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Evaluation of the impact of different policy options for managing to water quality limits

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Evaluation of the impact of different policy options for managing to water quality limits

Final Report – Appendices

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Landcare Research
Manaaki Whenua

Appendices: Evaluation of the impact of different policy options for managing to water quality limits

Lead Authors

Adam Daigneault[a] and Hugh McDonald[b]

Contributing Authors

Sandy Elliott[c], Clive Howard-Williams[c], Suzie Greenhalgh[a], MAGusyev[d], Suzi Kerr[b], James Lennox[a], U Morgenstern[d], Ned Norton[c], John Quinn[c], Kit Rutherford[c], Ton Snelder[c], and Bob Wilcock[c]

Prepared for:

Ministry for Primary Industries

Pastoral House
25 The Terrace
PO Box 2526
Wellington 6140

October 2012

[a] Landcare Research, 231 Morrin Road, St Johns, Private Bag 92170, Auckland 1142, New Zealand, Ph +64 9 574 4100, Fax +64 9 574 4101, www.landcareresearch.co.nz

[b] Motu Economic and Public Policy Research, Level 1, 97 Cuba Street, PO Box 24390, Wellington 6142, New Zealand, Ph +64 4 939 4250, http://motu.org.nz

[c] National Institute of Water and Atmosphere, Gate 10 Silverdale Road, Hillcrest, PO Box 11115, Hamilton 3216, New Zealand, Ph: +64 7 856 7026, Fax: +64 7 856 0151 www.niwa.co.nz

[d] GNS Science, P O Box 30368, Lower Hutt 5040, New Zealand, Ph +64 4 570 1444, Fax +64 4 570 4600 www.gns.cri.co.nz

Reviewed by:	*Approved for release by:*
Oshadhi Samarasinghe Junior Researcher Landcare Research	Karen Cronin Science Team Leader Governance & Policy
Landcare Research Contract Report:	LC 979

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Appendix A – Technical details of New Zealand Forest and Agriculture Regional Model (NZFARM)

1.1 Overview

The New Zealand Forest and Agriculture Regional Model (NZFARM) 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 net revenue (π) from land-based activities as well as a host of other economic or environmental performance indicators that are important to decision-makers and rural landowners. The model can track changes in land-use, land management, greenhouse gas emissions (GHG) nitrogen (N) leaching, and phosphorous (P) loss by imposing a variety of policy options for instance, establishing a catchment-level cap-and-trade programme to imposing nutrient leaching constraints at the enterprise-level. A detailed schematic of the components of NZFARM is shown in Figure 1.

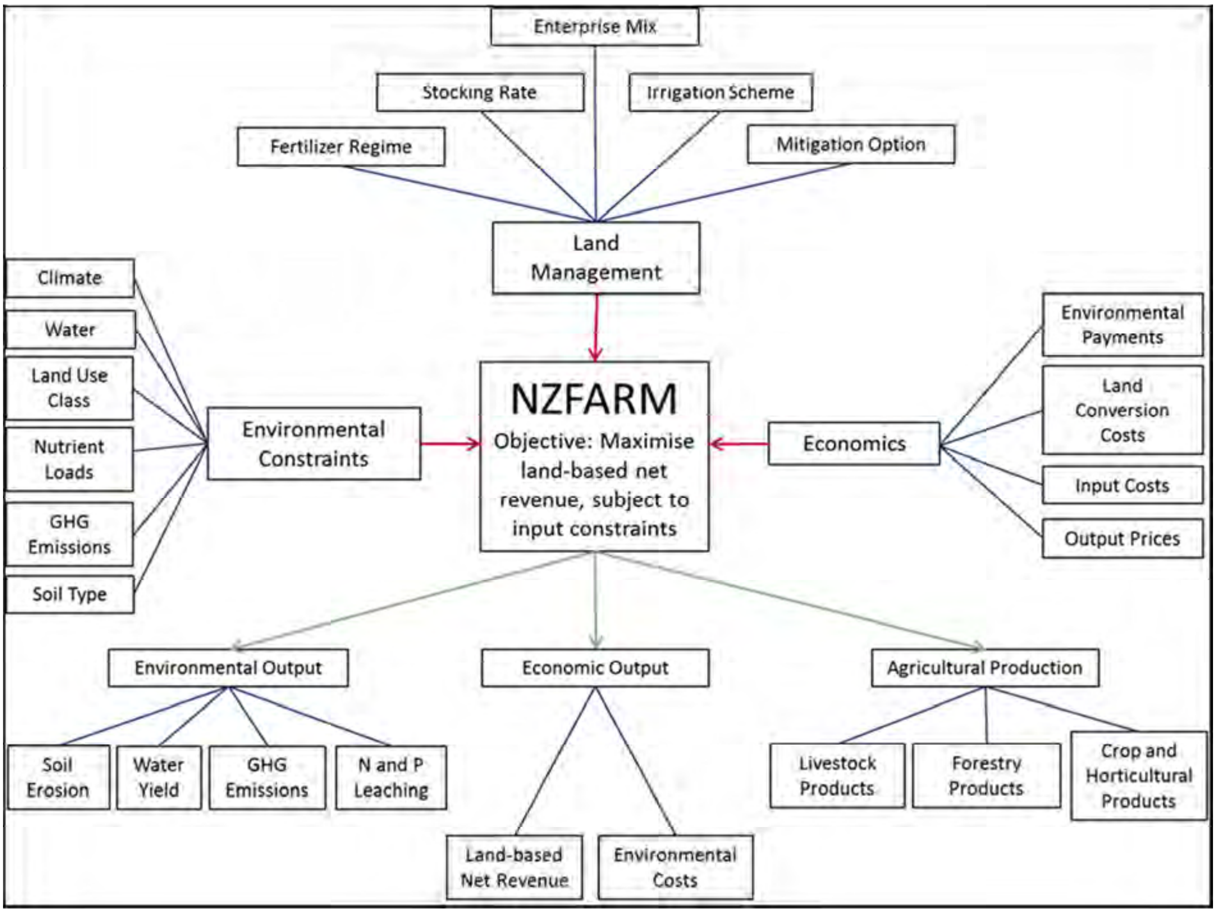

Figure 1 New Zealand Forest and Agriculture Regional Model (NZFARM)

1.2 Model Structure

1.2.1 Objective function

The model's objective function is to estimate the optimal level of outputs that maximize the net revenue from land-based activities across the catchment, given its land-use, enterprise-mix, land-management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and regulated environmental outputs imposed in a given region. Regions within a catchment are differentiated by land-use capability (LUC) classification in the model, such that all land in the same NZFARM region will yield the same level of productivity for a given enterprise and land management scheme. The objective function is mathematically specified as:

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{array}{c} PY_{r,s,l,e,m} \\ -X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Q_{r,s,l} \end{array} \right\} \qquad (3.1)$$

where P is the product output price, Y is the product output, X is the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective the livestock, variable, and fixed input costs, τ is an environmental tax (if feasible), γ^{env} is an environmental output coefficient, ω^{land} is a land-use conversion cost and Q is the area of land-use change from the initial allocation. Summing the revenue and costs of production across all NZFARM regions (r), soil types (s), land-uses (l), enterprises (e), and management options (m) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production, but also by a number of production, land, technology and environmental constraints. 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). More details on the specific land management, economic, and environmental factors tracked in the model are described in the data section below.

The production in the catchment is constrained by the product balance equation by a processing coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

$$Y_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \quad (3.2)$$

Landowners are permitted to include a certain level of irrigation (γwater) for their farming activities, provided that there is excess water (W) available in the catchment:

$$\sum_{s,l,f,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq W_r \qquad (3.3)$$

Land-use in the catchment is constrained by the amount of land available (L) on a particular soil type in a given region:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \qquad (3.4)$$

and landowners are constrained by the their initial land-use allocation (Linit) and the area of land that they can feasibly change:

$$L_{r,s,l} \leq L_{r,s,l}^{init} + Q_{r,s,l} \quad (3.5)$$

The level of land-use change in a given region is constrained to be the difference in the area of the initial land-based activity (Xinit) and the new activity:

$$Q_{r,s,l} \leq \sum_{e,m}\left(X_{r,s,l,e,m}^{init} - X_{r,s,l,e,m}\right) \quad (3.6)$$

and we assume that it is feasible for all land-uses to change with the exception of native forestland and the areas protected by the Department of Conservation (DOC).

$$L_{r,s,DOC} = L_{r,s,DOC}^{init} \quad (3.7)$$

In addition to estimating economic output from the agriculture and forest sectors, NZFARM also tracks a series of environmental factors including N and P leaching and GHG emissions. In the event that the central government or regoinal council regulates farm-based nutrient leaching or greenhouse gas emissions (γ^{env}) by placing a cap on a given environmental output from land-based activities (E), landowners could also face an environmental constraint:

$$\sum_{s,l,f,m} \gamma_{r,s,l,e,m}^{env} X_{r,s,l,e,m} \leq E_r \quad (3.8)$$

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

$$Y, X, Q, L \geq 0 \quad (3.9)$$

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 which then determines the level of agricultural outputs produced in the final nest. Figure 2 shows the potential nest for an irrigated dairy farm in New Zealand that uses a feed pad and produces a series of outputs from pasture grown on Balmoral soil.

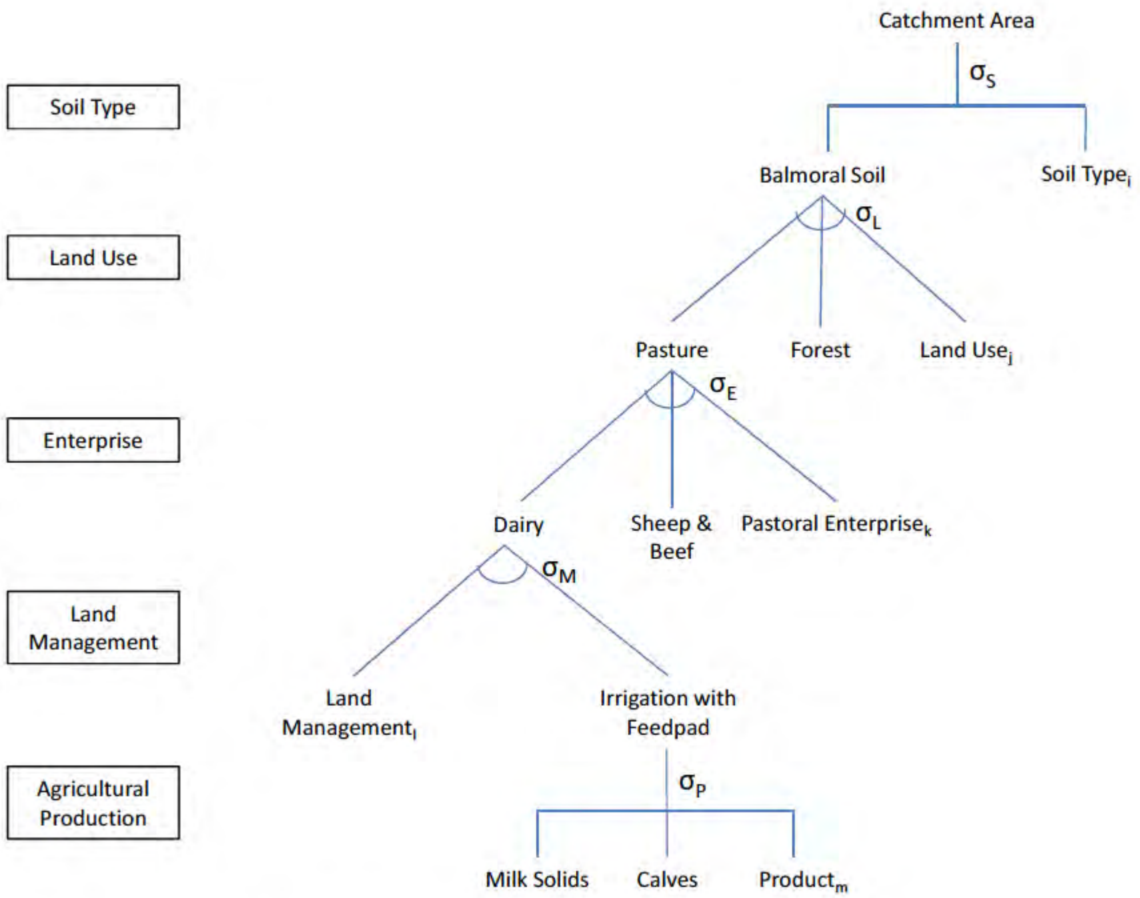

Figure 2 Structure of CET Function Nest in NZFARM

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 NZFARM 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 to shift land-use across soil types. The CET parameter for soil (σ_S) is set to 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 activity produces a fixed set of outputs, as specified in equation 3.2.

NZFARM 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).

1.2.2 Management practices

NZ-FARM has the option to differentiate between ‘business as usual’ (BAU) practices and other management practices that can mitigate GHGs and other environmental pollutants. Farm management practices tracked in the model include:

- Adding DCDs (nitrogen inhibitors)
- Constructing feedpads on dairy farms
- Changing fertiliser regime
- Wintering dairy cows off farm
- Adjusting stocking rate
- Changing land-use or distribution of enterprise mix
- Remove land from production

Some of these mitigation options result in a decline in productivity, while others could potentially increase farm productivity and/or cost more than business as usual practices. The level of uptake of these management practices will vary based on the stringency of the environmental restriction and the relative cost of the different options.

1.2.3 Estimating agricultural productivity

A majority of the yields in NZFARM were estimated using two biophysical models – Farmax and CenW. Farmax is a whole-farm decision support model that uses monthly estimates of pasture growth, farm, and herd information to determine the production and economic outcomes of managerial decisions for the typical types of livestock in New Zealand. CenW is a forest growth model that uses daily climate and nutrient estimates to simulate timber yields. Outputs produced from all other land-uses estimated using a variety of sources.

Livestock

Outputs produced from the livestock sector in NZFARM were estimated using Farmax, a whole-farm decision support model that uses monthly estimates of pasture growth, farm and herd information to determine the production and economic outcomes of managerial decisions (Bryant et al. 2010). The model includes mechanistic and empirical representations of animal and pasture biology. Key inputs for Farmax include fertilizer application rate, stocking rate, supplements bought, and mitigation options. Outputs from the model are all listed on a per hectare basis and include pasture consumed and meat, wool, and milk solids produced.

Simulations from Farmax revealed that there is generally a linear relationship between the N fertiliser application and stocking rate and a non-linear relationship between N application and supplementary feed use. As a result, NZFARM was configured such that the stocking rate for a particular pastoral-farm management option changes proportionally to the change in N fertiliser application rate, but the relationship between N fertilizer and supplementary feed is not directionally proportional. The functional relationships between fertiliser, stocking rate, supplemental feed use are specific for each catchment.

Forestry

Forest plantation yields were estimated using forest growth model CenW (Kirschbaum 1999). The model runs on a daily time step and simulates stand characteristics such as leaf-area development, litter fall, and exchange of water, nitrogen, and carbon. The stand-level dynamics of CenW are explicitly linked to carbon and nitrogen cycling in plants and the soil that allows multiple factors to constraint estimates of growth and carbon exchange of the stand at daily and longer time scales. The model has been used extensively in Australia and New Zealand to predict the growth of forests, notably *Pinus radiata* plantations, in response to silvicultural management options, climate and land-use change (Kirschbaum & Watt 2011; Kirschbaum et al. 2012).

CenW is typically run over periods of many decades to account for the long-term nature of forest production that takes several years to reach economic and biological maturity. The model requires a small set of daily climatic inputs including temperature and precipitation. CenW also requires an estimate of site fertility, soil water-holding capacity, silt and sand fraction as a measure of soil texture, initial stand stocking and the timing and intensity of any silvicultural management operations that occur on stand.

Key outputs from CenW include mean tree height and stand basal area, woody biomass, and wood-volume growth. NZFARM uses the total wood volume at the time of harvest to estimate the annual output of sawn logs and pulp logs (m^3/ha) from timber species located in a given region of the catchment that is roughly a 67/33 percent split between two products.

Other Enterprises

There is no model available to estimate arable and horticultural crop yields consistently for New Zealand. Thus, NZFARM used several sources of literature (e.g. Lincoln University 2010; MAF 2010) and expert opinion (e.g. regional farm consultants) to estimate output productivity for enterprises such as grains, fruit, and vegetables. We assumed that no economic outputs are produced from scrub and natural/DOC land with the exception that some landowners are eligible to receive payments for forest carbon sequestration.

1.2.4 Environmental output estimates

NZFARM model has the ability to track environmental outputs such as nitrogen (N) leaching and phosphorous loss (P), CH_4 emissions from animals, N_2O emissions from livestock and soil, and CO_2 emissions from fuel, electricity, and fertilizer used in the production process. Data on environmental output coefficients were obtained from several sources, as discussed below.

Nutrients

N and P leaching rates for pastoral farming in NZFARM were obtained from the most recent version of OVERSEER (2012), while N and P leaching rates for all other enterprises were constructed using SPASMO (2010). The OVERSEER nutrient budget model is an empirical, annual time-step model which provides average estimates of nutrient loss N, P, 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 (Ledgard et al. 1999). These are used for estimating nutrient inputs and outputs on a per-hectare basis. OVERSEER is used extensively throughout New Zealand by farmers, farm consultants, and fertiliser representatives (Wheeler et al. 2006). The model is increasingly being used as a tool for implementing regional council resource management requirements to limit N and P losses to waterways. The model uses an N balance model concept whereby ∑N inputs = ∑N outputs and assumes that the soil organic N is at an equilibrium level (Thomas et al. 2005).

OVERSEER is site-specific and requires the user to enter readily obtained farm information. 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. Excretal N is calculated as the difference between N intake by grazing animals and N output in animal products, based on user inputs of stocking rate or production and an internal database with information on the N content of pasture and animal products (Thomas et al. 2005). The loss factor for urine or dung is dependent on soil and rainfall, based on New Zealand and overseas research (Ledgard et al 1998). The OVERSEER model does not differentiate between leached N and runoff N, but, based on the limited New Zealand data available for NO_3 runoff, it is expect that the contribution of N from runoff is small (Thomas et al. 2005).

N and P responses for crops and horticulture in NZFARM were estimated using the Soil Plant Atmosphere System Model (SPASMO). 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 (Carbon (C) and N), as well as growth and nutrient uptake by crops. SPASMO uses a daily time-step, and the model is run using 20–30-year weather records (Plant and Food Research 2011). The 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 animals (Rosen et al. 2004). SPASMO has been used primarily for horticultural enterprises, although it is capable of estimating nutrient leaching from all land types (Cichota & Snow 2009).

The set of information and data required to run the nutrient budget models are shown in Table 1 to estimate the N leaching and P loss coefficients on a per hectare basis (γ^{env}) for all feasible farm activities tracked in NZFARM. Summing up the outputs across all farm activities yields the total N leaching (E^N) and P loss (E^P) in the catchment.

Table 1 Key inputs for modelling nutrient outputs

Input	Description
Area of farm block	Hectares (ha)
Farm location	Canterbury, Waikato, etc.
Slope	Steep, easy, rolling, etc.
Soil group/type	Recent, Gley/Balmoral, Lismore etc.
Soil drainage	Free- or poor-draining
Rainfall and irrigation	Milimetres per annum
Fertiliser type	N,P,K, etc.
Fertiliser application	Rate per month for cropping
Management options	Feed pad, applying DCD, etc.
Animal type	Sheep, dairy cows, etc.
Stocking rate	Animals per ha
Yield	Milksolids, wool, etc. (kg per ha)
Feed brought-in or sold	Type and amount in tonnes dry matter (tDM) per ha
Winter management	Grazing, feed-pad, off-farm, etc.

Greenhouse Gas Emissions and forest carbon sequestration

GHG emissions in NZFARM were derived using the IPCC's Good Practice Guidance (2000). Categories of emissions were based on those included the New Zealand GHG Inventory (2010). The specific emissions coefficients included in NZFARM are listed in Table 2, and are estimated on a kg/ha basis. All coefficients were converted to kg carbon dioxide equivalent (kgCO2e) using the same 100 year global warming potentials (GWP) as MfE (2010).

Table 2 GHG coefficients

GHG Coefficient	Description
$\gamma^{enteric\_fermentation}$	CH_4 from enteric fermentation
$\gamma^{manure\_management}$	CH_4 from manure management
γ^{AWMS}	N_2O from animal waste management systems
$\gamma^{grazing}$	N_2O from grazing land
$\gamma^{fertiliser}$	N_2O from fertiliser - direct and indirect
γ^{energy}	CO_2 from petrol, diesel, and electricity
$\gamma^{CSequest}$	CO_2 sequestration from forests

Table 3 provides detail on the sources used to estimate the per hectare GHG emissions from pastoral and arable enterprises in NZFARM. Key data needed to calculate these emissions include stocking rate, fertilizer input, and energy use.

Table 3 GHG emission factors used in calculation of greenhouse gasses

Name	Description	Value	Unit	Reference
EF_{volat}	Indirect emissions from volatilising nitrogen	0.01	kg N2O/kg N	MfE (2010b)
EF_{leach}	Indirect emissions from leaching nitrogen	0.025	kg N2O/kg N	MfE (2010b)
GWP_{N2O}	Global warming potential (GWP) of N2O	310	GWP over 100 yrs	MfE (2009)
GWP_{CH4}	Global warming potential (GWP) of N2O	21	GWP over 100 yrs	MfE (2009)
$C\text{-}CO_2$	Conversion factor C to CO2e	3.67	CO_2/C	n/a
N2O-N	Conversion factor N2O-N emissions to N2O	1.57	N_2O/N	n/a
$Frac_{Leach}$	Percent N leached	0.07	Percent	MfE (2010b)
$Frac_{Leach\_DCD}$	Percent N leached following DCD	0.03	Percent	Clough et al. (2008)
$Frac_{volat}$	Fraction of N that volatilizes	0.10	Percent	MfE (2010b)
$EF_{embodied\ emissions}$	Embodied emissions in N fertilizer	3.00	kg CO2e/kg active ingredient	Wells (2001)
$EF_{direct\ L}$	Lime-direct EF	0.12	kgC/kg lime	IPCC (2006)
$EF_{direct\ N}$	Direct emissions from nitrogen	0.01	kg N2O/kg N	IPCC (2006)
$EF_{direct\ N\ DCD}$	Direct emissions from nitrogen following DCD	0.0033	kg N2O/kg N	Clough et al. (2008)
EF $AW_{anaerobic}$	N – Animal Waste, Anaerobic Lagoons	0.001	kg N2O/kg N	MfE (2010a)
EF AW_{solid}	N – Animal Waste, Solid storage and drylot	0.02	kg N2O/kg N	MfE (2010a)
EF AW_{other}	N – Animal Waste, Other	0.005	kg N2O/kg N	MfE (2010a)
$EF_{electricity}$	Purchased electricity emission factor	0.195	kg CO2e/kWh	MfE (2009)
EF_{diesel}	Diesel emission factor	2.69	kg CO2e/litre	MfE (2009)
EF_{petrol}	Petrol emission factor (default)	2.34	kg CO2e/litre	MfE (2009)
Ent_ferm_{dairy}	Enteric fermentation- dairy cattle	77.07	kg CH4/head/yr	MfE (2010b)
$Ent\_ferm_{non\text{-}dairy}$	Enteric fermentation- non-dairy cattle	56.62	kg CH4/head/yr	MfE (2010b)
Ent_ferm_{sheep}	Enteric fermentation – sheep	11.29	kg CH4/head/yr	MfE (2010b)
Ent_ferm_{deer}	Enteric fermentation – deer	22.42	kg CH4/head/yr	MfE (2010b)
Ent_ferm_{pigs}	Enteric fermentation – pigs	1.5	kg CH4/head/yr	MfE (2010b)
$Manure_{dairy}$	Manure management – dairy cattle	3.3	kg CH4/head/yr	MfE (2010b)
$Manure_{non\text{-}dairy}$	Manure management – non-dairy cattle	0.69	kg CH4/head/yr	MfE (2010b)
$Manure_{sheep}$	Manure management – sheep	0.11	kg CH4/head/yr	MfE (2010b)
$Manure_{deer}$	Manure management – deer	0.2	kg CH4/head/yr	MfE (2010b)
$Manure_{pigs}$	Manure management – pigs	20	kg CH4/head/yr	MfE (2010b)

The digestion of ruminants (such as cows, sheep, and deer) and some non-ruminant animals (such as pigs) causes methane gas to be released as a bi-product of the digestive process. Methane is primarily caused by the breakdown of carbohydrates in ruminant stomachs through a process called enteric fermentation. As a process, enteric fermentation is important as it accounts for most of the emissions associated with livestock (MfE 2010a). Emission from enteric fermentation is calculated as follows:

$$\gamma_{r,s,l,e,m}^{enteric\_fermentation} = SR_{r,s,l,e,m} * \ Entferm_{r,s,l,e,m} * \ GWP_{CH4} \tag{3.10}$$

where, *SR* is the stocking rate for a given activity and type of livestock.

Livestock manure is made up of organic matter and is an important source of emissions. There are two ways animal waste can produce emissions. First, there is the CH_4 associated with the production and decomposition of animal waste. Second, the handling of the waste as it decomposes is an important determinant of the resulting emissions due to the presence or absence of oxygen. The methane emissions associated with the production and decomposition of animal waste is calculated as:

$$\gamma_{r,s,l,e,m}^{manure\_management} = SR_{r,s,l,e,m} * \ Manure_{r,s,l,e,m} * \ GWP_{CH4} \tag{3.11}$$

The handling of manure, referred to as animal waste management systems (AWMS), is estimated in a separate calculation. Table 4 lists the different handling systems manure might be collected in, and the typical fraction of waste from each enterprise for each handling system. Where enterprises use anaerobic lagoons or solid storage, the following calculation is used to determine the N2O released:

$$\gamma_{r,s,l,e,m}^{AWMS} = \begin{bmatrix} SR_{r,s,l,e,m} * N2Oexcretion_{r,s,l,e,m} * Fracdisposal_{r,s,l,e,m} \\ * EF\ AW_{r,s,l,e,m} * (\mathrm{N_2O - N}) * \ \mathrm{GWP}_{N2O} \end{bmatrix} \tag{3.12}$$

Table 4 Non-CO2 emissions per head for each of the five main livestock types, and the fraction of manure

		Fraction of manure to treatment type (Frac$_{disposal}$)			
Livestock	**N_2O excretion (kg N/head/yr)**	**Anaerobic lagoons**	**Pasture**	**Solid storage**	**Other***
Dairy cattle	112.86	0.05	0.95	0	0
Non-dairy cattle	72.99	0	1	0	0
Sheep	15.57	0	1	0	0
Deer	29.79	0	1	0	0
Pigs	16	0.55	0	0.17	0.28

* MfE simply states that this system is not included in the previous 3 categories

Emissions from manure deposited directly onto pasture are calculated separately/as part of equation 3.13 as a majority of manure from most enterprises is deposited directly onto pasture:

$$\gamma_{r,s,l,e,m}^{grazing} = \begin{bmatrix} SR_{r,s,l,e,m} * N2Oexcretion_{r,s,l,e,m} * Fracdisposal_{r,s,pasture,e,m} \\ * EF_{direct\ N} * (\mathrm{N_2O - N}) * \ \mathrm{GWP}_{N2O} \end{bmatrix} \tag{3.13}$$

Many farm activities involved the use of fertilisers that can create positive levels emissions. There are three processes which cause emissions from fertiliser application: direct emissions from application, emissions from volatilisation (vaporisation), and emissions from leaching. These are calculated separately, and summed:

$$\gamma_{r,s,l,e,m}^{fertiliser} = \gamma_{r,s,l,e,m}^{direct} * \gamma_{r,s,l,e,m}^{volatile} * \gamma_{r,s,l,e,m}^{leaching} \tag{3.14}$$

where each component of the right hand side of equation is calculated as follows:

$$\gamma_{r,s,l,e,m}^{direct} = Quantity\ Urea * \ \%N * \ EF_{direct\ N} * \ \mathrm{GWP}_{N2O} \tag{3.15}$$

$$\gamma_{r,s,l,e,m}^{volatile} = Quantity\ Urea * EF_{volat} * \ Frac_{volat} * (\mathrm{N_2O - N}) * \ \mathrm{GWP}_{N2O} \tag{3.16}$$

$$\gamma_{r,s,l,e,m}^{leach} = Quantity\ Urea * EF_{leach} * \ Frac_{leach} * (\mathrm{N_2O - N}) * \ \mathrm{GWP}_{N2O} \tag{3.17}$$

Emissions from fuel such as petrol and diesel used for on-farm activities are estimated based on a litre per annum basis according equation 3.18:

$$\gamma_{r,s,l,e,m}^{fuel} = \ Quantity\ Petrol * \ EF_{petrol} * Quantity\ Diesel * \ EF_{diesel} \tag{3.18}$$

Emissions from electricity used on the farm to run generators and irrigation systems are estimated based on a kWh per annum basis in the following equation:

$$\gamma_{r,s,l,e,m}^{electricity} = Quantity\ Electricity * \ EF_{electricity} \tag{3.19}$$

The total annual GHG emissions from land-based activities in a given region of NZFARM are estimated by summing across all GHG coefficients from all activities:

$$E_r^{GHG} = \ \textstyle\sum_{s,l,e,m} \gamma_{r,s,l,e,m}^{GHG} X_{r,s,l,e,m} \tag{3.20}$$

Forest carbon sequestration rates ($\gamma^{Csequest}$) in NZFARM are derived from the Scion regional lookup tables (Paul et al. 2008). Look-up tables are a series of pre-calculated values of forest carbon stocks, by age, for a given forest type. The carbon sequestration values are equivalent to the weight of CO_2 that is removed from the atmosphere and stored in the forest during growth and expressed in units of tonnes of CO_2 per hectare (tCO_2/ha). Total annual sequestration in a given region is calculated as:

$$E_r^{CSequest} = \ \textstyle\sum_{s,l,e,m} \gamma_{r,s,l,e,m}^{CSequest} X_{r,s,l,e,m} \tag{3.20}$$

The forest carbon sequestration rates in NZFARM include all carbon in all components of a forest namely the stem, branches, leaves and roots, and in the coarse woody debris and fine litter on the forest floor. We assume that all of the CO_2 sequestered in the growing stock and forest is immediately released into the atmosphere at the time of harvest. A typical pine plantation with a 30-year rotation cycle in the North Island has a carbon sequestration rate of about 27 tCO_2/ha/yr, while a stand in the South island is sequesters approximately 22 tCO_2/ha/yr (MAF 2011).

The NZFARM baseline calibration assumes that all harvested forests are immediately replanted and thus net annual emissions/sequestration from plantations are equal to zero. This is not necessarily the case for policy scenarios though where we measure changes in carbon sequestration from plantation forests as the net difference in the area planted. That is, if more forests are planted in a scenario case than the baseline, we consider this as a net increase in annual sequestration. Conversely, if more forests are felled than in the baseline case, we would estimate there would be net emissions from that activity.

The carbon sequestration rates for scrub were estimated using the methods from Trotter et al. (2005) and average about 3 tCO_2/ha/yr. Forests situated on conservation land are typically to be close to a steady state of growth and therefore are assumed to have a carbon sequestration rate of approximately 2 tCO_2/ha/yr. Annual net sequestrations from scrub and conservation land were calculated in the baseline calibration because it is assumed that these two land-uses are left undisturbed.

Net GHG emissions for a region are estimated by deducting the total carbon sequestration from the total emissions:

$$E_r^{NetGHG} = E_r^{GHG} - E_r^{CSequest} \tag{3.20}$$

In the event that a region has a significant amount of scrub or conservation land or new plantations, it is possible for net GHGs to be negative because the annual forest carbon sequestration is greater than the annual emissions.

1.3 Data Sources

We use a case study approach for two catchments in New Zealand to assess the economic and environmental impacts of land-use based policies and climate change: the Hurunui-Waiau catchment in the Canterbury region and the Manawatu catchment in Manawatu-Wanganui region. A more detailed description of the two catchments and data sources used to parameterise NZFARM is provided below.

1.3.1 Hurunui-Waiau

Input data used for the Hurunui-Waiau catchment in NZFARM were obtained from several sources. A summarised list of all the different sets for which data can be obtained (enterprise, soils, etc.) is listed in Appendix A2. Sources of these data are discussed in the following subsections. In total, there were nearly 2,000 combinations of enterprise, input, and mitigation options modelled for the catchment.

Biophysical information and land-use

The Hurunui-Waiau was divided into several regions identified primarily on biophysical properties based on the Land-use Capability (LUC) classes from New Zealand Land Resource Inventory (NZLRI) data. LUC classes are an assessment of the land's capability for use, taking into account its physical limitations and its versatility for sustained production. LUC classes are based on five physical factors: rock type, soil, slope angle, erosion type and severity, and vegetation cover (Lynn et al. 2009). The 6 NZFARM regions for the catchment include the plains, foothills, and the hills where plains are predominantly LUC class 1–5 land, foothills are predominantly LUC class 6 land, and hills are LUC class 7–8 land. A map of the catchment with the NZFARM regions is shown in Figure 3.

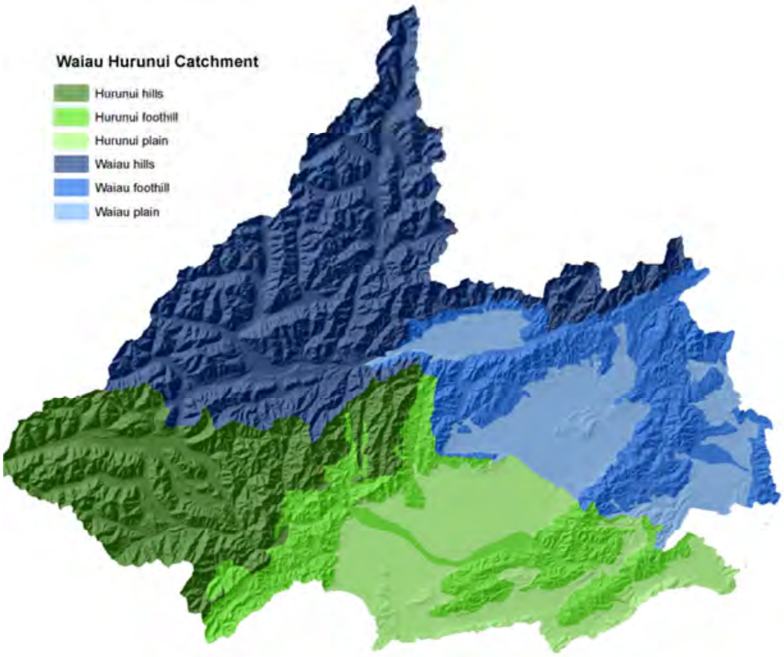

Figure 3 NZFARM regions in the Hurunui-Waiau Catchment

Soil maps (New Zealand Fundamental Soil Layer) for the catchment were used to divide the area into four dominant soil types in the region (Figure 4). These include Balmoral (very light and other), Lismore (light), Templeton (medium) and Hatfield (heavy and deep), which were primarily categorised based on the drainage and profile available water (Webb 2009). The soil data is primarily used to estimate the N leaching and P loss coefficients from different farm activities.

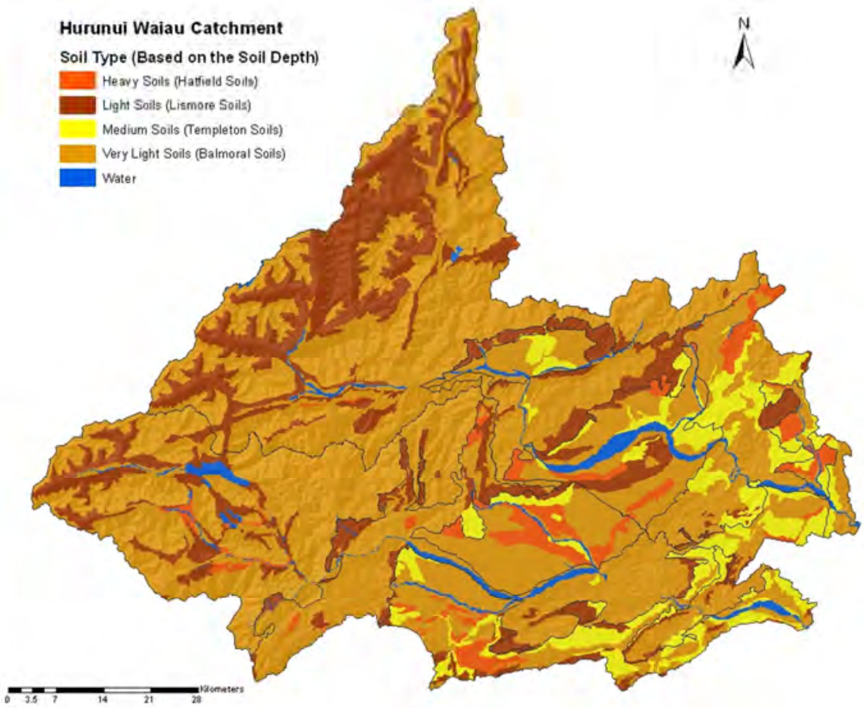

Figure 4 Soil types in the Hurunui-Waiau Catchment

The baseline temperature and precipitation for Hurunui-Waiau catchment were based on average historical climate data from 1980–1999 (1990 for short) recorded by NIWA, who maintains a Virtual Climate Station Network of daily weather data at a regular grid across New Zealand. Daily data were estimated for the whole of New Zealand on a 0.05° latitude/longitude grid (Tait et al. 2006, 2008; Tait & Liley 2009). These data were then aggregated up to an annual basis for the six NZFARM regions in the catchment, as shown in Figure 5.

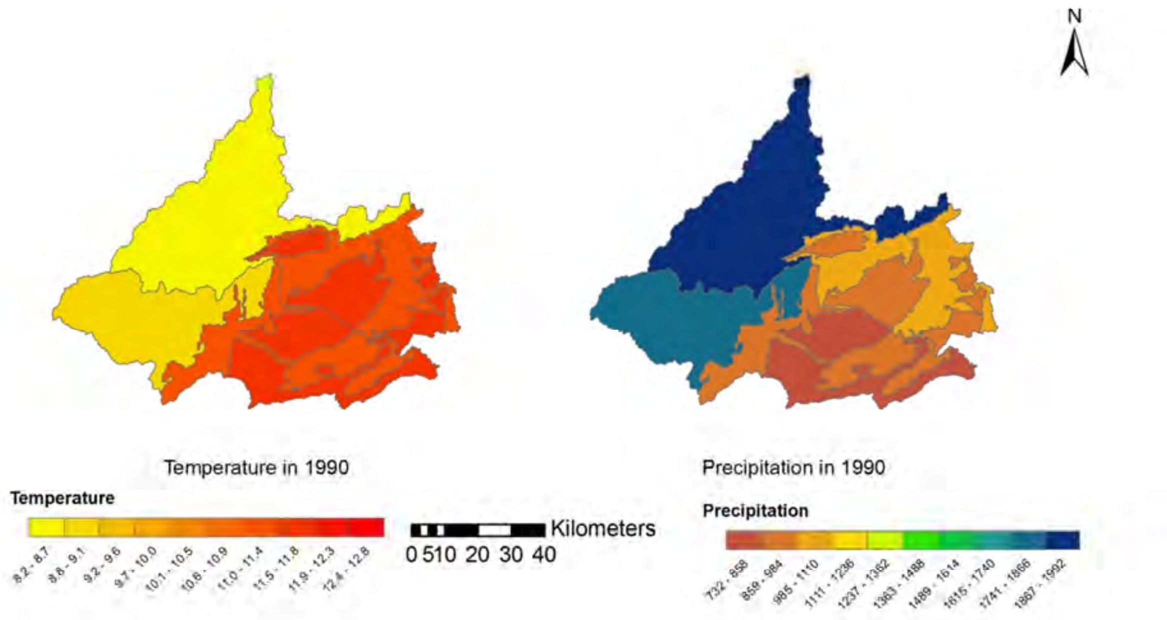

Figure 5 Average annual historical (1980–1999) temperature (C) and precipitation (mm) for Hurunui-Waiau Catchment

Land in each NZFARM region was categorized by six distinct uses: forest, cropland, pasture, horticulture, mānuka-kānuka (scrub), and Department of Conservation (DOC) land. Baseline land-use at property-scale was provided by Environment Canterbury (ECan) (October 2010). The GIS land-use map provided by Environment Canterbury is based on four datasets: AgriBase™, the Land Cover Database (LCDB2), 1:50,000 topographic maps and a map of irrigation derived from consent information, and/or from remote sensing (Hill et al. 2010). AgriBase™ is compiled and maintained by AsureQuality (http://www.asurequality.com/geospatial-services/agribase.cfm) and it is the only comprehensive source of land-use data at a property-scale that is available for the whole catchment. The Land Cover Database (LCDB2) is a national land-use classification provided by the Ministry for the Environment for public use and this was used to fill spatial gaps in AgriBase™ where survey data were incomplete. Topographic maps (sourced from Land Information New Zealand or LINZ) were used to identify golf courses which are not identified by either AgriBase™ or the LCDB2. Irrigated areas within the Canterbury Region were identified using ECan Resource Consent Database and the interpretation of satellite imagery taken during the irrigation season. Refer to Hill et al. (2010) for detailed information on the process of deriving the GIS map. Land-use categories in the Environment Canterbury GIS map are presented in Table 5.

Table 5 Environment Canterbury GIS Map land-use categories

LUWQ land-use	Description
Arable	Arable farms – may have some seasonal grazing
DaiMilk	Dairy milking platforms – no associated runoff land
DaiSup	Dairy farms with some dairy support (runoff block) – irrigated
DaiSupDry	Dairy farms with some dairy support (runoff block) – dryland
Deer	Deer farms (land < 15°)
Def	Default – unable to be classified
For	Plantation forestry
Golf	Golf course
GrazDry	Grazing other people's animals – dryland
GrazIrrig	Grazing other people's animals – irrigated
Hor	Horse farm
Lif	Lifestyle
Msk	Masked-out land, e.g. towns
Nat	Native forestry and other woody non-plantation vegetation
Pig	Pig farm
Scrub	Grassland with woody biomass
ShpDry	Intensive dryland sheep farm
ShpIrrig	Intensive irrigated sheep farm
SnBDry	Intensive dryland sheep & beef farm
SnBHigh	Extensive high country sheep & beef farm
SnBHill	Extensive hill country sheep & beef farm
SnBIrrig	Intensive irrigated sheep & beef farm
Tuss	Tussock
Vit	Viticulture
Water	Water body

Land-use categories from ECan were then renamed to represent all major enterprises tracked in NZFARM (Table 6). Key enterprises include dairy, sheep, beef, deer, timber, barley, wheat, and fruit.

Table 6 Enterprises in NZFARM for Hurunui-Waiau Catchment

ECan Map Categories	NZFARM Categories
Arable	Split evenly between barley/wheat and soils
DaiMilk	3 (VL), 3.5 (M) & 4 (D) dairy cows/ha wintered off farm_irrigated
DaiSup	3 (VL/L/PD), 3.5 (M) & 4 (D) dairy cows/ha wintered on farm_irrigated
DaiSupDry	Dairy_3cows/ha_wintered off/on farm
Deer	Deer
For	Forestry
GrazDry	Sheep and beef 50:50
GrazIrrig	Sheep and beef 50:50_irrigated
Nat	Cons
Pig	Pigs
Scrub	Scrub
ShpDry	Sheep 100%
ShpIrrig	Sheep 100%_irrigated
SnBDry	Sheep and beef 50:50
SnBHigh	Sheep and beef 50:50
SnBHill	Sheep and beef 50:50
SnBIrrig	Sheep and beef 50:50_irrigated
Tuss	Cons
Vit	Grapes
Water	n/a
Other	n/a

NZFARM includes 20 unique enterprises for the catchment. Most NZFARM regions only allow a subset of enterprises and activities that can be carried out on the land there. These sets were determined by bio-geographical characteristics like slope, soil type, and access to water. Figure 6 shows the distribution of aggregate enterprises in the Hurunui-Waiau catchment.

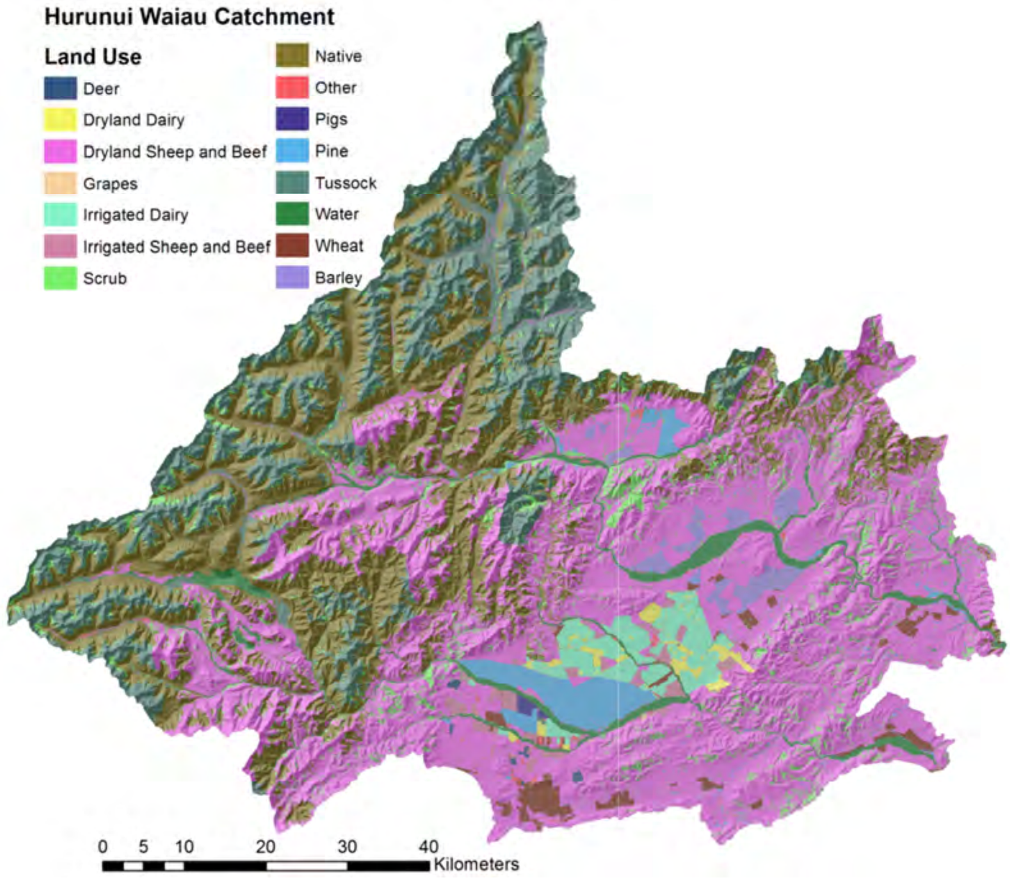

Figure 6 Aggregate enterprises in the Hurunui-Waiau Catchment

Inputs, outputs and prices

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. 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 for pastoral enterprises were calculated based on Farmax (Bryant et al. 2010). Forestry production data was obtained from the CenW model (Kirschbaum et al. 2012). Prices and other outputs were gathered from data provided by consultants, Lincoln University (2010), Ministry of Agriculture and Forestry (MAF) farm monitoring report (2010), and the 2010 State of New Zealand Agriculture and Forestry (SONZAF), and listed in 2009 New Zealand dollars (NZD). Forestry production data was obtained from the CenW model (Kirschbaum 2010). Sources of the outputs and prices from for the Hurunui-Waiau catchment are listed below in Table 7.

Table 7 Sources of price and yield of commodities in NZFARM for Hurunui-Waiau Catchment

Output	Unit	Consultant	Farmax	Lincoln Financial Budget Manual	MAF SONZAF	MAF Farm monitoring reports	Other Source
Milk solids	kg	√	√		√		
Dairy calves sold	kg			√			
Heifers sold	kg	√	√		√		
Steers sold	kg	√	√		√		
Bulls sold	kg	√			√		
Lamb sold	kg	√	√		√		
Wool	kg	√	√		√		
Mutton	kg	√	√		√		
Cull cows sold	kg	√	√		√		
Stag venison	kg	√	√		√		
Hind venison	kg	√	√		√		
Velvet	kg		√	√			
Pigs	kg						NZ pork industry board
Berry fruit – Blackcurrant	kg						Berryfruit Industry
Grapes	kg			√			
Wheat	kg			√			
Barley	kg						United wheat growers NZ Ltd
Sawn logs sold for export	m3				√		CenW
Timber sold for pulp and paper (m^3/ha)	m3				√		CenW

Each enterprise also faces a large set of fixed and variable costs ranging from stock replacement costs to depreciation, which were obtained from personal communication with consultants, Ministry of Agriculture and Forestry (MAF) farm monitoring report (2010), and Lincoln University (2010). The cost series was developed for each enterprise and varied across all regions. Altering the cost of inputs or price of outputs as well as the list of enterprises available for a given NZFARM region will change the distribution of regional enterprise area, but the total area is constrained to remain the same across all model scenarios. Sources of these costs are listed in Table 8.

Table 8 Key data sources: Input and production costs in NZFARM

Category	Consultant	Lincoln University Financial Budget Manual	MAF Farm Monitoring Reports	Other Source
Variable Costs				
Stock replacement costs	√		√	NZ pork industry board
Wages	√		√	
Animal health cost	√		√	
Dairy shed expenses	√		√	
Breeding cost	√		√	
Electricity cost	√		√	Berryfruit industry
Fertiliser cost ($/ha)	√		√	Berryfruit industry
Cartage expenses ($/ha)	√		√	
Cost of fertilizer application ($/ha)	√		√	
Fuel costs ($/ha)	√		√	
shearing cost ($/ha)	√		√	
seed costs ($/ha)	√		√	Berryfruit industry
Imported feed costs ($/ha) – hay and silage	√		√	
Imported feed costs ($/ha) – crops	√		√	
Imported feed costs ($/ha) – grazing	√		√	
Imported feed costs ($/ha) – other	√		√	
Water charges ($/ha)	√	√	√	Berryfruit industry
Contractors (fencing, spraying, etc.) ($/ha)	√	√	√	
Weed & Pest control costs ($/ha)	√	√	√	Berryfruit industry
Pollination ($/ha)		√	√	
Frost protection ($/ha)		√		
Freight costs ($/ha)	√	√		
Vehicle Maintenance ($/ha)	√		√	
General repair and maintenance ($/ha)	√		√	
Accountant costs ($/ha)	√		√	
Legal and farm consultancy costs ($/ha)	√		√	
Phone and mail costs ($/ha)	√		√	
Any other administrative costs ($/ha)	√		√	
Rates (property taxes) ($)	√		√	
Insurance ($)	√		√	
Other standing costs (including ACC) ($/ha)	√		√	
Other expenditure ($)	√		√	
Wages on management (Drawings) ($/ha)	√		√	
Depreciation on capital items ($)	√		√	
Harvesting costs ($/ha)		√		
Annualised Fixed Cost				
Cultivation cost ($/ha)		√		
Roading costs for forest plantations	√			
Average land preparation (from mānuka/kānuka and gorse) ($/ha) amortized over harvest length	√			
Planting costs ($/ha) amortized over harvest length	√			
Annual forest management fee ($/ha)	√			
Herbicide costs and application ($/ha) amortized over harvest length	√			
Fungicide costs and application ($/ha) amortized over harvest length	√			
Silvicultural mgt – one hit prune ($/ha) amortized over harvest length	√			
Silvicultural mgt – one hit thin ($/ha) amortized over harvest length	√			
Harvest costs ($/ha) amortized over harvest length	√			
Harvest preparation costs (e.g. cost of landings) ($/ha) amortized over rotation length	√			
DCD Costs ($/ha/yr)				Ravensdown Fertiliser
Feedpad Costs ($/ha/yr)	√			Wolken 2009, Dairy NZ 2008

Most enterprises in the catchment have the option to vary the use of fertilizer. NZFARM tracks changes in product and environmental outputs from changes in fertilizer for the following applications: 100% of recommended 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, no N application, but 100% of recommended application of all other fertilizers, 0% of recommended lime, but 100% of recommended application of all other fertilizers, and finally, no fertilizer application. The physical levels of fertilizer applied were constructed by consultants based on information from a survey of farmers in the catchment. The amounts of nutrients applied were calculated using the nutrient content of the types of fertiliser applied. Examples of N fertiliser and nutrient application rates for some mitigation options are presented in Table 9. Table 10 presents the nutrient content of the most widely used fertiliser products from Ravensdown.

Table 9 Fertiliser and nutrient N application rates for selected pastoral enterprises for Hurunui-Waiau Catchment (Kg/N fertiliser/ha)

Business as usual Fertiliser Application Rate	Irrigated Dairy Wintering On 3 cows/ha Waiau Plains	Irrigated Dairy Wintering Off 3 cows/ha Waiau Plains	Irrigated Sheep and Beef Hurunui Foothills	Dryland Sheep and Beef Hurunui Foothills	Irrigated Dairy Wintering On 4 cows/ha Hurunui Plains	Irrigated Dairy Wintering Off 4 cows/ha Hurunui Plains
100%	300	138	260	119.6	500	230
80%	240	110.4	208	95.68	400	184
60%	180	82.8	156	71.76	300	138
50%	150	69	130	59.8	250	115
0%	0	0	0	0	0	0

Table 10 Fertilizer nutrient contents, Hurunui-Waiau Catchment

Fertilizer	N	P	K	S	Ca	Mg
	Nutrient contents (%)					
Urea	46%	0%	0%	0%	0%	-
Superphosphate	0%	8%	0%	24%	18%	-
50% Potash Super	0%	5%	25%	5%	10%	-
Lime	0%	0%	0%	0%	87%	-
Magamp	7%	17%	5%	-	-	12%
DAP 13S	11%	15%	0%	13%	6%	-
RPR/Sulphur Super	0%	11%	0%	12%	26%	-
Crop master 20	19%	10%	0%	13%	0%	0%
Early potato base	12%	8%	7%	11%	4%	1%
Ammonium Sulphate	21%	0%	0%	24%	0%	0%
Maxi sulphur super	0%	5%	0%	47%	11%	0%

Source: http://www.ravensdown.co.nz/

Stocking rates used for the different NZFARM regions in the Hurunui-Waiau catchment are listed in Table 11–Table 12. In each dairy enterprise, cows can be wintered off site (W/O), irrigated (IRR) or any combination, and could include the use of DCDs (DCD). For all pastoral enterprises except dairy (below), stock numbers change with differing fertiliser regimes: 100N is the recommended N fertiliser applied; 80N is an application of 80% recommended fertiliser level, and so on. Lime is also experimentally removed (0L), as is all fertiliser (NONE).

Table 11 Dairy stocking rates, Hurunui-Waiau

	Stocking rate per ha					
Dairy enterprises	HH	HP	HF	WH	WP	WF
Dairy 3 cows/ha		2.7	3		2.7	3
Dairy 3 cows/ha IRR		3	3		3	3
Dairy 3 cows/ha W/O		2.7	3		2.7	3
Dairy 3 cows/ha W/O IRR		3	3		3	3
Dairy 3.5 cows/ha		3.5	3.5		3.5	3.5
Dairy 3.5 cows/ha IRR		3.5	3.5		3.5	3.5
Dairy 3.5 cows/ha W/O		3.5	3.5		3.5	3.5
Dairy 3.5 cows/ha W/O IRR		3.5	3.5		3.5	3.5
Dairy 4 cows/ha		4	4		4	4
Dairy 4 cows/ha IRR		4	4		4	4
Dairy 4 cows/ha W/O		4	4		4	4
Dairy 4 cows/ha W/O IRR		4	4		4	4
Dairy 5 cows/ha		5	5		5	5
Dairy 5 cows/ha IRR		5	5		5	5
Dairy 5 cows/ha W/O		5	5		5	5
Dairy 5 cows/ha W/O IRR		5	5		5	5
Dairy support		1			1	
Dairy support IRR		2.5			3	

Note: blank values represent enterprises not found in each region. HH = Hurunui Hills, HP = Hurunui Plains, HF = Hurunui Foothills, WH= Waiau Hills, WP = Waiau Plains, WF = Waiau Foothills.

Table 12 Deer and pigs stocking rates, Hurunui-Waiau

	Stocking rate per ha					
Deer and pig enterprises	HH	HP	HF	WH	WP	WF
Deer	2	9	5	2	9	5
Deer with DCD	2.1	9.4	5.2	2	9.4	5
Deer IRR 100N		21.7			21.7	
Deer IRR 80N		21.3			21.3	
Deer IRR 60N		20.9			20.9	
Deer IRR 50N		20.7			20.7	
Deer IRR 0N		19.6			19.6	
Deer IRR 0L		21.7			21.7	
Deer IRR NONE		19.6			19.6	
Deer IRR DCD 100N		22.2			22.2	
Deer IRR DCD 80N		22			22	
Deer IRR DCD 60N		21.8			21.8	
Deer IRR DCD 50N		21.8			21.8	
Deer IRR DCD 0N		21.3			21.3	
Deer IRR DCD 0L		22.2			22.2	
Deer IRR DCD NONE		21.3			21.3	
Pigs		4	4		4	4

Table 13 Stocking rates used in the calculation of Sheep and Beef greenhouse gasses

	Stocking rate per ha					
Sheep and beef enterprises	HH	HP	HF	WH	WP	WF
SNB (sheep only)	1	4.5	2.5	1	4.5	3
SNB (sheep only) with DCD	1	4.7	2.6	1	4.7	3
SNB (beef only)	1	4.5	2.5	1	4.5	3
SNB (beef only) with DCD	1	4.5	2.6	1	4.5	3
SNB (sheep only) IRR 100N		10.9	10.9		10.9	
SNB (sheep only) IRR 80N		10.6	10.6		10.6	
SNB (sheep only) IRR 60N		10.4	10.4		10.4	
SNB (sheep only) IRR 50N		10.3	10.3		10.3	
SNB (sheep only) IRR 0N		9.8	9.8		9.8	
SNB (sheep only) IRR 0L		10.9	10.9		10.9	
SNB (sheep only) IRR NONE		9.8	9.8		9.8	
SNB (sheep only) IRR DCD 100N		11.3	11.3		11.3	
SNB (sheep only) IRR DCD 80N		11.1	11.1		11.1	
SNB (sheep only) IRR DCD 60N		10.9	10.9		10.9	
SNB (sheep only) IRR DCD 50N		10.7	10.7		10.7	
SNB (sheep only) IRR DCD 0N		10.2	10.2		10.2	
SNB (sheep only) IRR DCD 0L		11.3	11.3		11.3	
SNB (sheep only) IRR DCD NONE		10.2	10.2		10.2	
SNB (beef only) IRR 100N		10.9	10.9		10.9	
SNB (beef only) IRR 80N		10.6	10.6		10.6	
SNB (beef only) IRR 60N		10.4	10.4		10.4	
SNB (beef only) IRR 50N		10.3	10.3		10.3	
SNB (beef only) IRR 0N		9.8	9.8		9.8	
SNB (beef only) IRR 0L		10.9	10.9		10.9	
SNB (beef only) IRR NONE		9.8	9.8		9.8	
SNB (beef only) IRR DCD 100N		11.3	11.3		11.3	
SNB (beef only) IRR DCD 80N		11.1	11.1		11.1	
SNB (beef only) IRR DCD 60N		10.9	10.9		10.9	
SNB (beef only) IRR DCD 50N		10.7	10.7		10.7	
SNB (beef only) IRR DCD 0N		10.2	10.2		10.2	
SNB (beef only) IRR DCD 0L		11.3	11.3		11.3	
SNB (beef only) IRR DCD NONE		10.2	10.2		10.2	

Mitigation options

The set of mitigation options for the aggregate enterprises tracked in the Hurunui-Waiau are listed in Table 14. The response of mitigation options on output, stocking rate, and supplements bought for pastoral enterprises were calculated based on Farmax (Bryant et al. 2010). All other enterprises were assumed to follow only the business-as-usual management practices. That being said, landowners with limited mitigation options could still adjust their enterprise mix by planting forests or leaving some land fallow.

Table 14 Mitigation options in Hurunui-Waiau Catchment

Enterprise	Mitigation Options
Irrigated Dairy	Feed pad, stocking rate, fertiliser, winter off, DCD, land-use change
Dryland Dairy	Feed pad, stocking rate, fertiliser, winter off, DCD, land-use change
Irrigated Sheep and Beef	Stocking rate, fertiliser, DCD, land-use change
Dryland Sheep and Beef	Stocking rate, DCD, land-use change
Irrigated Deer	Stocking rate, fertiliser, DCD, land-use change
Dryland Deer	Stocking rate, DCD, land-use change
Pigs	Stocking rate, DCD, land-use change
Arable Crops	Land-use change
Horticulture	Land-use change
Forestry	Land-use change
Scrub	Land-use change
Natural/Conservation	None (held fixed for all scenarios)

Net revenue

As mentioned during the discussion on defining the NZFARM regions for the catchment, productivity can also vary across different regions of the catchment due to climatic or physical conditions. This has an impact on the amount of net revenue a landowner can feasibly earn, given that the output price and costs of input remain constant. The range of net revenue possibilities for key enterprises in the catchment are shown in Figure 7.

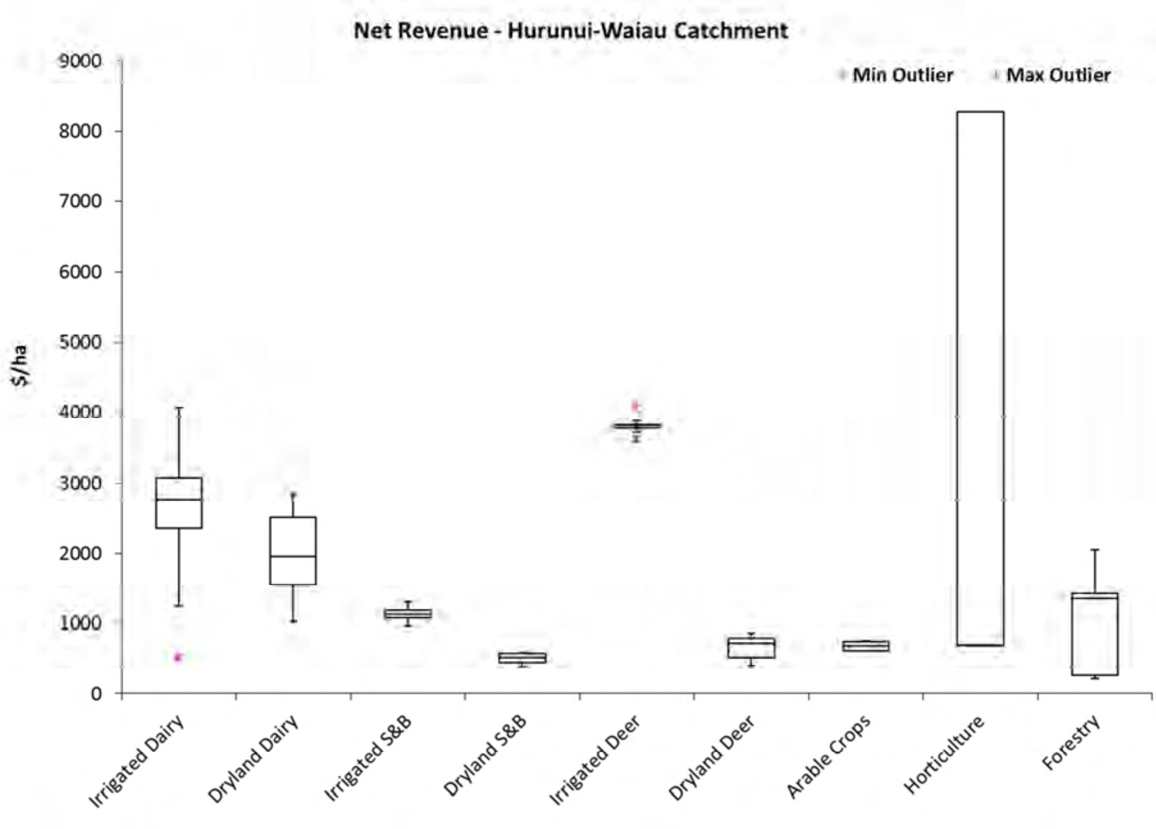

Figure 7 Range of net revenue potential for key enterprises ($/ha) in Hurunui-Waiau Catchment

Environmental outputs

NZFARM has the ability to track environmental outputs such as CH_4 emissions from animals, N_2O emissions from livestock and soil, and CO_2 emissions from fuel, electricity, and fertilizer used in the production process, N leaching, and P loss. Data on environmental output coefficients were obtained from several sources, as discussed in Section 3.2.4. Figure 8 shows the variation in GHG emissions from key enterprises in the Hurunui-Waiau catchment.

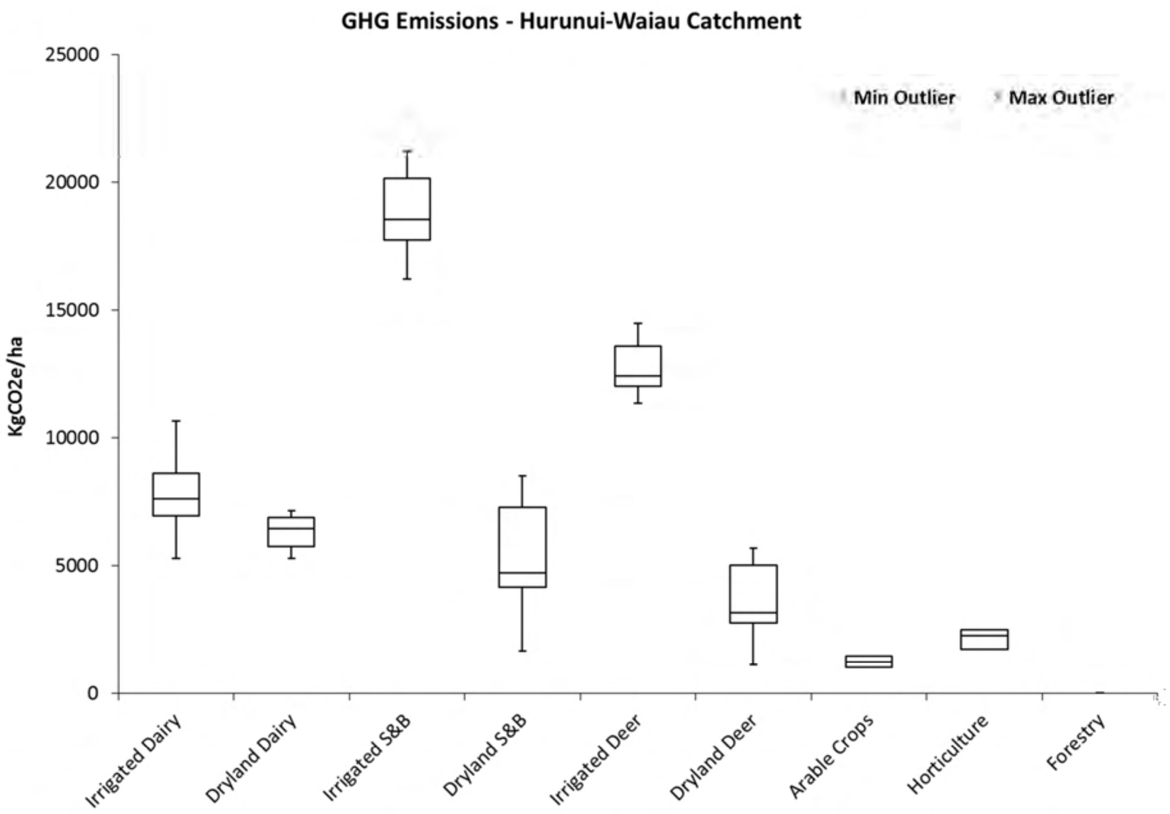

Figure 8 Range of GHG emissions (kgCO2e/ha) in Hurunui-Waiau Catchment

N leaching and P loss rates for pastoral farming were estimated using the 5.4.9 version of OVERSEER (2010). Nutrient leaching rates from arable and horticultural crops were estimated using a recent version of SPASMO (2010). Values for N leaching from pine plantations and native vegetation were taken as an average from the literature (e.g. Parfitt et al. 1997; Menneer et al. 2004). We assumed zero P loss from plantations or native forest lands.

The variations in N leaching and P loss from key enterprises in the Hurunui-Waiau catchment are shown in Figure 9 and Figure 10, respectively. These figures demonstrate the variability in nutrient leaching rates for the same enterprise across the catchment. This relates to differences in stocking rate, soil type, irrigation scheme, fertiliser application, and mitigation options implemented. The large spread in N leaching rates for dairy, irrigated sheep and beef, and arable crops indicates that they have greater mitigation potential on a per ha basis compared to other enterprises, while dryland sheep and beef the largest mitigation potential for P.

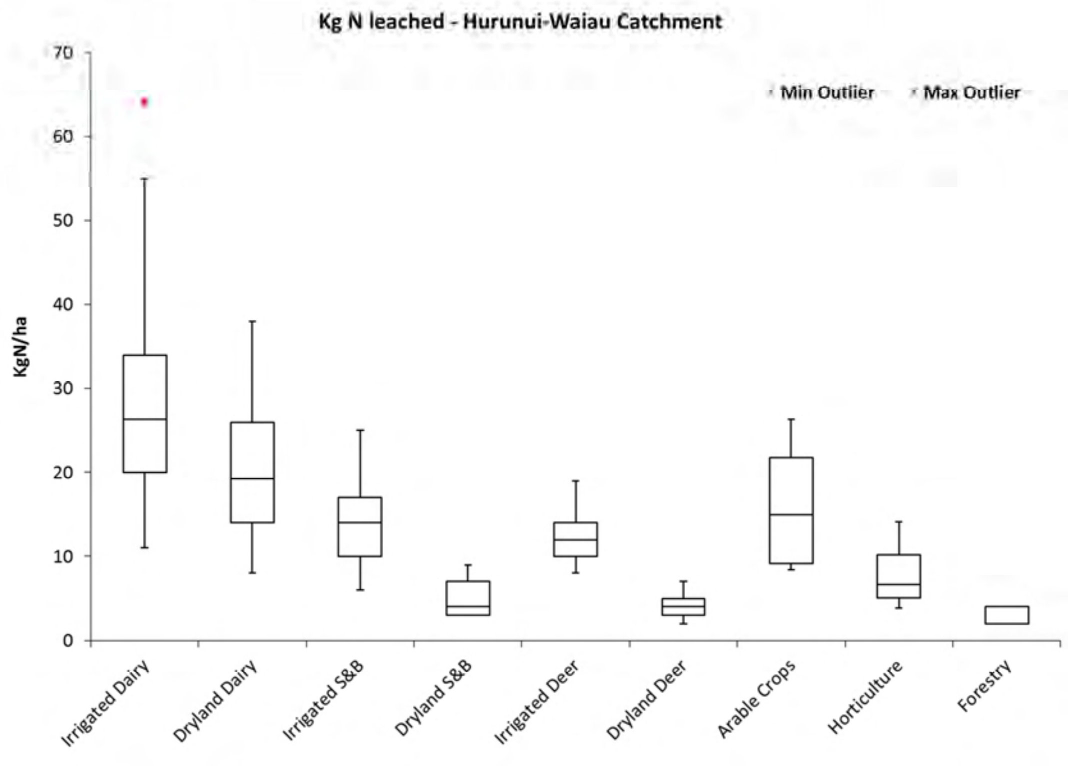

Figure 9 Range of N leaching rates (kgN/ha) for key enterprises in Hurunui-Waiau Catchment

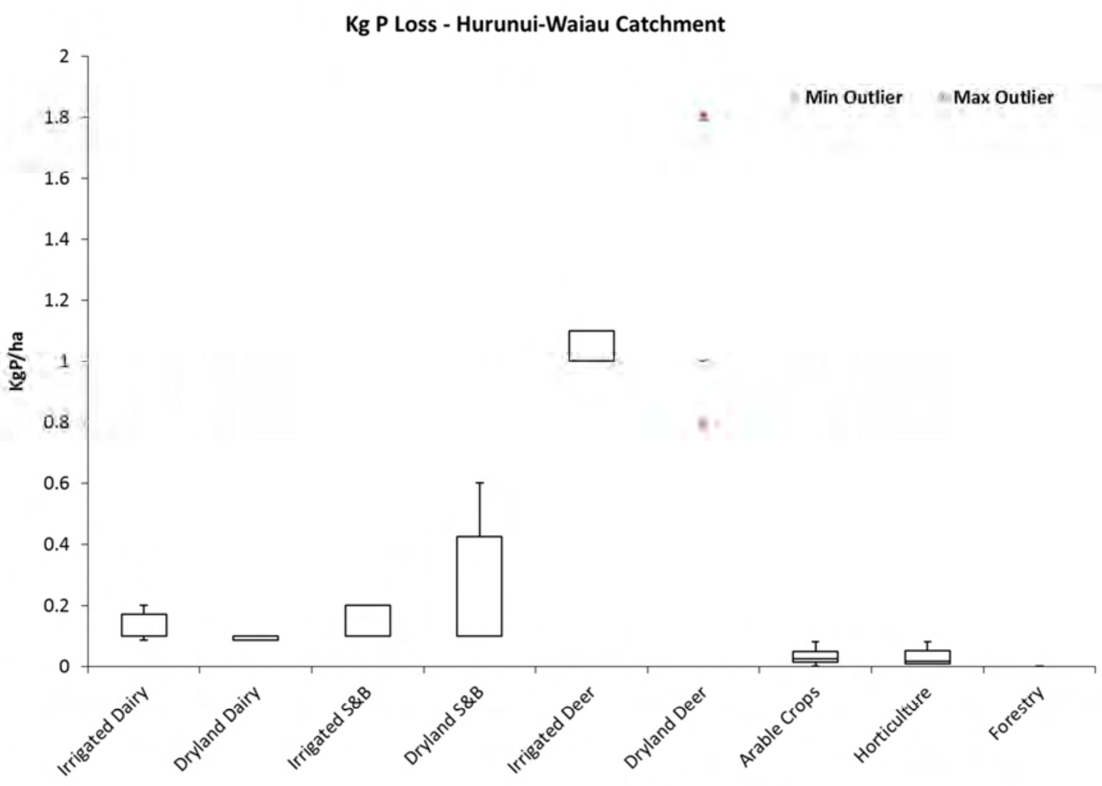

Figure 10 Range of P loss rates (kgP/ha) for key enterprises in Hurunui-Waiau Catchment

1.3.2 Manawatu

Input data used for the Manawatu catchment in NZFARM was obtained from several sources. A list of all the sets for which data was obtained for the Manawatu catchment (enterprise, soils, mitigation options, etc.) is shown in Table 25 of Appendix A2. Sources of these data are discussed in the following subsections. In total, there were nearly 800 combinations of enterprise, input, and mitigation options modelled for the Manawatu catchment.

Biophysical Information and Land-use

Manawatu catchment area was divided into four NZFARM regions based primarily on biophysical properties derived based on the Land-use capability (LUC) classes from New Zealand Land Resource Inventory (NZLRI) data. LUC classes are an assessment of the land's capability for use, while taking into account its physical limitations and its versatility for sustained production. LUC classes are based on five physical factors; rock type, soil, slope angle, erosion type and severity and vegetation cover (Lynn et al. 2009). The 4 regions include the flats, and the hills where flats are predominantly LUC class 1-4 land, and hills are predominantly LUC class 5-8 land. A map of the catchment with the NZFARM regions is shown in Figure 11.

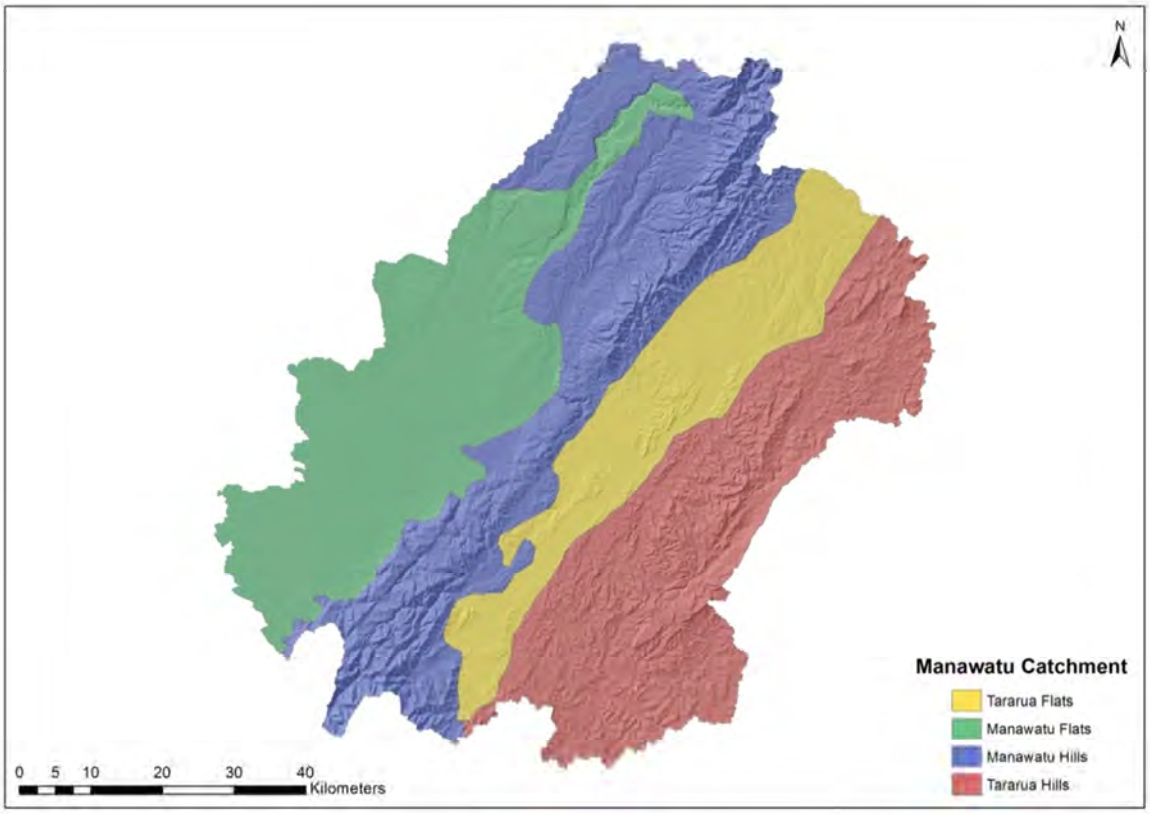

Figure 11 Regions in the Manawatu Catchment

Soil types in the catchment were grouped based on soil orders from the New Zealand soil classification, obtained from New Zealand fundamental soil layer soil maps. Figure 12 shows the simplified soil map used in NZFARM which include the three predominant soil orders in the catchment: Brown soils, Gley Soils and Pallic soils.

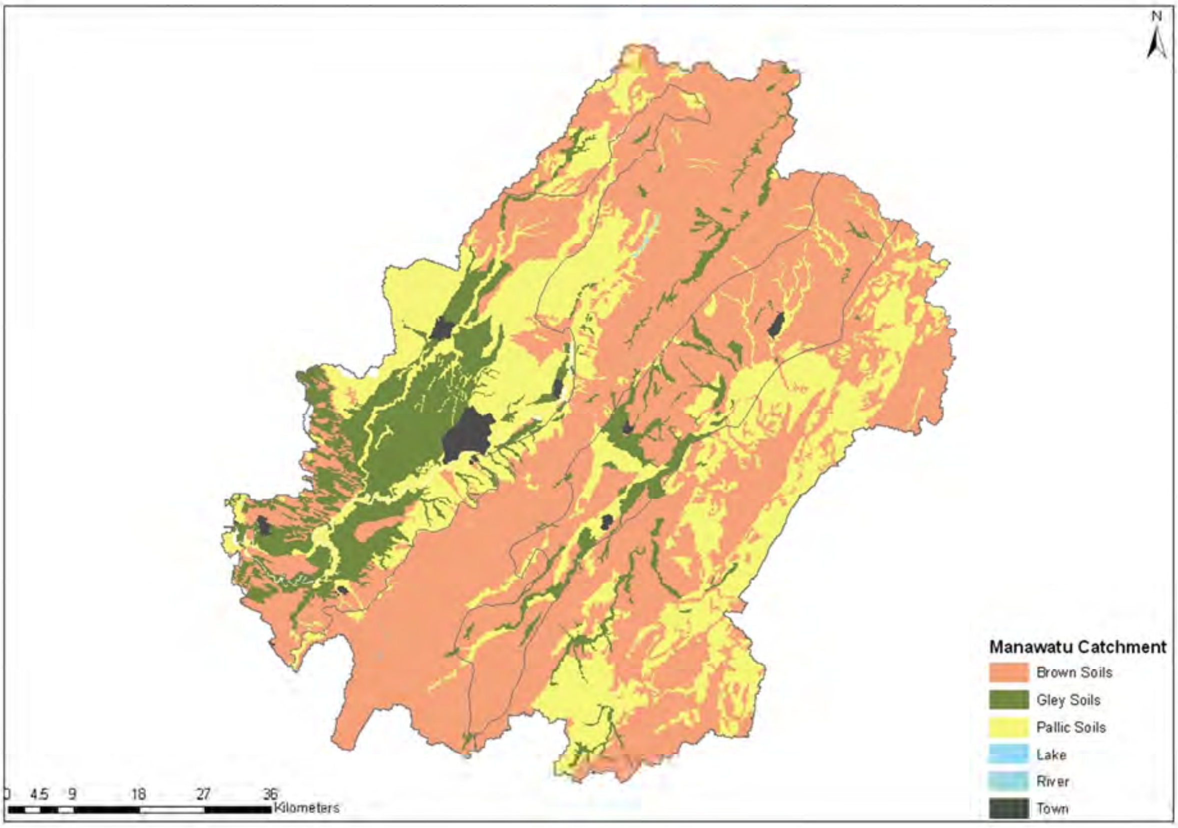

Figure 12 Primary Soil Types in the Manawatu Catchment

The baseline temperature and precipitation for the Manawatu catchment were based on average historical climate data from 1980-1999 (1990 for short) recorded by NIWA, who maintains a Virtual Climate Station Network of daily weather data at a regular grid across New Zealand. Daily data were estimated for the whole of New Zealand on a 0.05° latitude/longitude grid (Tait et al. 2006, 2008; Tait & Liley 2009). These data were then aggregated up to an annual basis for the four NZFARM regions in the catchment, as shown in Figure 13.

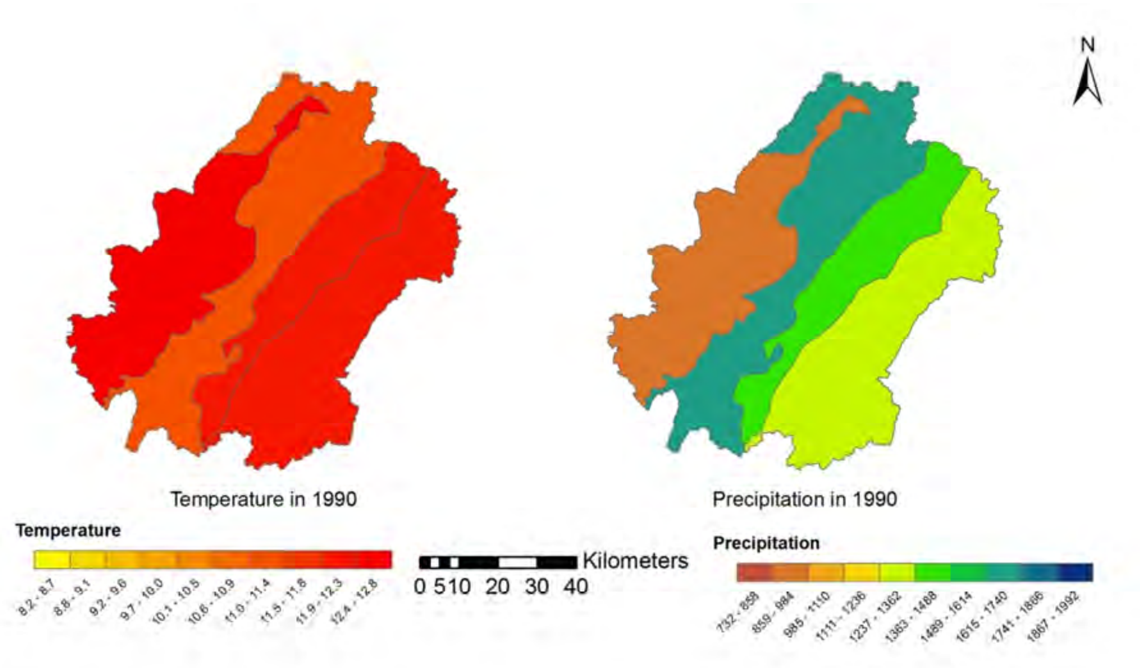

Figure 13 Average annual historical (1980-1999) temperature (C) and precipitation (mm) for Manawatu Catchment

Land in each NZFARM region was categorized by six distinct uses: forest, cropland, pasture, horticulture, Manuka-Kanuka (scrub), and Department of Conservation (DOC) land. Baseline land-use at property-scale was obtained from AgriBase™ (2007) and confirmed by experts[1] in the catchment. AgriBase™ is compiled and maintained by AsureQuality (*http://www.asurequality.com/geospatial-services/agribase.cfm*) and it is the only comprehensive source of land-use data at a property-scale that is available for the whole catchment. 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, barley and potato. AgriBase™ land-use categories were grouped to form the enterprise categories tracked in NZFARM. Table 15 shows land-use categories in AgriBase™.

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[1] Expert opinion from Manawatu farm consultants Sheppard agriculture (Sheep and Beef), and Agriculture NZ Ltd (Dairy), and forestry experts of Forestrymaps (forestry Ariel Mapping) and NZ Farm Forestry Association

Table 15 NZFARM Enterprises for Manawatu Catchment

AgriBase™ land-use categories	Description	NZFARM enterprise categories
ARA	Arable cropping or seed production	Arable – maize, barley and wheat
BEF	Beef cattle farming	Sheep and beef – area split between breeding, breeding and finishing and finishing and trading
DRY	Dairy dry stock	
GOA	Goat farming	
GRA	Grazing	
SHP	Sheep farming	
SNB	Mixed Sheep and Beef farming	
DAI	Dairy cattle farming	Dairy – irrigated and non-irrigated
DEE	Deer farming	Deer
DOG	Dogs	n/a
EMU	Emu bird farming	
LIF	Lifestyle blocks	
NEW	New Record - Unconfirmed Farm Type	
NOF	Not farmed (i.e. idle land or non-farm use)	
OAN	Other livestock (not covered by other types)	
OPL	Other planted types (not covered by other types)	
OST	Ostrich bird farming	
OTH	Enterprises not covered by other classifications	
UNS	Unspecified (i.e. farmer did not give indication)	
VIT	Viticulture, grape growing and wine	
ZOO	Zoological gardens	
HOR	Horse farming and breeding	
PIG	Pig farming	
POU	Poultry farming	
FLO	Flowers	Horticulture - potato
FRU	Fruit growing	
NUR	Plant Nurseries	
VEG	Vegetable growing	
FOR	Forestry	Forest – Pine, Douglas fir and Eucalyptus
NAT	Native Bush	Natural – mānuka kānuka and conservation land

NZFARM includes 18 enterprises for the catchment, but most NZFARM regions have only a subset of practices that can be carried out on the land there. These sets are determined by bio-geographical characteristics like slope, soil type, access to water, etc. Figure 14 shows the aggregate land-use in the Manawatu catchment.

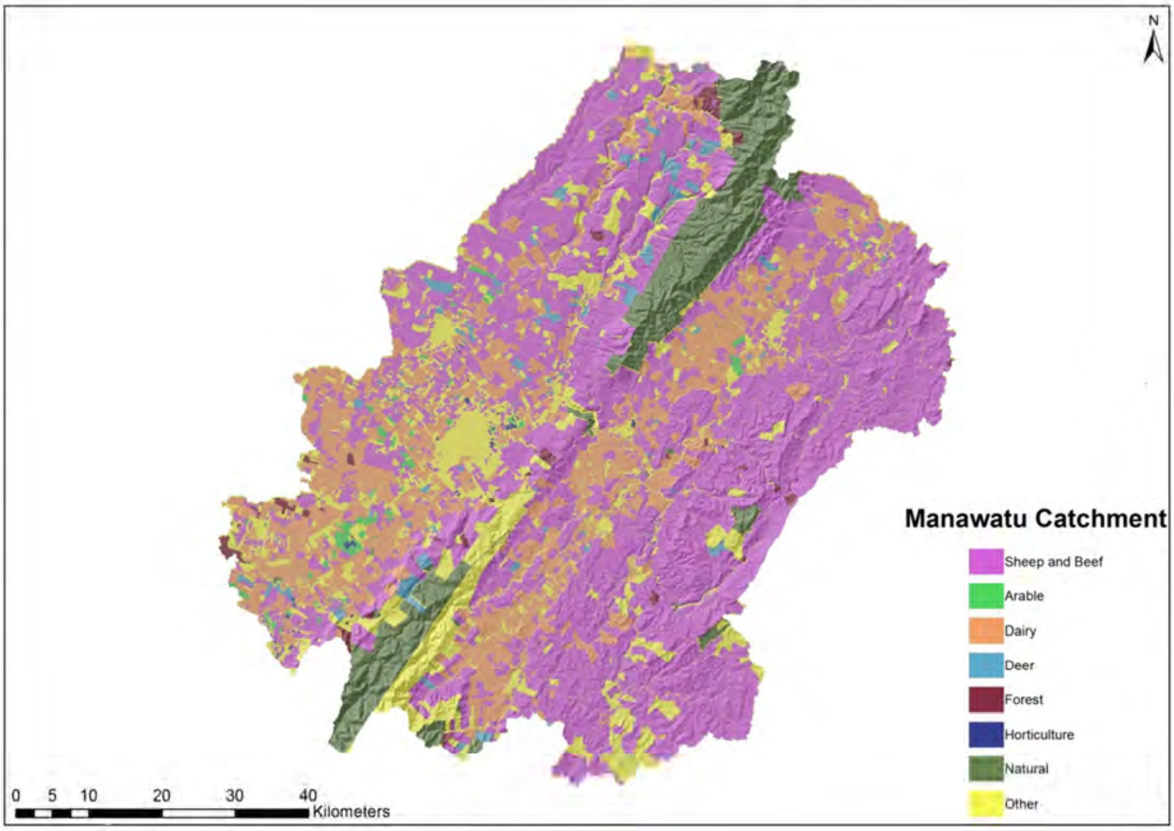


Figure 14 Land-use for Manawatu Catchment

Inputs, outputs and prices

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 for pastoral enterprises were calculated based on Farmax (Bryant et al. 2010). Forestry production data was obtained from the CenW model (Kirschbaum et al. 2012). Prices and other outputs were gathered from expert opinion, and data provided by Ministry of Agriculture and Forestry (MAF) farm monitoring report (2007), the 2007 State of New Zealand Agriculture and Forestry (SONZAF), and Lincoln University Financial Budget Manual (2008), and listed in 2007 New Zealand dollars (NZD). Table 16 presents the sources of the outputs and prices.

Table 16 Key data sources for commodity prices in NZFARM

Output	Unit	Consultant	Farmax	Meat and wool NZ economic service	Lincoln Financial Budget Manual	MAF SONZAF	MAF Farm monitoring reports	Other Source
Milk solids	kg	√	√			√	√	
Dairy calves sold	kg	√						
Heifers sold	kg	√	√			√	√	
Steers sold	kg	√	√			√	√	
Bulls sold	kg	√	√			√	√	
Lamb sold	kg	√	√	√		√	√	
Wool	kg	√	√	√		√	√	
Mutton	kg	√	√	√		√		
Cull cows sold	kg	√	√	√		√	√	
Stag venison	kg					√	√	
Hind venison	kg					√	√	
Velvet	kg						√	
Wheat	kg				√			
Barley	kg				√	√		United Wheat growers NZ Ltd
Maize-silage	kg					√	√	
Maize-grain	kg					√	√	
Potato	kg	√					√	
Sawn logs	m^3				√	√		CenW
Pulp logs	m^3				√	√		CenW

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 experts, Ministry of Agriculture and Forestry (MAF) farm monitoring report (2007), and Lincoln University Financial Budget Manual (2008). Table 17 lists the sources for each cost component for the Manawatu. The cost series was developed for each enterprise and varied across all four regions. 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.

Table 17 Key data sources: input and production costs in NZFARM

Category	consultant/ experts	Lincoln University Financial Budget Manual	MAF Farm Monitoring Reports	Other Possible Source
Variable Costs				
Stock replacement costs	√		√	
Wages	√		√	
Animal health cost	√		√	
Dairy shed expenses	√		√	
Breeding cost	√		√	
Electricity cost	√	√	√	
Fertiliser cost ($/ha)	√	√	√	Ravensdown price list
Cartage expenses ($/ha)	√	√	√	
Cost of fertilizer application ($/ha)	√	√	√	
Fuel costs ($/ha)	√	√	√	
shearing cost ($/ha)	√		√	
seed costs ($/ha)	√	√	√	
Imported feed costs ($/ha) – hay and silage	√		√	
Imported feed costs ($/ha) – crops	√		√	
Imported feed costs ($/ha) – grazing	√		√	
Imported feed costs ($/ha) – other	√		√	
Water charges ($/ha)	√	√	√	
Contractors (fencing, spraying, etc.) ($/ha)	√	√	√	
Weed & Pest control costs ($/ha)	√	√	√	
Frost protection ($/ha)		√		
Freight costs ($/ha)	√	√		
Vehicle Maintenance ($/ha)	√		√	
General repair and maintenance ($/ha)	√		√	
Accountant costs ($/ha)	√		√	
Legal and farm consultancy costs ($/ha)	√		√	
Phone and mail costs ($/ha)	√		√	
Any other administrative costs ($/ha)	√		√	
Rates (property taxes) ($)	√		√	
Insurance ($)	√		√	
Other standing costs (including ACC) ($/ha)	√		√	
Other expenditure ($)	√		√	
Wages on management (Drawings) ($/ha)	√		√	
Depreciation on capital items ($)	√		√	
Harvesting costs ($/ha)		√		
Annualised Fixed Cost				
Cultivation cost ($/ha)		√		
Roading costs for forest plantations	√			
Average land preparation (from mānuka/kānuka and gorse) ($/ha) amortized over harvest length	√			
Planting costs ($/ha) amortized over harvest length	√			
Annual forest management fee ($/ha)	√			
Herbicide costs and application ($/ha) amortized over harvest length	√			
Fungicide costs and application ($/ha) amortized over harvest length	√			
Silvicultural mgt – one hit prune ($/ha) amortized over harvest length	√			
Silvicultural mgt – one hit thin ($/ha) amortized over harvest length	√			
Harvest costs ($/ha) amortized over harvest length	√			
Harvest preparation costs (e.g. cost of landings) ($/ha) amortized over rotation length	√			
DCD Costs ($/ha/yr)	√			Ravensdown Fertiliser price list
Feedpad Costs ($/ha/yr)	√			Wolken 2009, Dairy NZ 2008

Many enterprises in the catchment have the option to vary the use of fertilizer. NZFARM tracks changes in product and environmental outputs from changes in fertilizer for the following applications: 100% of recommended 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, no N application but 100% of recommended application of all other fertilizers, 0% of recommended lime but 100% of recommended application of all other fertilizers, and finally, no fertilizer application. The physical levels of fertilizer applied were constructed based on data provided by the experts. Amount of nutrients applied were calculated using the nutrient content of the types of fertiliser applied. Example of N fertiliser and nutrient application rates for some mitigation options are presented in Table 18.

Table 18 Fertiliser and nutrient N application rates for select pastoral enterprises, Manawatu Catchment (Kg/N fertiliser/ha)

N Mitigation Option	DAIRY_MF Kg/N fertiliser/ha	DAIRY_TF Kg/N nutrient/ha	SNB_B_MH Kg/N Fertiliser/ha	SNB_BF_MF Kg/N nutrient/ha	SNB_BF_MH Kg/N nutrient/ha	SNB_FT_TF Kg/N fertiliser/ha
100%	120.00	120.00	7	15	7	15
80%	96.00	96.00	5.6	-	5.6	-
60%	72.00	72.00	-	9	-	9
50%	60.00	60.00	-	7.5	-	7.5
0%	0	0	0	0	0	0

Table 19 presents the nutrient content of the most widely used fertiliser products in Manawatu.

Table 19 Fertiliser nutrient contents, Manawatu Catchment

Fertilizer	N	P	K	S	Ca	Mg
	Nutrient contents (%)					
Urea	46%	0%	0%	0%	0%	-
Superphosphate	0%	8%	0%	24%	18%	-
50% Potash Super	0%	5%	25%	5%	10%	-
Lime	0%	0%	0%	0%	87%	-
Magamp	7%	17%	5%	-	-	12%
DAP 13S	11%	15%	0%	13%	6%	-
RPR/Sulphur Super	0%	11%	0%	12%	26%	-
Crop master 20	19%	10%	0%	13%	0%	0%
Early potato base	12%	8%	7%	11%	4%	1%
Ammonium Sulphate	21%	0%	0%	24%	0%	0%
Maxi sulphur super	0%	5%	0%	47%	11%	0%

Source: http://www.ravensdown.co.nz/

Stocking rates used for the different NZFARM regions in the Manawatu are listed in Table 20–Table 22.

Table 20 Dairy stocking rates, Manawatu

	Stocking rate per ha			
Dairy enterprises	**MF**	**MH**	**TF**	**TH**
Dairy	2.9	2.9	2.7	2.7
Dairy_IRR	2.9	2.9	2.7	-

Note: blank values represent enterprises not found in each region. MF= Manawatu Flats, MH = Manawatu Hills. T= Tararua. IRR = irrigated. 100N is the recommended N fertiliser applied; 80N is application of 80% recommended fertiliser level, and so on. Lime is also experimentally removed (0L), as is all fertiliser (NONE).

Table 21 Sheep and beef stocking rates, Manawatu

	Stocking rate per ha			
Sheep and beef enterprises	**MF**	**MH**	**TF**	**TH**
Sheep and Beef Breeding				
SNB_B_100N		8.90		8.90
SNB_B_100N_DCD		9.24		9.24
SNB_B_80N		8.88		8.88
SNB_B 80N_DCD		9.21		9.21
SNB_B 60N		-		-
SNB_B 60N_DCD		-		-
SNB_B 0N		8.78		8.78
SNB_B 0N_DCD		9.11		9.11
SNB_B 0L		8.90		8.90
SNB_B 0L_DCD		9.24		9.24
Sheep and Beef Breeding and Finishing				
SNB_BF_100N	11.00	10.00	11.00	10.00
SNB_BF_100N_DCD	11.20	10.18	11.20	10.18
SNB_BF_80N	-	9.97	-	9.97
SNB_BF_80N_DCD	-	10.15	-	10.15
SNB_BF_60N	10.88	-	10.88	-
SNB_BF_60N_DCD	11.07	-	11.07	-
SNB_BF_50N	10.85	-	10.85	-
SNB_BF_50N_DCD	11.03	-	11.03	-
SNB_BF_0N	10.70	9.86	10.70	9.86
SNB_BF_0N_DCD	10.86	10.03	10.86	10.03
SNB_BF_0L	11.00	10.00	11.00	10.00
SNB_BF_0L_DCD	11.20	10.18	11.20	10.18
Sheep and Beef Finishing and Trading				
SNB_FT_100N	11.10		11.10	
SNB_ FT _100N_DCD	11.91		11.91	
SNB_ FT _80N	-		-	
SNB_ FT _80N_DCD	-		-	
SNB_ FT _60N	10.92		10.92	
SNB_ FT _60N_DCD	11.79		11.79	
SNB_ FT _50N	10.88		10.88	
SNB_ FT _50N_DCD	11.76		11.76	
SNB_ FT _0N	10.65		10.65	
SNB_ FT _0N_DCD	11.61		11.61	
SNB_ FT_0L	11.10		11.10	
SNB_ FT_0L_DCD	11.91		11.91	

Note: blank values represent enterprises not found in each region. MF= Manawatu Flats, MH = Manawatu Hills.

T= Tararua. SNB_B = Sheep and Beef breeding enterprises, SNB_BF = Sheep and Beef breeding and finishing enterprises, SNB_FT = Sheep and Beef finishing and trading enterprises. 100N is the recommended N fertiliser applied, and 80N is application of 80% recommended fertiliser level, and so on. Lime is also experimentally removed (0L), as is all fertiliser (NONE). DCD = application of nitrogen inhibitors.

Table 22 Deer stocking rates, Manawatu

	Stocking rate per ha			
Deer enterprises	**MF**	**MH**	**TF**	**TH**
Deer_0Nitrogen	15.70	15.70	15.70	15.70
Deer_0Nitrogen_DCD	15.97	15.97	15.97	15.97

Mitigation Options

The set of mitigation options for the aggregate enterprises tracked in the Manawatu Catchment are listed in Table 23. The response of mitigation options on output, stocking rate and supplements bought for pastoral enterprises were calculated based on Farmax (Bryant et al. 2010). All other enterprises were assumed to only follow the business as usual management practices. That being said, landowners with limited mitigation options could still adjust their enterprise mix by planting forests or leaving some land fallow.

Table 23 Mitigation options in Manawatu Catchment

Enterprise	Mitigation Options
Irrigated Dairy	Feed pad, stocking rate, fertiliser, winter off, DCD, land-use change
Dryland Dairy	Feed pad, stocking rate, fertiliser, winter off, DCD, land-use change
Dryland Sheep and Beef	Stocking rate, fertiliser, DCD, land-use change
Dryland Deer	Stocking rate, land-use change
Arable Crops	Land-use change
Horticulture	Land-use change
Forestry	Land-use change
Scrub	Land-use change
Natural/Conservation	None (held fixed for all scenarios)

Net revenue

As mentioned earlier, productivity can also vary across different regions of the catchment due to climatic or physical conditions. This has an impact on the amount of net revenue that a landowner can feasible earn, given that the output price and costs of input remain constant. The range of net revenue possibilities for key enterprises in the Manawatu Catchment are shown in Figure 15.

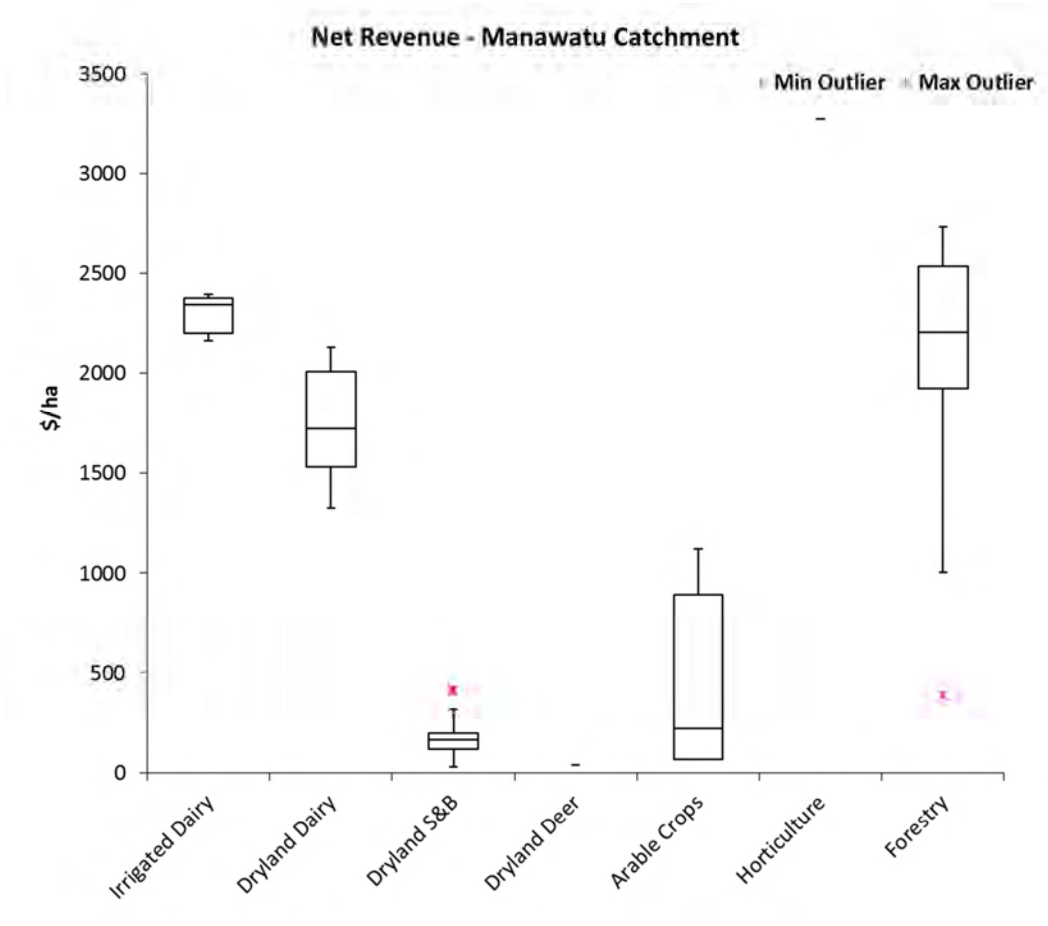


Figure 15 Range of net revenue potential for key enterprises ($/ha) in Manawatu Catchment

Environmental outputs

NZFARM model has the ability to track environmental outputs such as CH_4 emissions from animals, N_2O emissions from livestock and soil, and CO_2 emissions from fuel, electricity, and fertilizer used in the production process, N leaching, and P loss. Data on environmental output coefficients were obtained from several sources, as discussed in Section 3.2.4. The variation in GHG emissions from key enterprises in the Manawatu catchment is shown in Figure 16.

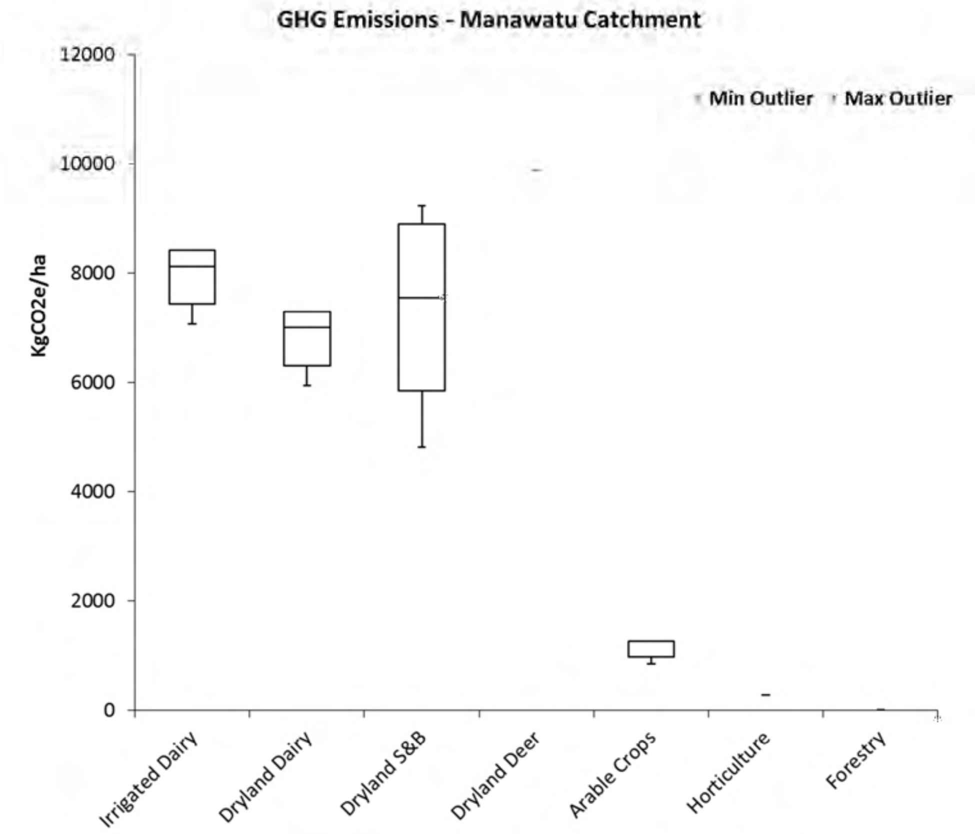


Figure 16 Range of GHG emissions (kgCO2e/ha) in Manawatu Catchment

N leaching and P loss rates for pastoral farming, wheat and barley were estimated using the 5.4.9 version of OVERSEER (2010). Potato leaching rates were estimated using a recent version of SPASMO (2010). Values for N leaching from maize, pine plantations and native were taken as an average from the literature (e.g. Parfitt et al. 1997; Menneer et al. 2004). We assumed zero P loss from plantations or native forest lands.

The variation of N leaching and P loss rates in the Manawatu catchment are shown as box plots in Figure 17 and Figure 18, respectively. These figures demonstrate the variability in nutrient leaching rates for the same enterprise across the catchment. This relates to differences in stocking rate, soil type, irrigation scheme, fertiliser application, and mitigation options implemented. The large spread in N leaching rates for grains and horticulture indicates that it has greater mitigation potential on a per-ha basis compared with other enterprises, while sheep and beef and deer have the best mitigation potential for P.

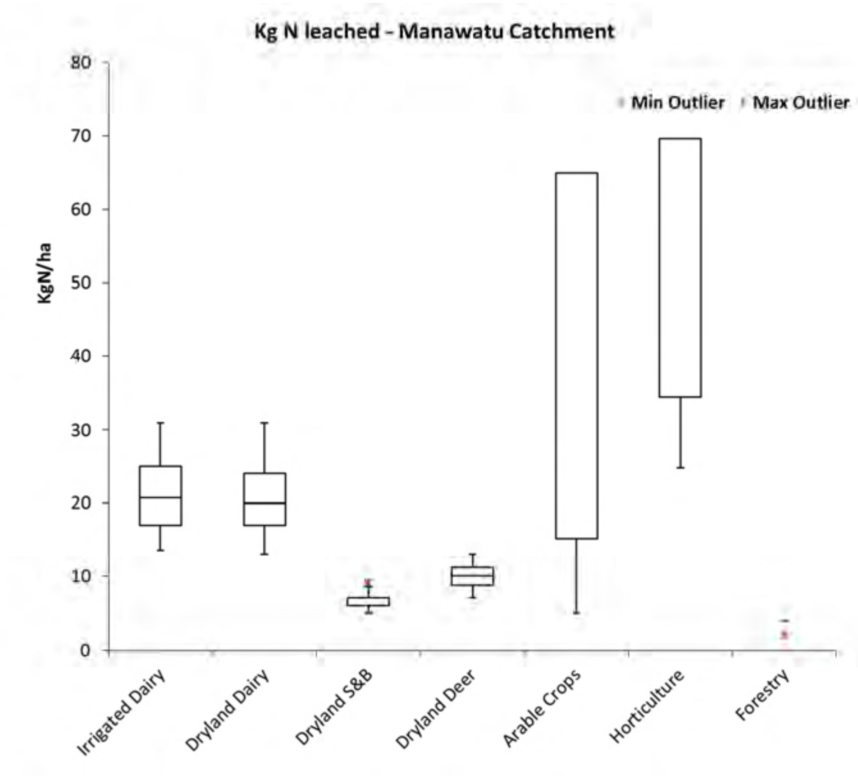


Figure 17 Range of N leaching rates (kgN/ha) for key enterprises in Manawatu Catchment

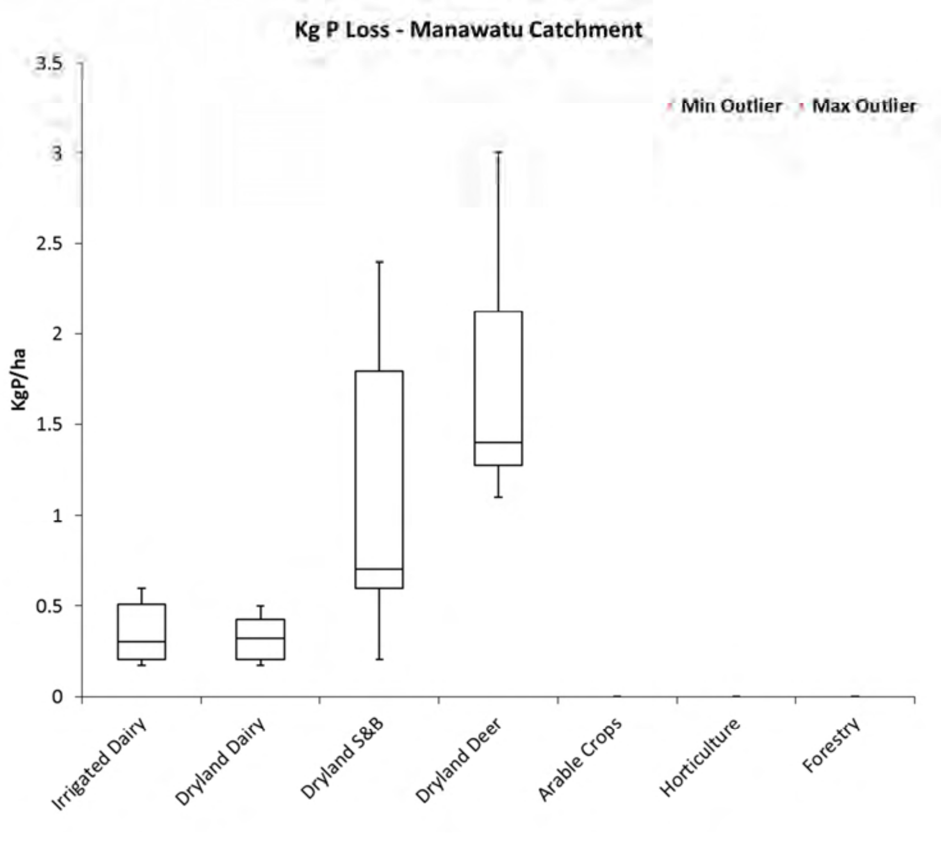


Figure 18 Range of P loss rates (kgP/ha) for key enterprises in Manawatu Catchment

Appendix A2 – Key components of NZFARM

Table 24 Key components of NZFARM for Hurunui-Waiau Catchment

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs	Climate and Productivity Inputs
Plains	Lismore	Pasture	Dairy – 3 Cows per ha, wintered on farm	Irrigated Land	100% rec. all nutrients	DCDs	Beef stock replacement costs	Property taxes	Milk solids	N leached	Dairy calves purchased	Temperature
Foothills	Balmorals	Cropland	Dairy – 3 Cows per ha, wintered off farm	Dry Land	80% rec. N, 100% rec. all other nutrients	Feed Pads	Sheep Stock Replacement cost	Insurance	Dairy calves	P lost	Lambs purchased	Rainfall
Hills	Hatfield	Horticulture	Dairy – 3.5 Cows per ha, wintered on farm		60% rec. N, 100% rec. all other nutrients	Fertiliser	Deer Stock replacement cost	Land prep	Lambs	Methane from animals N_2O emissions – direct excreta and effluent	Rams purchased	Metabolisable Energy
	Templeton	Forest	Dairy – 3.5 Cows per ha, wintered off farm		50% rec. N, 100% rec. all other nutrients		Dairy Stock replacement cost	Tree planting	Mutton	N_2O emissions – indirect excreta and effluent	Ewes purchased	
		Scrub	Dairy – 4 Cows per ha, wintered on farm		No N, 100% rec. all other nutrients		Pig stock replacement cost	Forest harvest	Wool	CO_2 emissions – N fertiliser	Cows purchased	
		Natural/ DOC	Dairy – 4 Cows per ha, wintered off farm		0% rec. Lime, 100% rec. all other nutrients		Wages – permanent	Cultivation	Cull cows	CO_2 emissions – Lime	Heifers purchased	
			Deer		No fertilizer applied		Wages – casual	Forest management fee	Heifers	N_2O emissions – direct and indirect N from fertiliser	Steers purchased	
			Pigs				Animal Health	Herbicide application	Steers	CO_2 emissions – fuel	Bulls purchased	
			Mix of Sheep and Beef Grazing				Dairy shed	Fungicide application	Bulls	CO_2 emissions – electricity use Annual Forest C Sequestration	Pigs purchased	
			100% Sheep Grazing				breeding	Pruning	Deer: hinds		Dry matter	
			100% Cattle Grazing				Electricity	Thinning	Deer: stags		Electricity used	
			Grapes				Cartage	Harvest costs	Deer: velvet		Fertiliser used – Urea	
							Fertiliser	Harvest preparation	Pigs		Fertiliser used – Super	
							Fertiliser	DCD Application	Berryfruit		Fertiliser used – Lime	
								Feed pad construction	Grapes		Fertiliser used – other	
									Wheat		Nutrients used – N	
									Barley		Nutrients used – P,K,S	
									Logs for pulp and paper		Nutrients used –	
									Logs for Timber			
									Other Misc.			

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

Table 25 Key components of NZFARM for Manawatu Catchment

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs	Climate and Productivity Inputs
Manawatu Flats Manawatu Hills Tararua Flats Tararua Hills	Brown soils Gley Soils Pallic Soils	Pasture Cropland Horticulture Forest mānuka-kānuka (scrub) DOC	Dairy Sheep and Beef – breeding Sheep and Beef – breeding and finishing Sheep and Beef – finishing and trading Deer Maize – silage Maize – grain Wheat Barley Potato Pine Radiata Plantations Douglasfir Eucalyptus Mānuka-Kānuka Conservation Land	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	Winter off DCDs Feed Pads Fertiliser	Beef stock replacement costs Sheep Stock Replacement cost Deer Stock replacement cost Dairy Stock replacement cost Contractor cost (e.g. Harvesting, fencing, spraying) Wages – permanent Wages – casual Animal Health cost Dairy shed expenses Breeding cost Electricity costs Cartage costs Fertiliser Fertiliser application Fuel Weed and pest control cost Shearing cost Seed cost	Property taxes Insurance Land preparation Accountancy cost Other standing costs (e.g. ACC levy) 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 Maize – silage Maize- grain Wheat Barley Potato Logs for pulp and paper Logs for Timber Other Misc.	N leached P loss CH4 – Enteric Fermentation CH4 Manure management N2O – AWMS N2O Soil – direct and indirect from fertiliser CO2 emissions – fuel CO2 emissions – electricity Annual Forest C Sequestration	Dairy calves purchased Lambs purchased Rams purchased Ewes purchased Cows purchased Heifers purchased Steers purchased Bulls purchased Dry matter Electricity used Fertiliser used – Urea Fertiliser used – Super Fertiliser used – Lime Fertiliser used – other Nutrients used – N Nutrients used – P,K,S Nutrients used –	Temperature Rainfall Metabolisable Energy

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs	Climate and Productivity Inputs
							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 Vehicle maintenance and repair cost Fuel cost Freight costs Administration costs Legal and farm consultancy	Wages on management (drawings)			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	

Appendix B – Hurunui-Waiau Catchment impacts for various management practices, nutrient eeduction targets, and nutrient taxes

Good Management Practices

Table 26 GMP measures in the Hurunui-Waiau dairy sector, by region

GMP	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Fertiliser to 80%	Yes	HF	0.8	1.4		71	6%		51		4%
		HP	16	57		1990	8%		35		4%
		WF	0	0.1		4	7%		52		4%
		WP	1.5	4.4		133	6%		30		3%
Fertiliser to 60%	Yes	HF	0.9	3.1		155	13%		50		7%
		HP	16	109		3840	16%		35		8%
		WF	0.1	0.2		11	13%		55		6%
		WP	1.6	9		270	12%		30		5%
Fertiliser to 50%	No	HF	0.9	3.6	-	202	15%	-	56	-	9%
		HP	16.2	130.3	-	4752	19%	-	36	-	10%
		WF	0.1	0.2	-	15	13%	-	64	-	8%
		WP	1.7	10.7	-	344	14%	-	32	-	7%
DCD	Yes	HF	0.4	2.9	-	-125	21%	-	-43	-	-12%
		HP	11.1	113.4	-	-2700	21%	-	-24	-	-8%
		WF	0	0.1	-	-2	21%	-	-37	-	-10%
		WP	1.4	13.9	-	-223	21%	-	-16	-	-5%
Feedpad	Yes	HF	0.4	2.1	-	-67	15%	-	-32	-	-6%
		HP	11.1	82.4	185.1	-551	15%	15%	-7	-3000	-2%
		WF	0	0	-	-1	15%	-	-31	-	-6%
		WP	1.4	10	20.3	181	15%	15%	18	9000	4%

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Winter off	Yes	HF	0.4	6.3	-	405	44%	-	65	-	39%
		HP	11.1	209.5	-	7818	38%	-	37	-	23%
		WF	0	0.1	-	9	47%	-	68	-	41%
		WP	1.4	23.7	-	856	36%	-	36	-	20%
Max Stocking Rate of 3 cows/ha	No	HF	-	-	-	-	-	-	-	-	-
		HP	4.3	125	430	5290	53%	50%	42	12000	36%
		WF	-	-	-	-	-	-	-	-	-
		WP	-	-	-	-	-	-	-	-	-
DCD + Winter off	Yes	HF	0.4	7.9	-	327	56%	-	41	-	31%
		HP	11.1	287.4	-	3195	52%	-	11	-	9%
		WF	0	0.2	-	7	58%	-	42		31%
		WP	1.4	33.3	-	350	50%	-	11	-	8%
Feedpad + winter off	Yes	HF	0.4	7.4	-	367	53%	-	49	-	35%
		HP	11.1	260.4	185.1	7985	47%	15%	31	43000	23%
		WF	0	0.2	-	8	55%	-	54	-	38%
		WP	1.4	30.1	20.2	920	45%	15%	31	46000	21%
Exclude Stock via Fencing	Yes	HF	0.1	0.1	0.3	3	0.2%	1%	44	9347	2%
		HP	1.0	1.0	18.4	44	0.1%	1%	44	2410	1%
		WF	0.0	0.0	0.0	0	0.3%	1%	44	14897	2%
		WP	0.1	0.1	1.9	5	0.1%	1%	44	2899	1%
Riparian Planting	No	HF	0.6	0.7	8.7	62	2.3%	23%	83	7096	4%
		HP	8.5	10.2	459.8	841	1.4%	23%	83	1830	3%
		WF	0.1	0.1	0.8	9	2.9%	23%	83	11310	4%
		WP	1.0	1.2	46.9	103	1.5%	23%	83	2201	3%

Table 27 Mitigation measures in the sheep and beef sector, by region

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Fertiliser to 80%	Yes	HP	1.9	3.1	-	127	7%	-	42	-	6%
		WP	0.5	0.9	-	31	8%	-	34	-	5%
Fertiliser to 60%	Yes	HP	1.9	6.8	-	215	16%	-	31	-	9%
		WP	0.5	1.8	-	52	16%	-	29	-	9%
Fertiliser to 50%	No	HP	1.9	7	-	255	16%	-	36	-	11%
		WP	0.5	2	-	62	16%	-	33	-	11%
DCD	Yes	HH	29	-	-	3224	-	-	-	-	23%
		HF	59	-	-	-	-	-	-	-	-
		HP	37	64	-	2664	20%	-	42	-	13%
		WH	24	-	-	2698	-	-	-	-	23%
		WF	57	-	-	-	-	-	-	-	-
		WP	44	74	-	3198	20%	-	43	-	14%
Exclude Stock via Fencing	Yes	HH	17	17	1294	751	15%	9%	44	581	9%
		HF	35	35	525	1538	20%	9%	44	2930	7%
		HP	22	22	15	974	7%	9%	44	63694	8%
		WH	14	14	1298	628	15%	9%	44	484	9%
		WF	34	34	637	1479	20%	9%	44	2321	7%
		WP	28	28	16	1212	7%	9%	44	76384	8%
Riparian Planting	No	HH	14	17	3235	1426	15%	23%	83	441	20%
		HF	29	35	1312	2918	20%	23%	83	2225	17%
		HP	19	22	38	1848	7%	23%	83	48356	19%
		WH	12	14	3245	1192	15%	23%	83	367	20%
		WF	28	34	1593	2808	20%	23%	83	1762	17%
		WP	23	28	40	2301	7%	23%	83	57990	18%

Table 28 Mitigation measures in the deer and pig sectors

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Fertiliser to 80%	Yes	HP	0.1	0.1	-	1.6	8%	-	17	-	1%
		WP	0.01	0.01	-	0.2	8%	-	17	-	1%
Fertiliser to 60%	Yes	HP	0.1	0.2	-	3.8	12%	-	17	-	1%
		WP	0.02	0.03	-	0.5	12%	-	17	-	1%
Fertiliser to 50%	No	HP	0.2	0.3	-	6.7	12%	-	21	-	1%
		WP	0	0	-	0.9	12%	-	21	-	1%
DCD	Yes	HF	0	0	-	1.2	32%	-	102.4	-	18%
		HP	0.8	1.9	-	79.7	24%	-	42.6	-	8%
		WF	0	0	-	1.4	28%	-	101.3	-	14%
		WP	0	0.1	-	-1.9	23%	-	-22	-	-2%
Exclude Stock via Fencing	Yes	HF	0.0	0.0	0.8	0.3	17%	9%	44	345	7%
		HP	0.7	0.7	52.9	30.1	6%	9%	44	570	2%
		WF	0.0	0.0	0.5	0.3	13%	9%	44	543	4%
		WP	0.0	0.0	6.8	1.9	5%	9%	44	279	1%
Riparian Planting	No	HF	0.0	0.0	1.9	0.5	17%	23%	83	262	15%
		HP	0.6	0.7	132.1	57.2	6%	23%	83	433	5%
		WF	0.0	0.0	1.4	0.6	13%	23%	83	412	10%
		WP	0.0	0.0	16.9	3.6	5%	23%	83	211	3%

Catchment-wide cap-and-trade with grandparenting, various levels of reduction from baseline estimates

For this policy scenario, we assume that irrigation area is held at 2010 levels (pre-Waitohi scheme), nutrient discharges are allocated via grandfathering, and that there is a catchment-wide trading policy. As shown in the comparison of the policy scenarios, this is one of the most cost-effective policies to reduce nutrient loads in the catchment (ignoring administrative costs). Total reductions in P loss are sometimes greater than the mandated percentage reduction because the optimal economic response of landowners to a policy that requires equal and simultaneous reductions in N and P is to reduce additional P to meet the N target.

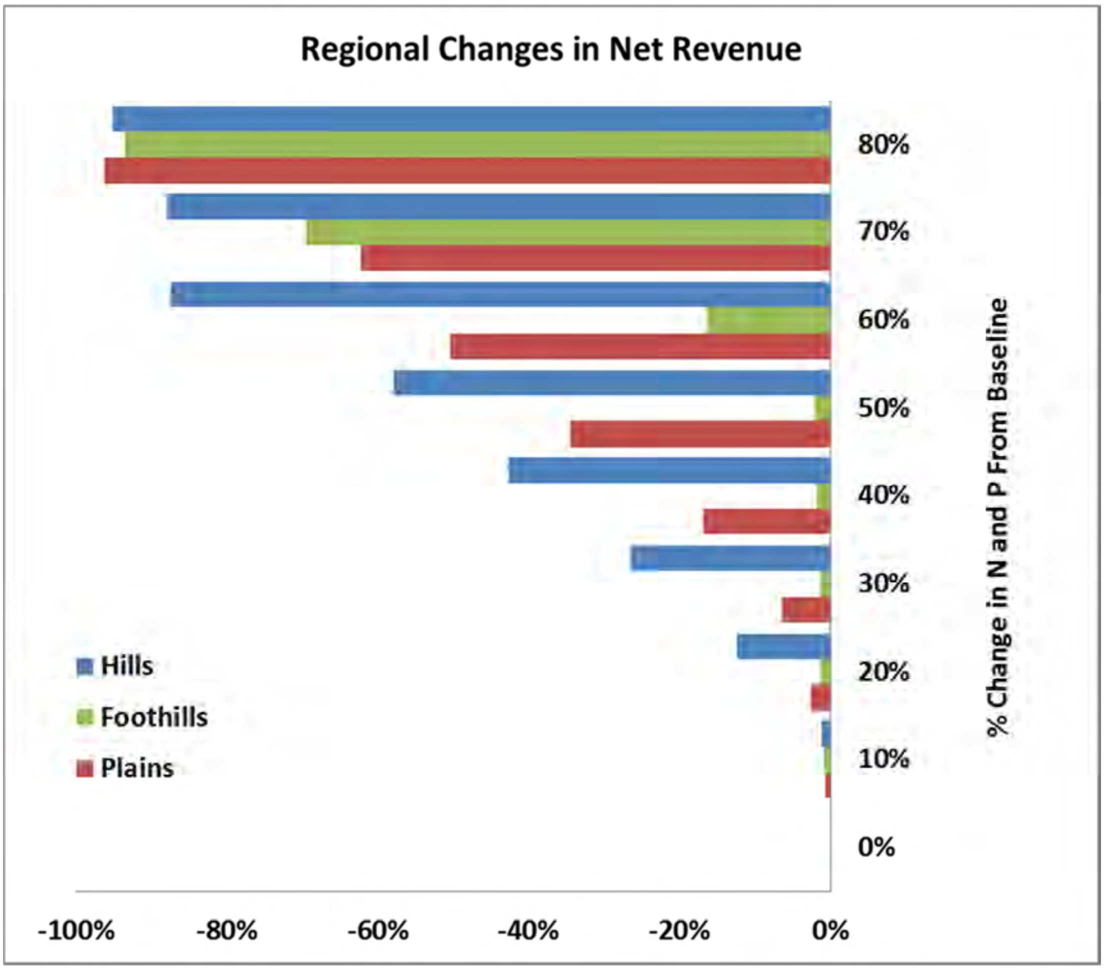


Figure 19 Percentage change in regional revenue from baseline for Hurunui-Waiau Catchment

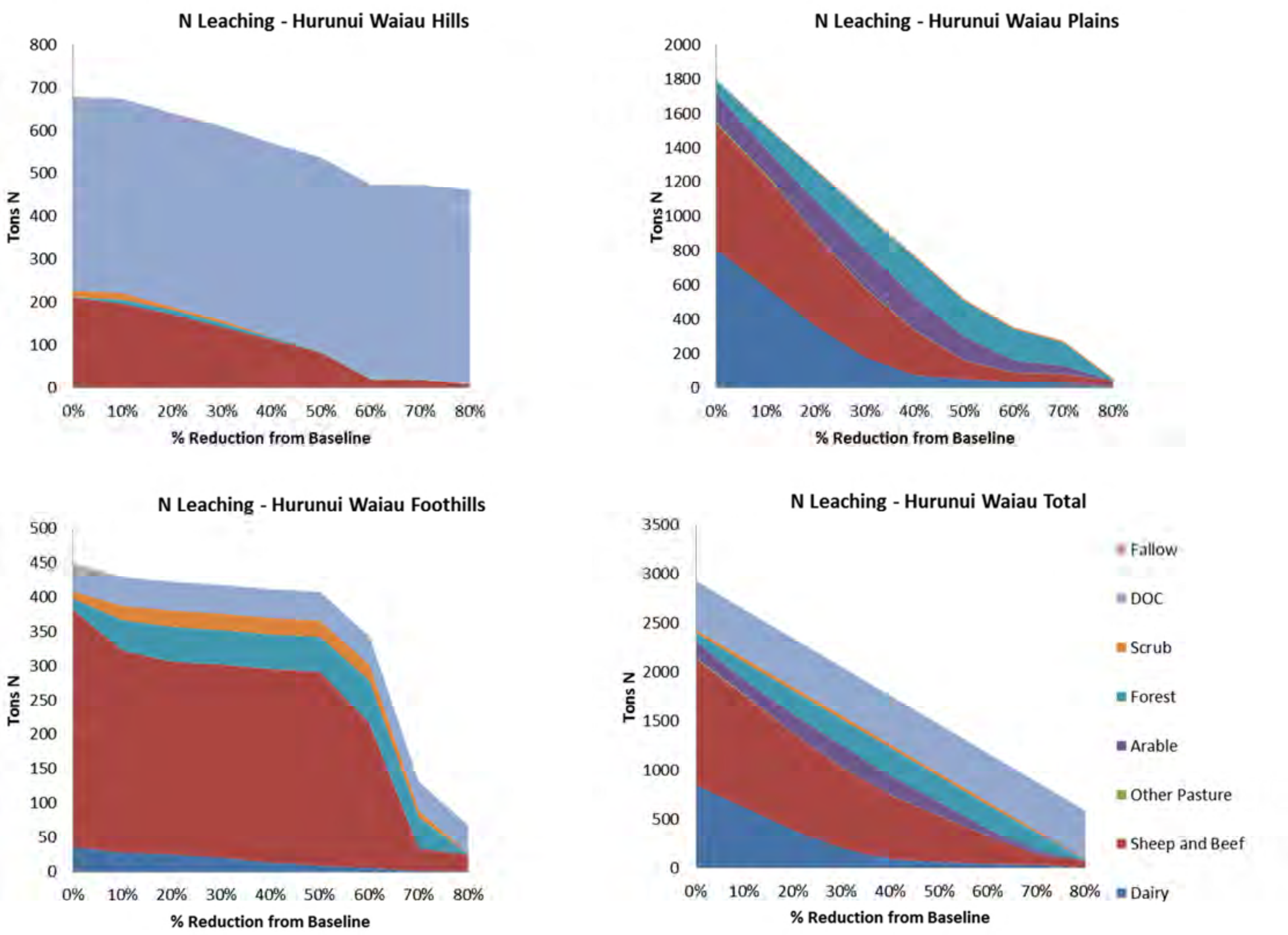


Figure 20 Regional change in total nitrogen leaching from baseline for Hurunui-Waiau Catchment, catchment-wide cap-and-trade

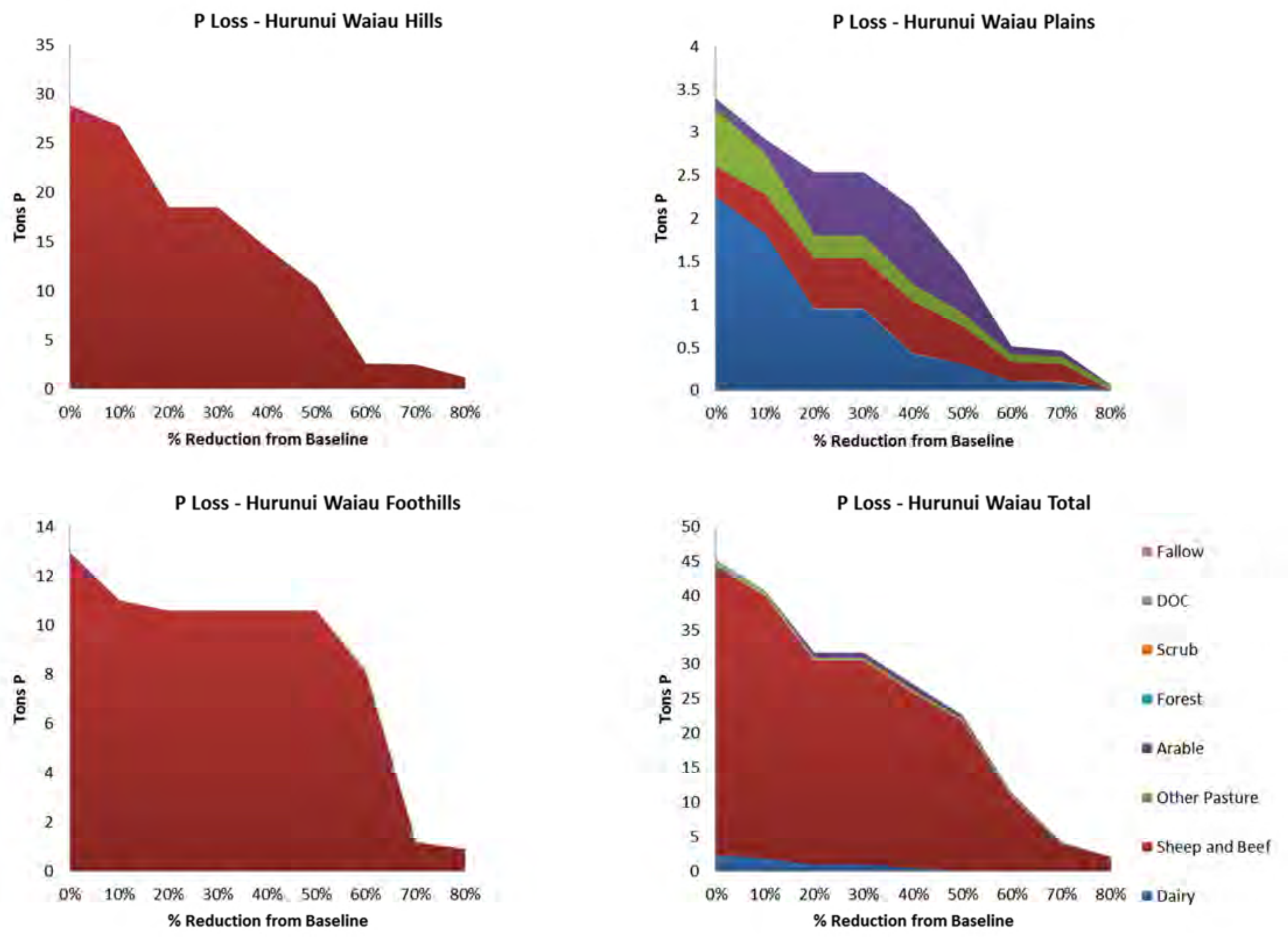


Figure 21 Regional change in total phosphorus loss from baseline for Hurunui-Waiau Catchment, catchment-wide cap-and-trade

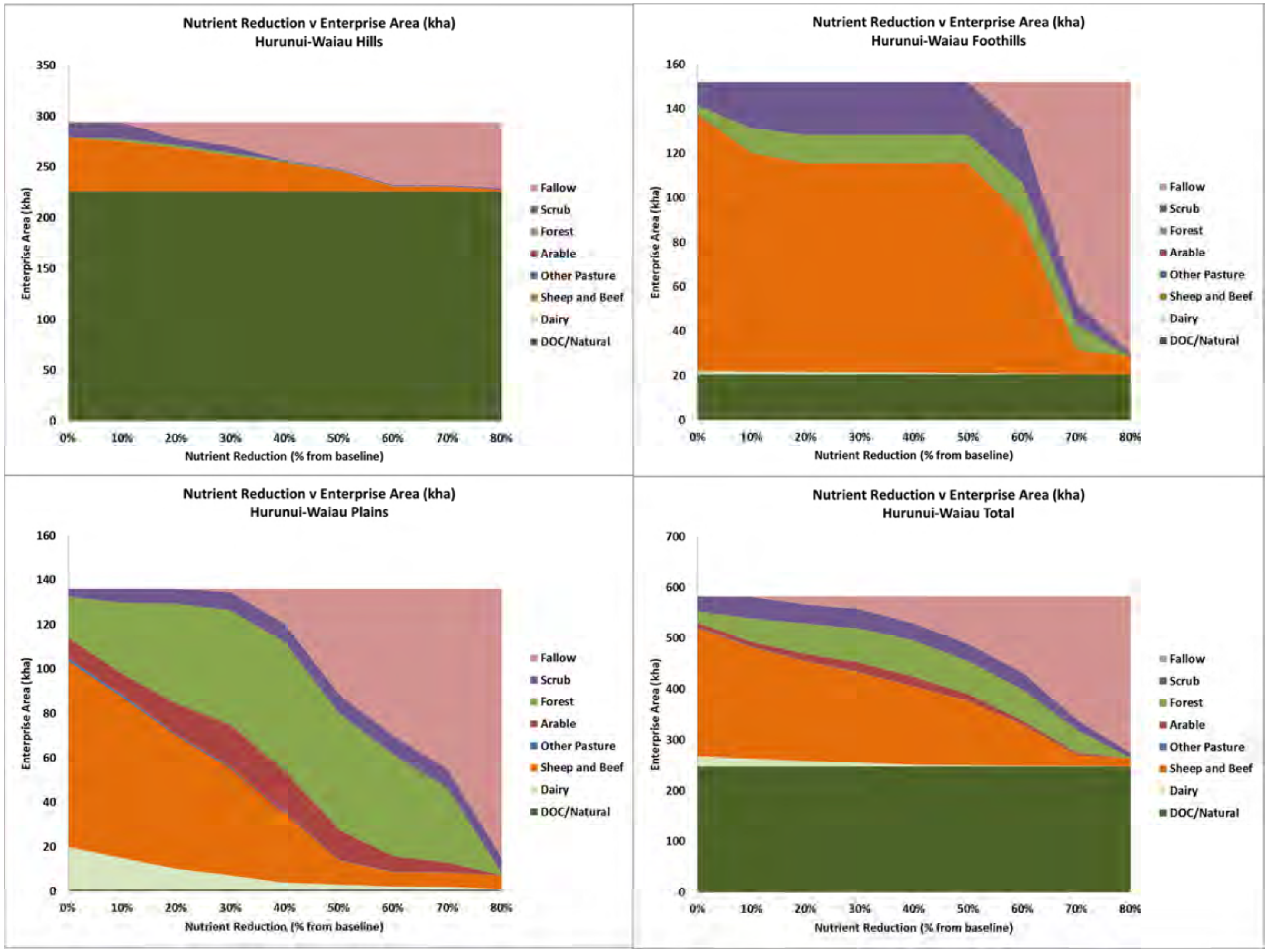


Figure 22 Regional change in land-use from baseline for Hurunui-Waiau Catchment, catchment-wide cap-and-trade

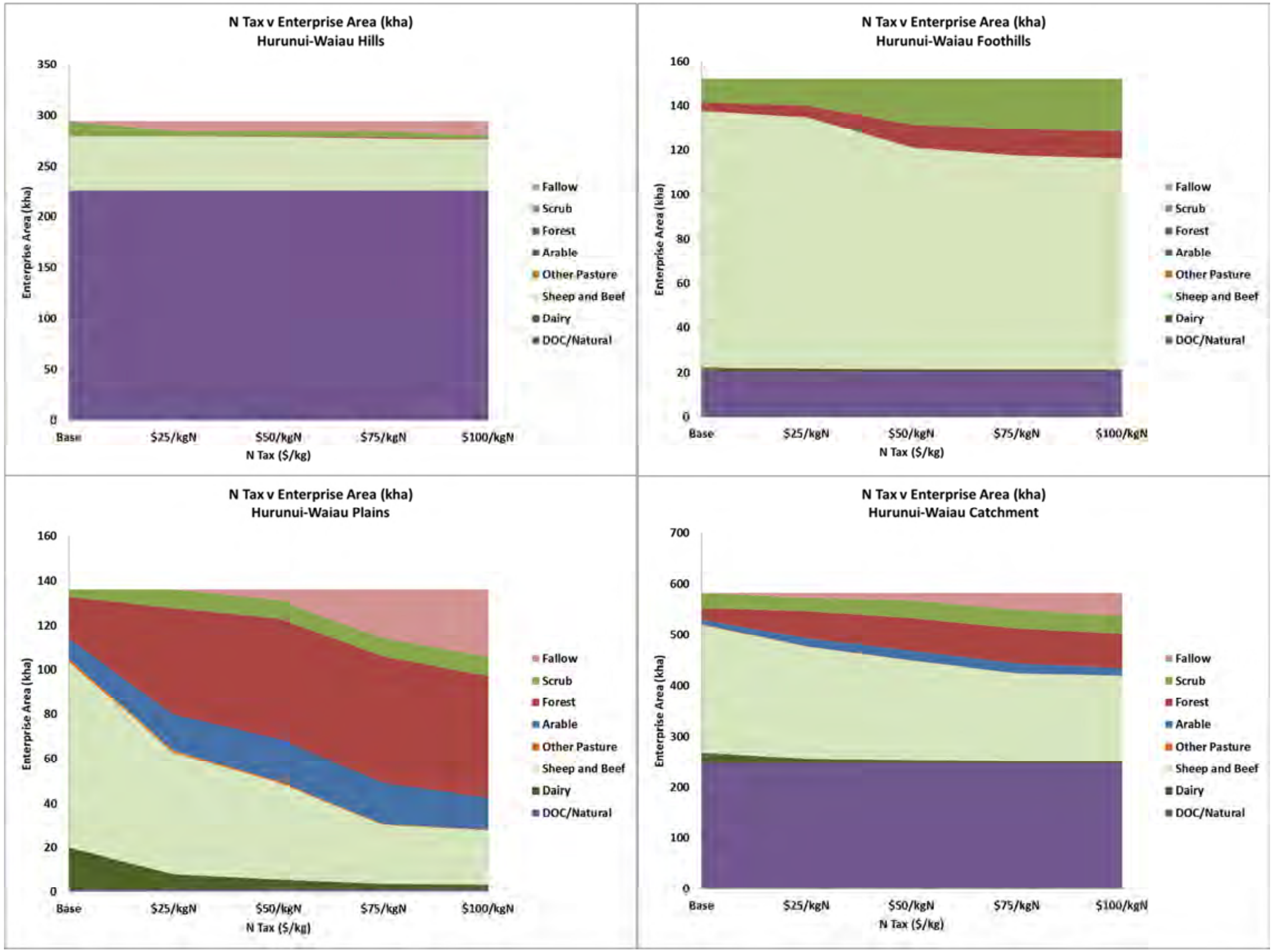


Figure 23 Regional change in land-use for various N discharge tax rates

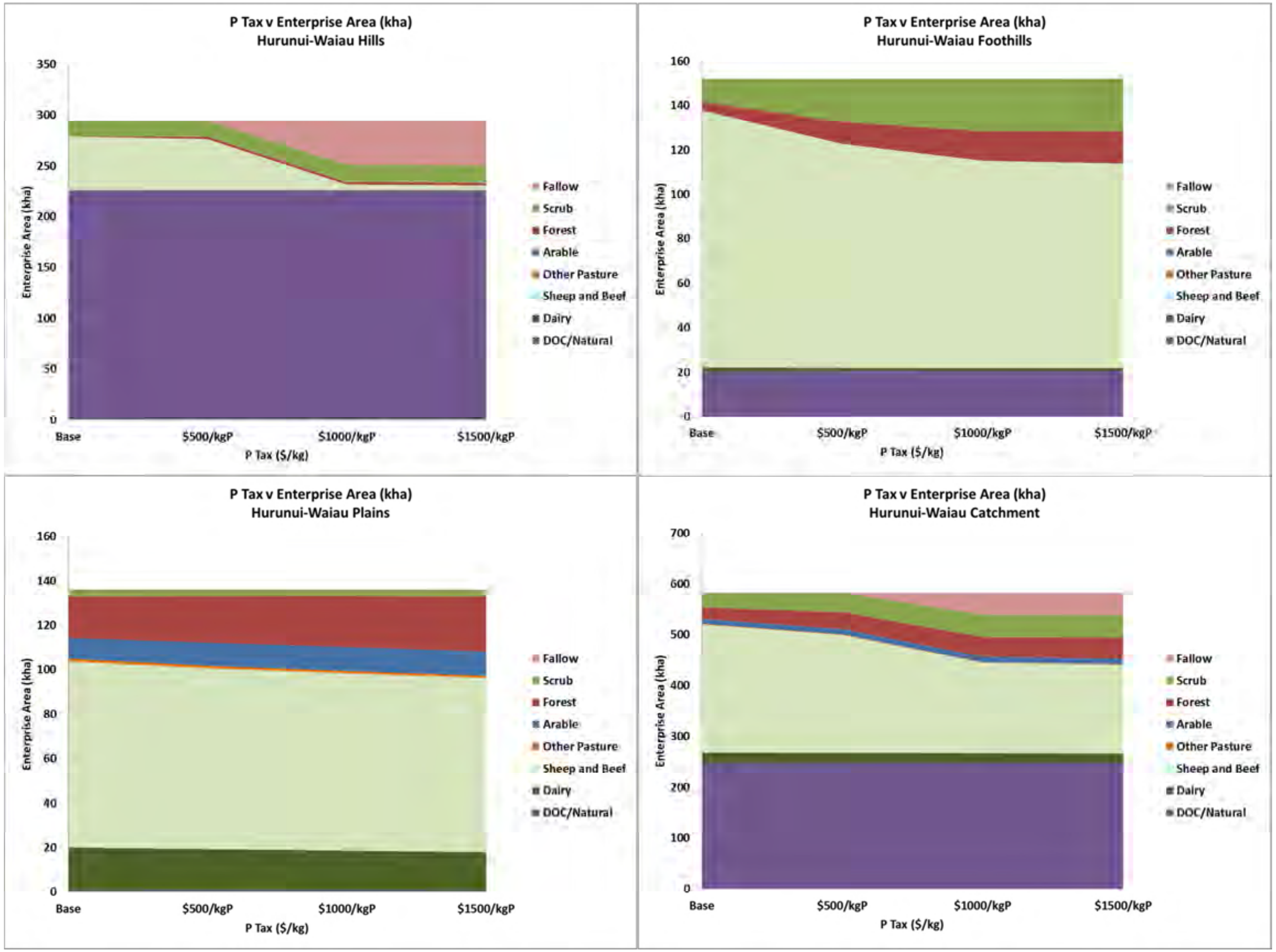


Figure 24 Regional change in land-use for various P discharge tax rates

Appendix C – Detailed estimates for water quality policy scenarios, Hurunui-Waiau Catchment

Table 29 Regional nutrient discharges under various policy scenarios, Hurunui-Waiau catchment

Policy Scenario	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Total
			Tonnes N				
Baseline	275	1182	239	404	615	212	2927
Waitohi – Unregulated	275	1873	238	404	615	212	3617
Waitohi – Catchment Trading	271	1371	226	397	452	210	2927
Waitohi – Zonal Trading	275	1182	239	404	615	212	2927
Waitohi – ECan Allocation	275	1203	221	404	452	208	2927
Nutrient Tax	271	1371	226	397	452	210	2927
			Tonnes P				
Baseline	14.4	2.8	5.9	14.4	0.6	7.1	45.2
Waitohi – Unregulated	14.4	4.5	5.9	14.4	0.6	7.1	46.8
Waitohi – Catchment Trading	14.3	4.1	5.5	13.7	0.8	6.9	45.2
Waitohi – Zonal Trading	14.4	2.8	5.9	14.4	0.6	7.1	45.2
Waitohi – ECan Allocation	14.4	3.7	5.0	14.4	0.8	6.6	45.2
Nutrietn Tax	14.3	4.1	5.5	13.7	0.8	6.9	45.2

Table 30 Value of nutrient discharge permits under various policy scenarios, Hurunui-Waiau Catchment

Policy Scenario	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Catchment
			$/kgN				
Waitohi – Catchment Trading	n/a	n/a	n/a	n/a	n/a	n/a	$23.30
Waitohi – Zonal Trading	$0	$21.55	$0	$0	$0	$0	n/a
Waitohi – ECan Allocation	$0	$24.50	$24.50	$0	$0	$0	n/a
			$/kgP				
Waitohi – Catchment Trading	n/a	n/a	n/a	n/a	n/a	n/a	$118.70
Waitohi – Zonal Trading	$0	$1,936.60	$0	$0	$0	$0	n/a
Waitohi – ECan Allocation	$0	$200.80	$200.80	$0	$0	$0	n/a

Table 31 Total net revenue (million $) for aggregate enterprises under various policy scenarios, Hurunui-Waiau catchment

	Dairy	Sheep and Beef	Deer and Pigs	Arable	Forestry	Total
Baseline	$60.1	$140.1	$2.7	$ 6.7	$30.6	$240.3
Waitohi – Unregulated	$68.7	$167.5	$2.6	$8.3	$17.5	$264.6
Waitohi – Catchment Trading	$49.6	$152.0	$2.3	$11.6	$39.8	$255.3
Waitohi – Zonal Trading	$48.6	$150.6	$1.2	$13.7	$37.3	$251.3
Waitohi – ECan Allocation	$47.3	$151.3	$2.1	$11.9	$39.8	$252.5
Nutrient Tax*	$49.6	$152.0	$2.3	$11.6	$39.8	$255.3

*Assumes tax collected from nutrient discharges would be recycled back to landowners, so changes in net revenue only reflect lower production and/or higher costs of production absence of tax impact.

Table 32 Total product output (tonnes or thousand m^3), Hurunui-Waiau catchment

Product Output	Baseline	Waitohi – Unregulated	Waitohi – Catchment Trading	Waitohi – Zonal Trading	Waitohi – ECan Allocation	Nutrient Tax
Milk Solids	24693	28296	20186	19553	19190	20186
Dairy Calves	1605	1796	1276	1238	1213	1276
Lambs	16637	26540	23716	21416	22660	23716
Mutton	1976	2133	1696	1764	1718	1696
Wool	2777	3116	2616	2632	2656	2616
Cows	4846	5264	4061	4043	3914	4061
Heifers, Bulls, Steers	46056	56760	49928	49096	49947	49928
Deer	447	479	413	207	380	413
Pigs	3058	287	318	287	332	318
Fruit	120	209	3349	3706	3954	3349
Grains	77124	95468	131696	149433	128618	131696
Timber and Pulp Logs	509	268	659	645	669	659

Appendix D – Manawatu Catchment impacts for various management practices, nutrient reduction targets, and nutrient taxes

Good Management Practices

Table 33 GMP measures in the Manawatu dairy sector, by region

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Fertiliser to 80%	Yes	TH	3.5	8.9		-71	9%		-8		-1%
		TP	-	-		-	-		-		-
		MH	5.2	14		-90	10%		-6		-1%
		MP	-	-		-	-		-		-
Fertiliser to 60%	Yes	TH	3.8	13		-113	12%		-9		-2%
		TP	-	-		-	-		-		-
		MH	5.4	20		-131	13%		-7		-1%
		MP	-	-		-	-		-		-
Fertiliser to 50%	No	TH	4	16		-144	15%		-9		-2%
		TP	-	-		-	-		-		-
		MH	6	24		-164	15%		-7		-2%
		MP	-	-		-	-		-		-
DCD	Yes	TH	3	13		-668	16%		-50		-15%
		TF	27	122		-5361	16%		-44		-15%
		MH	5	23		-1103	17%		-48		-12%
		MF	45	165		-9615	16%		-58		-12%
Feedpad	Yes	TH	3	13	144	-949	15%	15%	-75	-7	-22%
		TF	27	114	1061	-7623	15%	15%	-67	-7	-21%
		MH	5	21	183	-1566	15%	15%	-75	-9	-17%
		MF	45	153	1993	-13675	15%	15%	-89	-7	-17%

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
Winter off	Yes	TH	3	3	-	0	4%	-	-	-	0%
		TF	26	26	-	0	3%	-	-	-	0%
		MH	5	4	-	0	3%	-	-	-	0%
		MF	45	20	-	0	2%	-	-	-	0%
DCD + Winter off	Yes	TH	3.2	17	-	-664	20%	-	-40	-	-16%
		TF	26	148	-	-5333	19%	-	-36	-	-15%
		MH	5	27	-	-1097	19%	-	-41	-	-12%
		MF	45	179	-	-9573	18%	-	-54	-	-12%
Feedpad + winter off	Yes	TH	3.2	15	143	-943	18%	15%	-61	-7	-22%
		TF	26	136	1055	-7578	18%	15%	-56	-7	-21%
		MH	5	24	182	-1557	18%	15%	-64	-9	-17%
		MF	45	169	1983	-13608	17%	15%	-81	-7	-17%
Exclude Stock via Fencing	Yes	TH	1.3	1	58	58	1%	4%	44	1011	3%
		TF	11.2	11	425	486	1%	4%	44	1141	3%
		MH	1.7	2	62	74	1%	4%	44	1200	2%
		MF	14.8	15	644	646	1%	4%	44	1002	2%
Riparian Planting	Yes	TH	2.5	3	321	246	2%	23%	83	768	7%
		TF	20.7	25	2364	2048	2%	23%	83	867	7%
		MH	3.1	4	343	312	2%	23%	83	911	5%
		MF	27.5	33	3579	2723	3%	23%	83	761	5%

Table 34 GMP measures in the Manawatu sheep, beef, and deer, by region

Measure	Voluntary Practice	Region	Area (k ha)	N (t)	P (kg)	Cost $'000	N reduction %	P reduction %	$/kg N	$/kg P	Profit Reduction %
DCD	Yes	TH	133	39		-1658	4%		-43		-11%
		TF	18	31		-608	20%		-20		-19%
		MH	78	48		-1077	9%		-23		-12%
		MF	40	40		-1287	15%		-32		-19%
Exclude Stock via Fencing	Yes	HH	81	81	18216	3509	9%	9%	44	193	37%
		HF	27	27	1368	1186	8%	9%	44	867	17%
		HP	47	47	6928	2053	9%	9%	44	296	37%
		WH	44	44	3928	1918	10%	9%	44	488	17%
Riparian Planting	Yes	HH	67	81	45540	6661	9%	23%	83	146	85%
		HF	23	27	3420	2251	8%	23%	83	658	40%
		HP	67	81	45540	6661	9%	23%	83	146	85%
		WH	23	27	3420	2251	8%	23%	83	658	40%

Cap-and-trade

For this policy scenario, we assume that nutrient discharges are allocated via grandfathering, and that there is a catchment-wide trading policy. As shown in the comparison of the policy scenarios, this is one of the most cost-effective policies to reduce nutrient loads in the catchment (ignoring administrative costs). Total reductions in P loss are sometimes greater than the mandated percentage reduction because the optimal economic response of landowners to a policy that requires equal and simultaneous reductions in N and P is to reduce additional P to meet the N target.

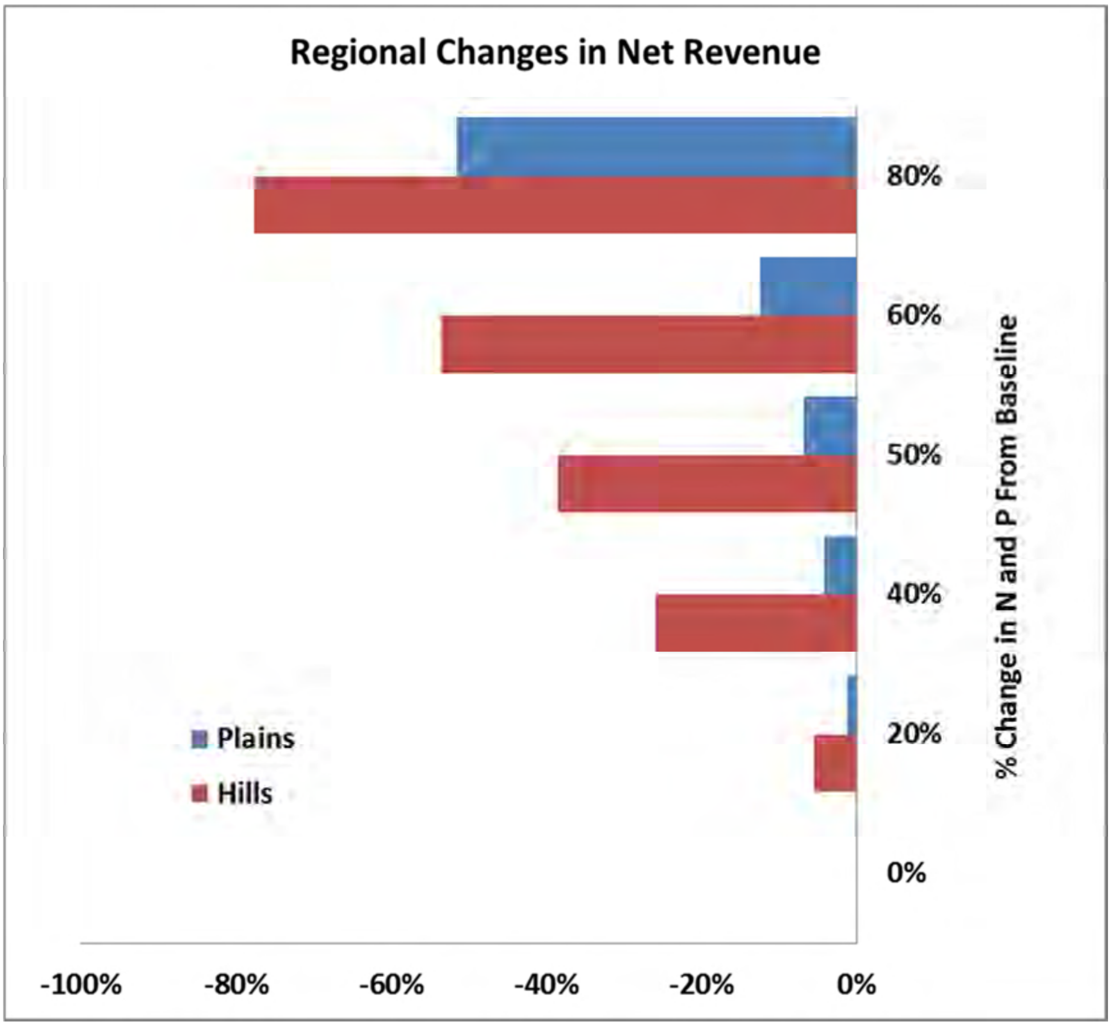


Figure 25 Percentage change in regional revenue from baseline for Manawatu Catchment

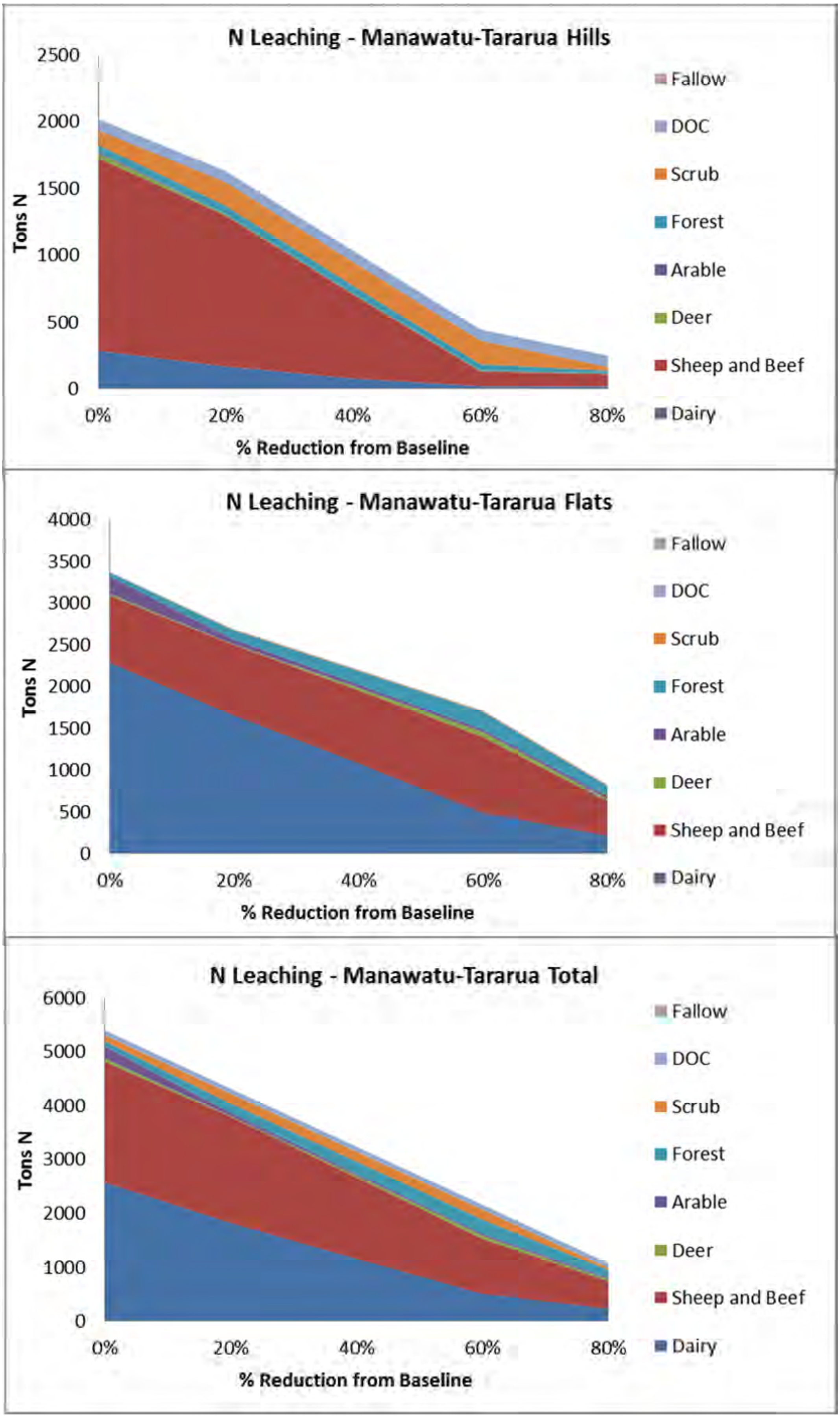


Figure 26 Regional change in total nitrogen leaching from baseline for Manawatu Catchment

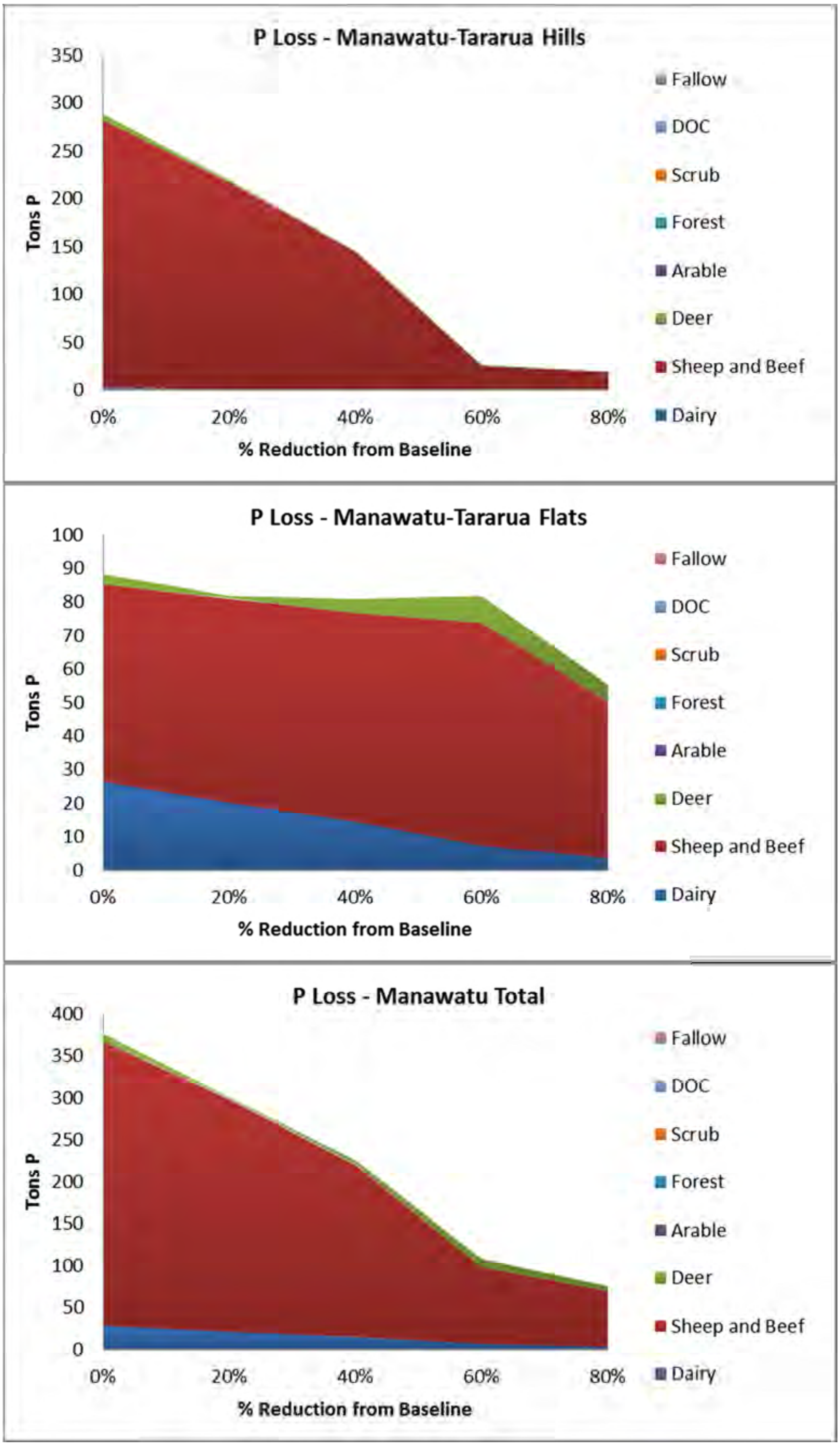


Figure 27 Regional change in total phosphorus loss from baseline for Manawatu Catchment

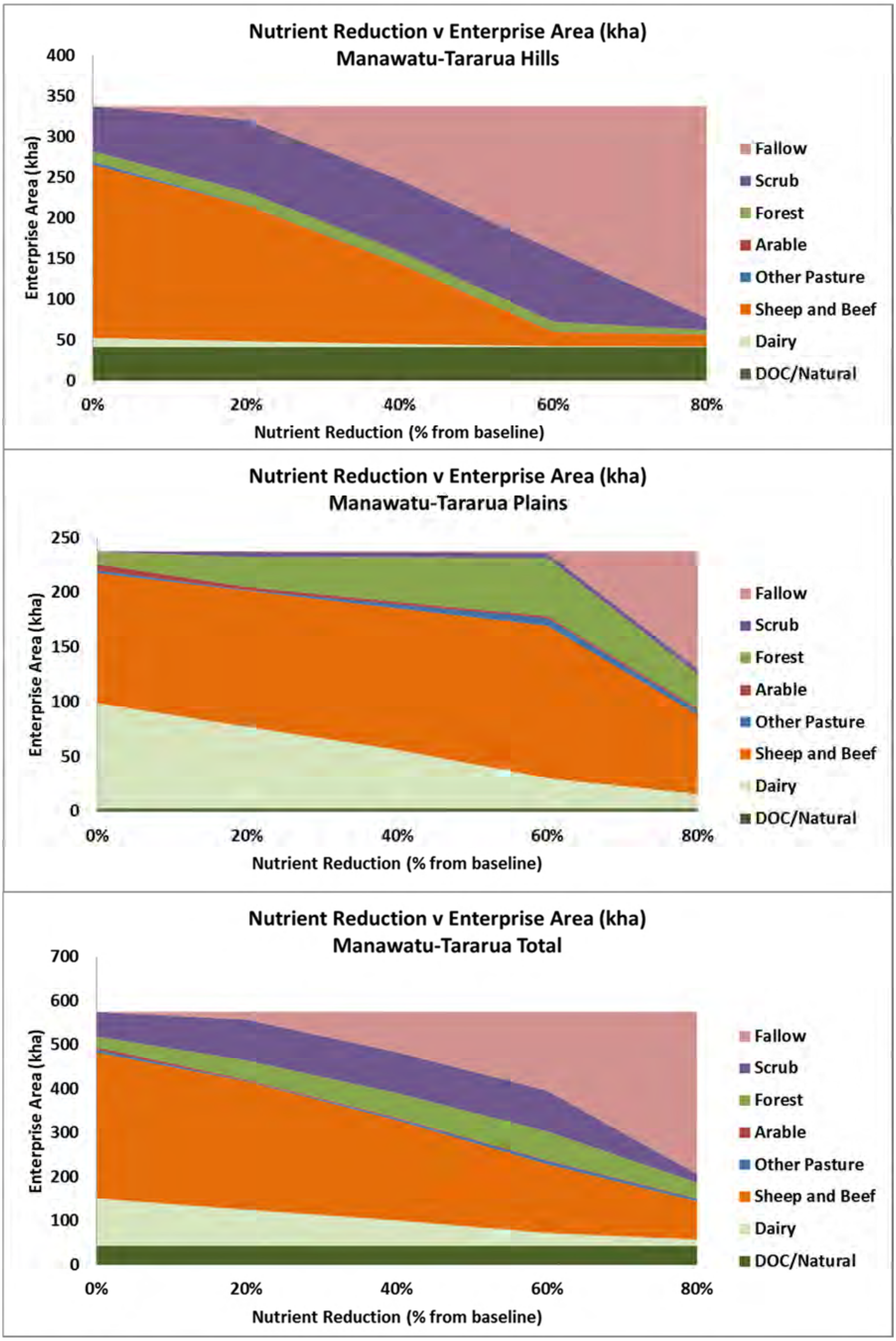


Figure 28 Regional change in land-use from baseline for Manawatu Catchment, catchment-wide cap-and-trade

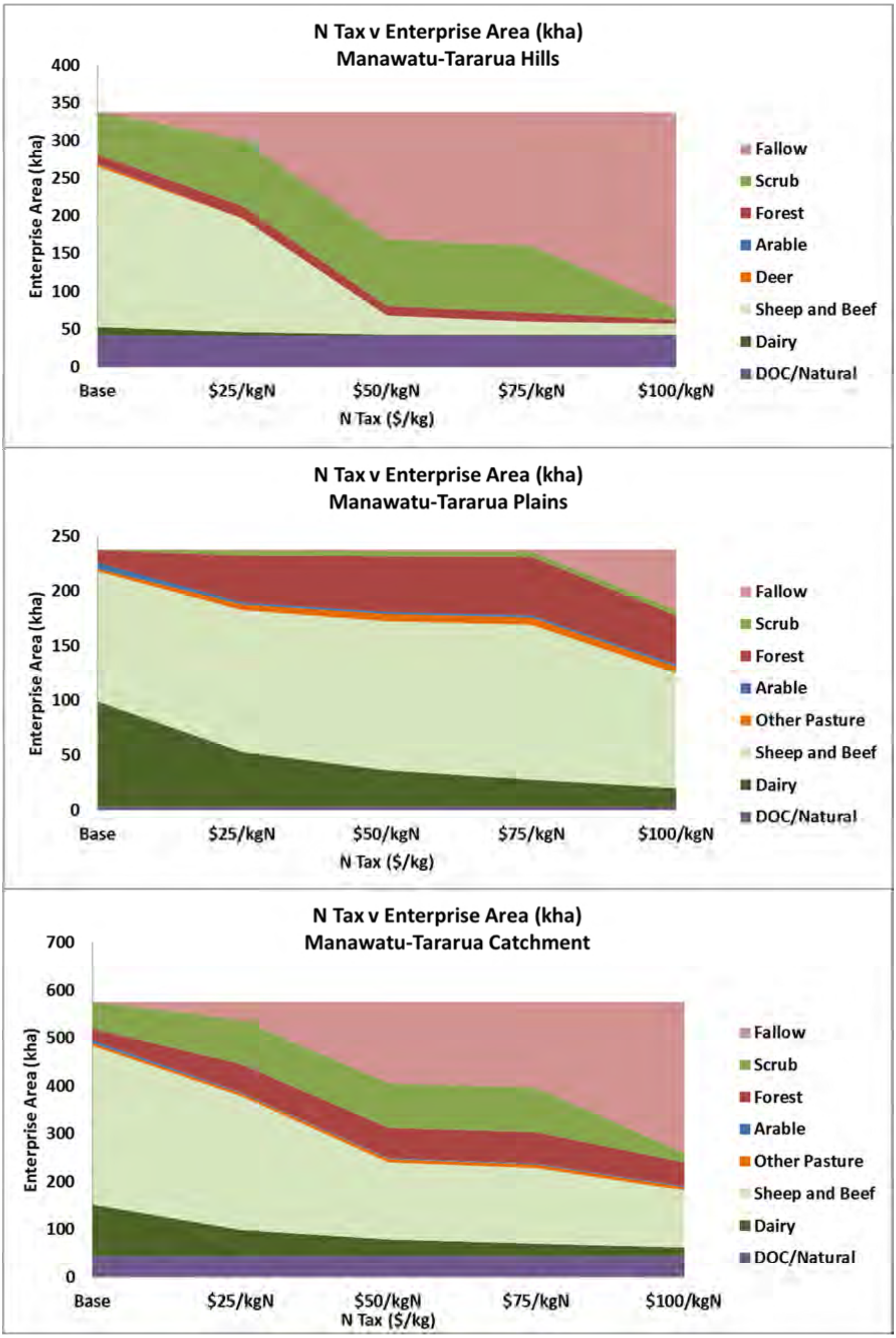


Figure 29 Regional change in land-use for various N discharge tax rates

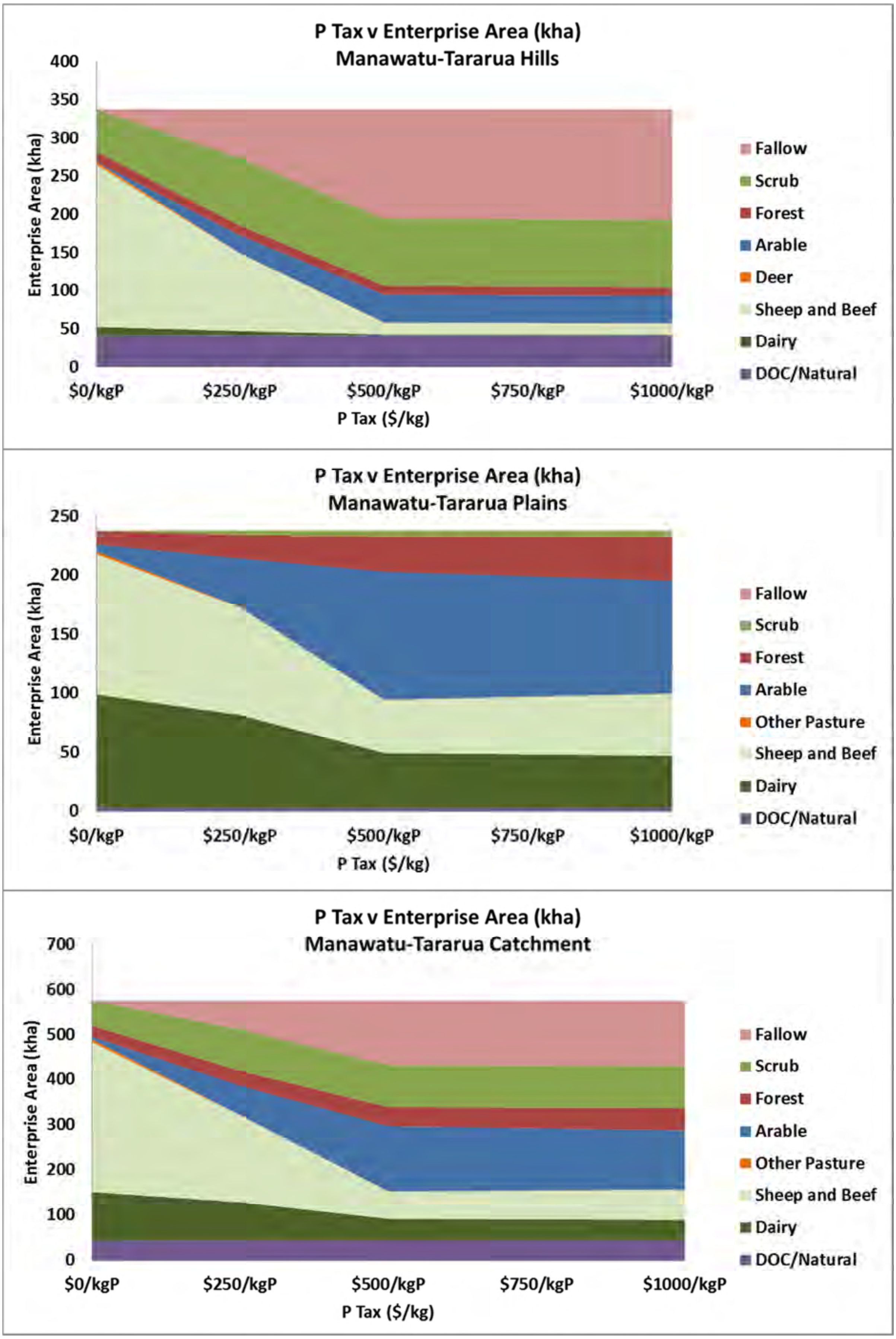


Figure 30 Regional change in land-use for various P discharge tax rates

Appendix E – Detailed estimates for water quality policy scenarios, Manawatu Catchment

Table 35 Regional nutrient discharge permits, Manawatu Catchment

Policy Scenario	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Total
			Tons N		
Baseline	1881	922	1493	1099	5395
Catchment-wide Grandparenting	1118	435	831	152	2536
Zone Restricted Grandparenting	884	627	612	396	2519
Natural Capital Approach - all	1118	435	831	152	2536
Nutrient Tax	1118	435	831	152	2536
			Tons P		
Baseline	62	84	26	205	376
Catchment-wide Grandparenting	59	43	23	23	148
Zone Restricted Grandparenting	32	43	13	104	192
Natural Capital Approach - all	59	43	23	23	148
Nutrient Tax	59	43	23	23	148

Table 36 Value of nutrient discharge permits, Manawatu Catchment

Policy Scenario	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Catchment
			$/kgN		
Catchment-wide Grandparenting	n/a	n/a	n/a	n/a	$36.60
Zone Restricted Grandparenting	$34.40	$18.71	$89.70	$35.40	n/a
Natural Capital Approach – all	n/a	n/a	n/a	n/a	$36.10
			$/kgP		
Catchment-wide Grandparenting	n/a	n/a	n/a	n/a	$0
Zone Restricted Grandparenting	$2096	$109	0	0	n/a
Natural Capital Approach – all	n/a	n/a	n/a	n/a	$0

Table 37 Total net revenue (million $) for aggregate enterprises, Manawatu Catchment

	Dairy	Sheep and Beef	Deer	Arable	Forestry	Total
Baseline	$182.1	$ 55.8	$ 0.2	$ 9.0	$ 54.1	$ 301.2
Catchment-wide Grandparenting	$ 81.9	$ 37.9	$ 0.3	$ 1.8	$ 129.6	$ 251.5
Zone Restricted Grandparenting	$ 36.6	$ 32.3	$ 0.0	$ 29.2	$ 91.9	$ 189.9
Natural Capital Approach – all	$ 81.9	$ 37.9	$ 0.3	$ 1.8	$ 129.6	$ 251.5
Nutrient Tax*	$ 81.9	$ 37.9	$ 0.3	$ 1.8	$ 129.6	$ 251.5

*Assumes tax collected from nutrient discharges would be recycled back to landowners, so changes in net revenue only reflect lower production and/or higher costs of production absence of tax impact.

Table 38 Total product output (tonnes or thousand m^3), Manawatu Catchment

Product Output	Baseline	Catchment Grandparent	Regional Grandparent	Natural Capital Approach - all	Nutrient Tax
Milk Solids	106550	43592	19334	43592	43592
Dairy Calves	5705	2256	996	2256	2256
Lambs	72067	59081	44709	59081	59081
Mutton	14649	9763	8423	9763	9763
Wool	11410	5688	6315	5688	5688
Cows	15387	5717	3185	5717	5717
Heifers, Bulls, Steers	34143	29924	22267	29924	29924
Deer	4857	6704	7003	6704	6704
Potatoes	75337	6474	6493	6474	6474
Grains	37086	9246	283516	9246	9246
Timber and Pulp Logs	810	1875	1356	1875	1875

Appendix F – Net revenue per kg N leached and per kg P loss for aggregate enterprises in Hurunui-Waiau and Manawatu Catchments

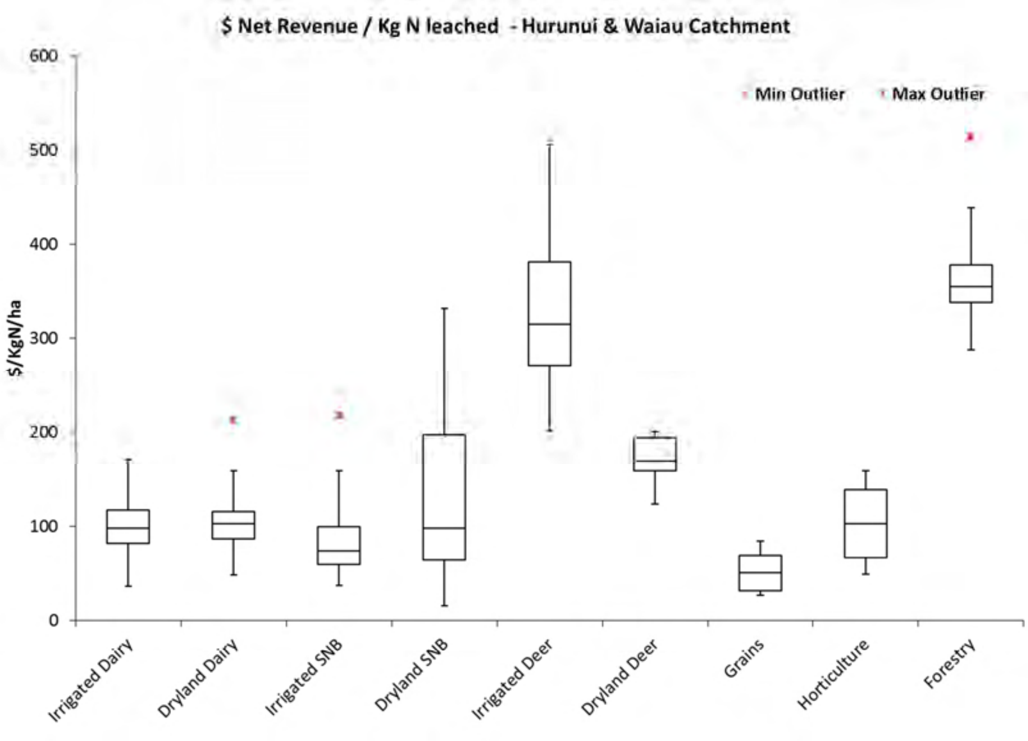


Figure 31 Net revenue per KgN leached Hurunui-Waiau catchment

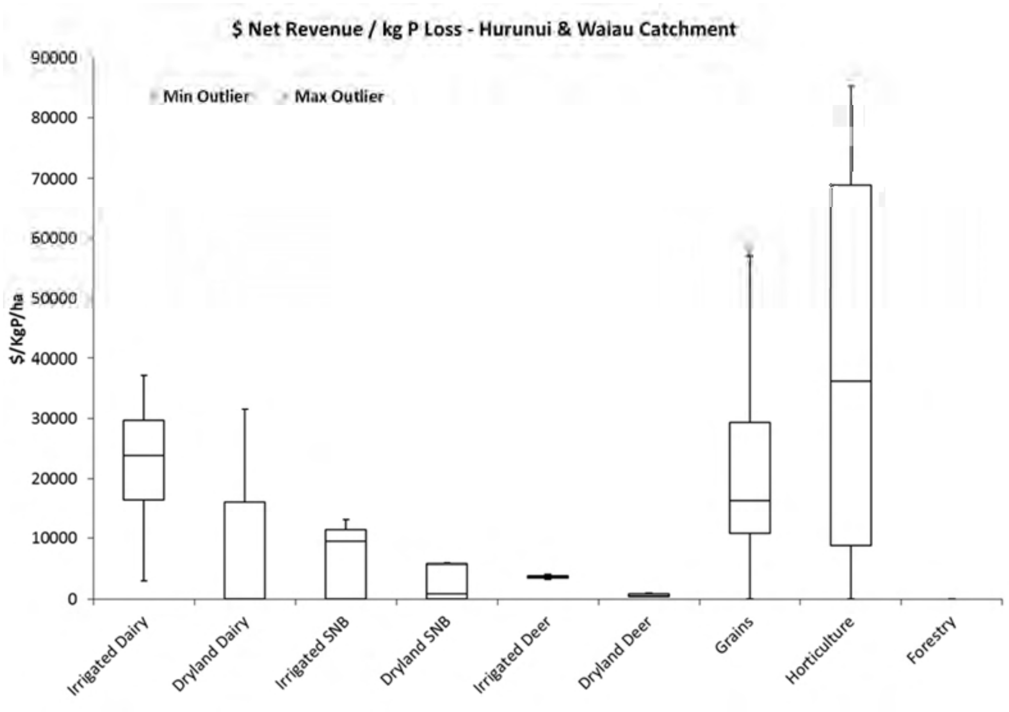


Figure 32 Net revenue per KgP loss, Hurunui-Waiau catchment

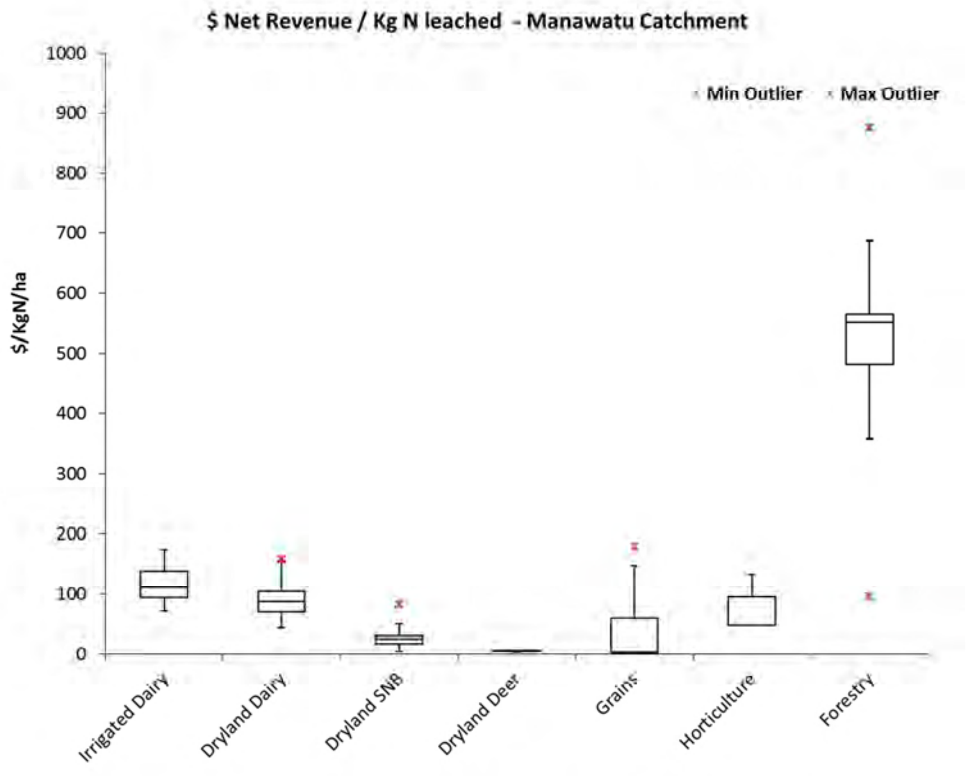


Figure 33 Net revenue per KgN leached, Manawatu catchment

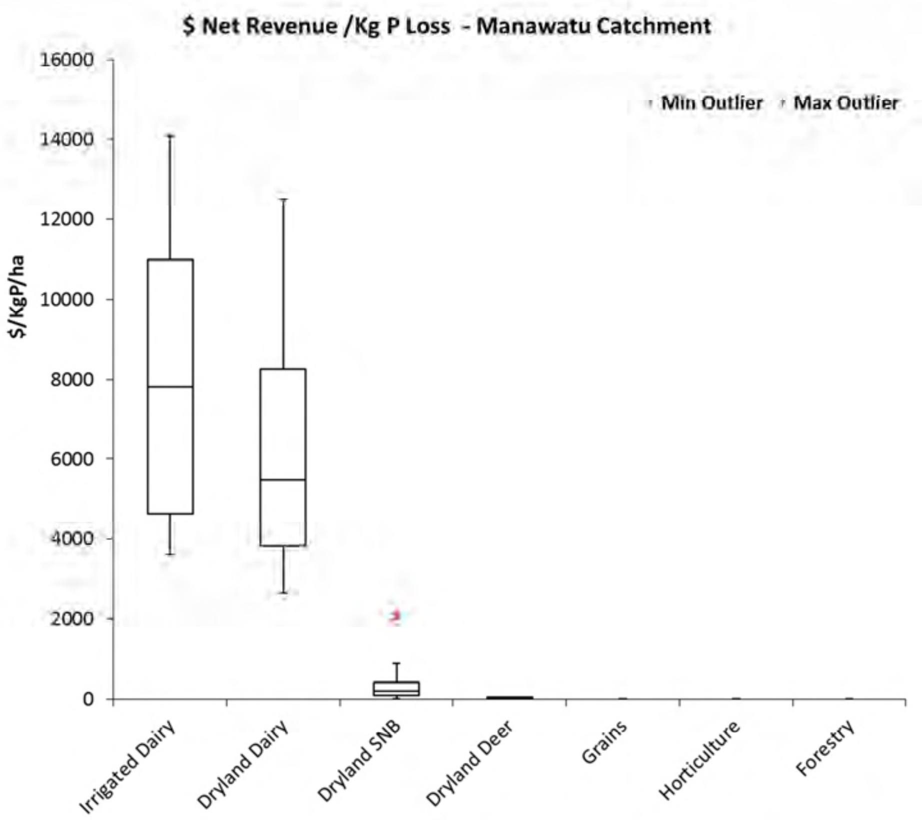


Figure 34 Net revenue per KgP loss, Manawatu catchment

Appendix G – Estimated costs and effectiveness of nutrient mitigation from alternative studies

Table 39 Estimated costs of mitigating nitrogen and phosphorus in Lake Rotorua

	Action	N reduction (T/yr)	P reduction (T/yr)	Cost ($)		Time-frame
				Per year	Per kg	
Council approved actions	Rotorua Wastewater Treatment Plant upgrade	15	0	$1,484,320	$99 (N)	By 2006
	Community wastewater reticulation or OSET upgrade for Rotorua	10.8	0.25	$4,990,637	$460 (N) max	By 2014
	Storm water upgrades within Rotorua urban	3	0.5	$1,046,080	$348 (N) $2,092 (P)	By 2017
	Tikitere geothermal	30	0	$108,200	$4 (N)[3]	By 2009
	[P flocculation in the Utuhina Stream]	[0][4]	[2]	$420,000	$210 (P)	By 2006
Potential actions	[P flocculation in two other streams]	[0]	[4]	$840,000	$210 (P)	~
	Constructed wetlands	N reductions, costs and timeframes will depend on the site and proposal. Further evaluation is required				
	In-lake/in-stream nutrient removal using biomass	N reductions, costs and timeframes will depend on the site and proposal. Further evaluation is required				
	Lakebed sediment treatment	0[5]	25	$25 million estimated total cost	~	By 2011
	Hamurana Stream diversion to the Ohau Channel	53 (2005)[6] 92 (2055)[7]	6.3	$3,030,000[8]	$57 ('05) $33 ('55) $481 (P)	After 2011
	Land use management and land use change	170	6	~	~	By 2017
Total		228.8 + 53/92 Hamurana	12.75 (inc flocculants) + 25 (lakebed tmt) + 6.3 (Hamurana)			

Source: Environment Bay of Plenty (2011)

Table 40 Mitigation practices of relevance to cattle-grazed farming enterprises in the Hurunui

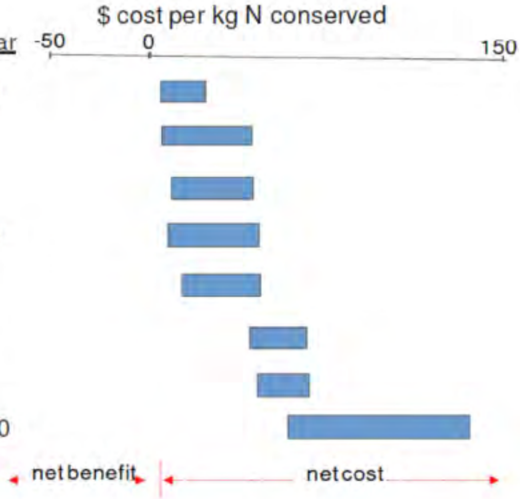
Mitigation practice	Effectiveness[2] %	Cost effectiveness	Comment
Tier 1 practices			
Improved management of FDE (storage; low rate and low depth application)	20 (P)	High	Of most relevance to heavy or poorly drained soils; will also help reduce faecal pollution
Increased irrigation efficiency (improved uniformity of application, scheduling according to need, capture of irrigation by-wash, etc.)	Modest reductions in N leaching; ~10%?	High	Border dyke by-wash capture will also help to reduce P losses
Stock exclusion from streams and wetlands	High for P	High	Many ancillary benefits such as habitat protection, fewer stock losses etc
Nutrient management plans	High (P and N)	High	
Tier 2 practices			
Use of nitrification inhibitors	10-15 (N)	High	
Wintering cows in Herd Shelters	32 (N)	Medium	High capital cost
Wintering in Herd Shelter+ Restricted grazing of pastures in autumn	49 (N)	Medium	High capital cost
Limiting N fertiliser use	40 (N)	Low	Large reductions in profit
Changing from border dyke to spray irrigation	20 (P)	High	High capital cost, but does bring production benefits
Tracks and lanes sited away from streams & lane runoff diverted to land	Medium	High	Important for minimising localised impacts on streams
Substituting N-fertilised pasture with low N feeds	Modest	Medium	Cost-effectiveness very dependent on milk payout price and cost of low N feed supplement
Grass buffer strips	Modest to low	Low	
Facilitating the development of natural wetlands	Medium for N, high for sediment	Medium	Efficiency at removing faecal bacteria
Constructed wetlands	High for N, sediment and faecal bacteria	Low	

Source: Brown et al. (2011)

[2] Percentage values documented in the Table are those derived from the farm-scale modelling undertaken for the project and reported in Appendix I of the Brown et al. (2011) report.

Table 41 Cost and effectiveness of mitigation practices for cattle-grazed farming enterprises in New Zealand

	Effectiveness %	Cost $/cow/year
Nitrification inhibitors	25 -35	10 – 30
Stream fencing	3 – 13	6
Optimal effluent mgmt	2 – 6	6
Wintering shelter	25 – 35	13 – 73
Restricted aut grazing	30 – 50	65
Low N feed	10 – 15	40
Nil N fertiliser	20 – 30	73
Dry stock farming	55 - 65	160 – 700



Source: Monaghan (2009a)

Table 42 Indicative capital and annualised costs for some management practices relevant to farms in Horizons' Region. Cost assumptions derived from Monaghan (2009b)

Mitigation measure	Capital cost	Annualised cost estimate ($/ha/yr, unless otherwise indicated)
Nitrification inhibitors (DCD)	Nil Dependent on land-use, soil type, climate	can typically range from a net benefit of $150 to a net cost of approx. $120
Winter shelter (dairy)	Typically $500–2,000 per cow. Can range between nil and $500	
Avoiding fertiliser applications during high-risk drainage months	Nil	Minor
Stand-off pads (dairy)	Typically $100-200 per cow	$50–100
Substituting N fertiliser with a low N feed (dairy)	May require construction of a feeding pad and/or purchase of a feedout wagon	Can range between nil and $500; very dependent on payout and price of low N feed
Nil N fertiliser	Nil	Varies according to product prices, cost of N fertiliser, etc.; mostly incurs a significant net cost
Constructed wetlands	$800 per ha of "treated" farmland, assuming 1% of farm area taken out of production	$100–120
Effluent storage ponds	$35–100+ per cow depending on pond lining requirements	$20+
Low-rate effluent application	$14–20 per cow (not including cost of storage ponds or drying beds)	$10–16, depending on type of applicator used (K-line pods usually the cheapest option)
Stream fencing	Dairy: $2–6 per m Sheep: $10–16 per m Deer: $12–20 per m	Dairy: $0.25–0.70 per m Sheep: $1.10–1.80 per m Deer: $1.30–2.00 per m
Reduced shed water use and effluent volume generated, e.g. "Dungbuster"	$5 per cow	Typically less than $5

Source: Monaghan (2009b)

Table 43 Summary of efficacy and cost of phosphorous mitigation strategies for low-, average-, and high-producing farms and for an average farm in the Waikakahi, a dairy farmed catchment in New Zealand

Strategy	Main targeted P form(s)	Effectiveness (% total P decrease)	Cost, range ($ per kg P conserved)†	Cost, Waikakahi ($ per kg P conserved)†
Management				
Optimum soil test P	dissolved and particulate	5–20	highly cost-effective‡	(15)
Low solubility P fertilizer	dissolved and particulate	0–20	0–20	0
Stream fencing	dissolved and particulate	10–30	2–45	14
Restricted grazing of cropland	particulate	30–50	30–200	na
Greater effluent pond storage/application area	dissolved and particulate	10–30	2–30	13
Flood irrigation management§	dissolved and particulate	40–60	2–200	4
Low rate effluent application to land	dissolved and particulate	10–30	5–35	27
Amendment				
Tile drain amendments	dissolved and particulate	50	20–75	na
Red mud (bauxite residue)	dissolved	20–98	75–150	na
Alum to pasture	dissolved	5–30	110 to >400	na
Alum to grazed cropland	dissolved	30	120–220	na
Edge of field				
Grass buffer strips	dissolved	0–20	20 to >200	30
Sorbents in and near streams	dissolved and particulate	20	275	na
Sediment traps	particulate	10–20	>400	>400
Dams and water recycling	dissolved and particulate	50–95	(200) to 400¶	200
Constructed wetlands	particulate	–426 to 77	100 to >400#	300
Natural seepage wetlands	particulate	<10	100 to >400#	na

† Numbers in parentheses represent net benefit, not cost. Data taken as midpoint for average farm in Monaghan et al. (2009a).
‡ Depends on existing soil test P concentration.
§ Includes adjusting clock timings to decrease outwash <10% of inflow, installation of bunds to prevent outwash, and releveling of old borders.
¶ Upper bound only applicable to retention dams combined with water recycling.
# Potential for wetlands to act as a source of P renders upper estimates for cost infinite.

(McDowell & Nash 2012)

Appendix H – Technical details of NManager

This appendix details key updates and additions to NManager since Anastasiadis et al. (2011), summarises the greenhouse gas result of each nutrient policy, and outlines future work.

NManager Additions

Calculating GHG emissions under different policies

One of the key additions to NManager is the ability to compare long-run GHG emissions under different policies. We estimate GHG emissions under different policies based on predicted nitrogen discharges. Below we explore the strength of this relationship between GHG emissions and nitrogen discharges, explain how the changes in emissions are estimated by NManager, and outline how we are dealing with forestry sequestration in the model.

Nitrogen leaching versus GHG emissions

The profit/leaching curves that are used in NManager (Anastasiadis et al. 2011) were estimated by using OVERSEER and FARMAX (Smeaton et al. 2011). Smeaton et al. (2011) estimated nitrogen leaching, GHG emissions, and profitability for an average Rotorua dairy farm and an average Rotorua sheep/beef farm under a number of different management approaches. We exploit the relationship between nitrogen leaching and GHG emissions to use in NManager to estimate GHG outcomes of different policies. The strength of this relationship between nitrogen leaching and GHG emissions is shown in Figure 35 for both sheep/beef and dairy farms under different management regimes.

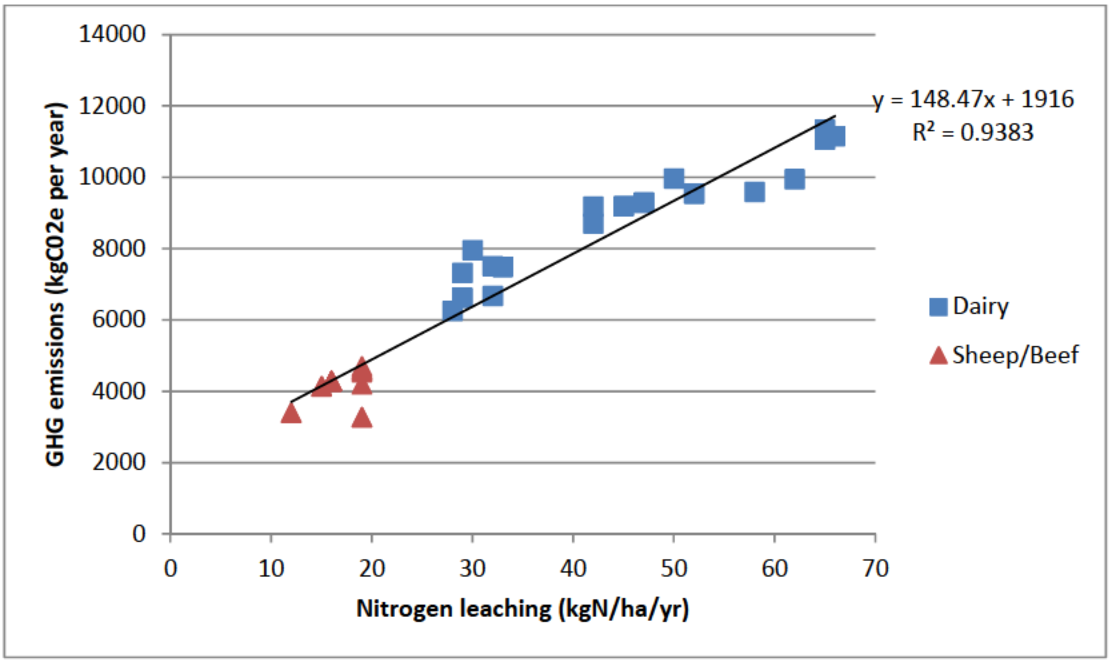


Figure 35 GHG and Nitrogen Leaching (Smeaton et al. 2011)

We estimate the linear relationship between these two variables using ordinary least squares on all of the data points. This relationship is then used to estimate the change in GHG emissions that result from nitrogen reduction policy. We calculate GHG emissions for dairy and sheep/beef on the same curve, as we believe a significant amount of mitigation will occur through gradual land-use change from dairy to sheep/beef. When NManager predicts nitrogen leaching above the sheep/beef points but below dairy points we interpret this as partial land-use change where a proportion of the land is in dairy, and the rest is in sheep/beef. Figure 35 shows that the relationship between GHG emissions and nitrogen leaching appears relatively consistent across both land-uses.

Transition into forestry land is calculated slightly differently. When NManager predicts that a land parcel has nitrogen leaching levels below sheep/beef levels we interpret that a portion (x%) of that parcel will be in forestry, with (1–x%) remaining in sheep/beef land. We estimate GHG emissions for this parcel i as follows:

$$GHG_i = size_i[x(GHG_{Forest}) + (1 - x)(GHG_{SB(10)})]$$

Where $GHG_{SB(10)}$ is the GHG emissions associated with sheep/beef land at the lowest leaching rate of 10 kgN/ha/yr, and $size_i$ is the size of the parcel in question. In NManager we use GHG_{Forest}=0; that is, we assume GHG emissions of forest land is 0. The justification for this is discussed below.

Forestry

Calculating the GHG emissions or sequestrations from additional forestry land requires consideration of both the short and long run GHG effects of transitioning land from sheep/beef or dairy into forestry. The long-run impact of permanently shifting from a high emissions land-use to a net zero emissions land-use is a long-run decrease in emissions.[3] Additionally, there are short run GHG benefits of converting land to forestry that exist over the length of forestry rotation. While forests grow they sequester and store carbon; however, when they are cut down they release this stored carbon slowly back into the atmosphere. In NManager we assume that new forestry land is put into productive rotation forestry that maximizes the profitability of the land-use. Rotation forestry has no long-term net carbon sequestration, as at every rotation (approximately 30 years) forests are harvested and replanted. The carbon captured in each rotation slowly leaches back into the atmosphere when it is chopped down. However, while average *flows* of carbon sequestration are zero, average *stocks* of carbon in any given year are positive. We report the additional average stock of carbon in any year as a result of the policy as a separate environmental measure.[4] However, at any one year (in the long run), the results we give for additional carbon stock can be interpreted as the expected additional tonnes of carbon being stored in trees in Rotorua as a result of the nutrient policy. To put this number in context we also calculate what proportion of baseline GHG emissions this stock represents.

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[3] Given the stringency of the nitrogen cuts required to achieve long run environmental goals for Lake Rotorua, we assume that land-use transitions to forestry will be permanent.

[4] Average long run stock is calculated using MAF look up tables for Bay of Plenty for radiata pine with a 28-year rotation, assuming that rotations continue infinitely (MAF 2011).

Allocation module

The second major change to the NManager model is the addition of a module that allows us to explore the distribution of costs under different policies, environmental goals, and allocation regimes. Specifically, the allocation module allows us to explore the distribution of costs to different communities in the catchment, such as across different farm types (sheep/beef, dairy, and the wider community).

We calculate cost as follows, where *M* is the cost of mitigation, *P* is the market price of allowances over time, *A* is the free allocation of allowances, and *N* is the level of nitrogen leaching:

$$Cost_i = M_i + P(A_i - N_i)$$

Our allocation module calculates distributions of cost assuming zero transaction costs. Under zero transaction costs the allocation of allowances to participants should have no effect on the efficient distribution of production, and will only effect the wealth of participants (Coase 1960). This assumption of zero transaction costs will not be met in reality; even in a flexible and well-designed nutrient trading market participants will face significant costs of trading (McDonald & Kerr 2011). However, we currently lack the ability to model market outcomes with transaction costs in NManager. This unrealistic assumption of zero transaction costs should be kept in mind when considering allocation results. Under non-zero transaction costs allocation decisions will not only impact on the allocation of wealth around the catchment, but will also affect efficiency. The higher the transaction costs (or equivalently, the less flexible the regulation), the more regulators will need to consider the efficiency of the production implied by their initial allocation of allowances. High transaction costs will mean this initial allocation may not be traded to move to the most efficient distribution of mitigation.

NManager heterogeneity limitations

The simulations we produce are also limited by the homogeneity of participants' mitigation costs in NManager. Due to data constraints, the current version of NManager assumes that all farms of the same land-use face identical marginal mitigation costs, and the only heterogeneity in mitigation costs occurs across land-uses. However, mitigation costs vary across different farms and farmers (Anastasiadis & Kerr, forthcoming). Additionally, Doole (2010) shows that the degree of heterogeneity captured by a simulation model correlates with estimated costs of policies; the higher degree of heterogeneity, the lower the cost of trading markets relative to command and control-type policies such as the GMP policies, both of which are discussed below. On-going work to investigate the sensitivity of our results to heterogeneity is discussed in the future work section below.

Greenhouse gas results

The impact on greenhouse gas emissions under each policy is assessed here.

Good management practice

Due to complementarities between GHG emissions and nitrogen discharges, as we restrict nitrogen leaching, GHG emissions also fall (see Table 44). In the long run, restricting all Rotorua farmers to the BoPRC BMP will have the additional environmental benefit of a long run decrease in annual emissions of 16,393 tonnes CO_2-e (approximately 14% of baseline). If farmers are required to meet the Anastasiadis BMP this decrease in GHG emissions will be equal to 30% of baseline. As land-use change is not permitted to meet BMP targets there is no additional forestry land under either of these definitions of BMP. As a result, the only decrease in GHG emissions comes in decreases on farm; as there is no forestry planting, there is no additional sequestration to report.

Table 44 Change in GHG emissions resulting from nitrogen GMP regulations

Decrease in GHG emissions (tonnes CO2-e)	BoPRC GMP	Anastasidis GMP
SB decrease in emissions	3,652	13,697
Dairy decrease in emissions	12,741	22,296
Decrease in emissions	16,393	35,993

Nutrient trading

The land-use and farm management changes required to achieve these nitrogen cuts would have complementary impacts on GHG emission reductions (Table 45). Meeting the 270 tN cap would result in a long run decrease in the catchment's annual agricultural GHG emissions by a third. Meeting the more ambitious 320 tN cap would see catchment-wide emissions fall by almost 45%. In addition to this 45% cut in annual emissions, achieving the 320 tN target would require new forestry, which in an average long run year would hold a carbon stock of 761 000t CO_2-e, which is the equivalent to 6.3 years of annual BAU emissions.

Table 45 Long-run change in GHG emissions under cap-and-trade regulation with a nitrogen reduction target of 270t by 2022

Decrease in GHG emissions (tonnes CO2-e)	270tN reduction	320tN reduction
Sheep/Beef decrease in emissions	13 405	21 090
Dairy decrease in emissions	27 780	32 975
Total decrease in emissions	41 185	54 065
Sequestration		
Additional carbon stock, long run average	0	760 970
Proportion of annual BAU emissions	0%	630%

Future work

Future work is planned for two major areas: allocation, and heterogeneity.[5] In terms of allocation, we plan to assess two additional allocation schemes. The first assesses the distribution of costs when sheep/beef and dairy landowners are allocated proportionately less than business as usual discharges, such that the sum of allocation equals the target nutrient discharges. We would also like to investigate the distributional impacts of allocating on land's potential production and nitrogen leaching, where potential production is defined by a land quality measure such as average stock carrying capacity. However, this will require changes to NManager's current set up which could be time-consuming. This will only be carried out if time and funding allow.

Our highest priority for future work is to increase the heterogeneity of mitigation costs within NManager. We want to do this for two key reasons. First, the current homogeneity of marginal mitigation costs for parcels in the same land-use is inconsistent with data. We would like to test how sensitive our results are to the level of heterogeneity captured by NManager. The second motivation for increasing the heterogeneity of our model is that it will allow us to understand the distributional impacts of allocation better. Including farmers with different degrees of profitability will help us understand how costs of meeting environmental targets in Lake Rotorua will be shared across different farmers within the same land-use, and how this cost sharing is affected by different allocation approaches.

[5] We also plan to test our GHG estimation model further, and test the sensitivity of our results to changes in forestry profitability.

Appendix I – Estimating lag times based on Mean Residence Time (MRT) from hydrogeologic properties

Groundwater residence times at sampling points such as groundwater wells, springs, and rivers have been determined from isotope concentration using lumped-parameter (box) models (Maloszewski & Zuber 1982). Such sampling points represent mixtures of groundwater with different transit times along all the flow paths in the hydrogeological system. The isotope concentration in groundwater recharge is convoluted with a lumped-parameter (box) model to obtain measured isotope concentration at a sampling point such as a well or outflow from a surface water sub-catchment.

In the absence of isotope tracers, Maloszewski and Zuber (1982) provide a relationship for the Exponential Model (EM) between MRT of groundwater and aquifer properties in a partially confined aquifer:

$$\mathrm{MRT} = \frac{nH}{R} \tag{1}$$

where n [-] is the aquifer porosity, H [m] is the thickness of the confined aquifer or the average saturated thickness of the unconfined aquifer, R [m/year] is the groundwater recharge. The possible range of MRT can be assessed by applying the range of realistic values of aquifer porosity, aquifer thickness, and groundwater recharge to equation (1) (Gusyev et al. 2011a, b).

The estimated MRT can be used to construct cumulative frequency distribution (CFD) that indicates a distribution of groundwater transit times at the sampling point (Haitjema 1995):

$$\mathrm{C}FD = 1 - e^{-\frac{t}{MRT}} \tag{2}$$

where t [years] is the groundwater transit time in the aquifer.

Using (1) MRTs were estimated for both Waiau-Hurunui and Manawatu surface water catchments (Tables 1 and 2). The groundwater recharge was estimated as the difference between average precipitation and evaporation values. The average annual precipitation data for 1960–2006 were sourced from Tait et al. (2006) and average annual evaporation data for 1960–2006 were sourced from Tait and Woods (2006). For the average aquifer porosity and saturated thickness, we selected three values to represent a range of typical values.

Using (2) with estimated MRTs we obtained CFDs that are shown in Figure 1 for Waiau-Hurunui and in Figure 2 for Manawatu surface water catchments. These CFDs represent a composition of the groundwater transit time at the catchments outflows. For the Waiau-Hurunui catchment, the residence time distribution with MRT of 12.28 years indicates that 90% of groundwater is younger than 28 years. For the Manawatu catchment, the residence time distribution with MRT of 14.39 years indicates that about 90% of groundwater is younger than 32 years.

Table 46 Estimated MRTs for average hydrogeologic parameters in Waiau-Hurunui surface water catchment

Recharge, [m/year]		0.7327479	0.7327479	0.7327479
n, [-]		0.01	0.155	0.3
H, [m]	10	0.14	2.12	4.09
	20	0.27	4.23	8.19
	30	0.41	6.35	12.28

Table 47 Estimated MRTs for average hydrogeologic parameters in Manawatu surface water catchment

Recharge, [m/year]		0.6252893	0.6252893	0.6252893
n, [-]		0.01	0.155	0.3
H, [m]	10	0.16	2.48	4.80
	20	0.32	4.96	9.60
	30	0.48	7.44	14.39

For the Waiau-Hurunui and Manawatu catchments, a porosity of the aquifers of 0.15 is considered realistic. The resulting mean residence time of the groundwater for both catchments is therefore estimated to be in the range between 2 and 7 years in average.

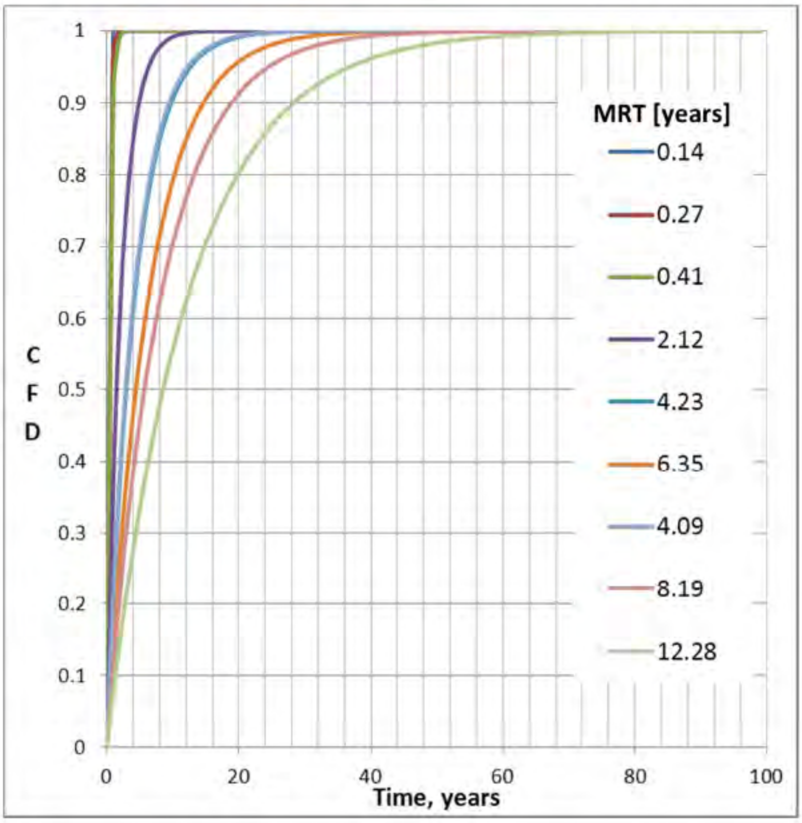

Figure 36 Cumulative frequency distributions (CFDs) for the Waiau-Hurunui surface water catchment

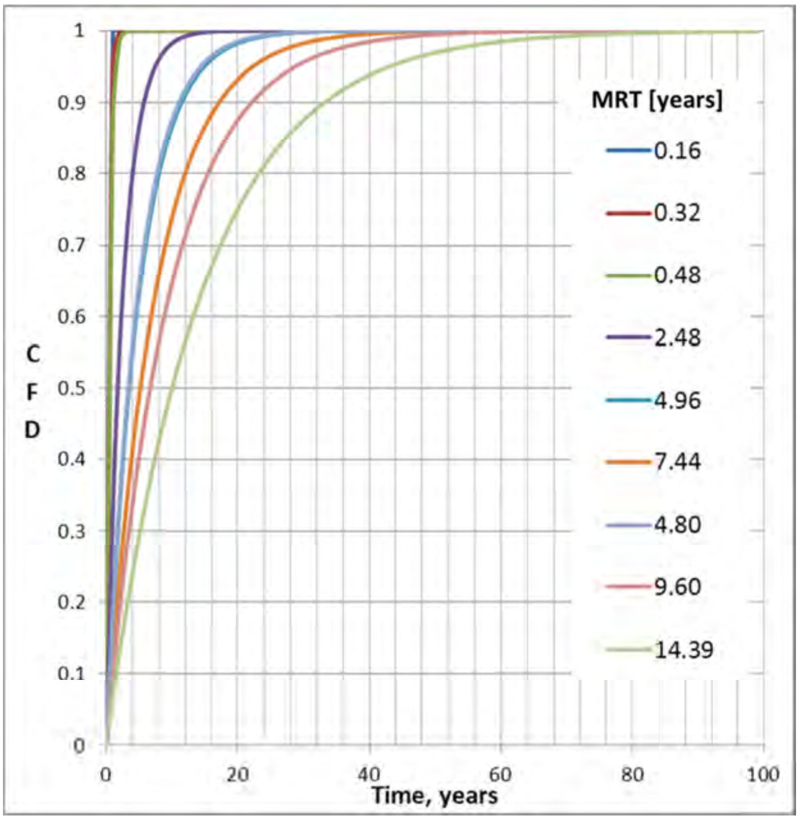

Figure 37 Cumulative frequency distributions (CFDs) for the Manawatu surface water catchment

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