Evaluation of policies for water quality improvement in the Upper Waikato catchment

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1. Introduction

The National Policy Statement (NPS) for Freshwater Management 2011 provides the foundation for regional councils in New Zealand to set the appropriate objectives and targets for freshwater quality. The National Objectives Framework (NOF) provides guidance to regional bodies for this activity, while also providing some national integration. The NOF primarily provides an extensive list of potential values—such as electricity generation, swimming, and irrigation—that regions can determine as appropriate activities to safeguard from water quality decline. Two values are compulsory across all regions: (1) ecosystem health and general protection for indigenous species, and (2) safety for secondary human contact. Each value has a set of related attributes of water quality; for example, irrigation requires that *Escherichia coli*, flows, and sediment levels are appropriately managed. The NOF provides specific water quality targets—organised into A, B, C, and D bands—associated with each attribute. The D level is not an appropriate goal, but rather represents deterioration beyond an acceptable standard. Each region can select which values are important to safeguard and to what degree these should be satisfied, on a case-by-case basis.

By design, policies to improve the quality of freshwater resources have strong potential to impact current and future management through manipulating the set of incentives that various stakeholders face. Achieving water quality improvement in many New Zealand catchments will likely require significant manipulation of existing land management, given the intensive nature of New Zealand's agricultural industries and that point sources have been now been well regulated in most places. The New Zealand Government seeks to support regional bodies in managing water quality. Accordingly, the Ministry for the Environment, DairyNZ, Waikato River Authority, and Waikato Regional Council have recently combined within the Waikato Joint Venture Project (WJVP) to provide robust input into water quality outcomes in the Waikato River catchment.

The primary objective of this study, as a project funded by the WJVP, is to assess the economic impact of various policies to improve water quality outcomes in the Upper Waikato catchment. Economic modelling provides an important means to assess the cost and distributional implications of alternative policies associated with improved water quality (Doole, 2012). Accordingly, a flexible framework for land-use optimisation within the context of various policy options is developed and applied.

The report is structured as follows. Section 2 provides a concise description of the model and summarises the policy scenarios. Section 3 presents results and discussion, while Section 4 summarises the key findings of this research.

2. Methods

2.1 The Land Allocation and Management (LAM) model

The applied framework—the Land Allocation and Management (LAM) model—integrates information from a variety of sources to provide steady-state predictions of the possible impacts of agri-environmental policy (Doole et al., 2013). Variants of this framework have been applied throughout New Zealand (Howard et al., 2013) and Australia (Doole et al., 2013). The LAM model is a nonlinear optimisation model (Bazaraa et al., 2006) that identifies the land-use pattern and the management within each land use that maximises profit. Different policy instruments may be simulated through setting constraints on relevant decision variables within the model. For example, the NPS scenarios in the following application involve median nitrate and chlorophyll-A concentrations not going above their current level. This is simulated through setting constraints on these quantities.

This section describes the LAM model and how different policy scenarios are simulated. The model is based on two important concepts. A *land use* describes the type of enterprise that exists on that parcel of land (e.g. dairy, forestry). A *management option* for a given land use represents a specific type of management within that land use.

The Upper Waikato catchment represented in this study consists of 24 subcatchments (Figure 1) that have been formulated based on their common hydrological attributes and placement relative to Waikato Regional Council water monitoring stations. Each one of these subcatchments is associated with a given monitoring station at its terminal point. The economic model is thus defined over a set of 24 subcatchments.

DairyNZ divided the dairy farming systems found across the catchment into 14 representative types or clusters, which are scattered across 23 of the 24 subcatchments in the absence of dairy conversion and all of the subcatchments in the presence of dairy conversion. AgFirst divided the sheep and beef farming systems found across the catchment into 2 representative types: an extensive hill property, and an intensive finishing property. The extensive hill property is 440 ha in size and involved rolling to steep hill country. The intensive finishing property is 286 ha and involves rolling to easy hill country. These farms are found across all subcatchments. The extensive and intensive sheep and beef farms are described as the hard hill country and easy hill country land uses, in the following.

Figure 1. Map of the subcatchments studied in the Upper Waikato catchment. Black text states the names of the relevant monitoring stations. Source: Sandy Elliott (NIWA).

A certain amount of exotic forestry exists in every subcatchment in the baseline. Moreover, the area of exotic forestry in some subcatchments is reduced due to conversion to dairy and other land uses in a set of model scenarios. Only a single management option is represented inside the forestry land use, given the limited mitigation options available therein.

The amount of each land type found in each subcatchment in the baseline model is listed in Table 1. The existing area of land used for each farm type in each subcatchment was determined by Fiona Pearce (Ministry of Primary Industries) based on leaching vulnerability, slope, and current land use information. Leaching vulnerability is used to classify different dairy farms, according to their respective impact of on water quality outcomes. However, it is recognised that this is not currently used by most, if not all, dairy farmers when making land use decisions. Urban and miscellaneous land uses do not change across scenarios and have a fixed leaching load associated with them.

Table 1. Areas of each subcatchment in the Upper Waikato catchment model.

Subcatchment name	**Dairy area**	**Support area**	**Easy hill**	**Hard hill**	**Exotic forest**	**Urban**	**Misc.**	**Total**
Pueto	0	0	1,881	36	16,728	56	1,327	20,029
Waikato at Ohaaki	2,792	572	9,247	611	8,130	699	6,958	29,009
Torepatutahi	7,342	1,504	898	62	11,126	54	736	21,721
Waiotapu at Campbell	378	77	1,566	370	2,955	2	731	6,079
Kawaunui	1,103	226	233	147	214	0	211	2,134
Mangakara	387	79	890	412	42	0	425	2,235
Waiotapu at Homestead	6,134	1,256	417	34	10,247	13	2,376	20,478
Whirinaki	136	28	557	340	0	0	19	1,080
Otamakokore	2,113	433	831	222	81	21	871	4,573
Waikato at Ohakuri	12,972	2,657	17,005	5,392	8,306	26	6,781	53,139
Tahunaatara	4,682	959	4,163	863	5,153	0	4,996	20,816
Mangaharakeke	823	169	179	14	4,230	0	0	5,415
Waipapa Stream	2,965	607	2,789	127	885	2	2,674	10,049
Waikato at Whakamaru	7,362	1,508	4,524	1,358	24,116	36	5,762	44,665
Mangakino	4,795	982	6,340	704	1,252	0	8,112	22,186
Waikato at Waipapa	9,271	1,899	8,233	1,496	28,662	351	19,480	69,392
Whakauru Stm	1,329	272	1,267	32	1,720	146	537	5,302
Mangamingi	2,024	415	280	52	1,137	679	589	5,175
Pokaiwhenua	10,684	2,188	1,579	92	14,418	28	3,713	32,701
Little Waipa	6,678	1,368	1,094	66	807	0	637	10,649
Waikato at Karapiro	21,216	4,346	8,907	2,000	5,680	195	11,624	53,969
Karapiro Stream	1,989	407	2,629	614	66	0	1,036	6,741
Mangawhero	2,778	569	463	157	11	33	1,337	5,347
Waikato at Narrows	5,048	1,034	394	165	79	895	5,372	12,987
Totals	115,00	23,555	76,36	15,36	146,04	3,236	86,30	465,871

1	6	6	5	4

The proportion of each land use in the Upper Waikato catchment is represented in Figure 2. Land use within each of the farm types is allocated between a range of management options. For example, if 200 ha is allocated to dairy farming in a given subcatchment, then this will be split between a set of management options (e.g. 150 ha to standard production and 50 ha with standard production and a stand-off pad). Each of the 14 dairy farm types have 7 basic management options that represent a range of farming systems. These management options differ markedly, but are designed so that leaching rates range from the baseline level to 50% of the baseline level. This diversity allows the analysis of broad changes in dairy farm management under a given policy. These 7 management options are replicated across 3 different situations: (1) spray effluent from the sump, (2) spray effluent from a holding pond, and (3) use a stand-off pad and spray effluent from a holding pond. Thus, there is a total of 21 dairy farm management options within each of the 14 farm types. The production, management, and leaching loads associated with each management option are determined using DairyNZ information, nutrient modelling using OVERSEER (Wheeler et al., 2006), and optimisation modelling using GSL (Ridler et al., 2001).

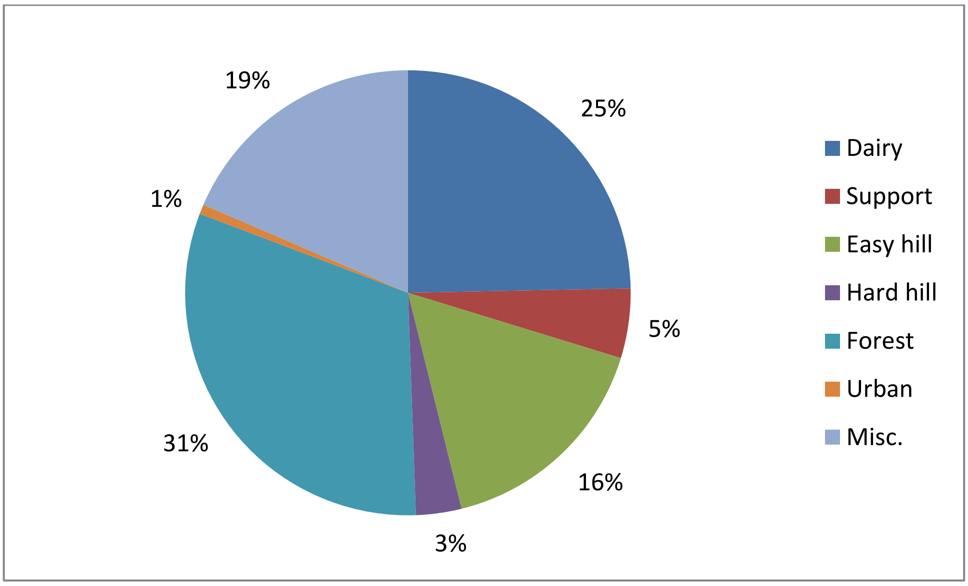

Figure 2. The proportion of each land use in the Upper Waikato catchment.

There are 28 management options for each of the hard hill country and easy hill country land uses. The production, management, and leaching loads associated with each option are determined by AgFirst using FARMAX, discounted cash flow modelling, and OVERSEER modelling. Forestry options generated by AgFirst are not considered since Scion information provides more accurate values for the value of forestry management in each subcatchment. Also, 2m riparian strips considered in the AgFirst data are not replicated in the model since Waikato Regional Council has confirmed that these are not generally considered of appropriate effectiveness in the study region to be incorporated. However, 4m and 6m riparian strips considered in the AgFirst data are incorporated.

The catchment model identifies the decision variables that maximise the total operating surplus, subject to the constraints defined in the model. It is appropriate to study operating surplus in the model, as a lack of information prevents an accurate depiction of how tax, depreciation, drawings, and interest payments affect returns on all land uses (especially forestry and sheep and beef land). The primary decision variables in the model are those representing the area (ha) allocated to each management option within each land use. The total operating surplus is determined through multiplication of the area of each land use option employed and its associated level of operating surplus per ha. The total nitrogen load for each subcatchment 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. The total phosphorus load for each subcatchment is computed through the multiplication of the area of each land use option employed and the phosphorus leaching load per ha associated with each option.

The nutrient loads for each subcatchment are subject to attenuation (nutrient losses between their source and subsequent monitoring stations), described through a hydrological model (Elliott and Semadeni-Davies 2013) that has been replicated in the economic model. The incorporation of these factors allows the nutrient load arising from each subcatchment reaching the monitoring station within another subcatchment to be explicitly defined. The loads present at each monitoring station are used as inputs to calculate median total nitrate, total N (TN), and total P (TP) concentrations at each station, for catchment equilibrium conditions.

The hydrological model is described further in Elliott and Semadeni-Davies (2013), but is summarised briefly here.

The catchment is broken into 24 subcatchments, based on the location of water quality monitoring stations. For each subcatchment, the mean annual load of nutrients generated within the catchment is determined based on a) pasture losses, as provided by the economic model; b) exotic forest, urban, and other diffuse losses (e.g. scrub), determined from land areas multiplied by yield coefficients; c) point sources, derived from discharge records; and d) geothermal inputs of nitrogen, derived from analysis of stream water quality.

The diffuse sources are subject to attenuation before entry into the main stem of the river network. The subcatchment-average attenuation factors for phosphorus are taken from the CLUES catchment model and then modified to improve the match to measured mean annual loads for TP. For TN, the situation is more complicated, and it is inappropriate to calibrate solely to measured loads, because the current measured TN load may underestimate the equilibrium situation, due to groundwater lags. An approach is adopted whereby three different levels of attenuation are analysed, bracketing the expected range. The largest attenuation is estimated by calibrating to match current measured mean annual loads exactly; this will over-estimate the attenuation in many cases, because the current load at calibration sites will be lower than the steady-state value. Some judicious lumping of decay coefficients between adjactent subcatchments is required to avoid unreasonable decay coefficients (such as negative attenuation). The resulting loss percentages ranged from 0 to 75%, with a median of 45%. The low attenuation scenario applied an estimated lower bound of the attenuation coefficient, generally a loss of 20%, except where the 'maximum' attenuation as described above was already less than this value. This approach will tend to be conservative, in the sense that it will tend to provide higher load estimates. An intermediate attenuation scenario is also applied, in which the attenuation was between the maximum and minimum values, and typically represented a 30% loss.

Attenuation within the main-stem (including the hydro reservoirs) is also applied. This attenuation, which is generally only a few percent, is taken from the CLUES catchment model (which uses an effective settling velocity), with an adjustment in some cases for TN to ensure that the within-catchment attenuation is within reasonable bounds.

The resulting load at a monitoring station is then determined as the sum of the loads from upstream, discounted for within-subcatchment and mainstem attenuation.

The mean annual concentrations are then determined from load in the following way. For TP, the proportional change in load under a scenario is applied to the current measured TP concentration to derive the predicted concentration for the scenario. For example, if the loads increased by 10% at a monitoring station, then the concentration increases by 10% from the current mean value. For TN, a similar approach is adopted, except that the proportional increase in load is determined with reference to the current concentration as estimated from the low-attenuation scenario (which matches current measured loads, where available).

The TN and TP concentrations are each related to chlorophyll-A concentration at 5 sites along the Waikato River: Ohaaki, Ohakuri, Whakamaru, Waipapa, and the Narrows. The relationship between nutrients and chorophyll is derived from regression relationships going down the stream network, with an adjustment to ensure that the predicted value at a particular station matches the current measured value. The hydrological model provided by NIWA computes two quantities of chlorophyll-A: one quantity of chlorophyll-A determined as a function of N, and one quantity of chlorophyll-A determined as a function of P. Constraints placed on chlorophyll-A in the simulations require both quantities to be less than the relevant threshold. This is necessary because the joint distribution of chlorophyll-A as a function of both N and P is unknown and could not be determined from the available data. However, this implies that neither of these nutrients is specifically limiting chlorophyll-A populations in this waterway. Any interpretation of model output must account for this limitation, given that a management focus on one nutrient, relative to less attention paid to another, may be warranted if one is specifically limiting.

Land use allocation is governed by a series of model constraints. The total land allocated between the management options in a given land use is constrained by the maximum area covered by that land use in each subcatchment (Table 1). Each dairy management option requires a given number of rising 1-year old, rising 2-year old, and mature cows to be grazed off farm for a proportion of the year. The total number of each type of cow that requires grazing off for a given set of management options is computed. Equations are then defined to ensure that each cow type can be supported, under an assumption that 10% of cows are grazed outside of the catchment (Ross Abercrombie, pers. comm.). Cows can be grazed on the dedicated area of the catchment that consists of support blocks for dairy farms or on the easy hill country (Table 1).

A high proportion of dairy farmers currently use holding ponds for effluent treatment. (Survey information from DairyNZ highlights that this proportion is around 72% in the catchment.) The proportion of farmers in each dairy farm type in each subcatchment with a holding pond is drawn from DairyNZ survey information. A constraint for each subcatchment is then defined to set a lower bound for the use of holding ponds. Holding ponds are more expensive than spraying from the sump; thus, this constraint is met with equality in the optimal solution. However, the proportion of farms with a holding pond supersedes this baseline level when greater mitigation using this strategy is cost-effective.

The dynamics of land use change are difficult to describe in a land use optimisation model. However, some land use change is permitted in this model to ensure that simulated targets are feasible. By allowing this to happen, it is demonstrated how extreme remediation activity has to be to achieve certain goals. There are several ways that land use can change away from its baseline in the model. First, sheep and beef operations in the hard hill area can change their sheep:beef ratio. Second, sheep and beef operations in the easy hill area can change their sheep:beef ratio, fatten bulls, or graze dairy cows. Third, sheep and beef operations on the easy and hard hill areas can be planted to exotic forest. Last, dairy and support land can be planted to exotic forest or be used for sheep and beef farming. Simulating the afforestation of agricultural land is controversial, but is undertaken in this study, given that NPS standards cannot be met under the existing land allocation. While land use change is possible in the model, it is only employed if on-farm mitigation practices within a given land use are relatively unprofitable.

The model is solved using nonlinear programming with the CONOPT4 solver in the General Algebraic Modelling System (GAMS) (Brooke et al., 2012). The catchment model contains around 3,000 equations and around 18,000 decision variables.

2.2 Annual returns for dairy farms

Annual returns are computed with more detail for dairy farms, relative to the sheep and beef farms incorporated in the catchment model, because of the detailed information provided by the WJVP partner, DairyNZ. The method used and its description here follows Howard et al. (2013).

Each dairy farm type contains a given number of farms in the baseline; these are considered as individual enterprises in the model. We do not consider sharemilkers receiving only a proportion of farm revenue. This is consistent with the available data and sharpens the focus on the impact of alternative N leaching goals on farm profitability and viability.

Annual returns per ha for a single dairy farm are computed as: returns = surplus + dividend – tax – depreciation – drawings – interest. Annual returns are computed with drawings (denoted WD) and without drawings (denoted WOD) included, to demonstrate the impact of their inclusion on annual returns. Farm operating surplus for a given farm type is mean operating surplus per ha for that type. This is determined within the objective function of the model for each farm type. Dividend is calculated through computation of mean milk production per ha for that cluster. The assumption that a dividend of $0.35 per kilogram of milk solids is paid is provided by DairyNZ. It is assumed that all farms in the catchment receive a dividend. This is necessary since the number of suppliers to competing processing companies is unknown and we do not know how the DairyBase data used to estimate debt level (see below) is impacted by money borrowed to finance share purchases.

Tax is only borne if taxable income is positive. Taxable income is profit per ha after interest payments and depreciation, but before drawings, have been accounted for. The tax rate is set at $0.28 per dollar of taxable income based on the New Zealand company tax rate. Asset depreciation is determined as a function of milk production. The $0.31 per kg MS assumption for depreciation is taken from 2011/12 DairyBase data collected from 125 owner-operators in the Waikato region. Drawings are calculated using the 2012 DairyBase labour adjustment for management to represent the cost of owner-operator labour. This is determined as a function of the number of cows on a given farm.

Annual interest costs are computed through multiplication of the interest rate and the total debt level measured through closing term liabilities. (Liabilities and interest costs are therefore underestimated due to the exclusion of current liabilities.) Annual interest costs (*r*) are assumed to be 7 per cent of closing term liabilities (McCall, 2012). Closing term liabilities per ha are taken from 2011/12 DairyBase data collected from 125 owner-operators in the Waikato region. A cumulative distribution function for closing term liabilities is estimated from this data using a kernel density estimator implemented in MATLAB (Miranda and Fackler, 2002). Kernel density estimation is a non-parametric statistical estimation technique that overcomes the need to make strong assumptions regarding the distribution of the probability density function associated with a given data set (Greene, 2012). This function is then used to generate a cumulative distribution function for each cluster for closing term liabilities.

Land use change has no effect on the proportion of farmers who can cover costs in the model. Given a lack of suitable resources, there is no link represented between these processes in the model. Thus, the costs of land use change are not transferred to other land uses. The only costs faced by dairy farmers are those imposed on dairy land that remains in dairy production. As abatement costs are borne, this increases costs and hence decreases the proportion able to cover costs.

A limitation of the approach described in this section is that debt levels are not related to other farm factors, such as production and profitability. Thus, low-producing farms may end up with higher debt levels that could be observed in reality. However, based on the same arguments, high-producing farms may end up with lower debt levels also. The extent to which effect is dominant is unknown.

2.3 Model runs

A number of different scenarios are simulated. These are listed in Table 2. Scenarios 1–3 are the baseline solutions for the model, representing the current situation under different assumptions regarding attenuation. This is justified since all subcatchments currently meet the NOF standards, no trading takes place under current management, and no dairy conversion is simulated within these runs.

Three different goals are simulated. Some relate to the historic medians of nitrate and chlorophyll-A concentrations. The historic median for nitrate is the 20-year corrected median (Sandy Elliott, pers. comm.). The historic median for chlorophyll-A is the 5-year uncorrected median (Sandy Elliott, pers. comm.). The NOF goal requires that chlorophyll-A targets to attain the Level C grade (less than 0.012 g/m^3) are met at the Ohaaki, Ohakuri, Whakauru, Waipapa, and Narrows stations on the Waikato River. Moreover, nitrate levels must achieve at least a Level C grade (less than 6.9 g/m^3) at all stations. Thus, nitrate and chlorophyll-A levels may get worse than their current point, provided they do not reach the C grade. NOF standards for TN and TP are not focused on specifically, as the chlorophyll-A target accounts for these, at least to some extent, through its explicit relationship with these nutrient levels. The NPS-av (NPS-average) standards are defined through requiring that the average chlorophyll-A level across the Ohaaki, Ohakuri, Whakauru, Waipapa, and Narrows stations on the Waikato River is maintained or improved. Additionally, the average nitrate level across all relevant sites must be maintained or improved. This scenario is consistent with the overall maintenance or improvement of water quality standards across the catchment, allowing water quality in some specific subcatchments to degrade relative to the current baseline and improve at others, provided the overall average is maintained or improved. The NPS-all standards are defined through requiring that the chlorophyll-A levels at the Ohaaki, Ohakuri, Whakauru, Waipapa, and Narrows stations on the Waikato River are maintained at or below their historic medians. Additionally, nitrate levels must not surpass their historic medians at all stations. The stringency of these simulated environmental standards increases as we move rightwards across the list of: NOF – NPS-av – NPS-all.

Three assumptions regarding attenuation are simulated. An optimistic (high attenuation) (HAT) scenario is simulated, in which high attenuation rates are used that are consistent with existing increasing trends of N in the Upper Waikato catchment levelling off at the present level from the current period onwards. A pessimistic (low attenuation) (LAT) scenario is also simulated, in which low attenuation rates are used that are consistent with current increasing trends of N in the Upper Waikato catchment continuing at their present rate to the point where the concentrations reach a limit based on loading and with a small amount of attenuation. A third scenario, a low-moderate attenuation (LMAT) rate, is also simulated for illustrative purposes. It should be noted that there is considerable uncertainty around estimates of attenuation. The HAT, LMAT, and LAT scenarios are consistent with average losses across the catchment of 50%, 30%, and 20% between source and measurement.

The high attenuation scenario is consistent with short lag times between N loss and its expression in waterways, and thus infers that there is a minor N load to come. In contrast, the low attenuation scenarios are consistent with long lag times between N loss and their expression in waterways, and thus infer that there is a significant N load arising from past agricultural production yet to arrive.

The presence of different assumptions regarding attenuation rate alter the relationship between the extent of mitigation activities and their impact on water quality outcomes. This obviously has broad implications for the adoption of such activities and the associated abatement cost. The concentration of chlorophyll-A is determined based on fixed relationships that determine a level based on either TN and TP concentration, which are computed from post-attenuated loads of N and P, respectively. However, within the results of the economic modelling, the chlorophyll-A concentrations vary greatly across the different scenarios (Table 9), in response to variation in TN and TP. This arises directly from the fact that optimal levels of TN and TP change within each scenario, as alternative attenuation assumptions are simulated.

Two scenarios are simulated for forestry conversion. First, a baseline case with no conversion is simulated. This is based on the fact that water in the catchment is at, or close to being fully allocated, constraining conversion. Second, the Waikato Regional Council, the Ministry for the Environment, the Waikato River Authority, and DairyNZ have provided a scenario whereby 25,000 ha is converted from exotic forestry to dairy production. This is based on the assumption that some allocated water is not currently utilised, and/or that trading of water may enable some conversions to take place. The subcatchments in which the hypothetical conversions could potentially take place are unknown. For the purposes of this modelling exercise, the areas have been allocated across subcatchments with significant areas on forestry on easier country.

Table 2. Scenarios evaluated in the model. Scenarios 1–3 represent the baseline solutions under the different attenuation assumptions.

No.	Goal	Trading	Attenuation assumption	Dairy conversion (ha)
1	NOF	No	HAT	0
2	NOF	No	LMAT	0
3	NOF	No	LAT	0
4	NOF	No	HAT	25,000
5	NOF	No	LMAT	25,000
6	NOF	No	LAT	25,000
7	NPS-av	No	HAT	0
8	NPS-av	No	LMAT	0
9	NPS-av	No	LAT	0
10	NPS-av	No	HAT	25,000
11	NPS-av	No	LMAT	25,000
12	NPS-av	No	LAT	25,000
13	NPS-all	No	HAT	0
14	NPS-all	No	LMAT	0
15	NPS-all	No	LAT	0
16	NPS-all	No	HAT	25,000
17	NPS-all	No	LMAT	25,000
18	NPS-all	No	LAT	25,000
19	NOF	Yes	HAT	0
20	NOF	Yes	LMAT	0
21	NOF	Yes	LAT	0
22	NOF	Yes	HAT	25,000
23	NOF	Yes	LMAT	25,000
24	NOF	Yes	LAT	25,000
25	NPS-all	Yes	HAT	0
26	NPS-all	Yes	LMAT	0
27	NPS-all	Yes	LAT	0
28	NPS-all	Yes	HAT	25,000
29	NPS-all	Yes	LMAT	25,000
30	NPS-all	Yes	LAT	25,000

Scenarios are further distinguished by the absence or the presence of a trading program. The solutions obtained in Scenarios 1–18 are consistent with trading occurring at the subcatchment level, in accordance with standard environmental economics theory. However, it is infeasible to run a trading program within each individual subcatchment, based on the high administration costs involved and the possibility of thin markets given limited land use heterogeneity in some of them. Accordingly, a trading system is simulated based on the chlorophyll-A level at the terminal node of the Upper Waikato catchment (the Narrows station on the Waikato River). The two relevant levels involve:

1. The chlorophyll-A target under the trading system within the NOF scenario is that chlorophyll-A at the Narrows must be less than 0.012 g/m^3. Additionally, total nitrate levels must satisfy the NOF standards.
2. The chlorophyll-A target under the trading system within the NPS-all scenario is that chlorophyll-A at the Narrows must be equal to or less than its historic median of 0.008 g/m^3. Additionally, total nitrate levels must satisfy the NPS-all standards.

Table 3 describes the key variables used to describe model output. Operating surplus is important because it indicates the overall cost to land managers of a given policy simulation. Land use areas are significant since they indicate the most cost-effective land use allocation associated with reaching a certain goal. These are most informative when they are considered relative to the baseline land use allocation. Levels of agricultural output indicate the degree of land-use change required within a given policy, while also showing how the change in land use and management affects production. The flow-on effects of this decreased production are important. For example, if milk production falls by 20%, then it is imperative to consider the impacts of this fall in production on regional economies. This is beyond the scope of this analysis, but is nevertheless important. The WJVP partner, DairyNZ, provided detailed information that allowed a rich description of the region's dairy farms to be modelled.

Table 3. Description of key output variables used in tables providing model output.

Variable	Unit	Description
Operating surplus	$m	This is the total operating surplus earned in the catchment from all land uses.
Land use areas		
Dairy	ha	Total area of dairy farms, incorporating the current area and that from forest conversion.
Support	ha	Dedicated support land linked to dairy farms.
Easy sheep	ha	Sheep and beef farms on easy hill country.
Easy support	ha	Dairy support by sheep farms on easy hill.
Hard sheep	ha	Sheep and beef farms on hard hill country.
Forest	ha	Total forest area in the catchment.
Production		
Milk	t MS	Tonnes of milk solids produced.
Wool	t	Tonnes of wool produced.
Mutton	t	Tonnes of mutton carcass produced.
Lamb	t	Tonnes of lamb carcass produced.
Beef	t	Tonnes of beef carcass produced.
Timber	m m^3	Annual timber production for all forestry land. This is measured in millions of cubic metres.
Dairy statistics		
Milk production	t MS	Milk solids produced.
Cows	head	Number of dairy cows milked.
N fertiliser	t urea	Urea applied on dairy land.
Supplement	t DM	Supplement fed on dairy land.
Farm labour	FTE	On-farm labour on dairy land.
% VWD	%	Percentage of viable dairy farmers that can cover all costs, when drawings are considered.
% VWOD	%	Percentage of viable dairy farmers that can cover all costs, when drawings are not considered.
% FSS	%	Percentage of farmers that spray effluent from the sump. A proportion of farmers still do this in the catchment.
% FHP	%	Percentage of farmers that spray effluent from a holding pond. Most dairy farmers in the catchment do this at present.
% FSO	%	Percentage of farmers that spray effluent from a holding pond and use a stand-off pad.

3. Results and Discussion

3.1 Simulation of NOF standards without trade

Table 4 reports the output for Scenarios 1–6 concerning simulation of the NOF standards without trade. Scenarios 1–3 replicate the baseline land use pattern provided by MPI. This is achieved without the use of calibration functions. Thus, movements away from the baseline scenario do not reflect arbitrary weighting factors imposed when trying to make landuse allocation within the baseline model match reality (Doole and Marsh, 2013). The historic medians for nitrate concentration attain Level C, Level B, and Level A in 24, 22, and 16 of the 24 subcatchments, under the NOF standards. The historic medians for chlorophyll-A concentration attain Level C, Level B, and Level A in 5, 3, and 1 of the 5 subcatchments in which this concentration is measured, under the NOF standards. Thus, the historic median concentrations for each subcatchment already satisfy these standards in the simulated NOF scenarios. This is identified in the equivalency of results for the baseline model (Scenarios 1–3), where the simulation of NOF standards does not restrict nitrate or chlorophyll-A levels.

The baseline operating surplus is around $506m. Dairy conversion of 25,000 ha is simulated (Section 2.3). This will increase operating surplus by around $56m (~11%), while promoting milk production by around 14%. An increase of around 200 units of on-farm labour may also be expected. Converted land is allocated between dairy production and associated support blocks. However, the additional dairy and support land does not sum to 25,000 ha since to satisfy the NOF standards, a total of 2,918 ha (12% of potentially-converted land) must remain in forest. Some of this forest must remain in place across all subcatchments in which conversion is expected to take place. If more than 22,000 ha of dairy conversion occurs, it is predicted in the model that NOF standards will be breached in at least 1 subcatchment. This outcome is observed under all attenuation scenarios.

Table 4. Key model output for Scenarios 1–6. No trading takes place within these scenarios.

Variable	**Unit**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**
Goal	-	NOF	NOF	NOF	NOF	NOF	NOF
Attenuation	-	HAT	LMAT	LAT	HAT	LMAT	LAT
Conversion	ha	0	0	0	25,000	25,000	25,000
Surplus	$m	505.72	505.72	505.72	562.22	562.22	561.90
Land use							
Dairy	ha	115,001	115,001	115,001	132,833	132,833	132,983
Support	ha	23,554	23,554	23,554	27,804	27,804	27,804
Easy sheep	ha	39,239	39,239	39,239	34,926	34,926	34,928
Easy supp.	ha	37,124	37,124	37,124	41,437	41,437	41,435
Hard sheep	ha	15,365	15,365	15,365	15,365	15,365	10,835
Forest	ha	146,099	146,099	146,099	124,017	124,017	128,397
Production							
Milk	t MS	115,024	115,024	115,024	130,983	130,983	130,943
Wool	t	1,739	1,739	1,739	1,609	1,609	1,445
Mutton	t	921	921	921	848	848	772
Lamb	t	4,755	4,755	4,755	4,400	4,400	3,951
Beef	t	10,339	10,339	10,339	9,296	9,296	9,048
Timber	m m^3	4.85	4.85	4.85	4.02	4.02	4.18
Dairy stats.							
Cows	head	281,350	281,350	281,350	321,066	321,066	321,066
N fertiliser	t urea	9,498	9,498	9,498	10,309	10,309	10,252
Supplement	t DM	152,398	152,398	152,398	159,437	159,437	158,416
Farm labour	FTE	1,504	1,504	1,504	1,715	1,715	1,715
% VWD	%	68	68	68	67	67	67
% VWOD	%	78	78	78	77	77	77
% FSS	%	22	22	22	22	22	22
% FHP	%	78	78	78	78	78	78
% FSO	%	0	0	0	0	0	0

3.2 Simulation of NPS-av standards without trade

Table 5 reports the output for Scenarios 7–12 concerning simulation of the NPS-av standards without trade. Scenario 7 replicates the baseline solutions found in Scenarios 1–3 above (Table 4). Maintenance of average nitrate and chlorophyll-A levels across the catchment under the LMAT case (Scenario 8) lowers operating surplus by 4%, with 90% and 40% of the hard and easy sheep land, respectively, being planted to forest. Surplus is not greatly impacted, given the relative value of forestry and sheep and beef returns, though the time required to achieve forestry returns, relative to the current use, is obviously broadly dissimilar. The intensity of dairy farming is also reduced. Cow number is reduced by 8%, while N fertiliser and supplement use decrease by 20% and 25%, respectively. Moreover, 9% of producers use holding ponds, instead of spraying effluent directly from the sump, while over half use stand-off pads. Maintenance of average nitrate and chlorophyll-A levels across the catchment under the LAT case (Scenario 9) lowers operating surplus by 8%, with 100% and 45% of the hard and easy sheep land, respectively, being planted to forest. Cow number drops by 11%, due to a reduction in dairy area and farm intensity (e.g. the stocking rate over the catchment falls by around 10%). Around 75% of dairy farmers must also use a stand-off pad. Overall, these factors demonstrate that with a high expected load of N to come under the LAT scenario, there will be a moderate drop in surplus across the catchment. Importantly, these losses occur under the NPS-av case since they are more binding than the national bottom lines simulated here within the NOF case.

Dairy conversion of 25,000 ha is simulated. This will increase operating surplus by around $60m (~11%), while promoting milk production by around 12%. This increase in surplus is higher than that observed in the equivalent NOF scenario (Scenario 4 in Table 4), as allowing degradation and improvement across sites within the catchment introduces a flexibility that is absent when requiring the NOF standards to be met at all sites concomitantly. An increase of around 200 units of on-farm labour may also be expected. Converted land is allocated between dairy production and associated support blocks. However, the additional dairy and support land does not sum to 25,000 ha since to satisfy the standards levied on the catchment averages, a total of 2,794 ha (11% of potentially-converted land) must remain in forest, while 2,094 ha (8% of potentially-converted land) is allocated to bull production. Some of this forest must remain in place across all subcatchments in which conversion is expected to take place. If more than 22,206 ha of dairy conversion occurs, it is predicted in the model that NOF standards will be breached in at least 1 subcatchment.

The simulation of moderate to high N loads to come in the LMAT and LAT scenarios, respectively, has significant implications. 8,415 ha (34%) of potentially-converted land must remain in forest in the LMAT case, while 14,182 ha (57%) of potentially-converted land mush remain in forest in the LAT case. An additional 7% and 10% of dairy farmers are unable to cover their costs in the LMAT and LAT cases. Sheep and beef production also declines by around 50%. The cost of this standard is $52m (9%) in the LMAT case, and $75m (13%) in the LAT case. This cost consists of the opportunity cost of foregone conversion and the need to reduce the intensity of dairy farms across the catchment. Various mitigations are necessary across the dairy land. First, N fertiliser use and supplement use drops. For example, N fertiliser application and supplement feeding fall by 30% and 25%, respectively, in the LAT case due to foregone conversion and de-intensification of existing systems. Cow number drops significantly, but this occurs largely due to the reduction in dairy area and not reductions in stocking rate on land that remains in dairy farming. These factors are discussed further in Section 3.6. Second, discrete mitigations must be adopted by a high proportion of farmers. Around 80% of producers must use a stand-off pad within the LMAT and LAT scenarios with dairy conversion (Table 5).

Overall, the results reported in Table 5 show the significant sensitivity of the results to different assumptions regarding attenuation level. Moreover, the NPS-av case provides more flexibility in that water quality at some sites can be degraded below its current level, provided that water quality is improved in others. However, the goal to maintain or improve water quality at the catchment level is more restrictive than the NOF case. Accordingly, the cost accruing to the NPS-av case is higher than that associated with reaching the national bottom lines simulated in the NOF case.

Table 5. Key model output for Scenarios 7–12. No trading takes place within these scenarios.

Variable	Unit	Sc. 7	Sc. 8	Sc. 9	Sc. 10	Sc. 11	Sc. 12
Goal	-	NPS-av	NPS-av	NPS-av	NPS-av	NPS-av	NPS-av
Attenuation	-	HAT	LMAT	LAT	HAT	LMAT	LAT
Conversion	ha	0	0	0	25,000	25,000	25,000
Surplus	$m	505.72	484.47	465.91	565.23	513.67	489.97
Land use							
Dairy	ha	115,001	115,001	111,483	132,958	127,907	122,140
Support	ha	23,554	22,679	22,983	23,554	27,233	27,233
Easy sheep	ha	39,239	23,780	21,661	30,916	23,532	20,699
Easy supp.	ha	37,124	35,440	32,277	44,516	35,924	32,118
Hard sheep	ha	15,036	2,000	0	9,913	0	0
Bull beef	ha	0	0	0	2,039	0	0
Forest	ha	146,428	177,482	187,978	132,486	161,786	174,192
Production							
Milk	t MS	115,024	110,074	105,142	128,787	119,557	113,005
Wool	t	1,727	788	652	1,290	708	623
Mutton	t	916	435	366	689	398	350
Lamb	t	4,722	2,156	1,783	3,529	1,937	1,704
Beef	t	10,321	5,865	5,242	9,101	5,695	5,009
Timber	m m^3	4.86	5.87	6.09	4.23	5.09	5.3
Dairy stats.							
Cows	head	281,350	258,356	249,460	315,853	294,092	277,406
N fertiliser	t urea	9,498	7,592	6,598	9,814	7,500	6,848
Supplement	t DM	152,398	113,266	98,229	135,380	108,415	101,590
Farm labour	FTE	1,504	1,441	1,379	1,688	1,567	1,477
% VWD	%	68	66	64	67	60	58
% VWOD	%	78	77	74	77	71	68
% FSS	%	22	13	9	21	9	10
% FHP	%	78	33	17	73	12	8
% FSO	%	0	54	74	6	79	82

3.3 Simulation of NPS-all standards without trade

Table 6 reports the output for Scenarios 13–18 concerning simulation of the NPS-all standards without trade. The NPS-all standards are much more stringent than the NOF standards, as the median nitrate and chlorophyll-A concentrations observed at the given subcatchments are, in most cases, well below the relevant NOF standards. Moreover, the NPS-all standards are more restrictive than the NPS-av standards because degradation of individual sites, provided this loss in water quality is compensated elsewhere, is not permitted. Rather, the NPS-all standards require the maintenance or improvement of water quality at each site. This emphasises the need to practice mitigation across all subcatchments, as spatial diversity in abatement cost cannot be exploited to improve water quality at the catchment level.

The optimal solution for Scenario 13 is equivalent to that for the baseline model (Scenarios 1–3 in Table 4). In the absence of dairy conversion, operating surplus decreases by around $59m (~12%) and $85m (~17%), relative to the baseline, under the LMAT (Scenario 14) and LAT (Scenario 15) cases. These costs are significantly higher than the 4% and 8% losses experienced in the equivalent LMAT and LAT scenarios in the NPS-av simulations (Table 5). This emphasises the cost associated with maintaining or improving water quality at all sites, relative to maintaining water quality above the national bottom lines or at the catchment average, when there is a significant N load to come.

Significant land-use change occurs in Scenarios 14 and 15, to satisfy the stricter NPS limits under the lower attenuation cases (LMAT and LAT). An additional 49,651 ha (~34%) and 66,097 ha (~45%) of forest is grown in the LMAT and LAT cases, while dairy and sheep farming also contract significantly in both scenarios. Substantial afforestation is required because the available mitigations simulated in each land use are insufficient in their effectiveness to meet the NPS standards, without significant land use change, when lower attenuation cases are simulated.

The dairy industry is significantly impacted under the LMAT and LAT assumptions in Scenarios 14–15. In Scenario 14, the optimal cow number declines by 36,590 cows (~13%) and milk production falls by 16,154 t MS (~14%). Also around 200 on-farm dairy jobs are lost. In Scenario 15, the optimal cow number declines by 57,511 cows (~20%) and milk production falls by 24,269 t MS (~21%). Also, around 300 on-farm dairy jobs are lost. An additional 7% and 10% of dairy farms are unable to cover their costs in an average year under the NPS standards in the LMAT and LAT scenarios, respectively, in the absence of dairy conversion. Around 70% of remaining dairy farmers must utilise a stand-off pad when lower attenuation scenarios (LMAT and LAT) are simulated in the absence of dairy conversion. This shows that while significant land use change is required to achieve the more stringent NPS standards, it also requires considerable on-farm mitigation by a large proportion of the dairy farms within the catchment.

Additionally, beef and lamb production decline by more than half under the lower attenuation scenarios (LMAT and LAT) in the absence of dairy conversion. The lower profitability of sheep and beef farming, relative to dairy production, necessitates greater afforestation of this land to achieve the NPS targets.

Dairy conversion adds around $55m (~11%) in the HAT case (Scenario 16). However, dairy conversion reduces operating surplus across the catchment by 8% and 14% in the LMAT and LAT scenarios (Scenarios 17–18), respectively, since the profitability of all forms of agriculture in this scenario is constrained by the more stringent degree of environmental regulation and a lower amount of nutrients are lost to attenuation. Not all deforested land is used for dairy production within the dairy conversion scenarios. It is again apparent that it is necessary to keep a proportion of this land within exotic forest to ensure that the environmental standards are not breached. To satisfy the NPS-all standards in the HAT case, a total of 6,361 ha (25% of potentially converted land) must remain in forest, across all subcatchments in which conversion takes place. To satisfy the NPS-all standards in the LMAT case, around 22,808 ha (91%) potentially-converted land must remain in forest. To satisfy the NPS-all standards in the LAT case, all potentially converted land must remain in forest. More forest should remain under the NPS scenarios involving dairy conversion (Scenarios 10–12 and 17–18), relative to the NOF scenarios involving dairy conversion (Scenarios 4–6), given the more stringent requirements simulated within the NPS scenarios. Accordingly, the model predicts that the NPS standards will be breached in at least 1 subcatchment if the full 25,000 ha of forest is converted to dairy production.

Significant land-use change occurs in Scenario 17, to satisfy the stricter NPS limits under the LMAT case with dairy conversion. Mainly, an additional 48,591 ha (~35%) of forest is grown relative to the case where dairy conversion occurs under high attenuation (Scenario 16), while dairy and sheep and beef farming all contract significantly. Thus, though dairy conversion takes place in some key areas, significant afforestation is required to satisfy the NPS standards given the low-moderate level of attenuation that occurs. This indicates that flexibility around the placement of dairy farming and forestry through the allowance of conversion does allow greater income to be earned within the catchment.

The dairy industry is significantly impacted under Scenario 17. Cow number declines by 56,131 cows (~18%) and milk production falls by 23,875 t MS (~19%), relative to the case where dairy conversion occurs under high attenuation (Scenario 10). Also, around 300 on-farm dairy jobs are lost. An additional 12% of farms are unable to cover their costs in an average year under the NPS-all standards with the LMAT case and dairy conversion (Scenario 17). Around 68% of dairy farmers must utilise a stand-off pad in Scenario 11. Moreover, beef and lamb production decline by around 40% and 45%, respectively.

Significant land-use change occurs in Scenario 18, to satisfy the stricter NPS-all limits under the low attenuation scenario case with dairy conversion. Mainly, an additional 67,181 ha (~49%) of forest is grown relative to the case where dairy conversion occurs under high attenuation (Scenario 10), while dairy and sheep and beef farming all contract significantly. This leads to a decline in beef and lamb production by more than half. Thus, though dairy conversion takes place, significant afforestation is required to satisfy the NPS-all standards with lower attenuation rates.

The dairy industry is significantly impacted under Scenario 18. Cow number declines by 78,444 cows (~25%) and milk production falls by 32,195 t MS (~25%), relative to the case where dairy conversion occurs under high attenuation (Scenario 10). Also, around 400 on-farm dairy jobs are lost. An additional 16% of farms are unable to cover their costs in an average year under the NPS-all standards in the low attenuation case with dairy conversion (Scenario 12). Additionally, around 75% of dairy farmers must utilise a stand-off pad in Scenario 12.

Table 6. Key model output for Scenarios 13–18. No trading takes place within these scenarios.

Variable	Unit	Sc. 13	Sc. 14	Sc. 15	Sc. 16	Sc. 17	Sc. 18
Goal	-	NPS-all	NPS-all	NPS-all	NPS-all	NPS-all	NPS-all
Attenuation	-	HAT	LMAT	LAT	HAT	LMAT	LAT
Conversion	ha	0	0	0	25,000	25,000	25,000
Surplus	$m	505.72	446.52	420.6	560.68	466	438.27
Land use							
Dairy	ha	115,001	105,781	97,241	132,958	114,446	104,196
Support	ha	23,554	22,051	22,051	24,236	26,301	26,301
Easy sheep	ha	39,239	20,370	16,705	30,065	18,566	14,635
Easy supp.	ha	37,124	29,705	25,464	43,714	28,398	23,972
Hard sheep	ha	15,036	2,725	2,725	8,038	2,709	2,726
Forest	ha	146,428	195,750	212,196	137,371	185,962	204,552
Production							
Milk	t MS	115,024	98,870	90,755	128,475	104,600	96,280
Wool	t	1,727	712	602	1,197	657	539
Mutton	t	916	390	328	643	359	293
Lamb	t	4,722	1,947	1,646	3,273	1,797	1,475
Beef	t	10,321	5,079	4,192	7,717	4,642	3,692
Timber	m m^3	4.86	6.2	6.46	4.35	5.48	5.75
Dairy stats.							
Cows	head	281,350	244,760	223,839	314,962	258,831	236,518
N fertiliser	t urea	9,498	6,022	5,115	9,584	5,911	5,319
Supplement	t DM	152,398	88,986	78,205	134,303	88,310	79,397
Farm labour	FTE	1,504	1,305	1,204	1,684	1,384	1,268
% VWD	%	68	61	58	67	56	52
% VWOD	%	78	71	68	78	65	62
% FSS	%	22	7	7	22	7	8
% FHP	%	78	22	25	63	24	27
% FSO	%	0	71	68	15	68	75

3.4 Simulation of NOF, NPS-av, and NPS-all standards with trading

The solutions for each scenario are the same, with and without trading. Thus, model output for scenarios 1–6 is equivalent to that for scenarios 19–24, and model output for scenarios 13–18 is equivalent to that for scenarios 25–30. The linked nature of the catchment network means that satisfaction of the NOF and NPS standards for chlorophyll-A at solely the terminal node (Waikato River at the Narrows) requires the satisfaction of the NOF and NPS-all standards, respectively, for chlorophyll-A at the other four nodes at which chlorophyll-A is measured. Also, the maintenance of constraints on nitrate levels in each individual subcatchment within the trading scenarios reduces the amount of N reaching the main stem of the Waikato River and consequently contributing to promoting the chlorophyll-A concentration found there.

Experiments with the model show that the nitrate constraints under the NPS scenarios are the most important in the LMAT and LAT cases because the NOF/NPS-all standards for chlorophyll-A are automatically satisfied downstream when the NOF/NPS-all standards for nitrate within each subcatchment are met. However, this changes with the high attenuation case. Here, chlorophyll-A constraints are the most binding. This finding motivates the simulation of two additional scenarios, which are run for the LMAT and LAT cases with dairy conversion. These runs involve the definition of NPS standards requiring that the chlorophyll-A levels at the relevant sites on the Waikato River are maintained at or below their historic medians. In contrast to earlier runs, nitrate levels are not constrained to be beneath their historic medians. This scenario is not repeated for the high attenuation (HAT) case since the result is equivalent to the output reported for Scenario 16 in Table 6.

Results for the sensitivity analysis are reported in Table 7. Setting a constraint on chlorophyll-A levels in the LMAT and LAT cases increases operating surplus in the catchment by around $20m. This increase mainly arises from a larger dairy sector, in which production is 6% and 8% higher in the LMAT and LAT cases, respectively, relative to when nitrate is constrained in each subcatchment, as well. Also, with constraints only set upon chlorophyll-A levels, the area of forestry decreases by around 5,500 ha and 8,000 ha in the LMAT and LAT cases, respectively, while around 20% more dairy farmers use a stand-off pad to decrease their leaching rates.

Table 7. Key model output for sensitivity analysis scenarios.

Variable	Unit	Sc. 17	Chl.-A only	Sc. 18	Chl.-A only
Goal	-	NPS	NPS	NPS	NPS
Attenuation	-	LMAT	LMAT	LAT	LAT
Conversion	ha	25,000	25,000	25,000	25,000
Surplus	$m	466	486.6	438.27	460.05
Land use					
Dairy	ha	114,446	118,182	104,196	109,286
Support	ha	26,301	27,804	26,301	27,804
Easy sheep	ha	18,566	19,349	14,635	15,859
Easy supp.	ha	28,398	30,785	23,972	26,944
Hard sheep	ha	2,709	0	2,726	0
Forest	ha	185,962	180,262	204,552	196,489
Production					
Milk	t MS	104,600	111,046	96,280	103,537
Wool	t	657	582	539	477
Mutton	t	359	327	293	268
Lamb	t	1,797	1,592	1,475	1,305
Beef	t	4,642	4,682	3,692	3,838
Timber	m m^3	5.48	5.4	5.75	5.64
Dairy stats.					
Cows	head	258,831	273,097	236,518	253,369
N fertiliser	t urea	5,911	6,386	5,319	5,185
Supplement	t DM	88,310	97,639	79,397	92,580
Farm labour	FTE	1,384	1,457	1,268	1,348
% VWD	%	56	57	52	54
% VWOD	%	65	67	62	63
% FSS	%	7	8	8	3
% FHP	%	24	6	27	0
% FSO	%	68	86	75	97

3.5 Water quality with NOF, NPS-av, and NPS-all standards

Table 8 reports nitrate concentrations for the HAT and LAT cases for each standard with forest conversion. It is most profitable to degrade 21 of the 24 sites below current water quality standards under the NOF scenarios in the HAT case. Moreover, it is most profitable to degrade 22 of the 24 sites below current water quality standards under the NOF scenarios in the LAT case. Overall, it is evident for the NOF scenarios that the nitrate concentrations reported at each site are substantially below the national bottom lines. The Managamingi site records the highest nitrate levels under the NOF scenario. In the HAT scenario, it has a nitrate concentration of 4.39 g m^{-3}. This is 57% higher than its baseline value, but is still well below the national bottom line of 6.9 g m^{-3}.

The NPS-av scenarios allow nitrate concentrations to go above and below their baseline values, provided that the average across the catchment is either maintained or improved. The HAT scenario is characterised by small deviations above and below the baseline medians. In contrast, the LAT scenario is characterised by larger deviations, overall. For example, the concentration at Torepatutahi is more than double its baseline, while that for Kawaunui is a quarter of its baseline value, under the LAT scenario. This pattern is evident since less attenuation infers there is a high N load to come in the model, and greater spatial diversity in the placement of mitigation strategies, particularly exotic forestry, is required to maintain the catchment average.

The NPS-all scenarios require nitrate concentrations to be equal or beneath their median value. Accordingly, this output shows that concentrations computed in the model are less than or equal to their measured median values. One evident trend is that nitrate concentration is well below its baseline value at some sites in both the HAT and LAT cases. For example, in the LAT scenario, the concentration is below the baseline level at more than half of the sites. The subcatchments throughout the catchment are hydrologically linked, such that nutrient loads in one subcatchment can influence those in others. Hence, it is sometimes important to mitigate below current median levels in one subcatchment, to achieve downstream goals with regards to both nitrate and chlorophyll A concentrations. Indeed, all subcatchments are linked to Subcatchment 24 (Waikato River at the Narrows) that is the terminal node for the catchment. The nitrate concentration is satisfied with equality at this site (Table 8), reflecting that mitigation beyond the current median is required within many linked subcatchments to allow for targets to be met upon aggregation at this downstream site.

Table 8. Nitrate concentrations (g m^{-3}) at each subcatchment monitoring site for different scenarios.

Subcatchment name	**Current median**	**Sc. 4**	**Sc. 6**	**Sc. 10**	**Sc. 12**	**Sc. 16**	**Sc. 18**
Goal		NOF	NOF	NPS-av	NPS-av	NPS-all	NPS-all
Attenuation		HAT	LAT	HAT	LAT	HAT	LAT
Conversion		25,000	25,000	25,000	25,000	25,000	25,000
Pueto	0.48	0.747	0.781	0.64	0.437	0.478	0.47
Waikato at Ohaaki	0.04	0.048	0.049	0.044	0.031	0.04	0.034
Torepatutahi	0.56	0.673	1.841	0.672	1.268	0.56	0.56
Waiotapu at Campbell	0.93	1.36	1.235	1.126	0.543	0.93	0.635
Kawaunui	2.71	2.748	2.612	1.954	0.668	2.141	1.014
Mangakara	1.41	1.604	1.995	1.268	0.713	1.362	1.358
Waiotapu at Homestead	1.37	1.601	1.807	1.365	0.965	1.328	1.112
Whirinaki	0.78	1.216	1.447	0.872	0.249	0.78	0.336
Otamakokore	0.81	0.815	1.362	0.781	0.496	0.785	0.577
Waikato at Ohakuri	0.1	0.108	0.152	0.1	0.091	0.097	0.098
Tahunaatara	0.57	0.666	1.068	0.643	0.765	0.57	0.57
Mangaharakeke	0.62	0.619	0.573	0.538	0.449	0.538	0.362
Waipapa Stream	1.28	1.323	2.046	1.304	1.678	1.278	0.918
Waikato at Whakamaru	0.13	0.147	0.212	0.136	0.135	0.13	0.13
Mangakino	0.67	0.715	0.892	0.672	0.779	0.654	0.572
Waikato at Waipapa	0.19	0.209	0.306	0.197	0.214	0.19	0.19
Whakauru Stm	0.29	0.285	0.600	0.294	0.521	0.281	0.238
Mangamingi	2.79	2.802	4.392	2.811	3.936	2.767	2.789
Pokaiwhenua	1.84	2.084	3.368	2.077	2.874	1.84	1.84
Little Waipa	1.66	1.706	3.479	1.679	2.843	1.66	1.66
Waikato at Karapiro	0	0	0	0	0	0	0
Karapiro Stream	0.59	0.665	0.665	0.665	0.557	0.589	0.589
Mangawhero	2.29	2.351	2.289	2.289	1.896	2.288	2.221
Waikato at	0.28	0.302	0.412	0.291	0.31	0.28	0.28

Narrows

Table 9 reports chlorophyll-A concentrations for the HAT and LAT cases for each standard with forest conversion. These concentrations are equivalent or above their current median values under the NOF scenarios. This is also observed with the NPS-av scenarios. All values are still well below the national bottom lines set within the NOF standards (0.012 g m^{-3}). The NPS-all standards also have little impact on the baseline levels of chlorophyll-A.

Table 9. Chlorophyll-A concentrations (g m^{-3}) at each relevant monitoring site for different scenarios.

Subcatchment name	**Current median**	**Sc. 4**	**Sc. 6**	**Sc. 10**	**Sc. 12**	**Sc. 16**	**Sc. 18**
Goal		NOF	NOF	NPS-av	NPS-av	NPS-all	NPS-all
Attenuation		HAT	LAT	HAT	LAT	HAT	LAT
Conversion		25,000	25,000	25,000	25,000	25,000	25,000
Waikato at Ohaaki	0.0009	0.001	0.001	0.0009	0.00028	0.0009	0.00041
Waikato at Ohakuri	0.0033	0.004	0.004	0.003	0.003	0.003	0.002
Waikato at Whakamaru	0.0059	0.007	0.007	0.006	0.006	0.0059	0.004
Waikato at Karapiro	0.004	0.004	0.004	0.004	0.005	0.004	0.003
Waikato at Narrows	0.0077	0.008	0.008	0.008	0.009	0.0077	0.006

3.6 Impacts of different environmental standards on dairy farms

Table 10 presents more detailed data for dairy farms under the NOF standards for both the HAT and LAT cases, with and without dairy conversion. Only output for the extreme scenarios incorporating high and low attenuation is reported, given that the intermediate case provides little additional insight. It is apparent that NOF standards have little impact on key output computed per ha for the dairy farms. This is intuitive given that the simulation of the NOF standards has such a small overall impact on model output, given that they define a threshold substantially above what exists presently.

Table 10. Key per ha output for dairy farms for selected scenarios.

Variable	Unit	Sc. 1	Sc. 3	Sc. 4	Sc. 6
Goal	-	NOF	NOF	NOF	NOF
Attenuation	-	HAT	LAT	HAT	LAT
Conversion	ha	0	0	25,000	25,000
Mean return WD	$	326	326	219	219
Mean return WOD	$	684	684	516	516
Stocking rate	cows	2.81	2.81	2.78	2.78
Milk production	kg MS	1,150	1,150	1,133	1,132
N fertiliser	kg urea	95	95	89	89
Supplement	t DM	1.52	1.52	1.38	1.37
N leaching	kg N	32.31	32.31	31.74	31.67
P leaching	kg P	2.56	2.56	2.56	2.56

Table 11 presents more detailed data for dairy farms under the NPS-av standards for both the HAT and LAT cases, with and without dairy conversion. Mean returns are considerably reduced by a need to satisfy the NPS-av standards, particularly when drawings are included. However, the effect of policy on mean returns has the greatest effect in the dairy conversion scenario, as existing farmers must perform substantial mitigation to allow the expansion of the dairy industry within this catchment. For example, around 80% of farmers must use a stand-off pad in the LAT case with dairy conversion (Scenario 12). Stocking rates only change a little (~5%) when the NPS-av standards have to be met in the LAT case. Additionally, milk production changes little (~6%), while N fertiliser and supplement use decrease by around a third. This highlights that the most-profitable mitigation incorporated in the model requires afforestation on the least-efficient dairy farms and efficient conversion of inputs to milk on the remaining farms, if the NPS-av standards are to be met. Low N leaching rates are evident on dairy farms in the LAT case. This indicates the broad adoption of stand-off pads on dairy farms in Scenarios 9 and 12 (Table 5).

Table 11. Key per ha output for dairy farms for selected scenarios.

Variable	**Unit**	**Sc. 7**	**Sc. 9**	**Sc. 10**	**Sc. 12**
Goal	-	NPS-av	NPS-av	NPS-av	NPS-av
Attenuation	-	HAT	LAT	HAT	LAT
Conversion	ha	0	0	25,000	25,000
% viable WD	%	68	64	67	58
% viable WOD	%	78	74	77	68
Mean return WD	$	326	165	216	-1
Mean return WOD	$	684	509	511	278
Stocking rate	cows	2.81	2.67	2.73	2.67
Milk production	kg MS	1,150	1,085	1,113	1,087
N fertiliser	kg urea	95	68	84	66
Supplement	t DM	1,52	1.01	1.17	0.98
N leaching	kg N	32.31	23.6	30.57	22.67
P leaching	kg P	2.56	2.54	2.55	2.52

Table 12 presents more detailed data for dairy farms under the NPS-all standards for both the HAT and LAT cases, with and without dairy conversion. Mean returns are considerably reduced by a need to satisfy the NPS-all standards, particularly when drawings are included. Stocking rates only change a little (~5%) when the NPS-all standards have to be met in the LAT case. Additionally, milk production changes little (~5%), while N fertiliser and supplement use decrease by around a third. This highlights that the most-profitable mitigation incorporated in the model requires afforestation on the least-efficient dairy farms and efficient conversion of inputs to milk on the remaining farms, if the NPS-all standards are to be met. Low N leaching rates are evident on dairy farms in the LAT case. This indicates the broad adoption of stand-off pads on dairy farms in Scenarios 15 and 18 (Table 5).

Table 12. Key per ha output for dairy farms for selected scenarios.

Variable	**Unit**	**Sc. 13**	**Sc. 15**	**Sc. 16**	**Sc. 18**
Goal	-	NPS-all	NPS-all	NPS-all	NPS-all
Attenuation	-	HAT	LAT	HAT	LAT
Conversion	ha	0	0	25,000	25,000
% viable WD	%	68	58	67	52
% viable WOD	%	78	68	78	62
Mean return WD	$	326	-40	206	-187
Mean return WOD	$	684	283	501	72
Stocking rate	cows	2.81	2.69	2.72	2.71
Milk production	kg MS	1,150	1,092	1,111	1,102
N fertiliser	kg urea	95	62	83	60
Supplement	t DM	1.52	0.94	1.16	0.91
N leaching	kg N	32.31	23.7	29.35	23.7
P leaching	kg P	2.56	2.53	2.55	2.48

4. Conclusions

The primary objective of this study, as a project funded by the WJVP, is to assess the economic impact of various policies to improve water quality outcomes in the Upper Waikato catchment. Economic modelling provides an important means to assess the cost and distributional implications of alternative policies associated with improved water quality (Doole, 2012). A large nonlinear optimisation model, the Land Allocation and Management (LAM) framework, is employed to evaluate these standards. The LAM model provides a flexible and rich framework in which to consider the integrated economic and hydrological implications of various policies for water quality improvement.

A number of key findings are apparent:

- Model output indicates that the achievement of NOF standards does not require any change of land use or management in the absence of dairy conversion. This statement remains valid regardless of which assumption regarding attenuation is utilised.

- Maintaining or improving water quality across the catchment as a whole (the NPS-av scenario) in the absence of dairy conversion has a cost of 4% and 8% in the LMAT and LAT cases, respectively. These scenarios require a 21% and 29% increase in forest area, with sheep and beef production falling by around 50%. More than half of dairy farmers must also use a stand-off pad.
- Maintaining or improving water quality at all sites (the NPS-all scenario) in the absence of dairy conversion has a cost of 12% and 17% in the LMAT and LAT cases, respectively. These scenarios require a 34% and 45% increase in forest area, with sheep and beef production falling by around 60%. Around 70% of dairy farmers must also use a stand-off pad. An additional 7% and 10% of dairy farmers are unable to cover their costs in the LMAT and LAT cases, when water quality cannot degrade at any site.
- Dairy conversion adds around $56m (~11%) to operating surplus within the catchment. This also leads to an additional 200 labour units on dairy farms. The NOF standards are maintained, provided that only 22,000 of the 25,000 ha of forest is converted. If more than 22,000 ha of forest is converted, then the national bottom lines will be breached in at least 1 subcatchment.
- The NPS-av standards can be satisfied with no change in management in the absence of dairy conversion and with high attenuation. However, the dairy conversion scenario requires some forest that could potentially be converted to remain in forest, if the NPS-av standards are to be satisfied in the HAT case.
- The NPS-all standards cannot be satisfied without a change in management in the absence of dairy conversion and with high attenuation.
- Dairy conversion adds 2% and -3% of surplus in the LMAT and LAT cases when seeking to maintain or improve water quality at all sites (the NPS-av scenarios). It is necessary to maintain a significant proportion of potentially-converted land as forest. For example, 34% and 57% of this land must remain in forest in the LMAT and LAT cases, respectively.
- The NPS-av scenarios require large changes to the dairy industry with high N loads to come. Cow number declines by 8% and 11% in the LMAT and LAT cases, respectively. Moreover, an additional 12% and 16% of farmers are unable to cover their costs. Around 70% of farmers must also use a stand-off pad in both scenarios.

This requires significant capital investment and for some farms this is not a viable option. 300 and 400 jobs on dairy farms are also lost in the LMAT and LAT cases, respectively.

- Dairy conversion reduces surplus by 8% and 13% in the LMAT and LAT cases, respectively, when seeking to maintain or improve water quality at all sites (the NPS-all scenarios). It is necessary to maintain a significant proportion of potentially-converted land as forest. For example, 91% and 100% of this land must remain in forest in the LMAT and LAT cases, respectively.
- The NPS-all scenarios require large changes to the dairy industry with high N loads to come. Cow number declines by 18% and 25% in the LMAT and LAT cases, respectively. Moreover, an additional 7% and 9% of farmers are unable to cover their costs. Around 80% of farmers must also use a stand-off pad in both scenarios. This requires significant capital investment and for some farms this is not a viable option.
- Experiments with the model show that nitrate standards for each individual subcatchment are critical in the lower attenuation cases, compared with chlorophyll-A targets. Indeed, satisfaction of the nitrate standards in each subcatchment, within either the NOF or NPS programmes, causes downstream targets for chlorophyll-A to be automatically satisfied in the lower attenuation (LMAT and LAT) cases. Model output suggests that setting a constraint just on chlorophyll-A within the NPS program, and not nitrate, could yield an additional $20m in farm surplus through allowing expansion of the dairy sector within this catchment.
- When there is a considerable N load to come, significant afforestation is required within the NPS-av and NPS-all scenarios because the available mitigations are insufficiently effective to meet them without land use change.
- Achievement of the NPS-av and NPS-all standards under the low-moderate and low attenuation cases will have a significant impact on agriculture.
- Achievement of NPS standards requires afforestation of the least-efficient dairy farms and efficient conversion of inputs to milk on the remaining farms. Stand-off pads will be required on around 70–85% of remaining farms, to allow them to reduce leaching rates while maintaining production levels.
- The simulated standards will be breached in at least 1 subcatchment if the full 25,000 ha of forest is converted to dairy production and associated support.

- The optimal placement of forest that is allocable towards conversion, but is not optimal to fell, is within each subcatchment in which dairy conversion is permitted to occur. This highlights that the amount and placement of dairy conversion should be considered carefully if environmental standards are to be achieved across all subcatchments.

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