NZARES New Zealand Agricultural & Resource Economics Society (Inc.)

Estimated Impacts of New Zealand Agriculture Climate Policy: A Tale of Two Catchments

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Paper presented at the 2011 NZARES Conference

Tahuna Conference Centre – Nelson, New Zealand. August 25-26, 2011

Estimated Impacts of New Zealand Agricultural Climate Policy: A Tale of Two Catchments*

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Selected paper prepared for presentation at the New Zealand Agricultural and Resource Economiscs Society Annual Meeting, Nelson, New Zealand 25-26 August, 2011

* This research was made possible by generous funding from NZ Ministry of Agriculture and Forestry and the NZ Foundation of Research, Science and Technology. The authors also wish to acknowledge the assistance of Greg Sheppard (Sheppard Agriculture), Brian Clarke, 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.

ABSTRACT

Agricultural and forestry greenhouse gas (GHG) emissions are a key feature of New Zealand's emissions profile, and New Zealand is the only country, to date, to have indicated that agricultural and forestry emissions will be covered under their domestic climate policy – the New Zealand Emissions Trading Scheme (NZETS). Forestry entered the NZETS in 2008 while agricultural emissions are expected to enter in 2015. Coupled with climate policy development is the increasing scrutiny of agricultural impacts on water in New Zealand. Given the multiple forms of environmental regulation facing the agricultural and forestry industries we explore, at the catchment level, the impacts of climate policy on the agricultural and forestry industries, including those on farm returns, GHG emissions, carbon sequestration, water quality and induced land use change. We use the recently developed New Zealand Forest and Agriculture Regional Model (NZ-FARM) to assess potential economic and environmental impacts of a climate policy that imposes a series of carbon prices on GHG emissions of land-based production in the Manawatu and Hurunui/Waiau catchments in New Zealand.

KEYWORDS: Agriculture and Forestry Modelling, Land Use, Climate Policy, Greenhouse Gas Emissions, Nutrient Loadings

INTRODUCTION

Agriculture is an important part of New Zealand's economy, and the sector faces similar challenges like other large producing countries of the world while it strives to maintain or enhance the level of output while keeping its resource use and environmental integrity in check. The country is unique from a regulatory perspective as it implemented a climate policy in 2008, the New Zealand Emissions Trading Scheme (ETS), which already covers many major sectors of the economy, including forestry. Agriculture is scheduled to enter the ETS in 2015 because approximately 47% of New Zealand's greenhouse (GHG) emissions occur in the agricultural sector (MfE, 2011). Discussions are currently underway on developing a way to bring this sector into the ETS and meet emissions targets without placing a large burden on its stakeholders. In addition, the New Zealand government recently announced plans to improve efforts to clean up its waterways while at the same time increasing its support for regional irrigation projects that create additional output in the sector (New Zealand government, 2011). This paper uses an economic model to assess potential economic and environmental impacts of a climate policy on land-based production in two New Zealand catchments that are large contributors to the nation's agricultural output: Manawatu in North Island and Hurunui/Waiau in South Island.

Despite the importance of the agricultural and downstream processing sectors in the New Zealand economy, there is not a strong tradition of using partial or general equilibrium models to evaluate domestic policies or other measures directed at the agricultural sector. Policy-makers have instead relied on the development of ad hoc scenarios of land use change, farm budget models, and simple multiplier analysis of flow-on effects. To redress this situation, we have developed a catchment-scale partial equilibrium framework, the New Zealand Forest and Agriculture Regional Model (NZ-FARM), that is capable of assessing both economic and environmental impacts of a variety of policies that could affect regional land use and rural livelihoods.

This paper uses NZ-FARM to assess the economic and environmental impacts of a GHG emissions reduction policy at the catchment level. We do this by imposing a series of carbon prices on GHG emissions at the farm activity level for the Manawatu and Hurunui/Waiau catchments in New Zealand. NZ-FARM is a comparative-static, non-linear mathematical programming model of regional New Zealand land use and it's structure is similar to that of the US Department of Agriculture's Regional Environment and Agricultural Planning (REAP) model (Johansson et al., 2007). The model maximizes income from land-based activities across a catchment, accounting for the environmental impacts of land use and land-use changes. It can be used to assess how changes in technology (e.g., GHG mitigation options), commodity prices, resource constraints (e.g., water available for irrigation), or how proposed farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers, land managers and communities.

This analysis is unique because, unlike proposed climate policies in North America and Europe where landowners can generally voluntarily enlist in a climate program to receive offset payments for changing their practices from business as usual, the New Zealand government has mandated that agriculture be regulated under a now operational ETS beginning in 2015. In addition, forests established before-1990 are already regulated under the ETS, while post-1990 forests can be voluntarily enrolled in the programme. Thus, the potential changes to land use in New Zealand could be significant and serve as an important guide to other regions of the globe that are considering similar policies in the future. Additionally, using NZ-FARM to model climate policy on land use allows us to assess the potential co-benefits on the catchment's land and water, such as changes in fertilizer application and nutrient loading levels. These findings could be used to assess whether it is necessary to impose additional environmental regulations on land use within the catchment, or whether a climate policy could provide the co-benefits of nutrient reductions as well.

Studies have been conducted to assess the economic and environmental impacts of changes in GHG emissions, water use, and nutrient loading in New Zealand, but only a few have been developed to address this issue at the catchment level. Kerr and Zhang (2009) review empirical studies on the impacts of a carbon price on NZ agriculture and conclude that a carbon price of $25[1] per ton of carbon dioxide equivalent (tCO_2e) would impact the profitability of dairy and sheep-beef farms but still not be high enough to induce significant changes in production intensity or land use. Rae and Strutt (2011) use a computable general equilibrium (CGE) model for New Zealand to simulate a range of scenarios involving changes in fertiliser use and stocking rates on dairy farms to reduce the nitrogen balance from between 10% to 30%. They find that value added for just the dairy farm sector could fall between 2% and 13%, while export earnings from dairy products may fall by between US$269 million and US$1,145 million. Tee et al. (2011) looked at the impacts of a carbon price on radiata pine forests in New Zealand and found that the value of land employed in forestry planted before 1990 increases significantly at a modest price of $10/$tCO_2e$, but do not investigate where additional forestland would come from. NZ-FARM has the ability to investigate both the important economic and environmental impacts of climate policy as well as detailed land use and farm activities at the catchment level.

The paper is organized as follows. First, we present the theoretical foundation of the NZ-FARM model, and describe the details of the data sources specific to the catchment. Next, we describe the GHG and nutrient mitigation options for the two catchments. Then, we present baseline land use, farm production, GHG emissions, water use, and other environmental outputs, followed by results from a series of policy scenarios. The final section provides a conclusion of our findings.

NZ-FARM MODEL

NZ-FARM is a comparative-static, mathematical programming model of regional New Zealand land use. Production activities in each region of NZ-FARM are differentiated in a variety of ways, including a set of fixed and variable input costs, use of inputs such as fertilizer and water, and output price. Production and land use are endogenously determined in a nested framework such that landowners simultaneously decide on the optimal mix of land use for their fixed area, given

[1] All monetary values are listed in New Zealand dollars, unless specified otherwise. At time of publication, exchange rates were as follows: 1 NZD = 0.82 USD, 0.57 EUR, and 0.79 AUD.

their land use classification (LUC) and soil type, and then how to allocate their land between various enterprises such as grains, livestock, and horticultural crops that will yield the maximum net return for their land use. Two other land uses are also tracked in the model; scrubland, which is allowed to vary across scenarios, and Department of Conservation (DOC) land that is assumed to be fixed as land use change for DOC land is not typically driven by economic forces. The model is written and maintained in General Algebraic Modeling System (GAMS). The baseline calibration and estimates for the scenario analysis in this paper are derived using the non-linear programming (NLP) version of the COIN IPOPT solver. More information on the model specifications for the two catchments is provided below.

Objective Function

The core objective of the model is to determine the level of production outputs that maximize the net revenue (NR) of production across the entire catchment area subject to the cost of production inputs, land available for production, and water available for irrigation. Formally, this is:

$$Max\ \text{NR} = \sum_{R,S,E,I,F,M,IO} \begin{matrix} \text{Output Price*Output Quantity} \\ -\text{ Livestock Input*Unit Cost} \\ -\text{ Variable Cost*Unit Cost} \\ \text{-Annualized Fixed Costs} \\ \text{-Land Conversion Cost*Hectares Converted} \\ +\text{ Forest Carbon Sequestration Payments} \end{matrix}$$

Subject To:

$\text{Inputs}_R \leq \text{Inputs Available}_R$
$\text{Land Use}_R \leq \text{Land Available}_R$
$\text{Irrigated Enterprises}_R \leq \text{Irrigated Land Available}_R$
$\text{Environmental Outputs}_R \leq \text{Regulated Environmental Output}_R$

where R is region, S is soil type, E is enterprise, I is irrigation scheme, F is fertilizer regime, M is mitigation practice, and IO is a set of enterprise input costs and output prices. Summing across all sets yields the total net revenue for the entire catchment.

As mentioned above, production and land use are endogenously determined in a nested framework (Figure 1). First, landowners decide on the optimal land mix for their fixed area within a sub-zone, given their soil type. Second, the landowner determines the allocation of land between various enterprises such as grains, livestock, and fruits and vegetables that will yield the maximum net return for his land use. Last, the decision is made on what outputs to produce given the mix of enterprise and output price.

The allocation of land to a specific land use, enterprise, 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 possibilities. The CET function itself is calibrated using the share of total returns for each element included in the stage and a parameter, σ_i, where $i \in \{L, L2E, E\}$ for the three separate nests, land (L), land to enterprise (L2E), and enterprise to output (E) . In general, CET parameters can range from 0 to infinity, where 0 indicates that the input (land, enterprise) 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., Johansson et al. 2007). In our case, CET values ascend with the level of the nest, as a landowner likely has more flexibility to transform its enterprise mix compared to changing the share of land use (e.g., forest v. pasture).

NZ-FARM also has the option to differentiate between 'business as usual' (BAU) practices and other production practices that can mitigate/reduce GHGs and other environmental pollutants by tracking several environmental outputs. For nutrients, the model can track changes in N and P leaching rates from several land uses and farm management practices. Constraints on loading levels can be set at the enterprise, regional, or catchment level to estimate the potential changes in land use, fertilizer application and farm management to reduce nutrient runoff. For example, NZ-FARM tracks changes in product and environmental outputs from changes in the following fertilizer regimes:

- 100% of recommended Nitrogen (N) and all other fertilizers
- 80% of recommended N but 100% of recommended application of all other fertilizers
- 60% of recommended N but 100% recommended application of all other fertilizers

- 50% of recommended N but 100% recommended application of all other fertilizers
- 0% N application but 100% of recommended application of all other fertilizers
- 0% Lime application but 100% of recommended application of all other fertilizers
- No application of any fertilizers

The model tracks GHG emissions in categories that mimic those in the New Zealand National Inventory (MfE, 2011). These include methane (CH_4) from enteric fermentation and manure management, nitrous Oxide (N_2O) from pastoral grazing, animal waste management systems, and fertilizer application, and carbon dioxide (CO_2) from on-farm use of fuel and electricity as well as emissions from deforestation and land use change. The model can also account for the following GHG emission mitigation options:

- Extended rotations for forest plantations or tax for harvests;
- A direct tax on agricultural inputs such as fertilizers or pesticides;
- The reduction of CH_4 and N_2O from livestock through manure management and installation of feed pads;
- The reduction of N_2O through the application of nitrogen inhibitors (DCDs);
- Improving farming efficiency and altering stocking rates;
- Moving stock off the farm during winter months.

Additional mitigation practices intend be added to the model as data and options become available.

CATCHMENT-SPECIFIC DATA

Data for the inputs used for the catchment in NZ-FARM was obtained from several sources. A list of all the different sets for which data was obtained for the Hurunui and Waiau catchment (enterprise, soils, etc.) is shown in Table 1[2]. Sources of these data are discussed in the following subsections. In total, there are nearly 1200 combinations of enterprise, input, and mitigation options modelled for the Hurunui/Waiau catchment and 800 combinations for the Manawatu catchment.

Geographic Area and Land Use

[2] The list of enterprises presented in Table 1 differs slightly for the Manawatu catchment, but aggregated categories discussed in this paper (e.g., Forest, Arable, Dairy, etc.) remain the same.

This paper focuses on the Hurunui/Waiau catchment in North Canterbury and the Manawatu catchment in Lower North Island. Maps of the two catchments are shown in Figures 2a and 2b. The catchment area is divided into sub-catchment zones based primarily on biophysical properties derived based on LUC classes from New Zealand Land Resource Inventory (NZLRI) data and availability of water for irrigation. These areas include the flats/plains, foothills, and hills (Figures 3a and 3b). Land in each zone is categorized by five distinct uses: forest, arable, pasture, scrub, and natural/Department of Conservation (DOC) land.

Enterprises, Inputs, Outputs and Prices

Enterprises tracked in the model cover most of the agricultural and forestry sector for the catchment. Key enterprises include dairy, sheep, beef, deer, timber, maize, wheat, and fruit. NZ-FARM includes 18 enterprises for the Hurunui/Waiau catchment and 16 for the Manawatu catchment. Every catchment zone has a subset of these practices that can be undertaken, which is restricted by the enterprises undertaken in the baseline scenario. These sets are determined by bio-geographical characteristics like slope, soil type, access to water, etc., as well as the enterprises shown in most recent land use maps.

Each enterprise requires a series of inputs to maximize production yields. The high cost of given inputs coupled with water and input constraints can limit the level of output from a given enterprise. Outputs and prices are primarily based on data provided by Lincoln University (Lincoln University, 2008 and 2010), Ministry of Agriculture and Forestry (MAF) farm monitoring report (MAF, 2008 and 2010a), and the Situation and outlook for New Zealand Agriculture and Forestry (SONZAF) (MAF, 2010 b), and are listed in 2009 New Zealand dollars (NZD). Stocking rates for pastoral enterprises were established to match figures included in the FARMAX model (Bryant et al., 2010). The physical levels of fertilizer applied were constructed from a survey of farmers in each catchment.

Each enterprise also faces a large set of fixed and variable costs ranging from stock replacement costs to deprecation that were obtained from personal communication with farm consultants, the MAF farm monitoring report (MAF, 2008 and 2010a) and Lincoln University (Lincoln University, 2008 and 2010). The cost series was developed for each enterprise and varied across all sub zones for both catchments. Altering the cost of inputs or price of outputs as well as the list of enterprises available for a given region will change the distribution of regional enterprise area, but the total area is constrained to remain the same across all model scenarios.

Environmental Outputs

Data on environmental output coefficients were obtained from several sources including, but not limited to, output from the OVERSEER and SPASMO models and findings from the literature. N and P leaching rates for dairy and sheep and beef enterprises in Hurunui/Waiau were taken from OVERSEER (2010), while N and P leaching rates for arable crops, horticulture, pigs, and deer enterprises were constructed using SPASMO (2010). All livestock N and P leaching estimates for Manawatu were derived using OVERSEER. Values for N leaching from pine plantations and native vegetation for Hurunui/Waiau and Manawatu were taken as an average from the literature (e.g., Parfitt et al 1997; Menneer et al 2004, etc), as were values for arable crops in Manawatu[3]. We assumed that no P leaches from plantations or native lands.

GHG emissions for most enterprises were derived using the same methodology as the New Zealand GHG Inventory (NZI), which follows the IPCC's *Good Practice Guidance* (2000). Pastoral emissions were calculated using the same emissions factors as the NZI, but applied to per hectare stocking rates specific to the catchment. Forest carbon sequestration rates were derived from regional lookup tables for a 300 index scaled radiata pine pruned[4], medium fertility site (Paul et al., 2008). All emission outputs are listed in tons per CO_2 equivalent. To be consistent with the inventory (MfE, 2011), we convert all emissions CO2e using the same 100 year global warming potentials of 21 for CH_4 and 310 for N_2O.

[3] The sole exception is potatoes in Manawatu, which used SPASMO estimates

[4] A 300 Site Index is a typical volume measurement for radiata pine in New Zealand, representing the mean annual volume increment, in m^3/ha/yr, of a stand at an age of 30 years, assuming a final stocking of 300 stems/ha

CARBON PRICE SCENARIOS

The current ETS in New Zealand covers all major sectors of the economy, with the exception of agriculture that is due to be regulated in 2015. Besides forestry, most emissions are covered through an upstream point of obligation on fossil fuels. For this analysis, we impose a climate policy on agriculture through a unit price per tonne of GHG emissions ($/t$CO_2$e) for all farm inputs (e.g., fertilizer), livestock activity (e.g., beef and sheep grazing), and energy used in primary production (e.g., fuel for tractors and electricity for irrigation). All activities conducted outside the farm gate, such as the production of fertilizer or transportation of output to the processing plant, are not covered in this analysis. The maximum price of a New Zealand Unit[5] (NZU) in 2011 was capped at $25, and many sectors were only obligated to trade in one NZU for each two units of emissions. As a result, we restrict the policy scenarios in this analysis to two GHG price levels;

- ETS_12.50_HUR = scenario with GHG price of $12.50/t$CO_2$e in the Hurunui/Waiau catchment
- ETS_25_HUR = scenario with GHG price of $25/t$CO_2$e in the Hurunui/Waiau catchment
- ETS_12.50_MAN = scenario with GHG price of $12.50/t$CO_2$e in the Manawatu catchment
- ETS_25_MAN = scenario with GHG price of $25/t$CO_2$e in the Manawatu catchment

For the baseline calibration (BASE_HUR/ BASE_MAN), we assume that there is not a price imposed on emissions from agricultural production, but landowners do face increased costs of electricity and fuel used as farm inputs. Additionally, forestry activities are allowed to receive credits for carbon sequestration in all scenarios.

BASELINE AND SCENARIO ANALYSIS

Baseline

The Hurunui/Waiau catchment comprises nearly 582,000 ha, of which about 22,000 ha are currently irrigated. Almost all of the catchment's irrigation occurs in the plains area, as that is typically the zone with the highest productivity and revenue potential. Total catchment income

[5] One NZU is equivalent to one tonne CO_2e of GHG emissions

derived from baseline figures for input costs, output prices, and current enterprise productivity is estimated at 236.5 million NZD. The aggregate area for major enterprise types for each region is listed in Table 2. Dryland sheep and beef farming dominate the region, especially in the hills and foothills (Figure 4a). A majority of the dairy production currently takes place in the plains region, as it is heavily reliant on access to water. With exception of some forest plantations in the foothills, nearly all of the non-sheep and beef production in the catchment occurs on the plains region that has greater access to irrigation and is overall better growing conditions.

The Manawatu catchment comprises nearly 576,000 ha, of which only 6,000 ha are irrigated for dairy production. Total catchment income is estimated at $390.4 million. Pastoral enterprises dominate the region, especially dryland sheep and beef farming (Figure 4b). As with Hurunui/Waiau most of the dairy production takes place in the more productive flats region. Unlike the other catchment in this paper, Manawatu constitutes very little area of forest, scrub, or natural/DOC land (aggregate of 18%). Additionally, about 6,000 ha (1%) are used to produce arable crops such as maize, barley, wheat, and potatoes.

The total and net GHG emissions for the two catchments are listed in Table 4 and the total GHG emissions is estimated to be about 1,535,000 tCO_2e for Hurunui/Waiau and 3,382,000 tCO_2e for Manawatu. The bulk of emissions come from non-CO_2 gases in the livestock sector, which is typical for most agriculture-intensive catchments in New Zealand. The GHG emissions for Manawatu are much larger than Hurunui/Waiau because a higher proportion of land is designated as pasture (81% v. 47%). As in the latest national GHG Inventory (MfE 2011), enteric fermentation is the largest source of emissions, followed by N_2O from grazing land. Annual carbon sequestration from native vegetation on scrub and DOC land reduces net emissions[6] in the Hurunui/Waiau catchment by about 29% and emissions in the Manawatu by 24%. Total leaching levels are estimated at 3050 tons N and 38 tons P for Hurunui/Waiau and 5612 tons N and 389 tons P for Manawatu.

[6] Note that in the baseline of this static model, we assume that all plantations immediately replant the area that is harvested, and thus the baseline amount of forest carbon sequestration for pine is zero.

AGRICULTURE CLIMATE POLICY SCENARIOS

The following sections discuss the findings from the policy scenarios for the Hurunui/Waiau catchment and the Manawatu catchment with two sets of GHG emissions prices on land-based production. The initial scenario imposes a GHG price of $12.50 (ETS_1250) per tCO_2e on GHG emissions for all stages of production at the farm level, while the second scenario imposes a price of $25/$tCO_2e$ (ETS_25). For forest plantations, landowners receive a credit for carbon sequestered beyond the baseline from changes in forest management or adding new plantations, but must submit a payment for felling trees and converting to another land use. The relative change in revenue, GHG emissions, and nutrients compared to the baseline are shown in Figure 5, while the breakout of GHG emissions from the catchment for each scenario is shown in Figure 6.

Hurunui/Waiau Estimates

At $12.50/$tCO_2e$, net revenue for the catchments is reduced by $17.8 million (8%) while total GHGs are reduced by 146,000 tCO_2e (10%). Land use shifts from dairy, sheep and beef, and other pasture to lower emitting enterprises such as arable (21% increase) and forests (45% increase). Scrubland also increases by about 3,700 ha as farmers take some land out of production (i.e., lay fallow) (Table 5). A co-benefit of the GHG policy is that N and P are reduced by about 5% and 0.5%, respectively. Our findings are relatively consistent for the scenario with a carbon price of $25/$tCO_2e$. Estimated net revenue declines by 14% from baseline levels while total GHGs are reduced by 21%. Total N and P leaching is reduced by 11% and 4% respectively. Land use change for the higher GHG emissions price also indicates that landowners are expected to shift from pasture to forest, arable, and scrubland, which all increase by more than 40% over baseline levels. Not all enterprises change by the same relative magnitude with the doubling of the GHG price though, indicating that the economic and environmental impacts to an increase in carbon prices are non-linear.

Manawatu Estimates

Net revenue for the catchments is estimated to be reduced by $37.6 million (10%) for the $12.50/$tCO_2e$ scenario, while GHGs are reduced by 451,000 tCO_2e (13%). As with Hurunui/Waiau, land use shifts from dairy, sheep and beef, and other pasture to lower to arable, forests, and scrub. The increase in forests and scrubland leads to an increase in carbon sequestration, reducing net GHGs to about 1.6 million tCO_2e. As a result of this land use change N and P are reduced by about 0.7% and 14%, respectively. Nitrogen leaching levels in the Manawatu are only reduced slightly because the substitution of pastoral enterprises to arable crops in the region can often lead to a higher level of N leaching per hectare from the application of additional fertilizer on a per hectare basis.

Estimates for the scenario with a carbon price of $25/$tCO_2e$ found that net revenue in Manawatu declines by 19% from baseline levels while total and net GHGs are reduced by 16% and 43%, respectively. Total N and P leaching are reduced by about 0.4% and 15% respectively. Land use change estimates for the higher GHG emissions price indicate that landowners are still expected to shift from pasture to forest, arable, and scrubland, however not at levels much higher than in the lower GHG price scenario. This suggests that landowners in Manawatu could be more willing to pay the price to keep their land in dairy and sheep and beef and impose better management practices that reduce GHG emissions rather than switch to an alternative land use.

CONCLUSION

This paper uses an economic catchment model, NZ-FARM, to assess changes in land use, agricultural output, and environmental factors from a climate change policy that imposes two levels of GHG emissions prices on the Hurunui/Waiau and Manawatu catchments in New Zealand. We investigate the potential impacts of imposing a GHG price on farm-level activities.

Directional changes in land use were relatively consistent regardless of the GHG price or catchment. The added cost of GHG-intensive agricultural production induced shifts from pastoral enterprises to arable land and forests, but not all enterprises are expected to change by the same relative magnitude with the doubling of the carbon price. Thus, our general finding is that economic, environmental, and land use impacts to carbon prices are non-linear.

This paper also finds a national level policy pricing agricultural GHG emissions such as the NZ-ETS would help reduce some of the regional nutrient leaching rates, hence improving New Zealand's water bodies without placing additional regulatory burdens on its landowners. Our estimates show that impact of the climate policy on reducing N and P loadings can vary between catchments, and a carbon price of \$25/tCO_2e would not likely be high enough to reduce nutrients to levels that have been discussed in several catchments across the country (i.e., 20% or more). Further research needs to be conducted to determine if the findings for the Hurunui/Waiau and Manawatu catchments investigated in this study are consistent for other major farming regions of New Zealand, and the potential impacts of adding or removing different mitigation practices from the suite of options included in this modelling exercise.

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TABLES

Table 1. Key Components of NZ-FARM, Hurunui Catchment, Canterbury, New Zealand

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
Plains Foothills Hills	Lismore Balmorals Hatfield Templeton	Pasture Cropland Horticulture Forest Scrub Dept of Conservation	Dairy - 3 Cows per ha, wintered on farm Dairy - 3 Cows per ha, wintered off farm Dairy - 3.5 Cows per ha, wintered on farm Dairy - 3.5 Cows per ha, wintered off farm Dairy - 4 Cows per ha, wintered on farm Dairy - 4 Cows per ha, wintered off farm Deer Pigs Mix of Sheep and Beef Grazing 100% Sheep Grazing	Irrigated Land Dry Land	100% rec. all nutrients 80% rec. N, 100% rec. all other nutrients 60% rec. N, 100% rec. all other nutrients 50% rec. N, 100% rec. all other nutrients No N, 100% rec. all other nutrients 0% rec. Lime, 100% rec. all other nutrients No fertilizer applied	Forest Carbon Sequestration DCDs Feed Pads	Beef stock replacement costs Sheep Stock Replacement cost Deer Stock replacement cost Dairy Stock replacement cost Pig stock replacement cost Wages - permanent Wages - casual Animal Health Dairy shed breeding Electricity Cartage Fertiliser Fertiliser application Fuel Shearing	Property taxes Insurance Land prep Tree planting Forest harvest Cultivation Forest management fee Herbicide application Fungicide application Pruning Thinning Harvest costs Harvest preparation DCD Application Feed pad construction	Milk solids Dairy calves Lambs Mutton Wool Cull cows Heifers Steers Bulls Deer: hinds Deer: stags Deer: velvet Pigs Berryfruit Grapes Wheat Barley Logs for pulp and paper Logs for Timber Other Misc.	N leached (kg N) P lost (kg P) Methane from animals (kg CO2e) N2O emissions – direct excreta and effluent (kg CO2e) N2O emissions – indirect excreta and effluent (kg CO2e) CO2 emissions - N fertiliser (kg CO2e) CO2 emissions – Lime (kg CO2e) N_2O emissions – direct and indirect N from fertiliser (kg CO2e) CO2 emissions – fuel (kg CO2e) CO2 emissions - electricity use (kg CO2e) Annual Forest C Sequestration (kg CO2e)	Dairy calves purchased Lambs purchased Rams purchased Ewes purchased Cows purchased Heifers purchased Steers purchased Bulls purchased Pigs purchased Dry matter Electricity used Fertiliser used - Urea Fertiliser used - Super Fertiliser used - Lime Fertiliser used - other Nutrients used -N

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
			100% Cattle Grazing Grapes Berry Fruit Wheat Barley Pine Radiata Plantations				Seeds Imported Feed costs - hay & silage Imported feed costs - crops Imported feed costs - grazing Imported feed costs - other Water charges Depreciation on capital Roads for forest plantations				Nutrients used -P,K,S Nutrients used -Lime Nutrients used -Other Fuel used - Petrol Fuel used - Diesel Irrigation rate Irrigation type Irrigation- number of days Seed used Supplementary feed bought - hay & silage Supplementary feed bought - crops Grazing Supplementary feed bought - other Harvest length

Table 2. Baseline Enterprise Area for Hurunui/Waiau and Manawatu Catchments (thousand ha)

Hurunui/Waiau Catchment

Enterprise	HH	HP	HF	WH	WP	WF	Total
Arable	0.0	5.6	0.0	0.0	7.5	0.0	13.2
Forest	0.0	12.1	5.1	0.1	3.0	0.4	20.8
Dairy	0.0	19.5	1.3	0.0	0.8	0.1	21.7
Sheep and Beef	28.7	34.2	57.5	24.0	46.0	56.7	247.2
Other Pasture	0.0	2.5	0.0	0.0	0.0	0.0	2.6
Scrubland	6.1	1.9	0.5	9.1	1.8	9.8	29.2
DOC	76.7	0.3	7.2	149.4	0.6	13.3	247.6
Total	111.5	76.1	71.6	182.6	59.9	80.4	582.1

Manawatu Catchment

Enterprise	MF	MH	TF	TH	Total
Arable	4.2	0.1	1.5	0.1	5.9
Forest	5.2	5.3	4.7	4.5	19.6
Dairy	51.1	8.5	40.8	5.4	105.8
Sheep and Beef	80.7	95.7	45.7	136.5	358.6
Other Pasture	0.3	1.2	0.0	0.0	1.6
Scrubland	0.7	28.3	0.1	10.6	39.7
DOC	1.4	35.9	1.5	5.4	44.3
Total	143.6	175.1	94.3	162.6	575.5

Table 3. Baseline GHG Emissions for Hurunui/Waiau and Manawatu Catchments (thousand tCO_2e)

Hurunui/Waiau Catchment

GHG	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Total
CH4 Enteric Fermentation	41	327	210	34	308	203	1123
CH4 Manure Management	0	10	3	0	4	2	19
N2O Animal Waste Mgmt Systems	0	1	0	0	0	0	1
N2O Grazing	12	100	63	10	92	61	339
N2O Fertilizer	0	22	1	0	7	0	30
CO2 Fuel	0	9	1	0	7	1	17
CO2 Electricity	0	4	0	0	1	0	6
Forest C Sequestration	-178	-8	-16	-259	8	6	-447
Total Emissions	54	473	278	45	418	268	1535
Net Emissions	-124	464	262	-214	426	274	1088

Manawatu Catchment

GHG	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Total
CH4 Enteric Fermentation	785	500	497	670	2453
CH4 Manure Management	16	7	12	8	43
N2O Animal Waste Mgmt Systems	0	0	0	0	1
N2O Grazing	234	154	142	205	735
N2O Fertilizer	46	10	34	10	100
CO2 Fuel	14	4	11	4	32
CO2 Electricity	8	2	6	1	17
Forest C Sequestration	-3	-121	-2	-37	-163
Total Emissions	1104	676	702	899	3382
Net Emissions	1100	556	700	862	3218

Table 4. Change in Enterprise Area from Baseline (thousand ha)

	ETS_1250_HUR		ETS_25_HUR		ETS_1250_MAN		ETS_25_MAN	
Enterprise	Change	Aggregated % Change	Change	Aggregated % Change	Change	Aggregated % Change	Change	Aggregated % Change
Arable	2.77	0%	6.70	1%	7.75	1%	11.67	2%
Forest	9.28	2%	25.09	4%	8.20	1%	12.55	2%
Dairy	-2.01	0%	-6.31	-1%	-8.04	-1%	-15.34	-3%
Sheep and Be	-13.57	-2%	-37.10	-6%	-59.17	-10%	-61.35	-11%
Other Pasture	-0.22	0%	-0.78	0%	-0.93	0%	-0.83	0%
Scrubland	3.74	1%	12.22	2%	52.19	9%	53.28	9%
DOC	0.04	0%	0.19	0%	0.00	0%	0.00	0%

Figure 1. Structure of Nest for Allocation of Land to Land Use to Enterprise to Output in NZ-FARM

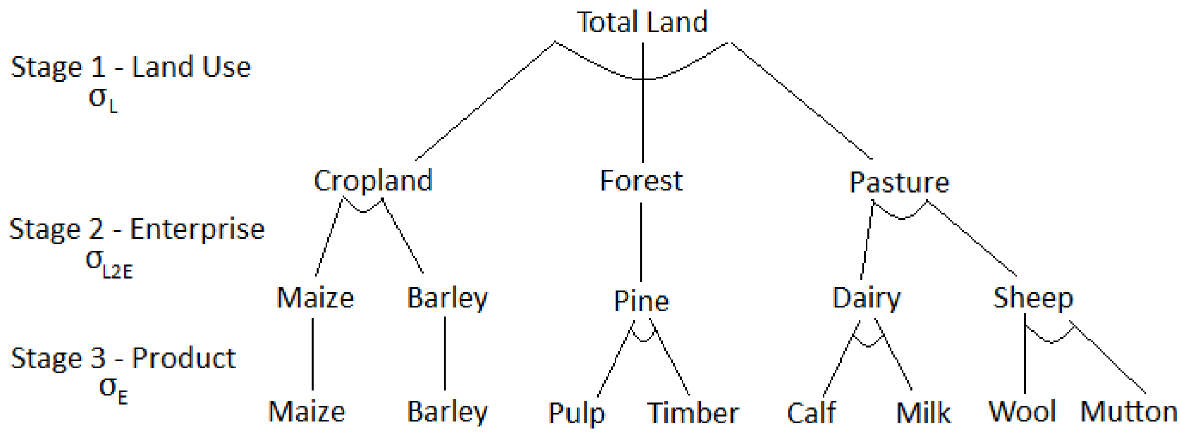

Figure 2a. Hurunui and Waiau Catchments, South Island, New Zealand

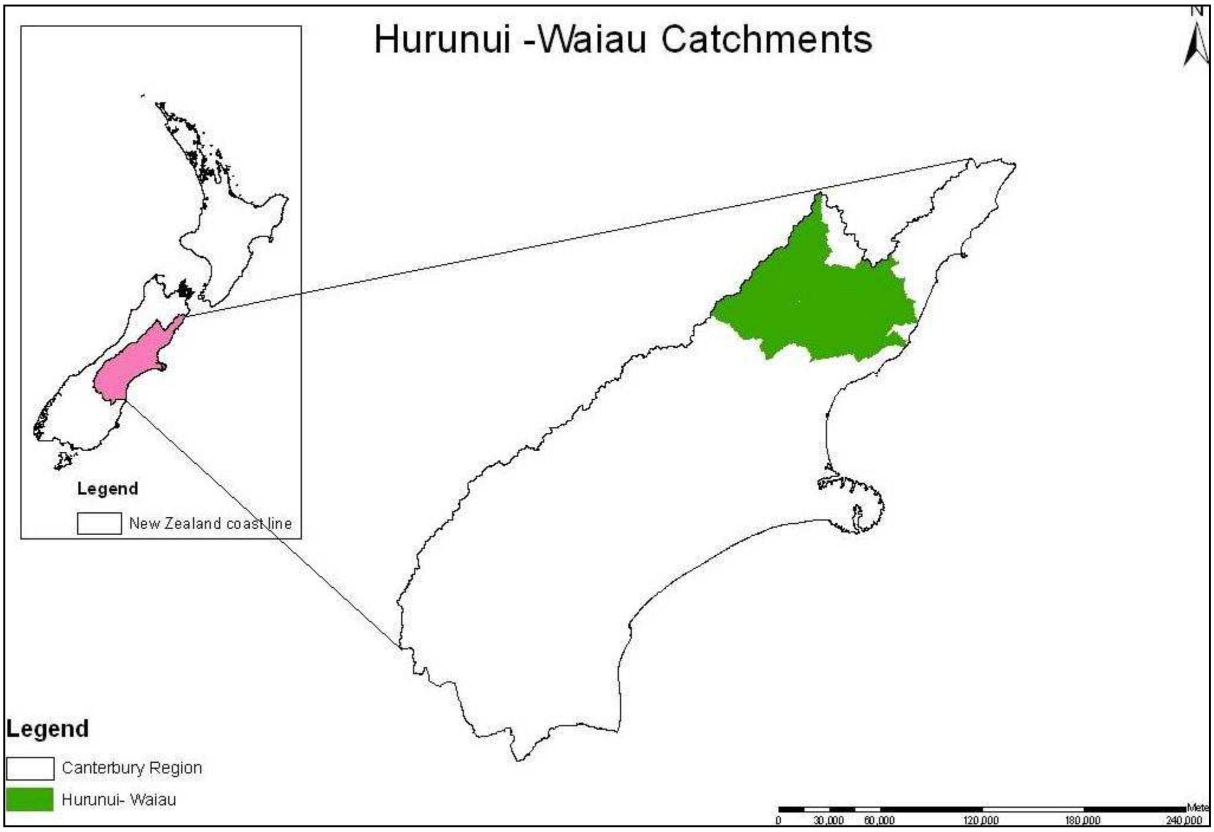

Figure 2b. Manawatu Catchment, North Island, New Zealand

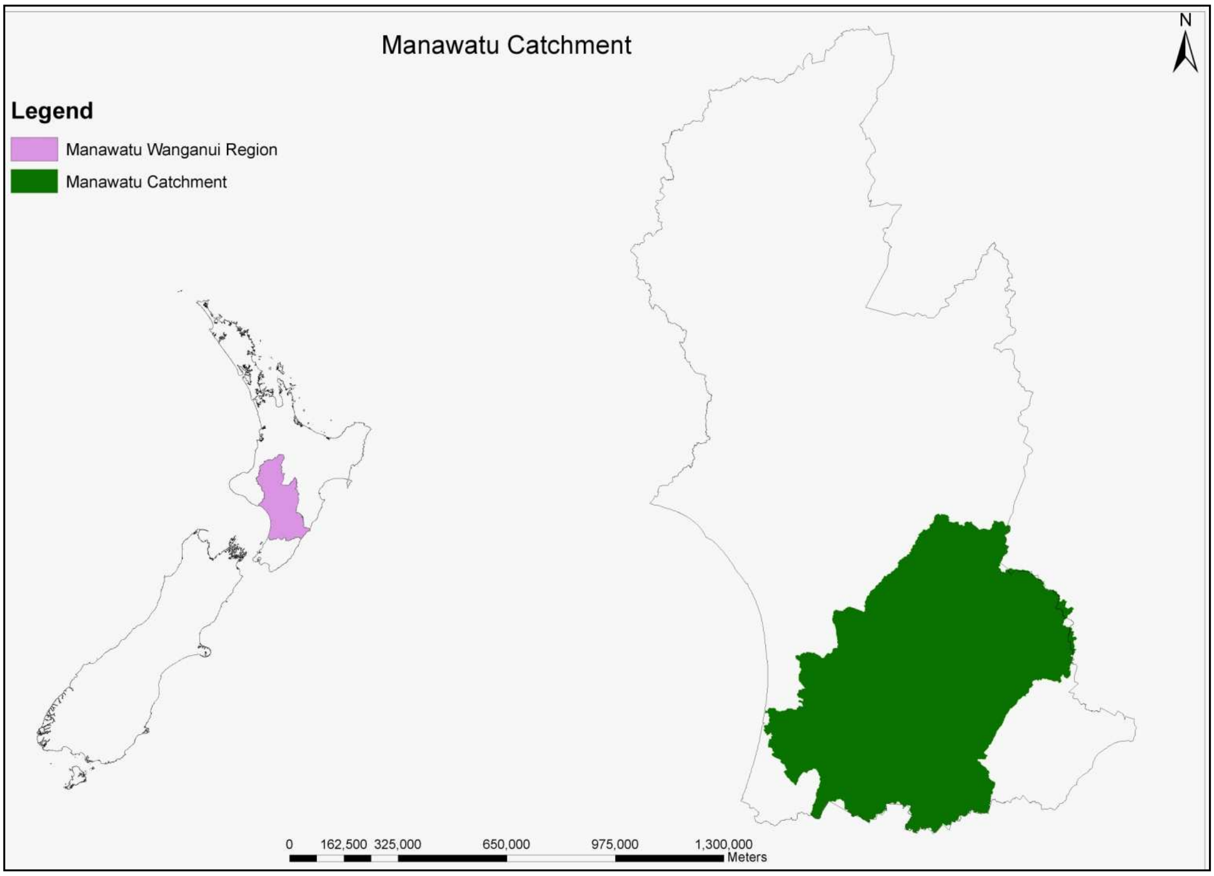

Figure 3a. Sub-catchment zones in Hurunui/Waiau Catchment

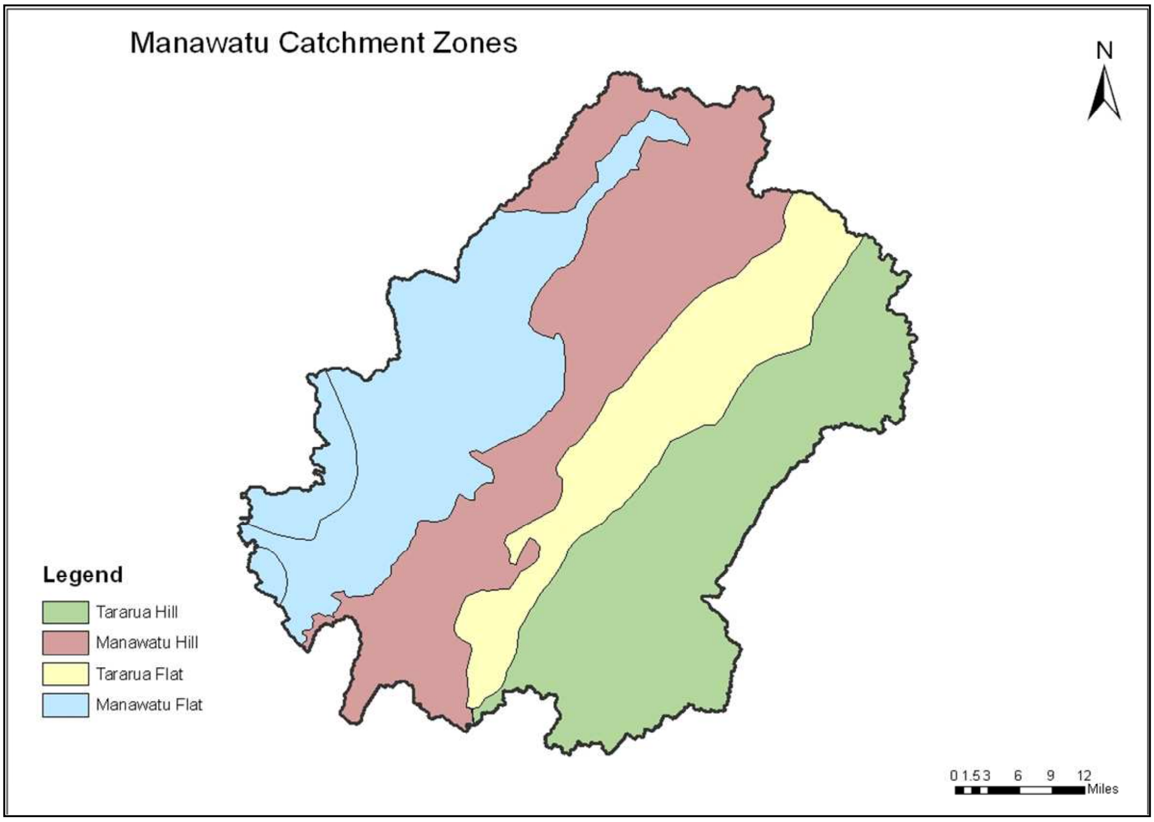

Figure 3b. Sub-catchment zones in Manawatu Catchment

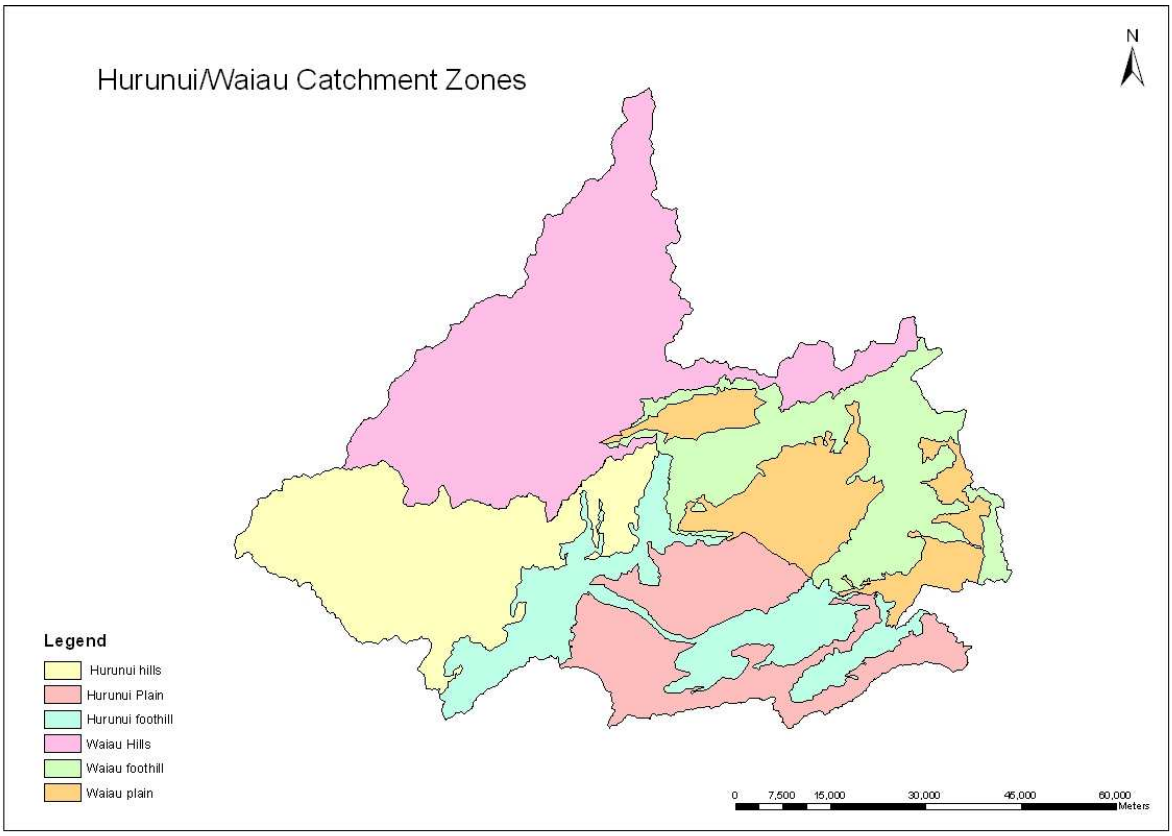

Figure 4a. Baseline Enterprises for Hurunui/Waiau Catchment

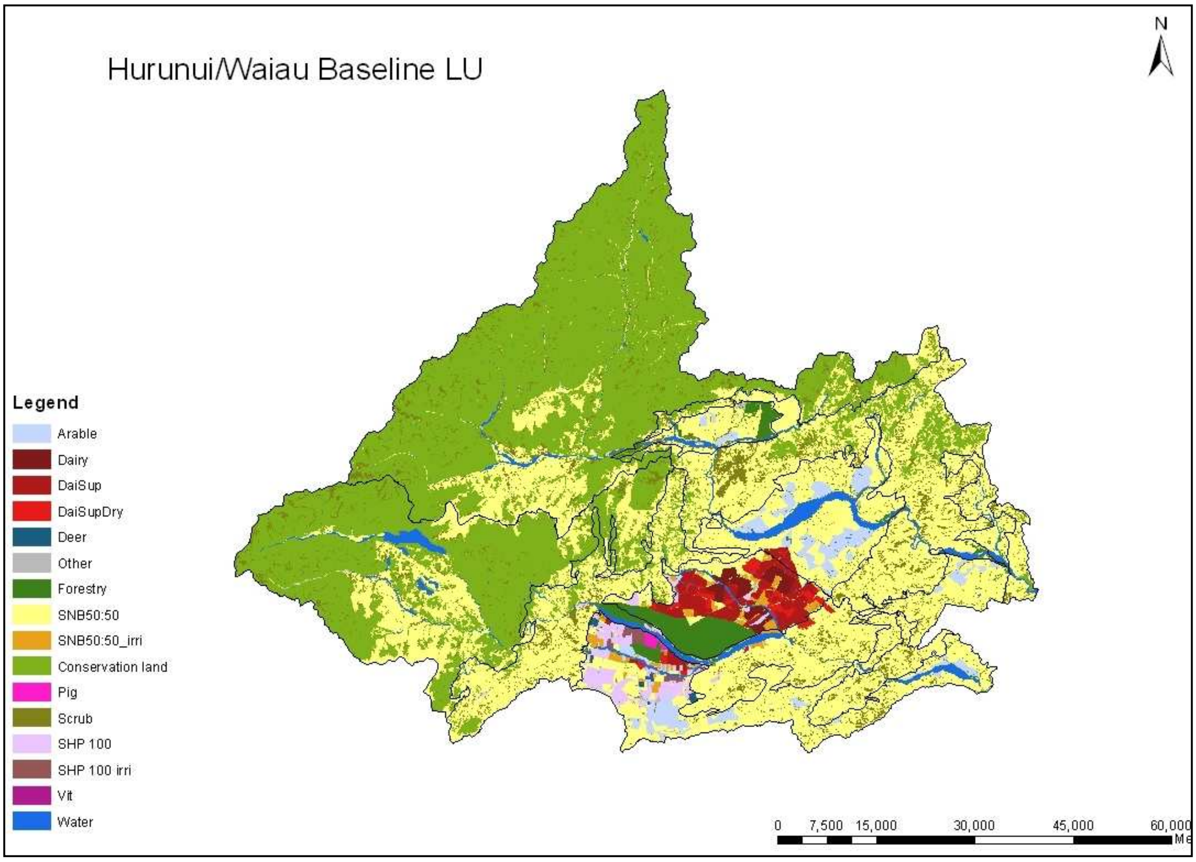

Figure 4b. Baseline Enterprises for Manawatu Catchment

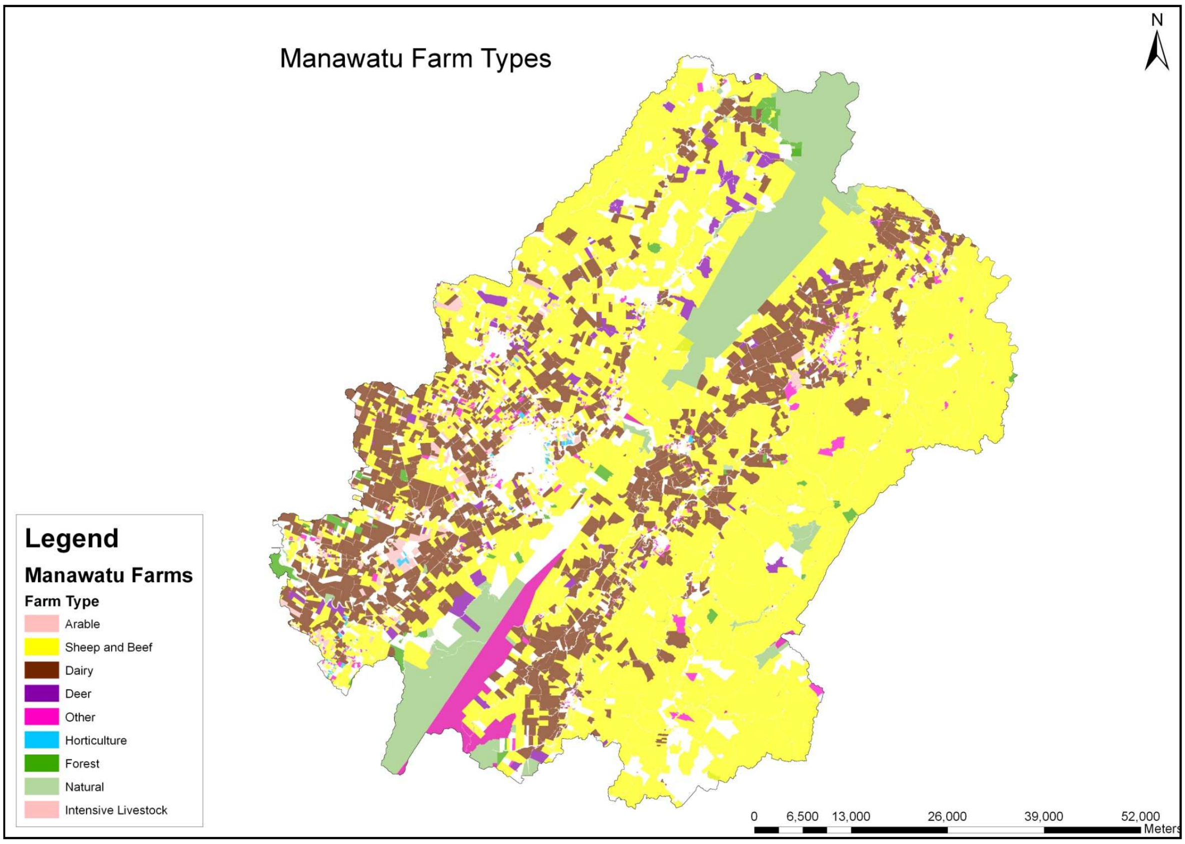

Figure 5. Percentage change from baseline, net catchment revenue and environmental outputs

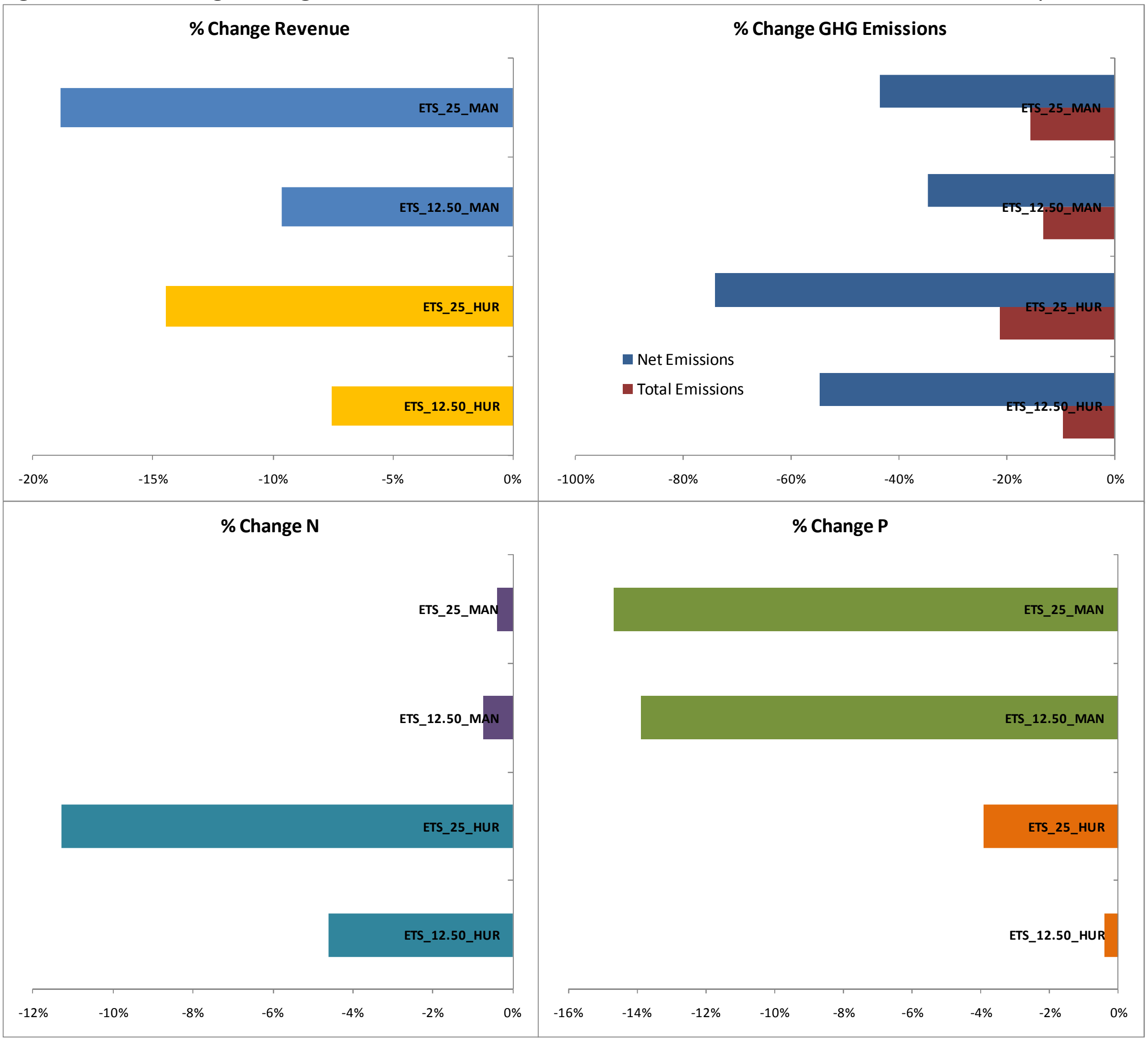

Figure 6. GHG Emissions, Baseline and Policy Scenarios