Potential impacts of water-related policies in Southland

On the agricultural economy and nutrient discharges

NZIER report to the Ministry for the Environment

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Executive summary

Background

We investigate impacts of nutrient caps and mandated farm practices in the Southland region on its economy and environment. We use a tailored Multi-Agent Simulation (MAS) model to evaluate explicitly how individual farmers respond to the caps and mandates. The model includes:

- scientific data on pasture productivity and nutrient discharges
- production and environmental data for 121 farming activities across three industries: dairy, sheep and beef, and forestry
- GIS information of soil classes and drainage in the Southland region
- bundles of mitigation practices developed by agricultural experts to represent the options available to farmers to reduce their environmental impact
- farmer behaviours informed by rural sociology about farmer decision-making and agricultural economics.

We model a baseline out to 2037, using 16 model scenarios that are combinations of caps on nitrate leaching (15 – 60 kg/ha) and phosphorus (0.5 – 2 kg/ha) loss applied uniformly across the region. We also analyse four scenarios that include non-uniform nutrient caps, grandparenting of dairy farms, and mandated mitigation practices. We then repeat the same modelling, but assume that farmers may use DCD.

The Ministry for the Environment provided these model scenarios to investigate a range of possible water quality and economic outcomes. Our results compare Southland in 2037 with and without these caps. Dollar figures in the report are presented in 2012 dollars, i.e., deflated from 2037 values[1].

Baseline includes increased dairying

Our baseline projection is based on current trends in land use and farming practices in Southland, without nutrient caps. In the baseline, dairying is expected to increase in Southland, and sheep and beef is expected to decrease. These changes would increase the N discharges by 16% to 19,039 tonnes in 2037; P losses would increase 28% to 539 tonnes in 2037. The baseline projection is for total value of agricultural production to increase in real terms to $4.6 billion per annum.

Wide range of modelling results

We find a wide range of results in terms of impacts on nutrient losses and economic impacts. The 16 uniform tools can be clustered into five sets based on their economic and environmental impact (Table 1):

- set A, tools 1 and 2, has no impact on land use or dairy practices because the caps are too high

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[1] We deflate the 2037 nominal results by 2% per year for 25 years, resulting in a factor of 1.64 for the ratio of 2037 nominal dollars to 2012 real dollars.

- set B, tools 3, 5, 6 and 7, delivers a 5% reduction in N leaching, a 23% reduction in P loss risk, and a 13% reduction in *E. coli* load for zero cost in the value of agricultural production
- set C, tools 4 and 8, delivers a 19% reduction in N leaching, a 40% reduction in P loss, and a 14% reduction in *E. coli* load at a cost of 25% of the value of agricultural production. The economic cost is due entirely to land-use change, with a small offset for the increased productivity from improved farm efficiency
- set D, tools 9, 10, 11 and 12, delivers a 25% reduction in N leaching, a 40% reduction in P loss, and a 14% reduction in *E. coli* load for a cost of 26% of the value of agricultural production. Nearly all of the cost in the scenarios is due to land-use change; mitigation accounts for less than 10% of the economic cost
- set E, tools 13, 14, 15 and 16, delivers a 45% reduction in N leaching, a 59% reduction in P loss, and a 7% reduction in *E. coli* load for a cost of 81% of the value of agricultural production.

The clustering of the uniform caps indicates that the N cap is predominantly the binding cap, while the P cap is only binding in two scenarios. The report therefore tends to focus on the cost-effectiveness of N mitigation.

The modelling also examined the following scenarios:

- set F includes non-uniform nutrient caps (tools 17 and 18). The results suggest that tailoring nutrient caps to farms' productive capacity and potential leaching rates provide mitigation that is more cost-effective than uniform caps
- set G includes grandparenting existing dairy farms (tool 19) with nutrient caps. It suggests that grandparenting is less cost-effective than other tools when it limits conversion to dairying
- set H includes tool 20, which focuses on farm practices rather than nutrient caps. By promoting widespread adoption of mitigation, set H is more cost-effective than most tools while achieving a comparatively high level of mitigation.

Finally, all 20 model scenarios were re-analysed to estimate the impacts of including DCD in mitigation practices.

Table 1 Regional results for 2037

Financial results in 2012 dollars

Farm-level tool set	Tool / scenario numbers	N mitigation (tonnes)	P mitigation (tonnes)	Change in gross margin ($ million)	Change in value of production ($ million)	Change in production / kg N mitigated ($)
A	1,2	0	0	0	0	0
B	3,5,6,7	-1,000 (-5%)	-125 (-23%)	+120 (+5%)	0 (0%)	0
C	4,8	-3,500 (-19%)	-215 (-40%)	-670 (-24%)	-1,200 (-25%)	-330
D	9,10,11,12	-4,900 (-25%)	-215 (-40%)	-850 (-31%)	-1,200 (-26%)	-250
E	13,14,15,16	-8,500 (-45%)	-315 (-59%)	-2,200 (-82%)	-3,700 (-81%)	-440
F	17	-1,400 (-7%)	-175 (-33%)	+$180 (+6%)	0 (0%)	0
	18	-2,500 (-13%)	-180 (-33%)	+$30 (+1%)	-$61 (-1%)	-24
G	19	-4,700 (-25%)	-225 (-41%)	-$980 (-36%)	-$1,500 (-32%)	-320
H	20	-6,300 (-33%)	-254 (-47%)	-190 (-7%)	0 (0%)	0

Source: NZIER
Note: The results are aggregate impacts at the regional level.

Costs of compliance is much higher when land-use change is required

In the modelled scenarios, farmers can achieve compliance with the nutrient limits in two ways (Table 2). They can adopt on-farm mitigation practices, modelled as three bundles of increasingly effective and cumulative mitigation practices (M1-M3). Alternatively, they can shift their land use to another industry with a smaller environmental footprint. The cost of compliance through land-use change is much higher than the cost through adoption of mitigations, as shown by comparing results across sets of farm-level tools:

- set A induces adoption of mitigation bundles but no land-use change. These deliver a 5% reduction in N leaching and a 23% reduction in P loss for zero cost in the value of agricultural production
- set B induces both land-use change and adoption of mitigation bundle 2. Set C also induces the same amount of land-use change, but adoption of mitigation bundle 3 rather than 2. The difference in costs and N mitigation between these scenario clusters is large – using M3 delivers 1,400 tonnes of

N mitigation more than using M2, for a negligible cost. This improves the cost effectiveness of set C, relative to set B

- set D achieves N mitigation by land-use change. This is the most costly set, delivering mitigation at $440/ kg N mitigated.

Table 2 How compliance to environmental caps is achieved

Farm-level tool set	Change in dairy hectares vs. baseline 2037	Dairy practices	Land-use change
A	0	No change	No change in land use
B	0	64% of dairy farmland uses M2	No change in land use
C	-84,000 (-28%)	All farms adopt M2	Some land-use change
D	-84,000 (-28%)	All farms adopt M3	Some land-use change
E	-303,000 (-100%)	Dairying unable to comply with discharge caps	Largest land-use change

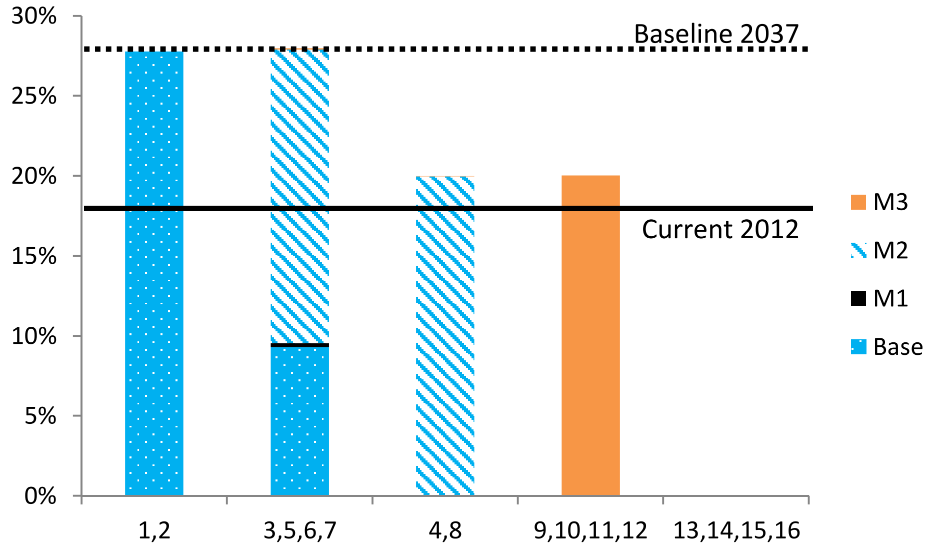
Source: NZIER

Dairying expands under all but the 15 kg N/ha cap

Under sets A through D, there is growth in dairying relative to today, even with N and P caps. Under set E, which imposes an N cap of 15 kg N/ha, there is a complete change in land use away from dairying, as the modelled dairy farming practices do not comply with this cap (Figure 1).

Figure 1 Dairy share of land use in Southland

% hectares, 2037



Source: NZIER

Sheep and beef practices are barely constrained by any of the caps

The lowest nutrient caps modelled (set E, a 15 kg/N cap) lead to adoption of mitigation M2 on 14% of sheep and beef farms. In these scenarios, sheep and beef farmers contribute 5% of mitigation. In all other scenarios, over 99% of the mitigation occurs on dairy farms.

Better quality land bears the load because it has the majority of the high N leaching farms

The majority of the N mitigation occurs in the Lowland water management zone, an area of good quality land that accounts for between 65% and 85% of total N mitigation, depending on the scenario. By contrast, the Hill water management zone – with steeper slopes and poorer soils – contributes at most 5% of total region N mitigation. The Basin water management zone contributes between 15% and 30% of total region N mitigation.

The Lowland zone, comprised almost entirely of LUC 1 to LUC 4 land, is most affected because it has 97% of the region's dairying that occurs on LUC 1 and LUC 2 land[2]. This type of land is the most productive and has the highest N leaching rates.

Mitigation practices across all land uses can reduce nutrients at one-fifth of the cost of uniform caps

To estimate the impact of non-uniform approaches, we analysed the results from all farms adopting the M3 mitigation bundle (scenario 20). This mitigation bundle creates the largest reduction in nutrient leaching, and we modelled its adoption across both dairy and sheep and beef land uses. We estimate that this situation

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[2] Land Use Capability (LUC) is used to classify land parcels according to their agricultural potential, with LUC 1 and LUC 2 land being the most productive and versatile.

would mitigate 6,300 tonnes of N leaching (around one-third of the 2037 baseline) at a cost of just $190 million in gross margins. This equates to a cost to the farmer of $30/kg N mitigated. This amount is about one-fifth the cost to the farmer of set D tools, which deliver 4,900 tonnes of N mitigation at a cost of $170/kg N mitigation. In addition, because the N mitigation is achieved through changes in farm practice rather than changes in land use, there is no cost to total agricultural production.

The difference in costs arises because the scenario relies on widespread mitigation rather than land-use change. Under the uniform caps, sheep and beef farms do not mitigate N leaching. These farms already have low levels of N leaching relative to dairy farms, and almost all are under even the strictest cap of 15kg N/ha that was considered. However, we project that in 2037 sheep and beef farms could be 65% of land use, contribute 39% of N leaching, and have mitigation options available that could mitigate over a third of their N leaching.

Wintering-off adds N leaching to the total but doesn't change key findings

In Southland, dairy cows tend to be 'wintered-off' – moved off the core dairy farm (the 'milking platform') to other locations during winter. The initial analysis (above) does not consider the N leached by dairy cattle during any wintering-off period. Including this leaching in the analysis (and assuming that all of the wintering-off occurs within Southland) adds between 10% and 13% to the total amount of N leached under scenarios with dairying (Table 3). Under set E tools, there is no leaching from wintering-off because dairy farming is not compliant with the model parameters.

There are two key findings from the analysis:

- including wintering-off increases the cost effectiveness of each scenario. This is because the analysis includes more of the N leaching, but the farm-level costs of wintering-off are already included in the farm budgets of the initial scenarios, so there is no change in costs
- including wintering-off does affect each scenario by different amounts, but the rank of scenarios by cost effectiveness is not changed.

Table 3 Total region N leaching with and without wintering-off

Tonnes N

Farm-level tool set	Total excluding wintering-off	Total including wintering-off	Percent difference
Baseline	19,000	21,400	13%
A	19,000	21,400	13%
B	18,000	20,400	13%
C	15,600	17,200	10%
D	14,100	15,700	11%
E	10,500	10,500	0%

Source: NZIER

Limitations of the analysis

This analysis has provided some information on the costs and impacts of nutrient discharge caps on Southland, but its limitations should be acknowledged:

- **wintering-off –** our approach to analysing wintering-off does not account for decisions by farmers to participate in dairy support, nor does it account for geographic concentration of dairy support. Managing the three- to five-month winter period could be a part of the farm system where future mitigation strategies focus
- **system change as a mitigation option –** in this modelling, if a nutrient cap requires more mitigation than the highest mitigation level, then farmers resort to land-use change. The modelling does not include the potential for radical system change in dairying methods, particularly de-intensification
- **bundling mitigation options –** mitigation options were grouped into three bundles, whereas farmers will actually be able to choose from a number of specific options. The impact is that the modelling overstates the total impact of each tool – economic and biophysical – because farmers are mitigating somewhat more than necessary to meet the caps. The net impacts of bundling on price per kg of N and P reduction are ambiguous, because they depend on the costs of specific practices and their individual and aggregate efficacy
- **barriers to adoption –** the model does not account for hurdles or barriers to adoption that affect the total cost of selecting new farm practices or changing land use. For example, some potential practices seem to be both economically profitable and efficient with nutrients. We would expect those practices to be more widespread than they actually are, suggesting that there exist some constraints to adoption for which we have not accounted
- **farmer behaviour –** our modelling extends analysis of environmental policy from a single, average, profit maximising farmer, to multiple, heterogeneous farmers with differing objectives. If our description of those behaviours is incorrect, we could be biasing the model results in unknown ways
- **corporate farms –** we do not explicitly consider corporate farms within the model, so the model may understate the amount of profit maximising or financially driven decision making
- **capacity of regional resources –** we do not explicitly consider the capacity of regional resources, including water, to sustain the growth in dairying in the baseline, although the projected growth path is in line with past levels of conversions
- **farmer debt and stranded assets –** debt and access to credit affect a farmer’s ability to adopt new practices. We do not explicitly include debt or assets in the model. However the impacts of credit constraints and debt are implicitly captured in the ‘aversion-to-change’ parameter that limits farmers from changing land use, and has been calibrated on the historical behaviour of farmers

- **technological improvements over time –** we include growth in agricultural productivity based on the gains over the last 20 years. We do not include any growth in the performance of current mitigation practices or any possible new ‘silver bullets’ that significantly reduce agriculture’s environmental footprint.

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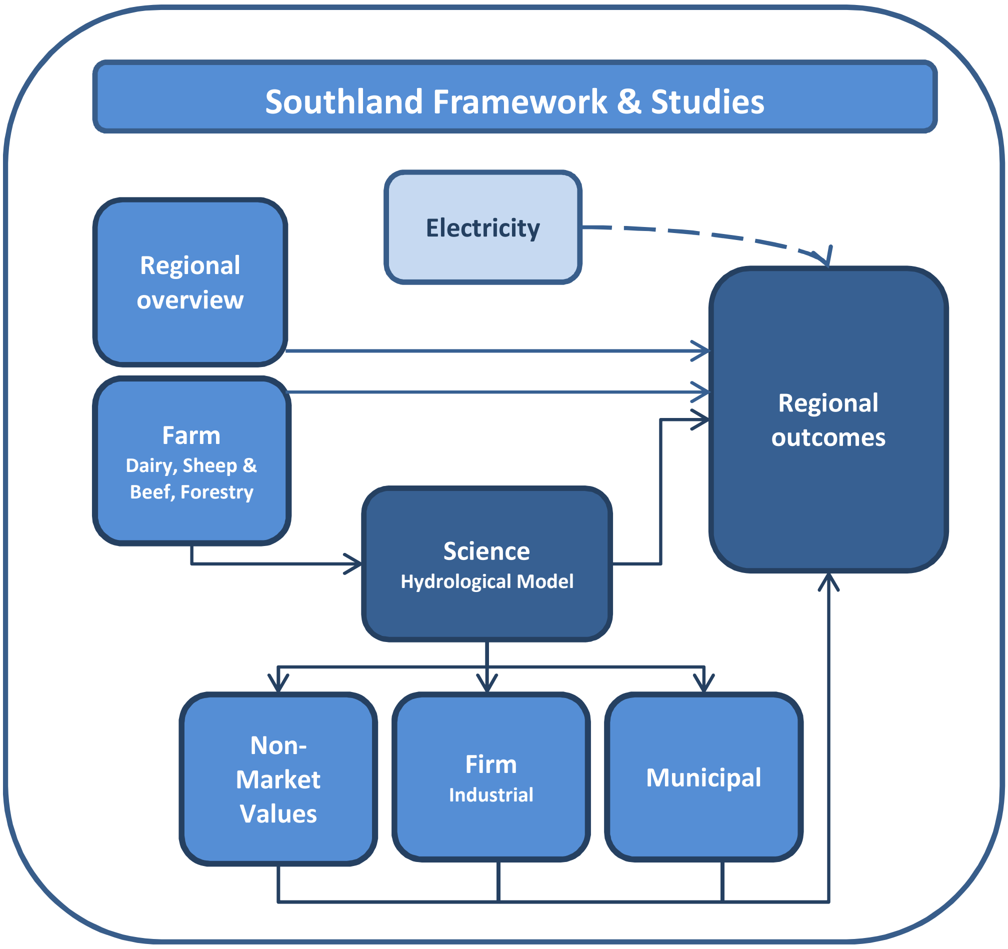
1. Introduction

The Ministry for the Environment (MfE) engaged NZIER and AgResearch to help examine the economic impacts of water quality policies. This report presents research on the potential impacts of a defined set of tools for the agricultural economy of the Southland region of New Zealand. The tools were specified as strict limits on the amount of nitrogen (N) and phosphorus (P) discharges per hectare for all farms in Southland, or as mandated farm practices. Economic impacts were measured as the change in farms' output – total revenue from sale of agricultural products – and gross margin – revenue less direct costs of production. The role of NZIER/AgResearch was to conduct the 'Farm' research shown on the left-hand side of Figure 2.

Figure 2 Structure of overall project



Source: MfE

The main tool for the farm-level analysis is the Rural Futures MAS model. It is a multi-agent simulation (MAS) model that has been developed over the last five years in the Rural Futures programme led by AgResearch to model multiple pressures on farming systems. It models the behaviour of representative farmers on a landscape defined using data from actual regions, such as Southland. These farmer-agents are subjected to drivers and changes like drought, price fluctuations, and new policies, and their reactions produce outputs from the model. The MAS model incorporates a range of data:

- biophysical – pasture productivity and nutrient discharges that vary by soil and land characteristics
- behavioural – farmer decision making that accounts for differences across age groups and other factors, so that farmers can be expanding, maintaining, or contracting their farms
- economic – financial results that are based on biophysical potential and the decisions by farmers.

The MAS model has been validated against land use change in Southland over the last 20 years, as described in Appendix A.2.9.

The results in this report should be interpreted in their proper context:

- they are based specifically on Southland data, and the applicability to other regions has not been assessed
- the model scenarios are broad-brush attempts to understand a range of future possibilities rather than specific recommendations
- the water quality tools have been modelled without consideration of how they would be implemented
- the results are not intended to be specific predictions, but to help us understand the magnitude of impacts and the relationships amongst different parts of the regional agricultural system.

2. Model scenarios

2.1. Overview

Environmental policies can be formulated in many ways, for example, mandating specific practices, setting limits or creating price mechanisms. They can also apply to different economic units or actors in the production or supply chain.

We examined the impact of strict limits or caps on the level of nutrient discharges[3] from individual farms. Because of the state of scientific knowledge and the analytical tools available, the model scenarios were specified in terms of N and P discharges from the farm. Each combination of N and P caps formed a different scenario or 'tool'. They were used as inputs for the MAS model; the model was run with each scenario or 'tool'.

The levels of N and P caps were selected through discussion with MfE. The choices were driven by a desire to have a wide range of final impacts, to get a sense for the full scope of possible economic and environmental outcomes. The higher limits were expected to have little effect on farming, but would allow the modelling to produce results that could be analysed for their impacts on water quality indicators. The stricter limits, on the other hand, might be required in order to reach specific water quality targets. It was therefore important to model their potential economic impacts.

The caps are applied within each of three water management zones, shown in Figure 3:

- Lowland
- Basin – Five Rivers Basin, Te Anau Basin, Waimea Basin
- Hill.

The MAS model assessed each zone separately, so caps could be applied either across all of Southland or by zone.

The caps are applied only to pastoral farms and managed forestry blocks in the water management zones, so were not applied to any other parcels of land in the zones, such as national parks or arable farms. The final land dataset includes over 1 million hectares.

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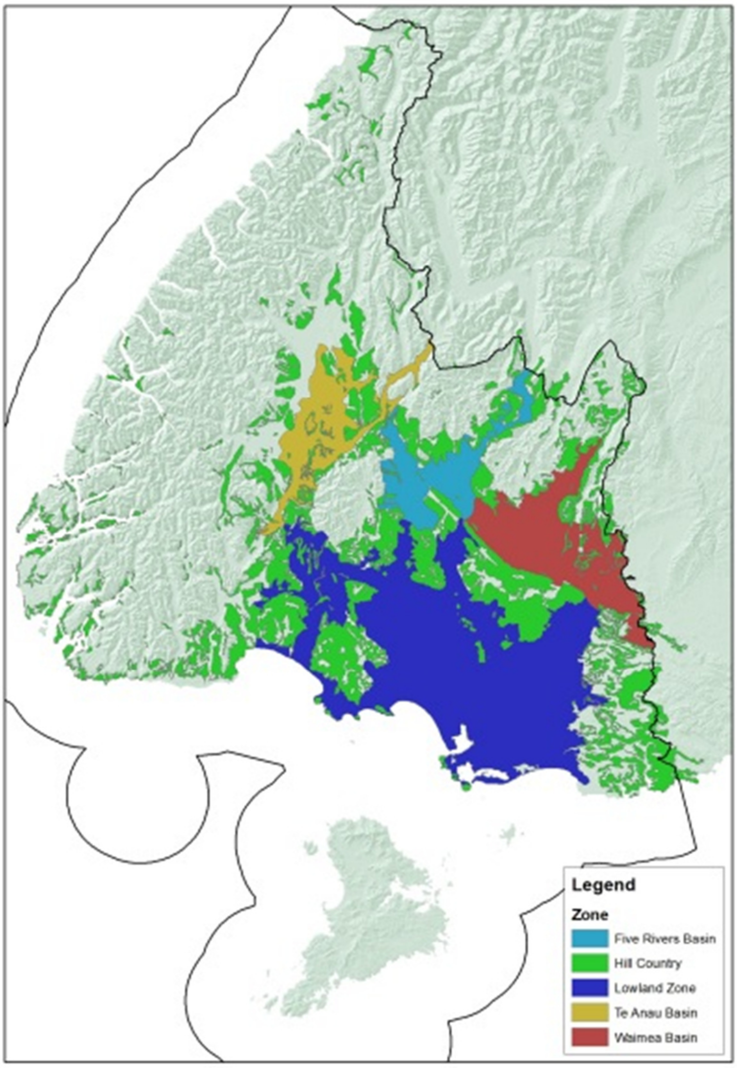
[3] Throughout the report, 'leaching' and 'discharge' are used interchangeably, although not all discharge to waterways occurs through leaching. For instance, overland flow is usually the more important phosphorus (P) loss pathway, rather than leaching. In addition, the P loss metric is better described as a 'P loss risk' rather than 'P leaching'. Current models are better at predicting the potential risk of P loss rather than actual losses. However, for the sake of simplicity, the term 'leaching' is used in a more general sense in this report.

Figure 3 Map of water management zones in Southland



Source: AgResearch

2.2. N and P discharge caps

To begin, we model 16 scenarios that are combinations of N and P leaching caps (Table 4). The caps are applied uniformly to all farms in each zone.

Table 4 Uniform tools modelled

Tool/scenario #	N cap kg/ha/year	P cap kg/ha/year
1	60	2.0
2	60	1.5
3	60	1.0
4	60	0.5
5	45	2.0
6	45	1.5
7	45	1.0
8	45	0.5
9	30	2.0
10	30	1.5
11	30	1.0
12	30	0.5
13	15	2.0
14	15	1.5
15	15	1.0
16	15	0.5

Source: MfE

2.3. Implementation of nutrient caps

For the modelling, the N and P caps are enforced in 2013 and remain in place. The choice of 2013 is arbitrary, and was chosen to allow the caps to have full effect. It is not meant to indicate any actual or potential regulatory timeframe. The model runs from 2012 until 2037.

We assume the caps are actively enforced across all farms, not just those farms converting to dairying. Farms in the model are not allowed to be non-compliant.

3. Summary of input data and MAS model

3.1. Farmer data

Farmer demographic data were sourced from Agribase[4]. They were used to establish the number of farmers in each of seven age bands and to determine the probability of having identified successors for farms. These two factors have been shown to influence the goals of farmers (Burton, 2009). Farmers with identified successors tend to have more of a focus on expanding the farm to make it economically viable for the next generation. Farmers without successors or in stages of their lifecycles when economic performance is not the most important goal, may instead focus on maintaining the farm or consolidating their financial positions.

Demographic data was used to assign farmers to one of three categories:

- cost minimisers – focused on keeping the farm going and consolidation
- profit maximisers – focused on their gross margin
- profit maximisers high change – focused on their gross margin, with a higher propensity to change.

The categories are consistent with the findings of rural sociologists' description of farmer behaviour, and are informed by AgResearch's Rural Futures research programme.

Farmers were described according to two other factors:

- existing membership in an industry – this factor affects who they know and where they get information (their peer group). It also affects their willingness to change to other land uses
- risk aversion – this factor influences the probability of changing farming practices.

3.2. GIS land information

The GIS land information has been sourced from the Agribase database. Environment Southland has provided the boundaries to the three zones: Lowland, Basin and Hill. In all, we model almost 1,100,000 hectares within the MAS model (Table 5). This represents 65.2% of the total area of the zones; the remaining area (towns, waterways, native bush) is not considered within this analysis. The results from the MAS modelling are therefore representative of the entire zone area, and there is no need to upscale results.

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[4] Agribase is a database of rural land parcels and land uses. It is maintained by AsureQuality (http://www.asurequality.com).

Table 5 Area by zone

Hectares

Zone	Dairy	Sheep & Beef	Forestry	Total
Lowland	131,615	260,041	1,742	393,398
Basin	33,317	216,411	599	250,327
Hill	11,006	417,518	25,162	453,686
All zones	175,938	893,970	27,502	1,097,411

Source: AgResearch, NZIER

3.3. Farm parameters

We model 121 different farm types across the three industries of dairy, sheep and beef and forestry. For dairy and sheep and beef, we consider differences in farms by:

- intensity of farming (low, average, high)
- quality and versatility of the land (LUC 1-2, 3-4 and 5-7)
- soil drainage (well and poorly drained)
- mitigation level (low, middle and high mitigation bundles, on top of the base farm).

For each farm type, analysis using the Farmax model calculated the productivity of the farm, the carrying capacity in stock units, the required supplementary feed (if any), total farm costs and output. The Overseer model (version 6) was then used to estimate N and P discharges from the farm.

The farm parameters do not include water use, so the modelled farming activities are not affected by water availability.

Base farms include a level of environmental mitigation practices that is representative of the current average across the region. The mitigation bundles discussed below extend the mitigation level of these farms.

3.4. Base farms

Dairy farming is by far the most profitable of the three industries. However, it has the highest amount of N and P leaching (Table 6).

Table 6 Typical farm parameters

Industry	N leaching (kg/ha)	P loss risk (kg/ha)	Gross margin, 2012 ($/ha)
Dairy	29-49	0.8-2.1	$3,000-$4,500
Sheep and beef	8-18	0.1-0.5	$50-$800
Forestry	2	0.1	$250

Source: AgResearch

Note: The gross margin figures are for 2012 data on prices, costs and productivity.

In the first set of results reported, there is no calculation of the N leaching from dry dairy cows during approximately 10 weeks in the winter. The result of this omission is to understate the reduction in N leaching from land-use change by up to 15%, and thereby overestimate the per-kilogram cost of N reduction. It does not affect the results about the extent of land use change, mitigation adoption or agricultural production.

The wintering-off period contributes to N leaching from dairying. The impacts of wintering off on N leaching are calculated, and N leaching results including wintering off are reported and discussed separately in section 8.

3.5. Mitigation bundles

A summary of the mitigation bundles available to dairy farmers to help meet an environmental cap is shown in Table 7, and a complete description is in Appendix A. These mitigation bundles are based on work by AgResearch on methods for reducing environmental impacts of farms, and they were assembled by farm systems experts with knowledge of Southland farming systems. They are cumulative, so that M3 includes both M1 and M2.

Table 7 Description of mitigation bundles

Bundle	Activities	Description
M1	Stock exclusion from waterways Improved nutrient management	Minor improvements in efficiency
M2	M1 Improved animal productivity	Major productivity improvements
M3	M1 M2 Restricted grazing using animal shelters Grass buffer strips	Capital investments that deliver mitigation at a cost

Source: AgResearch

The implications of the mitigation bundles at the farm level are shown in Table 8 as average impacts by bundle. Mitigation bundle M1 improves profitability slightly and mitigates a small amount of N and P. Mitigation bundle M2 delivers a larger profit gain than M1, as well as slightly more N mitigation. Mitigation bundle M3 costs the farmer money, but delivers the largest amount of N mitigation.

Table 8 Farm-level impacts of mitigation bundles on nutrient losses

Bundle	N mitigation (kg/ha)	P mitigation (kg/ha)	Change in profitability (2012 $ /ha)
M1	4.3	0.6	$24
M2	5.3	0.7	$213
M3	13	0.6	-$315

Source: AgResearch, NZIER

In addition, the impacts on *E. coli* losses were calculated from the change in mitigation practices. Richard Muirhead (AgResearch) provided the reduction factors shown in Table 9. Of the mitigations practices (Appendix A), only fencing off streams and farm dairy effluent practices on dairy farms would have an effect on E. coli losses during base-flow conditions. These practices enter the mitigation bundles in M1 for dairy and M2 for sheep and beef. A single estimate for all mitigation bundles was appropriate across LUC class and drainage types[5].

Table 9 Reductions in *E. coli* loads from mitigations

Percentage change in loads entering waterways

Bundle	Dairy	Sheep and beef
M1	-69%	0%
M2	-69%	58%
M3	-69%	58%

Source: AgResearch, NZIER

Because the modelling follows each one of the over 3000 farms from 2012 to 2037, it is possible to output the change in *E. coli* impacts for each one. This output provides a location-specific indication of the change in *E. coli* going into waterways. These data were provided to Niwa for use in their water model. In the present report, summary impacts are reported.

3.6. Price and cost projections

We make the following assumptions about productivity, cost and prices for sheep and beef and dairy, in both the baseline and scenario analysis:

- 0.5% annual growth in sheep and beef productivity/ha; 2% annual growth in dairy productivity/ha, based broadly on averages over the last 20 years

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[5] Muirhead, R., pers. comm., 28 March 2013.

- prices are difficult to project: we assume 2% nominal annual growth for both milk and meat prices, but with volatility added to the milk prices such that over the 25 year simulation period there are 6 price spikes where milk prices rise by 15% or more before returning to trend
- 2% annual nominal cost growth for sheep and beef; 4% annual nominal cost growth for dairy, based broadly on averages over the last 20 years.

The model runs forward based on nominal projections. The final 2037 results have been deflated to 2012 dollars using a 2% annual inflation rate.

3.7. MAS model functioning

In the model, farmers make decisions about how to use their farms. They do this by comparing their own performance every year with a group of peers. They consider the different farm management options available to them (which are the farming systems used by their peers), assess how their peers are performing in the current economic and regulatory climate, and compare these results to their own personal goals and objectives for their farm. In doing this, they consider prices, profits, and costs, but they also take into account their time in the industry and affinity with their peers. If they find a system that achieves their own goals better than their current system, they may change to that system. The model then applies the farmer's choice to the farm and calculates the results – production, costs, profits, N leaching, and P loss. The model also considers employment, carbon emissions, use of specific inputs like supplements and fuel, and a number of other factors.

Mitigation bundles increase the number of options available to farmers. Once the bundles are introduced, farmers not only have base farming systems – which are described by their industry and intensity – but also have variations that include the costs and impacts of using mitigation techniques. Farmers can select from amongst all the options available to them.

Nutrient caps, on the other hand, restrict the options available to just those that are compliant. When a farmer considers what to do with the farm, only compliant activities are possible.

The zone and regional results are aggregated from the farm-level results. The production, profits and costs, as well as the nutrient impacts, are summed by zone and region. This is possible because each farm is located geospatially through the GIS database.

4. Understanding the results

4.1.1. 2037 comparative static

The results we present here are ‘comparative static’: they compare the baseline outcomes in 2037, 25 years from the assumed implementation, with the outcomes in 2037 under each of the scenarios. The difference is the impact of the scenario in 2037. The values are in 2012 dollars, so the impact of inflation over time has been removed.

2012 vs 2037 dollars

The MAS model works in nominal figures. However, a dollar in 2037 is not equivalent to a dollar in 2012.

When discussing future dollars, it is important to distinguish two concepts: deflating and discounting. **Deflating** is a calculation that removes the effect of inflation. **Discounting** is a calculation that accounts for time preferences (having money now rather than later) and opportunity cost (what you could do with the money in the meanwhile). Both deflating and discounting lead to additional controversies about their precise meaning and appropriate calculation.

In this final report, we report our findings in 2012 dollars. We calculated those figures by dividing 2037 results by 1.64, or 1.02^{25}. This factor accounts for 2% inflation over 25 years. The 2% figure is the mid-range of the Reserve Bank of New Zealand’s inflation target band.

4.1.2. Region versus zone

We present first the overall regional results that sum the results from across the three zones. This provides an overview of the results at the regional level. We then provide zone by zone breakdown of key results.

4.1.3. Key metrics

We report the following key metrics:

- gross margin – this is total revenue minus total costs, excluding any depreciation, income taxes or family drawings. Gross margin is analogous to the economic measure of value-add, which is the impact of a farm on Gross Domestic Product
- total gross margin – this is the sum of the gross margins of all the farms in the area being considered
- value of agricultural production – this is the value of the farms’ agricultural production. Value of production is important because it includes payments

to suppliers, so it gives an indication of potential impacts beyond the farm gate

- total value of agricultural production – this is the sum of the agricultural production of all the farms in the area being considered
- N and P loss to water – this is the sum of all the N and P discharges from all the farms (dairy, sheep and beef, forestry) in the area being considered. This does not include leaching from areas outside the farm hectares such as natural scrub
- cost-effectiveness – this is the total cost of the scenario divided by the kilograms of N mitigated. The higher the dollars per kilogram of N mitigated, the less cost-effective the scenario is. The cost-effectiveness of P is not reported, because P did not tend to be the limiting factor in most scenarios.

We have not calculated Effective Farm Surplus, farmer drawings, or Farm Surplus for Reinvestment. These metrics account for additional items, such as taxes and living costs. Calculating these amounts properly would require additional modelling assumptions about the business and tax structure of Southland farms. In addition, including taxes or consumption/drawings is inappropriate from an economic perspective: earnings from productive activity (value-add) are expected to fund taxes and consumption.

4.1.4. Gross margin or agricultural production – which metric to use?

The gross margin and value of agricultural production metrics both give indications of the economic cost of the scenarios, however from different perspectives:

- gross margin is a farm-level metric that indicates the economic cost to the farm. It approximates the ‘value-add’ of the farm, which is the farming sector’s contribution to GDP
- value of agricultural production is an output metric.

Typically economists prefer the GDP/gross margin rather than the output metric, because the GDP metric identifies the direct extra value that an industry creates. However in this case, there are large upstream and downstream flow-on impacts from changes to the farming sector. The value of agricultural production metric is useful for understanding the flow-on implications for outside the farm-gate. For example, this metric gives an indication of the reduced level of agricultural processing and exports that result from the scenario.

5. Baseline results

5.1. Overview

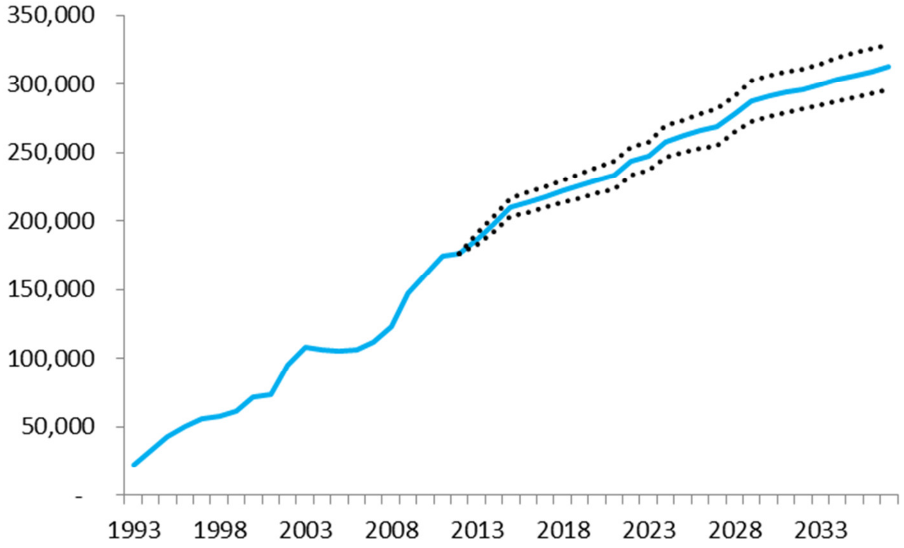
This section provides a baseline for agricultural land use in Southland. We project growth in dairying and the impact on N and P discharges across each of the three zones. The baseline will be used to compare against other model results to evaluate the cost and benefits of tool. We are seeking to provide insight over a 25-year period; this baseline is not an explicit forecast of exactly what we think will happen, but a plausible future that we can compare against. The projections are computed using the MAS model that incorporates a range of biophysical, behavioural and economic factors.

5.2. Land use to 2037

We project dairy to continue to grow strongly over the next few years. However over the 25 year simulation period, growth in dairying starts to taper off. By 2037, we project dairying to cover 303,000 hectares of Southland. This is an increase of 127,000 hectares over the period.

Figure 4 Dairy projections

Hectares. Dotted lines = 1 standard deviation



Source: NZIER

The largest areas of growth are projected to come in the Lowland and Basin zones (Table 10).

Table 10 Change in dairying 2012 to 2037

Hectares

Zone	2012	2037	Change
Basin	33,310	92,389	59,079
Hill	11,006	19,667	8,661
Lowland	131,619	190,833	59,214
Total	175,935	302,889	126,954

Source: AgResearch, NZIER

5.3. N and P discharges

We estimate there are currently 16,449 tonnes of N leached across the zones, and we expect this to grow to 19,039 tonnes by 2037 (Table 11) without a change in technology, an increase of 16%.

Table 11 Change in N leaching 2012 to 2037

Tonnes N leached per year

Zone	2012	2037	Change
Basin	3,878	5,130	1,252
Hill	4,031	4,168	137
Lowland	8,540	9,741	1,201
Total	16,449	19,039	2,590

Source: AgResearch, NZIER

We estimate there are currently 421 tonnes of P loss across the zones, and we expect this to grow to 539 tonnes by 2037 (Table 12), an increase of 28%.

Table 12 Change in P loss 2012 to 2037

Tonnes P loss per year

Zone	2012	2037	Change
Basin	83	135	52
Hill	90	100	10
Lowland	248	304	57
Total	421	539	118

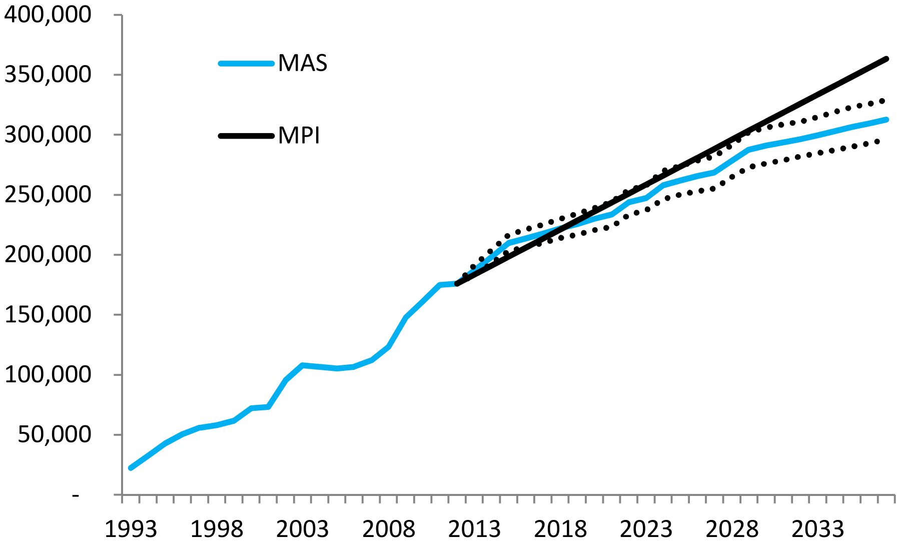
Source: NZIER, AgResearch

5.4. Discussion of baseline projections

Environment Southland provided MPI projections to 2021 that we have extrapolated out to 2037 (Figure 8). The MPI projection suggests stronger dairy growth than is predicted by the MAS model.

Figure 5 Comparison of dairy projections for Southland

Hectares. MPI projections extrapolated linearly from 2021



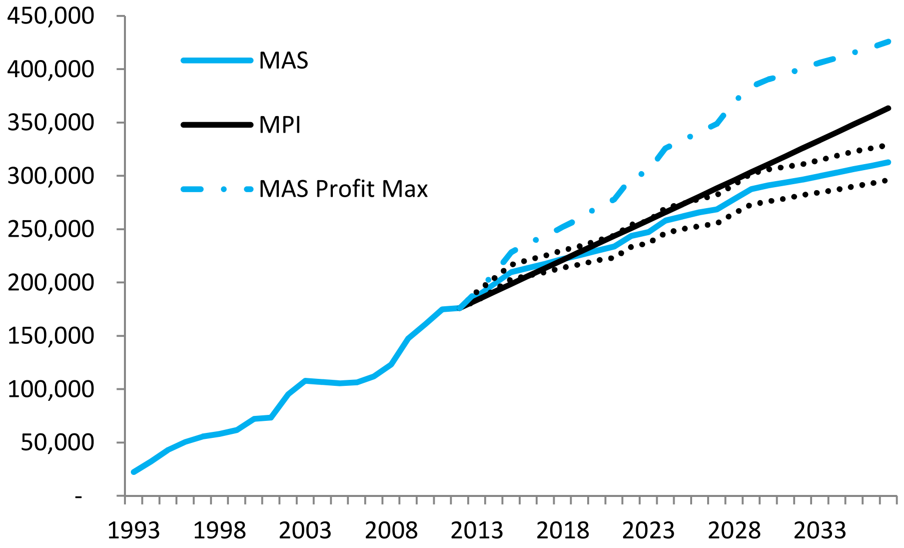
Source: NZIER, Environment Southland

We believe the MPI projections do not consider all of the biophysical, economic and behavioural factors that constrain conversion to dairy. In particular, the MAS model includes a proportion of farmers that are cost minimisers. Cost minimisers, in comparison to profit maximisers, do not wish to change land use to the most profitable activity. They are content with their farming systems and seek to minimise costs and risks. These farmers constrain the growth in dairying. This is a realistic constraint to the continual growth of dairying that other trend-based projections do not capture.

We can see the impact of cost minimisers on the baseline projections by running the MAS model with 100% profit maximisers and 0% cost minimisers. The result is a much higher projection for dairy hectares in 2037.

Figure 6 Impact of cost minimisers on baseline projections

Hectares. MPI projections extrapolated linearly from 2021



Source: NZIER, Environment Southland

The difficulty with including farmer behaviours into any modelling is gathering data on the proportion of each type of farmer. Our initial analysis of land-use change over the last 15 years suggests that about 45-50% are cost minimisers rather than profit maximisers, although this changes over time with the age of the farmer. We have used this in our baseline. However, without specific farmer surveys we are unable to definitively conclude if this is too high or too low.

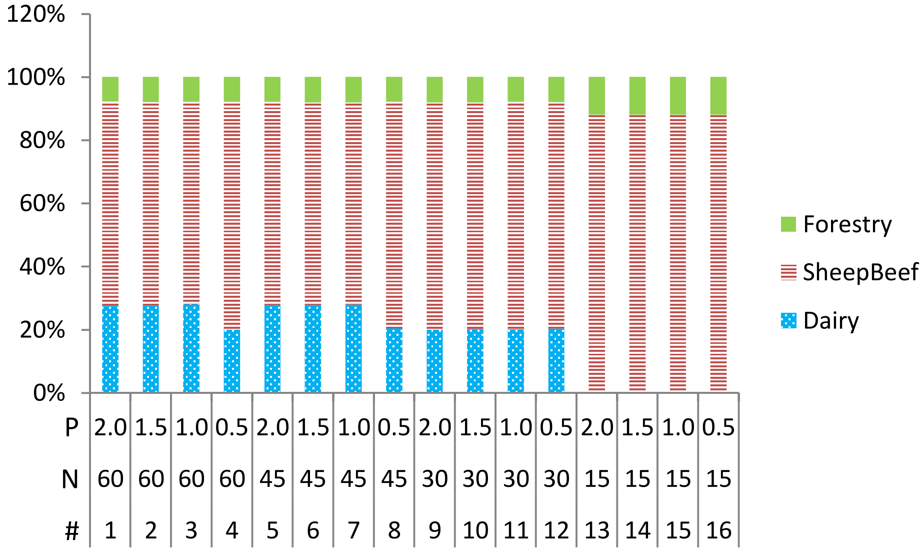
6. Results for Southland region

6.1. Land use

Figure 7 shows the share of land in each industry under each of the 16 scenarios. The baseline is most similar to scenario 1 and 2, in which the caps have nearly no impact.

Figure 7 Land use by scenario

2037



Source: NZIER

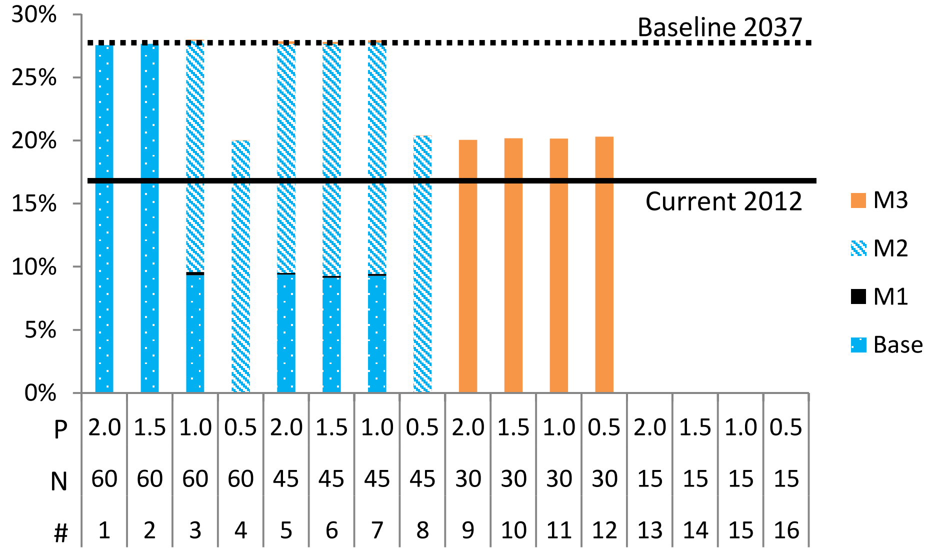
In section 3.4, we showed that the scenarios have a very minor direct impact on sheep and beef and forestry land uses, as these activities have N and P leaching rates per hectare that are mostly below even the most stringent of the scenarios. Much of the discussion therefore focuses on dairying.

6.2. Dairy hectares

The 2037 share of dairy hectares with each tool is shown in Figure 8. The total height of the bar shows the share of the region in dairying. The bars are colour-coded to show which dairy mitigation practice is being used. The figure also includes two reference lines: the current 2012 share of dairying (17%), and the baseline 2037 share of dairying (28%). When the bar is under the 2037 baseline, this means the scenario forces land-use change away from dairy (to sheep and beef predominantly). When the bar changes colour or shading, the change means the scenario forces dairy practices towards mitigation options.

Figure 8 Dairy share of land use in Southland

% hectares, 2037



Source: NZIER

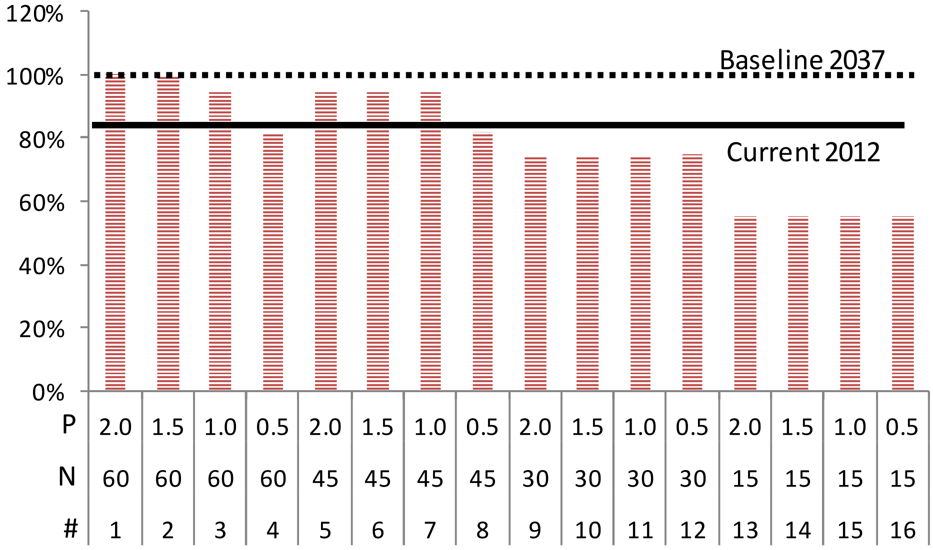
- set A – scenarios 1 and 2 do not induce any significant change in the total amount of dairying in Southland or the type of dairy farming practices. An N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B – scenarios 3, 5, 6 and 7 deliver the same total amount of dairying in 2037 as there would be under the 2037 baseline; about two-thirds of the dairy hectares use mitigation bundle M2
- scenarios 4, 8, 9, 10, 11 and 12 reduce the total amount of dairying in Southland in 2037 from the baseline 28% to about 20%. This is still higher than today (17%) which means that dairy still expands under these scenarios
  - set C – in scenarios 4 and 8, all dairy farms use mitigation bundle M2, as base dairy farming does not comply with a P cap of 0.5 kg/ha
  - set D – in scenarios 9, 10, 11 and 12, all dairy farms use mitigation bundle M3, as this is the only dairy farming practice to comply with the N cap of 30 kg/ha
- set E – under scenarios 13, 14, 15 and 16, there is no dairy farming in Southland as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha
- under scenarios 1-12 dairy expands relative to today.

6.3. Nitrate leaching

Figure 9 shows the total N leaching from all industries across the region with all tools, as a proportion of leaching in the baseline, which we expect to reach around 19,300 tonnes in 2037. It also shows the current amount of N leaching of 16,500 tonnes, which is 85% of the 2037 level.

Figure 9 Nitrate leaching

100% = baseline 2037



Source: NZIER

These changes in land use and farming practices lead to the following results:

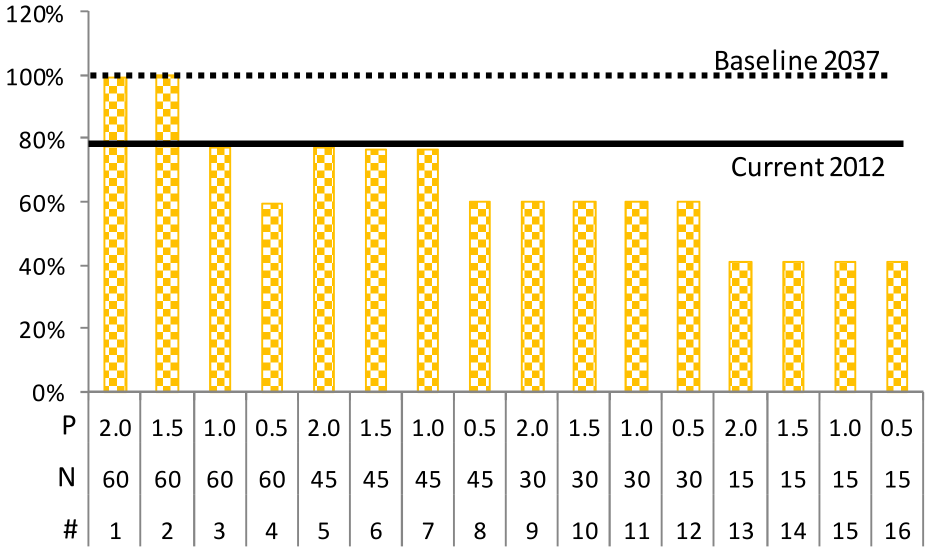
- set A does not induce any significant reduction in N leaching, as an N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B delivers a 5% reduction (1,000 tonnes) in the amount of N leaching in 2037 as about two-thirds of the dairy hectares use mitigation bundle M2
- set C delivers an 18% reduction (3,500 tonnes), as the amount of dairying is reduced relative to the baseline and mitigation bundle M2 is adopted by all remaining dairy farms
- set D delivers a 25% reduction (4,900 tonnes), as the amount of dairying is reduced relative to the baseline and mitigation bundle M3 is adopted by all remaining dairy farms
- with set E, there are no dairy farms in the model as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha. This reduces N leaching by 45% or 8,500 tonnes.

6.4. Phosphorus loss risk

Figure 10 shows P loss risk from all industries across the region with each tool, as a proportion of the baseline, which we expect to reach around 540 tonnes in 2037. It also shows the current amount of P loss risk of 430 tonnes, which is 80% of the 2037 level.

Figure 10 Phosphorus loss risk

100% = baseline 2037



Source: NZIER

These changes in land use and farming practices lead to the following results:

- set A does not induce any significant reduction in P loss, as an N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner.
- set B delivers a 23% reduction (125 tonnes) in the amount of P loss in 2037 as about two-thirds of the dairy hectares use mitigation bundle M2.
- set C and D deliver a 40% reduction (215 tonnes), as the amount of dairying is reduced relative to the baseline. Mitigation bundles M2 and M3 are adopted in different proportions in these scenarios but this has little overall impact on P loss as the bundles do not differ significantly in P mitigation.
- with set E, there are no dairy farms in the model as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha. This reduces P loss by 59% or 316 tonnes.

6.5. *E. coli* impacts

To summarise the data, we calculated the average reduction in *E. coli* load factor, weighted by area. These summary figures are provided in Table 13. The load is reduced by most mitigation bundles, but not by land-use change. The change is fairly constant over groups B, C, and D, as a result of uptake of mitigation practices. Group E provides a lower level of *E. coli* mitigation, because it includes a lower level of adoption of M2 and M3 for sheep and beef.

Table 13 Weighted average change in *E. coli* load

Farm-level tool set	Change in *E. coli* load
B	-13%
C	-14%
D	-14%
E	-7%

Source: NZIER

6.6. Value of agricultural production

Figure 11 shows the value of agricultural production from all the industries within the region with each tool, as a proportion of the baseline, which we expect to reach around $4.6 billion in 2037.

Figure 11 Value of agricultural production

Source: NZIER

These changes in land use and farming practices lead to the following results:

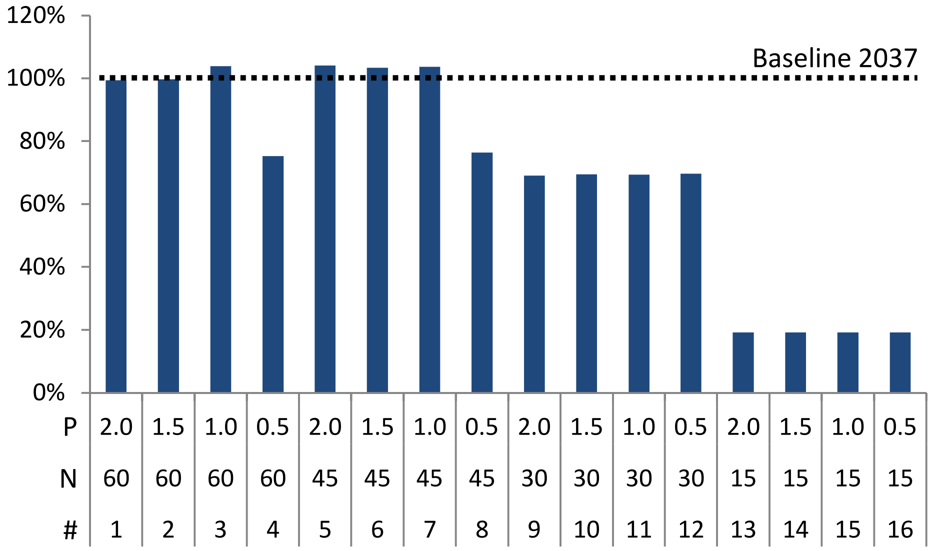
- set A – scenarios 1 and 2 do not induce any significant reduction in agricultural production, as an N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B – scenarios 3, 5, 6 and 7 do not induce any significant reduction in agricultural production as overall dairy hectares are maintained, and the use of mitigation bundle M2 does not reduce dairy production relative to base dairying (it increases it in some cases)

- set C – scenarios 4 and 8 reduce the value of agricultural production by 26% ($1.2 billion), as the amount of dairying is reduced relative to the baseline and mitigation bundle M2 is adopted by all remaining dairy farms
- set D – scenarios 9, 10, 11 and 12 reduce the value of agricultural production by 27% ($1.2 billion), as the amount of dairying is reduced further relative to the baseline and mitigation bundle M3 is adopted by all remaining dairy farms
- set E – under scenarios 13, 14, 15 and 16, there are no dairy farms in the model as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha. This reduces the value of agricultural production by 81% or $3.7 billion.

6.7. Farm gross margin

Figure 12 shows the value of gross margin from all the industries in the region with each tool, as a proportion of the baseline, which we project to reach around $2.7 billion in 2037.

Figure 12 Total farmer gross margin



Source: NZIER

These changes in land use and farming practices lead to the following results:

- set A – scenarios 1 and 2 do not induce any significant reduction in total farmer gross margin, as an N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B – scenarios 3, 5, 6 and 7 increase total farmer gross margins by 5% ($120 million) as overall dairy hectares are maintained, and the use of mitigation bundle M2 increases dairy gross margins; these scenarios model increased efficiency both economically and environmentally

- set C – scenarios 4 and 8 reduce the value of total farmer gross margins by 24% ($670 million), as the amount of dairying is reduced relative to the baseline. This is offset slightly by the adoption of mitigation bundle M2 by all remaining dairy farms, which increases dairy gross margins relative to base dairying
- set D – scenarios 9, 10, 11 and 12 reduce the value of gross margins by 31% ($850 million), as the amount of dairying is reduced relative to the baseline and mitigation bundle M3 is adopted by all remaining dairy farms (mitigation bundle M3 reduces dairy gross margins relative to base dairying)
- set E – under scenarios 13, 14, 15 and 16, there are no dairy farms in the model as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha. This reduces the total farm gross margins by 81% or $2.2 billion.

6.8. Cost effectiveness

Table 14 and Table 15 summarise the impact of the tools on N mitigation, gross margin and value of production respectively. The cost effectiveness of the tools can then be calculated as the cost in dollars per kilogram of N mitigated.

Table 14 Cost effectiveness (change in value of production)

Negative dollar values are costs; positive values are increased production

Farm-level tool set	N mitigated (tonnes)	Change in value of production ($ million)	$/kg N mitigated
B	1,000	0	0
C	3,500	-1,200	-330
D	4,900	-1,200	-250
E	8,500	-3,700	-440

Source: NZIER

Table 15 Cost effectiveness (change in gross margin)

Negative dollar values are costs; positive values are increased gross margins

Farm-level tool set	N mitigated (tonnes)	Change in gross margin ($ million)	$/kg N mitigated
B	1,000	120	120
C	3,500	-670	-190
D	4,900	-850	-170
E	8,500	-2,200	-260

Source: NZIER

Note: Scenarios 3,5,6,7 involve greater efficiency of resource use, with positive effects on both gross margins and N leaching.

The results by tool set are:

- set B delivers 1,000 tonnes of N mitigation at no cost to agricultural production and a gain of $120/kg N in gross margins. These scenarios show the level of mitigation that is available from scenarios that drive efficiency gains in dairy practices
- set C delivers 3,500 tonnes of N mitigation at a cost of $340/kg N in lost value of agricultural production and $190/kg N in reduced gross margin. This cost arises because scenarios are stringent enough to reduce the total amount of dairying by almost 30%
- set D delivers more tonnes of N mitigation than scenarios 4 and 8 (4,900 tonnes versus 3,500 tonnes), and at a lower cost to agricultural production ($240/kg N versus $340/kg N). These scenarios also reduce the total amount of dairying, but use mitigation bundle M3 rather than M2. Mitigation bundle M3 is more cost effective in terms of $/kg N mitigated
- with set E, there is no dairy farming in Southland as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha. This delivers the most N mitigation, 8,500 tonnes, but at the highest cost of $440/kg N in lost agricultural production and $260/kg N in lower gross margins.

6.9. Summary of regional results

We have modelled 16 scenarios in the Southland region that are combinations of nitrate (15 – 60 kg/ha) and phosphorus (0.5 – 2 kg/ha) caps. We find that the 16 scenarios can be clustered into 5 sets based on their impact on land use and dairy practices (Table 16):

- set A – scenarios 1 and 2 have no impact on land use or dairy practices because the caps are too high
- set B – scenarios 3, 5, 6 and 7, do not change land use but do force some farms to use the middle mitigation bundle M2
- set C – scenarios 4 and 8 reduce the hectares in dairy by 24% relative to the 2037 baseline, and force all farms to use the middle mitigation bundle M2
- set D – scenarios 9, 10, 11 and 12 reduce the hectares in dairy by 24% relative to the 2037 baseline, and force all farms to use the high mitigation bundle M3
- set E – under scenarios 13, 14, 15 and 16, there is no dairy farming in Southland as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha.

Table 16 Land use and farming practice impacts

Set	Tool #	N kg/ ha	P kg/ ha	Hectares in dairy in 2037		Dairy practices	Changes in agricultural production
				vs. 2012	vs. 2037 baseline		
A	1	60	2	+72%	0%	No change	No change in land use or dairy practices
	2	60	1.5				
B	3	60	1.0	+72%	0%	64% of dairy farmland uses M2	No change in land use but some change in dairy practices
	5	45	2.0				
	6	45	1.5				
	7	45	1.0				
C	4	60	0.5	+24%	-28%	All farms adopt mitigation bundle M2	Change in land use and change in dairy practices to middle mitigation option
	8	45	0.5				
D	9	30	2.0	+24%	-28%	All farms adopt mitigation bundle M3	Change in land use and change in dairy practices to highest mitigation option
	10	30	1.5				
	11	30	1.0				
	12	30	0.5				
E	13	15	2.0	-100%	-100%	Dairying unable to comply with discharge caps	Change in land use away from dairy
	14	15	1.5				
	15	15	1.0				
	16	15	0.5				

Source: NZIER

7. Results by zone

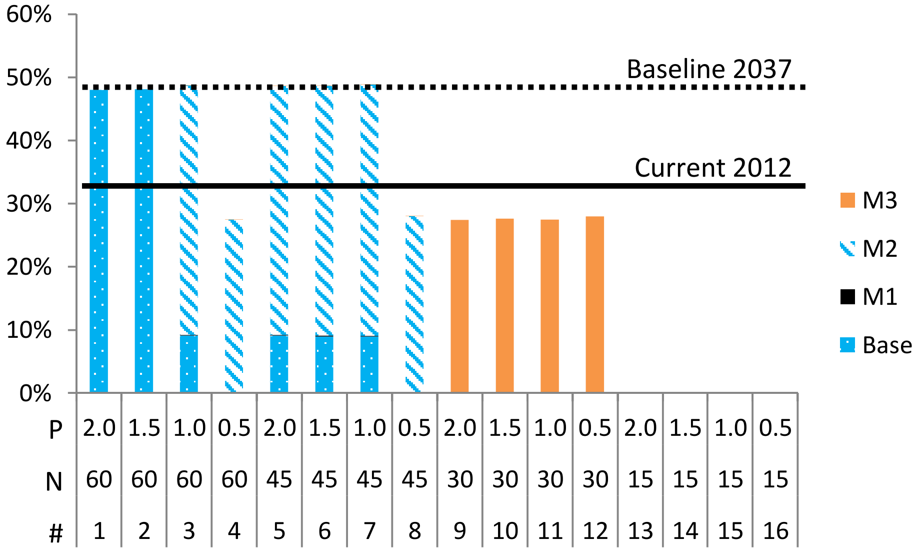
7.1. Land use

7.1.1. Lowland zone

The 2037 share of dairy hectares with each tool for the Lowland zone is shown in Figure 13. The bars are colour-coded to show the level of mitigation bundles that are adopted under each scenario. The figure also includes two reference lines: the current 2012 share of dairying (33%), and the baseline 2037 share of dairying (48%).

Figure 13 Dairy share of land use in the Lowland zone

% hectares, 2037



Source: NZIER

- Set A – scenarios 1 and 2 do not induce any significant change in the total amount of dairying in the Lowland zone or the type of dairy farming practices. An N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B – scenarios 3, 5, 6 and 7 deliver the same total amount of dairying in 2037 as there would be under the 2037 baseline; about 80% of the dairy hectares use mitigation bundle M2
- scenarios 4, 8, 9, 10, 11 and 12 reduce the total amount of dairying in the Lowland zone in 2037 from the baseline 48% to about 28%. This is lower than today (33%) which means that dairy contracts under these scenarios
  - in set C, scenarios 4 and 8, all dairy farms use mitigation bundle M2, as base dairy farming does not comply with a P cap of 0.5 kg/ha

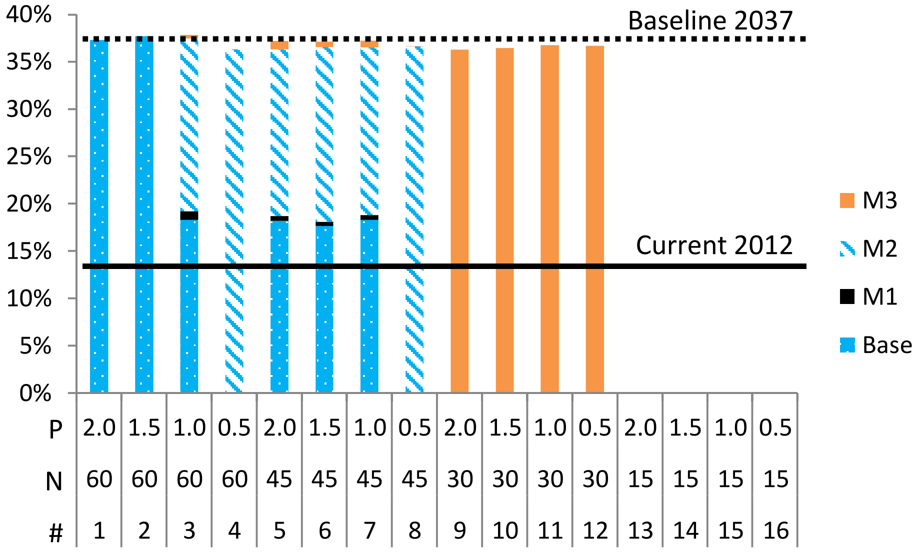
  - in set D, scenarios 9, 10, 11 and 12, all dairy farms use mitigation bundle M3, as this is the only dairy farming practice to comply with the N cap of 30 kg/ha
- set E – under scenarios 13, 14, 15 and 16, there is no dairy farming in the Lowland zone as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha.

7.1.2. Basin zone

The 2037 share of dairy hectares with each tool for the Basin zone is shown in Figure 14. The bars are colour-coded to show the level of mitigation bundles that are adopted under each scenario. The figure also includes two reference lines: the current 2012 share of dairying (13%), and the baseline 2037 share of dairying (38%).

Figure 14 Dairy share of land use in the Basin zone

% hectares, 2037



Source: NZIER

- set A – scenarios 1 and 2 do not induce any significant change in the total amount of dairying in the Basin zone or the type of dairy farming practices. An N cap of 60 kg/ha or over and a P cap of 1.5 kg/ha or over do not restrict dairying in any significant manner
- set B – scenarios 3, 5, 6 and 7 deliver the same total amount of dairying in 2037 as there would be under the 2037 baseline; about half of the dairy hectares use mitigation bundle M2, and a small proportion uses mitigation bundle M3
- scenarios 4, 8, 9, 10, 11 and 12 very slightly reduce the total amount of dairying in the Basin zone in 2037 from the baseline 38% to about 37%. This is significantly higher than today (13%) which means that dairy still expands under these scenarios

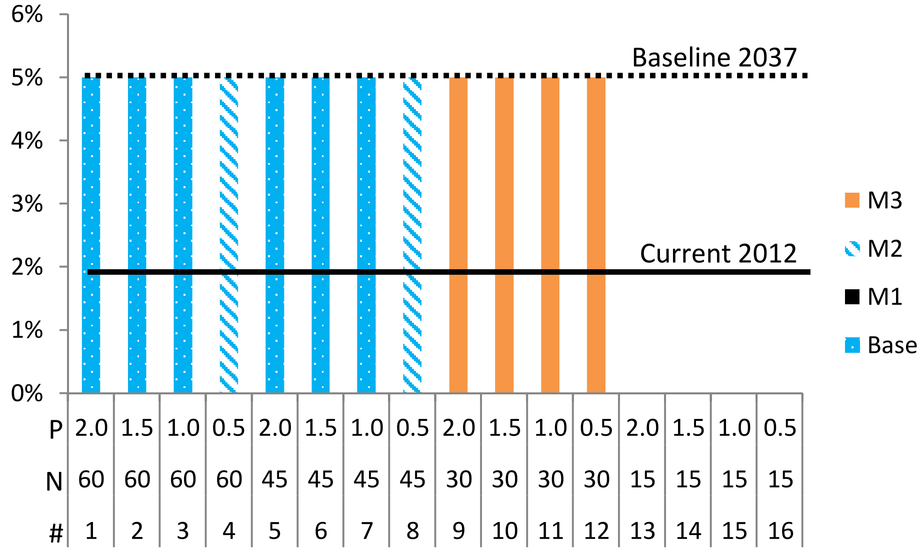
  - in set C, scenarios 4 and 8, all dairy farms use mitigation bundle M2, as base dairy farming does not comply with a P cap of 0.5 kg/ha
  - in set D, scenarios 9, 10, 11 and 12, all dairy farms use mitigation bundle M3, as this is the only dairy farming practice to comply with the N cap of 30 kg/ha
- set E – under scenarios 13, 14, 15 and 16, there is no dairy farming in the Basin zone as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha.

7.1.3. Hill zone

The 2037 share of dairy hectares with each tool for the Hill zone is shown in Figure 14. The bars are colour-coded to show the level of mitigation bundles that are adopted under each scenario. The figure also includes two reference lines: the current 2012 share of dairying (2%), and the baseline 2037 share of dairying (5%).

Figure 15 Dairy share of land use in the Hill zone

% hectares, 2037



Source: NZIER

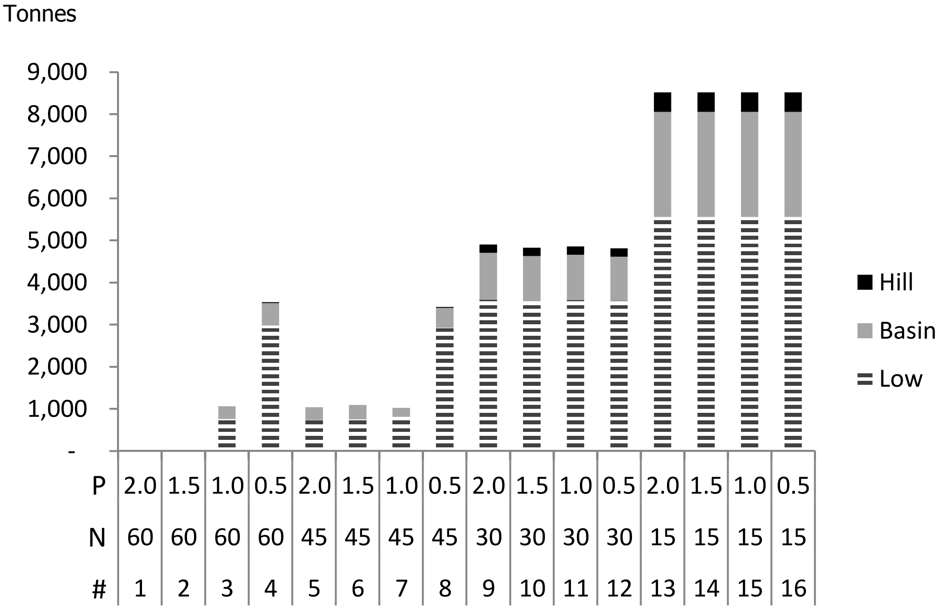
- Sets A and B – scenarios 1, 2, 3, 5, 6 and 7 do not induce any significant change in the total amount of dairying in the Hill zone or the type of dairy farming practices. An N cap of 45 kg/ha or over and a P cap of 1.0 kg/ha or over do not restrict dairying in any significant manner
- sets C and D – scenarios 4, 8, 9, 10, 11 and 12 do not reduce total dairying in the Hill zone but do change dairy practices:
  - in set C, scenarios 4 and 8, all dairy farms use mitigation bundle M2, as base dairy farming does not comply with a P cap of 0.5 kg/ha

  - in set D, scenarios 9, 10, 11 and 12, all dairy farms use mitigation bundle M3, as this is the only dairy farming practice to comply with the N cap of 30 kg/ha
- set E – under scenarios 13, 14, 15 and 16, there is no dairy farming in the Hill zone as the modelled dairy farming practices do not comply with the N cap of 15 kg/ha.

7.2. Nitrogen results

Figure 16 shows where the N mitigation occurs.

Figure 16 N mitigation by zone



Source: NZIER

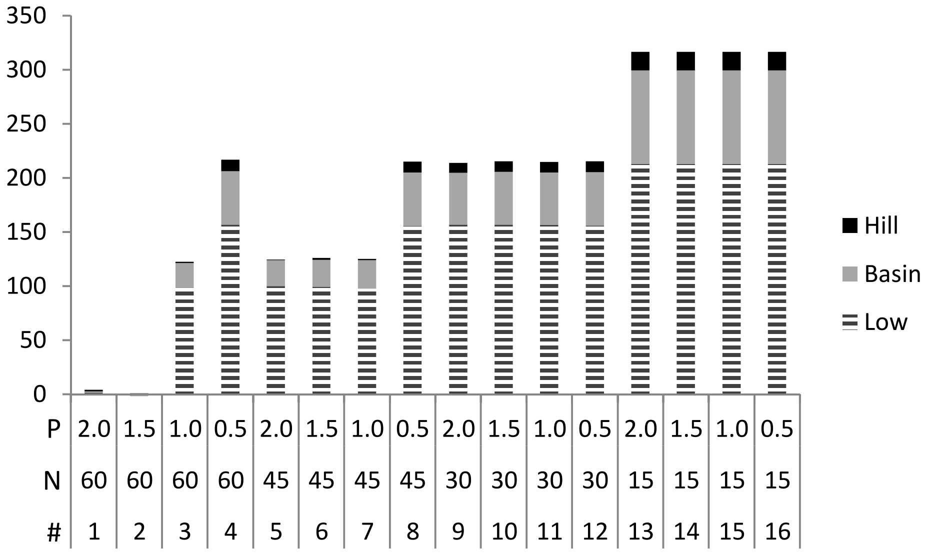
- In the Lowland and Basin zones, N mitigation occurs under all but the first two scenarios
- in the Hill zone, N mitigation occurs only in scenarios with an N cap of 30 kg/ha or lower, or at a P cap of 0.5 kg/ha
- the majority of mitigation occurs in the Lowland zone. It contributes at minimum 65% of total mitigation (under the 15 kg N/ha cap in set E) and a maximum of 86% of mitigation (under the 0.5 kg P/ha cap in set C). This is because the Lowland zone has the largest proportion of the high quality soils and thus the highest level of N leaching in the baseline. It is therefore impacted the most at high N caps.

7.3. Phosphorus loss risk

Figure 17 shows where the P mitigation occurs.

Figure 17 P mitigation by zone

Tonnes



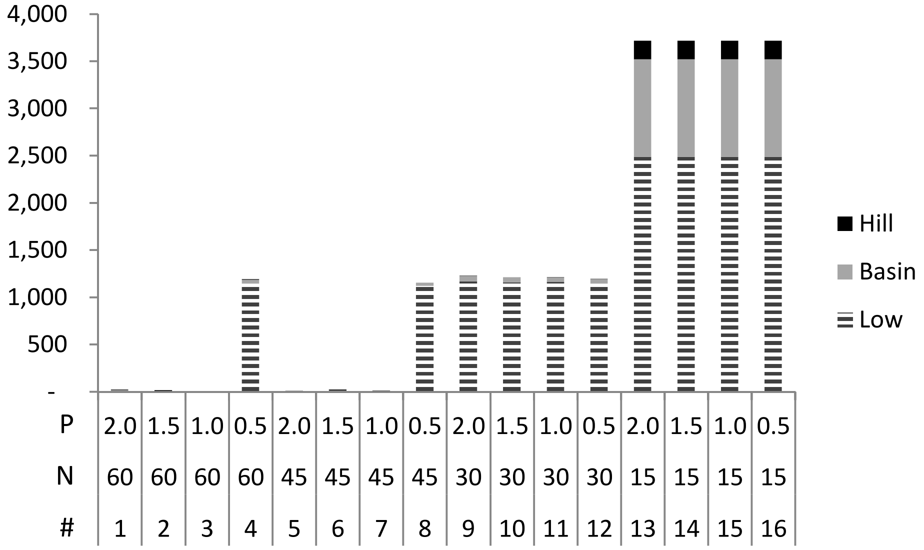
Source: NZIER

- In the Lowland and Basin zones, P mitigation occurs under all but the first two scenarios
- in the Hill zone, P mitigation occurs only in scenarios with an N cap of 30 kg/ha or lower, or at a P cap of 0.5 kg/ha
- the majority of mitigation occurs in the Lowland zone. It contributes at minimum 67% of total mitigation (under the 15 kg N/ha cap in set E) and a maximum of 80% of mitigation (under scenarios 5, 6, and 7). This is because the Lowland zone has the largest proportion of the high quality soils and thus the highest level of P loss risk in the baseline. It is therefore impacted the most at high N caps.

7.4. Value of agricultural production

Figure 18 shows the location of the losses in the value of agricultural production.

Figure 18 Losses in agricultural production by zone



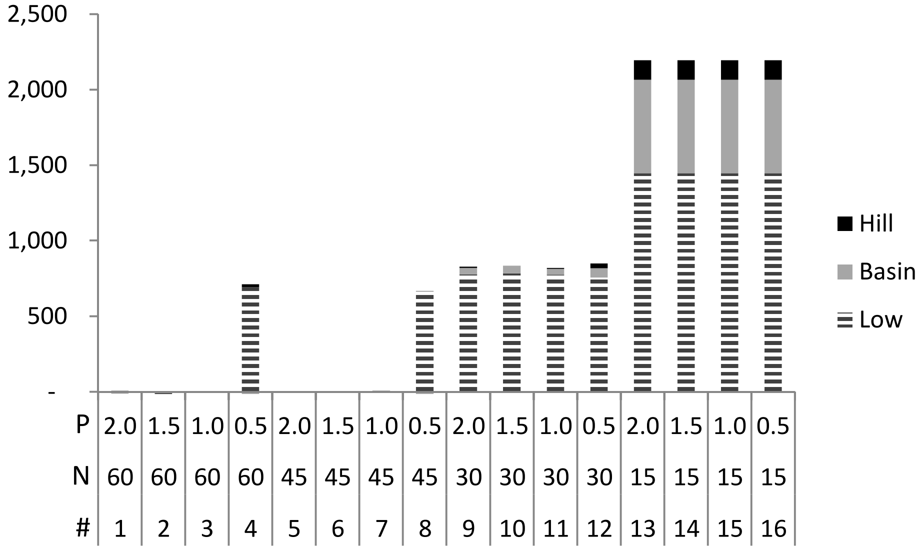
Source: NZIER

- In the Lowland and Basin zones, agricultural production costs occur in 10 of the 16 scenarios
- in the Hill zone, the key impacts occur with the 15 kg N/ha caps
- the majority of costs occur in the Lowland zone. It faces at minimum 67% of total production costs (under the 15 kg N/ha cap in set E) and a maximum of 97% of costs (under sets C and D).

7.5. Farmer gross margins

Figure 19 shows the location of the losses in the total farmer gross margins.

Figure 19 Losses in total farm gross margin by zone



Source: NZIER

- In the Lowland and Basin zones, agricultural production costs occur in 10 of the 16 scenarios
- in the Hill zone, the key impacts occur with the 15 kg N/ha caps
- The majority of costs occur in the Lowland zone. It faces at minimum 66% of total production costs (under the 15 kg N/ha cap in set E) and a maximum of 97% of costs (under sets C and D).

7.6. Cost effectiveness

Table 17 and Table 18 summarise the impact of the tools on N mitigation, by value of production and gross margin respectively, for each zone. The cost effectiveness of the tools can then be calculated as the cost in dollars per kilogram of N mitigated.

Table 17 Cost effectiveness (value of production)

Negative dollar values are reductions in value of production

Farm-level tool set	Zone	N mitigated (tonnes)	Change in total value of production ($ million)	$/kg N mitigated
B	Lowland	768	0	0
	Basin	291	0	0
	Hill	0	0	0
C	Lowland	2,958	-1100	-380
	Basin	503	-37	-73
	Hill	0	0	0
D	Lowland	3,578	-1200	-320
	Basin	1,077	-51	-48
	Hill	199	-2	-9
E	Lowland	5,562	-2500	-450
	Basin	2,494	-1000	-420
	Hill	463	-200	-420

Source: NZIER

Table 18 Cost effectiveness (gross margin)

Negative dollar values are costs; positive values are increased gross margins

Farm-level tool set	Zone	N mitigated (tonnes)	Change in total gross margin ($ million)	$/kg N mitigated
B	Lowland	768	85	110
	Basin	291	37	130
	Hill	0	0	0
C	Lowland	2,958	-680	-230
	Basin	503	27	53
	Hill	0	0	0
D	Lowland	3,578	-770	-220
	Basin	1,077	-47	-44
	Hill	199	-12	-61
E	Lowland	5,562	-1400	-260
	Basin	2,494	-620	-250
	Hill	463	-130	-280

Source: NZIER

- Set B achieves mitigation by the adoption of mitigation bundles but no land change. These have zero cost in the value of agricultural production and positive impacts on farm gross margins across all zones
- sets C and D induce land use change in the Lowland zone. It therefore has a high cost of mitigation when compared to the Basin or Hill zones
- set E achieves N mitigation by land use change in all zones. This is the most costly cluster of scenarios, delivering mitigation at $250 to $280 / kg N mitigated for each zone.

7.7. Conclusion

The analysis at the zone level shows that the economic costs of tools are distributed unevenly across the Southland region. The areas most affected are those with the most versatile soils and the highest production, as well as the highest leaching. The cost of mitigation per unit of N is higher on more productive soils.

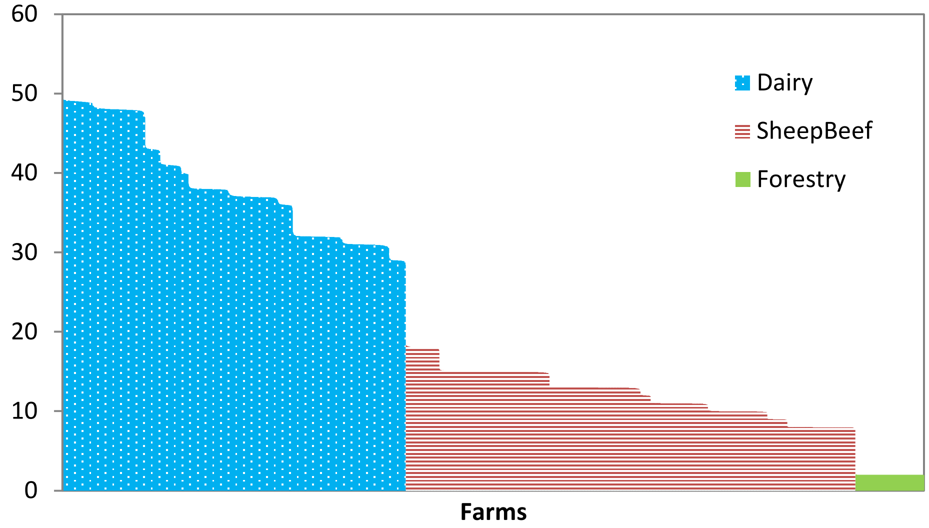
8. Non-uniform nutrient caps – Set F

8.1. Context in Southland

Farms in Southland have different N leaching rates, as shown in Figure 20. N leaching varies by industry (dairy, sheep and beef, forestry) as well as by farming intensity, adoption of mitigation practices and status of soil drainage.

Figure 20 Distribution of N leaching by farm

kg N/ha; 2037 baseline



Source: NZIER

This variation makes uniform caps a blunt instrument. They affect only a subset of total farms – farms with discharges above the cap. Non-uniform caps can help to broaden the scope (the number of farms affected) of any cap by making the cap specific to the farm. For example, the cap could be defined according to a farm's current practice, the soil class or drainage.

This variation also makes the cost of mitigation different across farms. Mitigating up to 13 kg N/ha on dairy farms can be achieved by adopting mitigation bundle M3 at a cost of about $380/ha (2012 dollars). However any further mitigation requires land-use change away from dairying to the next best land use – either forestry or sheep and beef at a cost of around $7,600/ha in foregone gross margin[6]. Mitigation on sheep and beef farms can achieve up to 5 kg N/ha of mitigation at a cost of around $100/ha. By broadening the number of farms affected, non-uniform caps are likely to improve the cost-effectiveness of nutrient caps. This is because all farms have a

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[6] This figure takes into account the forecast price and productivity changes described in section 3.6, and is in 2012 dollars.

moderate amount of low-cost mitigation potential. A non-uniform cap can make use of these low-cost mitigation options to help lower the overall cost of meeting a given environmental objective, when compared to a uniform cap.

8.2. Scenarios

We consider two non-uniform caps based on soil drainage (Table 19). Scenario 17 imposes a 45 kg N/ha cap on well-drained soils, but a lower N cap on poorly-drained soils. We can compare scenario 17 to scenarios 5-7 which impose a uniform 45 kg N/ha limit. Under the uniform cap, farms on poorly-drained soils are unaffected because their leaching falls below the 45 kg N/ha cap. Under the non-uniform cap they must adopt a mitigation bundle to be compliant.

Scenario 18 takes a slightly different approach. It increases the cap to 37kg N/ha for farms on well-drained soils that cannot meet 30 kg N/ha by mitigation alone. This should allow farms that had to change land use under a uniform 30 kg N/ha (scenarios 9-12) to remain in dairying.

Table 19 Non-uniform cap scenarios

Scenario	Soil drainage	N cap kg/ha	P cap kg/ha
17	Well-drained	45	0.6
	Poorly-drained	38	1.2
18	Well-drained	37	0.6
	Poorly-drained	30	1.2

Source: NZIER

8.3. Results

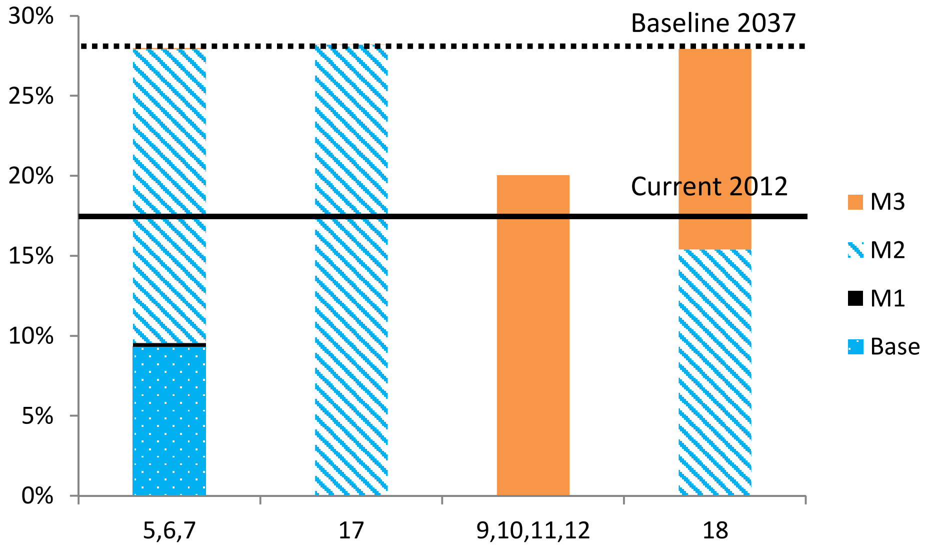
Figure 21 shows the results from non-uniform tools alongside the results from comparable uniform tools. Results are expressed as the percentage of land use in Southland in dairy, which is a key factor in N leaching and economic impacts across the region.

Scenario 17 can be compared to scenarios 5-7. Under scenarios 5-7, dairy farms on poorly-drained soils do not need to adopt mitigation practices and are able to remain in dairying using base farm practices. By contrast, under the non-uniform cap scenario 17, these dairy farms must also adopt mitigation practices, in this case mitigation bundle M2. The amount of land in dairying is the same, but mitigation is more widespread.

Scenario 18 can be compared to scenarios 9-12. It allows more farms to remain in dairying by using mitigation bundle M3. It also allows other farms to meet their caps with mitigation bundle M2 rather than M3, which is a less expensive change in farm practices.

Figure 21 Dairy share of land use in Southland

% hectares, 2037



Source: NZIER

The results on N leaching, P loss, total gross margin and value of agricultural production are shown in Table 20. Gross margin and production values are reported as changes from the 2037 baseline. Compared to the uniform cap scenarios 5-7, the non-uniform cap scenario 17 mitigates 400 tonnes more of N and reduces P loss by 50 tonnes, while at the same time increasing total regional gross margin by $180m, which is $60m more than the gross margin impact of scenarios 5-7.

Compared to the uniform cap scenarios 9-12, the non-uniform cap scenario 18 mitigates 2,400 tonnes less of N and increases P loss by 35 tonnes. However, scenario 18 costs much less than scenarios 9-12 in lost production ($60m versus $1,200m), and actually improves gross margins by $30m, whereas the uniform cap scenarios cost $850m. Thus, while scenario 18 mitigates less in total terms than scenarios 9-12, it is much more cost effective.

Table 20 Non-uniform cap results

Relative to 2037 baseline (2012 dollars)

Farm-level tool set	Scenario	Change in N leaching (tonnes)	Change in P loss (tonnes)	Change in total gross margin ($ million)	Change in value of production ($ million)
B	3,5,6,7	-1,000 (-5%)	-125 (-23%)	+$120 (+4%)	$0 (0%)
F	17	-1,400 (-7%)	-175 (-33%)	+$180 (+6%)	$0 (0%)
	Difference	-400	-50	+$60	$0
D	9,10,11,12	-4,900 (-25%)	-215 (-40%)	-$850 (-31%)	-$1,200 (-26%)
F	18	-2,500 (-13%)	-180 (-33%)	+$30 (+1%)	-$61 (-1%)
	Difference	+2,400	+35	+$880	+$1,200

Source: NZIER

8.4. Summary

These modelling scenarios provide two findings about non-uniform nutrient caps:

- non-uniform caps have the potential to be more cost-effective than uniform caps because they tailor the discharge cap to the potential of the farm for mitigation. In some situations, non-uniform caps can achieve significant reductions in nutrient discharges for no economic cost
- non-uniform caps encourage the use of lower-cost options, but across a wider range of farms. As a result, non-uniform caps help lower the overall cost of meeting a given total N or P load.

9. Grandparenting – Set G

9.1. Background

'Grandparenting' refers to a type of policy that bases limits on current practice. This is distinct from uniform caps, which apply a blanket limit across the region. It is also distinct from non-uniform caps, which apply limits based on the farm physical characteristics such as LUC and soil drainage, but apply to all farms regardless of past activities.

9.2. Model scenario

The scenario we model, tool 19, grandparents all dairy farms with N and P discharge limits that are 25% below current practice. This can be achieved by adoption of mitigation bundle M3 (which mitigates 25-42% of N and 45-51% of P).

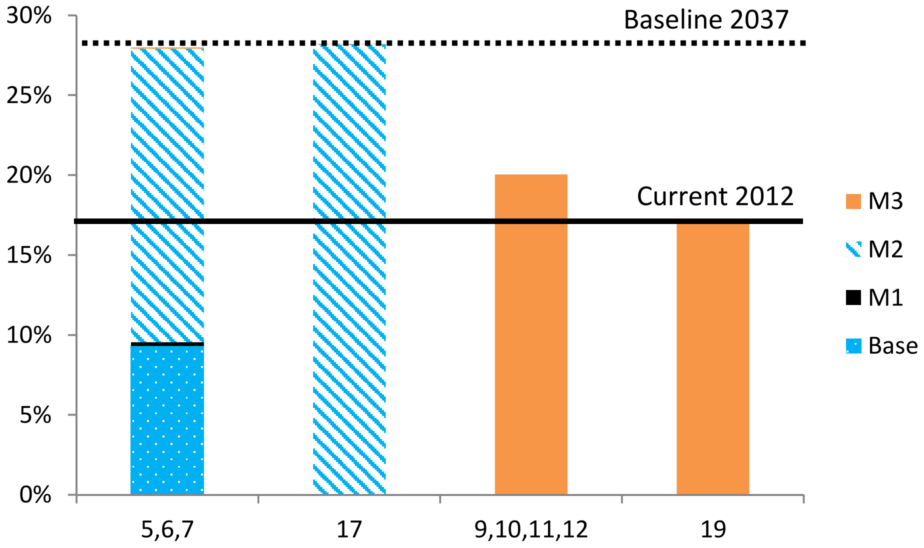
Sheep and beef farms are grandparented with N and P limits that are at their current level. This allows them to continue sheep and beef farming, but does not allow them to convert to dairying, which has much higher N and P discharges. This is achieved in the model by restricting all farms to current practices.

9.3. Results

Figure 22 shows the land use results under grandparenting: the amount of dairying remains at 17% of the region as it is in 2012. However, all of these dairy farms use mitigation bundle M3 to be compliant with the limit. Additional scenarios are included for the sake of comparison.

Figure 22 Dairy share of land use in Southland

% hectares, 2037



Source: NZIER

The results on N leaching, P loss, total gross margin and value of agricultural production are shown in Table 21. The grandparenting scenario reduces N discharges by 4,700 tonnes relative to the baseline 2037 discharges, and reduces P loss by 225 tonnes. This impact is approximately the same as the mitigation achieved by set D tools (uniform caps of 30kg N/ha)[7]. However, the costs of the grandparenting scenario are higher. This is because it limits conversion to dairying, relative to baseline and relative to set D tools.

Table 21 Grandparenting results

Farm-level tool set	Scenario	Change in N leaching (tonnes)	Change in P loss (tonnes)	Change in total gross margin ($ million)	Change in value of production ($ million)
B	3,5,6,7	-1,000 (-5%)	-125 (-23%)	+$120 (+4%)	$0 (0%)
F	17	-1,400 (-7%)	-175 (-33%)	+$180 (+6%)	$0 (0%)
D	9,10,11,12	-4,900 (-25%)	-215 (-40%)	-$850 (-31%)	-$1,200 (-26%)
F	18	-2,500 (-13%)	-180 (-33%)	+$30 (+1%)	-$61 (-1)
G	19	-4,700 (-25%)	-225 (-41%)	-$980 (-36%)	-$1,500 (-32%)

Source: NZIER

9.4. Summary

The modelling on the impacts of grandparenting suggests the following:

- grandparenting that limits conversion to dairying imposes large opportunity costs. These are higher than the economic costs of all uniform nutrient caps except set E
- grandparenting that limits conversion to dairying is less cost-effective than model scenarios that improve farm practices without limiting land-use change.

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[7] The difference in N leaching is not significant, and results from the reduced land-use change into forestry in scenario 19. This lack of change is an effect of constraining all farms to 2012 land use in order to model grandparenting.

10. Mandated mitigation practices – Set H

10.1. Introduction

In this section, we estimate the potential gains from mandating or encouraging mitigation practices across both the dairy and the sheep and beef sector. Dairy farming is currently estimated at 17% of land use and is projected to grow to 28%. Most of the rest of the agricultural land is in sheep and beef. We estimate the impact of all dairy and sheep and beef farms using mitigation bundles.

We compare the outcome of widespread adoption of mitigation practices to the uniform cap scenarios modelled previously. We do not consider the specific design mechanisms or transaction costs, thus our estimate can be thought of as the total *potential* impact from some system that encourages widespread mitigation, with the costs yet to be deducted.

Widespread mitigation can be effective at mitigating N losses in catchments by encouraging low-cost mitigation by sheep and beef farms. By contrast, nutrient discharge targets that necessitate land-use change are comparatively expensive per kg N, both for farmers and for regional economic output. Note, however, that the capacity for sheep and beef farms to mitigate is finite, and that at some target level of overall regional mitigation, dairy farmers might have no option but to change land use.

10.2. Quantifying the potential

One way to estimate the potential impacts is to calculate the costs and mitigation that would be possible if all farms adopted mitigation bundle M3, which we have done in scenario 20. The cost of mitigating using these bundles is relatively similar between sheep and beef and dairy.

We calculate that if all dairy and sheep and beef farms were to use mitigation bundle M3, 6,300 tonnes of N leaching (a third of total 2037 baseline) could be mitigated at a cost of $190 million in total gross margins. This equates to a cost of $30/kg N mitigated – or about one-fifth the cost of group D tools which deliver 4,900 tonnes of N mitigation at a cost of $170/kg N mitigated (Table 22). Because of the widespread use of mitigation, the average reduction in *E. coli* per hectare is 57%.

Table 22 Cost effectiveness (gross margin)

Negative dollar values are a cost; positive dollar values are increased gross margin

Farm-level tool set	Scenarios	N mitigated (tonnes)	Gross margin ($ million)	$/kg N mitigated
B	3,5,6,7	1,000	+120	+120
C	4,8	3,500	-670	-190
D	9,10,11,12	4,900	-850	-170
E	13,14,15,16	8,500	-2,200	-260
H	20	6,300	-190	-30

Source: NZIER

10.3. Why this is potentially cost effective

This approach is cost effective because it utilises the lowest cost options for mitigation. Under the uniform caps, sheep and beef farms do not mitigate N leaching. These farms already have low levels of N leaching relative to dairy farms, and nearly all sheep and beef farming activities were compliant under even the strictest cap of 15kg N/ha that was considered. However, we expect sheep and beef farms to be 65% of land use in 2037 and to contribute 39% of N leaching. Mitigation options on sheep and beef farms can mitigate over a third of their N leaching. Scenario 20 makes use of the mitigation potential on sheep and beef farms to reduce or eliminate the amount of mitigation required through land-use change.

11. Impact of wintering-off

11.1. Overview

'Wintering off' is a specifically Southland practice for dairy farms. Some farms send their dry cows away from the core dairy farm (the 'milking platform') for some period of the winter. On the wintering-off block, cows feed on forage crops (kale, swedes, or the like). The wintering-off block might be owned by the dairy farmer, or could be owned by a farmer who provides 'dairy support' – who supplies the dairy industry but does not milk cows. N leaching from winter forage paddocks can be high relative to actively growing pasture.

In the initial analysis reported above, the wintering-off period is excluded. In the calculations reported in this section, the wintering-off period is included in the within-zone N leaching calculations. These two sets of calculations provide a range for Southland, where some dairy cows remain on or near the milking platform and others are sent out of the catchment or even out of the region. They also provide a suggestion of the potential impacts of mitigation strategies that focus specifically on the winter period.

11.2. N leaching with wintering-off

In the current Southland MAS model, developed by NZIER and AgResearch, there is no explicit 'dairy support' industry. We have therefore made supplemental calculation to estimate the impact of wintering off on N leaching in Southland. The method for the calculation is explained in Appendix B.

Importantly, the wintering-off calculations should be understood in context:

- the addition of wintering-off increases both the baseline and the scenario N leaching results
- the impact is up to 13% difference, as shown in Table 23
- the MAS model includes N leaching from 42 weeks on the milking platform, and the supplemental calculation accounts for the rest of the year. Actual farm practices may vary, from having cows on the milking platform the entire year to sending them off for 20 weeks. With these supplemental calculations, the full year is included in the analysis; the allocation of the year between the milking platform and wintering off time is inconsequential.

Table 23 Total region N leaching

Tonnes N

Farm-level tool set	Scenario	Total excluding wintering-off	Total including wintering-off	Per cent difference
	Baseline	19,000	21,400	13%
A	1,2	19,000	21,400	13%
B	3,5,6,7	18,000	20,400	13%
C	4,8	15,600	17,200	10%
D	9,10,11,12	14,100	15,700	11%
E	13,14,15,16	10,500	10,500	0%

Source: NZIER

11.3. Impacts on results

11.3.1. N mitigation

The impact of wintering-off on N mitigation for each scenario is shown in Table 24.

Table 24 N mitigation

Tonnes N mitigated versus 2037 baseline

Farm-level tool set	Scenario	Mitigation excluding wintering-off	Mitigation including wintering-off	Per cent difference
A	1,2	0	0	0%
B	3,5,6,7	1,000	1,000	0%
C	4,8	3,400	4,200	24%
D	9,10,11,12	4,900	5,700	16%
E	13,14,15,16	8,500	10,900	28%

Source: NZIER

The key findings from Table 24 are:

- in sets A and B, scenarios 1, 2, 3, 5, 6 and 7, wintering-off has no impact on N mitigation. In these scenarios, there is no land-use change, so the extra amount of N leaching from the wintering-off that is added to the baseline is also added to the scenario result
- in the remaining scenarios, including wintering-off increases the N mitigation induced by the scenarios by between 16 and 28%. This is because these scenarios cause a land-use change away from dairying. This mitigates N directly from the reduced hectares in dairying (i.e. reduced milking platform hectares) as well as from the reduced amount of wintering-off.

11.3.2. Cost effectiveness

The cost effectiveness of each scenario with and without wintering-off is shown in Table 25 and Table 26.

Table 25 Cost effectiveness (value of production)

Negative dollar values are reductions in value of production

Farm-level tool sets	Scenarios	$/kg N mitigated excluding wintering-off	$/kg N mitigated including wintering-off	Per cent difference
B	3,5,6,7	0	0	0%
C	4,8	-340	-280	-19%
D	9,10,11,12	-250	-210	-14%
E	13,14,15,16	-440	-340	-22%

Source: NZIER

Table 26 Cost effectiveness (gross margin)

Negative dollar values are costs; positive values are increased gross margins

Farm-level tool sets	Scenarios	$/kg N mitigated excluding wintering-off	$/kg N mitigated including wintering-off	Per cent difference
B	3,5,6,7	+120	+120	0%
C	4,8	-190	-160	-17%
D	9,10,11,12	-170	-150	-14%
E	13,14,15,16	-250	-260	+2%

Source: NZIER

The cost-effectiveness calculations demonstrate two key findings:

- overall, including wintering-off increases the cost effectiveness of each scenario. This is because the scenarios mitigate more N with the inclusion of wintering-off, for no increase in costs
- the inclusion of wintering-off does affect each scenario by different amounts, but the rank of scenarios by cost effectiveness is not changed.

12. The impact of DCD

12.1. Background

DCD is a chemical nitrification inhibitor. It is a possible option for mitigating N discharges, and it was not included in prior modelling because of potential trade concerns that arose in 2012. The results presented above do not include the use of DCD as a mitigation option. In this section, we present an analysis that includes DCD in mitigation bundles.

12.2. Farm-scale modelling of DCD

The modelling of DCD using Farmax and Overseer shows that:

- DCD adds between 2.6 and 7.2 kg N/ha of mitigation to the M2 and M3 bundles (Table 27)
- DCD adds more mitigation to well-drained soils than to poorly-drained soils
- DCD adds costs of between $144/ha and $196/ha.

Table 27 Impact of DCD on N mitigation and costs

Soil drainage	Mitigation option	Increase in N mitigation from DCD kg N/ha	Increase in cost of mitigation from DCD $/ha
Well-drained	M2	7.2 (167%)	$144 (68%)
	M3	4.8 (37%)	$196 (62%)
Poorly-drained	M2	4.3 (69%)	$144 (68%)
	M3	2.6 (21%)	$196 (62%)

Source: AgResearch

12.3. Results

The farm-level tool sets used to group the scenario results were based on findings without DCD. Regional results for the same tools, but with DCD in the mitigation bundles, are presented in Table 28. In all cases but one, the impact on production per kilogram of N mitigated is lower with DCD. Results for tool set E do not change, as an N cap of 15 kg / ha is still fully binding for dairying. Including DCD in the mitigation bundles changes the interaction between mitigations and nutrient caps somewhat, so that the scenarios do not group in quite the same way. Details on comparative results by scenarios are therefore provided in section 12.4.

Table 28 Regional results for 2037, with DCD

Financial results in 2012 dollars

Farm-level tool set	Tool / scenario numbers	N mitigation (tonnes)	P mitigation (tonnes)	Change in gross margin ($ million)	Change in value of production ($ million)	Change in production / kg N mitigated ($)
A	1,2	0	0	0	0	0
B	3,5,6,7	-2,000 (-10%)	-125 (-23%)	100 (+4%)	0 0%	0
C	4,8,12*	-4,300 (-23%)	-215 (-40%)	-700 (-26%)	-1,200 (-25%)	-280
D	9,10,11	-4,100 (-22%)	-175 (-32%)	-100 (-4%)	0 0%	0
E	13,14,15,16	-8,500 (-45%)	-315 (-59%)	-2,200 (-82%)	-3,700 (-81%)	-440
F	17	-2,900 (-15%)	-175 (-33%)	100 (+4%)	0 0%	0
	18	-2,500 (-13%)	-180 (-33%)	100 (+4%)	0 0%	0
G	19	-5,400 (-28%)	-225 (-41%)	-$980 (-36%)	-$1,500 (-32%)	-280
H	20	-7,600 (-40%)	-254 (-47%)	-400 (-15%)	0 0%	0

Source: NZIER

Note: With DCD, Scenario 12 moves from the D group to the C group. The P cap becomes binding, rather than the N cap.

12.3.1. Uniform caps

In scenarios 1 and 2 there is no change to farming practices, with or without DCD, as the caps are not binding.

In scenarios 3 to 8, there is widespread adoption of mitigation bundle M2. Overall, the inclusion of DCD delivers around 5% reduction in N leaching because M2 with DCD delivers much higher levels of mitigation relative to M2 without DCD. However this comes at a cost to gross margins which are 3 to 4% lower due to the higher costs of DCD.

In scenarios 9 to 11 without DCD, some dairy farms would be non-compliant at a cap 30kg N/ha even after adopting mitigation M3. These farms had to change out of dairying. Adopting M3 with DCD allows these farms to remain in dairying. Similarly, other dairy farms needed to adopt mitigation M3 to be compliant with a cap of 30kg N/ha. When DCD is included, many of these farms need only adopt M2. As a result, when DCD is included, scenarios 9 to 11 leach about 5% more N and 12% more P than when DCD was excluded. This is because more land remains in dairying. By contrast, gross margins and value of production are about 40% higher with DCD included. Thus while the total mitigation under these scenarios falls, the cost per mitigation changes from a cost in agricultural production losses of $408 per kg N mitigated, to a gain of $24 per kg N mitigated.

In scenario 12, the inclusion of DCD allows dairy farms to use M2 instead of M3. However the P cap of 0.5 kg/ha is still binding on some farms, as DCD has no impact on P loss. Overall the N and P mitigation in scenario 12 is the same with and without DCD, as mitigation M2 with DCD is comparable to mitigation M3 without DCD. However M2 with DCD saves farmers some money while M3 without DCD is a $315/ha cost. Thus gross margins are in scenario 12 are about 5% higher when DCD is included.

12.3.2. Non-uniform caps – Set F

In the original scenario 17, the non-uniform caps induce all dairying into the use of mitigation bundle M2. With the inclusion of DCD about 20% of dairying is now compliant using mitigation bundle M1, with the remainder still using mitigation bundle M2. However, M2 with DCD generates both more mitigation and higher costs. Overall the N leaching is reduced by 9%, while the total gross margin falls by 4%.

In the original scenario 18, the non-uniform caps induce dairying to move to M2 (55%) and M3 (45%). With the inclusion of DCD, dairy farms are compliant with M1 (20%) and M2 (80%). Overall, the N leaching is reduced by 2% while the total gross margin increases by 2% as M2, even with extra DCD costs, is more profitable than M3.

12.3.3. Grandparenting – Set G

In scenario 19, grandparenting allocations force all dairy farms into M3 and limit conversion to dairying. With DCD, M3 generates both more mitigation and higher costs. Overall the N leaching decreases by 4% while the total gross margin falls by 3% when DCD is included.

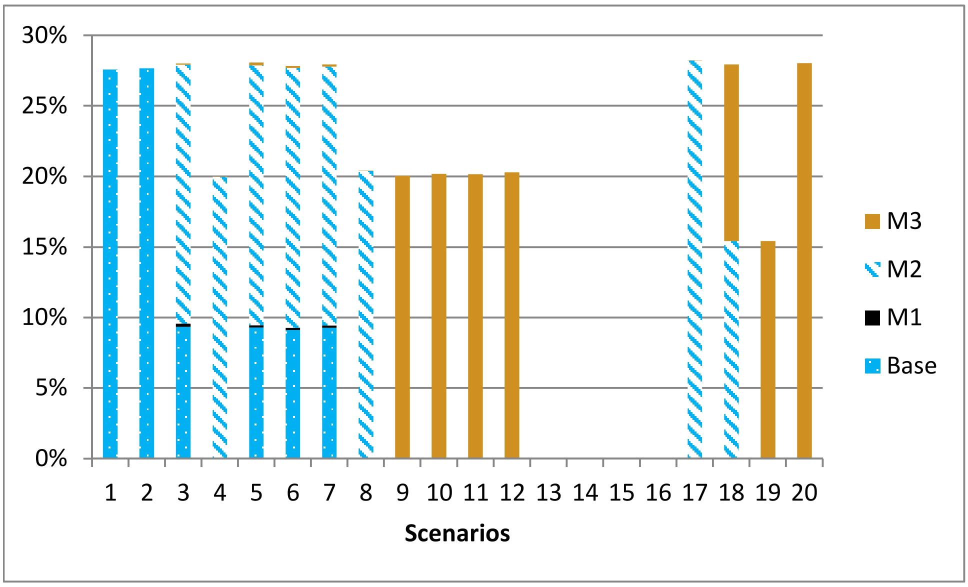
12.3.4. Mandated mitigation practices – Set H

In scenario 20, all farms adopt mitigation bundle M3. Without DCD, this reduced 2037 N leaching from the baseline 19,000 tonnes to 12,700 tonnes – a reduction of 33%. With the inclusion of DCD, N leaching drops to 11,400 tonnes, a reduction of 40% versus baseline. With or without DCD, there is no significant impact on the value of agricultural production in the region.

12.4. Charts and tables

Figure 23 Share of dairy by mitigation option, without DCD

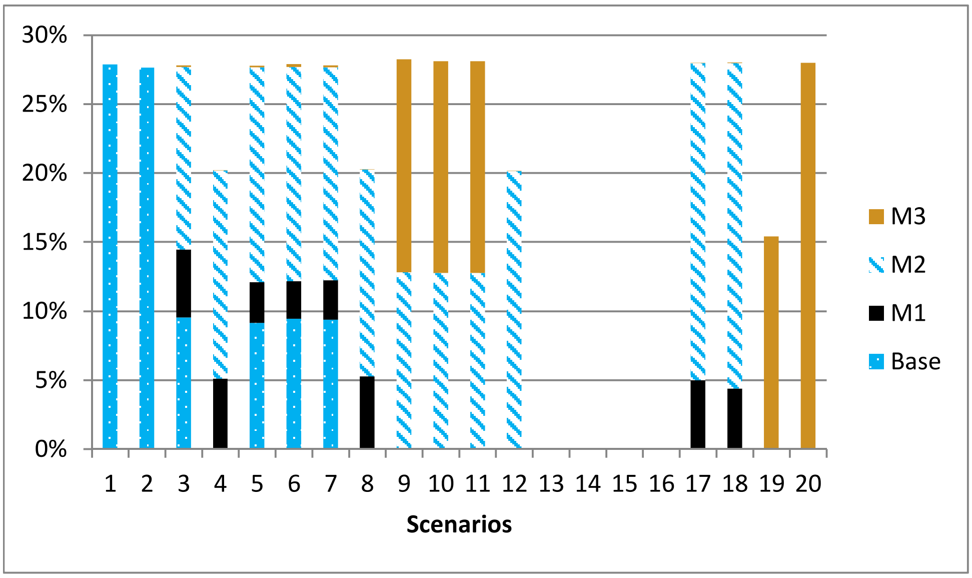
Proportion of area in dairy farms in 2037



Source: NZIER

Figure 24 Share of dairy by mitigation option, with DCD

Proportion of area in dairy farms in 2037



Source: NZIER

Table 29 N leaching

2037 total region (tonnes)

Scenario	Without DCD	With DCD	DCD impact
Baseline	19,039	19,039	0%
1	19,039	19,039	0%
2	19,039	19,039	0%
3	18,007	17,067	-5%
4	15,555	14,752	-5%
5	18,007	17,067	-5%
6	18,007	17,067	-5%
7	18,007	17,067	-5%
8	15,555	14,752	-5%
9	14,185	14,926	5%
10	14,185	14,926	5%
11	14,185	14,926	5%
12	14,185	14,398	1%
13	10,520	10,520	0%
14	10,520	10,520	0%
15	10,520	10,520	0%
16	10,520	10,520	0%
17	17,674	16,143	-9%
18	16,580	16,171	-2%
19	14,314	13,685	-4%
20	12,700	11,420	-10%

Source: NZIER

Table 30 P loss

2037 total region (tonnes)

Scenario	Without DCD	With DCD	DCD impact
Baseline	539	539	0%
1	539	539	0%
2	539	539	0%
3	415	415	0%
4	323	323	0%
5	415	415	0%
6	415	415	0%
7	415	415	0%
8	323	326	0%
9	324	364	12%
10	324	364	12%
11	324	364	12%
12	324	324	0%
13	222	222	0%
14	222	222	0%
15	222	222	0%
16	222	222	0%
17	360	360	0%
18	360	360	0%
19	316	316	0%
20	285	285	0%

Source: NZIER

Table 31 Value of agricultural production

2037 total region ($ millions)

Scenario	Without DCD	With DCD	DCD impact
Baseline	4,600	4,600	0%
1	4,600	4,600	0%
2	4,600	4,600	0%
3	4,600	4,600	0%
4	3,400	3,400	0%
5	4,600	4,600	0%
6	4,600	4,600	0%
7	4,600	4,600	0%
8	3,400	3,400	0%
9	3,400	4,600	38%
10	3,400	4,600	38%
11	3,400	4,600	38%
12	3,400	3,400	2%
13	900	900	0%
14	900	900	0%
15	900	900	0%
16	900	900	0%
17	4,700	4,600	-1%
18	4,500	4,600	3%
19	3,100	3,100	0%
20	4,600	4,600	0%

Source: NZIER

Table 32 Total gross margins

2037 total region ($ million)

Scenario	Without DCD	With DCD	DCD impact
Baseline	2,700	2,700	0%
1	2,700	2,700	0%
2	2,700	2,700	0%
3	2,900	2,800	-4%
4	2,100	2,000	-3%
5	2,900	2,800	-4%
6	2,900	2,800	-4%
7	2,900	2,800	-4%
8	2,100	2,000	-3%
9	1,900	2,600	39%
10	1,900	2,600	39%
11	1,900	2,600	39%
12	1,900	2,000	3%
13	500	500	0%
14	500	500	0%
15	500	500	0%
16	500	500	0%
17	2,900	2,800	-4%
18	2,800	2,800	2%
19	1,700	1,700	-3%
20	2,500	2,300	-5%

Source: NZIER

Table 33 DCD summary changes from initial scenarios

Percentage changes from non-DCD scenario findings

Scenario	Change in N leaching	Change in P loss	Change in agricultural production	Change in gross margin
Baseline	0%	0%	0%	0%
1	0%	0%	0%	0%
2	0%	0%	0%	0%
3	-5%	0%	0%	-4%
4	-5%	0%	0%	-3%
5	-5%	0%	0%	-4%
6	-5%	0%	0%	-4%
7	-5%	0%	0%	-4%
8	-5%	0%	0%	-3%
9	5%	12%	38%	39%
10	5%	12%	38%	39%
11	5%	12%	38%	39%
12	1%	0%	2%	3%
13	0%	0%	0%	0%
14	0%	0%	0%	0%
15	0%	0%	0%	0%
16	0%	0%	0%	0%
17	-9%	0%	-1%	-4%
18	-2%	0%	3%	2%
19	-4%	0%	0%	-3%
20	-10%	0%	0%	-5%

Source: NZIER

12.5. Implications

DCD is a cost-effective mitigation option that can lower the cost of meeting a given environmental objective. The specific implications for each scenario depend on where the caps fall relative to the leaching rates with and without DCD. The impacts depend on the specific tool and its interaction with results of farm practices. For many of the modelled scenarios, DCD reduces N by a few percentage points and economic measures by about the same amount. For a few uniform caps – scenarios 9, 10, and 11 – DCD makes the difference between dairy being compliant and not being compliant for large areas. The result is a small increase N and a large increase in production and gross margin.

13. Limitations

13.1. Wintering-off

Our initial analysis does not consider the N leached by dairy cattle during any wintering-off period. However we quantify the impact of wintering-off on the amount of N leaching in section 8.

A limitation of this approach is that the wintering-off is not determined by farmers within the model, but assumed to occur independently of any land use or farming practice decision. The N leached during wintering-off is also not considered as part of the sheep and beef farms' total leaching when enforcing compliance to environmental caps. However as the caps become more stringent, there is less dairying and thus less N from wintering-off. Our analysis shows that there are no scenarios where the N leaching from wintering-off pushes sheep and beef farms over the caps imposed. This means the land use and farmer practice decisions in our initial results are not impacted by our simplification of wintering-off.

13.2. System change as a mitigation option

Our modelling allows for three levels of mitigation for each farm. If an environmental cap requires more mitigation than the highest mitigation level, then the only way the farmer can meet this cap is by land-use change. This occurs particularly in scenarios 13, 14, 15 and 16 when a 15 kg N/ha cap is imposed, forcing all farmers out of dairying.

A limitation of our modelling is that we do not consider the possibility of a more fundamental change in the farming system. For example, one possible way that a farmer could continue to practice dairying under a tight N leaching cap is to change to a low-input farming system. Such a system would use less inputs and therefore have a smaller environmental footprint. However the gross margin obtained would most likely be significantly less than current dairy systems. If the gross margin obtained by such a low-input system is comparable to a sheep and beef farmer, then our results broadly hold. Dairy farmers moving from current practice to a low-input system would suffer a similar gross margin penalty as if they moved to sheep and beef. However, if a low-input dairy farming system can achieve a significantly higher gross margin than a sheep and beef farm, for the same environmental footprint, our results would overstate the true cost of meeting the environmental objectives.

13.3. Bundling mitigation options

Our modelling allows for three levels of mitigation for each farm. These have been derived by agricultural scientists at AgResearch to be representative of the options available to farmers in Southland. The on-farm impacts have been estimated through Overseer modelling.

In practice, a farmer does not need to select a bundle of mitigation options but can pick and choose what options are most suitable to their situation. They would be able to select just those activities that bring them into compliance. The impact is that the modelling overstates the total impact of each tool, because farmers are mitigating somewhat more than they need to be to meet the caps. However, impacts on price per kg of N and P reduction are ambiguous. As the modelling demonstrated, moving from M2 to M3 entailed a drop in cost per kg of N savings; the mitigation increased proportionally more than the costs. More detailed modelling is needed to draw out the costs and benefits of individual mitigation options.

13.4. Barriers to adoption

The model does not consider barriers to adoption or adoption costs. We do include the cost of undertaking mitigation practices, but not any costs that are specifically associated with making a change. In fact, there may be some costs from making changes. These costs have two impacts. First, they act as a brake on change; they reduce the propensity of farmers to change. We do account for this to some extent in the base model, because it is calibrated to the actual rate of change observed in Southland. The second impact of these costs is to create an additional economic loss. We have not investigated the size of this loss.

The impacts of these assumptions are clearest with mitigation bundle M1. The farm system and environmental modelling found that M1 improves the efficiency of nitrogen use on farm, which has the twin effects of increasing gross margins and reducing N leaching. That is, M1 improves both the economic and environmental performance of farms. We would therefore expect to see M1 more widely used in Southland than it actually is. This observation suggests that there are barriers to adoption, such as hidden costs, fit with existing production systems, lack of information, management constraints, or variability in performance across farm types. These barriers are not included in the research.

13.5. Farmer behaviour

Our modelling is innovative because it extends analysis of environmental policy from a single, average, profit maximising farmer, to multiple, heterogeneous farmers with differing objectives. We believe this adds realism to the modelling and therefore improves the results. For example, our baseline projections for conversion to dairy are lower than those from MPI. This is because we explicitly include farmers with a cost-minimising objective, for whom conversion to dairying is unattractive.

The difficulty with including farmer behaviours into any modelling is gathering data on the proportion of each type of farmer. Without specific farmer surveys we are unable to definitively conclude that we are using appropriate farmer behaviour parameters. We are aware that farmer behaviour surveys are under way in multiple regions of New Zealand, and that these surveys have been designed specifically to information agent-based models. This work should help overcome the present limitation.

However we have validated our modelling of farmer-behaviour by conducting an historical simulation of land-use change in Southland over the last 20 years. We calibrated our farmer-behaviour parameters to ensure that, given the economic conditions of the last 20 years, the model accurately replicated the historical growth in dairying in Southland.

13.6. Technological improvements over time

We include growth in agricultural productivity (in terms of output per hectare) that is based on the gains over the last 20 years. Dairy production per hectare is expected to grow at 2 per cent per annum; sheep and beef production per hectare is projected to grow at half a per cent per annum.

We do not include any growth in the performance of current mitigation practices or any possible new 'silver bullets' that can significantly reduce agriculture's environmental footprint. If there is such a development that is economic and compatible with the farms in Southland, our results will overstate the true cost of meeting the environmental objectives. However at present, to the best of our knowledge, no such developments exist.

13.7. Capacity of regional resources

We do not consider the capacity of regional resources to sustain the growth in dairying in the baseline, which predicts dairying could reach 28% of land use by 2037. In particular, we have not examined the availability of water or how farmers would respond to availability constraints. If resource constraints would limit dairy expansion to below the projected baseline, the economic baseline and the nutrient discharge baselines would be lower. As a result, the findings reported above for the impacts of farm-level tools would overstate the impacts created by nutrient discharge caps. The reductions in nutrient discharges would be smaller, and the economic impacts would be smaller, too.

13.8. Farmer debt and stranded assets

Debt and access to credit impact on a farmer's ability to adopt new practices. We do not have data on how these vary across farmers in Southland however, and so do not model debt or credit constraints explicitly. However the impacts of credit constraints and debt are implicitly captured in the farmer 'aversion-to-change' parameter. Dairy farming is much more profitable than all other land uses but accounts for only 17% of land use in Southland. There are a variety of reasons that restrict farmers from converting, and debt and credit constraints are two of them. These reasons are all captured within the model by an 'aversion-to-change' parameter that limits farmers from changing land use, and has been calibrated on the historical behaviour of farmers (see Section A.2.9).

When a farmer is forced to convert to sheep and beef to meet an environmental cap, we do not explicitly consider the cost of any stranded assets. When discussing stranded assets, it is important to beware of double counting. The lost production presented as a key output of the model is a source of income that would have been used to pay a return on the stranded assets, whether for servicing debt or as a return on equity. If stranded assets are an issue of concern, then an analysis that accounts for them needs to be done explicitly.

13.9. Corporate farms

We do not explicitly consider any corporate farms within the model. There may be some differences between the farm budgets and practices of corporate farms that we do not capture. We would expect that corporate farms act in a profit-maximising way however, and therefore the land-use decisions should be well-represented by the profit maximising farmers in the model.

Appendix A Model description and method

A.1 Overview

There are two main parts to this discussion of the method for the research:

- section A.2 describes the multi-agent simulation (MAS) model used in this research, including the land data, farm production budgets, and nutrient discharges in the base model
- section A.3 describes the mitigation activities that were included in the research, and details the farm systems (Farmax) and nutrient discharge (Overseer) modelling that were used to generate parameters for the MAS model

A.2 MAS model

A.2.1 Introduction

The MAS model is a flexible framework designed to model New Zealand’s pastoral industries, incorporating inputs from social and physical sciences. The model describes the strategic decisions and behaviours of individual farmers in response to changes in their operating environment. Individual farmer’s responses determine production, economic and environmental outcomes. The MAS model can represent the differences that exist among farmers, their systems, their responses to interventions and environmental changes, and the resultant consequences for the industry. The MAS model is designed for modelling location-specific data for an agricultural region. The Southland MAS includes data specifically from Southland, including data on the land, farms, and people.

The MAS model makes projections about farmer behaviour. In particular, it projects farmer decisions about which land use to select, what level of intensity to farm, and what environmental practices to adopt. It does this using a complex mix of bio-physical and socio-economic inputs: the type of land available to the farmer, the costs of each farming practice and the prices received for the various agricultural commodities, the farmer’s age and the presence of a successor to the farm, and the farmer’s risk profile.

The model inputs are first drawn from available research when possible. Where additional assumptions are needed to complete the model, they are based on review of the literature and calibration of the model with observed system behaviour. Any remaining uncertainty may be highlighted in discussions about the model or examined through sensitivity analysis.

This section provides detail on the model, starting with data requirements and moving on to how the model operates.

A.2.2 General data requirements

A large amount of data is brought together in the MAS model. Information from a range of disciplines is used to create parameters for the model. The specific data included are as follows:

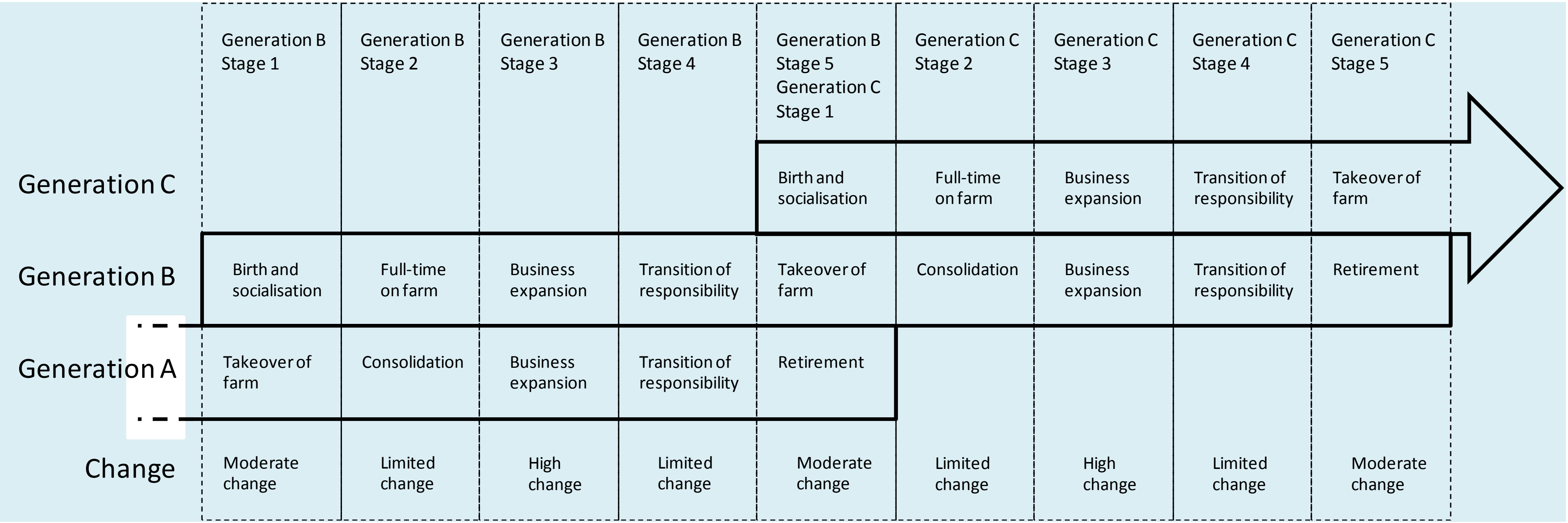
- Geographical Information System (GIS) data: This is data from a GIS database which describes the land parcels for any specific region to be used for the farms
- industry mix data: This describes the initial proportion of farms in dairying, sheep and beef and forestry
- biophysical data: This data relates to the actual annual input costs and other factors (fertilizer, cost of supplementary feed, stocking rate etc) and kilograms annual output produced per hectare of product (milk solids, meat, wood) and other things, such as nutrient losses and emissions, for the different farm types for each of dairy and sheep and beef, and for forestry. Because the land data is based on GIS data, the biophysical data can also be specific to a farming region
- other financial data: This data relates to all farm types and to expenses not directly related to the performance/intensity of the farm, such as cost of overheads, labour, stock, other farm expenses, depreciation, etc. There is also other financial data, e.g., interest rates
- economic data: This is data which may vary over the period of the simulation and affects the economic outcomes of the simulation. These include prices obtained for milk solids, meat and wood, and production costs such as cost of supplementary feed
- social data: This data describes the age profile of farmers in the region (in up to five age cohorts), the economic drivers and behaviour characteristics for each age-band. The key social data are farmer age, presence of successor to the farming business, farmer risk profile, and peer networks.

A.2.3 Farmer data

Relying on Burton (2009), we assume that farmers have a lifecycle that affects how they run their farms.

Figure 25 Farmer lifecycle and business goals

Three overlapping generations shown



	Generation B Stage 1	Generation B Stage 2	Generation B Stage 3	Generation B Stage 4	Generation B Stage 5 Generation C Stage 1	Generation C Stage 2	Generation C Stage 3	Generation C Stage 4	Generation C Stage 5
Generation C					Birth and socialisation	Full-time on farm	Business expansion	Transition of responsibility	Takeover of farm
Generation B	Birth and socialisation	Full-time on farm	Business expansion	Transition of responsibility	Takeover of farm	Consolidation	Business expansion	Transition of responsibility	Retirement
Generation A	Takeover of farm	Consolidation	Business expansion	Transition of responsibility	Retirement				
Change	Moderate change	Limited change	High change	Limited change	Moderate change	Limited change	High change	Limited change	Moderate change

Source: Burton (2009)

The typology in Figure 25 needed to be converted into probabilities in order to be implemented in the MAS model. There were several steps in that process:

- linking a farmer's goal to age and succession
- determining peer group and information
- assigning probability of change.

Linking goal to age

The MAS model has three different goals for farmers. The economic term for these goals is 'objective function' – they are what the farmer is targeting. The three goals are cost minimisation, profit maximisation, and high profit maximisation.

The goal is linked to age, which the model has in five cohorts. It is also linked to the presence of a successor – someone to take over running the farm.

Probabilistic analysis of Census data for 2001 and Agricultural Census data for 2002 and 2010 was used to estimate two sets of proportions:

- the proportion of farmers in each age cohort
- the proportion of type of farmer in each age cohort.

The result was the assignment of goal to age group shown in Table 34 and the percentage of farmers in each age group shown in Table 35.

Table 34 Farmer goal by age cohort

With successor

	Cost min	Profit max	Profit max high
25-34	42%	39%	19%
35-44	50%	32%	18%
45-54	52%	33%	15%
55-64	47%	33%	20%
65+	47%	33%	20%

Without successor

	Cost min	Profit max	Profit max high
25-34	45%	37%	19%
35-44	51%	31%	18%
45-54	52%	31%	17%
55-64	51%	29%	20%
65+	55%	30%	15%

Source: AgResearch

Table 35 Proportion of farmer age by industry

Industry	Production Intensity	25-34 Years	35-44 Years	45-54 Years	55-64 Years	65 to 74
Sheep & beef	HIGH	23%	30%	22%	14%	10%
	MEDIUM	24%	30%	23%	14%	10%
	LOW	23%	29%	23%	15%	11%
Dairy	HIGH	24%	31%	23%	12%	10%
	MEDIUM	27%	29%	22%	12%	10%
	LOW	26%	31%	22%	12%	9%
Forestry		22%	30%	23%	15%	10%

Source: AgResearch

Determining peer group and information

When the model is initialised, each farmer is assigned a social network of other farmers or 'peer group'. This a Jung network which provides a simple representation of a social network built using the 'Small World' algorithm (see Jin et al 2001). The size of the network can be determined by the user.

The farmer compares performance with that of the peer group, focusing on the economic objective (cost or profit). Peer groups are a mix of either similarly-aged farmers or those in the same industry. The two types of peer groups are then merged so that each farmer ends up with a network of peers, some in the same age group, some in the same industry and some in both.

After each step (one year) of the simulation the farmer then looks at the farm's performance and compares it with what the peers are doing (e.g. what type and intensity of farming they are doing, and what results they have achieved) according to their economic objective. Each farmer then uses this information when making a decision regarding what to do next: whether to continue doing the current activity or copy peers who are performing better.

Assigning probability of change

We can observe the actual pace of change in Southland, using things like conversions to dairying, trends in breeding and uptake of urea. Also, sociological research suggests that some farmers have a low propensity to change.

We created an equation for the propensity to change that both increased the probability of change over time and included a maximum propensity to change. The function is:

$$C = \alpha - \alpha/(1+e(t-min)) \tag{1}$$

where

C = probability of acting on observation and changing land use

t = time since last change

min = minimum-time-to-change

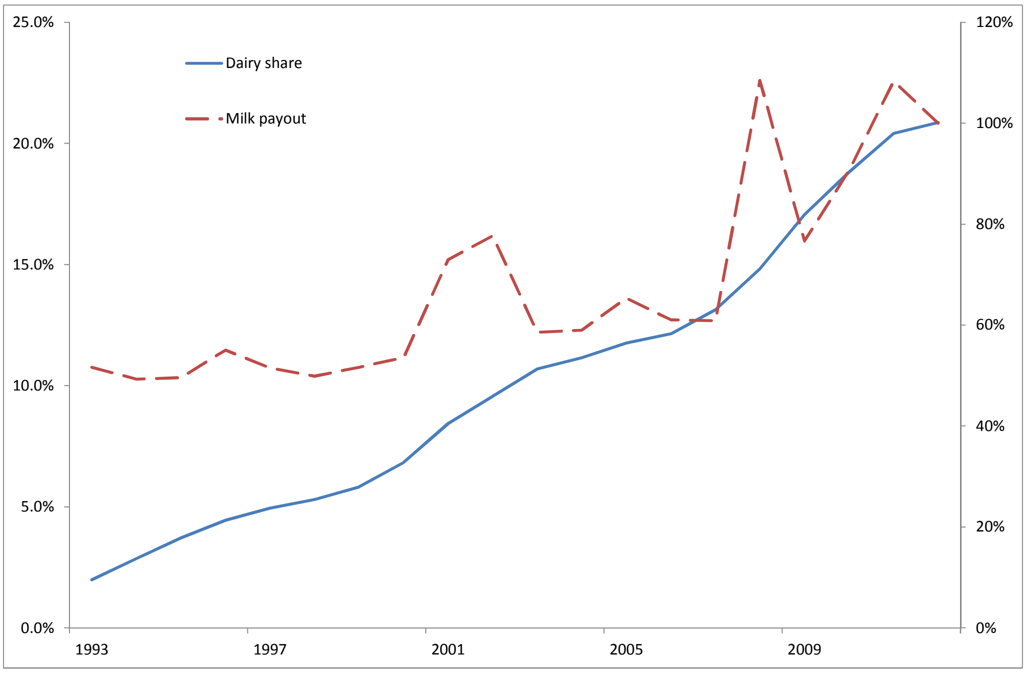
α = upper asymptote

This equation allows the model to have a lower bound for the probability of not changing so that some farmers, even after many years, would not be likely to change.

In addition, the experience in Southland suggests that price spikes in the dairy sector affect conversion rates, as shown in Figure 26. Milk solids price spikes in 2001/2002 and 2008/2011 are associated with an increase in the proportion of agricultural land in dairying. The basic decision algorithm described above assumes that the propensity to change is invariant to new information, but large increases in returns to dairying appear to affect the base propensity to change.

Figure 26 Price spikes and dairy conversions

LHS axis= dairy share of agricultural land in Southland
RHS axis = milk solids pay-out index (2012 = 100%)



Source: NZIER, Dairy NZ, Statistics NZ, Beef and Lamb NZ

To capture this behaviour, the model has a further step in the decision-making algorithm. We observe the commodity prices of the industry the farmer is considering changing to. If prices in this industry have spiked above a certain growth rate, we increase the likelihood of the farmer changing land use. The algorithm is as follows:

$$\text{If } p(t)/p(t-1) - 1 > \text{minimum spike} \tag{2}$$

then

$$C = C * (1 + \text{impact spike}) \tag{3}$$

where

p(t) = the commodity price in year t

minimum spike = the minimum price spike required to induce the additional behavioural response impact_spike = the impact of the price spike on the probability of land-use change

C = probability of acting on observation and changing land use.

The parameters in the equations for change of enterprise were calibrated on the actual experience in Southland of conversions to dairying. The final parameters are shown in Table 36.

Table 36 Parameter values

Parameter	Value
% peers	3%
Comparison weighting factor	0.75
Minimum-time-to-change (inertia)	7
Maximum change α	3%
Minimum spike	15%
Impact spike	1.5

Source: NZIER

The result of this work on farmer behaviour and propensity to change is a model that is sensitive to:

- farmer age
- presence of successor
- economic objective
- large price fluctuations
- time since last change in farming activity.

A.2.4 Land data

The land data used in the model are partially derived from GIS land information and the Agribase database. Environment Southland has provided the boundaries to the three water management zones: Lowland, Basin and Hill. The zones are areas of Southland that may be approached similarly from a policy perspective. Data are also taken from the New Zealand National Soils Database Spatial Extension. The land parcels in the Southland region that are presently in a ‘pastoral’ or ‘forestry’ land use and of LUC 1-7, were analysed. In all, we model almost 1,100,000 hectares within the MAS model. This represents 65.2% of the total area of the zones; the remaining area (towns, waterways, native bush) is not considered within this analysis (Table 37). This means the results from our MAS modelling are representative of the entire zone area, and there is no need to upscale results.

Table 37 Area modelled

Hectares

	Hectares	%	Comment
MAS model	1,097,411	65.2%	Considers dairy, sheep and beef and forestry > 20 hectares
Agribase	1,397,767	87.6%	Difference with MAS model is 91% native bush
Total	1,695,863	100%	Difference with Agribase is towns, waterways etc.

Source: AgResearch

The Hill zone is the largest by area. It is dominated by sheep and beef farming. The Lowland zone has significantly more dairying. The Basin zone is the smallest zone (Table 38).

Table 38 Land use by zone

Hectares (<20 hectare parcels are ignored)

	Basin	Hill	Lowland	Total
Dairy	33,317	11,006	131,615	175,938
Forestry	599	25,162	1742	27,502
Sheep and beef	216,411	417,518	260,041	893,970
Total	250,327	453,686	393,398	1,097,411

Source: AgResearch,Environment Southland

Land class

The MAS model considers three different classes of land quality. The three land classes have been defined based on Land Use Capability classes, and related to topography:

- Land class A – LUC 1-2, predominantly flat
- Land class B – LUC 3-4, predominantly flat
- Land class C – LUC 5-7, predominantly rolling.

For the model, dairy farming is restricted to land classes A and B only, while sheep and forestry can occur on all three.

Drainage class

Two drainage classes have been defined, based on the New Zealand Soil Classification drainage classes.

- **Poorly drained:** NZSC drainage classes 1-3 (very poor, poor, imperfectly drained)
- **Well drained:** NZSC drainage classes 4-5 (moderately well, well drained).

Soil drainage affects N and P discharge rates. All three water management zones are predominantly well-drained (Table 39).

Table 39 Soil drainage by zone

Hectares (<20 hectare parcels are ignored)

	Basin	Hill	Lowland	Total
Poor	75,889	38,029	180,139	294,058
Well	174,437	415,657	213,259	803,352
Total	250,327	453,686	393,398	1,097,411

Source: AgResearch/Environment Southland

Topography

Slope was divided into four categories that correspond approximately to the slope classes used by Overseer. The percentage of each land and drainage class in each topographical class was as follows. The percentages were rounded for modelling purposes, to simplify the design of farm systems that would represent an 'average' property in that LUC × drainage class.

Table 40 Land class, drainage, and topography

LUC	Drainage	Actual data (%)				Modelled data (%)		
		Flat (0-7.5°)	Rolling (7.5-16°)	Easy hill (16-26°)	Steep hill (>26°)	Flat (0-7.5°)	Rolling (7.5-16°)	Easy hill (16-26°)
1-2	Well	99.52	0.37	0.09	0.01	100	-	-
1-2	Poorly	99.91	0.09	0.00	0.00	100	-	-
3-4	Well	93.63	6.17	0.17	0.03	100	-	-
3-4	Poorly	96.07	3.79	0.14	0.00	100	-	-
5-7	Well	27.85	43.97	24.97	3.20	25	50	25
5-7	Poorly	51.79	42.53	5.60	0.09	50	50	-

Source: AgResearch

As shown in Table 40, an LUC 1-2 farm (land class A) was modelled as a single block of flat land, while an LUC 5-7 (land class C) poorly drained farm was modelled as two equal-sized blocks of land, one flat and one rolling.

Soil order

The major soil order on each land × drainage class was defined using the NZSC soil orders. The soil order was found to vary primarily with drainage class rather than topography. This single dominant soil type was assumed to be the sole soil across the entire property for modelling purposes, as modelling multiple soils would have greatly increased the complexity of Overseer models for probably negligible gain in this particular project. For this reason the actual area coverage and the second most common soil are presented below purely to provide background information on the appropriateness of this assumption.

Table 41 Soil order

LUC	Drainage	Dominant soil order	% area	Second soil	% area
1-2	Well	Brown	72	Recent	28
1-2	Poorly	Pallic	74	Gley	26
3-4	Well	Brown	72	Recent	17
3-4	Poorly	Pallic	49	Brown	21
5-7	Well	Brown	79	Melanic	12
5-7	Poorly	Brown	58	Pallic	18

Source: AgResearch

A.2.5 Farm system data

Sheep & Beef – Farmax modelling

The farm system was based on the Farmax models behind Vibart et al. (2011). LUC 1-2 and 3-4 were based on 90:10 (rolling:hill), and LUC 5-7 was based on 70:30 models. This work used Farmax Pro 6.4.6.07 AgResearch Science Edition.

Pasture production generated from LUC was based on area-weighted averages of standard sheep carrying capacities for each LUC.

For each land class, the ‘Low’, ‘Medium’ and ‘High’ intensity farms were used as modelled by Vibart et al. The following key changes were made to each model:

1. LUC 1-2, 3-4: The ‘rolling’ block was renamed ‘flat’, and increased to 450ha. The ‘hill’ block was removed
2. LUC 5-7: The ‘rolling’ block was renamed ‘combined’, and increased to 450ha. The ‘hill’ block was removed. Average pasture growth rates for the farm were available from the land data, but not individual growth rates for the different blocks, so it was simpler to combine all blocks for Farmax purposes and only separate them in Overseer
3. The existing seasonal pattern of pasture growth used in the majority of the original files was used across all of the new files, but scaled to achieve the following annual pasture intakes (kgDM/ha) in each individual model
    3.1 Total growth was entered into the model. Farmax Pro calculates how much feed will actually be available to be eaten by livestock from this data, after growth restrictions due to the grazing regime and decay. The actual intake (i.e. utilisation) achieved from this feed varied between farms due to different management systems

3.2 Pasture growth was determined by:

3.2.1 Calculating historical pasture intakes, from ewe carrying capacity multiplied by 600kgDM/ewe (120% lambing) on LUC1-4 and 550kgDM/ewe (100% lambing) on LUC5-7 to reflect historic production when these carrying capacities were determined

3.2.2 Dividing pasture intake by 70% utilisation to obtain total yield.

Pasture quality was set as defined in the Table 42.

Table 42 Pasture yield and quality by LUC group

		Pasture quality		
LUC	kgDM yield	Low intensity	Medium intensity	High intensity
1-2	13583	Med	Med	High
3-4	9457	Med	Med	High
5-7	3135	Low	Low	Med

Source: AgResearch

Adjustments were also made to livestock numbers. On LUC 1-2 and 3-4 land in Southland, breeding cattle are rare, and a farm is more likely to have around 10% of the livestock numbers in cattle than the approximately 20% used in the original models. These cattle will usually be trading bulls / steers and dairy heifers.

- for these land classes, the existing 'Cattle' enterprise was removed
- the existing but unused 'Bull Beef' enterprise was used to add sufficient beef cattle to increase cattle feed demand to 10% of total stock units (bulls purchased in April and sold the following April / May)
- where dairy heifer numbers already met or exceeded 10% of total stock units, no bulls were added, but the existing number of dairy heifers was retained.

The livestock numbers in all enterprises were scaled to achieve maximum livestock production at the new level of pasture production, using the 'Modify' tool. To ensure the systems did not depart from reality during this automated scaling process, the following adjustments were then made:

- the number of ewe hoggets retained was adjusted to achieve a ewe replacement rate of approximately 28% on all models
- the number of heifers retained was adjusted to achieve a cow replacement rate of approximately 18% on all models
- the number of hind fawns retained was adjusted to achieve a hind replacement rate of approximately 18% on all models.

Supplements did not greatly exceed around 50% of winter intake on LUC 1-2 or 3-4. However on LUC 5-7 they comprised up to 100% of intake following these adjustments. A number of changes were made to supplements to achieve realistic yields and management for Southland.

- swede yields were increased to 10, 12, and 14t DM/ha for low, med, high intensity (from 7.5, 9, and 10.5t DM/ha originally)
- ryecorn green feed crop removed wherever present (not common practice)
- LUC 5-7 swede area halved from 22 to 11ha
- LUC 5-7 hay area halved from 20 to 10ha
- all supplement quantities fed adjusted to balance supplement supply & usage

The final livestock numbers were scaled again using the 'Modify' tool to optimise production levels following these adjustments to the system. Death and/or sale numbers were adjusted where necessary to ensure livestock numbers were balanced.

Sheep & Beef – Overseer modelling

For all data entry to Overseer, wherever no value is stated below, the default values from Overseer were used.

A large quantity of livestock numbers had to be copied from Farmax to Overseer to make the stock reconciliations for Overseer. Farmax reports stock numbers in each class on the last day of the month. Overseer expects average stock numbers for the entire month. For practicality, given the very large number of models in this project, it was assumed that the stock numbers at the end of the month equalled the average stock numbers for that month. This simplification will push stocking dates in Overseer slightly earlier than in Farmax, as when animals were brought in partway through a month they were assumed to be present for the whole month, and when present at the start but all sold within that month none were assumed to be present in that month at all.

Soil descriptions

Everything other than what is mentioned here remained at default values. All soil fertility test values were averages from Overseer.

- Well drained Brown soil (LUC 1-2, 3-4, 5-7)
  - Soil order = 'Brown'
  - Profile drainage class = Well
  - Pugging = Rare
- Poorly drained Pallic soil (LUC 1-2, 3-4)
  - Soil order = 'Pallic'
  - Texture = silt loam
  - Profile drainage class = Poor
  - Pugging = Winter or rain
  - Drainage = Mole/tile
  - Chemical & physical parameters: Clay = 25%, subsoil clay = 35%

- Poorly drained Brown soil (LUC 5-7)
  - Soil order = ‘Brown’
  - Profile drainage class = Poor
  - Pugging = Winter or rain

Other parameters

- Pasture type set to ryegrass / white clover (LUC 1-2,3-4) and Browntop (LUC 5-7).
- For LUC 5-7, the only differences between the 2-3 blocks were as follows:
  - Topography (Flat, Rolling, Easy hill)
  - Relative productivity between blocks was assumed to be Flat: 1.2, Rolling: 1.0, Easy hill: 0.7.
  - Hay was grown only on the flat block
  - Swedes were grown on the flat and rolling blocks (as once wetlands were added the flat block was too small in some scenarios to contain the swede crop rotation).
- Maintenance P and S fertiliser applied
  - All fertiliser applied as single superphosphate
  - Brown soils: Sufficient super applied to meet maintenance of both P and S.
  - Pallic soils: Very high sulphur requirements made it unrealistic to apply maintenance S using superphosphate. Applied 2 kgS/ha below maintenance S, resulting in well above maintenance P applications. To improve in mitigation scenarios.
  - Hill block (well drained LUC5-7) did not receive higher fertiliser applications than the rolling block, even if this resulted in below maintenance applications. The maintenance requirement of the hill block was in some cases higher than the rolling block, but few farmers are likely in reality to put more fertiliser on their poorest land, as the cost-benefit of this is questionable.

Dairy – Farmax modelling

DairyNZ production systems 2, 3 and 4 (herein systems; Hedley et al., 2006; Hedley and Kolver, 2006; DairyNZ 2010) were modelled using Farmax Dairy Pro v. 6.4.0.12 AgResearch Science Edition. The original modelling work was conducted by Vicki Burggraaf (Rural Futures Project), and adjusted to a number of modifications, as specified below.

A brief description of the dairy systems included in the current modelling exercise follows:

- System 2: Feed is imported to the system, either as a supplement or grazing off farm (non-lactating stock categories). Approximately 4 to 14% of the total feed is imported
- System 3: Feed is imported to extend lactation, typically autumn feed. Approximately 10-20% of total feed is imported

- System 4: Feed is imported and used at the beginning and end of lactation. Approximately 20-30% of total feed is imported to the farm.

As mentioned above, pasture production was generated from LUC area-weighted averages of assumed sheep carrying capacities. A 7% increase in dairy pasture production was added above that of sheep and beef (S&B) systems due to improvements in forage genetics (Smith, 2012). A non-irrigated 'South Island' ryegrass/white clover-type pasture was set in Farmax, and all three systems were assumed to produce the same amount (and growth patterns) of annual pasture dry matter (DM).

Briefly, a balance of whole-farm feed supply and demand is created in Farmax. If pasture cover predicted from this balance is below or noticeably above the minimum required by the herd, an 'infeasible' status appears on screen, and changes in management are required to achieve feasibility.

For each dairy system, a number of key variables and key changes were made to the original models:

- LUC 1-2, 3-4: 'Non-effluent' (no liquid effluent applied) and 'Effluent' blocks were established on flat topography. The size of these (land) blocks varied by system; the Baseline effluent blocks accounted for 25.3% (System 2) to 29.5% (System 4) of the total farm size (190 ha)
- The existing seasonal patterns of pasture growth used in the original files (Burggraaf, 2012) were used for all the new simulations, scaled to achieve the following annual pasture yields and intakes (kg DM/ha), as in Table 43

Table 43 Annual pasture yields and intakes by dairy system

	System 2		System 3		System 4	
LUC	**1-2**	**3-4**	**1-2**	**3-4**	**1-2**	**3-4**
Pasture yield, kg DM/ha	14534	10119	14534	10119	14534	10119
Pasture intake, kg DM/ha	13012	9665	13014	9727	12822	9596
Size of blocks, ha						
Non-effluent	142	142	137	137	134	134
Effluent	48	48	53	53	56	56

Source: AgResearch

Given a target milksolids (MS) production per cow (360, 380 and 420 kg MS/cow for systems 2, 3, and 4, respectively), livestock numbers in each system were scaled to achieve maximum pasture utilisation at the new levels of pasture production, using the 'Modify' tool in Farmax. To ensure the systems did not depart from reality during this automated scaling process, the following adjustments were made:

- milking herd replacement rates were set at 21% on all models, one milking herd considered

- mean mating and calving dates were 04-Nov and 10-Aug, respectively
- body condition scores (BCS) at calving were set at 5.0
- liveweights (LW) and BCS at 01-Jun were set at 440 kg/and 4.5, respectively
- replacement heifers were sent off-farm on 16-Dec, at a mean age of 126 d
- remaining bobby calves and additional heifers were sold every 5 d in synchrony with calving schedules.

No forage crops were used, since no dry livestock wintering on-farm was considered in these models. Dry cows and replacement heifers were sent off-farm. The impacts are further described in Appendix B on wintering-off.

Nitrogen (N) fertilisation rates were set at 150 kg/ha for all systems and non-effluent blocks (3 applications of 50 kg N each, with a response of 10 kg DM/kg N applied). Baseline N fertilisation rates were also set at 150 kg N/ha for effluent blocks, but this value was not exported to Overseer. Because Farmax does not recognize liquid effluent as a source of N applied to pastures, fertiliser amounts were kept consistent with those applied to non-effluent blocks. This was done to maintain pasture production and stock carrying capacity.

The final livestock numbers were scaled again using the “Modify” tool to optimise pasture utilisation following these adjustments to the system. As with sheep & beef systems, death and/or sale numbers were adjusted where necessary to ensure livestock numbers and lactation lengths were balanced and equivalent within each system.

Supplements were made and fed to all systems, as shown in Table 44.

Table 44 Dairy systems farm data

	System 2		System 3		System 4	
LUC	**1-2**	**3-4**	**1-2**	**3-4**	**1-2**	**3-4**
Cow numbers, 01-Jul	631	473	638	480	659	495
at peak lactation	628	470	635	477	656	493
MS (to factory), kg/ha	1196	891	1275	956	1146	1086
MS (to factory), kg/cow	362	360	381	381	419	419
Stocking rate, at peak	3.31	2.47	3.34	2.51	3.45	2.59
Days in milk	259		266		273	
Breeding worth (BW)	84		88		93	
kg MS/kg cow	0.89	0.88	0.94	0.94	1.04	1.04
kg DM intake/kg MS	11.2		11.1		10.9	
Supplements (S), t DM						
Silage, made	90	69	69	54	54	42
Baleage, imported	0	0	192	144	265	199
Palm kernel, imported	0	0	0	0	386	290
Total S/feed eaten, %	2.9	3.0	7.8	7.8	18.6	18.6
Imported S/feed eaten, %	0.1	0.1	5.8	5.8	17.2	17.3

Source: AgResearch

Dairy – Overseer modelling

For all data entry to Overseer, the default values were used, unless stated otherwise. Farmax livestock numbers were imported into Overseer v. 6.0 via an older version of Overseer. Mean annual rainfall set at 1000 mm.

Soils have been described previously in the S&B section. Briefly, all soil fertility test values were typical values suggested by Overseer, except for Olsen P values, which were raised from 30 (Overseer default) to 35. The soil information was as follows:

- Well drained Brown soil (LUC 1-2, 3-4)
  - Soil order = “Brown”
  - Profile drainage class = Well drained
  - Pugging = Rare
- Poorly drained Pallic soil (LUC 1-2, 3-4)
  - Soil order = “Pallic”
  - Profile drainage class = Poorly drained
  - Pugging = Winter or rain
  - Drainage = Mole/tile on 100% of the block
  - Chemical & physical parameters: Clay = 25%, subsoil clay = 35%

N fertilisation rates were set at 150 kg/ha for all non-effluent blocks; N fertilisation rates were set at 100 kg N/ha for effluent blocks, irrespective of effluent N applied. Maintenance P and S fertiliser applied, according to the following:

- all fertiliser applied as soluble fertiliser in November
- fertiliser applied was tailored to individual nutrient maintenance requirements as suggested by Overseer.

The dairy effluent system included a holding pond, with no solids separation before effluent enters the holding pond. The disposal method of liquid effluent included 'spray regularly' and liquid applications were not ‘actively managed’. Effluent blocks for Baseline simulations were 25.3% (48 ha), 27.9% (53 ha) and 29.5% (56 ha) for systems 2, 3, and 4 respectively.

A feed pad was added to system 4 simulations (for palm kernel feeding); manure removal method from the pad was via scraping (no water), and solids were separated before entering the pond and spread on both blocks. Solid effluent storage method before disposal included cover from rain and storage available for 6 months. Initial time spent on feed pad was 1.0 hour daily for Baseline farms.

Data inputs for MAS model

The Farmax and Overseer modelling produced inputs for the MAS model, including farm budgets and leaching rates. Farms budgets vary by intensity and LUC group. The calculations of sheep & beef farm budgets result in positive gross margin for all combinations of intensity and LUC group, excluding any taxes, depreciation or family drawings (Table 45). Dairy farming is significantly more profitable; however, dairying is unsuitable on LUC group C, as shown in Table 46.

Table 45 Sheep and Beef farm budgets

$/Ha

Intensity	**Low**	**Low**	**Low**	**Ave**	**Ave**	**Ave**	**High**	**High**	**High**
LUC	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Revenue	862	694	256	1,031	870	298	1,473	1,188	377
Cost	597	499	205	673	586	235	761	634	245
Gross margin	265	196	50	357	284	63	712	554	132

Source: AgResearch

Table 46 Dairy farm budgets

$/Ha

Intensity	Low	Low	Low	Ave	Ave	Ave	High	High	High
LUC	A	B	C	A	B	C	A	B	C
Revenue	7,458	5,558		7,932	5,948		8,961	6,730	
Cost	2,875	2,399		3,327	2,744		4,406	3,552	
Gross margin	4,583	3,158		4,605	3,204		4,555	3,178	

Source: AgResearch

Price and cost projections

We make the following assumptions about productivity, cost and prices for sheep and beef and dairy.

- 0.5% annual growth in sheep and beef productivity/ha; 2% annual growth in dairy productivity/ha, based broadly on averages over the last 20 years
- prices are difficult to project: we assume 2% annual growth for both milk and meat prices, but with volatility added to the milk prices such that over the 25 year simulation period there are 6 price spikes where milk prices rise by 15% or more before returning to trend
- 2% annual cost growth for sheep and beef; 4% annual cost growth for dairy, based broadly on averages over the last 20 years.

N and P leaching rates for sheep and beef and dairy vary by LUC class (A = 1,2; B = 3,4; C = 5-7) and intensity (Table 47, Table 48). We assume forestry leaches 2kg N/ha and 0.1kg P/ha annually for all LUC and intensity.

Table 47 Annual N leaching by soil drainage

Kg N/Ha

Intensity	Low	Low	Low	Ave	Ave	Ave	High	High	High
LUC	A	B	C	A	B	C	A	B	C
Dairy									
Well	48	36	NA	49	38	NA	48	37	NA
Poor	40	29	NA	41	31	NA	43	32	NA
SheepBeef									
Well	15	13	8	15	13	8	18	15	8
Poor	12	10	8	11	10	9	13	11	9

Source: AgResearch

Table 48 Annual P loss by soil drainage

Kg N/Ha

Intensity	**Low**	**Low**	**Low**	**Ave**	**Ave**	**Ave**	**High**	**High**	**High**
LUC	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Dairy									
Well	1.0	0.8	NA	1.0	0.8	NA	1.1	0.9	NA
Poor	1.9	1.5	NA	1.9	1.6	NA	2.1	1.8	NA
SheepBeef									
Well	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2
Poor	0.5	0.4	0.2	0.5	0.4	0.2	0.5	0.5	0.2

Source: AgResearch

A.2.6 Initialisation

Initialisation of the model creates a synthetic population of farmer-agents that is representative of the region as described by the input data. Land as described in the GIS database is assigned to farmers. Farmers are assigned an age, offspring and a spouse based on the population demographics of the region. The risk profile of the farmer, and the economic objective of the farmer are then determined based on these socio-demographics.

In the MAS model, the risk profile governs the farmer’s behaviour to decisions such as expansion or contraction, contracting business or renting out land, and changes to land use and production techniques. A farmer may be risk-loving, risk-neutral or risk-adverse. Their economic objective might be profit maximisation, cost minimisation or production maximisation. For the present research, the economic objectives have been set for cost minimisation, profit maximisation with low change, and profit maximisation with high change.

A.2.7 Execution

The model is designed to run for time steps of one year. Because the farmers interact within the model, all decisions of all farmers must be completed for each year before the model moves on to the next year.

For every time step, the model executes pre, main and post processing. Pre-processing completes the calculation of parameters required for the main decision-making algorithm, e.g., the farmer’s financial position. The main processing executes the farmer decision making. Here, the farmer’s social network and risk profile become important. Before each farmer makes a decision, they review two sets of farming activities:

- the available options for their land type, given the policies in place
- what their peers have done over the last 3 years.

The available options determine the set of feasible activities that the farmer can pursue. Where the peers have comparable soil types, the farmer considers the peers’ actions and outcomes in their own decision-making. If a peer has had better success in meeting the farmer's objective with a different land use or production level, the farmer can learn from the peer and adopt the same production. Actual adoption rates are governed by the risk profile of the farmer. A risk-loving farmer will be more likely to adopt the peer's practice when compared to a risk-averse farmer.

Once the actions of all farmers have been computed for the year, post-processing can be completed for the region, e.g., summing total dairy production.

A.2.8 Using the model

The MAS model can be used to estimate industry mix and production levels under a range of different price projections, policy scenarios and future external drivers. It considers input prices (water, supplements), output prices (meat, milk, wood), externality prices (emissions, nitrates), and limits (N, P). Price paths can be set by the user, either as a vector of future prices or as a distribution.

The model outputs a wide range of information. Dairy, sheep/beef and forestry production, as well as total emissions can be viewed as a time series over the course of the simulation. The farming intensity of sheep/beef and dairy is also shown over time, so that moves towards or away from intensification are easily identifiable. In addition, histograms of farm size, farm profits and operating expenditure, and farmer demographics are available that show how the heterogeneity of the farming systems and the region change over time.

The model can also be used for a 'comparative statics' analysis, which compares results between two scenarios in a given year.

The MAS is a probabilistic model. This means that decisions are not deterministic (or 'hard-coded') but influenced by probabilities. For example, risk loving farmers are more likely to adopt a new enterprise (that is, have a higher probability); however there is a chance that at the individual farmer level they may not adopt. Running the model many times trends the results towards the average probability of each decision. The system level results are an aggregation of the individual agent results.

A.2.9 Validating the MAS model

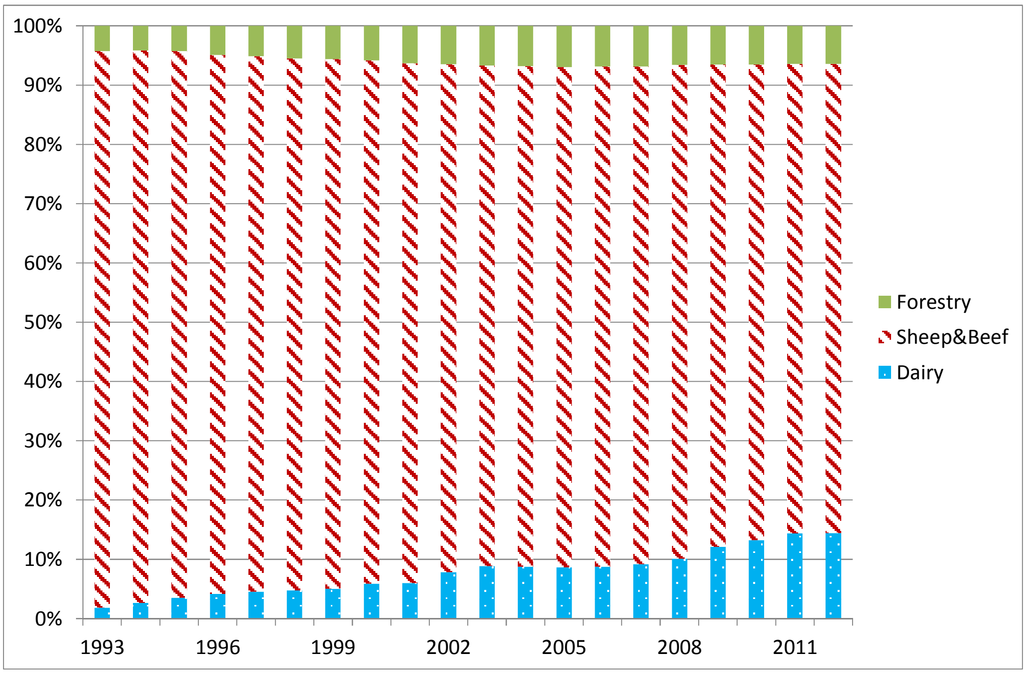
As part of research conducted in the Rural Futures programme, we calibrated the MAS model using a backcasting technique. The aim of the backcasting was to ensure that the model accurately mimicked historical land-use change in Southland over the last 20 years. Sheep and beef remains the predominant land use in Southland, however dairying has grown from around 2% in 1993 to almost 20% today. In the backcasting exercise, we used the known prices and costs over the last 20 years to calibrate the model's decision-making algorithm so that the model output matched the historically observed land use. In this way, we could achieve some measure of confidence that the model was appropriately calibrated to forecast future changes in agriculture in Southland.

Outputs: Land use

In 1993, less than 2% of land was used for dairy farming. Since then, dairying has grown strongly, to now account for between 15 and 20% of agricultural and forestry land use within Southland. Forestry has also grown, but at a slower rate than dairy, from 4% of land use in 1993 to 7% in 2012.

Figure 27 Historical land use in Southland

Major land uses



Source: NZIER, Stats NZ, MPI, Dairy NZ

Calibrating the algorithm

Our calibration focused on the parameters that we have the least certainty about, and to leave unchanged the parameters and algorithms where there is more confidence.

The bio-physical and economic rules are reasonably straightforward. For example, we know that dairying is on the whole confined to LUC 2-4, simply because of the inability to farm cows on the poorer land classes. Similarly, farm budgets are well understood – we know the profitability of dairying versus sheep and beef.

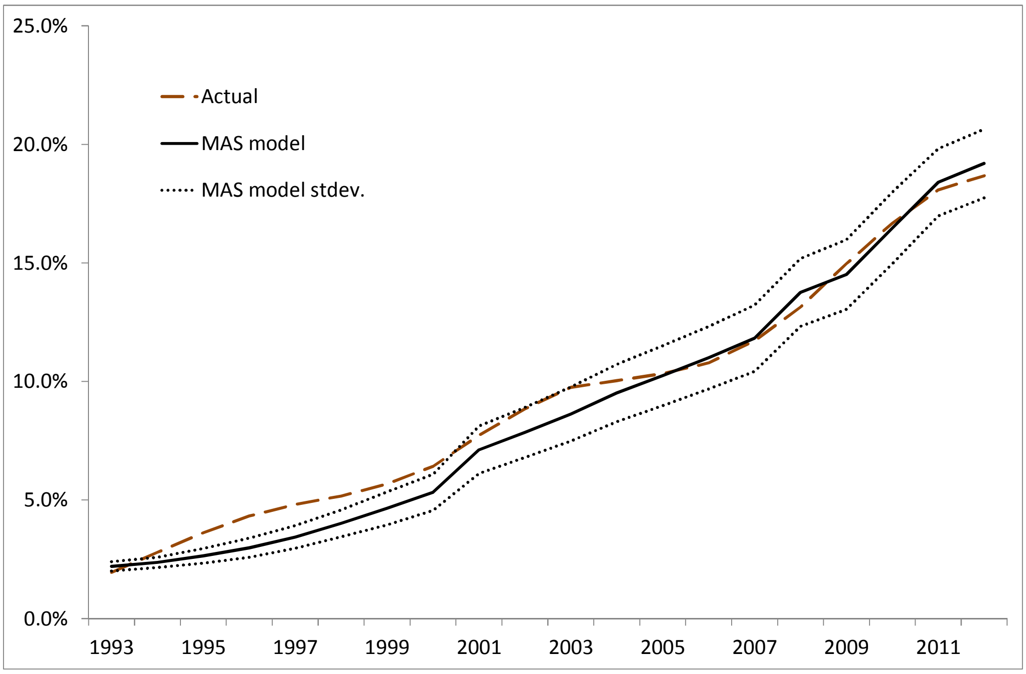
What are less well-understood are the peer networks and behavioural responses of farmers. We do not know the size of farmer peer groups. Prior reseach has identified that farmers move between stages (or 'typologies') over the life-course: risk-taking and profit-maximising in their early years of farming before typically becoming more risk-averse and cost-minimising as they near retirement. However the link between these dynamics and actual farmer behaviour with respect to land-use change has not been readily quantified. We therefore used the backcasting to calibrate the probability of change parameters.

Results

Figure 28 compares the share of dairying in Southland predicted by the MAS model versus the actual growth in dairying over the last 20 years. The figure suggests that the MAS model is able to replicate the growth in dairying. It is particularly accurate for the later years of the comparison as the share of dairying grows.

Figure 28 MAS model versus actual dairy conversion

Percentage area of agricultural land used for dairying



Source: NZIER

As a result of this work on backcasting and calibration, we are confident that the MAS model is a reasonable proxy for the real agricultural sector in Southland and can safely be used to forecast the impact of future policies.

A.3 Mitigation of N and P

A.3.1 Introduction

Farmers can modify farming activities to produce lower levels of N and P leaching. Their choices mitigate the nutrient discharge from farming. In the MAS model, farmer-agents are able to choose from a menu of options that include bundles of mitigation activities that reduce discharges. In addition to the baseline activities, three mitigation bundles were developed and modelled. These bundles have different implications for discharges and on-farm costs.

The bundles were modelled as cumulative. Mitigation 2 includes Mitigation 1, and Mitigation 3 includes Mitigations 1 and 2.

A.3.2 Sheep & Beef mitigation bundles

Mitigation 1

Three mitigations were applied:

- Optimised nutrient inputs
- Low solubility P
- Wetlands

The following changes were made in the models to achieve this:

Farmax

- Wetlands:
    - Grazing area reduced by 5ha, to 445ha, to account for 5ha being removed from grazing for wetlands. Livestock numbers in all enterprises were reduced to compensate for reduced pasture availability.
- It was presumed that optimisation of nutrient inputs and moving to low solubility P would not, at least in the long run, alter pasture growth rates.

Overseer

- Wetlands:
    - A 5ha wetland block was added, with the "Flat" block reduced in area by 5ha to compensate.
    - Wetland details: "Artificial type 2", Type "B", Catchment area = 225ha (50% of farm), Convergence = high for poorly drained, little for well drained soil[8]. Default aquitard depth.
    - Poorly drained Pallic soils with tile drainage only (LUC 1-2, 3-4): Flat block divided into one 225ha block and one containing the remainder of the farm area. Tile drainage from 225ha block diverted into the wetland.
    - Stock reconciliations updated to align with new Farmax data.
- Low solubility P:
    - Each fertiliser application changed to apply fertiliser by form, with all P as RPR and all S as elemental S.
- Optimised nutrient inputs:
    - Exact maintenance fertiliser requirements of P and S were applied to all flat and rolling blocks.
    - Hill blocks received the lesser of maintenance fertiliser and the fertiliser rate applied to the rolling block.

Mitigation 2

In addition to all the mitigations in the "M1" bundle, the following two mitigations were applied:

- Stock exclusion from streams
- Reduced stocking rates, improved productivity

The following changes were made in the models to achieve this:

Farmax

- Reduced stocking rates, improved productivity:

---

[8] The convergence should not have been changed between soil types, this error was identified following the modelling. This will make no difference to the results for the flat LUC 1-2 and 3-4 land, so no dairy farms and few S&B farms are affected. It will slightly increase the N removal by the wetland in LUC 5-7 poorly drained scenarios, and slightly reduce the N removal in LUC 5-7 well drained scenarios. This should have virtually nil overall impact on the MAS model outputs.

    - Raised lambing % by 15 percentage points from the current level (which differed between intensity scenarios).
    - Raised calving and fawning % by 5 percentage points wherever breeding cattle and hinds were present.
    - Reduced livestock numbers using "modify" tool to compensate for greater feed demand from young livestock, sale numbers tweaked to balance stock reconciliations where necessary.
    - This resulted in a reduction in livestock numbers over the winter period, but an increase in overall stocking rate as measured by feed intake due to the larger numbers of progeny consuming feed over the summer period.
- Stock exclusion from streams:
    - It was presumed the area fenced off would be insignificant, so no changes were made.

Overseer

- Reduced stocking rates, improved productivity:
    - Stock reconciliations were updated.
- Stock exclusion from streams:
    - Beef / dairy grazing "Access to streams" was unchecked on each grazing block.
- Fertiliser levels were adjusted to maintenance requirements where these had changed.

Mitigation 3

In addition to all the mitigations in the "M2" bundle, the following two mitigations were applied:

- Grass buffer strips
- Feed pad for beef cattle

The following changes were made in the models to achieve this:

Farmax

a) Grass buffer strips:
    - Grazing area reduced by a further 9 ha, to 436 ha.
    - Livestock numbers reduced using "modify" tool to account for reduced pasture availability, sale numbers tweaked to balance stock reconciliations where necessary.

b) Feed pad for beef cattle:
    - Presumed no impact on pasture production, and presumed using existing supplements, so no changes made.

Overseer

a) Grass buffer strips:

  - Added a 9-ha riparian block, reducing area of “Flat” block to compensate (Pallic soils with tile drainage: reduced area of smaller flat block).
  - Catchment area supplying riparian strip = entire farm area (450ha). Length of strip = 12860 m. Width of strip = 7 m. Age = 5 years, entry condition = “Bottom of hill, flat entry”. Strip type = “Dense, healthy grass”. Percentage of surface flow that drains through the strip = 95%. Percentage of runoff intercepted by the strip = 50%. Percentage of length of strip ponding water upslope = 50%.
  - Updated stock reconciliations.

b) Feed pad for beef cattle:
  - Added an animal shelter for beef / dairy grazing livestock.
  - Hay destination changed to “Beef / dairy grazing – Wintering pad”
  - Pad type: “Covered wintering pad or animal shelter”. No bunker lining material (ie concrete only), cleaned by scraping (no water). Liquid effluent treatment method: Holding pond, spraying infrequently (presuming infrequent spraying using a slurry tanker). Pond solids disposal method: Spread on selected blocks. Management: Wintering pad only, animals on from May – July, percentage time varied between models to maximise time in wintering pad using available supplement.
  - Effluent spread over entire area in Flat and Rolling blocks, not on hill (presuming using a slurry tanker, so can reach much of the farm): Liquid effluent from wintering pad selected, application depth 12-24mm, effluent applied in September, October and November. Solid effluent applied in September and October.

c) Fertiliser levels were adjusted to maintenance requirements where these had changed.

A.3.3 Dairy mitigation bundles

Mitigation 1

Three mitigation activities were applied:

a) stock exclusion from streams
b) improved nutrient management
c) improved farm dairy effluent (FDE) management.

Below, we detail the changes made in Farmax and Overseer to reflect these activities. The letters in the description link to the modelling changes to the specific mitigation activity.

Farmax

No changes were made.

Overseer

a) Dairy cattle were excluded from streams

b) Soil tests, P source, and N application:

  - Olsen P was reduced from 35 (Baseline) to 30 (typical value suggested by Overseer based on soil chosen)
  - fertiliser P inputs were switched from superphosphate to reactive phosphate rock (RPR), with the assumption that these changes would not affect long-term pasture production
  - utilisation of imported supplements was improved from 'average' to 'very good'
  - time spent on feed pad was increased to 2.0 h per day
  - the amount of fertiliser N applied to the effluent block was adjusted to 150 kg total N based on the amounts of N applied as effluent, rather than 2/3 of the amount applied on the non-effluent block (Baseline Overseer)

c) The disposal method of liquid effluent included 'stir and spray regularly' (only 'spray regularly' for Baseline). Also, liquid applications are now actively managed.

Mitigation 2

In addition to all the mitigations in the Mitigation 1 bundle, the following three mitigations were applied:

a) wetlands

b) improved FDE management

c) reduced stocking rates, improved per animal productivity.

Below, we detail the changes made in Farmax and Overseer to reflect these activities. The letters in the description link to the modelling changes to the specific mitigation activity.

Farmax

a) The sizes of the non-effluent blocks were reduced by 2.0 ha. Livestock numbers were reduced accordingly

b) No changes

c) Genetic merit values (BW) were set at 101, 106 and 112 for systems 2, 3, and 4, respectively. MS were increased to 396, 419, and 461 kg MS/cow, with similar MS/ha relative to previous bundles. Weights (LW) were increased to 480 kg/cow (systems 2 and 3) and 500 kg/cow (system 4). Stock numbers were reduced using the ‘modify’ tool, and SR were reduced according to Table 49.

Table 49 Mitigation 2 dairy parameters

	System 2		System 3		System 4	
LUC	**1-2**	**3-4**	**1-2**	**3-4**	**1-2**	**3-4**
Cow numbers, 01-Jul	577	430	583	437	588	446
at peak lactation	574	427	580	434	585	444
MS (to factory), kg/ha	1221	910	1299	971	1433	1088
MS (to factory), kg/cow	400	401	421	421	460	461
Stocking rate, at peak	3.05	2.28	3.08	2.31	3.12	2.36

Source: AgResearch

Overseer

a) Wetlands:
  - a 2.0-ha wetland block was added, at the expense of a 2.0-ha loss from the non-effluent block
  - wetland details: “Artificial type 2”, Type “B”, Catchment area = 95 ha (50% of farm), Convergence = high for poorly drained, little for well drained soil
  - the non-effluent block was divided into one 95-ha block and one containing the non-effluent remainder of the farm area. Tile drainage from the 95-ha block was diverted into the wetland
  - herd size was updated to align with new Farmax data.

b) liquid effluent: A low application rate method was put in place (switched from an application depth of 12-24 mm); applications are now actively managed

c) reduced stocking rates: Animal numbers were imported from Farmax. It is important to note that MS/ha remained at similar values, whereas MS/cow increased considerably.

Mitigation 3

In addition to all the mitigations in the other bundles, the following three mitigations were applied:

a) Restricted grazing strategies

b) Grass buffer strips

c) Improved FDE management

Below, we detail the changes made in Farmax and Overseer to reflect these activities. The letters in the description link to the modelling changes to the specific mitigation activity.

Farmax

a) No changes

b) grass buffer strips:

  - the grazing area was reduced by a further 3.8 ha (5400 m length * 7 m width) to 184.2 ha; non-effluent and effluent blocks were reduced by 2.8 and 1.0 ha, respectively
  - livestock numbers reduced accordingly using the ‘modify’ tool to account for reduced pasture availability

c) after adjusting for the reduction in size due to grass buffers, effluent blocks were doubled in size to handle additional nutrients captured from feed and wintering pads.

Overseer

a) An animal wintering pad was put in place

  - it included cover for animal shelter, the bunker had no lining material, and the cleaning method was by scraping (no water), with solids separated before the regular effluent treatment
  - solids were spread on selected blocks. Storage method included cover from rain and 6-month storage
  - the liquid effluent portion was treated the same as the farm effluent
  - the time spent on pad varied (i.e. 10% of milking cows for Dec through Feb; up to 75% for May and Aug). Accordingly, the time spent grazing also varied throughout the year

b) Grass buffer strips:

  - added a 3.8-ha riparian block, at the expense of both blocks, as described previously
  - the catchment area supplying riparian strip = entire farm area (190 ha). Dimensions of the strip = 5400 m length * 7 m width. Strip condition and hydraulic performance equivalent to those described for S&B farms

c) Improved FDE management: Effluent blocks were doubled in size, after adjusting for the reduction due to riparian areas. This mitigation strategy was put in place to account for the additional nutrients captured on wintering pads. These include nutrients imported in purchased feed offered on feed pads (i.e. system 4).

It is important to note that N fertiliser inputs were reduced significantly as the dairy mitigation bundles were applied, particularly as Mitigation 3 was put in place, which accounted for a greater capture of nutrients, particularly those from imported feed, and greater effluent block sizes (liquid effluent spread over larger areas of land).

Appendix B Accounting for wintering off

B.1 Introduction

A farming practice particular to the Southland region is for dairy cows to spend the winter months away from the main farm (the milking platform), a practice known as ‘wintering off’. The paddock where dry cows winter off can either be owned by the owner of the milking platform or be a separate farm providing dairy support in addition to other pastoral agriculture (mainly sheep and beef). Due to the climate of Southland, pasture growth essentially stops in winter. Winter paddocks are therefore commonly forage paddocks where kale, swedes, or other forage crops have been grown. For a number of reasons, N leaching from winter forage paddocks can be high relative to the baseline of actively growing pasture.

In the current Southland MAS model, developed by NZIER and AgResearch, there is no explicit ‘dairy support’ industry. Models are always simplifications, and dairy support has not appeared to be sufficiently different from sheep and beef to warrant developing a separate industry. However, questions raised by Dairy NZ and Environment Southland have challenged this assessment. Where dry cows spend the winter is seen as an important issue. Partly, this is because of the particular challenges posed by Southland’s winter climate. Partly, the concern is in response to Horizon’s One Plan, which accounts for N leaching differently depending on whether dry cows remain on the home farm or are wintered off farm. This appendix describes a method for assessing the impact of wintering off, given the current configuration of the existing Southland MAS model.

B.2 Current MAS model

Currently, the MAS model only partly accounts for the dairy support industry. As a result, several dairy support functions are not fully captured within the model. The main dairy support functions are:

- replacement heifers – the sheep & beef farms in the model include heifer rearing. There is no direct linkage between the number of heifers in the region and the number of dairy farms, however this is unlikely to have a great impact on the results given that the sheep and beef sector supplies replacement heifers in lieu of raising other cattle beasts which themselves would have similar environmental impact to rearing heifers. Replacement heifers are adequately accounted for in the model
- wintering off – dry cows are not included in the Overseer calculations of dairy farms in Southland that inform the MAS model. The sheep and beef sector in the model does include some cattle beasts, but the environmental impact of wintering off is much greater than typical sheep and beef farming
- supplemental feed – more-intensive dairy operations increase the amount of supplement feed brought in from off farm. This feed can be produced in

the area or purchased from international source (e.g., palm kernel extract – PKE). Production and sale of this feed from sheep & beef properties is not considered in the MAS model.

The impact of these simplifications is difficult to determine because it depends on a number of factors, including the extent of current practices. For example, current practice in Southland includes sending dry cows out of the region as well as wintering off on dairy support farms within the region. These two practices have different impacts on water quality in Southland catchments. Supplemental feed can be sourced locally or internationally, with different impacts on the choices of neighbouring farms.

Importantly, the MAS model is focused on decision making by farmer-agents. These farmer-agents choose how to use their individual farms, including which products to produce and what methods to use. In the Southland model, the key driver of regional production and regional environmental changes is the extent of conversions from sheep and beef farms to dairying. Dairy support is a secondary industry that depends on dairy conversions. That is, the conversion to dairy brings along with it a certain amount of dairy support; it is not conversion to dairy support that drives the level of dairying. In the range of conversions modelled in the research to date, the limiting factor has been the interest in converting and resources available locally to permit conversion. In addition, there appears to be little scientific information on the thinking that leads farmers to participate in dairy support as opposed to any other farming activity, phrased in ways that would allow these choices to be modelled.

From the perspective of the MAS model, the limited inclusion of the dairy support industry has the following implications:

- the current model is based on currently available scientific data on farmer behaviour, while the alternative would be to construct a model of the industry based on limited information
- it may understate income to the sheep and beef sector by an unknown amount, which is the increased earnings available from wintering dairy cows and sale of supplementary feed, should these be more profitable than the current practices on the modelled farms
- it understates the environmental impact of dairying by an unknown amount, which is affected by the extent to which dry cows are actually wintered off in Southland.

For the current research for the Ministry for the Environment, the most important issue is the understated environmental impact. The rest of the paper investigates this impact.

B.3 Including leaching from wintering off

Currently, the MAS model removes the dry cows from the region for the winter. This situation can be viewed as an endpoint for a continuum. The other endpoint is that all dry cows are wintered in Southland. Actual practice will be something in the middle, in which some cows remain in the region and some are transported out. The current environmental results from the MAS model are therefore taken as lower bound of nitrogen (N) leaching associated with dairying. The next task is to calculate the upper bound, which includes leaching from wintering off.

As discussed above, dairy support activities do not drive the functioning of the MAS model. Therefore, including the environmental impact of wintering off is simply a case of supplemental calculations using the results of modelling runs. The steps in those calculations are described below, using 2012 figures as an example. There is also an associated Excel file with calculations.

Step 1. Calculate dairy support land required

The amount of land required for dairy support depends on the extent of the dairy industry, but also on a number of other factors:

- intensity of the dairy industry – more intensive dairying requires more supplemental feed and thus greater dairy support
- Land Use Capability (LUC) of the dairy farms – dairy farms on better land can have higher stocking rates so they require more dairy support
- LUC of support farms – dairy support farms on poorer quality land must be more extensive, so they increase the area required for dairy support.

Table 50 shows figures for the amount of dairy support land required, taking into account the intensity of dairying and the LUC of support farms, based on a dairy farm on LUC Class 2. The calculation indicated that a Dairy system 2 farm on LUC 2 land would require 0.33 ha of LUC 2 support land for every 1 ha of milking platform. Dairy system 3 and 4 required 0.47 ha and 0.69 ha of land, respectively.

Table 50 Dairy support area required

Dairy system	LUC1&2 SU/ha	LUC1&2 ha support/ha milking platform	LUC3&4 SU/ha	LUC3&4 ha support/ha milking platform
2	18.9	0.33	14.2	0.25
3	18.9	0.47	14.2	0.35
4	18.9	0.69	14.2	0.52

Source: AgResearch, NZIER
Notes: SU/ha = stock units per hectare; required dairy support for LUC3&4 dairy farms accounts for lower stocking rates on those farms

Step 2. Calculate wintering off area

Dairy support includes several activities, only one of which is wintering off. The dairy support areas in Table 50 should be reduced to remove the areas for replacement heifers and supplemental feed. The calculations are given below, and include the tonnes dry matter required per mature cow.

Table 51 Wintering off areas required

Assuming wintering off areas are LUC1&2

Dairy system	Total dairy support (t DM/ mature cow)	Wintering off (t DM/ mature cow)	Wintering off (proportion)	Wintering off for dairy LUC1&2 (ha)	Wintering off for dairy LUC3&4 (ha)
2	1.61	0.893	0.555	0.18	0.14
3	2.19	0.813	0.371	0.17	0.13
4	2.97	0.720	0.242	0.17	0.13

Source: AgResearch, NZIER

A key result from these calculations is that the wintering off areas are equal to approximately 15% of total dairy area, assuming the wintering off happens on the best class of land.

Step 3. Calculate N leaching from wintering off area

Winter forage areas have high rates of leaching relative to pasture and relative to other times of the year. Information provided by Ross Monaghan (AgResearch) indicates leaching rates of 60 to 78 kg N/ha/yr from forage paddocks. As the forage crop takes an entire year to be grown, grazed, and resown in new pasture, this leaching loss can be attributed entirely to the dry cows themselves, not any other livestock on the farm. Table 52 presents the N loss from this activity.

Table 52 N leaching from wintering off areas

Based on data from two field experiment areas

Woodlands (kgN/ha/yr)	Five Rivers (kgN/ha/yr)	Average leaching (kgN/ha/yr)
60	78	69

Source: Ross Monaghan (AgResearch)

Step 4. Calculate total N leaching from zone/region

At this point, the land area of dairy support for wintering off is known and the N leaching rate from those areas is also known. These figures can be used to calculate total N leaching from wintering off areas, based on the area in each dairy system and each LUC group. The total can be calculated for the relevant geographic region. In the present research, Southland is divided into water management zone. The Lowland zone figures for 2012 are used here for illustrative purposes.

Table 53 Total N leaching from wintering off

Assuming wintering off areas and leaching field research areas are all LUC1&2

Dairy system	MAS model Dairy LUC1&2 (ha)	MAS model Dairy LUC3&4 (ha)	Wintering off for Dairy LUC1&2 (ha)	Wintering off for Dairy LUC3&4 (ha)
2	7,941	8,223	1,454	1,127
3	30,713	28,831	5,361	3,768
4	30,613	22,953	5,119	2,874
Total wintering off area required (ha)				19,703
Leaching from forage (kgN/ha)				69
Total N leaching (kg)				1,359,473

Source: NZIER, AgResearch

Step 5. Calculate total N leaching allocation for sheep and beef area

One of the information gaps is the distribution of dairy support activities across the Southland region. The geographic distribution is important for the water quality impacts, because leaching may be more or less concentrated. In the absence of better information, one approach is to distribute the N leaching from wintering off evenly across the area. This simulates wintering off spread across the landscape and not concentrated near any one waterway.

Because the geographic basis of the Southland MAS model for the Ministry for the Environment are the Environment Southland water management zones, wintering off can be restricted to occur within each zone. The 2012 figures for the Lowland zone are again used for the calculations in the table below.

Table 54 Wintering off N leaching per hectare of sheep/beef farming

Assuming even distribution of wintering off across water management zone

LUC group for sheep/beef	Area (ha)	N allocation factor*	Wintering off leaching (N kg)	Wintering off leaching (kg N/Ha)
Total	246,764	1.00	1,359,473	-
S_LUC1&2	63,854	0.32	432,321	6.8
S_LUC3&4	182,910	0.68	927,151	5.1

Source: NZIER, AgResearch

Note: The N allocation factor weights area in ha by carrying capacity (18.9 and 14.2 SU/ha, see Table 50) to apportion the N leaching load across the different LUC groups.

The N leaching in Table 54 is the total amount of leaching from wintering off, distributed across sheep and beef farming in LUC1 to LUC4. Providing a winter forage areas for dairy cows also takes some land out of sheep and beef production. The leaching from the sheep and beef industry needs to be correspondingly decreased. The calculations are shown in Table 55. They start with the N leaching from wintering off, calculate the offset N leaching from sheep and beef, and then distribute the net result. The final number is the average increase in N leaching across sheep and beef farming in LUC1 to LUC4 as a result of wintering off to support the dairy industry.

Table 55 Increased N leaching due to wintering off

Difference from sheep/beef to wintering off, per hectare of sheep/beef farming

LUC group for sheep/beef	Wintering off leaching (kg N/Ha)	Reduction in S&B N loss	Net increase in S&B N loss (total kg N)	Net increase in S&B N loss (kg N/ha)
Total	-	275,835	1,083,638	-
S_LUC1&2	6.8	87,717	344,604	5.4
S_LUC3&4	5.1	188,118	739,034	4.0

Source: NZIER, AgResearch

Note: Total reduction in S&B N loss is the required hectares of wintering area (19,703, Table 53) times the average N leaching from LUC1 and LUC2 sheep and beef farms (14 kg N/ha/yr). This total is then allocated by the N allocation factor (Table 54).

Step 6. Allocate N leaching to sheep and beef farms

The final step is to apply the allocation of increased leaching shown in Table 55 to the sheep and beef farms in the MAS model. This is a simple calculation – area of farms multiplied by N leaching allocation. The effect is to gross up the total N leaching in the zone to account for wintering off, and to spread this leaching across the zone. The result is that wintering off is fully included in the N leaching figures for the zone.

As discussed above, another type of dairy support activity is providing supplemental feed. The adjustment calculated through this process does not account for supplemental feed grown on sheep and beef farms. Therefore, this is not an adjustment for total dairy support, only for wintering off. The N leaching from the sheep and beef sector may still be overstated by not accounting for acreage taken out of livestock production and used for grown supplemental feed.

B.4 Discussion of results

The net increase in sheep and beef N loss from wintering off shown above (Table 55) indicates that sheep and beef farms would have higher annual leaching rates, by 5.4 or 4.0 kgN/ha/yr, in the Lowland water zone in 2012. This increase compares to a baseline leaching rate of 8 to 18 kgN/ha/yr (with an average of 14 kgN/ha/yr). Including wintering off increases leaching from the sheep and beef sector by roughly 25 to 50 percent. The total impact across the whole region is to increase N leaching by 7.7 percent. The impact increases as the area in dairying increases, with the regional impact reaching 11 percent in 2037. The impacts are also different by water management zone, with the Lowland zone having the largest impact.

Appendix C References

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