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Water Quality Management in Lake Rotorua: A Comparison of Regulatory Approaches using the NManager Model

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Abstract

This paper examines six different approaches to nutrient management and simulates the economic costs and environmental impacts associated with them using NManager, a partial equilibrium simulation model developed by Motu and NIWA. In particular, we focus on Lake Rotorua in the Bay of Plenty in New Zealand, where the regional council is concerned with the decline in water quality in the lake and has set a goal to restore the lake to its condition during the 1960s.

Reaching this goal will require significant reductions in the amount of nutrients discharged into the lake, especially from non-point sources such as farm land. Managing water quality is made difficult by the presence of groundwater lags in the catchment: nutrients that leach from the soil arrive at the lake over multiple years. The mitigation schemes we consider are land retirement, requiring best practice, explicit nitrogen limits on landowners, a simple export trading scheme and two more complex trading schemes that account for groundwater lags.

We demonstrate that best practice alone is not sufficient to meet the environmental target for Lake Rotorua. Under an export trading scheme the distribution of mitigation across the catchment is more cost effective than its distribution under explicit limits on landowners or land retirement. However, the more complex trading schemes do not result in sufficient gains in cost effectiveness over the simple scheme to justify their implementation as there is minimal (or negative) improvement in the cost of mitigation given the increase in complexity.

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1. Introduction

Lake Rotorua is one of thirteen major lakes in the Bay of Plenty region of New Zealand. It has significant cultural value and provides numerous tourism opportunities. Te Arawa (the local iwi) have ancestral ties to the lake and surrounding land reaching back more than 600 years and today 35% of residents are of Maori ancestry. The Ministry of Tourism estimates the region attracts three million visitors annually, a quarter of whom are from overseas.

Land use in the catchment surrounding the lake has intensified since the 1960s and this has resulted in increased discharges to the lake of nitrogen Prabodanie, R. A. Ranga et al. (2003), (Rutherford, 2008) and phosphorus (Rutherford, Kit et al., 1989) to the lake. These nutrient discharges have led to a decline in water quality, eutrophication, toxic algal blooms and the intermittent closure of the lake due to health risks Parliamentary Commissioner for the Environment: Te Kaitiaki Taiao a Whare Paremata, 2006.

Through discussion with the Rotorua District Council, Te Arawa and the community, the Bay of Plenty Regional Council (BoPRC) has set a target for water quality to be the same as it was in the 1960s (Environment Bay of Plenty et al, 2009). This involves reducing lake loads, the amount of nutrients arriving at the lake, to 435 tonnes of nitrogen per year (tN/yr) and 37 tonnes of phosphorus per year (tP/yr). However, in 2009 total nutrient exports were estimated to be 746 tN/yr and 39.1 tP/yr and lake loads were estimated to be 556 tN/yr and 39.1 tP/yr (Environment Bay of Plenty et al, 2009). As a result of groundwater lags not all exports reach the lake at once but will be realized as lake loads over multiple years. Reaching the environmental targets for the lake within 100 years will require nutrient exports to decrease beneath the long run targets in the short term.

There is considerable concern about the cost of these reductions and how this cost will be distributed. To inform decision makers and stakeholders Motu and NIWA have developed NManager, a research tool for nitrogen management.

This paper considers six approaches to reducing nitrogen levels in Lake Rotorua through changes in land use and management. The approaches are: explicit nitrogen limits on landowners, requiring landowners to use best management practice, land retirement, a simple export trading scheme, and two more complex trading schemes base on lake loads that account for groundwater lags. Where possible we require the different approaches to have the same environmental outcomes.

We demonstrate that an export trading scheme is significantly more cost effective than explicit nitrogen limits on landowners and land retirement. But our research suggests that more complex trading schemes do not result in sufficient gains in cost effectiveness over the simple scheme to justify their additional complexity and the associated administration costs.

The Bay of Plenty Regional Council (BoPRC) has begun to address the decline in water quality. Their initiatives include upgrades to the storm water system and to septic tanks, treating phosphorus in streams and addressing land management practices (Environment Bay of Plenty et al, 2009). They have also introduced 'Rule 11' to freeze nutrient loss from land-use at 2001-2004 levels (Environment Bay of Plenty, 2008b).[1] Despite these initiatives it appears that further intervention will be necessary to meet lake quality targets.

A nitrogen trading system is expected to be a cost effective approach to control leaching into the lake (Lock and Kerr, 2008). The literature on trading systems to manage environmental outcomes has been historically focused on air quality from point sources. See for example Montgomery (1972), Krupnick et al (1983), McGartland and Oates (1985), Hahn (1986) and Ermoliev et al (1996). Water quality has been considered more recently by Hung and Shaw (2005) and Prabodanie, R. A. Ranga et al. (2010). In 2008 Selman et al (2009) identified 57 trading systems focused on water quality, most of which were inactive. Of these, the majority are concerned with point sources though some allow point sources to purchase reductions from nonpoint sources.

New Zealand has some experience with allowance trading systems, namely: the Individual Transferable Quota (ITQ) system used to manage marine fisheries; the New Zealand Emissions Trading Scheme (NZETS) used to manage greenhouse gases covered by the Kyoto protocol; and an export trading system that was recently established by Environment Waikato to manage the Lake Taupo catchment.

In the Lake Taupo catchment, farms occupy about 20% of the land; however, they contribute more than 90% of the manageable nitrogen load (Rutherford, Kit and Cox, Tim, 2009). Environment Waikato has implemented a straightforward 'cap-and-trade' scheme to prevent nutrients in the lake increasing beyond their present levels and has overseen the creation of a charitable trust called the Lake Taupo Protection Trust charged with the permanent removal

1 A review of 'Rule 11' suggests there is little quantitative evidence of its effectiveness and that more active enforcement is required (Foster et al, 2009).

of 20 percent of the manageable nitrogen Young et al, 2010. Table 1 gives the land areas, leaching and total exports of the different land types included in NManager.[2]

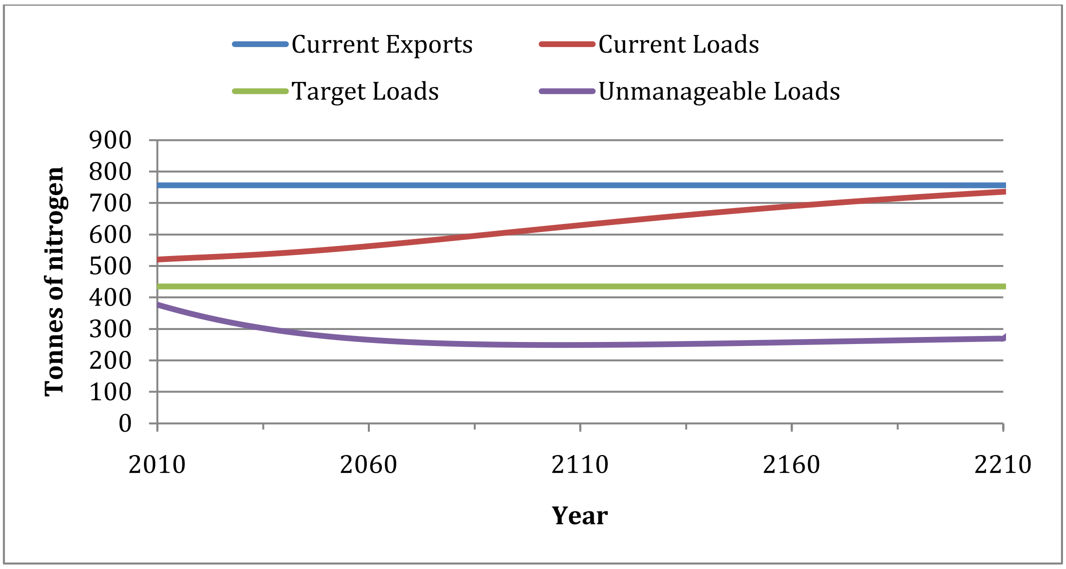
Table 1: Land area and base leaching in NManager

	Land Area	Leaching per Hectare (kg N / ha / yr)	Exports to the Lake (t N / yr)
Dairy	5,363	56	300
Sheep & Beef	14,481	16	232
Forestry	19,437	4	78
Waipa Forest	1,586	2	3
Lifestyle	894	16	14
Urban	2,076	10	28
Septic Tanks	256	85	22
Tikitere	28	1071	30
Whakarewarewa	24	10	0.24
Rotorua Land Treatment System	300	112.2	34
Total	45,185		756

Figure 1 gives nitrogen exports and loads in the Lake Rotorua catchment used in NManager assuming current land use and farming practices continue. It also provides the target of 435 tN/yr specified by EBOP et al (2009) and the unmanageable N loads used in NManager.

2 Note the total exports to the lake are not equal to the sum of the exports to the lake as they include some nitrogen from outside the surface water catchment that enters the catchment via groundwater (Rutherford et al, 2011).

Figure 1: Exports and Imports with no change in land-use



At present NManager assumes that 756 tN/yr are exported from the catchment but only 520 tN/yr are currently realized as lake loads (Environment Bay of Plenty et al, 2009). This difference is due to the delay of nitrogen in the groundwater. Unmanageable loads are those arising from nutrients already in the groundwater and exports that cannot be controlled via land management. The unmanageable exports consist of 4 kg/ha/yr across the entire catchment (the minimum possible leaching per hectare) and all leaching from the Rotorua Land Treatment System, septic tanks, and geothermal and urban areas. NManager considers 278 tN/yr as unmanageable exports. These are being addressed by other BoPRC initiatives.

It is obvious that significant reductions in nitrogen are required to meet the water quality targets specified by BoPRC. Rutherford et al (2011) calculate that exports need to be reduced by c. 320 tN/yr in order to meet the load target. Hence more severe intervention will be needed for Lake Rotorua than was necessary for Lake Taupo.

The paper is set out as follows: Section 2 gives an overview of the models which support our research and Section 3 introduces the NManager model. Different regulatory approaches are introduced in Section 4 and methods of solving them in Section 5. The performance of different regulations is discussed in Section 6. Section 7 concludes.

2. Supporting Models

NManager combines data from several external models with its own internal calculations. In this section we give an overview of the different models and the inputs they provide to NManager.

2.1. Farmax

Farmax is a decision support model developed by AgResearch. It has been designed to assist dairy and sheep & beef farmers to maximize their productivity by simulating the profitability of farms under different management scenarios. Farmax has been evaluated against two independent New Zealand data sets (Bryant, Jeremy et al., 2010).

Many management decisions affect not only the profitability of a farm but the amount of nutrient that leaches from it. In Farmax these decisions include: farm type (for dairy, the milking herd and dry stock were treated differently), stocking rate, fertilizer use, supplementary feed use, the choice of winter fodder crops and whether animals are grazed on or off the land (Bryant, Jeremy et al., 2010). Research by Male et al (2010) suggests that clearing gorse has real mitigation potential, however this is not included in Farmax.

Outputs from Farmax are used, in conjunction with OVERSEER, to give feasible and realistic combinations of profit and nutrient exports. From these we express profit per hectare per year as a function of mitigation per hectare per year. Further details are given in section 3.4 and Appendix B. For the simulations run in Farmax we direct the reader to Smeaton et al. (forthcoming).

2.2. OVERSEER

OVERSEER is a farm management tool developed by AgResearch to help farmers maximize the productivity of their land AgResearch, 2010. It also calculates nutrients lost to the environment, and this has drawn the attention of regulatory bodies. OVERSEER is used to quantify the export of nitrogen from each farm in the catchment as a function of land use and the type of soil.

The data inputs for OVERSEER are extensive and include: farm type, productivity (e.g., tonnes/year milk solids for dairy), soil type, soil drainage class, slope, rainfall, stocking rate, fertiliser use, supplementary feed and area for effluent irrigation. The use of nitrogen inhibitors is included for on-farm mitigation. Changes in any of these inputs affect nutrient loss.

2.3. ROTAN

The Rotorua and Taupo Nutrient model (ROTAN) is a geographic information system (GIS) based catchment hydrology and water quality model developed by the National Institute of Water & Atmospheric Research (NIWA) (Rutherford et al, 2008).

ROTAN simulates the hydrogeology of the Lake Rotorua catchment. It distinguishes between nutrient exports and nutrient loads. Nutrient exports are the quantity of nutrients discharged from the land. Nutrient loads are the quantity of nutrients reaching the lake. The translation from exports to loads is neither complete nor immediate due to *attenuation* and *groundwater lags* (Kerr and Rutherford, 2008).

Attenuation is the temporary storage and/or permanent removal of nutrients from runoff, groundwater or stream flow. Some nutrients are taken up by plants before reaching the lake. However, this uptake is temporary; the nutrients are released following the death of the plant. Permanent removal of nitrogen occurs principally through denitrification, the conversion of nitrate into nitrogen gas. Attenuation has been found to be minimal in most of the Lake Rotorua catchment, with the exception of the Puarenga (Rutherford et al, 2009) (Rutherford et al, 2011).

Groundwater lags are present across the Lake Rotorua catchment due to the presence of large underground aquifers. When nitrogen leaches off farmland, a certain amount is carried by surface water (streams) and enters the lake directly. The remainder enters the underground aquifers from where it is slowly released into the lake. ROTAN simulations suggest that 30% of nitrogen reaches the lake via surface water and 70% via groundwater. Groundwater lags determine the speed at which the nitrogen in the aquifers arrives at the lake.

Groundwater lags are defined for each parcel of land in the catchment. The lag for each parcel is described by its mean residence time (MRT), the mean time that nitrogen spends in the groundwater. They depend on the distance of the exports from the lake, the size and speed of surface water streams, and the geology of the soil and underlying rock. For land close to the lake groundwater lags are small. The lags increase the further land is from the lake and probably exceed 200 years for some nitrogen emitted at the edge of the catchment.

NIWA has extensively calibrated ROTAN to historical data from the Lake Rotorua catchment using information about groundwater lags estimated using tracers, and aquifer boundaries, provided by GNS-Science (Rutherford et al, 2009) (Rutherford et al, 2011). GNS-Science is using a fine detailed finite-element model to refine the current estimates of aquifer boundaries, flow pathways and travel times (Dr Chris Daughney, GNS-Science, pers. comm.). Refinement of aquifer boundaries and associated residence times within ROTAN are the subject of ongoing NIWA and GNS-Science research (Rutherford et al, 2008).

3. The NManager Model

NManager is intended to reflect the complex biophysical properties of the catchment and the behavior of landowners under regulation. This section details how the reality of the catchment is represented in NManager.

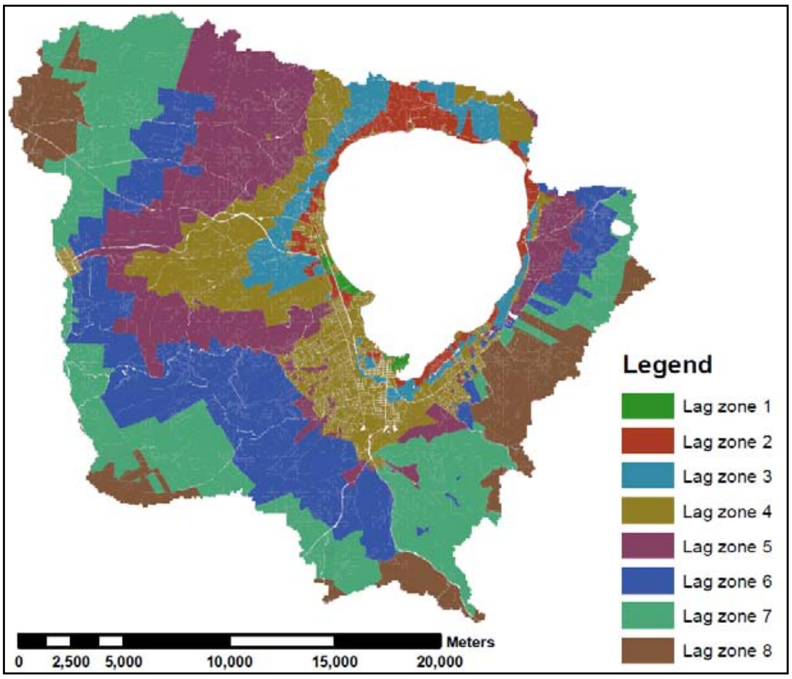
3.1. Modelling the transportation of nutrients to the lake

Groundwater lags are represented in NManager using simplified output from ROTAN. For ease of analysis parcels were aggregated into eight groundwater lag zones based on their MRTs. All parcels within the same zone were treated as having the same MRT. Lag zone 1, the closest to the lake, has the smallest MRT and lag zone 8, the furthest from the lake, has the largest MRT. Table 2 gives the MRT, size and percentage of nutrients in the catchment for each lag zone. Figure 2 shows the catchment by groundwater lag zone.

Table 2: Overview of the groundwater lag zones.

Lag Zone	1	2	3	4	5	6	7	8
MRT (years)	2.5	8	15	30	50	70	90	110
Number of ha	150	1,390	2,335	6,855	8,290	9,440	11,610	5,090
Nutrients Transported (%)	0.2	3.4	5.1	12.8	19.0	25.5	24.7	9.3

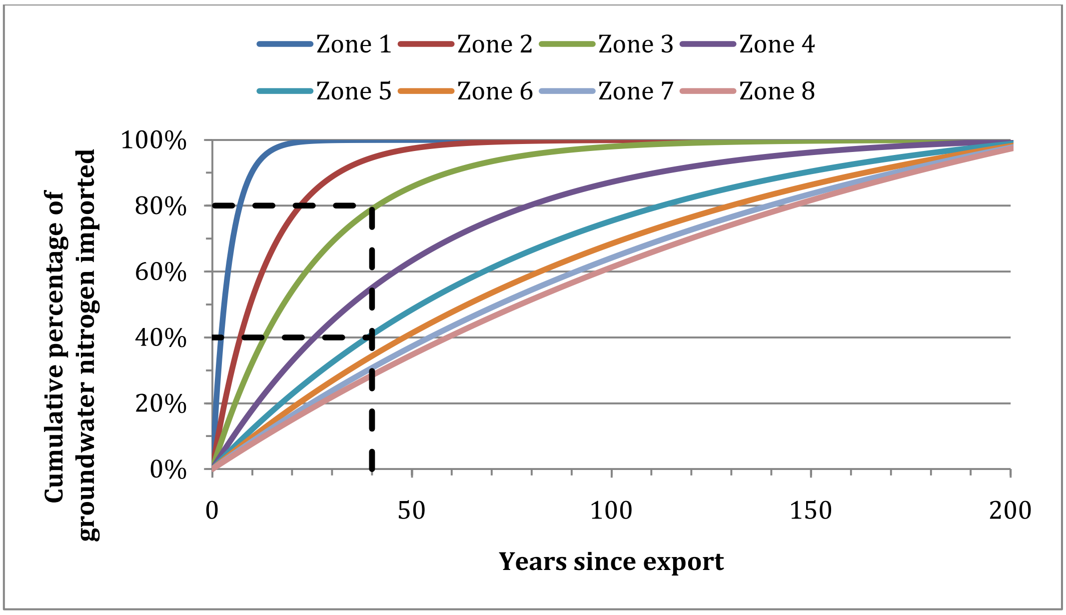
Figure 2: NManager groundwater lag zones



In NManager groundwater lags are described by a series of Unit Response Functions (URFs), one for each lag zone. URFs describe the nitrogen loads from a single unit of nitrogen entering the groundwater as a function of time since export. They were constructed by fitting an exponential curve to output from ROTAN adjusted for MRT. See Cox et al, (forthcoming) for further details.

Figure 3 gives the URFs used by NManager. Each curve gives the cumulative percentage of nitrogen, from the groundwater, exported at time zero that has since arrived in the lake as a function of time. For example, if nitrogen is exported from lag zones 3 and 5, then after 40 years 80% of the nitrogen from lag zone 3 and 40% of the nitrogen from lag zone 5 that entered into the groundwater will have reached the lake.

Figure 3: Unit Response Functions by groundwater lag zone



Nitrogen exports from a single year result in loads to the lake over multiple years as expressed by the URFs. These loads are additive across time and across different locations in the catchment. The nitrogen load at time t, from parcel i, delivered via groundwater can be expressed as follows:

$$Load_{GW}^{i}(t) = \rho_{GW} \sum_{\tau=0}^{\tau=t} f^{i}(\tau)\, h^{i}(t-\tau)$$

Where ρ_{GW} is the proportion of nitrogen exports delivered to the lake via groundwater (ROTAN suggests $\rho_{GW} = 30\%$), $f^{i}(\tau)$ is the quantity of N exported from parcel i at time τ; and $h^{i}(\cdot)$ is the URF for the lag zone associated with the parcel. NManager evaluates this sum using an annual time step for each time t.

Nitrogen loads delivered via surface water arrive in the lake in the same year they are exported. The load, from parcel i, delivered via surface water at time t, can be expressed as follows:

$$Load_{SW}^{i}(t) = (1 - \rho_{GW}) f^{i}(t)$$

And the total load to the lake at time t can be expressed as:

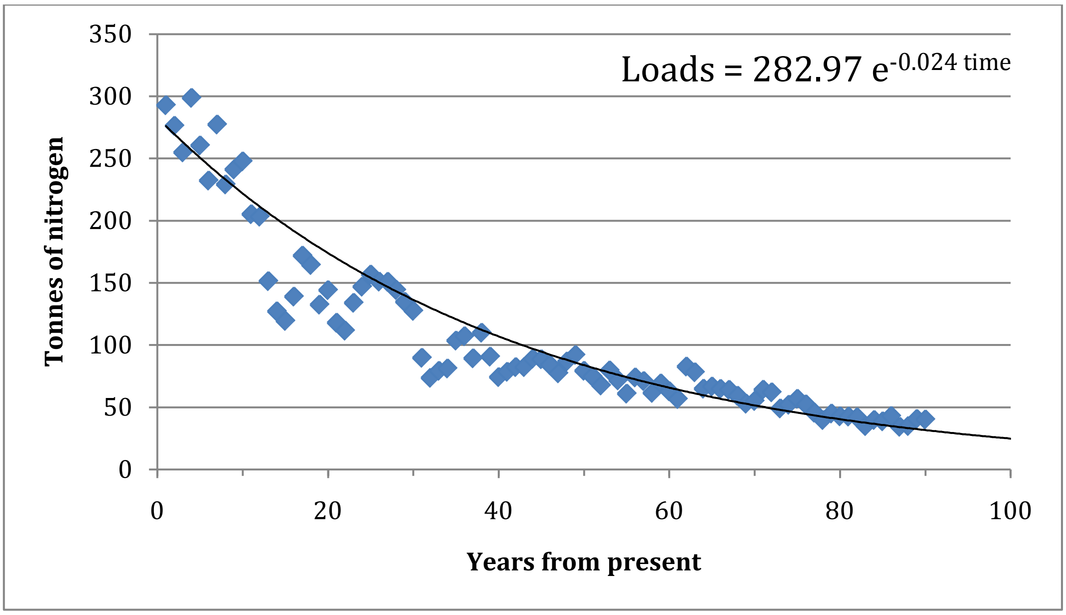
$$Load_{tot}(t) = \sum_{i=1}^{i=n} (Load_{GW}^{i}(t) + Load_{SW}^{i}(t))$$

3.2. Legacy loads

BoPRC has specified environmental targets for Lake Rotorua in terms of annual nitrogen loads. The regulations considered by NManager largely affect dairy and sheep & beef farming. Legacy loads and loads arising from unmanageable exports contribute to the total lake load and must therefore be adjusted for when considering what loads should be targeted by changes in land management practices.

Legacy loads are the nitrogen loads already present in the Lake Rotorua groundwater that will be realized as inputs to the lake in future years. These loads are the result of groundwater lags acting on historic exports from agricultural land-use and septic tanks. They are independent of future land-use and cannot be targeted by mitigation. Figure 4 gives the legacy loads estimated by ROTAN. These are incorporated into NManager using the exponential curve fitted to the results.

Figure 4: Legacy loads: ROTAN results from 2009



3.3. Modelling the use of land in the catchment

Landowners' responses to regulation will depend on their current land-use. We are interested in the uses that land is being put to and where those land uses are taking place.

Land-use and location are specified in NManager using the ROTAN map for current land-use (National Institute of Water and Atmospheric Research, dataset, 2011). This map was constructed in two steps: A 2005 land use map was constructed by BoPRC based on 2003 aerial photographs of land cover and results from a land use questionnaire sent to landowners in 2005. This map was updated to a 2010 land use map using 2007 aerial photographs, a map of dairy land cover and local knowledge (Rutherford et al, 2011).

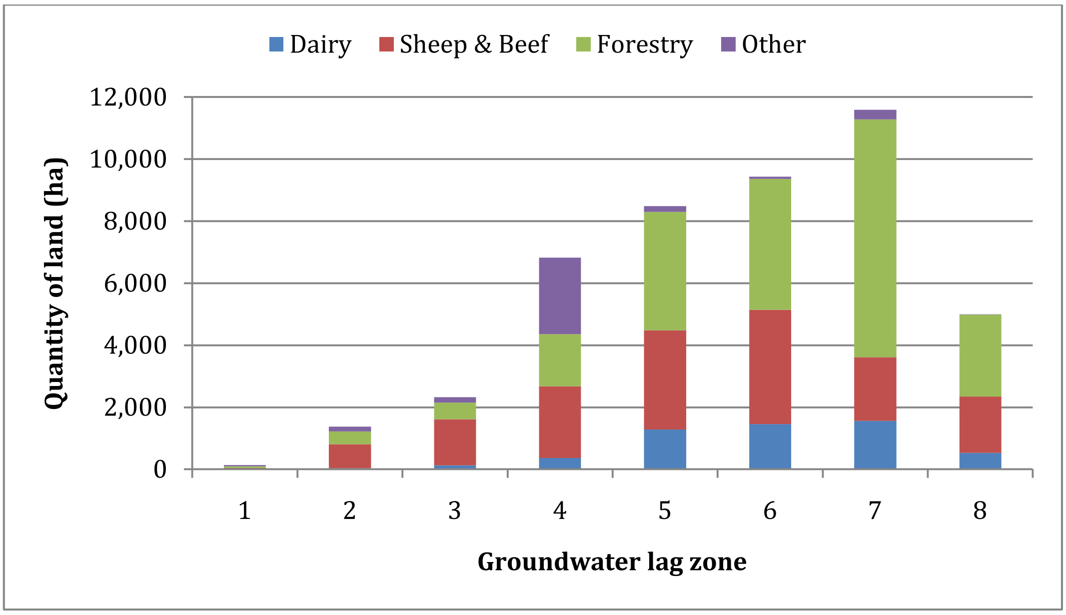
Due to similarities between leaching rates, and uncertainty, some land use categories were merged together. Bare ground, horticulture, lifestyle, dairy drystock and different types of sheep and cattle farming were merged into a sheep & beef category. Scrub, wetlands and different types of forest were merged into a forestry category. Cropping was merged with dairy. The resulting land-use categories in NManager are: Dairy, Forestry, Sheep & Beef, the Rotorua Land Treatment System, Septic Tanks, Tikitere geothermal area, Whakarewarewa geothermal area, Urban and Urban open space. These are estimated to a 1 hectare spatial scale.

Of these categories only nitrogen exports from the dairy and sheep & beef farming categories are considered manageable by landowners' farming practices. Other initiatives have been launched by BoPRC to address nitrogen leaching from septic tanks, the geothermal areas and urban runoff (Environment Bay of Plenty et al, 2009).

Leaching from forestry and scrub land is small and cannot be further mitigated via different land management. However, some land classified as scrub is covered in gorse and has a high rate of nitrogen loss. Replacing gorse land with forestry is expected to result in a 40 tN/yr reduction in nitrogen leaching Male et al, 2010. Separating gorse from other scrub land has been left for future research.

Figure 5 gives the distribution of land-use in each lag zone. We have combined the smaller land uses into a single category labelled 'Other'. We observe that there is very little land in the first three lag zones, dairy is concentrated in lag zones 4 to 7 and sheep & beef farming is spread across all lag zones.

Figure 5: Proportion of land use by groundwater lag zone



3.4. The shape of the profit functions

We model landowners' land management practices using profit functions. Profit functions express the profit of the farm, per hectare per year, as a function of mitigation, per hectare per year. Mitigation occurs via changes in stocking rates, fertiliser and nitrogen inhibitor usage and farm management. Farms are permitted to change to less nitrogen intensive land-uses.

NManager distinguishes between land used for dairy farming and sheep & beef farming by representing each with a different profit function. It assumes farms of both types are homogeneous and have the same leaching and profit per hectare before regulation across the catchment. These are given in Table 3.

Table 3: Leaching and Profit by land-use before regulation

Land-use	Dairy	Sheep & Beef	Forestry
Leaching (kg/ha/yr)	56	16	4
Manageable Leaching (kg/ha/yr)	52	12	0
Profit ($/ha/yr)	1,400	450	267

Under regulation landowners may choose less nitrogen intensive land uses. Dairy farm land may be converted to sheep & beef farming or forestry and sheep & beef farm land may be converted to forestry. This is represented in the model by continuous profit functions that span the uses each category of land may be converted to.

Figure 6 and Figure 7 give the profit functions for dairy farm land and sheep & beef farm land respectively. These are fitted as quadratic curves to simulation results from Farmax and OVERSEER. As the curves are concave, the marginal cost of mitigation increases as mitigation increases.

Note that the profit curve for dairy farms spans the simulation results for sheep & beef farms and intersects the result for forestry profit, and that the profit curve for sheep & beef farms intersects the result for forestry profit. In addition, some results were included even though they were dominated by other results. This was done in an attempt to recognise heterogeneity between farmers, so the curves are more reflective of an average farmer.

Figure 6: Dairy land profit function

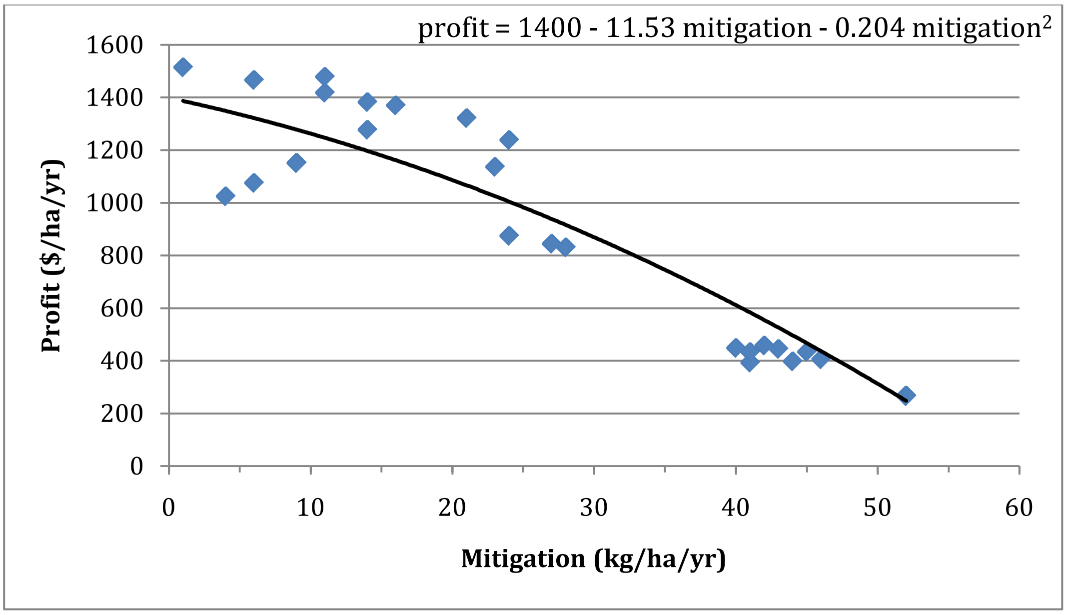
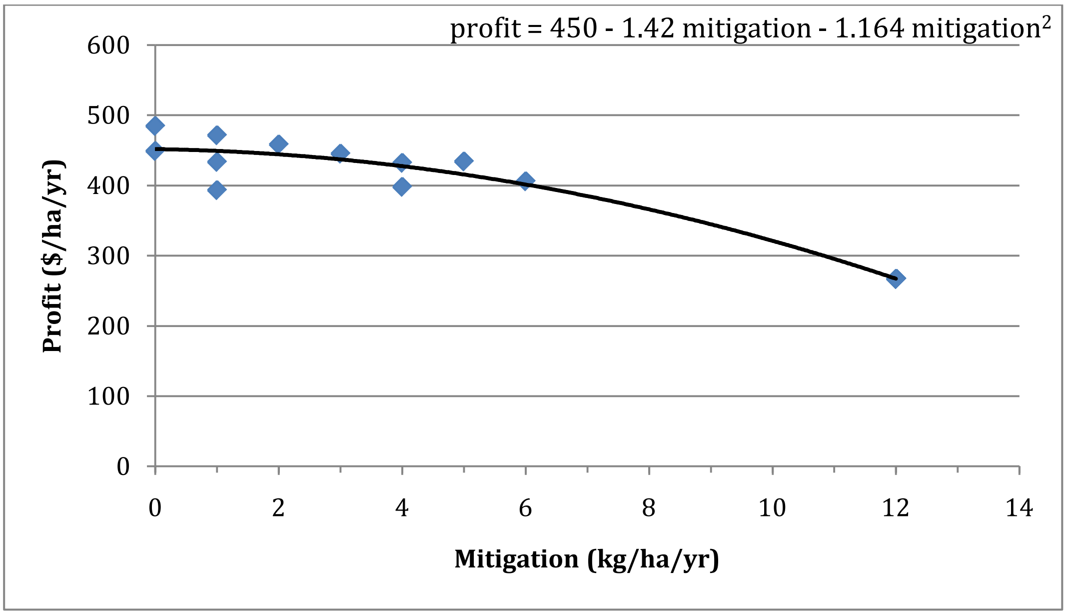


Figure 7: Sheep and Beef land profit function



These profit functions make a number of assumptions: First, they assume that the cost of converting land to a less nitrogen intensive land-use is small. Second, as they are expressed on a per hectare basis, they assume there are no fixed costs for farm management and hence no economies of scale. And last, they assume present conditions persist. Abnormal weather conditions (e.g. drought) and changes in commodity prices may give significantly different results from those predicted. Refining the profit functions to address these assumptions and to represent heterogeneity among farmers remains a topic for future research.

4. The Design of Regulation

Regulation could be used to improve the water quality of Lake Rotorua. Without regulation, landowners' profit maximizing objectives are not consistent with the wider society's water quality objectives. Regulation aims to control landowners' behaviour or to provide financial incentives for landowners to manage and reduce their nitrogen exports to meet the objectives of society.

We are interested in the implications of different regulations and their cost effectiveness for reaching the mitigation targets. In this section we specify six approaches available to BoPRC. In order of complexity they are: requiring best practice; land retirement; an export capping scheme, requiring all landowners to reduce their nitrogen export by a specified percentage; an export trading scheme where landowners must hold sufficient allowances to cover nitrogen leaching from their property each year; and two vintage trading schemes which attempt to incorporate the timing of nitrogen loads, via groundwater, into the regulatory scheme in a simple way. The trading schemes follow the design given in Lock and Kerr (2008) and Kerr et al (2007). These approaches will be evaluated using NManager in section 6.

4.1. Best practice

Output from Farmax and OVERSEER provides estimates of the standard and minimum possible leaching for dairy and sheep & beef farming. We model the adoption of best practice by assuming leaching is reduced to the minimum possible leaching suggested by the Farmax and OVERSEER results included in our profit functions.

This is modelled as a step change in leaching from business as usual in 2015. Leaching from all dairy land is reduced to 28 kg/ha/yr and leaching from all sheep & beef land is reduced to 10 kg/ha/yr. We assume that there is no change in land-use.

4.2. Land retirement

For modelling land retirement we assume all mitigation comes from some landowners changing their land-use to al less nitrogen intensive use. This occurs as a step change in 2015. There is no change in the leaching rates per hectare for each land-use.

In NManager, sheep & beef land is initially retired to become forest before dairy land is retired to new sheep & beef land. If necessary, this new sheep & beef land is then retired into forestry. We assume that land is retired equally across the catchment, hence land retirement in each year can be described by three percentages: the percentage of initial sheep & beef land that has been retired into forest, the percentage of dairy land that has been retired into new sheep & beef land, and the percentage of this new sheep & beef land that has been retired into forestry.

We briefly consider retirement of land as specified in the R-300 ROTAN scenario which reduces exports from their current level by 300 tN/yr by a step change in 2015. The R-300 scenario details that all dairy land is converted to sheep & beef, and around 16% of the sheep & beef land is converted to new lifestyle blocks or forestry (Rutherford et al, 2011). The leaching from sheep & beef land decreases to 14.4 kg/ha/yr and the leaching from new lifestyle blocks is 10 kg/ha/yr.

4.3. An export capping scheme

Under an export capping scheme the regulator specifies the maximum acceptable levels of nitrogen exports for all land in the catchment. This is similar to 'Rule 11' where nutrient leaching on each property in the catchment has been capped at 2001-2004 levels (Environment Bay of Plenty, 2008a). An export capping system could be thought of as a tightening of the caps on each property imposed by 'Rule 11'.

The export capping scheme we consider requires all landowners to reduce the manageable nitrogen leaching from their property to a fixed level of leaching. The acceptable levels of leaching are determined by a percentage reductions in the manageable leaching estimated in OVERSEER for dairy and sheep & beef farming. For example, with a 30% reduction landowners must ensure that the manageable leaching from dairy and sheep & beef land is less that 36.4 and 8.4 kg/ha/yr (30% reduction from 52 and 12) respectively. The percentage reduction would be uniform across the catchment but could change from year to year.

These reductions may result in levels of total leaching that are less than the minimum possible leaching from the current land-use (for example: total leaching under regulation must be less than 10 kg/ha/yr for a sheep & beef farm). Where this occurs changes in land-use will be necessary to meet the leaching reduction. We assume that the landowner will convert some proportion of their land to a less nitrogen intensive land-use and will satisfy the leaching reduction 'on average' across their farm.

Using a uniform percentage reduction in manageable leaching across the catchment is unlikely to be cost effective. In order to determine more cost effective percentages to assign to each lag zone or to each land-use type the regulator must have information about the mitigation costs faced by each landowner. Acquiring this information is recognised as being difficult and costly Tietenberg, 1996. Hence we assume the absence of this information and use a uniform percentage across the catchment.

An export capping scheme may be desirable as the approach is well established, both in the literature and in practice, and is typically straightforward to implement. Unfortunately there has been no evidence that 'Rule 11' has been successful in capping nutrient exports since its introduction. Recommendations to BoPRC identify weaknesses in the monitoring and enforcing of 'Rule 11' (Foster and Kivell, 2009). As the export capping scheme could be introduced in a very similar way it may inherit the faults of the 'Rule 11' regulation.

4.4. An export trading scheme

The environmental targets for Lake Rotorua are specified in terms of acceptable nitrogen loads to the lake. However, landowners manage the amount of nitrogen they put onto the land, from which it is relatively easy to estimate exports from their property (for example, using OVERSEER), but difficult to estimate loads reaching the lake. This suggests that regulation which targets exports will be more straightforward than regulation which targets lake loads.

Under an export trading scheme the regulator provides a supply of export allowances. At the end of each year landowners must surrender sufficient allowances to cover the nitrogen leaching from their property for that year. Landowners who do not have sufficient allowances to cover their leaching will have to purchase unused allowances from landowners with excess allowances, reduce their exports or risk non-compliance. By controlling the supply of export allowances a regulator can manage the amount of nitrogen that reaches the lake.

There has already been experience with this design of regulatory scheme in New Zealand. An export trading scheme has been implemented in the catchment about Lake Taupo, the biggest lake in New Zealand. Although groundwater lags are present in the Lake Taupo catchment, Environment Waikato chose not to implement regulation that incorporated groundwater lags or attenuation, because of uncertainty in the underlying biophysics, and because of the likely complexity of the regulatory and trading schemes. Some farmers lobbied for both attenuation and groundwater lags to be considered. However it was felt that this was unnecessary (Environment Waikato, 2003).

A trading scheme is desirable as it encourages mitigation to occur where it is most cost effective. Profit maximizing landowners will mitigate as long as the cost of mitigation is less than the price of the allowances they would otherwise have to hold. The price of allowances will be such that all allowances are used and the marginal landowner is indifferent between further mitigation and purchasing additional allowances. It follows that under a trading scheme the least costly mitigation activities will take place first. For this reason a trading scheme is generally more cost effective than an export capping approach.

In this study there is no difference between farms of the same type (e.g. between dairy farms) in their nitrogen exports of costs of mitigation. Hence trading encourages mitigation on whichever land-use it is cheapest. In reality, there are differences between farms of the same type, so trading will encourage mitigation on whichever farm it is cheapest.

Despite this, a trading scheme does not overcome all the administrative difficulties of an export capping scheme. Successful implementation of a trading scheme requires the regulator to have good monitoring and enforcement in place. Furthermore, the regulator must determine the initial allocation of allowances. This can be an extensive political process with high potential costs.

4.5. Vintage trading

Groundwater lags are known to be prevalent in the Lake Rotorua catchment. Taking account of groundwater lags in the design of regulation may result in more cost effective regulation as landowners will surrender allowances that better correspond to their lake loads. We consider two simple vintage trading schemes that attempt to reflect the timing of nitrogen loads to the lake. These schemes attempt to link lake loads to exports via vintage allowances.

A vintage trading scheme works in a similar way to an export trading scheme. The main difference is that vintage allowances permit landowners to release nitrogen into the lake, rather than to export nitrogen from their land. Therefore landowners are trading rights for lake loads not exports. Under regulation, landowners need to surrender allowances at the end of each year to cover the lake loads that will be caused by the nitrogen leaching from their property from that year.

Due to the continuous nature of groundwater leaching some approximation is required for a vintage trading scheme to be implemented in practice. The design of regulation must provide some convention that specifies for landowners the vintage allowances they need to surrender in each year. We consider two possible regulatory conventions; the one pulse vintage scheme and the two pulse vintage scheme. These follow the design of a vintage scheme given in Kerr et al (2007).

The one pulse vintage scheme allocates every lag zone a lag time to approximate the mean groundwater lag time. In each year, landowners must surrender allowances of the vintage that corresponds to the current year plus their lag time. For example, suppose a landowner with a lag time of 6 years exports nitrogen in 2020. Under the one pulse trading scheme they must surrender vintage allowances for the year 2026.

Table 4 summarizes the lags for the one pulse vintage scheme. These lags were selected as the average travel time for all water (30% of the surface water time of zero plus 70% of the groundwater time represented by the MRTs for each lag zone). They correspond to the time by which all of the surface water and at least one third of the groundwater have reached the lake.

Table 4: Lag Times for the One Pulse Vintage Scheme

Groundwater lag zone	1	2	3	4	5	6	7	8
Lag times	1 yrs	6 yrs	11 yrs	21 yrs	35 yrs	49 yrs	63 yrs	77 yrs

Recall that 30% of nitrogen reaches the lake via surface water and 70% via groundwater. The two pulse vintage scheme allocates every lag zone a lag time but this lag time applies only to groundwater leaching. In each year landowners surrender allowances for the nitrogen leaching from their property in that year. 30% of these allowances must be from the vintage that corresponds to the current year (to cover surface water leaching) and 70% of these allowances must be from the vintage that corresponds to the current year plus their lag time (to cover groundwater leaching). For example, a landowner with a lag time of 15 years exports 100 kg of nitrogen in 2020. Under the two pulse trading scheme they must surrender 30 kg worth of 2020 vintage allowances and 70 kg worth of 2035 vintage allowances. These allowances are surrendered in the year 2020.

Table 5 summarizes the lags for the two pulse scheme. These lags were selected to match the MRTs for each lag zone. They correspond to the time at which 60% of nitrogen exports from the current year will have arrived at the lake.

Table 5: Lag Times for the Two Pulse Vintage Scheme

Groundwater lag zone	1	2	3	4	5	6	7	8
Lag times	2 yrs	8 yrs	15 yrs	30 yrs	50 yrs	70 yrs	90 yrs	110 yrs

Under a vintage trading scheme, gains in cost effectiveness may arise from trading between lag zones. A landowner at the back of the catchment may choose either to mitigate in the present year or to purchase allowances from a landowner closer to the lake. Purchasing allowances from a landowner closer to the lake delays the timing of mitigation: rather than the landowner at the back of the catchment mitigating now, the landowner at the front of the catchment will mitigate in the future. Consequently, this sort of trading reduces the net present value of the cost of mitigation.

In theory a trading scheme is desirable as it encourages mitigation to occur where it is most cost effective. The advantage of a vintage trading scheme over an export trading scheme is that the vintage scheme attempts to incorporate groundwater lags and treats landowners differently depending on the timing of their contribution to lake loads. This may result in a more cost effective allocation of mitigation as the distribution of mitigation may be closer to the distribution of the generation of lake loads.

However, unlike the export trading scheme, vintage trading schemes have never been implemented. This may be because the complexity of these schemes would make them difficult to implement and administer. There may also be significant price risk for some landowners. For a landowner close to the lake who sells allowances, there is a risk the price of mitigation will increase, so they will not be able to afford to mitigate in the future. Conversely, if the same landowner buys allowances now to use in the future they run the risk that the price of allowances will drop. Furthermore these risks will differ between landowners: landowners with the longest lag times will face the least uncertainty as they are the first to surrender allowances of any given vintage, while landowners with the shortest lag time are the last to surrender allowances of any given type. There may also be dependences between vintages (see Appendix C).

5. Simulating Landowner Behaviour under Regulation

For a specified regulatory system, NManager determines the pattern of nitrogen exports that will be chosen by profit maximizing landowners. Furthermore, for a specified set of environmental targets and given regulatory scheme NManager can determine the appropriate reductions in total exports that will ensure landowners' profit maximizing behavior meets those targets. These solutions are unique. This section specifies how NManager solves for the optimal pattern of nitrogen exports to meet given targets under the different regulatory schemes.

5.1. Solving the export capping scheme

Under the export capping scheme landowners' profit maximizing quantity of nitrogen exports is the maximum quantity of nutrients permitted for their land. This result holds assuming there are no voluntary changes in land-use.

Given the current regulation imposed by 'Rule 11' landowners are prohibited from increasing their nutrient use above current levels. This prevents landowners changing their current land-uses to more nitrogen intensive and potentially more profitable land-uses.[3] Furthermore, as less nutrient intensive land uses are less profitable it is reasonable to assume that most landowners will not voluntarily change their land-use to a less nutrient intensive land-use.

For a specified series of environmental targets NManager determines the percentage reductions in manageable exports required for each year that ensures nutrient targets are met. We can establish a series of equations that express lake loads as a function of exports as follows:

Let $y_{s,t}$ be the amount of nitrogen that leaches from dairy and sheep & beef land, and let $z_{s,t}$ be the amount of nitrogen that leaches from all other land, at time s ($s \geq 0$) and arrives in the lake at time t before the introduction of regulation ($y_{s,t}$, $z_{s,t} = 0$ if $s > t$). We can therefore express the total lake loads in year t, as:

$$\text{total loads}_t = \sum_s y_{s,t} + \sum_s z_{s,t}$$

As the export capping scheme enforces equal reductions for all land across the catchment a percentage decrease in exports results in the same percentage decrease in corresponding loads to the lake. Let d_s be the percentage decrease in exports imposed by regulation for year s. We can express the total lake loads, under regulation, in year t, as:

$$\text{total loads under regulation}_t = \sum_s (1 - d_s)\, y_{s,t} + \sum_s z_{s,t}$$

To determine the percentage reductions that should be imposed by regulation we fix some bound on time and consider exports and loads up to this time, so $t \in [0, T]$. We can then express the required total loads as a function of the percentage reductions using the above

3 Anecdotal evidence suggests 'Rule 11' has assisted in preventing an increase in dairy farming in the Lake Rotorua/Rotoiti catchment (Maki, 2009).

equation. This results in a system of simultaneous equations that we solve for d_s for all s. As $y_{s,t} = 0$ if $s > t$ this system will always have a unique solution.

5.2. Solving for land retirement

We solve for the percentage of dairy and sheep & beef land retired under land-retirement regulation using a three-step extension of the export capping solution. We determine the percentage of original sheep & beef land retired into forestry, followed by the percentage of dairy land retired into sheep & beef, and finally the percentage of new sheep & beef land retired into forestry.

First redefine $y_{s,t}$ to be the amount of nitrogen that leaches from original sheep & beef land in excess of that which would leach from the same land if it were used for forestry, and redefine $z_{s,t}$ to be all other leaching. The percentage of sheep & beef land retired is then given by d_s. We interpret $d_s > 1$ (more than 100% of sheep & beef land retired) as $d_s = 1$ (100% of sheep & beef land retired) with the retirement of some dairy land required.

Given this solution we redefine $y_{s,t}$ to be the leaching from dairy land, and redefine $z_{s,t}$ to be all other leaching (after the retirement of sheep & beef land). The percentage of dairy land retired is then given by d_s. We interpret $d_s > 1$ (more than 100% of dairy land retired) as $d_s = 1$ (100% of dairy land retired) with the retirement of some new sheep & beef land required. The percentage of new sheep & beef land retired is calculated in the same way.

5.3. Solving a trading scheme

For a trading scheme with given allowance caps, NManager determines landowners' profit maximising quantity of nitrogen exports, in each time period, by finding the allowance price under which the supply of allowances equals the demand for allowances. This price will be equal to the cost of the last unit of mitigation. The algorithm attempts to replicate the behaviour of a decentralized market by updating the price of allowances in response to excess supply and excess demand.

We next give a formal presentation of the model used in NManager[4], non-technical readers may wish to skip forward to section 8.2. The vintage trading schemes can be understood using a generalization of the export trading scheme approach, see Appendix A for further details.

4 We thank Andrew Coleman who provided a prototype of this optimization routine.

Suppose there are M landowners. Production for landowner i at time t depends on their quantity of nitrogen exports x_{it}. The profit for landowner i, at time t is given as follows.

$$\pi_{it} = f_i(x_{it})$$

Let P_t be the current price of allowances in year t. Profit seeking landowners will choose x_{it}^* the quantity of N exports that maximizes their profit less the opportunity cost of holding allowances as follows:

$$x_{it}^* = x_{it}^*(P_t) = \mathbf{arg\,max}\ [f_i(x_{it}) - x_{it}\, P_t]$$

The total demand for allowances of in year t is given by:

$$D_t = \sum_i x_{i,t}^* = g(P_t)$$

Let S_t be the allowance cap (the supply of allowances) in year t. The excess demand for allowances, F_t, can be expressed as follows:

$$F_t = D_t - S_t = g(P_t) - S_t$$

The market clearing prices will be $\{P_t\}$ such that for all allowances:

$$F_t \le 0 \quad and \quad F_t\, P_t = 0$$

In a decentralized market the price depends on the supply and demand in that market. Therefore we may express the price for each allowance as follows:

$$P_t = h(D_t, S_t) = h(g(P_t), S_t)$$

Given price in this form we then use an iterative numerical method to determine the price of allowances in equilibrium. See Appendix A for further details.

For a specified environmental target, NManager determines the allowance caps for each year that ensures nutrient targets are met. This is done using an iterative approach. We compare the lake loads that result from a set of caps with the acceptable lake loads. The allowance caps are then tightened if the current lake loads exceed acceptable loads and are loosened if acceptable lake loads exceed current lake loads.

6. The Performance of Different Regulatory Schemes

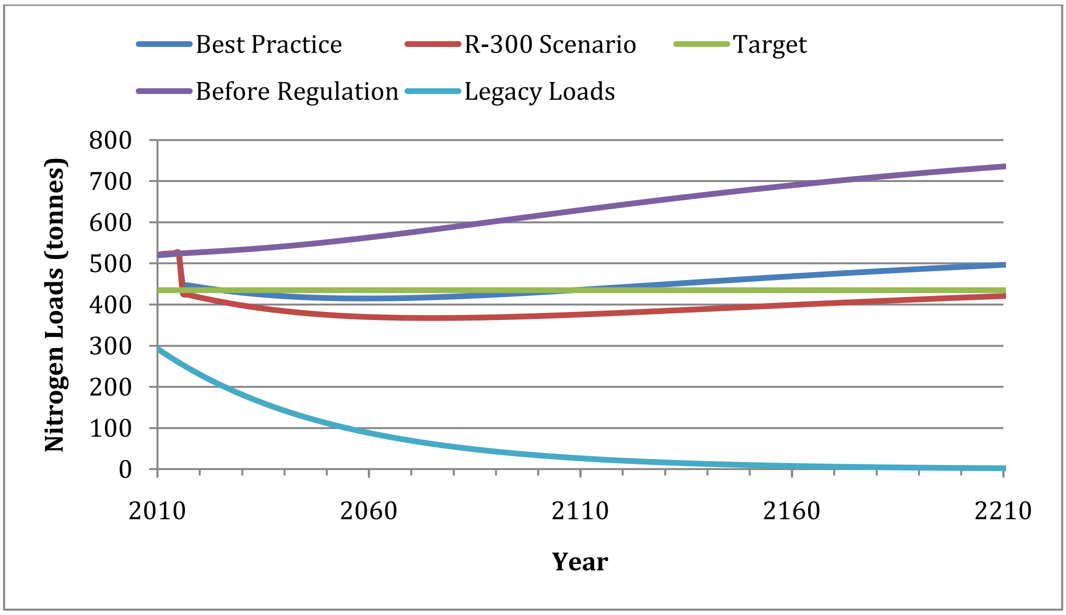
This section presents simulation results from NManager for the regulatory schemes introduced in section 4. We compare the results for the different schemes and discuss their possible implications for future regulatory decisions.

6.1. Requiring best practice

We first consider the environmental outcome from best management practice. This is compared to the environmental target specified by BoPRC and the cost of achieving the same environmental outcome using the export capping and export trading scheme approaches.

Figure 8 gives the total lake loads under best practice regulation and under the R-300 scenario. The load paths for both schemes assume that there is a step change in land-use, and hence exports, in 2015. We also give the load path without regulation and the legacy loads for comparison.

Figure 8: Nutrient Loads under best practice regulation



We observe that the load paths for best practice and land retirement result in lake loads that are less than the environmental target in the short run and increase to exceed the environmental target in the long run. The shape of these load paths is due to the abrupt change in nitrogen leaching in 2015. Under regulation the manageable loads have a step decrease, due to surface water, in 2015 and then slowly build up as nitrogen flows through the groundwater. The unmanageable and legacy loads decrease smoothly. The aggregate effect is that loads decrease in the short run before rising to their long run values.

If regulation were to be implemented in the Lake Rotorua catchment, we would most likely observe a more gradual decrease in lake loads as landowners would require a transition period toward full regulation.

In our model all approaches reach their long-run lake loads by 2210 and are flat after this. Requiring landowners to implement best practice on their land results in long run loads of 499 tN/yr. The R-300 scenario results in long run loads of 421 tN/yr.[5]

Implementing best practice results in a decrease in nitrogen exports and long-run lake loads by 242 tN/yr in the long run. Although this satisfies the environmental target in the short run, by itself it is not sufficient to ensure acceptable lake quality in the long run. This suggests that some land retirement will be necessary to meet the environmental target for the lake.

Using NManager we estimated the cost of best practice. For comparison we estimated the cost of achieving an identical environmental impact using the export capping and export trading approaches. Table 6 gives the net present value (NPV) of the cost of mitigation for the different approaches.[6]

Table 6: NPV of the cost of mitigation for best practise load path

Scheme	Best Practice	Export Capping	Nutrient Trading
NPV ($ millions)	36.4	35.0	37.0

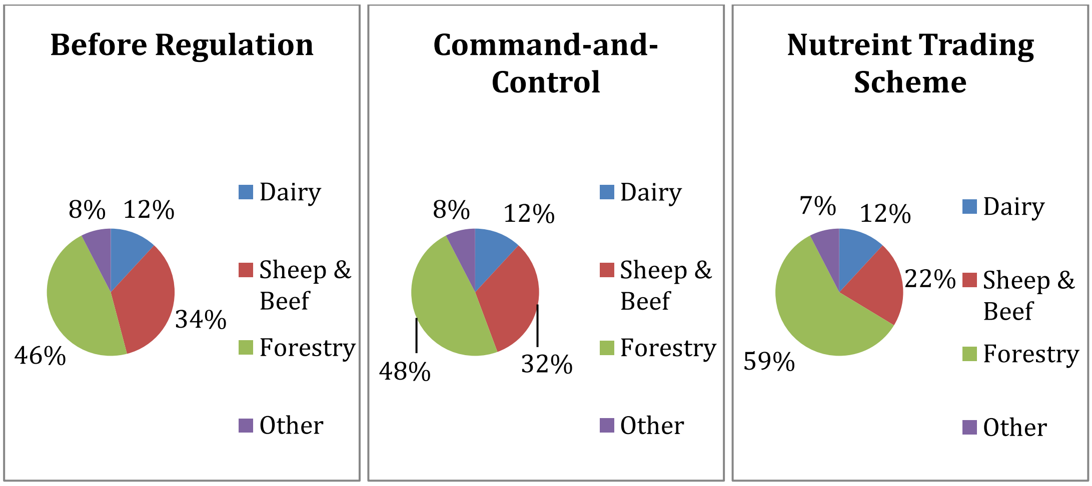
We observe a similar NPV for the cost of mitigation, required to achieve the load path given in Figure 8, for all three regulatory approaches. The differences in cost will be due to how mitigation is distributed between the different farm types under the different regulations.

Figure 9 gives estimates for the long run proportion of land in each of the land-uses under the different regulatory approaches. Land-use under best practice regulation is identical to land-use before regulation.

5 This assumes that nutrient leaching per ha stays constant within each land use.

6 The NPV of the cost of mitigation for the R-300 scenario is $61.0 million. As this cost arises from a different environmental outcome to best practice it is not directly comparable.

Figure 9: Long Run Distribution of Land corresponding to Best Practice Lake Loads



We observe that there is minimal change in the land used for dairy farming, this is due to amount of mitigation possible on dairy land without land-use change. Under export trading regulation, NManager estimates that only sheep & beef land is retired into forestry. The land use changes associated with the export trading scheme could be associated with a 27% decrease in agricultural employment, a 26% increase in forestry employment and 10% decrease in total employment.[7]

These figures were constructed assuming that where a change in land-use is necessary dairy land is replaced by sheep & beef land, and sheep & beef land is replaced by forestry.[8]

6.2. The performance of straightforward regulation

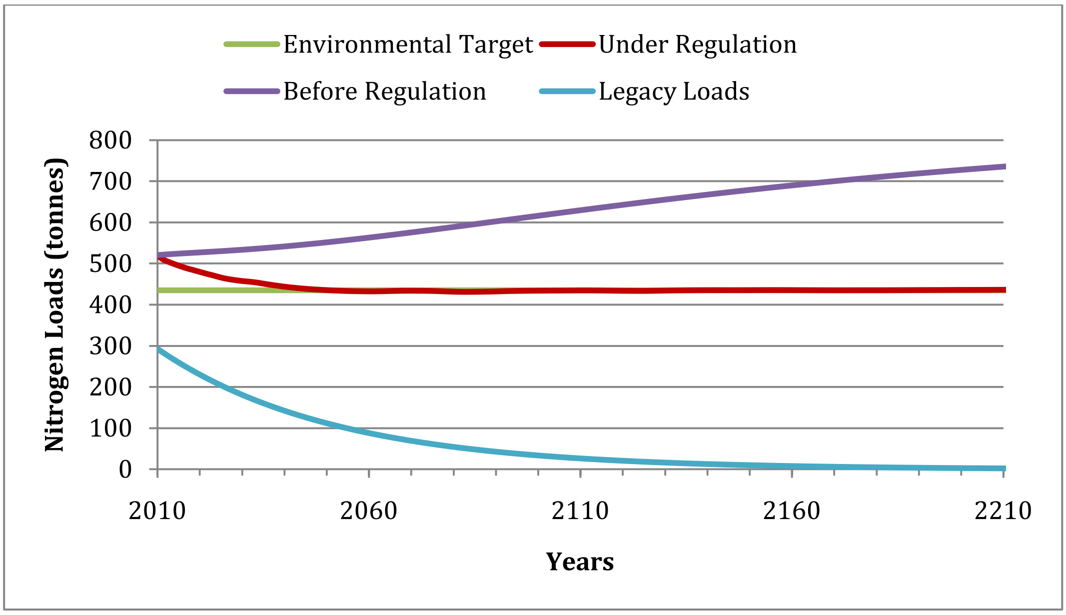
We now consider the effect of land retirement, the export capping scheme, and nutrient trading. For these approaches we require that regulation results in the lake loads under regulation given in Figure 10. The load path without regulation and the legacy loads are provided for comparison.[9]

7 From the Agricultural Census, June 2007, and the Linked Employer-Employee Database, Junes 2007, both provided by Statistics New Zealand, we estimate 4.48 Agricultural (dairy and sheep & beef) employees per 1000 hectares and 2.09 forestry employees per 1000 hectares. Before regulation this gives 93 agricultural employees, 44 forestry employees and 137 employees across both categories.

8 Any change in other land-use is due to rounding.

9 As these lake loads differ from those shown in Figure 8 we cannot compare the NPV of the costs of mitigation given in section 6.1 with the costs of mitigation given in sections 6.2 and 6.3.

Figure 10: Nutrient loads required for regulation comparison



The load path under regulation was specified so that the long run environmental target for the lake would be reached in fifty years and nitrogen loads would remain approximately constant from then onwards. Although lake loads reach their long run value in fifty years, due to groundwater lags, nitrogen exports must be managed for much longer and allowance caps are reduced over 200 years.

The lake loads under the different regulatory schemes were matched to the specified load path by controlling the stringency of the regulation. For land retirement, NManager determined the percentages of dairy and sheep & beef land to retire as a function of time such that, after accounting for groundwater lags, the lake load matched the specified environmental outcome. For the export capping scheme, NManager determined the percentage reduction in leaching required from year to year such that, after accounting for groundwater lags, the lake loads matched the specified target trajectory. For the trading schemes, NManager determined the allowance caps necessary for each year.

Despite these regulatory approaches having identical environmental outcomes, the cost of mitigation under these schemes is not the same. Under the regulatory schemes the distribution of mitigation between dairy farmers and sheep & beef farmers differs. The cost of mitigation is not uniform for either type of farmer. The more mitigation a farmer must conduct the more expense each additional reduction in nitrogen becomes; the marginal cost of mitigation increase. It follows, that a regulatory scheme where one type of farmer must do the majority of the mitigation will be more costly overall than a scheme where mitigation is shared between both types of farmers.

Note that this does not imply that the quantity of mitigation required should be divided evenly between all farmers. Some farmers will face lower costs of mitigating so they can mitigate more than others farmers for the same total cost to each farmer. Ideally, each farmer would pay an equal share of the cost of reducing lake loads.

Table 7: NPV of the Cost of Mitigation for Straightforward Regulatory Systems

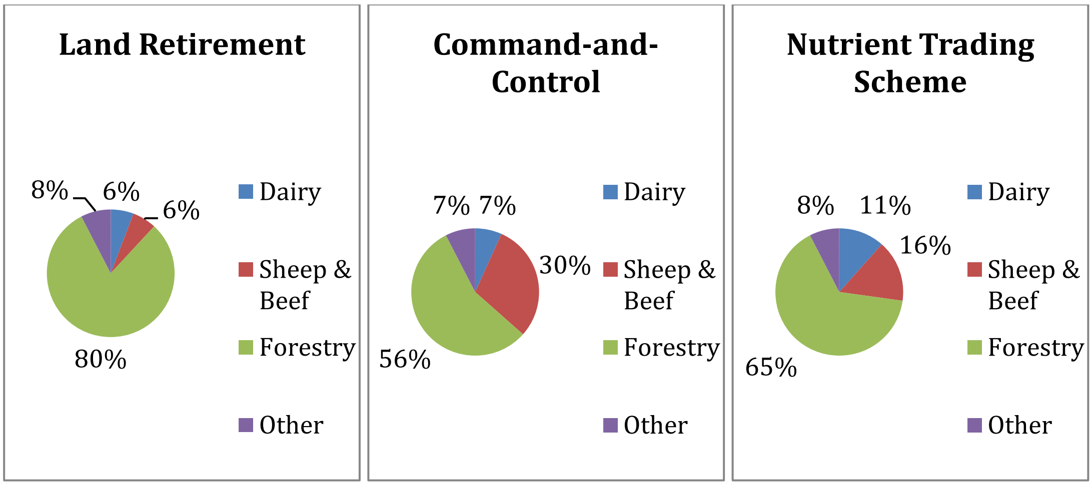
Scheme	Land-Retirement	Export Capping	Nutrient Trading
Cost to Dairy ($ millions)	1.6	18.9	9.7
Cost to Sheep & Beef ($ millions)	28.0	4.7	10.1
Total Cost ($ millions)	29.6	23.6	19.8

Table 7 gives the NPV of the cost of mitigation, estimated by NManager, under each of the schemes. [10] We observe that the cost of mitigation under the export capping scheme is 20% less than under land-retirement and that the cost of mitigation under the export trading scheme costs 16% less than under the export capping scheme.

Under the export trading scheme the marginal cost of mitigation is the same for both types of farmers. In contrast, under land retirement and the export capping scheme a greater proportion of the mitigation is borne by sheep & beef farmers and dairy farmers respectively who therefore face a higher marginal cost of mitigation. While this reduces the cost of mitigation faced by the other type of land-use, it results in an overall increase in the cost of mitigation.

All three forms of regulation result in changes in land-use in the surrounding catchment. Figure 11 estimates the long run proportion of land in each of the land-uses under the different approaches.

Figure 11: Distribution of Land under different regulatory schemes



10 In this section dairy land and sheep & beef land refers to the land-use before regulation.

We observe that land retirement results in a significant decrease in the amount of land used for dairy and sheep & beef farming in the catchment. This is because all land that was initially sheep & beef land was converted to forestry and about half of the dairy land was retired to sheep & beef; no mitigation took place other than via a change in land-use.

Under an export capping scheme the higher cost of mitigation borne by dairy farmers, in comparison to the export trading scheme, results in a greater reduction in the land used for dairy farming. Although the net change in the percentage of land used for sheep & beef farming is only two percentage points under the export capping scheme, the actual change in land-use would be much more significant as less productive sheep & beef land is retired into forestry and less productive dairy land is retired into sheep & beef.

We observe minimal change in the amount of land used for dairy farming under an export trading scheme because of the high potential for mitigation to take place on dairy land without a change in land-use and the high profitability of dairy relative to sheep & beef.[11] The contrast between land-use under land retirement and land-use under export trading suggests that there is significant potential for mitigation to take place without a change in land-use.

The changes in land-use given in Figure 11 imply changes in employment under regulation. Land retirement results in a 74% decrease in agricultural employment, a 73% increase in forestry employment and a 27% decrease in total employment. The export capping scheme results in a 20% decrease in agricultural employment, a 20% increase in forestry employment and a 7% decrease in total employment. The export trading scheme results in a 41% decrease in agricultural employment, a 40% increase in forestry employment and a 15% decrease in total employment.

6.3. More complex trading schemes

We have observed a gain in the cost effectiveness of regulation when moving from an export capping scheme to an export trading scheme. This gain in cost effectiveness arises from a change in the distribution of mitigation between dairy farmers and sheep & beef farmers.

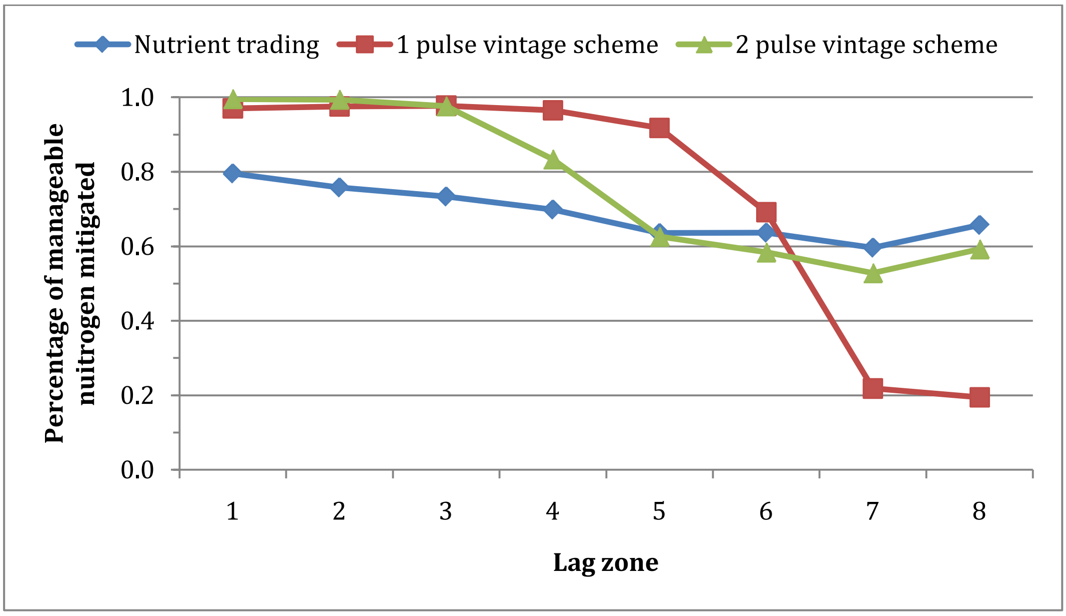
We now consider the vintage trading schemes to determine whether further gains in cost effectiveness are possible from further changes in the distribution of mitigation. Following the work in section 6.2, we require that the vintage schemes result in the lake loads under regulation given in Figure 10.

11 Recall dairy land can mitigate to have leaching of 28 kg N/ha/yr.

Under a vintage trading scheme, lag times differ about the catchment As a result, there are possible trade-offs between landowners at the back of the catchment initially delaying mitigation, by buying allowances from landowners at the front of the catchment, although this means landowners at the front of the catchment will need to mitigate more heavily in the future.

Figure 12 gives the percentage of manageable nitrogen within each lag zone, before regulation, that is mitigated under regulation.[12] For example, 70% of the nitrogen in lag zone 4 is mitigated under an export trading scheme. This percentage rises to 83% under the 2 pulse scheme and to 97% under the 1 pulse vintage scheme.

Figure 12: Percentage of nutrients within each lag zone mitigated



From the export trading scheme, we observe that approximately 70% of all manageable nitrogen must be mitigated to reach the environmental target. Under an export trading scheme this mitigation is relatively evenly distributed across the catchment. Both the vintage schemes result in an increase in the percentage of mitigation for lag zones closer to the lake and a decrease in mitigation for the lag zones further from the lake. This effect is much more pronounced for the 1 pulse vintage scheme that for the 2 pulse scheme.

Under the export trading scheme landowners in each lag zone faced the same price for allowances in each year and therefore will have the same marginal costs of mitigation per hectare. However, under the vintage schemes the nominal price of allowances changes from year to year

12 For each lag zone: percentage mitigated = (exports before regulation – exports after regulation) / exports before regulation.

with the interest rate as the real value of allowances remains the same.[13] Hence, under the vintage schemes, landowners face different nominal prices of allowances, depending on the year in which they must surrender allowances, and therefore will have different marginal costs of mitigation per hectare. Table 8 gives the NPV of the cost of mitigation under each of the trading schemes.

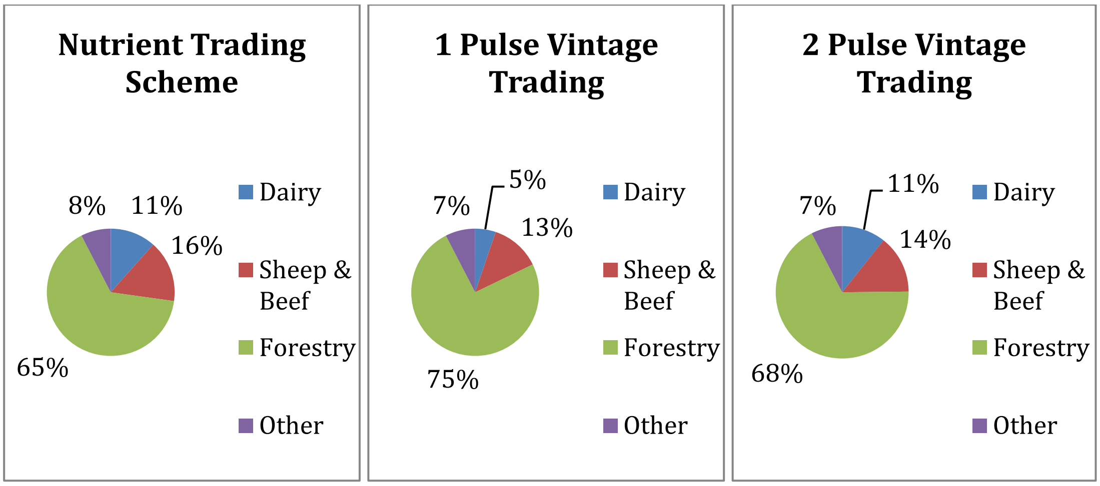
Table 8: Comparison of Different Trading Schemes

Scheme	Nutrient Trading	1 Pulse Vintage Trading	2 Pulse Vintage Trading
NPV ($ millions)	19.8	24.0	19.6

We observe that the 1 pulse vintage scheme is less cost effective than the export trading scheme and that the 2 pulse vintage scheme has about the same cost of mitigation as the export trading scheme. This suggests that there are not significant gains in cost effectiveness from introducing a more complex regulatory scheme and that a poor choice of regulatory lag times may result in less cost-effective regulation.

All the schemes will result in changes in land-use in the catchment. Figure 13 gives the long run proportion of land in each of the land-uses under the different trading schemes.

Figure 13: Distribution of Land under different trading schemes



Both vintage trading schemes result in almost all the nitrogen in lag zones 1-3 being mitigated and the land converted to forestry. However, as these lag zones are small they only contribute to about a two percentage point increase in the amount of land in forestry over the export trading scheme.

13 Landowners should be indifferent between buying an allowance now for $30 and investing the cost of the allowance for a year and buying the same allowance next year for $(1 + r) \times \$30$, where r is the interest or discount rate.

The significant change in the percentage of land in forestry between the export trading and 1 pulse vintage schemes is due to mitigation in lag zones 4 and 5. At least 90% of the nitrogen in these lag zones is mitigated under the 1 pulse scheme and hence much of the land is converted to forestry. Despite this, the 1 pulse vintage scheme does not result in as much land being retired to forestry as we observe under the land retirement approach. As all three schemes result in the same loads to the lake each year they will also result in similar exports from the land each year.

7. Discussion and Conclusions

We have described NManager and used it to evaluate a range of possible designs of regulations to improve water quality. Our results suggest that different designs of regulation will result in significant differences in the cost of mitigation.

Simulation results of regulation requiring best practice suggest that changes in nitrogen leaching without changes in land-use will not be sufficient to meet the environmental target for the lake in the long run. In contrast, simulation results of land retirement regulation suggest that a significant proportion of the catchment would need to be retired into forestry in order to meet the environmental target. It is likely that a mixture of these two approaches, as represented by the export capping or export trading regulation, would be preferable.

By controlling the stringency of regulation we were able to ensure that the land retirement, export capping, export trading and vintage trading schemes resulted in the same environmental outcome: to achieve the lake load target of 435 tN/yr within fifty years. There is at least a 16% reduction in the cost of mitigation between the export capping and export trading schemes where the lake loads match those given in Figure 10 due to changes in the distribution of mitigation between dairy farmers and sheep & beef farmers.

However, it is likely that our results under-estimate the gain from trading schemes over an export capping scheme as we has assumed all farms of the same type are homogeneous. Where there are heterogeneous farmers we would expect greater gains from the implementation of a trading scheme. Estimation of the real gain from trading scheme regulations would require knowledge about the heterogeneity in the actual mitigation costs faced by farmers. These will be farm specific and require more detailed information than we had access to for this research.

It should also be noted that our load fitting algorithm depends on the shape of our profit functions. In constructing the profit functions used in NManager we have assumed that the cost of converting land to a less nitrogen intensive land-use is small. Introducing costs for land conversion would encourage mitigation to take place with minimal change in land-use and could significantly increase the cost of mitigation for all results where mitigation requires changes in land-use.

The costs of mitigation quantified in this report are not the total costs of restoring the lake. There will be additional costs to the regulator associated with implementing and administrating the regulation that are not accounted for in the costs reported here.

Comparing the export trading and vintage trading schemes suggests that there are minimal (or negative) gains in cost effectiveness to be made from more complex regulation. This may be due to the choices of lag times or due to the nature of the catchment. We observe that there is only a small amount of land in lag zones 1-3, hence only a small amount of mitigation can be traded from the back of the catchment to the front. The share of nitrogen that travels via groundwater is 70% and some nitrogen takes more than 200 years to reach the lake. If the distribution of land were more equal between lag zones or the groundwater flow different then the vintage trading schemes might have been more cost effective.

Our estimates of land-use change suggest that meeting the environmental target for Lake Rotorua will require the amount of land used for forestry to increase by 10-20% of the catchment area. This will be supported by a reduction in the amount of dairy and sheep & beef land. We observe that the percentage of dairy land need not decrease significantly under regulation. This suggests that there is significant potential for mitigation to occur on existing dairy farms.

In our analysis we have assumed that all land in the catchment is affected by regulation. In practice, some land will be excluded from regulation due to the high cost of including it relative to the possible nitrogen reduction from that land. Some properties, for example below a certain size, might be excluded from regulation. This would increase the quantity of unmanageable loads from those estimated in this paper and decrease the amount of land available for mitigation. The same amount of mitigation would be distributed over a smaller area and hence the cost of mitigation would rise from that estimated here.

NManager is a partial equilibrium model. Its solutions assume that regulation within the catchment does not affect input prices.[14] This may not be reasonable in the short run when workers are immobile and capital for investments in mitigation is scarce. NManager also ignores the pressure imposed on land outside the catchment as land-use within the catchment changes

14 It also assumes that output prices are unaffected. Given that most output is exported this is a reasonable assumption.

under regulation. As more complex regulatory schemes have higher costs of information landowners will be more likely to seek satisfactory rather than optimal solutions. There will be a range of satisfactory solutions many of which will be similar but not identical to the optimal solution. Determining the implications of this range of solutions is beyond the scope of this paper.

The current version of NManager ignores uncertainty as assuming that landowners have perfect information and foresight to plan 100, or more, years ahead. However landowners are unlikely to plan more than 10 years ahead due to uncertainty and bounded rationality (the longest bond offered by the New Zealand Treasury is 12 years). Uncertainty could be introduced into the model by considering landowners' expectations of future leaching and land-use. This has been left for future research.

Our results have been discussed in the context of nitrogen levels in the Lake Rotorua catchment in the Bay of Plenty, New Zealand. The management of nutrients in water ways and water bodies is a potential issue in any environment where nutrient use is intensifying. The NManager model is not bound to the Lake Rotorua catchment and could be parameterized to conduct the same analysis in another context.

8. Appendix A: The Optimization of Nutrient Trading Systems

In section 5.3 we gave a formal presentation of the model for an export trading scheme. We now present how this model is generalized to account for a vintage trading scheme and the optimization routine that is used to solve both approaches.

8.1. Solving the vintage trading schemes

Suppose there are M landowners. Production for landowner i at time t depends on their quantity of nutrient exports x_{it}. The profit for landowner i, at time t is given by:

$$\pi_{it} = f_i(x_{it})$$

Let $\{v_{ik}\}$, $k = 1, \ldots, K$, be the lag times specified by the regulatory scheme for landowner i. The percentage of exports it carried to the lake at lag time k is given by θ_k. In the one pulse vintage scheme K$= 1$ and $\theta_1 = 1$. In the two pulse vintage scheme $K = 2$, $\theta_1 = 0.3$ and $\theta_2 = 0.7$. The surface water flow has a lag time of zero for all lag zones ($v_{i1} = 0$ for all).

For each lag time landowners must surrender $\theta_k x_{it}$ allowances of vintage $t + v_{ik}$. Profit seeking landowners will choose x_{it}^* the quantity of N exports that maximizes their profit net of allowance holdings as follows:

$$x_{it}^* = x_{it}^*(\{P_\mathrm{t}\}; r, \{v_{ik}\}) = \mathbf{arg\,max}\left[f_i(x_{it}) - x_{it}(\sum_k \theta_k \frac{1}{(1+r)^{v_{ik}}} P_{t+v_{ik}})\right]$$

Where r is the discount rate and P_t is the price of allowances of vintage t. Vintage trading schemes require landowners to hold allowances of the same vintage in different years. All landowners must face the same real price for allowances. As mitigation each year is determined by the nominal price of allowances NManager discounts the price of each allowance into the year of purchase. Results in this paper use a 7% discount rate.

The total demand for allowances of vintage t is given by:

$$D_t = \sum_i \sum_{\mathrm{k}=1}^{\mathrm{K}} \theta_k \, x_{i,t-v_{ik}}^* = g(P_{t-v_{iK}}, \dots, P_t, \dots, P_{t+v_{\mathrm{iK}}}; r, \{v_{ik}\})$$

Let S_t be the supply or quota of allowances available for vintage t. The excess demand for allowances, F_t, can be expressed as follows:

$$F_t = D_t - S_t = g\big(P_{t-v_{iK}}, \dots, P_t, \dots, P_{t+v_{\mathrm{iK}}}; r, \{v_{ik}\}\big) - S_t$$

The market clearing prices will be $\{P_t\}$ such that for all vintage markets:

$$F_t \le 0 \quad and \quad F_t \, P_t = 0$$

The price in each market will depend on the supply and demand in that market. Therefore we may express the price for each vintage as follows:

$$P_t = h(D_t, S_t) = h\big(g\big(P_{t-v_{iK}}, \dots, P_t, \dots, P_{t+v_{\mathrm{iK}}}; r, \{v_{ik}\}\big), S_t\big)$$

Given price in this form we then use an iterative numerical method to determine the price of vintage allowances in equilibrium.

8.2. Handling boundary conditions

Incorporating groundwater lags in the vintage trading schemes requires landowners to hold allowances of the same vintage in different years. Unless these schemes have a fixed duration, finding an exact solution would require solving over an infinite length of time.

We may find a finite approximation to the solution under two assumptions: The first is weak dependence between markets: If we choose ω sufficiently large then the dependence between markets at time t and $t + \omega$ is weak. The second is price convergence: All the prices beyond some time T are constant and equal to price P_T. This assumption is reasonable so long as by time T the number of allowances is constant.

Assuming convergence of vintage prices may introduce error into the results by creating artificially stable prices. Testing of different thresholds suggests that $T = 400$ is sufficient to minimize any artificial stability if we limit our results to the first 200 years.

8.3. Solving trading schemes numerically

A solution over T time periods may be found using the Newton-Raphson algorithm: Starting from an initial price vector $[P_t]^0$ iterate, until all prices satisfy the market clearing conditions, updating the prices at each iteration as follows:

$$[P_t]^{i+1} = [P_t]^i - \left[\frac{\partial g_j}{\partial P_\delta}\right]^{-1} [F_t]^i$$

Where $[P_t]^i$ and $[F_t]^i$ are column vectors and $\left[\frac{\partial g_j}{\partial P_\delta}\right]$ is the $T \times T$ derivative matrix.

The vector $[F_t]^i$ is calculated numerically as given above. An approximation to the $(j, \delta)^{th}$ entry of the derivative matrix is calculated as follows:

$$\frac{\partial g_j}{\partial P_\delta} = \frac{\left(g_j^*\left([P_k]^i; r, \{v_{ik}\}\right)\right) - \left(g_j^*\left([P_k]^i + \partial P_\delta; r, \{v_{ik}\}\right)\right)}{\partial P_\delta}$$

Where ∂P_δ is a vector of zeros except for the δ^{th} entry which suitably small, and $g_j^*\left([P_k]^i; r, \{v_{ik}\}\right)$ is the demand for allowances of vintage j if landowners have optimized their allowance holdings.

We include an adjustment to handle the situation where the vintage caps are non-binding. This occurs where $P_t = 0$ and $F_t < 0$. In this situation we wish to prevent any further decrease in the price of the vintage. This can be done by deleting the rows of $[P_t]^i$ and $[F_t]^i$ and the rows and columns of $\left[\frac{\partial g_j}{\partial P_k}\right]$ that correspond to the non-binding vintage caps before updating $[P_t]^i$ to generate $[P_t]^{i+1}$.

9. Appendix B: The Input for the Profit Functions

The profit functions used in NManager were fitted to estimated profit and mitigation points for dairy, sheep & beef farming and plantation forestry. This section explains how these points were estimated.

9.1. Profit and leaching for dairy and sheep & beef farming

Output from Farmax was used to determine the profitability and leaching of different farm management practices for dairy and sheep & beef farming. Farmax works from baseline scenarios provided by monitor farms. Monitor farms are theoretical farms, constructed from current data, designed to represent a typical farm in a specific region Ministry of Agriculture and Fisheries, 2010b.

The Waikato/Bay of Plenty dairy monitor farm is representative of approximately 5060 dairy farms in the Waikato and Bay of Plenty regions. The monitor farm has 110 hectares of land, milks 310 cows (heifers are grazed off the farm for 12 months) and produces around 97,000 kg of milk solids in a normal season. This implies a gross profit of around $127,000 in 2009 Ministry of Agriculture and Fisheries, 2010a.

The Waikato/Bay of Plenty sheep & beef monitor farm is representative of approximately 720 sheep & beef farms in the Waikato and Bay of Plenty regions. The monitor farm has 300 hectares of land, 2900 stock units and a gross profit of around $53,000 in 2009 Ministry of Agriculture and Fisheries, 2010a.

Different scenarios for the dairy model included various combinations of changes in cow stocking rates, wintering patterns, imported feed usage and nitrogen fertilizer usage. Different scenarios for the sheep & beef model included changes to stocking rates, animal ratios (sheep vs. cattle; bulls vs. cows) and nitrogen fertilizer usage. Although Farmax is designed to assist the user to maximize their profit per hectare the model is dependent on the user to propose and assess the feasibility of different management decisions. We recognise and thank Smeaton who used his farming knowledge and expertise in attempting to define profit maximizing strategies for landowners while maintaining specified leaching targets (Smeaton, Duncan et al., 2011).

9.2. Profit and leaching for forestry

Forestry is the least nutrient intensive land-use considered for the Lake Rotorua catchment. Landowners may choose to convert land to forestry as part of managing their nutrient leaching.

Annual profits per hectare from forestry were calculated for all non-urban parcels in the catchment. Profit for each parcel was calculated using a forest profitability map from 2009, see documentation in Zhang (2010). This considers information on land slope, soil type and the distance from the nearest port. These measures were used to estimate wood yield and the costs of planting, pruning and logging. Lastly, profit for each land parcel was averaged over the entire catchment.

New Zealand has implemented an Emissions Trading Scheme. Under this scheme the profitability of forestry is expected to increase. However, landowners are currently behaving as though the effective long term price for carbon is close to zero. This is due to uncertainty in the future price of carbon and the lack of relevant standards (Karpas and Kerr, 2011). The potential gain in profits from forestry under New Zealand's Emission Trading Scheme is therefore not included in NManager.

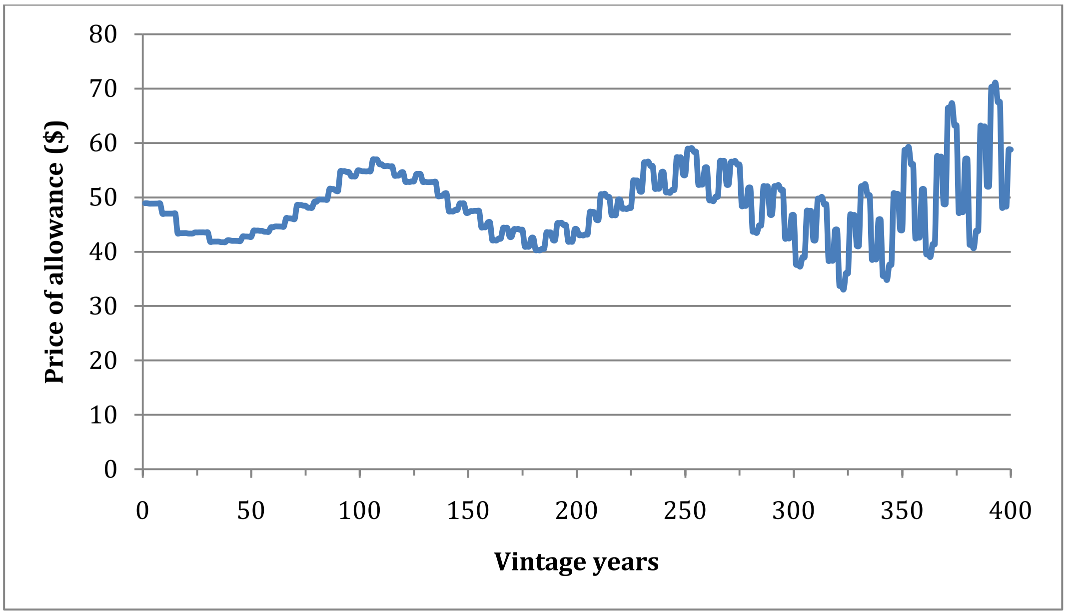
10. Appendix C: Risks of the Two Pulse Vintage Scheme

We observed in section 8.1 that under the two pulse vintage scheme the price of each vintage allowance depends on the prices of all other vintage allowances. A two pulse vintage scheme can result in short term oscillations in the equilibrium price of vintages. This is due to landowners demanding vintages of two different types to cover leaching from a single year of production.

Regulatory schemes that result in price oscillations may have additional costs associated with them. There may be adjustment costs in responding to changes in vintage prices or the cost effectiveness gains of the trading scheme may decrease if allowance trading is discouraged.

Figure 14 gives the equilibrium prices of allowances arising from the two pulse scheme. We observe short run oscillations in prices with a period of 20 years. Please note that these oscillations do not affect the accuracy of our results as we only consider the first 200 years of vintages, where price oscillations are minimal, elsewhere in this paper.

Figure 14: Oscillations in the equilibrium prices of vintages under two pulse regulation



The short run price oscillations are the result of regularities in the lag times. Consider the differences between the lag zones as given in Table 5. There is a 20 year difference between consecutive lag times for the five lag zones at the back of the catchment (lag zones 4 – 8). This corresponds perfectly to the 20 year periodicity of the short run price oscillations.

While oscillations are demonstrated here using the two pulse vintage scheme they are a possible phenomenon of any regulatory scheme where landowners must surrender allowances of more than one vintage in any given year. Experiments have shown that the frequency and magnitude of price oscillations depends on the lag times. This suggests that price oscillations may be avoidable given careful design of the regulatory scheme.

The price oscillations demonstrated here occur under the assumption that each landowner's mitigation decisions are independent across time. However, if landowners have adaptive price expectation or the cost of changing mitigation practises is significant then landowners will have incentives to keep the same mitigation practises over several years. This may reduce the magnitude of the price oscillations (Krugman, Paul, 1991). Incorporating landowner expectations into NManager is an area for future research.

An observant reader may have noted the suggestion of long run cycles, with a period of 150 years, in Figure 14. Experiments suggest this cycle is independent of the timing of pulses. It is likely that this is an unavoidable phenomenon of a two pulse regulatory scheme. As the long run cycle has minimal affect on allowances prices between years (less than a $1 or 2% effect) we do not consider this cycle to be worrisome and investigate it no further.

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