Nutrient Trading in Lake Rotorua: Goals and Trading Caps

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Abstract

For a nutrient trading system to achieve the desired environmental outcome, or goal, this outcome needs to be translated into nutrient flows and allowances. To connect the nutrient loss provided for under the allowances with the environmental goal, a number of decisions need to be made. These decisions will shape the nutrient trading system. This paper looks at the information and analysis needed to ultimately define allowances and set trading caps for a nutrient trading system.

JEL classification
Q53, Q57, Q58

Keywords
Water quality, nutrients, trading, Lake Rotorua

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1 Introduction—scope and linkages in paper

This paper looks at the information and analysis needed to ultimately define 'allowances' and set trading caps for a nutrient trading system. In this paper, we deal with this in a deterministic way. Although there is uncertainty in many dimensions of the problem, we will act as though there is not and make a fixed decision based on the best information currently available. The issue of how to build a system that can create new information, incorporate new information as it is revealed, and handle irresolvable uncertainty will be dealt with in a future paper.

We cannot directly observe the impacts of each landowner's behaviour on lake quality. Thus we are always controlling monitorable proxies for these impacts. These proxies are related to our ultimate goal through models. What we put a cap on (lake inputs) is intrinsically linked to what we can monitor (property exports or proxies of these exports). Thus we need to address the problem of setting a trading cap from both ends: the water quality goal, and the technology for modelling nutrient loss and transport. This paper focuses on the former but identifies links to the latter. Two nutrients matter in Lake Rotorua, nitrogen (N) and phosphorus (P). We will discuss P first and then proceed with a focus on N, remembering that many of the same issues apply to both.

Out of this discussion, we would like to provide preliminary decisions on several aspects of the nutrient trading system. In some cases, this could consist of several options and a short discussion of their relative merits.

- Which nutrients should be controlled under a trading cap?
- Should goals be defined in terms of nutrient loss (exports), nutrients entering the lake (inputs), or nutrient concentrations (stocks) in the lake?
- What do currently defined goals imply for trading caps?
- What periods of time and spatial zones should allowances apply to?

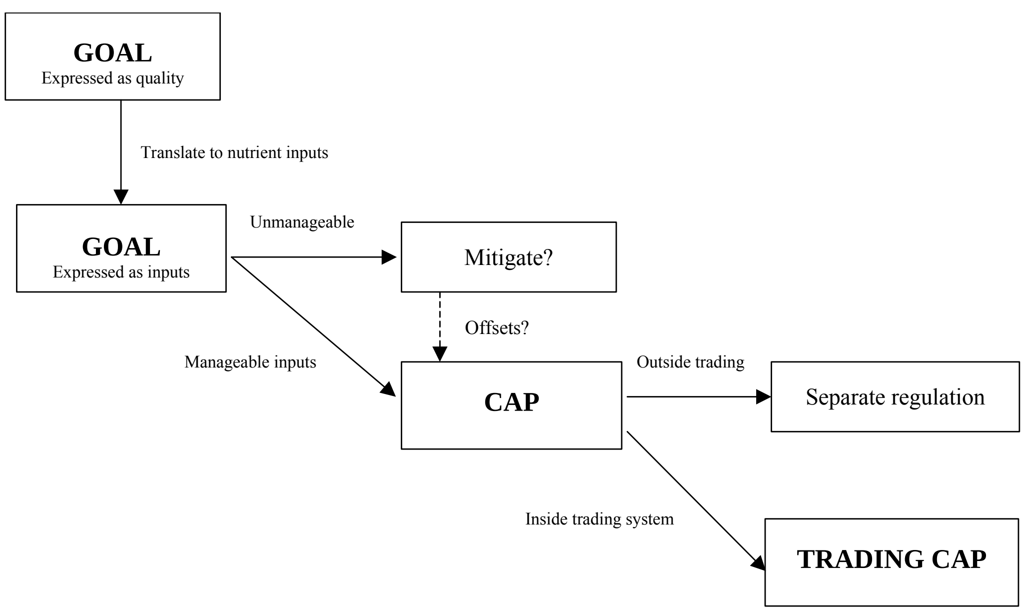
1.1 Definitions—the nutrient chain

We define the 'goals' as what society ultimately cares about. This goal is first defined in terms of qualitative factors that directly affect human activities (in Rotorua, "… water quality as it was in the 1960s before there was widespread concern about algal blooms …”). This goal is then translated into lake nutrient and chlorophyll concentrations and water clarity as an observable proxy for the expected goal (in Rotorua, a Trophic Lake Index, or TLI, value of 4.2). Of particular interest for a nutrient trading system is the translation of the water quality goal into nutrient inflows, or ‘inputs’, in each time period. Once the goal is expressed as nutrient inputs, ‘unmanageable’ nutrient inflows need to be estimated. These jointly define a ‘cap’ on manageable nutrient inflows into the lake.

Some nutrient flows that are not created by human activity, and that are hence included in unmanageable flows, may be able to be influenced by treatment in the short-term or by investment in mitigation or diversion projects. These options could be included in the trading system by creating ‘offsets’ that are approved as allowances, thus increasing the cap.

Because the mean residence time in the lake is very short, 1–2 years, we look at inputs only, rather than lake concentrations.[1]

Figure 1 The nutrient regulatory chain



[1] GNS Science talks about ‘mean residence times’. The model they use is a mixed model. Part of the water (somewhere around 50%) goes through as piston flow, in which case all the water has the same residence time. The other part goes into a mixed reservoir, and the MRT is exactly analogous to the half-life of a radioactive compound.

Then, by defining the scope of the trading system and estimating the implied inflows that are outside the system, a 'trading cap' can be defined. This can be devolved to individual landowners2 and others who control nutrient flows and defined in terms of nutrient loss at the property level or 'exports'. Parts of the Rotorua catchment are underlain by large aquifers with residence times of 15–100 years. Nutrients may take many years to travel from the farms where they are generated to the springs that feed into the lake. This gives rise to 'groundwater lags' between changes in exports from the land and nutrient inputs to the lake. This paper focuses on defining the cap and converting a series of caps on inputs into caps on exports. A future paper will discuss the 'scope' of the system and hence the trading cap.

1.2 Why use nutrient trading to achieve the cap?

Scientists, regulators, and politicians have the best information on the nutrient impacts of land-use activities and management, and on public concerns about lake quality. Consultants may have useful information on the feasibility and profitability impacts of different land-use and management options. Landowners, however, are likely to have the best information on their own land and the profitability and costs of changes in their behaviour. If they don't, they have incentives to get information if it is offered.

Nutrient trading gives landowners the incentive to use their information, within the constraints of regulation, to achieve the goals set by regulators in the most efficient way possible. Nutrient trading may also be more acceptable to landowners than prescriptive regulation because it is less coercive and restrictive. It puts the focus of regulation on issues of public interest (the environmental outcome) rather than issues of private interest (e.g., on which properties nutrient losses occur).

A nutrient trading system will encourage landowners to use nutrients in the most efficient way possible by aligning economic returns with environmental issues. This system will help the individuals understand the impact that their decisions are having on the lake water quality and may allow maximisation of

[2] For simplicity in this paper, we refer to all individuals who participate in the nutrient trading as landowners.

wealth creation through the flexible manner in which nutrient losses can be achieved.

Nutrient trading is most useful where there are large numbers of heterogeneous agents (e.g., landowners) and where the actions required occur over long periods of time so that the information that agents hold is important. With a small number of agents, negotiation or modelling of decisions is more likely to get close to an efficient outcome. With large numbers of agents across a long time period, technical 'experts' and regulators are unlikely to be able to identify economically optimal sets of mitigation measures.

If the nutrient cap is set and monitored in such a way that compliance with it ensures that the environmental goal is met, the regulatory system does not need to define how that cap is achieved.

2 Are we targeting only nitrogen (N) or also phosphorus (P) in the nutrient trading programme?

Both N and P are important in determining lake water quality in Rotorua. Although lake phytoplankton are currently limited by the supply of N in the short-term, the lake is nearly in balance in its demand for N and P. N load is increasing, whereas P load is almost static, so the lake could become P limited in the future. High P loads tend to favour undesirable N-fixing blue-greens. The scientific consensus is that both N and P need to be controlled (see Environment Bay of Plenty, 2004). Goals have been set for reductions in both N and P inputs.

The key question is whether P should be controlled, at least in part, through the nutrient trading programme or whether it should be addressed separately, with some benefits from the trading programme flowing indirectly through actions aimed primarily at controlling N.

The same on-farm measures control both N and P but with differences (sometimes significant) in performance. A number of 'sound farming practices' are advocated by AgResearch and included in the OVERSEER® model. Environment Bay of Plenty (EBOP), in developing the Nitrogen Phosphorus Load

Assessment System (NPLAS), has defined various P attenuation options (e.g., constructed wetlands). P and N may behave quite differently in the groundwater and may not have the same lags. The extra cost of monitoring P once N is monitored is low.

Discussion at the Technical Advisory Group is about targeting N and P separately, although some approaches to reduction will address both simultaneously. This is probably the optimal approach. At this stage, we will proceed on the assumption that P will also be included in the trading system.

3 Goals and caps

This section first discusses what we are trying to control and how goals concerning water quality relate to caps that ultimately limit nutrient loss from individual properties at specific points in time. We then take this framework and link it to what has already been decided and what is already known in the Lake Rotorua catchment.

3.1 Goals and caps in theory

In this study group, we are not revisiting the issue of how to set appropriate water quality goals for Lake Rotorua. We are concerned only with how those goals are achieved. The current goal was set through a political process, with input from a combination of scientific and economic research on the benefits and costs of controlling nutrients. This is not a purely technical decision. It will need to be reassessed over time as more economic and scientific information becomes available and as social attitudes change.

A realistic series of goals

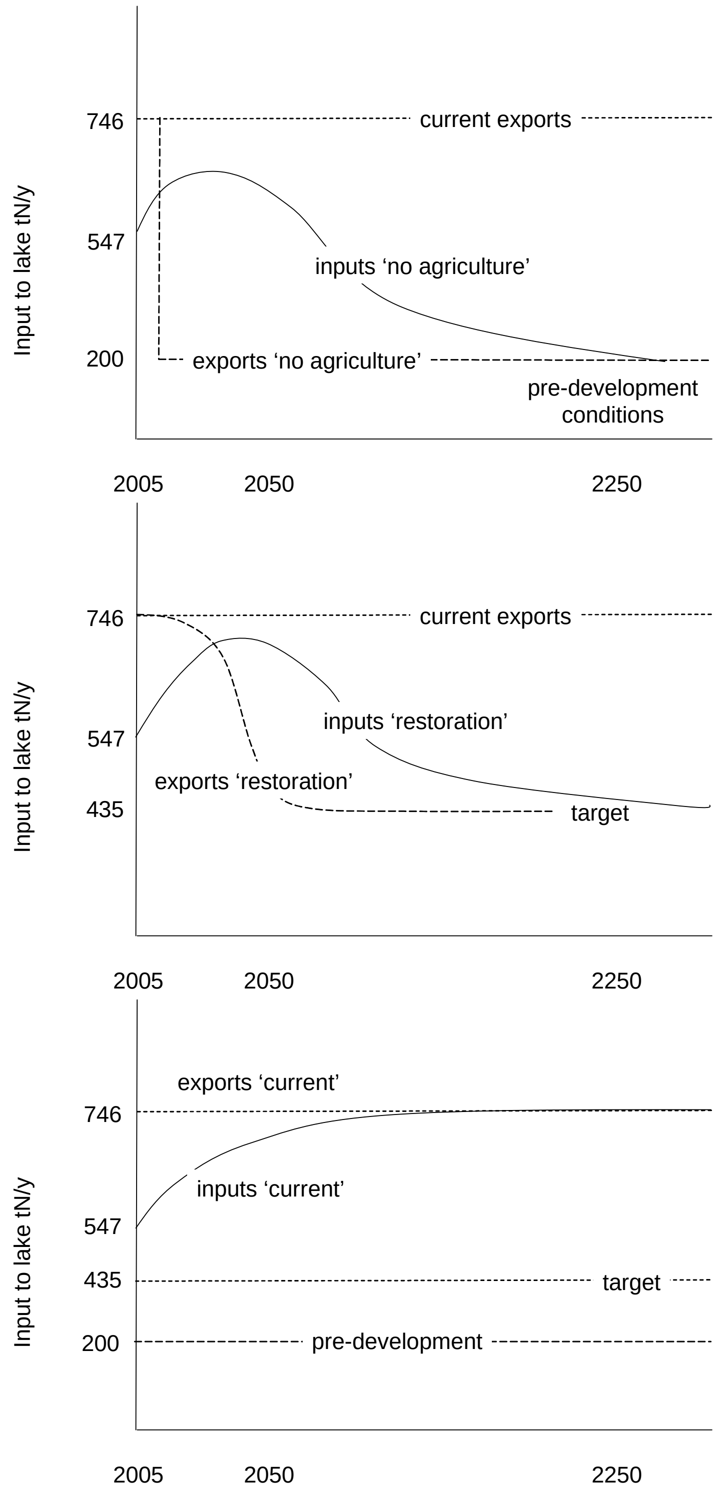
For a trading programme, the goal has to be realistic and defined for specific time frames. Once the water-quality goal for the lake has been agreed, the nutrient inputs to achieve this goal (the input targets) are estimated and these become a series of caps on inputs. The caps *will* be achieved as long as the trading programme to manage exports is implemented—it is not a target that *might* be achieved. The water quality goal might or might not be achieved in any particular year (e.g., because of random variations in weather).

What can be achieved in the short term is different from in the long term. This is partly because of the long lags of unmanageable groundwater flows coming into the lake. Also, the costs of change are higher if change is rapid. Costs will change over time with changes in the relative profitability of the different land uses and management practices. These costs will also be affected by the nutrient regulation put in place. It may be appropriate to have a gradual adjustment to the long term targets. The time series of input targets needs to be set via consultation between managers and stakeholders, with input on the science, economics, and social effects of possible alternatives.

Figure 2 shows three scenarios that illustrate the challenges in setting realistic input targets to restore the lake. It illustrates the likely magnitude of unmanageable N inputs in the short and long run. The first graph shows a scenario where N exports from all manageable sources are instantly reduced to pre-development levels (i.e., no people or human activity in catchment). Even in this extreme scenario, the target of 435 tonnes nitrogen per year (tN/y) is not reached for more than 50 years. The second simulation illustrates a more gradual reduction in exports, where input targets are not met for nearly 200 years. The third shows the effect of freezing exports at current levels. These scenarios illustrate the potential importance of mitigation and treatment of streams, lake water, and sediments if we are to make significant gains in the short term.

Figure 2 **An illustration of how nutrient inputs to the lake may change over time for various management scenarios.**

Top—steep reduction of exports in 2007 to 200 tN/y, the estimated pre-development exports. Middle—phased reduction of exports from the current 746 tN/y to the target 435 tN/y. Bottom—continued exports of the current 746 tN/y. Numbers and timing are only indicative.



The potential for 'banking'

It may be that a political compromise is made to reduce short term costs. Goals are often less ambitious in the early years of a trading programme to get the system going. If goals are set in such a way that the environment would benefit from overachieving the goal in the early years, even if the more stringent goals were offset by a looser goal in later years, a provision called 'banking' can be included in a trading programme. Allowances that were part of the cap in one period can be 'banked' and then withdrawn in a later period. These banked credits maintain their true value in terms of nutrients. This can lower the cost of the overall programme because relatively low-cost reductions are achieved early on while the cap is loose and, in exchange, high costs of compliance are avoided in later periods when the cap is very tight. Another potential advantage of banking in a 'thin' market (i.e., where there are few participants) is that landowners have more flexibility within their own properties if the market is not functioning smoothly. Banking also tends to smooth allowance prices over time. The cost of nutrient reductions (which determine the allowance price) tend to vary from year to year with commodity prices and weather. Banking allowances in low-cost years and withdrawing them in high-cost years smoothes the allowance price and reduces economic uncertainty.

Banking that is driven by short term economic variation and that does not make the nutrient-loss path flatter (by banking when nutrient losses are high and withdrawing when they are lower) creates a trade-off between environmental certainty and management of economic risk.[3] Banking involves overachievement in some years and underachievement in others. The net environmental damage depends on how much lower the value of overachieving is relative to the damage from underachieving. This needs to be traded off against the net reductions in economic cost over the banking and withdrawing periods.

[3] This is a common and well-studied issue in environmental regulation. The classic reference is Weitzman (1974).

3.2 Goals and caps in practice for Lake Rotorua

Water quality goal

The draft Action Plan (Joint Strategy Committee, 2007) sets the goal for Lake Rotorua's water quality as the water quality in the mid-1960s. This translates to a Trophic Lake Index[4] (TLI) of 4.2. Currently, the TLI is 5.0. No time limit is set for achieving the goal. The goals in the Action Plan are set in terms of nutrient inputs.

Nutrient goal

Translating the water quality goal into nutrient inputs to the lake, the Action Plan adopts, as the long-term target, the estimated load in the mid-1960s (435 tN/y excluding internal loads, 30 tP/y excluding internal loads).

Current exports from the catchment are around 746 tN/y and 40 tP/y (estimates from Morgenstern and Gordon, 2004). These are the inputs that would be expected to occur at 'steady state' (in ~200 years) if land use remained the same as it is at present and there were no attenuation (viz., nutrient loss in the groundwater or streams after nutrient has left the land). Current N inputs to the lake are lower than current exports from the catchment because of groundwater lags and possibly because of attenuation. Current inputs are around 547 tN/y and 40 tP/y (Morgenstern estimates). The N inputs are expected to increase gradually over the next ~200 years as groundwater N concentrations slowly increase in response to historic land use changes.

Cap

The Action Plan estimates the changes in N and P inputs expected to occur over the next ~200 years as a result of recent land use changes and groundwater lags (time delays in these nutrients reaching the lake). From these figures, estimates are made of the reductions in N and P inputs that are required to meet the load targets and hence the goals for lake water quality.

[4] The TLI is an index calculated from measured total nitrogen, total phosphorus, chlorophyll concentrations, and water clarity.

Table 1 **Deriving a nitrogen input cap from the defined Lake Rotorua goals and planned actions—Step 1: define goal and planned reductions in inputs relative to status quo**

	N exports from land (assuming current land use)[1]	Estimated N inputs to lake (including effect of groundwater lags)[2]	Goal—inputs	Required reductions in inputs		Required additional reduction
				Total	Agreed actions	
2005	746–783	547	435	112	59[3]	53[4]
2017	746–783	n.a.	435	250[5]	59	191[6]
2055	746–783	659	435	224[5]	59	165
2105	746–783	699	435	264	59	205
2205[7]	746–783	746	435	311	59	252

[1] Independent estimates by Morgenstern (746 tN/y) and McIntosh (783 tN/y) are similar.
[2] Morgenstern estimates, Table 5.
[3] This figure comprises (1) upgrades to the PCP (15 tN/y), (2) sewerage of small communities (11 tN/y), (3) urban storm water (3 tN/y), and (4) treatment of Tikitere (30 tN/y). Table 2 of the draft Action Plan.
[4] A further reduction of 53 tN/y is required to bring the current load of 547 tN/y down to the target of 435 tN/y.
[5] A reduction to inputs of 250 tN/y will accelerate improvements in lake water quality.
[6] The draft Action Plan aims for a 170 tN/y reduction in export from improved land-use management.
[7] The draft Action Plan gives these as the targets for 2050, but this may be a typo.

Once N enters the groundwater, it is largely unmanageable.[5] In theory, N can be removed from groundwater, but in practice, this would be very expensive and is not being seriously considered in Rotorua. In theory, N and P can be removed from stream and spring water. Trials are being conducted using alum dosing to remove dissolved reactive phosphorus (DRP, or soluble phosphorus) from water in the Utuhina Stream. This is seen as a short-term measure to reduce P inputs while other input-reduction measures are put in place. There has been some general discussion about N removal from streams (e.g., wetlands, advanced treatment systems), but no detailed investigations are being conducted at present. The principal controls on N inputs are seen to be land-use change, on-farm mitigation measures (e.g., constructed wetlands and riparian buffers), and treatment/diversion of high load sources (e.g., sewerage, urban storm water, and the Hamurana Stream).

Thus we can think of the lagged groundwater flows as unmanageable nutrient flows and the required reductions in N and P to meet the target inputs as defining the cap for the trading system. Other unmanageable sources include rainwater, waterfowl, and the baseline flows from exotic forestry (3 kg/ha/y),

[5] There is a debate about the level of in-stream attenuation.

which is the lowest export rate from any land use (see Table 6 in Appendix 1). We do not yet have good estimates of unmanageable groundwater flows for N. A current estimate of pre-development N inputs (all other unmanageable flows) is 200 tN/y. Estimates of the pre-development P inputs have not yet been calculated, but these are likely to be similar to the current 30 tP/y as the majority of P inputs come from the rocks.

The caps are a time series of manageable lake inputs that is agreed by a political process. In setting the caps, it will be necessary to:

1. agree a time series of total input targets within the community—as in Table 1 from the Action Plan—e.g., 435 tN/y, 30 tP/y
2. model nutrients already in groundwater in 2007 (start of programme) that will reach the lake in each given year and estimate unmanageable flows
3. subtract the unmanageable inputs in 2 from the total input targets in 1 to give the potential series of caps for the trading system
4. through discussion in the community, reassess feasibility of these caps and hence the original input targets and agree on a satisfactory cap.

In addition to the goals stated above, the draft Action Plan sets the goal of reducing exports from farmland by 170 tN/y and total exports by 250 tN/y by 2017. To achieve the export reductions off farmland a combination of improved farming practices and/or land-use changes will be used.. Depending on where these exports are reduced, this export reduction may go beyond the short term target of reducing inputs by 53 tN/y in 2005 and by 165 tN/y in 2055. If nitrogen exports are reduced on farms 'close to the lake' (in the sense that they are not in sub-catchments affected by large groundwater lags), then lake inputs will reduce quickly (~10–15 years) and lake water quality should improve quickly. On farms 'distant from the lake' (where groundwater lags are very long), reductions in exports may not be reflected in reductions in lake inputs for many years.

Decisions about the required reductions of inputs need to be translated into caps by defining what the reductions are relative to. Ultimately, the reductions need to be translated into caps on the sum of exports from the combinations of groundwater zones and time periods that affect the lake at a specific point in time.

Table 2 shows a rough calculation in which incremental reductions in exports of tN/y are assumed and the reductions in lake inputs are shown over time.

Table 2 Export reductions and associated input reductions to meet goals—a possible scenario

	Groundwater lag zone (years of lag)	Incremental export reduction	Incremental input reduction					
Year			2010	2030	2050	2070	2090	2110
2010	0 40	53 50	53	53	53 50	53 50	53 50	53 50
2030	20 40	65 25			65	65 25	65 25	65 25
2070	20 40	15 40					15	15 40
Cumulative export reduction			103	193	193	248	248	248
Cumulative input reduction			53	53	168	193	208	248
Goal—exports (Table 1)				**191**				
Goal—inputs (Table 1)			**53**		**165**	**165**	**205**	**252**

These reductions imply that by 2070 we have reduced annual nutrient loss in the 0-year lag zone by 53 tN/y, in the 20-year lag zone by 80 tN/y, and in the 40-year lag zone by 115 tN/y. These reductions may not be practical, of course —it's only an illustration.

Length of periods

Currently, goals are set at 50-year intervals. They do not explicitly address the timing between the defined points. In a nutrient trading market, the input goals will need to be defined for the current year and then possibly for longer time intervals thereafter—but with the possibility of banking to allow more temporal flexibility.

Definition of groundwater zones

Exports from each zone at each point in time will be related to a specific temporal input goal (or group of goals—see section 4.2). Each property could be associated with one specific groundwater lag (i.e., assume that all nutrients from that property reach the lake at the same time). Some very large properties might overlap zones, and we could consider separating them. However, this could create monitoring difficulties for management practices (because, for example, animals are counted at the property level but probably move between zones on the farm) even if it does not create difficulties for land use. It may be better to compromise by allocating each property to the zone where most of their nutrients flow.

The question is: How many zones should we include, and how should they be defined? The advantage of having more zones is that the control over timing of impacts of nutrient loss is more accurate and hence the system will more efficiently control water quality at the times when this is most critical. One disadvantage of having too many zones is that our knowledge of groundwater lags is not perfect, meaning that gains from efficient targeting may be illusory.

One possible number of zones is one. This is the solution chosen in Taupo, but we should not default to this without serious consideration of the value of having more. The catchment could be divided into sub-catchments with 'short' and 'long' groundwater lags. In another alternative, each of the eight major catchments could be ascribed a single 'lag', estimated from GNS Science data on groundwater age. GNS Science is currently working to define groundwater catchment boundaries.

4 Temporal markets

4.1 Translating input caps into export caps by zone

The nutrients in a lake are 'uniformly distributed' pollutants, in the sense that it does not matter where they come from, and are not significantly accumulative in the lake (lake residence is only 1–2 years). But the spatial distribution of current nutrient loss has large implications for water quality at different times in the future because of the groundwater lags. Analogous to the spatial zones that are used in markets where the location of pollution matters (e.g., the Los Angeles air pollutant market, Los Angeles Regional Clean Air Incentives Market or RECLAIM), we could create a series of temporal markets where different locations would contribute to different input goals depending on the groundwater zone they were located in. Each goal would be associated with one market. Having a series of temporal markets would allow us to achieve the cost-effective allocation of allowances. (See Appendix 2 for the theoretical proof.)

For example, if there were two groundwater zones, 0-year lag (instant—like a point source) and 1 year lag, we would need at least two markets to operate in 2007: one for inputs entering the lake in 2007 and another for 2008 inputs. In these markets, landowners would surrender allowances to match their net exports. Each market would have a cap, CAP_{2007} for the 2007 market and CAP_{2008} for the 2008 market, with corresponding allowances of 'vintages' A_{2007} and A_{2008}. Each allowances from each vintage could be used to match exports that affected inputs in the stated year. Landowners would own allowances from each future vintage that they would need. Their ownership would be recorded in a registry. In 2007, the landowners in the 'instant' zone would need to surrender A_{2007} allowances to match their net exports; in 2008, they would surrender A_{2008} allowances. In contrast, in 2007 landowners in the 1-year lag zone would surrender A_{2008} allowances to match their net exports because 2008 is when the impact of their exports would be felt; in 2008, they would surrender A_{2009} allowances.

The difference between spatial and temporal markets is that space does not move but time does. If we had a market for each future year, as above, the allowances surrendered to each market would simply sum over time as the markets stepped forward. In 2008, the A_{2008} allowances already surrendered to cover nutrient loss in 2007 would be excluded automatically from the remaining CAP_{2008} because they would be removed from the registry when they were surrendered.

Allowance trading could occur within groundwater lag zones because all will use the same vintage allowances for exports in a given year. Trading could also occur between groundwater lag zones as long as the vintage of allowances bought and sold is the same. Trading between groundwater lag zones will change the timing of exports but not the timing of inputs.

Table 3 Illustration of how impacts (and hence allowances) sum over periods to equal the cap

	Exports by groundwater zone (spatial)		Sum of impacts
	Instant	1-year lag	
2007 impact	100	n.a.	$Cap_{2007} = 100$
2008 impact	75 (from 2008 exports) +	75 (from 2007 exports) =	$Cap_{2008} = 150$

4.2 Combining markets

Creating one market per future year would create up to 200 markets for Rotorua, which would probably make markets too thin at any point in time. In addition, the definition of groundwater lags, especially for the longer lags, is not exact, so this may imply spurious accuracy.

Instead of having one market per year, for periods further away, markets could be combined temporarily in ‘pools’ where groundwater lags are long. We would still have allowances, with vintages for each of the 200 years, A_{2007} to A_{2207}. The second market could, for example, cover exports that reach the lake with 1–3 years of lag, the ‘+1–3 pool’. Landowners in groundwater zones with 1–3 years of lag could surrender any of the allowances in that pool to match their current exports. In 2007, this pool would cover inputs that would reach the lake in 2008–10.

Each year, the exact vintages in the +1–3 pool would change. New ones would enter from the older vintage pools, and the remaining allowances with the current year vintage would leave that pool and go into the current pool. In 2008, the +1–3 pool would include 2009–11 vintages.

5 Summary—preliminary decisions

- We will proceed with our analysis on the assumption that N and P are included in trading. The final decision can be made later.
- We cannot define caps on inputs for the trading programme until flows of nutrients already in the groundwater that will reach the lake in each year are estimated by current GNS Science research. The Rotorua community may not wish to directly translate their currently defined input goals into short term binding targets for a trading regime if the

reductions required are seen to be unreasonably expensive in the short term.

- We will be able to define spatial zones based on groundwater lags when current GNS Science research is complete. At that point, we will need to decide how, and whether, to combine for trading purposes the zones they identify.

To close, we offer an illustration of what temporal trading would mean for a landowner. His property would at the start of the programme be assigned to a specific groundwater lag zone. This would not change. It would define which vintages of allowances he must surrender to match each year's exports.

Thus a property with a 2-year groundwater lag would need to hold 2012 vintage input allowances to match 2010 exports. The landowner would (probably) be allocated some allowances relating to each of the future markets in which he would participate for a number of years into the future. If his exports in 2010 exceeded his level of 2012 allowances, he would need to buy more allowances from other landowners. If his 2010 exports were lower than his level of 2012 allowances, he could sell the excess allowances.

If he could anticipate his exports several years in advance, he could also buy or sell allowances several years in advance. If he made an investment this year that lowered his nutrient exports in every future year by 1 tonne, he would need fewer allowances in all future periods and could sell his excess holdings of future allowance vintages.

These temporal markets are conceptually complex but achieve the input targets with the greatest possible flexibility. Each landowner needs only to know which vintages of allowances match his exports in each year and how to monitor/model his net nutrient losses.

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Appendix 1

Table 4 Lake Rotorua's nutrient inputs versus targets (summarises the calculation of the nitrogen and phosphorus reduction target needed for Lake Rotorua to attain its target TLI)

Description	Nitrogen (t/y)	Phosphorus (t/y)
Catchment nutrient inputs to Lake Rotorua	783	40
Nutrient inputs to the lake itself, measured from 2002–05 inflows into Lake Rotorua	2005: 547 2055: 659 2105: 699 >2205[6]: 746	39.1
Nutrients that cycle from the sediment–water interface into the lake	360 (up to 10 times per year)	36 (up to 10 times per year)
Estimated 'sustainable' nutrient inputs to Lake Rotorua[7]	435, excluding internal lake cycling	30, including internal lake cycling
Estimated total nutrient reduction needed	2005: 112 2055: 224 >2205: 311	10 catchment, 25 in-lake cycling
Nutrient reduction targets	By 2017: 250 By 2050: 311	By 2017: 35

The 'nutrient reduction targets' (last row above) are higher than the 'estimated total nutrient reduction needed' (second-to-last row) for Lake Rotorua. This is because the nutrient-enriched state of Lake Rotorua will take many decades to begin to restabilise at its long-term water-quality goal, unless the total nutrient reduction needed is reached earlier.
Source: Lakes Rotorua and Rotoiti Action Plan Draft 2.5, March 2007, p. 51

[6] This is the steady-state loading if nutrient loss from the catchment remains the same as in 2005.
[7] This calculation was made as part of the resource consent for the Rotorua Wastewater Treatment Plant.

Table 5 Nutrient reduction actions for Lake Rotorua and Lake Rotoiti

	Action	N reduction (t/y)	P reduction (t/y)	Cost ($) Per year	Cost ($) Per kg	Time frame
Lake Rotorua: confirmed actions	Rotorua Wastewater Treatment Plant upgrade	15	0	$1,484,320	$99 (N)	By 2006
	Community wastewater reticulation or OSET upgrade for Rotorua	10.84	0.25	$4,990,637	$460 (N) max	By 2014
	Storm-water upgrades within Rotorua urban	3	0.5	$1,046,080	$348 (N) $2,092 (P)	By 2017
	Tikitere geothermal	30	0	$108,200	$4 (N)[8]	By 2009
	{Phosphorus flocculation in the Utuhina Stream}	{0}[9]	{3}	$420,000	$140 (P)	By 2006
Lake Rotorua: potential actions	{Phosphorus flocculation in two other streams}	{0}	{6}	$840,000	$140 (P)	~
	Constructed wetlands	N reductions, costs, and time frames will depend on the site and proposal. Further evaluation is required.				
	In-lake/in-stream nutrient removal using biomass	N reductions, costs, and time frames will depend on the site and proposal. Further evaluation is required.				
	Lake-bed sediment treatment	0[10]	25	~	~	~
	Hamurana Stream diversion to the Ohau Channel	53 (2005)[11] 92 (2055)[12]	6.3	$3,030,000[13]	$57 (2005) $33 (2055) $481 (P)	~
	Land-use management and land-use change	170	6	$1,000,000	$6 (N) max[14]	By 2017
Total Lake Rotorua		**228.84 (+ Hamurana)**	**15.75 (inc flocculants) + 25 (lake-bed treatment) + 6.3 (Hamurana)**			
Lake Rotoiti: confirmed actions	Ohau Channel diversion to Kaituna River	150	15	$1,790,000	$12 (N) $120 (P)	By mid-2008
	Land use diverted by Ohau Channel diversion	6	0.07	~	~	~
	Community waste-water reticulation or OSET upgrade for Rotoiti	5.94	0.21	$4,290,643	$722 (N) max	By 2010
	Land-use management and land-use change	0	0	0	0	By 2017
Lake Rotoiti: proposed action	Treatment of Lake Rotoiti's lake-bed sediments. Further evaluation is required once the effect of the Ohau Channel diversion has been assessed in the 6-year review.					
Total Lake Rotoiti		**161.94**	**15.28**			

Source: Lakes Rotorua and Rotoiti Action Plan Draft 2.5, March 2007, p. 17

[8] This cost per kg N is lower than other actions because the Tikitere geothermal flow has a high nitrogen concentration and low volume and is close to existing reticulation infrastructure.

[9] {#} means that the action is only temporary until long-term land use change/management actions can take effect.

[10] Lake-bed sediment treatment will reduce N releases. However, these reductions are not calculated towards the N reduction target as sediment N releases are excluded (see sections [5] and [9.10] in Action Plan).

[11] The 'true' N and P reduction for Lake Rotorua is expected to be lower than this. A Hamurana diversion would increase the lake water residence time and decrease oxygenation of bottom waters, thereby increasing the influence of other nutrient sources on in-lake nutrient concentration. The actual impact of a Hamurana diversion on Lake Rotorua's water quality needs a full assessment.

[12] This load is expected to increase to 92 tonnes N/year in 50 years' time, and 118 tonnes at 'steady state' (> year 2200).

[13] Presuming mid-range capital cost = $25 million, maintenance costs $30,000 per year, 50 year lifespan.

[14] $6 per kg N is simply a budgeted average for expected costs over 10 years. The nutrient reductions from land use/land-use management changes will continue beyond 10 years, but total costs will be capped at $10 million.

Table 6 Lake Rotorua's nutrient inflows using land-use nutrient export coefficients

Land use	**Area (ha)**	**N loss coefficient(kg/ha/y)**	**N load (t/y)**	**% of total N**	**P loss coefficient (kg/ha/y)**	**P load (t/y)**	**% of total P**
Native forest and scrub	10,588	4	42.1	5.4	0.12	1.31	3.3
Exotic forest	9,463	3	28.4	3.6	0.10	0.95	2.4
Cropping and horticulture	282	60	16.9	2.2	2.00	0.56	1.4
Pasture [***p***]	20,112	See table below	563.0	71.9	0.84	16.93	42.5
Lifestyle	556	20	11.1	1.4	0.90	0.50	1.3
Urban [***u***]	3,267	See table below	50.1	6.4	1.17	3.82	9.6
Springs						13.00	32.7
Geothermal			42.2	5.4		1.40	3.5
Waterfowl[15]			*1.4*	*0.2*		*0.80*	*2.0*
Rain	8,079.0	3.6[16]	29.2	3.7	0.16	1.33	3.3
Total catchment inflows	**52,347**		**783.1**	**100**	**0.76**	**39.80**	**100**

Plus lake-bed sediment releases: About 360 tonnes N and 36 tonnes P can be recycled into the water column from the lake bed up to 10 times per year.

Pasture [*p*] land use includes:	**Area (ha)**	**N loss coefficient (kg/ha/y)**	**N load (t/y)**	**% of *n***	**P loss coefficient (kg/ha/y)**	**P load (t/y)**	**% of *p***
Beef	1,196	35	41.9	7.4	0.9	1.08	6.4
Sheep	28	16	0.5	0.1	1.0	0.03	0.2
Sheep and beef	10,240	18	184.3	32.7	0.9	9.22	54.4
Deer	418	15	6.3	1.1	0.9	0.38	2.2
Deer/sheep/beef	1,294	18	23.3	4.1	0.9	1.16	6.8
Dairy	5,883	50	294.1	52.2	0.7	4.12	24.3
Grassland	425	12	5.1	0.9	0.9	0.38	2.2
Other	628	12	7.5	1.3	0.9	0.57	3.4
Total	**20,112**	**28**	**563.0**	**100**	**0.8**	**16.93**	**100**

Urban [*u*] land use includes:	**N (t/y)**	**% of *u***	**P (t/y)**	**% of *u***
Sewerage	28.0	55.9	1.00	26.2
Septic tanks	12.0	23.9	0.53	13.9
Storm water	10.1	20.2	2.29	59.9
Total	**50.1**	**100**	**3.82**	**100**

Note: These figures are not time bound. They reflect steady-state loading rather than lower nutrient loads now that gradually increase to steady state over time.

Source: Lakes Rotorua and Rotoiti Action Plan Draft 2.5, March 2007, p. 49

[15] The nutrient inputs resulting from waterfowl grazing will vary considerably from year to year as numbers of birds in the Lakes Rotorua and Rotoiti catchments fluctuate. In terms of 'strict' nutrient budgeting, most of the nutrient inputs are termed 'recycling' when the waterfowl eat lake plants. The waterfowl figures are included in this table for comparison only and are not included in the total tonnages or percentages.

[16] Rounded to 1 decimal point. Actual coefficient = 3.6155.

Appendix 2

The following formal derivation of an optimal nutrient trading system with attenuation and groundwater lags draws heavily on Tietenberg (1985).

Nutrient input targets have been defined for the Lake Rotorua catchment. These targets, if not exceeded, will allow the water quality goals defined by Environment Bay of Plenty (EBOP) to be achieved because the lake residence time is only 1–2 years. Thus the nutrients can be considered to be 'assimilative' rather than 'accumulative'. Nutrients are considered to be uniformly mixed within the lake. However, the nutrients are not a standard mixed assimilative pollutant because we can monitor nutrient loss, or exports, from properties but want to control nutrient input to the lake each year.

The level of nutrients entering the lake, or inputs, from a particular property may be lower than the level of exports due to attenuation. Thus the level of nutrients reaching the lake depends on where in the catchment the nutrients are lost from, introducing a spatial component to the system.

Because of groundwater lags, in some areas of the catchment, it can take up to 200 years for the nutrients lost from a property to reach the lake. Thus the exports and inputs are unlikely to be equal in a given year. This time lag between nutrients leaving the property and reaching the lake introduces a temporal component to the system.

6.1 Cost-effective allocation

The environmental quality–nutrient loss relationship for an assimilative system with varying temporal lags can be written as follows:

$$A = a + \sum_{j=1}^{J} d_j (\bar{e}_j - r_j(x_{j,-s})) \qquad (1)$$

where A is the level of lake inputs, a is the nutrient input from unmanageable sources and sources not in the nutrient trading system, d_j is the attenuation associated with property j, J is the total number of properties in the nutrient trading system, and $\bar{e}_j$ is the nutrient loss from property j if there were no controls on nutrient loss. r_j is the reduction in nutrient export from property *j*. These reductions may result from changes in nutrient loss from the property up to 200 years before the inputs enter the lake—the lag depends on the groundwater lag associated with the property. There will be a lag, *s*, between the economic activity, which reduces nutrient loss (which when the costs are incurred) and the time when the lake inputs fall. (*S* is the maximum lag between the economic activity that reduces inputs and when the inputs reach the lake). The cost of this economic activity at time –*s* on property *j* is represented by $x_{j,-s}$.

Let $C_j(r_j(x_{j,-s}))$ be the continuous cost function, which represents the minimum cost to the property of achieving any level of nutrient loss reduction. Generally, as $r_j(x_{j,-s})$ increases, the marginal cost of achieving additional reductions will increase. Thus we can write the cost-effective allocation of reductions as follows:

$$\min_{r_j, x_s} \sum_{j=1}^{J} \sum_{s=0}^{S} \frac{C_j(r_j(x_{j,-s}))}{(1+\rho)^{-s}} \qquad (2)$$

subject to $\quad \bar{A} \geq a + \sum_{j=1}^{J} d_j(\bar{e}_j - r_j(x_{j,-s}))$

$$r_j(x_{j,-s}) \geq 0$$

where ρ is the discounted rate. Solving this maximisation problem through the Kuhn-Tucker conditions gives us the following:

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} - \lambda\, d_j \geq 0 \qquad j = 1,\ldots,J \qquad (3)$$

$$s = 1,\ldots,S$$

$$r_j \left[\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} - \lambda\, d_j \right] = 0 \qquad j = 1,\ldots,J \qquad (4)$$

$$s = 1,\ldots,S$$

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial x_{j,-s}} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{\partial r_j(x_{j,-s})}{\partial x_{j,-s}} \cdot \lambda\, d_j \geq 0 \quad j = 1,...,J \tag{5}$$

$$s = 1,...,S$$

$$x_s\left[\frac{\partial C_j(r_j(x_{j,-s}))}{\partial x_{j,-s}} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{\partial r_j(x_{j,-s})}{\partial x_{j,-s}} \cdot \lambda\, d_j\right] = 0 \quad j = 1,...,J \tag{6}$$

$$s = 1,...,S$$

$$\overline{A} - a - \sum_{j=1}^{J} d_j(\overline{e}_j - r_j(x_{j,-s})) \geq 0 \qquad j = 1,...,J \tag{7}$$

$$s = 1,...,S$$

$$\lambda\left[\overline{A} - a - \sum_{j=1}^{J} d_j(\overline{e}_j - r_j(x_{j,-s}))\right] = 0 \qquad j = 1,...,J \tag{8}$$

$$s = 1,...,S$$

$$r_j(x_{j,-s}) \geq 0; \lambda \geq 0 \qquad j = 1,...,J \tag{9}$$

When some control is being exercised, $r_j(x_{j,-s})$ is expected to be positive, implying that nutrient input reductions are made. The cost of achieving these reductions in exports will be equated across sources, with an adjustment made for the level of attenuation between properties. This can be seen below.

From equation (3), for property *j*, the cost of reducing nutrients is equated over time, adjusted by a discounted rate.

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} = \lambda\, d_j \tag{10}$$

For another property, *k*, the same equation can be developed.

$$\frac{\partial C_k(r_k(x_{k,-s}))}{\partial r_k} \cdot \frac{1}{(1+\rho)^{-s}} = \lambda\, d_k \tag{11}$$

By combining equations (10) and (11), we can see that the marginal cost of reducing exports is equated across sources, with an adjustment for the level of attenuation. Thus the marginal cost of achieving reductions in lake inputs is equated across sources in a cost-effective allocation.

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j}\cdot\frac{1}{d_j}=\lambda\ =\frac{\partial C_k(r_k(x_{k,-s}))}{\partial r_k}\cdot\frac{1}{d_k}\qquad k\neq j \qquad (12)$$

The cost of reducing nutrient exports is likely to be positive. Thus we expect equation (5) to be binding when some control is being exercised. Thus in a cost-effective allocation, the following from equation (5) will hold:

$$\lambda\ d_j=\frac{\dfrac{\partial C_j(r_j(x_{j,-s}))}{\partial x_{j,-s}}\cdot\dfrac{1}{(1+\rho)^{-s}}}{\dfrac{\partial r_j(x_{j,-s})}{\partial x_{j,-s}}}=\frac{\dfrac{\partial C_j(r_j(x_{j,-s-1}))}{\partial x_{j,-s-1}}\cdot\dfrac{1}{(1+\rho)^{-s-1}}}{\dfrac{\partial r_j(x_{j,-s-1})}{\partial x_{j,-s-1}}} \qquad (13)$$

Thus the marginal costs of the economic activities undertaken to reduce nutrient exports on property *j* rise over time at rate ρ. The discounted costs of these activities are equated across all *s*.

We expect that λ will be positive for Lake Rotorua catchment because the current nutrient export and input levels are greater than the maximum level that would allow water quality goals to be achieved. Thus we expect equation (7) to always be binding so that the level of nutrients entering the lake equals $\overline{A}$.

6.2 Nutrient trading system

To implement a nutrient trading system in this catchment, allowances need to be created such that the permissible level of nutrient loss from the allowances, *N*, equals the trading cap, $\overline{A}-a$. Allowances are created for ‘vintage’ markets. Each source must hold allowances for the vintage market corresponding to the year that their exports impact on the lake.

Once allowances are issued, they will command a positive price if introduction of the system corresponds to a reduction in nutrient loss. Each property should attempt to acquire the number of allowances that will minimise their total cost. Suppose that each source has an initial allowance endowment, n_j, which allows q_j^0 tonnes of nutrient loss, and that the allowances across all sources, $N = \sum_{j=1}^{J} n_j$, allow $\overline{A}$ tonnes of nutrient loss. Faced with this control, each property is faced with the problem below:

$$\min_{r_j, x_s} \sum_{s=0}^{S} \frac{C_j(r_j(x_{j,-s})) + P_s(d_j(\overline{e}_j - r_j(x_{j,-s})) - q_j^0)}{(1+\rho)^{-s}} \tag{14}$$

where P_s is the forward price of acquiring an additional allowance or the price received for selling an allowance. So the price for an allowance expressed in the year of the vintage, P, can be written as $P = \frac{P_s}{(1+\rho)^{-s}}$ or, alternatively, as $\frac{P}{(1+\rho)^{s}} = P_s$. Solving this optimisation gives the following:

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{P_s d_j}{(1+\rho)^{-s}} \geq 0 \qquad j = 1, \ldots, J \qquad s = 1, \ldots, S \tag{15}$$

$$r_j \left[\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{P_s d_j}{(1+\rho)^{-s}} \right] = 0 \qquad j = 1, \ldots, J \qquad s = 1, \ldots, S \tag{16}$$

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial x_{j,-s}} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{\partial r_j(x_{j,-s})}{\partial x_{j,-s}} \cdot \frac{P_s d_j}{(1+\rho)^{-s}} \geq 0 \qquad j = 1, \ldots, J \qquad s = 1, \ldots, S \tag{17}$$

$$x_s \left[\frac{\partial C_j(r_j(x_{j,-s}))}{\partial x_{j,-s}} \cdot \frac{1}{(1+\rho)^{-s}} - \frac{\partial r_j(x_{j,-s})}{\partial x_{j,-s}} \cdot \frac{P_s d_j}{(1+\rho)^{-s}} \right] = 0 \qquad j = 1, \ldots, J \tag{18}$$

$$s = 1,\ldots,S$$

$$r_j \geq 0 \qquad j = 1,\ldots,J \qquad (19)$$

Combining equations (3) and (15), when there is control on the exports, yields the following:

$$\frac{\partial C_j(r_j(x_{j,-s}))}{\partial r_j} \cdot \frac{1}{(1+\rho)^{-s}} = \lambda\, d_j = \frac{P_s d_j}{(1+\rho)^{-s}} \qquad j = 1,\ldots,J \qquad (20)$$

$$s = 1,\ldots,S$$

Equation (20) can be reduced to $\lambda = \frac{P_s}{(1+\rho)^{-s}} = P$. Thus the allocation will be cost effective when the discounted price of an allowance equals the value to the catchment of allowing an additional unit of nutrients to enter the lake at time –*s*.

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