Economic analysis of the re-allocation of nutrient entitlements in the Lake Rotorua catchment

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1. 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. The Regional Council has set a nitrogen (N) limit for Lake Rotorua of 435 t N per year, through the Proposed Plan Change 10 (Lake Rotorua Nutrient Management) to the Bay of Plenty Regional Policy Statement (BOPRPS). This limit is set to require an estimated total reduction of 320 t N per year across the catchment, with about 270 t N per year expected to arise from the pastoral sector. An intensive participatory process—involving a Stakeholder Advisory Group (StAG)—was undertaken to develop an appropriate regulatory mechanism to achieve these reductions. This program is based around the development of a trading scheme and associated allocation system to assign nutrient-loss entitlements among farmers in the catchment.

The evaluation of alternative allocation systems was explored in the research of Parsons et al. (2015). These authors focused on how diverse allocation mechanisms could be expected to influence farmer decision making—encompassing both land-use decisions and on-farm mitigation behaviour—in the Lake Rotorua catchment and how trade in nutrient entitlements could be utilised to overcome distortions arising from their initial allocation. Feedback received on this assessment has brought to light the potential for alternative allocation systems. These alterative mechanisms centre around forested land receiving a higher initial nutrient allocation, at the expense of the pastoral sector. These scenarios have been developed based on the hypothesis that it will provide increased land-use flexibility to forestry owners, providing an incentive for them to move better classes of land out of forest.

Six new management scenarios (Scenarios 9–14) are evaluated in this analysis, each an extension of the Sector Range 2 scenario (Scenario 8 or S8) considered by Parsons et al. (2015). The Range 2 scenario is the appropriate counterfactual in this study, given that this has been selected by the stakeholder group as their preferred management option. The re-allocation scenarios studied here increase the nitrogen allocation to forestry, simultaneously reducing the allocation of entitlements to other sectors by the corresponding amount. The results of this analysis contribute to knowledge about private benefits and costs, resource efficiency, and the ease of transfer of nitrogen-leaching entitlements. 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 the pastoral sector. The distributional impacts of each re-allocation scenario are also paid particular attention.

2. Methods

2.1 Economic model

This study involves the employment of a non-linear optimisation framework (Bazaraa et al., 2006). This model identifies how land use and land management must change under different circumstances to mitigate nitrogen loss at least cost, given the data defined in the model. 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 (Howard et al., 2013; Holland and Doole, 2014) and internationally (Beverly et al., 2013; Doole et al., 2013). This modelling framework is valuable due to its flexibility, straightforward calibration, use of a consistent and defensible objective to select between alternative outcomes, and capacity to efficiently describe trading activity in a market for nutrient entitlements (Doole et al., 2011; Doole, 2015).

The catchment is divided into a high number of diverse spatial zones in the model, each varying by slope, rainfall, and soil type. These were further partitioned into different types of representative farms, based on the typical systems observed in each spatial zone. Within each zone, the model can select from several management strategies, each with its own level of nitrogen loss, profit, and production. The model selects the most-profitable combination of these choices across the catchment, when optimised for a given scenario. The intention is to gain insight into how an average producer in a given rainfall, slope, soil, and land-use partition would profitably respond to the regulatory reality simulated in the model.

In this model, the limit for leaching is implemented through the representation of permits. Entitlements are allocated among the population according to diverse allocation systems, with the total level of entitlements being set to the nitrogen target for the catchment. Under these different allocation mechanisms, farms are required to reduce their nutrient loss equal to or beneath their allocated level of entitlements or else they have to buy entitlements from a party that has a surplus. This requirement for some or all the producers within the catchment to reduce their nitrogen loss beneath their accumulated set of entitlements increases the area of land on which a mitigation option is used—rather than the baseline (current) management option. This will 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 than utilise a mitigation option within the baseline land use.

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 over time 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 and are therefore costly from a project-resourcing perspective (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.

2.2 Economic data

This section outlines the input data used within this application of the LAM model to the Lake Rotorua catchment. Some input data involves capital expenditures; for example, the sale of livestock. These capital expenditures are annualised using an 8% interest rate over a 25-year period.

The catchment is divided into a large number of spatial zones depending upon soil type, slope, and rainfall level. 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 being a relatively-small area of the catchment, with the added complexity required to incorporate them deemed to provide limited additional insight into the economic and environmental trade-offs that exist at the catchment level. 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 and 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. For this reason, three different sizes of drystock farm were included: large (>300ha), medium (40–300ha) and small blocks (2–40ha). A large proportion (40-50%) of the drystock-farming area is in a small number of large farms. These are generally the most-economic units, operating at (or with potential to operate at) the level of Beef and Lamb New Zealand production systems 4–5 in terms of intensity. Typically, these operations possess a 50:50 sheep:cattle ratio with a breeding-ewe flock lambing at 130–140%, combined with either a cattle-trading or dairy-support enterprise. Medium-size drystock farms tend to be centred on beef, dairy support, and cropping/baleage production, but with a few farms focused on deer production or maintenance of a breeding-ewe flock. About half of these blocks are leased by dairy farmers as runoffs and most require less than 1 full-time equivalent (FTE) of labour. In general, these blocks are similar to large drystock blocks in terms of management options, but on average will earn slightly lower profit per hectare due to scale, productivity, and management constraints.

The Rotorua catchment has a large number of small blocks. Though individual small blocks do not contribute much to the total nitrogen load to the lake, some uses are relatively intensive and they represent a large area, contributing an estimated 130 tonnes of nitrogen per annum. Small blocks are extremely diverse and include lease blocks, dairy support, drystock, cropping, and lifestyle enterprises. Sheep are rare on these blocks, due to the lack of appropriate infrastructure. Some small blocks are run quite intensively (e.g. break-feeding dairy cows and feeding out supplement for them over winter). The majority of these small blocks are on pumice soils on flat land close to the lake. Small blocks have limited mitigation options and limited land-use change options; for example, plantation forestry is unlikely to be economic at this scale. Small blocks are constrained within the catchment model to prevent land-use change to forestry or sheep enterprises, based on these factors. Values that do not impact on the profitability of businesses, such as lifestyle or aesthetic preferences, are difficult to incorporate directly in this study. However, the constraints to land-use change and trading used in the catchment scenarios indirectly represent these non-economic preferences (Scenario 2.3).

The majority of dairy farms in the Lake Rotorua catchment are located in the higher-rainfall areas possessing podzol and pumice soils. 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 geophysical zones.

Ownership of land is not represented within the model. Thus, any distinction between individual farms and ownership (e.g. multiple-owned iwi land) is not made. Rather, the main building block of the analysis is the individual zones—describing individual land uses and the biophysical zones in which they are located—that are delineated within the catchment.

The cost of reducing nitrogen loss from each land use in each spatial zone is evaluated for representative farms, which are developed according to knowledge of typical practice in these areas. A representative farm for each relevant land use is developed for each partition, based on the observation of typical characteristics of farms within each geographical 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 file is created utilising the baseline physical and financial data defined for each representative dairy and drystock farm. 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 in the generation of input data 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.

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 wide-scale disparity in their individual characteristics.

The alternative mitigation strategies represented in the model and their impacts on nutrient loss, production, and profit are outlined in the Appendices in the Parsons et al. (2015) report. These results are summarised for dairy (Appendix 1), sheep and beef (Appendix 2), sheep and dairy support (Appendix 3), dairy support (Appendix 4), and forestry (Appendix 5).

Transition costs are those costs associated with changing from one land use to another. These are estimated and incorporated, so that each land-use change that occurs bears any 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 1 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. livestock, supplier shares). These transition-cost data involve many capital expenditures—for example, the sale of livestock—that are annualised in model output to avoid bias. These capital expenditures are annualised using an 8% interest rate over a 25-year payback period, according to convention.

It is observable that 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. 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. However, when interpreting output, it is important to recognise that forestry returns are highly intermittent and not constant across years.

The LAM model is solved in this application using non-linear programming in the General Algebraic Modelling System (GAMS) (Brooke et al., 2017).

Table 1. 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. All values are drawn from Matheson (2015).

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

2.3 Scenarios

Parsons et al. (2015) analysed eight scenarios involving different scenarios for initial allocation. These are extended here to include an additional six—hereafter referred to as Scenarios 9–14 (Table 2). Two levels of re-allocation are explored; these are 14 t and 28 t of nitrogen. These levels have been identified using Overseer version 6.2.0. The model has been developed using data from an earlier Overseer version (version 6.1.2); thus, a calibration method is used to generate a re-allocation level equivalent to that reported under Overseer version 6.2.0. The equivalent amounts are 10.8 and 21.6 tonnes, respectively. Table 2 outlines the re-allocation scenarios explored in this report. A key point from Table 2 is that re-allocation from drystock enterprises is assumed to impact dairy support, sheep and beef, and sheep and dairy-support activities.

Table 2. Re-allocation scenarios for nitrogen (N) analysed in this report.

Scenario name	Short version	Description
Scenario 8 From Parsons et al. (2015).	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}.
Scenario 9	S9	A variant of Scenario 8 in which the upper limit of dairy leaching is reduced such that the dairy allocation is reduced by 10.8 tonnes. The 10.8 tonne reduction is now allocated to forestry land.
Scenario 10	S10	A variant of Scenario 8 in which the upper limit of dairy leaching is reduced such that the dairy allocation is reduced by 5.4 tonnes. Also, non-benchmarked drystock allocations are reduced to achieve a reduction of 5.4 tonnes. The drystock reduction is spread across dairy support (12.3%), sheep and beef (60.5%), and sheep and dairy support (27.2%) activities. The 10.8 tonne reduction is now allocated to forestry land.
Scenario 11	S11	A variant of Scenario 8 in which non-benchmarked drystock allocations are reduced to achieve a reduction of 10.8 tonnes.

		The drystock reduction is spread across dairy support (12.3%), sheep and beef (60.5%), and sheep and dairy support (27.2%) activities. The 10.8 tonne reduction is now allocated to forestry land.
Scenario 12	S12	A reduction by 21.6 tonnes, achieved through a combination of S9 and S11. The reduction of 21.6 tonnes from pastoral land is now allocated to forestry land.
Scenario 13	S13	A flat-rate percentage cut across all pastoral sectors, to achieve a 10.8 tonne reduction. The 10.8 tonne reduction is now allocated to forestry land.
Scenario 14	S14	A flat-rate percentage cut across all pastoral sectors, to achieve a 21.6 tonne reduction. The 21.6 tonne reduction is now allocated to forestry land.

These scenarios are evaluated for two different trading contexts.

The first context involves no trading frictions and a restriction of land-use change to 5000 ha. This limit for land-use change is valuable because it is consistent with stakeholder expectations, helps to capture important constraints absent from the model (e.g. risk aversion, lifestyle impacts), aids calibration while remaining transparent to stakeholders, allows straightforward sensitivity analysis, and does not require historical data for its use.

The second context involves unlimited land-use change and frictions in the trading market for nutrient entitlements. This demonstrates how a potential undersupply of leaching entitlements in the market could affect the performance of alternative policies. The impacts of changes in the efficiency of the trading market were explored through allowing only 50% of the optimal level of trading in nutrient-leaching entitlements to occur, as simulated in Parsons et al. (2015). The remaining nutrient entitlements are retained by the producers they are allocated to.

There is broad empirical evidence outlining that markets for water quality may not always function efficiently due to a reluctance of farmers to trade due to risk aversion, information constraints, and high uncertainty (Howard et al., 2013; Shortle, 2013). Farmers are aware that retaining leaching rights provides some protection against risks posed by further changes in environmental, market, and political conditions. Furthermore, when faced with the possibility of adopting a given practice, risk aversion is a key factor that prevents most people using that option (Rogers, 2003). This is especially an issue with agricultural populations, given that in applied research most farmers are found to be risk averse (Pannell et al., 2006, 2014). These observations are consistent with recent experimental evidence that highlights that human subjects in a simulated market for pollution entitlements broadly failed to achieve the predicted equilibrium outcomes, especially due to people's aversion to losing entitlements that they already had in hand (Marsh et al., 2014). This observation is further 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).

Previous work has showed that restrictions on nitrogen leaching may motivate a leftward shift of the distribution of farm profit within a farm-sector population (Howard et al., 2013). This is difficult to analyse in this application because, in line with standard catchment models, the framework applied here does not represent individual farms. Frameworks that represent individual farms exist and are generally referred to as "agent-based models". Indeed, these have been applied throughout New Zealand, such as in the Canterbury (Daigneault and Morgan, 2012), Hawkes Bay (Schilling et al., 2012), and Waikato regions (Doole, 2010; Doole et al., 2011; Doole and Pannell, 2012; Doole et al., 2012). Such frameworks provide a very rich description of individual agents, with diversity represented in risk aversion, personal networks, management objectives, and production-system intensity, among other factors. An agent-based framework is not utilised here because of a lack of suitable empirical data that can be used to generate a realistic description of the personal characteristics of diverse individual producers within a given catchment and/or allow a validation of model predictions outside of the baseline situation. These are common constraints accruing to the application of agent-based models (Windrum et al., 2007), but are particularly relevant in New Zealand because of privacy restrictions, integral data being held across diverse organisations (Doole et al., 2011), and the significant cost and time associated with collecting suitable data from producer populations to inform model development.

Nevertheless, while the model cannot be used to analyse the variation among individual farms, the standard deviation of average profit earned across each partition is used to provide some insight into the effects of different scenarios on the distribution of profit within the catchment. Variation in farm profit across partitions is reported in this analysis through the use of the standard deviation and the coefficient of variation. The coefficient of variation is computed as the ratio of the standard deviation and the mean, with a higher value indicating a greater degree of dispersion within a sample.

3. Results and Discussion

This section reports the results of the analysis and provides a discussion of them. The following tables are presented. Table 3 reports key model output for the baseline run, Scenarios 8–14 for the case where trading is optimised and there is a 5000 ha limit on land-use change, and Scenarios 8–14 for the case where trading frictions exist and there is no limit on land-use change. Table 4 presents information that attests to the dispersion of farm profit (after trade) for the case where trading is optimised and there is a 5000 ha limit on land-use change. By contrast, Table 5 reports information regarding the variation of farm profit (after trade) for the case where land-use change is unlimited, but there are frictions present in the market for nutrient entitlements. Forest profit is also provided in these tables, for ease of comparison. Table 6 outlines the sale and purchase of nutrient-leaching entitlements where trading is optimised and there is a 5000 ha limit on land-use change. In comparison, Table 7 reports information attesting to the sale and purchase of entitlements where trading is subject to frictions and land-use change is unlimited.

3.1 Scenarios 9–14 with limited land-use change and optimal levels of trade

Table 3 reveals several important insights. Catchment profit increases in all scenarios, relative to the baseline. Substantial increases are observable, with catchment profit increasing by 15% when land-use change is unlimited and there are no frictions; 14% when land-use change is limited at 5000 ha and there are no frictions; and around 8%, on average, when land-use change is unlimited and there are frictions. These outcomes highlight that mitigation has potential benefits for farm-level profit, when land-use change is flexible and there is active trading of nitrogen-leaching entitlements. The inclusion of the incentives fund buying nitrogen (represented in the model as an annualised payment) also has a significant influence.

Table 3. Model output for baseline run, with optimal trading patterns and a 5,000 ha limit on land-use change, and with trading frictions and no limit on land-use change. S8 outcomes are taken from Parsons et al. (2015). "Kg N" is short for "Kg N ha^{-1}".

Variable	**Unit**	**Output**									
Scenario	-	Current	Optimal	S8–S14	S8	S9	S10	S11	S12	S13	S14
Trading	-	Base	Opt. trade	Opt. trade	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.
LU change	-	0	Optimal	5,000 ha	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Total profit	$m	14.44	16.63	16.43	15.76	15.47	15.57	15.68	15.36	15.67	15.55
Area											
Dairy	ha	5,024	3,046	2,754	2,889	2,986	2,920	2,853	2,958	2,882	2,866
Dairy sup.	ha	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358
Sheep & beef	ha	6,682	4,666	5,752	7,133	7,442	7,573	7,717	7,884	7,433	7,781
Sheep & sup.	ha	3,007	999	1,900	1,080	1,163	1,129	1,094	1,097	1,165	1,167
Forestry	ha	7,095	13,098	11,403	10,707	10,216	10,187	10,144	9,870	10,329	9,995
Leaching											
Dairy	kg N	70	67	66	54	54	50	52	53	50	53
Dairy sup.	kg N	33	20	18	26	26	27	26	26	27	27
Sheep & beef	kg N	22	13	21	19	19	19	18	18	18	18
Sheep & sup.	kg N	21	19	16	14	14	14	14	14	14	14
Forestry	kg N	3	3	3	3	3	3	3	3	3	3
N price	kg N	-	60	118	444	444	444	444	444	444	444
Production											
Milk	t MS	5,142	3,389	3,039	3,128	3,228	3,163	3,097	3,198	3,127	3,108
Wool	t	509	334	412	484	505	509	515	526	504	527
Sheep meat	t	1,584	1,049	1,290	1,512	1,576	1,591	1,610	1,646	1,577	1,652
Beef	t	2,191	1,631	1,746	297	2,081	2,089	2,097	2,132	2,078	2,144
Farm stats.											
Cows	head	13,614	8,540	7,711	8,080	8,382	8,191	8,002	8,303	8,079	8,033
N fertiliser	t urea	923	407	363	430	444	435	427	439	432	429
Supplement	t DM	26	19	17	19	20	20	19	20	19	20
Farm labour	FTE	157	132	127	44	45	44	43	45	44	43

Table 4. Sector-level farm profit per hectare (after trade) when land-use change is limited at 5,000 ha and there are no frictions in the entitlements market. "Av. profit" denotes average profit. "Std. dev." denotes standard deviation. "CoV" denotes coefficient of variation. The coefficient of variation is the ratio of the standard deviation and the mean, and hence is a measure of dispersion. The standard deviation is computed based on variation in profit across partitions, not within partitions, given the structure of the model.

Variable	**Unit**	**Output**							
Scenario	-	**Current**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**
Trading	-	Base	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade
LU change	-	0	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha
Total profit	$m	14.44	16.43	16.43	16.43	16.43	16.43	16.43	16.43
Av. profit									
Dairy	$/ha	1,638	1,925	1,901	1,913	1,925	1,901	1,918	1,910
Dairy sup.	$/ha	515	1,218	1,218	1,215	1,211	1,211	1,213	1,208
Sheep & beef	$/ha	388	454	454	451	447	447	452	449
Sheep & sup.	$/ha	333	283	283	273	265	265	281	278
Forest	$/ha	283	606	612	612	612	618	610	615
Std. dev.									
Dairy	$/ha	401	8	10	9	8	10	9	10
Dairy sup.	$/ha	217	413	413	420	424	424	407	406
Sheep & beef	$/ha	82	98	98	103	107	107	98	98
Sheep & sup.	$/ha	129	69	69	74	79	79	69	69
CoV									
Dairy	-	0.24	0.00	0.01	0.00	0.00	0.01	0.00	0.01
Dairy sup.	-	0.42	0.34	0.34	0.35	0.35	0.35	0.34	0.34
Sheep & beef	-	0.21	0.22	0.22	0.23	0.24	0.24	0.22	0.22
Sheep & sup.	-	0.39	0.24	0.24	0.27	0.30	0.30	0.25	0.25

Table 5. Sector-level farm profit per hectare (after trade) when land-use change is unlimited and there are frictions in the entitlements market. "Av. profit" denotes average profit. "Std. dev." denotes standard deviation. "CoV" denotes coefficient of variation. The coefficient of variation is the ratio of the standard deviation and the mean, and hence is a measure of dispersion. The standard deviation is computed based on variation in profit across partitions, not within partitions, given the structure of the model.

Variable	**Unit**	**Output**							
Scenario	-	**Current**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**
Trading	-	Base	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.
LU change	-	0	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Total profit	$m	14.44	15.76	15.47	15.57	15.68	15.36	15.67	15.55
Av. profit									
Dairy	$/ha	1,638	1,717	1,619	1,667	1,717	1,619	1,690	1,664
Dairy sup.	$/ha	515	1,671	1,675	1,659	1,643	1,829	1,657	2,044
Sheep & beef	$/ha	388	439	436	435	434	425	434	432
Sheep & sup.	$/ha	333	291	292	386	392	392	287	282
Forest	$/ha	283	701	701	708	714	686	716	671
Std. dev.									
Dairy	$/ha	401	305	395	356	305	407	302	298
Dairy sup.	$/ha	217	616	599	1,760	1,758	1,801	609	853
Sheep & beef	$/ha	82	98	99	135	133	134	98	98
Sheep & sup.	$/ha	129	50	50	234	241	241	49	50
CoV									
Dairy	-	0.24	0.18	0.24	0.21	0.18	0.25	0.18	0.18
Dairy sup.	-	0.42	0.37	0.36	1.06	1.07	0.98	0.37	0.42
Sheep & beef	-	0.21	0.22	0.23	0.31	0.31	0.32	0.23	0.23
Sheep & sup.	-	0.39	0.17	0.17	0.61	0.61	0.61	0.17	0.18

Table 6. Trading of nitrogen (N) entitlements between different sectors when land-use change is limited at 5,000 ha and no frictions exist. Sale and purchase amounts are rounded to the nearest tonne. Sale and purchase totals may not be equivalent for each scenario, due to rounding error.

Variable	**Unit**	**Output**							
Scenario	-	**Current**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**
Trading	-	Base	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade	Opt. trade
LU change	-	0	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha	5,000 ha
Total profit	$m	14.44	16.43	16.43	16.43	16.43	16.43	16.43	16.43
Area									
Dairy	ha	5,024	2,754	2,754	2,754	2,754	2,754	2,754	2,754
Dairy support	ha	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358
Sheep & beef	ha	6,682	5,571	5,571	5,571	5,571	5,571	5,571	5,571
Sheep & sup.	ha	3,007	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Forest	ha	7,095	11,403	11,403	11,403	11,403	11,403	11,403	11,403
Sale of N									
Dairy	t N	-	0	0	0	0	0	0	0
Dairy sup.	t N	-	20	20	20	20	20	19	19
Sheep & beef	t N	-	11	11	9	7	7	9	7
Sheep & sup.	t N	-	2	2	1	1	1	1	1
Forest	t N	-	123	134	134	134	144	130	138
Purchase of N									
Dairy	t N	-	41	52	46	41	52	44	47
Dairy sup.	t N	-	0	0	1	1	1	0	0
Sheep & beef	t N	-	0	0	1	2	2	1	1
Sheep & sup.	t N	-	7	7	8	9	9	7	8
Forest	t N	-	0	0	0	0	0	0	0
Incentive fund	t N	-	108	108	108	108	108	108	108

Table 7. Trading of nitrogen (N) entitlements between different sectors when land-use change is unlimited and frictions exist. Sale and purchase amounts are rounded to the nearest tonne. Sale and purchase totals may not be equivalent for each scenario, due to rounding error.

Variable	**Unit**	**Output**							
Scenario	-	**Current**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**
Trading	-	Base	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.	50% frict.
LU change	-	0	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal	Optimal
Total profit	$m	14.44	15.76	15.47	15.57	15.68	15.36	15.67	15.55
Area									
Dairy	ha	5,024	2,889	2,986	2,920	2,853	2,958	2,882	2,866
Dairy support	ha	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358
Sheep & beef	ha	6,682	7,133	7,442	7,573	7,717	7,884	7,433	7,781
Sheep & sup.	ha	3,007	1,080	1,163	1,129	1,094	1,097	1,165	1,167
Forest	ha	7,095	10,714	10,216	10,187	10,144	9,870	10,329	9,995
Sale of N									
Dairy	t N	-	0	0	0	0	0	0	0
Dairy sup.	t N	-	16	16	16	16	19	15	23
Sheep & beef	t N	-	2	2	2	1	1	2	1
Sheep & sup.	t N	-	3	3	2	2	0	1	0
Forest	t N	-	95	95	96	96	95	98	92
Purchase of N									
Dairy	t N	-	8	8	7	7	7	8	8
Dairy sup.	t N	-	0	0	0	1	1	0	0
Sheep & beef	t N	-	0	0	0	0	0	0	0
Sheep & sup.	t N	-	0	0	0	0	0	0	0
Forest	t N	-	0	0	0	0	0	0	0
Incentive fund	t N	-	108	108	108	108	108	108	108

The optimal level of profit identified with the presence of no frictions in the market for leaching entitlements—even when land-use change is limited to 5,000 ha—is close to that reported for the optimal solution with trade and land-use change unrestrained. Indeed, the profit in the unrestrained case (\$16.63 m) is only \$0.2 m above that reported for the case where limits to land-use change are simulated (\$16.42 m). This translates to a reduction of only 1%. The optimal level of profit identified with the presence of no frictions and with land-use change limited to 5,000 ha is the same as that reported for Scenario S8 in Parsons et al. (2015) (Table 3). Chiefly, the efficiency of trading is sufficiently high in this set of runs that no matter what the initial allocation, nutrient entitlements can be traded with such flexibility that they reach their most-profitable equilibrium distribution across the catchment. This is observable in the low price for nitrogen entitlements (\$60 kg N^{-1}), relative to the cases where substantial trading frictions are represented and a high price for nitrogen in the market for nutrient entitlements results (\$118–\$444 kg N^{-1}) (Table 3).

High-level characteristics of the optimal outcomes are consistent for Scenarios S8–S14 when land-use change is limited to 5,000 ha (Table 3). Key output for which no change is observed includes land areas allocated to the dairy, drystock, or forestry sectors; production of milk, wool, sheep meat, and beef meat; dairy-cow numbers; nitrogen-fertiliser application; supplementary-feed use; and farm labour (Table 3). In addition, the level of farm profit earned *before* monies involved in the trading of entitlements (e.g. money earned/expended from the sale/purchase of nutrient entitlements) are accounted for does not change (data not shown).

The primary differences that arise between Scenario S8 and Scenarios S9–S14, when trading is unconstrained and land-use change is limited at 5,000 ha, are the profit levels for each farm sector that are observed *after* monies from the trading of nutrient entitlements are accounted for. This is shown in Table 4 that reports the variation of farm profit after trade for each pastoral sector. Re-allocation of entitlements taken from the pastoral sector potentially reduces management flexibility therein. It also incurs a loss of asset value, given that leaching entitlements represent an economic asset that can be traded for money and allow land owners to meet their environmental obligations and thus avoid penalisation. The model predicts that producers would likely respond to this loss of flexibility through the purchase of entitlements for leaching; in fact, this would occur to the extent that the purchase of these leaching entitlements would exhibit little difference across S8–S14 when trading is frictionless (Table

6). Indeed, under the re-allocation scenarios (S9–S14), it is apparent that forestry by and large sells their additional leaching entitlements rather than using them to drive intensification relative to any other scenario in Table 6. This trend is also observed when frictions exist in the market for nutrient entitlements; this is discussed in detail in Section 3.2, with respect to the data presented in Table 7.

These purchase and sale patterns under re-allocation drive disparate outcomes across profit for each sector. Several key outcomes are observed with respect to this feature of model output, reported in Table 4:

a. Dairy profit after trading decreases in S9–S10 and S12–S14 because dairy farms must now purchase more entitlements for nitrogen, relative to S8, to reach their optimal level. The exception is S11 in which re-allocation does not affect dairy farms, only drystock operations. The maximum decrease in dairy profit is \$24 ha^{-1}; this is observed in S9 and S12, when 10.8 t[1] of nitrogen is taken solely from the dairy sector (Table 4).
b. Re-allocation from the drystock sector is assumed to involve dairy support in the modelling (see Table 2). Profit after trading in this land use decreases in all scenarios, relative to S8, except for in S9 where re-allocation does not affect drystock farms. The decrease is between \$3 ha^{-1} and \$10 ha^{-1} for the dairy-support sector (Table 4). Profit decreases because there is a net purchase of entitlements in this land use. The greatest reduction in profit is observed from S14 where 21.6t is taken as a percentage reduction from all pastoral sectors.
c. Re-allocation from the drystock sector is assumed to involve the combined sheep and dairy-support activity represented in the modelling application (see Table 2). Profit after trading decreases from between \$2 ha^{-1} to \$18 ha^{-1} in this land use relative to S8, except for in S9 where the drystock sector is not affected by re-allocation (Table 4). Profit decreases because there is a net purchase of entitlements in this land use. The greatest reductions in profit are observed from those scenarios that remove 10.8 t[2] of nitrogen from non-benchmarked drystock (S11 and S12).
d. Re-allocation from the drystock sector is assumed to involve sheep and beef activity in the modelling application (see Table 2). Profit after trading decreases from between

[1] Equivalent to 14 tonnes of nitrogen under Overseer version 6.2.0
[2] Equivalent to 14 tonnes of nitrogen under Overseer version 6.2.0

$2 ha^{-1} to $7 ha^{-1} in this land use, relative to S8, except for in S9 where the drystock sector is not affected by re-allocation (Table 4). The greatest reductions in profit are observed from those scenarios that remove 10.8 t[3] of nitrogen from non-benchmarked drystock (S11 and S12).

e. The forestry sector is the beneficiary of the re-allocated nitrogen. Indeed, profit more than doubles for Scenarios S8–S14, relative to the baseline level of profit, because of the additional value accruing to this land use when a market for nutrient entitlements is established (Table 4). Re-allocation further augments forest profit since the model predicts that this sector is most likely to sell the additional rights they receive under this action (Table 6). In line with this assertion, forestry profit after trading is greatest under those scenarios in which 21.6 t[4] of nitrogen is removed (S12 and S14) since here re-allocation allows this sector to receive a larger allocation of nutrient entitlements that they can subsequently sell. This highlights how leaching entitlements are indeed a capital asset to the forest business once a market for them is established within the catchment. Under these conditions, profit per ha increases by $9–$12 ha^{-1}. In contrast, all of those scenarios that increase the allocation to forestry by 10.8 t (S9, S10, S11, and S13) increase per-hectare profit to forestry by about $6 per hectare (Table 4).

The introduction of nitrogen limits changes the shape and location of the distribution of farm profit (after trade). The impacts on the central moment (average) of the distribution are outlined above. Overall, this discussion identifies how re-allocation aids the forest sector, at the expense of the pastoral sectors, but not significantly. While the model cannot be used to analyse the variation in profit observed among individual farms (see Section 2.3), the standard deviation of average profit across each partition can provide some insight into the effects of different scenarios on the distribution of profit within the catchment. This data is provided in Table 4 for the case where land-use change is limited to 5,000 ha, but there are no frictions in the entitlements market. This data shows several interesting trends; noting hereafter that this discussion concerns the variation of profit across, and not within, model partitions.

[3] Equivalent to 14 tonnes of nitrogen under Overseer version 6.2.0
[4] Equivalent to 28 tonnes of nitrogen under Overseer version 6.2.0

1. The allocation of nitrogen under Plan Change 10 limits the variability observed in dairy profit across the diverse spatial zones of the Lake Rotorua catchment (Table 4). When the market for nutrient entitlements is frictionless, the model predicts that this sector becomes concentrated on podzol soils in high-rainfall areas and thus inter-zonal heterogeneity is limited, resulting in lower variability in returns in the model.
2. The level and variability of returns to dairy support under S8-14 are very similar (Table 4) since land use for this activity does not change. However, average profit increases dramatically in this enterprise, compared to the baseline, given the capacity to sell nutrient entitlements to the dairy sector and incentives fund following allocation (Table 6).
3. Returns to sheep and beef increase by about 15% and become slightly more variable as area increases (Table 3) and management options change, particularly to exploit win-win opportunities available within this sector across the catchment (Parsons et al., 2015).
4. The dispersion of farm profit for the combined sheep and dairy support activity falls, compared to the current baseline, as returns increase/decrease for less/more profitable partitions.

Overall, these findings highlight that changes in farm profit, both positive and negative, are to be an expected outcome from nitrogen allocation under Plan Change 10 and the various re-allocation scenarios and will vary significantly according to sector and spatial zone.

3.2 Scenarios 9–14 with optimal land-use change and limited levels of trade

The presence of frictions in the market for nutrient entitlements hampers the capacity for the catchment to attain higher-profit outcomes. Scenarios 8–14 exhibit a level of catchment profit that is from \$0.67 m to \$1.07 m lower, relative to the case where trading is subject to no rigidity but land-use change in constrained at 5,000 ha (Table 3). Moreover, Scenarios 8–14 exhibit a level of catchment profit that is from \$0.87 m to \$1.27 m lower, relative to the case where optimal trading and land-use change are observed (Table 3).

There are multiple sources of this inefficiency when trading is constrained:

1. A lack of entitlements distorts the market, with a restricted supply amplifying the equilibrium price of a unit of nitrogen. The optimal price of nitrogen is \$60 kg N^{-1},

but this increases to \$118 kg N^{-1} with restricted land-use change and to \$444 kg N^{-1} with the presence of frictions (Table 3). These higher-price outcomes are intuitive because they reflect an increased scarcity of nutrient entitlements in the market, arising from a reduced supply. (This can be conceptualised as a leftward-shift of the supply curve in the market for nutrient entitlements.)

2. A higher price promotes on-farm costs associated with nutrient mitigation within a given land use, as farmers have less flexibility with respect to how they mitigate contaminant loss. They cannot purchase affordable leaching entitlements in the market; thus, to meet their environmental obligations, they must utilise more mitigation activities on their land. The presence of frictions means that, on average, the leaching levels for dairy are around 20% too low, while the leaching levels for dairy support are about 25% too high (Table 3). This reflects the inability of dairy farmers to purchase enough nitrogen to maintain their most-profitable management plan (Table 7).
3. The lack of entitlements in the market restricts the amount that producers can acquire to permit them to change land use. The presence of frictions means that—relative to the optimal land-use pattern—the area of dairy and forestry is too low, while the area of drystock operations is too high (Table 3).
4. A higher price for entitlements inflates the amount of money utilised by the incentives fund to purchase a given level of nitrogen.

Where frictions in the entitlements market are present, there are significant changes observed in each sector, relative to the proposed S8 allocation. The upper leaching limit of dairy farms is reduced in Scenarios S9, S10, and S12 (Table 2). This leads to more dairying, more cows, more milk, more urea, more supplement, less forest area, and less leaching from dairy farms, relative to S8 (Table 3). A key cause is that, with frictions, insufficient afforestation occurs on dairy land, especially on allophanic and recent soils. Forest area decreases by 5, 8, 4, and 7% in Scenarios S9–S11, S12, S13, and S14, relative to S8. Further, the amount of dairy land converted to forest decreases by 9, 7, 4, 23, 2, and 24% in Scenarios S9, S10, S11, S12, S13, and S14, respectively. This causes a substantial drop in profit in the forest sector. For example, relative to S8, it falls by 14% and 13% in S12 and S14, respectively. (These scenarios are those that involve the largest re-allocations of nitrogen from the pastoral sector to the forest sector.) This is primarily a result of less forest area being planted, while also reflecting lower returns per ha (Table 5).

Additionally, costs increase in the dairy sector. First, around 15% more cows are managed on stand-off pads within these scenarios. This is significant given that the cost of stand-off use is \$125 cow^{-1} in the model, given the expenditure required for the development of the stand-off asset and ongoing maintenance costs (Doole and Romera, 2015). Second, less conversion of dairy land means that less entitlements are available for sale (Table 7). This increases the per-unit cost of nutrient entitlements to those dairy farms that utilise such a purchase to drive intensification. Indeed, while the price for nitrogen entitlements is low under optimal management (\$60 kg N^{-1}), this increases to \$444 kg N^{-1} when substantial trading frictions are simulated (Table 3). Third, dairy farms are the only land use that purchase meaningful amounts of nutrient entitlements in these solutions—the other purchaser is the incentives fund (Table 7). Thus, the dairy sector not only needs to purchase a high amount of nitrogen, but also at an inflated price. Last, the post-allocation but pre-trade position of the dairy sector changes following re-allocation in Scenarios S9, S10, and S12, as the upper limit of leaching in the dairy sector is reduced. Accordingly, the very act of re-allocating nutrient entitlements away from dairying imposes a cost on this sector. Together, these drivers lead to greater falls in dairy profit on a per-hectare basis in S9, S10, and S12, relative to S8. Indeed, profit falls—relative to S8—by 6, 3, and 6% in Scenarios S9, S10, and S12, respectively. This translates to a cost of around \$98, \$50, and \$98 ha^{-1} for dairy farms in these scenarios, respectively.

While the model cannot be used to analyse the variation among individual farms, the standard deviation of average profit across each partition can provide some insight into the effects of different scenarios on the distribution of profit within the catchment. This data is provided in Table 5 for the case where the scope of land-use change is unconstrained, but there are frictions in the market. This data shows several interesting trends; noting hereafter that this discussion concerns the variation of profit across, and not within, model partitions:

a. The diverse impacts of frictions on the productivity and management of dairy farms serves to increase the distribution of income across dairy farms in the catchment, but not by much. The coefficient of variation for profit per hectare increases from 0.18 in S8 to 0.24, 0.21, and 0.25 for Scenarios S9, S10, and S12, respectively (Table 5). This highlights how the frictions in the market for nutrient entitlements preclude a large concentration of dairy production on podzol soils; indeed, with frictions, dairy area after trading is distributed across recent, allophanic, and podzol soil types.

b. Returns to dairy support are much more variable with the modelled scenarios, compared to the current baseline, since land use for this activity does not change, but average profit increases dramatically given the capacity to sell nutrient entitlements to the dairy sector and incentives fund (Table 5). A feature of Scenarios S12 and S14 are the 9% and 22% increases observed in profit in the dairy-support sector after trading, relative to what is observed in S8. This is the result of multiple factors. First, dairy farms purchase a significant amount of nutrient entitlements, to allow them to maintain profitable levels of production (Table 7). Second, the impacts of trading activity are magnified in this scenario because the price of nutrient entitlements is very high (\$444 kg N^{-1}) (Table 3). Last, the dairy-support sector sells the highest amount of nutrient entitlements of any pastoral land use (Tables 6–7). Around 80% of nutrient entitlements sold by the pastoral sector generally come from dairy-support land, but this increases to around 95% in Scenarios S12 and S14 as these runs both involve the highest levels of re-allocation away from pastoral land uses (21.6 tonnes) (Table 7). The dispersion of farm profit is so broad that the coefficient of variation is around one for S10, S11, and S12. Nonetheless, though mean profit and dispersion of profit are both high in this sector, relative to the current state, a high proportion of dairy-support farms still earn negative returns. Indeed, around a third of dairy-support farms earn negative profits across S8–S14 because they are required to purchase leaching entitlements to maintain operation on mainly pumice, but also some podzol, soil types. The cost of doing so is inflated in this case, due to the high cost of nutrient entitlements when frictions exist in the market.

c. The greatest levels of variation in farm profit across each constituent part of the drystock sector (dairy support, sheep and beef, and sheep and dairy support) are reported for scenarios S10–S12. This is a direct effect of re-allocation imposing opposing impacts across different partitions within the catchment. Some drystock farms have their nutrient entitlements taken from them with re-allocation; this leaves them needing to buy rights to leach, but at an inflated price for nutrient entitlements due to the presence of market frictions (Table 7). In contrast, some drystock farms are still able to sell nutrient entitlements, and these farms directly benefit from the inflated price (Table 7). These dual effects serve to increase the variation of farm profit across the drystock sector when re-allocation policy affects their initial allocation.

Overall, these findings highlight that changes in farm profit, both positive and negative, are an expected outcome from the various re-allocation scenarios and will vary significantly according to sector and spatial zone. This application highlights that such variation will be inflated by market frictions, given that these will impair the capacity for producers in the catchment to move towards less-costly outcomes.

4. Conclusions

There is extensive empirical evidence that the costs of reducing nitrogen loads from intensive agriculture are limited when there is substantial scope for the trading of nutrient entitlements and land-use change (Doole, 2012, 2013; Parsons et al., 2015). This is because both trading and land-use change allow substantial flexibility with regards to how nitrogen-leaching losses are cost-effectively mitigated within a catchment.

Substantial inefficiency arises when frictions arise in the market for nutrient entitlements. A reduced supply of entitlements increases their price. This means that not enough land-use change occurs, too much mitigation occurs on farm, and dairy farms are prevented from intensifying to their optimal level. It is also much more expensive for the incentives fund to purchase their target level of nitrogen. Model output demonstrates that Scenarios S10–S12 will have a significant impact on the variability of profit within the dairy support, sheep and beef, and sheep and dairy support sectors; in some instances, around a third of dairy-support units will become uneconomic because of their need to purchase nitrogen at an inflated price. Scenarios that take 10.8 t of nitrogen from dairy (S9 and S12) create the greatest variability for the dairy sector. In comparison, Scenarios S13 and S14 that take a percentage reduction from all pastoral blocks appear to have the least distributional impacts, compared to what is expected to occur under Plan Change 10, as notified.

The strategic re-allocation of nutrient entitlements could conceptually address limitations on the productive potential of forestry land within the context of Plan Change 10 for the Lake Rotorua catchment. However, this analysis highlights that the small quantity of nitrogen that is re-allocated within Scenarios 9–14 is unlikely to be sufficient to drive significant changes in land use across the catchment when broad-scale trading of entitlements is possible. The overall lack of modification observed in model output, relative to those outcomes reported in Parsons et al. (2015), highlights that foresters who receive additional nitrogen-leaching entitlements are predicted to most likely sell them. This arises from the value of these entitlements in the market and the limited size of the new allocations, which are likely too small to allow the profitable intensification of land that is currently forested.

This evaluation emphasises that the liquidity of the market for nutrient entitlements is of primary importance for determining the cost of the regulatory program. Simulated frictions in this market lead to significant price distortion, with the optimal price of nitrogen climbing by more than seven times. This leads to sub-optimal management decisions across the catchment, regardless of the specific structure of the proposed allocation program. This directly affects the capacity for the incentives fund to purchase nitrogen, while also augmenting the variance of pastoral income through harming the capacity for producers to cost-effectively offset higher leaching losses.

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