Modelling Economic Impacts of Water Storage in North Canterbury[*]

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ABSTRACT

This paper uses a new comparative-static, partial equilibrium model of regional New Zealand land use, the New Zealand Forest and Agriculture Regional Model (NZ-FARM), to assess the growing concern over water use and environmental flows in North Canterbury. We estimate changes in land use, agricultural output, and environmental factors from additional irrigation developed from a proposed infrastructure improvement project in the Hurunui Catchment of North Canterbury, New Zealand. Preliminary results show that increasing the amount of water available for irrigation by as much as 86% will primarily affect production in the more fertile plains region. Total catchment income from agricultural and forestry production is expected to increase by about 1.7% with the new water quantity supply relative to the base case, and land use is expected to shift out of shrub and pasture to arable crop and horticultural land as well as forest plantations. Environmental outputs such as N and P leaching as well as CO_2 from additional farm operations and energy used for irrigation are all expected to increase if the new irrigation scheme is implemented. If landowners are constrained to keep their environmental outputs at baseline levels, few of them will opt to invest in the new irrigation scheme. These findings suggest a strong trade-off between achieving both improvements in water quantity and water quality in the Hurunui catchment.

KEYWORDS: Partial Equilibrium Modelling, Agriculture and Forestry Sector, Land Use, Water Quantity, Water Quality

INTRODUCTION

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

The model used for this paper is the New Zealand Forest and Agriculture Regional Model (NZ-FARM), a new comparative-static, regional, mathematical programming model of regional New Zealand land use. Its structure is similar to that of the US Department of Agriculture's Regional Environment and Agricultural Planning (REAP) model (Johansson et al., 2007). The model maximizes rural farm income across a catchment, accounting for the environmental impacts of land use and land-use changes. It can be used to assess how changes in technology (e.g., GHG mitigation options), commodity supply or demand, resource constraints (e.g., water available for irrigation), or how proposed farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers, land managers and communities. The environmental impacts currently considered in NZ-FARM include GHG emissions (and sequestration), water use, soil erosion, and nutrient and pesticide losses. Future updates will include additional GHG mitigation options and a wider array of ecosystem services.

In this paper, we present an application of NZ-FARM in which we assess several scenarios for the development of irrigated area under several water storage options for the Hurunui Catchment in North Canterbury. This application is timely, given that there are increasing pressures on water resources in the catchment, and frequent conflicts between abstractive users (mainly pastoral), recreational users (e.g. kayaking, fishing) users, and environmental needs. Proposals have recently been developed to build a control weir and/or dam in the upper Hurunui catchment. Currently, a 'Water Management Zone Committee' is developing a strategic approach to managing water in the Hurunui and adjacent Waiau catchments. At the same time, water quality limits are also being developed for the Hurunui catchment that would constrain nitrogen and phosphorous loadings. This paper discusses both the potential impacts of water quantity supply and water quality constraints on land use and farm income.

Several modelling efforts have been used in the past to investigate the economic and environmental impacts of changes in water use, but few have been developed to address this issue at the catchment level in New Zealand. Lennox (201X) uses a CGE model to estimate the economic impacts of constraints on water supply for irrigation in the greater Canterbury region and finds that an increase in the scarcity of water would have a negative impact on dairy farming, whilst other sectors would benefit because they are less water intensive. An econometric study of the Mackenzie Basin, in inland south Canterbury, found that rights to irrigation water could generate a land sale price premium up to 50% relative to similar land without irrigation (Grimes and Aitken, 2008). Ex post evaluations of specific irrigation schemes in Canterbury found significant socio-economic benefits for improved irrigation in the region (Ford, 2002; Harris et al., 2006). None of these studies have investigated the issue of water management in Canterbury at the level of detail available in NZ-FARM.

The paper is organized as follows. First, we present the theoretical foundation of the NZ-FARM model, and describe the details of the data sources specific to the Hurunui catchment. Next, we lay out the issues surrounding water management specific to the catchment or wider Canterbury region and describe a series of irrigation schemes that have been proposed. Following that, we present baseline land use, farm production, water use, and environmental outputs, and compare them to the estimates from our scenario analysis. The final section provides a conclusion of our findings.

NZ-FARM MODEL

The New Zealand Forest and Agriculture Regional Model (NZ-FARM) is a comparative-static, mathematical programming model of regional New Zealand land use. Production activities in each region of NZ-FARM are differentiated in a variety of ways, including a set of fixed and variable input costs, use of inputs such as fertilizer and water, and output price. Production and land use are endogenously determined in a nested framework such that landowners simultaneously decide on the optimal mix of land use for their fixed area, given their soil type, and then how to allocate their land between various enterprises such as grains, livestock, and horticultural crops that will yield them the maximum net return for their land use. Two other land uses are also tracked in the model, Manuka-Kanuka (scrub) land, which is allowed to vary across scenarios, and Department of Conservation (DOC) land that is assumed to be fixed as land use change for DOC is not typically driven by economic forces.

Objective Function

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

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

Subject To:

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

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

Production activities in each region are differentiated in several ways. Each production activity uses information on input cost, input use, and output price. As mentioned above, production and land use are endogenously determined in a nested framework. First, landowners decide on the optimal land mix for their fixed area, given their soil type. Second, the landowner determines the allocation of land between various enterprises such as grains, livestock, and fruits and vegetables that will yield the maximum net return for his land use. Last, the decision is made on what outputs to produce given the mix of enterprise and output price.

The allocation of land to a specific land use, enterprise, and product output is represented with constant elasticity of transformation functions (CET). The transformation function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of possibilities. The CET function itself is calibrated using the share of total returns for each element included in the stage and a parameter, σ_i, where $i \in \{L, L2E, E\}$ for the three separate nests, land (L), land to enterprise (L2E), and enterprise to output (E) . In general, CET parameters can range from 0 to infinity, where 0 indicates that the input (land, enterprise) is fixed, while infinity indicates that the inputs are perfect substitutes. The CET functions used in NZ-FARM are parameterized based on the estimates from existing literature of regional economic land use models (e.g., Johansson et al. 2007). In our case, CET values ascend with the level of the nest, as a landowner likely has more flexibility to transform its enterprise mix compared to changing the share of land use (e.g., forest v. pasture). An illustrated description of the nested structure is shown in Figure 1. The model is written and maintained in General Algebraic Modeling System (GAMS). The baseline calibration and estimates for the scenario analysis in this paper are derived using the non-linear programming (NLP) version of the PATH solver (Ferris and Munson, 2000). More information on the model specifications particular to the Hurunui catchment is provided below.

HURUNUI CATCHMENT DATA

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

Geographic Area and Land Use

This paper focuses on Hurunui catchment in North Canterbury, New Zealand. The catchment area is divided into 3 sub-catchment zones based primarily on biophysical properties and availability of water for irrigation. These areas include the plains, foothills, and hills. A map of the catchment is shown in Figure 2. Land in each zone is categorized by six distinct uses: forest, cropland, pasture, horticulture, Manuka-Kanuka (scrub), and Department of Conservation (DOC) land. Baseline land use was provided by Environment Canterbury and allocated on land use capability classes from New Zealand Land Resource Inventory (NZLRI) data.

Enterprises, Inputs, Outputs and Prices

Enterprises tracked in the model cover most of the agricultural and forestry sector for the catchment. Key enterprises include dairy, sheep, beef, deer, timber, maize, wheat, and fruit. NZ-FARM includes 18 enterprises for the Hurunui catchment, however each region has 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.

Each enterprise requires a series of inputs to maximize production yields. The high cost of given inputs coupled with water and input constraints can limit the level of output from a given enterprise. Outputs and prices are primarily based on data provided by Lincoln University (2010) and the 2010 State of New Zealand Agriculture and Forestry (SONZAF), and listed in 2009 New Zealand dollars (NZD)[1]. Stocking rates for pastoral enterprises were established to match figures included in the FARMAX model (Bryant et al., 2010). Each enterprise also faces a large set of fixed and variable costs ranging from stock replacement costs to deprecation that were obtained from

[1] All results are also listed in New Zealand Dollars (NZD). At time of publication, exchange rates were as follows: 1 NZD = 0.76 USD, 0.77 AUD, and 0.56 EUR.

personal communication with farm consultant Stuart Ford and Lincoln University (2010). The cost series was developed for each enterprise and varied across all three zones. 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.

Fertilizer and Mitigation Options

Most enterprises in the catchment have the option to vary the use of fertilizer. This model 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 from a survey of farmers in the greater Canterbury region (Ford, 2010).

NZ-FARM also has the option to differentiate between 'business as usual' (BAU) practices and other production practices that can mitigate/reduce greenhouse gases (GHGs) and other environmental pollutants. Some of these mitigation options result in a decline in productivity, while others increase farm productivity and/or cost more than business as usual practices. The current array of options modelled is:

- Adding DCDs (N inhibitors),
- Constructing feedpads at dairy farms,
- Providing payments for forest carbon sequestration.

Environmental Outputs

The model has the ability to track environmental outputs such as nitrogen and phosphorous leaching, N_2O emissions from excreta and effluent, and CO_2 emissions from fuel, electricity and fertilizer used in the production process. Data on environmental output coefficients were obtained from several sources. Nitrogen and Phosphorus leaching rates for pastoral farming were obtained from the most recent version of OVERSEER (2010), while N and P leaching rates for all other enterprises were constructed using SPASMO (2010). Forest carbon sequestration rates were derived from regional lookup tables for a 300 index scaled radiata pine pruned[2], medium fertility site (Paul et al., 2008). GHG emissions for all other enterprises were derived using the IPCC's *Good Practice Guidance* (2000).

WATER QUANTITY AND QUALITY SCENARIOS

The current level of irrigated area in the Hurunui catchment is about 22,300 ha. Nearly all of this is centralized in the plains region, where a majority of the area's agricultural output is produced, including 98% catchment's of the dairy production. Lack of additional water available for irrigation in the region means that there is little (if any) additional water available to be allocated. This has led to a large difference in farm incomes for farms with and without irrigation and to recent farmer demands for supply-side development that would allow them to begin irrigating, expand their current irrigation or increase the reliability of their water supply. One proposal to improve the water supply situation has been to build a dam on the South Branch of the Hurunui River (costing upwards of $42 million) and/or to construct a control weir (costing about $3 million) at the outlet of Lake Sumner in the western part of the catchment (See Figure 4). A recent study of this proposal commissioned for the purpose of this research found that this could increase the amount of irrigated land in the region on average to about 42.2 thousand hectares (Aqualink, 2010).

This study looks at the potential changes in total catchment income, land use, output produced and environmental outputs as a result of the increase in irrigated land. We account for the increase cost of irrigation (both capital and operation) faced by the landowner as well as the costs of changing land types. The two key scenarios we assess are the baseline with 22,300 ha of

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

irrigated land (BASE) and a proposed irrigation scheme that would increase the amount of irrigated land to 42,200 ha (IRR), based on the Aqualink (2010) study. While New Zealand regulations dictate that farmers must obtain resource consents for irrigated land that are typically given on a first-come, first-served basis, we make no assumptions about how those consents are granted. An additional scenario is also evaluated where environmental outputs are constrained to match the baseline scenario to estimate the potential impact on farm production and land use when irrigation is added relative to the case when there are no environmental constraints.

BASELINE AND SCENARIO ANALYSIS

Baseline Calibration

The entire catchment comprises 246,600 ha, of which 22,300 ha are irrigated. Almost all (99.7%) of the base irrigation occurs in the plains area, as that is the typically the zone with the highest productivity and revenue potential. The other 0.3% of irrigation occurs in the foothills. Total catchment income is estimated at 222.4 million NZD. Regional output is shown in Table 2. Sheep and beef farming is dominant in the dryland foothills, while most other production occurs on the irrigated plains.

Land use in the catchment is dominated by pasture in the plains and foothills, and by DOC in the higher and steeper hill region. Plantation forests encompass very little of the 'managed' land in the catchment, as do arable cropland and horticultural land. Manuka-Kanuka (scrub) land comprises about 12% of total land use in the catchment and thus has the largest capability of being converted to other uses[3]. The total area and distribution of baseline land use by zone is listed in Table 3.

Additional Irrigation Scenarios

The additional irrigation scenario added access to water for nearly 20,000 additional hectares, an increase of 86%. As in the base case, nearly all of this increase is expected to occur in the plains zone, which in this scenario now has almost has two-thirds of its land irrigated. If

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

environmental outputs are constrained to baseline levels (IRR + ENV CONS scenario), only 24,600 ha are irrigated, an increase of only 10%, as most landowners are unable to economically change their enterprise or input mix and meet the environmental limits. The distribution of irrigated and dryland area is listed in Table 3.

Total catchment income is estimated at 226.2 million NZD, an increase of 3.8 million NZD or 1.7% over the base case for scenario for the IRR scenario. The estimated increase in net income is relatively small despite the large change in irrigation due to higher costs faced by the landowner to pay for capital costs to access the water as well as an increase in annual operational costs. In the IRR+ENV CONS scenario, total catchment income is 223.1 million NZD, an increase of only 0.3%, again because few landowners are expected to change their current practice if forced to keep their environmental outputs constant.

Land use is estimated to change in the plains zone for both the IRR and IRR+ENV CONS scenarios, while the other two zones are not likely to see any benefits of the irrigation programme and hence have a similar distribution of land use (Figure 5). Results for IRR indicate that pastureland in the plains is expected to decrease by 8% relative to the base case, while horticulture increases 77% and cropland increases by 477%. This is because crop and horticulture based enterprises are quite water intensive. The area of planted forests also increases by about 4,300 ha (58%), while Manuka-Kanuka land is reduced by about 11,300 ha, or 64%. Land use for the IRR+ENV CONS scenario is similar to the baseline, with the exception that the area of cropland is estimated to increase by about 79%. Most of this increase in cropland is expected to come from the conversion of scrubland and pasture. Forest area is also expected to decline by about -1%.

The distribution of regional production for IRR also changes relative to the baseline, but again mostly in the plains zone where most of the irrigation was added (Figure 6). Largest changes are expected to occur for grapes, berryfruit, wheat, and barley, which is consistent with the expected shift in land use when more water is available for irrigation. Changes in production are also estimated to occur in the IRR+ENV CONS scenario, but again at a much smaller level than the less constrained IRR scenario.

Figure 7 highlights the changes in environmental outputs. It is apparent that 'negative' environmental outputs such as N and P leaching from fertilizer application and CO_2 emissions from farm production increase for all metrics relative to baseline scenario, with the exception of N_2O from direct excrement and effluent, which declines by 9%, mainly because of the decline in dairy-based output. Annual forest carbon sequestration for the IRR scenario increases by 30 tonnes of CO_2e (7%) because of the increase in forest plantations, while sequestration for the IRR+ENV CONS scenario actually declines by 9 tCO_2e (-2%). This is because the limited change in land use is estimated to shift from forests and scrubland to cropland.

CONCLUSION

This paper uses an economic catchment model to assess changes in land use, agricultural output, and environmental factors from additional irrigation developed from a proposed infrastructure improvement project in the Hurunui Catchment of North Canterbury, New Zealand. Preliminary results show that increasing the amount of water available for irrigation by as much as 86% will generally affect the more fertile plains sub-catchment. Land use is expected to shift out of shrub and pasture to arable crop and horticultural land as well as forest plantations. Total catchment income is expected to increase by about 1.7% after you take into account additional capital and operation costs from the new irrigation project are accounted for.

Environmental outputs such as N and P leaching as well as CO_2 from additional farm operations and energy used for irrigation are all expected to increase if the new irrigation scheme is implemented. This indicates that while the new infrastructure to improve water quantity in the region provides an overall benefit to landowners directly involved in agriculture, it could also increase costs to other sectors of the local economy that are reliant on good water quality as well as New Zealand as a whole, which is investigating ways to effectively reduce its comprehensive GHG emissions. If landowners in the region were constrained to hold their environmental outputs at baseline levels, it is estimated that less than 4,000 of the nearly 20,000 ha of new irrigated water available for consumption would be used on a year-by-year basis. On the contrary, if landowners are constrained to keep their environmental outputs at baseline levels, NZ-FARM estimated an increase of only 10% in irrigated area over the baseline as most landowners are unable to economically change their enterprise or input mix while meeting environmental limitations. This suggests that there is a potentially a strong trade-off between water quantity and water quality in the Hurunui region.

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TABLES

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

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

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

Table 2. Baseline Regional Output* for Hurunui Zones

Output	HH	HP	HF	Total
Milk Solids	0.0	26144.7	402.5	26547.2
Dairy Calves	0.0	1703.2	31.6	1734.8
Lambs	703.1	1721.6	3416.9	5841.6
Mutton	99.4	136.5	482.8	718.7
Wool	106.5	247.7	517.5	871.6
Cows	199.0	3725.7	1972.9	5897.6
Heifers	1821.3	1064.5	17443.2	20329.0
Steers	2025.7	3843.3	19382.9	25251.9
Bulls	0.0	1.4	0.0	1.4
Hinds	0.0	106.0	0.1	106.1
Stage	0.0	74.3	0.1	74.5
Pigs	0.0	3895.4	42.2	3937.6
Berryfruit	0.0	32.9	0.0	32.9
Grapes	0.0	2.8	348.6	351.3
Wheat	0.0	14441.0	0.0	14441.0
Barley	0.0	2686.1	0.0	2686.1
Pulp Logs	0.1	31.6	6.4	38.1
Timber	0.3	126.6	25.5	152.3

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

Table 3. Baseline Land Use for Hurunui Zones

	HH	HP	HF	Total	Percent
Forest	0.0	7.2	1.4	8.6	3%
Cropland	0.0	2.6	0.0	2.6	1%
Horticulture	0.00	0.02	0.03	0.06	0%
Pasture	28.6	48.0	55.3	131.9	51%
Manuka-Kanuka	6.2	17.8	7.2	31.1	12%
DOC Land	76.7	0.3	7.5	84.5	33%

Table 4. Irrigated Area in Hurunui Basin for Baseline and Irrigation Scenarios

	Hurunui Hills		
	BASE	**IRR**	**IRR+ENV CONS**
Irrigated	0.0	0.0	0.0
Dryland	111.3	111.3	111.3
	Hurunui Plains		
	BASE	**IRR**	**IRR+ENV CONS**
Irrigated	22.2	41.4	24.5
Dryland	41.8	22.5	39.5
	Hurunui Foothills		
	BASE	**IRR**	**IRR+ENV CONS**
Irrigated	0.1	0.1	0.1
Dryland	71.2	71.2	71.2
	Total Catchment		
	BASE	**IRR**	**IRR+ENV CONS**
Irrigated	22.3	41.6	24.6
Dryland	224.3	205.1	222.1

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

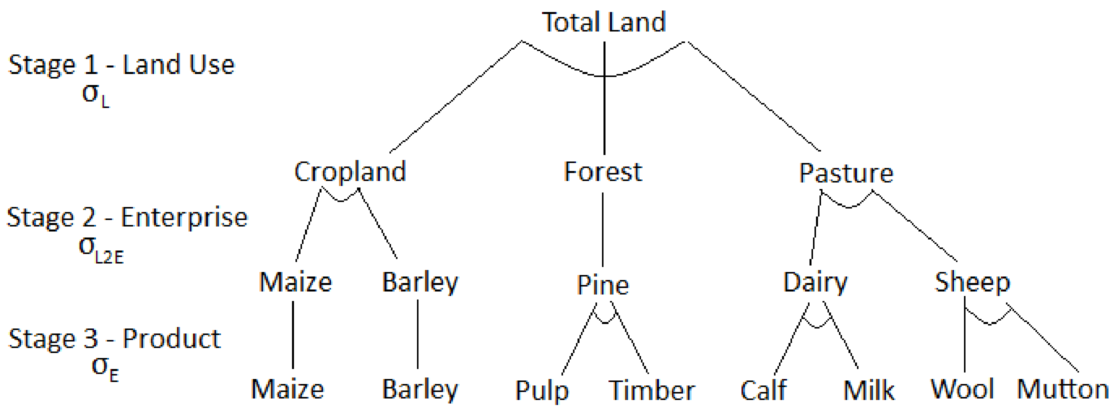

Figure 2. Hurunui Catchment, North Canterbury, New Zealand

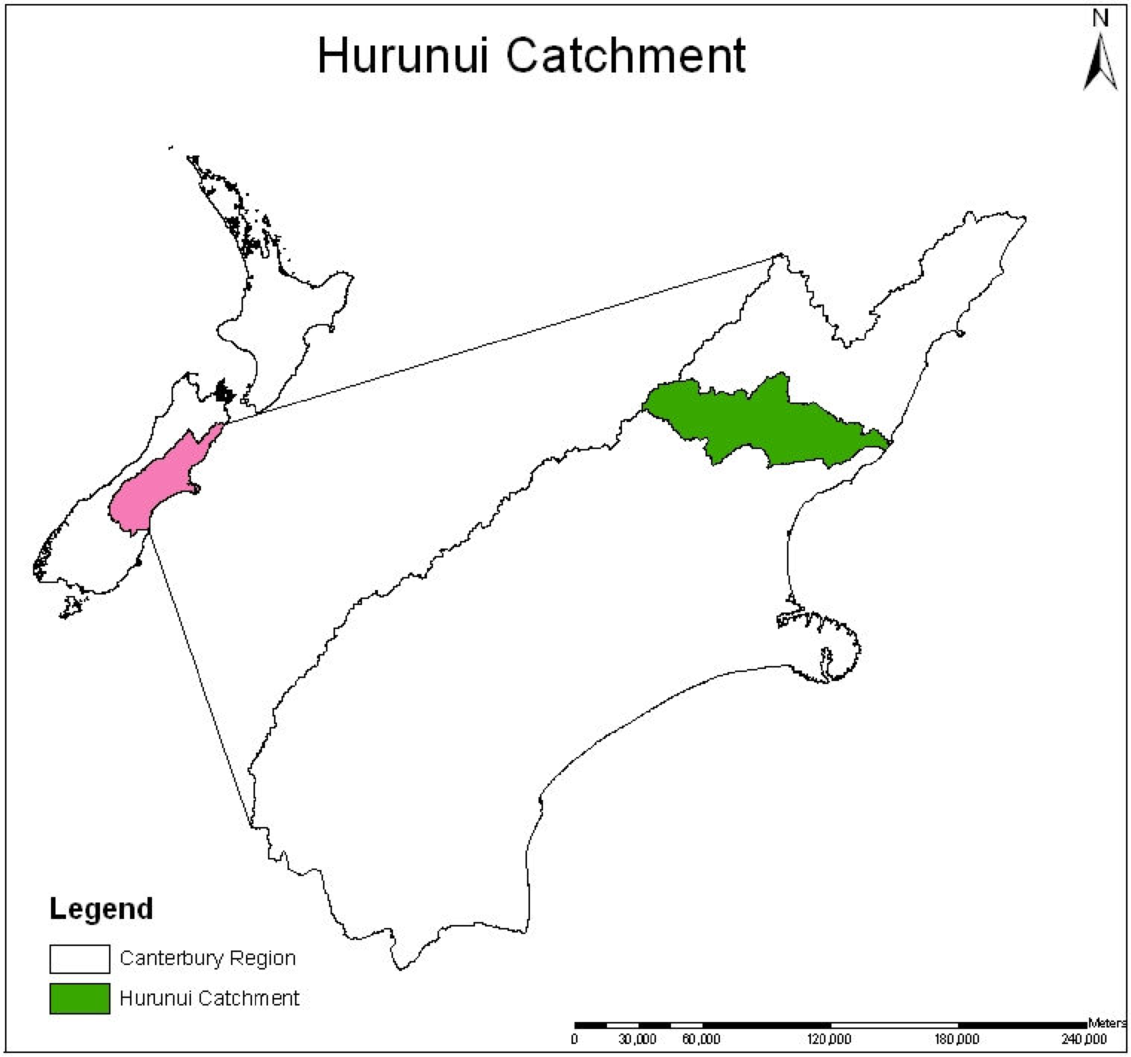

Figure 3. Distribution of Zones for Hurunui Catchment

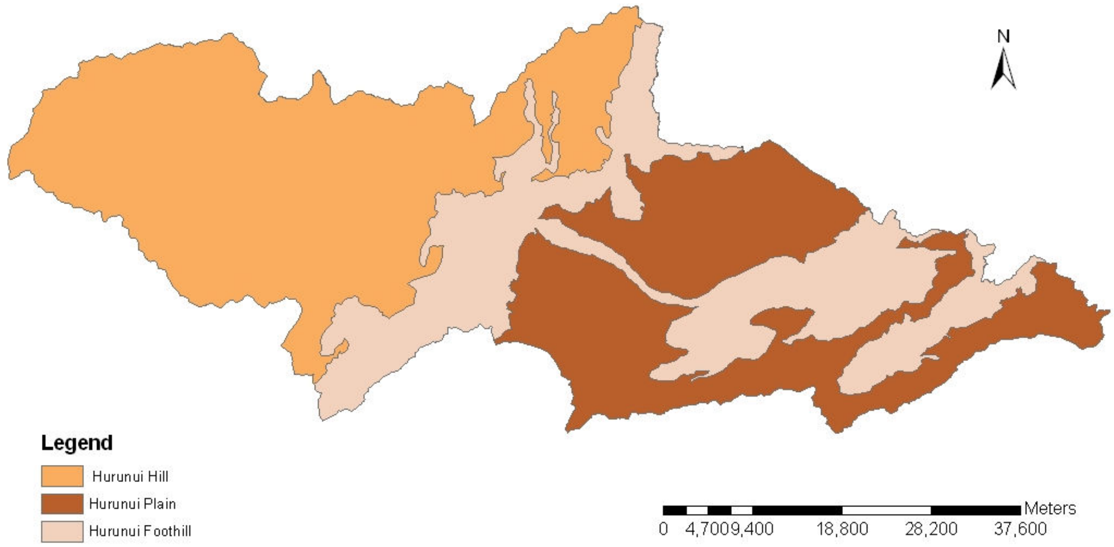

Figure 4. Baseline Enterprises and Water Storage Proposal Sites for Hurunui Catchment

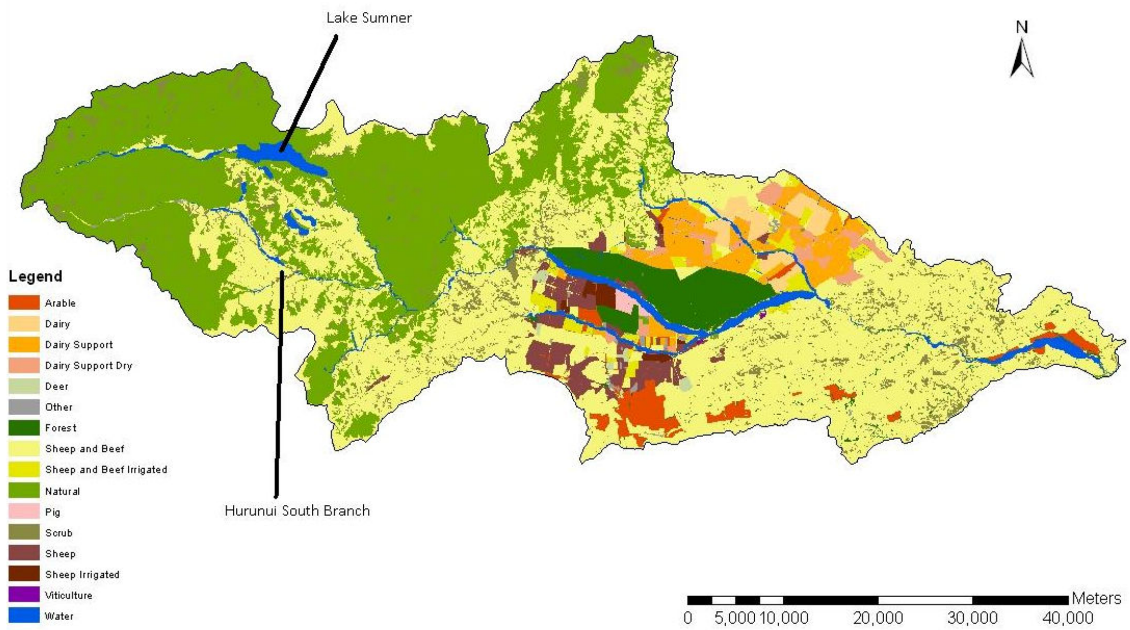

Figure 5. Regional Land Use for Hurunui Catchment, Baseline and Irrigation Scenarios

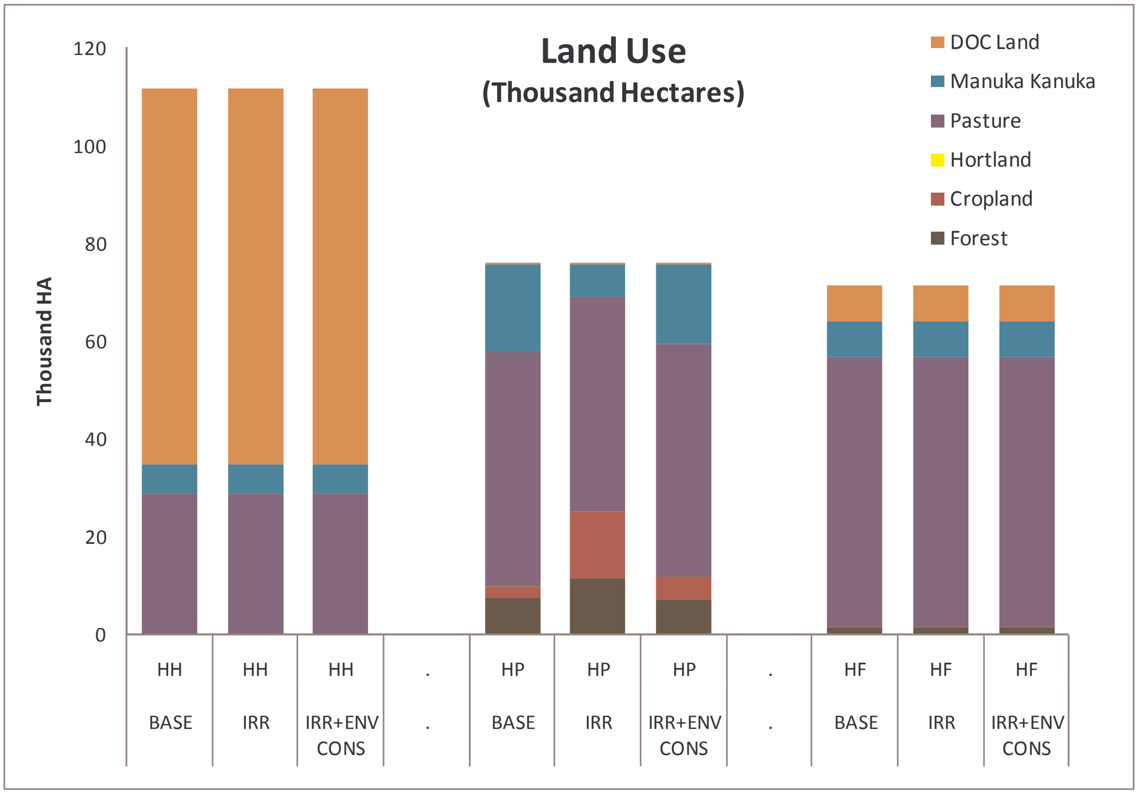

Figure 6. Distribution of Production in Hurunui Catchment for Baseline and Irrigation Scenarios

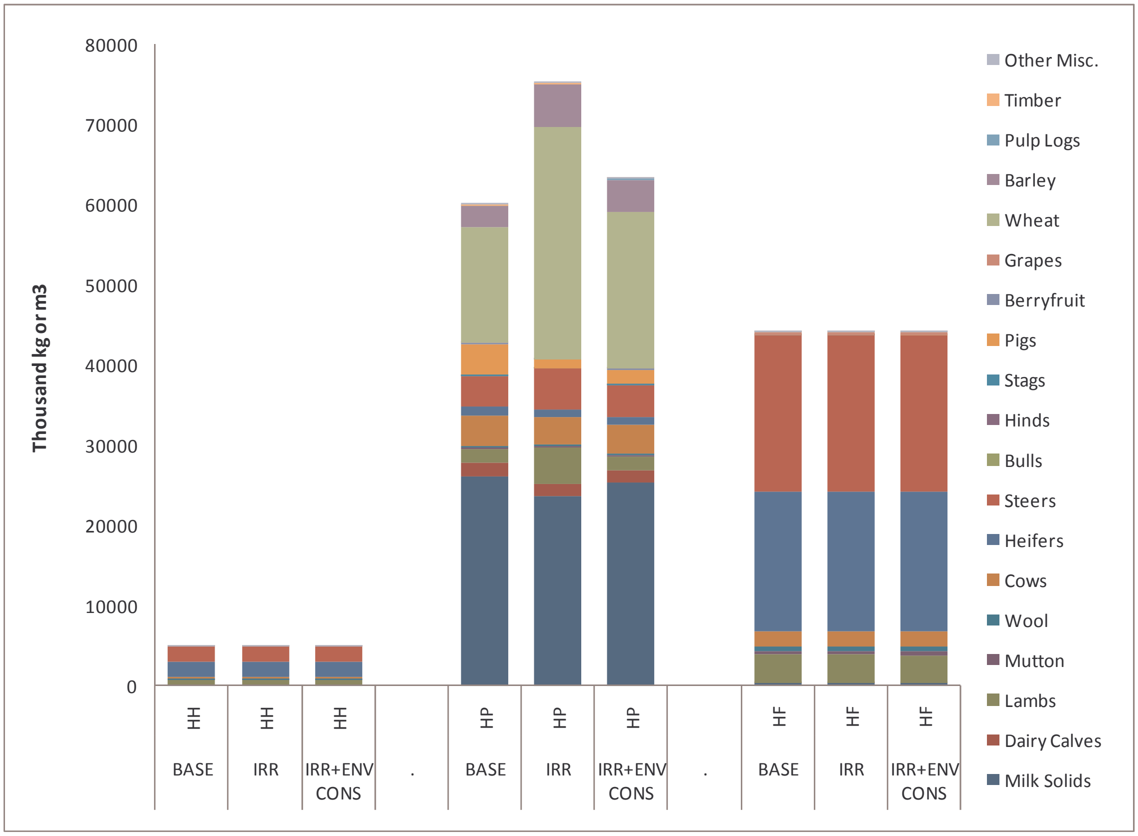

Figure 7. Environmental Outputs Baseline and Irrigation Scenarios, Hurunui Catchment