hurunui/Waiau catchment could serve as an important guide for other catchments in New Zealand as they consider similar policies.

Adoption of land management and mitigation practices

The concept of Involvement has been used to understand adoption of agricultural innovation (Kaine 2008; Bewsell and Kaine 2005; Bewsell and Brown 2011). Involvement is considered to be a motivational state indicating the cognitive effort that will be devoted to an activity and results from perceptions that a product or activity can contribute to satisfying farmer goals (Kaine 2008). The choice to adopt an agricultural innovation is identified as a high involvement purchase decision by Kaine (2008), and high involvement may imply a complex decision-making process. Pannell *et al.* (2006) emphasise the importance of landowners' goals as a major factor affecting adoption of mitigation practices. Landowners will not adopt particular management options if they cannot see that these options allow them to better achieve their goal. These goals include economic, social or environmental outcomes and are likely to vary between landowners. Furthermore, Pannell *et al.* (2006) state that adoption is based on subjective perceptions or expectations, which typically depend on the following issues: the process of learning and experience, the characteristics and circumstances of the landholder within their social environment, and the characteristics of the management practice.

Only a limited number of studies have looked at farmer perception of environmental regulation and adoption of management practices in New Zealand. MfE (2008) explored the efforts farmers put into responding to the Clean Streams Accord, a voluntary policy initiative led by the dairy industry. One of the targets in the Clean Streams Accord is that all dairy farmers have systems to manage nutrient inputs and outputs. The completion of a nutrient budget is used as a measure of achievement of this target (Bewsell and Brown 2011). The level of interest and trust that dairy farmers currently have in nutrient budgeting and planning is used by Bewsell and Brown (2011) as a proxy to understand farmers' involvement with, and hence response to, nutrient budgets. This study assumed that involvement in nutrient budgeting could underpin farmers' response to the above mentioned policy and have an influence on their response to it. Responses from 20 in-depth dairy farmer interviews revealed a low level of involvement in nutrient budget development. Bewsell and Brown (2011) concluded that farmers will continue to comply with policy requirements without necessarily making significant changes to the way in which they manage their farms, until their involvement in nutrient budgets increases.

In another study, Bewsell and Kaine (2005) interviewed dairy farmers in four New Zealand catchments to identify the factors that influence farmers' propensity to adopt sustainable land management practices. Interviews covered farmer perception of several land-management practices such as fencing off streams, reducing phosphorus use, and managing effluent and wet soils. They found that farmers' decision to adopt management practices depends on their perception of the benefits of those practices. Results also indicated that these perceptions are based on the systematic evaluation of practices in terms of significant characteristics of the production context of the individual farmer (e.g., commercial and practical realities of dairying) rather than on sustainability and the environment.

Our study uses responses from a series of in-depth face-to-face interviews with farmers in the Hurunui/Waiau region to characterise the farmer perception of predetermined land management options and environmental regulations. Constraints on land-management options in NZ-FARM were then adjusted to reflect the probability of farmer uptake of those options in simulating the potential impacts of introducing a nutrient reduction policy.

The paper is organized as follows. First, we present the NZ-FARM model, and describe the data for the Hurunui catchment. Next, we describe the data sources, including farmer survey responses to land management options for the catchment. Following that, we present baseline land use, enterprise mix, nutrient loads, and GHG emissions. We then present the estimates from our policy scenarios. The final section provides a conclusion of our findings.

METHODS

Agro-Environmental Economic Model

The New Zealand Forest and Agriculture Regional Model (NZ-FARM) is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale. Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as on how a policy aimed at one environmental issue could affect other environmental factors. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decision-makers and rural landowners. The model can track changes in land use, land management, N leaching, and P loss through imposing a variety of policy options that range from establishing a catchment-level cap and trade programme to imposing nutrient leaching and loss constraints at the enterprise-level. A detailed schematic of components of NZ-FARM is shown in Figure 1.

The model's objective function is to determine the level of production outputs that maximize the net revenue (NR) of 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 regulated environmental outputs (e.g., nutrient leaching limits) imposed on the region. This is specified as:

$$\text{Max NR} = \sum_{r,s,l,e,m,io} \begin{array}{c} \text{Output Price*Output Quantity} \\ -\text{Livestock Input*Unit Cost} \\ -\text{Variable Cost*Units Used} \\ -\text{Annualized Fixed Cost} \\ -\text{Environmental Tax} * \text{Units Emitted} \\ -\text{Land Conversion Cost*Hectares Converted} \end{array} \tag{1}$$

subject to:

$$\text{NR}_{r,s,l,e,m} \geq 0$$
$$\text{Land Use}_{\text{r}} \leq \text{Land Available}_{\text{r}}$$
$$\text{Water Available for Irrigation}_{\text{r}} \leq \text{Irrigated Area}_{\text{r}}$$
$$\text{Environmental Output}_{\text{r}} \leq \text{Regulated Environmental Output}_{\text{r}}$$

where *r* is the catchment region, *s* is soil type, *e* is enterprise, *l* is land-use type , *m* is land management practice, and *io* is a set of enterprise-specific input costs, output prices, and environmental outputs. Summing the revenue and costs of production across all enterprises and regions yields the total net revenue for the catchment. Regions within a catchment are differentiated by land use classification, such that all land in the same region will yield the same level of productivity for a given enterprise and land management scheme. A formal mathematical representation of the model is listed in Appendix A.

In addition to estimating economic output from the agriculture and forest sectors, NZ-FARM also tracks a series of environmental factors including N and P leaching, GHG emissions, water yield, and soil erosion. 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 agricultural output, nutrient leaching, and GHG emissions, amongst other things. Key land management options tracked in the model include changing fertilizer regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of nitrogen inhibitors (DCDs). Including a wide range of management options allows us to assess what levels of regulation might be needed to bring new technologies into general practice. Details on the specific land management, economic, and environmental factors tracked in this paper are described in the data section.

The optimal distribution of soil type$_{1 \ldots i}$, land use$_{1 \ldots j}$, enterprise$_{1 \ldots k}$ land management$_{1 \ldots l}$, and agricultural output$_{1 \ldots m}$ in a particular region are simultaneously determined in a nested framework that is calibrated based on the shares of current land use in the region. At the highest levels of the nest, land use is distributed over the region based on the fixed area of various soil types. Land use is then allocated between several enterprises such as arable crops (e.g., wheat or barley), 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., stocking rate, fertilizer regime, etc.) are then imposed on an enterprise that then determines the level of agricultural outputs produced in the final nest. Figure 2 shows the potential nest for an irrigated dairy farm that uses a feed pad and produces a series of outputs from pasture grown on Balmoral soil.

The allocation of land to a specific soil type, land use, enterprise, land management, and product output is represented with constant elasticity of transformation functions (CET). The transformation function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. The CET functions are calibrated using the share of total baseline area for each element of the nest and a parameter, σ_i, where $i \in \{s, l, e, m, p\}$ for the respective soil type, land use, enterprise, land management, and product output. CET 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. The CET functions used in NZ-FARM are parameterized based on the estimates from existing literature of regional economic land-use models (e.g., Adams *et al.* 1996; Hendy *et al.* 2006, Johansson *et al*. 2007). The elasticities in the model ascend with each level of the nest between land use and land management, as there is typically more flexibility to transform the enterprise mix compared with altering the share of land use or shifting land use across soil types. The CET parameter for soil (σ_S) is set be 0, as the amount of a particular soil type in a region is fixed. In addition, the parameter for agricultural production (σ_P) is also assumed to be 0, implying that a given enterprise and management option produces a fixed set of outputs.

The model is written and maintained in General Algebraic Modelling System (GAMS), and the baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the COIN IPOPT solver (GAMS 2011).

Farmer Survey

A series of in-depth face-to-face interviews with 20 farmers in the Hurunui/Waiau region (De Oca Munguia and Walcroft 2011) were used to characterise farmer perception of predetermined land management options and environmental regulations. The interviews consisted of five linked sections including how respondents currently manage their perceived environmental challenges, their priorities, and their opinions about several predetermined land management options. Management options tracked in the survey included reduced animal stocking rates, reduced nitrogen use, and plantation forestry, among other things. Constraints on land management options in NZ-FARM were then adjusted to reflect the probability of farmer uptake of those options. Findings from the survey responses used to derive land management constraints are discussed in the next section.

DATA SOURCES

NZ-FARM Data

Data are collected from various sources to calibrate NZ-FARM for the Hurunui/Waiau catchment. GIS analysis is used to divide the catchment into smaller regions based on biophysical properties, to identify current land use, enterprises, and underlying soil types, and to calculate the area under each land use/enterprise/soil type. The catchment area is then divided into three homogeneous regions based on biophysical properties derived from Land Use Capability (LUC) classes from the New Zealand Land Resource Inventory (NZLRI), and availability of water for irrigation. The three regions are named: plains, foothills, and hills. A map of the catchment is shown in Figure 3, which identifies the regions. Soil maps (New Zealand fundamental soil layer) for the catchment are used to divide the area into four dominant soil types (Balmoral, Hatfield, Lismore and Templeton), which are categorized based on the drainage and profile available water (Webb 2009).

Land in the catchment is categorized by six distinct uses: forest, cropland, pasture, horticulture, scrub, and DOC land. The baseline enterprise distribution for the catchment was provided by Environment Canterbury (October 2010), and is shown in Figure 4. NZ-FARM includes 18 different enterprises, which cover nearly all the enterprises recorded in the current land use maps. Key enterprises in the Hurunui/Waiau catchment include dairy, sheep, beef, deer, timber, grains, fruit production, scrubland, and Department of Conservation (DOC) land.[4] The feasibility and productivity of each enterprise are determined based on bio-geographical characteristics such as slope, soil type, and access to water. Each enterprise requires a series of inputs to maximize production yields. The following land management options are included in the models analysis:

- Fertilizer regimes (use of recommended amounts of N fertilizer, use of 80%, 60% or 50% of the recommended amounts of N fertilizer, use of no N fertilizer)
- Use of nitrogen inhibitors (DCD) to help reduce nutrient leaching
- Altering stocking rates
- Installation of dairy feed pads
- Plantation of forestry

The high cost of particular inputs coupled with water and input constraints can limit the level of output from a given enterprise.

Outputs from each enterprise and prices per unit of output are primarily based on published data, including financial budgets (Lincoln University, 2010), Ministry of Agriculture and Forestry (MAF) agricultural reports (MAF 2010a, 2010b), and are listed in 2009 New Zealand dollars (NZD). Stocking rates for pastoral enterprises were based on those used in the FARMAX model (Bryant *et al*. 2010) as FARMAX is used to estimate the productivity changes in pastoral enterprises resulting from changes in fertiliser inputs. The physical levels of fertilizer applied were derived based on expert knowledge (Stuart Ford, The AgriBusiness Group, 2010, pers. comm.). Each enterprise also faces a large set of fixed and variable costs ranging from stock replacement costs to depreciation that were obtained from published data (Lincoln University 2010; MAF 2010a), and expert knowledge (Stuart Ford, The AgriBusiness Group, 2010, pers. comm.). Cost series were developed for each enterprise and varied across all fertilizer and mitigation regimes.

[4] Note for this study we hold DOC land fixed, as land-use change for DOC land is not typically driven by economic forces

GHG emissions are derived using the same methodology as the New Zealand GHG Inventory (NZI) (MfE 2011), which follows the IPCC's *Good Practice Guidance* (2000). Pastoral emissions are calculated using the same emissions factors as the NZI, but applied to per hectare stocking rates specific to the catchment. Forest carbon sequestration rates are derived from regional lookup tables (Paul *et al*., 2008). All emission outputs are converted to tons per CO_2 equivalent (tCO_2e) using 100 year global warming potentials of 21 for CH_4 and 310 for N_2O (MfE 2011).

N and P leaching rates for the various enterprises included in NZ-FARM are obtained from several sources. Leaching rates for pastoral enterprises are taken from OVERSEER model (2011), while the leaching rates for arable crops and horticulture enterprises are constructed using SPASMO model (Plant and Food Research, 2011). Values for N leaching from pine plantations and native vegetation for all three datasets are taken as an average from the literature (e.g., Parfitt *et al.* 1997; Menneer *et al.* 2004, etc.). We assume that no P leaches from plantations or native land.

Estimates from the Farmer Survey

Responses from a number of questions from a series of in-depth face-to-face farmer interviews undertaken in the Hurunui- Waiau region are used to derive land management constraints in NZ-FARM. 20 farmers were interviewed in the Hurunui-Waiau region, of which 16 were sheep and beef farmers, and 4 were dairy farmers. Refer to Walcroft and De Oca Munguia (2011) for details of the survey methods. Summary of responses for questions related to the analysis in this paper and how it is used to derive the land management constraints are described in this section.

Reduced Stocking rates

Many of the farmers interviewed felt that the stocking rate on their farms is already low due to enforced destocking after recent significant weather events such as drought. The majority felt that if the stocking rate dropped further, their income would decline. Most of the farmers were not in favour of decreasing stock numbers, given that the stocking rates are already low; in fact some dairy farmers had plans to increase their stocking rate in the near future. However, a very few sheep and beef farmers stated that they would decrease their stocking rate and grow more crops, as it would reduce animal management costs.

When asked about regulation on reduced stocking rate to mitigate negative environmental impacts, none of the farmers agreed on compulsory restrictions. Most farmers felt that voluntary involvement in regulation is a better option, and comments like *"I think the best person to decide...is the guy doing it"* revealed that decisions about stocking rates are their personal responsibility. However, at least half the farmers interviewed said they are willing to engage with regulators if they have the ability to negotiate how the regulation applies to them. Many of the farmers expressed a desire to work on a one-to-one basis with regulating bodies in order to feel in control and to reach a solution that practically applies to their situation.

Dairy Feed pads

The option of installing a dairy feed pad was not one of the main management options covered in the interviews. The management option did arise, though, when discussed in the context of general changes in farm management as an investment in infrastructure. For the dairy farmers in this catchment, feed pads did not seem to be a likely management option. None of the dairy farmers interviewed had feed pads on their properties and they did not discuss the possibility of building one to mitigate nutrient leaching from the farm.

Reduced use of N fertiliser

A common response to question regarding N fertilizer use was *"I don't use much anyway"* and this was sometimes accompanied with the comment that it is too expensive to waste. Dairy farmers were using N fertilizer on a regular basis but the majority of the sheep and beef farmers used it strategically for establishing crops or for pasture set aside for silage or hay. Responses from dairy farmers indicated that the cheapest option of feed is the use of N fertilizer to grow grass over buying other feed.

Although most farmers claimed to use N fertilizer lightly, when they were asked about regulation on use they objected to compulsory regulations. These farmers wanted proof that applying nitrogen fertiliser the way they were using it was actually harmful to the environment. They were also open to trying new products if they were proved to be beneficial and some of the dairy farmers interviewed were already using DCD products on their farms.

Tree planting

All the farmers planted trees for shelter and shade for stock and also for controlling weeds, although the farmers putting in pivot irrigators reported that they had removed shelter trees to accommodate the irrigator. A common concern amongst the farmers interviewed was that the costs of establishing forestry blocks and then the real returns after all the costs of harvesting were not great enough to warrant investing in such ventures in the first place.

Sheep and beef farmers strongly objected to forest conversions, with comments like *"....It's a waste of even poor land, it's a waste of land"* and *"the only reason why I wouldn't put more trees in is because I don't like seeing trees go into good farming country".* Dairy farmers on the other hand would not rule out switching to forestry if it became profitable to do so.

Land-use conversions

Farmer opinion on transformation between sheep and beef and dairy enterprises was revealed in responses to questions on the outlook of the agricultural economy. Dairy farmers were happy with their business and the financial situation, but did not think that the financial situation for dry stock farmers is positive. Comments like "*...no, you couldn't pay me to be a sheep farmer or a cropping farmer*" indicated low likelihood of conversion from dairy to dry stock enterprises. A majority of the sheep and beef farmers acknowledged the positive financial situation of dairy enterprises; however, they did not seem to be keen to convert to dairy. They were generally optimistic about their financial outlook and think that it is "*coming right*" and "…*getting there*".

Priorities

Interview responses indicated that for 95% of the farmers interviewed, financial viability and freedom from external regulation were the most important priorities. Increasing the level of income as well as improvement of water quality were important priorities for 85%, while flexibility of farming system was important for 80% of the farmers. 70% of the farmers saw development or use of technical resources as important priories. Intensification was the least important priority. Moreover, a majority of the farmers said that reducing stocking rate and planting trees have negative financial impacts. Reducing the use of N fertiliser had negative impacts for all dairy farmers, while it had positive impacts for at least 3 dry stock farmers.

Based on the interview responses to land management options, regulation, and farmer priorities, we specified the following land management constraints for NZ-FARM:

- Constrain the uptake on feed pads to not increase beyond the baseline levels
- Fertiliser regime option of zero N fertiliser use is not allowed for dairy farmers
- For dairy farmers, likelihood of transformation from higher stocking rate to lower stocking rate is low
- Conversion from dairy to sheep and beef enterprises is not allowed to increase beyond the baseline levels, and only 50% of the current dairy enterprises are allowed to convert to other enterprises

RESULTS

This study models the impacts of two nutrient reduction policy scenarios that place caps on N leaching in the catchment. The first caps N leaching at 15% below N baseline levels and the second caps N leaching at 30% below N baseline levels. The cap on N leaching is placed for the entire catchment, thus allowing landowners to trade N leaching loads across enterprises and farm management practices to meet a comprehensive target for the region. This is more flexible and cost effective than having all landowners meet individual targets, and is consistent with both existing and proposed nutrient trading programmes in New Zealand (Environment Waikato 2009). Each of these policies is analysed with two sets of land management constraints. The first set (UNIFORM) of land management and enterprise adoption rates is based on the shape of the CET function where land use and land management are subject to no constraints beyond baseline elasticities of transformation discussed in the methods section. Uptake of land management practices is constrained to reflect the farmer survey responses in the second set (BEHAVIOUR). The policy scenarios analysed are:

- N15_UNIFORM = scenario with a cap of 15% below baseline levels of N leaching calculated with no constraints on land management options.
- N15_BEHAVIOUR = scenario with a cap of 15% below baseline levels of N leaching calculated with land management constraints informed by the Farmer Survey.
- N30_UNIFORM = scenario with a cap of 30% below baseline levels of N leaching calculated with no constraints on land management options.
- N30_BEHAVIOUR = scenario with a cap of 30% below baseline levels of N leaching calculated with land management constraints informed by the Farmer Survey.

Baseline Calibration

NZ-FARM is calibrated for the Hurunui/Waiau catchment to represent baseline practices with two sets of land management constraints, UNIFORM and BEHAVIOUR. An area of 22 000 ha of the total catchment area of more than 582 000 ha is irrigated, all of which occur in highly productive plains region. Total net revenue is estimated for the catchment for all farm practices derived from baseline figures for current input costs, output prices, and enterprise productivity. The total area and distribution of baseline enterprises for the catchment are listed in Table 1, while production output is listed in Table 2. Enterprise area in the catchment is dominated by DOC land (43%) followed by sheep and beef (42%). Dairy encompass about 4% of the catchment area, while plantation forests and scrubland comprise about 10%. Estimated net revenue is around $250 million with the UNIFORM constraints, while it is slightly higher with the BEHAVIOUR land management constraints at $251 million. This difference is because estimates indicate there is a greater area of densely stocked dairy farms (4 cows/ha) and viticulture enterprises in the BEHAVIOUR specification that yield some of the highest net returns in the catchment.

N leaching total estimated with the UNIFORM land management constraints for the catchment is 3040 tons per annum (t/yr), while total P leaching is estimated at 45 t/yr. Baseline total GHG emissions for the catchment are estimated to be approximately 924 000 tCO_2e with UNIFORM land management constraints. On the other hand, N leaching total estimated with the BEHAVIOUR land management constraints is slightly lower at 3016 t/yr, P leaching total is similar at 45 t/yr. Estimated total GHG emissions with the BEHAVIOUR land management constraints is approximately 919 000 tCO_2e. The bulk of emissions comes from non-CO_2 gases in the livestock sector, which is typical for most agriculture-intense catchments in New Zealand. As in the latest national GHG Inventory (MfE 2011), enteric fermentation is the largest source of emissions, followed by N_2O from agricultural/grazing soils. Baseline annual carbon sequestration from plantations is close to zero because it is assumed that any baseline forest felled is immediately replanted. Baseline carbon sequestration is estimated to be about 177 700 tCO_2e/yr for both sets of land management constraints.

Scenario Analysis

The following sections discuss the findings from nutrient reduction policy scenarios for the Hurunui/Waiau Catchment with the UNIFORM and BEHAVIOUR land management constraints. The changes in key outputs tracked by NZFARM such as net revenue, GHG emissions, and nutrients relative to the baseline are listed in Table 3, while the percentage change in enterprise area for each policy scenario is shown in Figure 5. Table 4 shows NZ-FARM estimates for changes in production relative to baseline production for each of the policy scenarios analysed. These results are discussed in the subsequent sections.

Nutrient reduction policy one: 15% reduction in N leaching

Results show that a N reduction target of 15% can be met with relatively modest declines in total net revenue (1%) for the catchment for both UNIFORM and BEHAVIOUR land management constraint sets. N leaching levels are exactly reduced by 15% in both scenarios, while P leaching levels are not estimated to change with a 15% N cap. GHG emissions are reduced by 12% with both sets of land management constraints as land use shifts out of intensive pasture, indicating that nutrient leaching and emissions are highly correlated for the catchment. Land use in the catchment is estimated to change by about 5% for both sets of land management constraints, with slightly smaller land-use changes when farmer perceptions are taken in to account. Enterprise area is estimated to change from dairy, scrubland and sheep and beef to forest, arable and fallow land, as landowners shift to less intensive land uses to meet the N reduction target. Figure 5 shows the aggregate change in enterprise area for each scenario. Fruit, grain, and wood production levels are estimated to increase, while output levels decline for almost all pastoral enterprise (see Table 4). These declines are attributed both to changes in land use and shifts in management such as reducing fertiliser and stocking rates, which reduce nutrient leaching and also pasture productivity.

Nutrient reduction policy two: 30% reduction in N leaching

The results for the 30% N cap are similar in direction to the scenarios with a 15% N cap, but with a much larger impact on revenue, production, and environmental outputs in the catchment. The cap for N was met with 30% reduction in leaching with both sets of land management constraints, while P loss levels are estimated to decline by 2–9%. Net revenue for the catchment is reduced by 6–10%, which is dramatically higher than the losses in income (–1%) compared with the less restrictive 15% N reduction policy. GHG emissions are reduced by 25–32%. Land use in the catchment is estimated to change by about 10% of the area for both sets of land management constraints under the 30% cap. Consistent with the 15% N reduction policy scenarios, the enterprise area shifts from dairy, scrubland and sheep and beef to forest, arable crops and fallow land for each of the two sets of land management constraints analysed (see Figure 5).

Estimated results with the UNIFORM land management constraints indicate the catchment net revenue to be reduced by 6%, while total GHG emissions are estimated to reduce by 25%. Estimates also indicate reduction in total P leaching by 2%. With UNIFORM land management constraints sheep and beef experience the largest area decline (–5%), while forestry experiences the largest increase (6%). The dairy land area in the catchment declines by 3%.

Results for the scenario with BEHAVIOUR land management constraints indicate a greater reduction in net revenue (10%), which is expected because the model is parameterized to make landowners are less flexible in their response to environmental policy. BEHAVIOUR land management constraints estimates higher decline in sheep and beef enterprise area (8%) relative to the UNIFORM constraints, but the change in area is lower for dairy (–2%) and forestry enterprises (+3%). A lot more land is expected to become fallow in this scenario as well, indicating that farmers might be more willing to abandon production on some of their land rather than try to introduce a new enterprise or management system to meet the N reduction requirements. The percentage change in product output is noticeably different from the UNIFORM scenario (Table 4). The change in land use and land management also reduces emissions in the catchment by about 32% and total P loss by 9%. Comparison of the scenario results for the two land management constraints shows that imposing constraints based on farmer perceptions towards environmental policy leads to differences in estimated results when the policies are more stringent. For the scenarios with 15% reduction in catchment N leaching levels, estimates showed no significant difference in key outputs between UNIFORM and BEHAVIOUR land management constraints. However, for the 30% N cap policy scenario significant differences between the estimated results from the two land management constraints were evident. With the BEHAVIOUR land management constraints catchment revenue was reduced by 4% more compared with UNIFORM land management constraints, which did not take farmer perceptions towards policy in to account. The absolute change in catchment revenue was significant at around $10.5 million, showing that when farmer perceptions are taken into account the cost of reaching N reduction targets becomes higher for the catchment. To comply with the stricter 30% N reduction target, landowners will have either to move away from more intensive enterprises or to change their land management practices at a much higher level than the 15% target, indicating that many of the low-cost options have been exhausted. As discussed in earlier sections, adoption of such changes will depend on the farmer perception towards policy or the current use of management practices. When some farmers are more reluctant to change to less intensive enterprises and management, others in the catchment will have to take additional measures on their own land to meet catchment wide targets. With a cap and trade policy such as the one we have modelled in this paper, some landowners are more willing to purchase nutrient reduction permits from their neighbours in the catchment rather than make additional changes on their own land, and we would expect to see more trades than the UNIFORM scenarios. When analysing policy scenarios, assuming that all farmers will take on mitigation options alike will lead to unrealistic estimates of expected changes. Results from this study show that incorporating farmer perceptions and current uptake of management options is important when analysing environmental policy scenarios.

Moreover, as the farmer survey responses revealed, approaches to encourage farmer adoption of policies may vary depending on the type of policy. Finding the preferred approach at the beginning of a policy process will encourage farmer involvement. Additionally, coupling such approaches with the priorities of the farmers in a catchment will lead to higher involvement. Thus the cost of such approaches should also be taken into account when assessing the catchment-wide economic impacts of environmental policies.

CONCLUSION

This paper uses an economic catchment model, NZ-FARM, to assess changes in land use, enterprise distribution, nutrient leaching, and GHG emissions for two policies that introduce nutrient reduction caps on land-based production in the Hurunui catchment of North Canterbury. We estimate changes in net revenue, land use, enterprise mix, and environmental outputs when landowners in the Hurunui catchment must reduce aggregate nitrogen leaching targets by 15% and 30% below baseline levels. Furthermore, we investigate how NZ-FARM estimates may vary when uptake of possible land management options to meet policy targets differs. Indication of land management adoption probabilities are obtained from a series of face-to-face interviews with farmers in the Hurunui/Waiau region that identify farmers' perceptions of environmental policies.

Results show that the proposed environmental targets can be met with relatively modest reductions in total net revenue for the region, ranging between 1 and 10% across all the policy scenarios analysed. The difference in absolute changes in revenue can vary significantly depending on which land management set is used for analysis. Moreover, we found that differences in the key indicators are more evident for the stricter policies.

Our analysis suggests that the introduction of an N leaching reduction target would result in a shift away from N intensive operations such as dairy, sheep and beef into less intensive enterprises such as forest and arable. The analysis also shows that setting a catchment-scale cap on nutrient leaching could provide significant co-benefits by concurrently reducing GHG emissions produced by the agricultural sector. Finally, our analysis highlights the importance of incorporating farmer perceptions towards environmental policies in policy impact analysis. Policy makers should consider the economic cost of approaches to encourage farmer adoption of policies alongside catchment-wide revenue impacts.

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Appendix A. Mathematical Representation of NZFARM

Variables

NR	net returns to agriculture and forestry production (million $)
X	activity (ha)
L	available land (ha)
Q	land use change (ha)
Y	product output (kg, m^3)
W	irrigation water consumption (m^3)
E	environmental output (kg CO_2e, N, P)

Parameters

P	price ($/kg, $/$m^3$)
τ	environmental tax ($/kg)
α^{proc}	processing coefficient (kg/ha, m^3/ha)
ω^{live}	livestock input cost ($/ha)
ω^{vc}	variable input cost ($/ha)
ω^{fc}	fixed input cost, annualised over 20 years ($/ha)
ω^{land}	land use conversion cost
γ^{env}	environmental output coefficient (kg/ha)
γ^{water}	irrigation water input (m^3/ha)
L^{init}	initial land area (ha)
X^{init}	initial activity area (ha)

Indices

r	*region*
s	*soil*
l	*land use*
e	*enterprise*
m	*land management*

Objective Function

$$\text{Max } NR = \sum_{r,s,l,e,m} \left\{ \begin{matrix} pY_{r,s,l,e,m} \\ - X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Q_{r,s,l} \end{matrix} \right\} \quad \text{(A1)}$$

Subject to:

Product Balance

$$Y_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \quad \text{(A2)}$$

Land Use Balance

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \quad \text{(A3)}$$

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Q_{r,s,l} \quad \text{(A4)}$$

$$Q_{r,s} \leq \sum_{l,e,m}\left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m}\right) \quad \text{(A5)}$$

$$L_{r,s,DOC} = L_{r,s,DOC}^{init} \quad \text{(A6)}$$

Irrigation Constraint

$$\sum_{s,l,f,m} \gamma_{r,s,l,e,m}^{water} X_{r,s,l,e,m} \leq W_r \quad \text{(A7)}$$

Environmental Constraint

$$\sum_{s,l,f,m} \gamma_{r,s,l,e,m}^{env} X_{r,s,l,e,m} \leq E_r \quad \text{(A8)}$$

Non-negativity Constraint

$$Y, X, Q, L, W, E \geq 0 \quad \text{(A9)}$$

Table 1. Baseline Enterprise Area for Hurunui/Waiau Catchment (000 ha)

Enterprise	BASE_ UNIFORM	BASE_BEHAVIOUR
Arable	10.2	10.2
Forest	27.7	27.7
Dairy	23.9	23.7
Sheep and Beef	243.6	243.3
Deer	0.6	0.6
Pig	0.5	0.5
Fallow	0.0	0.0
Scrubland	27.8	28.2
DOC	247.8	247.8
Total	582.1	582.1

Table2. Baseline production output for Hurunui/Waiau Catchment (tons or k m^3)*

Output	BASE_ UNIFORM	BASE_BEHAVIOUR
Milk Solids	28222.4	27956.5
Dairy Calves	1855.1	1832.3
Lambs	15057.6	15100.2
Mutton	1920.3	1919.2
Wool	2627.6	2628.2
Cows	5372.8	5319.8
Heifers	13191.5	13149.1
Steers	31259.4	31315.3
Bulls	1.5	1.5
Deer Hinds	267.3	267.3
Deer Stags	177.1	177.0
Velvet	0.0	0.0
Pigs	2532.6	2527.4
Berryfruit	29.9	29.7
Grapes	108.8	121.0
Wheat	72211.4	71633.9
Barley	12477.6	13419.8
Pulp Logs	127.5	127.8
Timber	510.1	511.0

*Agriculture products in tonnes, while forest products are in thousand m^3

Table3. Change in Key Outputs from Baseline for Policy Scenarios for the Hurunui/Waiau Catchment

Policy Scenario	Change in Net Revenue	Change in Total GHG Emissions	Change in Total N Leaching	Change in Total P Leaching
N15_ UNIFORM	-1%	-12%	-15%	0%
N15_BEHAVIOUR	-1%	-12%	-15%	0%
N30_ UNIFORM	-6%	-25%	-30%	-2%
N30_BEHAVIOUR	-10%	-32%	-30%	-9%

Table 4. Change in Production Outputs from Baseline for Policy Scenarios for the Hurunui/Waiau Catchment

Output	N15_ UNIFORM	N15_BEHAVIOUR	N30_ UNIFORM	N30_BEHAVIOUR
Milk Solids	-30%	-21%	-70%	-45%
Dairy Calves	-31%	-22%	-70%	-43%
Lambs	-5%	-6%	-8%	-28%
Mutton	-11%	-8%	-18%	-23%
Wool	-12%	-10%	-20%	-28%
Cows	-23%	-17%	-53%	-34%
Heifers	-3%	-2%	-7%	-11%
Steers	-10%	-11%	-21%	-32%
Bulls	-35%	-23%	-74%	-45%
Deer Hinds	-2%	-3%	-28%	-51%
Deer Stags	-2%	-3%	-28%	-51%
Velvet	7%	10%	24%	85%
Pigs	-24%	-35%	-88%	-80%
Berryfruit	583%	611%	2254%	820%
Grapes	127%	62%	2949%	740%
Wheat	-53%	-63%	-69%	-69%
Barley	455%	458%	923%	1019%
Pulp Logs	69%	47%	124%	71%
Timber	69%	47%	124%	71%

Figure 1. Structure of Inputs and Outputs in NZ-FARM

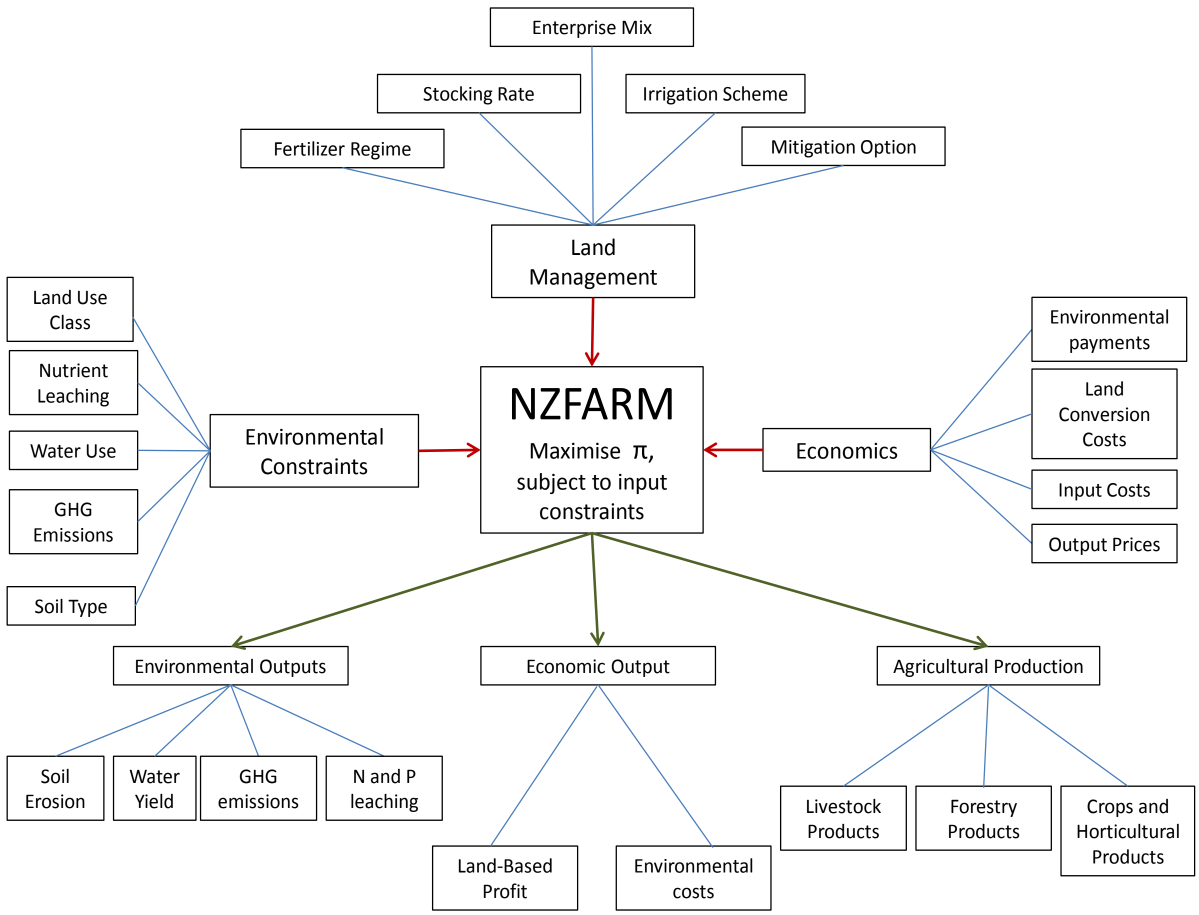

Figure 2. Structure of CET Function Nest in NZ-FARM

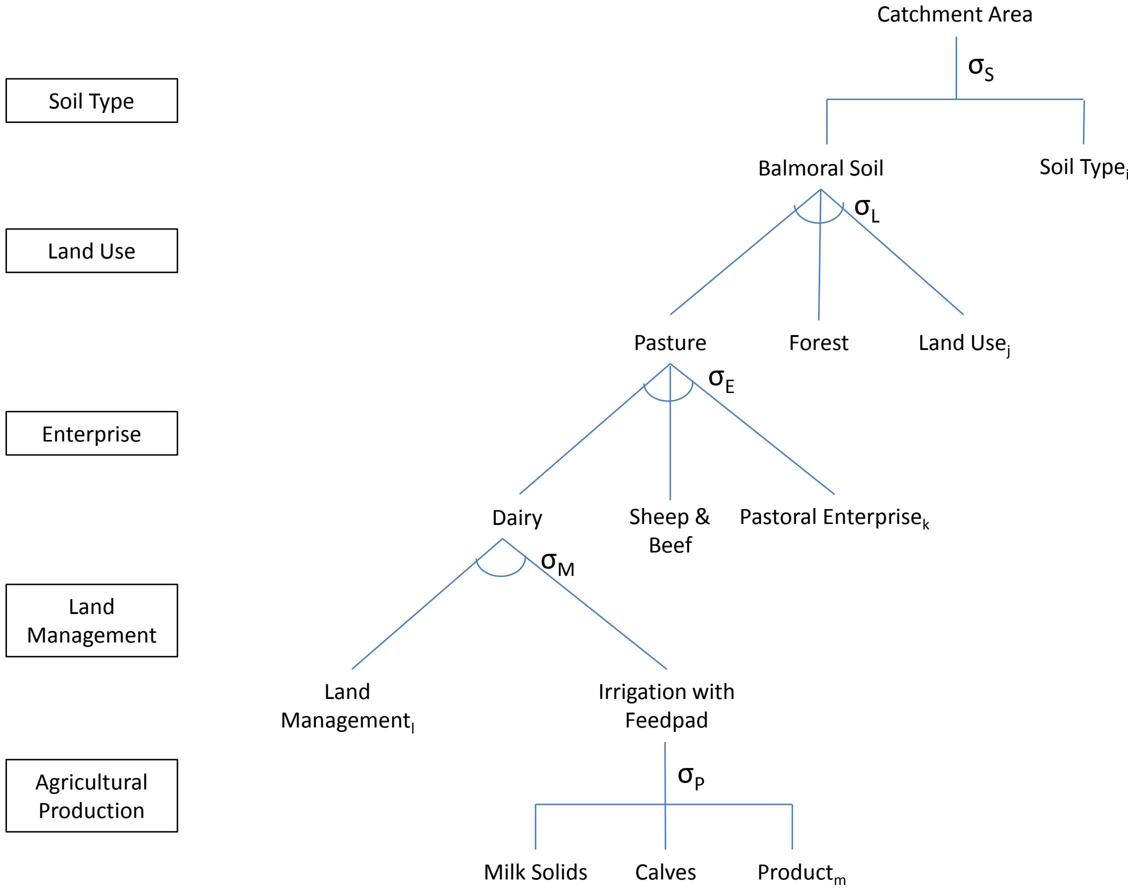

Figure3. Hurunui/ Waiau Catchments, New Zealand

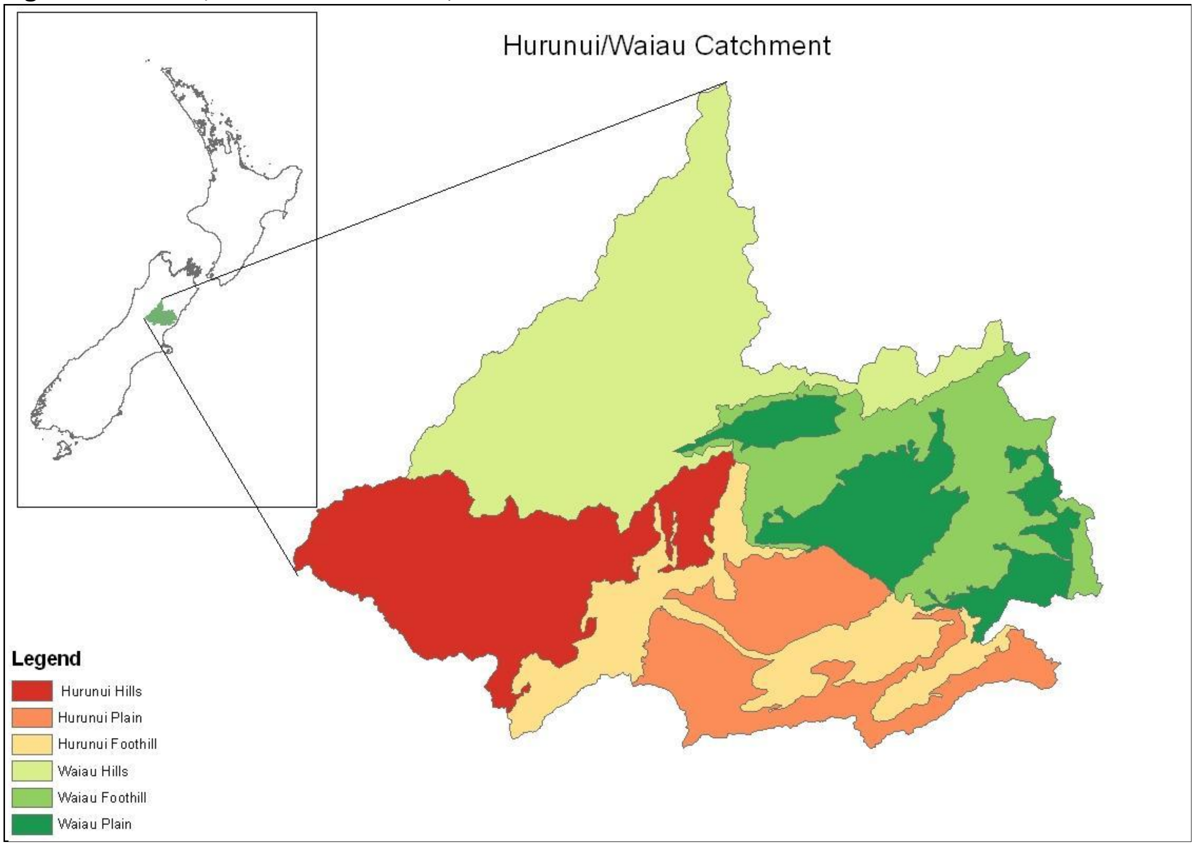

Figure 4. Baseline Enterprises for Hurunui/Waiau Catchment

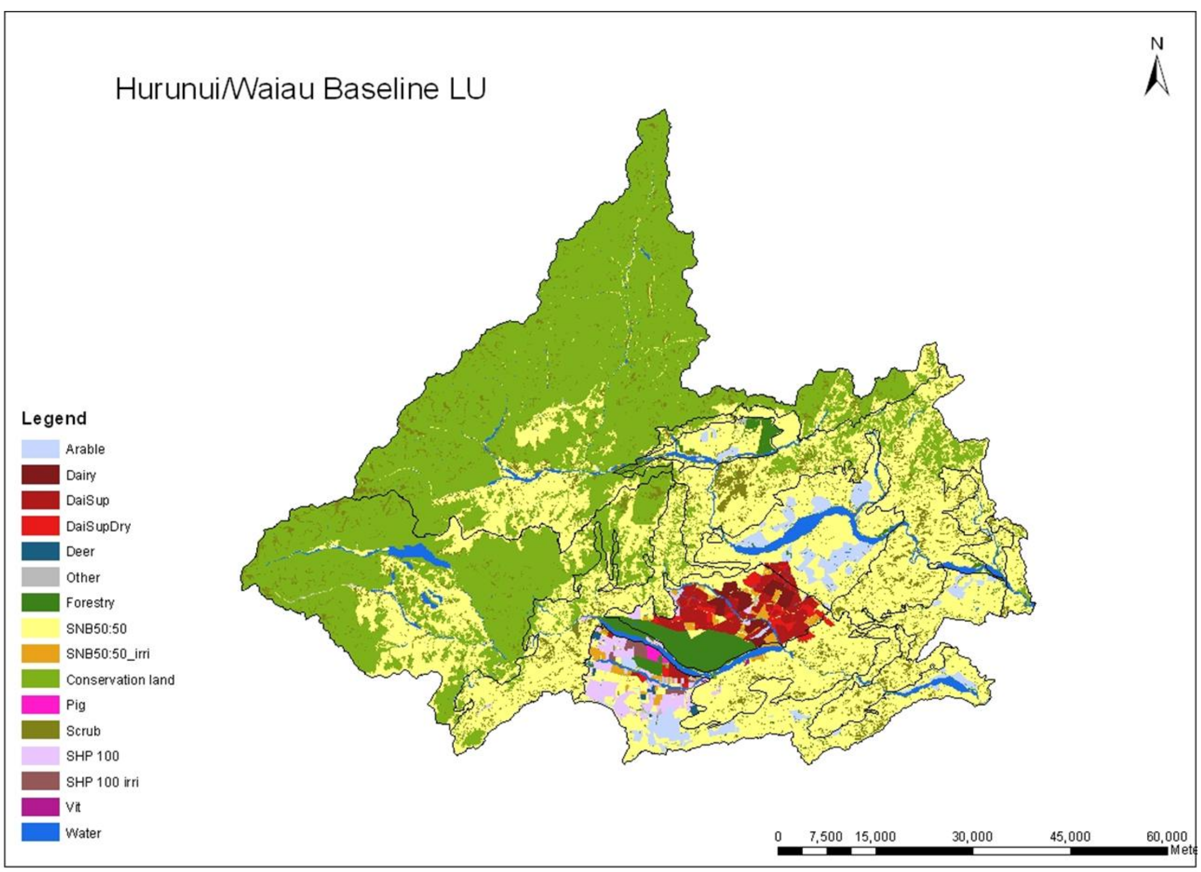

Figure 5. Aggregate Change Relative to the Baseline in Enterprise Area for Policy Scenarios