Modelling Economic Impacts of Nutrient Reduction Policies in the Hurunui Catchment, Canterbury

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ABSTRACT

This paper uses NZ-FARM, an economic catchment model to assess changes in land use, enterprise distribution, nutrient loading levels and greenhouse gas emissions from a series of policies that introduce nutrient reduction caps on land-based production in the Hurunui catchment, North Canterbury. We estimate changes in net revenue, land use, enterprise mix, and environmental outputs when landowners in the plains region of the catchment must reduce their aggregate nitrogen and phosphorous loading targets of 15% and 30% below baseline levels. Furthermore, we investigate the potential differences when farm nutrient budgets are derived primarily from two different biophysical models, OVERSEER and SPASMO, as well as a hybrid approach that combines estimates from these two models and other literature. Our findings suggest that environmental targets can be met with relatively modest changes in total net revenue for the region, but the difference in absolute changes in revenue can vary significantly depending on which estimated leaching rates are used to develop the nutrient budgets.

KEYWORDS: Agriculture and Forestry Modelling, Land Use, Nutrient Budgeting, Water Quality, Greenhouse Gas Emissions

INTRODUCTION

Agriculture is an important part of New Zealand's economy, but the sector faces several challenges as it strives to maintain or enhance the level of output while keeping its resource use and environmental integrity under control. Agricultural production in most parts of the country has improved significantly in recent decades through the increased use of inputs such as fertilizer, irrigation, and supplemental feeds. The increase in input use has also put a strain on the country's freshwater resources, as many lakes and streams are becoming degraded from the high levels of nutrient and sediment runoff associated with more intensive land use. The New Zealand government recently announced plans to increase its support for regional irrigation projects that create additional output in the sector while at the same time funding efforts to clean up its waterways (Carter 2011, NZ Government 2011, Smith 2011). There is still debate though as to whether policies to meet water quality targets, such as by reducing the level of nutrient runoff from the farm, can be feasibly met while still maintaining economic viability and expected gains in agricultural productivity. This paper uses an economic catchment model to assess potential economic and environmental impacts of a nutrient reduction policy on land-based production in a major farming region in Canterbury.

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 model, 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.

NZ-FARM, is a comparative-static, non-linear mathematical programming model of regional New Zealand land use. The model'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., greenhouse gas 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.

The model is used in this paper to assess the economic and environmental impacts of a nutrient reduction policy at the sub-catchment level. We do this by imposing caps of nitrogen (N) and phosphorous (P) at 15% and 30% below baseline levels on the plains region of the Hurunui Catchment in Canterbury. We use these cap levels because they are in the range of the nutrient reduction targets of 7% to 49% for N and 20% to 33% for P for the Hurunui case study area reported in the Hurunui Waiau draft Zone Implementation Programme (Canterbury Water Management Strategy 2011). The caps in this paper are also within the range of the targeted 20% reduction in N from Lake Taupo imposed through a nutrient trading programme currently managed by the Lake Taupo Protection Trust (Environment Waikato 2009), and the N reduction target range of 22%-42% in Lake Rotorua (Environment Bay of Plenty et al 2007).

Using NZ-FARM to model nutrient reduction policies on farm management and land use also allows us to assess the potential co-benefits on the catchment's land and water, such as changes in greenhouse gas (GHG) emissions. 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 nutrient policy could provide the co-benefits of GHG emissions reductions as well. This is an important consideration as approximately 47% of New Zealand's GHG emissions occur in the agricultural sector (Ministry for the Environment, 2011), and agriculture is scheduled to enter the New Zealand Emissions Trading Scheme (ETS) in 2015. 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 . Thus, having a better idea about the potential reductions in GHGs from alternative policies under consideration at the regional level could prove valuable insight into the formulation of national level climate policy. The estimated impacts on the Hurunui catchment could be significant and serve as an important guide to other regions of New Zealand that are considering similar policies in the future.

In addition to looking at the impact of a nutrient reduction policy on land management, this paper also assesses the potential difference in estimates from primarily using N and P leaching rates from two different biophysical models of New Zealand agriculture, OVERSEER and SPASMO, which have both been used extensively to derive farm-level nutrient management plans (Cichota and Snow, 2009). Additional literature was also used to derive estimates for forests and natural vegetation and arable crops, and combined with estimates from both OVERSEER and SPASMO to develop a hybrid set of per hectare leaching rates. This paper presents results from three distinct sets of data and then compares the estimated changes in net revenue, enterprise distribution, nutrient levels and GHG emissions at the regional scale for policy scenarios with different nutrient caps.

There have been limited studies on the comprehensive economic and environmental impacts of regional nutrient reduction policies in New Zealand at the catchment level. Monaghan et al (2008) conducted a modelling analysis to look at the effectiveness of best management practises in reducing nutrient losses in case study dairy farms in four catchments (Toenepi, Waiokura, Waikakahi and Bog Burn), and presented the effectiveness of the mitigation options in terms of dollars saved per kg of nutrient conserved. Using the simulation model Land Use in Rural New Zealand version 1 - climate (LURNZv1-climate), Hendy et al (2006) simulated the effects of an agricultural land-use emissions charge and a reward for native forest and scrub regeneration and presented the land use impacts at the national scale. Also, the N-Manager simulation model was used in the Rotorua catchment for preliminary analysis of six different approaches to nutrient management and estimates the economic costs and environmental impacts associated with them

(Anastasiadis et al 2011). However, none of these studies have investigated the issue of nutrient reduction in the Hurunui at the level of economic detail available in NZ-FARM.

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 nutrient mitigation options for the catchment and the potential issues from using different models and data sets to estimate nutrient budgets. Following that, we present baseline land use, enterprise mix, nutrient loads, and GHG emissions. We then present the estimates from our policy scenarios that assess potential impacts to the region from a 15% and 30% reduction in nutrient loading from baseline levels using three different sets of N and P leaching rates. 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 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: scrub land, 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 particular to the catchment 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:

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

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.

Production activities in each region are differentiated in several ways. Each production activity uses information on input cost, input use, and output price. As mentioned above, production and land use are endogenously determined in a nested framework (Figure 1). First, landowners decide on the optimal mix of land use for their fixed area within a sub-zone, given their soil type. Next, 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 altering 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 various enterprises and land management. Constraints on loading levels can be set at the enterprise, regional, or catchment level to estimate the potential changes in agricultural practices and land use to reduce nutrient runoff.

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

In the climate arena, NZ-FARM tracks GHG emissions in categories similar to 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); and
- Improving farming efficiency and altering stocking rates.

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

NUTRIENT BUDGETING MODELS

Nitrogen leaching is a complex process and is affected by a number of soil, environmental and management conditions (Di and Cameron 2000). N leaching loss is the amount of N that has moved down through the soil to the ground water below the plant rooting depth or is lost as runoff (Overseer, 2010). The leaching of nitrate from agricultural land and the subsequent contamination of water resources have been recognized as a major environmental issue because high concentrations of nitrate in drinking water are deemed to be detrimental to human health (Di and Cameron 2002). Nitrates leached from agricultural land that drain into surface water bodies may also cause deterioration in quality though algal blooms. The actual loss to receiving water (e.g., aquifers, rivers, etc.) depends on the degree of attenuation that occurs during the passage of N from the ground water just below rooting depth to the receiving water, including that which may be attenuated in wetlands (Overseer, 2010).

Phosphorous (P) loss to waterways in New Zealand mainly occurs through surface run-off, and to a much lesser degree by subsurface flow. The range of P losses from agricultural systems is generally much less than N losses (e.g. 0.11-1.6 versus 21-177 kg ha-1 yr-1, respectively) and appears to be minor in comparison (Menneer et al 2004). Aquatic primary producers such as freshwater algae can be extremely sensitive to even small increases in P though, especially in waterways where the nutrient is limited (McDowell et al., 2004). About 80% in of phosphorous run-off is in the form of particle-bound P (e.g., bound to sediment or organic material) while less than 20% is present as dissolved P (Menneer et al 2004). Thus, the properties of the soil can have significant impacts on how much P reaches New Zealand's lakes and streams.

The OVERSEER nutrient budget model is a site specific, empirical, annual time-step model which provides average estimates of nutrient loss (N, phosphorus, potassium and sulphur) in kg/ha/yr, ignoring year to- year variability due to climate. (Ledgard et al. 1999, Wheeler et al. 2003). The model contains a number of internal databases with nutrient concentrations of fertilisers, animals, products, crop management, and crop residues which are used to estimate nutrient inputs and outputs on a per-hectare basis (Ledgard et al. 1999). OVERSEER is used extensively throughout New Zealand by farmers, farm consultants and fertiliser representatives. The model is increasingly being used as a tool for implementing regional council resource management requirements to limit N and P losses to waterways (Wheeler et al. 2008). OVERSEER uses an N balance model concept whereby $\sum$N inputs = $\sum$N outputs and assumes that the soil organic N is at an equilibrium level (Thomas et al, 2005). In pastoral systems, the calculation of N leaching includes the amount of N applied in fertiliser, calculated amounts of N in farm dairy effluent, and N excreted in urine and dung by grazing animals where excretal N is calculated as the difference between N intake by grazing animals and N output in animal products. Leaching figures differ based on user inputs of stocking rate or production and an internal database with information on the N content of pasture and animal products. The OVERSEER model does not differentiate between leached N and runoff N, but, based on the limited New Zealand data available for nitrate runoff, it is expect that the contribution of N from runoff is small (Thomas et al, 2005).

The Soil Plant Atmosphere System Model (SPASMO) is a dynamic model for water and solute (e.g., N and P) transport through productive soils. The model integrates those factors that affect environmental processes and plant production (e.g. climate, soil, water) to predict the fate of water, nutrients (N and P), contaminants (pesticides, heavy metals, and e coli), and dissolved matter (C and N) as well as the growth and nutrient uptake by crops. SPASMO uses a daily time-step, and the model is run using long-term weather records of 20-30 years (Plant and Food Research, 2011). The computer model links the mechanisms of soil water flow through the root zone with the complex N transformations that result from natural processes, and those resulting from the application of N fertilizer, N uptake and recycling by the vegetation, and the returns of dung and urine from the sheep (Rosen et al 2004). The model has been mainly used for horticultural enterprises, although it is capable of estimating nutrient leaching from all land types (Cichota and Snow, 2009).

HURUNUI CATCHMENT DATA

Data for the inputs used for the Hurunui catchment in NZ-FARM was obtained from several sources. A list of all the different sets for which data was obtained (enterprise, soils, etc.) is shown in Table 1. Sources of these data are discussed in the following subsections. In total, there are nearly 1,200 combinations of enterprise, input, and mitigation options modelled for Hurunui catchment. This analysis focuses specifically on the plains region, which has more than 550 combinations.

Geographic Area, Land Use, and Soil Type

The entire catchment area is divided into 3 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 plains, foothills, and hills. A map of the catchment is shown in Figure 2. Land in each zone is categorized by six distinct uses: forest, cropland, pasture, horticulture, scrub, and DOC land. Baseline land use was provided by Environment Canterbury (October 2010). Soil maps (New Zealand fundamental soil layer) for the region were used to divide the area into four dominant soil types, which were categorised based on the drainage and profile available water (Webb 2009). For the Hurunui region, we aggregated the soils into the following:

- Very light/other: Balmoral
- Light: Lismore
- Medium: Templeton
- Heavy: Hatfield

These soil types mainly have an effect on the leached of nutrients that are leached from various enterprises and management practices.

Enterprises, Inputs, Outputs and Prices

Enterprises tracked in the model cover most of the agricultural and forestry sector that occur in the catchment. Key enterprises include dairy, sheep, beef, deer, timber, grains, and fruit. NZ-FARM includes 18 different enterprises, where feasibility and productivity are determined by bio-geographical characteristics like slope, soil type, access to water, etc. All of the enterprises tracked in the model are considered feasible options for the plains region.

Each enterprise requires a series of inputs to maximize production yields. The high cost of particular inputs coupled with water and input constraints can limit the level of output from a given enterprise. Outputs and prices are primarily based on published data provided by Lincoln University (Lincoln University, 2010), Ministry of Agriculture and Forestry (MAF) farm monitoring report (MAF, 2010a), and the 2010 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 the greater Canterbury region (Stuart Ford, personal communications, October 2010). Most enterprises in the plains region of catchment have the option to vary the use of fertilizer inputs, with the exception of forestry and horticulture.

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 Stuart Ford, the MAF farm monitoring report (MAF, 2010a) and Lincoln University (Lincoln University, 2010). Cost series were developed for each enterprise and varied across all fertilizer and mitigation regimes. 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.

Nutrient Leaching Rates

N and P leaching rates for the various enterprises included in NZ-FARM were obtained from several sources including output from the OVERSEER and SPASMO models and findings from the literature. For the purpose of this paper, we collected three sets of N and P leaching rates to assess the potential difference in estimated impact from nutrient reduction policies. The three sets of leaching rates are defined as: (1) OVERSEER; (2) SPASMO; (3) Hybrid. A thorough description of the key models was described in the Nutrient Budgeting Models section above, although additional literature was needed to populate these datasets with leaching rates for all of the enterprises in the catchment.

N and P leaching for the OVERSEER dataset include all pastoral enterprises calculated using the most recent version of OVERSEER (2010). Values for fruits and arable crops came from the Environment Canterbury nutrient leaching lookup tables (Lilburne et al 2010), which were mostly obtained using calculations from LUCI framework model for crops (Zyskowski et al 2007). The dataset from SPASMO was more comprehensive than OVERSEER, as we were able to obtain leaching rates for all enterprises with the exception of forest and natural land. The hybrid dataset combines what we believed to be the 'most reasonable' estimate of N and P from our various sources. Leaching rates for dairy and sheep and beef enterprises were taken from OVERSEER (2010), while N and P leaching rates for arable crops, horticulture, pigs, and deer enterprises were constructed using SPASMO (2010). Values for N leaching from pine plantations and native vegetation for all three datasets were taken as an average from the literature (e.g., Parfitt et al 1997; Menneer et al 2004, etc.). We assumed that no P leaches from plantations or native lands. An example of the wide range of nutrient leaching rates for key enterprises in the catchment is listed in Table 2.

Greenhouse Gases Emissions

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[1], 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.

BASELINE

The plains region of the catchment comprises over 76,000 ha, of which about 22,000 ha are irrigated. This region has the highest productivity and revenue potential in the catchment and also produces a high proportion of the catchment's nutrient loads and GHG emissions. It is also the region that has the greatest potential to alter its level of environmental outputs through changes in farm inputs, enterprise mix, and land use and is thus the focus of our policy analysis.

Total net revenue for all farm practices in income derived from baseline figures for current input costs, output prices, and enterprise productivity is estimated at $94.0 million. The total area and distribution of baseline land use for the region is listed in Table 3, while output is listed in Table 4. Enterprise area in the catchment is dominated by sheep and beef (45%) and dairy (26%). Plantation forests encompass about 16% of the area, while arable land (i.e., grains and fruit) and other pasture (i.e., pigs and deer) comprise about 11%. There is little scrubland or DOC/natural area in the region, indicating that there is limited room for expansion of agricultural activities[2].

Baseline estimates for total N and P leached from on-farm production in the region are listed in Table 5. It is apparent that the estimates for total N for the three data-sets are relatively close, with the SPASMO estimating a lower-bound of 1,266 tons per annum (t/yr) and the hybrid data indicating a level of 1,316 t/yr (4% greater). The range of estimates for total P are much larger though, with OVERSEER indicating that annual P leaching levels in the catchment could be more than

[1] 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

[2] Note for this study we hold DOC land fixed, so it must remain constant for all scenarios.

twice as much. One potential reason for this is that the OVERSEER model outputs at in increments of 0.1 kilogram per hectare (kg/ha), while SPASMO lists outputs as low as 0.001 kg/ha. Additionally, SPASMO estimated that there is P leached from pastoral enterprises on Hatfield/heavy soils (often 0.002 kgP/ha or less), while OVERSEER listed leaching rates in the range of 0.1 to 0.2 kg P/ha.

GHG emissions for the Hurunui catchment are about 470,000 tCO2e. The bulk of emissions come 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 N2O from agricultural/grazing soils. Annual carbon sequestration from plantations in the baseline is close to zero because it is assumed that in this static model, exactly the baseline area of forest felled is immediately replanted. Carbon sequestration from scrub and native forests is estimated to be about 3,500 tCO_2e/yr, which is limited by the relatively small area of native vegetation in the region.

NUTRIENT REDUCTION POLICY SCENARIO ANALYSIS

Our policy analysis places caps of 15% and 30% below baseline levels of N and P outputs in the Hurunui plains region. The constraint is placed on nutrient output for the entire catchment, thus allowing landowners to trade nutrient loads across enterprises and farm management practices to meet a comprehensive target for the region. This is obviously more flexible and cost effective than commanding that all landowners meet individual targets. Because we are focusing on the potential differences in results from nutrient leaching rates from the three separate data-sets, there are a total of six policy scenarios:

- OVER_15 = scenario with a cap of 15% below baseline levels of N and P outputs calculated with OVERSEER leaching rates dataset
- SPAS_15= scenario with a cap of 15% below baseline levels of N and P outputs calculated with SPASMO leaching rates dataset
- HYBRID_15= scenario with a cap of 15% below baseline levels of N and P outputs calculated with HYBRID leaching rates dataset

- OVER_30= scenario with a cap of 30% below baseline levels of N and P outputs calculated with OVERSEER leaching rates dataset
- SPAS_30= scenario with a cap of 30% below baseline levels of N and P outputs calculated with SPASMO leaching rates dataset
- HYBRID_30= scenario with a cap of 30% below baseline levels of N and P outputs calculated with HYBRID leaching rates dataset

Details on how the nutrient leaching datasets were constructed are described in the Catchment Data Section above. Estimates for changes in enterprise area relative to the baseline are shown in Table 6 and the change in production is listed in Table 7. The percentage changes in revenue, nutrient loads, and GHG emissions relatively to the baseline are shown in Figure 3, while the aggregate enterprise area for each scenario is shown in Figure 4.

15% Reduction in N and P

Results show that a nutrient reduction target of 15% can be met with relatively modest declines in total net revenue for the region, ranging from 0.5% to 1.6%. Both N and P are exactly reduced by 15% in all scenarios, while declines in GHG emissions are in the range of 11% to 14%. For each of these metrics, the greatest changes were expected to occur using the OVERSEER data-set, while the smallest changes were estimated to occur using SPASMO. The hybrid datasethad estimates in the middle of the range, which makes sense given that it used a combination of the other two datasets.

Enterprise area under the 15% cap is expected to shift from pastoral to forest and arable for all three sets of nutrients leaching rates, as landowners must shift to less intensive types of land use. Because product output is highly correlated with enterprise area, the greatest annual declines in production are expected to occur in dairy, sheep, beef, and pigs, with some of the revenue losses being made up from increased output of fruit, grain, and wood. All three data-sets showed relatively correlated changes in production with the exception of lambs and deer. Additionally, the scenario using the hybrid model estimated that scrubland area would actually decline despite its very small leaching rate of 1.0 kgN/ha and 0.0 kgP/ha. The absolute change in area is still relatively modest though as there were only 1,480 ha of scrubland in the baseline.

30% Reduction in N and P

The trend in the results for the 30% reduction in nutrient loads was similar to the scenarios with a 15% cap. The scenario using the SPASMO dataset estimated a 2.4% reduction in net revenue under the 30% cap, while the OVERSEER data estimate was at the high range (-6.2%). Despite the large gap in estimates between the two datasets, with the hybrid data again being in the middle (-3.9%). These results indicate that landowners could meet the comprehensive cap without significant declines in farm income. Caps for N and P were both met for each of the data-sets, with SPASMO actually estimating that farmers would reduce P loads in the catchment by about 36%. This is because the optimal change in farm management and enterprise area needed to meet the N constraint could not be met without going beyond the requirements needed to meet the cap on P. Our results also found that GHG emissions are expected to decline from baseline levels by 22% or more. If you include the additional carbon sequestration that will be accrued in new pine plantations over the next 30 years, then net emissions for the region are expected to decline even more. These results support our hypothesis that a nutrient reduction policy can potentially help New Zealand meet its national climate mitigation targets without needing additional regulation on the agricultural sector.

As with the earlier scenarios, enterprise area under the more restrictive cap is expected to shift from pastoral to forest and arable crops for all data sets, and the largest annual declines in production are expected to occur in dairy, sheep, beef, and pigs. Some of the revenue losses will again be made up from an increase in the output of fruit, grain, and wood. All three data-sets continued to show relatively correlated changes in production with the exception of lambs and deer. For nearly every case, the SPASMO dataset predicted small changes in enterprise area and production while OVERSEER was generally at the higher end of the range.

CONCLUSION

This paper uses an economic catchment model, NZ-FARM, to assess changes in land use, enterprise distribution, nutrient loading levels and GHG emissions from a series of policies that introduce nutrient reduction caps on land-based production in Hurunui plains region of North Canterbury. We estimate changes in net revenue, land use, enterprise mix, and environmental outputs when landowners in the Hurunui plains sub-catchment must reduce their aggregate nitrogen and phosphorous loading targets of 15% and 30% below baseline levels. Furthermore, we investigate the potential differences when farm nutrient budgets are derived primarily from two different biophysical models, OVERSEER and SPASMO, as well as a hybrid approach that combines estimates from these two models and other literature.

Results show that the proposed environmental targets can be met with relatively modest declines in total net revenue for the region, ranging from 0.5% for the SPASMO data with a required 15% reduction in N and P, to more than 6% for a 30% decline in N and P when using the data derived primarily from OVERSEER. The difference in absolute changes in revenue can vary significantly though, depending on which set of leaching rates are used to derive the nutrient budgets. The hybrid dataset constructed from 'most reasonable' estimates of per hectare leaching rates for the 18 feasible enterprises in the region yields changes in net revenue in between the SPASMO and OVERSEER data sets, resulting in an estimated reduction of 1% and 4% for the two nutrient policy scenarios. Estimated changes in enterprise area were not always consistent across the three data-sets though, but the general trend indicated that there would be a shift away from nutrient intensive operations such as dairy, sheep and beef into less intensive land uses such as forest and arable land. Additionally, analysis conducted from all of the data-sets revealed that setting a cap on nutrient loads could provide significant benefits to reducing GHG emissions from the agricultural sector. Our findings indicate that while it would be more tedious to construct a datasetfrom several sources to conduct policy analysis, the estimates derived from the extra effort could yield more realistic results and insight. Further research must be conducted to assess whether our assumptions to construct the ‘most reasonable’ hybrid dataset are indeed accurate for the Canterbury region and whether the same approach can be transferred to other catchments in New Zealand.

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TABLES AND FIGURES

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 Scrubland DOC land				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. Nutrient Leaching Rates for Hurunui Plains, Baseline Management Practices (kg/ha)

			Nitrogen				Phosphorous		
Enterprise	Irrigation	Soil	OVERSEER	SPASMO	ECAN Report*	Literature Review	OVERSEER	SPASMO	Literature Review
Dairy 3 Cows Winter On	Irrigated	Balmoral/VL	48.00	43.30	43.80	-	0.1	0.018	-
Dairy 3 Cows Winter Off	Irrigated	Balmoral/VL	31.00	37.00	32.80	-	0.1	0.012	-
Sheep and Beef	Irrigated	Balmoral/VL	25.00	42.40	40.30	-	0.0	0.004	-
Sheep and Beef	Dry	Balmoral/VL	9.00	6.50	18.40	-	0.0	0.008	-
Deer	Irrigated	Balmoral/VL	19.00	64.6	26.3	-	1.0	0.006	-
Pigs	Dry	Balmoral/VL	8.00	27.30	20.00	-	0.0	0.004	-
Wheat/Arable	Irrigated	Balmoral/VL	-	24.20	21.90	-	-	0.013	0.10
Berryfruit	Irrigated	Balmoral/VL	-	5.40	6.80	-	-	0.007	0.10
Pine	Dry	Balmoral/VL	-	-	1.73	4.00	-	-	0.00

*ECAN Report (Lilburne et al 2010) figures are taken from Darfield climate. VL=very light

Table 3. Baseline Enterprise Area and Distribution (k ha)

	Baseline	Area %
Arable	5.95	7.8%
Forest	12.31	16.1%
Dairy	19.90	26.0%
Sheep and Beef	34.18	44.6%
Other Pasture	2.49	3.3%
Scrubland	1.48	1.9%
DOC	0.29	0.4%
Total	76.6	100.0%

Table 4. Baseline Output*

Product	Output
Milk Solids	23253.8
Dairy Calves	1522.9
Lambs	2972.8
Mutton	342.5
Wool	621.8
Cows	3331.4
Heifers	951.8
Steers	7423.7
Bulls	1.2
Deer Hinds	224.7
Deer Stags	148.7
Pigs	9888.3
Berry fruit	18.5
Grapes	19.1
Wheat	43267.9
Barley	6444.1
Pulp Logs	53.9
Timber	215.7

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

Table 5. Baseline Nutrient Outputs for 3 Data-sets (tons)

	Total N	Total P
OVERSEER	1281.6	3.49
SPASMO	1265.5	1.57
Hybrid	1315.8	2.39

Table 6. Change in Enterprise Area Policy Scenarios

Aggregate Enterprise	Policy Scenario					
	OVER_15	SPAS_15	HYBRID_15	OVER_30	SPAS_30	HYBRID_30
Arable	8%	12%	33%	43%	35%	80%
Forest	98%	53%	78%	169%	114%	150%
Dairy	-27%	-13%	-20%	-53%	-30%	-41%
Sheep and Beef	-21%	-12%	-18%	-36%	-26%	-35%
Other Pasture	-37%	-35%	-52%	-61%	-70%	-76%
Scrubland	36%	19%	-21%	36%	27%	-87%
DOC	0%	0%	0%	0%	0%	0%

Table 7. Percentage Change in Production for Policy Scenarios

	Policy Scenario					
Output	OVER_15	SPAS_15	HYBRID_15	OVER_30	SPAS_30	HYBRID_30
Milk Solids	-24%	-10%	-19%	-49%	-26%	-40%
Dairy Calves	-24%	-12%	-19%	-49%	-27%	-39%
Lambs	12%	-8%	-7%	18%	-12%	-19%
Mutton	-23%	-14%	-20%	-37%	-28%	-38%
Wool	-20%	-13%	-19%	-33%	-26%	-36%
Heifers	-24%	-12%	-19%	-49%	-27%	-39%
Steers	-9%	-10%	-12%	-20%	-21%	-27%
Bulls	-28%	-14%	-22%	-54%	-33%	-45%
Deer	-47%	-4%	1%	-82%	-16%	-7%
Pigs	-34%	-44%	-66%	-55%	-85%	-95%
Fruit + Grains	9%	10%	29%	45%	28%	70%
Timber and Pulp	98%	53%	78%	169%	114%	150%

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

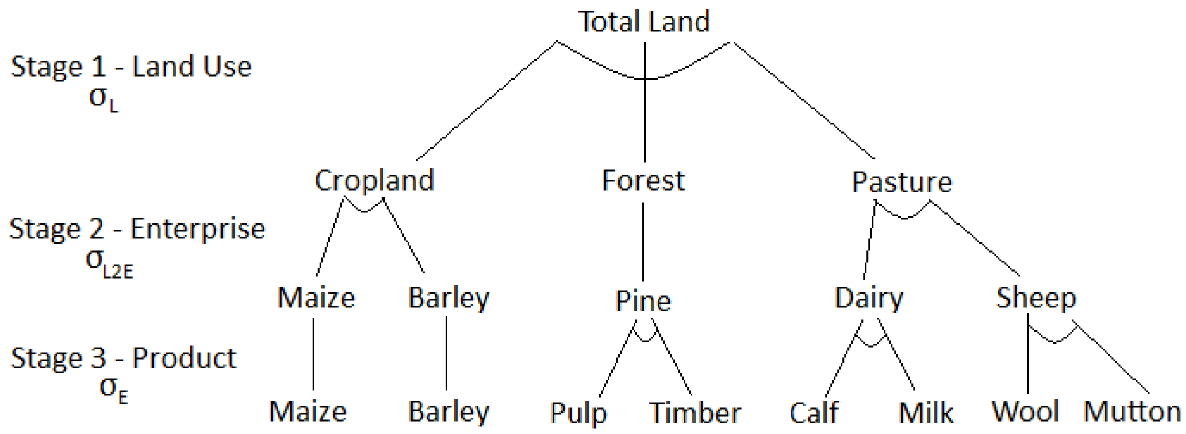

Figure 2. Baseline Enterprises for Hurunui Catchment

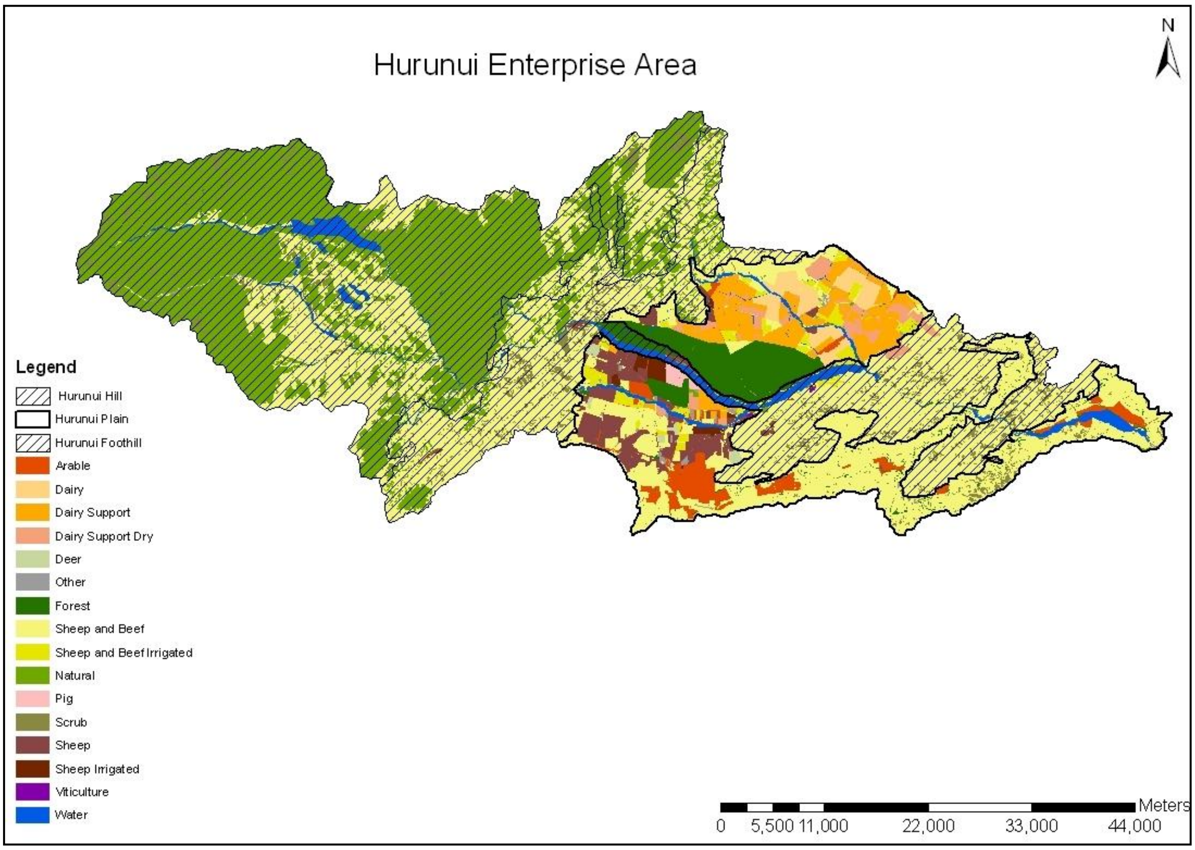

Figure 3. Percentage change from baseline, net catchment revenue and environmental outputs

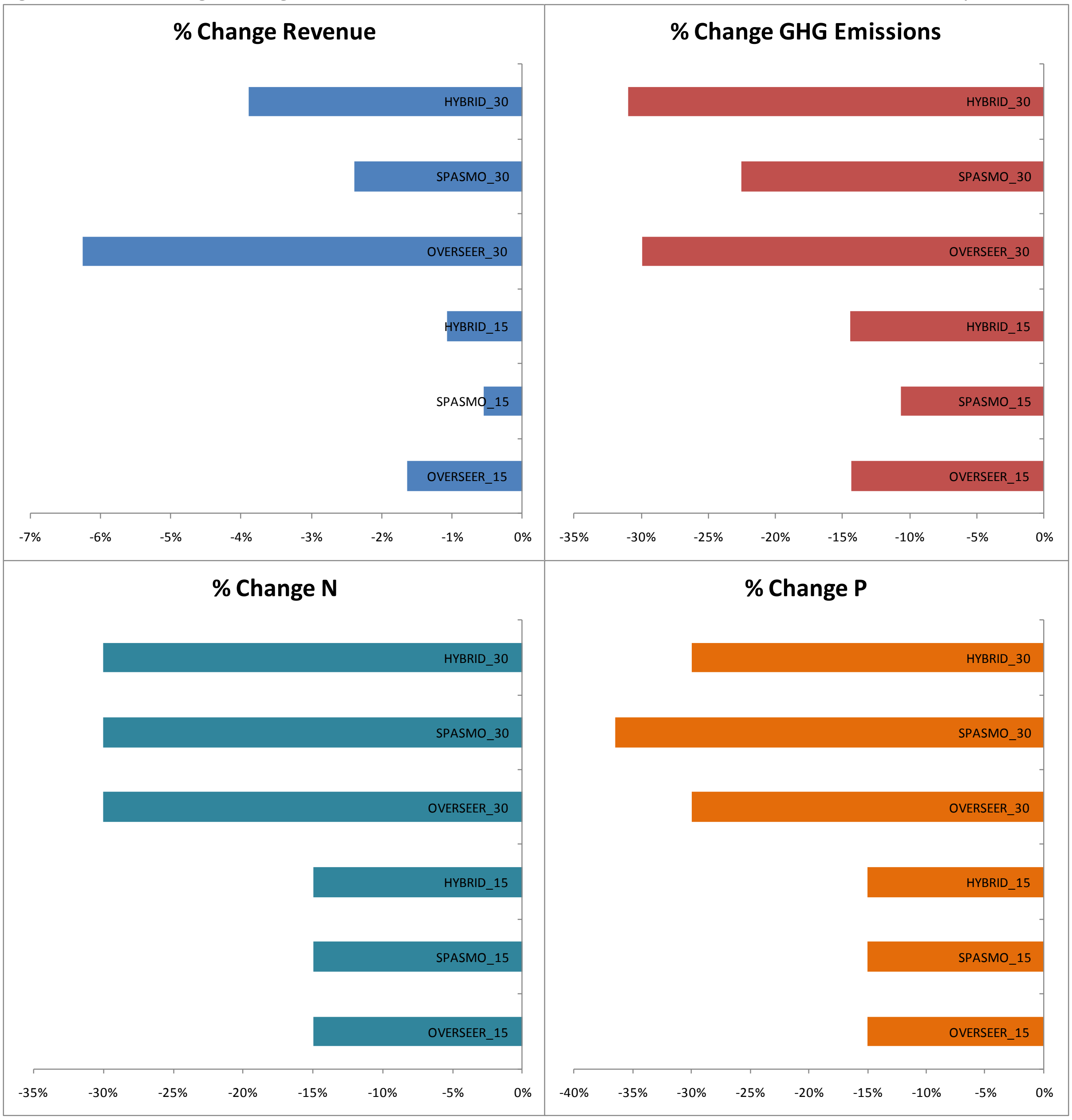

Figure 4. Regional Enterprise Area for Hurunui Catchment, Baseline and Policy Scenarios