How should we manage diffuse water pollution? Insights from recent NManager simulations on Lake Rotorua

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1. Introduction

Falling water quality as a result of diffuse water pollution is a pressing issue for a number of catchments around New Zealand (Ministry for the Environment, 2007). Halting this decline and introducing policies that will improve water quality is the focus of a number of regional councils. But how should regional councils achieve environmental goals? Crucial to this decision is an understanding of how much different policy approaches will cost. This report sheds light on this issue by examining the economic costs and environmental outcomes of a number of water-quality management policies in Lake Rotorua using a simulation model, NManager.

Lake Rotorua has seen significant decreases in water quality over the past 40 years. Largely, this is as the result of land-use intensification and resulting increase in diffuse nutrient pollution leaching into the lake (Parliamentary Commissioner for the Environment, 2006). The local community has indicated that this decline in water quality is not acceptable, and regional council is currently considering the optimal policy mix to achieve sizable nitrogen discharge reductions. The most recent statements from the council indicate that they aim to decrease annual nitrogen exports in the lake Rotorua catchment from 755 tonnes per year by 320 tonnes to achieve a sustainable load of 435 tonnes per year (Bay of Plenty Regional Council, 2012). As pastoral farming is the source of approximately 80% of nitrogen flowing into Lake Rotorua, reaching this goal will require large cuts in agricultural leaching through land management and land use change (Bay of Plenty Regional Council, 2012.).

We consider a number of policies that could achieve the intended nitrogen cuts. The first option we consider is to require all farms to implement 'best management practice' (BMP), and reduce from profit-maximising intensity of production to a lower production level to achieve a lower nitrogen leaching rate. The second policy we consider is a nitrogen cap and trade scheme, where a cap is placed on the total leaching of all pastoral sources of nitrogen and sources can trade nitrogen discharge permits amongst themselves to maximise catchment-wide production whilst still achieving the environmental goal. We devote the majority of the report to assessing variants of this policy and assess a number of environmental targets. The third option we consider is a tax on nitrogen leaching; for this option we also consider the sensitivity of environmental outputs to a wrongly specified tax. Finally, we assess how different allocations of allowances will affect the distribution of costs across different land uses and the community. For each policy we report the cost, how this cost is distributed across land uses, land use change, the resulting nitrogen loads entering Lake Rotorua, and changes in greenhouse gas (GHG) emissions.

All policies are estimated using the simulation model NManager, a partial-equilibrium simulation model that uses bio-physical properties of the Lake Rotorua catchment and farmer nitrogen mitigation costs to estimate environmental outcomes and costs of nitrogen regulation in Lake Rotorua. While an earlier version of NManager has been applied to measure the costs of a few of the policies discussed here previously (see Anastasiadis et al, 2011), this paper presents the first simulations since a number of extensions have been made to the model. Two key extensions are an allocation module and a GHG emissions module. These extensions allow us to investigate a number of issues crucial for policy design, including the impact of different allocation mechanisms on the distribution of costs, and the wider environmental impacts of nutrient policy.

The report continues as follows: chapter two provides a background on Lake Rotorua and the environmental challenge. Chapter three introduces our simulation model, NManager, and how it has been updated to produce output required for this report. We then discuss each policy in turn. Chapter five concludes and outlines future work.

2. Lake Rotorua: background

Water quality has been declining in Lake Rotorua for at least the last 30 years due to increased levels of nutrients entering the lake. The increase in nutrient levels has led to increased frequency of algal blooms, which limit recreational water use and affect the local fish, plant and animal populations (Parliamentary Commissioner for the Environment, 2006). This decline in water quality has resulted from years of unsustainable nutrient releases by agricultural, residential, and commercial sources. These historical nutrient exports are still arriving in the lake today because of the time lags involved with transporting discharges from their source through groundwater to the lake (Rutherford et al., 2011). Alongside these historical releases, current exports of nutrients are too high to maintain lake water quality. The sources of nutrient exports are shown in Table 1 (Bay of Plenty Regional Council, 2012).

The Bay of Plenty Regional Council (BOPRC) has set a goal of returning water quality to levels last seen in the 1960s (Environment Bay of Plenty et al., 2009). Achieving this goal requires a cut in the amount of nitrogen arriving in the lake each year to 435 tonnes. Nitrogen reaches Lake Rotorua through surface water and ground water. As a result of groundwater lags (potentially up to 200 years), there are significant differences between the amount of nitrogen arriving in the lake in any one year and the amount exported each year. In 2009 inputs into the lake were estimated to be 593tN/yr, whilst exports were estimated to be 771tN/yr (Anastasiadis et al., 2011). If current exports of nitrogen remain constant, then annual nitrogen loads entering the lake will continue to increase over the next 60-70 years and will approach a steady state of current exports around 2080 (Rutherford et al., 2011).

Table 1: Land use and nutrient sources

Land use	2010 Area(ha)	% of total catchment	Nitrogen exports, tN/yr (2010)	% of total N	total P/yr (2007)	% of total P
Dairy	5050	10.9	273	36.2	4.1	10.5
Drystock	15072	32.5	236	31.3	12.8	32.7
Forest	21182	45.7	75.4	10	2.2	5.6
Urban	3961	8.5	93.4	12.4	3.8	9.7
Lifestyle	1053	2.3	16.7	2.2	0.5	1.3
Geothermal	59	0.1	30.3	4	1.4	3.6
Lake & rain	n/a	n/a	30	4	1.3	3.3
Springs	n/a	n/a	n/a	n/a	13	33.2
Total	46377	100	755[1]	100	39.1	100

Substantial effort has already been undertaken to improve water quality by reducing the nutrient levels within the lake. Since 2005 Lake Rotorua has had a rule in place to cap nitrogen and phosphorus losses to the lakes. Attention has since shifted from capping to reducing nutrient discharges. Various methods, including land use change, best management practice, nutrient trading, and others, have been considered to decrease discharges, but the final policy mix to achieve community water quality goals is yet to be decided.

The level of phosphorus leaching is also important for water quality. However, the most recent BOPRC policy documents indicate that "targets for phosphorus in the catchment are on track to be met" (Bay of Plenty Regional Council, 2012). Therefore, the focus of this paper is on managing nitrogen leaching.

3. NManager Simulation Model

To assist policy decisions in Lake Rotorua Motu Research has developed NManager, a partial-equilibrium simulation model that combines bio-physical properties of the Lake Rotorua catchment with a model of farmer nitrogen mitigation responses to regulation. Full information on the NManager model can be found in Anastaidis et al. (2011), but we summarise key points of the model here for convenience. We also outline any changes to the model, and the model's strengths and key assumptions.

[1] Note, NManager uses slightly different land use maps which result in slightly different predicted Nitrogen leaching. See section three below.

NManager uses biophysical maps of groundwater and surface water nitrogen flows to accurately model the environmental outcomes of farm nitrogen discharges. Farmer responses to nitrogen leaching regulation are simulated using OVERSEER and FARMAX runs that estimate mitigation costs for a representative dairy and a representative sheep/beef farm under different nitrogen mitigation management. NManager uses these inputs to estimate farmer mitigation and land use change over time. Outputs of the model include costs and environmental impacts of different policies. A key strength of NManager is the linkage to biophysical data to accurately predict the environmental outcomes of policies over time.

Costs of policy options are calculated as the net present value (NPV) of meeting the nitrogen reduction target using the BOPRC standard discount rate of 7%. This cost is the discounted sum of all mitigation costs required to meet the nitrogen reduction target, where mitigation costs are calculated using the profit-mitigation curves outlined in Anastasiadis et al. (2011). As a result, estimated costs of policies do not include the costs of set-up and administration of policies. They also do not include the impact of regulation on land values. Our costs are likely to be underestimates as our simulations assume that farmers adjust instantly and optimally to changes in costs; in reality these adjustments are likely to be slower and less optimal. However, as the current version of the NManager is static we do not allow for any technology change, which will result in overestimates of cost.

Table 2: Baseline profits

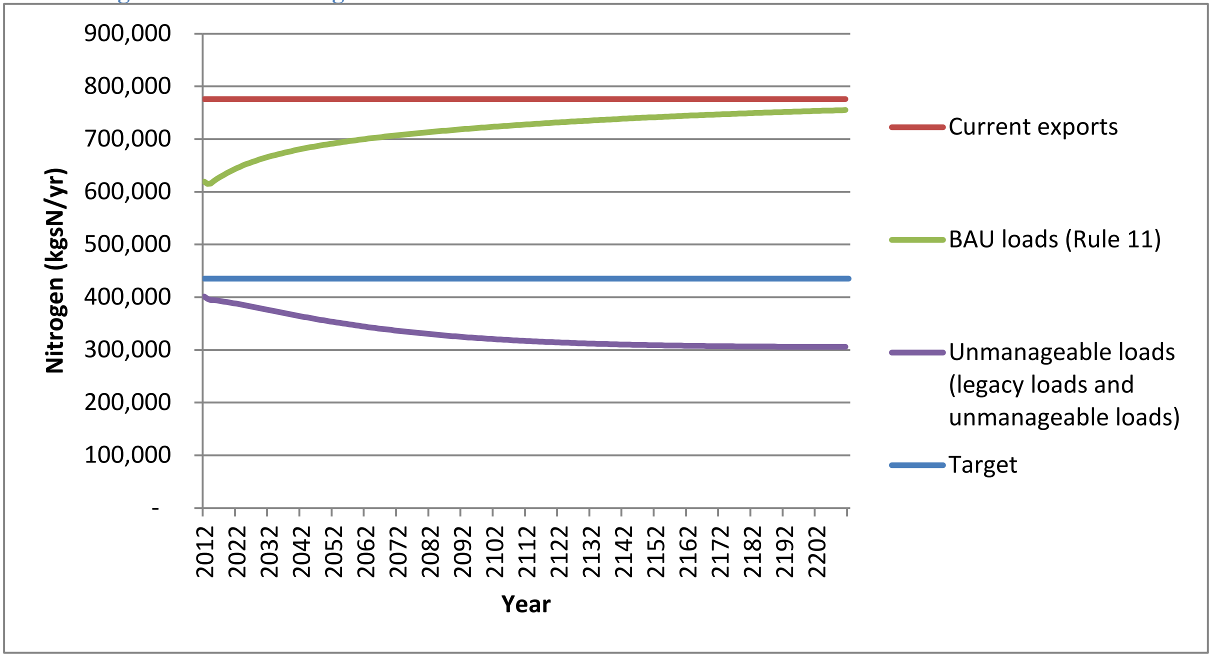
NPV of Profits	total	per ha
Dairy profits	$ 110,265,206	$ 20,559
Sheep/Beef profits	$ 110,460,117	$ 7,184
Total	$ 220,725,323	
GHG emissions		
Long run annual emissions (tonnes CO_2-e)	120,851	

All costs are calculated relative to a baseline of business as usual under current regulation. Under the current regulation 'Rule 11' landowners cannot change their land use or land management if it will increase their current discharges[2] (Environment Bay of Plenty et al., 2009). As profitability is positively correlated with nutrient discharges we assume that this upper limit on discharges is and will continue to be binding; for the baseline case we assume that discharges

[2] Landowners can increase discharges if they offset this by decreasing discharges elsewhere. To our knowledge, this proto-trading system has never been applied by a farmer in the catchment.

will continue at current rates into the future. Key outputs of the baseline scenario are captured in Figure 1[3] and Table 2.

Figure 1: Baseline nitrogen flows



3.1. *Model extensions*

We have added two extensions to NManager since Anastasiadis et al. (2011): an allocation module and a GHG emissions module. These extensions allow us to investigate a number of issues crucial for policy design, including the impact of different allocation rules on the distribution of costs, and the complementary GHG impacts of implementing nutrient policy.

3.1.1. Calculating GHG emissions under different policies

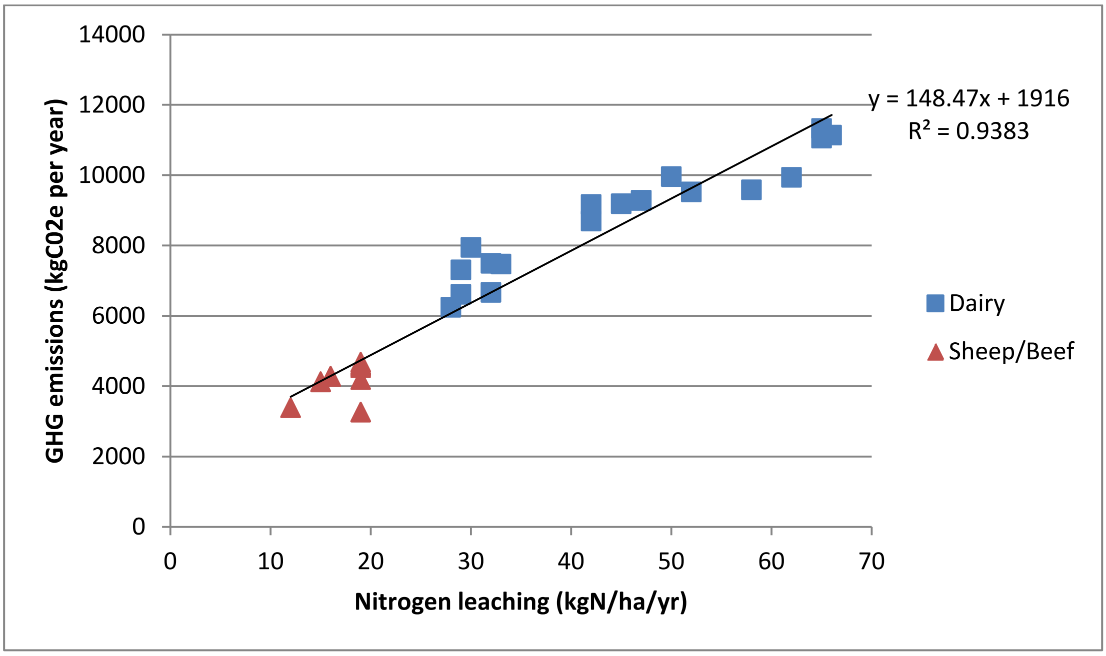
One of the key additions to NManager is the ability to compare long run GHG emissions under different policies. We estimate GHG emissions under different policies based on predicted nitrogen discharges. Below we explore the strength of this relationship between GHG emissions and nitrogen discharges, explain how the changes in emissions are estimated by NManager, and outline how we are dealing with forestry sequestration in the model.

Nitrogen leaching versus GHG emissions

[3] 'Unmanageable loads' are made up of legacy loads and loads considered unmanageable by NManager. Legacy loads are the nitrogen loads that have been released in the past but, as a result of the slow groundwater transport times, are still to arrive in the lake. Unmanageable loads are made up of a catchment-wide allowance of 4kgN/ha/yr, which is the lowest nitrogen leaching can be lowered to, and nitrogen from sources which we do not have mitigation cost curves for such as urban sources. It is imagined that these urban sources will be managed separately in addition to the mitigation carried out on agricultural land.

The profit/leaching curves that are used in NManager (Anastasiadis et al., 2011) were estimated by using OVERSEER and FARMAX (Smeaton et al., 2011). Smeaton et al. (2011) estimated nitrogen leaching, GHG emissions, and profitability for an average Rotorua dairy farm and an average Rotorua sheep/beef farm under a number of different management approaches. We exploit the relationship between nitrogen leaching and GHG emissions to use in NManager to estimate GHG outcomes of different policies. The strength of this relationship between nitrogen leaching and GHG emissions is shown in Figure 2 for both sheep/beef and dairy farms under different management regimes.

Figure 2: GHG and Nitrogen Leaching (Smeaton et al., 2011)



We estimate the linear relationship between these two variables using ordinary least squares on all of the data points. This relationship is then used to estimate the change in GHG emissions that result from nitrogen reduction policy. We calculate GHG emissions for dairy and sheep/beef on the same curve as we believe that a significant amount of mitigation will occur through gradual land-use change from dairy to sheep-beef. When NManager predicts nitrogen leaching above the sheep/beef points but below dairy points we interpret this as partial land-use change where a proportion of the land is in dairy, and the rest is in sheep/beef. Figure 2 shows that the relationship between GHG emissions and nitrogen leaching appears relatively consistent across both land uses.

Transition into forestry land is calculated slightly differently. When NManager predicts that a land parcel has nitrogen leaching levels below sheep/beef levels we interpret that a portion (x%) of that parcel will be in forestry, with (1-x%) remaining in sheep/beef land. We estimate GHG emissions for this parcel *i* as follows:

$$GHG_i = size_i[x(GHG_{Forest}) + (1-x)(GHG_{SB(10)})]$$

Where $GHG_{SB(10)}$ is the GHG emissions associated with sheep/beef land at the lowest leaching rate of 10kgN/ha/yr, and $size_i$ is the size of the parcel in question. In NManager we use $GHG_{Forest}=0$, that is we assume that GHG emissions of forest land is 0. The justification for this is discussed below.

Forestry

Calculating the GHG emissions or sequestrations from additional forestry land requires consideration of both the short and long run GHG effects of transitioning land from sheep/beef or dairy into forestry. The long run impact of permanently shifting from a high emissions land use to a net zero emissions land use is a long run decrease in emissions[4]. Additionally, there are short run GHG benefits of converting land to forestry that exist over the length of forestry rotation. While forests grow they sequester and store carbon. However, when they are cut down they release this stored carbon slowly back into the atmosphere. In NManager we assume that new forestry land is put into productive rotation forestry that maximizes the profitability of the land use. Rotation forestry has no long term net carbon sequestration as every rotation (approximately 30 years) forests are harvested and replanted. The carbon captured in each rotation slowly leaches back into the atmosphere when it is chopped down. However, while average *flows* of carbon sequestration are zero, average *stocks* of carbon in any given year are positive. We report the additional average stock of carbon in any year as a result of the policy as a separate environmental measure.[5] However, at any one year (in the long run), the results we give for additional carbon stock can be interpreted as the expected additional tonnes of carbon being stored in trees in Rotorua as a result of the nutrient policy. To put this number in context we also calculate what proportion of baseline GHG emissions this stock represents.

3.1.2. Allocation module

The second major change to the NManager model is the addition of a module that allows us to explore the distribution of costs under different policies, environmental goals, and allocation regimes. Specifically, the allocation module allows us to explore the distribution of

[4] Given the stringency of the nitrogen cuts required to achieve long run environmental goals for Lake Rotorua, we assume that land use transitions to forestry will be permanent.

[5] Average long run stock is calculated using MAF look up tables for Bay of Plenty for radiata pine with a 28 year rotation, assuming that rotations continue infinitely(Ministry of Agriculture and Forestry, 2011).

costs to different communities in the catchment, such as across different farm types (sheep/beef, dairy, and the wider community).

We calculate cost as follows, where M is the cost of mitigation, P is the market price of allowances over time, A is the free allocation of allowances, and N is the level of nitrogen leaching.

$$Cost_i = M_i + P(A_i - N_i)$$

Our allocation module calculates distributions of cost assuming zero transaction costs. Under zero transaction costs the allocation of allowances to participants should have no effect on the efficient distribution of production, and will only effect the wealth of participants (Coase, 1960). This assumption of zero transaction costs will not be met in reality; even in a flexible and well designed nutrient trading market participants will face significant costs of trading (McDonald and Kerr, 2011). However, we currently lack the ability to model market outcomes with transaction costs in NManager. This unrealistic assumption of zero transaction costs should be kept in mind when considering allocation results. Under non-zero transaction costs allocation decisions will not only impact allocation of wealth around the catchment, but will also affect efficiency. The higher the transaction costs (or equivalently, the less flexible the regulation), the more regulators will need to consider the efficiency of the production implied by their initial allocation of allowances. High transaction costs will mean that this initial allocation may not be traded to move to the most efficient distribution of mitigation. Allocation results are presented in section 4.5.

4. Potential policies and results

There are a number of policies that could be implemented by regional council to meet environmental goals. In this section we consider mandatory best management practice, a nitrogen cap and trade scheme, and nitrogen export taxes. We also summarise the results of additional relevant simulations from Anastasiadis et al. (2011).

4.1. Best Management Practice (BMP)

One policy that could be implemented to achieve environmental goals in Lake Rotorua is requiring all farms to mitigate nitrogen leaching down to some defined level of Best Management Practice (BMP). We simulate this by estimating outcomes when mitigation is carried out using the least cost combination of on-farm mitigation methods, but not land use change. Dairy mitigation methods considered include application of nitrification inhibitors (DCDs), alterations to stocking rate, use of nitrogen fertiliser, wintering cows off the dairy farm, use of imported feed and combinations of these mitigation methods. Sheep/beef mitigation methods include stocking rate alterations, use of N fertiliser, alterations in the mix of stock classes, use of very high fertility ewes and combinations of these mitigation options.

We consider two BMP definitions: first we follow Anastasiadis et al. (2011) and consider a best practice definition of nitrogen leaching of 28kgN/ha/yr for dairy land (down from baseline leaching of 56kgN/ha/yr) and nitrogen leaching of 10kgN/ha/yr for sheep/beef land (down from 16kgN/ha/yr current leaching). We also assess outcomes under a less stringent BMP definition proposed by BoPRC: dairy nitrogen leaching of 40kgN/ha/yr , and 14.4kgN/ha/yr nitrogen leaching for sheep/beef (Bay of Plenty Regional Council, 2012). We assume that the BMP regulation is implemented in equal steps over ten years, with farmers required to meet progressively more restrictive discharge limits each year until it is fully implemented in 2022.

4.1.1. Results

Figure 4 shows that while both definitions of BMP will decrease the nitrogen loads arriving at Lake Rotorua relative to baseline, neither will achieve the regional council's long run environmental goal of 435tN/yr. Indeed, the BoPRC BMP will not even restrict loads to current levels: nitrogen arriving in the lake will continue to increase over time due to historical discharges and unmanageable loads, despite the long run decrease in nitrogen exports from farmland of approximately 110tN/yr[6].

[6] BoPRC recognise this and argue that land use change will also be required to meet the communities' environmental goals.

Figure 3: Nitrogen loads resulting from BMP regulation

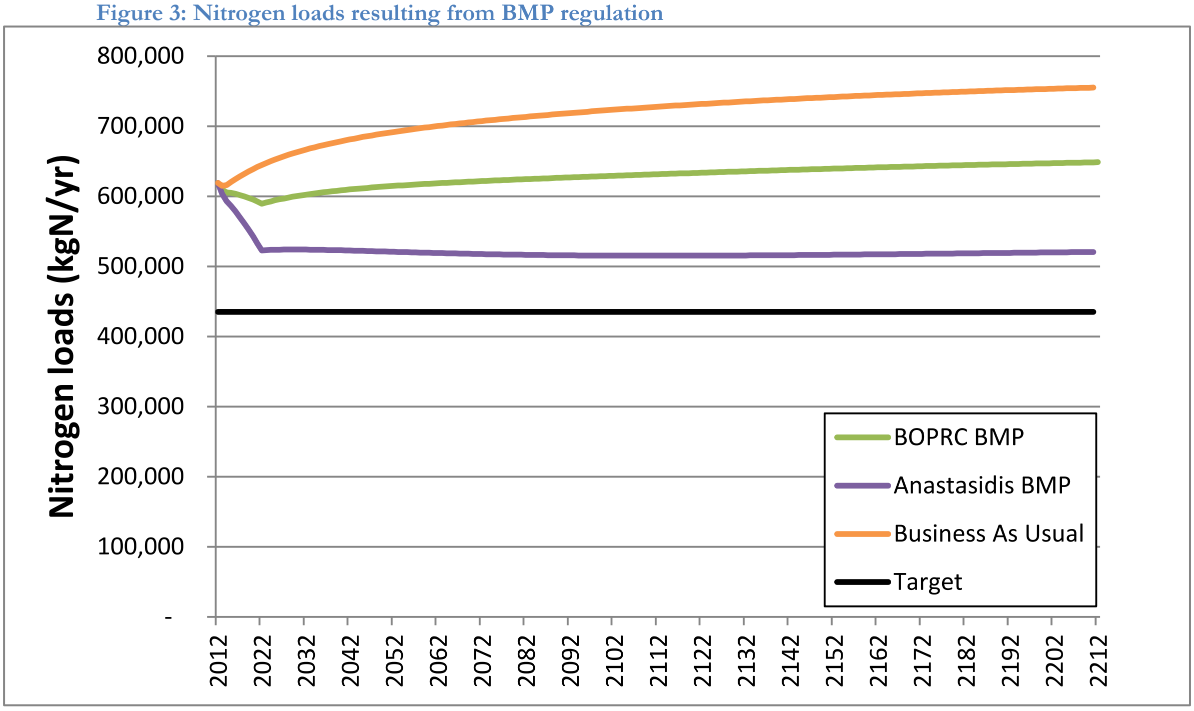


Table 3 shows that the costs borne by farmers to mitigate to meet the BMP requirements are significant. Meeting the less restrictive BoPRC BMP restrictions will decrease total long run farm profits by approximately 5%, while meeting the more stringent Anastasidis BMP regulations will reduce the net present value of long run profits from agricultural production in the Rotorua catchment by 10%. Under both definitions of BMP mitigation will be carried out disproportionately more on dairy land than on sheep/beef land due to the tighter cuts called for on dairy land, and the greater costs in terms of lost profit required to achieve BMP leaching rates on profitable dairy land. A final point to note is that while the Anastasiadis BMP costs are 330% of the BoPRC BMP costs, the reduction in exports is 220% of the BoPRC BMP. The non-linearity of costs occurs as there are increasing marginal costs of mitigation: the more farmers have to mitigate, the harder (and more expensive) it becomes.

Table 3: Mitigation costs of meeting BMP regulations

NPV of mitigation costs	BoPRC BMP			Anastasiadis BMP		
	Total	per ha (NPV)	% decrease in BAU profits	Total	per ha (NPV)	% decrease in baseline profits
Dairy mitigation costs	$10,660,054	$1,988	-10%	$24,303,975	$4,532	-22%
Sheep/Beef mitigation costs	$1,265,667	$82	-1%	$14,901,353	$969	-13%
Total	$11,925,721		-5%	$39,205,327		-18%

Due to complementarities between GHG emissions and nitrogen discharges, as we restrict nitorgen leaching GHG emissions also fall (see Table 4). In the long run, restricting all

Rotorua farmers to the BoPRC BMP will have the additional environmental benefit of a long run decrease in annual emissions of 16,393 tonnes CO_2-e (approximately 14% of baseline). If farmers are required to meet the Anastasiadis BMP this decrease in GHG emissions will be equal to 30% of baseline. As land use change is not permitted to meet BMP targets there is no additional forestry land under either of these definitions of BMP. As a result, the only decrease in GHG emissions comes in decreases on farm; there is no forestry planting so no additional sequestration to report.

Table 4: Change in GHG emissions resulting from nitrogen BMP regulations

Decrease in GHG emissions (tonnes CO2-e)	BoPRC BMP	Anastasidis BMP
SB decrease in emissions	3,652	13,697
Dairy decrease in emissions	12,741	22,296
Decrease in emissions	16,393	35,993

4.2. Cap and trade

Cap and trade schemes are increasingly being applied to address nutrient pollution. Unlike command and control policies like the BMPs discussed above, nutrient cap and trade markets do not place individual restrictions on dischargers. Instead, nutrient trading markets limit (or cap) the total annual nutrient leaching permitted in a catchment to a level that will achieve the environmental goal. This cap is then divided up into allowances to discharge (permits) and participants in the trading scheme are required to return a permit for every unit of leaching from their property. Those participants who do not hold enough permits to cover their discharges must either reduce their discharges or buy additional permits from other participants who have surplus allowances.

Nutrient trading markets are attractive for a number of reasons. Because regulation targets the cumulative total of discharges rather than individual discharges, participants have flexibility in their own level of discharging: they can increase, maintain, or decrease their discharges, as long as they hold enough allowances to cover their leaching. They can also mitigate leaching in any way, including land-use change. This flexibility encourages profit maximizing landowners to mitigate as long as their cost of mitigation is less than the market price of a permit; those with low mitigation costs will mitigate and profit by selling permits to those with higher mitigation costs. This will equalize marginal mitigation costs around the catchment and ensure that that mitigation is carried out by those who can do so most cheaply.

Using NManager, Anastasiadis et al. (2011) find that a trading scheme will achieve environmental goals for Lake Rotorua at a lower total mitigation cost than other options.

However, implementing and administering a trading scheme can be complex and more expensive for both administrators and participants than simpler command and control regulation. These set-up and administration costs cannot be calculated using NManager. Additionally, if a trading scheme is to be implemented the regulator must allocate allowances. This can be a time-consuming and politically contentious process. Allocation is discussed in section 4.5.

The simulations we produce are limited by the homogeneity of participants' mitigation costs in NManager. Due to data constraints, the current version of NManager assumes that all farms of the same land use face identical marginal mitigation costs, and the only heterogeneity in mitigation costs occurs across land uses. However, mitigation costs vary across different farms and farmers (Anastasiadis and Kerr, forthcoming). Additionally, Doole (2010) shows that the degree of heterogeneity captured by a simulation model correlates with estimated costs of policies; the higher degree of heterogeneity, the lower the cost of trading markets relative to command and control-type policies such as the BMP policies discussed above. We discuss ongoing work to investigate the sensitivity of our results to heterogeneity in section 5.

In this paper we model an export trading market based on that outlined in Kerr and McDonald (2011). At the end of each year participants have to return enough allowances to cover the nitrogen that leaches from their property over the year, which are estimated using OVERSEER. Participants can trade freely throughout the year to ensure that they will be in compliance. Participants are not responsible for the level of leaching associated with forestry (4kgN/ha/yr) as leaching cannot be decreased below this level.

4.2.1. 270tN reduction by 2022

BoPRC have indicated that they wish to reduce 200tN through land use change and 70tN from moving all farms to BMP. We first examine the costs of meeting the BoPRC goal of reducing nutrient leaching from rural land by 270tN by 2022, with the remaining reductions to meet their 320tN reduction target to be achieved by non-agricultural sectors. We allow this reduction to occur through the most efficient combination of land use and management change, and transition to this 270tN reduction target in ten annual 27tN reduction steps. We assume that the additional 50tN of reductions decrease unmanageable discharges by annual 5tN reduction steps (denoted 'In lake decreases' in the appropriate figures). Later in this section we investigate the additional costs associated with achieving the 320tN reduction through agricultural abatement alone, and also consider the potential savings of achieving environmental targets over a longer time frame. The distribution of costs under different allocation schemes is explored in detail in section 4.5.

Figure 4 gives the environmental outcomes of an export cap and trade scheme with a 270tN nitrogen leaching target by 2022. Immediately clear is the importance of unmanageable loads: while nutrient exports decrease by 270tN within ten years, the loads of nitrogen reaching the lake do not achieve the long run sustainable load goal of 435tN per year until approximately 2100 due to the legacy loads that are unmanageable. These long delays between costly nitrogen export cuts and nitrogen load outcomes could be an issue in any catchment where nitrogen travels at least in part through groundwater and the groundwater lags are long.

Figure 4: Nitrogen loads resulting from cap and trade regulation with a2022 reduction target of 270tN

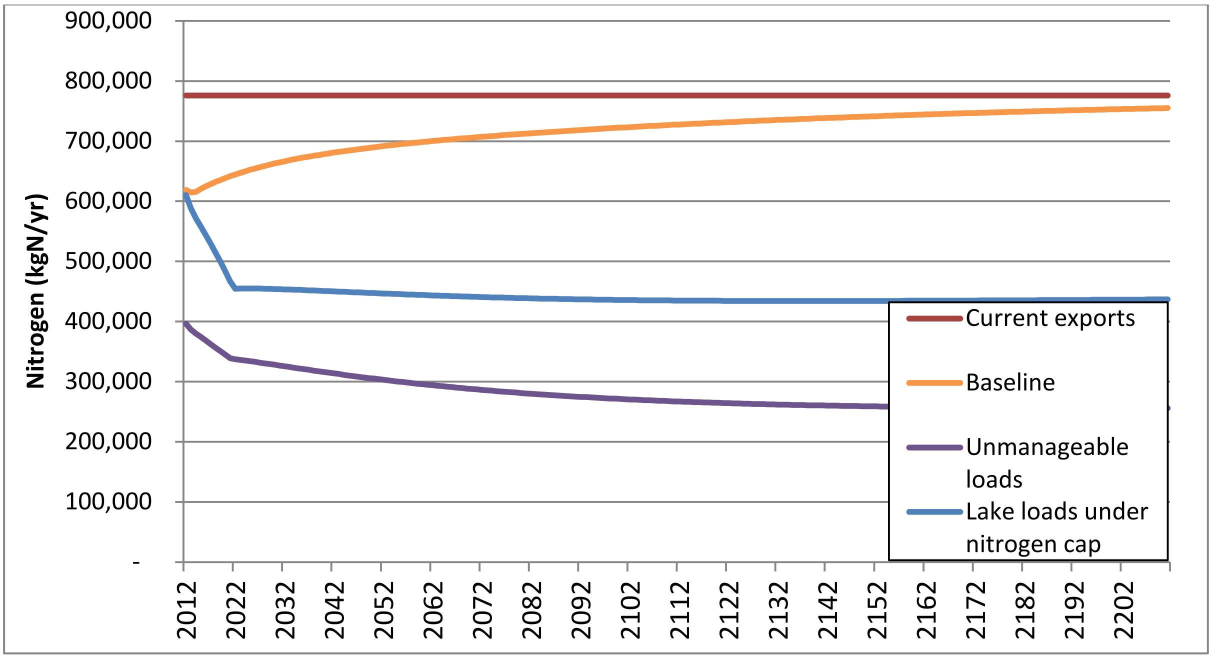


Table 5 makes clear that land use change is sure to play a significant role in achieving nitrogen cuts in the catchment. NManager predicts that in the long run cost effectively reducing nitrogen discharges by 270t will require that more than 55% of current dairy land will need to convert into sheep/beef land. Land use change would be even greater if the full 320tN reduction was to be achieved on agricultural land alone: efficiently achieving this goal would result in zero dairy land in the catchment and approximately 2000ha of new forestry land.

Table 5: Land use change under a cap and trade scheme with a nitrogen reduction target of 270t by 2022

Long run land use	**BAU**		**270tN reduction**		**320tN reduction**	
	Area(ha)	Percentage	Area(ha)	Percentage	Area(ha)	Percentage
Dairy	5,363	13%	2,285	5%	0	0%

Sheep/Beef	15,375	37%	18,453	44%	18,564	44%
Forestry	21,023	50%	21,023	50%	23,198	56%

The land-use and farm management changes required to achieve these nitrogen cuts would have complementary impacts on GHG emission reductions (Table 6). Meeting the 270tN cap would result in a long run decrease in the catchment's annual agricultural GHG emissions by a third. Meeting the more ambitious 320tN cap would see catchment wide emissions fall by almost 45%. In addition to this 45% cut in annual emissions, achieving the 320tN target would require new forestry which in an average long run year would hold a carbon stock of 761,000t CO_2-e, which is the equivalent to 6.3 years of annual BAU emissions.

Table 6: Long run change in GHG emissions under cap and trade regulation with a nitrogen reduction target of 270t by 2022

Decrease in GHG emissions (tonnes CO2-e)	**270tN reduction**	**320tN reduction**
Sheep/Beef decrease in emissions	13,405	21,090
Dairy decrease in emissions	27,780	32,975
Total decrease in emissions	41,185	54,065
Sequestration		
Additional carbon stock, long run average	0	760,970
Proportion of annual BAU emissions	0%	630%

We also consider the cost of achieving the environmental goal, and distribution of mitigation cost across the different land uses (Table 7). Reducing nitrogen discharges by 270tN by 2022 will cost approximately $49million in net present value terms. Efficiently achieving this goal will see a disproportionate amount of mitigation cost spent on mitigation on dairy land. Achieving the 320tN reduction agricultural land will cost an additional $16 million. These additional cuts are considerably more expensive: costs increase by 32% but nitrogen is only reduced by an extra 19%, again reinforcing the non-linearity of achieving tighter targets. The long run allowance price gives an indication of the additional cost of mitigating at higher levels: at the 270tN target participant would be charged $30 to be allowed to release an additional kg of nitrogen, while at the margin under the 320tN target they would be charged $34.40.

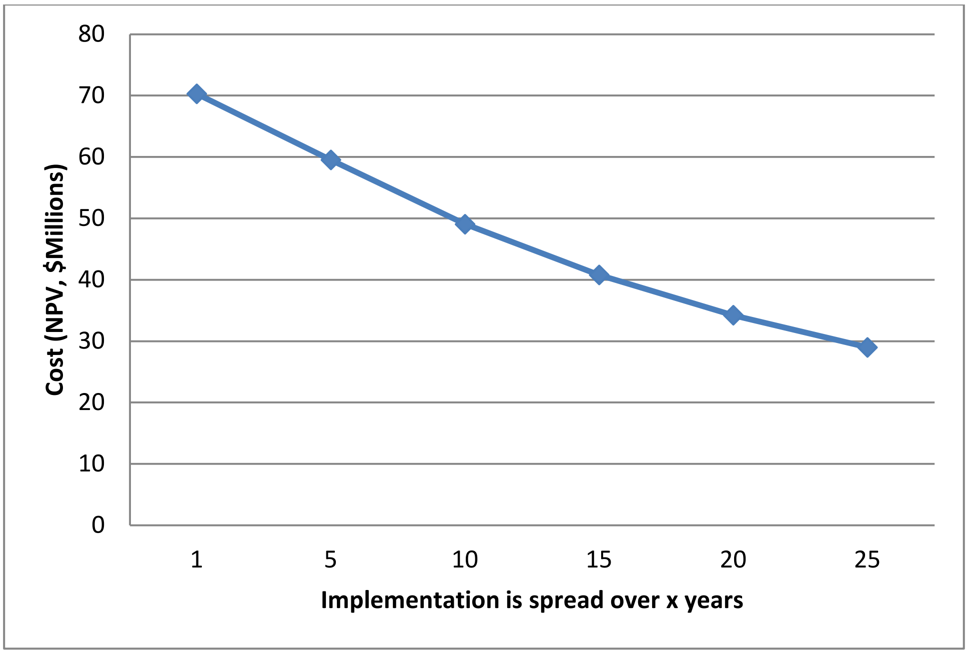
Table 7: Costs of meeting nitrogen targets under cap and trade policy

NPV of mitigation costs	**270tN (by 2022)**		**320tN (by 2022)**	
	Total	per ha (NPV)	Total	per ha (NPV)
Dairy mitigation costs	$34,269,011	$6,390	$45,288,083	$8,444
S/B mitigation costs	$14,764,576	$960	$19,491,564	$1,268
Total	$49,033,587		$64,779,647	
Long run allowance price	$30.0		$34.4	

4.2.2. Achieving environmental targets over a longer time period

The final cap and trade policy approach we consider is the potential cost savings of delaying mitigation. Implementing caps more slowly will decrease costs for a number of reasons, only some of which are captured by NManager. A key cost saving occurs because of discounting: we value costs faced today more than future costs. Following BoPRC we discount future costs at a 7% annual rate in NManager, which effectively means that we value costs faced in ten years time half as much as those we face today. As well as discounting, we would expect that achieving environmental goals over a longer time period will be cheaper because it allows time for learning and technology development. Additionally, achieving 270tN of nitrogen leaching cuts in ten years may be seen as politically unacceptable and therefore not credible. A key determinant in the success of environmental markets is participant certainty, ensuring that participants see targets as credible and sustainable in the long run will be crucial to incentivize the learning and behaviour change needed (Karpas and Kerr, 2011). Finally, the evidence we have on land use change in response to changes in market conditions suggests that land users switching land use is a slow process (Kerr and Olssen, 2012). These evidence suggest that adjusting land use quickly will be costly, and may justify slower transitions to minimize cost.

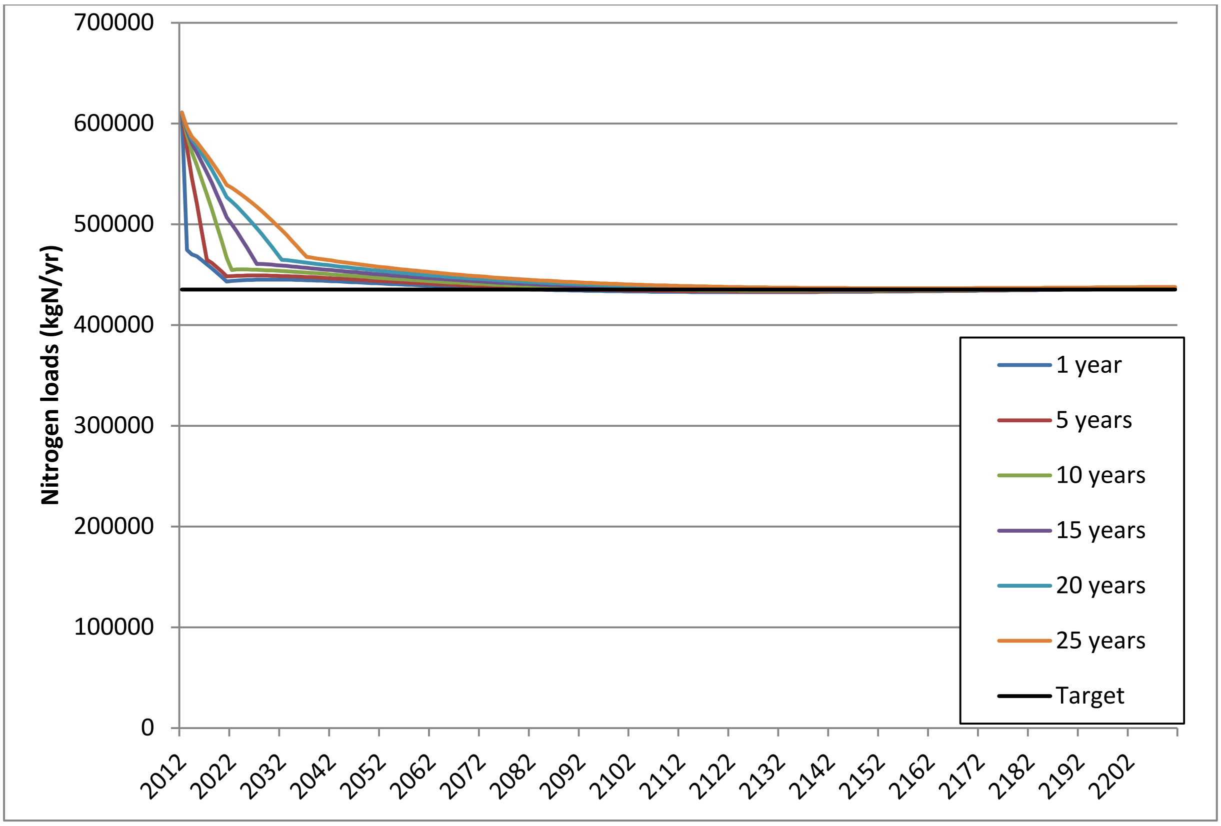
Figure 5: Cost savings of delaying nitrogen target implementation under cap and trade policy



To investigate the potential cost savings of delaying policy we simulated a number of 270tN nitrogen leaching reduction caps in NManager that differed by the speed of implementation. The fastest sees full implementation occur in one year, the slowest phases in the reduction over twenty-five years. Figure 5 shows the cost savings of slowing implementation. Implementing the reductions in one year rather than over ten years would increase costs by 43%, while the savings from spreading over ten years rather than five years are still 21%. Delaying full implementation of the policy by an additional five or ten years will save even more; they are 17% and 30% cheaper respectively. The additional savings from delaying further become increasingly smaller; delaying so that implementation occurs over twenty five years saves only an additional 11% compared to the twenty year target.

Of course, delaying the full implementation of regulation will also delay improvements in the lake. Figure 6 shows the environmental impacts of delaying policy. In the short term there are differences in the nitrogen loads reaching the lake under the different policy timelines, however, these loads converge in the long run. Given the long run nature of the water quality goals of the Lake Rotorua catchment and the significant cost savings of achieving these goals more slowly, achieving these targets over a somewhat longer time horizon may be justified.

Figure 6: Nitrogen loads resulting from delaying implementation of nitrogen targets



4.3. Nitrogen taxes

The final policy we consider is nitrogen export tax. Profit maximizing nitrogen dischargers will decrease their nitrogen leaching if the benefit of leaching another unit of nitrogen is less than the tax rate of exporting an additional kg of nitrogen. This ensures that marginal costs of mitigation will be equalized at the level of the tax rate across the catchment, and the efficient distribution of mitigation occurs.

There are benefits and costs of implementing an environmental tax on nitrogen exports relative to other policies. A tax provides a certain price for landowners and is easy to understand. It allows participants to plan ahead and invest with confidence. The tax collected can be used by the council to decrease other taxes (a so-called 'double dividend'), or can be invested in research and innovation and education to further address the environmental problem. By equalising marginal costs of mitigation across the catchment a nitrogen tax will efficiently distribute mitigation effort, identical to a cap and trade scheme. Administering a nitrogen tax will be simpler and therefore cheaper than a cap and trade scheme, although regulators will still need to collect data to estimate nitrogen exports which will be difficult and costly relative to command and control type regulation. However, there is a key downside of using environmental taxes over a cap and trade scheme: environmental uncertainty. To know what level of mitigation would occur at any tax rate regulators would need to know dischargers' mitigation cost curves, which is potentially an unreasonably high knowledge requirement. Setting the tax rate at too high or too low a level will result in a different environmental outcome to that intended.

In this section we use NManager to explore the potential for adverse environmental outcomes or higher costs under imperfectly set taxes. We assume that the council's environmental aim remains to reduce agricultural nitrogen leaching by 270tN/yr by 2022[7]. The tax rate that will achieve this goal is equal to the nitrogen permit prices estimated under the cap and trade scheme with the same environmental goal. We assess the environmental and cost outcomes of setting this tax 10% higher or lower than this optimal tax to assess the sensitivity of outcomes to tax rate misspecifications. The long run tax rates are shown in Table 8.

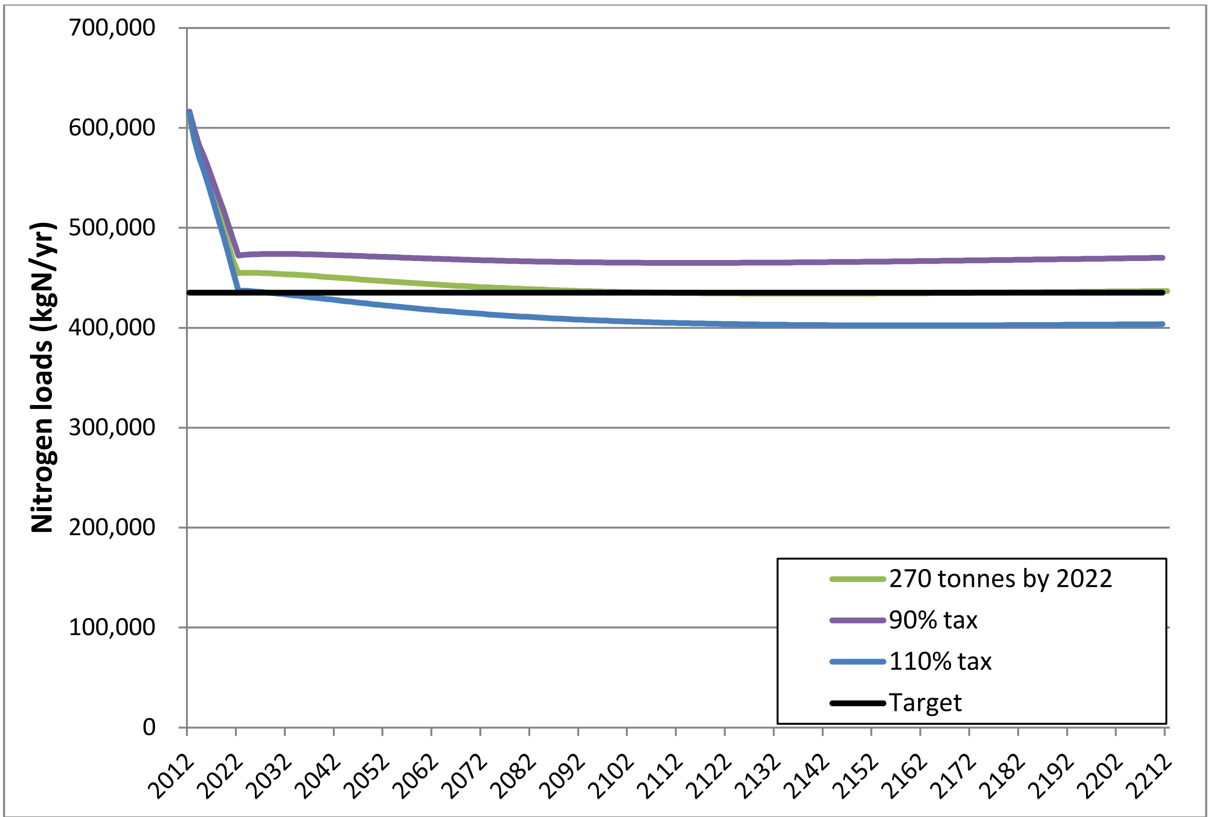
4.3.1. Tax rate sensitivity results

The environmental outcome of misspecifiying the tax rate is shown in Figure 7. Setting the tax rate at 90% of the correct level, that is a long run tax of $27.00 per kgN/yr rather than $30.00 per kgN/yr, means that the environmental goal is never met; in the long run the level of

[7] We also assume that the council removes an additional 50tN from other sources by 2022.

nitrogen loads are 30tN more than the goal: the reductions carried out are only 88% of the reductions required. Conversely, setting the cap too high, that is at a long run rate of $33.00 per kgN/yr rather than $30per kgN/yr, means that the environmental target will be overshot by approximately 33tN. It also means that the environmental target is met more quickly; the 435tN goal is achieved before 2030, approximately 70 years earlier than the optimal tax achieves the goal.

Figure 7: Nitrogen loads resulting from a tax on nitrogen exports



However, this additional environmental benefit comes at significant cost. Table 8 shows that the 110% tax rate results in additional mitigation costs of 22%. This occurs despite the tax rate only increasing by 10%. This makes intuitive sense as all of the cheap mitigation options have already been carried out under the $30 tax, the mitigation carried out under the $33 tax all costs between $30 and $33 dollars per kgN. One caveat is that the simulations we have run do not allow for the regulator to 'learn' and alter the tax rate. If the regulator was monitoring farmers' nitrogen exports to enforce compliance with the policy it would be straightforward for the council to measure the responsiveness to the initial tax rate. They could then adjust this tax rate to ensure that total nitrogen exports were meeting the desired levels. Incorporating this learning would significantly lower the cost of over- or under- shooting the optimal tax rate.

Table 8: Mitigation costs under nitrogen taxes

NPV of mitigation costs	90% of 270tN tax rate		270tN (by 2027)		110% of 270tN tax rate	
	Total	per ha (NPV)	Total	per ha (NPV)	Total	per ha (NPV)
Dairy mitigation costs	$27,304,573	$5,091	$34,269,011	$6,390	$41,966,547	$7,825
Sheep/Beef mitigation costs	$11,776,956	$766	$14,764,576	$960	$18,071,552	$1,175
Total	$39,081,529		$49,033,587		$60,038,099	
Long run tax	$27.0		$30.0		$33.0	

4.4. Other simulations

Anasastiadis et al. (2011) simulate the costs of two additional policies to achieve nitrogen reductions in Lake Rotorua: land retirement, and a more complex 'vintage' trading market that considers the time lags between nitrogen export and arrival in the lake. These simulations were carried out under slightly different nitrogen targets, but the general results will still apply. We summarise the key conclusions from these simulations below.

4.4.1. Land retirement

Anastasiadis et al. (2011) investigate the cost of achieving nitrogen reduction targets through land use change alone, with no on-farm mitigation. The authors first transition sheep/beef land into forestry, then dairy land into sheep/beef land, and if the nitrogen reduction target has still not been reached, transition this new sheep/beef land into forestry land. This equalises the marginal cost of land use change, but does not equalise both marginal costs of mitigation and land use change as in the export trading market. Anastasiadis et al. find that as a result using a land retirement scheme is almost 25% more expensive than an export trading scheme.

4.4.2. Vintage trading scheme

Anastasiadis et al. (2011) also investigate the potential efficiency gains of taking account of the time that nitrogen exports from properties actually arrive as lake loads. Due to significant groundwater lags in Lake Rotorua, cost effectiveness gains could be achieved by shifting the timing of mitigation between different areas of the lake so that those properties closest to the lake, whose nitrogen leaching most immediately impacts lake loads, can mitigate more now. This would allow those properties in the back of the catchment, whose nitrogen exports will not affect lake loads for decades, to defer the cost of mitigating nitrogen until later, reducing the net present value of mitigation. To test the cost savings of such a policy Anastasiadis et al. simulate a 'vintage' market, where participants have to hold allowances time-dated with the average year their nitrogen leaching will arrive in the lake.

Clearly such a scheme would be administratively complex and more difficult for participants to understand. Anastasiadis et al. also find that, for Lake Rotorua, the costs savings of increasing complexity are very small. The authors emphasise that this result is specific to the Lake Rotorua catchment, and that significant savings may be available in other catchments under the following conditions: where nitrogen reaches the water body predominantly through groundwater with little immediate surface water nitrogen leaching; in catchments where there is a more even distribution of land with short lag times relative to land with long lag times; or in catchments with less stringent environmental targets that allow for more flexibility in mitigation.

4.5. Allocation

In this section we assess the wealth impacts of introducing nitrogen reduction policy and how this is distributed across communities in the catchment under various free allocation schemes. The cost estimates presented in earlier chapters are the total cost of mitigation required to achieve the nitrogen reduction goal on each land use and in total. The simulations in earlier chapters show that to cost effectively achieve the nitrogen reduction target the majority of mitigation expenditure should occur on dairy farms. However, this is not the same as saying that dairy farmers will bear the cost of this mitigation; that is determined by the allocation of allowances. Free allocation of allowances effectively works as a lump sum transfer of wealth to the recipient and can be used to distribute the costs of achieving nitrogen reduction policy across different land users and the community. There is no 'right' way to allocate allowances as there is no generally agreed upon definition of how cost should be fairly shared. The 'best' allocation system will be the one that the community agrees is fair and is politically feasible. Kerr and Lock (2009) discuss a number of potential principles for cost sharing to achieve nitrogen reduction goals in Lake Rotorua, and outline the importance of considering efficiency alongside equity if allocation occurs in a trading scheme with limited flexibility or transaction costs.

We assess the wealth implications of achieving the proposed BoPRC target of a 270t reduction in nitrogen by 2022 under the export trading policy described in section 4.2. All wealth comparisons are relative to the baseline case outlined in section 3. As a result, the option values of being able to increase nitrogen leaching are not included in the wealth changes documented below: these options were lost at the implementation of 'Rule 11' restrictions on expansion in 2005. For this reason we do not report the wealth implications of introducing a cap and trade scheme on foresters; as the cap and trade scheme we simulate allows for a baseline leaching of

4kgN/ha/yr, forestry will be relatively unaffected by the implementation of such an export trading system. If instead we quantified the costs of this policy relative to a no-regulation state we would have to consider wider costs, including the cost of losing the option to intensify on forestry and underdeveloped land at the time Rule 11 was introduced[8]. The three allocation schemes we consider are outlined below.

Auction

The first allocation mechanism we assess is 100% auctioning, that is, zero free allocation. Under this allocation scheme farmers both sheep/beef and dairy, must purchase an allowance for every unit of nitrogen they discharge. Allowances end up in the hands of those who value them the most through an auction where farmers will theoretically bid up to their marginal cost of mitigation for an allowance. We assume no transaction costs. As mentioned in section 4.2, the first 4kgN/ha/yr considered unmanageable and participants are not held responsible for this leaching.

Grandparenting with buyback

We also investigate outcomes under a grandparenting allocation; that is, participants are freely allocated allowances at a rate proportionate to their leaching before the introduction of regulation. To avoid strategic behaviour grandparenting should be based on unchallengeable data on leaching rates prior to any indication that free allocation based on current leaching will occur. If care is not taken recipients may boost current exports in order to get more generous free allocations. Grandparenting can be at any proportion of previous discharges, below we present outcomes under 100% free allocation, where all sources are freely granted allowances equal to their baseline discharges. The regulator would have to then buyback enough of the freely allocated allowances at the market price to achieve the nitrogen reduction goal. Because the market price will be equal to the marginal cost of mitigating the last unit of nitrogen to meet the cap and sources have increasing marginal costs of mitigation, this buyback will more than fund the mitigation of sources, whose initial mitigation costs will be lower than the market price of allowances.

Bay of Plenty Regional Council 'Best management practice' allocation

[8] In actual fact, owners of underdeveloped land and foresters will benefit from a move to a trading system such as that simulated here, relative to the status quo of Rule 11. A trading scheme allows these landowners to purchase nitrogen credits and intensify their land use if the benefits of intensifying outweigh the costs of allowances and conversion. While this additional flexibility is a benefit relative to Rule 11, the costs borne by these landowners at the introduction of Rule 11 will only be outweighed if this flexibility is matched by generous free allocations of permits that allow these affected landowners to intensify at little cost.

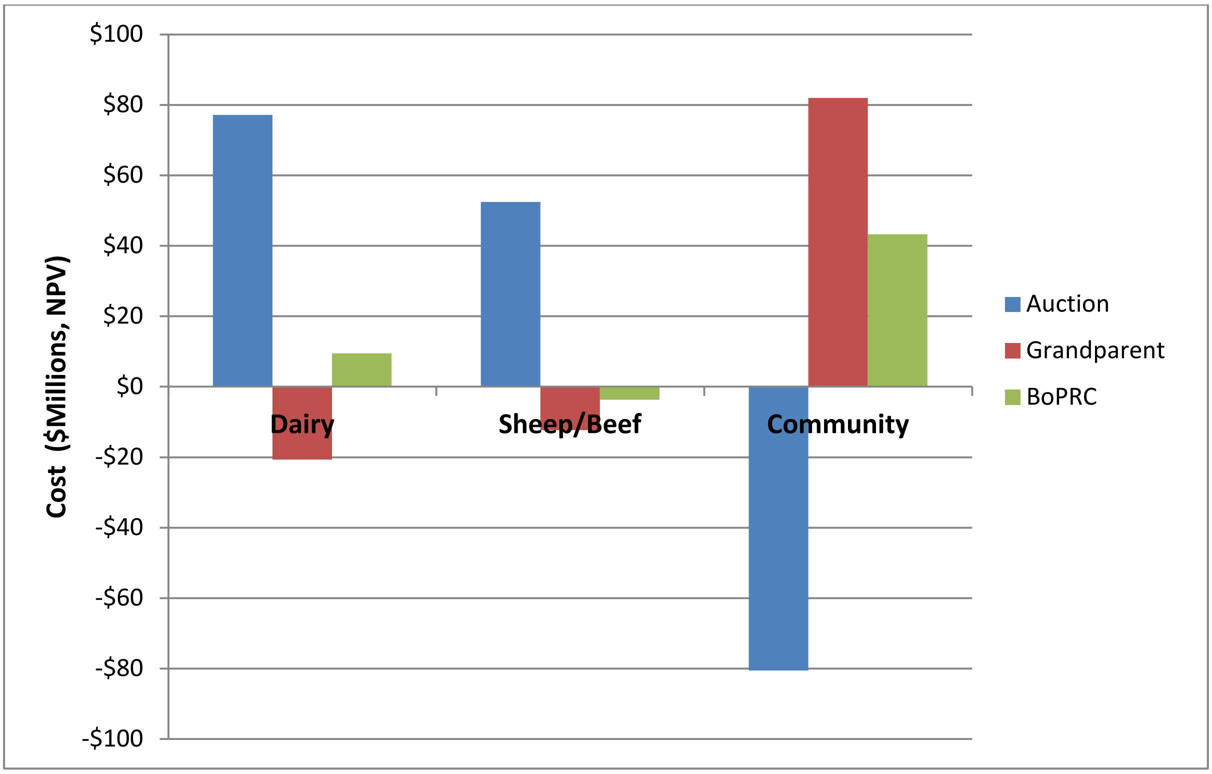
The final allocation regime we consider is motivated by a BoPRC cost sharing proposal in the recent proposed regional plan information documents (Bay of Plenty Regional Council, 2012). They propose a cost sharing arrangement where farmers are responsible for shifting their farm to best practice while the rest of the costs of achieving the nitrogen reduction target will be covered by the wider community (local, regional, and central government). BoPRC defines best practice for dairy farms as nitrogen leaching of 40kgN/ha/yr (a decrease of 16kgN/ha/yr, or approximately 30%), and nitrogen leaching of 14.4kg/ha/yr for sheep/beef farms (a decrease of 1.6kg/ha/yr, or 10%).

4.5.1. Allocation results

Figure 8 compiles the total costs borne by land owners currently in dairy, sheep/beef, and the community to meet the 270tN by nitrogen reduction by 2022 on agricultural land[9]. If all allowances are auctioned, that is there is zero free allocation, the community will receive more than $80 million in allowance payments. This money can be spent in any way the community sees fit, it could be used to reduce rates, pay for additional mitigation, invested in research on mitigation options, or spent on other priorities. The money could also be returned to land owners to help offset the cost of purchasing allowances and carrying out the mitigation required to achieve the nitrogen reduction goal. The total cost of mitigating and purchasing allowances is large for both sheep/beef and dairy land owners, in total in NPV terms it costs them approximately $77million and $52million respectively. Table 9 presents these costs in per ha terms: under an auction allowance regime sheep and beef farmers will see a reduction in per ha profits of 47% relative to baseline profits. Dairy farmers will see an even larger reduction in baseline profits of 70%.

[9] Note that if the community will fund the additional 50tN reduction required to reach the 320tN reduction goal, the cost of this mitigation to the community will be additional to the numbers reported here. Any costs of scheme set up and administration on the regulator side, or compliance costs on the participant side are also absent from our analysis.

Figure 8: Distribution of costs under a nitrogen cap and trade scheme with varying allocation of allowances



Both sheep/beef farmers and dairy farmers would see their profits increase under a 100% grandparenting with buyback allocation scheme. Sheep/beef profits would increase by 11% on BAU, while dairy would see an even larger increase in BAU profits of 19%. This occurs because the community buyback will more than cover the mitigation costs farmers face. Using this allocation mechanism the community would face a total cost of $81 million to achieve the nitrogen reduction goal, while sheep/beef farmers and dairy farmers in aggregate benefit by more than $30million. Allocating allowances to cover more than the cost of mitigation could be justified if the aim of free allocation was to compensate for the lost option value that farmers faced when Rule 11 was imposed. However, if this was the aim of the allocation regime additional allowances should go to the land that was most likely to intensify if it was not restricted by Rule 11. The land most likely to intensify would have been underdeveloped land with low nitrogen leaching[10]. Instead, grandparenting gives the majority of these extra allowances to dairy land which presumably was already at the limits of intensification and therefore faced a relatively small lost option cost.

[10] A large portion of underdeveloped land in the catchment is Maori land. This land was underdeveloped at the time of Rule 11 due management restrictions, limited investment funds, and conscious decisions to minimise the impact on the lake.

Table 9: Distribution of cost per ha and relative to baseline profits under a nitrogen cap and trade scheme with varying allocation of allowances

Cost per ha under allocation ($NPV/ha)	Dairy		Sheep/Beef	
	Costs per ha	% change in baseline profits	Costs per ha	% change in baseline profits
Auction	$14,390	-70%	$3,410	-47%
Grandparent with buyback	-$3,852	19%	-$800	11%
BoPRC	$1,761	-9%	-$239	3%

The final allocation scheme we consider is a cost sharing between BoPRC and landowners where the council will freely allocate allowances up to a best management practice level, and buyback allowances to ensure that the nitrogen reduction target is reached. Landowners are expected to cover the costs of any leaching above the BMP level. The total cost faced by regulators to achieve the nitrogen reduction target under this allocation scheme is just under $43 million. Under this allocation dairy farmers will see their costs decrease by a total of just under $10million, or 9% of BAU profits. Comparatively, sheep/beef farmers will see a slight increase on BAU profits of 3%, a cumulative gain of just over $3million. The different outcomes for dairy and sheep/beef landowners reflect the relative cuts in BAU dischargers and their respective marginal costs of mitigation.

5. Conclusions and future work

In this paper we have considered a number of policies that could achieve nitrogen reduction targets in Lake Rotorua including mandatory 'best management practice' (BMP), a tax on nitrogen exports, and a nitrogen cap and trade scheme. We have assessed a number of variants of each policy and have also considered the sensitivity of results to different stringencies of targets and timing of regulation implementation. For each policy we have reported the mitigation costs of achieving the nitrogen reduction target and how this will be efficiently spent across land uses. Where appropriate we have also reported the predicted land use change resulting from policy. While we cannot quantify the benefits of each policy in dollar terms, we have reported the Lake Rotorua nitrogen loads that will result from policy and the complementary long run GHG emissions reductions. Finally, we have discussed the distributions of cost across different land uses and the wider community under a selection of different free allocation schemes. We have assessed the sensitivity of results to model assumptions where possible.

These results offer two key conclusions about how diffuse water pollution should be managed. Firstly, increasing the flexibility of regulation can decrease the mitigation costs of achieving the environmental goal. These decreases may or may not offset the increased administration and monitoring costs often associated with these more complex policies, but these results should motivate policy makers to consider the cost of overly prescriptive regulation such as uniform reductions or best management practice. Secondly, the allocation results clearly illustrate the importance of allocation decisions in determining distribution of cost. The costs borne by polluters depend far more on the allocation of allowances than the environmental goal; this has important implications for the political economy of designing and implementing nutrient trading schemes.

Future work is planned for two major areas: allocation, and heterogeneity[11]. In terms of allocation, we plan on assessing two additional allocation schemes. The first is assessing the distribution of costs when sheep/beef and dairy landowners are allocated proportionately less than business as usual discharges, such that the sum of allocation equals the target nutrient discharges. We would also like to investigate the distributional impacts of allocating on land's potential production and nitrogen leaching, where potential production is defined by a land quality measure such as average stock carrying capacity. However, this will require changes to NManager's current set up which could be time-consuming. This will only be carried out if time and funding allow.

Our highest priority for future work is increasing the heterogeneity of mitigation costs within NManager. We want to increase the heterogeneity of mitigation costs in NManager for two key reasons. Firstly, the current homogeneity of marginal mitigation costs for parcels in the same land use is inconsistent with data. We would like to test how sensitive our results are to the level of heterogeneity captured by NManager. The second motivation for increasing the heterogeneity of our model is that it will allow us to better understand the distributional impacts of allocation. Including farmers with different degrees of profitability will help us understand how costs of meeting environmental targets in Lake Rotorua will be shared across different farmers within the same land use, and how this cost sharing is affected by different allocation approaches.

[11] We also plan on testing our GHG estimation model further, and testing the sensitivity of our results to changes in forestry profitability.

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