On-Farm effects of diverse allocation mechanisms in the Lake Rotorua catchment

Report for the Rotorua Stakeholder Advisory Group, August 2015.

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Acknowledgements

The authors are particularly grateful for the input and feedback of Sandra Barns, Alastair MacCormick and Michele Hosking (Bay of Plenty Regional Council), Carly Sluys, Andrew Burtt and Ben O'Brien (Beef + Lamb New Zealand), Sharon Morrell (DairyNZ), Lee Mathieson (PerrinAg), Phil Journeaux and Mark MacIntosh (AgFirst), Simon Park (Landconnect), and the Rotorua Stakeholder Advisory Group.

Contents

1. Executive summary

The objective of this report is to evaluate a number of proposed nitrogen (N) allocation systems for producers in the Rotorua catchment. The results of this analysis provide information about private benefits and costs in terms of farm profit (EBIT) and capital impacts on land value. The different scenarios also provide insights about resource efficiency and the ease of transfer of the entitlements to leach nitrogen that each farm could receive across these allocation mechanisms.

Context

This report is intended to provide direct information for the Rotorua Stakeholder Advisory Group (STAG) and Bay of Plenty Regional Council (BOPRC), as well as to support wider district economic modelling undertaken by Market Economics. These discrete pieces of work support the section 32 report associated with new nitrogen rules for the Lake Rotorua catchment. The project brief was developed collaboratively between BOPRC, DairyNZ, Beef + Lamb New Zealand, with input from STAG members during the latter part of 2014. Draft modelling results were presented to StAG in March, April, May, June and July 2015, and feedback was incorporated up until August 2015.

Methods

The evaluation of allocation mechanisms involves the application of a catchment-level optimisation model. The method for developing this model involved:

1. Dividing the catchment into biophysical zones based on soil type, slope and rainfall.
2. Establishing representative farm systems (dairy, sheep and beef, sheep and dairy support, and specialist dairy support) for each biophysical zone. Drystock enterprises include small, medium, and large farms.
3. Developing agreed and consistent modelling protocols to reflect how Rotorua farmers would be most likely to mitigate nitrogen losses.
4. Applying the modelling protocols to each farm system, using FARMAX and OVERSEER (version 6.1.2), to establish relationships between profit and nitrogen leaching.

5. Obtaining annualised forestry-profit information from SCION (including carbon at a price of \$4 tonne^{-1}).
6. Obtaining data on the financial costs and benefits of land-use change from Waikato Regional Council.
7. Integrating this information on profit and nitrogen leaching for individual farm types into an economic model describing the whole catchment. This model incorporates trading of N leaching rights both among farmers, and with an incentives fund that buys out nitrogen. Nitrogen prices are generated endogenously by the catchment model based on mitigation costs which drive supply and demand.

The optimisation model focuses on alternative steady-state or equilibrium outcomes. That is, it does not study the transition pathways between the current state and where alternative policy outcomes are predicted to lead. This approach is consistent with standard practice regarding the economic evaluation of alternative environmental policy instruments. Where time has a major impact on economic aspects (for example, capital impacts), results are discounted to 2015 dollar impacts.

Ownership of land is not represented within the model. Thus, any distinction between individual farms and ownership (e.g. iwi-owned property) is not made. Rather, the main building blocks are the individual zones, describing given land-uses and the biophysical conditions under which they are located (see steps 1–2 above).

Representative farm systems and mitigation protocols (each specifying the sequence of mitigation use for each farm type) were developed in workshops involving Bay of Plenty Regional Council (BOPRC) staff, DairyNZ, Beef + Lamb New Zealand, scientists, local extension agents, and agricultural consultants. Mitigation curves were not smoothed; accordingly, gaps between individual scenarios were not filled with hypothetical information. This approach was applied to ensure the maximum amount of rigor, transparency, and repeatability of the results (a full list of all input information into the economic model is provided in the Appendices).

The mitigation protocols, in most cases, result in costs arising on farms as they undertake nitrogen mitigation. This is in agreement with mainstream environmental-economics theory, but the relationship is not forced. Indeed, in some cases, increases in profit occur from improvements in efficiency (for example, by eliminating unprofitable inputs). These "win-win" outcomes occur on a number of different individual farm types, as has been previously documented in New Zealand case studies. In general however, the scale of reductions required in the Rotorua catchment is so significant that most individual farmers experience a net cost due to mitigation.

The costs and benefits of transition from the current land use to a new one are included in the catchment model. While some transitions impose a cost to producers, de-intensification also has some benefits in that it frees up capital invested in certain fixed assets (e.g. livestock or supplier shares). Carbon liability is incorporated in the computation of transition costs, and is also factored into the profitability of the forest sector (determined by SCION) incorporated within the model at \$4 tonne^{-1}.

A number of different scenarios are analysed. This includes eight different allocation options (Table E1). These are evaluated for two levels of market efficiency for nutrient trading, and two levels of land-use change (Table E2). These scenarios are based on the needs articulated by the stakeholder group for the Lake Rotorua catchment. Market efficiency is explored through allowing free trade in entitlements and then only 50% of the optimal level; in the latter case, the remainder of the entitlements being retained by producers following allocation. Simulation of market inefficiency is consistent with experience in water quality and quantity markets where levels of rigidity are present, often due to risk aversion. The constraint on land-use change is introduced to reflect the fact that it is unlikely that the full amount of land-use change predicted by optimisation would occur in reality. This is because land-use change from pasture to forestry is tempered by factors such as the lack of an annual return, or negative impacts on land prices.

Other scenarios have been explored (e.g. greater or lesser levels of land-use change), but are omitted from this report for brevity. The predominant focus of analysis has been on the impacts on farm profit, the level of nutrient trading that occurs, and the distribution of income under different scenarios. This has been explored in considerable depth at the zone- and farm-level with stakeholders[1], but is limited to selected examples for this report.

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[1] E.g. meetings of the Rotorua Stakeholder Advisory Group of 17 March, 28 April, 23 June and 21 July.

Table E1. Eight allocation options studied for the Lake Rotorua catchment.

Allocation scenario number	Allocation option
Base	Baseline
S1	Sector averaging
S2	Sector averaging with biophysical adjustment
S3	Single range
S4	Natural-capital allocation
S5	Equal allocation
S6	Range 0A
S7	Range 1
S8	Range 2

Table E2. Scenarios used to explore the relative value of each allocation option.

Catchment scenario	Description
Base	This represents the status quo.
Optimal trading, optimal land-use (Scenario #1)	A theoretical outcome of perfect efficiency for comparison.
Optimal trading, 5000 ha land-use change constraint (Scenario #2)	A scenario where not all efficient land-use change occurs due to risk-aversion by producers, but nutrient trading is efficient. Total land-use change is limited to 5000 ha.
50% trading frictions, optimal land-use change (Scenario #3)	This scenario includes optimal land-use change, but a constraint on the efficiency of nutrient trading, with 50% of allowances being retained by original holders.
50% trading frictions, 5000 ha land-use change constraint (Scenario #4)	This scenario includes a constraint on land-use change, as well as a constraint on the efficiency of nutrient trading, with 50% of allowances being retained by original holders.

Results

Overall, catchment-level impacts on total profit are modest, with slight increases for most scenarios and slight decreases for the natural-capital and equal allocation options, when these allocations are modelled with market inefficiency. However, this is distributed very unevenly across land-uses and biophysical conditions. Some enterprises experience benefits, while others face significant costs. Capital impacts on land values are significant across all land-uses. This poses particular risks in relation to the equity position of producers and their ability to manage commodity price volatility.

Several key general relationships are observed in model output. First, land-use transition is significant if cost-effective mitigation is to be attained. However, the study of land-use change in economic models of this kind is difficult, and this output is therefore subject to a range of restrictive assumptions outlined in the report. Second, nitrogen restrictions motivate deintensification of dairy production and associated support activities. Third, reducing high leaching rates involves a mixture of land-use change and on-farm mitigation. Last, inefficiency in the level of trading observed in the market for nutrient entitlements has significant impacts on the extent and distribution of farm returns. Expected values of N produced from the modelling were extrapolated to assess the likely impacts on land value associated with decreased rights to leach N.

More specifically, key impacts across all scenarios are:

1. An increase in forestry area, around 85% and 60% in Scenarios 1 and 2 (an increase from 7,095 ha to 13,085 and 11,403 and ha respectively)
2. A reduction in dairying area of around 40% from 5024 to 3046 ha.
3. A reduction in sheep and dairy support area of approximately 37% from 3007 to 1900 ha.
4. Remaining dairy farm types must purchase N in order to remain viable. Changes to the allocation vary the costs for these farms, but not the optimal-management regime.
5. Lower-intensity dairy-support options involve substantial scope for de-intensification at reasonable cost, though this is balanced by relatively high capital impacts.
6. The profit of many drystock enterprises benefits from a capacity to increase their nitrogen use efficiency and sell entitlements to dairy farms and the incentives fund.

7. The impacts on land prices from reducing nitrogen-leaching entitlements are significant for both drystock and dairy farms. Profit data and regional analysis masks significant risk to existing farm businesses and potential for adverse social impacts as a result of negative equity positions.
8. A significant reduction in cow number, nitrogen fertiliser application, supplement use, and farm labour, with each effect likely to have regional implications.
9. Changes in the efficiency of land-use change or nutrient trading have large implications for the overall cost.

Results show a modest overall impact on total catchment profit. However, the impacts on profit are distributed unevenly across sectors, land-uses, and biophysical zones. Different allocation regimes create further variation in this distribution of cost. In general, drystock farm profits benefit from the ability to sell N (to businesses with higher profit per kilogram of N and the incentives fund). Dairy farm profits fall due to the need to acquire N in order to continue operating. Under allocations with more redistribution (such as equal allocation and natural-capital systems), dairy farm profits fall further, but drystock profits are not correspondingly improved. This is due to a large number of allowances being transferred from dairy farms to foresters under these regimes, rather than other pastoral uses. Allocation regimes which require a large amount of redistribution also result in increases in the N price, due to greater dependence on trading and increased market demand.

Pastoral farming profit within the catchment is reduced by around 5% in both land-use scenarios when a 50% trading friction is introduced to the model. Trading rigidities in the market have significant implications for the price of N, increasing the price for perpetual allowances from around \$118 and \$60 kg N^{-1} in the 5000 ha limited and unlimited land-use change scenarios, to around \$444 (up to \$551 for natural-capital allocation). This higher price reflects an increased scarcity of nutrient entitlements in the market and is consistent with economic theory. This highlights that practices to pragmatically address rigidities in the market for nitrogen-leaching entitlements in the Lake Rotorua catchment will have direct benefits for increasing the amount of nitrogen that could be purchased by the incentive fund, while also reducing on-farm costs through promoting more cost-effective nutrient mitigation.

Likely capital impacts due to the change of rights in land are large, particularly when market frictions are considered. The capital costs on farms range from \$2.5m to \$18.4m under the range scenarios (S6–S8 in Table E1), to \$22.9m under natural-capital allocation. Capital impacts are larger on dairy farms under all scenarios. The natural-capital allocation results in the majority of capital impacts falling on dairy and dairy support farms ($6,906 and $1,449 per hectare, respectively), with large gains to forestry owners relative to the current rules ($2,413 per hectare). Smaller capital costs occur for sheep and dairy and sheep and beef farms ($201 and $405).

The Range allocation scenario still produces higher capital costs for dairy farms ($2,357 per hectare) than other land-uses, due to the higher percentage clawbacks proposed for these land uses by the Stakeholder Advisory Group, relative to drystock. Dairy support, sheep and dairy, and sheep and beef experience costs of $1,074, $401, and $585 per hectare, respectively. Due to the fact that the range scenario does not allocate additional nutrients to forestry, there is no change for this sector relative to the current regulatory environment under Rule 11.

While the impacts on dairy capital value are higher (even in a proportional sense), it is important to recognise that the estimated capital impacts of Rule 11 are higher for drystock farms and the impacts of new rules are in addition to this. These capital impacts are of significant concern due to the possibility of debt exceeding equity for some farms in the catchment, creating significant social disruption.

2. Introduction

The Bay of Plenty Regional Council (BOPRC) is seeking to improve water quality in Lake Rotorua through restricting diffuse discharges of nitrogen (N) from agricultural land. Through the Bay of Plenty Regional Policy Statement (BOPRPS), the Regional Council has set a nitrogen (N) limit for Lake Rotorua of 435 t N per year. To achieve this, the estimated total reduction is 320 t N per year, with about 270 t N per year expected to come from reducing nitrogen loss from the pastoral sector. A stakeholder group has been appointed to guide the development of an appropriate method to limit these discharges, based around the development of a trading scheme and associated system to allocate nutrient-loss entitlements among farmers in the catchment. This study is a joint effort between BOPRC, DairyNZ, and Beef + Lamb New Zealand and seeks to inform the stakeholder group about the potential economic implications of proposed approaches.

The primary objective of this analysis is to evaluate a number of proposed systems regarding the allocation of entitlements to leach nitrogen among commercial farmers within the catchment of Lake Rotorua. A particular focus of the study is the Range 2 scenario that has been selected by the stakeholder group as their preferred management option. Under the Regional Policy Statement, the BOPRC must consider a range of principles and considerations. The results of this analysis contribute to knowledge about private benefits and costs, resource efficiency, and the ease of transfer of the allocation. Some analysis of likely impacts on capital values and equity are inferred from analysis of profit and nitrogen-pricing data. Key factors included are the consideration of the impact of trade in nutrient entitlements, diverse allocation instruments, and the consideration of transition costs between alternative land-use activities, all of which are important examples of how alternative policies could potentially impact capital investment. It is anticipated that the results of the analysis will contribute to the recommendations on allocation the Stakeholder Advisory Group make to Council.

The evaluation of the diverse allocation mechanisms involves the application of a catchment-level economic model that integrates important information outlining the relative cost of reducing nitrogen loss to water across the diverse land-uses and natural characteristics of the land (defined in this study using parcels that are a combination of slope, soil type, and rainfall characteristics) present in the Lake Rotorua catchment. Thus, a parcel is a given area of land (defined in ha) associated with a given land-use and the slope, soil type, and rainfall characteristics of that given area.

The catchment-level model is based on the Land Allocation and Management (LAM) framework broadly applied throughout Australasia to evaluate the impact of diverse policy mechanisms on water quality and economic outcomes (Doole, 2015). This framework involves the use of nonlinear programming (Bazaraa et al., 2006) to identify how land-use and farm management will have to change to achieve water-quality aspirations, while analysing how different allocation systems impact the distribution of income across sectors.

The report is structured as follows. The next section outlines the justification for the selected method, describes the key input data, and the scenarios that are evaluated. Section 4 outlines the results of the empirical-modelling process, and discusses the key points in the context of the project. Section 5 concludes. A series of appendices outline key input information used within the model.

3. Methods

3.1 Catchment optimisation model

This section outlines the economic modelling approach employed in this analysis (though further detail is provided regarding the choice of approach in Appendix 2). The model is an optimisation model; that is, an iterative search process is employed to identify how different management activities must change from their current level to minimise the cost incurred by a change in the management environment (e.g. as experienced with the introduction of an N limit). This catchment model integrates economic and land use information across the catchment and optimises levels of mitigation for each farm type (outlined further in section 3.2). In line with the policy scenario that is proposed, trading of N leaching rights is enabled among farms, which generates a price for N in the model based on market supply and demand.

The model used here is a special type of optimisation model, involving a method known as nonlinear programming (Bazaraa et al., 2006). This generally involves the definition of a model in which both the profit specification and constraints contain nonlinear expressions. Solution of this model outlines how land-use and land management must change under different circumstances to mitigate nitrogen loss at least cost. Its structure is loosely based on that of the Land Allocation and Management (LAM) catchment framework (Doole, 2015). The flexibility of this model is demonstrated in its broad utilisation across a number of nonpoint-pollution contexts, both nationally (Doole, 2013; Howard et al., 2013; Holland and Doole, 2014) and internationally (Beverly et al., 2013; Doole et al., 2013a).

Optimisation of the economic model identifies the values for decision variables that maximises the total profit earned on farms across the catchment, subject to the constraints defined in the model. The primary decision variables in the model are those representing the area (ha) allocated to each management option within each land-use in each zone. Primary constraints are those limiting the land-use in a given zone to the area available within that spatial area. Total profit is determined through multiplication of the area of each land-use option employed and its associated level of profit per ha. The total nitrogen load is computed through the multiplication of the area of each land-use option employed and the nitrogen leaching load per ha associated with each management option. With the introduction of a limit on nitrogen leaching, the area of each land-use utilised for a mitigation option, rather than a baseline (current) management option, will typically increase. This will concomitantly reduce nitrogen loss from that land area, but also increase/decrease profit. In some cases, it may be more cost-effective to change land-use away from the current land-use, in order to achieve a given nitrogen-leaching target at the catchment level. In this model, the limit for leaching is implemented through the representation of permits required for representative farms to leach, which are allocated among the population according to diverse systems (see below).

The optimisation model focuses on alternative steady-state or equilibrium outcomes. That is, it does not study the transition pathways between the current state and where alternative policy outcomes are predicted to lead. Indeed, it focuses solely on characterising just the equilibria themselves. This approach is consistent with standard practice regarding the economic evaluation of alternative environmental policy instruments (e.g. Hanley et al., 2007; Daigneault et al., 2012; Doole, 2013). It is possible to incorporate the study of temporal processes, such that the time path of adaptation practices can be characterised and then considered during evaluation (Pindyck, 2007). However, this is rare in practice, especially in the evaluation of regional policy, because (a) there is little empirical work available that characterises how farmers in the Lake Rotorua catchment would be expected to adapt to limits, (b) the scarcity of data is compounded when variation over time in key drivers of management behaviour (e.g. output price, input price, productivity, climate, innovation) is high and difficult to predict, (c) dynamic models are difficult to develop and utilise (Doole and Pannell, 2008), and (d) output from dynamic models is heavily biased by the initial and terminal conditions defined during model formulation (Klein-Haneveld and Stegeman, 2005). Overall, these issues provide a strong justification for the employment of a steady-state modelling framework.

Alternative approaches for the economic evaluation of environmental policy instruments exist and evaluation of these approaches is contained in Appendix 6.

3.2 Input data

This section outlines the input data used within this application of the LAM model to the Lake Rotorua catchment. Further detail is provided in Appendix 5. Some input data involves capital expenditures; for example, the sale or purchase of breeding stock. These capital expenditures are annualised using an 8% interest rate over a 25-year period.

Representative farm types

The catchment is divided into a large number of spatial zones depending upon soil type, slope, and rainfall level (Table 1). These spatial zones are then partitioned according to the current type of land-use that is present; constituent land-uses are defined as dairy, dairy support, sheep and beef, sheep and dairy, and forestry enterprises. Deer enterprises are omitted due to them constituting a relatively small area of the catchment. Indeed, the added complexity involved with their inclusion is deemed to outweigh the added richness accruing to a more nuanced description of regional environmental and economic outcomes. The appropriate number and nature of the zones, as well as the farm types necessary to represent them, was determined through workshops involving experts from local farm consultancies, BOPRC, Beef + Lamb New Zealand, and DairyNZ.

For drystock farming, the size of farms was identified as critical to determining productivity and the most appropriate farm system description. For this reason, three different sizes of drystock farm were included:small (2-40ha), medium (40-300ha), and large (>300ha) farms. A large proportion (40-50%) of the drystock-farming area is encompassed in a small number of large farms. These are generally the most economic units, operating at (or with potential to operate at) Beef + Lamb New Zealand Class 4 or 5 in terms of intensity. Typically these are 50/50 sheep/cattle operations with a breeding-ewe flock (lambing at 130-140%), combined with either the trading of beef cattle or the existence of a dairy support activity. Medium-size drystock farms tend to be centred on beef, dairy support, and cropping and/or baleage production (with some outliers involving deer and breeding ewes). About half of these blocks of land are leased by dairy farmers as runoffs and most require less than 1 fulltime equivalent (FTE) of labour. In general, these are similar to large drystock farms in terms of management options, but on average will perform with slightly lower profit per hectare due to scale, productivity, and management constraints.

The Rotorua catchment has a large number of small blocks under 40ha. Though individual small blocks do not contribute much to the total nitrogen load to the lake, some uses are relatively intensive and in sum cover a large area, contributing an estimated 138 tonnes of nitrogen, according to ROTAN. Small blocks are extremely diverse and include lease blocks, dairy support, drystock, cropping, and lifestyle. Sheep are rare due to the lack of appropriate infrastructure. Some small blocks are run quite intensively (e.g. break-feeding and feeding out with dairy cows over winter). The majority of these are located on pumice soils on flat land close to the lake. Small blocks have limited mitigation options and limited land-use change options (for example, forestry is unlikely to be economic at this scale). Because of this, small blocks are represented as low-productivity drystock farms, but are constrained within the catchment model to prevent unrealistic land-use change to forestry or sheep enterprises. Due to the optimisation approach adopted in this study, values that do not impact on the profitability of businesses – such as those associated with lifestyle or aesthetic preferences – cannot be incorporated directly. However, the constraints to land-use change and trading used in the catchment scenarios indirectly represent these non-economic preferences.

The majority of dairy farms in the Rotorua catchment are located in the higher-rainfall areas with podzol and pumice soil types. Dairy systems in the catchment are relatively similar in terms of policies for wintering and young stock. However, feeding regimes and cost structures tend to vary around the catchment, according to the amount of home-grown feed that can be produced. This loosely correlates to the spatial zones incorporated in the model (see below for more information).

Ownership of land is not represented within the model. Thus, any distinction between individual farms and ownership (e.g. iwi-owned property) is not made. Rather, the main building block of the analysis is the individual zones, describing individual land-uses and the biophysical characteristics in which they are located, that are delineated within the catchment. Individual zones are identified using Geographic Information Systems. This process involves the consideration of catchment boundary, rainfall, soil type, and slope (Table 1). Small areas are aggregated in some instances, to sharpen the focus of the analysis on the key areas located within the study area.

Table 1. Size (ha) of each soil type, slope class, and rainfall zone used to characterise the Lake Rotorua catchment under current land use.

Soil type[1]	Rainfall (mm)	Slope (degrees)	Forestry	Dairy support	Dairy	Sheep and beef	Sheep & dairy	TOTAL
Al	LT1500	0-8	109	0	0	31	14	154
Al	LT1500	8-16	33	0	0	10	5	48
Al	LT1500	16-26	35	0	0	11	5	50
Al	LT1500	>26	32	0	0	14	6	52
Al	1500-1700	0-8	652	37	288	439	197	1612
Al	1500-1700	8-16	476	31	140	254	114	1015
Al	1500-1700	16-26	452	24	73	188	85	821
Al	1500-1700	>26	275	8	15	101	46	446
Al	1700-2000	0-8	6	13	0	118	53	190
Al	1700-2000	8-16	8	11	0	97	43	159
Al	1700-2000	16-26	12	8	0	72	32	123
Al	1700-2000	>26	14	3	0	24	11	52
Al	GT2000	0-8	0	0	0	6	3	9
Al	GT2000	8-16	0	0	0	6	3	9
Al	GT2000	16-26	0	0	0	4	2	7
Al	GT2000	>26	0	0	0	1	1	2
Po	1500-1700	0-8	13	16	14	98	44	185
Po	1500-1700	8-16	18	17	5	116	52	209
Po	1500-1700	16-26	20	12	2	97	44	174
Po	1500-1700	>26	29	3	1	38	17	89
Po	1700-	0-8	499	49	0	277	125	950

	2000							
Po	1700-2000	8-16	291	30	0	235	106	663
Po	1700-2000	16-26	150	15	0	181	82	428
Po	1700-2000	>26	56	10	0	109	49	224
Po	GT2000	other	183	0	0	56	25	265
Po	GT2000	0-8	1099	465	1852	667	300	4383
Po	GT2000	8-16	367	190	604	238	107	1506
Po	GT2000	16-26	219	86	230	151	68	754
Po	GT2000	>26	110	27	46	79	36	298
Pu	LT1500	0-8	1	10	0	101	45	157
Pu	LT1500	8-16	3	0	0	61	27	91
Pu	LT1500	16-26	4	0	0	46	21	71
Pu	LT1500	>26	3	0	0	23	10	36
Pu	1500-1700	0-8	225	15	24	223	100	587
Pu	1500-1700	8-16	283	14	13	132	60	502
Pu	1500-1700	16-26	317	8	4	100	45	474
Pu	1500-1700	>26	226	2	0	50	23	302
Pu	1700-2000	0-8	50	68	276	345	155	894
Pu	1700-2000	8-16	31	33	143	140	63	409
Pu	1700-2000	16-26	38	19	84	80	36	256
Pu	1700-2000	>26	21	7	28	22	10	89
Pu	GT2000	0-8	36	57	560	401	180	1235
Pu	GT2000	8-16	18	20	206	186	84	513
Pu	GT2000	16-26	19	10	88	101	46	264
Pu	GT2000	>26	15	3	28	37	17	100
Re	LT1500	0-8	19	8	211	226	102	565
Re	LT1500	8-16	31	0	49	111	50	240
Re	LT1500	16-26	36	0	27	114	51	228
Re	LT1500	>26	41		12	53	24	129
Re	1500-1700	0-8	71	12	0	63	28	175
Re	1500-1700	8-16	122	10	0	104	47	282
Re	1500-1700	16-26	166	5	0	118	53	343
Re	1500-1700	>26	148	1	0	41	18	208
Re	1700-2000	0-8	7	0	0	13	6	26

Re	1700-2000	8-16	1	0	0	6	3	10
Re	1700-2000	16-26	0	0	0	3	1	5
Re	1700-2000	>26	0	0	0	0	0	0
Re	GT2000	0-8	3	0	0	0	0	3
Re	GT2000	8-16	0	0	0	0	0	0
Re	GT2000	16-26	0	0	0	0	0	0
Re	GT2000	>26	0	0	0	0	0	0
Or	LT1500	0-8	0	0	0	32	14	46
Or	LT1500	8-16	0	0	0	0	0	0
Or	LT1500	16-26	0	0	0	0	0	0
Or	1500-1700	0-8	0	0	0	32	14	46
Or	1500-1700	8-16	0	0	0	0	0	0
Or	1500-1700	16-26	0	0	0	0	0	0
TOTAL			7095	1358	5024	6682	3007	23166

[1] The soil classes are Al = allophanic, Po = podzol, Pu = pumice, Re = recent, Or = organic. Very small areas of "Other" are not included in the table.

Estimating mitigation costs for each farm type

The cost of reducing N loss from each land-use in each spatial zone is then evaluated for representative farms, which are developed according to knowledge of typical practice in each of these spatial zones. A representative farm for each relevant land-use is used for each parcel, based on the observation of typical characteristics of farms within each zone. This action is performed by Lee Matheson (Director, Perrin Ag). The current organisation of each of these farms—as indicated by measures such as production, stocking rate, enterprise mix, fertiliser use, level of imported feed, level of winter cropping, and levels of different types of revenue and cost—is referred to as the *baseline situation* throughout this report.

A baseline FARMAX (Bryant et al., 2010; White et al., 2010) file is created utilising the baseline physical and financial data defined for the dairy and drystock farm systems that represent each zone. OVERSEER (Version 6.1.2) and FARMAX are then used simultaneously to evaluate a number of alternative means for each farm to mitigate nitrogen. The aim of this exercise is to delineate a relationship (i.e. a mitigation-cost curve) between the level of abatement of nitrogen loss and the economic benefit/cost associated with this action for each farm operation. These cost curves are an integral input to the catchment-level model that seeks to identify how the economic impacts of given allocation systems on farms can be minimised across the catchment. The dual use of these two programs (FARMAX and OVERSEER) is necessary because FARMAX allows the user to ensure that energy requirements are met for stock and the impact of mitigation options on farm financial records is clear, while OVERSEER allows the impact of disparate mitigation options on nitrogen loss to be modelled.

FARMAX is the leading software product in New Zealand utilised for evaluating alternative management systems in pastoral farming. It has been extensively applied and validated under New Zealand conditions (e.g. Bryant et al., 2010), and is broadly-used for extension (e.g. PAC, 2014) and research (e.g. Li et al., 2012) purposes. FARMAX provides a consistent benchmark for estimating profitability across the dairy, dairy support, and drystock enterprises. As a simulation model, it does not endogenously identify the management system that maximises profit within a given scenario, such as one involving a certain level of use of a given mitigation or requiring a given level of reduction in leaching to be achieved (Doole, 2015). Accordingly, the personal preferences and experience of the user are likely to have a significant impact on the quality of model output. For this reason, the FARMAX simulations that were undertaken across all enterprises were guided by the application of mitigation protocols (see below), developed before the modelling took place through workshops involving extension agents and scientists. This was deemed to be a more rigorous process than employing optimisation models to identify these relationships, despite the capacity of optimisation models to more efficiently identify those management plans that maximise farm profit in a given set of circumstances (Doole, 2014, 2015). This decision is appropriate because the protocols can be used to ensure that the simulated producer response is in line with expectations regarding the response of real farmers to the imposition of limits. This is in contrast to optimisation models, in which management plans can change drastically and be inconsistent with expected responses, even if such actions are converse to intuition because the model has not been calibrated accurately. Moreover, it is consistent with significant doubts raised with the ability of commercial linear-programming models to adequately describe New Zealand grazing systems (Doole et al., 2013b) and their much lower use in industry, compared with FARMAX.

The OVERSEER model is employed to estimate the nitrogen-leaching loads associated with different enterprises. It is the leading software used to identify the implications of alternative management strategies for nitrate-leaching loads in New Zealand farming systems (Doole and Paragahawewa, 2011). Hence, it is extensively used for this purpose. In particular, it is widely applied for extension (PAC, 2014, 2015) and research (Doole and Pannell, 2011) purposes. Cichota and Snow (2009, p. 243) highlight that, “it is well suited for handling management practices and environmental conditions particular to New Zealand”. Extensive validation of OVERSEER has occurred (Shepherd and Wheeler, 2012).

Mitigation protocols

A structured means to identify alternative mitigation practices is employed. Such mitigation protocols have been used in previous studies (e.g. DairyNZ Economics Group, 2014) to allow broad peer review of the selected strategies and coherent and consistent generation of mitigation-cost curves, which is particularly important when diverse consultants are used to estimate these curves for different industries (Doole, 2013). The mitigation protocols described what, when, and to what degree different mitigation options were enacted on each farm, so that all farms generally followed the same overall process. Nonetheless, there were subtle differences in mitigation use between farms, due to disparities in their individual characteristics. There, the process relied on the expertise of the consultant and their knowledge of the area.

Modelling of dairy-farm profit and leaching under different mitigation scenarios is undertaken using the following modelling protocol, set out in Figure 1.

1st stage: Maintain stocking rate and production through substitution with supplements.

a) Utilise a stand-off pad if it is exists on the farm already. Hold supplement and production level constant at the current level. The grazing time will be maintained to above 8–10 hours per day; thus, it can be assumed that pasture intake remains more or less constant (Doole et al., 2013b).
b) Remove summer crop (turnips) and replace these with supplements. This will have a substantial benefit for leaching and is easier logistically on-farm than removing a winter crop.
c) Reduce autumn N fertiliser application and replace with lower-protein feed. Palm Kernel Expeller (PKE) has lower protein than pasture, and maize silage is a good available option in April and May, especially as it has very low protein. Use low protein feed to slow down the grazing round heading into winter.

d) Culling early. Cut feed input as demand decreases. Cut PKE demand in late summer/early autumn through strategic culling. Get 10% of cows off in early February, and 10% of cows off in early March.

e) Replace high-nitrogen supplements with low-nitrogen supplements. Maize silage is typically not used in January–March, as it is difficult for many farmers to carry it through from the previous year.

2nd stage: Allow production decreases.

a) Reduce stocking rate and/or production until it is consistent with the new feed profile. Alternate between removing supplement and N fertiliser, first taking out autumn use and then spring use. Pull out autumn feed and N application first, as conversion into milk is lower at this stage (because cows are producing at the tail end of their lactation curve) and the contribution to leaching is more pronounced.

b) Take out supplement and N fertiliser use in stages, starting with the supplement that has the lowest impact on profit. Decrease stocking rate as feed is extracted from feed gaps. N application is very cost-effective as a source of additional feed, so it should not be decreased right away. Use a 20% reduction in supplement as the maximum that a farm can employ, given a restriction to stay at its current broad level of intensity.

c) Retire marginal land and decrease stocking rate.

These runs are replicated with the inclusion of a stand-off pad, where one does not exist currently. A barn option is not considered as this requires a change in management style and the cost is too high to warrant its broad adoption (Doole, 2014).

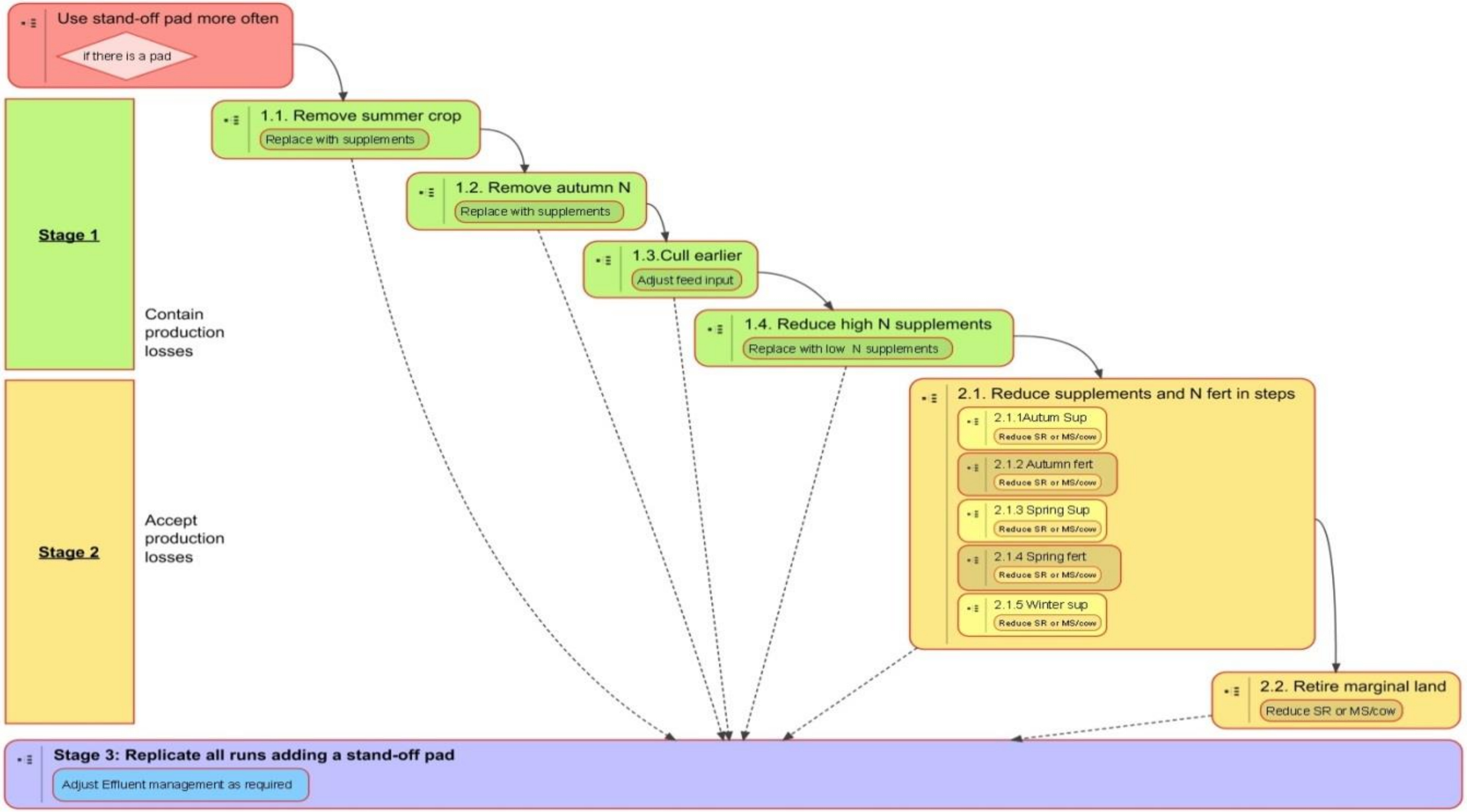
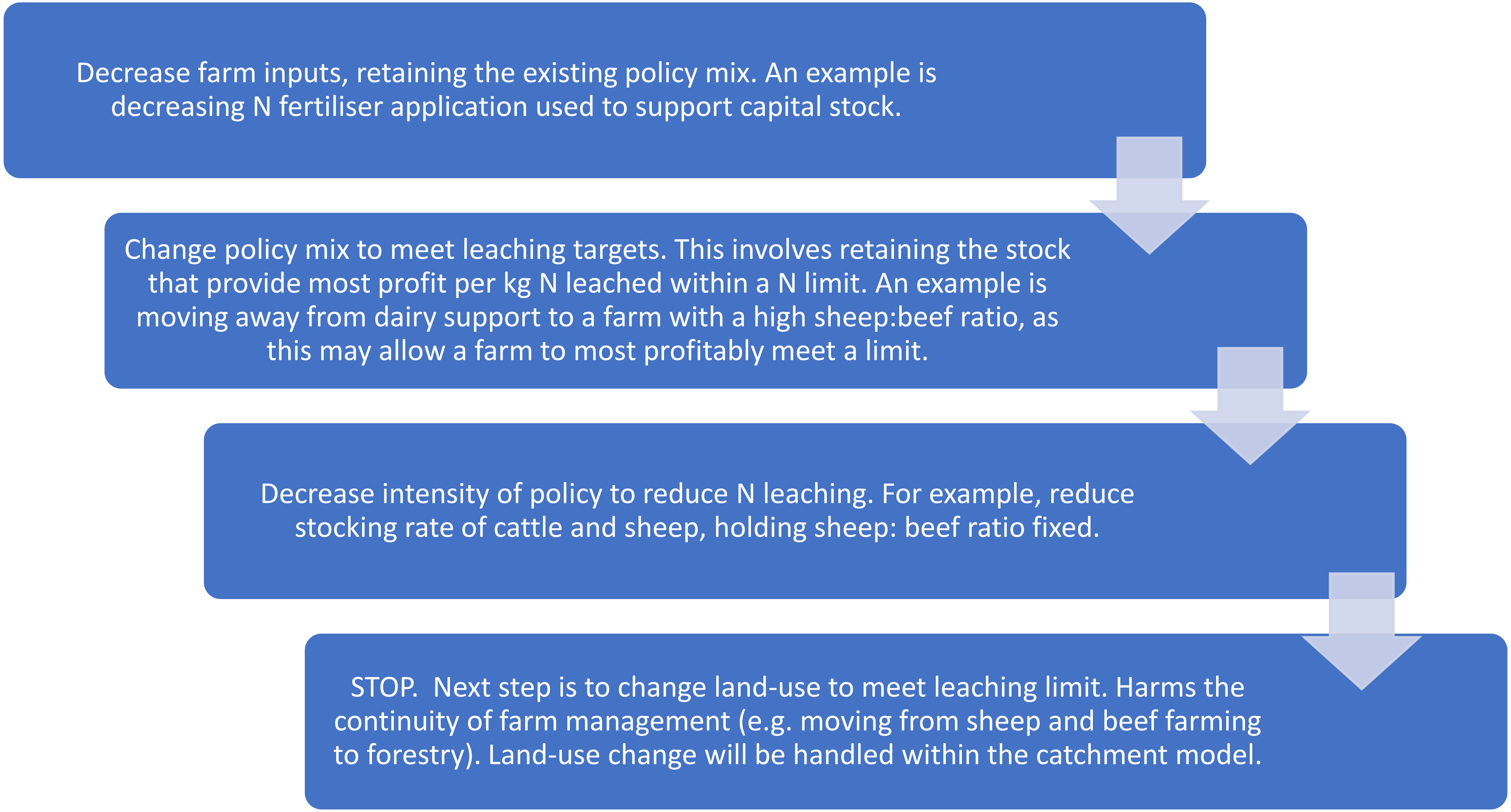


Figure 1. Mitigation protocol employed to assess the cost of reducing N leaching from Rotorua dairy farms.

In comparison, modelling of drystock farm profit and leaching under different scenarios is undertaken using the modelling protocol shown in Figure 2. The order of use for different mitigations within this protocol is:

a) Reduce N fertiliser application that supports the maintenance of capital stock.
b) Reduce winter cropping, ensuring this does not undermine the viability of the dairy-support enterprise, if one exists.
c) Lamb hoggets and decrease ewe numbers.
d) Decrease young dairy stock. Run bulls and steers instead.
e) Take out dairy-support activity. Increase the stocking rate of existing stock.
f) Graze off hoggets. Increase feed to ewes and other stock, though this could decrease productivity on the grazing block.
g) Increase the percentage of sheep on farm.
h) Adopt land-use change. (This is actually studied utilising the catchment model, and not on an individual farm basis. This was deemed to be more appropriate since a key element of a catchment model is its ability to determine land-use allocation based on the relative profitability of different enterprises.)

The diversity of drystock systems makes it difficult to apply this protocol consistently. Thus, the goal of the exercise, in contrast to the dairy-modelling protocol, was to instead establish a generic protocol that could be employed as a foundation for the development of a relevant procedure for modelling mitigation in each representative drystock farm. For any of the steps within the generic protocol depicted in Figure 2, productivity increases were only assumed when they reflected changes in feed available per animal, not when they implied non-trivial increases in management skills, consistent with the work of PAC (2015).



Decrease farm inputs, retaining the existing policy mix. An example is decreasing N fertiliser application used to support capital stock.

Change policy mix to meet leaching targets. This involves retaining the stock that provide most profit per kg N leached within a N limit. An example is moving away from dairy support to a farm with a high sheep:beef ratio, as this may allow a farm to most profitably meet a limit.

Decrease intensity of policy to reduce N leaching. For example, reduce stocking rate of cattle and sheep, holding sheep: beef ratio fixed.

STOP. Next step is to change land-use to meet leaching limit. Harms the continuity of farm management (e.g. moving from sheep and beef farming to forestry). Land-use change will be handled within the catchment model.

Figure 2. Mitigation protocol employed to assess the cost of reducing N leaching from Rotorua drystock farms.

Abatement curves

The curvature of the relationship between nitrogen loss and profit for each land-use is a critical part of the economic model used for the evaluation of different allocation mechanisms. The mitigation protocols, in most cases, generate abatement-cost curves that are upward sloping (i.e. abatement imposes a cost on farmers). This is in direct agreement with mainstream environmental-economics theory (Hanley et al., 2007). However, this relationship is not forced and in some cases profit is increased and contaminant loss is reduced. Such outcomes are referred to colloquially as “win-win” options and mostly correspond to improvements in the efficiency associated with nutrient use (Doole and Kingwell, 2015). This is in line with a number of New Zealand case studies on New Zealand pastoral farms (AgFirst, 2009; Doole, 2012; Ridler et al., 2014; Doole and Kingwell, 2015). Efficiency gains may be achieved either through farm system improvement (such as the elimination of unprofitable or excessive inputs), or through increased management skill and productivity.

Within output from the farm modelling undertaken for this study, win-win outcomes driven through the elimination of unprofitable input use on some farms are identified for some reductions in N loss. For example, from the mitigation-cost curves developed in the context of this study, there is capacity to increase profit by around \$50 ha^{-1} and reduce leaching by around 8 kg N ha^{-1} on drystock farms on allophanic soils, through reducing applied nitrogen. Further examples are discussed below, in the context of Figures 3 and 4. However, the scale of such gains is predominantly limited. Indeed, nitrogen reductions of the scale required by the policy framework that is being modelled are beyond what could be achieved without imposing cost on at least some farmers in the catchment.

Overall, we do not assume additional efficiency gains through widespread increased productivity and management skill. There are several additional reasons to justify this approach generally in the context of this study:

a) Representative farms are developed to describe average farmers within a population. This reduces any bias associated with the delineation of producers that are above or below industry average. Adoption rates for innovations that achieve win-win solutions—such as efficiency improvements—are more common among top farmers (Rogers, 1995). There remains a clear lack of empirical evidence surrounding the capacity of win-win management options to spread/diffuse across a population of producers with diverse biophysical assets and management skill.

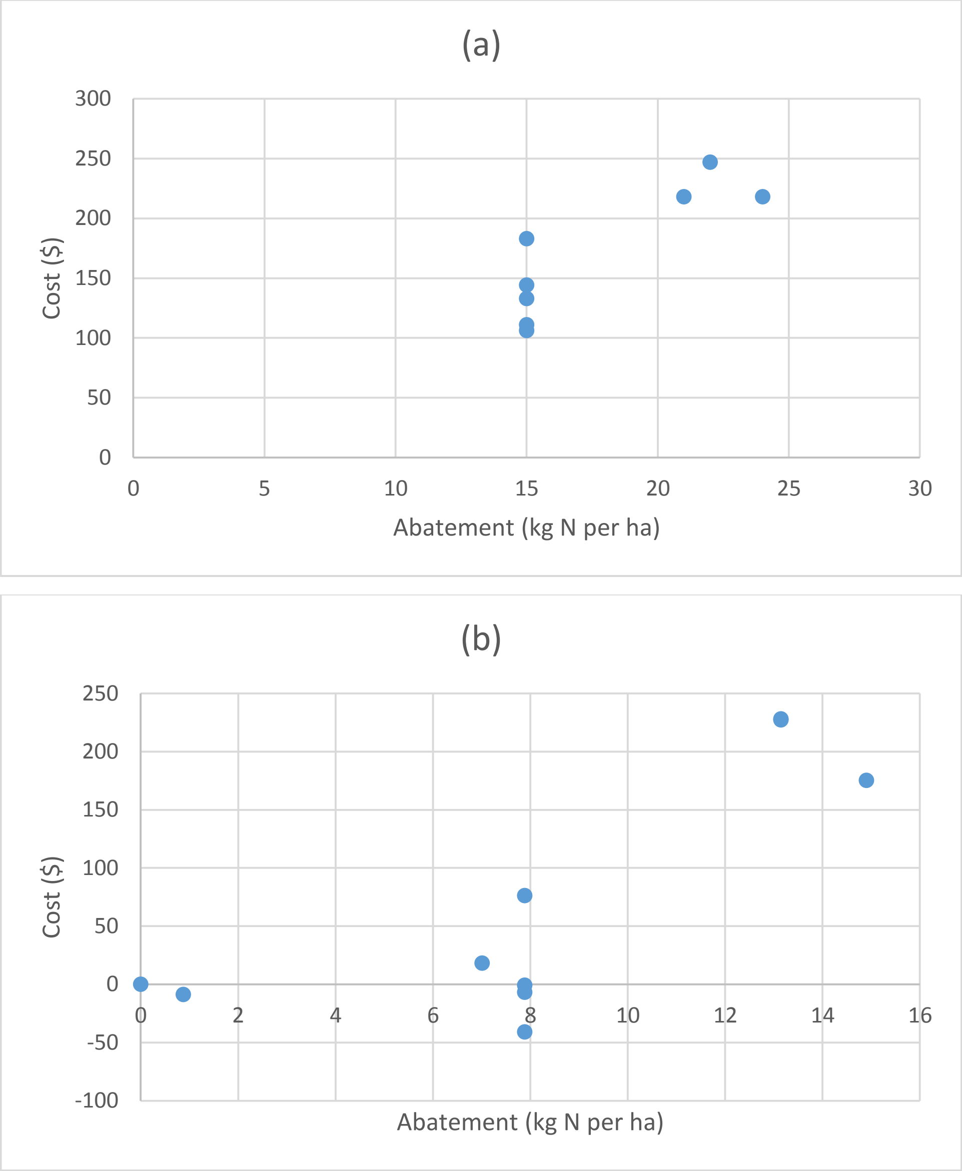
b) Win-win outcomes have been identified using financial modelling (e.g. AgFirst, 2009; Ridler et al., 2014), but the true extent of their actual uptake is primarily constrained by factors that are not considered during standard financial evaluations. Such barriers can be related to risk, uncertainty, adjustment costs, system impacts, incompatibility with lifestyle and values, and complexity (Pannell et al., 2006, 2014). Additionally, some managers are unwilling to deviate from established management plans, given a strong drive to repeat learned actions, even in the presence of new opportunities or constraints (Gonzalez and Dutt, 2011). This is identified in the case of water quality improvement in New Zealand by AgFirst (2010), who found that the adoption of win-win solutions identified in AgFirst (2009) was marred in several circumstances because of risk aversion and perceived limitations in the economic assessment of these practices (AgFirst, 2010).

c) Broad evidence of win-win solutions in grazed dairy systems arises from linear-programming models of these enterprises (e.g. Doole, 2010; Ridler et al., 2014). These linear-programming models provide a very coarse and restrictive description of grazed dairy systems due to their high level of linearity. For example, the linear-programming frameworks utilised by these authors assume fixed pasture growth and quality, constant cow intake, and represent no endogenous feedback between stocking rate, herbage allowance, and pasture utilisation. These simplified assumptions greatly reduce the complexity of the model, allowing it to be developed and solved much more easily. Nevertheless, linear-programming frameworks of grazed dairy systems have been shown to provide inaccurate predictions of how these systems behave in reality, given these simplifying assumptions (Doole et al., 2013b).

The alternative mitigation strategies represented in the model are outlined in the data provided by Perrin Ag. These results are summarised for dairy (Appendix 1), sheep and beef (Appendix 2), sheep and dairy support (Appendix 3), and dairy support (Appendix 4) in the appendices accompanying this report. Due to privacy requirements, raw data for forestry are not presented. Methods and assumptions are outlined in Appendix 5.

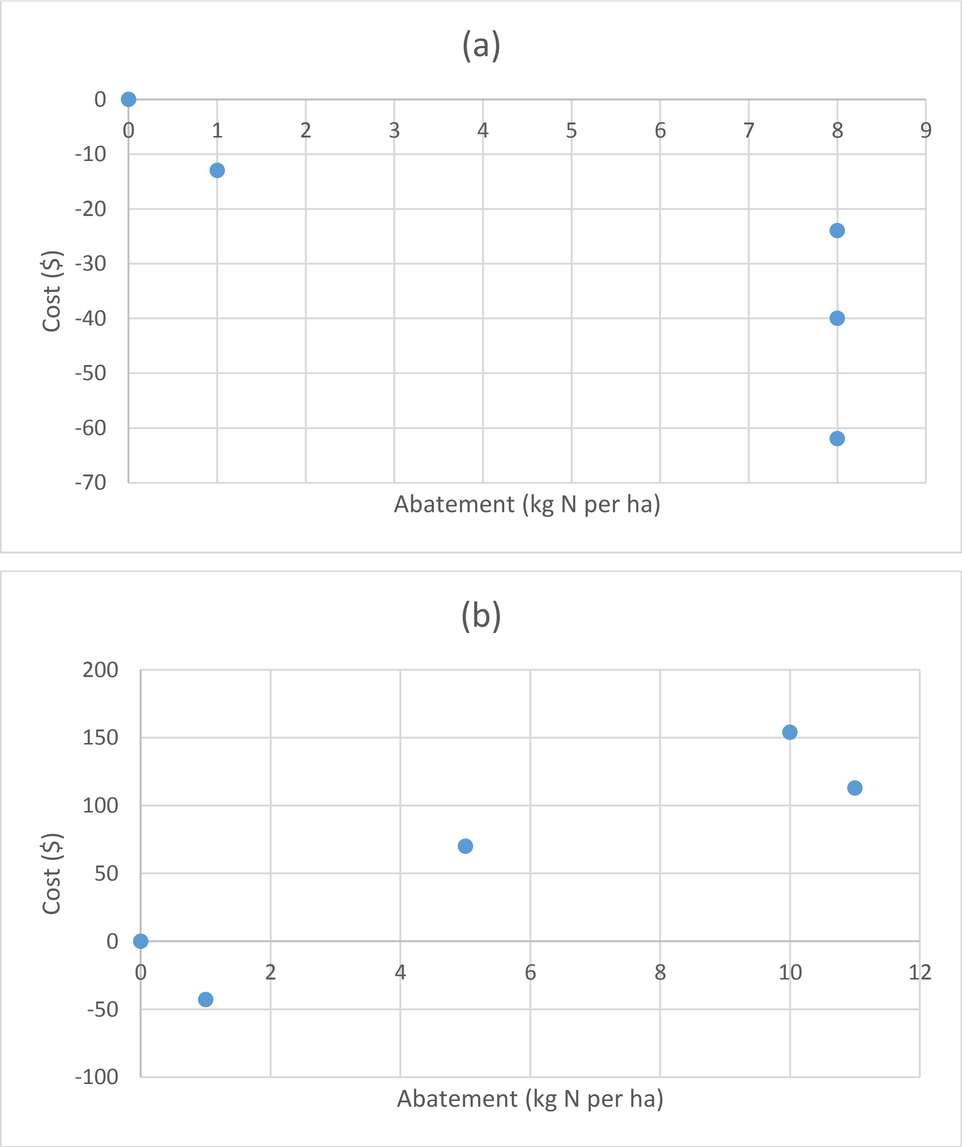
Mitigation-cost relationships are shown for two dairy farms—one on allophanic soils (Figure 3a) and the other on pumice soils (Figure 3b)—in Figure 3. These farms are both on slope classes of 0–8 degrees and have an annual rainfall of 1500–1700 mm. A single spatial zone is focused on to provide a better basis for comparison. Indeed, it is a feature of reality, the input data, and the catchment-level model that mitigation-cost relationships will typically differ according to slope and annual rainfall. It can be seen that there is broad diversity in the estimated cost of different abatement options (Figure 3); mitigation cost generally increases with the level of abatement, but there are also some options that impose win-win outcomes on the pumice soil (Figure 3b). Nevertheless, a key difference is the level of abatement achieved on the allophanic soil as the mitigation protocol is applied; comparison of Figure 3a and 3b demonstrating that a number of the levels of abatement shown on the allophanic soil are substantially higher than those shown for the pumice soil.

Figure 3. The relationship between abatement cost (dollars per ha) and level of mitigation (kg N per ha) for two dairy farms on (a) allophanic soils, and (b) pumice soils. Both are on slope classes of 0–8 degrees and have an annual rainfall of 1500–1700 mm. Points further to the right indicate a greater reduction in nitrogen leaching. Points higher up indicate greater costs for each farm.



In contrast, Figure 4 presents examples of abatement-cost relationships for two sheep and beef farms (one on allophanic soils and the other on pumice soils). These farms are both on slope classes of 0–8 degrees and have an annual rainfall of 1500–1700 mm (the same spatial zone that the dairy farms in Figure 3 are located on). It can be seen that the farm on allophanic soils (Figure 4a) experiences an increase in profit (i.e. a negative cost) as N leaching is reduced, mainly through reducing the level of N fertiliser application used to support capital stock. In comparison, the cost of mitigation rises significantly on the farm on pumice soils as abatement increases.

Figure 4. The relationship between abatement cost (dollars per ha) and level of mitigation (kg N per ha) for two sheep and beef farms on (a) allophanic soils and (b) pumice soils. Both are on slope classes of 0–8 degrees and have an annual rainfall of 1500–1700 mm.



Both Figure 3 and Figure 4 show the discrete nature of the mitigation scenarios that were modelled. Standard economic analysis (e.g. Doole, 2012) typically involves the employment of continuous (i.e. smooth) abatement-cost curves to represent the relationship between leaching and farm profit. However, the discrete points generated by Lee Matheson in this study were not transformed into continuous relationships through the statistical estimation of abatement-cost relationships based on the raw data provided. This is consistent with standard practice (Doole, 2013, 2015), given that such smooth relationships are difficult to estimate using a valid statistical methodology because of low sample sizes and also because it makes it more difficult to establish the relationship between mitigation level and other aspects of farm management that change with abatement (e.g. labour use and fertiliser level). The latter is a problem, because the estimation of smooth relationships allows intermediate abatement points to be utilised, for which primary data (e.g. labour use, as stated above) does not exist.

Transitions costs and benefits

Transition costs are associated with changing from one land-use to another. These are estimated and incorporated, so that each land-use change that occurs bears the costs that are typically associated with such activity. The costs of transition between alternative land-uses are based on data drawn from Matheson (2015). These costs are summarised in Table 2 below. It is observable that while some transitions impose a cost to producers, de-intensification also has some benefits in that it frees up capital invested in certain fixed assets (e.g. sale of livestock or supplier shares). Carbon liability is incorporated in the computation of transition costs, and is also factored into the profitability of the forest sector (determined by SCION) incorporated within the model at a carbon price of \$4 tonne^{-1}. The profitability of a forest stand is annualised using an 8% interest rate over the life of the stand, given that returns from this land-use are highly episodic. The implications of this approach are that the profit streams from forested land are directly comparable to those of other land-uses, such as dairy and sheep and beef.

Table 2. Summary of land conversion costs for the Lake Rotorua catchment. All values are reported in dollars per ha, with positive values representing costs and negative values representing revenues. These values are drawn from Matheson (2015). Forestry establishment costs are included separately within the figures provided by SCION.

Old land-use	**Forestry**	**Support**	**Sheep and beef**	**Forestry**	**Dairy**	**Sheep and beef**	**Forestry**	**Dairy**	**Dairy support**
New land-use	**Dairy**	**Dairy**	**Dairy**	**Dairy support**	**Dairy support**	**Dairy support**	**Sheep and beef**	**Sheep and beef**	**Sheep and beef**
Carbon liability	4,800	-	-	4,800	-	-	4,800	-	-
Pasture development	5,959	801	801	5,959	-	153	5,959	-	-
Fencing, water and electricity	2,506	1,406	1,522	2,072	92	157	1,860	487	708
Buildings	11,272	9,761	7,610	2,024	375	-	2,199	1,708	664
Professional services	197	120	99	101	5	3	100	22	14
Livestock	6,156	6,156	4,780	-	-6,154	-1,371	1,371	-1,371	1,371
Plant and machinery	1,206	854	1,050	352	-854	196	156	196	-196
Supplier shares	5,450	5,450	4,632	-	-6,412	-	-	-6,412	-
Total costs	37,547	25,548	20,494	15,307	-12,949	-863	16,445	-5,370	2,561

3.3 Scenarios

Geographic Information Systems are used to isolate commercial land from the total amount of 27,250 ha of non-commercial and commercial land in the catchment. The area of land within the Rotorua catchment identified through this process and that is hence studied in this analysis is 23,166 ha. This is divided among 5,024 ha of dairy (22%); 1,358 ha of dairy support (6%); 6,682 ha of sheep and beef (29%); 3,007 ha of sheep and dairy support (13%); and 7,095 ha of commercial forest (30%). Mean sectoral loads are 70 kg N/ha for dairy, 33 kg N/ha for dairy support, 21 kg N/ha for sheep and beef, 22 kg N/ha for sheep and dairy support, and 3 kg N/ha for commercial forestry.

The proposed regulatory framework is designed to achieve a total catchment load to the lake of 435 t N. This involves spreading the cost of a 270 t N reduction across the catchment through reducing 30 t N from management of gorse, 140 t N from primary producers and 100 t through an incentives fund. These figures are based on previous modelling using OVERSEER V5 and do not account for any attenuation of N in groundwater. In order to update these figures to reflect attenuation, these totals were converted into OVERSEER 6.1.3. BOPRC provided information from data generated from OVERSEER version 6.1.3, which highlighted that primary producers are required to together achieve a 25% overall reduction in their baseline loads. The baseline leaching in the catchment represented in the catchment-level economic model is 633 t N; this represents 76% of the total catchment load (833 t). The target load for the land-uses represented in the catchment in the model is therefore 479 t N, representing a 25% reduction in baseline load.

An incentive fund has been created that will purchase nitrogen-leaching entitlements from farmers. The total aim of the incentive fund is to purchase 142 t N from non-commercial and commercial land in the catchment. The level of the incentive fund considered in the modelling is 108 t N, which represents 76% (see previous paragraph) of the total incentive fund. This working is based on an assumption that contributions of the incentive fund will be broadly apportioned according to the relative proportions of nitrogen loss from commercial and non-commercial sources in the baseline. The 108 t N level is computed based on the correction of the 142 t N total computed using OVERSEER version 6.1.3, to account for the level of baseline nitrogen loss (633 t N) computed in the model. This estimate does not align exactly with the BOPRC estimate, given that the level computed in this model is generated based on the use of representative farm types, estimation of their coverage of the catchment, and estimation of their constituent leaching loads based on expected farm management. This contrasts the estimates developed by BOPRC, who base their estimates on detailed OVERSEER analysis of individual blocks. The latter approach would potentially have provided more precise insight, but could not be emulated here because of the resources that would be required to estimate mitigation-cost curves for each individual block, which is required to compute the total cost of mitigation across the catchment for alternative policy instruments.

It is evident from the material above that the catchment-level analysis presented here captures the stylised facts of the problem, as is typical for catchment modelling of this nature. It is nonetheless important to recognise that modelling abstracts from the problem in its entirety because of its focus solely on the commercial sector. Accordingly, given the adoption of these restrictions, there are some small differences evident between the allocation scenarios generated by the stakeholder group and those represented in the model. Indeed, because the BOPRC have generated nitrogen-leaching estimates for individual farms and used this to generate the series of allocation scenarios, there is some discrepancy between this reality and what is represented in the model. The key factor driving this result are that resource constraints (mainly related to time, data, and cost) preclude the estimation of mitigation-cost relationships for each individual unit and justify a sole focus on the depiction of representative commercial enterprises in this analysis.

Allocation options

The study involves the analysis of eight allocation scenarios (Table 3).

Table 3. The eight allocation scenarios evaluated for the Lake Rotorua catchment.

Scenario number	Scenario name	Description
Base	Baseline	This represents the status quo.
S1	Sector averaging	Each sector is allocated a constant amount. This corresponds to allocations to dairy of 45.52 kg N $ha^{-1}yr^{-1}$, to drystock of 20.78 kg N $ha^{-1}yr^{-1}$, and to forestry of 3 kg N $ha^{-1}yr^{-1}$.

S2	Sector averaging with consideration of biophysical characteristics	The dairy and drystock sectors experience a uniform proportional reduction to achieve the sector averages identified in Scenario 1.
S3	Single range	A single percentage clawback is applied to all commercial-grazing properties, with final allocations within the range of 16–52 kg N $ha^{-1}yr^{-1}$.
S4	Natural-capital allocation	Allocation is based on the inherent productivity of each spatial zone.
S5	Equal allocation	Equal allocation with a partition between land less than 26 degrees in slope and land greater than 26 degrees in slope.
S6	Range 0A	Final drystock allocations within a range of 15.5–31 kg N $ha^{-1}yr^{-1}$, with an average of 20.4 kg N $ha^{-1}yr^{-1}$. Final dairy allocations within a range of 43.5–58 kg N $ha^{-1}yr^{-1}$, with an average of 46.6 kg N $ha^{-1}yr^{-1}$.
S7	Range 1	Final drystock allocations within a range of 15.5–43.5 kg N $ha^{-1}yr^{-1}$, with an average of 20.4 kg N $ha^{-1}yr^{-1}$. Final dairy allocations within a range of 43.5–58 kg N $ha^{-1}yr^{-1}$, with an average of 46.6 kg N $ha^{-1}yr^{-1}$.
S8	Range 2	Final drystock allocations within a range of 15.5–31.5 kg N $ha^{-1}yr^{-1}$, with an average of 20.4 kg N $ha^{-1}yr^{-1}$. Final dairy allocations within a range of 40–53 kg N $ha^{-1}yr^{-1}$ with an average of 46.6 kg N $ha^{-1}yr^{-1}$.

A number of the allocation scenarios outlined in Table 3 require further description.

Scenario S2 is based on manipulating scenario S1, so that it considers variation between different spatial zones. It involves taking the sector averages for dairy and drystock sectors from scenario S1, and identifying the uniform percentage reduction in load for each sector required to achieve this average. Farm types in different zones have different levels of baseline leaching. This scenario assigns a different sector average for each zone which takes into account these different starting points, but achieves the same overall sector average across the catchment.

Natural-capital allocation (scenario S4) regards the allocation of entitlements based on the inherent productivity of the land type on which farming takes place. A number of steps were employed to represent natural-capital allocation within the context of the study. First, average pasture production (tonnes of dry matter (DM) per ha) per year is estimated for each spatial zone (Table 1) based on expert opinion, reported pasture production for farms in the region and data available for the representative farm types generated in the context of the study. Second, the total pasture production for each zone is then generated through the multiplication of this level of annual production by the area of each zone (ha) (Table 1). Third, the levels of total pasture production for all zones are added together to estimate an average level of pasture grown for the entire catchment. Fourth, the level of total pasture production for each zone is divided by the total level of pasture production for the entire catchment to identify the proportion of the total production arising from that zone. For example, if a particular spatial zone grew 10 t DM/ha/yr over 10 ha and the 100 ha catchment within which that zone was present grew a total of 1000 t DM, then the total production for the zone is 10 t DM/ha * 10 ha=100 t DM and the proportion grown in this zone is 0.1 (or 10%) of the catchment total. Last, the total amount of nitrogen to be allocated among farmers in each zone is then distributed according to the proportion of total production achieved within that zone. For example, if a total of 3,000 kg N is to be allocated across the 100 ha catchment described in our example, then the 10 ha zone of interest mentioned above receives 0.1*3,000 kg N=300 kg N, which corresponds to 300 kg N/10 ha=30 kg N/ha being allocated within this particular zone.

It is recognised that this way of representing natural-capital allocation does not correspond with the practice of using New Zealand Land Resource Inventory (NZLRI) stock carrying capacities to define nitrogen allocation in some regions. The known pasture production approach we have used draws on available data and is consistent with the structure of the modelling framework that is being applied, but does not consider Land Use Capability (LUC) specifically. In this case, we use measured pasture production as a proxy. Given NZLRI stock carrying capacities are a proxy for productive capacity, results at the catchment level should be broadly similar.

Equal allocation involves the allocation of 3 kg N/ha for all land above 26 degrees in slope (2026 ha or 9% of the catchment). The total level of leaching allocated to this land is then subtracted from the target load for the catchment, with the residual amount allocated equally across all land that is less than 26 degrees in slope (21,140 ha or 91% of the catchment). This results in an allocation of 22.4 kg N/ha across the remaining (flatter) land.

Land-use change and trading constraints

In the absence of constraints, an optimisation model may return unrealistic results, due to the lack of accounting for factors other than that being optimised (in this case, annualised profitability). Scenarios are explored with and without a 5000ha constraint on land use change. The constraint on land-use change is introduced to reflect the fact that it is unlikely that the full amount of land-use change predicted by optimisation would occur in reality. This is because land-use change from pasture to forestry is tempered by factors such as the lack of an annual return to landowners, or negative impacts on land prices resulting from conversion (for example, in the loss of option value that occurs with conversion from pasture to forestry). This effect has been documented in the comparison of observed land use change in New Zealand to expected results from modelling (Anastasiadis et al, 2014). A variety of amounts of land-use change were explored in modelling. The 5000ha constraint was determined to be most appropriate through discussion with stakeholders as yielding the most realistic results and is the only constraint presented here, in the interest of brevity.

The model is used to explore a number of different trading scenarios. A frictionless trading scenario is simulated, which depicts farmers trading permanent entitlements to leach among themselves. There is broad empirical evidence that despite the existence of markets for water quality, these may not always function efficiently due to a reluctance of farmers to trade due to risk aversion, information constraints, and high uncertainty (Shortle, 2013). Also, the fact that this may occur is supported by the analysis of trading behaviour within New Zealand water-quantity markets, which occurs well beneath efficient levels given a lack of information, small markets, and infrastructure constraints (Robb et al., 2001). Thus, a scenario involving frictions is also explored. This demonstrates how a potential undersupply of entitlements to leach in the market could affect the performance of alternative policies. Undersupply can arise for a number of reasons, but a key driver is risk aversion driving farmers to retain entitlements as a hedge against future uncertainty.

3.4 Estimating land value impacts

Defining what impacts on land values are likely to occur from a given regulatory restriction on nitrogen loss is a difficult undertaking, as no standard methodology exists. In assessing likely capital impacts, we assume that the price of productive land reflects a bundle of rights in land that relate to its potential profitability. In an unconstrained environment, this is likely due to two key factors. First, the profitability of the current activity that is undertaken on that land and any associated built capital that has been invested. Second, an element of option or speculative value will apply, depending on the best use of that land.

For example, flat, versatile land that is used for drystock farming will typically have a higher price than would be expected based solely on its profitability. This reflects that the land might also be converted to cropping, dairy farming, or other uses. Land that is used for dairy farming typically has a higher price than this again, reflecting the investment that has gone into infrastructure, pasture improvement, and fertility improvement.

Land in the Rotorua catchment has already had its level of permitted nitrogen leaching capped at 2001-2004 levels under the *Bay of Plenty Regional Water and Land Plan* Rule 11. This makes the task somewhat simpler since option value (for intensification of existing use or conversion to a more intensive use) has already been extinguished. This is reflected in work presented to BOPRC on the impacts of Rule 11 on land values in the catchment, showing average impacts on dairy land values of 10%, with an average of 10-20% for drystock land.[2] The greater impact on drystock land value likely reflects the loss of option or speculative value.

To estimate the likely capital impact on different types of farming, we have calculated the value of the nitrogen reduction from farms' baseline (Rule 11) nitrogen leaching rights compared to the final 2032 allocations, as perpetuities at a range of nitrogen prices (in contrast to other parts of the report concerned with annual profit impacts, which use annualised nitrogen prices). We do this by multiplying the reduction in nitrogen leaching rights for each sector (from their baseline relative to their final allocation) by the perpetual nitrogen value generated by the catchment model for each scenario. This reflects the cost of returning a farm to its current Rule 11 leaching cap, which is the likely discount that a new buyer would apply to the land. We do not include further reduction in land values that would result from land use change by landowners that opt to sell off N, since this further reduction in land value can be cashed out and realised by those landowners. The value of N relative to Rule 11 is then discounted to 2015 dollars, to reflect that a present-day buyer would account

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[2] http://www.rotorualakes.co.nz/vdb/document/934

for the fact that these farms will not be limited to such a low level in the short term. The proposed policy of staged reductions over time is not included, due to the lack of any clear trajectory to apply to prices over time.

Multiple-owned Māori land within the catchment poses a particular challenge for assessing capital impacts, as it will not be sold. However, the same principle of option value applies, with respect to current and future generations. The costs expressed in this report are one-off capital values. For Māori land, this should be considered in terms of an annualised cost (through reduced potential for profit) that will be experienced in perpetuity.

4. Results and Discussion

4.1 Baseline management and general results

Table 4 presents model output for the baseline scenario and trading scenarios with alternative levels of land-use change allowed. Two levels of land-use (LU) change are simulated for the purposes of this report. The first (5000 ha LU change) reflects the implementation of a constraint stating that baseline land-use cannot change by more than 5000 ha. The second (optimal LU change) reflects no upper bound being placed on land-use change. (Other levels of land-use change that are simulated, but for which output is not reported here, are 0; 2,500; and 7,500 ha.) Both of these scenarios represent the optimum solution of the model once allocation has taken place within scenarios S1–S8 and frictionless trade. The impacts of frictions in trading are studied in Section 4.3.

A number of important insights are apparent from Table 4 below. First, catchment profit actually increases under both scenarios, by around 14% and 16% in the first and second scenarios, respectively. This result is counterintuitive, and as discussed in section 4.4 needs to be read in the context of capital impacts. The small benefit accruing to the second scenario, relative to the first, reflects that the mitigation of nitrogen away from the current level of nitrogen loss in the catchment has some potential benefits for farm-level profit, when land-use change can occur and the sale of nitrogen discharge allowances is frictionless. As profit within the model also includes annualised costs and benefits of nutrient trading, the inclusion of the incentives fund buying nitrogen is also likely to have a positive impact on profits.

Nevertheless, costs vary significantly by sector and spatial zone; with important implications for the distribution of these benefits across individual farm types (see Section 4.2). Baseline leaching within dairy and dairy support land-uses is significant, around 70 and 33 kg N per ha, respectively. The imposition of a nitrogen-leaching limit alongside permitting land-use change leads to a significant change in the baseline.

Table 4. Key model output for the baseline scenario and the optimal solution with trading, in the 5000ha LU change and optimal LU change scenarios. The price of nitrogen is the price associated with the permanent entitlement.

Variable	**Unit**	**Output**		
Trading	-	Base	Efficient trading	Efficient trading
LU change scenario	-	0	5000 ha	Optimal
Catchment profit	$m	14.44	16.43	16.63
Land-use				
Dairy	ha	5,024	2,754	3,046
Dairy support	ha	1,358	1,358	1,358
Sheep & beef	ha	6,682	5,752	4,666
Sheep & support	ha	3,007	1,900	999
Forestry	ha	7,095	11,403	13,098
Leaching				
Dairy	kg N/ha	70	66	67
Dairy support	kg N/ha	33	18	20
Sheep & beef	kg N/ha	22	21	13
Sheep & support	kg N/ha	21	16	19
Forestry	kg N/ha	3	3	3
N price	$/kg N	-	118	60
Agricultural production				
Milk	t MS	5,142	3,039	3,389
Wool	t	509	412	334
Sheep meat	t	1,584	1,290	1,049
Beef	t	2,191	1,746	1,631
Farm statistics				
Cows	head	13,614	7,711	8,540
N fertiliser	t urea	923	363	407
Supplement	t DM	26	17	19
Labour	FTE	157	127	132

Notable changes include a significant reduction in dairy area (around 40%). This is due to some types of dairy farm having comparatively low profit per hectare relative to the amount of nitrogen that they leach, which makes land-use change and the sale of N a more profitable option than mitigation (see example in Box 1).

Box 1: Land-use change decision-making on a dairy farm type in a high-rainfall zone with a pumice soil.

- This farm type leaches 84 kgN ha^{-1} yr^{-1}, making \$934 ha^{-1} yr^{-1} EBIT.
- Assume this farm type is allocated 53 kgN ha^{-1} yr^{-1} (e.g. range scenario 8).
- What are the mitigation options?
    - According to the mitigation protocol outlined in Section 3, this farm type can mitigate leaching as low as 73 kgN ha^{-1} yr^{-1}, making \$812 ha^{-1} yr^{-1}. This is still 20 kg N ha^{-1} yr^{-1} above their allocation.
- Is buying N worthwhile?
    - This farm type needs to purchase 20 kg N ha^{-1} yr^{-1} (a total cost of \$118.20 ha^{-1} yr^{-1} at an N price of \$5.91 kg^{-1} yr^{-1}, the annualised price for the 5000 ha land-use change scenario with frictionless trading).
    - This leaves a residual profit of \$693.80 ha^{-1} yr^{-1}
- Is land-use change worthwhile?
    - In this case, a specialist dairy support operation on the same land can earn \$954 ha^{-1} yr^{-1}, leaching 36 kg N ha^{-1} yr^{-1}.
    - This land-use change would enable the sale of 17 kgN ha^{-1} yr^{-1} (\$100.47 ha^{-1} yr^{-1}).
- Impact on profit (EBIT after trading)?
    - This land-use change yields a residual profit of \$1054.47 ha^{-1} yr^{-1}.
    - This is in addition to one-off transition benefits of \$12,949 ha^{-1} (as per Table 2).

It is important to note that in an unconstrained environment for nitrogen, the land-use change from dairy to dairy support would be unlikely due to the similar profit levels and sunk cost in infrastructure. However, with the introduction of the opportunity to sell N, this land-use change becomes significantly more attractive.

The remaining dairy farm types are those that generate high profits per hectare, relative to the amount of nitrogen that they leach. Despite some mitigation capacity, these farm types still typically need to leach more nitrogen than is allocated in the scenarios in order to sustain their on-going profitability. These farm types buy N under all scenarios, with more N required under scenarios that are more different to the status quo such as natural-capital and averaging approaches. These farm types experience costs of mitigation, as well as costs to buy N in order to remain viable (as per Box 2). These impacts are not apparent at the sector level, since costs falling on less-profitable farm types changing land-use are not apparent in the extent of the costs that fall on the farm types that remain in business.

Box 2: Costs for a high rainfall podzol dairy farm type

- This farm type leaches 70 kgN ha^{-1} yr^{-1}, making \$2011 ha^{-1} yr^{-1} EBIT.
- Though allocated less, it is only economic for this farm type to mitigate to 65 kg N ha^{-1} yr^{-1}.
- This farm type needs to buy N to stay viable under all scenarios (though different amounts for each scenario). Assuming the same annualised N price of \$5.91 kg^{-1} yr^{-1}
  - This will cost \$84.26 ha^{-1} yr^{-1} under scenario 8 (just over 14 kgN yr^{-1} under Range 2).
  - This will cost \$257.32 ha^{-1} yr^{-1} under scenario 5 (just over 43 kgN yr^{-1} under equal allocation).
- Impact on profit (EBIT after trading)?
  - Residual profit is highly-sensitive to allocation, with a 4% loss of EBIT under scenario 8 and a 13% loss under scenario 5.

All scenarios involve an increase in forestry area, around 60% and 85% in the first and second scenarios, respectively. Lower-intensity dairy-support options involve substantial scope for stocking-rate reductions at a reasonable cost, with marked benefits for nitrogen leaching (Box 3 and Appendix 4).

Box 3: Mitigation and N purchase on a podzol dairy support farm type

- This farm type leaches 29 kg N ha^{-1} yr^{-1}, making \$813 ha^{-1} yr^{-1}
- Assume it is allocated 19 kgN ha^{-1} yr^{-1}.
- Step 1 – remove N use?
  - Cost \$20 ha^{-1} yr^{-1} to reduce N leaching to 22 kgN ha^{-1} yr^{-1} – this is likely as it produces a cost effective reduction in N.

- Step 2 – remove calf grazing?
    - Increase in profit of \$22 ha^{-1} yr^{-1}/ha to reduce to N leaching 20 kgN ha^{-1} yr^{-1} – this is highly-likely given the potential increase in profit from reducing N (a win-win outcome).
- Step 3 – remove winter cows?
    - Cost \$379 ha^{-1} yr^{-1} to reduce N leaching to 18 kg N ha^{-1} yr^{-1} – unlikely as this is not cost-effective.
- Buy N?
    - Cost \$5.91 ha^{-1} yr^{-1} to increase allocation to 20 kg N ha^{-1} yr^{-1} – highly cost effective.
- Final outcome is a net profit \$809.09 ha^{-1} yr^{-1}, with leaching of 20 kg N ha^{-1} yr^{-1}, by removing N use and calf grazing, but buying N leaching rights in order to maintain the cow wintering component of the business.

Overall, the impacts identified in Table 4 highlight a significant reduction in dairy and beef production, given the higher leaching losses emanating from land on which these animals are grazed. There is a significant reduction in cow number, nitrogen fertiliser application, supplement use, and farm labour, with each effect likely to have regional implications. Also, allowing the optimal level of land-use change to occur reduces the price of nitrogen permits, as producers are not so constrained by the availability of nitrogen given that management is sufficiently flexible to fully exploit any net benefits accruing to this action.

Tables 5 and 6 present the impact of each allocation scenario (see Table 3 for a list) on operating profit within each of the sectors, for the 5000ha land-use change and the optimal land-use change scenarios, respectively, using efficient trading. The value of trade in nitrogen entitlements is determined using the annualised value of entitlements; this is computed using an 8% interest rate over 25 years. The first five rows of data present in both tables outline the operating profit for the management activity on each farm type, without considering the change in net revenue arising from trade. These outcomes are closely equivalent across all of the allocation scenarios, given that trading removes any distortions away from the optimal point associated with the initial allocation (Howard et al., 2013). Nevertheless, the disparate allocation scenarios drive a need for some substantial trading across many of the simulated programs. For example, dairy farm types, on average, must purchase 39 and 43 kg N per ha under natural-capital (S4) and equal (S5) allocation scenarios (Table 4) when a maximum bound of 5000 ha is placed on land-use change. Additionally, dairy farm types must purchase an average of 42 and 45 kg N per ha under natural-capital (S4) and equal (S5) allocation scenarios (Table 4) when no maximum bound is placed on land-use change. Additionally, the sales made by sheep and dairy support land experience substantial diversity, with a mean of 31 kg N per ha sold and this activity being augmented by land-use change when a bound of 5000 ha is placed on land-use change. However, when no bound is placed on land-use change, there is a substantial reduction in the trade in entitlements from sheep and support land, with this loss being offset by an increase in trade from sheep and beef land. This change partly reflects a further loss of land in sheep and dairy support, particularly those areas of land on which more-intensive sheep and dairy support activity is sustained. As expected, the highest sales from forested land occur under the natural-capital (S4) and equal (S5) allocation scenarios, but a consistent level of sale is present across all scenarios, driven also by land-use conversion (Table 3).

There is substantial diversity in the change in operating profit. Profit increases in all land-uses in all scenarios, with the exception of profit on sheep and dairy support with optimal land-use change (Table 6). To some extent, this demonstrates the existence of some cost-effective mitigation options and win-win strategies, coupled with the opportunity to sell N to the incentives fund, or to other farmers. However, in many cases, this is due to less profitable farm types changing land use, which results in the average profit going up despite significant costs faced by remaining farm types. This overall result conceals significant disparity in costs and benefits for diverse land-uses across different spatial regions. Moreover, while the overall level of profit may not fall, this is not necessarily a good indicator of overall economic activity (Howard et al 2013). Further analysis of regional impacts due to changes in revenue and services purchased are required to understand how this change in farm-systems is likely to impact on the wider community. These values are studied in further detail in an accompanying report that outlines a regional economic study performed by Market Economics. It is also important to note that these profit impacts are based on EBIT and do not include the likely capital impacts of a change in leaching rights (section 4.4) or their implications for debt servicing.

Table 5. Key model output for each sector across all allocation scenarios, including transition costs, when a maximum land-use change of 5000 ha is permitted and trading is efficient. Positive/negative values for the net trade in entitlements represent the purchase/sale of permits.

Variable	**Base**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Operating profit without consideration of trade in entitlements ($/ha)									
Dairy	1,638	2,015	2,015	2,006	2,015	2,015	2,015	2,015	2,015
Dairy support	515	1,124	1,124	1,210	1,124	1,124	1,124	1,124	1,124
Sheep and support	324	343	343	357	343	343	343	343	343
Sheep and beef	387	447	447	447	447	447	447	447	447
Forestry	283	537	537	524	537	537	537	537	537
Net trade in entitlements (kg N/ha)									
Dairy		20	20	5	39	43	15	15	14
Dairy support		-12	-16	-6	-1	-3	-15	-15	-15
Sheep and support		-31	-31	-29	-31	-31	-31	-31	-31
Sheep and beef		-5	-5	-1	-4	-4	-2	-2	-2

Forestry		-11	-10	-4	-17	-18	-11	-11	-11
Change in operating profit arising from trade in entitlements ($/ha)									
Dairy		-118	-119	-31	-229	-257	-88	-88	-84
Dairy support		69	96	38	7	20	89	90	88
Sheep and support		183	183	171	183	183	183	183	183
Sheep and beef		28	27	5	23	26	10	10	11
Forestry		63	61	24	102	104	65	65	63
Operating profit with consideration of trade in entitlements ($/ha)									
Dairy	1,638	1,897	1,896	1,975	1,786	1,758	1,927	1,927	1,931
Dairy support	515	1,193	1,220	1,248	1,132	1,144	1,213	1,214	1,212
Sheep and support	324	526	526	528	526	526	526	526	526
Sheep and beef	387	476	475	452	470	473	457	457	458
Forestry	283	600	598	548	639	641	602	602	600

Table 6. Key model output for each sector across all allocation scenarios, including transition costs, when any level of land-use change can occur and trading is efficient. Positive/negative values for the net trade in entitlements represent the purchase/sale of permits.

Variable	**Base**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Operating profit without consideration of trade in entitlements ($/ha)									
Dairy	1,638	1,879	1,879	1,879	1,879	1,879	1,880	1,880	1,880
Dairy support	515	1,193	1,193	1,193	1,193	1,193	1,193	1,193	1,193
Sheep and support	324	266	266	266	266	266	266	266	266
Sheep and beef	387	457	457	457	457	457	457	457	457
Forestry	283	526	526	526	526	526	526	526	526
Net trade in entitlements (kg N/ha)									
Dairy		23	24	18	42	45	19	19	18
Dairy support		-9	-13	-11	0	-1	-12	-12	-11
Sheep and support		-2	0	-1	1	0	0	0	0
Sheep and beef		-10	-25	-6	-23	-13	-5	-5	-6

Forestry		-11	-10	-11	-17	-18	-11	-11	-11
Change in operating profit arising from trade in entitlements ($/ha)									
Dairy		-70	-72	-56	-127	-139	-56	-56	-54
Dairy support		26	39	34	-1	3	35	35	34
Sheep and support		5	0	2	-3	0	1	1	1
Sheep and beef		30	76	18	71	40	15	15	18
Forestry		35	32	33	50	54	33	33	32
Operating profit with consideration of trade in entitlements ($/ha)									
Dairy	1,638	1,809	1,807	1,823	1,752	1,740	1,823	1,823	1,825
Dairy support	515	1,219	1,233	1,227	1,192	1,196	1,228	1,229	1,227
Sheep and support	324	271	267	268	264	267	268	268	268
Sheep and beef	387	487	533	475	529	497	472	472	475
Forestry	283	561	558	559	576	580	559	559	558

4.2 Implications of scenarios for each baseline land-use

This section focuses on land-use change in scenarios S4 and S8. These scenarios are selected because they are broadly divergent, they are the focus of the regional analysis, and scenario 8 is the preferred option of the stakeholder group.

Table 7 presents the level of land-use change observed when this action is unconstrained. (Only changes larger than 1 hectare are reported.) The outcomes for S4 and S8 differ by a fraction of a hectare; thus, only the solution for S8 is presented. Significant land-use change is observed, especially in the dairy sector due to its high level of nitrogen leaching. Indeed, around 1,700 ha of dairy to forest conversion is observed. Dairy support area is also reduced, with around 400 ha of dairy activity converted to support on high-loss pumice soils (most in higher-rainfall areas), while support land on other soil types is reduced. In particular, around 655 ha of dairy-support land is converted to sheep and beef activity on podzol soils. Some sheep and beef land (around 500 ha) is converted to sheep and dairy support, but most conversion of this land-use (around 3000 ha) involves transition to forest. Most land-use change as a proportion of baseline land-use occurs in the sheep and dairy-support option. Around 165 ha is converted to dairy production, while 500 ha, 900 ha, and 1000 ha is converted to standard dairy support, sheep and beef, and forestry activities, respectively.

Overall, the results outlined in Table 7 demonstrate that the proposed allocation systems will likely have a significant effect on the way that land is managed in the catchment, especially given the capacity to trade entitlements. The land-use changes observed are significant, for a number of reasons. First, there is substantial diversity in economic and environmental outcomes between the individual zones represented in the catchment model. Second, the allocation mechanisms simulated represent a substantial distortion with respect to the current situation, so significant changes are expected. Last, the responses are not arbitrarily dampened through the use of calibration functions estimated from data obtained from other catchments (Doole and Marsh, 2014a, b). These issues are discussed further in the conclusions.

Table 7. Patterns of land-use change observed in scenario S8 when land-use change is unconstrained and trading is efficient.

Baseline land-use	New land-use	Soil	Hectares
Dairy	Dairy	Podzol	14
Dairy	Support	Allophanic	39
Dairy	Support	Pumice	414
Dairy	Forest	Allophanic	428
Dairy	Forest	Pumice	1041
Dairy	Forest	Recent	260
Support	Support	Pumice	7
Support	Forest	Allophanic	49
Support	Forest	Podzol	153
Support	Forest	Pumice	47
Support	Forest	Recent	38
Support	Sheep and beef	Podzol	655
Sheep and beef	Dairy	Podzol	38
Sheep and beef	Forest	Allophanic	587
Sheep and beef	Forest	Organic	64
Sheep and beef	Forest	Podzol	335
Sheep and beef	Forest	Pumice	1173
Sheep and beef	Forest	Recent	852
Sheep and beef	Sheep and support	Allophanic	415
Sheep and beef	Sheep and support	Podzol	109
Sheep and support	Dairy	Podzol	165
Sheep and support	Support	Pumice	489
Sheep and support	Forest	Allophanic	264
Sheep and support	Forest	Organic	29
Sheep and support	Forest	Podzol	25
Sheep and support	Forest	Pumice	292
Sheep and support	Forest	Recent	365
Sheep and support	Sheep and beef	Allophanic	168
Sheep and support	Sheep and beef	Podzol	734

Table 8 presents how total profit for each land-use differs under the baseline, S4, and S8 scenarios for the 5000 ha land-use change scenario. S4 is the natural-capital allocation, while S8 is the Range 2 scenario developed by the stakeholder group. The natural-capital allocation involves a significant amount of trade (Table 4), with dairy farm types required to spend around \$229 ha^{-1} yr^{-1} for purchasing permits and sheep and dairy support farm types selling permits for a mean return of \$183 ha^{-1} yr^{-1}. Dairy-support operations benefit from conversion from dairy farm types to sheep and support farm types, with transition benefits arising from the sale of dairy shares and livestock. Moreover, conversion to forestry land benefits from the sale of livestock in drystock operations and shares and livestock in the dairy areas. In comparison, under scenario S8, dairy farm types trade much less than under the natural-capital allocation scenario (S4) because the allocations within the S8 system are much more in line with historical levels of nitrogen loss. Once again, there are significant transition benefits for dairy-support and forestry operations. Interestingly, profit is higher under the Range 2 scenario (S8) relative to the baseline, and for all enterprises except sheep and beef and forestry relative to S4. This is due to lower-profit (relative to their nitrogen leaching) types of farming changing land-use, so that only the most efficient remain in that land-use. However, at a finer resolution, many of these farm types experience costs.

Table 9 reports how total profit for each land-use differs under the baseline, S4, and S8 scenarios for the instance when total land-use change is unconstrained. Lower distortions to profit arising from the trading of nutrient entitlements are observed because land-use change is less constrained and, therefore, producers can rely more on land-use change than the purchase of entitlements to attain their profit-maximising position under the imposed nitrogen-leaching limit. The impact of a greater reliance on land-use change is a greater distortion to farm profit arising from transition costs. A transition cost is associated with dairy operations, as it is optimal when land-use change is unconstrained to convert some sheep and beef land and some sheep and dairy support land on podzol soils to dairy production, given its high profitability and low level of environmental footprint on this given soil type. Similarly, transition costs are borne for sheep and beef conversion, arising from the conversion of dairy support and sheep and dairy support operations located on podzol soils and, to a lesser extent, allophanic soils. In contrast, dairy-support operations benefit from conversion from dairy farm types to sheep and support farm types, with transition benefits arising from the sale of dairy shares and livestock. Moreover, conversion to forestry land benefits from the sale of livestock in drystock operations and shares and livestock in the dairy areas. Profit is higher for both scenarios S4 and S8, relative to the baseline, for all land-uses except sheep and dairy support. Profit is also greater for each land-use in scenario S8, relative to scenario S4, except for sheep and beef and forestry enterprises.

Table 8. Change in farm profit for the baseline, Scenario S4, and Scenario S8 in the optimal solutions obtained when a maximum of 5000 ha land-use change is simulated. The units of all numbers in this table are dollars per ha.

Land-use	**BASE**	**S4**	**S4**	**S4**	**S4**	**S8**	**S8**	**S8**	**S8**
Land-use	**Profit**	**EBIT**	**Trans. cost**	**Trade**	**Profit**	**EBIT**	**Trans. cost**	**Trade**	**Profit**
Dairy	1,638	2,018	0	-229	1,789	2,006	0	-84	1,922
Dairy support	515	697	427	7	1,131	694	515	88	1,297
Sheep and support	324	338	0	183	521	357	0	183	540
Sheep and beef	388	442	0	23	465	448	0	11	459
Forestry	283	326	213	102	641	322	202	63	587

Table 9. Change in farm profit for the baseline, Scenario S4, and Scenario S8 in the optimal solutions obtained when land-use change is unlimited. The units of all numbers in this table are dollars per ha.

Land-use	**BASE**	**S4**	**S4**	**S4**	**S4**	**S8**	**S8**	**S8**	**S8**
Land-use	**Profit**	**EBIT**	**Trans. cost**	**Trade**	**Profit**	**EBIT**	**Trans. cost**	**Trade**	**Profit**
Dairy	1,638	2,008	-128	-127	1,753	2,008	-128	-54	1,826
Dairy support	515	774	420	-1	1,192	774	420	34	1,227
Sheep and support	324	258	9	-3	263	258	9	1	267
Sheep and beef	388	508	-51	71	528	508	-51	18	475
Forestry	283	326	200	50	576	326	200	32	558

4.3 Impacts of frictions

The material presented in Sections 4.1 and 4.2 are consistent with frictionless trade within the market for nitrogen permits. However, frictions may occur within such markets, especially because producers may hoard entitlements as a hedge against future uncertainty regarding further cuts to leaching loads (Howard et al., 2013). The impact of such frictions was evaluated, to identify how they could affect the relative performance of each allocation instrument. This was done through restricting trade volumes to 50% of the optimal level observed when no frictions were simulated. In the scenario that also included a 5000 ha restriction on land-use change, the total amount of entitlements that were to be bought by the incentive fund was also reduced by 50%, as otherwise there were not enough permits available for purchase by the incentive fund. This is consistent with the reasoning that frictions will lower the amount of supply of permits in the market, and thus restrict the purchase of entitlements for both producers and the incentive fund.

Profit within the catchment is reduced when frictions are present within the market for nitrogen permits. Indeed, catchment profit decreases by around 5% in both land-use scenarios relative to the scenarios without frictions, though this is still higher than baseline profit. This highlights that hoarding within a permit market reduces efficiency at the catchment level, and the cost of this inefficiency falls on the producer population. A key source of this inefficiency is barriers to land-use change. For example, the presence of frictions means that the area in dairy and sheep and beef farming is higher than optimal, while the area of sheep and dairy support and forestry is lower than optimal when a maximum bound of 5000 ha land-use change is simulated. In contrast, the presence of frictions means that the amount of dairy and forested land is lower than optimal in the unlimited land-use change scenario due to an inability to acquire allowances, while sheep and beef and sheep and dairy support is too high.

These rigidities in the market for emissions entitlements have significant implications for leaching within each land-use. A significant impact is that they increase the perpetualised price for nitrogen from around \$118 and \$60 kg N^{-1} in the 5000 ha and unlimited land-use change scenarios, to around \$444 kg N^{-1} (\$551 kg N^{-1} under the natural-capital scenario). This higher price reflects an increased scarcity of nutrient entitlements in the market and that practices to pragmatically address rigidities in the market for nitrogen-leaching entitlements in the Lake Rotorua catchment will have direct benefits for increasing the amount of nitrogen that could be purchased by the incentive fund, while also reducing on-farm costs through promoting more cost-effective nutrient mitigation.

Table 10. Key model output with 50% frictions and no frictions in the nitrogen-permit trading market, for the case of a maximum bound of 5000 ha and unlimited land-use change. This is for the Scenario 8 Range allocation.

Variable	**Unit**	**Output**				
Trading	-	Base	Trading (50% fr.)	Trading	Trading (50% fr.)	Trading
LU change scenario	-	0	5000 ha	5000 ha	Optimal	Optimal
Catchment profit						
	$m	14.44	15.49	16.43	15.76	16.63
Land-use						
Dairy	ha	5,024	3,400	2,754	2,889	3,046
Dairy support	ha	1,358	1,358	1,358	1,358	1,358
Sheep & beef	ha	6,682	7,823	5,571	7,133	4,666
Sheep & support	ha	3,007	1,513	1,900	1,080	999
Forestry	ha	7,095	9,074	11,403	10,714	13,098
Leaching						
Dairy	kg N/ha	70	55	66	54	67
Dairy support	kg N/ha	33	26	18	26	20
Sheep & beef	kg N/ha	22	20	21	14	13
Sheep & support	kg N/ha	21	19	16	19	19
Forestry	kg N/ha	3	3	3	3	3
N price	$/kg N	-	444	118	444	60
Agricultural production						
Milk	t MS	5,142	3,648	3,039	3,128	3,389
Wool	t	509	533	412	484	334
Sheep meat	t	1,584	1,660	1,290	1,512	1,049
Beef	t	2,191	2,198	1,746	297	1,631
Dairy statistics						
Cows	head	13,614	9,874	7,711	8,080	8,540
N fertiliser	t urea	923	515	363	430	407
Supplement	t DM	26	21	17	19	19
Farm labour	FTE	157	138	127	131	132

4.4 Implications of scenarios for land prices

As for section 4.2, we consider allocation scenario 4 (natural-capital) and scenario 8 (range 2). These scenarios are selected because they are broadly divergent, they are the focus of the regional analysis, and scenario 8 is the preferred option of the stakeholder group. Impacts are assessed for optimum land-use change with 50% frictions, 5000 ha of land-use change with optimum trading, and for 5000ha of land-use change with 50% frictions to trading. Under the latter scenario, the supply of N is so restricted that the incentives fund only achieves half of its target. To provide decision-makers with total costs, the full 142 t reduction required by the incentives fund has been used here, rather than the 108 t used to model the commercial sector only within the catchment model. Since the allocations are for 2032, impacts on farmers are discounted at a rate of 8% to reflect impacts in the present (i.e. land values in 2015). The incentives fund on the other hand is operational currently and will be buying N from farmers in a way that requires land-use change in the short-term. Because of this, costs to the incentives fund are not discounted.

There is a wide range in potential capital impacts. This reflects the fact that N price is highly sensitive to market efficiency. This is likely to be reflected in reality, as a highly-efficient market with readily-available nitrogen credits will greatly dampen the limitations to management faced by any individual block of land in the catchment.

Table 11 shows the impact of natural-capital allocation (scenario S4). The total impacts on farmers range from \$2.5 m to \$22.9 m. Under this scenario, the majority of capital impacts fall on dairy farms. Drystock farms also experience a cost, but this is relatively modest. The large costs on pastoral land are balanced by significant benefits for forestry land relative to the current rules.

Table 12 shows the impacts on capital value under the proposed range 2 allocation (scenario S8, the Stakeholder Advisory Group’s preferred option). Again, capital impacts are high, but are distributed more evenly across pastoral land-uses. Dairy farming still experiences higher capital impacts than drystock farming, due to the higher percentage reductions applied to the sector than for drystock farms. As forestry land receives the same allocation as it holds currently, the overall cost to pastoral land is lower.

The difference in cost is particularly evident under the 5000 ha with 50% frictions scenario. Under the natural-capital allocation, a large amount of trade is required to reach an efficient land-use outcome. This increases demand for nitrogen discharge allowances, increasing the price from $444 to $551 per kg N for a perpetual discharge right. The overall capital impact on farmers is $18.4m under the range scenario. This cost is 24% higher ($22.9m) under the natural-capital allocation. It is a feature of a regulatory scenario featuring nutrient trading, that impacts on land flexibility and capital value are to a large extent dependent on the price and availability of leaching rights. That is, making the best use of one piece of land becomes dependent on other farms making the best use of their land, including if this involves selling nutrient rights.

Overall, the assessment of capital values contrasts starkly with the assessment of profit, in that the estimated costs to the pastoral sector are significant. Indeed, this novel approach captures a key element missing from previous economic analysis—the fact that a high proportion of the returns to agricultural land are attributable to capital gain, and this appreciation in value is compromised through limits placed on intensification by nitrogen-leaching constraints. This should be particularly be of concern for farmers that carry higher levels of debt, especially given that this will compound the effects on capital value arising from the prior imposition of Rule 11. It is an interesting feature of the analysis in this report that significant negative impacts on land value are expected, even though profit across the catchment is expected to increase. This increased profit is associated with transition benefits and with option value being extinguished. Essentially, this represents a trade-off of the option value in land for operating profit.

Table 11. Capital impacts on different sectors under scenario 4 (natural-capital allocation) for three different catchment scenarios and associated values for N. The N prices used ($61, $118 and $551) are all prices generated by the 2032 policy scenario. Accordingly, the costs associated with these N prices have been discounted (at a rate of 8%) to show costs in 2015. Forestry costs in this table are negative (i.e. they are benefits).

	"Natural-capital" allocation									
	Base		Scenario 4		Opt LU 50% frictions		5000ha no frictions		5000ha 50% frictions	
	Load (tN)	ha	Allocated (tN)	Reduction (tN)	Cost at $61/kg	cost per ha	Cost at $118/kg	cost per ha	Cost at $551/kg	cost per ha
Dairy	354	5024	121	233	$3,841,627	$ 765	$ 7,431,343	$1,479	$ 34,700,595	$6,906
Dairy support	45	1358	32	13	$ 217,853	$ 160	$ 421,420	$ 310	$ 1,967,820	$1,449
Sheep and dairy	63	3007	59	4	$ 67,026	$ 22	$ 129,657	$ 43	$ 605,432	$ 201
Sheep and beef	150	6682	132	18	$ 299,335	$ 45	$ 579,042	$ 87	$ 2,703,833	$ 404
Forestry	21	7095	136	-115	-$1,895,174	-$ 267	-$ 3,666,074	-$ 517	-$ 17,118,703	-$2,413
Total farm	**633**	**23166**	**480**	**154**	**$2,530,667**	**$ 109**	**$ 4,895,389**	**$ 211**	**$ 22,858,977**	**$ 987**
Incentives	0		-142	142	$8,662,000		$16,756,000		$39,121,000	
									$ 39,121,000	Shortfall
TOTAL					$11,192,667		$21,651,389		$101,100,977	

NOTE - incentives fund fails under 5000ha/50% scenario - leaving a 71t shortfall

Table 12. Capital impacts on different sectors under scenario 8 (range 2) for three different catchment scenarios and associated values for N. The N prices used ($60, $118 and $444) are all prices generated by the 2032 policy scenario. Accordingly, the costs associated with these N prices have been discounted (at a rate of 8%) to show costs in 2015.

	"Range" allocation									
	Base		Scenario 8		Opt LU 50% frictions		5000ha no frictions		5000ha 50% frictions	
	Load (tN)	ha	Allocated (tN)	Reduction (tN)	Cost at $60/kg	per ha	Cost at $118/kg	per ha	Cost at $444/kg	per ha
Dairy	354	5024	255	99	$1,600,644	$ 319	$ 3,147,934	$ 627	$11,844,767	$ 2,357
Dairy support	45	1358	33	12	$ 197,064	$ 145	$ 387,560	$ 285	$ 1,458,276	$ 1,074
Sheep and dairy	63	3007	53	10	$ 162,861	$ 54	$ 320,293	$ 107	$ 1,205,170	$ 401
Sheep and beef	150	6682	117	33	$ 528,661	$ 79	$ 1,039,704	$ 156	$ 3,912,105	$ 585
Forestry	21	7095	21	0	$ -	$ -	$ -	$ -	$ -	$ -
Total farm	633	23166	480	154	$ 2,489,232	$ 107	$ 4,895,490	$ 211	$18,420,319	$ 795
Incentives	0		-142	142	$ 8,520,000		$16,756,000		$31,524,000	
									$31,524,000	Shortfall
TOTAL					$11,009,232		$21,651,490		$81,468,319	

NOTE - incentives fund fails under 5000ha/50% scenario - leaving a 71t shortfall

4.5 Implications of scenarios for debt servicing and equity

The levels of debt held by land owners in the Rotorua catchment are of particular concern for two reasons. First, falls in profit may make it difficult for farmers to continue to service debt, resulting in an increasing number of farms with negative returns. Second, drops in land value associated with nitrogen restrictions (as outlined in section 4.4 above) may exceed the equity held by some farmers.

In purely economic terms, this impact is neutral at the catchment scale, as some farms that go bankrupt would be expected to be bought by others that would continue to farm them for profit. Farms that are sold after the rules are in place are likely to be cheaper, and so the return on capital for these farms would return to normal, while the majority of the costs of transition fall on one generation of farmers. Any bankruptcies associated with this transition would create a significant social impact on the community.

5. Conclusions

The primary objective of this analysis has been to evaluate a number of proposed systems regarding the allocation of entitlements to leach nitrogen among commercial farmers within the catchment of Lake Rotorua. A catchment-level economic model was utilised to explore the biophysical and economic implications of diverse allocation systems for nitrogen-leaching entitlements. Key impacts across all scenarios are:

1. An increase in forestry area, around 85% and 60% in Scenarios 1–2 (an increase from 7,095 ha to 11,403 and 13,085 ha respectively)
2. A reduction in dairying area of around 40% from 5024 to 3046 ha.
3. A reduction in sheep and dairy support area of approximately 37% from 3007 to 1900 ha.
4. Remaining dairy farm types must purchase N in order to remain viable. Changes to the allocation system vary the costs for these farm types, but not the optimal management regime.
5. Lower-intensity dairy-support options involve substantial scope for de-intensification at reasonable cost to profit, though this is balanced by relatively high capital impacts.

6. The profit of many drystock enterprises benefits from a capacity to increase their nitrogen-use efficiency and sell entitlements to dairy farm types and the incentives fund.
7. The capital impacts on land prices from reducing nitrogen leaching entitlements are significant for both drystock and dairy farm types.
8. A significant reduction in cow number, nitrogen fertiliser application, supplement use, and farm labour in the dairy sector, with each effect likely to have regional implications.
9. Changes in the efficiency of land-use change or nutrient trading have large implications for the overall cost.

Results show a modest impact on total catchment profit. However, the impacts on profit are distributed unevenly across sectors, land-uses, and spatial zones. Large-scale changes in land-use will also have district or regional implications due to the change in services provided.

Different allocation regimes create further variation in the distribution of cost. In general, drystock farm profits benefit from the ability to sell N (to higher profit per kilogram of N businesses and the incentives fund). Dairy farm profits fall due to the need to acquire N in order to continue operating. Under allocations with more redistribution (such as equal allocation and natural-capital systems), dairy farm profits fall further, but drystock profits are not correspondingly improved. This is due to the majority of redistributed allowances (relative to the current state) being transferred from dairy farms to foresters under these regimes, rather than other pastoral uses. Allocation regimes that require a large amount of redistribution also result in the N price rising due to increased dependence on trading and increased market demand.

Likely capital impacts due to the change of rights in land are significant, particularly when market friction is included and particularly under natural-capital allocation. The combination of profit and capital impacts will have negative consequences for many farmers, though some will be more affected than others. The interaction of profit, debt servicing requirements, and equity impacts may be severe for some farmers, with corresponding social impacts.

6. Limitations

A number of limitations are evident in the study, as with any modelling exercise. Indeed, all modelling studies are inherently flawed given that they cannot replicate reality, and must try to balance capturing the key stylised facts of the problem at hand while also working within real resource constraints, especially those related to budget, data, and time.

The main restrictions of this analysis are:

1. Non-commercial land-uses have not been considered in any detail due to a paucity of data and broad heterogeneity surrounding the cost of mitigating nitrogen loss from this source.
2. The study focuses on dairy, dairy support, sheep and beef, sheep and dairy support, and forestry sectors due to their significance in the study region, relative to other commercial land-uses, and their broad distribution across a number of biophysical conditions. Other commercial land-uses are important in this region, but are not studied here given their smaller contribution (both to the economy and total level of N leaching) and because limited resources complicated extending the coverage of the study to include them.
3. It is difficult to classify land-use among different biophysical zones since land-use changes across time and databases are not updated continuously. Moreover, databases had to be merged to form input data for this modelling, and these different sources differed in their level of quality and recency.
4. The model focuses on the identification of steady-state solutions, and therefore does not directly attempt to address the difficult topics of adaptation and optimal transition. This approach is justified given the complexity of studying intertemporal behaviour in economic models (section 2.1), yet means that innovation and the process of diffusion for mitigation technologies (Pannell et al., 2006) are not represented with any richness. Nevertheless, the implications of land-use transition are considered thoroughly through the incorporation of a detailed description of transition benefits and costs that are borne when such change occurs.
5. A lack of resources (primarily budget, data, and time) has precluded a rich definition of the likely mitigation-cost relationships that exist for individual farms within the catchment. Instead, this analysis follows typical practice (e.g. Doole, 2012;

Daigneault et al., 2012) and integrates average abatement-cost relationships generated for representative farms.

6. The mitigation-cost curves for each farm are estimated by a single farm consultant (Lee Matheson, Perrin Ag Consultants, Rotorua), based on mitigation protocols developed through a deliberative process. However, broader consultation with other consultants and producers during the generation of these curves could have improved their richness and level of representativeness.
7. The model is deterministic and thus does not consider variability in any economic (e.g. product price) or biophysical (e.g. climate) relationships or how farmers can best be expected to respond to this variation. This follows standard practice, given practical difficulties associated with estimating how broadly-diverse farms may respond to such stochasticity in their decision-making environment.
8. An optimisation approach is used to predict expected population responses to the introduction of alternative allocation and trading systems. Neo-classical economics is based on a central premise of perfectly-rational decision making, despite a wealth of experimental evidence opposing this general view (Angner and Loewenstein, 2012). Nevertheless, the utilisation of optimisation methods allows the employment of a consistent way of selecting among alternative solutions, avoiding the arbitrary nature of trial-and-error search that would be required if optimisation were not adopted as the overarching modelling approach at the catchment level. Indeed, the size of the model also complicates any capacity for such a search procedure to efficiently identify suitable optima, further motivating the use of an optimisation methodology.
9. Inherent to the use of a deterministic-optimisation framework, such as that applied in this analysis, is the assumption that the relative impact and value of alternative mitigation options is known with certainty by a central planner with full flexibility, and these options are adopted instantaneously to meet a target at least cost. This provides a highly-optimistic view of the problem facing regulators, given that it typically takes many years for bundles of conservation practices to be adopted across a farming population, particularly given the high level of heterogeneity between farms and farmers (Pannell et al., 2006).
10. Land-use change is a temporal process influenced by many factors, such as input and output price trends, innovation, expectations, productivity, and environmental policy. Sophisticated methods are available to richly represent these dynamics, based on historical trends (Heckelei et al., 2012). A limitation of this analysis is that it does not

deal with land-use change at this level of sophistication. However, a scenario-based approach is deemed to be more valuable, because it links closely with recommended practice for participatory modelling alongside stakeholders (Harris and Snelder, 2014), it bypasses technical difficulties involved with representing land-use change in optimisation models (Doole and Marsh, 2014a, b), it integrates easily with stakeholder expectations regarding the degree of land-use change that will occur, and it is consistent with the fact that it is problematic to estimate future land-use change based on historical data, given that the introduction of nitrogen-leaching limits will introduce a new evolutionary force that will likely affect the trajectory of land-use change in this catchment. There was also strong stakeholder feedback regarding the degree of land-use change allowed in the model, with unlimited conversion being a key scenario to show to what extent management would have to change, relative to the current position, in order to achieve cost-effective mitigation at the catchment scale.

11. The output of the model concerns only farm-level costs, and not those associated with regional impacts. For example, milk production falls by 40% in some scenarios in this report, and this would likely have flow-on impacts to the viability of related industries (such as milk-processing firms) in the region that are not considered in this study. Nonetheless, regional-level impacts have been considered in a related economic study, undertaken by Market Economics.
12. The proximity of land analysed in this study to Lake Rotorua has meant that attenuation has not been represented. This is an apparent simplification given that the groundwater processes present in this catchment are complex and affect the spatial link between nitrogen loss on land and its delivery to the lake (Anastasiadis et al., 2014).
13. The relationship between profit and leaching has been generated using two simulation models—FARMAX and OVERSEER. Both are leading forms of software used to estimate the implications of farm management for profit and leaching, respectively. However, both ultimately provide abstract descriptions of reality.
14. The mitigation protocols used in this study were generated using a deliberative process, building on past experience and research. Nevertheless, there is no guarantee that the mitigation protocols generated represent the best response that average farmers could be expected to have to limits placed on nitrogen leaching. This is particularly so because co-learning across a population of farmers in response to

limits and innovation are both ignored, given pragmatic difficulties associated with estimating these in reality.

15. Distributional impacts across different farmers are not calculated specifically. Fairness and equity principles are difficult to quantify (Holland and Doole, 2014) and capture richly in a model that utilises representative farms to depict mitigation-cost relationships for diverse spatial zones. Nevertheless, distributional impacts are a core focus of the discussion presented in section 4.

Despite these limitations, the development and application of the catchment-level model here is in accordance with standard practice in this field. Hence, it provides a pragmatic and valid method to assess the relative value of diverse allocation mechanisms in the Lake Rotorua catchment.

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