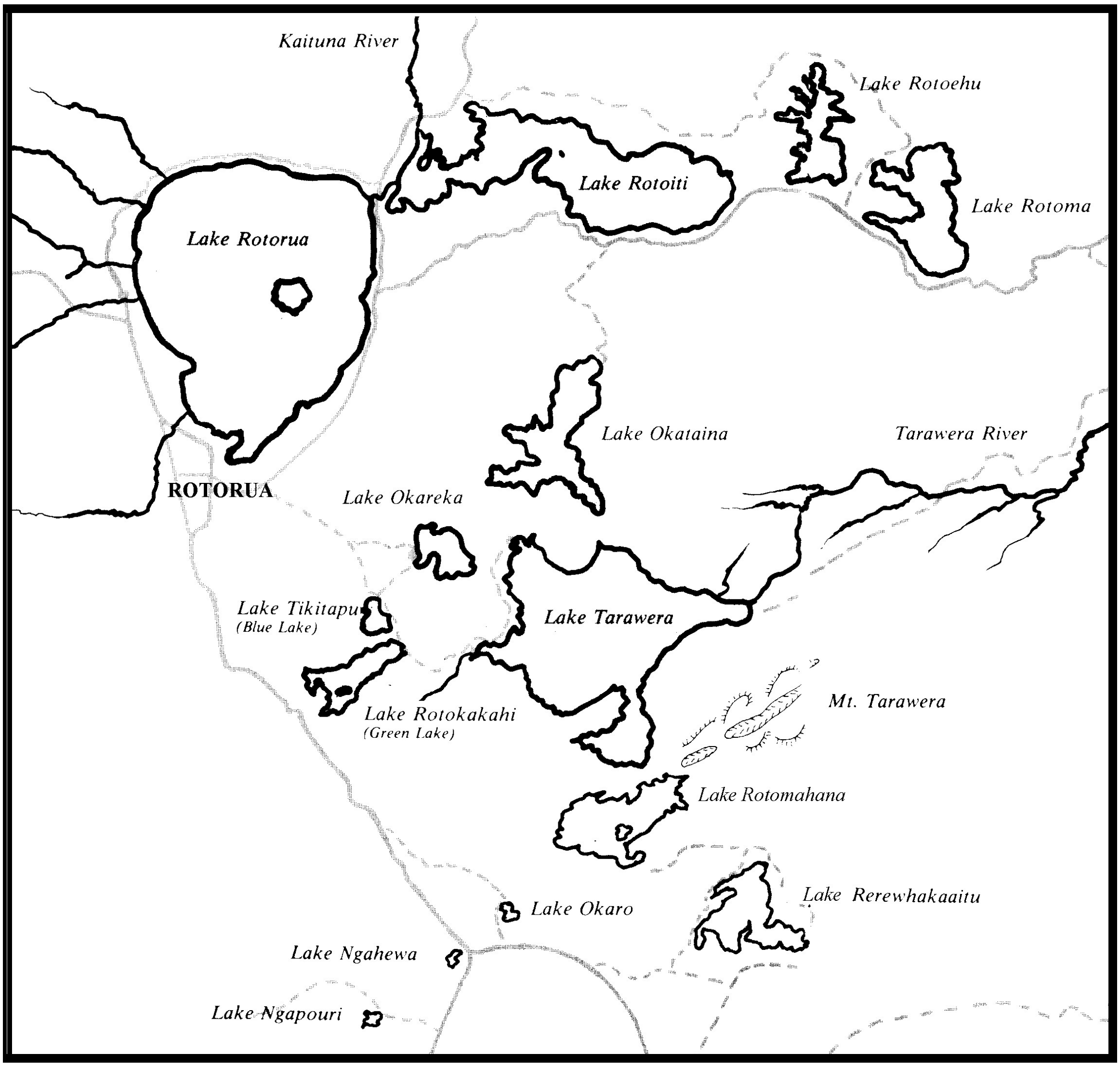
Proceedings

ROTORUA LAKES 2003
Practical Management for Good Lake Water Quality



Proceedings

ROTORUA LAKES 2003
Practical Management for Good Lake Water Quality

9 -10 October 2003
Centra Hotel, Rotorua

Jointly hosted by

LakesWater Quality Society Inc.
and
The Royal Society of New Zealand
(Rotorua Branch)

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Editors' Note

Material for the Symposium Proceedings has been received in a variety of formats, from formal, referenced papers to computer 'PowerPoint' presentations. Some presentations were fully or partly transcribed from audio tapes. The editors have endeavoured to leave the material included in these Proceedings largely as it was received by us. We have corrected obvious spelling and grammatical errors, and imposed a standard formatting on Paper titles, authors' names and their affiliations, and general layout, but have not attempted to impose an overall uniform format, preferring to leave this to the authors' discretion. Illustrations from PowerPoint presentations etc. have been incorporated at the editors' discretion, with an eye on file and document size. Colour printing has been used, to a limited degree, where it significantly enhances the effect or comprehension of an illustration. Where there are multiple authors, presenting authors' names are shown in bold at the beginning of papers.

Audience questions and presenter's answers have been included where available, but owing to gaps in the transcript caused by tape changeovers, a very few questions and answers are not available for publication. Where material from the tape transcripts of papers appears particularly relevant or explanatory and does not appear in the written Paper as supplied, it is inserted and italicised. The editors take full responsibility for this.

A full transcript of the Forum sessions has been supplied, with minimal editing and that only in the interests of clarity and readability.

Poster presentations have been included in full where supplied in useable format, otherwise the abstract has been published.

Non-scientific readers are reminded that a scientific glossary, useful in understanding these Proceedings, was published in the Symposium Handbook.

Nick and Elizabeth Miller

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Foreword - Rotorua Lakes 2003

Ian McLean
Chairman, LakesWater Quality Society

The Symposium ***Rotorua Lakes 2003*** was the third annual event of its kind led by the LakesWater Quality Society. Its focus was described in its sub-title: ***Practical Management for Good Lake Water Quality.***

In previous years ***Rotorua Lakes 2001*** dealt with research needs, and ***Rotorua Lakes 2002*** covered lakeside communities and sewerage. All were prompted by public concern over the decline in water quality in these beautiful lakes.

The background to the ***Rotorua Lakes 2003*** was a concern about cyanobacterial blooms blighting more waters and for a longer period than ever before. Research showed that several lakes are losing oxygen from the bottom up, and the threat to Lake Rotoiti of anoxia is severe. Environment BOP had a Regional Water and Land Plan close to determination, the Rotorua District Council was putting in more sewerage treatment, and both were cooperating in the preparation of Action Plans designed to improve the water quality in lakes.

The purpose of the Symposium was to present up-to-date science on practical management action that can be taken to save and help restore the lakes. Like its predecessors it was unusual in that while it was a scientific event, it sought to share knowledge with scientists, land managers, local residents and public authority members and managers.

These proceedings record the presentations made at the Symposium, both oral and poster.

The Royal Society of NZ (Rotorua Branch) again joined in holding this Symposium. It was funded by the Environment Bay of Plenty Environmental Enhancement Fund, with support as well from Environment Waikato.

On behalf of the LakesWater Quality Society and the lakes themselves, I extend grateful thanks to all those who have prepared papers, to RDC and to the voluntary committee who carried out the major task of organizing the Symposium.

Workshops and Symposia such as ***Rotorua Lakes 2003*** have a most useful purpose on presenting and discussing technical information. But the ultimate test of their value is action that improves the water quality in the lakes. The 2001 Symposium led to a surge in new research on the lakes, and the 2002 Symposium brought support for sewerage at Mourea/Okawa Bay and Okareka.

The value of ***Rotorua Lakes 2003*** will be measured by the practical action that it triggers. The LakesWater Quality Society is following it up by encouraging work to be done in the lakes and in their catchments.

The Symposium steering committee:

Brentleigh Bond	*LWQS*	Greg Manzano	*Rotorua District Council*
Rowland Burdon	*RSNZ (Rotorua Branch),*	Ian McLean	*LWQS*
Paul Dell	*Environment BOP*	Elizabeth Miller	*LWQS*
Professor David Hamilton	*University of Waikato*	Nick Miller	*LWQS*
John McIntosh	*Environment BOP*	Anaru Rangiheuea	*Te Arawa*
Kim Macrae-Jonson	*Environment Waikato*	Chris Sutton	*Federated Farmers*

ORAL PRESENTATIONS (in order of presentation)

An Historical and Contemporary Review of Water Quality in the Rotorua Lakes

David P. Hamilton
Department of Biological Sciences, University of Waikato
Email: d.hamilton@waikato.ac.nz

ABSTRACT

The Rotorua lakes may be separated into four main categories based on mixing regimes and seasonal depletion of oxygen in the hypolimnion:

(1) Eutrophic monomictic lakes where the hypolimnion becomes anoxic and blue-green algae (cyanobacteria) dominate the summer phytoplankton assemblage (e.g. Lakes Okaro and Rotoiti). These lakes are characterised by a positive feedback loop; high rates of phytoplankton sedimentation increase oxygen depletion in the hypolimnion, which leads to significant internal loading (sediment release) of nutrients that further enhances phytoplankton production and sedimentation. The dominance of phosphorus over nitrogen in nutrients sourced from the bottom sediments leads to a competitive advantage for cyanobacteria, both nitrogen (N)-fixing and non N-fixing species.

(2) Mesotrophic monomictic lakes where the bottom of the hypolimnion may become anoxic briefly at the end of the stratified period (e.g. Lakes Okareka, Tikitapu, Rotokakahi and Okataina). These lakes can be categorised as 'at risk' because the positive feedback loop that characterises eutrophication of Lakes Okaro and Rotoiti is not yet fully developed, though decadal trends in bottom-water oxygen levels suggest that it may become prevalent.

(3) Oligotrophic monomictic lakes that are characterised by a hypolimnion that is not severely deoxygenated, and low concentrations of chlorophyll *a* (e.g. Lakes Tarawera, Rotoma and Rotomahana). Water quality in these large lakes appears to be relatively stable.

(4) Meso- and eutrophic polymictic lakes (e.g. Lakes Rotorua, Rotoehu and Rerewhakaaitu). Trophic status in these lakes tends to be higher naturally, due to high ratios of catchment area to lake volume compared with the deep monomictic lakes. Rapid changes in water quality associated with temporary stratification events in these lakes mean that conventional sampling regimes may provide limited evidence for trends in water quality without knowledge of the duration of stratification and deoxygenation cycles.

Lakes in category 1 may require costly intervention strategies to improve water quality, whereas sound land management practices may be appropriate for categories 2 and 3. Lakes in category 4 may require more innovative management regimes centred round managing nutrient loads from the catchment, but perhaps also involving intervention strategies.

INTRODUCTION

Lake eutrophication may occur naturally over long time scales as lakes fill with sediment and become more productive (Hutchinson, 1973), but it is most commonly associated with impacts of human activities at shorter time scales. It can increase biomass at several levels of the food chain, but is more often associated with generation of algal blooms, deoxygenation of bottom waters and, in severe cases, fish kills and deoxygenation of the entire water column.

The sources of nutrients that contribute to eutrophication arise from lake catchments, as point and diffuse sources, and as internal loads from bottom sediments. Changes in phosphorus loads are generally most important as phosphorus is the nutrient that has most commonly been found to limit primary production in freshwater systems. White *et al.* (1985) found, however, that lakes in the central volcanic plateau of the North Island may sometimes be limited by nitrogen.

Amongst the Rotorua lakes, the major point source of nutrients has been associated with direct inputs of sewage to Lake Rotorua, which resulted in a substantial nutrient load to the lake, especially in the late 1980s prior to diversion of sewage inflows to land-based treatment (Rutherford *et al*., 1986). There is evidence to suggest that time scales for recovery of water quality following diversion of sewage effluent may be on the order of 20 years for the water column, and 200 years for the bottom sediments (Rutherford *et a*l., 1986).

Of the non-point sources, nutrients arising from agriculture have contributed most to human-induced nutrient loads to lakes in New Zealand (Ministry for the Environment, 1997), though contributions from septic tanks and stormwater are significant. Removal of the natural vegetation cover and destruction of the mechanisms that conserve nutrients in natural ecosystems, together with fertiliser applications, can greatly increase export of nutrients associated with agricultural development (Moss, 1998). The relationships between agricultural development in catchments and eutrophication of lakes have been demonstrated locally (McColl, 1972; Malthus and Mitchell, 1988) and globally (Foy and Withers, 1995). In New Zealand, Mitchell (1988) found that of 17 lakes with >40% catchment area developed for agriculture, 14 were eutrophic. He noted that eutrophication problems associated with agriculture are exacerbated when mean lake water depth is less than 30m. A major challenge is now to find ways to minimise nutrient and sediment losses from agricultural catchments while land intensification and nitrogenous fertiliser use increase.

The effect of increased nutrient supply to the surface waters of lakes is stimulation of production of organic matter associated with increased algal growth. Sedimentation and decay of this material increases the demand for oxygen in bottom waters. This process is most critical when there is temperature stratification of the water column. Stratification commences in spring in deep New Zealand lakes, when cool dense water at the bottom of the lake becomes isolated from warm, buoyant water at the surface. This cuts off bottom waters from major sources of oxygen, namely surface aeration and photosynthesis, and concentrations of dissolved oxygen decline progressively prior to winter mixing. Oxygen concentrations in the bottom waters of stratified lakes provide a highly reliable and easy method of integrating variations in time and space, to allow determination of trends in organic matter loading associated with variations in nutrient supply. Other indices of

eutrophication, such as phytoplankton biomass and nutrient concentration, may be complicated by determinations that are often close to analytical detection limits, relative complexity and cost of analysis that can impose constraints on measurement frequency, and difficulties in interpretation associated with limitation by different nutrient species or succession of phytoplankton populations.

Oxygen depletion initiates a series of reduction reactions that result in dissolution of metal cations from sediments and release of sediment-bound phosphorus (Golterman, 1977). Levels of ammonium also increase when loss of oxygen prevents ammonium oxidation to nitrate. Lewis (2000) reviewed these processes in tropical lakes, where the duration and extent of deoxygenation events in bottom waters generally exceeds that of temperate lakes. He suggested that sediment regeneration of nutrients brought about low ratios of nitrogen to phosphorus in the water column. A reduction in this ratio may favour the development of blue-green algae (cyanobacteria), which are better able to compete for N than other phytoplankton when N is scarce (Havens *et al*., 2003). Furthermore, N-fixing species of cyanobacteria may overcome periods of nitrogen limitation by utilising nitrogen dissolved in the water column, effectively providing access to a limitless source of nitrogen.

The objective of this paper is to document changes in water quality of the Rotorua lakes using dissolved oxygen concentrations, which provide the most continuous and reliable indicator of changes in water quality of Rotorua lakes over the past 4 decades. Nutrient release from bottom sediments of one of these lakes is estimated from the relationship between concentrations of dissolved oxygen and phosphorus in bottom waters. Considerations are also given to remediation strategies necessitated by the ongoing changes in water quality of the Rotorua lakes.

METHODS

The Rotorua lakes were formed and modified through a series of volcanic eruptions up to 140,000 years B.P., which have produced explosion craters, or damming of rivers or drainage basins by lava flows (Lowe and Green, 1986). These eruptions have resulted in a wide range of lake sizes and catchment areas in the Rotorua area (Figure 1).

The twelve Rotorua lakes listed in Table 1 are sampled routinely as part of the State of the Environment monitoring programme conducted by Environment Bay of Plenty (2000). Data from this programme have been supplemented in this paper with past limnological investigations of several Rotorua lakes by Jolly (1968) and McColl (1972), Lakes Rotorua and Rotoiti by Fish (1975) and Lake Rotoiti by Vincent *et a*l. (1984). These studies used standard techniques to carry out profiles of temperature and dissolved oxygen, as well as taking discrete measurements of nutrients at selected depths. In most cases a central station was used, though several stations have been used over the years for large lakes such as Rotorua and Rotoiti.

Figure 1. Major lakes of the Rotorua region showing twelve lakes sampled routinely.

Table 1. Maximum lake depth, lake volume, catchment area, ratio of catchment area to volume, and trophic state of lakes of the Rotorua region. Trophic state indices are O = oligotrophic, M = mesotrophic and E = eutrophic.

	Lake depth (m)	Lake volume (km^3)	Catchment area (km^2)	Ratio (km^{-1})	Trophic state
Tarawera	87.5	2.274	150.0	66	O
Rotoma	83.0	0.429	33.9	79	O
Rotomahana	125	0.479	89	185	O
Okataina	78.5	0.466	63.6	136	O
Tikitapu	27.5	0.026	6.0	227	M
Rotokakahi	32.0	0.077	17.5	227	M
Okareka	33.5	0.064	17.5	275	M
Rotoehu	13.5	0.061	42.3	693	M
Rerewhakaaitu	15.8	0.037	40.6	1107	M
Rotoiti	124.0	1.042	578	555	E
Rotorua	44.8	0.802	482	601	E
Okaro	18.0	0.003	3.6	1084	E

RESULTS

The Rotorua lakes have been divided into four categories according to their mixing regimes and extent of depletion of dissolved oxygen in bottom waters. One category includes lakes that undergo seasonal stratification of temperature, with a small volume of bottom water that becomes anoxic prior to winter mixing. Lake Okareka represents an

example of lakes that fall into this category, where separation of surface and bottom water temperature occurs for about 8 months of the year (Fig. 2A) and there is progressive depletion of oxygen in the bottom waters until winter mixing (Fig. 2B). Other lakes that fall into this category include Tikitapu, Rotokakahi and Okataina. Each of these lakes shows a trend, exemplified by Lake Tikitapu (Fig. 3), of reduced levels of oxygen in the bottom waters compared with previous years.

Another category of lakes has remained relatively stable through time, with respect to the duration and extent of seasonal decline in oxygen. Lakes Tarawera, Rotoma and Rotomahana are large lakes that also stratify seasonally, but where oxygen levels in bottom waters rarely decline below 50% of saturation. Lake Rotoma shows a peak in dissolved oxygen at about 25m depth in the middle of summer (Fig. 4), most likely due to a deep chlorophyll maximum (see Ryan *et al*., this volume).

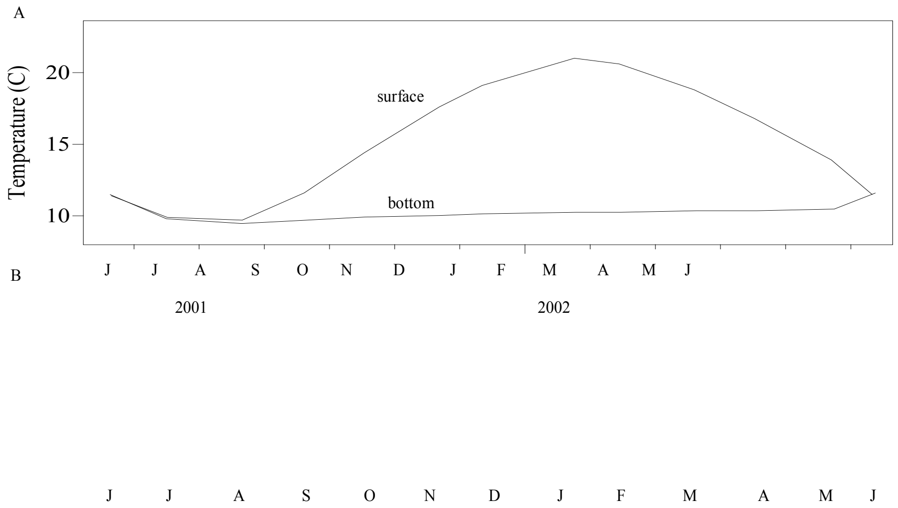

Figure 2. A) Surface and bottom temperature and B) water column concentrations of dissolved oxygen in Lake Okareka, 2001-2.

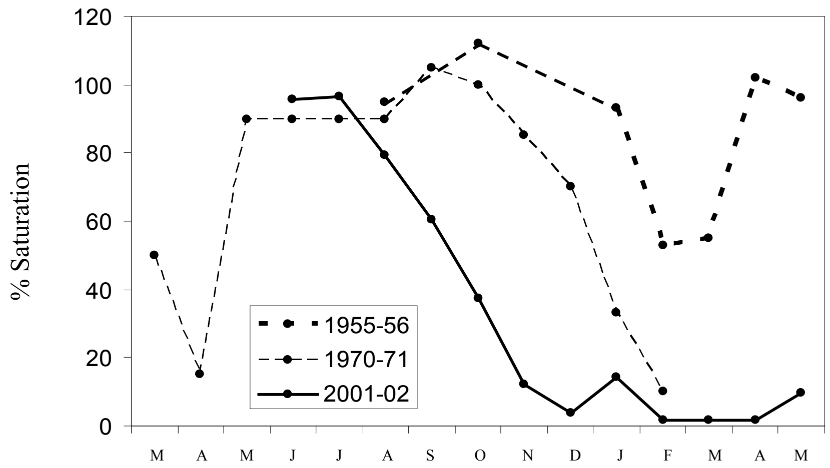

Figure 3. Percent saturation of dissolved oxygen in Lake Tikitapu as a function of time of year, for three different periods: 1955-56 (Jolly, 1968), 1970-71 (McColl, 1972) and 2001-2 (Environment Bay of Plenty data).

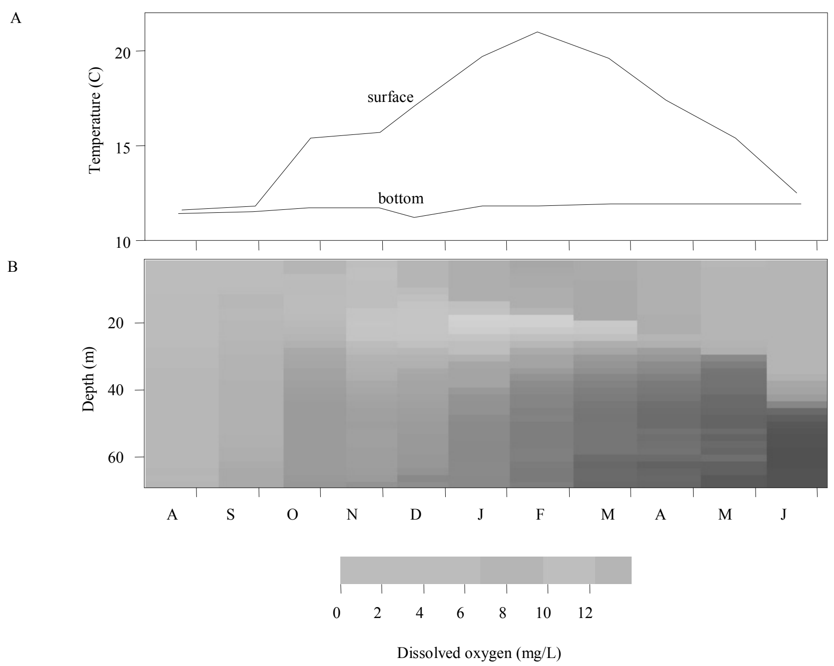

Figure 4. A) Surface and bottom temperature and B) water column concentrations of dissolved oxygen in Lake Rotoma, 2001-2.

The third category of lakes is also strongly stratified but undergoes strong seasonal declines in oxygen to the extent that the entire hypolimnion is anoxic relatively early in the stratified period. This category includes Lake Okaro (Fig. 5) and Lake Rotoiti, both of which are eutrophic. In Lake Okaro, there was a rapid decline in oxygen levels in the hypolimnion between the first (years 1955-56) limnological study by Jolly (1968) and a subsequent study (years 1961-63) by Fish (1970). Fish (1970) found that oxygen remained in the hypolimnion for the entire stratified period in 1961-62, but had disappeared by 1962-63 and 1963-64. Similarly, but over a longer time scale, Lake Rotoiti has become severely anoxic in its bottom waters (Fig. 6). A corollary to the Lake Rotoiti case is provided by Gibbs *et al*. (this volume) in which they showed no clear trend in the duration and extent of anoxia in Lake Rotoiti since the 1980s.

The fourth category of lakes is shallower and does not stratify seasonally, but intermittently, on time scales of a few hours to several days. Lakes Rotorua, Rotoehu and Rerewhakaaitu are mesotrophic or eutrophic. These lakes are characterised by large catchment land areas to lake volumes (Table 1), a high proportion of agricultural development within the catchment (Environment Bay of Plenty, 2000) and, in the case of Lake Rotorua, a prior history of direct inputs of wastewater to the lake. The duration of intermittent stratification events is sufficiently long in Lake Rotorua to effect deoxygenation of bottom waters (Rutherford *et al.*, 1996). Furthermore, these deoxygenation events contribute significant inputs of ammonium and phosphate to the water column, that in years of prolonged stratification (i.e. weeks) may produce internal nutrient loads comparable to those arising as point and diffuse sources from the lake catchment (Burger *et al*., this volume).

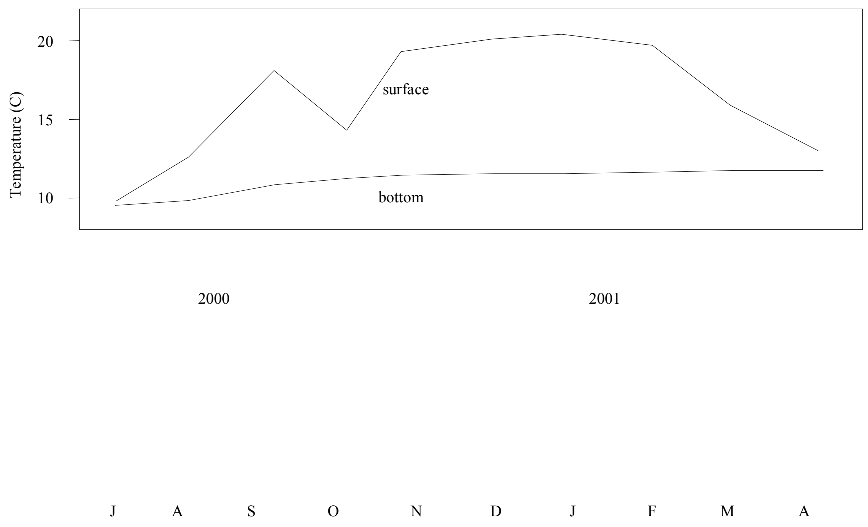

Figure 5. A) Surface and bottom temperature and B) water column concentrations of dissolved oxygen in Lake Okaro, 2000-1.

The effect on total phosphorus concentrations of the seasonal decline in dissolved oxygen in Lake Rotoiti is demonstrated (Fig. 7) for 3 years (1991-94) when there are good time series data. Concentrations of total phosphorus at 40-m depth increase to c. 80 mg m^{-3} just prior to winter mixing. Similar data for nitrogen demonstrate a rapid increase in ammonium concentrations at the onset of stratification. This is followed by a nitrification phase when ammonium is oxidised to nitrate while oxygen is still present in the hypolimnion. Denitrification then occurs as nitrate is reduced to nitrogen gas with the disappearance of oxygen from the hypolimnion, and finally there is reappearance of ammonium in the bottom waters as it is regenerated from organic matter decomposition, but without oxygen to transform it to nitrate. In Lake Rotoiti, the net effect of anoxia-induced release of nutrients is a preferential release of phosphorus over nitrogen due in large part to loss of nitrogen via denitrification. Mass ratios of total nitrogen to total phosphorus (TN:TP) decline to very low levels; well below 5, in the bottom waters of Lake Rotoiti near the end of the stratified season. Similarly, ratios of TN:TP typically decline to c.3:1 in the bottom waters of Lake Okaro just prior to turnover.

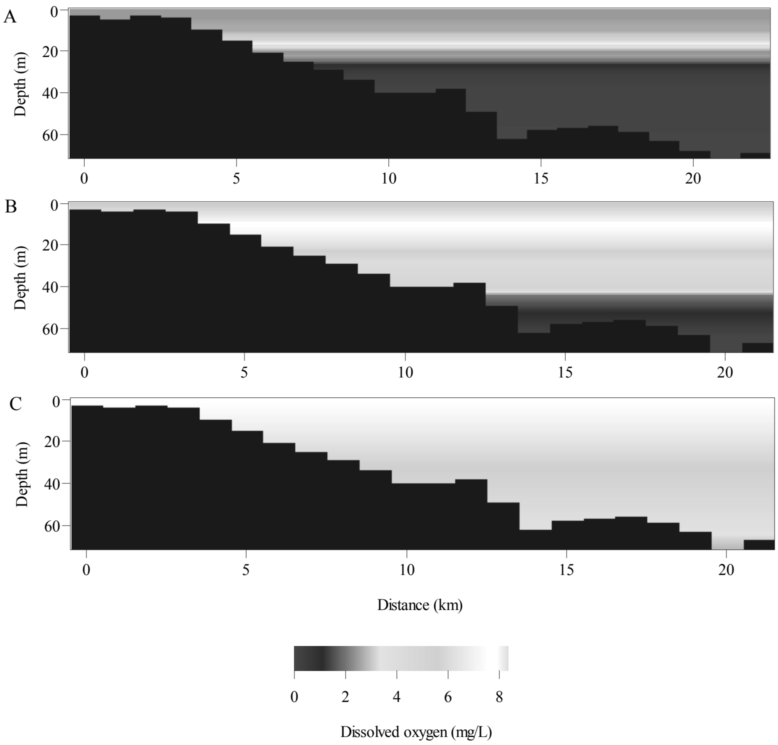

Figure 6. A west to east profile of Lake Rotoiti from Okawa Bay (left) to mid-lake (right), showing the bottom of the lake (black), and the water column as grey-scale shading to represent concentrations of dissolved oxygen in March for A) 2002 (Environment Bay of Plenty monitoring data), B) 1968 (Fish, 1975) and C) 1956 (Jolly, 1968).

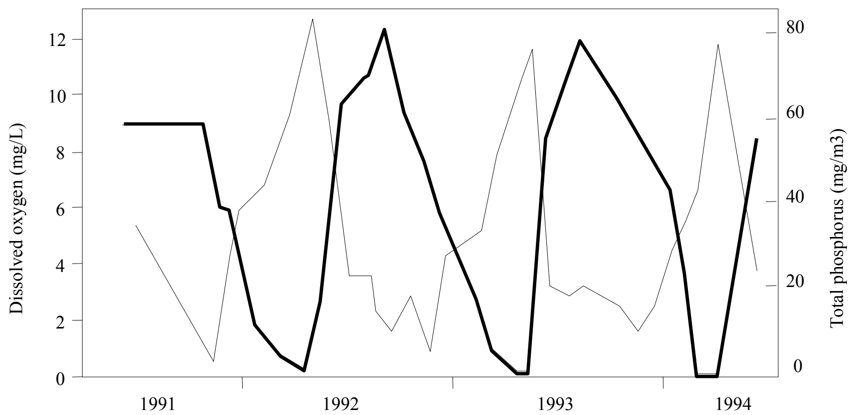

Figure 7. Concentrations of dissolved oxygen (coarse line) and total phosphorus (fine line) at 40-m depth in Lake Rotoiti for 1991-94.

DISCUSSION

Separation of the Rotorua lakes into four categories appears to appropriately recognise both differences in physical features of the lakes and different requirements for nutrient management. Lakes Okataina, Tikitapu and Okareka are lakes that can be considered 'at risk', as further increases in the extent and duration of anoxia in bottom waters could trigger significant internal loading of nutrients that may fuel a self-perpetuating cycle - a 'nutrient treadmill' (Fig. 8).

Lakes in this category have few cyanobacterial blooms but their relatively small size (Table 1) and the current trend of progressive oxygen depletion may make them particularly susceptible to eutrophication. Nutrient inputs from these lake catchments will need to be carefully managed and controlled, though it is surprising that Lake Okataina, a lake with nearly 90% of its catchment in native or exotic forest, should fall into this category.

The large oligotrophic lakes (Tarawera, Rotoma and Rotomahana) will respond only slowly to changes in catchment land use. These lakes are largely unaffected by internal loads of nutrients, so sound land management principles that limit erosion, maintain deep-rooted vegetation, and balance fertiliser applications with plant requirements on land, will ensure continuity of current high water quality. These lakes will have cyanobacterial blooms occasionally, however, because their large size may bring about high lake-wide biomass of cyanobacteria in warmer months. The combination of large lake-wide mass of buoyant cyanobacterial cells and calm conditions may allow surface blooms to form (e.g. Robson and Hamilton, 2003), or light winds may drive surface blooms into bays, concentrating biomass of cyanobacteria several-fold under these circumstances.

The eutrophic lakes (Okaro and Rotoiti) have experienced major blooms of cyanobacteria (e.g. Walsby *et al.*, 1987; Vincent *et al.*, 1984). Ratios of nitrogen to phosphorus decline with increased internal loading in these lakes and this may be important in the growth of cyanobacteria, in a similar manner to the cycle proposed for tropical lakes where there is

anoxia of bottom waters (Lewis, 2000). Smith (1983) used TN:TP mass ratios of 29:1 for differentiation of lakes with cyanobacteria dominance (TN:TP < 29:1) and without (TN:TP > 29:1) though Smith *et al*. (1995) subsequently proposed a ratio of 22:1, a value that is not commonly exceeded through the water column in either Lake Okaro or Lake Rotoiti. These lakes already have a well-established nutrient treadmill fuelled by internal loading (Fig. 8B) that has resulted from many years of catchment nutrient loads that exceed the assimilative capacity for aerobic breakdown of organic matter in bottom waters and the lakebed. The likelihood of nitrogen limitation in these two lakes may confer a competitive advantage to nitrogen-fixing cyanobacteria that are potentially bloom-forming and toxic under the nutrient-enriched conditions in the lakes. While controls on catchment nutrient inputs are necessary to ultimately improve water quality in these lakes, they will have long response times because of the delay caused by internal nutrient loads arising from the sediment nutrient store. Only more drastic intervention measures will bring about substantial improvement in water quality on shorter time scales than those over which the deterioration originally occurred.

Figure 8. Conceptual relationship between algal growth and nutrient inputs to stratified Rotorua lakes. Increased shading with depth is used to represent declining levels of dissolved oxygen. A) The case where catchment loads dominate the lake nutrient budget. B) The case where internal loading contributes substantially to the lake nutrient budget, with increasing dominance of N-fixing cyanobacteria.

The types of management actions that may be necessary for Lakes Okaro and Rotoiti, and which have been utilised elsewhere, include:

- Destratification to break down the seasonal temperature stratification, providing continuity between bottom waters and oxygen inputs from surface aeration and photosynthesis. Destratification has been accomplished by a variety of methods, including compressed air bubble plumes, water pumps and underwater propellers (Schladow and Fisher, 1995). It has had mixed success as partial destratification has the potential to increase nutrient concentrations in surface waters. In large lakes there is a major energy requirement to overcome seasonal stratification as efficiencies of water entrainment in bubble plumes - the common method of destratification - are low.
- Oxygenation using complete dissolution of pure oxygen in bottom waters to offset the oxygen demand from bacterial breakdown of organic matter, without disrupting the natural stratification cycle. Oxygenation has also had mixed success (Gächter and Wehrli, 1998) and from a mechanical viewpoint, complete dissolution of oxygen in water has proven problematic in some cases.
- Various chemical treatments to adsorb and sediment out phosphorus and bind it irreversibly in the bottom sediments. Compounds such as aluminium sulphate (alum), calcium nitrate and modified clays have been used, as the metal cations in these compounds tend to be less redox-sensitive than iron and manganese flocculants (Cooke *et al*., 1993).

There are major costs associated with any one of the three treatments listed above. Oxygenation and destratification have high power and maintenance costs and moderate success rates, while one-off chemical treatments may have limited duration of effectiveness. It is essential that all possible actions are taken to manage catchment nutrient inputs before lakes progress to a state where only costly and ongoing lake and catchment remediation programmes will improve water quality.

QUESTIONS

Phil Shoemack, Medical Officer of Health with the District Health Board: David, what if any impact does the geothermal activity have in the area?

D.H.: I certainly don't know enough about the relative contributions of geothermal versus other inputs coming into the lakes. I think that we really need to focus on all sources of nutrients, particularly to the at-risk lakes. Most of those at-risk lakes don't have particularly large geothermal inflows that might be a major consideration.

Ian Kusabs, Fisheries consultant: Have you any comments on Lake Taupo?

D.H.: All the indications are that Taupo is certainly nitrogen-limited and you would imagine will remain so, provided there's not a major change in levels of oxygen in the bottom waters of the lake. Obviously the focus should be on maintaining the current condition, essentially, and preventing any changes that might bring about that decline in oxygen. If the decline in oxygen was severe, and we wouldn't anticipate that, obviously, for timescales in the order of decades, then phosphorus also has to be a major consideration.

Tawiri Hakopa: What effect does phosphorus have on the blue-green algae? My

understanding is that the blue-green algae fix their own nitrogen, but unlike clover they utilise the nitrogen for themselves. Where does the phosphorus come into it?

D.H.: Both phosphorus and nitrogen are potentially limiting nutrients and been found in many aquatic systems to be the nutrients that most commonly limit the rate of growth, so in many cases if you reduce the nitrogen to phosphorus ratio, then species that are able to overcome that imbalance by fixing nitrogen from the atmosphere will be at an advantage. That's exactly the case in the Rotoiti/Okaro type situation.

T.H.: Yes that's understandable, but in the absence of phosphorus, because of the ability of blue-green algae to fix its own nitrogen, does it still grow?

D.H.: Not in the absence of phosphorus, that's for sure, so as the levels of phosphorus decline, you see quite a marked decrease in phytoplankton in general and often in blue-greens more specifically. Blue-greens have quite an affinity for phosphorus in many cases and in some cases are able to actually luxury-uptake phosphorus. Therefore, as you increase the trophic status or increase the amount of nutrients in the environment in the water systems, you are effectively bringing about a greater potential for nitrogen-fixation and dominance by blue-greens.

T.H.: So what you are saying is that phosphorus has to be a part and parcel of the existence of blue-green algae.

D.H.: Yes, very much so.

ACKNOWLEDGEMENTS

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A Tangata Whenua perspective on the best path to an innovative and desirable solution

Towards decision-making balance with regard to our social, economic, environmental and cultural well-being

Te Kipa Kepa Brian Morgan BE(Civil) MBA MIPENZ
Ngati Pikiao, Te Arawa, Ngati Kahungunu, Kai Tahu
Senior LecturerCivil & Environmental Engineering
Faculty of Engineering, University of Auckland

INTRODUCTION

The legacy of inappropriate management of our lakes' catchments and hydrology is the focus of this symposium. It is the opinion of the Tangata Whenua that essential improvements to lake water quality would not be necessary if previous management regimes had been more effective in protecting the mauri of both Rotoiti and Rotorua.

It is possible to develop resource management policy and engineering design for solutions consistently. The reality however is that the choice of what options are investigated and developed further is strongly influenced by the practitioners' background. Professional experience has identified the need for a model that can be used to identify and explain the different planning and engineering priorities that result when practitioners develop solutions from different cultural backgrounds.

In searching for solutions the potential contribution of the Tangata Whenua is considered in this paper in the context of the Mauri Model. This model can assist decision making by constraining personal bias and therefore ensuring that the choice of solution is balanced with regard to our social, economic, environmental and cultural well-being.

GOVERNANCE FRAMEWORK

Local government is now guided by the Local Government Act, 2002. This legislation prescribes that in their activities Regional and Territorial Authorities are to provide for democratic and effective local government and play a broad role in promoting the social, economic, environmental, and cultural well-being of their communities, taking a sustainable development approach.

The Resource Management Act, 1991 defines sustainable development as sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and avoiding, remedying, or mitigating any adverse effects of activities on the environment.

These two acts form to a large extent the basis upon which local governance occurs in New Zealand. Neither of these documents exclude the input of the Tangata Whenua but rather acknowledge and indeed reinforce the indigenous concepts of kaitiakitanga and whakatipuranga. Never-the-less resource management in New Zealand has often been at odds with Tangata Whenua values and thinking.

To gain an understanding of this, it is necessary to consider the issues influencing the contemporary paradigm within which decisions are currently made. Trust is an issue

because there is suspicion and fear of the indigenous values and practices of the Tangata Whenua and these are not very well understood. Power is also an issue, as the customary control of resource management has resided entirely with local government and there is a reluctance to undermine that perceived authority by sharing power with the indigenous people.

Further, the goodwill of the Tangata Whenua has a reciprocal expectation of trust, of power sharing and a significant role in decision-making. The loss and erosion of indigenous knowledge through lack of use or relevance, and the isolation from its origins in the physical environment, is a huge threat to the cultural identity of hapu. Finally the Tangata Whenua or people of the land have nowhere else to go. Nowhere else in the world is it more appropriate to assert Te Arawa cultural values and beliefs in relation to the environment, than within the Te Arawa rohe.

HUMAN EFFLUENT

The issue of appropriate treatment and disposal of human effluent has been the focus of research for more than one hundred and fifty years. When water-based transport and disposal of effluent was being adopted in the 19th century, a paper by scientist James Prescott Joule in 1855 proposed that waste from London should not be dumped into the Thames through open drains, but collected in tanks under each street, and transferred by force-pump to carts to take it to the rail system, and to the farms.

Early in the 20th century, the British Royal Commission into Sewage Disposal (1898 to 1915) recommendations led, almost 100 years ago on the other side of the world, to the adoption of a narrow range of sewage options. This has formed the basis for predominant practice in many countries of the world including New Zealand. This approach continues to be promoted as the most efficient and effective approach for dealing with human effluent today.

Does the consideration and adoption of land-based disposal in recent times really indicate that much significant progress has been made or that much effort has even been applied to developing the alternatives available?

Is this as far as alternative approaches to the disposal of human effluent have come in 150 years? Certainly the discharge of treated effluent onto land at Rotorua, Taupo and Levin attract a significant amount of scrutiny. Proponents of the discharge to water bodies are quick to point out problems that have been experienced with these systems.

What is not acknowledged however is that there are no water-based disposal examples in New Zealand that have not had problems in the past and several territorial authorities continue to fail to meet the environmental standards required in their resource consents. Certainly most have breached resource consent conditions unintentionally as a result of plant failure or loadings that exceed their design capacity.

A New Zealand-wide survey of Local Authority approaches to municipal wastewater treatment and disposal (Burkhardt Macrae, 2002) found that increasing pressure from public and government is driving the industry to provide higher standards of treatment and more appropriate methods of disposal. Trends have been identified that indicate increased use of land-based treatment and disposal with a move away from discharges to

water bodies. In particular the research identified that planned (2010) flow discharged to ocean will reduce by 12%, flow discharged to rivers, lakes and estuaries will reduce by 27%, and flow discharged to land or wetlands will increase by 300% to one fifth of total surveyed flow.
A recent study of international trends (18 countries) in stormwater management (Marsalek & Chocat, 2002) suggests that there is widespread acceptance of a holistic approach to stormwater management promoting sustainable urban drainage systems. "All national reports share a common vision with respect to the basic philosophy of coping with stormwater problems – by means of a holistically- based management, rather than continuing the traditional expansion (or neglect) of urban drainage systems."

This study goes on to conclude that best management practice incorporates:

- Preserving water balance
- Preventing entry of sediment and pollutants into stormwater
- Emphasising source controls and preventing runoff generation
- Green infrastructure such as ponds, wetlands, swales and infiltration sites
- Public awareness, education, and participation

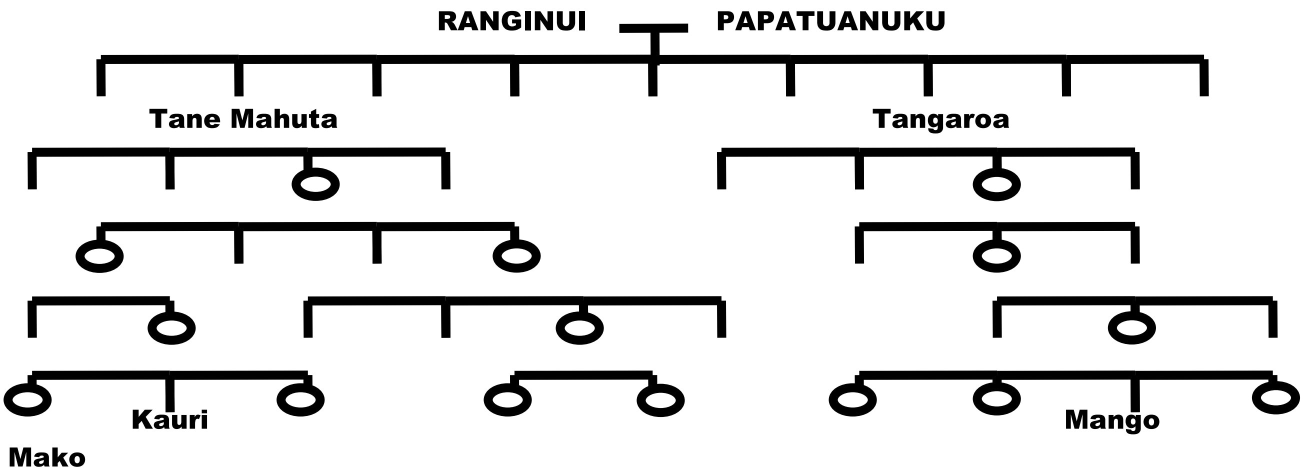
Recognition of the real value of potable water is being reflected internationally in project case studies promoted by the World Business Council for Sustainable Development. These studies feature several examples where significant economic savings have resulted from reductions in potable water use on industrial sites through collection and use of stormwater, separation of wastewater streams, and treatment and reuse of greywater. This approach stems from the realisation that waste streams from industry should be viewed as a mixture of the semi-processed raw materials that enter the process and therefore a recoverable source of some of those raw materials. This approach is more consistent with indigenous thinking in that the Tangata Whenua have not traditionally considered waste stream as being useless, but rather that wastes of different types had physical and spiritual attributes such as their associated tapu and could therefore have value in either context.

Finally to quote the New Zealand Waste Strategy (MfE March 2002);
"Maori have a unique perspective and role in waste minimisation and management. They have **played an important role in pushing change in the area of wastewater treatment and disposal**… As New Zealand moves towards zero waste Maori are expected to become more active in waste management planning and waste prevention. **Decision-making must allow for direct Maori input into policy, standards and guidelines, monitoring and evaluation**, and iwi consultation in preparing waste minimisation and management plans.

WHAT IS MAURI?

The concept of mauri is central to indigenous belief regarding the environment. Mauri is the binding force between the physical and the spiritual. When the mauri is totally extinguished, this is associated with death. Mauri is the essence that has been passed from Ranginui and Papatuanuku to their progeny Tane mahuta, Tangaroa ma, and down to all living things through whakapapa in the Maori notion of creation. Mauri is considered to be the essence or life force that provides life to all living things. Water also has mauri. The concept is central also in the context that whaikorero is often begun with the phrase *Tihei Mauri Ora.* This is literally interpreted as the 'sneeze of life'.

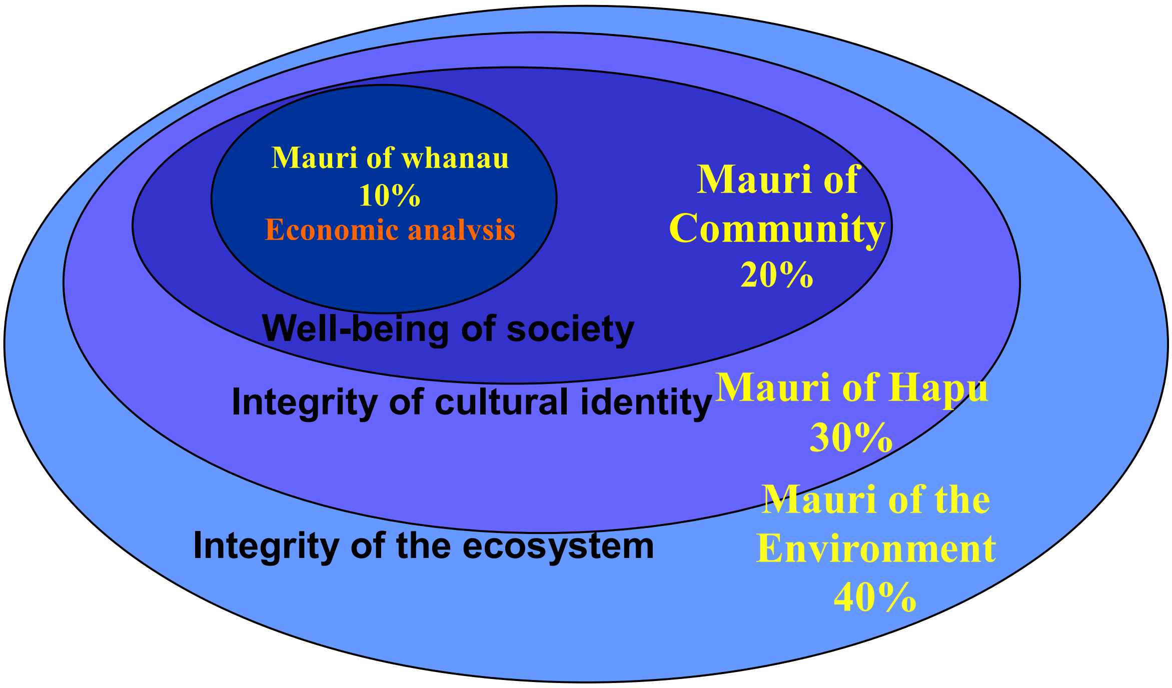
The concept of mauri was incorporated into the Resource Management Bill, however it did not progress through to New Zealand legislation. Part II Section 7 of the Resource Management Act 1991, *Other matters* includes 7(d) *Intrinsic values of ecosystems* which originally read *The mauri of ecosystems* in the Resource Management Bill that first went before parliament.
Mauri also establishes the inter-relatedness of all living things. The linkages between living things within the ecosystem is based on the whakapapa or genealogies of creation. This establishes the basis for the holistic view that Tangata Whenua have of the environment and our ecosystem.



THE MAURI MODEL

The mauri model is based on four circles that represent interactive aspects of the ecosystem. These aspects have been adopted from the Resource Management Act 1991 and the Local Government Act 2002, and are identified as the economic, social, cultural, and environmental effects associated with a particular process or technology. These have been interpreted as the impact on the mauri of the family, the community, the hapu, and the environment respectively. The relative importance of these mauri can be addressed independently by all users by choosing a weighting that is applied to each aspect once scoring has been completed.
The Tangata Whenua evaluation is based on whether the option is identified as enhancing, diminishing, or neutral for the mauri of the aspect being considered. The impact on the mauri is assessed independently from the weighting applied to the aspect. In a similar way the pakeha community can also use the model defining their own interpretation of what sustainability should reflect in each context.
There are five ratings for the mauri of each aspect. A rating of 4 is considered an acceptable technique which is considered as enhancing mauri and therefore totally sustainable. A rating of 2 is neutral, and a rating of 0 means that the technique is considered to be diminishing mauri and therefore unacceptable and unsustainable.
Thus the mauri model has been developed as a tool to investigate the differing value systems of the Tangata whenua and pakeha. The model is based on a system which parallels the criteria identified in the Local Government Act 2002. These criteria are identified also in the Sustainable development for New Zealand programme of Action 2003 regarding achieving sustainable development. Specifically model requires taking account of the social, economic, environmental and cultural effects of our decision-making.

The Mauri model is represented diagrammatically below:



WEIGHTING OF ASPECTS

The relative weightings chosen for each aspect has been based on the Tangata Whenua understanding of traditional practices or tikanga and how these relate to our ecosystem. The environment is considered the all-encompassing aspect being assessed and is given priority over the other aspects. In particular the environment encompasses culture as demonstrated by the tikanga of rahui. A rahui or prohibition is placed on an area or resource when its mauri is being jeopardised by overuse or some other significant event. This process prioritises the environment ahead of the other aspects until the mauri of that area or resource has recovered.

In terms of hierarchy the mauri of the hapu takes precedence over that of the community and the whanau. This is because of the relationship that exists between the Hapu and a specific geographic location or rohe. This relationship is permanent and established by whakapapa (genealogy) in the context of the Hapu practice of identifying with geographical features of their specific environment. This relationship is eternal and the relationship to the landscape is central to the identity and mana of the hapu. The relationship that the community, or a whanau has with the environment is more transient than this traditional relationship.

The mauri or well-being of the community takes precedence over that of the whanau. This is demonstrated in the sacrifices made by whanau to ensure the security of the community and hapu. Examples of this are the commitment of time and resources made by our kaumatua to counter the impact of external influences on the environment.

CRITERIA FOR MAURI ASSESSMENT

The mauri of the Environment
This is effectively measuring the integrity of our ecosystem. The mauri of the ecosystem is directly impacted upon by the state of the environment. The state of the environment is considered by the Tangata Whenua to reflect its mauri. This includes all land, air, flora and fauna, and water - nga taonga I tuku iho. This holistic perspective of indigenous peoples is supported by the Resource Management Act 1991, in that clause 7d) identifies the intrinsic values of ecosystems as being a matter for which practitioners shall have due regard.

Okawa, Rotoiti viewed from State Highway 33 looking north.

The haapu was the traditional level for resource management decision making. Catchments are the natural partitions of the environment that were used by the Tangata Whenua to define the rohe of hapu. The state of these catchments and how they are managed impact directly on the state of the environment. Tangata Whenua have stated that the mauri of water bodies must be protected.

The mauri of the environment is therefore measured in the context of both the physical health of the environment and its spiritual integrity. Consideration of the mauri in this context is related to the geographic boundaries established by a water catchment, typically the rohe of a specific hapu, and thus by definition includes consideration of impacts on the land, air, fauna and flora as well as the water within the rohe.

Therefore the effects of a specific sustainable technique need to be considered in terms of the effect on the waters within a specific catchment, and also the related impacts on harbours and the moana. The Tangata Whenua have stated that water is a taonga over which they have kaitiakitanga. Further cross rohe transfer and disposal of wastewater is a serious concern.

The mauri of the Hapu

Rotoiti and Matawhaura viewed from the marae atea of Taurua marae.

The mauri of the hapu is measured in a variety of ways:

1. The state of the environment that a particular hapu have mana whenua over reflects on their mana and their authority to continue in the role of kaitiaki for that rohe or catchment. This is reinforced in clause 7(a) of the RMA 1991. The Waitangi Tribunal Kaituna Report (Wai 4) demonstrates the challenge made by Ngati Pikiao in 1984 to prevent the discharge of sewage into the headwaters of the Kaituna river. The Tangata Whenua have stated that the actions to protect the waters of the Kaituna at its source shall be continued along its course to its connection with the moana. Further, the mauri of the hapu is related to the mauri of the moana.

2. The condition of the environment that is passed on to future generations is most important and can be demonstrated in whakatauki referring to nga whakatipuranga.

3. The state of the environment also influences the ability of a hapu to manaaki their visitors both on their marae and in their homes. Case law regarding Te Runanga O Taumarere *vs*. Northland Regional Council (NZRMA77) demonstrates the importance of this practice.

4. Maintenance of the knowledge base for the hapu is linked to the physical landscape and its appearance, as the whakapapa of the hapu includes the place names within the rohe. Refer TV3 Network Ltd *vs* Waikato District Council 1997 (NZRMA 539). The mauri of areas of cultural significance is to be protected, with no infrastructure on ancestral sites.

5. The ability of tohunga to teach traditional practices associated with weaving, customary food gathering, or carving is also dependent on the resources being available from the rohe. This was raised by Te Runanga O Ngati Pikiao *vs* Minister for the Environment in 2000 (NZLR). The mauri of cultural resources shall be protected.

These factors among many others impact directly on the mauri of the hapu.

The mauri of the Community
The community at large includes pakeha and taurahere as well as the Tangata Whenua. The general health, safety and well-being of the community is important in this context and includes the ability to accommodate future needs such as land availability to satisfy housing demand.

Rotorua western shores from Hamurana Road.

Community well-being includes most aspects of day-to-day life such as recreational access to parks, forests, beaches, reserves, rivers, lakes, estuaries and the ocean or opportunities for employment. This aspect of well-being is reasonably well represented by Local Authority decision-making in their current capacity of providing local government, although historically this has taken place in a relatively narrow consideration of issues that relate to the community at large.

RDC water safety indicator State Highway 33 before Okawa / Mourea.

The mauri of the Whanau
This is a measure of the direct personal effect that a specific technique will have. The way that this is perceived varies from whanau to whanau. The relevance of the state of the environment and the status of the hapu are taken into account under these specific considerations. The health and well-being of the whanau are taken into account within the context of the mauri of the community. Thus the direct personal effect is how the whanau or family is effected and this is primarily measured in economic terms in today's world. Therefore it may be considered as the impact of infrastructure on the individual:

1. as levied directly in terms of individual contribution, in terms of Development Impact Fees for example, towards the capital cost of a reticulated water supply for an existing community
2. through a portion of rates used to repay long-term borrowing by local government
3. as a component of the purchase price for a section in a new subdivision.

This tends to be the level of analysis best understood when considering the options available for a technological solution of an infra-structure requirement.

ANALYSIS USING THE MAURI MODEL

A completed analysis using the mauri model in relation to the SmartGrowth BOP strategy has demonstrated that there is general agreement with regard to the sustainability of

techniques associated with water supply technology and best practice stormwater solutions being used in Europe.

Comparison of stormwater options demonstrated a high level of agreement with the exception of reticulated stormwater and tertiary treatment of stormwater before disposal to water bodies. Both of these options rated poorly for sustainability using the mauri model. This demonstrated the relatively limited recognition of the impacts of concentrated disposal of stormwater to water bodies. These impacts interfere significantly with the local receiving environment during standard conditions. However they have catastrophic impacts in flood events due to the flushing effect through the system.

Although comparison of the results for the wastewater options demonstrated some agreement, a general trend is that while the mauri model rated composting systems higher in terms of sustainability, it also rated all reticulated systems lower, specifically the traditional reticulated pipe in pipe out approaches.

THE LAKES SITUATION

Discussion regarding deterioration in the mauri of the Waiariki lakes with several Ngati Pikiao kaumatua and members of the Te Arawa Trust Board identified these primary contributors to the changes they had observed in their lifetimes:

- The introduction of trout over 100 yrs ago. In 1908 the Arawa people presented a claim to the Native Land Commission (Stout-Ngata) concerning the use of their main lakes in the Rotorua District. The Commissioners commented as follows "The trout were placed there as a great attraction to tourists and others visiting the Thermal Springs District. That the Maoris have suffered a grievous loss by the destruction of the indigenous fish cannot be denied."
- Land development for farming in the late '40s resulted in the wholesale clearance of huge areas of native vegetation with consequences for the catchment characteristics.
- Superphosphate application increased from the late '40s with corresponding increases in nutrients entering the lakes.
- Rotorua reticulation of sewage with concentrated discharge from the early '60s with corresponding increases in nutrients entering the lakes.
- Lake margin development from the early '60s as holiday baches spread along the lake shores using septic tanks for effluent treatment. These systems are not suited to holiday accommodation or the increased loads on these systems associated with holiday activities.Modification of the Ohau Channel in the early '80s to increase water flows from Rotorua into Rotoiti also increased the flow of nutrients from Rotorua to the Rotoiti.
- Flow control at Okere / headwaters of the Kaituna in the late '80s resulted in altered flow patterns in Rotoiti, the loss of beaches due to artificially high lake levels, and ineffective septic tank systems.Rafting activities on the headwaters of the Kaituna at Okere desecrating urupa along the banks.The proliferation of swans on the lakes reducing water quality for swimming and their aggressive behaviour towards other lake users.

DISCUSSION

The primary driver in our contemporary society is capitalism. Environmental issues are a relatively recent concern, and social and cultural considerations even more so. This is demonstrated by the fact that historic decision-making has been based on economic cost/benefit analysis. New models allow the factoring in of environmental impacts in the context of the cost to avoid, remedy or mitigate the negative effects of a particular development activity. Methods for effectively incorporating the social and cultural impacts of a particular development activity have yet to be created.

Infrastructure and urbanisation technologies have generated the momentum that allows denial of the true capacity of our natural resources. Indigenous perspectives of the Tangata Whenua suggest that this will continue to be a problem until our collective cultural paradigm matures. With strong leadership approaches can be adopted that reverse the inconsistent direction chosen in the 1900's.

CONCLUSION

Our contemporary way of life tends to prioritise economic well-being ahead of the other three criteria. Recognition of the relative importance of the environment for our continued existence is improving, however the connection between activities in the environment and social and cultural well-being is still not very well understood.

The case study referred to identifies the contrasting results that are likely when Tangata Whenua values are used as the decision-making criteria. In particular the new challenge is to develop the model for inclusion of Tangata Whenua values and priorities in the Lakes strategy for the future.

Risk communication – how bad is it Doctor?

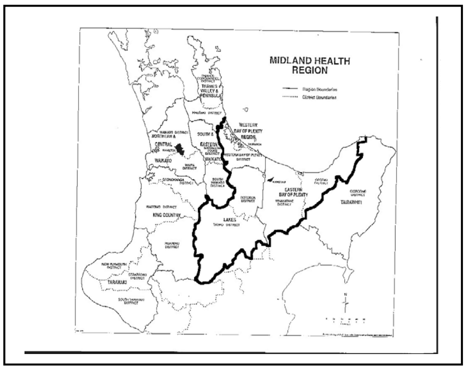
Dr Phil Shoemack
Medical Officer of Health, Bay of Plenty

I am Dr Phil Shoemack, Medical Officer of Health for the Bay of Plenty region. I'd just like to start by thanking the organising committee for putting together such a comprehensive programme and to all of you for being here. It's interesting to reflect on the different perspectives and backgrounds that people come from. That's really valuable and also vitally important, because it's only by everybody working together that we're going to improve the situation that we're talking about.

What I'm going to talk a little bit about is the practical issue of how to get across to the general public at large what the problem is, what we're talking about and what they can do about it. That's one of the organisms we're talking about (*left*), but trying to explain what that is to the general public is pretty difficult. When things get really bad, that's what people see and that's a sample that was taken not too long ago in May from the foreshore at Ngongotaha (*right*). So that's the sort of appearance that the water can get to and when it's that bad obviously there's no doubt that most people would stay away.

So what's the role of public health? The way I put public health in a nutshell is that we have two basic functions. One is what we call the watchdog role, which basically means a general surveillance function looking at all the health issues that might affect a population in an area. We do that partly through some of our own surveillance systems and partly in conjunction with all the various other organisations that are involved, whether it's environmental health, clinical care, climate change, you name it. All of those things have an impact on health, so we don't do it by ourselves, we pick on support from various organisations. And then there's an advocacy role. Once we find something that's an issue as a result of that surveillance, something has to be done about it. At times that means invoking a piece of legislation, more often it means working with people, trying to sort out the problem and trying to take a cooperative approach to improving the situation. Or at times it might be just warning people that they need to avoid something or change something. It might be behaviour.

When I talk about the Bay of Plenty region, that's the region that I cover (*next page*). It's unfortunate in a way that in New Zealand we have all these different boundaries and they're not all coterminous. For instance we have two district health boards within there and parts of two regional councils, as well as seven district councils and several iwi authorities, etc. More specifically, as David has already shown, that's the area that's the focus of most of what we're talking about over the next couple of days, although there will be some talks to do with Lake Taupo as well.

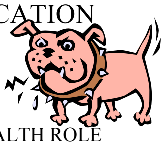


So from the perspective of where we come in, in the Bay of Plenty region, as in the Waikato region in terms of Taupo, it's the regional council that takes the prime responsibility for the surveillance of the water quality. We also occasionally get ad hoc reports from members of the public who just happen to come across a bloom or a problem and they'll phone ourselves or the regional council or the district council, sometimes other people as well, DoC, to bring the issue to the attention of the right authorities. The results of any testing done by the regional council are then fed through to us in the public health unit and if there's a need to advise the public that there's a problem and they need to stay away from a water body, then it's me as Medical Officer of Health that issues that public health warning, because it is a health issue. The local authority, in this case the Rotorua District Council, helps in terms of alerting the public specifically with the putting up of signs, making sure that the signs are appropriately sited, dated and kept up to-date.

MANAGING THE PROBLEM

- REGIONAL COUNCIL CONDUCTS REGULAR WATER MONITORING & LABORATORY ANALYSIS
- ADHOC REPORTS FROM PUBLIC
- RESULTS TO PUBLIC HEALTH UNIT
- MOH ISSUES HEALTH WARNINGS
- TLA ERECTS SIGNS, LOOKS AFTER WATER SUPPLY ISSUES

RISK COMMUNICATION



- IMPORTANT PUBLIC HEALTH ROLE
- PRESENT EVIDENCE RE RISKS
- ADVISE PUBLIC REGARDING PREVENTION/RISK REDUCTION
- KEEP ADVISING…..
- MONITOR WHAT HAPPENS

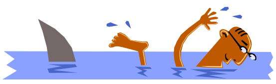
Although that all sounds pretty straightforward, unfortunately it's not. Trying to get across to the public what is the risk of any issue is very difficult. Most of us like to see things as either being safe or dangerous - unfortunately life's not quite that black and white. There are levels of risk and how people perceive risk depends on where they come from. It's certainly an important public health role. Whether we're talking about the cyanobacteria in lakes, the impact of smoking on health or nutrition – no matter what you are talking about, the concept of getting across to people how to manage a risk is incredibly important.

What we tend to do is present the evidence to assist people with the interpretation of that evidence, but in the end it's up to people themselves to make their own determination of how that risk impacts on them. So what we do with respect to the lakes is advise people in terms of risk reduction, that when there's a bloom where there may be an impact on people's health, then you really should stay away from that water. Don't use it for drinking, don't use it for bathing, don't use it for recreational pursuits. We have to keep advising, because in recent years we've had blooms which have continued for 6-8 months in some cases.

So it's one thing issuing a warning when the bloom first occurs, but how are people going to remember 6 months down the track, assuming that we're talking about the same people and often that's not the case. People are coming in and out of the area all the time for holidays or whatever. It's also important, having advised people of the risk, to monitor what actually is the result. To what extent do people heed the warning, or do they carry on using the lake.

It’s important to recognise the difference between banning something and advising people that there’s a warning in place. In this example we are warning people, we are advising them that there is a level of risk should they continue to swim in the lake they may suffer a health impact. We do not have the power and nor do I think it’s appropriate to say that a lake is closed or to ban people from using a lake. That’s an important difference when you compare it with other things, where occasionally a ban is put in place. It’s important that we keep on advising people, that we keep reissuing the warning based on the best available evidence that we have. The other thing with the shark and people, we live all the time in the coastal beaches around New Zealand with the potential risk of shark attacks. It doesn’t happen very often and most people don’t think about it and they keep on swimming, but there is a risk. You can’t say that there is no risk of being eaten by a shark.

RISK COMMUNICATION & CYANOBACTERIA BLOOMS



- ADVISE RE THREATS TO HEALTH
- ISSUE HEALTH WARNINGS
- cf WARNING vs BAN/CLOSURE
- KEEP ON WARNING
- MONITOR OUTCOMES

So how do we actually do this with respect to the cyanobacteria blooms? Well, there’s a list there. We issue media releases, we respond to enquiries from the public, we advise a whole long list of people and with the electronic media we can do that very quickly with the push of a button with an email group. If anyone wants to be on that email list, then please give us a ring at the public health unit. I’ve mentioned that the District Council assist with putting signs up, and they have on occasions done mail drops to ratepayers in the affected areas. I’ll show you some photos in a minute of some permanent signs that are now up, and just general awareness raising through talking at groups like this.

HOW & WHO TO WARN…..

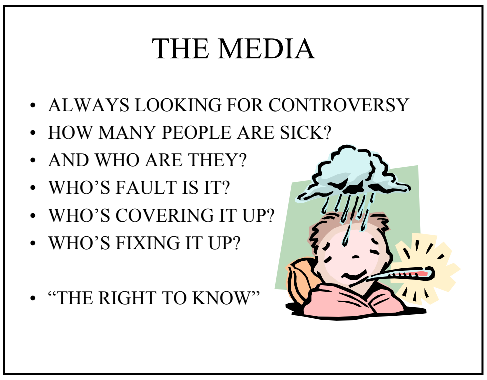
- ISSUE MEDIA RELEASES
- RESPOND TO ENQUIRIES/”QUERIES”
- ADVISE RATEPAYER GROUPS, IWI
- SIGNAGE ROUND AFFECTED WATER
- MAIL DROPS
- PERMANENT SIGNS
- GENERAL AWARENESS RAISING

In terms of what can happen, if people are exposed to cyanobacteria blooms and/or the toxins which these organisms can product, there’s a list of symptoms there which people may experience. Skin rash is not that uncommon unfortunately with swimming in lakes anyway, because of other things that might be in the water and because skin rash is a common complaint which at any given time a proportion of the population will have. Certainly the toxins are capable of sparking an asthma attack or hayfever attack in someone who is prone to that happening anyway. Some of the toxins can affect the nervous system, resulting in tingling around the mouth or numbness. They can also result in gastro-intestinal symptoms, in other words a tummy bug, diarrhoea, possibly even vomiting. One of the toxins is particularly known to affect the liver. However, most of the time if you are exposed to an area with a bloom in the water, nothing will happen. You’ll have a good time and you won’t have any health effects, but there is always that potential risk for it happening, because at any given time virtually all of the species that

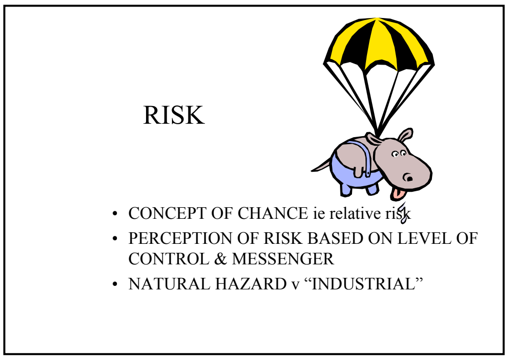
CYANOBACTERIA POISONING

- ? CASE DEFINITION…..
- SKIN RASH
- ASTHMA/HAYFEVER
- NEUROLOGICAL SYMPTOMS
- GASTRO-INTESTINAL SYMPTOMS
- HEPATIC SYMPTOMS

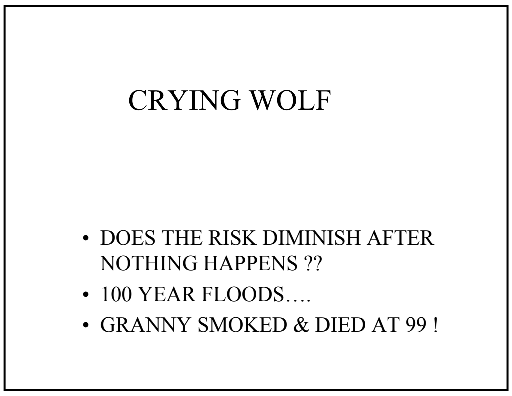
have been identified in New Zealand are capable of producing toxins. They may not do so today and they may not do so in that bay, but tomorrow or in the next bay they could, and we can't just rely on the appearance of the water to the naked eye.



The media are a great help; at the same time we have to be careful in dealing with the media to make sure that we get the message across that we want the public to receive. Media are often looking to blame somebody, often looking for something controversial, whereas usually when we go to the media because of a cyanobacteria bloom, we are wanting a straight story put out – that there's a health warning in place and telling the action that we want people to take. Yes, there is the longer term issue that we're talking about over the next couple of days with what we can do about it, but that is very much a longer term thing.



What is the risk? It's incredibly difficult to quantify the risk in a given situation. What we do is based on experience from overseas, principally Australia, when it comes to cyanobacteria blooms. We say that once the cell count gets above a level of 2000 cells cyanobacteria per ml of water, that that water should not be used for drinking purposes. Once the cell count gets above 15000 cells per ml, that water should not be used for recreational pursuits, because we know from experience that about that level people are more likely to start suffering a health impact.



One of the difficulties of advising the public of a risk like this which as I said earlier can go on for months, is that there may be a perception amongst the public that nothing's happened for the last 2 months in terms of health impact, while I've continued to swim every day in the bay, that the risk must have gone away. Well unfortunately it doesn't work like that, because as I said earlier, at any given time any of these blooms could start producing toxins, and it's largely the toxins which cause the major significant health impacts, not the bacteria themselves. It's, if you like, akin to the 100 year floor as well – once you've had the 100 year flood, does that mean it's not going to happen again for the next 100 years? Well unfortunately no, it doesn't. It just means statistically on average that's how often something is going to occur. Because you haven't had a problem swimming in the bay for the last 2 months doesn't meant to say that it's not going to happen tomorrow. Everyone's got anecdotal stories about their granny who smoked continuously until 99 and died a peaceful death. Similarly people will have stories of lots of people still water-

skiing in the bay, still swimming in the bay – and question whether that means that there's no problem. No it doesn't, it just means that those people are incredibly lucky.

TWO PROBLEMS WITH CYANOBACTERIA

- BACTERIA & TOXINS
- WARNING LEVELS BASED ON CELL COUNTS
- HOW MANY SAMPLING SITES ??
- HOW FREQUENTLY TO TEST ??
- TOXINS CAN BE RELEASED AT ANY TIME; POSITIVE TEST OF SOME HELP

In terms of surveillance of the lakes, ideally we'd sample all the water all the time continuously, but obviously in a practical sense that's not possible. There's no right answer to the questions; how many sampling sites, how frequently do you test. It comes down to a practical thing of resources. In a big lake of up to 40 or 50 square kilometres, we may only have 2 or 3 testing sites. Based on history we can put the sites where the blooms are most likely to occur, but obviously sometimes we are going to miss them, so we're also always looking for reports coming in from the public.

YOU CAN'T PLEASE ALL THE PEOPLE ALL THE TIME

- "BUT WE'RE COMING TO THE LAKE FOR A FAMILY HOLIDAY"
- "THERE AREN'T ENOUGH SIGNS"
- "I HAVE A BUSINESS TO RUN"
- "THE SIGNS ARE OLD & TOO SMALL"
- "WHAT ABOUT THE TOURISTS"
- "IS WARNING REALLY NECESSARY"

It's not possible to please everybody. Some people complain because there's a warning put out because it interrupts their business or the value of their property or whatever, and other people unfortunately are going to complain because they didn't know there was a bloom. It's not possible to keep everybody happy.

UNRESOLVED ISSUES

- INFORMED CONSENT - HOW TO WARN PEOPLE & HOW OFTEN ?
- IMPACT ON PROPERTY VALUES
- COST TO FIND ALTERNATIVE WATER SUPPLY.
- IMPACT ON TOURISM
- IMPACT ON INCOMES
- ? ROLE OF TLA …

  water supplies, campgrounds, lodge

Just a few photos – that's one of the permanent signs that the council has erected as you're heading south from Okawa Bay. Obviously we compete with other people wanting to put signs up as well, so there's an example of 3 different signs at the same place (*not shown*).

And we have problems with signage too (*next page, left*).

But when the lake looks this murky (*photo not shown*), it's obvious what you have to do. And then we come back to keeping ahead of the threat. Thank you.

QUESTIONS
Jock Schoeller, LWQS. I am a resident on Lake Rotoiti. I would just like to ask you, I've noticed over the last 3 years that the level of signage often goes up late and isn't updated very often, and I'm just wondering what you intend doing this year in terms of regularity of update, because it's quite a critical issue. The sign goes up, it stays up, it never gets changed and no one knows what's going on, and so the frequency issue of update is my question. Thank you.

P.S. It's a fair question. We need to do more and we need to do better. The three main organisations that work together on this issue are the Regional Council, the District Council and ourselves, and we meet frequently. Yes I take your point, we need to do better to make sure the signs are updated and we can't stop them being vandalised, but when we find that they are then they need to be replaced.

J.S. However, how often are they going to be updated, what is your plan and target for update this year?

P.S. Okay, we don't put new signs up every time a new test is done. We know that, for example, when a bloom begins at Okawa Bay and Lake Rotoehu it's usually there for months, rather than days or weeks. The assumption that all residents should take is that if there is a warning sign up, then it is current.

J.S. I find that somewhat unsatisfactory and I would like at least to have my question answered as to how often, because I think it should be done on a regular basis, and I'd like you to confirm the time frames that you are going to do it on, because it's quite important. I mean even if it's the same, it should at least be updated on a regular basis and it should be known to be updated on a regular basis, so the public knows that it has been updated – every 2 weeks or every 4 weeks. Can you do a time frame?

P.S. *W*ell I can make suggestions as to what is an appropriate time frame.

Chair. I'm sure it will be addressed because it is important. One more question please.

Richard Wilson, Lake Rotoiti Ratepayers Association. Phil, a number of people on Lake Rotoiti tell me that they can filter the lake water and it's perfectly safe. Is there really any method of making the lake water safe, because I actually don't believe these people?

P.S. You can filter out, to some extent the bacteria, but unfortunately that's not going to deal with any toxins that are present, so the easy answer is no. The public health units

have been advising people for years all around New Zealand that it’s not good first principles to drink lake water for all sorts of reasons – cyanobacteria just being one of them.

Cyanobacterial Toxins Occurring in New Zealand

David Stirling [1] and Susie Wood [2]
[1]Institute of Environmental Science and Research Ltd, PO Box 50348, Porirua
[2] Institute of Food Nutrition and Human Health, Massey University Wellington, Private Box 756, Wellington
[2] School of Biological Sciences, Victoria University of Wellington, PO Box 600, Wellington

INTRODUCTION:
Cyanobacterial toxins (cyanotoxins) are natural metabolites produced by cyanobacteria that are detrimental or fatal to other organisms (Briand *et al.*, 2003). These toxins occur world-wide and are certainly not unique to New Zealand (Haider *et al.*, 2003). Blooms of cyanobacteria would have been present in New Zealand before humans; it is the frequency of the blooms that is increasing with eutrophication of water bodies (Paerl *et al.*, 2001).

Cyanotoxins fall into three broad classes, the neurotoxins (e.g. anatoxins and saxitoxins) that affect the nervous system, the hepatotoxins (e.g. microcystins, nodularin and cylindrospermopsin) that attack the liver and the primary irritants that affect the skin causing rashes. This paper will discuss the neurotoxins and hepatotoxins only. The primary irritants are discussed in Codd (1997).

The structures of cyanobacterial toxins vary widely; there are 65 published microcystin structures; 24 saxitoxin structures; seven anatoxin structures; three cylindrospermopsin structures; and many more miscellaneous toxin structures. This huge variety of structures does cause some difficulties when analysing samples. Currently no one method can detect all known cyanotoxins and a range of assays are required to determine the toxicity or toxin content of samples. The diversity of cyanotoxins, and the variability within blooms of cyanobacteria, creates problems for health protection officers trying to give clear advice to members of the public.

TOXINS:

Microcystins

The microcystin group are the most common cyanobacterial toxins found around the world (Chorus, I., 2001). The toxins are produced by a number of genera including *Microcystis*, *Anabaena*, *Oscillatoria*, *Planktothrix*, *Hapalosiphon, Nostoc, Pseudoanabaena, Synechocystis* and *Anabaenopsis*.

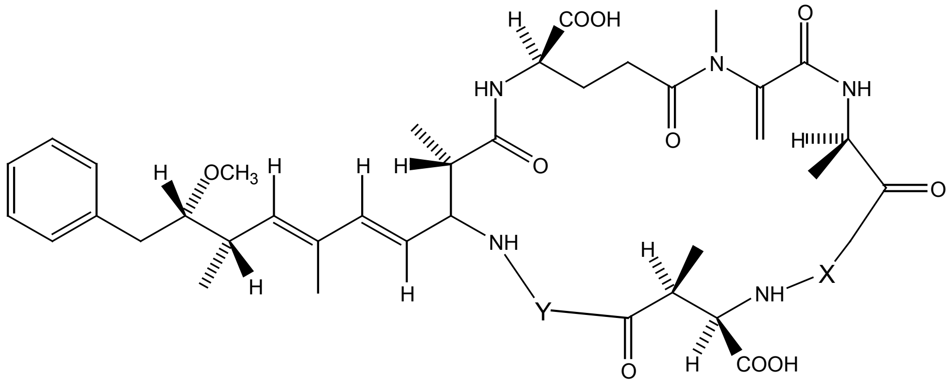


Figure 1: General structure of the microcystin series of toxins where X and Y are the common variable amino acids

Microcystins are acute hepatotoxic (liver damaging) poisons that have caused fatalities overseas. The most infamous case occurred in 1996 when processes at a water treatment plant failed and manual addition of chlorine to tanker loads of water was sporadic and of varying amounts. All the fatalities were at a dialysis treatment clinic in Caruaru, Brazil, the general populace was not acutely affected (Azevedo *et al.*, 2002). The typical way of expressing toxicity is to find out the dose of toxin required to kill half the subjects tested (dose having 50% probability of causing death) or Lethal Dose for 50% (LD_{50}). Microcystin LR, the most commonly found microcystin, has an LD_{50} of ≈55 µg/kg body weight by intraperitoneal (ip) injection into mice. Effectively the ip route puts the toxic material into the body cavity. Since people rarely consume water in this way a more useful measure is by the oral route. The mouse oral LD_{50} for microcystin LR is 5000-10900 µg/kg body weight. This difference in toxicity between ip and oral routes may explain why the general populace in Caruaru was unaffected. Another case from Brazil put the death toll at 88 people after a new constructed dam was filled and a *Microcystis* bloom occurred (Teixeira *et al.*, 1993). There are a number of reports world-wide where illness has been associated with recreational contact in or on water contaminated with cyanobacteria (Ressom *et al.*, 1994). In one instance two British soldiers were hospitalised with pneumonia after kayaking and practising "Eskimo rolls" in a water-body that contained a bloom of *Microcystis aeruginosa* (Turner *et al.*, 1990).

One more insidious side of the microcystin class of compounds is that they are considered chronic carcinogens; that is, continual low dose of microcystins have been linked to primary liver cancer from drinking surface water collected from such sources as ponds and ditches (Yu, 1995; Carmichael *et al.*, 1988; Yu *et al.*, 1990; Zhang *et al.*, 1991; Ueno *et al.*, 1996).

Microcystins are capable of bioaccumulation in salt-water mussels, flounder and sea-run salmon (Williams *et al.*, 1997; Sipia *et al.*, 2002; Andersen *et al.*, 1993) but does not appear to intoxicate cows milk (Orr *et al.*, 2001) or beef (Orr *et al.*, 2003) when water contaminated with *Microcystis aeruginosa* is fed to cattle. Microcystins are toxic to zooplankton (Blom *et al.*, 2001; Christoffersen and Burns, 2000), ducks (Matsunaga *et al.*, 1999) and flamingos (Krienitz *et al.*, 2003).

Most water treatment plants are typically ineffective in the complete destruction of these

toxins. A combination of coagulation, flocculation, filtration and chlorination will usually significantly reduce the concentration of microcystins, but during bloom events the capacity of the plant can be overwhelmed. As the microcystin toxins are contained within the cells, it is important for water treatment plants to ensure that their coagulation and flocculation steps are gentle enough to prevent cell lysis. Once the microcystins are in the water stream, advanced treatment such as activated carbon filtration or ultraviolet light treatment is required to destroy the toxins.

Occurrence of microcystins in the Rotorua Lakes

An enzyme-linked immunosorbent assay (ELISA) using the methods of Fischer *et al.*, (2001) detected low levels of microcystins in Lakes Okaro, Ngahewa, Ngapouri, and Rotorua. This ELISA uses antibodies raised to the Adda moiety that is present in most (>80%) of the known toxic penta- and heptapeptide toxin congeners. This ELISA was developed by the Toxinology Group at AgResearch, Ruakura near Hamilton. It has a number of advantages over other currently available analytic methods; it is cheap, quick, reliable and eventually field-usable. Maximum total microcytsin values of 25 μg/L have been detected in a cyanobacterial bloom samples from Lake Rotoehu.

Samples collected from Lake Rotoiti in April 2003 contained higher levels of microcystin; Okawa Bay had 44 μg/L of microcystins, Te Weta Bay 350 μg/L microcystins and the Western Basin contained 330 μg/L microcystins. These levels pose a substantial health risk especially if there is repeated exposed to this water. Based on lowest observed adverse effect levels (LOAEL) data (Falconer *et al.*, 1994) with microcystin levels of 350 μg/L a 10 kg child would only need to repeatedly ingest 1.14 mL to potentially cause health impairment. Ingestion of this amount of water is very likely during recreational activities or during bathing.

The World Health Organisations specifies a maximum of 1 μg/L microcystins for drinking water. While levels for recreational should be significantly higher than the drinking water standard, there is some debate about what level is acceptable. Usually cells counts are used to determine a risk level (Pilotto *et al.*, 1997).

Occurrence of microcystins in other areas of New Zealand

Lake Waitawa, just north of Wellington, had a severe bloom of cyanobacteria in 1998. The owner of the surrounding land complained of the smell and said “Someone has dumped sewerage in my lake”. The smell was of the rotting cellular material of the dying (senescent) bloom. Microcystins LR, RR, WR, LA and (either Fr or M(O)R or HphR) were detected by liquid chromatography-tandem mass spectrometry (LC-MS/MS), as was cylindrospermopsin (Stirling and Quilliam, 2001). To date these are the only microcystin variants that have been shown to occur in New Zealand. The lake was cleared for recreational use after several weeks by use of the AgResearch microcystin ELISA.

Lake Horowhenua, near the town of Levin, now seems to be suffering from an annual bloom of *Microcystis* causing a pungent smell and a highly visible bloom. As this lake is privately owned it is very easy to ban the recreational use of the lake. Typically 30 to 50 μg/L total microcystins are found in the lake water by the microcystin ELISA. Maximum levels of 24 000 μg/L total microcystins have been found in scum samples collected from this lake.

Until recently little has been known about the occurrence of microcystins around New

Zealand (Christoffersen and Burns, 2000). As part of a PhD study by Susie Wood investigating cyanotoxins in New Zealand, microcystins have now been identified in over 50 waterbodies across the country. Maximum levels of 42 000 µg/L have been detected in some scum samples.

Saxitoxins (Paralytic Shellfish Poisoning [PSP] toxins)

This series of approximately 24 published compounds was first isolated from toxic marine shellfish, hence the name paralytic shellfish poisoning toxins. However, in the marine case they are produced by marine dinoflagellates that the shellfish feed upon. In freshwater these toxins are produced by *Anabaena*, *Aphanizomenon*, *Planktothrix, Lyngbya* and *Cylindrospermopsis*.

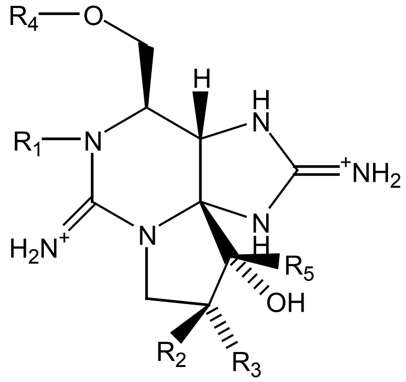


Figure 2: General structure of the saxitoxin (PSP) series of toxins where the various R groups designate variable components

The saxitoxins are neurotoxins with saxitoxin *sensu stricto* having an ip LD_{50} of 10 µg/kg body weight (mouse) and an oral LD_{50} of 263 µg/kg body weight (mouse). Other analogues are mostly less toxic than saxitoxin.

Saxitoxins are bioaccumulated by fresh water mussels and this may be a pathway for accumulation or toxication of organisms higher in the food web (Negri and Jones, 1995). Saxitoxins have caused sheep mortalities in Australia (Negri *et al.*, 1995) and in one incident, over 1000 km of the Murray-Darling River system was a grass green colour from a bloom of toxic *Anabaena circinalis* and at least 1600 sheep and cattle died (Bowling and Baker, 1996).

Most water treatment plants are typically ineffective in the destruction of these toxins and they are resistant to boiling (Rositano *et al.*, 1998). Once again, saxitoxins are retained within the cells until lysis or membrane disruption so water treatment practices and processes may either exacerbate or mitigate the risk.

Occurrence of saxitoxins in the Rotorua Lakes

A freeze-dried sample of cellular material from Lake Rotoiti contained low levels of saxitoxins when tested using a saxitoxin ELISA. This result was confirmed by a neuroblastoma assay. The neuroblastoma assay is an effect-based assay and hence gives an independent measure of toxicity to that of the structure-based ELISA. Cellular material from Lakes Ngapouri and Rotoehu also showed low levels of saxitoxins by ELISA but these cases have not yet been backed up by the neuroblastoma assay.

Occurrence of saxitoxins in other areas of New Zealand

The Waikato River suffered from a bloom of cyanobacteria in early 2003. This problem manifested itself as a taste and odour problem in the drinking water supplied to the city of Hamilton and other towns along the length of the Waikato River. Saxitoxins were detected by ELISA in water samples taken from the water treatment intake and throughout the water treatment process but these levels were below the levels allowed under the proposed drinking water guideline. The neuroblastoma assay subsequently concurred with the ELISA test for the presence of saxitoxins. To date the saxitoxin-producing organism has not been identified.

Using the ELISA and neuroblastoma assays, saxitoxins have been detected in samples from a number of water bodies around New Zealand. Further work is required to establish which species are responsible for saxitoxin production, the toxin variants present and the levels of saxitoxins being produced.

Anatoxins

Anatoxin-a and homoanatoxin-a are produced by *Anabaena*, *Oscillatoria* (*Phormidium*), *Planktothrix*, *Raphidiopsis, Aphanizomenon*, and *Cylindrospermum* sp. The LD_{lo} (the lowest dose causing death. *c.f.* LD_{50}) is 250 µg/kg body weight ip. (mouse). As a comparison strychnine has a LD_{lo} (in humans) of 5-8 mg/kg body weight, some 20 times less toxic than anatoxin-a.

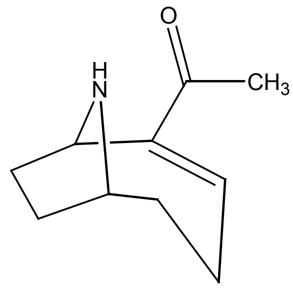


Figure 3: Structure of anatoxin-a

Anatoxin-a and homoanatoxin-a are neurotoxic poisons. In dogs, these lead to convulsions, coma, rigors, cyanosis, limb twitching, hypersalivation and/or death. Dogs tend to be the first victims noted during an anatoxin event (Edwards *et al.*, 1992) as they forage widely and seem to have a peculiar affection for cyanobacterial mats. Anatoxin-a is rapidly broken down in sunlight once it is released from the cells and sub-lethal doses do not have any apparent effect (Fawell *et al.*, 1999).

Occurrence of anatoxins in Rotorua lakes and elsewhere in New Zealand

Anatoxin-a was detected using high performance liquid chromatography with fluorescence detection (HPLC-FLD) in a cyanobacterial bloom (*Anabaena* sp.) sample collected from Lake Rotoehu in 2001. However, at the time a quantitated standard of anatoxin-a was not available thus the quantity of anatoxin-a in the sample was not established.

Over a three-day period from Boxing Day 1998, five to seven dogs died within 24 hours of contact with the Waikanae River just north of Wellington. One dog died very rapidly within 10 minutes of contact with the riverbed. An *Oscillatoria* species was identified

growing as a mat at the bottom of the river. Sodium monofluoroacetate (1080) assays were carried out on stomach contents but were negative. Fortunately a concerned citizen stored a sample of the algae in their freezer for three months before rediscovering it and forwarding it onto the local council. A sample of this material was tested by mouse bioassay and found to be very toxic with the average death time being 3 min 50 seconds. Anatoxin-a degradation products were subsequently positively identified in this sample by instrumental analysis.

In 1999 the Mataura River, near Gore, had an incident where six dogs died after walking along the banks. An *Oscillatoria* species was also identified from mats along the bottom of the river (Hamill, 2001). The disused Lower Karori water reservoir had a bloom of *Anabaena* in 2003 that tested positive for anatoxin-a. As a wildlife sanctuary now encloses this lake, it was easy to prevent human contact with the water.

Miscellaneous toxins not associated with the Rotorua lakes

Cylindrospermopsin

Cylindrospermopsin is produced by *Cylindrospermopsis*, *Umezakia, Aphanizomenon, Anabaena* and *Raphidiopsis* species of cyanobacteria. The LD_{50} is 200 µg/kg body weight i.p. (mouse, 5d observation time), the no observable adverse effect level (NOAEL) based on this data is 30 µg/kg/day (mouse). One of the more insidious aspects to this toxin is that it is a slow-acting toxin (hence the 5 day observation time in the mouse bioassay) but this toxin is readily destroyed by chlorination, ozonation or activated carbon treatment of water (Griffiths and Saker, 2003). Cylindrospermopsin may be a potential chronic carcinogen (Falconer and Humpage, 2001).

Cylindrospermopsin is difficult to detect not only because of the long observation time required in the mouse bioassay but also because the only alternative is an liquid chromatograph-mass spectrometer analysis with associated high capital cost. This toxin was first detected in New Zealand in 1999 (Stirling and Quilliam, 2001) but the causative organism was only recently identified as *Cylindrospermopsis raciborskii* from a sample collected from Lake Waahi in the Waikato(Wood and Stirling, 2003).

Nodularin

Nodularin is a toxin with a very similar structure to the microcystins and is produced by *Nodularia spumigena,* a cyanobacterium found in brackish waters such as the Canterbury lakes Ellesmere (Te Waihora) and Forsyth (Wairewa). After stock deaths in the 1980's research at the University of Canterbury identified the Adda moiety which is required for toxicity of the seven published nodularins and the microcystins (Rinehart *et al.*, 1988). Nodularin has the same mode of action as the microcystins.

CONCLUSIONS

The cyanotoxins microcystin, anatoxin-a, cylindrospermopsin, nodularin and saxitoxin have now being identified in water samples from around New Zealand. Microcystins are the most common cyanotoxin in New Zealand. At times these cyanotoxins can reach levels that are hazardous to humans and animals. There are a number of documented animal deaths related to ingestion of toxic cyanobacteria in New Zealand and these toxins do affect the food web.

The cyanotoxins microcystins, anatoxin-a and saxitoxins have being detected in lakes in the Rotorua district. Cyanotoxin levels and species composition of blooms in the Rotorua

lakes should be monitored and the public made aware of potential dangers.

QUESTIONS

Hailong Wang, Forest Research: Just a simple question. How are the toxins degraded in the water?

D.S.: The microcystins are degraded by other bacteria in the water and they also can be broken down by ultra-violet light, but typically sunlight is not that strong. Anatoxins are very rapidly broken down by sunlight. Saxitoxins are once again broken down by bacteria. If you have periodic blooms and they're toxic, the best thing that could have happened is that you had a bloom 3 months ago, because the bacteria that degrade the toxins will still be around. If you have a new bloom, you've got a problem because there is a 2-week lag phase, while bacteria build up to degrade the toxins. So typically if you have a short bloom and you've had a bloom previously, it'll only be 3 days before the toxin levels start plummeting. But if you haven't had a bloom for a long time and you have a new bloom, a short term bloom, you have a 2-week lag phase during which the bloom may have gone but the toxins are still in the water. This gives Phil Shoemack another problem, because the people perceive the water as being clear and yet it's still toxic, so that's another problem for the medical people.

John Davies: Do we know what triggers the production of the toxins, is it something in the water that they feed on?

D.S.: What triggers toxin production, yes there's ongoing scientific debate about that. The easy answer to that is competition. When they are in a competitive environment they will produce the toxins to suppress other organisms like green algae, diatoms and things like that. So that's the general easy answer, that it's competition. So when they are being suppressed, their ecological niche is being pushed by other species and they'll produce toxins to try and knock off the other species. That's the easy answer. Whether it's the correct answer I don't know.

Mark Bellingham, Massey University: You mentioned the effect on fish through the food chain, I am going to go home tonight to where my brother-in-law has cooked a whole lot of nice trout. What's the accumulation? And the other question too is what is the effect on the fish anyway?

D.S.: Yes, fish are susceptible to these toxins. There was an incident in Canada where there were caged fish and those caged fish died when a cyanobacterial bloom occurred. Now fish are pretty smart, they know when there's a bloom and they go and swim somewhere else. Now one of the problems with the low oxygen level is that all the fish are being crammed into the top level as well, and so the old fish might not be able to swim away from the blooms and yes, you will get deaths of the fish. The fish are susceptible to these organisms. Why ducks can swim through this stuff, I've got no idea, but ducks are special.

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Controlling Land-based Nutrient Sources and Transport: Integration of Science, Management and Policy

Norman E. Peters
U.S. Geological Survey, 3039 Amwiler Rd., Suite 130, Atlanta, GA 30360 USA

ABSTRACT

Freshwater nutrient concentrations, and related eutrophication, are increasing globally, which also has been observed in the Rotorua Lakes Region, New Zealand. In general, the increases around the world from the 1940s through the 1970s were due to ineffective solid and liquid waste treatment and disposal, i.e., *dilution is the solution to pollution* mentality. In many geographic areas, this problem has been addressed through applications of technological advances and investments in more effective treatment facilities. Increases in both surface water and ground water nutrient concentrations since the 1950s also have been due to increasing rates of fertilizer application, coupled with inadequate or ineffective management practices. Even in pristine catchments, the transport of fossil fuel emissions and other airborne emissions cause increasing atmospheric nitrogen deposition.

The result of the increasing application of nutrients to the landscape has been a general increase in eutrophication of freshwater. Water pathways and nutrient availability control nutrient transport, and therefore, the timing of waste disposal and fertilizer application with respect to hydrologic conditions are major factors that determine nutrient availability and speciation. Temporal trends and spatial patterns of streamwater nutrient concentrations and fluxes reflect sources and hydrologic controls on nutrient transport and have been used effectively with other methods such as nitrogen and oxygen isotopes to differentiate nutrient sources.

For lake systems, the internal release of nutrients from sediments is another mechanism to be considered in management of nutrients. Hydrochemical and ecological modelling have aided in data synthesis, assessing processes, and testing hypotheses, but have been difficult to develop, calibrate, and test due to the myriad of processes, lack of understanding, and general lack of model input data. Nevertheless, some empirical and quasi-empirical models have produced relatively accurate estimations of nutrient load and some numerical models have been useful in developing hypotheses about the most sensitive components of nutrient transformations.

Long-term monitoring, i.e., ground-water and surface-water sampling sites with similar collection frequency and sampling and analytical methods, is a key component for assessing water-quality trends given changing land use, human activities, and climate. Given the current status and inferred rates of water-quality degradation in the Rotorua Lakes area, a primary objective is to reduce nutrient concentrations and loads to the lakes to improve water quality or at least reduce the rate of water-quality degradation. In this regard, plans and results from monitoring and science, basin development, remedial actions, and regulatory prescriptions, should be developed in consort with and transparent to all stakeholders within a watershed framework, particularly those actions that affect nutrient sources, availability and transport.

INTRODUCTION

As observed from catchment studies around the world, catchments are relatively unique, at least with respect to some processes. However, basic processes are evident in each of these catchments. For the characteristics of the catchments of the Rotorua Lakes Region, many folks ranging from scientists to residents and farmers have contributed to my understanding of the basic and site specific processes affecting eutrophication. Although I don't have the time to list all of those who helped shape my understanding, I do want to mention a couple of the key local scientists who have helped me. John Quinn was one of my first contacts and he passed me on to Kit Rutherford, who has conducted catchment research here and his publications have been instrumental in shaping my understanding of the local situation. I have also met with farmers and residents, who have provided me with a practical local guide to day-to-day land and water management. I have been on local field trips organized by Ian McLean, and therefore, have actually been able to see the catchments and see some of the issues about which I had a pre-conceived understanding. My conceptualisation changed dramatically during the week following my arrival in New Zealand. I think that the major issues are still the same, but my view of the relative importance of some of the processes has changed, particularly due to the volcanic history and its effect on the hydrogeology.

The content of this paper will extend beyond the controls of land-based nutrient sources and transport, and will include scientific techniques used to understand the controls and linkages among various factors. I also will discuss how the science of understanding may lead to more effective management and policy. I will touch less on the management and policy issues, because those are foreign to me. I am a research hydrologist and I work in catchments. My research focus is the understanding of hydrological and hyrochemical processes and this is mainly a product of both basic and applied research; I don’t write policy, nor am I an environmental manager.

The primary problem in the Rotorua Lakes Region, is eutrophication. David Hamilton did an excellent job of presenting the basic problem of increasing frequency and severity of algal blooms including effects of historical development in the Rotorua Lakes region, which turns out to be somewhat unique (Hamilton, this publication). These lakes are national treasures and should be preserved.

NUTRIENT SOURCES

Nutrients can be derived from in-lake and catchment sources. There has been a focus in the international literature on remobilisation of phosphorus (P) from the lake-bottom sediments, but there are natural and several important land-use practices that also contribute nutrients. Sewage effluent discharge to Lake Rotorua from the city of Rotorua increased through the 1970s and into the 1980s, and this increase was directly related to lake P increases (Rutherford, 1984). Consequently, the control of this point source of P was and still is a major but tractable issue (Rutherford *et al.*, 1989). In contrast, natural sources, i.e., weathering of apatite, can produce high P concentrations as observed in many springs (Timperley, 1983) and other diffuse sources, such as P fertilizer use.

Most fresh waters are P-limited (Correll, 1999), as observed throughout the World, with the most extensive research being conducted in the U.S., England, and Europe. Some of the Rotorua lakes are at least periodically nitrogen (N) limited, and consequently, have blooms of N-fixing algae.

But even in these lakes, the problem ultimately is the reduction of P. When P is in excess, N fixation occurs, resulting in blue-green algal blooms. Generally, P is released from sediments of eutrophic lakes for the reasons that David Hamilton discussed, i.e., stratification and subsequent oxygen depletion in the bottom waters resulting in metal (Fe, Mn) oxide reduction and P mobilization. However, the excess P in the sediment was originally derived from the catchment.

And despite the nature of the blooms, reductions are required in P transport to the lake from the catchment. Research has shown that total P should be less than 50 ppb in flowing waters, and much less to return lakes to oligotrophic conditions (Correll, 1999). But the lake data from the Rotorua area indicate that the P concentration of oligotrophic lakes is less than 10 ppb, and the P concentration of the mesotrophic lakes is less than 20 ppb (Gibbons-Davies, 2003).

It has been shown (Hamilton, this publication) that the eutrophic lakes of the Rotorua Lakes Region have high ratios of catchment area to lake volume, i.e., lakes having large catchment areas relative to a small lake volume. The ratio of catchment area to lake volume, therefore, is quite useful because it clearly indicates that the catchment is the primary source of nutrients causing the lake eutrophication.

SCIENTIFIC TECHNIQUES USED TO ASSESS NUTRIENT-RELATED ISSUES

What is the water-quality problem and how do we know that we have one? And if so, specifically what is it? In this case it's gleaned from scientific information. Hopefully the environment agencies among others are collecting the data, which are necessary for a successful environmental and in this case water-quality assessment (Chapman, 1992). In the US my agency is science-based, i.e., no regulatory mandate, and we monitor hydrology and water quality at sites distributed throughout the United States. Water-quality monitoring stations on streams and lakes, in addition to stations to monitor atmospheric deposition and groundwater are used to assess spatial and temporal trends. Many of these monitoring stations have been collecting data for a long time, which allows us to evaluate long-term changes in water quality. If a broad suite of constituents are monitored, i.e., not just nutrients, then we can maybe detect water-quality changes that may be related to issues that we generally never knew or expected. However, science is relatively imperfect, in that we don't have all of the knowledge that we would like, nor do we have a plan to address all of the actual issues, mainly because we don't know what they are, and therefore, haven't anticipated them. Even with nearly infinite funding, I don't think we would be able to sort out all of the details of that complexity, at least not in the short term; it is added to a bit at a time.

A nutrient mass balance helps determine or at least compartmentalise the relative contributions of known sources., i.e., what is coming in, where it is going, where it is stored, how and potentially when it is moving. Another technique is to use a mobile and conservative constituent as a reference , i.e., one that is relatively non-reactive, and to which you compare a less mobile or more reactive and non-conservative constituent. The relative rates of change of the reactive or slow-moving constituent to the other mobile and conservative constituent, will provide some information about the retention characteristics of the reactive constituent. For example, if chloride (Cl) was relatively mobile and conservative in the catchments of the Rotorua lake region and it was only derived from the atmosphere, an evaluation of nutrient species concentrations relative to Cl concentrations would provide some information about processes affecting the temporal and spatial retention/reactivity of nutrients. Isotopic techniques are relatively new but I

see that they are already being applied to understand processes in the Rotorua Lakes Region. The isotope techniques are very powerful for source tracking, and for assessing biochemical reactions causing N-species transformations within lakes and even within catchments. In addition some isotopes are useful for age dating, but the age dating is more effectively achieved for young groundwater (<50 years old) using CFCs and SF6 (Cook and Böhlke, 2000). The combination of techniques produces the most definitive process understanding.

NUTRIENT TRENDS — AN INTERNATIONAL PERSPECTIVE

The change in N and P use in the United States from 1950 through 1994 is shown in Figure 1. N fertiliser use increased rapidly from the 1960s through the 1970s and then remained relatively constant, but is highly variable from year to year since 1980. P fertiliser use correlates with the N fertiliser use until 1980, and since 1980, P fertiliser use has decreased; note that the scale for fertiliser sales (use) is millions of metric tons. Also we see from our monitoring, and this is primarily from groundwater wells in the Midwest, that groundwater NO_3 concentrations (10-averages shown as bars) are highly correlated with the N use (Figure 2).

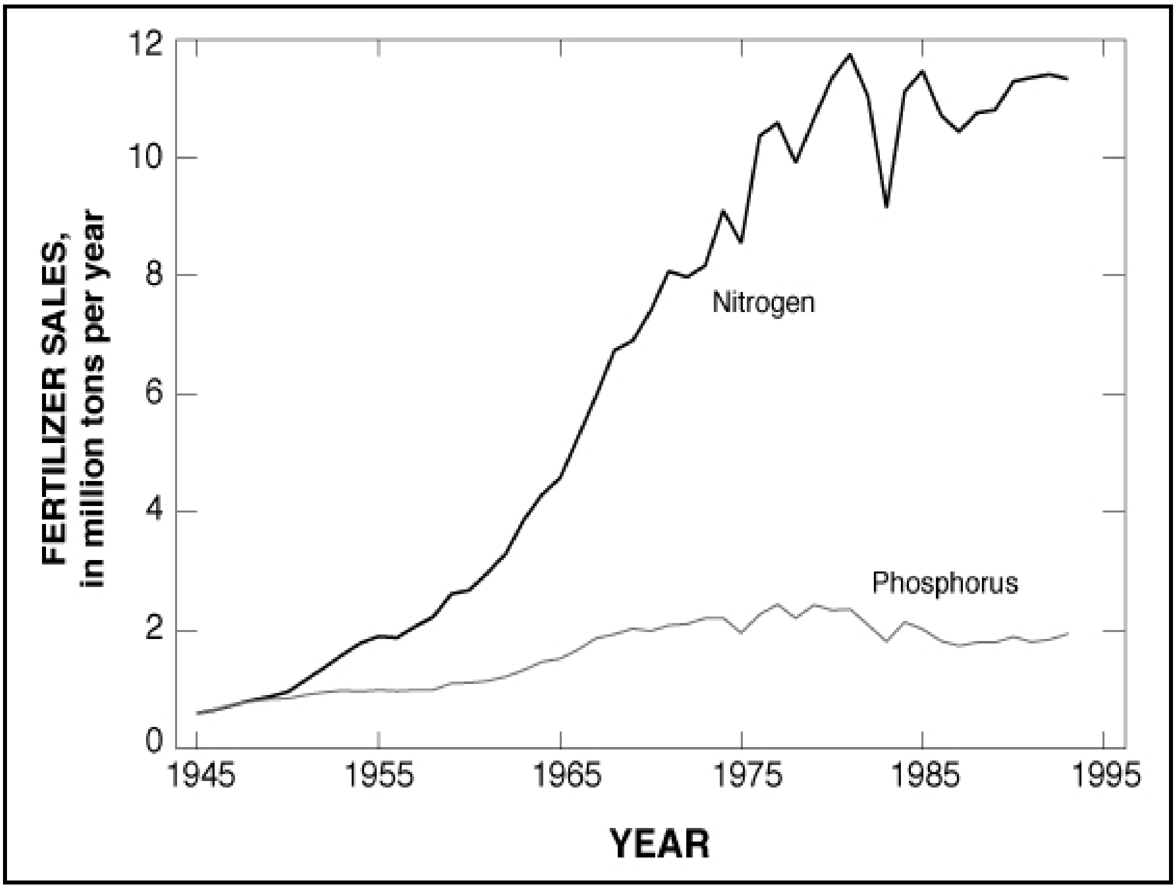


Figure 1 Fertilizer N and P sales (use) in the U.S. from the 1940s to the 1990s (modified from U.S. Geological Survey, 1999)

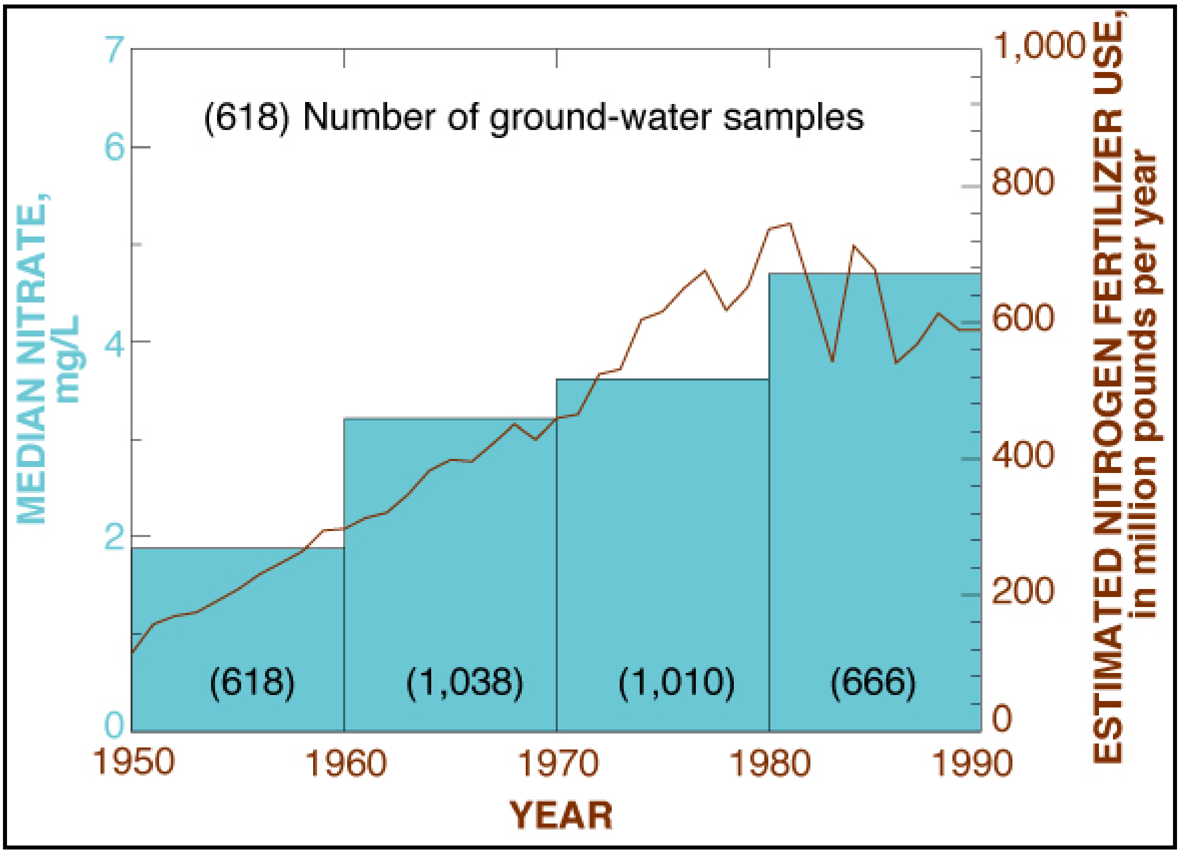
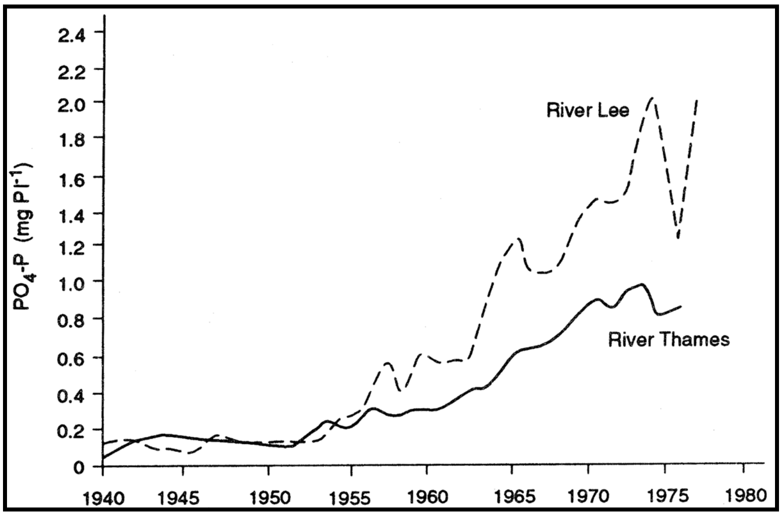


Figure 2 Relation between 10-year average groundwater NO_3 concentration and annual inorganic N fertiliser use in the Midwestern U.S. from 1950 to 1990 (U.S. Geological Survey, 1999).

In addition to NO_3 being mobilised through soils to groundwater, some N is exported to the atmosphere by denitrification and volatilisation, and some N is transported in streamwater. The increase in stream N loads is highly correlated with increases in N fertiliser use. Nutrient concentration and load increases have been reported for streams, lakes, and groundwater throughout the World, or at least in areas where fertiliser use and/or nutrient-rich sewage effluent discharges have likewise increased (Sutcliffe *et al.*, 1982; Heathwaite *et al.*, 1996). For example, Figure 3 (*below and next page*) shows increases in PO_4 concentration for two UK rivers and average changes in NO_3 concentration for a Latvian river.



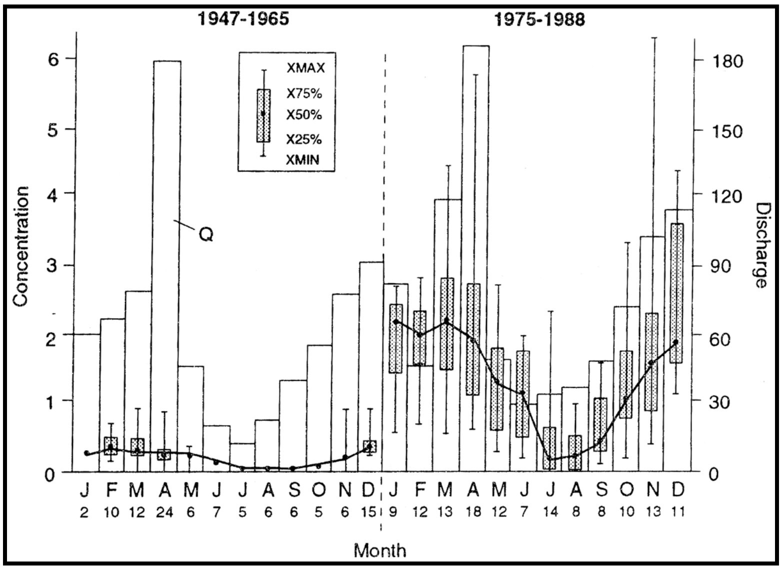


Figure 3 Temporal trends in the total P concentration in the River Thames and the River Lee in the UK (DOE, 1978) and NO_3 concentrations of the Venta River, Latvia (Tsirkunov *et al.*, 1992).

AN INVESTIGATION OF NUTRIENT TRANSFORMATIONS

The cycling of the N and P is complex, consisting of interactions with biota that typically require linkage between the cycles and other biotic and abiotic processes. New techniques have been developed to assess the complexity of these cycles, specifically to identify species transformations and to quantify the various processes.

A detailed study of a groundwater transect from cultivated land through a riparian wetland to a stream in Minnesota by Bohlke *et al.* (2002) highlights the importance of applying multiple techniques for understanding and quantifying processes (Figure 4). A variety of hydrometric and hydrochemical measurements, and age dating techniques were used. The oldest groundwater dates to the 1950s (Figure 4A). The age of the groundwater, solute concentrations of N species and other potentially reactive constituents, and the temporal patterns of crop type and associated fertiliser use were evaluated and processes could be differentiated using the N and oxygen isotopes and the age-dating techniques.

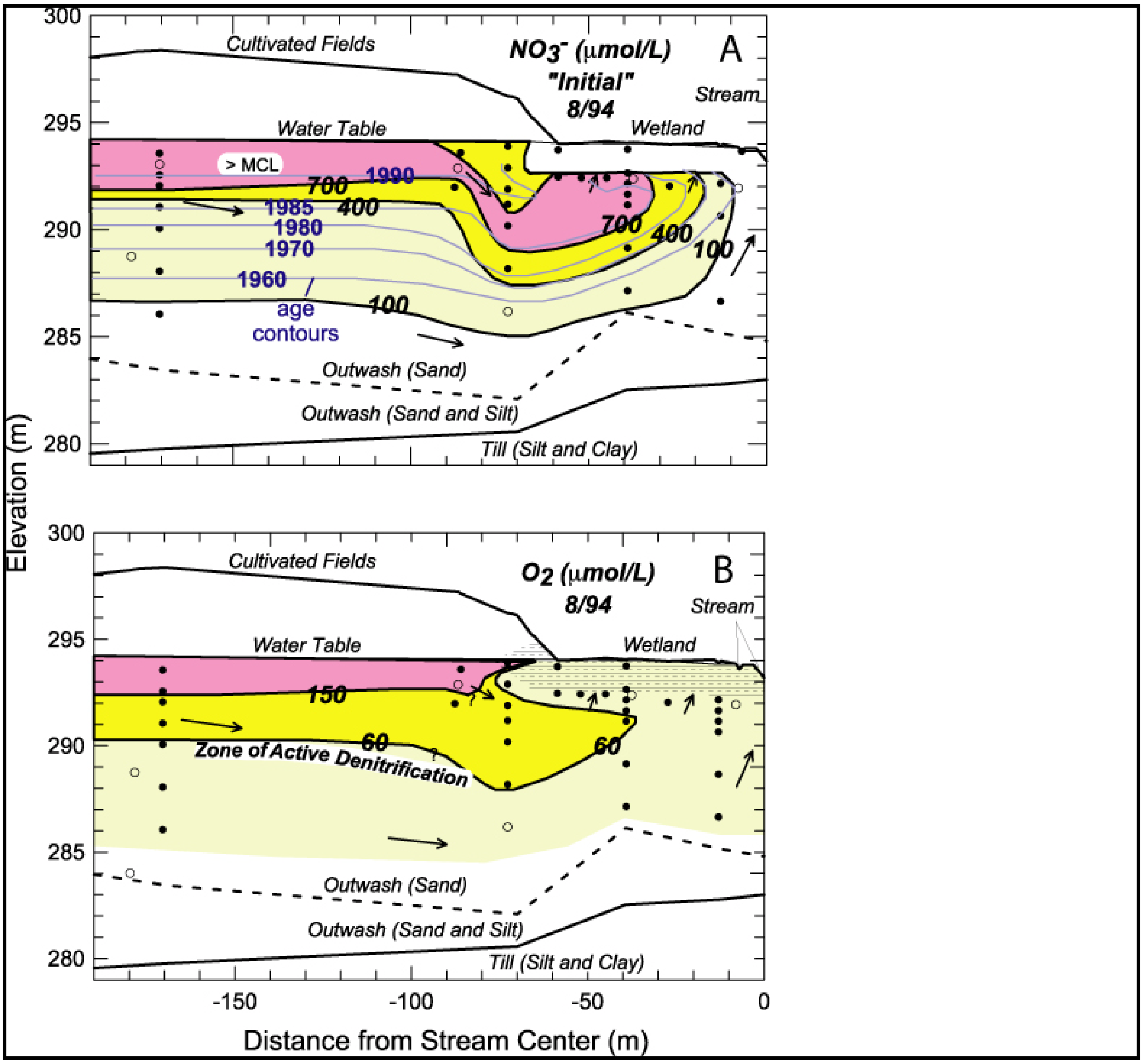


Figure 4 Vertical sections along a transect approximately parallel to groundwater flow, showing the distributions of geochemical quantities related to progress of the NO_3 contaminated plume. Arrows indicate general directions of groundwater flow. Contours are based mainly on samples collected in August 1994 (solid symbols) with a few additional ones from July 1993 (open symbols); ‘‘>MCL’’ indicates NO_3 concentrations higher than the maximum contaminant level for drinking water (714 µmol/L = 10 mg/L as N). (A) CFC-12 model recharge dates and NO_3 concentrations. (B) O2 concentrations with the distribution of active denitrification defined by the coexistence of NO_3 and excess N_2 (modified from Böhlke *et al.* (2002).

A recurring pattern has emerged from other studies in which NO_3 concentrations in groundwater are linked to the relative N fertiliser use, which was expected at the site in Minnesota. The NO_3 concentrations do not progressively change with depth or time as might be suggested by N fertiliser use (Figure 5). Consequently, there are nuances (or complexities) as to how N species are altered or processed. The N concentrations are highest in the middle and decrease to the edges, i.e., with depth and down the hydrologic gradient. The reduction in N concentrations results from an active, but thin, anerobic Fe-rich zone where the N is lost due to denitrification at the boundaries of the plume (Figure 4B). The process (denitrification) is the same as that observed in lake sediments.

Most of our knowledge about denitrification has come from studies of waterlogged soils particularly in riparian zones and wetlands. It seems remarkable that the problem of excess N can be resolved by a very thin zone which contains sufficient organic carbon (decaying plant material) and is under reducing conditions (no oxygen) that results in the transformation of the N into a gas (N_2 or N_2O), which is transported back to the atmosphere. The relation between groundwater NO_3 concentrations and time and cropping history for a Minnesota research site is shown in Figure 5. There are biochemical reactions making the actual characteristics of the site much more complex, i.e., including sulphide reduction and methanogenesis, than simply losses through denitrification.

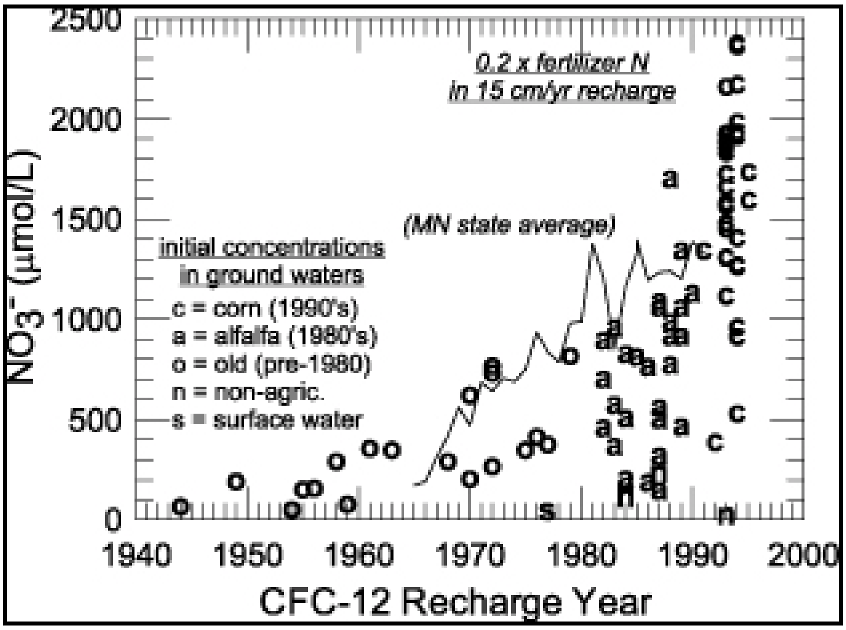


Figure 5 Relation between CFC recharge date and initial NO3 concentrations (modified from Böhlke *et al.* (2002)). A recharge category (old, non-agricultural, alfalfa, or corn) was assigned to each sample reflecting its recharge date and the generalized chronology of land use at the site. Included with the transect samples are shallow time series samples collected from within 1 m of the water table beneath the E field, all labelled ''c'' for recharge under corn. Solid lines indicate concentrations that would result from nitrification and leaching of 20% of the known or inferred fertilizer-N application rates per unit area of fertilized land, dissolved in 15 cm/yr recharge; MN state average is from Alexander and Smith (1990).

NUTRIENT CYCLES

The biogeochemical cycle of P is shown in Figure 6. P is biologically active and is a limiting nutrient in most freshwater systems. Consequently, if one removes P, biological productivity will decrease. If one increases it, productivity will increase. P has an affinity for binding to sediment, particularly Al and Fe oxides and hydroxides. An effective way of getting rid of dissolved P is to mix the water with alum (aluminum sulphate) or clay-sized particles having high Al and Fe content. The particles settle taking the P with them. A P-buffer mechanism causes the P on the solid to equilibrate with the P in solution and the amount in solution depends on the chemical characteristics of the solid and the P concentration in solution. P is typically less strongly bound to soil particles than to alum. The P-buffer mechanism will cause the P to be desorbed from a high-P soil if it is mixed with very low P water. Furthermore, there are two rates, a fast rate associated with desorption of P from the surface of the particle and a slow rate associated with the diffusion of P from more interior sites of the particle.

In addition to desorption, the primary source of P in these lake basins is from the weathering of apatite, which occurs through dissolution, This typically is a relatively slow process, but the high natural P concentration in the groundwater results from the relatively high abundance of apatite in the rocks. Once the P is incorporated into the biota, it is recycled through decay. Soil erosion also contributes P to water (P-buffer mechanism). Atmospheric deposition can contribute P but most is organically/biologically bound (Graham and Duce 1982, Duce 1983, Peters and Reese 1995). Even the organically-bound P may become rapidly biologically available.

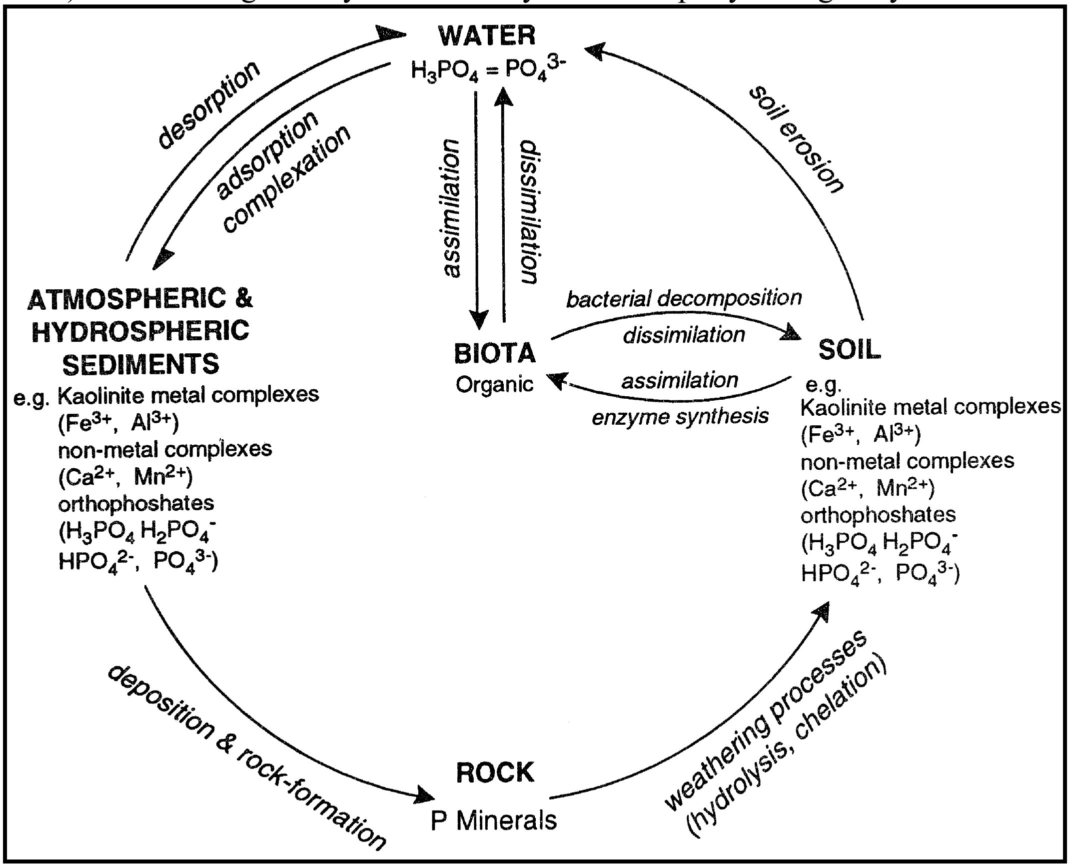


Figure 6 Phosphorus cycle (Heathwaite *et al.*, 1996).

The biogeochemical cycle of N is shown in Figure 7. N also is biologically active, but unlike P, N is generally mobile, i.e., it doesn't readily attach to particles. N species transformations are generally redox and biologically controlled. The amount of N taken up by biota in most freshwaters is limited by available P. The main processes affecting inorganic N species are ammonification (formation of NH_4), nitrification (formation of NO_3) and denitrification (formation of N_2O and N_2 gases), which puts the N back in the atmosphere. N-fixation is another major process that takes the N from the atmosphere and incorporates it in biomass, e.g., clover fixes N in pastures and some blue-green algae fix N in water bodies.

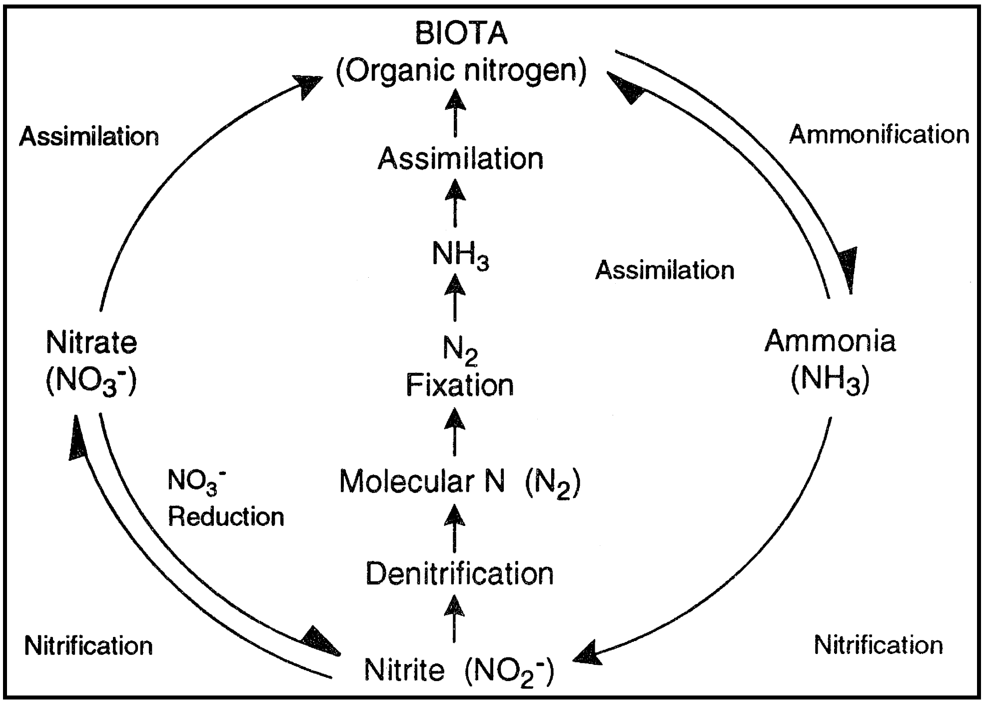


Figure 7 Nitrogen cycle (Heathwaite *et al.*, 1996).

NUTRIENT TRANSPORT

Several factors affect P transport. First of all, P has a strong affinity for adsorbing to solids (strongest for Fe and Al oxides and hydroxides), and typically, total P concentrations are highly correlated with suspended sediment concentrations in rivers, as indicated in Figure 8 for some streams in the south-eastern U.S.; the y-axis scale is logarithmic and consequently, those data for which the box plots indicate a normal distribution are actually skewed. This figure shows the concentrations of P and suspended sediment separated by flow condition (base flow and stormflow), predominant land use in the watershed, and physiographic province in which the watershed is located. Both the P and suspended-sediment concentrations are much higher during stormflow than during base flow.

Erosion occurs during storms resulting in the higher suspended-sediment concentrations than during baseflow. Soils on the Coastal Plain are coarse (sandy) and have higher quartz content than those on the Piedmont, which are typically more clay-rich with high Fe and Al oxide and hydroxide content. Consequently, P is more tightly bound to the Piedmont soils because of the smaller grain size and is more easily eroded than in the Coastal Plain, as shown by the higher suspended-sediment concentrations during stormflow than on the Coastal Plain. The box plot indicates that suspended-sediment concentrations generally are similar among the dominant watershed land-use categories within a physiographic province.

Stream P concentrations during either stormflow or baseflow generally are highest in the poultry and urban watersheds on the Piedmont compared to the other land-use types. Also, dissolved P concentrations, the readily bioavailable form of P, are proportionally much higher in these watersheds. Although the patterns suggest an association with a particular land-use (poultry or urbanization), the specific causes are much more complex and require additional research to differentiate specific processes or relations.

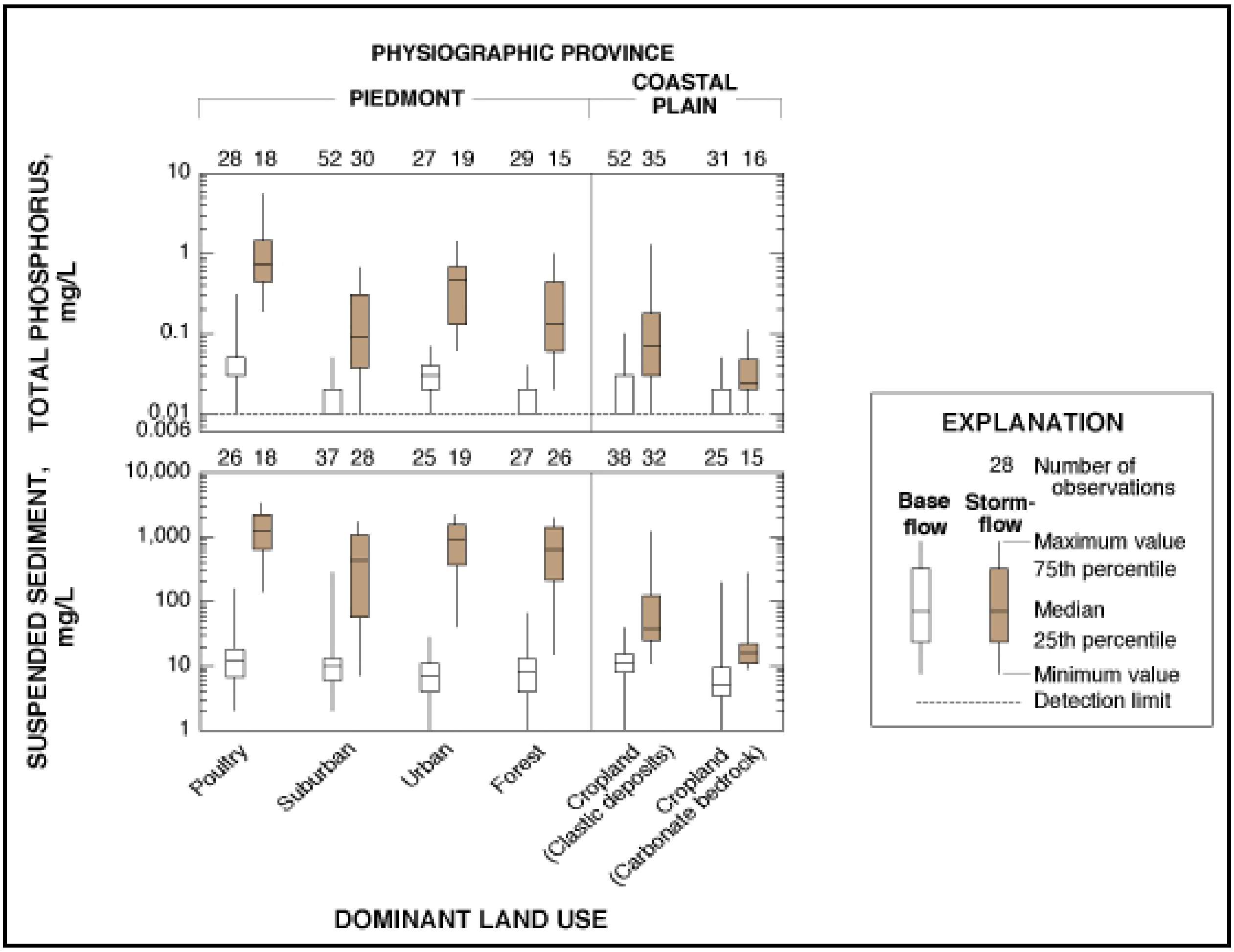


Figure 8 Distributions of total P (upper graph) and suspended-sediment (lower graph) concentrations in streams of the Apalachicola-Chattahoochee-Flint River Basin in the southeastern U.S. By dominant land-use type in the watersheds and by physiographic province from March 1993 through September 1995 (modified from Frick *et al.* 1998).

As indicated by the previous examples, several techniques are available for evaluating nutrient transport from a catchment to a lake. One technique is to evaluate the temporal patterns of concentrations, and also to combine them with discharge for evaluating flux, from long-term water-quality stream monitoring sites. A 25-year trend analysis of the nutrient concentration in rivers and lakes of Finland revealed marked P concentration (total and PO_4) decreases of large rivers and lakes where point-source wastewater treatment was implemented, but revealed increases in smaller rivers and lakes where diffuse agricultural sources dominate (Räike *et al.,* 2003). Routine fixed-time interval sampling, e.g., weekly or monthly, may not be sufficient to capture the actual transport of P, which is mainly sediment bound. The routine samples are mainly collected during non-stormflow (base flow) periods when sediment is not very mobile and hence flux estimates are skewed. Unfortunately, it's not easy to sample storms and the suspended-sediment concentrations vary among stormflows, with the highest suspended-sediment concentrations typically preceding the streamflow peak. If the variation in suspended-sediment concentration can be obtained or a flow-composite storm sample collected, fluxes can be determined and to this end the use of real-time turbidity monitoring to augment routine sampling is beginning to provide much needed information on the suspended-sediment concentration variations (and associated fluxes when combined with discharge). More temporal or composite information reduces the flux estimate uncertainty.

An alternative technique for assessing P transport is to investigate the sediment history from lake sediment cores; this has been conducted for pigmentation (associated with algal content) from local lake sediment cores (Gall and Downes, 1997). Jordan *et al.* (2001) reconstructed and modeled the 90-year diffuse loading of P from an agricutural watershed in Northern Ireland using palaeolimnological data from sediment cores. In addition, they observed high P concentrations in aerobic littoral-zone sediments draining highly P-fertilized land and attribute the increase to P mobility in groundwater (Jordan and Rippey, 2003). Using various dating techniques, the temporal varation in sedimentation rate can be determined, and by evaluating chemical content of the sediment, the concentration history can be inferred.

My concept of catchment processes is biased because the catchments where I conducted research are dissimilar hydrologically/hydrogeologically to those of the Rotorua Lakes Region. The geology and hydrogeology of "my" catchments provides an areally-proportional increase in the groundwater contribution to streamflow. The volcanic deposits of the Rotorua Lakes Region provide underground conduits and fractures that control groundwater flow and are responsible for the many springs in the area and disproportionate and discrete areal contributions of groundwater to streamflow. The groundwater recharge and discharge vary markedly across the landscape. Consequently, some areas have streams that begin at a spring, whereas some areas have no streams. The hydrogeologic characteristics therefore confound hydrological and hydrochemical process identification with respect to nutrient transport and transformation.

Groundwater nutrient concentrations will vary depending on the linkage between the sampled groundwater and the nutrient source, which will be affected by the hydrological pathway and biogeochemical processes affecting the nutrient as the water moves along the pathway. Therefore, nutrient concentrations will vary with the depth of the groundwater below land surface and the land use and associated nutrient management in the source area of the groundwater; note that this may not be the land-use around the well, depending on the hydrological pathway. Groundwater nutrient concentrations also will vary depending upon the geology.

AN EXAMPLE OF NUTRIENT TRENDS AND TRANSFORMATIONS

The nutrient species transformations observed in the bottom waters of some of the lakes as shown by Hamilton (this publication) also can occur in streams. For example, I will show some nutrient dynamics from the Chattahoochee River, Georgia (Figure 9).

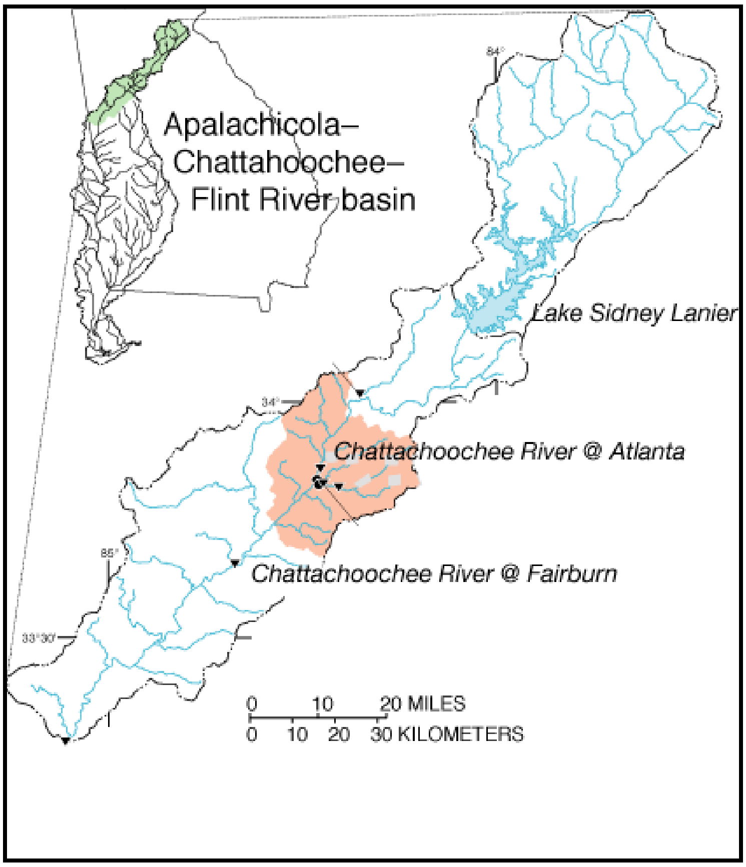


Figure 9 Map of the Chattahoochee River Basin, Georgia.

A box plot of nutrient concentrations for tributaries and the main stem of the Chattahoochee River are shown in Figure 10; the x-axis is the approximate main-stem river mile location of the station on the river or the tributary confluence with the river. The city of Atlanta site is immediately upstream of an outflow from one of Atlanta's two major wastewater treatment plants, which is associated with the pronounced increase in total P concentration. We have as many people in Atlanta as you have in New Zealand, so you can imagine that even with the wastewater treatment process, a high contaminant (nutrient) load is discharged to the river; even with 95% removal of the P in the wastewater, there is still a lot of P in the treated wastewater.

The P concentration remains high and relatively constant for a long distance downstream of Atlanta. NH_4 concentration increases markedly immediately below the wastewater treatment plant outflow, and continues to increase downstream of Atlanta, and then finally begins to decrease several miles downstream. The continued NH_4 concentration increase is caused by in-stream nutrient transformations, mainly ammonification, i.e., conversion of organic N to NH_4 under low dissolved oxygen conditions. The river is clearly not P-limited.

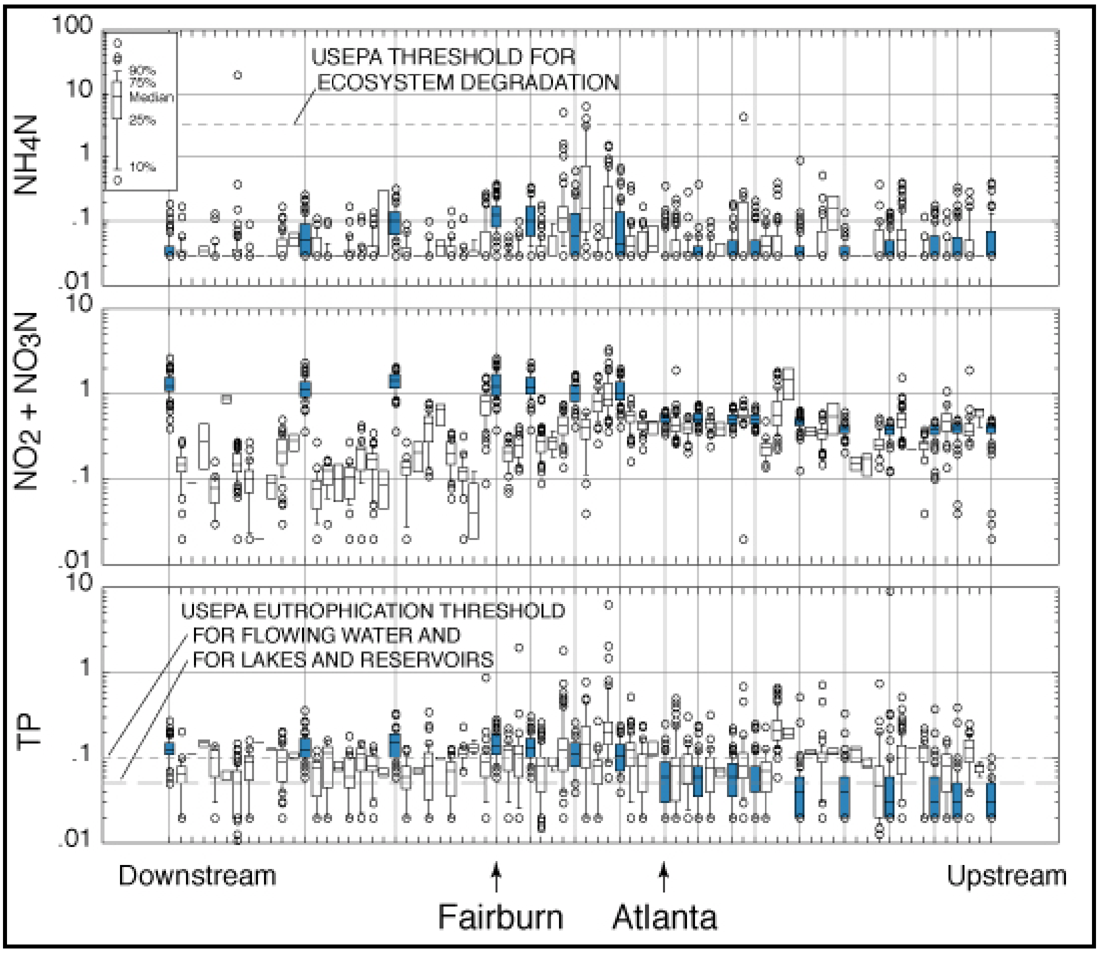


Figure 10 Spatial variation of streamwater nutrient concentrations (mg l^{-1}) among sampling sites in the Chattahoochee River Basin during May through October 1994 and 1995. Vertical grey lines and grey boxes denote main-stem sites, and the open boxes denote tributary sites. Arrows denote the long-term monitoring sites shown in Figure 11.

A comparison of the temporal trends in the nutrient concentrations at the long-term main-stem monitoring stations on the Chattahoochee River provide some additional information about the relative role of catchment and in-stream processes (Figure 11). Consistent with the box plot (Figure 10), nutrient concentrations at the Atlanta main stem station are markedly lower than those downstream at Fairburn; note the difference in y-axis values for the nutrient concentrations at each station. Total P concentration at each station increases and then decreases in the late 1980s. The change is caused by rapid population growth (P increase) and a ban on the use of phosphate detergents (decrease). NO_3 concentration at each site generally increases during the period of record; the shorter term variations at each site are associated with hydrological conditions with concentrations highest at low flows (and during summer) and lowest at high flows (and during winter). The increased NO_3 concentration is attributed to increased fertilizer use and leaching of NO_3 from septic systems, as land is being converted from forest to residential. The trend in NH_4 reflects the change in total P concentration; when P is high, the dissolved oxygen is low, promoting ammonification below Atlanta. When concentrations decrease ammonification still occurs in some reaches, but oxygen levels have recovered somewhat.

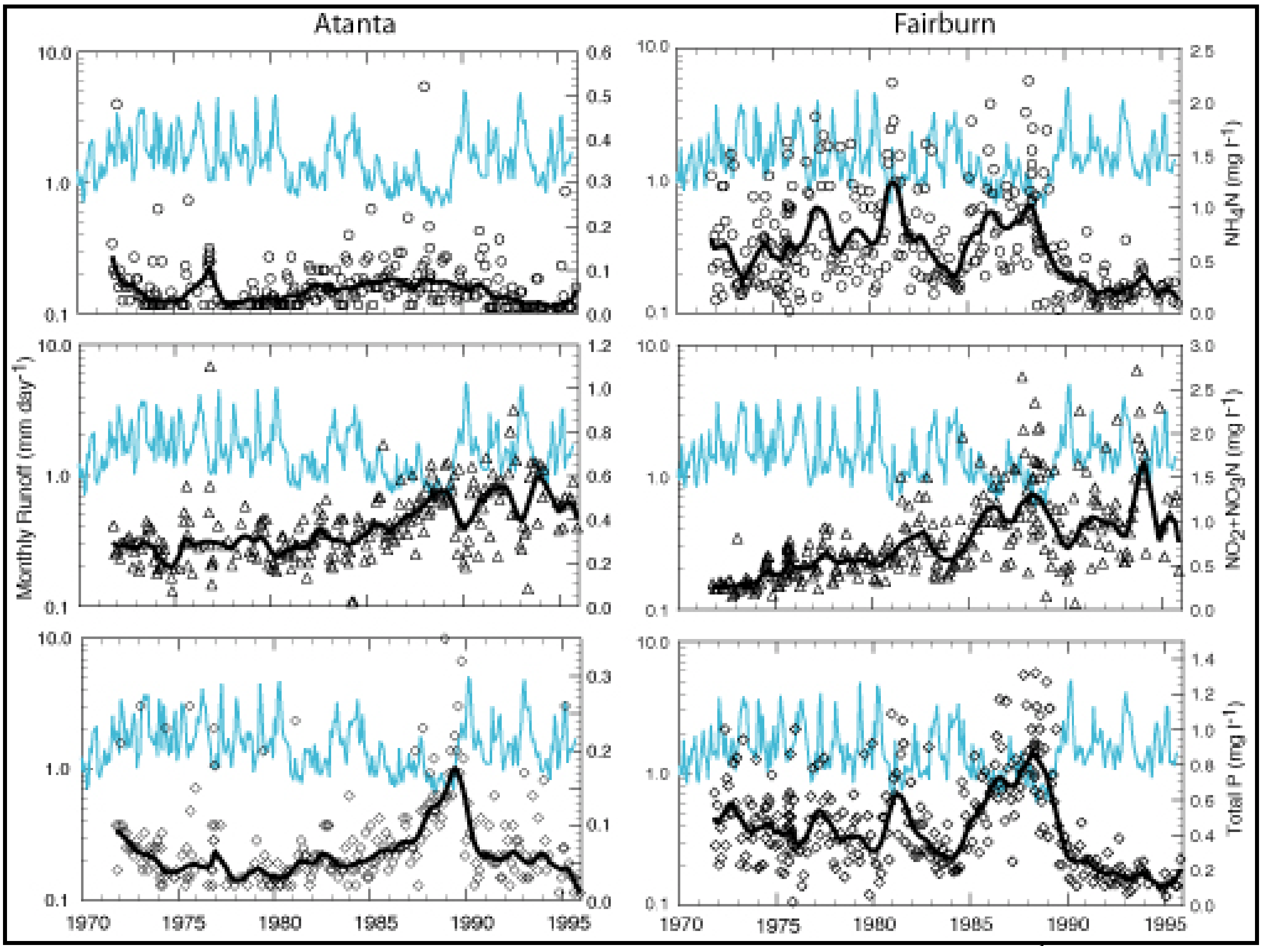


Figure 11 Temporal variations in streamwater nutrient concentrations (mg l^{-1}; open symbols), LOWESS curve (1.5 year averaging window; solid line) and monthly runoff (mm day^{-1}) of the Chattahoochee River at Atlanta (left panels), immediately downstream of waste-water treatment outflow but upstream of the confluence with the major urban tributaries, and at Fairburn (right panels), downstream of Atlanta (Peters *et al.* 1997).

NUTRIENT MANAGEMENT

Catchment P fluxes should be reduced, which entails either removing it from the water entering the lake and/or decreasing the fertilizer application of P on the catchment. P could be removed from the inflows, including those where P concentration is naturally high, i.e., from weathering, or from urban areas, or where there are P contributions from septic tank and sewage effluent discharges and stormwater. It generally is easier to treat streamwater than groundwater, and it may be most cost effective to treat those streams having the highest P concentrations and/or fluxes to the lake. One approach is to filter the streamwater through Al or Fe oxides.

An idea discussed during a local (pre-symposium) field trip was to add alum to a high-P stream; the P is adsorbed on the alum and the alum will settle near the confluence of the stream with the lake. Alum is very effective at removing P and is a standard technique for pre-treatment of drinking water.

Riparian wetlands can be used to remove nutrients (Lowrance *et al*. 1985; Cooper 1990, 1994; Tanner *et a*l. 1995; Mitsch *et al*. 2000; Nairn and Mitsch 2000). Wetlands trap

sediment, and because P is strongly adsorbed to sediment, the wetland will remove almost 100% of the P.

During storms wetlands may be less efficient because of the increased discharge and associated higher flow velocities, which may cause some of the streamflow to bypass or flow over the wetland. Also, some consideration should be given to treating ground water because in some lakes this may be a major source of P; techniques for removing nutrients from groundwater *in situ* are not particularly advanced, but treating abstracted (pumped) groundwater should be the same as the treatment of sewage, though relative volume may need careful consideration.

Alternatively, the abstracted groundwater could be diverted through a wetland. Within the lake, increases in P concentrations from mobilization from the bottom sediments can be treated through oxygenation of the bottom water. Alum could be added directly to the lake, but this may have more spatially-extensive deleterious ecological effects than adding alum to a stream. The reduction of N from the catchment is more challenging. Wetlands are not as effective in removing N as they are P, mainly because the inorganic N species are more mobile and must either be removed by biological uptake or denitrification. In either case, wetlands can become saturated with respect to P and N, at least the biological uptake component, and more likely for P than N due to denitrication of NO_3. As stated previously, when P becomes saturated, some the P will desorb from the sediment and increase the P concentration in the water exported from the wetland. Management of the wetland can be achieved by removing the P-saturated sediment and harvesting the biomass. Some of these management schemes are discussed in more detail by other conference participants.

FUTURE CONSIDERATIONS

Although the science has provided some useful information about hydrological and hydrochemical processes in the catchments and catchment nutrient transport, there are many remaining issues to which additional catchment research can contribute understanding for better resource management. Maybe this research is being or has been conducted but I am not aware of it yet. Hopefully I'll find out more while I'm here, and specifically about the stream water-quality characteristics of these different land use types. Many pastures flood during storms, and if it hasn't been done, the pasture runoff water quality should be investigated during rainstorms, particularly under alternate scenarios of land use activity and with respect to the timing of fertilizer application. Likewise for urban areas, stormwater runoff can contain high concentrations of nutrients and other harmful contaminants, and the water quality of the stormwater should be investigated; I understand that some studies have been conducted, but I don't know what the results show with respect to nutrients. Typically, nutrient applications vary temporally and in magnitude for different types of agriculture. Consequently, different responses are likely with respect to temporal concentrations and loads in receiving waters including groundwater and streamwater. Some research has been conducted on the hydrogeology in the Rotorua lakes area, but more should be done in the future. Specifically, additional ground water investigations of agricultural areas are warranted, particularly those in areas with potentially short residence times and high nutrient application rates. Groundwater-lake studies should likewise be conducted in some urban areas, such as Rotorua.

In addition to establishing long-term monitoring sites for evaluating the long-term trends of catchment-derived stream nutrient concentrations and fluxes, sites should be instrumented and studies conducted to evaluate the effects of remediation. A detailed history/inventory of the contaminant transport and sedimentation should be established for each of the lakes from sediment geochronology or palaeohistory. These sediment cores should be evaluated concurrently for a suite of parameters including age determinations (radioactive isotopes), chemistry (nutrients, metals, persistent organic pollutants), physical characteristics of the sediments, and biological composition.

PERSONAL OBSERVATIONS

The science can give you understanding, but the decisions are yours. The problem is complex and we, the scientists, aren't going to know all of the processes and linkages. Furthermore, I think that when you develop a plan and implement a solution, if that solution doesn't work, admit it and go on and find/implement another solution. I feel that it is a good idea for folks to listen to even the most hair-brained ideas. Those ideas might lead to the right solution. We may have pre-conceived ideas of how things work, but they may not be the right ones. Last, keep your dialogue going and keep it out of the Courts. Fifty-five percent of the lawyers in the world are in the U.S., and if you want some of them, we can send some of them to New Zealand.

QUESTIONS

Kepa Morgan, Auckland University: A very intriguing presentation and it certainly gave us a broader view of what's going on. I was interested in the phosphorus levels in the river analysis going past the land with the sewage treatment plant. Just by way of comparison, what would be the effect if you actually dammed the river just downstream from that for a period of time and then released it, what would be the effect in terms of the phosphorus, the ammonia and nitrate.

J.P.: Well I think David could answer that and we have had discussion about it. Clearly, if you can remove the phosphorus, you're still going to be getting it out of the water markers, so you know that's going to occur until the system has flushed itself. If you remove the P, you still need to flush it, and so that's a natural process. Even in the most pristine areas in the United States, we see that the natural process of eutrophication and filling in of lakes is normal. But if you want to make them become oligotrophic, then they need to flush that phosphorus out. It's a good thing in a way that it's actually coming back to the water column and if you have an outflow then some of it will go each year. There are other solutions to maybe try and seal the sediments or get it out of the water column entirely and seal off the phosphorus from coming out of the sediment. That's a rather drastic approach, but it may be one of the most effective approaches.

John Davies, Taupo Lakes & Waterways: You mentioned wetlands, but not planting buffer zones around the lake, with, say, nitrogen strippers. A harebrained idea, but such as hemp. Has there been much work done in this area in the US? Hemp is actually a very high nitrogen user.

J.P.: If you want to get rid of nitrogen, sure, wetlands are a very effective way because they allow denitrification. Wetland zones around a lake are probably very effective. Nitrogen has only been really targeted in the Mississippi River basin because of hypoxia

in the Gulf of Mexico. We really haven't done an extensive amount of work of trying to reduce nitrogen, as we have been trying to reduce phosphorus. The only reason that we do that is, that we move from a freshwater system that is P-limited into estuarine or saltwater which is nitrogen limited. Nitrogen is the cause for the hypoxia in the Gulf of Mexico, but we've got to reduce our nitrogen loads coming out the Mississippi River basin. So we're targeting things like wetlands and streams to remove it from agricultural areas. I don't know of a lot that's been done for reducing nitrogen loads in lakes. There has been some work, certainly. Taking sewage and running it through wetlands is a standard practice, but I don't think that people are wanting to give up their camps to make them into a wetland, and that's probably been one of the biggest stumbling blocks for lakes.

Paul Dell, EBOP: Jake, I noticed in your talk that you touched on the change in fertiliser reduction. In terms of wider land use changes, I was just wondering what your experiences were in catchments like Lake Okeechobee where there had to be a change in land use, not just trying to modify the nutrients after they have been created, but actually to reduce their creation. Would you comment on that, thanks.

J.P.: No. Sorry Paul. I would defer that to Del (Bottcher). Del has an extensive knowledge of what is going on in the Lake Okeechobee case and the various things that have been tried at various times – do you want to comment on that Del?

Del Bottcher, Soil and Water Engineering Technology Inc.: I gather the questions was, how have the land use changes affected the changes of concentrations coming to the river and using land use change as a management practice. That has been suggested. But changing land use management as a policy is difficult because the economics control how land is managed. I'll just give one example where it was forced. They decided dairies needed to be eliminated so they did a call-share programme to buy out dairies and take them out of the basin. They did change the land use from an active dairy to an abandoned site, and that abandoned site, because it wasn't being managed, has over 10 years released more nutrients than the dairies that went under the best management programmes. So land use change has, I think, a whole series of issues that are more complicated than just making it as a practice to try to improve water quality.

J.P.: Again, the comment about the wetlands and the wetland margins of lakes is not something I am familiar with, but they have been used very effectively in stream systems for removing nutrients.

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Nitrogen and phosphorus cycling within pastoral farming systems in New Zealand

Ross Monaghan[1], Stewart Ledgard[2] & Richard McDowell[1]
[1]*AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel*
[2]*AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton*

INTRODUCTION

Nitrogen (N) and phosphorus (P) are increasingly recognised as important contributors to the eutrophication of surface water bodies and the consequent deterioration of ecosystem health. In a predominantly rural landscape, such as New Zealand's, leakages of these 2 nutrients from farming systems invariably make a significant contribution to nutrient loadings to streams, lakes and estuaries. Here we outline some of the principles involved in N and P cycling within grazed pastoral farming systems, and draw attention to parts of each nutrient cycle where efficiencies can be achieved through the adoption of improved and novel farm management systems. In most cases, application of these management practices can also optimise financial returns or are cost-neutral. Our focus is on what happens on-farm and does not consider the fate of these nutrients once they have exited the root zone in drainage water or are lost to surface waters.

PRINCIPLES OF N CYCLING IN PASTORAL FARMING SYSTEMS

Research addressing nitrogen flows through our pastoral landscapes clearly establishes the important role that clover plants play in the introduction of fixed N into pastures, and how this drives pasture yield (e.g. Ledgard 2001). In recent times this clover N fixation has been supplemented with increasing amounts of N fertiliser, particularly on dairy farms, allowing farms to both increase pasture yields and provide some strategic control over the timing of when additional N-boosted pasture is required. A consequence of increased N cycling intensity has been the inevitable 'leakage' of increasing amounts of N from the soil-plant system, mostly from concentrated urine patches deposited on the soil by the grazing animal. Because grazing stock typically retain less than 15% of the N that they ingest in their pasture diet, most of the N consumed is excreted back to pasture in the form of dung and urine (Figure 1). These excretal patches represent 'hot-spots' where N losses, either in drainage or via gaseous forms, are exacerbated. Field trials in New Zealand have demonstrated that, under typical farming practices, these 'hot-spots' contribute the bulk of the N lost in drainage waters. Direct losses of recently applied fertiliser N are usually low unless applications have been made at a time when pasture uptake is low, such as during winter (Ledgard *et al.* 1999).

Another key feature of the grass-clover based pastoral system is the self-regulation or feedback that occurs between legume N fixation and the soil inorganic N pool. Legume N fixation is known to decrease as the amount of inorganic N in the soil increases. Because of this feedback mechanism, long-term established pastures solely reliant on legumes for supplying N are effectively limited to total N inputs of less than 250 kg N/ha/yr. The availability of N fertiliser removes this limitation and allows for potentially much greater N inputs. Figure 2 shows how this intensification inevitably leads to greater losses of nitrate in drainage waters. The challenge for current research is to see how we can decrease the amount of N leached per unit of N input, i.e. decrease the slope of the line of best-fit in Figure 2.

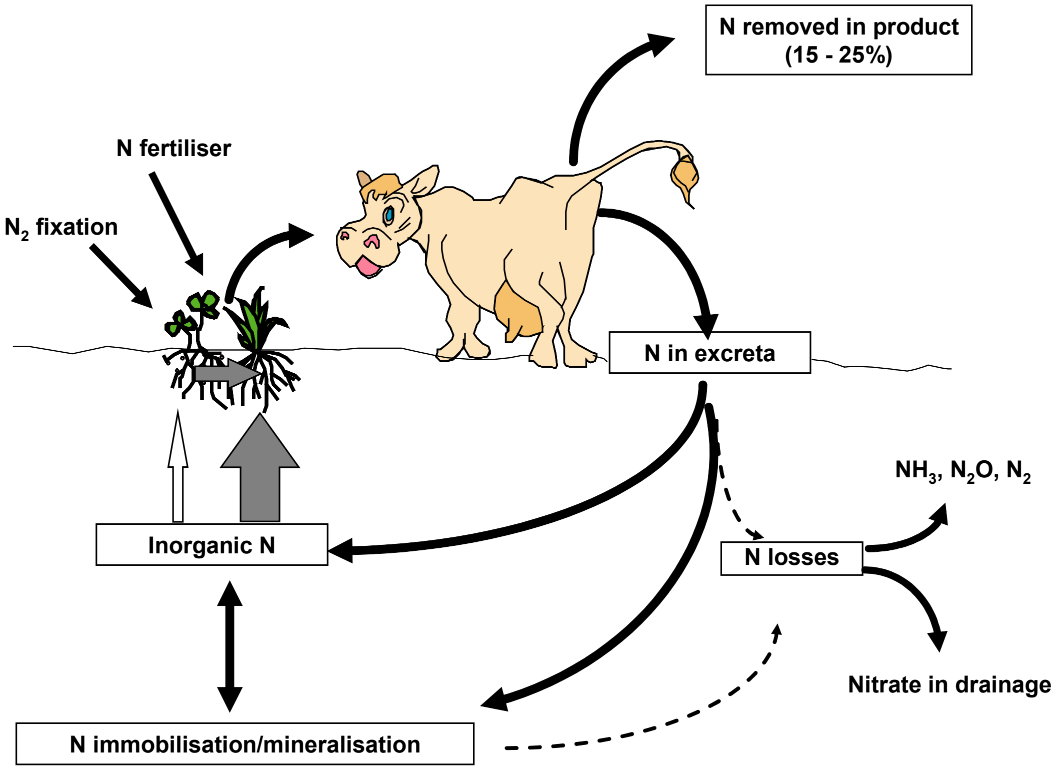

Figure 1. The nitrogen cycle of grazed pastoral farming systems.

Options for decreasing N losses

Much of the historical research on N losses to waterways has been conducted within the context of protecting groundwater drinking supplies from excessive nitrate contamination. When interpreting findings from field studies and thus deciding on 'Best Practice' for farming systems we have tended to use a concentration of 11 mg N/l (the maximum permissible level for nitrate in drinking water) for defining upper limits for N inputs to farming systems. However, the role of nitrate in contributing to nuisance weed and algal growths in lakes has been increasingly recognised in some lake catchments of New Zealand. Because N guideline concentration values for protecting these nuisance growths are considerably lower (*c*. 20-fold) than that for drinking water, greater attention and effort is required to ensure that leakages from farming systems are minimised. Recent and on-going research seeks to minimise these leakages by targeting and manipulating the amounts and timing of N excretion. The rationale of these strategies is to (i) decrease the amount of N excreted by the animal, thus decreasing the amount of urine N in the soil that is potentially available for loss, and (ii) avoid applying or depositing N to the soil at times of high risk. Situations of high risk are when there is a high likelihood of subsequent drainage, typically between mid-autumn and mid-winter.

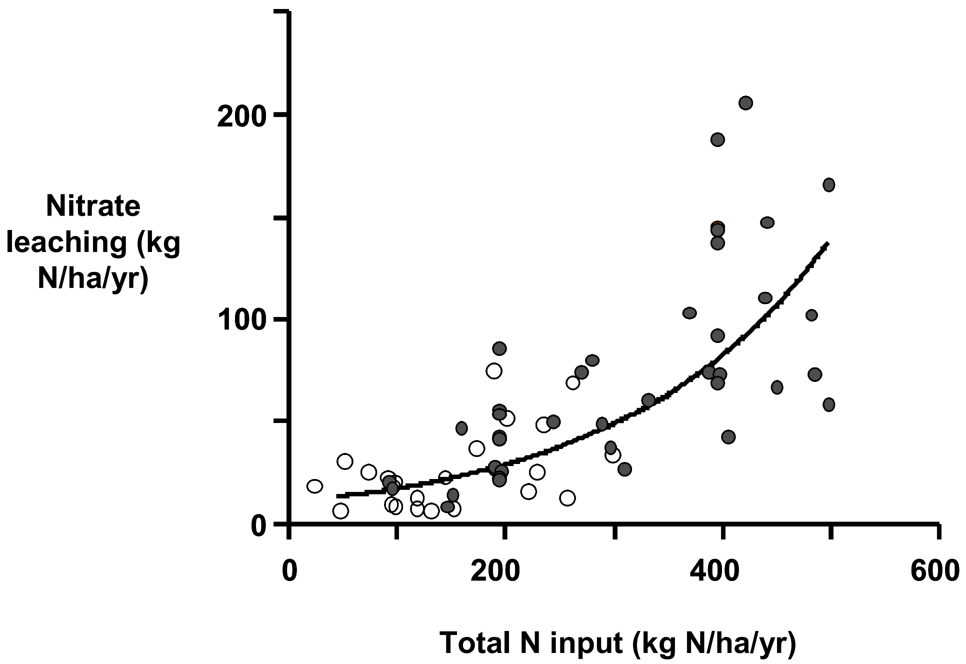

Figure 2. Relationship between N inputs to grazed pastoral systems and nitrate leaching losses. Open circles represent studies where no N fertiliser was applied; solid circles represent studies where N fertiliser was added. All data are from farm system research studies in NZ and Europe.

Strategies for reducing the amount of N excreted by the grazing animal rely upon decreasing the concentration of N in the diet. This can be achieved by replacing N-boosted pasture with low-N/high-C feedstuffs such as maize or cereals. As well as significantly decreasing N leaching losses from farms, such strategies can also lead to improved animal performance and, if expressed on a per unit product basis, can deliver lowered emissions of other environmental contaminants such as methane and nitrous oxide.

Strategies that focus on avoiding high-risk timings of N applications (fertiliser or excreta) also have proven merit. In terms of N fertiliser applications, current recommendations advocate avoiding applications at times when pasture growth rates are low (e.g. in winter). In principle, if farmers adhere to 'Best Practice' of targeting individual fertiliser applications to match plant demand, we suggest that there is little scope for further efficiency gains. In contrast, the deposition of urine N in amounts that far exceed plant demand, and at times of the year when drainage is imminent, mean that considerable efficiency gains in N cycling could be achieved with regard to manipulating urine N. Field studies in Waikato, Taranaki, Otago and Southland demonstrate significant decreases in drainage N losses where feedpads have been used to feed animals during autumn and winter, avoiding the deposition of urine N to pasture during relatively high risk seasons. The decreases in N leaching due to restricted autumn/winter grazing of field trials in Taranaki and Southland are shown in Figure 3. For the Restricted Grazing treatment in the Southland study, cows were allowed to graze pasture for 3 hours during each autumn rotation, thus decreasing the feeding requirement while animals needed to be on the feedpad. Implicit in such a management approach is the requirement for adequate effluent collection and storage facilities as part of the feedpad system. Collected effluent is then returned to pasture during the relatively low risk seasons of spring and summer.

For a full description and theoretical consideration of such systems, the reader is directed to publications by de Klein and Ledgard (2001) and de Klein (2001).

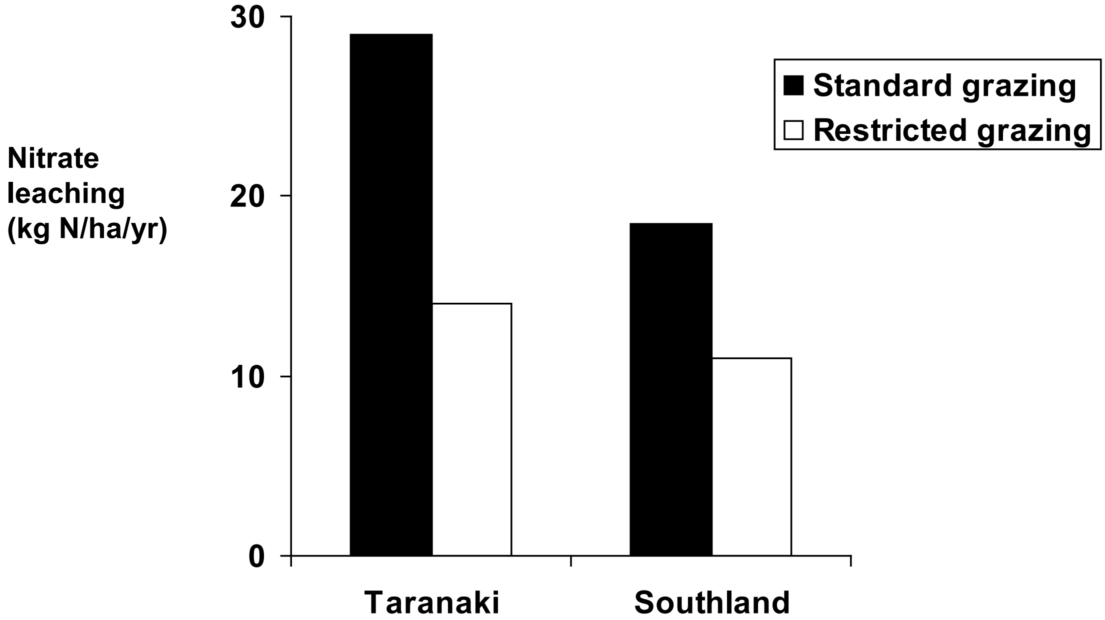

Figure 3. Nitrate leaching losses under Standard and Restricted (nil grazing in autumn/winter) grazing treatments in field studies conducted in Taranaki and Southland (mean losses for 2 years of measurement).

The on-farm implementation of such management systems provides a cautionary tale of how farm systems can adapt in such a way to effectively decrease the environmental gains suggested from research experiences. In the case of farms within the Taupo catchment, a participatory approach with farmers identified that changes to winter grazing management (e.g. grazing off outside the catchment) could also lead to changes in farm stocking rates and autumn grazing management. The net result was that this combination of management changes resulted in decreases in N leaching losses of only 18%, rather than the 35% decrease that was predicted to occur as a result of the isolated change to winter grazing management. Lessons learnt from this exercise suggest that activity rules will not always work if taken in isolation. Furthermore, management solutions that address economic and social considerations, as well as environmental ones, should have some degree of flexibility to ensure that they can be adapted by the diverse configuration of farming businesses.

PRINCIPLES OF P CYCLING IN PASTORAL FARMING SYSTEMS

In contrast to N, our understanding of P flows and losses from pastoral farming systems is less well advanced. Annual inputs of relatively high amounts of P fertiliser, by international standards, are required to support clover growth and N fixation, resulting in topsoil that is P enriched. Although it has been traditionally believed that P was relatively immobile and tightly held within the soil, more recent research has demonstrated that

small yet environmentally significant amounts of soil P can be lost in overland and subsurface flow. Large amounts of P can also be displaced from soil to water via soil erosion (Figure 4).

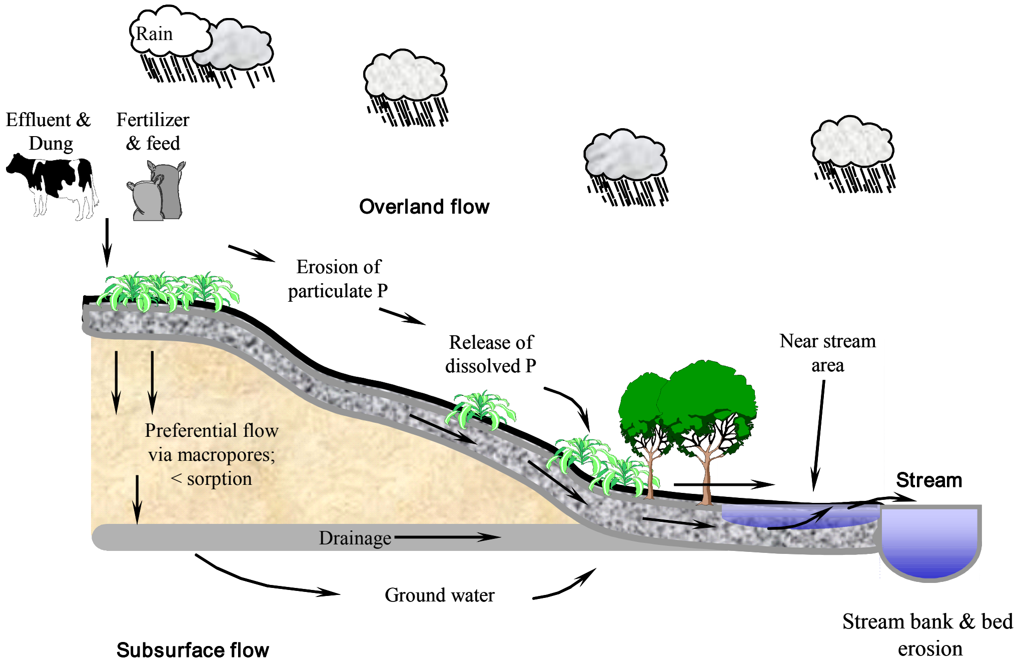

Figure 4. Pathways of phosphorus loss from land to water.

Potential P losses and concentration in water will increase with available soil P levels as demonstrated by the relationship between soil Olsen P and DRP (Dissolved Reactive Phosphorus) measured in rainfall-simulated micro-plots and shown in Figure 5 (McDowell *et al.*, 2003). For the weakly- weathered Pallic soils (Waikoikoi) that have few iron and aluminium oxides to retain P, losses are much greater than observed for Allophanic soils (Egmont), which by contrast have relatively high amounts of P-fixing clays. Phosphorus losses from the moderately-weathered Brown soils (Waikiwi) are intermediate between those of the Pallic and Allophanic soils. It should be noted that the data in Figure 5 indicate the patterns of dissolved soil P losses from ungrazed pastures and do not include contributions from dung and sediments eroded due to the actions of grazing animals. The data is presented here to show potential differences in P loss between soil types.

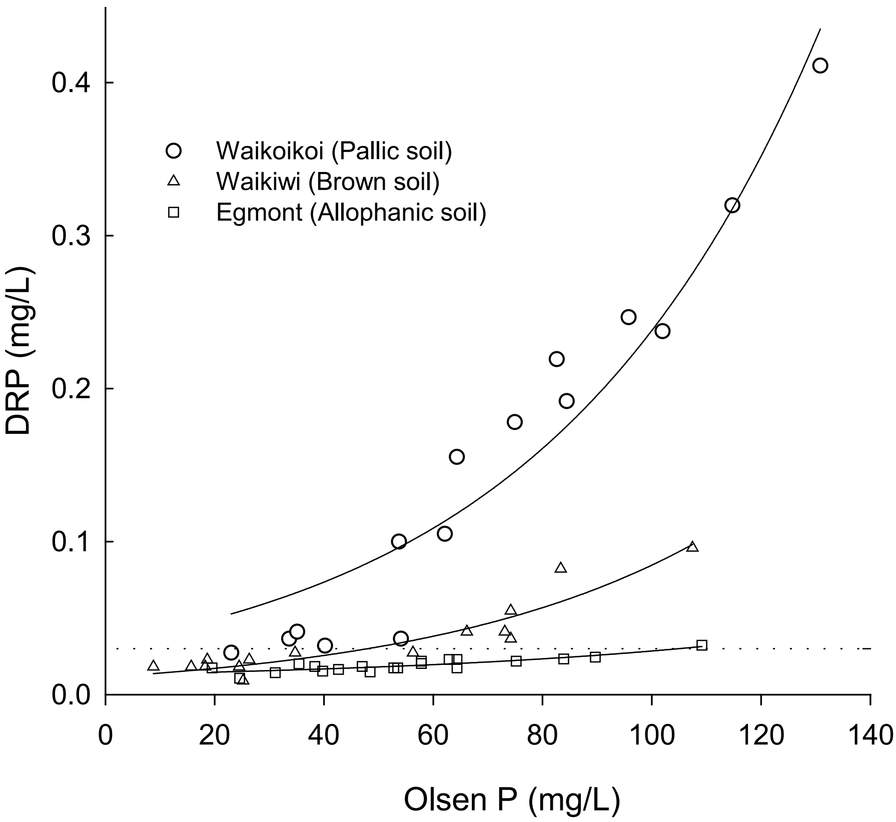

Figure 5. Losses of dissolved reactive P in overland flow from 3 contrasting soil types under a range of soil Olsen P levels (from McDowell *et al*. 2003).

Management practices for decreasing P losses
Research experiences indicate that the simplest measure for reducing potential P losses in runoff to waterbodies, whilst maximising economic returns (Morton *et al*. 1997), is to ensure that soil Olsen P levels are maintained in the target ranges for the appropriate soil types and farm production levels. These are (μg/ml):

for ash and sedimentary soils: 20-30
for pumice and peat soils: 35-45

Soil Olsen P levels above 30 on ash and sedimentary soils, and 45 on pumice and peat soils, can only be economically justified if milksolids production/ha is in the top 25% for the supply area (Morton *et al.* 1997). It is also important to minimise pugging of soil, especially soon after fertiliser P application or in close vicinity to streams and drains. Additional best practices, as recommended in the Fertiliser Code of Practice, include (i) allowing a margin of greater than 20 metres between the fertilised area and open water (applies to all fertiliser), (ii) fencing off all waterbodies from stock to prevent P entering from dung or streambank erosion, (iii) not applying P to saturated soils or before heavy rainfall, and (iv) fencing off a riparian strip on each side of all swamps, drains, streams and rivers. Some of these recommendations have more relevance to the less developed Recent and Pallic sedimentary soils because of their greater risk of P runoff. The OVERSEER® nutrient budget model is a useful tool for fine-tuning fertiliser management policies to ensure P inputs are in balance with outputs, thus avoiding the excessive accumulation of P in the soil (or conversely, the mining of soil P reserves where outputs

exceed inputs).

It is envisaged that future mitigations for controlling P losses from land to water will need to more closely consider spatial arrangements of land use and land managements, targeting those areas that are known to contribute much of the P loss from catchments.

CONCLUSIONS

Modern farming systems inevitably leak significant amounts of nutrients such as N and P. These leakages of nutrients are increasingly recognised as important contributors to the eutrophication of surface waters in many New Zealand catchments. Although it is unrealistic to expect that "infertile waters shall drain from fertile pastures", there are many land management practices that can minimise these losses whilst maintaining farm productivity and profitability. In nutrient sensitive catchments, such as around some of the Rotorua Lakes, additional measures will be required if environmental targets are to be achieved. Some of these measures will incur additional cost and require major changes in how soils, pastures and animals are managed, particularly during high risk times of the year.

QUESTIONS

Brian Riesterer – Environment Bay of Plenty. Could you just tell me where you take the cows off and put them on a feed pad over winter, if you assess the triple bottom line effect of enhancing that grass to feed to the cows?

R.M.
Yes. I didn't actually do that modelling analysis, but I believe that would have been factored in. The farmer reaction was to try and recover as much of that surplus pasture as possible, that's why stocking rates were increased and it did actually cause a bit more nitrate leaching.

B.R. What about the use of diesel on farms?

R.M. I can't comment on that, I'm not sure it would be an issue for the free draining soils around Taupo.

B.R. I'm talking about triple bottom line and the overall environmental effects.

R.M. I didn't see the figures myself, but I gather that was factored into it, and I'm not sure there was a lot of harvesting required. Now this point I might ask Bruce Thorrold over there, was that factored into the whole study?

Bruce Thorrold, Dexcel. Just to give you a bit of detail, in the Taupo catchment the solution for wintering off was to take those cows outside the catchment and winter them on a farm somewhere else, so while we include the cost of cartage, there is no need to include the cost of the housing. If you're in a situation where you want to house on the farm, there are all the issues of concrete, steel and animal welfare – would all these be factored into it, and would you anticipate that it would make it more expensive?

R.M.: I think the feed pad requirements in housing, though not the covered housing, was factored into those financial figures I presented there.

Rowland Burdon, Royal Society. I take it you are addressing purely leaching right through the soil column are you in this study?

R.M. In the Taupo Study? Yes in fact most of the data I was talking about was for this.

R.B. My question from there is, what about surface run-off in these pumice soils, if there is a dry spell the soil can become very resistant to re-wetting and if there is a high intensity storm after a considerable dry spell, there would seem to be considerable potential for large nitrogen losses and perhaps phosphorus losses through surface run-off. Not only that, but losses of that sort would represent major pulses of nutrient inputs. Would you like to comment on that?

R.M. Yes. The short answer is we don't have very good data that has measured that loss process. We do have some anecdotal evidence; again, my colleagues at Ruakura encountered this problem in a particular farm in Taupo, where they were trying to irrigate onto those dry soils that were repelling the water. So yes, I'm sure it's an important issue. We don't have a good understanding of it, but it's something that I believe should be factored into further research.

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From Audience To Action: A Dairy Farmer's Response

Chris Sutton
Farmer spokesperson for Project Rerewhakaaitu; Federated Farmers, Rerewhakaaitu, R.D.3, Rotorua

ABSTRACT
The Rerewhakaaitu community has had a long history of working with the Department of Conservation and Environment Bay of Plenty. Apart from the buffer zone around the lake most of the streams and springs have been fenced off and protected.

Project Rerewhakaaitu is a proactive initiative by farmers to access and understand their impact on the environment. The group is made up of farmers within the Lake Rerewhakaaitu catchment, Department of Conservation, and Environment Bay of Plenty. It has taken two years to secure funding and is only in its early stages.

The project will rely on total and full disclosure of information and on open debate and will provide much-needed "hands-on" experience to supplement today's desk-top modelling.

The farmers will get to see the results first-hand and consider options on how they can address the issues as they arise, rather than reading about them in the Press after they are presented at a Symposium.

I believe that if people are allowed to buy into the process at an early stage, they will take ownership of the final decision.

The farmers understand that they contribute to the catchment and believe that if we are all here for the environment the solutions should be easy to find. Farmers realise that living in a catchment has its price, as the lake is pivotal to the community.

(Tape Transcript)
It's the first time a farmer has actually, I suppose, had the opportunity to defend or put forward a response in any shape or form. In 2001 I was one of two dairy farmers who attended the first Rotorua Lakes Symposium. To put it mildly, it was an eye opener. I can understand the need for such a forum, however there is the potential to excite a lot of well-meaning people into an almost mob-like approach to issues that should really be handled with a lot of diplomacy and common sense. Today I wish to show you a group of slides from the Rotorua lakes area and some of you I know are unfamiliar with the lakes. Also to introduce you to the Rerewhakaaitu project and the lake itself.

The first slide as you see is Okawa Bay and Mourea, Ohau Channel, Lake Rotorua and Lake Rotoiti. The target TLI for Rotorua is 4.2 and for Rotoiti is 3.5. I have difficulty understanding that Rotoiti is going to get any better when you're putting 4.2 into 3.5, but anyway, it's not my job.

As you can see, they are joined at the hip quite well. Ohau Channel comes in quite close here to Okawa Bay, and Okawa Bay is just about land-locked in here. So the idea of district councils to pipe some of this through to Okawa Bay, or even ,I understand, as a few Australians would do, just drop a bully (*bulldozer*) in there and just poke a hole through, which could tidy that up a wee bit. The proposal before the Rotorua District Council was to take all of this, reticulate the sewerage from here (*Mourea and Okawa Bay, Ed.*) up into the pine trees and ground soakage up there.

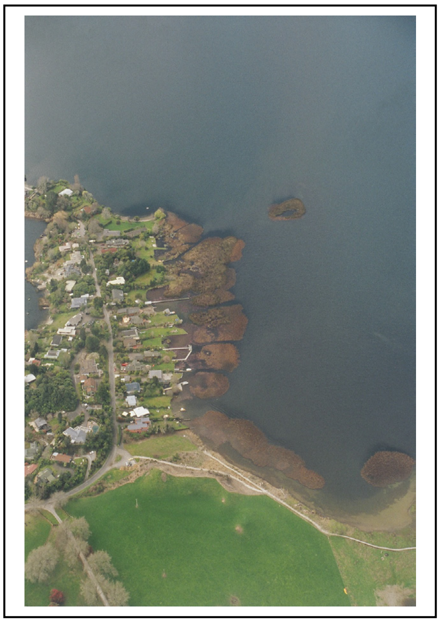
The proposal there was 550 cubic metres a day to ground soakage or a 1.5 hectare site. That's equivalent to 20 milk tankers plus trailers a day entering that site and letting it go. They were going to take the solids off and let the rest in. Milford Sound's highest recorded annual rainfall is 7 metres. This site would receive the equivalent of 14 metres of rain of treated sewerage a year. The ground water is estimated by the consultants at a depth of 20 metres. The site is 300 metres from Lake Rotorua and 700 metres from Okawa Bay. The consultants preparing the application estimated that the wastewater would take only 300 days, 10 months, before it was back in the lake. Thankfully wisdom prevailed and late last week the application for consent was withdrawn averting, I believe, a possible environmental disaster there. A proposal like this is not a silver bullet in today's environment. It's nothing more than a dum-dum from World War I. We need to get this sort of wastewater out of the catchment. We need it right out and we need to consider more modern options similar to those taken in Taupo and Mangakino. As a farmer I couldn't get away with what they were proposing.

The next slide is above Okawa Bay looking back into Rotorua. The white bit that you can see there is the bay in behind the Government Gardens and around Sulphur Point. It's basically where most of the catchment over here comes back in. So really the proposal is now to take the 20 tankers from Okawa Bay, head them down this way with a pipeline, and they all join all up with 1,000 tankers a day from the city of Rotorua and they'll head back into the catchment at the highest point and they'll spread that under the pine trees.

This is Sulphur Point here and you can see the entranceway here where it comes in. The sewerage treatment plant is here, you've got the Polynesian Pools, you've got the CBD or basically the run-off from the city, and that comes in through its own treatment station over here. This here must be quite warm, it has quite a high thermal activity. This is the stream that comes through the Hemo Gorge. The run-off from there is geothermal. There's a landfill out the back. Of course there's farming, there has to be farming. There's the Waipa Mill

site and it's just behind the Hotel here - you can wander along and have a look at it. It's where the Maori boys used to jump off the bridge for coins. And I say used to – if you have a good look at it, you'll understand why they don't now.

This is Lake Okareka. This was the subject of a lot of debate at the last symposium (workshop) and the main thing here was "the best bang for bucks". It was proposed that we could purchase farmland around this lake and plant it in forest, therefore removing sufficient nutrients and not having to worry about the septic tanks here. A wonderful example of a desktop model. I'm a great believer in having a buffer zone around a lake and as you can see we've started it here, around the side here and there's a man-made wetlands there. These slides were taken just after quite a bit of rain, so the lake is quite full.



This is Acacia Point at Okareka. This slide interests me quite a bit and has been a bit of a concern for me. Why do we spend public money purchasing properties to develop man-made wetlands, while turning a blind eye on this activity (*removal of in-lake vegetation Ed.*), especially if we believe so strongly in wetlands being such a silver bullet for improving the quality of this lake. Shouldn't we be considering the obvious options first, before we go asking Government for money to purchase properties in order to appease just a small sector of the community.

This is Lake Okaro from the air (*not shown*). Rainbow Mountain, the main State Highway, you're looking south towards Reporoa. It's in the Rotomahana catchment and there are not a great many farms there, it's a very small catchment, mainly over this side. Landcorp farms around here. There's one dairy farm over here and a dairy farm here. It's all Rotomahana mud, so that's come from the Tarawera eruption. This here is Lake Rotomahana (*not shown*), twice the size of what is was before the eruption, and that's Lake Rerewhakaaitu (*next page*). You can see that it's 100 metres above Rotomahana in height.

The farmers in the area are aware that they contribute to the lake and have had a history of involvement in improving and maintaining the quality of the lake. What they want to know from the project that's being started is more about how and where they contribute and the possible ways of reducing this. The contributors to the project are MAF, Dairy Insight, FertResearch and Environment Bay of Plenty. Those around the table are Environment Bay of Plenty, the landowners and the Department of Conservation. The reason the Department of Conservation is there is because they administer the buffer zone

around there with Rotorua District Council, but are the major players on the buffer zone, and we've had a long-standing relationship with them. The Rotorua District Council is involved, as they have purchased a farm in the catchment and are in the process of rezoning it so that they can establish a timber mill here. They are part of the project as a landowner.

The science providers are AgResearch through Martin Hawke and Mike O'Connor. The facilitator is Bob Parker of Agriculture New Zealand in Tauranga, and it has taken some time to finalise the funding. We are currently at a very early stage and nothing yet has been reported back to the group. I strongly believe that having been brought in early to any process, people tend to take ownership of the results and any action if required. Therefore, now that we're up and running I would expect that all proposals within the project will be presented to the group, so that they fully understand the science and the direction the work is taking before that is started. This is to eliminate misunderstanding, doubt and suspicion. This is another shot looking straight down.

This is looking over Blarney Lodge. You can see that it's not a deep lake. Blarney Lodge is a fishing lodge and it has a state of the art sewerage system costing about $20,000. This is as close as anyone can really get to the lake, that's the narrowest the buffer zone is in this area. The lodge was a category winner of the local Master Builders Award, however I'm not too sure whether there was an environmental category. Maybe it's something that they could think about next year. The lodge owner, Pat O'Keefe counted 250 Canada Geese in this one bay. The report by Environment Bay of Plenty has the geese population at 120 birds. I see Fish & Game believe the increase in geese numbers in New Zealand is due to the farmers growing more grass, so again it's our fault. I suggest that we leave it to the farmers because we can have a decent crack and maybe a decent shot at solving the problem on behalf of Fish & Game. The lake is home to hundreds of holiday makers over the summer months and is open all year round for fishing. That should tell you the quality of the lake. My understanding is that it hasn't recorded a bloom or anything like that, so it has a good history.

The evaluation of ground water wells.
Recently Environment Bay of Plenty commissioned a ground water survey. This was interesting for the locals because it gave an indication of what was below them. The slide (below) shows those wells measured within the greater Rerewhakaaitu and the Rainbow Mountain area. It does not show all the wells. There are something like 119. At a public meeting to explain their findings, they were told that all the ground water was flowing away from the lake, except that in the Araroa Stream. I've drawn a line along the Araroa Stream and basically where Yankee Road is. You can see it's a little bit confusing.

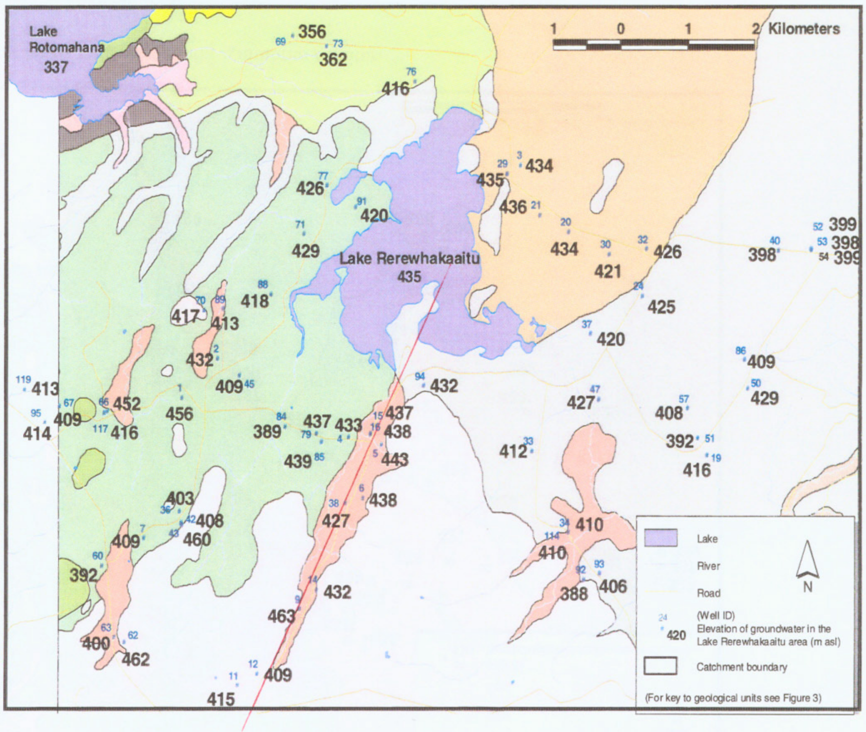
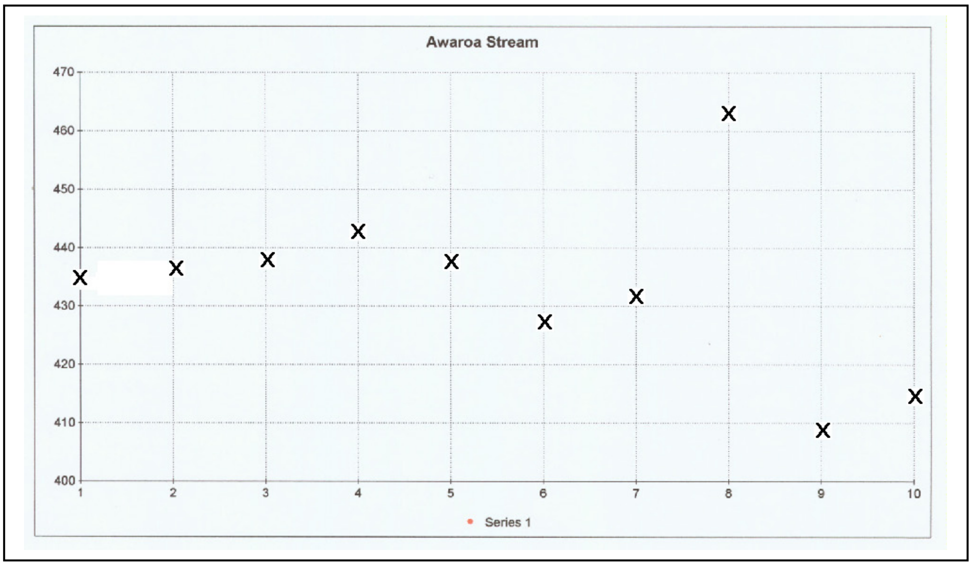


Figure 7. Elevation of groundwater in wells within the Lake Rerewhakaaitu area (meters above mean sea level).

For the upper levels of the water you really need another figure next to them that tells you where the ground is, because there are some levels there that if you were shown where the ground level was, you would find that it is below the level of the lake. It's still good information. I think the farmers really enjoyed the evening for that. If you have a look along the line that I've drawn there from Lake Rerewhakaaitu down, that's the level of the lake going down the Araroa Stream or Yankee Road, which you will go along today as part of the field day. You can see there's a cluster at the village. The road itself is about 3 km long. Unfortunately the Rotorua District Council's farm is out here, so it's quite at the extreme of the catchment and there was no data done on this at all.



So there we are, we can all do graphs but we try not to clutter these ones up, we're farmers don't forget.

There we are, we're coming from the lake over here, we're going up to the village and coming down here to the farms as they go down Yankee Road.

The Mangakino stream, there are two main catchments that enter the Rerewhakaaitu Lake, Mangakino and the Araroa.

This is the Mangakino catchment and stream, you're looking at Tarawera due north. There's a big spring over here that goes on down. The lake is around the corner here further to our right. Most of this catchment is fenced quite well back, even the swamps that are way out over here further are quite well fenced off. This is quite a good catchment here.

This is the Araroa Stream or catchment. You're looking straight to Tarawera. That's Mount Edgecumbe, so that gives you an indication of height.

John McIntosh of Environment Bay of Plenty, this is a normal spring set up in here, they're just seeping out of the ground, collecting here in a dam and then it just goes on down. The Araroa Stream dried up in the early 80's, so this will disappear. There's John McIntosh taking a water sample.

Now this is down further in that gully that we looked at before. John's doing work here for Landcare. They were looking at putting in a nutrient wall and that's quite a scientific sample, whereas you know he's doing a good job here because we need to know if nitrates are flowing here. That to farmers looks quite scientific. The only thing is that there are three other samples taken as part of another report that is part of the presentations that are here today for White and Gordon. For those it was basically nothing more than a post hole and taking the muddy water out of the bottom. Now scientists may think that that's okay, but as farmers we f look at what John's doing here and think that's pretty high tech and technical. But we can do that ourselves anyway, or dig a post hole and take the muddy water out, so we can do both.

Retirement of land.
We need to know what to do with retirement of land, because that is nothing more than land going to a place to die.

In conclusion, there are no "quick fix" ideas. There's no one silver bullet that will instantly help to maintain these lakes or restore some of them. It is a combination of actions assisted by good science, a degree of practical know-how and the will to bring about success. It is really a magazine of silver bullets. Some have already been fired successfully. We all contribute to the catchments that we reside in and there is a price to pay for being here. It is not just the farmers, but everybody. Fish & Game, Department of Conservation, Rotorua District Council, Environment Bay of Plenty, Bach owners, businesses, local Iwi and the residents of Rotorua. We all contribute, so therefore we all shoulder some of the responsibility. As I have said before, if we are here for the environment, the solutions are easy to find. It's the politics, the perceived property values, denial and fiscal avoidance that get in the way. So let's lock and load, it's time for action. Thank you.

QUESTIONS

Kepa Morgan: I really enjoyed the presentation, getting back to common sense, as you said. I particularly enjoyed the example you gave for Mourea where the idea was to take the sewerage, pump it up onto the hill and basically remove the solids and put the effluent onto the forest at a rate of twice what Milford Sound has a year. You suggested that

maybe the idea was to pipe it further away, but what would you think about the idea of not having the material in the water in the first place, because it's my understanding that we don't provide flush toilets for cows on farms, and I just wondered what you think about providing flush toilets for cows on farms in terms of practicality and what your ideas are about providing for humans. Kia ora.

C.S.: Okay, I was going to show a photograph of the genetic cow that I got in Auckland and explain that if we used those genetic cows that are on the billboards in Auckland, then we would reduce the nitrogen into the flow by about 90%! The only thing is it was using genetic corn and would need a pink support. What you're asking is a good question, but we have to look at it. We are all here now and it's not a case of turning back time and going back to our caves or whatever, it's a case of working out how to do things and do things better and do things smarter. We've come a long way by getting the sewerage out of the lake and we did that for about 80 years. I remember coming here in the 80's and it has improved since then markedly, but we have to move forward. Technology has moved forward, things have moved forward. I think Taupo District Council are going to explain what they're doing with theirs. I think that's up-to-date, I think that's modern, I think Mangakino is up-to-date and modern. I've heard people say that we should make the pipeline big enough, so that we can pump the stuff either way. I think that's a good idea. I don't believe that the sewerage is just one issue, I think it is a major issue and I think that it's input into one spot is a major issue. It think get it out of the catchment. There are people who propose to take it towards the sea up into the hills and find another catchment that we can use, something like Taupo and a combination of that. They all cost money, sure, but it has to happen and the longer we leave it, the more it will cost. But we can't turn back time and I don't believe that we can just say no flush toilets or anything like that. Some of those septic tanks at Mourea are below the ground-water level and the only difference between the proposal that they had to put it under the pine trees and the status quo in Okawa Bay there, was in fact the septic tank itself and a 10 month gap. That was all. And that's quite shocking that we were thinking about doing that up until last week, so we've got to get smarter about that really. If you go back the other way and we go back to the caves, well then we all just jump back in the boats and we push away from the island.

Sustainable farming in lake catchments – examples of projects at Lake Kapoai, Northland and Lake Rerewhakaaitu

R.Parker[1], M.B. O'Connor [2], **M.F. Hawke**[2], M. Gibbs[3], C. Sutton[a]
[1]*Agriculture New Zealand, PO Box 792, Tauranga*
[2]*AgResearch, Hamilton and Rotorua*
[3]*NIWA, P O Box 11115, Hamilton*
[a]*Rerewhakaaitu, R.D. 3, Rotorua*

ABSTRACT
Two projects have been undertaken; one a 3-year project almost completed in Northland and one recently commenced in the Bay of Plenty. The aim of the Northland project at Lake Kapoai was to maintain and/or enhance sustainable farming in the catchment of dune lakes through adoption of management practises which would prevent further deterioration of lake waters and, over time enhance the water quality in the lake. This is being achieved by combining local farmer and scientific knowledge in developing management options that will be practical and relevant. It has involved a farmer survey, development of farm plans, detailed lake water quality measurements, soil chemical analyses, kikuyu management, riparian fencing and fertiliser strategies. A major impact has been in giving landowners an 'understanding' of what happens in their lake which has then been followed by a greater willingness of those landowners to make management changes to enhance the lake water quality.

Likewise the experiences from Northland's Lake Kapoai will be valuable for the Lake Rerewhakaaitu catchment study which has similar aims. A farmer questionnaire is providing much of the background knowledge on current management practises and landowners are interacting with science providers. The outcome will be discussions of strategies that minimise N & P inputs into the lake without compromising sustainable farm businesses. Maintaining the natural character of the environment is also important.

Both projects have a high degree of farmer participation and aim to improve lake water quality by combining local farmer and scientific knowledge, to come up with a range of practical management options which can be adopted.

ROBERT PARKER
(*Tape Transcript*)
Today why I'm here is that I've been involved in the lake project in Northland which started in 1999. At that time there were farmers in a catchment on the west coast of Northland on the sand dunes and the lakes there were increasingly becoming polluted. As a result of that, one of the farmers put his hand up and said we want something done about it, but he actually also said that once we got the solution he didn't want to tell anyone else because he didn't want the general public and others to know what was going on. In other words, the farmers there were very wary and suspicious that if the problems on this particular lake were widely known, they'd have constraints and restrictions placed on how they farm. So that was really a problem – they were asking for help, but not asking for help in some ways. So just a bit about the area. The lakes have deteriorated over the last 20 years. There are more algal blooms and increasingly poor water quality. The farmers are concerned, as I've said, and they wanted help but they didn't want it advertised. We applied for funds from SMF (Sustainable Management Fund) and we succeeded on our second go. We had strong support from Fert Research, Dairy Research

Institute and MAF Policy. The aims of this project at the time were trying to get a win – win situation i.e. a twin outcome for the farmers both in terms of having sustainable farming systems and also for them to make changes in management that were going to be good for the lake, in this particular case.

The lake is Lake Kapoai, one of a whole series of these lakes on the west coast and we picked that one because of the range of farmers that were surrounding it. That's the

northern end of the lake. It's a very small lake. Over the hills in the background is the Tasman Sea and west coast beaches, about 800 metres away. It's a trap lake with a small outlet and a substantial area of the catchment, virtually all of it, was in farming. The lake had a lot of problems and the science providers we involved were able to quickly get a handle on things, but the key thing was that those science providers and the farmers worked in participation together from day one.

So at every stage and every step the science providers discussed with the farmers what was going on, they bought into it and we moved on to the next phase. The main science providers were AgResearch with Mike O'Connor and his team, and NIWA who looked at the water aspects, with Max Gibbs and his team. So the initial work was looking at the range of issues that the scientists thought were important and the farmers did. The survey of catchments to document all the current practices was done; they looked at fish populations in the lake and they did find that there were reasonable populations of coarse fish that had been released there. Wild fowl numbers on the lake were considered to be a problem and so they were looked at and counted. The nutrient levels in the lake and groundwater were investigated. The potential source of these nutrients, characteristics of the soil types in terms of their leaching and P-fixing ability, and the temperature conditions in the lake were also considered.

The project started in 2000 and at that time the farmers were very wary and very suspicious. They wanted help, but I'm not quite sure what they expected to have, what outcome they wanted that wasn't going to involve other people. However, in about 2001 they were starting to see some of the information that was coming out. A lot of the dynamics were similar to the first speaker this morning in this particular lake, so there was nothing special about it. The farmers wanted to know what they could do now that they had this information that was coming forward, so they decided to list some actions and they called it a wish list. These are farmer's ideas of what they could do in the catchment of this particular lake, and they listed them by difficulty.

In terms of these sorts of issues, as we went through the project all the way through there was a strong emphasis that the farmers were not going to be told what to do at any stage. All these ideas that came up were farmers', the science providers raised other issues with other solutions, and they were put together in sort of a toolbox, and out of that the farmers

WISH LIST ACTIVITIES

Fence my section of the riparian area and lake.	Low difficulty
Fence gullies on my farm to encourage vegetation growth to stabilise erosion. One wire electric fencing suitable.	Low difficulty
Make personal commitment to not cultivate paddocks close to lake (Pinaki).	Low difficulty
Adjust fertiliser strategy to minimise P and N applications to Pinaki sands.	Low difficulty
Fence off wetland areas close to lake to encourage all year round vegetation growth.	Medium difficulty
At strategic points on stock races construct run off channels to pasture. This will prevent nutrients/silt run off into the lake.	Medium difficulty
Develop retention dams in strategic locations in gullies to collect sediments and runoff.	Medium difficulty
Make personal commitment to consider the lake environment in making decisions on fertiliser use including fertiliser type, timing, weather conditions and proximity to lake. Interact with fertiliser spreader operator to ensure their commitment.	Medium difficulty
Plant riparian margin (at one of the nutrient sampling points) with selected plants and record any improvement in nutrient capture.	Medium (In conjunction with NIWA)
Prepare planting plan for the Lake surround and implement.	Medium-High difficulty

could pick the ones that applied to their farms and apply them, whereas other issues they would leave.

There were examples of some of these more difficult ones in the catchment already, and one of them was in one of the gullies that fed into the lake. At the top end of it there was a pond that the farmer had formed about 20-30 years ago. It was fenced and it was all overgrown, but it was actually catching a lot of sediment and water from the head of that gully. Sampling and monitoring found that the nutrients in that pond were equivalent to effluent ponds at dairy sheds, so that was capturing a lot. It could have been sprayed across the farms as fertiliser. So that was actually 30 years old, it was nothing to do with our project, but it was an example of the sort of activity that could be implemented. One of the special things that came out of this, and it just came out of the work that we did, was how to manage some of the gullies where the main water flows were coming from into the lake. Kikuyu grass is widespread there and it was filling up these gullies. We discovered from the sampling that it had a very strong nitrogen stripping effect, and this was explored further and managing that on an annual basis was a real option to help strip nitrogen, in particular, out of the groundwater before it reached the lake. At one of the sites, monitoring site 8, which had particularly high N and P levels at the start of the project, with fencing and with managing the kikuyu the nitrogen level dropped dramatically before the project finished. So within the time of the project, some big responses occurred in terms of stripping the nitrogen out of the groundwater, as opposed to the total amount of stuff that was in the lake. So those are some of the things we found on this lake.

SPECIFIC MANAGEMENT OF RIPARIAN AREA

JUNE 2002

- Develop specific strategies to best use Kikuyu in gullies and in the riparian zone.
- Focus on spot spraying problem vegetation in riparian zone.
- Stock are never to go inside the riparian fence.

At monitoring point 8 – N and P levels in groundwater have significantly lowered. This is due to the nitrogen stripping ability of Kikuyu

THIS HAS HAPPENED
IT IS REAL
IT IS WORKING

The key thing that I think is of use to bring it into the Rotorua lakes and Lake Rerewhakaaitu where we've started another project, is this process whereby the science providers (in this case here they were NIWA and AgResearch) had very close relationship with farmers from day one. Listening to the farmers' concerns, implementing some of the farmers' ideas, introducing some ideas that the science providers had into a joint deal that moved forward. At the end of this project, this lake which was not fenced, was fenced and quite a lot of those ideas on the wish list had been adopted by the key four or five farms that were surrounding that particular lake and were underway. So I think the key point that is important today is that strong association from day one. The wariness and the suspicion at the start disappeared completely and at

the end on the public day there was acknowledgment that they now understood the dynamics of the lake and the decisions they made and things they did were going to have an impact, and they weren't going to be a waste of time. I would just like to acknowledge the funders of this project that really allowed it to proceed: Ministry for the Environment Sustainable Management Fund, FertResearch, DRI and MAF Policy.

The key thing, the life beyond now that Kapoai is finished, is using the principles of the lake, and we now have a project as Rerewhakaaitu,. The environment and the lake are very different, but the principles of working together with the farmers are similar in bringing all the strands together, so that the farmers can see and understand and have confidence in the activities that have taken place, and so that there is adoption of the ideas coming out in the toolbox. MAF Sustainable Farming Fund, FertResearch, Dairy Insight and Environment BOP are active participants and funders of this new project which has just started this last July.

Now, Martin Hawke who is with AgResearch is just going to talk about a bit of the background and the starting process that we've initiated at Lake Rerewhakaaitu. Thank you.

MARTIN HAWKE
(*Tape Transcript*)

Chris set the scene very well for this particular project and it has similar aims to the Northland lakes. Lake Rerewhakaaitu is our southernmost lake (*in the Rotorua District*). I'd just like to give you a bit of brief information about the lake and about the project that we've just commenced.

LAKE REREWHAAITU

Lake Area		= 6.3 km^2
Average Depth		= 7.1m
Catchment Area		= 3816 ha
Comprising	% dairy	= 70
	% sheep/cattle	= 7
	% forestry	= 15
	% other	= 8

So the area is 6.3 square kilometres and as a comparison, Rotorua is 81 square kilometres. The average depth is 7.1 metres and the average depth of Lake Rotorua is 11 metres, so I think from the data that we saw earlier from David that it's the shallowest lake that we have in the Rotorua lakes. It has a catchment area of 3,816 hectares which is considerably smaller than the Rotorua catchment, about 8% of the Rotorua catchment. As Chris said, it's mainly agricultural, 70% dairy catchment, forestry 15%. Most of that forestry is where the trees were planted on the crater block in the 1970's.

Our involvement so far, and we're at year 1 of a three year project, is to assess all the resources of the catchment. Within the catchment there are 33 farms and we've designed this questionnaire which is a sort of follow-up to the one that Environment BOP had a couple of years ago. We visited every farm and we have asked them to fill out the questionnaire and so we've really got a tremendous amount of information on farming practices, on the physical features of farms. We are now at the stage of collating that

Lake Catchment

33 Farms

- 27 Dairy
- 1 Sheep
- 1 Deer
- 4 Dry stock

Main Soil Types

- Tarawera Ash/Gravel
- Rotomahana mud
- Kaharoa Ash

information. You can see the three main soil types – Tarawera ash or gravel, Rotomahana mud (they came from the 1886 eruption), Kaharoa ash from the eruption about 700 or 800 years ago. There's also Taupo pumice which came from the eruption about 1800 years ago.

Of the features of this project, I think the most important one is working with the community, so it's a farmer-initiated project – they've called us in and I suppose you could say that we are facilitators, but we're also science providers. AgResearch has a strong background of working with farmers and so we feel that it is right for the job. We've just recently completed this survey.

Using science technologies, that's the next step. As I said, we do have a background, and Ross talked about some of the work that we're doing. There is some information from four dairy and catchment studies that we've completed or we're involved with, one in Waikato, one in Taranaki, one in South Canterbury and one in Southland. There's a very big input of data collection going on in those catchments and quite a few of the people in the audience here are involved with them. We'll be using the 'Overseer' nutrient budget model. This was developed by AgResearch and has recently been updated and I think there are posters about this model. We'll also be using information from the Taupo studies which you've heard about from Ross. So we do have quite a background and quite a lot of data to provide to this project. In terms of evaluating and comparing with existing protocols, what we're talking about here is Fonterra who have a market focus protocol, so we'll be comparing it with that and seeing how these farms stack up. We'll be looking at best management practices, looking at the code of practice of fertiliser use and any other protocols that we think are relevant. Some of the funding criteria mean that we will be reporting to the particular groups on our findings, such as the Dexcel field offices and the fertiliser representatives. However our main thing is to report back to the farmers, and so if any of you want any information from the survey so far, I can't give it to you because we haven't reported to the farmers yet. When we've got here a wish list, it probably would be very different from the wish list that they had in the Northland lakes. There will be different issues - we're not speculating what they might be, but again there might be particular things that come out of the study that we can say, well, we can do something about it.

So in summary, I regard Lake Rerewhakaaitu as a gem of a lake. It is included in your field trip this afternoon. And AgResearch are really excited to be involved with a project like this one. Thank you.

QUESTIONS

Rob Pitkethley, Fish & Game: A question perhaps to Bob. In the Northland lakes you said at the end there that you had a fairly good understanding of the dynamics that were

going on with nutrients in the lake. Earlier on in the piece it had been identified that water fowl were a possible problem. Could you tell me if the nutrient input from the water fowl was actually evaluated and if so, how did it compare to other relative inputs into the lake.

R.P.: Good question. The wildfowl numbers were raised by the farmers and they contributed to the problem. In starting the study there we had someone go out and do counts on a regular basis. We found that the numbers were so low that the time spent trying to get a decent count was very difficult. We just weren't getting the numbers. We converted it so that one of the farmers was going down and measuring the lake levels each week as part of the project with the NIWA component. He was also doing a count on Paradise Ducks in particular and the numbers there again were very small. So for that part of the programme, we decided that because the numbers were so low, although we had thought they were contributors, it ended up that they weren't.

Tawiri Hakopa.: Can we take it that the kikuyu grass that strips nitrogen, strips phosphorus too?

R.P.: My understanding, and there again I'm just the facilitator and not experienced in this area, but the Kikuyu grass was nitrogen-stripping, rather than stripping the phosphate.

Max Gibbs, NIWA: How did you go about measuring the amount of nitrogen and phosphorus that was stripped in groundwater?

R.P.: It's a matter of looking at the amount of nutrients in the groundwater upstream of the buffer zone created by the kikuyu and also measure downstream of the buffer zone. About 95% of the nutrients, particularly the nitrogen, was removed as it passed through this buffer zone before it reached the lake.

Clean lakes and fertiliser use can co-exist

Dr Hilton Furness
New Zealand Fertiliser Manufacturers' Research Association, Auckland, New Zealand.

Paper presented by Lynne Moore

INTRODUCTION

I am Lynne Moore and I am the Technical Assistant at FertResearch. Dr Hilton Furness is not here today as he is in South Korea presenting a major paper on water quality indicators at the OECD and the EFA conference. He asked me to pass on his apologies for not attending, but he was unable to manage a return flight in time. We will be taking questions afterwards and Hilton has indicated that he'll be answering them all next week or the week after, on his return.

Justin Van Liebig is generally considered to be the father of the fertiliser industry. He recognised the importance of nutrients for plant growth and formulated the "Law of the Minimum" (IFDC/UNIDO, 1998).

In essence the law states that if a nutrient is deficient or lacking in availability growth will be poor even when all other elements are abundant. If the deficient element is supplied, growth will be increased in proportion to the amount supplied up to the point where the supply of that element is no longer the limiting factor (IFDC/UNIDO, 1998). This is illustrated in Figure 1.

Over time this law has been modified with the addition of elements found to be essential for plant growth. In addition, factors such as moisture, temperature, light etc have been included.

This explains why farmers have applied nutrients, particularly phosphate and nitrogen, to crops. These nutrients have been in the shortest supply relative to the crop needs hence even relatively small amounts have resulted in significant increases in growth.

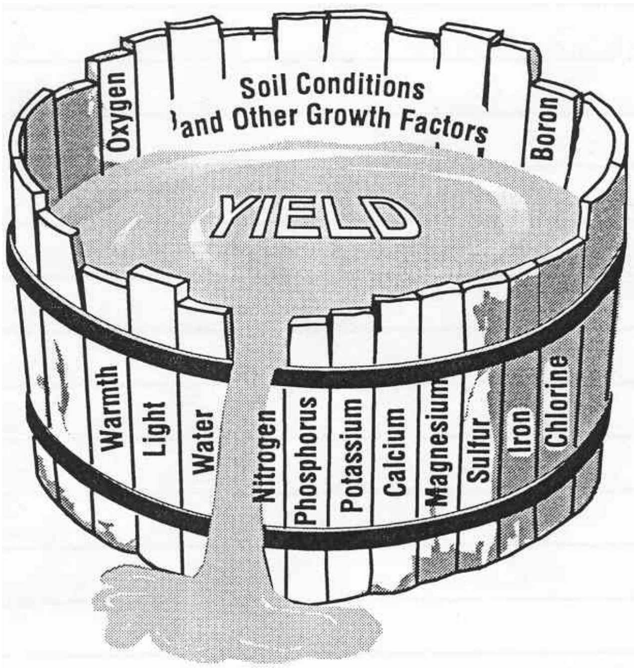


Figure 1. Liebig's "Law of the Minimum" – illustrated by barrel staves of varying lengths representing growth factors (IFDC/UNIDO, 1998)

Aquatic plants respond in a similar manner. Phosphate and nitrogen are often the limiting factors in aquatic systems hence the prolific growth response to relatively small increases of these nutrients.

The amounts of nitrogen and phosphorus that will stimulate growth are often very small. This can be gauged by the fact that eutrophic conditions can result from phosphate concentrations of 25 µg/l (i.e. 0.025 mg/l) (DWAF, 1996).

In such a case virtually any activity in the catchment, no matter how minor, that adds phosphate to the system can have significant adverse effects on receiving water quality.

NUTRIENT USE

Typically farmers use nitrogen and phosphorus to increase crop growth. These key nutrients are supplemented by a number of other essential nutrients.

With the onset of commercial farming in New Zealand in the 1800s it was quickly realized that fertilisers were needed. A comment by a farmer in the Reporoa District in 1894 was that the land "…demanded a lot of fertiliser, the more the better" (Bellamy, 1991). Superphosphate was found to be most suitable and amounts of "3 cwt to 5 cwt per acre" were applied – equivalent to about 375 – 625 kg/ha.

The use of phosphate increased sharply as the dramatic increases in production due to its addition to the soil were obtained. To a large extent nitrogen was supplied by clover. During the first half of the 20th Century there were significant advances in the use of fertiliser. Cobalt, molybdenum, copper and sulphur deficiencies were identified and addressed (NZ Rural Press, 1990). By 1980 fertiliser use, mainly in the form of superphosphate, had increased to 1.3 million tonnes per annum.

In the 1990s there was a dramatic increase in the use of nitrogen fertiliser. There are a number of reasons for this including dairy conversions, reduced occurrence of clover and the adverse effect the clover root weevil has had on nitrogen fixation. It is also possible that increasing phosphate levels in soils have resulted in increased responses to nitrogen additions.

Early fertiliser "recommendations" were based more on the farmers' observations of response to increased applications than a scientific evaluation of crop needs.

Refinements did evolve and by the early 1940s requirements had been assessed as:

Hill Country	5/6th	cwt per acre
Dairy Country	3	cwt per acre
Fattening Country	1.5	cwt per acre

Determining fertiliser requirements gradually became more scientifically based. Soil and plant tissue analysis was introduced. There was a realization that a wide range of factors should be taken into account when deciding on fertiliser needs. By the mid 1980s computer technology was also employed (Miller, 1990).

Today fertiliser recommendations are determined by considering a wide range of factors (Table 1) with the aim being to match nutrient supply with plant requirements.

Table 1. Factors considered when making fertiliser recommendations.

- Production Goals
- Farm Type
- Crop and Soil Type
- Soil and Plant Tissue Analysis
- Fertiliser History
- Soil Moisture Status
- Climate

Those making recommendations are expected to be qualified and highly skilled. The two major fertiliser companies in New Zealand employ university graduates who are required to undergo further in-house training. In addition all are required to successfully complete the post-graduate course "Sustainable Nutrient Management in New Zealand Agriculture" offered by Massey University.

These fertiliser advisers have a range of tools available to them including:

- OVERSEER® Nutrient Budgets 2 Model
- Econometric Models
- Code of Practice for Fertiliser Use
- Fertmark Programme
- Spreadmark Programme

The aim of these developments is to improve the efficiency and effectiveness of fertiliser

use. Nutrients that are purchased by a farmer and not incorporated into produce are a financial loss.

However despite significant gains in increasing the efficiency of nutrient use, agricultural systems are essentially biological systems and low levels of nutrients will be lost from these systems.

These losses coupled with other inputs from activities in the catchment (urban and industrial development, sewage discharges, septic tanks etc) mean that raised nutrient levels will occur in receiving waters.

IMPACTS ON RECEIVING WATERS

The range of activities within a catchment will result in increased nutrient loads to water bodies. As relatively low levels of nutrients, particularly nitrogen and phosphorus, can stimulate algal growth, increased use of catchments will adversely impact on receiving waters. The low levels of these nutrients that can impact on water bodies was acknowledged by Parkyn *et al.* (2002). They went on to suggest that where nutrient guideline values could not be achieved other mitigation measures may be useful.

Regional officials of the Ministry of Agriculture and Fisheries have identified sources of nutrients and ranked them (Table 2). Some important conclusions can be drawn from this ranking:

- There are a number of nutrient sources in a catchment
- Agriculture was regarded as the most significant nutrient source
- Removing agriculture from a catchment would not eliminate nutrient sources
- It will not be possible to eliminate all sources of nutrient from a catchment.

Table 2. Impacts on water quality as ranked by regional officials
(from Ministry for the Environment, 1997)

Source	Average Rank
Agriculture	4.9
Human Sewage	4.8
Urban Storm Water	3.9
Industry	3.8
Agricultural Processing	3.7
Mining	2.6
Forestry	2.6

Nutrient inputs to aquatic systems from these sources can be reduced but not eliminated. The rate of nutrient build-up can be significantly reduced but not prevented.

The main reason for this is that very low concentrations, and therefore inputs, especially for nitrogen and phosphorus can result in a significant increase in algal and aquatic macrophyte growth (DWAF, 1996).

This situation is exacerbated by the high water quality expectations of local communities.

FUTURE DEVELOPMENTS

Every effort should be made to minimize nutrient loading to water through addressing the range of sources in the catchment. An holistic approach to management on a catchment basis is essential.

However it is clear that it will not be possible to eliminate nutrient inputs to water bodies from the catchment. Increasing population growth increases nutrient loads directly (sewage, wastewater) and indirectly (increased runoff from urban areas). The New Zealand economy and standard of living is underpinned by agriculture. Agriculture is a major source of nutrients. Attempts to reduce nutrient loss from agriculture are ongoing but no matter how successful they may be nutrient loss will occur. As it is not feasible to reduce population size or significantly curtail agriculture alternative approaches to managing water resources need to be considered.

- **Water Quality Expectations and Standards:**

  Water Quality requirements are usually set at a regional level in accordance with community expectations.

  This can result, for example, in water quality within a catchment totally dominated by agriculture having to meet recreational standards, even though there is no recreational use in the catchment. This approach places unreasonable demands on agricultural practices with no benefit to the local community. The approach also has the effect of the local farming community having no commitment to achieve the desired standard. The regional authorities do not have the ability to police such regulations, further discrediting the process.

  To address this unsatisfactory situation consideration should be given to matching water quality standards with the dominant water quality requirements of the catchment, based on major water uses in the catchment. In other words develop and implement local water quality standards, based on the predominant local water use requirement(s) within a catchment or sub-catchment, while also taking account of downstream users.

  It is possible to recognise six user groups:

  - Domestic
  - Recreational
  - Industrial
  - Cultural
  - Environmental
  - Agriculture

  The water quality requirements for each user group can be identified. The dominant use (or uses) within a catchment or sub-catchment can be identified and the appropriate standards set. Having a single user group in a catchment makes the process easy but these situations will be rare and most cases it will be necessary to have a catchment water quality standard that has components of different user groups.

  As this approach takes the needs of all water users into account there will be buy-in

and commitment to the system.

This approach may result in adjacent catchments or different sections of the same catchment having different water quality requirements.

A significant advantage of this approach is that it brings together all water use groups within a catchment. This increases the understanding of the consequences of setting water quality standards and creates an awareness of the impacts of various catchment activities on receiving waters quality. The outcome is likely to be more realistic water quality expectations, a realization of the requirements of other users and an increased commitment to achieving catchment water quality standards.

- **Key Factors**

In many instances algal growth is limited by a key factor. Often this is a nutrient, usually either nitrogen or phosphorus, although factors such as light and temperature could have a similar limiting effect. Identifying the key factor and actively managing it so as to prevent algal growth may be a better option than an attempt to eliminate certain activities in a catchment.

If nitrogen is identified as the nutrient limiting algal growth, measures can be implemented to minimize its entry to water bodies. These would include best management practices coupled with preventing movement to water courses.

Best management practices are well known and understood and include:

- matching crop requirements to application amount and timing
- use of split applications
- avoiding applying nitrogen to saturated soils
- leave unfertilized strips next to waterways

The potential in reducing nitrogen use and loss to groundwater has been clearly demonstrated for vegetable crops in the Pukekohe area (Williams *et al*, 2000). This study showed the potential to significantly reduce nitrate leaching loss by implementing appropriate management techniques.

In addition to best management practices use can be made of riparian strips, wetland areas and reed-beds to remove nitrogen and significantly reduce amounts entering water bodies.

Key Factors

- **Identify key factor limiting algal growth**
- **Actively manage key factor to limit algal growth**
- **Couple key factor management with best practices in the catchment**
- **Reduce nutrient inputs to water bodies by using riparian strips, wetland areas and reed beds**

- **Active Management:**

There are a number of actions that could be used to limit or modify the effect of increased nutrient levels in lakes (Vant, 1987). These include:

  - Diversion of nutrient-rich water
  - Artificial aeration/destratification
  - Manipulation of biota
  - Nutrient precipitation
  - Removal of nutrient-rich sediment
  - Harvesting of aquatic macrophytes
  - Use of algicides and herbicides

Many of these management options have been used successfully internationally (e.g. Hart and Allanson, 1984) and locally proposals for aquatic weed control in the Rotorua lakes have been made (Froude and Richmond, 1990). They are particularly useful and applicable when specific catchment activities provide significant levels of benefit to the community (employment, economic development). Rather than limiting these beneficial land practices, management options can be applied to water bodies to maintain water quality and ecosystem functioning.

CONCLUSIONS

Human activities in catchments result in increased nutrient loads entering receiving waters.

There is a trend to focus on agriculture – but this is only one of a number of contributors and in many instances it is not the major contributor. The contribution of agriculture to the standard of living of all New Zealand (primary industry makes up about 70% of exports and 20% of GDP), means that it will continue to be part of the New Zealand economy for many years to come.

Clean lakes and fertiliser use can co-exist but only if appropriate management practices are coupled with realistic water quality expectations and active "in situ" management that will limit algal growth.

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Towards the Development of Best Management Practices for Pastoral Farming
An analysis of six farms in the Rotorua Lakes catchment

D C Edmeades and M R Taylor
agKnowledge Ltd, PO Box 9147, Hamilton

INTRODUCTION

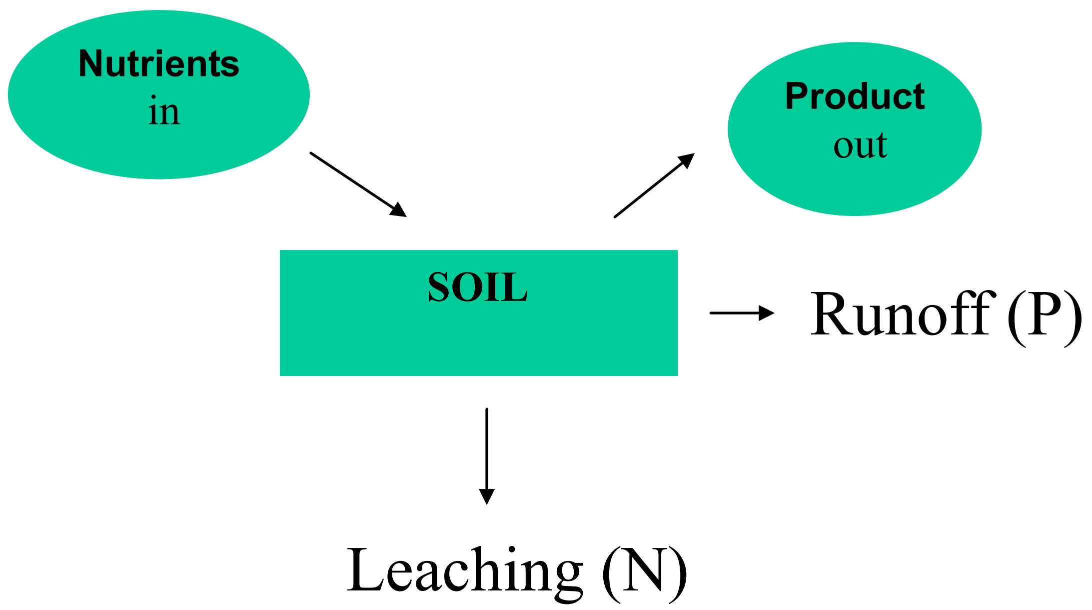
1. Environment Bay of Plenty (EBOP) wishes to develop Best Management Practices (BMPs) to assist farmers to develop nutrient management practices which optimise nutrient use efficiency - and hence farm profitability - and minimise avoidable nutrient loss to the Rotorua Lakes.

2. EBOP established a focus group to direct, manage and overview this project (Appendix 2).

3. EBOP engaged the services of agKnowledge Ltd to apply their Total Nutrient Management (TNM) system to six farms in the Rotorua Lakes catchment.

4. This report analyses and summarises the essential findings from this survey and identifies a minimum set of effects-based farm management practices, which could form the basis of nutrient BMPs.

THE DILEMMA



TOTAL NUTRIENT MANAGEMENT (TNM)

1. TNM has been developed as a practical process to apply the RMA and the Fertiliser Code of Practice to nutrient management at the individual farm level.

2. At its core TNM adopts the Framework for the Evaluation of Sustainable Land Management (FESLM) developed by Smyth and Dodunski (1994).

3. FESLM sets five criteria, or goals, that must be achieved if a given management practice is to be deemed sustainable. These are:
   - *Production* - does the practice achieve the desired production goal?
   - *Risk* - does the practice reduce the risk of achieving the production goal?
   - *Economic* - is the practice economic?
   - *Environment* - is the practice environmentally sustainable with respect to soil, water, air and other relevant resources?
   - *Social* - is the practice socially acceptable?

4. These criteria are applied to all aspects of nutrient management on a specific farm including: fertiliser and effluent management and other farm management practices such as stock, pasture and soil management practices which can affect nutrient use on the farm.

5. The essential steps and analyses within the TNM process are:
   - Definition of the goals (5 year) of the farm in respect to production, risk, economic, environmental and social
   - Assessment of the current fertility (chemical, biological and physical) of the farm taking into account soil, plant and animal health.
   - Analysis of the economic optimal nutrient levels (ie the levels which optimise long-term profitability) for the farm, given the farm goals.
   - Calculation of the nutrient inputs required to achieve the above.
   - Choice of the least-cost fertiliser product to deliver these nutrient inputs.
   - Calculation of the optimal area for land application of effluent
   - Determining the nutrient budget based on the above
   - Identifying and prioritising the most cost effective management options to reduce N and P loadings to acceptable levels.

METHODOLOGY

1. Six farms were chosen by Environment BOP for this survey. A description of each farm is given in Table 1.

2. Each farm was visited, the farm ‘walked’ and the essential data collected.

3. A TNM Report was prepared for each farm as outlined above. The details of these reports are, by agreement with the farm owners, EBOP and agKnowledge, confidential to the individual owners.

4. The TNM report was discussed with each farmer (1-2 hrs).

5. A questionnaire was put to each farmer to determine:
    a) Their knowledge and understanding of nutrient and environmental issues prior to the TNM process
    b) What aspects of the TNM plan they would implement
    c) Whether the TNM process helped them better understand nutrient and environmental issues
    d) What other plans they would be prepared to implement on their farms to reduce nutrient loadings
    e) What additional information did they require to make better nutrient-environment decisions.

6. Five of the six farms were revisited with scientists from NIWA to examine the extent and effectiveness of riparian plantings, wetlands and other features that may modify nutrient loadings. This information was used to apply NPlas to each farm to obtain a more reliable measure of nutrient loadings (At this stage this applies only to N).

7. Preparation of a summary of the essential findings from the survey relevant to the development of BMPs .

RESULTS: PRE-REPORTING TO FARMERS

1. Of the six farms, three were high-producing dairy farms, two were well-developed sheep and beef operations and one was an undeveloped sheep and beef farm. These six farms represented four lake catchments: Rotorua, Okareka, Tarawera and Rerewhakaaitu (Table 1).

2. All farms set high production targets although in one case this was not quantified. However, in all cases these production goals were qualified with the intention to optimise farm profitability and minimise environmental risks. "Production at all costs" was not an option on these six farms. In addition, all farmers were aware of their social responsibilities and the impact of their farm operations on the community (Table 2).

3. Based on their current soil nutrient levels, the three dairy farms contained between \$10,000 to \$15,000 worth of nutrients per hectare of topsoil and the three sheep and beef farms, \$5,000 to \$10,000 (Table 3).

4. Four of the farms (the three dairy farms and one of the sheep and beef farms) are currently operating at nutrient levels above the economic optimal (ie the Olsen P level which optimises farm profitability in the long term) and hence can reduce nutrient inputs without compromising profitability. One is at the economic optimal and therefore requires only maintenance inputs of nutrients and one is below the economic optimal and requires capital nutrient inputs to optimise profitability (Table 3).

5. The value of the nutrients in the dairy shed effluent produced annually by the three dairy farms ranged from \$7,000 to \$17,000 per farm annum. All three

dairy farms have sophisticated land application systems for dairy shed effluent but in all cases the effluent area would need to be increased if they were to apply not more than 150 kg N/ha/yr as effluent. All three farms have been unnecessarily applying normal fertiliser inputs to the land also receiving effluent (Table 4).

6. All six farms had either well-developed riparian plantings and buffer zones around significant water bodies on the farm, or the surface runoff exiting from the farm was via a 'natural riparian' system. Several farms had well-developed wetlands (to remover N and trap P) or dams to slow water movement and hence trap sediment including P.

7. Assuming that the TNM recommendations for each farm were followed, all but one farm will apply fertiliser N (average 118 (range 35-161) kg N/ha/yr). N inputs as symbiotic N fixation via clover were estimated to be on average 85 (range 16-146) kg N/ha/yr. Total N inputs including N from supplements averaged 266 (261 -270) kg N/ha/yr on the dairy farms and 118 (43-177) kg N/ha/yr on the sheep and beef farms (Table 5).

8. The estimated rates on N leaching averaged 72 (range 62-76) kg N/ha/yr on the dairy farms and 18 (range 10-29) kg N/ha/yr on the sheep and beef farms. With one exception the predicted nitrate concentrations in the drainage water were less than the WHO standard of 11 ppm (Table 5).

9. The estimated rates of P runoff were 1 kg P/ha/yr for all farms irrespective of their current soil P status. This figure does not take into account the effects of riparian planting on P runoff. Estimates of P runoff (generally referred to as transfer coefficients) from field studies range from 0.1 to 1.7 kg P/ha/yr (Table 6).

10. The management options available to each farmer to reduce nutrient loadings, and their priorities, were different for each farm (Appendix 1).

RESULTS: POST-REPORTING TO FARMERS

1. Prior to reading their TNM reports, 5/6 farmers had heard of the Clean Stream Accord and Nutrient Budgeting but only 2/6 had read the Accord and 3/6 had done a nutrient budget. Only 2/6 had heard of the Fertiliser Code of Practice and none had used it. Similarly, 2/6 had heard of OVERSEER® but only one had used it.
2. 6/6 farmers said they would adopt the TNM recommendation in full for their farm even though this represented a decrease in fertiliser P inputs (4/6), and/or a decrease in fertiliser N inputs 3/6. All three dairy farms said they would increase their effluent area and not apply fertiliser to it.
3. All six farmers said that the TNM process/report had made them more aware of environmental issues

4. All six farmers said that, as a result of the TNM process, they would consider further options (eg feed-pads, land retirement, reduction in stocking rates, further wetland/riparian modifications) to reduce nutrient loadings on their farms.
5. All six farmers said they needed further technical information and support, in particular cost-benefit analysis, to decide on options and priorities.

RESULTS: NPLas

1. Using NPlas the N leaching figures given earlier (Results: Pre-reporting to farmers) can be modified to take into account the extent and effectiveness of the riparian planting, buffer strips and wetlands on each farm. With these adjustments, the average N loading for the six farms was 30 kg N/ha/yr (range 14-53). The average loading for the three dairy farms was 40 kg N/ha/yr (range 31-53) and that for the three-sheep/beef farms was 19 kg N/ha/yr (range 11-28).
2. The proportion of the N loading derived from surface runoff - as distinct from N leaching - was about 1% (range 0.6-1.8) for the dairy farms and 12% (3.6-22) for the sheep and beef farms. This has important implications for the management of N loadings.
3. The predicted P loadings from OVERSEER® were 1 kg P/ha/yr. The P component of NPlas is not yet available and consequently these loadings do not represent the actual situation including the existing riparian and buffer plantings. Measured transfer coefficients from pasture reported in the literature range from 0.1 to 1.7 kg P/ha/yr.
4. Both N and P loadings on each farm could be reduced further if some or all of the management options available to them were implemented. The quantification of the benefit of each management option on each farm, on the N and P loadings awaits a) better estimates of the inputs into Overseer and b) further refinement of NPlas.
5. NIWA will be separately forwarding to EBOP a summary of their findings with respect to the ongoing development and application of NPlas.

BEST MANAGEMENT PRACTICES

It is clear from the analysis of these six farms that the management options to reduce nutrient loadings are farm specific. Each farm has a unique set of options and priorities. Some examples that reinforce this point are as follows:

- Withholding fertiliser inputs is not an economically viable option on all six farms.
- Changing the rate and timing of fertiliser N inputs are not options on some farms.
- Reducing fertiliser N inputs may not result in a decrease of N loading because it is normally accompanied by an increase in clover growth and hence N input

from this source (Table 5).

- Retiring less productive hillsides, without loss in total production, may be viable on some sheep and beef farms but is not normally an option on many smaller dairy farms.
- Reducing stocking rates may not necessarily have a large impact on reducing N loadings if the same amount of N (from pasture and feed) is consumed and recycled by fewer animals (Table 5).

Given the above, it is unlikely that imposing rules, for example, such as limiting N inputs or stocking rates, will achieve the desired outcome of reduced nutrient loadings. It is suggested therefore that the BMPs for nutrient management should be directed away from *rule-based* controls to *effects-driven* practices.

With this in mind some key practices, which, if adopted by farmers would improve their profitability, **and** reduce nutrient loadings to waterways include:

1. Applying the FESLM system to their nutrient management systems to ensure that they are sustainable.

2. Developing a robust soil testing and monitoring programme for the farm to follow changes in soil nutrient levels over time.

3. Operating their farms at the economic optimal nutrient levels.

4. Treating dairy shed effluent as an important nutrient source and applying it to an appropriate area of land to optimise nutrient efficiency and minimise nutrient losses. The effluent area should be treated separately with respect to soil testing and monitoring, and fertiliser nutrients applied only if required.

5. Calculating a nutrient budget for the farm to calculate the rates of nitrate leaching and P runoff and examining management options to minimise these nutrient losses. Both OVERSEER® and NPlas are appropriate tools for this purpose.

6. Undertaking cost-benefit analyses to determine which management practice(s) are most cost-effective in terms of reducing nutrient loadings of N and P to waterways.

SIX BMPs

- Apply FESLM (5 gaols)
- Develop soil nutrient monitoring program
- Operate at economic optimal nutrient levels
- Optimise use of effluent
- Nutrient budgeting (nitrate leaching, P runoff)
- Analysis of options (costs-benefits)

If these practices were adopted it would place the responsibility for nutrient management on the farmer. It is unlikely that this will be achieved without cost to the farmer because the knowledge, skills and tools required to achieve 1-6

above are beyond the scope of most farmers.

CONCLUSIONS

From this study it is concluded that, in terms of nutrient and fertiliser management:

1. There are currently many management options available to farmers, which can reduce soil nutrient loadings and hence total farm nutrient losses.
2. Most farmers are very aware of their environmental and social responsibilities.
3. Most farmers will readily change management practices when provided with understandable, credible, reliable, science-based information.
4. Most farmers need technical support and assistance to understand and hence manage nutrient inputs and losses from their farms.
5. The biology of the management of nutrient inputs and losses is complex and as such simple rules restricting specific activities are unlikely to be successful in terms of reducing nutrient loadings.
6. The general principles of the management of nutrient inputs and losses can be delivered by diffuse educational techniques such as brochures, booklets, BMPs etc.
7. However, nutrient management is farm specific and accordingly is most effectively delivered by well-trained, technically-competent personnel working one-on-one with the farmer.

This paper is based on a report of a project of the same name initiated by Environment BoP and submitted to them in August 2003.

QUESTIONS

Bill Vant, Environment Waikato: You make it sound very simple when you say that the farmers were using more nutrients than was optimal and that they realised that they could have been using effluent instead of nutrients. I guess I'm wondering why is it that they hadn't received the necessary advice previously.

D.E.: A good question which has a complex answer. In the last 15 years the farming community has had stripped away from it all the advisory channels by which it normally got information. So many farmers have been left completely isolated in terms of good sound information.

B.V.: Even though the fertiliser company employs graduates who have to go through a post-graduate course as advisers?

D.E.: I shall not comment further.

Don Atkinson, Okawa Bay: I've got a desire to understand how much P is lost through run-off. I understand that a significant amount is held in our soils anyway, even though it's not available for plant growth, but could you comment about what percentage. We understand from your earlier paper that about 35% of nitrogen is being leached. But I haven't got an understanding of the P.

D.E.: Ballpark figure, talking about run-off, about a kilogram of P per hectare per year.

With a variation of about 0.1 up to 3, something like that. I should add that most of that P is a particular P associated with soils, which affects the means of controlling that and keeping it on the land – things like erosion control around banks, erosion control on land, etc., etc.

Chris Hendy, Waikato University: Can you give us the ratio of the P that is put onto the land. It sounds to me like rather less than a percent.

D.E.: Typical sheep and beef farm may be putting on 25 kilograms of P to maintain the pool of P in the soil, so 1/25. Simple sums.

Table 1: Description of the six farms

No.	Farm Type	Catchment	Area (ha)	Current stocking rate	Current production
1	Dairy	Rotorua	125	3.7 cows/ha	180000 kg MS
2	Dairy	Rotorua	280	2.9 cows/ha	280000 kg MS
3	Dairy	Rerewhakaaitu	108	3.4 cows/ha	126795 kg MS
4	Sheep & beef	Okareka	585	11.7 SU/ha	162887 kg product
5	Sheep & beef	Tarawera	922	11.0 SU/ha	366160 kg product
6	Sheep & beef	Rotorua	892	16.4 SU/ha	Not available

Table 2: Farm goals (5 years)

FESLM Goals	Farm					
	1	2	3	4	5	6
Production	1400 kg MS/ha/yr	1070 kg MS/ha/yr	1000 kg MS/ha/yr	350 kg product/ha/yr	430 kg product/ha/yr	Maximise sustainable production
Risk[1]	2	2	2	1	2	1
Economic	Optimise EFS	Optimise EFS and equity growth	Optimise EFS	Optimise profit	Optimise EFS	Optimise gross revenue
Environmental	Achieve sustainability	Protect Lake Rotorua	Protect the environment	Best production best protection	Minimise avoidable environmental damage	Minimise environmental risks
Social	Aware of social responsibilities	Very aware of social impact of farm	Very aware of social responsibilities	Very aware of impact of farm on society	Operate for advancement of society	Develop aesthetically pleasing farm

Note 1) defined as the risk of not achieving the production goal (includes drought, flood, insect damage, financial)

Table 3: Nutrient Management Plan (a): Soil Fertility and Fertiliser

Farm	Value of nutrients on farm ($m)	Current fertility	Economic optimal Olsen P[1 & 2]	Recommended fertiliser plan	Economic outcome of proposed plan[3]
1	1.9	Olsen P > 100	40-54	Withhold P	Reduced fertiliser costs
2	3.2	Olsen P > 50	40-45	Withhold P	Reduced fertiliser costs
3	1.1	Olsen P > 50	40-45	Withhold P	Reduced fertiliser costs
4	2.8	Olsen P 10	25-30	Capital P	Increase in profitability
5	6.3	Olsen P 30	28-33	Maintenance	No change
6	8.8	Olsen P > 40	25-30	Withhold P	Reduce fertiliser costs

Note 1) Determined using OVERSEER 3 together with specific information from each farm.

2) P is the most expensive nutrient and thus the TNM philosophy is to bring all other nutrient to their biological optimal and then calculate the optimal Olsen P to maximise profits in the long-term.

3) The initial fertiliser costs are large as the soil is 'mined' down to the optimal nutrient levels. Thereafter a maintenance fertiliser input is required. Thereafter there are still cost benefits because the costs of maintaining the optimal nutrient levels are less than that of maintaining above optimal levels.

Table 4: Nutrient Management Plan (b): Effluent Management (Dairy Farms only)

Farm	Value of nutrients in effluent ($/yr)	Description of system	Current area (ha)	Recommended area (ha) (N input < 150 kg N/ha/yr)
1	9000	Land application	19	30
2	17500	Land application	50	60
3	7000	Land application	19	25

Table 5: Nutrient Management Plan (c): Nutrient Budget: Nitrogen

Farm	N inputs (kg N/ha/yr)			Fertiliser N last year (Kg N/ha/yr)	N leaching[2] (Kg/ha/yr)	Nitrate concentration drainage water[2] (ppm)	N loading[3] (Kg N/ha/yr)	N efficiency (%) (N in product/total N inputs)
	Fertiliser (Recommended)[1]	Clover	Supplements					
1	152	66	43	212	76	5	53 (1.8)[4]	40
2	127	129	12	192	62	12	36 (0.6)	31
3	150	146	9	144	74	9	31 (0.7)	32
4	0	43	0	0	10	1	11 (22)	35
5	161	16	0	161	29	3	28 (11)	7
6	35	101	0	27	16	1	19 (4)	11

Notes 1) All farmers have agreed to use fertiliser N as recommended by TNM

2) Derived from OVERSEER 4: typical levels for nitrate leaching are 30-45 for dairy and 5-25 for sheep and beef.

3) As determined by EBOP's NPlas program taking in to account riparian management, buffer strips and wetlands.

4) The figure in brackets is the proportion (%) of the N loading leaving the farm in overland flow.

Table 6: Nutrient Management Plan (d): Nutrient Budget: Phosphorus

Farm	P inputs (kg P/ha/yr)		Fertiliser P last year (kg/ha/yr	P runoff[2,3] (kg P/ha/yr)	P efficiency (%) (P in product/total P inputs)
	Fertiliser (recommended)[1]	Supplements			
1	0	6	40	1	300
2	15	2	54	1	88
3	0	2	97	1	750
4	100	0	34	1	1
5	36	0	44	1	3
6	0	0	32	1	Very high

Notes 1) All farmers have agreed to apply P as recommended by TNM

2) Derived from OVERSEER 4.

3) These calculated rates P runoff assumes no riparian management. Measured P transfer coefficients from pasture range 0.1 to 1.7 kg P/ha/yr.

Sustainable Development in the Rotorua Lakes: Deconstructing Development to Sustainable Limits

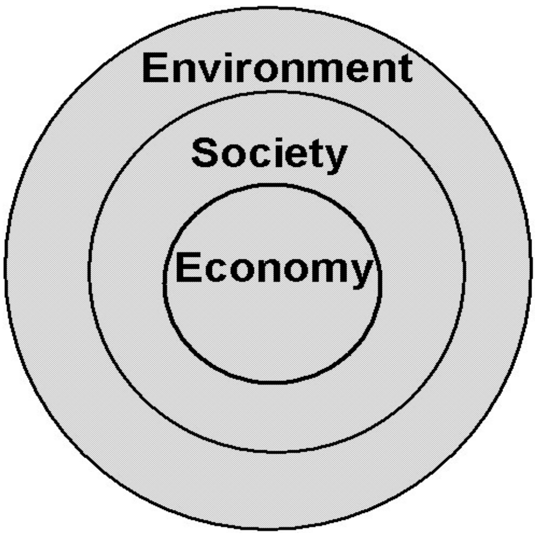
Mark Bellingham
Resource & Environmental Planning
Massey University at Albany
Private Bag 102 904
North Shore MC
m.Bellingham@massey.ac.nz

ABSTRACT

The present style of urban and rural development in the Rotorua Lakes catchments appears to be beyond the ecological capacity that these natural systems can sustain and the signs have been with us for many decades. But the problems for the Rotorua Lakes will remain until we devise land use planning policies and environmental standards for planning consents. This paper addresses the deficiencies in the local government statutory planning framework, the planning options for addressing the declining health of the Rotorua Lakes and options for sustainable development in these catchments. District and regional planning may need to reverse some land uses such as lakeside urban sprawl, and incremental agricultural and horticultural intensification. The pathway to ecologically sustainable development in the Rotorua Lakes may require some radical local solutions, including curtailing urban development or shifting it and the treated effluent outfall out of the lakes catchment and a change to the district's urban form. The Government's Programme of Action for Sustainable Development provides a pathway to achieving this.

WHAT IS SUSTAINABLE DEVELOPMENT?

The Government has recognised in the Programme of Action for Sustainable Development (NZ Govt 2003) that 'to build an innovative and productive New Zealand, the sustainable development approach will help us find solutions that provide the best outcomes for the environment, the economy and our increasingly diverse society.' A useful place to start in defining sustainable development in the Rotorua Lakes catchments context is the Parliamentary Commissioner for the Environment's report 'Creating our future: Sustainable development in New Zealand' (PCE 2002), which emphasises the critical place of the natural environment as a foundation for sustaining society and the economy in a strong sustainability system. When this foundational base of natural capital is eroded or damaged, then the sustainability of society and the economy are at risk. This is where sustainable management within the Resource Management Act 1991 (RMA) fits, as a mechanism for controlling uses of the



environment that breach these environmental bottom-lines.

But policies and plans under the RMA are only one part of the planning picture; their part is to control potentially unsustainable practices. Other informal strategies and plans including those under the Local Government Act 2002 are another part of the picture, which can provide incentives and broader community funding strategies to lead people and communities towards more sustainable practices. But these non-RMA strategies and plans generally lack the clear enforcement provisions of the RMA and cannot prevent unsustainable practices. Both the incentives and the disincentives are important.

Land use in these catchments is the key to sustainably managing the lakes, and the critical task for statutory planning is to control unsustainable practices by landowners, particularly for those who either don't understand the effects of their actions and those that do not care. Therefore it is important to assess the ability of the RMA plans that cover the Rotorua Lakes catchments to deliver on sustainability outcomes.

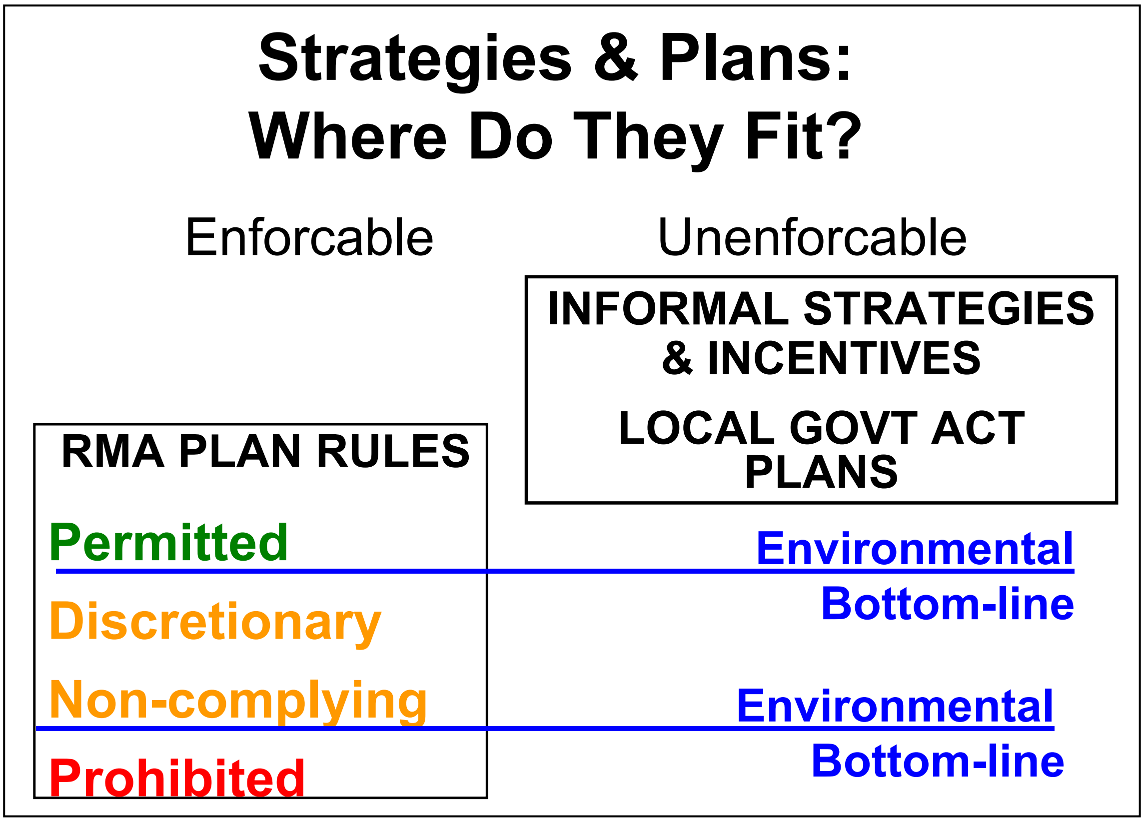
OVERVIEW OF DISTRICT & REGIONAL PLANNING

To reverse the decline of the health of the Rotorua Lakes within the statutory planning framework requires an understanding of the time scale of the Rotorua Lakes pollution problem, for the signs of ecological stress in some of these lakes have been evident since the 1970s and 1980s (Fish 1975, Hamilton 2004). Past and present research on water quality in the Rotorua Lakes has identified excess nutrients entering the lakes as the primary cause of their changing state (Hamilton 2004). This research has also identified a range of land uses in the catchments that have led to the change in the nutrient load, including treated sewage effluent (from treatment plants and septic tanks), fertiliser from agriculture and horticulture, and a change in nutrient budgets from changes in land use e.g. Conversion of native forest to exotic forests (Rutherford 2004). Also changes in stormwater hydrology in catchments, that lessen nutrient removal by soils biota and vegetation, has been identified as another factor from research in Auckland and overseas (Davis & Cassidy 2003). The present state of the Rotorua Lakes is a product of past and present land and water use, and the nutrients now causing the problems are in both the water column and the sediments of the lakes. Therefore simply arresting development where it is now is not enough, it will only leave the lakes in their present state.

PLANNING IN THE ROTORUA LAKES CATCHMENTS

The key planning agencies in these catchments are the Bay of Plenty Regional Council and Rotorua District Council. They have a number of land and water use plans that are operative or have been proposed and have some statutory force. The rules in these plans are the tools for delivering minimal sustainable practices. Activities in plans are classed as:
Permitted activities – The activity complies with standards set out in the plan for a permitted activity; you do not need a resource consent.
Controlled activities –The council may include conditions on how you carry out the activity, but only for those matters listed in the district or regional plan.
Discretionary activities –The council may decide to approve (often with conditions), or decline your application.
Restricted or limited discretionary activities –The council may approve (often with conditions), or decline your application, but may only consider a few matters it has listed

in the district or regional plan.
Non-complying activities –The council may approve (often with conditions), or decline your application. The council must decline your application if it has more than a minor effect on the environment and contravenes the district or regional plan.
Prohibited activities – You cannot get a resource consent for prohibited activities, as they are expressly prohibited in a plan (MfE 2003).



In district plans activities are permitted unless they are identified as one of the categories above where a consent is needed, whereas in regional plans all activities are non-complying unless they are permitted by a plan (Milne 1992). Within regional and district plans there is some overlap with land use as both regional and district plans can control aspects of land use. The fundamental purpose of statutory planning is to provide a framework of minimum standards that regulate people's behaviour and provide a climate of certainty in which they can use and develop natural and physical resources. In any plan its effectiveness can be assessed from the clarity of the objectives and policies, and the ability of these to be implemented by enforceable rules to achieve the desired outcomes that are sustainable (MfE 2003).

REGIONAL LAND & WATER PLANNING

The Rotorua Lakes catchments are within the Bay of Plenty Region and the Rotorua District. There are four RMA plans primarily affecting land and water resource management of these catchments: one district plan, and two operative and one proposed regional plan.

On-site Effluent Treatment Regional Plan (Environment Bay of Plenty 1996)
This operative regional plan controls the treatment and disposal of human effluent from

buildings not connected to sewerage systems. The plan is mainly directed towards minimising human health effects from poorly treated or untreated effluent. It identifies areas in the region that have poor drainage and where there are human health risks from bacterial and viral contamination, but it does not specifically identify known risks from nutrient contamination to streams and lakes from human effluent in the lakes catchments. The plan sets standards for effluent treatment, but these do not assess adverse effects or cumulative effects from excess nutrient loadings from effluent.

Regional Land Management Plan (Environment Bay of Plenty 2002)
This operative soil erosion control plan does not address the issue of nutrients and other contaminants from land affecting water. It relies almost entirely on voluntary landowner plans and has no useful provisions for controlling the discharge of nutrients into surface and groundwater from unsustainable land use. The plan proposes no improvement in the environmental condition of land in the region or the implementation of sustainable land use practices and does not address the erosion of phosphorus-laden sediments into the Rotorua Lakes.

Proposed Water & Land Plan (Environment Bay of Plenty 2003)
This regional plan proposes to manage the adverse effects of land and water use in the region. Specifically, it seeks to establish environmental standards to address the adverse environmental effects of the land and water use and development, the purpose to:

- Promote the sustainable management of land and water.
- Achieve the integrated management of land and water resources.
- Maintain or improve environmental quality in the region.
- Protect existing high quality environments and sensitive receiving environments.

There appears to be few potentially effective rules in the plan to control any increases in nutrients entering surface or ground water from land. The proposed Rule 11 relies on landowners applying for consents if they propose to intensify their land use, such as a change from dry stock farming to dairying or horticulture. But farming changes in the district have often come about from incremental changes in farm management and fertiliser use that probably would not need to be notified (they meet the test of having a similar scale and nature of effects to that carried out before). Yet it is these changes that have resulted in the problem we have today. Also the rule relies on farmers seeking consent for their land use activities, a stance that farmers and farming lobby groups have steadfastly opposed at RMA plan hearings throughout New Zealand.

Rotorua District Plan
The Rotorua District Plan has a sound policy base, particularly lake protection policies, but these have not been carried through into the plan's rules and the policies cannot be enforced. In effect, the plan has continued the residential sprawl around the lakes, especially Lakes Rotorua and Rotoiti, where in addition a large rural lifestyle zone has sprung up. If this follows the normal pattern of these developments – over the next 10-20 years it will turn into another urban area through incremental subdivision and addition of secondary dwellings. These non-urban dwellings around the lakes mainly are on septic tanks that release almost their entire nutrient load into the lakes.

Another source of contaminants to the lakes is from urban stormwater although the effects of this are not yet significant; they are detectable (Ray 2004) and can be treated. The subdivisional standards in the plan direct subdividers towards an urban form that makes it

difficult to treat urban stormwater. Significant advances in stormwater treatment have been made in the Auckland Region in the past five years (Waitakere City Council 2001). The simplest solutions for stormwater treatment appear to be the most effective, particularly using grass swales to trap and treat stormwater (Waitakere City Council 2003) and the free-draining soils of the Rotorua District are better suited to this than almost anywhere else in New Zealand. Experience in Auckland and Australia with swales show them to be often more economical than traditionally piped solutions and they deliver superior environmental outcomes.

WHY THE LOCAL GOVERNMENT PLANNING FAILURE?

All of the statutory plans for the Rotorua Lakes catchments permit a significant number of activities that individually and cumulatively are discharging nutrients into the lakes, and in the language of the RMA are producing significant adverse effects on the environment. Some activities require council approval, but often the council discretion does not appear to extend to controlling nutrient discharges. None of the activities that result in significant discharges of nutrients directly or indirectly to the lakes have been prohibited.

How Good is our Planning?

- **Clearly planning has failed in Rotorua**
- **It has failed to integrate past and present knowledge to direct future development**
- **It has failed to connect local people, decision-makers, scientists and other technical experts**

The regional plans are ineffective in setting any environmental standards that relate to the critical resource management issues for the lakes and they rely heavily on voluntary compliance. The district plan has some policies that address the state of the lakes, but no rules or standards to apply it. The plan continues the unsustainable urban and rural development patterns of the 1970s and 1980s. O'Connor (1993) contended that it would be difficult for councils to make defensible claims about the appropriateness of RMA plans for rural land use when there was little information about natural resources. In the case of the Rotorua Lakes, it is the opposite case where the ecological health of the Rotorua Lakes has been well documented, and there has been sufficient information since the 1980s to formulate planning policies and rules to address their declining health. In the 12 years since the RMA has been in force, statutory planning has failed to set minimum environmental standards on adverse environmental effects, effectively control activities (individually or cumulatively) that result in degradation of the ecological health of the lakes and provide incentives to enhance the state of the catchments.

Planning Failures

Strategic planning mistake –

- Mid-1980's did not address all the problems identified then………
- Only tackled City sewerage
- Did very little about
  - **Unsewered urban sprawl**
  - **Land clearance**
  - **Increasing fertiliser use**
  - **Future land intensification**

In hindsight, I contend that a strategic planning mistake was made in the 1980s, when a range of contributors to nutrient discharge into Lake Rotorua, in particular, were identified, but it was decided that the key issue to resolve was the upgrading of Rotorua City's sewerage treatment plant. The effort went into Rotorua's 'state-of-the-art' sewage treatment system, while land clearance, fertiliser leaching, septic tanks and urban effects continued discharging with minimal controls. Now 20 years later the time has come to address all of the problems, for the cumulative effects are even more evident.

Planning Failures

- **Central Government**
  Continued funding and supporting land clearance and unsustainable development
- **Regional Planning** – ineffective land & water management controls
- **District Planning** – (unsustainable) business as usual

Planning Failures: Regional Planning

- On-site Effluent Plan does not address nutrients in Rotorua Lakes
- Proposed Water & Land Plan
  - **Does not prohibit on-going loss of catchments' woody vegetation**
  - **Expects farmers to dob themselves in if they intensify production**
  - **No incentives to take land out of production**
  - **No incentives to protect or enhance forest & scrub in catchments**

Another factor that cannot be ignored has been the role of Central Government in encouraging unsustainable practices through subsidies, incentives in agriculture and forestry. From the late 1940s Government subsidised farmer land clearance and fertiliser prices, in addition to land clearance by Government Departments in the Rotorua Lakes catchments. These activities continued until 1986 and pressure from Government Ministries, including the Ministry for the Environment on Local Government to minimise land use regulations through the RMA has sustained this period of unsustainable development (Taylor 1996). A significant amount of fertiliser from past decades is in the sediments on the lake beds causing today's eutrophication problems.

Planning Failures: District Planning

- Allowed on-going urban sprawl (Rural E zone) and peri-urban sprawl
- Poor urban design
- Minimal provisions for reducing contaminants in urban stormwater

WHAT ARE THE OPTIONS FOR SUSTAINABLE DEVELOPMENT?

The first principle must be to identify development options in the Rotorua Lakes catchments that generate less water-borne contaminants, particularly phosphates and nitrates. The reality is that it cannot be achieved through a single large-scale engineering solution, if the lakes are to be recovered, then it needs to come from all land and water users in the catchments changing their personal actions that are threatening the lakes.

District Planning Actions needed

- Use the present low growth as an opportunity to point the District to a sustainable future
- Prohibit further non-sewered lakeside development
- Force development into the existing sewered area
- Consider development charges – ‘pollution charge’ on households

Also those Central and Local Government agencies that control and fund activities in the catchments of the lakes need to change the cumulative force of development pressures they are putting on land and water users to ensure they act beneficially for the health of the lakes.

Secondly, precautionary limits need to be set for lake catchments that take account of the cumulative effects of development. To some degree, all land and water users in the lakes catchments are the problem.

Thirdly, that the land uses with the highest contaminant loads need to be identified, so that the net adverse effect can be remedied or mitigated. In the case of pastoral farming or horticulture, this may have to come from retiring land from production to lessen the net effect of these activities.

WHAT ARE THE OPPORTUNITIES TO RECOVER THE HEALTH OF THE ROTORUA LAKES?

Funding Opportunities **Central Government**

Need to contribute for the on-going damage to the Lakes from past development incentives

Local Government

Pollution charges (Local Govt Act 2002)

•Rural land use charges

•On-site effluent charges

•Sewerage charges

•Urban stormwater charges

1. The District needs a sound statutory planning framework to set the environmental bottom-lines for people in the catchments. This will act as guidance for people to improve on their environmental management and to stop those few people who have little regard for the environment or the local community. Long-term studies of incentive programmes that lack statutory guidance, have consistently shown a lack of any environmental improvement (Bradsen 1993), whereas incentive programmes with sound and enforceable rules can produce consistent environmental improvements (Bellingham 2003).

2. Use the present low growth in Rotorua District as an opportunity to change to a sustainable future, by such measures as:
   - Prohibiting further development that does not include significant nutrient removal of sewage.
   - Directing urban and peri-urban development into the existing sewered area.
   - Consider development charges – 'pollution charges' on households and land users (either through RMA Financial Contributions or LGA Stormwater Charges) to contribute to a land retirement fund.
   - Changing the District Plan to promote 'Lake-Friendly' urban design measures, including minimal earthworks for subdivisions.
   - 'Soft Engineering' solutions to capture urban stormwater contaminants in grass swales and other 'at-source' solutions.
   - Retrofitting other part of the City to 'Lake-Friendly' urban design standards through maintenance programmes.
   - Minimising fertiliser use and earthworks in parks and golf courses.
   - Promoting lower fertiliser use to home gardeners

3. The local community, its politicians and local government officials need to face up to the reality that current unsustainable development cannot continue and that viable options exist. Making people in the catchments understand they are all part of the problem, and the solution. If environmental standards are set, councils can show people how to live sustainably, provide local examples of sustainable

development and develop funding structures to lead sustainable development.

4. Local Government leadership is a key ingredient to the community owning the problem and not blaming others. This could change the way people live and work in the Rotorua Lakes catchments and lead to sustainable development. Potentially this could position Rotorua at the vanguard of international tourism centres that have implemented sustainable development.

Challenges for a Lake-friendly Future

1. **Making people understand they are ALL part of the problem…….**
2. **……And the solution**
3. **Local Government Leadership is a key ingredient to owning the problem**

4. **Changing behaviour through**
5. **Showing how everybody can help to save Rotorua's Lakes**
   a) **practical examples,**
   b) **involvement,**
   c) **incentives,**
   d) **pollution controls and**
   e) **pollution charges**

QUESTIONS

Chair. You got a standing ovation! We've got time for just two questions.

Kepa Morgan: Kia ora Mark. I enjoyed your talk. It resonated I think a little with what I was talking about this morning. You mentioned the environmental bottom line and how it's way too high in terms of our planning structures, you talked about the 80's sewerage solution that was provided here in Rotorua, and you refer to plans and how they haven't been delivering. So I just wanted to know in terms of the sewerage solution, who drove that in terms of the actual solution we ended up with? And I also wanted to know in terms of the plans, whether you thought that incorporating the other cultural paradigm in this country would actually make any difference to those. Kia ora.

M.B. Who drove the sewerage solution? Well I think it was a combination of the local authorities who just simply had this antiquated system, the City Council did. They had to do something, they had some money to spend, the County Council at that stage had the same problem – lots of septic tanks and heading towards some sort of treatment, and then some government agencies. I remember the Freshwater people from the Wildlife Service were key drivers in trying to actually get some better system there. But behind that were a whole lot of local people who simply weren't happy with what was going on and that was the Kaitiaki of the lakes and a whole lot of other people. So it was politically driven and from the ground, but there were key people in those organisations who helped make it happen.

Paul East, Q.C. I used to be the Deputy Mayor at that time and I'd like to correct you on that. The position was that in the '60s Rotorua had virtually no sewerage at all, apart from very much the downtown area. Almost all the rating income through the '60s and '70s was spent on sewage reticulation. Then there was a major debate because at that stage the sewage went into the lake just by the stream and there was a major debate and the original Kaituna Catchment Commission Scheme provided for a pipeline to the Kaituna River. The Te Arawa and in particular Ngati Pikiao, took a case to the Waitangi Tribunal and that was upheld and the pipeline did not proceed. And I think we should be grateful for that, because we at least then thought we had a better solution. There had been an ongoing debate with the Mayor of the time, the Honourable Ray Boord, who brought Swedish scientists here who said that you could strip the nutrients and put it in the lake and the lake could handle the load. A number of us didn't believe that and thought that the problem would continue to grow and were of the view that we should have a land disposal system out of the catchment. Combine that also with nutrient stripping so that you had a belt and braces approach. That is what took place in the mid 1980s with a change of government and the Honourable Mick Connolly, the Minister of Works continued to proceed with the scheme. It was a $30 million dollar scheme, the largest environmental scheme undertaken in the country, and I think it was a credit to those involved to get that amount of funding and have the scheme implemented. Little did we know that it would continue to give problems only recently discovered in terms of the leaching of water back into the lake system, when we thought

a) it had been stripped pretty well and
b) it was out of the catchment system.

But knowing this now, the Rotorua District Council as I understand it is moving rapidly to increase the nutrient stripping that's going on at the plant and look at other ways of ensuring that it doesn't get back into the catchment. I think those are the facts as to how the scheme was implemented. (*The material was not removed from the catchment – Ed.*)

M.B. Just to finish that, on the second question: yes the model that you put up this morning is probably a better way forward for the Council to actually address this problem. In other places the nutrients flow out into the sea and they just hope they disappear. Here you don't have that. You're left with them and you've got a legacy of years of them and so you really have to change the way you think and the way you value the environment and what you're going to put first. And so I think that was part of your message this morning.

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Recycling sewage wastewater – profits with environmental protection

J. R. Crush, D. A. Care, S. N. Nichols, M. J. George
AgResearch
Ruakura Research Centre
Private Bag 3123, Hamilton

ABSTRACT
Using plants to strip sewage wastewater of nutrients likely to damage receiving waters can be accomplished with land-based treatment systems. The key to long-term effective nutrient stripping is regular harvesting of plant material containing nutrients and their removal from the treatment site. We propose a two-stage system for nutrient removal and revenue generation. In the first stage wastewater is used as a hydroponic solution to grow plants that will remove some nutrients and provide a commercial product. Eight plant species were tested and all grew in wastewater hydroponics although growth rates were lower than in a commercial hydroponic solution. The growth rates were lower because of the relatively dilute nutrient concentration of the wastewater. In the second stage, wastewater exiting the hydroponic system would be irrigated on to forage grasses under a silage cutting regime where more nutrients would be removed in the harvested silage. We examined growth and nitrogen removal rates for 5 alternative forages to ryegrass on the Taupo District Council wastewater irrigation site. Prairie grass and swamp phalaris removed significantly more nitrogen from the wastewater than the ryegrass currently used on the site. This shows that it is possible to improve the nutrient stripping efficiency of wastewater sites by choosing the best plant to grow.

KEYWORDS: land treatment, nutrient interception, nutrient recycling, sewage wastewater, water quality

INTRODUCTION
During agricultural production plants absorb and concentrate the dilute solutions of nutrients found in soils. These nutrients are further concentrated if the plants are eaten by grazing animals, and leave the farm in milk and meat. Most of the mineral nutrients (e.g. nitrogen and phosphorus) consumed by humans end up in the sewage system. Unless these nutrients are spread out over an area of land equivalent to that from which they were originally gathered, there is potential for nutrient concentrations to exceed the absorbing capacity of the receiving environment. When this happens we lose control of the nutrients and their escape and damage surface and groundwaters.
Access to clean water is becoming a major driver of geopolitical trends in many parts of the world. "The wars of this century will be fought not over ideology, but over natural resources like water" (ACIAR 2000). Efficient nutrient stripping from wastewaters so they can be reused will be a global imperative in the immediate future. For countries such as New Zealand that are relatively well-endowed with water, the major benefit may be protection of aquatic environments for the social, cultural and economic benefits that accrue to clean surface waters. In other cases, especially the Middle East, North Africa, South, West and Central Asia, shortage of potable water is the main driver.

Land-based treatment is the preferred option for cleaning up wastewater because the technology is widely achievable with low operating energy and engineering costs. It is therefore particularly suitable for intermediate- and smaller-sized communities where the

rating base may be inadequate to fund engineered options for wastewater treatment.

Land-based treatment differs from conventional irrigation in that contaminated water is applied far in excess of plant requirements for growth. The plants filter out most of the nutrients applied and the surplus water is available for reuse through recharge of ground or surface waters or directly by interception of drainage. The main nutrients in wastewater are nitrogen and phosphorus. Removing the nitrogen, which is highly mobile, is the key to reducing environmental risks of wastewater. Phosphorus is readily immobilised in soil and much less likely to leak to the wider environment.

Taupo District Council runs a very successful land-based treatment system for its sewage wastewater. The wastewater is spray-irrigated on to ryegrass swards with blocks being irrigated in turn, and then cut for silage. The silage is stored in wrapped bales until faecal coliforms drop to acceptable levels, and then the silage is sold to farmers for stock feed. Nutrients that were applied in the wastewater are therefore exported off the site, and the drainage water does not impose any threat to the environment.

Contamination of wastewaters with heavy metals or other toxic compounds can be a problem for land-based treatment systems. In our opinion these pollutants are best removed at source through trade waste regulations. Copper and zinc, probably from domestic plumbing, tend to be ubiquitous in wastewaters but many New Zealand soils are deficient in these elements (During 1984) and their application in wastewater may actually be beneficial. Long-term monitoring of accumulation rates of all applied metals should be mandatory.

We have looked into three questions concerning land-based wastewater treatment using the Taupo District Council wastewater site as a model:

1. Is it possible to improve the nitrogen trapping efficiency of a silage system by using grasses other than ryegrass?
2. Could hydroponic plant growth systems be part of land-based wastewater treatment?
3. Are there alternative plants and harvesting systems to a forage grass/silage system for nutrient interception and removal? For example could we use plants combining nutrient stripping with production of other industrial substrates such as latex, waxes, oils, fibres etc.

In this report we describe work addressing the first two issues. The third issue of using plants that produce an industrial substrate is important because we think it may be prudent to separate human wastewater from the human food chain. A brief summary of progress in this topic is given in O'Connor *et al*. (2002).

METHODS

Our concept, shown in Figure 1, is for two-stage utilisation of wastewaters. In stage 1, wastewater would flow through channels acting as hydroponic growth units. Plants with their roots exposed to the wastewater would absorb nutrients which would be removed in a product of some kind. Sale of the product would help defray operational costs. In stage 2, the partially depleted wastewater exiting the hydroponic system would be irrigated onto a grass crop for silage. This would complete clean up of the wastewater and provide a second revenue stream, and removal of nutrients as the silage is sold off the site.

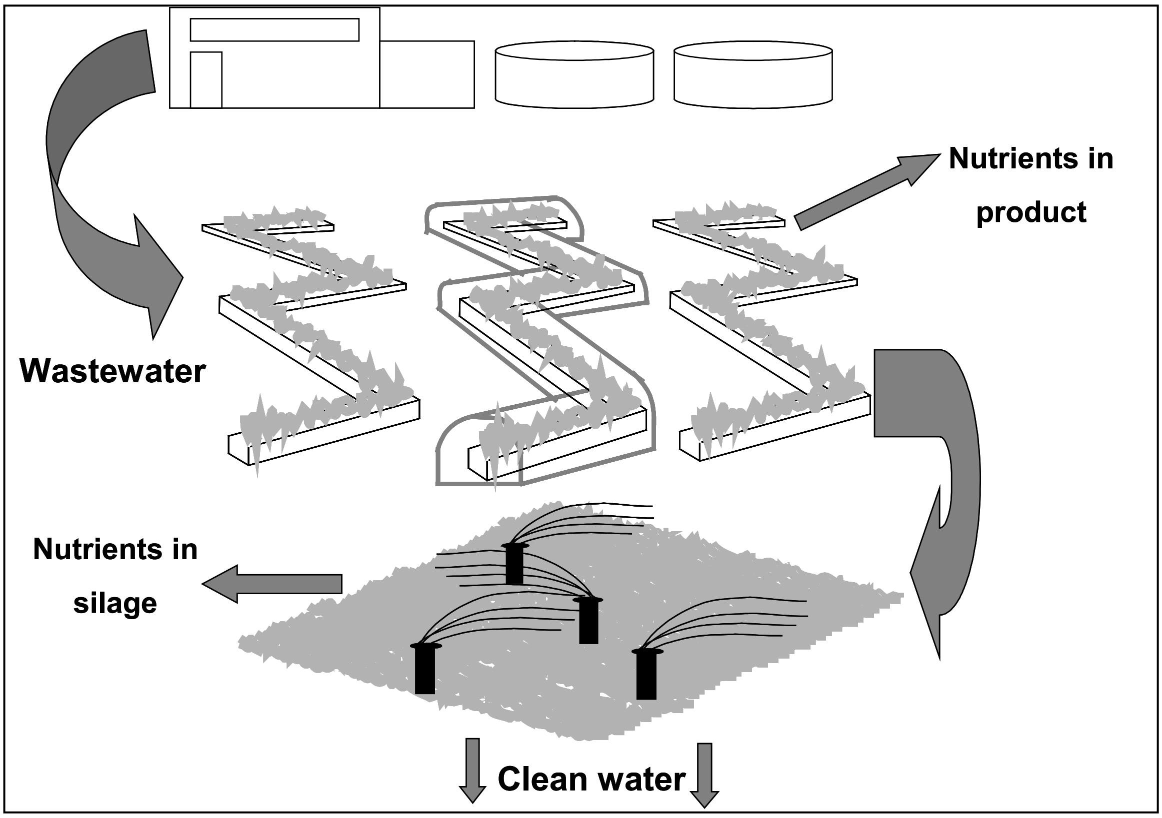

Figure 1 Conceptual diagram of a two-stage land-based system for nutrient removal from wastewater. Wastewater leaving the treatment plant flows through channels used to grow plants hydroponically, and then is irrigated onto a forage grass that is cut for silage.

Wastewater as a hydroponic plant growth medium
Wastewater samples from the Taupo District Council and Hamilton City Council treatment plants were analysed and a synthetic wastewater solution with matching nutrient content was developed (Table 1).

Table 1 Nutrient concentrations (ppm) in sewage wastewater, the synthetic wastewater used experimentally, and a typical plant nutrient solution. The non-nutrient chlorine is also shown.

	Sewage wastewater	Synthetic wastewater	Nutrient solution
Nitrate nitrogen	5	12	196
Ammonium nitrogen	2	3	14
Phosphorus	5	5	31
Potassium	19	20	234
Magnesium	3	3	48
Calcium	15	10	160
Sodium	69	41	Not known
Sulphur	17	17	64
Boron	0.3	0.4	0.5
Copper	0.02	1.0	0.02
Zinc	0.1	0.1	0.05
Iron	0.8	1.0	0.6
Manganese	0.06	0.3	0.5
Molybdenum	0.004	0.001	0.01
[Chlorine]	52	73	Not known

The synthetic wastewater provided the consistency of composition necessary for experimental work. Growth of 8 different plant species in the synthetic wastewater was compared with their growth in a commercial nutrient solution using a recycling nutrient film hydroponic system in a glasshouse. The plants were chosen to represent a range of plant families, and not for any particular perceived potential in wastewater treatment. There were 8 replicates of each plant type in both nutrient solutions. Plants were raised from seed, and grown in rock wool before being transferred into the test solutions. After 3 weeks growth in the test solutions the plants were harvested, and the shoots dried, weighed and analysed for nitrogen content.

Interception of nitrogen by forage grasses

Trial plots were established at the Taupo District Council effluent irrigation site on Rakaunui Road. An area of the existing ryegrass was sprayed with Roundup™ and the soil rotary hoed to prepare a seedbed. The area was divided into fifteen 5x10 metre plots, to which the test grasses were assigned at random. Seed was sown by hand in November 1999, and the trial ran until January 2003. A hand roller was used to compact the seedbed and increase the contact between the seed and the soil. The grasses sown were: Tall fescue (cv. Advance), prairie grass (cv. Matua), swamp phalaris, a mixture of prairie grass and swamp phalaris, ryegrass (cv. Bronsyn), and a chicory (cv. Puna)/ hybrid ryegrass (cv. Galaxy) mixture. The trial area was subject to the usual irrigation and silage cutting regime of the block. Unfortunately, accidental spraying of broadleaved weeds in the block eliminated chicory at an early stage in the trial. An attempt to re-establish the chicory by oversowing was unsuccessful.

Prior to each silage cut on the block, herbage samples were taken from the trial area. Three 0.28m^2 quadrats were cut at random within each of the fifteen plots. Three samples were also cut outside the trial area to compare the alternative forages with the existing ryegrass. Each sample was weighed fresh, and a subsample taken to determine dry weight after oven drying at 70°C. Due to varying lengths of time between cuts the number of days between each cut was used to convert production to a weekly basis.

After observing measured dry matter production for a number of months, the highest yielding treatments (prairie grass and prairie grass/swamp phalaris) were selected for analysis of nitrogen content along with the existing ryegrass. The samples from each cut for these three mixes were analysed for % nitrogen. DM yields were multiplied by the % nitrogen concentration in the herbage to obtain nitrogen off-takes per hectare. This was also converted to a weekly figure to account for variations in regrowth intervals.

RESULTS

Wastewater as a hydroponic plant growth medium

All 8 plant species grew in the synthetic wastewater, but their growth was much slower, and nitrogen concentrations in the shoots much lower, than for the plants in the commercial hydroponic solution (Table 2).

Table 2 Shoot dry matter (DM) yields and shoot nitrogen (N) contents for 8 plants grown in a synthetic wastewater and in a commercial nutrient solution.

	mg shoot DM	mg shoot DM	Shoot % N	Shoot % N
	Wastewater	Commercial	Wastewater	Commercial
Rocket	395	4165	2.8	6.6
Coriander	242	694	3.1	5.4
Basil	490	2074	1.9	5.0
Dill	246	1194	3.1	5.5
Lettuce	81	1971	3.9	5.7
Red clover	104	439	3.7	5.7
Radish	236	2373	3.5	4.4
Catmint	36	450	4.3	6.6

Interception of nitrogen by forage grasses

Analysis of the grass yield data for each harvest showed that although prairie grass was consistently the highest yielding species, this was statistically significant on only two occasions. Over the duration of the trial, prairie grass yielded an additional 7.6 t DM/ha compared with the existing ryegrass (Figure 2). There were no consistent, statistically significant differences in herbage nitrogen content among the three pasture mixtures.

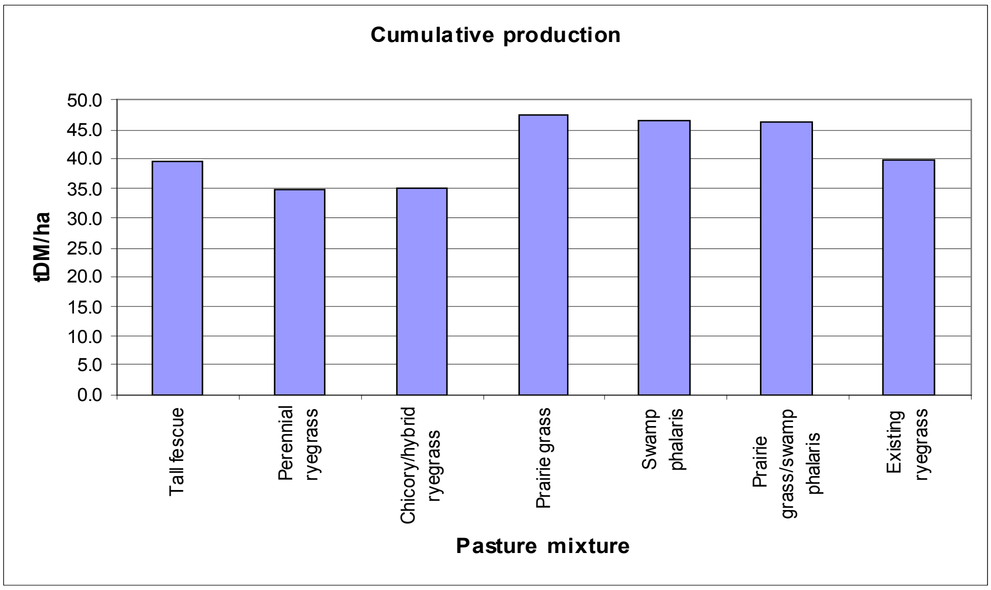

Figure 2 Cumulative herbage production (tonnes DM/ha) for 7 different grasses grown on the Taupo District Council wastewater irrigation site 28/02/00-16/01/03.

Total nitrogen off-take for the three mixtures is shown in Figure 3. The prairie grass and prairie grass/swamp phalaris mixture yielded significantly more nitrogen ($P<0.05$) than ryegrass over the duration of the trial.

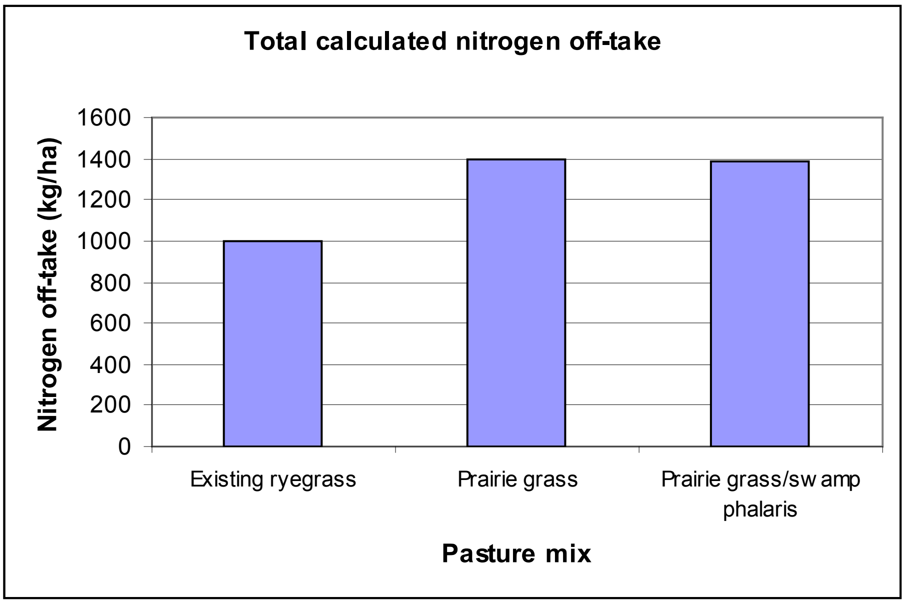

Figure 3 Total nitrogen off-take (kg N/ha) for the existing ryegrass, and plots of prairie grass and prairie grass/swamp phalaris over the duration of the trial.

DISCUSSION

The hydroponics experiment showed that it is possible to use sewage wastewater to grow a range of plants. The plant nutrient concentrations in the wastewater are much lower than those found in commercial hydroponic solutions. As a result plant growth and plant nitrogen contents were lower in the wastewater, than in a typical nutrient solution. This relative nutrient deficiency may be overcome by increasing the flow rate in the

hydroponic channels so that the roots are constantly exposed to near the maximum nutrient concentration possible with the wastewater. In a non-recirculation system this will inevitably lower nutrient interception rates so that the nutrient content of the wastewater entering the stage 2 process would be higher than if lower flow rates were used. The wastewater could be recycled past the plants until its nutrient content was significantly lowered but this would attract the costs of installing and operating pumps. It may be better to use hydroponics to generate revenue from wastewater, and depend on land-based systems for nutrient removal. Relatively low cost hydroponic systems using plastic sheeting lined trenches and gravity flow could be constructed and covered by tunnel houses so that heat demanding crops could be grown. The economics of an integrated wastewater treatment system would need to be assessed holistically, using whole-system environmental economics to include the tangible and intangible benefits from keeping surface waters clean.

Of the six alternative seed mixtures examined at Taupo only two – Matua prairie grass and swamp phalaris - looked to be worth considering as alternatives to ryegrass in terms of growth rate in this region. The tall fescue, hybrid ryegrass and newly-sown ryegrass were all very similar to the existing ryegrass. Prairie grass has been trialled successfully under effluent irrigation in the US (Miller *et al*. 2001) supporting the results of our investigation.

The nitrogen removed in the prairie grass and prairie grass/swamp phalaris plots exceeded that from the existing ryegrass by a clear margin in 2001 and 2002. In 2001 the N yield was at least equal to the nitrogen applied by the irrigation i.e. there was complete removal of the applied nitrogen. The nitrogen yields from all three treatments declined with time. For the prairie grass plots this was associated with a reduction in herbage yields over the last two regrowth periods. Whether this decline was permanent as a result of damage by pests such as Hessian fly, or temporary is unknown. Herbage yields from the swamp phalaris plots increased at this stage and probably contributed to better performance from the prairie grass/swamp phalaris mixtures. Nitrogen analysis of swamp phalaris from the December 2002 cut showed a nitrogen off-take that was 22 kg N/ha higher than the prairie grass/swamp phalaris mix and 76 kg N/ha higher than prairie grass alone. These results indicate that there is scope to increase nitrogen harvest rates on the wastewater site by sowing prairie grass or prairie grass /swamp phalaris mixtures. The additional nitrogen removed would provide a buffer at existing nitrogen loading rates, and provide some scope for an increase in loading rates, while maintaining low nitrogen concentrations in the drainage waters. Alternatively the capital costs of new wastewater sites could be deceased by using a smaller area of land.

CONCLUSIONS

The results show that it is possible to improve nitrogen interception rates on a conventional land-based wastewater irrigation site by using prairie grass or swamp phalaris as an alternative to ryegrass. Using hydroponic systems to extract nutrients from wastewaters requires more research. However such systems may provide opportunities to generate revenue from crops not able to be grown in the open.

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Stewart of PGG Seeds supplied the swamp phalaris seed.

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Rotorua Lakes: Plants tell the tale

John Clayton and **Paul Champion**
NIWA, P.O. Box 11-115, Hamilton

INTRODUCTION

Lakes unmodified by catchment development, human settlement and public access still retain much of their original status in terms of water quality and aquatic vegetation. Large lakes have a greater buffering capacity compared to small lakes, but even big clear water lakes such as Taupo and Wanaka are now showing disturbing signs of human impacts that include progressively reducing water clarity, increasing frequency of algal blooms and biodiversity impacts from invasive weed species.

Deterioration in the condition of the Rotorua Lakes has been occurring for many years (Rutherford 1984, Vincent *et al* 1984, White 1977). Apart from records on water quality decline, scientific papers have also been published comparing vegetation from the 1960s to the 1980s that showed parallel deterioration in abundance scores for total vegetation and key submerged species (Coffey & Clayton 1988).

This paper seeks to describe the status of the Rotorua lakes based on information revealed from recently assessing aquatic vegetation, discusses further threats to these water bodies and suggests what individual lake users can do to help reduce the risk of further deterioration.

AQUATIC VEGETATION INDICATES LAKE HEALTH

Aquatic plants can be used to assess lake ecological condition because the plants are perennial and respond cumulatively to changes in water clarity and nutrient status. Furthermore, plant species can be used directly to assess biodiversity values and the degree of impact from invasive plant species. Information gathered from aquatic vegetation within a lake can be used to rank the health or condition of a lake (Edwards & Clayton 2002). LakeSPI (Lake Submerged Plant Indicators) has been developed as a method for converting vegetation information into numerical scores for the purpose of graphically depicting lake status as well as enabling inter-lake comparisons, intra-lake status monitoring over time and to assist management agencies with State of Environment reporting. Two key factors affecting this ranking are water quality (i.e., clarity and nutrients) and impact from invasive plant species. Water clarity determines the depth to which submerged vegetation can grow, while nutrient enrichment affects the health of submerged plants by influencing the extent of periphyton (or algal growths) that cover the stems and leaves of submerged vegetation. Invasive plant species can be also ranked for their known invasiveness as well as the degree of habitat impact to any given water body. For example, *Elodea canadensis* has one of the lowest impacts, while *Ceratophyllum demersum* (hornwort) has the greatest known detrimental impact of any submerged weed species in New Zealand.

VALUE OF AQUATIC PLANTS

Aquatic plants can be a valuable component to the biodiversity found within a lake. New Zealand is well renowned for its abundance of internationally important aquatic vegetation communities, including native charophyte beds and deep-water bryophyte communities. Both of these communities are internationally in a state of decline and some

New Zealand lakes provide excellent remaining examples. Apart from biodiversity, submerged aquatic vegetation is also a key component of the primary production found with a lake, both directly and through provision of habitat for periphytic algae, which in turn is important for ecosystem function. Aquatic plants also provide valuable habitat for other organisms through the structural complexity they provide and by their increase of available surface area for attachment of other biota.

Submerged aquatic plants also assist in the maintenance of good water quality within a lake. They achieve this by dampening wave action, thereby reducing water movement and wave re-suspension of bottom sediments. This in turn helps to maintain or improve water clarity directly. Plants can also help improve water clarity through filtering of particles suspended in the water column and indirectly by uptake of dissolved nutrients and reducing the release of nutrients from sediments by release of oxygen from their roots.

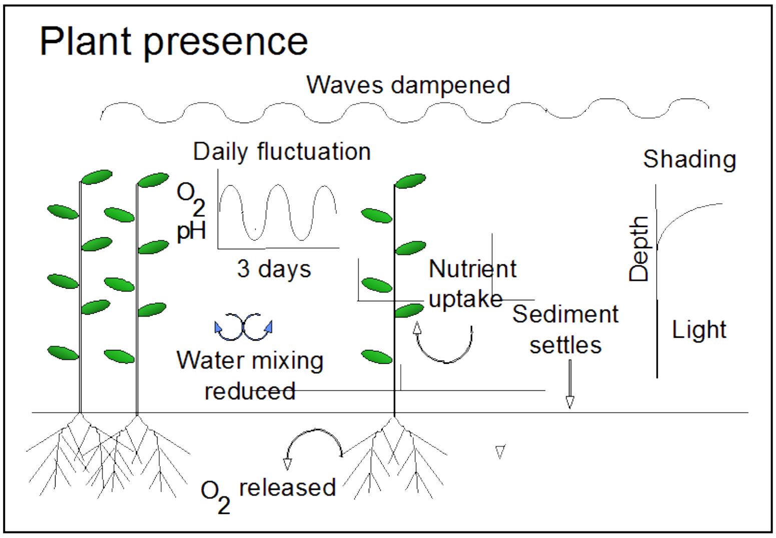


Figure 1. Inter-relationship of submerged plants and lake water quality

The development of planktonic algal blooms is lessened through this removal of nutrients from the water column. Many of these ecosystem functions are provided by introduced aquatic weed species.

The influence of submerged aquatic plants on the lake environment is related to the relative area they occupy. For steep-sided lakes like Tarawera only a narrow marginal band of plants is present over much of the lakes, whereas relatively shallow lakes like Rotorua and Rerewhakaaitu have a much greater littoral zone and aquatic vegetation has a greater impact on the lake.

STATE OF THE ROTORUA LAKES

The Rotorua Lakes can be conveniently grouped into three categories based on information reflected in their lake vegetation.

Status	Lakes	Properties
Best	Rotoma Rotomahana Tikitapu Okataina	Important native plant communities present Invasive weed impact only moderate Worst invasive weed species is absent
Not so good	Tarawera Okareka Rerewhakaaitu Rotoehu	Major invasive weed impact Declining vegetation depths
Worst	Rotorua Rotoiti Okaro	Plants showing signs of decline Blue-green algae abundant

Table 1: Eleven of the Rotorua Lakes grouped according to their ecological condition as defined by submerged aquatic vegetation properties.

Most of the Rotorua Lakes have been impacted significantly from progressive nutrient enrichment and by a range of invasive plant species. The lakes in the best condition presently are Rotoma, Rotomahana, Tikitapu and Okataina. The next best group of lakes is Tarawera, Okareka, Rerewhakaaitu and Rotoehu. The lakes clearly in the worst condition are Rotorua, Rotoiti and Okaro. This ranking of lakes, based entirely on information reflected by the aquatic vegetation within each lake, is considered to fit quite closely to public perceptions about the health and condition of these lakes.

Some lakes have a measure of self-protection, which helps to explain the group containing the four best lakes. Tikitapu has unusual water chemistry with exceptionally low calcium. It is also low in silica and all major ions, which has been thought to inhibit plant and algal growths (McColl 1972); Rotomahana has limited public access and has so far been protected from any problematic invasive weed species; and to some extent Rotoma and Okataina also have reduced public access, favourable catchment characteristics and deep water buffering capacities that help reduce the risk of introducing new weed species and minimise the impacts from nutrient enrichment. Rotoma also has several large lagoons around the margin that are thought to help reduce the amount of nutrients entering into the lake.
The following section considers some biosecurity and eutrophication issues affecting these lakes:

HOW HAS THIS HAPPENED?

Wildlife is not a factor in the spread of problematic weed species. Wildlife can only spread weed through consumption and transport of plant seeds in their gut, but none of the problematic submerged weed species produce seed in New Zealand. All of the nuisance weed species reproduce vegetatively and their spread is from movement of vegetative fragments. The key vector in movement of weed fragments is people; either through deliberate (e.g. ornamental ponds, release of aquarium contents) or accidental spread (e.g., contaminated boats, trailers and nets). This clearly demonstrates the benefits of isolation and explains the close association between lake access in the form of boat

ramps and the incidence of introduced weed species in lakes (Johnstone *et a*l 1985). Lake Rotomahana is dominated by native species, while the remaining group of “best” lakes (Rotoma, Okataina and Tikitapu) have not been affected by the worst invasive weed species to date.

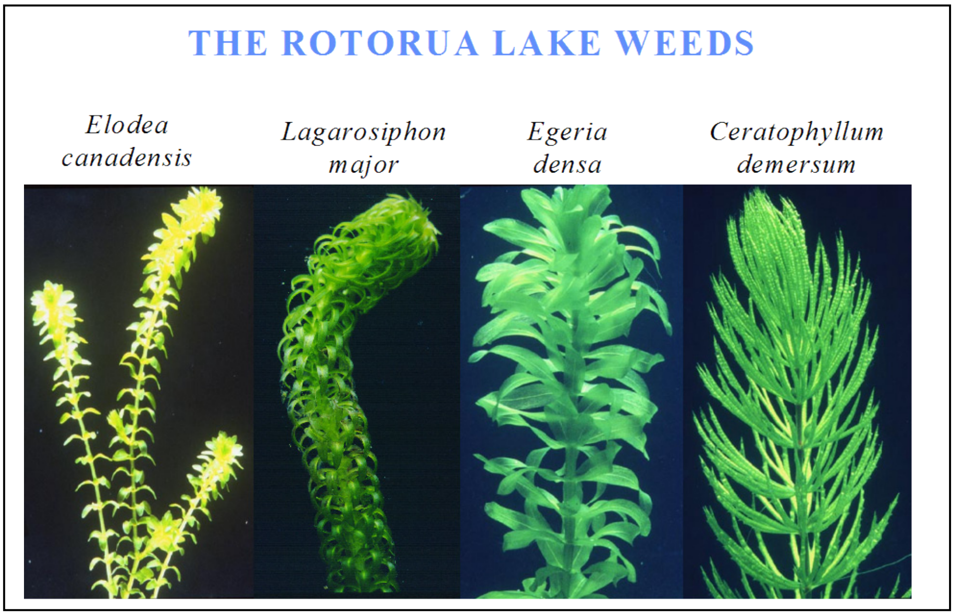


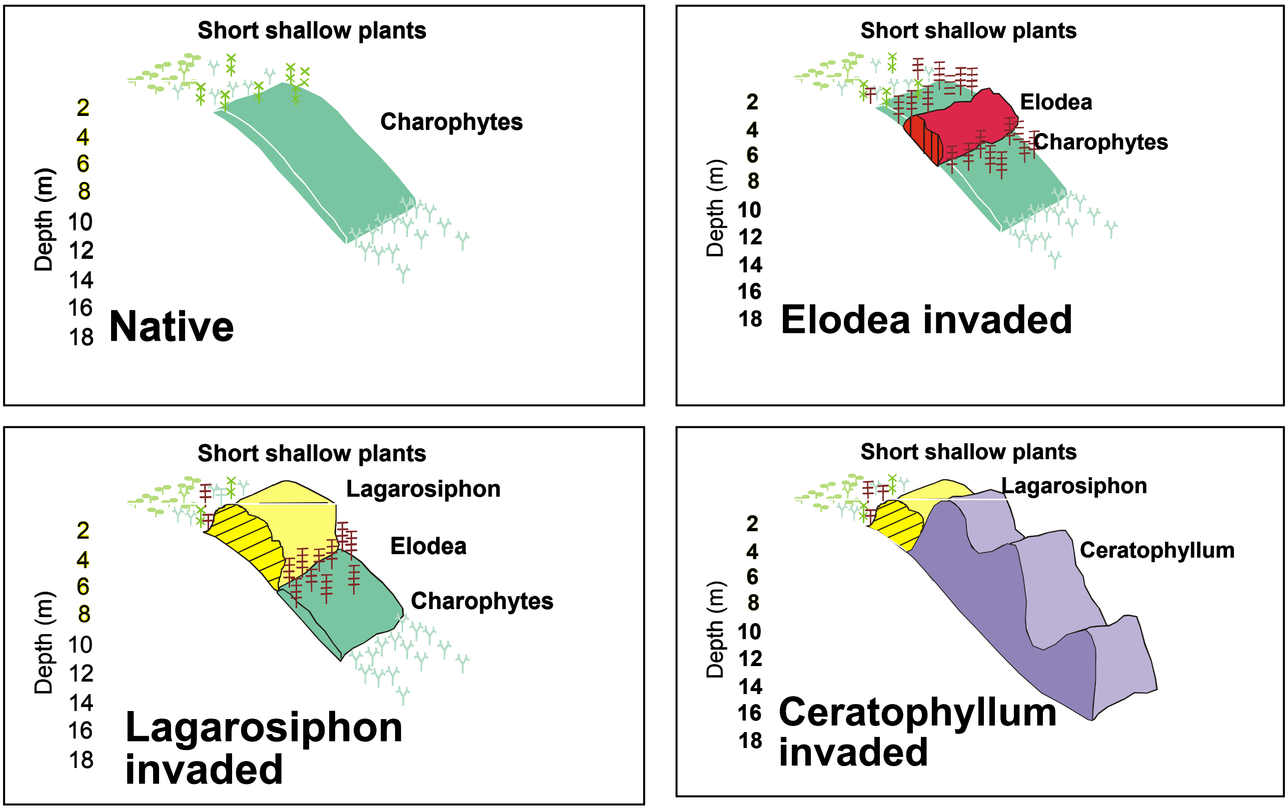
Figure 2. Problem submerged weeds (increasing weed impact from left to right)

Biosecurity issues are largely independent of water quality issues, unless eutrophication has progressed to the stage that water clarity is negligible and algal growths (e.g., blue-green algal blooms) become competitive. In this case submerged aquatic plant species are likely to have declined or even disappeared. Nutrient enrichment is in fact a natural process, but the influence of humans characteristically accelerates this process, often beyond the buffering capacity of a waterbody.

Deterioration in water quality can result from a complex array of factors. In the early stages of eutrophication nutrients affecting water quality tend to be associated with surface and groundwater inflows. Catchment modification (e.g., removal of marginal wetlands, forest clearance, fertilising of pasture, sewage or septic tanks inflows) is a key factor driving eutrophication, with acceleration most notable when lakes are small or where they have limited buffering capacity. One of the characteristics of advancing eutrophication is that bottom waters of a lake become depleted of oxygen during the summer months. When this happens it is common for years of accumulated nutrients previously locked up in the sediments to be released. Large pulses of nutrients subsequently mix with the upper layers of water, further accelerating the eutrophication process.

HOW MUCH WORSE CAN IT GET?

With the possible exception of Tikitapu, the group of lakes in best condition is still highly vulnerable to potential invasive weed impacts. Hornwort (*Ceratophyllum demersum*) in particular has the potential to destroy much of the biodiversity and beneficial vegetation features in these lakes. This weed, like many of the other invasive weed species, is able to



Figures 3-6. Diagrammatic representation of the invasion sequence in Lake Tarawera (native vegetation pre- 1900s, *Elodea* invasion 1930s, *Lagarosiphon* invasion 1960s, *Ceratophyllum* invasion 1990s)

effectively smother native plant communities through their tall dense growth (Howard-Williams *et al*. 1987). Furthermore, there are even worse weeds that could invade the Rotorua lakes that presently reside outside of the Rotorua region. For example, *Hydrilla verticillata* is regarded as one of the world’s worst submerged weed species, but it is presently restricted to several lakes in the Hawkes Bay Region. There are also other notorious weed species that have not yet entered New Zealand (e.g., *Myriophyllum spicatum*), yet there remains a real risk of breaches in Border Control through illicit trade, direct smuggling and inadequately controlled mail order distribution.

Apart from further invasive weed impacts, these lakes are also vulnerable to further nutrient enrichment. Although invasive species tend to displace native vegetation to the limits of vascular plant growth (around 10 metres, although hornwort can grow to around 15 m), progressive enrichment of water bodies and associated reduced water clarity has been responsible for the retraction of the lower depth limit of plant growth. One of the first valuable communities to disappear is the charophyte meadows in deeper water. An additional negative impact from eutrophication is the proliferation of blue-green algae that is not just limited to surface blooms. As lakes deteriorate it is common to see submerged vegetation become increasingly smothered in attached filamentous blue-green algae, which can often precede the complete collapse of submerged plant communities.

Figure 7. Impacts of cyanobacterial (blue-green) algal slimes on aquatic vegetation

Vegetation decline of this nature is quite detrimental to the ecology of a lake, especially where plants occupy a large percentage of the lake area. Vegetation decline has already occurred in other New Zealand lakes such as Lake Omapere in Northland and many of the Waikato lakes.

Once lakes become devegetated there is an associated loss of ecological moderating influences, which in turn leads to further decline in water quality (especially turbidity) and loss of biota (e.g. freshwater mussels and koura). The decline or loss of submerged aquatic plants is associated with the loss of many of the ecosystem benefits noted above. An 'alternative stable state' theory has been proposed (Scheffer *et al.* 1993) to describe two common alternative stable lake states: viz. a clear-water macrophyte-dominated condition versus a turbid-water devegetated condition.

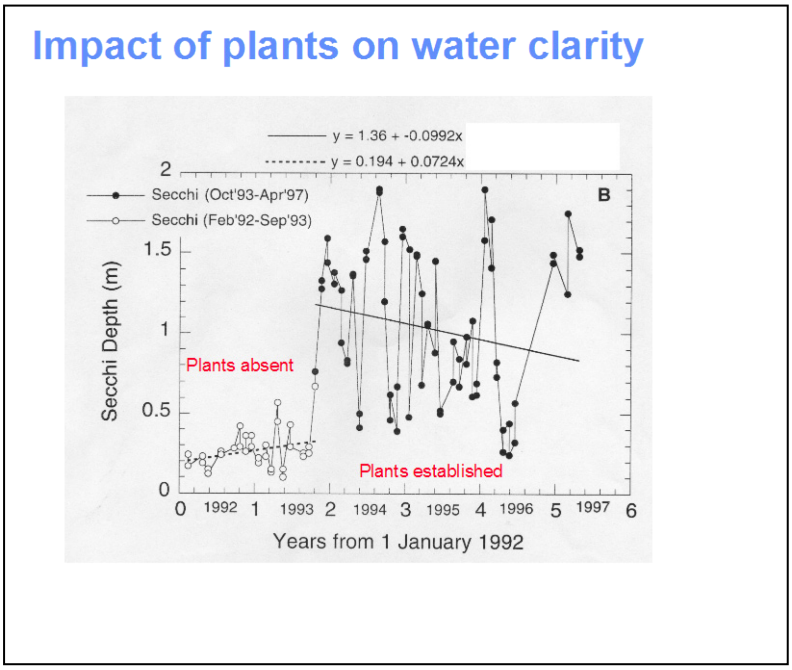
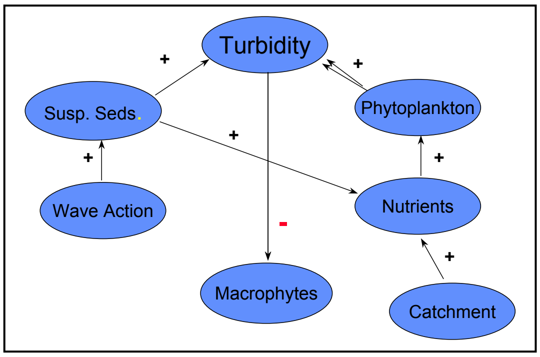
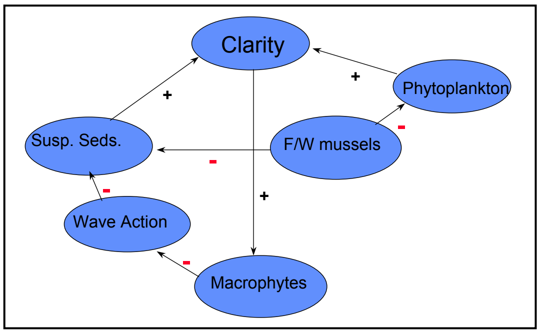


Figure 8. Graph showing the impact of vegetation presence on water transparency (Secchi depth)

Each state is surprisingly stable on account of self-regulating factors that buffer their respective properties. For example, turbid water results in the decline of submerged plants, but once vegetation has disappeared the lack of plant cover facilitates ready re-suspension of bottom sediments from wave action, thereby helping to maintain a turbid state (*Fig. 9,10 below*).





Figures 9-10. Alternative stable states and feed back mechanisms (algal and macrophyte dominated systems)

A further threat to the future condition of the Rotorua Lakes comes from the potential for pest fish species to establish. There is a range of pest fish species in New Zealand, including koi carp, catfish, rudd, perch and tench, that pose a risk of becoming established on account of human activities. All of these species have been deliberately introduced and established in a wide range of North Island lakes. Their impact on the Waikato lakes has been well documented and high populations have been implicated in the decline and loss of submerged vegetation in several lakes. Rudd feed directly on submerged plants, while other pest fish species are known to disrupt bottom sediments either directly through their feeding activities or other behavioural characteristics (e.g., breeding). A common outcome has been

resultant turbid and devegetated lakes with reduced biodiversity and highly compromised prospects for ecological restoration.

WHAT CAN YOU DO ABOUT IT?
Apart from management agencies, members of the public who use these lakes or reside close by also have a responsibility to protect and care for these lakes. Boat users can play a key role in preventing inter-lake spread of weed species. Boat owners and property owners with ornamental ponds need to know what plants they may be unwittingly harbouring that may pose a threat of transfer or escape. Surveillance by local lake residents can provide a valuable opportunity for early detection of new incursions. Further information and photographs of important aquatic plant species can be found on the NIWA website (http://www.niwa.co.nz/rc/prog/aquaticplants). Suspected sightings of new species should be reported. One effective option is to take a digital photograph of a healthy shoot tip, which can be emailed to agencies that can help with identification, such the Regional Council, Department of Conservation or Aquatic Plants staff at NIWA Hamilton.

Adjoining landowners to lakes can help arrest the progressive decline in water quality by identifying sources of sediment and nutrient input and taking active measures to minimise these inputs into lakes. Community groups can facilitate or become actively involved in a wide range of beneficial projects, such as fencing of catchment streams, planting of riparian margins and wetland buffer strips, and slope stabilisation to prevent excessive erosion. Management agencies can help support worthwhile community protection and restoration projects by provision of guidance, funding initiatives (e.g. fencing & planting), formulation of policy and purchase of sensitive land.

CONCLUSIONS
Protection of lakes is far more feasible and cost effective than attempting to restore them once they have become degraded. Some of the Rotorua lakes (e.g. Rotoma and Rotomahana) are of national and international significance and deserve more rigorous protection than they currently have. Although all of the Rotorua lakes show varying degrees of degradation, all of them can become significantly worse. Protection of these lakes can be improved and all lake users and residents have a role to play.

ACKNOWLEDGEMENTS
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QUESTIONS
Wayne Bettjeman, Ministry for the Environment: In the early '90s around Lake Rotorua, water net was a big problem. I haven't heard anyone mention it except for me now. What has happened to it, has it gone away or are we living with it?

P.C.: It's nowhere near what it used to be, you'd be hard pressed to find it now, and I'd like to think it was due to our research, but it disappeared in spite of actions. We don't really know why, but it could be because of natural predators – it's an algae, very single celled, and snails for example graze really voraciously. They may have built up to a population that wouldn't let it grow to those bloom proportions. The conditions are still the same – when you put a cage excluding all the grazers from it and then introduce water

net, it'll grow just as well as it did in the early '90s. However, you go down to Hawkes Bay and they've got the problems that were here in the early '90s, so that's a biosecurity one, but not an easy one to manage. Even things like dragonflies could potentially move the plant around, so there would be no way of stopping that spread.

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Approaches for Nutrient Management in the Lake Okeechobee Watershed

Del Bottcher, Ph.D.
Soil and Water Engineering Technology, Inc.
3448 NW 12th Ave., Gainesville, FL 32605, USA

ABSTRACT

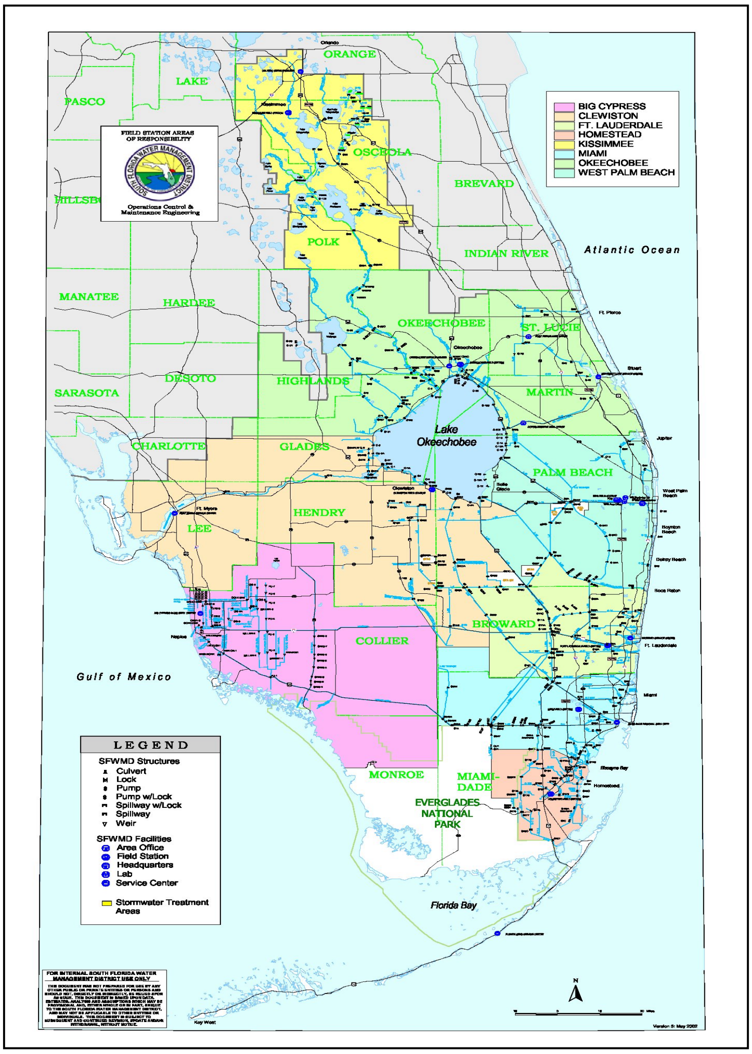
Lake Okeechobee has experienced numerous algal blooms over the past twenty five years due to elevated nutrient levels. Phosphorus has been identified as the primary limiting nutrient for algae growth, and therefore has been the focus of in-lake and watershed restoration programmes. The extent of the problem and potential solutions has been studied extensively and a number of state and federal programmes have and are continuing to be implemented to reduce phosphorus levels entering the Lake. A total maximum daily load (TMDL) has been recently set for the Lake that requires inflow phosphorus loads to be reduced by about 75% beyond current levels, which have already decreased by about 30% from historic highs during the 1970s. Watershed abatement or best management practices are expected to achieve about 1/3 of the required reduction while the remaining reduction is to be achieved by a series of large regional stormwater treatment areas (STAs). Though the STAs' designs and precise locations are not finalized, it is anticipated that more than 10,000 ha of wetland systems will be constructed to filter about 300 tons of phosphorus per year out of the Lake inflows.

Watershed modelling is playing a critical role in assisting water resource planners and regulators in spatially and temporally quantifying the existing conditions throughout the Okeechobee watershed, as well as providing cost-effectiveness information for various BMP scenarios. The Watershed Assessment Model (WAM) is being used because of its GIS-based structure that provides water and nutrient flows throughout the entire stream network. This localized stream information is useful for locating and sizing the STAs, as well as identifying nutrient source areas within the watershed.

In addition to summarizing the research, modelling, and water quality abatement programmes; social, economical, and political influences on the restoration process will be discussed.

BACKGROUND

Lake Okeechobee is a 1900 square kilometre shallow (average depth ~ 3.5 m) lake located in the south central part of Florida. The lake has a highly productive fishery as well as being a freshwater source / storage reservoir for agricultural irrigation and urban needs. Over the past forty years, fishermen have noted increases in algal blooms and exotic macrophytes. These observations are supported by measured increases in phosphorus (P) levels in the lake. Though fish populations do not appear to be adversely impacted at this time, lake access and aesthetic degradation (odours and unsightly conditions) have been a problem. A macrophyte control programme has been very costly and has had secondary consequences of localized increased soluble nutrient concentrations and associated algal blooms.



Lake Okeechobee historically was a eutrophic lake, but its eutrophic state has increased as the result of human development. Log entries from early explorers noted high fibrous contents in the lake water as well as large areas of macrophytes making access to some regions of the lake impossible.

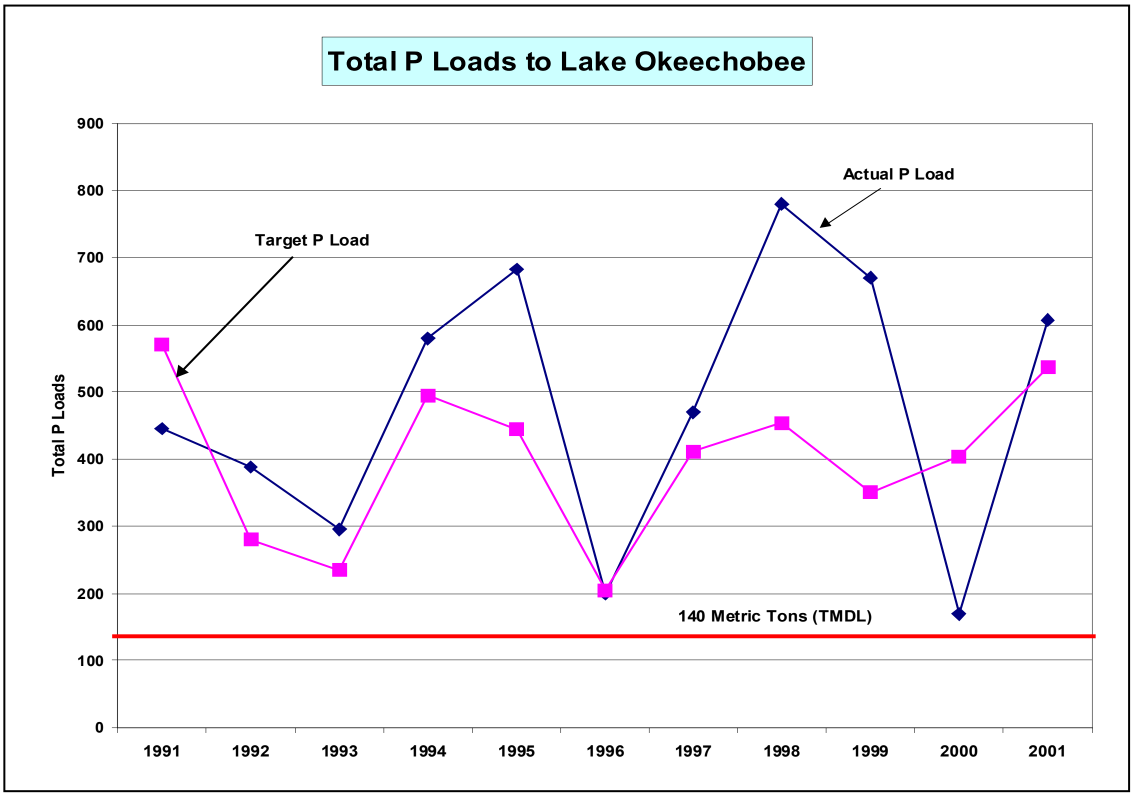
Historically, the lake only received runoff from the watersheds north of the lake. The outflow from the lake would sheet flow through huge mustard apple and sawgrass wetlands located around its entire southern boundary. Over about 5000 years these wetlands have created about a 2000 square kilometre expanse of deep muck soils through accretion. Lake discharge, after being stripped of nutrients, would continue to flow south and south west through the oligotrophic Everglades and ultimately to the Gulf of Mexico.

To allow development around the lake, a dike was constructed around the entire lake in the 1920s-30s and canals were dug to allow the lake's outflow to flow directly to either coast. The dike was later raised again after a hurricane caused the lake to top the dike and kill over 2500 people. These large construction projects allowed the muck soils south of the lake to be drained and farmed. Large pump stations and gate structures were built along the lake to drain and irrigate these lands, respectively. A complex network of canals was constructed to deliver water to and from the farm land as well as delivering freshwater to a thirsty urban area along the southeast coast of Florida.

Due to increased concerns about the lake water quality, back pumping of the muck farm drainage water was stopped in 1979, except for emergency conditions. This action had the unfortunate consequence of increasing nutrient loads to the Everglades because this was where the farm drainage was diverted to when it was no longer allowed in the lake. Other actions during this period included manipulation of lake levels for flood control and water supply. These water level control regulations had significant adverse impacts on the lake function, particularly littoral zone degradation due to limited water level fluctuations.

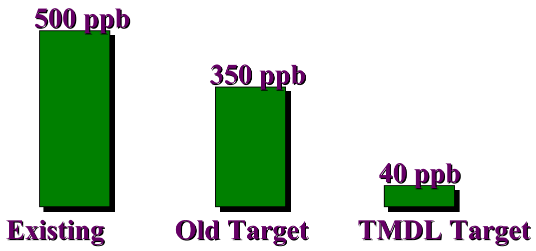
PHOSPHORUS MANAGEMENT TARGETS OR TMDLS

The total maximum daily load (TMDL) for Lake Okeechobee has recently been set to 40 ppb of P. This new TMDL target for P concentration represents about a 90% reduction over the previous target of 350 ppb for inflows to the lake. With a current average discharge concentration to the lake of about 500 ppb, it is clear that an extremely aggressive P reduction goal has been set. It is accepted that land source BMPs alone can not possibly meet these goals. Therefore, alternative innovative treatment technologies are also being considered including edge-of-farm and regional treatment systems.



Effect of New TMDL on Catchment Nutrient Management

- **Phosphorus Still the Focus**
- **Land BMPs Alone Will Not Meet Target**



The Upland or Up Hill Challenge

Land Use	Current P ppb	New BMPs P ppb
Dairy	1200	750
Beef	380	300
Citrus	350	250
Urban	280	150
Vegetable	1800	800
Sugarcane	300	250

Target = 40ppm

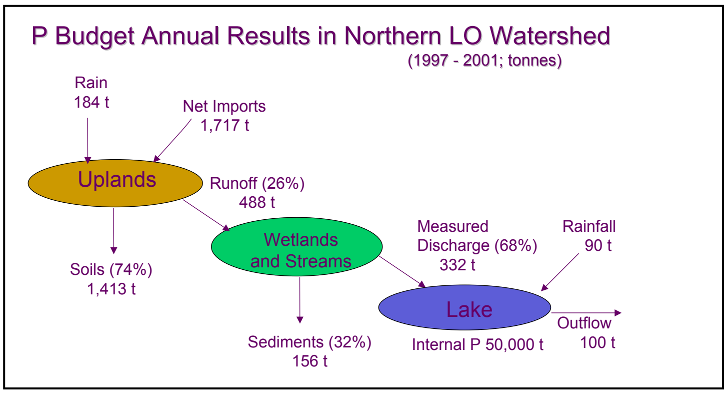
Numerous research and abatement programmes have been implemented in the Lake Okeechobee watershed as well as within the lake itself to address its eutrophic state increase. These programmes have focussed on best management practices (BMPs) and treatments systems for reducing P loads to Lake Okeechobee. Land source BMPs have included fertility management on farmland, manure management systems for dairies and cow/calf operations, improved irrigation/drainage management for field and tree crops, agricultural and urban stormwater retention/detention systems, on-farm sediment trapping, and edge-of-farm chemical treatment systems. In-stream sediment traps and large wetland stormwater treatment systems (STAs) are being built to further reduce stream flow P levels before entering the lake.

Best Management Practices (BMPs)

Best management practices have and are continuing to be implemented within the Okeechobee watershed through a variety of educational, incentive, and regulatory programmes. The US Department of Agriculture (USDA) cooperative extension service through the University of Florida has cooperated with the South Florida Water Management District to disseminate educational information on the Lake Okeechobee's water concerns and agricultural BMPs. These educational programmes alone have had limited success in gaining BMP acceptance and adaptation, but when used in concert with financial incentive programmes high BMP acceptance and implementation has occurred. The bottom line has been that the agricultural community was not economically able to implement most of the recommended BMPs without financial help. This financial help has been provided through BMP cost-share programmes from USDA and Florida Department of Agriculture and Consumer Services (FDACS), and grant programmes through the South Florida Water Management District. To date, these incentive

programmes have upgraded all of the dairy waste management systems and have fenced all dairy cows and many beef cattle from streams.

FDACS has recently completed nutrient management plans (NMPs) for all of the dairies and are in the process of completing plans for most cow/calf beef ranches, citrus groves, and row crop farms in the watershed. These NMPs provide specific plans for BMP implementation and other stormwater management alternatives for each farm. The stormwater management alternative is considered a key component for future nutrient reductions off farms. This system incorporates about 5 to 10 % land conversion to stormwater retention/detention (R/D) basins. Water within these basins can be used for irrigation or other on-farm beneficial uses, which significantly reduces off-farm discharge. Plus it is anticipated that the wetland vegetation that will develop within these R/D ponds will also significantly reduce nutrients. The Florida Legislature is presently considered a bill that would provide funding for a cost-share program to implement these practices.



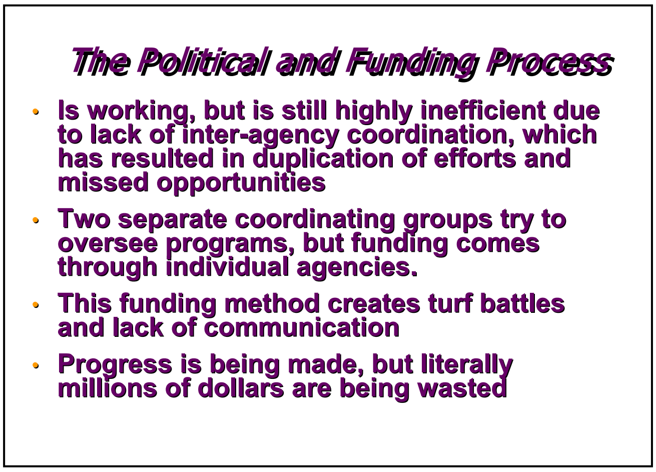
Regional Treatment Systems
The South Florida Water Management District in coordination with the US Army Corps of Engineers has purchased land in critical areas for the purpose of providing regional treatment systems to strip P from stream flow before it enters Lake Okeechobee. The systems currently being designed will use detention reservoirs upstream of the STAs to regulate flow through the wetland to increase P removal efficiencies. These reservoir assisted stormwater treatment systems (RASTAs) will require approximately 10,000 ha of land and are being designed to reduce P levels to the 40 ppb target with the assumption that the BMPs have also been implemented.

USE OF MODELLING TO SUPPORT LAKE RESTORATION

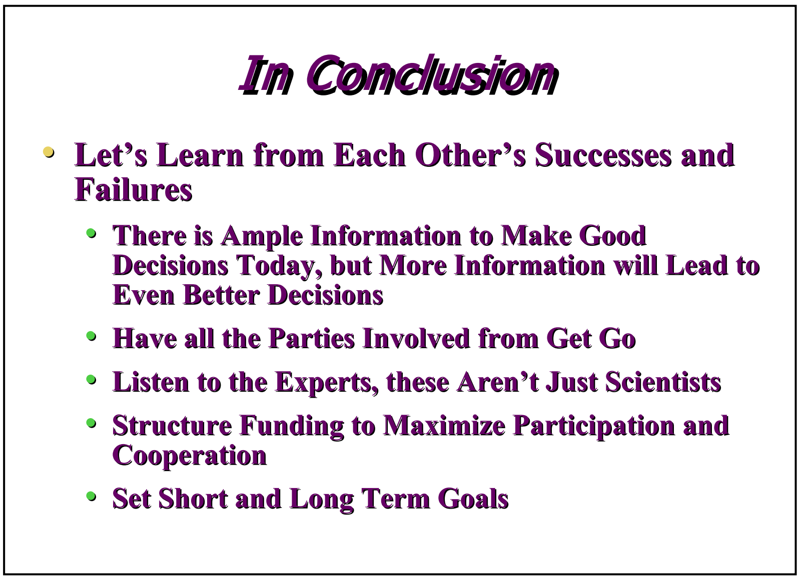
Watershed modelling is playing a critical role in assisting water resource planners and regulators in spatially and temporally quantifying the existing conditions throughout the Okeechobee watershed, as well as providing cost-effectiveness information for various BMP implementation scenarios. The Watershed Assessment Model (WAM) is being used because of its GIS-based structure that provides water and nutrient flows throughout the entire stream network. This localized stream information is useful for locating and sizing the STAs, as well as identifying nutrient source areas within the watershed.

Even though modelling is useful in assessing current conditions and prioritising P sources within the watershed, its primary benefit will comes from the assessment of abatement alternatives for the watershed. Coupling model predictions of P reductions from various management scenarios with costs will allow for better optimisation of potential BMP and regional treatment alternatives.

SUMMARY AND DISCUSSION



It has become clear that the 90% P load reduction goal for inflows to Lake Okeechobee will be extremely difficult to achieve and will require a multifaceted approach including innovative abatement technologies, political resolve, and financial commitments by all parties involved. An existing problem has been the grey area between the responsibilities of the numerous governmental agencies involved. Turf battles and lack of coordination between agencies has lead to inefficiencies in the Lake Okeechobee effort, but on the other hand has resulted in additional sources of funding for the overall restoration effort. A recently released Lake Okeechobee Protection Plan has more clearly laid out the rolls for the various participants and hopefully will result in a successful program to restore Lake Okeechobee's water quality to targeted levels.



The lessons learned have been to listen to the experts and to put agency competition aside for the betterment of the lake.

In conclusion, I think let's learn from each other's successes and also from our failures, and that's my goal. You've got the expertise here to solve your problems, but maybe there's some structural things, management things, political things, that we've tried, then things might work a little better.

I think I pointed out a couple that I warn you against, that have been a failure on our part. I wanted to make sure I had enough time to take some questions here, but the point is, I think you do have ample information to make some good decisions. We do too, but more information will always be better. But you've got to have all parties involved from the get go, so that everybody buys off what you're doing and it's critical to listen to the experts. They spent 2½ million dollars in that sediment dredging thing because they didn't listen to the experts. I'm not saying the experts are always the scientists, the local people may have the best expert knowledge of what's going on in the system – I learned that yesterday about sheep paddocks.

Structure the funding to maximise, participation and cooperation. Thought needs to go into how you can do that, and this is something for the Government bodies to think about, how they can actually do that. Set short and long term goals. A hundred years will come and things we do today have long-term impacts. It would be nice to get the lakes turned around and be cleared next month, that would be the ideal, but we've got to set a strategy that we know will get there in time and long-term, that we are able to maintain and is sustainable, that's critical. I think that the bottom line we've learned, though, is Lake Okeechobee is in pretty good condition in spite of all our efforts. (From tape transcript.)

QUESTIONS

Dr Jake Peters, US Geological Survey: One of the things that drove Government to try to do something in the short term was concern for the Everglades. The National Park Service has got a mandate to protect its reserve. The exotic species came in and there is a lack of hydro period in the Everglades which gets all of its flow from sheet flow basically, from the area from Okeechobee and from the canal system above the Everglades in the agricultural area. We were getting exotic species and things were in decline. They basically took the State of Florida to Court, which really pushed a lot of what came out of this, the management actions.

D.B.: The Federal Government sued the State of Florida over the protection of the Everglades and that drove a lot of the process, but also for a period of about 5 years it locked all scientists from talking with each other because of the legal battle, which was kind of weird.

Daphne Le Valliant: I'd just like to know, did the indigenous people of your country have input into your protection programme?

D.B.: In the Lake Okeechobee basin there are very few indigenous people and primarily the Seminole and the Moccasuk Indians live to the south of the lake. They have had major impact on the Everglades programme. As a matter of fact they have set and they own the lands between the discharge from that agricultural area and what goes into the Everglades, and they are trying to set standards for water coming through their property. They've been a very, very positive part of the process because they have been looking at it from the natural system. So yes, they have been highly involved and they've been very effective recently, because they've hired the attorney who was the federal attorney that sued the State of Florida in Federal Court, and he now represents them on these issues. But in Okeechobee, they're not involved in that area.

Effects of pine forest logging on stream water and nutrient yields in a Central North Island catchment

John M. Quinn, Eva Ritter
NIWA, PO Box 11115 Hamilton, New Zealand j.quinn@niwa.co.nz

This paper was presented by Dr Kit Rutherford, owing to Dr Quinn's absence due to injury.

INTRODUCTION

Changing land use from pasture to forestry usually reduces nutrient losses from the land, with benefits for eutrophication control in downstream lakes. Lower nutrient losses are attributed to reduced fertiliser input, reduced soil erosion, less nitrogen fixation by legumes, and removal of grazing animals that enhance nutrient losses by direct input to unfenced waterways and leaching from nutrient hot-spots in urine patches. Ten years after conversion of pasture to pine plantation on pumice soils at Purukohukohu, in the Central North Island, total nitrogen (TN) and total phosphorus (TP) yields were 11 and 6%, respectively, of yields from an adjacent pasture site (Cooper & Thomsen 1988). These findings are encouraging for lake eutrophication management in the Rotorua-Taupo area where many lakes have large areas of their catchments in pine forest and afforestation has been promoted as a tool to control lake nutrient loads in programmes such as the Upper Kaituna Catchment Control Scheme (Williamson *et al*. 1996).

However, there is concern that these benefits may be negated due to nutrient losses when the pines come to be harvested for their timber. Logging can increase nitrogen and phosphorus losses to streams due to disruption of the forest nutrient cycling (e.g., reduced ammonium N uptake by live trees (Cooper 1986)), and increases in particulate matter in surface runoff and overall water yield. For example, total nitrogen yields for a harvested beech forest catchment at Big Bush in southwest Nelson increased 10 times over the control and were still 3-5 times higher 4 years after logging, and total phosphorus yields went up 2–3 times (Fahey & Jackson 1997b).

This study builds on those of Cooper (1986) and Cooper and Thomsen (1988) by describing the effects on nutrient export or yield of clearfell logging of the pine plantation at Purukohukohu.

METHODS:

Study site and forestry practices:
The study catchments at Purukohukohu experimental basin, between Rotorua and Taupo (176° 14' E, 38° 27' S), comprised Purutaka pasture catchment (11 ha, cleared in 1920's, sheep and beef grazing, part of Mangimingi station), the adjacent Puruki pine plantation (34 ha, previously pasture since 1920's, planted in pines 1973, logged in January-July 1997), and the nearby Puruwai native forest (28 ha, 2000 year old podocarp/mixed hardwood forest). All three catchments have moderately steep topography (average slopes of 17°), possess porous Andisol soils (Oruanui sandy loam) formed in 1800-year old pumice, which is about 1 m thick (Parfitt e*t al*. 2002), overlying impermeable ignimbrite. Average rainfall is about 1550 mm of which c. 100mm is believed to be lost to deep groundwater (Dons 1987). Further background information in the hydrology of the

catchments is provided by Dons (1987). Puruki was planted in pines at 2000 stem/ha in 1973 and progressively thinned to 550 stems/ha during 1979-81. Canopy closure occurred in 1980. Further thinning to 275 stems ha^{-1} occurred in 26 ha of the catchment during 1983-84 (Cooper *et al.* 1987). Pines were logged between January and July 1997 with trees removed by skyline hauler (1/3 of area) and ground-based skidders (2/3 of area). Pine slash and needles were left onsite. The area was replanted in August 1997, mainly at 550-600 stems/ha, without fertiliser application. Herbicide was spot sprayed around individual trees (1.5 m diameters) a year after planting to suppress competition from rapid growth of groundcover vegetation (pers. comm. Peter Beets, Forest Research).

Sampling:
Water was collected as grab samples in acid-washed polyethylene bottles and flows were measured at 90° V-notch weirs at monthly intervals from September 1996 until September 2001. Flows were recorded at 15-minute intervals at the outlets from Puruki (pine) and Purutaka (pasture). Water samples were stored on ice for overnight transport to NIWA's chemistry laboratory where they were analysed by standard methods (e.g., APHA (1998) for dissolved reactive phosphorus (DRP, automated molybdenum blue/ascorbic acid), total phosphorus (TP, acid persulphate digestion followed by molybdenum blue colorimetry), ammonium nitrogen (NH_4-N, automated phenol/hypochlorite colorimetry method), nitrate nitrogen (NO_3-N, cadmium column reduction of NO_3 to NO_2, then diazotisation with sulphanilamide and NEDD and NO_2-N subtracted from NO_3-N), and total Kjeldahl nitrogen (TKN, acid digestion followed by indophenol blue colorimetry). Total nitrogen (TN) was estimated as the sum of NO_3-N and TKN.

Instantaneous nutrient yields (µg/ha/s) were calculated as the product of instantaneous measures of water yield (litres/ha/second) and nutrient concentrations (µg/l). The average post-harvest instantaneous nutrient yields (µg/ha/s) over 5 years from the pine catchment were also converted to estimated annual averages for the purpose of comparison with previous annual yield measurements shortly after canopy closure in the pine plantation.

RESULTS AND DISCUSSION:

Effects of land use and logging on water yield:
Average water yield from the mature pine forest was 76% of pasture (range 61-88%) over the 7 years before logging (Fig. 1). Water yield increased in the first 3 years after logging to 125-127% of pasture yield, representing a 65-67% increase over prelogging yield. However the relative yield from the pine and pasture catchments decreased to the pre-logging level between years 3 and 7 after logging and replanting. The magnitude and duration of these effects were very similar to effects of logging beech forest and replanting *Pinus radiata* at Big Bush, Nelson, where water yields from two logged catchments averaged 61% - 68% higher than a reference native forest catchment in the first four years after logging but dropped to pre-treatment levels after 7 years (Fahey & Jackson 1997a). The fraction of annual rainfall measured as runoff also increased in the year of logging and the following year. The runoff fraction dropped back to about the levels before logging in years 3 and 4 after logging, but increased slightly in years 5 and 6.

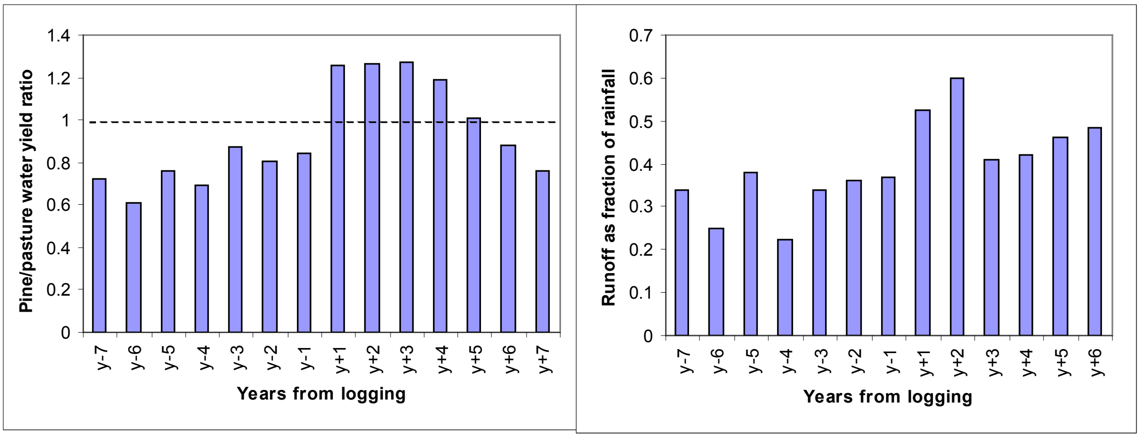


Figure 1: Effects of pine logging on the ratio of annual average water flow from adjacent pine (Puruki) and pasture (Purutaka) catchments and runoff as a fraction of rainfall for the pine catchment.

Effects of land use and logging on nutrient yields

An earlier comparison at Purukohukohu (Cooper and Thomsen 1988) showed that, shortly after canopy closure in the pine plantation (i.e., 9-12 years after planting), total phosphorus yield from pasture averaged 14-fold higher than native forest and 18-fold higher than the pine catchment (Fig. 2A). Average TP yield from the pine catchment was 4-fold higher than from native forest in the 5 years after logging, but was still 4-fold lower than from pasture (Fig. 2B).

Cooper and Thomsen (1988) also found that TN yield from pasture was 3-fold higher than from native forest and 9-fold higher than from the pine catchment shortly after canopy closure (Fig. 2C). Average TN yield from the pine catchment was higher after logging (Fig. 2D).

Actual yields of N and P from pasture are likely to be higher than the estimates from the present study because the monthly sampling missed many storms when a disproportionately large proportion of TP and TN are exported. This effect is likely to be most important for the pasture catchment because much of the nutrient export occurs in storms (Cooper and Thomsen 1988) but probably also results in underestimation of the pine catchment exports, particularly in the first 2 years after logging when the runoff fraction was 62 and 85% higher than on average before logging (Fig. 1).

The variations in logging effects on yields of TP and TN, and the dominant forms of N (nitrate and organic N as TKN) within the five years of the study are shown in Figure 3 by comparison of the average ratios of instantaneous yields from the pine catchment and the undisturbed native forest. Using these ratios helps to normalise the results for effects of differences in rainfall between periods.

The pine catchment TP yield was 9- to14- fold greater than that of the native forest immediately before and during logging (Fig. 3A). This increased to 24-fold more in the first year after logging but in years 2-4 after logging the relative yield from the pine and native declined from 6 to 3, and was lower than before logging.

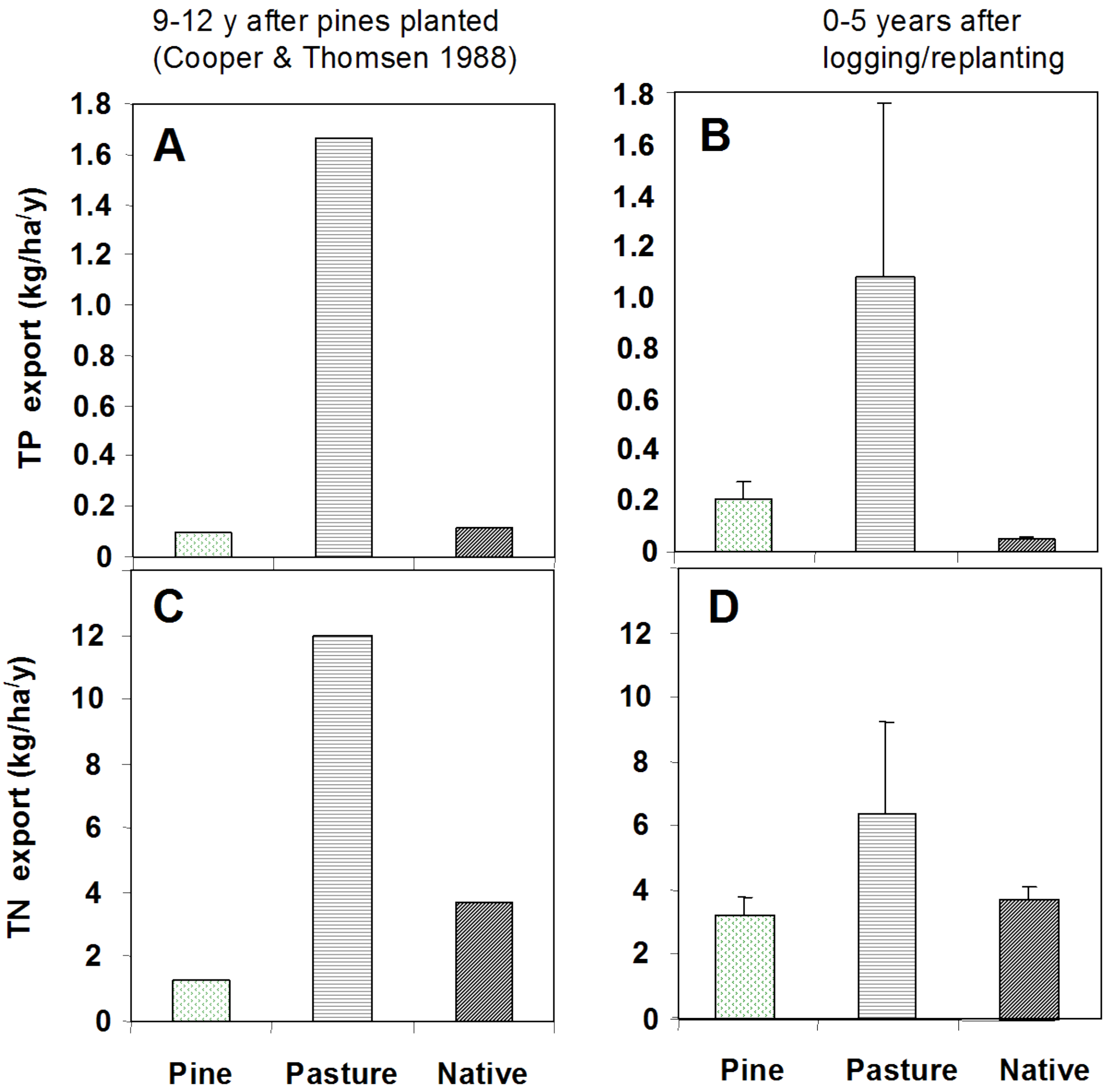


Figure 2: Land use effects on average yields of total phosphorus and nitrogen at Purukohukohu (A, C) after canopy closure (Cooper and Thomsen 1988) and (B, D) 0-5 years after logging and replanting (mean + standard error, n = 56, this study). Mean instantaneous yields measured in the present study (μg/ha/s) were converted to annual yields (kg/ha/y) for ease of comparison with earlier data.

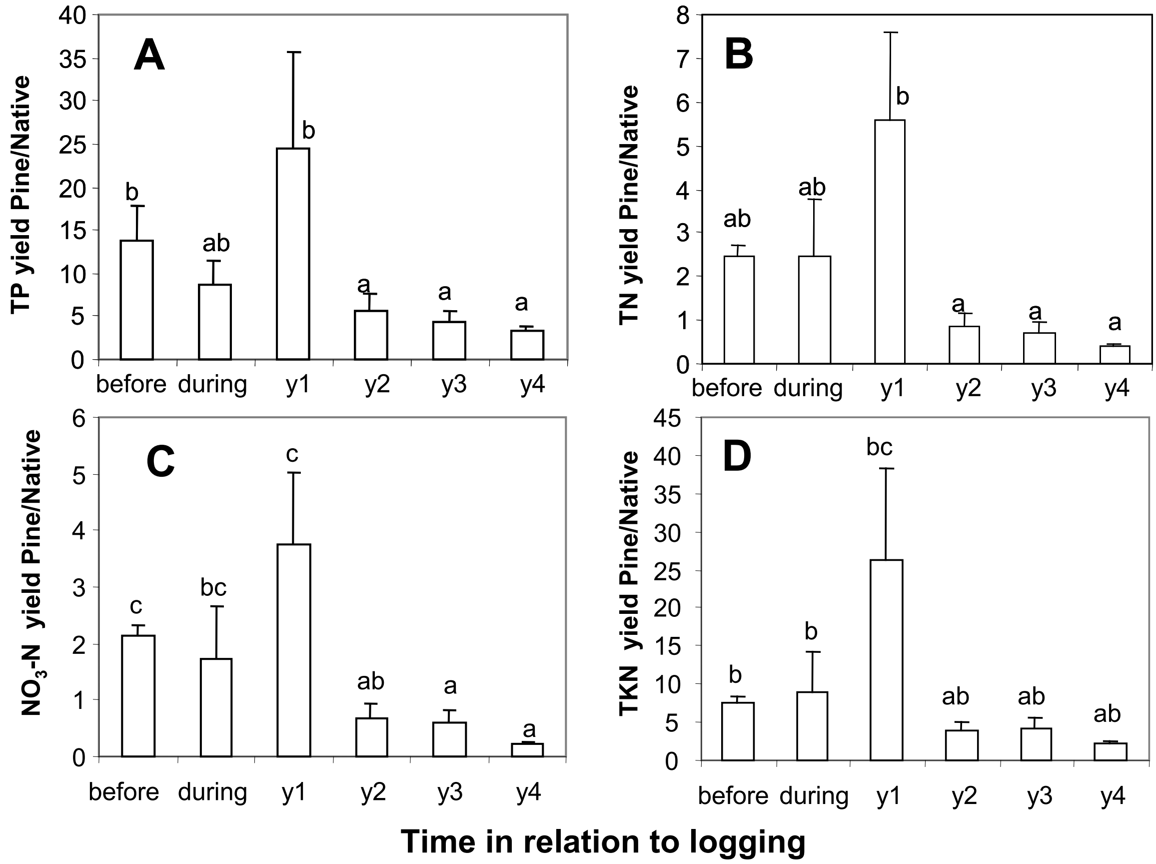


Figure 3: Changes in nutrient yield from pine and native forest streams at Purukohukohu (means + standard errors) in the 4 months before logging, 7 months during logging, and 12 month periods in years 1-4 after logging was completed. Different letters indicate statistically significant differences in yield ratios between periods (ANOVA with post-hoc LSD multiple comparisons, $P < 0.05$).

Comparison of nitrate concentrations in stream water from the native forest and the 8.7 ha Rua subcatchment of the 34 ha Puruki pine catchment (Parfitt *et al*. 2002) showed a similar pattern to that observed for the whole catchment in this study, with c.2-fold higher concentrations in Rua water before logging, and increase in the maximum 1 year after logging, followed by a drop to lower nitrate concentrations 3 years after logging. Parfitt *et al*. (2002) found large decreases in soil N after clearcutting and attributed this to increased N uptake by weeds and soil microbial biomass, both of which increased after clear-cutting, and the slow turnover of N through microbial pools in the soil.

These results of the present study indicate that increases in catchment nutrient yields after logging are short-lived and that high yields in year 1 are compensated for by lower yields in subsequent years.

Patterns of nitrate yield and concentration over 30 years provide a longer-term perspective on the effects of pine afforestation from pasture conversion to pine through to the first logging and replanting (Fig. 4). Nitrate yield and concentrations show a gradual

decline over the 5 years after conversion from pasture to pine in 1972. Average nitrate yield was almost an order of magnitude lower in the subsequent "young forest" phase (1978-85, Fig. 4). Nitrate concentrations and yields were higher from the "mature" pine forest, just before logging, than in the "young forest" phase. Although there are gaps in the monitoring record, this suggests that nitrate retention by the pine forest is greatest when the pine crop has established and is growing vigorously, but the forest becomes more nitrate-leaky as it matures. Yields and concentrations in the year of logging and the first year after logging increased to similar levels to those during the pasture-pine conversion phase, but decreased quickly towards levels seen during the "young forest" phase.

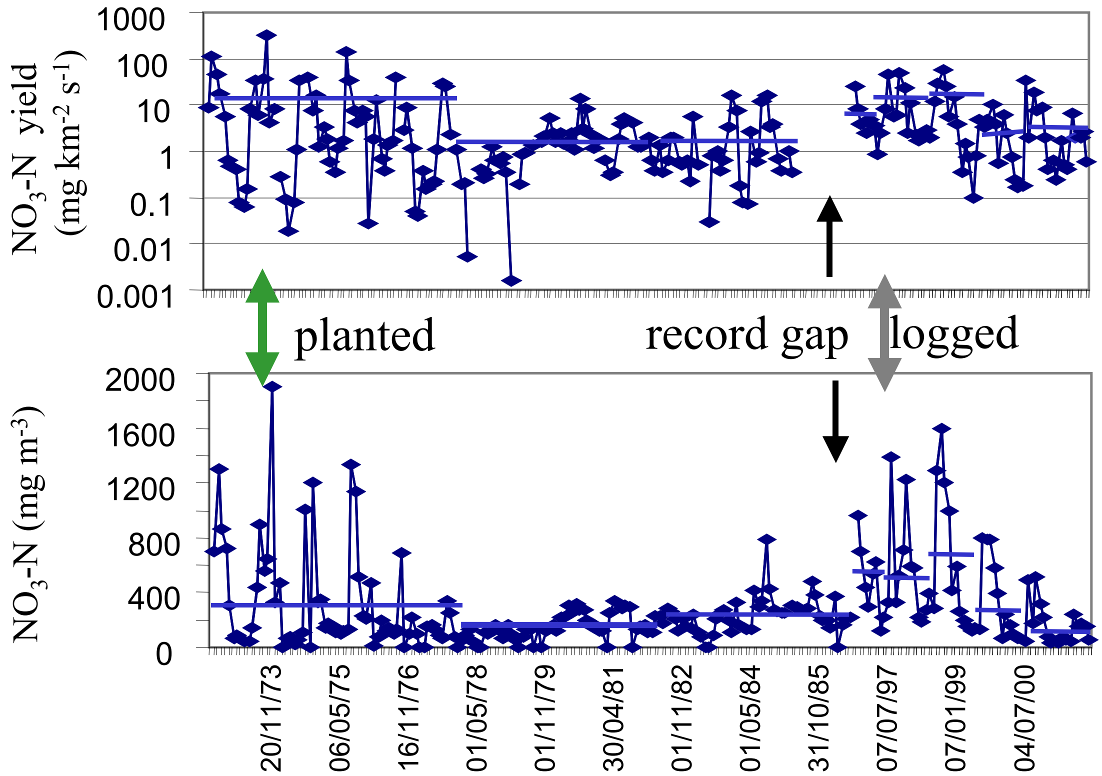


Figure 4: Long-term variations in nitrate yield and concentration from Puruki catchment from before pine planting of pasture (1973) through logging and replanting (1997) to regrowth of the second pine crop. Horizontal bars are mean values for various phases of the pine forest rotation.

CONCLUSIONS

The findings from long-term monitoring of nutrient yields from Purukohukohu experimental basin indicate that afforestation of pasture previously used for dry stock agriculture in pines results in significant reduction in yield of water and nutrients in streams. Harvesting of the pine crop is essential for commercial forestry. Logging increased water yield for seven years after logging and replanting. Nutrient yields also increased by about 2-fold at the time of logging and the following year, but this was counteracted by lower yields in years 3-5 after logging. The findings indicate that increases in nutrient yield are short-lived and do not negate the benefits of reduced yields compared to pastoral land use over the forestry rotation (i.e., planting, forest growth, logging and replanting). It is likely that site management practices including rapid pine

replanting after logging and limiting herbicide use to spot spray around individual trees contributed to the low nutrient losses after logging by increasing the rate of recolonisation by ground covering plants and trees.

Pine plantations within lake catchments in the Central North Island are likely to be at different rotation phases. Hence, short-term increases in nutrient yield around logging of one plantation forest patch will likely be more than compensated for by the low yield from younger pine forests elsewhere in the catchment so that the overall effect of afforestation of pasture on nutrient yields remains beneficial. The higher nitrate yields from "mature" than "young" forest and lower yields a few years after logging than immediately before also suggest that logging may be beneficial for long-term nutrient yield by resetting the forest into a vigorous growth mode with high nutrient retention.

This study highlights the benefits of long-term ecological research sites (LTERs) for comparative studies to evaluate the effects of ecosystem responses to land management. The Purukohukohu Experimental basin was set up in 1968 as a long-term site (to 2000) for research on hydrology and erosion under the auspices of the International Hydrological Decade (Beets & Brownlie 1987). This has brought together a wide range of researchers and provided a valuable legacy of information to help address issues of today and the future.

ACKNOWLEDGEMENTS:
Thanks to NIWA's Rotorua Field Team for sample collection and flow measurements, especially Walter Hillman and Wayne McGrath, and NIWA's Hamilton Chemistry laboratory staff, especially Marieke van Kooten and Denise Rendle. The paper has benefited from discussions with Eva Ritter, Kit Rutherford, Bryce Cooper, Bob Murray and Roger Parfitt. Peter Beets provided background information on the site and logging activities. The work was funded by the New Zealand Foundation for Research Science and Technology (CO4X0012) under a subcontract to Forest Research as part of the Sustainable Management of Forest Ecosystems Programme.

QUESTIONS

Leith Knowles, Forest Research: There's just one brief point I'd like to make regarding the yield of water you attributed to evapotranspiration. In a summer rainfall climate such as Purukohukohu, we would normally assign that to interception, so the tree canopy acts as an umbrella. It intercepts the rain which evaporates before it ever reaches the ground. And those changes that you showed there are probably entirely consistent with what we call the interception fraction, not the evapotranspiration component.

K.R.: Thank you for that.

Chayne Zinsli, CHH Forests: You may recall that early on the nutrient status of the soil was quite unusual. Are you able to comment on what you would expect in terms of those results for a normal soil?

K.R.: No. If you'd like to write that question down, I'll take it back to John and perhaps he can reply in writing. I am unable to comment I'm afraid.

(Subsequent reply received from John Quinn:)

I don't think that there is a "normal NZ soil" so I can't extrapolate beyond the Central North Island context of the study. The Puruki pine soil is probably pretty typical of Central North Island pumice soils. It has a high natural N status, believed to be due to input from N-enriched rain from volcanic activity over 1800 years since the Taupo eruption (Parfitt *et al*. 2002).

Ian McLean: Two days ago when Jake Peters was looking at some pasture, he was emphasising the need to monitor the run-off at heavy rain events, during and after. With this sampling, was there any account taken of such events or was this sampling just 12 samples a year regardless of the weather?

K.R.: That's a good point. The initial sampling carried out during the 70's was very detailed and included specific targeting of storms. The sampling that John carried out, because of budgetary constraints, did not target storms and I think I commented when I presented some of the graphs. There is some bias. We've done our best to make sure the bias didn't change the big picture, we're quite convinced that the overall picture is not wrong, but one mustn't compare those two numbers too carefully.

Jake Peters : My question is really for my own edification, it looks like there's a lot of different ways that people are logging here and I'm wondering what those effects might be, i.e. cable versus other methods. It seems that most of them are clear cuts. Obviously that is going to have different effect – there's sediment transport, roads being putting in, etc. Can you comment on some of these forestry issues, the effects different logging techniques are having?

K.R.: I would be more than happy if somebody from Forest Research answered your question, Jake.

Leith Knowles: Generally speaking, harvesting on the pumice plateau is pretty straightforward. There are pretty active measures with silt trapping and other things to stop run-off of sediment, which is a major concern. Revegetation is pretty rapid, certainly by North American standards. Our whole rotation here is about 28 years as you see and revegetation is about 2 or 3, so you get the short-term concern. So the idea is to just try and spread that sediment load around the forest, if you like, and dilute it that way as well. Perhaps other forestry people may like to add something.

Brenda Baillie, Forest Research: Just to add some comments, yes, you get quite a bit of difference in results between sites that have been hauler-logged and ground-based, so that Site A and B results are quite variable, but often a lot of the effects are diminished after about two years after harvest, so it is quite short-term.

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Linking catchment land use and lake water quality: A review of the Rotorua Lakes experience

Kit Rutherford, *National Institute of Water & Atmospheric Research, Hamilton*
John McIntosh, *Environment Bay of Plenty*
David Burger, *University of Waikato*.

ABSTRACT
Sewage diversion in 1991 was followed by significant improvements in lake water clarity, nutrient and chlorophyll concentrations from 1993-95 but since then lake water quality has deteriorated. An increasing trend in mean baseflow nitrate concentration has been identified in eight of the nine major streams, showing that the trend in the Ngongotaha Stream identified in 1996 is widespread throughout the catchment. The flow-weighted mean baseflow nitrate concentration is now nearly twice the value in 1970. Consequently the benefits from sewage diversion in 1991 have been negated by subsequent increases in the nitrogen load of streams. Part of the load increase is associated with 'leakage' from the land disposal site but the majority is nitrate leaching from agricultural land. Increasing nitrogen loads are causing lake total nitrogen concentrations to increase, although nutrient releases from the lakebed are also contributing to continued poor lake water quality. There is no evidence of increasing mean phosphorus concentrations in the major streams, although there appears to be a weak increasing trend in lake total phosphorus concentration. When the decisions were made in the 1980s to divert sewage away from the lake it was believed that control measures put in place through the Kaituna Catchment Control Scheme would reduce catchment nutrient loads. These control measures have reduced the inputs of sediment, total phosphorus and particulate nitrogen, but have not controlled nitrate inputs. Recent work in the Taupo catchment has detected increasing trends in stream nitrate, where it is believed that nitrate generated c. 50 years ago by land clearance is only now finding its way into the streams via deep groundwater. It seems likely that similar land-use/groundwater linkages operate in the Rotorua catchment.

INTRODUCTION

During the 1970s it was recognised that water quality was deteriorating in Lake Rotorua as a result of increased nutrient loads notably from treated sewage, streams draining pasture and aerial top-dressing. Public concerns prompted studies of stream nutrient inputs notably by Fisheries Research Division, MAF (1968-70); Hamilton Science Centre, MWD (1976-77); NIWA, Hamilton (1987-89); Environment B.O.P. (1991-95 and 2002-03) and Rotorua District Council (1991-2003).

Now this 'We' that I've been talking about, it was the days before' user pays' and the Bay of Plenty Catchment Commission as they were in those days, or the National Water & Soil Conservation Organisation, only had to snap their fingers and they could organise an ad hoc *technical working group of the best brains in the country. Nobody worried about the money. Things are a little bit different now.*

During the 1970-1980s several measures were put in place to reduce sewage nutrient loads, notably phosphorus stripping at the Rotorua sewage treatment plant prior to its discharge to the lake (1973-1990) and land disposal of treated sewage in the Whakarewarewa Forest (1991-present). Commencing in the late 1970s the Upper Kaituna Catchment Control Scheme encouraged fencing of stream margins to exclude stock, and retirement and/or planting of erosion-prone land. During the 1980s lake water quality

targets for Lake Rotorua were adopted by the regional council, the decision was made to divert treated sewage away from the lake, and nutrient load targets were set for sewage-derived nutrients (Table 1). These decisions arose as a result of acceptance that lake water quality in the 1960s did not give rise to significant public concern and evidence that in 1984-85 sewage-derived nutrients comprised 25-50% of the total load. The consensus amongst scientists and engineers at the time was that restoration to 1960s quality was achievable provided sewage nutrient loads could be reduced to 3 t-P/y and 30 t-N/y and catchment nutrient remained steady at about 34 t-P/y and 405 t-N/y (Rutherford *et al*. 1989). When these targets were set the scientific advice was that internal loads were likely to delay the recovery in lake water quality for several tens of years, macrophyte abundance might increase as a result of increased water clarity and that, as a result of measures put in place as part of the Kaituna Catchment Control Scheme, nutrient loads from rural land were expected to decrease.

Table 1. Lake Rotorua nutrient inputs and water quality 1965-1985.

	1965	1976-78	1981-82	1984-85	target
Population	25,000	50,000	52,600	54,000	-
Phosphorus input					
Raw sewage t/y	5	18	3	47	-
Treated sewage t/y	5	7.8	20.6	33.8	3
Stream t/y	34	34	34	34	34
Internal t/y	ND	0	20	35	0
Total t/y	39	41.8	74.6	102.8	37
Nitrogen input					
Raw sewage t/y	34	100	170	260	-
Treated sewage t/y	20	72.5	134	150	30
Stream t/y	455	485	420	415	405
Septic tanks t/y	50	80	15	10	0
Internal t/y	ND	0	140	>260	0
Total t/y	475	557.5	694	>825	435
Average lake quality					
Total phosphorus mg/m^3		23.8	47.9	72.6	20
Total nitrogen mg/m^3		310	519	530	300
Chlorophyll mg/m^3		5.5	37.8	22.6	10
Secchi disc m	2.5-3	2.3	1.9	1.7	2.5-3
Deoxygenation g/m^3/d		0.4	0.7	0.9	0.25

REVIEW OF RECENT STUDIES 1987-95

To aid the early detection of trends in lake water quality, Burns *et al*. (1999) developed the trophic level index (TLI) which is a single numerical index calculated from four measured lake water quality parameters: total nitrogen (TN), total phosphorus (TP) and chlorophyll a (CHLA) concentration, and secchi disc water clarity (SD). The target for Lake Rotorua is a three-year average TLI = 4.2 which comes from inserting the lake water quality targets in Table 1 into the equations used to calculate the TLI (Appendix 1).

Williamson *et al*. (1996) studied the Ngongotaha Stream to assess the effectiveness of the Kaituna Catchment Control Scheme. Conventional wisdom during the 1970s was that these measures (viz., fencing streams to exclude stock, replanting riparian zones to trap particulates in overland flow, and retirement and stabilisation of erosion prone land) would reduce soil erosion and hence reduce the loads of nutrient associated with erosion,

overland flow and stock in streams. Williamson found that the loads of sediment (-85%), particulate phosphorus (-27%) and soluble phosphorus (-26%) all decreased from 1976-78 to 1987-89. Loads of particulate nitrogen (-40%) may have also decreased although there are rather sparse data prior to implementation. However, the load of dissolved nitrogen (predominantly nitrate) increased (+26%) and offset the decrease in particulate nitrogen. It was estimated that control measures reduced phosphorus loadings to Lake Rotorua by ~20% but that nitrogen loadings were unchanged.

Park (2003) summarises nutrient losses from the Rotorua land treatment system (RLTS). When irrigation commenced it took ~2 years for any losses from the irrigation area to be detected but then TN and TP concentration increased steadily (Figure 3) to the point where they exceeded the targets for sewage (Table 1). Nutrient losses have been reduced recently by modifications at the treatment plant and changes to the irrigation routine. Three years after sewage diversion Hall *et al*. (1995) concluded that lake water clarity had improved, with the target mean depth of 2.5-3 m being achieved in 1991-93. Mean chlorophyll a and TN concentrations were close to meeting the targets of 10 and 300 mg/m^3 respectively, and there was a trend of decreasing chlorophyll and total nitrogen concentration. Mean TP concentration was almost double the target concentration of 20 mg/m^3 and showed an increasing trend but this apparently had not enhanced phytoplankton growth. Bioassay tests indicated that phytoplankton were strongly nitrogen- limited, and it was suggested that the severity of nitrogen limitation of phytoplankton growth and the excess phosphorus concentrations in the lake could potentially lead to nitrogen-fixing blue-green blooms.

TRENDS IN LAKE WATER QUALITY

Sewage diversion in 1991 was expected to decrease lake TP and TN concentrations with associated benefits for other parameters of lake water quality. There was a discernible ‘dip’ in lake TP, TN, CHLA (Figure 1) and TLI (Figure 2) immediately following sewage diversion but each increased from 1995-2002, although clarity remained high. Lake TP and TN concentrations are now approaching those during the mid-1980s. There are occasional high TP and TN concentrations that are possibly associated with release from the lakebed. There is an overall increasing trend in TP (weak) and TN (strong) from 1967-2002. TLI has fluctuated over this period but there is no discernible overall trend (Figure 2). This is in contrast with the public viewpoint that water quality in Lake Rotorua is steadily deteriorating and the overall increasing trend in TP and TN.

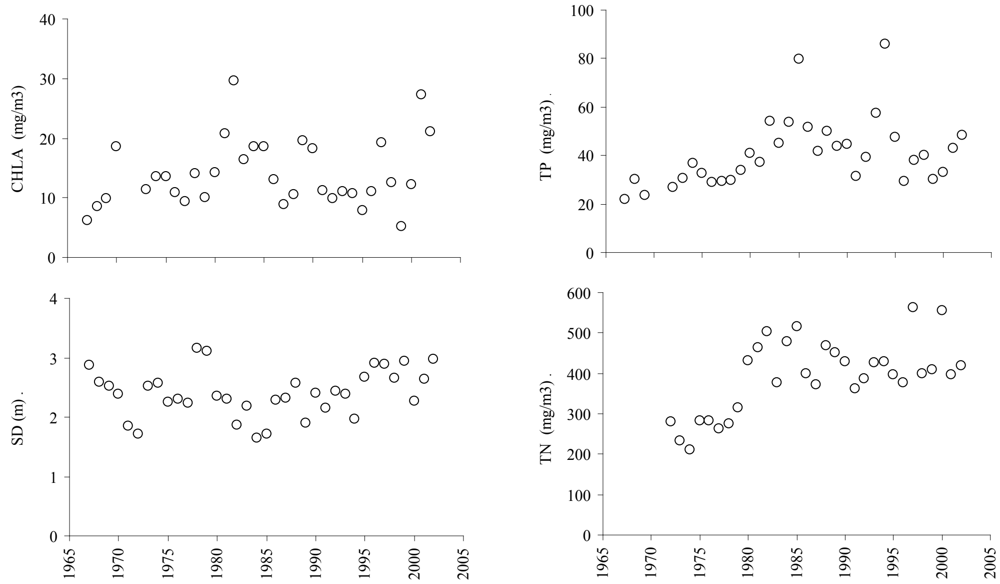


Figure 1. **Variation in annual average chlorophyll (CHLA), total phosphorus (TP), total nitrogen (TN) and secchi disc clarity (SD) in Lake Rotorua 1967-2002.**

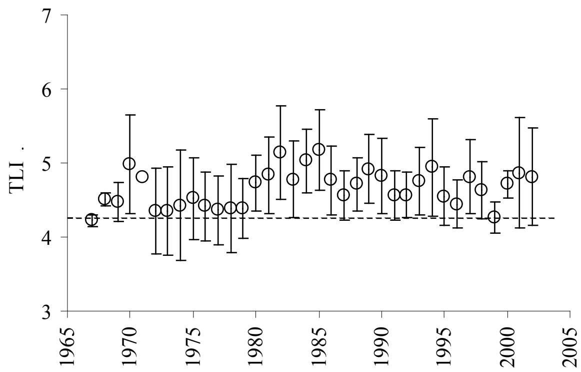


Figure 2. **Variation in annual average trophic level index (TLI) in Lake Rotorua 1967-2002.**

TRENDS IN NUTRIENT LOAD

During the 1970-80s there was a steady increase in sewage nutrient load from domestic sewage associated with reticulation in Rotorua City (Figure 3). Phosphorus stripping at the sewage treatment plant commenced in 1973 and low phosphorus loads during 1976-78 and 1987-88 correspond with periods when it was effective, while the peaks occurred in years when stripping was suspended or had low efficiency. Land disposal in 1991 resulted in a significant reduction of sewage derived nutrient inputs from 1991-1993. However, nutrient losses from the spray irrigation site increased from 1994-2001 as was discussed earlier.

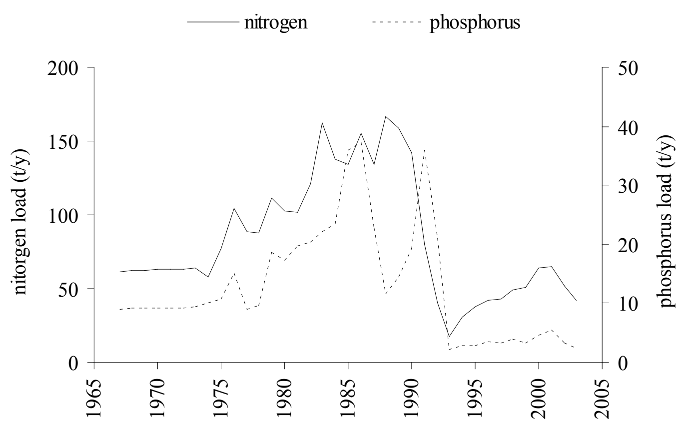


Figure 3. Nutrient loads from domestic sewage 1967-2002.

TRENDS IN STREAM NUTRIENT CONCENTRATION

The comparison of stream nutrient concentrations and loads is hazardous because: analytical methods have evolved over time, the concentrations of some constituents (notably particulates) are correlated with flow which means estimates of average storm flow concentration and load have a high uncertainty, hydrological regimes may not be identical between studies which affects average concentration, and the intensity of sampling differs between studies. Hoare (1980) found that baseflow supplied >90% of the annual total inflow to Lake Rotorua and that soluble nutrient concentrations did not vary with flow. In this study only baseflow nutrient concentrations are examined and attention is focused on trends in soluble nitrate (NO_3) and dissolved reactive phosphorus (DRP). The Ngongotaha is the best-studied stream in the Lake Rotorua catchment (Figure 4). DRP concentration decreased from 1968-70 to 1987-89 but appears to have increased in recent years. NH_4 concentrations are consistently low and soluble inorganic nitrogen is dominated by NO_3. The most striking feature of the dataset is that NO_3 concentration has undergone a steady increase between studies from 364 ± 2 mgN/m^3 in 1969-1970 to 738 ± 125 mgN/m^3 in 1991-2003 (~100% increase). Note that the 1968 NO_3 data are ignored because there is some debate about its reliability.

Hoare (1980) identified the nine 'major' streams that flow into Lake Rotorua (Table 2) for which trends in baseflow DRP and NO_3 concentration are shown in Figure 5. There is no difference in mean DRP concentration between the 1968-70 and 1991-2003 studies that is consistent across all streams, but there are indications that DRP was low during the 1976-77 study. There is no obvious land-use change between studies that could explain this cyclical pattern, which may be related to differences in annual rainfall. In the eight 'cold' streams NH_4 concentrations are very low and do not make a significant contribution to TN concentration, which is dominated by NO_3. The Waiohewa is a 'hot' stream receiving geothermal flow from the Tikitere geothermal field and has high NH_4 concentrations but there is no consistent trend in mean baseflow NH4 concentration. There is a consistent increasing trend over time in NO_3 for eight of the nine major streams (the exception being the Waiowhiro) (Figure 5), which is confirmed by an analysis of variance (details omitted for brevity). The trend in the Ngongotaha Stream (Figure 4) is

not confined just to that catchment, but also occurs in the other major inflows to Lake Rotorua. The most likely reason for the increase in NO_3 is the intensification of land-use.

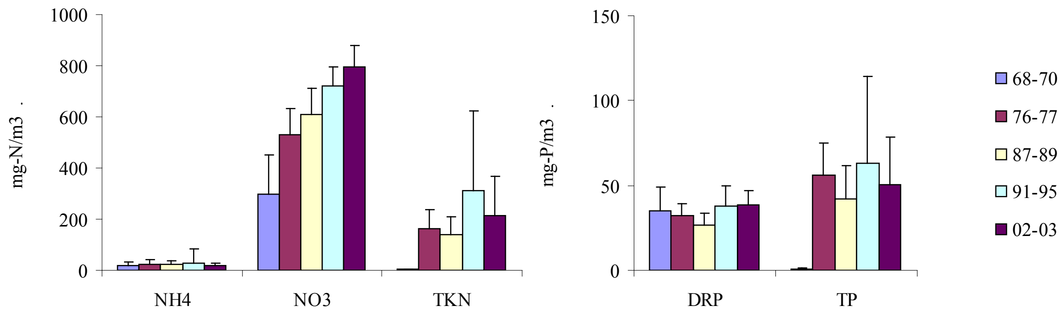
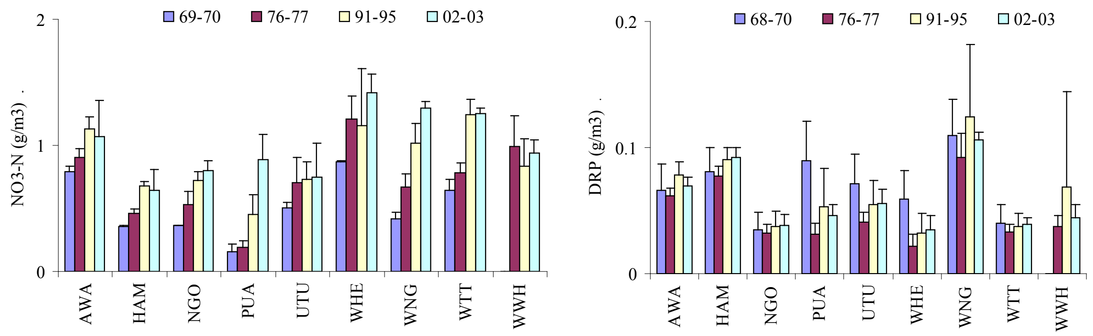


Figure 4. Mean baseflow nutrient concentrations in the Ngongotaha Stream Error bars are 1 standard deviation.

Table 2. Stream names, codes and mean baseflow.

Stream	site	code	1968-1970 m^3/s	1976 m^3/s	1987-89 m^3/s	1991-2003 m^3/s
Awahou	Hamurana Road Bridge	AWA	1.79	1.66		1.57
Hamurana	Hamurana Road Bridge	HAM	2.96	3.08		2.48
Ngongotaha	Town Bridge	NGO	2.29	1.98[a]	1.38	1.94
Puarenga	Forest Research Institute	PUA	1.92	2.05		1.89
Utuhina	Lake Rd Bridge	UTU	2.22	2.04		1.77
Waiohewa	Rangiteaorere Road Bridge	WHE	.48	.41		.33
Waingaehe	Walkbridge at SH 30	WNG	.29	.27		.24
Waiteti	Arnold Street Walkbridge	WTT	1.51	1.39		.96
Waiowhiro	Aquarius Drive Recorder	WWH	ND	.41		.32



[a] 1.79 m^3/s over the whole study 1976-78

Figure 5. Comparison of mean baseflow DRP and NO_3 concentration measured in 1968-70 (Fish), 1976-1977 (Hoare) and 1991-2003 (EBoP).

TRENDS IN CATCHMENT NUTRIENT LOAD

The most complete and reliable estimate of the nutrient load on Lake Rotorua was made by Hoare (1980) for the years 1976-77 (Table 3). Hoare found that soluble nutrients (DRP, NO_3 and NH_4) comprised a substantial fraction of the total load and their concentration did not vary much with flow. By contrast particulate nutrient concentrations were significantly higher during storms and highly variable between storms. There are insufficient stormflow samples to make reliable estimates of trends in stormflow load

over the period 1967-2002. However, we do have clear evidence of increases in baseflow NO_3 concentration in the major streams. The ratio of flow-weighted NO_3 concentration to that measured by Hoare for 1976-77 was 0.78, 1.34 and 1.39 in 1968-70, 1991-95 and 2002-03 respectively and this represents a near-linear increase by ~75% from 1968-2003.

The catchment (non-sewage) load of soluble nitrogen reported by Hoare (Table 3) was scaled by the trend in NO_3 identified in this study. We assumed that organic and particulate nitrogen loads remained constant. Since there is no evidence of trends in baseflow DRP we assumed that stream loads of phosphorus have not changed from 1967-2003.

The estimated stream and total nitrogen inputs to Lake Rotorua both show a significant increasing trend from 1967-2003 (Figure 6). There was a dip soon after sewage diversion but the decrease in nitrogen load that occurred as a result of sewage diversion has been offset by the increase in nitrogen load in streams during the last ten years. For phosphorus, catchment phosphorus load appears to have remained constant, and total load follows the trends in sewage load.

Table 3. Phosphorus and nitrogen loads to Lake Rotorua. Source: Hoare (1980)

	DRP	base flow PP+DOP	floods PP+DOP	Sewage
1976	25.9	9.0	10.0	7.5
1977	24.8	8.8	10.0	8.0
	TIN+DON	**PN**	**PN**	**Sewage**
1976	437	60	60	68
1977	412	50	50	64

units = tonne per year

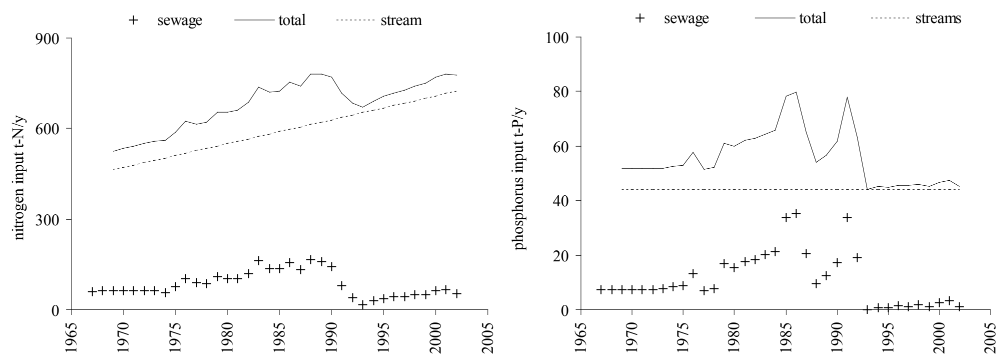


Figure 6. Sewage, stream and total loads of nitrogen and phosphorus 1967-2002.

INTERNAL NUTRIENT LOADS

Lake Rotorua occasionally stratifies for short periods of time during summer, and when this occurs oxygen concentrations in the bottom waters drop until eventually soluble nutrients become unbound from the sediment and are released into the bottom waters of the lake. The 'internal load' refers to the mass of soluble nutrient released from the lakebed that persists in the water column after the lake mixes. Internal loads are difficult to measure in Lake Rotorua because they only occur sporadically during calm, warm weather. Routine monthly monitoring is not normally frequent enough to accurately quantify releases although it can detect the net impact of large release events. White *et al.*

(1978) undertook detailed summer surveys in an attempt to measure the internal load but encountered cool, windy weather in which stratification was short-lived and the internal load small.

Vant (1985) collated the available estimates of the internal load, including those made during the several years when he arranged for daily monitoring of temperature and dissolved oxygen that enabled nutrient sampling during stratification events. Recently Burger has reported internal load estimates from two stratification events in the summer of 2002-03.

Figure 7 (below) shows a collation of the available internal load estimates. Fish (1975) documented a prolonged (30-40 day) period of stratification in the summer of 1969-70 but his data are too sparse to allow a reliable internal load estimate to be made. Monitoring data from 1990-2000 are not frequent enough to enable reliable estimates to be made of internal loads. The 2002-03 estimates are comparable with peak values during the 1980s and there is no evidence of a significant trend in internal loads. Internal phosphorus loads have occasionally reached 20-25 t which is comparable with the estimate of 25 t for the DRP load in streams in 1976-78 (Table 3) and ~50% of the total load in 1976-78 (including particulates, floods and sewage). Internal nitrogen loads have occasionally reached 150-250 t which is <50% of the soluble nitrogen load in streams in 1976-78 and <25% of the total load in 1976-77.

DISCUSSION AND SUMMARY

Sewage diversion was followed by significant improvements in lake water clarity, nitrogen and chlorophyll concentrations from 1991-95, but since then water quality has deteriorated. Burns (1999) suggested that the lack of a permanent improvement could be due to nutrient regeneration from the lakebed (in accord with earlier model predictions, Rutherford *et al.* 1996) and recent internal nutrient loads are comparable with those observed during the 1970-80s.

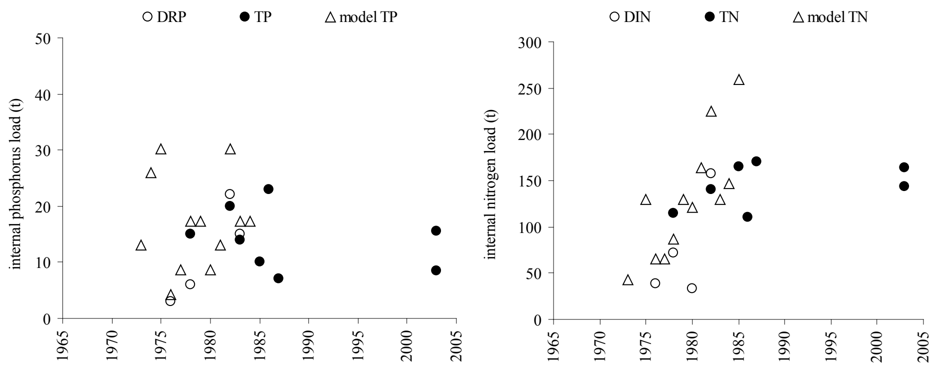


Figure 7. Internal nutrient load estimates for Lake Rotorua. DIN, DRP, TN and TP denote the nutrient type upon which the estimates are based.

While internal loads are likely to have caused year-to-year variations in lake nutrient and chlorophyll concentration and may have delayed lake recovery, this study indicates that another likely reason why lake water quality has not continued to improve since 1991 is that external nitrogen loads from the catchment have increased and negated the potential beneficial effects of sewage diversion. An increasing trend in mean baseflow nitrate concentration has been identified in eight of the nine major streams. Although some

evidence of increasing nitrate concentrations in the Ngongotaha Stream was found in an earlier study (Williamson *et al*. 1996), inclusion of the recent Environment B.O.P monitoring data in the dataset shows that this trend has continued in the Ngongotaha Stream and is widespread in the Rotorua catchment. When the increasing trend in stream nitrate is combined with well-documented changes in sewage nitrogen load, there is evidence that the benefits derived from sewage diversion in 1991 have been negated by subsequent increases in nitrogen load in streams. Part of this increase is associated with higher than expected 'leakage' from the sewage land disposal site but the majority is associated with increasing mean nitrate concentrations in streams draining agricultural catchments. There is an increasing trend in annual mean lake total nitrogen (TN) concentration over the period 1967-2003. This trend was temporarily interrupted following sewage diversion in 1991 but annual average lake TN concentrations are currently comparable with those during the mid-1980s.

When the decisions were made in the 1980s to divert sewage away from the lake it was thought that control measures put in place through the Kaituna Catchment Control Scheme would reduce catchment nutrient loads. These control measures were designed based on conventional wisdom in the late-1970s and included fencing streams to exclude stock and intercept overland flow, plus measures to reduce soil erosion. There is evidence that these control measures have reduced the loads of sediment, total phosphorus and particulate nitrogen in the Ngongotaha catchment (Williamson *et al*. 1996) and similar decreases are likely to have occurred in other catchments. However, stemming from this study there is now clear evidence that nitrate inputs have increased significantly in the majority of streams that drain agricultural land and that this has more than offset any benefits, in terms of reduced particulate nitrogen inputs, achieved through fencing streams, re-vegetating stream banks and retiring erosion-prone areas.

Increasing nitrate concentrations were first detected by Williamson *et al*. (1996). This occurred some time after the decision was made to divert sewage away from the lake. In hindsight it was incorrect to believe that the Kaituna Catchment Control Scheme would reduce catchment nutrient loads. Even at that time it was known that deep groundwater feeding springs in the Rotorua catchment was 50-100 years old, but the significance of this fact was not appreciated. The decision to divert sewage was influenced by the fact that it contributed 25-50% of the total nutrient load and, had the catchment nutrient load remained constant, sewage removal would undoubtedly have resulted in significant long-term benefits for lake water quality.

Recent work in the Taupo catchment has not only detected increasing trends in stream nitrate concentration but has also shown that nitrate concentration is inversely correlated with the age of the groundwater water. The hypothesis is that nitrate was liberated when land was converted from bush to pasture c. 70 years ago and is gradually moving down into the groundwater. 'Young' (shallow) groundwater has a higher nitrate concentration than 'old' (deep) groundwater because nitrate has had time to reach the former but not the latter. Subsequent more recent increases in land-use intensity are also likely to have liberated 'pulses' of nitrate that are now moving down through the vadose zone, and after some 'time delay', will eventually appear in the stream water. It seems likely that the same land-use/groundwater linkages operate in the Rotorua and Taupo catchments, given the similarities in the volcanic origin of the soils and underlying rocks.

What is not clear, however, is the time delay between land-use intensification and increasing stream nitrate concentration in the Rotorua catchment. Williamson *et al*. (1996) state that deep groundwater in the Ngongotaha catchment is 50-100 years old which coincides with conversion from bush to pasture. The implication is that it takes 50-

100 years for nitrate to leach from pasture, travel down through the vadose zone, mix with the groundwater and travel to where it enters the streams or lake. However, it is possible that some nitrate takes a shorter time to travel from the land surface to the stream because it is transported in shallow sub-surface or overland flow, and/or because the nitrate source lies close to the stream. It is important for management to know which parts of the catchment are 'connected' to which streams or springs (viz., the water and nitrate 'pathways'), the time it takes water and nitrate to travel along each of these pathways, and the amount of 'attenuation' (viz., denitrification or uptake by plants) that occurs along each pathway. If this information were available it would be possible to determine where mitigation measures (e.g., wetlands and/or riparian buffer zones that reduce nitrate concentrations by denitrification) could be located in the catchment. It would also enable areas to be identified where mitigation measures would not be effective (e.g., because the nitrate travels via deep groundwater to major springs thereby by-passing wetlands and riparian zones so that there is little opportunity for interception). If such information were available it would be feasible to develop a 'model' that summed the nitrate inputs from each part of the catchment, estimated the amount removed by the mitigation measures and/or natural attenuation processes thereby enabling an assessment to be made of whether or not nitrogen load targets could be achieved.

In marked contrast with nitrate, there is no evidence of increasing mean phosphorus concentrations in the major streams. The external phosphorus load over the period 1967-2003 exhibits a 'hump' during the 1980s, associated with high sewage phosphorus loads, but is currently comparable with that during the 1970s. There is a weak increasing trend in annual average lake TP concentration over the period 1967-2003. Lake TP was high during the mid-1980s, decreased following sewage diversion, but is currently approaching values in the 1980s. There is a slight inconsistency in that lake TP concentration exhibits a weak increasing trend but the external phosphorus load does not. It is not clear whether this discrepancy arises from uncertainties in the data or indicates some regulating mechanism within the lake (e.g., sorption/desorption).

This study raises some significant issues about the role of catchment nutrient loads in determining lake water quality. There is a clear need to revise the conclusion reached in the 1980s that the Kaituna Catchment Control Scheme would result in catchment nutrient loads remaining similar to, or less than, those measured by Hoare in 1976-77. Given evidence of a widespread and significant increase in baseflow stream nitrate concentration, it is desirable to make a more detailed analysis of catchment nutrient loads. Such an analysis needs to include the contribution from stormflows and particulates, transport pathways for the delivery of nitrate and the time lags involved, opportunities to intercept nitrate, and opportunities to reduce nitrate generation.

The confession that I want to make before I close is that we, that technical group, expected the catchment controls to reduce nutrient loads. The catchment controls that went in at that time were based on conventional wisdom – they were riparian buffer strips, fencing cattle out of streams so they didn't crap directly, converting a lot of marginal land into forestry. Now I've read through a lot of what we wrote at the time. I can't find direct reference to it, but I think the implication is that we assumed that these measures would offset any land use intensification. Now what we know is that the Kaituna catchment control scheme did reduce particulate loads, but it didn't reduce nitrate.

Now the Williamson paper pointed out that it didn't reduce nitrate. And I think that as a group of scientists we have to own up to the fact that we did not recognise the significance of the ground water delay. The work that Bill Vant's going to talk about

later on will have the benefit of hindsight. So stock numbers have gone up significantly since 1994. Dairy cattle in the Bay of Plenty have gone up by 16%, slightly less than the national trend. Agricultural statistics for the Rotorua catchment itself are very difficult to find. Fertiliser has gone up - although my mind has asked me to say that fertiliser isn't the problem, it's the fact that more fertiliser equals more cows equals more urine spots equals more leaching. And in my defence and in closing, when we set the targets, the Williamson study hadn't even started, let alone been published – it wasn't published until 1995. So we attributed the increase in trend in nitrogen concentration in the lake to the sewage. With the benefit of hindsight of course and particularly with the increased understanding of the time delay, things are beginning to click into place.

Now I'll just race through to my final slide (not shown). *This was how it behaved in the 70s and I don't think anything's changed. It depends on the sewage load, the sewage load is being managed – there are some blips, but it is being managed. The catchment load: I think we need a major rethink there. The stormwater: David Ray is going to talk about it. The stormwater is on the agenda. Despite what Mark Bellingham said yesterday, we think it's a bit player.*

Blue-green algal blooms: I think we need some more thought. I don't think the scientific community can really honestly say we know what causes blue-green algal blooms. The internal load: it's like the poor - it's going to be with us, but don't give up on it. I don't think you can hide behind the internal load and say there's no point in doing anything in the catchment because there's this big internal load there waiting to bite us on the bum. It will get better with time, but it'll take a long time to get better. And the other thing is don't panic. When a crisis comes along like this blue-green algal bloom, we immediately think, well, how can we intervene? Can we get the bulldozers out and solve the problem? I think there are so many examples of the bulldozers creating a worse problem than the one you're trying to solve. Consider them, absolutely, but think them through very carefully. Thank you.

QUESTIONS

Don Atkinson, Okawa Bay: NIWA in actual fact have been charged over decades with having the responsibility of monitoring the lakes and the health of the lakes and the things we are finding out now only really come to the fore when the public knows, since we've had the catastrophe of, effectively, Lake Rotoiti dying. Why have we had to wait such a long time?

K.R.: A point of correction, I think the monitoring of the lake has been passed around. Geoff Fish starting lake monitoring in the 60s, Ministry of Works became involved, DSIR Taupo became involved in the 80s and then we passed that baton on to Environment Bay of Plenty, who have done most of the monitoring since the early 1990s. My understanding is that that information is made available on a regular basis. I've certainly got copies of state of the environment reports published by Environment Bay of Plenty on possibly an annual basis – perhaps someone from EBOP could tell me how frequently those are released. I'm distressed to hear that information is not getting out to the general public, because I think it's a theme that one or two other speakers have said. I think there is a lot of information, there's a lot of knowledge in this room, and if it's not getting from one side of the room to the other, then it's something that we need to work on, we need to get right.

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APPENDIX 1

Trophic level index (TLI) is calculated

$$TLI = average(TLc, TLs, TLp, TLn)$$

where $TLc = 2.22 + 2.54\log_e(Chla)$, $\quad TLs = 5.56 + 2.60\log_e(\frac{1}{SD} - \frac{1}{40})$,

$$TLp = 0.218 + 2.92\log_e(TP) \qquad TLn = -3.61 + 3.01\log_e(TN)$$

and *Chla* = chlorophyll *a* concentration (mg/m^3), *SD* = secchi disc water clarity (m), *TP* = total phosphorus concentration (mg/m^3) and *TN* = total nitrogen concentration (mg/m3).

Using the stable isotope ^{15}N to derive a budget for effluent-derived nitrogen applied to forest

Wade Tozer[a], **Kate J. Wilkins**[a,] Hailong Wang [b], Mike van den Heuvel[b], Tim Charleson[c], **Warwick B. Silvester**[ad]

[a]Department of Biological Sciences, University of Waikato, Private Bag 3105, Hamilton
[b]Forest Research, Private Bag 3020, Rotorua
[c]Red Stag Timber Limited, PO Box 417, Rotorua
[d]Author to whom correspondence should be addressed w.silvester@waikato.ac.nz

INTRODUCTION

This talk was to be given by Wade Tozer, but unfortunately, or fortunately for him –Wade is currently riding a motorbike through the Atlas mountains in Morocco or in the Sahara somewhere. So I'm going to introduce it and then another of my research students, Kate Wilkins, who actually initiated some of this work, will take over.

Since October 1991 municipal wastewater has been treated and the product irrigated onto 192 ha of conifer forest in the Whakarewarewa Forest. The effluent irrigation area is part of the Waipa catchment, which flows via the Waipa Stream into the Puarenga Stream and then into Lake Rotorua.

The original design specifications of the Rotorua Land Treatment System (RLTS) allowed for 312 kg N ha^{-1} yr^{-1} to be applied to the forest, of which 35 kg N was expected to be taken up by trees, 65 kg N to be denitrified *in situ* and a further 85 kg N denitrified in adjacent wetlands (McLay *et al.,* 2000). The balance of these processes was expected to result in less than 24.5 t yr^{-1} of exported N in the Waipa Stream (Cooper and Cooke, 1990). Nitrate levels in the Waipa Stream have risen from a low of 0.3 to 2.0 ppm NO_3-N.

The increase in NO_3-N leaving the Waipa catchment is clearly a result of the RLTS and was always anticipated. The annual loss of NO_3-N from the catchment has risen over the period, but the fate of the applied N is unclear. It is not realistic to determine with confidence the fate of the influent N in contributing to plant biomass, or soil organic matter by mass balance. Our recent preliminary work on irrigation sub-plots in the irrigated area known as the WFIT (Whakarewarewa Forest Irrigation Trial) shows that the irrigated effluent has a significant isotopic signature that can be followed into trees, into soil and into groundwater and beyond. It has been possible to use these figures to produce a preliminary budget for N in the WFIT (Wilkins, 2003).

This work extends that methodology to the total irrigated area and provides for the first time an overall budget for the fate of N applied to the system over the period of irrigation. The complexity of the sites with many topographic, soil and vegetation gradients means that intensive sampling was not possible, both financially and logistically. None-the-less the mean data extracted give a fair approximation of the fate of the effluent N and allow us for the first time to put realistic figures for N storage in biomass, soils and groundwater and for the amount of effluent N directly or indirectly entering the groundwater and streams.

MATERIALS AND METHODS

Location Description

The investigation was conducted in the RLTS situated within the Whakarewarewa Forest and the Waipa Stream catchment (38^o 10’ S, 176^o 10’ E). The soils are classified as Typic Orthic Allophanic (Hewitt, 1993) and are predominately Whakarewarewa and Ngakura Sandy loams (Rijkse, 1979).

Vegetation

The irrigated area is plantation forest planted at various times before and during the irrigation which started in October 1991. The total irrigated area is 192 ha consisting of 36 ha of Douglas-fir, 102 ha of young *Pinus radiata* (10-14 years old) and 54 ha of old *Pinus radiata* (up to 30 years old) (Tomer *et al.,* 1997). A variety of understorey weeds are present including blackberry, buddleja, Himalayan honeysuckle, bracken and several epiphytes on tree trunks, especially in the irrigated area where overhead sprinkling intercepts the tree trunks. Tree age varies from c. 30 years to 13 years and represents a significant variable in sampling vegetation.

Effluent irrigation

The irrigated area is divided into 14 blocks, each of about 14 ha, and irrigation occurs via high pressure overhead sprinklers. Irrigation is maintained throughout the year and the high infiltration rate ensures there is negligible runoff (Tomer *et al.,* 1997). From the start-up of the RLTS in October 1991 until February 2002 the irrigation regime consisted of 2 blocks sprayed each day with a 6-day return period. Effluent was applied at 5 mm. hr $^{-1}$ for up to 16 hours per day (80 mm). Over this period the average application rate was 73 mm. The spray regime was changed in March 2002 and now consists of spraying each pair of blocks in sequence for a period of 2 hours (10 mm). Each block pair has a return period of 12 hours spraying time which means on average each block is sprayed daily. This “little but often regime” contrasts with the original “high and less often regime”.

Sample Collection and Analysis

The area was stratified into three groups: old and young pine and Douglas-fir. The young trees are defined as those planted within not more than two years prior to the start of irrigation. Within each area samples of foliage, wood and bark (via increment corer), LFH, soil 0-100, 100-200, 200-300 mm were sampled at three different sites within the irrigated block. Similar control sites were sampled outside the irrigated area to obtain background stable isotope information. Samples were dried, finely milled with a ball mill, weighed and analysed for ^{15}N.

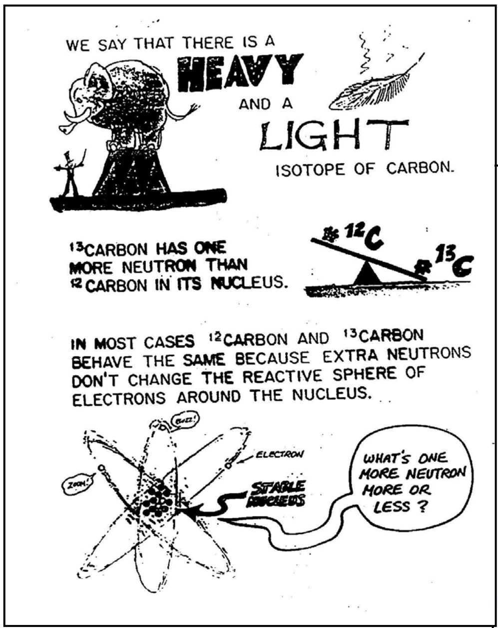
Samples of effluent, groundwater from piezometers, and Waipa Stream water were obtained from sites adjacent to both irrigated and control areas, both nitrate-N and, where measurable, ammonium-N, were analysed for ^{15}N.

Bulk density measurements of the soil were made to obtain total soil mass. Tree volume was estimated using the simple Shinozaki pipe stem model, which gives an approximation to total standing biomass, as opposed to timber volumes. This model proposes that the product of basal volume and height is a useful surrogate of total volume to include all branches. The model tends to slightly overestimate total volume in recently pruned trees. Mass analysis for wood was estimated using a conservative wood density of 0.45 Mg m^{-3}.

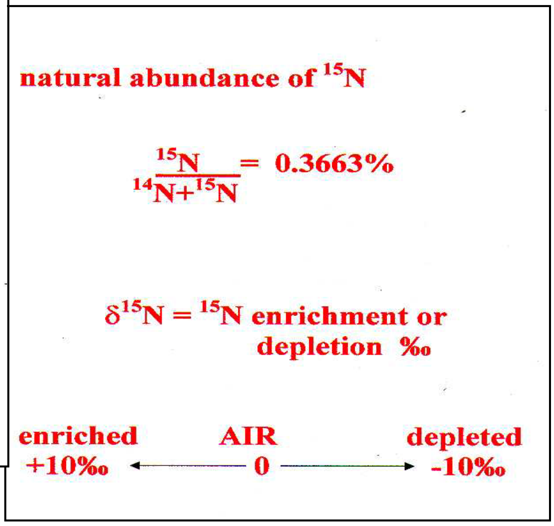
Foliage biomass was estimated using published figures and a mean value of 10 Mg ha^{-1} (Thorn *et al.,* 2000) used in this study.

Stable Isotope Analysis

Introduction



Nitrogen exists as two stable isotopes, the heavier and minor isotope ^{15}N occurs at 0.3663% of N_2 in air, while the balance is the lighter more common isotope ^{14}N.



Various natural processes discriminate between the two isotopes on the basis of their mass resulting in small differences in isotopic ratio that are measurable and significant. The differences are measured as parts per thousand (‰) or delta (δ) value either above or below the nominal normal abundance found in air. These differences can be readily measured by modern mass spectrometry to better than $\pm$0.5‰. The normal abundance of ^{15}N in air is given the arbitrary values of 0‰ and differences in parts per thousand are measured as positive (enrichment) or negative (depletions) in $\delta^{15}N$ with respect to air.

During biological processing of the effluent there are several processes that discriminate against the heavier isotope and perhaps the most important is in denitrification in which the lighter isotope tends to be selected and liberated as N_2 back to the atmosphere. The residual nitrate is correspondingly left with slightly more of the heavier ^{15}N and is enriched. Previous work has shown that NO_3-N in the effluent has an isotopic signature of +14‰ (Wilkins, 2003). Ammonia in the effluent is also enriched (c. +10‰), but represents only 5% of the inorganic N in the effluent. As the majority of control soils and plants have isotope values close to zero it is possible, knowing both the incoming isotopic signal and the background signal, to apportion the effluent N to various compartments, including drainage water in the irrigated zone.

Method

Dried and ball-milled samples of soils and plant material were analysed for ^{15}N using an IRMS isotope ratio mass spectrometer (20/20 Europa) coupled to an automated elemental

analyser. Liquid samples were concentrated for either nitrate or ammonia on appropriate ion exchange resins, eluted using at least five bed volumes and in the case of nitrate samples were distilled with Devarda's alloy to reduce nitrate to ammonia. Ammonia samples were alkali-distilled and dried in excess acid prior to mass spectrometry.

Calculations

Following calculation of N mass in each of the plant, soil or water samples, the isotope content can be used to calculate the contribution to that fraction that was derived from effluent. Thus if the $\delta^{15}N$ of the incoming effluent is +14‰ and the leaves of trees growing in the irrigated area are +14‰ it is safe to assume that all N in the leaves is derived from effluent.

$$\text{Thus \%N derived from effluent} = \frac{\delta^{15}N\text{ (treatment)} - \delta^{15}N\text{(control)}}{\delta^{15}N\text{ (effluent)} - \delta^{15}N\text{ (control)}}$$

The value $\delta^{15}N$ (effluent) is derived from the weighted mean of the isotope signatures of the nitrate and ammonia fractions in the effluent. Thus it becomes possible to estimate within some reasonable limits the proportion of effluent N to ambient N that is contained in each compartment of the treated area and further to determine what proportion of the NO_3-N in the Waipa Stream is effluent-derived.

RESULTS

Nitrogen Inputs and Losses

Nitrogen levels in the effluent and in the Waipa Stream have been measured since the start of the irrigation. These are shown in Fig. 1 and a summation of these shows that 849 Mg N has been applied to the forest and the total flow of N out of the catchment has been 242 Mg. N levels in the Waipa Stream have risen over the irrigation period, but it has been impossible to determine how much of the NO_3 in the stream is directly or indirectly due to the irrigation.

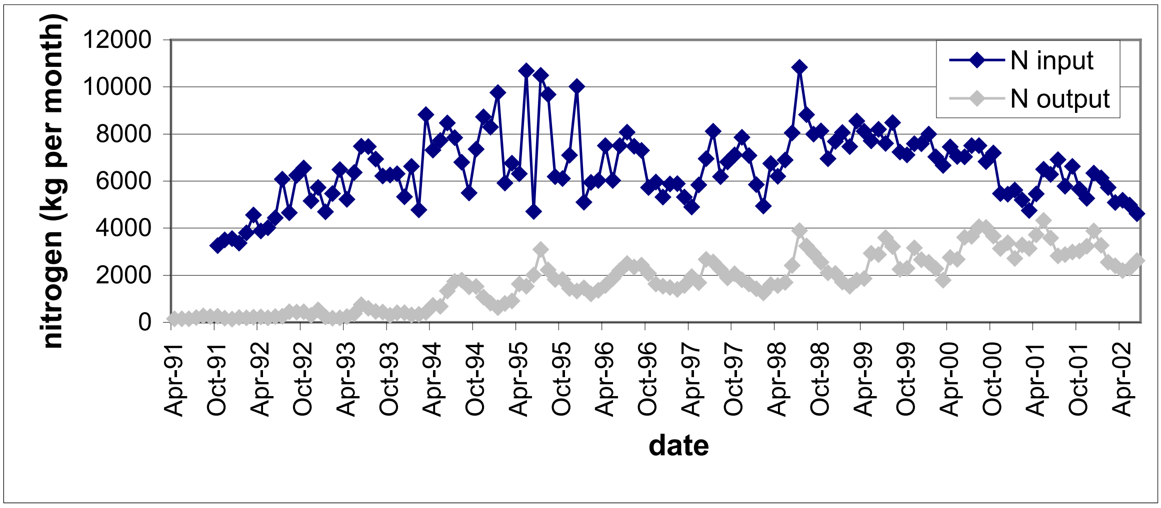


Fig.1: Nitrogen inputs and outputs from the Waipa Stream over effluent irrigation period

Irrigated Effluent

The effluent after treatment has a low inorganic N content averaging 6.3 g m^{-3} of which 97% is NO_3-N. The 3% ammonia contribution is insignificant in the total N input in the present composition of effluent, but was significantly higher prior to 2000. The isotopic enrichment ($\delta^{15}N$) of the nitrate N has been measured on four different occasions (Fig. 2) and the mean of these measurements is +14.12‰. This value is highly enriched compared with natural ^{15}N values and provides an excellent means to trace the N into the ecosystem, to measure storage and to measure losses.

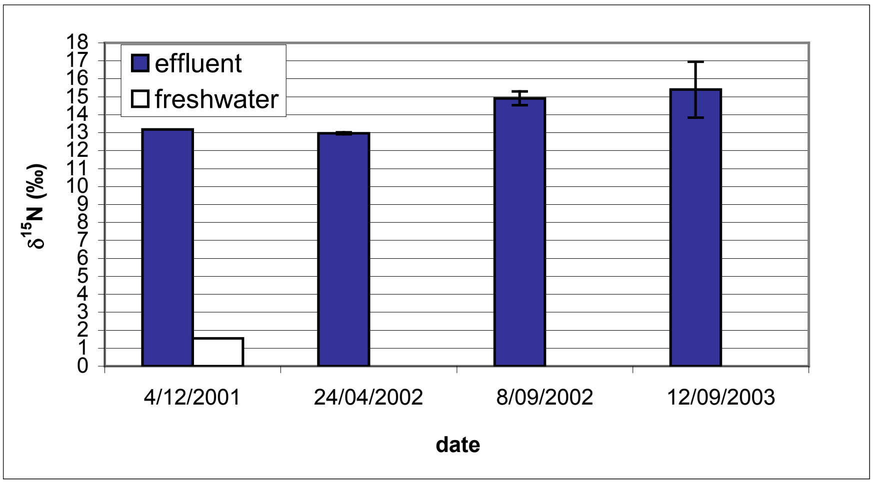


Fig. 2: $\delta^{15}N$ of the nitrate fraction of the effluent

Green Foliage Contribution

<u>Conifer Foliage</u>

The biomass of green conifer foliage is taken as 10 t ha^{-1} across all blocks (see methods) and for irrigated areas the N content of foliage is 1.57% for both Douglas-fir (Fig 3) and pine. An example of the isotopic composition of the foliage is shown in Fig. 4 and the contribution of effluent is given in Table 1. The foliage of canopy and sub-canopy species are all highly enriched in ^{15}N reflecting the high proportion of effluent N contained (Fig. 4 and Table 1). Conifer species show 90-100% of N is effluent-derived while the enrichment in sub-canopy species indicates 100% effluent N in most cases. With such high levels of isotope ratios the total N from effluent for the whole catchment in dominant tree foliage is 28.4 Mg or 148 kg N ha^{-1} (Table 1).

<u>Understory Foliage</u>

There is a diverse range of understory species which have, in some cases very high foliage N levels ranging from 2-5% (Fig. 3). A small sampling of this understory indicated a biomass of approximately 2.5 Mg ha^{-1} and using an N concentration of 3% gives a total understory N content of 75 kg N ha-1 or 14.4 Mg N stored in the total understory. The $\delta^{15}N$ values for the understory are at least +14‰ (Fig. 4), thus we assume all N in these plants is derived from effluent.

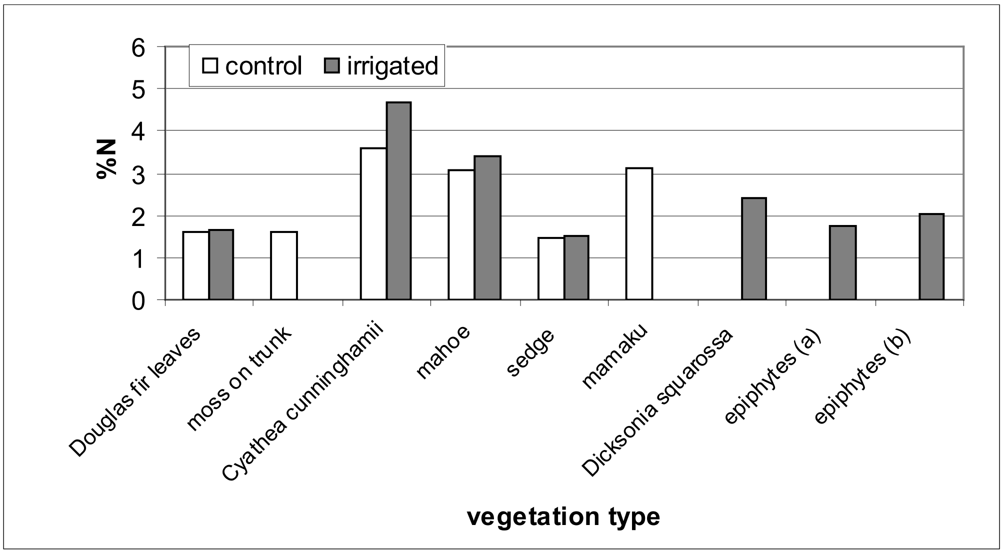


Fig. 3: %N in the vegetation of the Douglas-fir forest

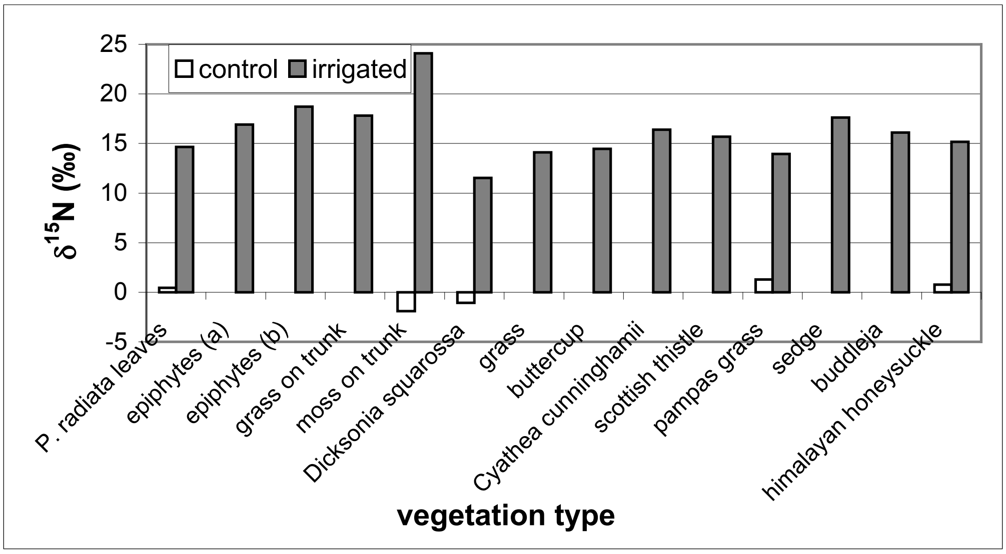


Fig. 4: $\delta^{15}N$ in the vegetation of the young *Pinus radiata* forest

Table 1: Conifer foliage biomass and proportion of N derived from effluent

Forest Type	Total N (kg ha^{-1})	Total N Irrigated Area (Mg)	$\delta^{15}N$	Proportion from Effluent	N from Effluent (Mg)
Douglas-fir	157	5.65	12.56	0.89	4.95
Pine young	157	16.0	14.65	1.04	16.0
Pine old	157	8.48	12.45	0.88	7.46
				Total N (Mg)	**28.41**

Standing Biomass Wood

Total standing wood biomass was estimated from diameter and height measurements made on four stands of trees. The Shinozaki model was used to estimate the contribution of all wood in trunk, branches and branchlets.

Wood volume in roots and fallen pruned branches was not directly measured.

N concentration in wood cores was measured at four points along an increment core and followed a typical profile with values around 0.4-0.5% for bark and 0.1-0.05% in the wood. Sap wood usually contains more N than heartwood (see Fig. 5 for an example).

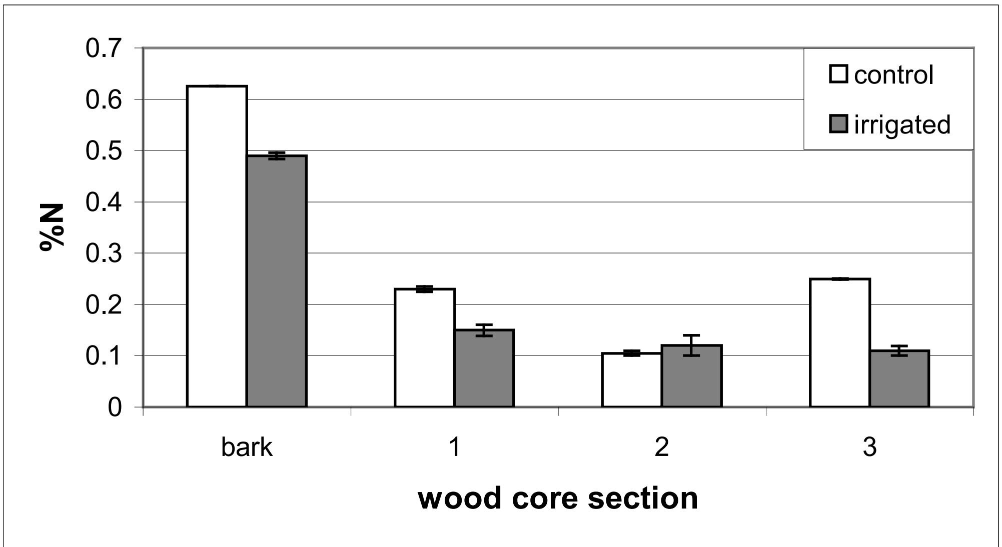


Fig. 5: %N in the bark and wood of the trees in the old *Pinus radiata* forest

There was little effect of effluent irrigation on wood N content except in the bark. N contents are estimated as shown in Table 2. The wood was proportioned as one third to each class.

Table 2: N concentration and N mass in the wood and bark of irrigated trees

	Bark		***Outer Wood***		***Middle Wood***		***Inner Wood***	
Forest Type	%N	Total N kg ha^{-1}	%N	Total N kg ha^{-1}	%N	Total N kg ha^{-1}	%N	Total N kg ha^{-1}
Douglas-fir	0.47	113	0.08	118	0.06	89	0.07	103
Pine young	0.49	59	0.15	109	0.12	88	0.11	80
Pine old	0.39	156	0.13	658	0.05	253	0.07	354

The majority of wood samples taken from irrigated trees showed significant isotopic enrichment (Fig. 6). As expected the heartwood of Douglas-fir trees, laid down in these 31 year old trees prior to irrigation, was not enriched to any significant degree. Contrary to this the heartwood of older pine trees was strongly enriched indicating a significant movement of N from the active sapwood into the heartwood (Fig. 5). The total N and N contribution from effluent is shown in Table 3, with 96 Mg of effluent N stored in the treated area.

Fig. 6: δ^{15}N in the bark and wood of the trees in the young *Pinus radiata* forest

Table 3: Total N contribution from effluent in wood and bark

Forest Type	kg N ha^{-1}	Total N (kg N)	Effluent Proportion	N from Effluent (Mg)
Douglas fir				
Bark	113	4068	0.92	3.74
Outer Wood	118	4248	0.56	2.38
Middle Wood	89	3204	-	-
Inner Wood	103	3708	0.09	0.33
Pine young				
Bark	59	6018	1.00	6.02
Outer Wood	109	1118	1.00	11.12
Middle Wood	88	8976	1.00	8.98
Inner Wood	80	8160	1.00	8.16
Pine old				
Bark	156	8424	0.78	6.46
Outer Wood	658	35532	0.81	28.78
Middle Wood	253	13662	0.84	11.48
Inner Wood	354	19116	0.45	8.60
			Total (Mg)	**96.0**

Soil Storage

The native pool of N storage in the soils is of the order of 7 t ha^{-1} (Tomer *et al.,* 1997). The work of McLay *et al.* (2000) indicated that there may be an increase of 750 kg N ha^{-1} but the variation was such that the increase was not significant. The isotope technique allows us to identify the effluent N in the soil profile. Total soil N in the top 300 mm ranges from 4.6 to 7.1 Mg ha^{-1} (Table 4). The control isotopic ratio shows a consistent increase, down the profile, which is commonly found, and the irrigated soils show a maximum of 61% of N derived from effluent. A total of 263 Mg of effluent-derived N is stored in soils, representing 1.37 Mg ha^{-1}, which is twice the amount indicated by McLay *et al*. (2000) in the mass balance analysis.

Table 4: Contribution of effluent N to soil storage

Forest Type	Soil Horizon	Bulk Density kg m^{-3}	%N	Total N kg ha^{-1}	$\delta^{15}N$ (‰)	$\delta^{15}N$ control	Proportion from Effluent	N ha^{-1} from Effluent	N from Effluent (Mg)
Douglas-fir	LFH	420	0.57	1676	6.17	2.60	0.31	520	18.72
	0-100 mm	600	0.29	1740	6.00	5.21	0.09	157	5.65
	100-200 mm	550	0.21	1155	6.58	6.17	0.05	58	2.08
	200-300 mm	750	0.19	1425	6.81	6.78	0.004	6	0.22
			Total	**5996**					
Pine young	LFH	120	1.22	732	12.14	0.73	0.87	637	64.97
	0-100	600	0.33	1980	7.83	3.08	0.43	851	86.80
	100-200	920	0.27	2484	5.27	5.30	-	-	-
	200-300	820	0.24	1968	5.38	5.71	-	-	-
			Total	**7164**					
Pine old	LFH	200	0.75	750	9.95	2.56	0.64	480	25.92
	0-100	820	0.23	1886	7.33	4.99	0.26	490	26.46
	100-200	920	0.12	1104	8.04	5.35	0.31	342	18.47
	200-300	820	0.11	902	8.18	5.73	0.29	262	14.18
			Total	**4642**				**Total (Mg)**	**263.47**

Groundwater

Piezometers were sampled for groundwater on two occasions and the average NO_3-N concentration was 5.0 g m^{-3}. The $\delta^{15}N$ of the groundwater was also measured on two occasions (Table 5).

Table 5: $\delta^{15}N$ of the Groundwater

Piezometer	Inside/Outside Spray Zone	$\delta^{15}N$ (‰) 1st Sampling	$\delta^{15}N$ (‰) 2nd Sampling
12C	O	-2.19	-0.95
12D	O	-3.32	
12G	O	-0.47	
5	I	+12.86	+8.70
9	I	+12.04	
15B	I	+10.53	

The average of the samples taken from inside the spray zone is +11.03‰, while the average outside value is -1.73‰. Thus the proportion due to effluent is 0.81.

The amount of groundwater stored in the soil profile has been assessed (Tomer *et al.,* 1997) by gravimetric and TDR (time domain reflectometry). Measurements are of the order of 35-45%, with a maximum of 54% during irrigation. As plots are now irrigated daily and the pore space of these soils averages over 50%, it is fair to assume that values of 40% will be maintained throughout the profile. The site runs from 336 m asl at stream level to 352 m at ridge tops (Tomer *et al.,* 1997), a 16 m elevation. If an average of 5 m of soil is achieved over the whole 192 ha then there is a total groundwater volume of 0.4 x 5 m x 192 ha x 10,000 m^2 ha^{-1} = 3.84 x 10^6 m^3 at an average concentration of 5 g m^{-3}. This is a total N of 19.2 Mg of which 81% or 15.5 Mg is from effluent.

Wetland

The 47 ha of wetland was not intensively sampled but plants growing in and around the wetland and water emerging from the wetland were highly enriched in ^{15}N (Table 6).

Table 6: $\delta^{15}N$ of plants in wetland and water emerging from wetland
(t = toetoe, y = Yorkshire fog)

Site	NO_3-N concentration ppm	$\delta^{15}N$ NO_3-N ‰	$\delta^{15}N$ plants
Above wetland	4.5	+14.31	t +15.47 y +19.87
Below wetland	4.5	+15.68	t +13.15 y +13.62

Apportioning a similar green biomass and soil N to the wetland as shown for the upland soils, and using a 2 m depth of ground water, the total contribution of effluent N to vegetation is 50 Mg, to soils is 64 Mg and to soil water is 2, giving a total of 116 Mg.

Denitrification

Denitrification is reported to account for 2 kg N ha^{-1} yr^{-1} in the upland and 37 kg N ha^{-1} yr^{-1} in the wetland making a total of 23 Mg of N loss over the 11 year period.

OUTPUT INTO THE WAIPA STREAM

$\delta^{15}N$ in NO_3^- in several tributaries within the irrigated area indicate high levels of effluent N. NO_3-N in water at the gauging station on the Waipa Stream taken on two different occasions gave $\delta^{15}N$ ratios of +12.88‰ and +12.86‰. This indicates 88% of the NO_3 in the stream being derived from effluent. Thus of the total of 242 Mg of N measured in the stream over the 11 years of operation as much as 213 Mg may have been derived from effluent.

DISCUSSION

Use of the naturally occurring ^{15}N isotope has allowed a reasonable approximation of storage and losses of N in the system. It has not been possible to account for changes in isotopic composition over the period, nor has there been an accounting for the small but variable organic load in the effluent. However, the majority of N, especially lately, has been in NO_3-N and it is this component that provides the major signal.

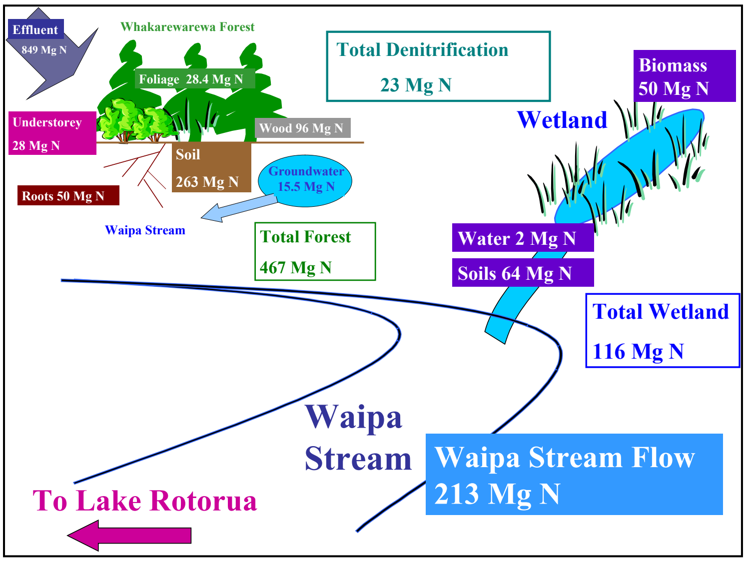
The site is naturally very variable with different species, ages and topography. It has not been possible to sample all of those variables to get a measure of the variability, however, the figures that have been obtained are a measurable measure of the storage parameters.

Another variable not addressed is the possibility of further N fractionation in uptake and processing. There is a small fractionation in uptake of N and if that was occurring there would be an underestimation of storage in the trees. As 100% effluent N is seen in many of the plant compartments we believe that uptake fractionation is not significant. Denitrification is a major fractionation step, however, when only a small amount of N is denitrified, there is no significant discrimination to be seen in the reactants.

The overall balance (Table 7) shows that 467 Mg N or 55% of the total incoming N is stored in the forest, the majority in the soil. The wetland accounts for 116 Mg and the total storage of 583 Mg represents 69% of the total. Adding the denitrification losses to that over 71% of the total incoming N is accounted for. An estimated 213 Mg of effluent N has left the catchment which is 25% of the incoming N over the 11 year period, leaving a small proportion 30 Mg unaccounted for.

Table 7: Nitrogen budget

N Input		**849**	**N Losses**		
Storage:			**Denitrification**	Upland Soils	4
				Wetland	19
				Total	**23**
Forest	Foliage	28	**Stream Flow**		**213**
	Wood/Bark	96			
	Soil	263			
	Roots	(50)			
	Understorey	14			
	Groundwater	16			
	Total	**467**			
Wetland	Biomass	(50)			
	Soils	(64)			
	Water	2			
	Total	**116**			
Total Storage		**583**	**Total Losses**		**236**
			Grand Total		**819**
			Unaccounted		**30**



QUESTIONS

Jim Crush, AgResearch: In the Taupo catchment, Manawatu and Southland catchments we find dissolved organic N which we think is probably short-chain peptides and can be as significant as nitrate is as a vehicle for loss of nitrogen. Though dissolved organic N may be more significant in pasture than in forest, but have you thought about checking on that in this system?

W.S.: The figures for the output through the Waipa actually come from RDC and by far the greater proportion of nitrogen in those streams is nitrate. The nitrate levels have risen, I think, in concentration between 5 and 8 times, and that's been the major output. No, we haven't looked at DON and it's obviously a possibility, but in forests of course and particularly as this flows through a wetland, there's a lot of uptake of that in the very large bacterial activity in the wetland. You could plough very big holes through this and I will not actually argue for any of the individual numbers like 4, but I will argue for every one of the order of magnitude. The isotope data doesn't rely on those, but DON, yes, we should measure that.

Roland Stenger, Lincoln Environmental: My question is a technical one. Do I understand it right that all your calculations here rely on the assumption that the ^{15}N enrichment of the effluent is not further changed through the whole system from effluent spray irrigation through to the output?

W.S.: A very good question for the technical people. Many of the processes that plants and bacteria undertake involve further fractionation and as carefully as we've looked at that, the major one that does that is denitrification. Denitrification is one of the most potent further fractionates of isotopic nitrogen. There is very little denitrification in the system and we've looked at the effect of denitrification on isotopic fractionation in the most likely place, which is the wetland. We cannot find it, but there's a good reason for that and it's highly technical, because when you are only denitrifying a small amount of nitrogen, the most fractionation you see is the in the product, not in the reactants. So because we've got most of the reactants left behind, we don't see much fractionation. The other most likely one is uptake. The uptake fractionation is a very small one and if we were seeing uptake fractionation, we would have seen a significant shift in isotopic

concentration in the leaves of the pines in particular. Again we can't see that. We don't deny it's happening, but it's small with respect to the major effects that we are seeing. I'm sure it's there, but with respect to these major effects, we believe it's small and would require a very large study to pick it up. But that's an excellent technical question.

ACKNOWLEDGEMENTS

We thank Duncan Miers for technical assistance. Financial assistance for this project has been supplied by Environment Bay of Plenty and Rotorua District Council. Isotope analyses were carried out by Waikato Stable Isotope Unit at the University of Waikato.

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Changes at Lake Taupo: the early warning signs?

Bill Vant
Environment Waikato, P.O. Box 4010, Hamilton

ABSTRACT
There have recently been a number of signs that Lake Taupo's near-pristine condition has begun to deteriorate. These include increases in the levels of nitrogen and algae in the lake, and a small but significant reduction in water clarity. In addition, loads of nitrogen and phosphorus from the catchment are thought to be considerably higher than they were before the land was developed. Levels of nitrogen in several streams draining large areas of pasture are higher than those in streams in undeveloped or exotic forest areas. Furthermore, nitrogen levels in several of the pasture streams have increased substantially since the 1970s, despite there having been little change in the intensity of farming since then.

Our water dating shows that a considerable proportion of the water in some pastoral streams is more than 40 years old. The changes in water quality that we are now seeing in the lake may therefore be a delayed response to land use changes that were made in the catchment 30–40 years ago. With the benefit of hindsight, we might ask whether this deterioration could have been better anticipated? Rather than waiting to see changes in lake water quality, could we perhaps have been monitoring processes or activities in the catchment, and thus have received earlier warning that deterioration had begun?

KEYWORDS: water quality; nitrogen; land use

(T*ape transcript*)
Thank you and good morning. Tony Petch and I are both going to talk about water quality and land use at Lake Taupo. I'm going to focus on the science and then Tony will tell you how Environment Waikato has gone about developing a strategy to manage the emerging issues. We thought we'd like to defer questions and discussions on both talks until after you've heard them both, so when I finish speaking, Tony is going to stand up and go from there, and then whatever time's left we'll take a joint discussion.

The main conclusion of my talk is that evidence is now mounting that there's been a lengthy delay between agricultural development in the Taupo catchment and the resulting increases in nitrogen loads in the streams which flow into the lake. Kit Rutherford hinted at this just before morning tea. This has mainly been due to the large underground storage of water that's possible in the Taupo catchments with thick deposits of highly permeable pumice. And in a situation like this you might argue that monitoring the lake is of limited value, since changes in lake water quality will only become apparent many years after the land use changes that caused them. If we're interested in early warning signs which is the theme of my talk, that there may be environmental issues to manage, then maybe the lake itself is not the best place to be looking for them.

So some key features of Lake Taupo, and straight away I'll contrast them with what we know about the Rotorua lakes. Lake Taupo is big – the area of Lake Taupo is about 8 times larger than the area of Lake Rotorua, the largest of the Rotorua lakes. Mean depth is 97 metres, than more than twice the depth of Okataina. The residence time of Lake Taupo is 11 years - if the lake was empty right now, it would take 11 years to fill up with

water.

Lake Taupo: key physical features

Area	620 km^2
Mean depth	97 m
Residence time	11 years

Key water quality processes

- Nutrients support algal growth
- Algae affect water colour and clarity
- Decay of algae consumes dissolved oxygen
- Nutrients are recycled from bottom waters

(Faecal contamination generally low)

Looking at some of the key water quality processes, just quickly running through them – I think most of us are familiar with them by now. Nutrients support algal growth, algae affect water colouring and clarity, the decay of algae consumes dissolved oxygen from the water and nutrients are recycled from the bottom waters. The little footnote there just reminds us that in Lake Taupo we're really not concerned about faecal bacteria, bad bugs.

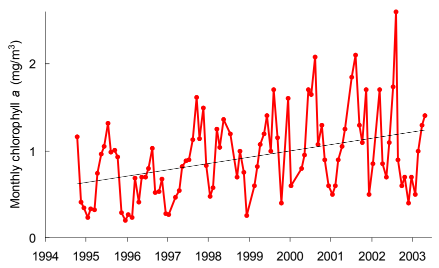
Current water quality

Total phosphorus (mg/m^3)	5.0
Total nitrogen (mg/m^3)	76
Algae (mg Chla/m^3)	0.9
Dissolved oxygen (min, g/m^3)	6.5
Clarity (Secchi depth, m)	14
Colour	Blue

The next slide shows the current water quality of Lake Taupo – we don't need to worry too much about these numbers. If we were to convert these nutrient concentrations, water clarity and algal levels, into TLI values, we'd say Lake Taupo has a TLI of 2.2. Now if you look at page 8 of the meeting notes, that's lower than any of the TLI values for the Rotorua lakes.

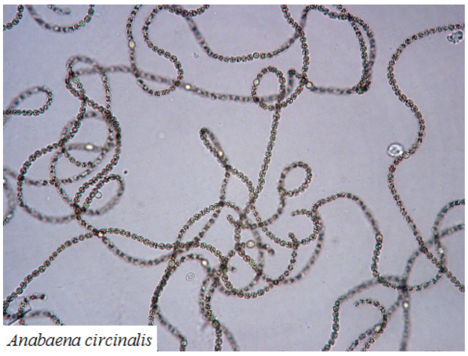
David Hamilton made some interesting points about dissolved oxygen the other day. The lowest dissolved oxygen level we've found in Lake Taupo over the last 9 years is 6½ grams per cubic metre. Even at the end of summer with oxygen depletion in the water column, there's still a good amount of oxygen in Lake Taupo, such that we're not concerned at this stage with bottom water anoxia and the internal loading of nutrients that's associated with it.

Algal biomass 1994-2003

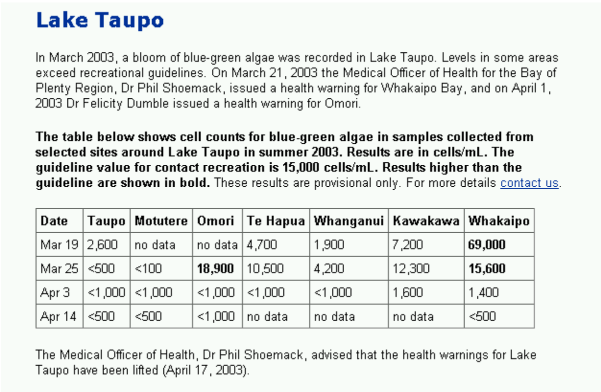


So Lake Taupo has got excellent water quality, but this slide shows the change over the last 9 years in the level of algal biomass in the lake, the average level has risen.

Furthermore, in two out of the last three summers we've had blooms of this blue-green



algae, *Anabaena*, in Lake Taupo. Now I have to say that for myself and all the colleagues from NIWA, this is something we never thought we'd see. We knew that *Anabaena* was present in Lake Taupo, it's been there for at least the last 40 years that people have looked for algae in the lake, but never before has it reached such high numbers and blooms. So we had a bloom in the year 2001 and then this summer we had another bloom.



Lake Taupo

In March 2003, a bloom of blue-green algae was recorded in Lake Taupo. Levels in some areas exceed recreational guidelines. On March 21, 2003 the Medical Officer of Health for the Bay of Plenty Region, Dr Phil Shoemack, issued a health warning for Whakaipo Bay, and on April 1, 2003 Dr Felicity Dumble issued a health warning for Omori.

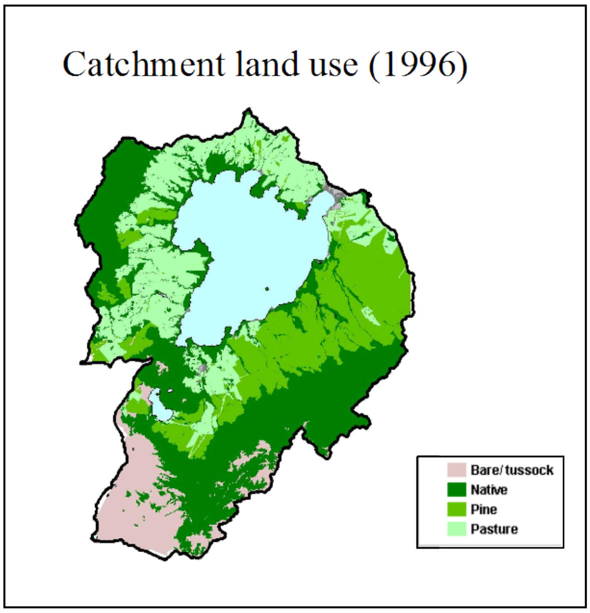
The table below shows cell counts for blue-green algae in samples collected from selected sites around Lake Taupo in summer 2003. Results are in cells/mL. The guideline value for contact recreation is 15,000 cells/mL. Results higher than the guideline are shown in bold. These results are provisional only. For more details contact us.

Date	Taupo	Motutere	Omori	Te Hapua	Whanganui	Kawakawa	Whakaipo
Mar 19	2,600	no data	no data	4,700	1,900	7,200	**69,000**
Mar 25	<500	<100	**18,900**	10,500	4,200	12,300	**15,600**
Apr 3	<1,000	<1,000	<1,000	<1,000	<1,000	1,600	1,400
Apr 14	<500	<500	<1,000	no data	no data	no data	<500

The Medical Officer of Health, Dr Phil Shoemack, advised that the health warnings for Lake Taupo have been lifted (April 17, 2003).

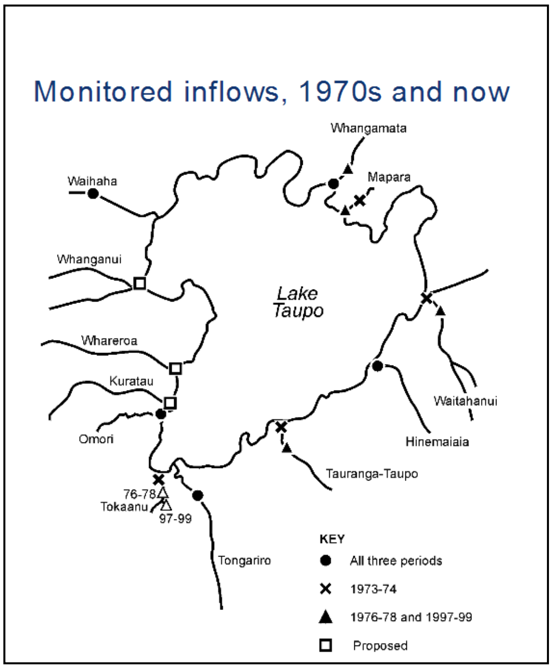
The magnitude of the bloom was such that Phil Shoemack who spoke yesterday issued a health warning for Whakaipo Bay at the north end of the lake and then later on Omori down in the south-west corner. So this was a real surprise to us, we didn't think we'd get blue-green algal blooms in Taupo.

So these are some of the other nuisance plants that we've had – here's the nitrogen-loving weed *Enteromorpha* (a green alga), washed up on beaches following high winds, and this weed causes a number of complaints as it decays.

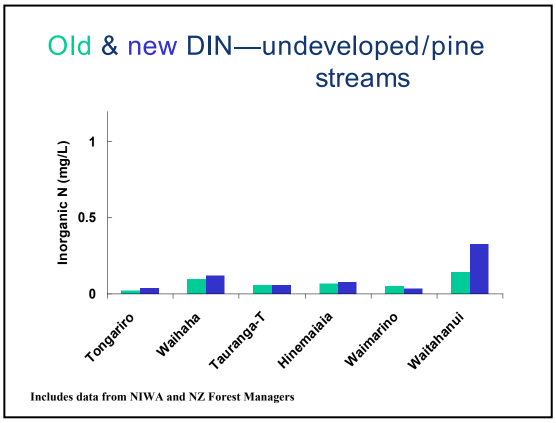


So that's a very quick overview of changes in the lake itself. I want to move on to changes in the catchment. This is a map showing roughly the land use in the catchment. Here's the National Park, with bush on this side, bush down here in the west, pine forest down the eastern side of the lake and areas of pasture on the western shores of the lake and across the north.

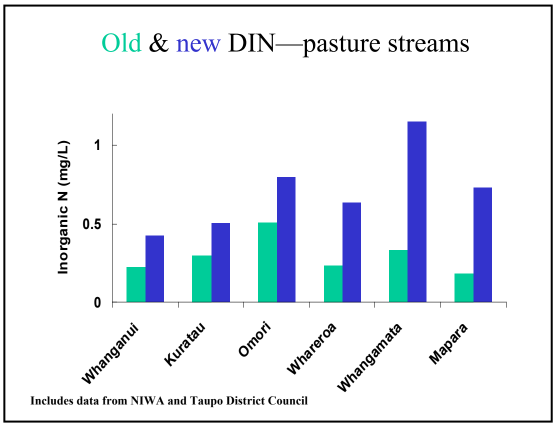
Now looking at information on some streams flowing down through those areas. These are a series of streams around the lake that were sampled by the DSIR lab based in Taupo in the 1970s, and for which we also have modern data. As you see, we've got streams in the pine area and the native forest and we've got streams draining the areas of pasture. So what do the results show us?

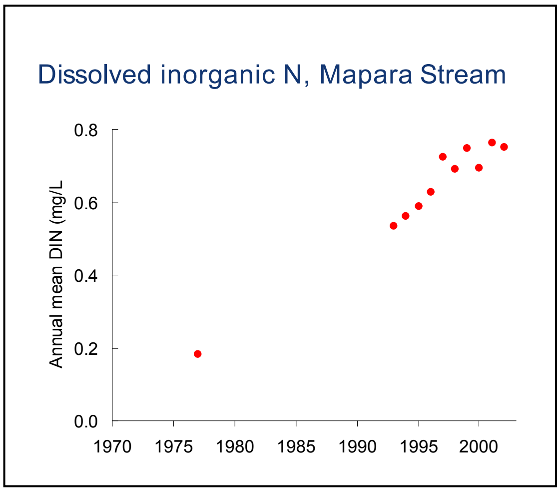


So, firstly looking at the results from the undeveloped or the pine streams. We've got six streams for which there's data. The green bars (pale) here show the average levels of inorganic nitrogen in those streams in the 1970s. The blue bars (dark) show the average levels in the same streams over the last 5 years. We have a few possible explanations as to what's happening here in the Waitahanui. I don't have time to go into them now but I'm happy to look at them later. But in most cases, the conclusion is there's been little change in the inorganic nitrogen level in the undeveloped or pine streams and that average levels are generally low.

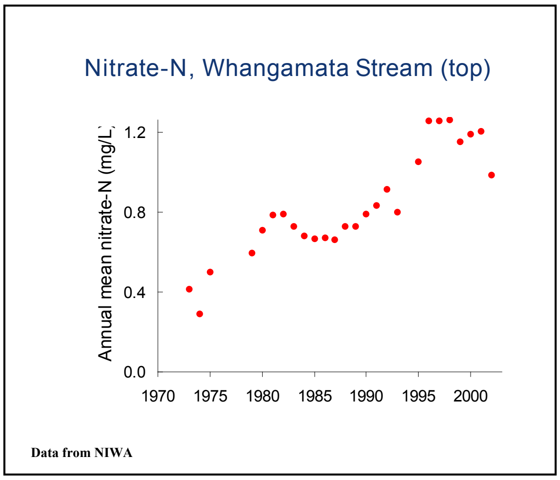


So contrast this with the information we have for streams draining areas of pasture. Concentrations are much higher than in the streams which drain pine and bush, and in each case concentrations have increased considerably since the 1970s. This is a Taupo version of the Rotorua streams that Kit Rutherford was telling us about before morning tea. There's been an increase in nitrogen concentrations over the past 20 or 30 years. The proportion of each of these streams catchment that's in pasture increases as we go across the graph. As you can see in the streams that have the highest level of pasture, the most dramatic change has occurred. So there's clearly a difference between streams draining areas of pasture and streams in the undeveloped parts of the catchment.



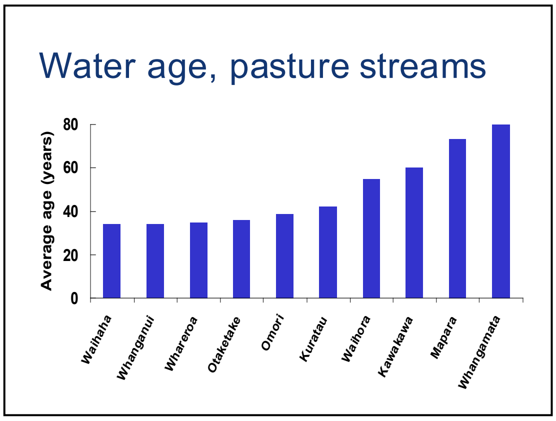


I want to now look a little bit more closely at the information for the Whangamata and Mapara Streams. This value for the Mapara Stream from the 1970s was Ministry of Works in their major study of Lake Taupo and this is Environment Waikato data. And you can see that over that 20 to 30 year period there's been a marked increase in the inorganic nitrogen levels in the stream.

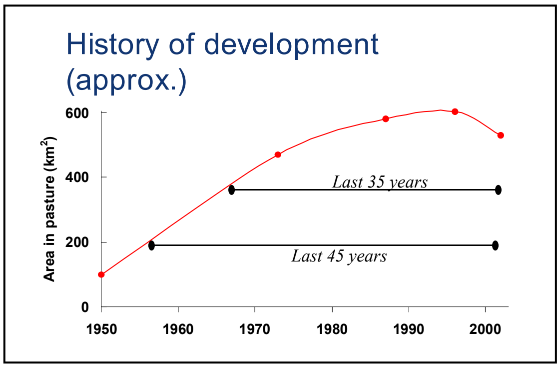


Data from NIWA

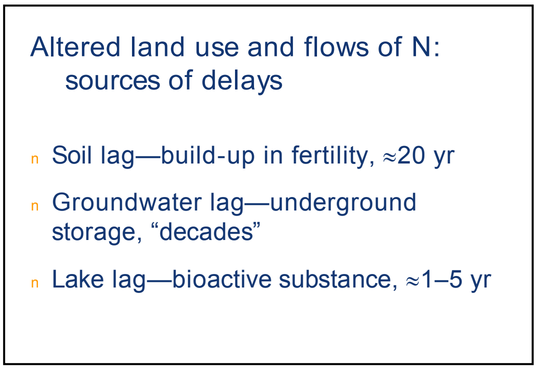
This is NIWA's data for the Whangamata Stream and it's an even more complete record and once again, there's a very striking increase. But in both of these streams we gather that there's been little change in the intensity of land use over that 20 or 30 year period. So despite there being no change in intensity of land use, we're seeing nitrogen levels go up. So what's happening in streams like this?

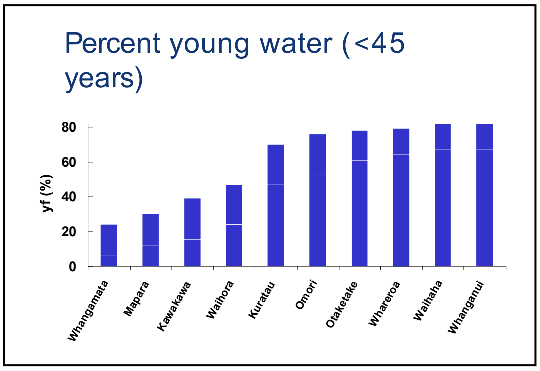


Kit Rutherford has already hinted at the answer. During the past couple of years Environment Waikato has been collecting samples of stream water in the catchment to have the age of the water determined. Now this is a fairly complicated process and I certainly haven't got time to go into the details, but the Institute of Geological & Nuclear Sciences in Wellington have developed a technique over the last 30 or 40 years for determining the age of water based on the amount of tritium that's present in it. Here's the information we have for the age of the water in 11 streams draining relatively large areas of pasture in the Taupo catchment.



So these were samples that we took from the mouth of the stream, sent them off to Wellington and the result came back saying this water is on average such and such years old. The youngest of the waters was about 34 years old on average and the oldest was about 80 years. I have to say right now that before I started doing this study, I had no idea that stream water could be decades old. There are things we're





starting to find out now that in the 80s we just didn’t give any thought to.

This is a graph (*previous page*) showing roughly the history of agricultural development in the Taupo catchment. In the 1950s there was a small amount of land in the catchment that had been developed and then there was a major land development phase in the 60s and 70s, tailing off over the last 20 years or so. And you can see that much of the agricultural development has occurred in the last 45 years.

So I’ve gone back to the stream water age information and asked what proportion of the water is young enough to have been affected by this agricultural development, particularly in the last 45 years. And that’s what we see on this graph. So here are the streams with relatively young water and in those streams about 80% of the water is young enough to have been affected by agricultural development. On the other hand those streams with very old water, Whangamata and Mapara, only about a quarter or a third of the water that’s currently flowing into the lake is young enough to have been affected by agricultural development. And of course what that means is even if nothing else happens, in streams like this as time goes on the clean predevelopment water that’s stored underground is going to be flushed out and replaced by newer water that’s been affected by agricultural development.

I’ve made some reasonably simple calculations based on quite a large number of assumptions, but they’re all stated assumptions, which show that given the land use we’ve had already, even if nothing else changes, then the nitrogen load to Lake Taupo from these streams – the nitrogen load that is already stored underground and has yet to come up – will increase the total load by somewhere between 20 and 40%. So even based on what’s happened in the past, there’s another 20 to 40% increase in nitrogen yet to come.

So in some of those streams like Whangamata and Mapara where I showed you there’s been a steady increase in nitrogen, my prediction is that those levels are going to continue to increase. I conclude then that means that for Mapara and Whangamata at least, it’s not surprising that nitrogen concentrations were relatively low when DSIR and Ministry of Works were collecting samples in the 1970s. Despite the appearance then when the scientists were out collecting their samples, of a developed catchment (one that was in agriculture) most of the water in the stream was old and unaffected water that had been stored out of sight underground.

Now of course once we have information like this and then we start to think back, we might ask when should we have anticipated this coming? I've looked through and found some indications that people were alert to possibilities. When DSIR’s Taupo book came out in 1983 they made quite a straightforward prediction then that intensified use of land

Other "early warnings"

- "intensified use of land … will inevitably lead to increased losses of nutrients to … Lake Taupo"
  DSIR 1983
- "in a similar volcanic region … groundwater residence times of more than 15 years have been reported"
  MWD 1981

will inevitably lead to increased losses of nutrients to Lake Taupo. For 20 years scientists have been telling us there's a land use and water quality issue to manage. The Ministry of Works in 1981 said that in a similar volcanic region, and, by the way, they were referring to Rotorua, ground water residence times of more than 15 years have been reported. The DSIR was doing water aging studies in the 1970s that when we now look back at it had the answer hidden in here – this old water, clean water story that I've been telling you.

Lessons—useful information for lake managers

- Knowledge of soil & aquifer processes and time scales
- Stream water ages
- Timeseries of stream water quality in developing areas
- Catchment & lake models for "what if?" scenarios

So now that we've got these new ways of looking at the world, let me share with you what I think are some of the lessons from this for lake managers. Managers in a system like Lake Taupo and, indeed, I think, in a number of the Rotorua lakes where the geology, I imagine, is quite similar. One of the things I think lake managers need to understand is soil and aquifer (that's underground water) processes. And like I said, I am willing to admit that until quite recently my understanding of these things was quite limited.

Clearly I'm an advocate now for knowing stream water ages. We need to know how old this water is that we're taking nutrient samples of, and we've been able to do this for at least the last 30 years. It's also clear from the work that Kit showed for the Rotorua area and what I showed for Mapara and Whangamata, that it's very useful to have long-term records of nutrient concentrations in the streams flowing into these systems. And yes, I am convinced that there is a definite role for modelling, both catchment modelling and lake modelling, to answer the 'what if' scenarios.

But you'll notice that this list doesn't mention anything about monitoring of lake water quality. It's becoming clear that by the time we see deterioration in the lake itself, the processes responsible for this deterioration are likely to be firmly bedded in.

QUESTIONS

Rowland Burdon, Royal Society of New Zealand, Rotorua branch: In contrast to what Kit Rutherford said that both phosphorus and nitrogen need to be managed, I note that neither of the speakers have said a word about phosphorus and that seems particularly interesting in view of the fact that Bill reported *Anabaena* blooms which are nitrogen fixing, having blown up in the last few years. Would they like to comment on the lack of mention of phosphorus?

B.V.: Back in 1970/1980s the DSIR lab demonstrated that as with many of the lakes in the central organic plateau, Lake Taupo was nitrogen-limited. Now we had that work

repeated 2 years ago, NIWA have confirmed that Lake Taupo is still nitrogen-limited. So nitrogen has been our major focus. Having said that, I think all of us would agree that in many cases the land management activities that we do to manage levels of nitrogen will probably also contain levels of phosphorus. Now I certainly take your point about blue-green algae being nitrogen-fixing. Of course we don't know whether they were nitrogen-fixing in Lake Taupo, but to me I think there's a larger scientific question and that is, what are they doing blooming in Lake Taupo at all? The phosphorus levels are way below the levels at which the Australians regard blue-green algal blooms as being likely in lakes. I think there's something unusual happening with blue-green ecology in that system.

David Stirling, ESR: Bill you might be interested to know that when I went to Australia some years ago and talked about blue-green algae there, they talked about slow uptake of phosphorus by cells of cyanobacteria that allowed them to undertake 16 cell divisions in the absence of phosphorus in the water. So you can get blooms when you don't have phosphorus.

B.V.: That's true – that's what we call luxury phosphorus uptake and yes, it is well recognised. Presumably that is what is actually going on in this situation.

For those of you who were at the Symposium in 2001, when Rod Oliver, one of the international experts on blue-green algal ecology, was here, you might recall he had a spreadsheet up on the screen which showed when blue-green algae were likely to be of concern. And I made a comment at the time that his starting point on that spreadsheet or that decision tree was: is your total phosphorus concentration greater than 10 parts per billion? And if it was, then you went in this decision tree about whether blue-green algal problems were likely. The total phosphorus concentration in Taupo is 5. Now Rod Oliver is as surprised as anybody that we're getting blue-green algal blooms in a very low phosphorus situation like that. Notwithstanding luxury uptake of phosphorus. And by the way, we can never find dissolved phosphorus in the water in Lake Taupo when we look for it. There just doesn't seem to be any there for any luxury uptake.

David Hamilton, University of Waikato: Bill, I just wondered whether Rod's analysis might have been slightly biased by the fact that they don't have such large lakes in Australia and in particular, if you consider the buoyancy of blue-green algae particularly under calm conditions. In Lake Taupo you effectively have about 35 metres or so where the water column is generally mixed from the surface and you congregate that up into perhaps a centimetre, which is typical of blooms. That's I guess a 350-fold increase. And then you just happen to have a light wind that pushes it into an embayment, then really that may be the mitigating factor in comparing Rod's analysis with what you're actually seeing.

B.V.: Yes, I agree.

Tawiri Hakopa, Taupo: Bill, you mentioned that *Anabaena* has been present in Lake Taupo for at least 40 years. Can you give us some idea as to why the presence of *Anabaena* has been brought to bear in the last 2 or 3 years?

B.V.: No I can't and that's a puzzle. I don't know the answer. NIWA, who I've spoken to, don't know the answer either.

Chris Hendy, University of Waikato: I have two related questions. The first one is following on from Bill's address and I was a little bit concerned that perhaps you are suggesting that we should cease to monitor the lakes?

B.V.: Well, no, I'm being provocative.

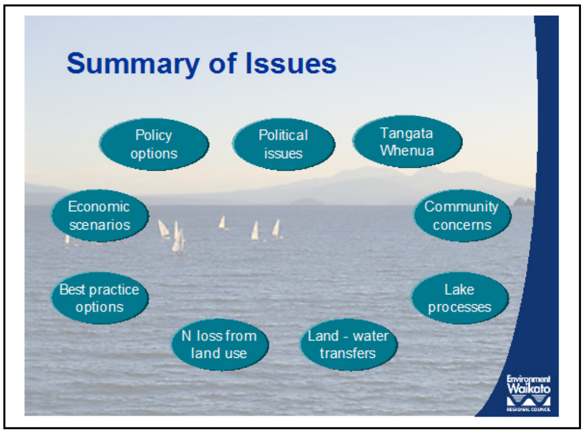
C.H.: Okay, then my next question goes back to the groundwater problem. You are obviously monitoring the streams, but I am also concerned about how much of the groundwater makes its way into the lake without the luxury of going through a stream at all and whether we should be looking at monitoring bores to get a better idea of what our groundwater composition and age and flow rate.

B.V.: I'm sure John Hadfield will be happy to go into great detail with you later on about what we're doing in groundwater, but just on that issue of how much nutrient gets into the lake totally hidden, never reaching a stream. I don't think we're ever going to get the real answer because all of these calculations are done by difference, we measure the amount of water going out of the lake in the surface outflows and comparing it with what we think is going in the inflows, and we say the difference must be the hidden underground water. But of course when you're doing calculations by difference, there's huge possibility for errors. I don't think we're ever going to really know, but there are a lot of estimates around. 10% would be the current best guess.

Managing water quality of Lake Taupo

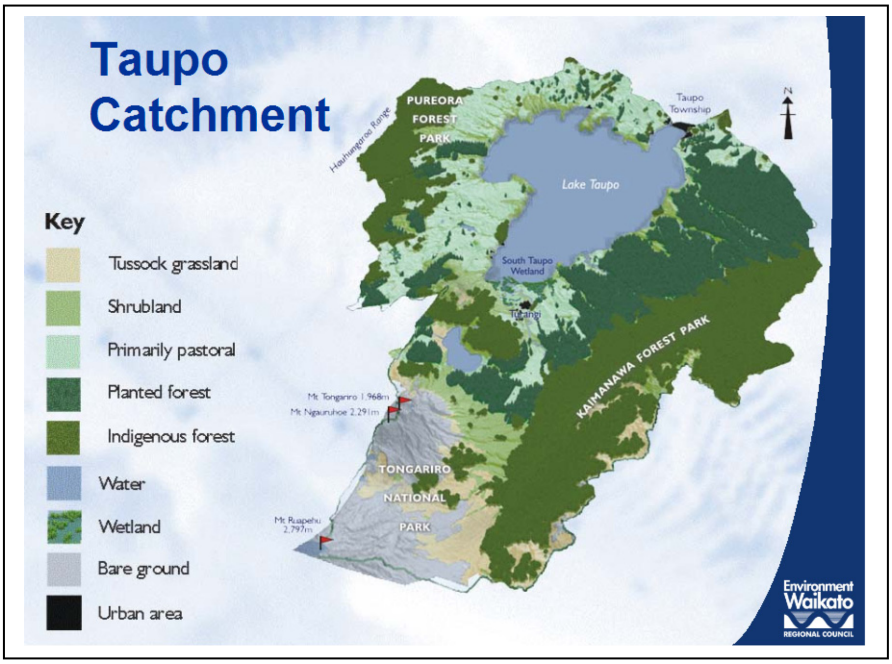
Tony Petch, Justine Young, Tony Fenton and Bill Vant,
Environment Waikato, P.O. 4010, Hamilton East, New Zealand,

Lake Taupo is one of the great lakes of New Zealand. It is a significant tourist icon known for its dramatic vistas, deep, clear, crystal blue waters, superb trout fishery and volcanic heritage. The lake is culturally and spiritually important to all New Zealanders and is a taonga of Ngati Tuwharetoa. The results of human activity in the lake's catchment in the last fifty years have caused an increase in the nitrogen entering the Lake through ground water and rivers. Nitrogen entering the lake promotes algal and phytoplankton growth and threatens water clarity. Nitrogen also encourages some types of nuisance weeds and slimes to grow adjacent to lake shore settlements.

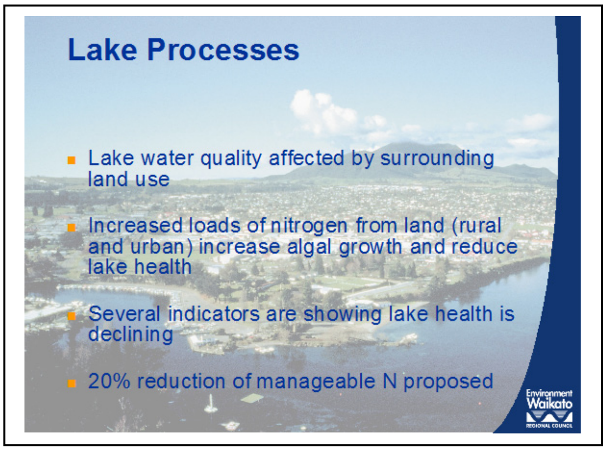


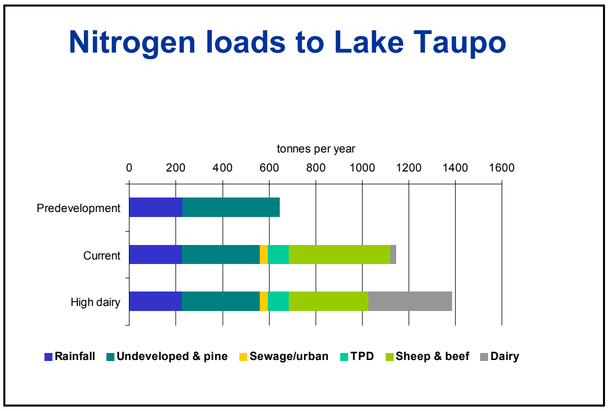
The management issue we face is challenging. Either the lake's value to local, regional and national communities will diminish or we must find new ways of managing the surrounding land so that the health of the lake and the economic and social health of the local community are sustained.

Environment Waikato is leading a project called 'Protecting Lake Taupo'. The project aims to maintain the current health of the lake by reducing the manageable sources of nitrogen from urban and pastoral activities in the catchment by 20 per cent. Urban runoff and sewage inputs amount to just 3 per cent of the combined load of nitrogen to the lake, while loads from pastoral agriculture contribute 35 to 40 per cent.



Managing the agricultural loads will require new approaches.

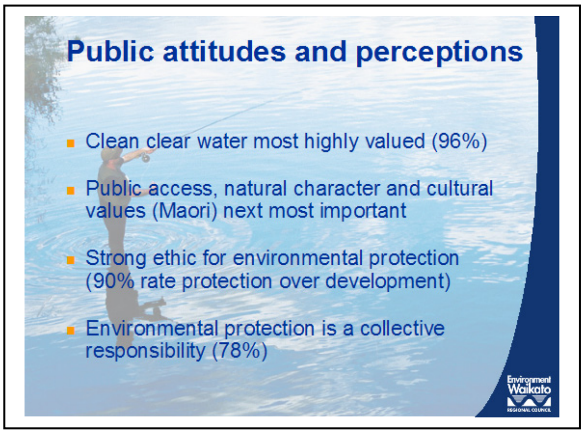


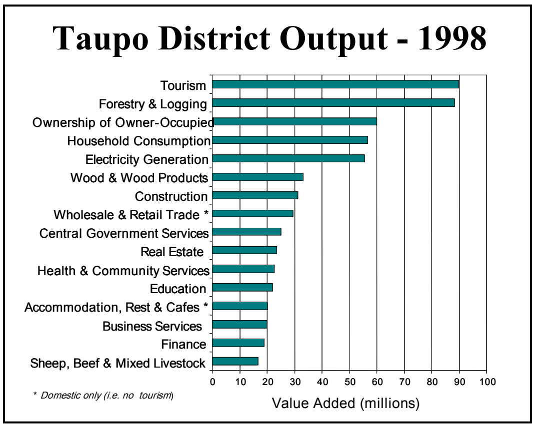


To achieve the change to more sustainable land use in the catchment, Environment Waikato, Tuwharetoa Maori Trust Board, Taupo District Council, and Central Government are working with affected landowners on actions that include:

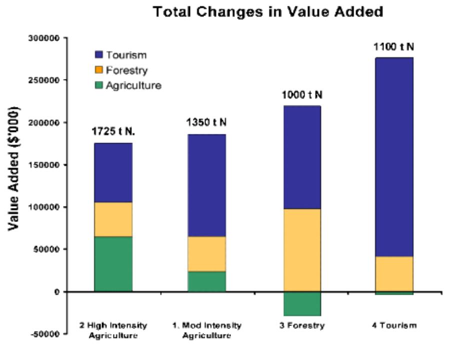
- reducing nitrogen discharged from urban areas by improved performance of sewerage and storm water systems,
- increasing the amount of forestry or other low nitrogen land use in the catchment,
- undertaking research and development of profitable low nitrogen pastoral systems and alternative land uses,
- supporting all of these actions by information, education and regulation, including consents for pastoral systems that limit the nitrogen emissions from farms.

The project combines the application of science, community consultation and participation and the use of regulation and non-regulatory methods to achieve change. The project causes the community to confront difficult issues and make change - to ensure a clean lake, a productive economy and a vibrant community.





Macroeconomic scenarios
1998-2030



On farm economic impacts
20% less N from pasture

- Some sheep and beef farms uneconomic
- Dairy farms marginally economic
- Land values blighted
- Lost opportunity valued between $112 and $175 million over next 10 y

Consultation

- Community groups, farmers, Government - local, regional & national
- Ngati Tuwharetoa
- Taupo Lake Care
- Support for action is widespread
- Public debate focused on landowner uncertainty

Achieving change
20% less N from urban & pasture areas

- New N stripping technologies for future subdivisions
- Upgrades to existing septic tanks and community sewage schemes
- New farm management systems to reduce N leaching

Achieving change
20% less N

- Increased area of low N leaching land use (forestry, new horticultural crops, forage harvesting)
- Change the way we view the use of land
- Very high standards are required for this catchment
- Recognise that *'no one is volunteering to go broke'*

Achieving change
a way forward

- Solution requires regulatory and non regulatory approach
- Financial assistance will help make the change
- Recognition of a sustainable development pathway
- Partnership - Government, Tuwharetoa, Taupo District Council, Environment Waikato

Achieving change
Proposal for community discussion

- Assistance to purchase or lease land and convert to low N land uses
- Assistance for research on new farm systems, land uses and markets
- Partnership (Tuwharetoa, community and local and central Government)
- Enhanced recreation and tourism
- Regulations - cap on N emissions from urban and rural sources

Achieving change
summary

- All share the burden of change
- Sustainable development pathway identified
- Community's social, economic, cultural and spiritual needs met
- Time to make changes

QUESTIONS

Chayne Zinsli, CHH Forests: You talked about regulation and capping emissions. Is that a cap across all land uses or is it specific to different caps at different levels for different land uses?

T.P.: The way we're imagining is capping at the current emissions from each land use. The foresters are currently having a discussion about the equity of that, because they are the lowest emitters, and a cap of course means that they cannot use their land in other ways because most other land uses would have a higher nitrogen emission. It does bring up the issue of nitrogen trading, which is not specifically excluded at all. So the current proposal is for capping at the current levels and the main reason for that is that it is actually the point of least societal change. People can carry on doing what they're doing. If we start saying "let's everybody have the average", then we have, potentially, windfall transfers to those who are emitting low amounts of nitrogen and then the requirement for those who are emitting high amounts of nitrogen to somehow buy back or obtain extra nitrogen credits, if you like. So that creates a greater societal change than to say, "okay let's accept what we are currently doing", and in that way the foresters contribute a little by foregoing some development opportunities. Farmers forego a little because they're foregoing future development opportunities, the urban areas have to continue to decrease their nitrogen emissions, so everybody is sharing a little bit. It's an interesting debate and one that hasn't finished yet.

Lake Rotoiti water quality: the role of the Lake Rotorua water underflow

Max Gibbs, Ian Hawes: *NIWA, PO Box 11-115, Hamilton*
David Hamilton: *Department of Biological Sciences, University of Waikato, Hamilton*

ABSTRACT:
Water quality of Lake Rotoiti is degraded and the algal blooms of the last few years place it firmly on the trophic classification scale as "eutrophic". A 1982 study to understand the cause of this degradation found that part of the nutrient load of Lake Rotoiti came from nutrient-rich Lake Rotorua water. This input is from the Ohau Channel inflow, which at times enters as a density current or "underflow" into the bottom waters of the lake. The underflow condition occurred for about 60% of the year, and replaced 25% of the volume of Lake Rotoiti annually. While the underflow was found to contribute 64% and 31% of the phosphorus and nitrogen input respectively to Lake Rotoiti, it also carried dissolved oxygen into the bottom waters of the lake and is therefore fundamental to the present dynamic equilibrium.

The importance of the hydraulic coupling between Lake Rotorua and Lake Rotoiti was clear. Either an improvement in the quality of water entering Lake Rotoiti via the Ohau Channel, or diversion of the Ohau Channel away from the lake would reduce nutrient loading to the lake. However, computer models also showed that diversion of the Ohau Channel and, consequently, oxygen in the underflow, would probably have very severe short- to medium-term (decades) effects on Lake Rotoiti water quality.

Comparison of data from 1981-82 with present data suggests that the continuing decline in water quality has not been as rapid as might have been expected from the trends seen before the 1980s. In this presentation, we show that trophic state indicators, including phytoplankton biomass, water clarity, hypolimnetic rates of oxygen depletion and nutrient transformation appear to have changed only gradually since the 1980s. Diversion of the Ohau Channel into the Kaituna River is now being considered as an engineering solution to the current water quality problem in Lake Rotoiti. The predicted consequences of this option remain the same as in 1982; potential reduction in oxygenation of the hypolimnion and, therefore, increased internal loading of nutrients.

A study in 1991 looking at the factors affecting the quality of water in the Ohau Channel, found that a large part of the nutrient and organic load to Lake Rotoiti came from wind-induced disturbance of the shallow sediments immediately adjacent to the entrance to the Ohau Channel. Recent work suggests that temporary stratification events in Lake Rotorua may also increase nutrient loads to Lake Rotoiti. This information may offer alternate management options to improve the quality of water entering Lake Rotoiti, without the potentially severe adverse effects predicted for complete diversion of the Ohau Channel.

INTRODUCTION:

Good morning ladies and gentlemen. I am one of the science providers who have been providing data for a number of organisations. I have been working on the Lake Rotoiti project since 1981 and today my role is to provide the information for everybody to have a look at, with some extra thoughts on the situations as they've developed.

Lake Rotoiti, in the central volcanic plateau of the North Island of New Zealand, has received much media attention in recent months, highlighting the poor water quality and extensive blue-green algal blooms that occurred in this lake last summer. Data presented in an earlier presentation by David Hamilton showed that the bottom water oxygen levels have declined since the earliest measurements in the 1950s, when they remained oxygenated throughout the year, to the present when, in summer, the bottom waters are devoid of oxygen. The cause of the deterioration in water quality is generally attributed to nutrient enrichment. The single largest nutrient input to Lake Rotoiti is the inflow of eutrophic water from Lake Rotorua via the Ohau Channel.

While the Ohau Channel discharges into the western basin of Lake Rotoiti about 2.5 km from the Kaituna River outlet, and would normally be expected to by-pass the rest of the lake on its way to the outlet, it is known that for about 60% of the year, that water underflows carrying eutrophic Lake Rotorua water deep into the eastern end of Lake Rotoiti.

When the underflow condition was first reported in the 1980s, there was a call to divert the Ohau Channel inflow directly to the Kaituna River outlet as a management strategy to restore the water quality of Lake Rotoiti. Although this would seem a simple solution, the consequences were predicted to produce a very severe deterioration in lake water quality in the short to medium-term (tens of years) before the water quality eventually improved (Vincent & Gibbs 1987). The recommended long-term strategy was to improve the water quality of Lake Rotorua. Since then considerable efforts have been made to do that.

However, following the recent blue-green algal blooms, diversion of the underflow to the Kaituna River is being considered once more.

Although the concept of underflow sounds simple, it is a very complex process and one which has operated between Lake Rotorua and Lake Rotoiti for hundreds of years. In this paper, we describe the Lake Rotorua water underflow and present our current understanding of this remarkable hydraulic coupling between these two lakes. We will look at the evidence for deterioration of Lake Rotoiti water quality, and compare data collected in 1981 with similar data collected in 2001 to look at the changes that have occurred in the last 20 years. We will also present some data on the quality of the water passing through the Ohau Channel, and conclude with some new thoughts on the role of the Lake Rotorua water underflow.

UNDERFLOW:

Underflow is a condition where a slightly denser body of water moves beneath a less dense water mass. Commonly, this occurs when denser saline water moves upstream as a salt wedge beneath the freshwater in an estuary on the rising tide. In freshwater systems, density differences can also be induced by temperature with colder water sinking below warmer water. This happens in the Lake Rotorua – Lake Rotoiti situation. Being a

shallow lake, Lake Rotorua heats and cools faster than the deeper Lake Rotoiti. In winter, the colder water from Lake Rotorua is denser than Lake Rotoiti water and it plunges as an underflow to the lake bed as it enters the western basin, and flows down the drowned river bed into the bottom of the eastern end of the lake. However, because the Lake Rotorua water enters Lake Rotoiti as a jet over a sudden steep drop-off, it entrains surface water from the western basin into that flow. Consequently, although there is only 15 $m^3. s^{-1}$ of Lake Rotorua water entering Lake Rotoiti, the density current moving into the eastern basin has a flow volume of about 70 $m^3 s^{-1}$. This volume was determined in the 1980s with a dye tracer study and current meter measurements.

The period of underflow was determined by measuring the temperature difference between the Ohau Channel water and at a depth of 5m in the western basin (Fig. 1). The results showed almost continuous underflow occurred between March and October with occasional underflow events in November and February associated with cold snaps.

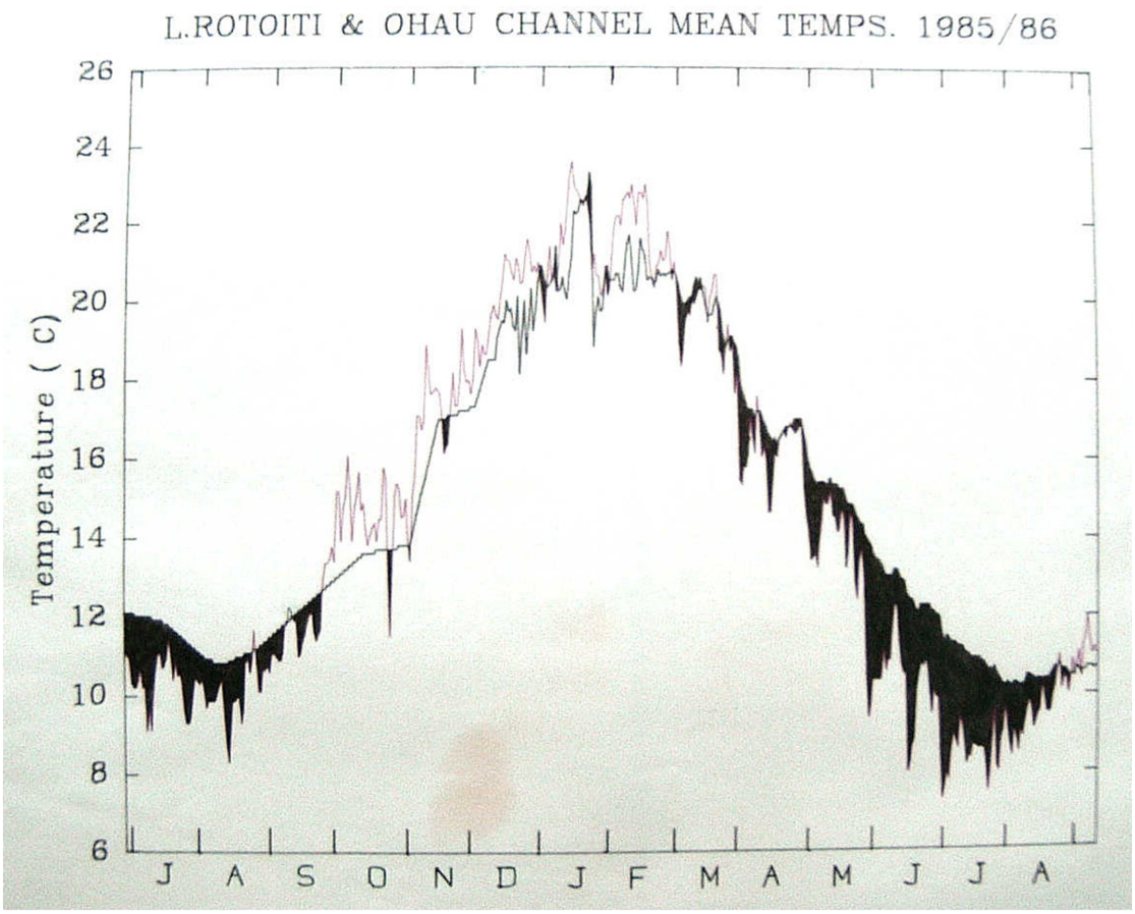


Fig. 1 Temperature differential between the Ohau Channel (dark line) and the western basin of Lake Rotoiti at 5 m depth (data averaged at 6-hr intervals). The shaded portion between the lines indicates periods of underflow. Underflow is essentially continuous between March and October. The 1985/86 data is the only time this feature has been measured.

During summer, the warmer water from Lake Rotorua flows across the surface of the western basin of Lake Rotoiti as an overflow and moves almost directly to the Kaituna River outlet. Dye studies in the 1980s demonstrated that the Lake Rotorua water remained as a discrete flow through most of that journey.

Table 1 gives a summary of the effects of underflow as found in the 1980s.

Table 1:	**Summary of Underflow effects** (TRL) data
Period	225 days (60% of year)
Timing	March through to October
Volume	25% of Lake Rotoiti each year
Residence Time	2.4 years (6.3 years without underflow)
Nutrient input	31% N 64% P
Oxygen transport	50-60 tonnes per day

The oxygen transport into the eastern basin of Lake Rotoiti in the underflowing density current is of key importance to the water quality of the lake. In 1981 it almost exactly balanced the estimated 50 tonnes per day oxygen demand in the lake. The loss of that oxygen input would dramatically change the chemistry of the lake and is the basis of the prediction of a rapid decline in water quality following diversion of the underflow to the Kaituna River outlet.

COMPARISON OF WATER QUALITY DATA

Although the general public opinion is that the water quality of Lake Rotoiti has rapidly deteriorated in recent years, the Environment Bay of Plenty (EBoP) monitoring data report (Gibbons-Davies 2003) when talking about the water quality of Lake Rotoiti states "The quality has stabilised from 1991 to 2002, and removal of Rotorua sewage effluent discharge to Lake Rotorua could have been effective in halting the decline".

Oxygen depletion rates in the bottom waters of Lake Rotoiti can be used as an indicator of change comparable over a much longer period (Fig. 2). These data suggest a statistically significant ($p < 0.01$, $r^2 > 0.9$) increase in oxygen depletion rates indicating deteriorating water quality from the 1950s through to about 1986. However, since 1986 there appears to have been a slight, but non-statistically significant, reduction in the oxygen depletion rate. This is consistent with the 2003 EBoP report conclusion. There is greater inter-annual variability in that annual oxygen depletion rate during the last 15 years, which may simply reflect the paucity of good monitoring data on which to base the annual estimate in the last 15-20 years, or a lack of contiguous data to show the degree of interannual variability before that.

Of particular interest is that the decline in water quality slowed about the time restoration measures, such as phosphorus-stripping, were implemented in Lake Rotorua. This again is consistent with an earlier presentation of data by Kit Rutherford.

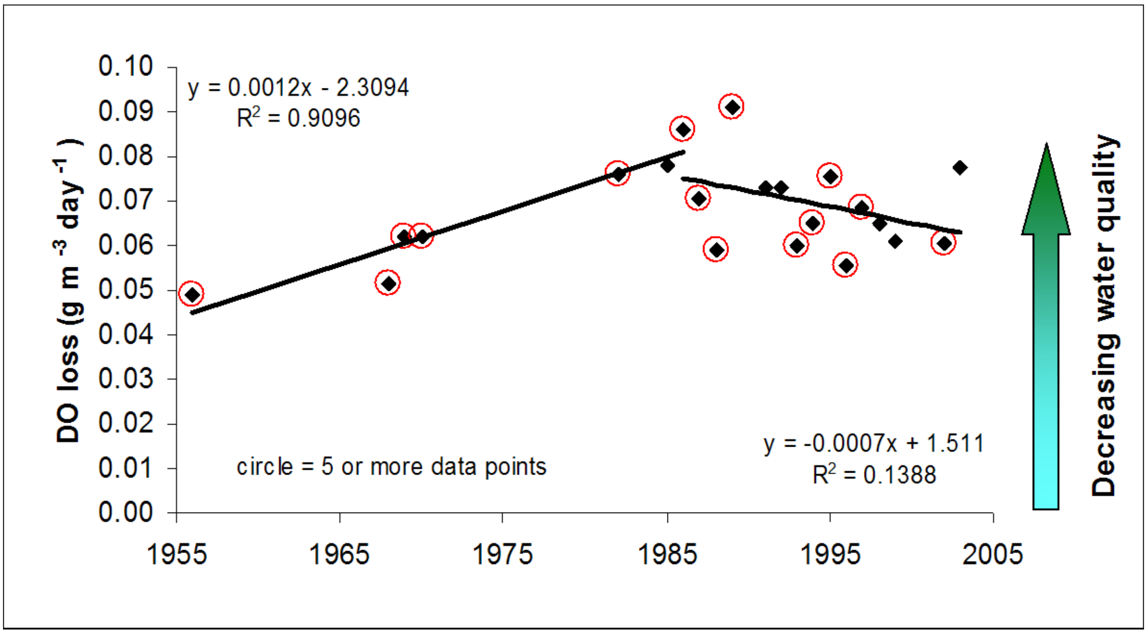


Fig. 2 Oxygen depletion rates in the bottom waters of Lake Rotoiti. Values given are regression slopes of the oxygen decline at 60 m depth during the annual stratified period between October and March but do not include any period where the oxygen has reduced to zero. Circled data are regressions which use 5 or more points and are therefore considered to be more robust. All individual regressions had $r^2 > 0.95$.

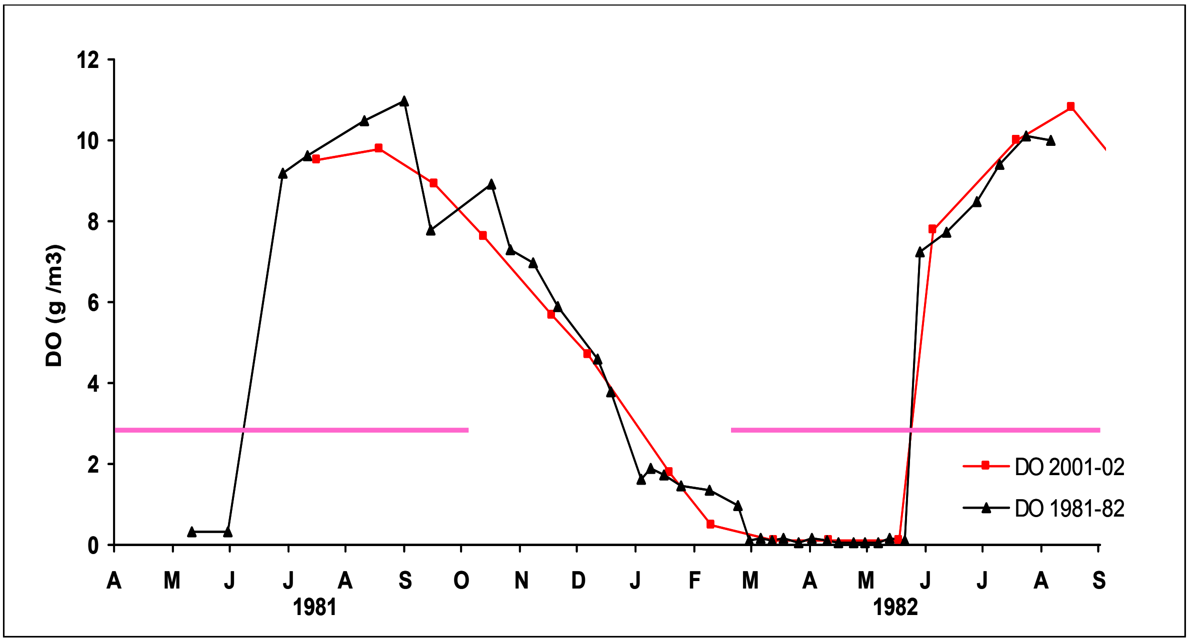


Fig. 3 Seasonal bottom water oxygen depletion in Lake Rotoiti in 1981/82 and 2001/02. The horizontal line indicates the period of permanent underflow.

Oxygen depletion is measured in the bottom waters, and a comparison of lake temperature structure in 1981-82 and 2001-02, years when measurements where taken sufficiently frequently to allow confident comparisons to be made, leads us to believe that there has been no major change in the either the period of seasonal stratification or the

thickness of the upper oxygenated water column in the last 20 years. A comparison of the seasonal cycle of oxygen depletion for these years (Fig. 3) shows that there has been no apparent change in the rate of that depletion or the timing. The solid bars indicate the period of underflow, as measured in 1985-86. Similar comparisons of nutrient data also show little or no apparent change, e.g. total phosphorus and even ammoniacal nitrogen.

How does this effect the 1980s prediction? If there has been no apparent change in water quality since the 1980s, then there is no reason to suggest any change in the prediction of the consequences of diverting the Ohau Channel water to the Kaituna River outlet.

While the accepted measures of assessing water quality show no change, public perception is one of rapid change. This apparent contradiction may be explained by a change in the algal species in the lake. A comparison of algal biomass, as indicated by chlorophyll *a* concentrations, shows a much greater amount of algae in the 1981-82 period than in 2001-02. In spring 1981, the biomass was mostly diatoms which disperse through the water column and quickly sink in calm conditions, while last spring (2002) the biomass comprised mostly blue-green species which float to the surface as a scum in calm conditions. This gives the lake the visual appearance of a much poorer condition than the other water quality measures indicate.

However, has there been a change in algal species composition? There is insufficient data to draw that conclusion and a paper by Noel Burns in 1999 would suggest that the trend is towards diatoms rather than blue-green algal dominance.

WATER QUALITY IN THE OHAU CHANNEL

A study in 1990 investigated the quality of the water passing through the Ohau Channel. It was found that this was effected by wind disturbance of the sediments across the shallow shelf near the entrance of the Ohau Channel in Lake Rotorua. The difference between calm and windy conditions is very obvious close to shore near the Ohau Channel entrance (Fig. 4A). The suspended solids and nutrient concentrations are substantially increased within 200 m from shore where they may be drawn into the Ohau Channel. Consequently, the sediment and nutrient load passing through the Ohau Channel increases in direct proportion to the on-shore wind speed (Fig. 4B). These observations show that most of the total phosphorus and total nitrogen passing through the Ohau Channel is not readily biologically available for plant growth and requires to be processed microbially in the lake sediments before it can be used.

If the Ohau Channel water came from further off-shore, the nutrient load transported into Lake Rotoiti might be less.

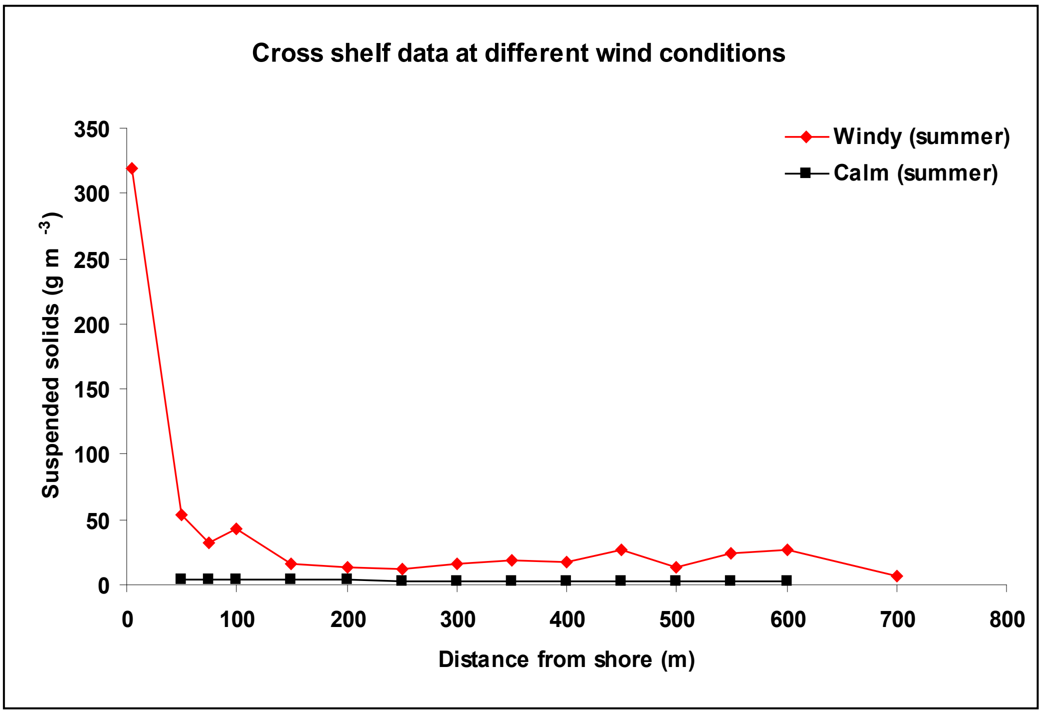


Fig. 4A Suspended solids concentrations versus distance from shore across the shallow shelf adjacent to the Ohau Channel under calm and strong wind conditions in summer. [Data made available by Department of Conservation].

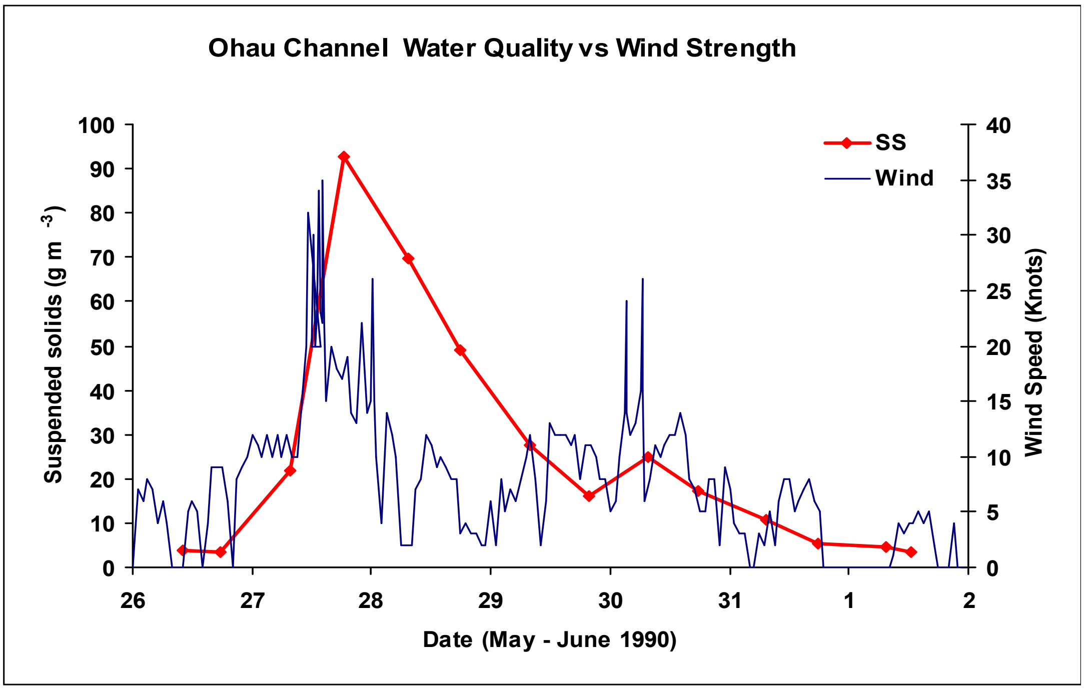


Fig. 4B Suspended solids (SS) concentrations in the Ohau Channel versus onshore wind speed in winter. The increase in SS concentration is attributed to the wind-induced sediment disturbance across the shallow shelf adjacent to the Ohau Channel entrance (Fig. 4A). [Data made available by Department of Conservation].

Although this data suggests that more material will be transported into the eastern basin of Lake Rotoiti by the underflow in windy than calm conditions, the amount transported is dependent on the velocity of the flow. It requires a velocity of more than 20 cm s^{-1} to keep this material suspended in the water column. As the flow velocity through the Ohau Channel is higher than this, once in the Ohau Channel that material will pass through to the western basin of Lake Rotoiti. There the "still" waters allow that material to settle to the lake bed. Consequently, almost all of the material from Lake Rotorua sediments in the western basin of Lake Rotoiti and is unlikely to reach the eastern basin of the lake, or the Kaituna River, although there is no data to confirm this.

Of particular significance is that, because underflow doesn't occur during summer, a summer algal bloom from Lake Rotorua will eventually migrate through the Ohau Channel and become concentrated in the western basin of Lake Rotoiti. As the latter has a much smaller volume, this magnifies the effect of that bloom, especially if it is a blue-green algal bloom that forms a surface scum.

A feature of blue-green algae is that they can fix or use atmospheric nitrogen for growth. To do this is energy intensive and the growth rate is slow. If we consider the residence time of water in the western basin with and without the circulation induced by the underflow density current (~70 m^3 s^{-1}), there is a marked difference at about 2 days with underflow and more than 30 days without. As 2 days is likely to be faster than the growth rate of the blue-green algae, this circulation current may prevent or delay the development of a bloom. Consequently, it may be no coincidence that blue-green algal blooms develop soon after the underflow stops in October. They also usually disappear soon after underflow restarts in autumn.

Last autumn was an exception, however, with the bloom still present in May. This can be put into context that most lakes in the central volcanic plateau, including Lake Taupo, developed blue-green algal blooms in the 2002-03 summer. Such a wide-ranging event encompassing so many lakes suggests an odd year "event" possibly due to local regional climatic conditions, rather than a sudden deterioration in the water quality of Lake Rotoiti.

THE BOTTOM LINE

The role of the underflow is:

- Transportation of oxygen and nutrients into the bottom of Lake Rotoiti. The oxygen input delays the onset of bottom water oxygen depletion in spring and oxidises the H_2S accumulation in the bottom waters in autumn before winter mixing;
- To maintain the present biogeochemical equilibrium of the lake;
- Displacement of surface water and the algal material in it from the eastern end of the lake to the western end where part of the circulation current (~20 m^3 s^{-1}) is skimmed off to the natural outlet, the Kaituna River;
- Maintenance of the very large circulation current (~70 m^3 s^{-1}) through the lake from autumn through to spring which may deter the growth of blue-green algae.

There are some big gaps in our understanding, that have previously been assumed:

- How much of the material entering the western basin of Lake Rotoiti is actually moved either into the main eastern basin of the lake or to the Kaituna River outlet?

- Has there really been a change in algal species dominance from diatoms to blue-green algal species ?
- Were the blue-green algal blooms of last year a sign of rapidly deteriorating water quality ?
- or was last summer just an odd year in the gradual recovery as indicated in the long-term oxygen depletion data (Fig. 2)?

QUESTIONS

Noel Burns, Lakes Consulting: I recently did a contract on Lake Pupuke which is similar in some ways to Lake Rotoiti. It stratifies for about 10 months of the year, the volume is very anoxic. It generates a huge amount of phosphorus and nitrogen. It also, as David Hamilton mentioned yesterday, I think (we haven't got the data) generates a large amount of manganese and iron. The finding that I have surprised me. The lake contained a maximum of phosphorus in August, but in October the lake contained a lesser amount of phosphorus for the whole period. What had happened is postulation that the manganese and iron oxidised, precipitated and scavenged out the phosphorus. Now I'm wondering if this process would happen in Rotoiti and to what degree. It might be a way of diminishing these effects.

M.G.: I'm not sure whether it's a management strategy for a lake of this size and yes, oxygen is scavenged by iron and manganese. In fact if you have a diver collect material from the top of the Champtaloup bank (*a bank rising to c. 20 m depth in the western part of the Eastern Basin of Rotoiti – Ed.*), you'll find there are manganese nodules on the top of it or down the sides of it at the boundary between the oxygen and anoxic water. When you look at the release of phosphorus into the water column in the bottom waters of Lake Rotoiti, the phosphorus begins to release at an oxygen concentration of around about 5 to 6 grams per cubic metre, which is well above anoxia. Manganese actually mobilises at about 3 ppm oxygen, not 5-6 ppm, and iron mobilises at 2 ppm. The observation that phosphorus appears to increase in the water column at 5-6 ppm oxygen is correct but the cause is therefore anomalous.

Additional note of clarification from Max Gibbs:
Since then I have had a much closer look at the relationship between oxygen concentration and phosphorus release in Lake Rotoiti. While I stand by the REDOX relationship between water column oxygen concentrations and the relative mobilisation DO concentrations for Manganese (~3ppm) and Iron (~2ppm), I have failed to find a substantial change in the rate of increase of phosphorus in the lower water column as oxygen depletion progresses through these Redox threshold points to anoxia.

Consequently, I believe the amount of phosphorus released by the mineralisation of Manganese and Iron is probably very small relative to the amount released associated with microbial decomposition in the sediments. This is entirely consistent with the expectation of lakes in the Rotorua area where iron and manganese are only a very small component of the mainly diatomaceous sediments.

The "oxygen effect" may be a critical issue in determining the internal P budget for Lake Rotoiti. It is something that needs urgent investigation - not only because it is an anomaly but also because it could have an impact on management decisions for the Rotorua Lakes.

Nick Miller, LWQS: Noel, in the paper you gave at the 2001 Symposium, amongst the data I noticed that Lake Rotorua and Rotoiti are both believed to be warming due to climatic changes, but Rotorua seemed to be warming at a different rate – I think it was faster, but I'm sure you'll correct me if I'm wrong – than Rotoiti is. What effect could this be expected to have on the underflow over the years.

N.B.: The strange thing is Pupuke is also warming up at a similar rate to Rotorua. It could be very dangerous to the lake, because it increases the stability of the water column, but because all that phosphorus is regenerated by the co-precipitation of the iron and manganese. The warming rate there has very little effect. That chemistry doesn't seem to be operating quite as effectively in Rotorua. And if there's a warming rate in Rotorua and increased stability in Rotorua, it could really be quite dangerous.

N.M.: What I'm really asking is, if Rotorua is in fact warming faster than Rotoiti is, could we expect the underflow to gradually operate for less and less of the year?

N.B.: It's a possibility, but bearing in mind that you're not just heating Rotorua, you're heating Rotoiti as well, both lakes may in fact warm at the same proportional rate. The critical thing there is that as the temperature goes up, of course the solubility of oxygen goes down, so the mass transport of oxygen may decline as the water column increases in temperature.

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Effects of Rotorua City stormwater discharges on Lake Rotorua

David Ray, Burns Macaskill, Ngaire Phillips, Lisa Golding, Eddie Bowman
NIWA, PO Box 11115, Hamilton

ABSTRACT
Rotorua District Council engaged NIWA to assess the impacts of stormwater discharges from Rotorua City on receiving streams and Lake Rotorua. This work will support a resource consent application for the stormwater discharges. Given the high values associated with the Rotorua Lake, a rigorous assessment was considered necessary by the Council.

A multi-disciplinary approach to assessing impacts was undertaken. Stormwater and lake sediment samples were analysed for contaminants and compared with water and sediment quality guidelines; toxicity tests were carried out on stormwater samples; stream ecology upstream and downstream of stormwater discharges was assessed; contaminant bioaccumulation in fish, mussels and snails was measured; and the invertebrate ecology of the lake sediments was assessed.

The main emphasis of the study was on those contaminants that are usually of most concern with urban stormwater, i.e., suspended solids, heavy metals, toxic organic compounds, and indicator bacteria. However, stormwater samples were also analysed for nutrients, and the total annual input of nutrients from the city's stormwater to the lake was estimated from these results (this work was done largely by Rotorua District Council staff). The yields for total nitrogen and total phosphorus were 10 and 2.3 t yr^{-1}, respectively. Hence Rotorua City contributes about 2% and 5% of the total catchment input of nitrogen and phosphorus to the lake, respectively.

The combined results of the investigations showed that, although there was some impact from stormwater on receiving streams, this impact had not resulted in unacceptable loss of ecological values. 'Signals' of urban stormwater discharge (mainly in terms of elevated heavy metal concentrations) were detectable in Lake Rotorua, but these signals were small, and, overall, effects were minor.

From tape transcript
Thank you and good morning ladies and gentlemen. I'd just like to acknowledge my co-authors on this paper – I'm really presenting this paper on behalf of the project team who you can see up there. Okay, well as a bit of an introduction, Rotorua District Council already has consents for the discharge of stormwater from the central business district of Rotorua City, but the Council are seeking a comprehensive permit for discharge of stormwater throughout the city. And they engaged NIWA to help them put together that consent application, so my talk this morning is covering the work that we've done. This presentation has a slightly different focus, I suppose, to a lot of the other presentations, because the consideration of nutrients was only quite a small part of the study. We were more focused on toxicants like heavy metals. Just a bit of an outline to the presentation, I'm going to start with a bit of background. I'll discuss the investigation strategy that we undertook and then I'll go through the results. I'm just going to look at the nutrients and heavy metal components of the stormwater this morning, and then I'll have a wrap up at the end.

This is a map of Rotorua City (*not shown – would not print*), so the blue lines indicate the major streams flowing through the city, the red area indicates the outlet of the drains from the CBD area. These are a couple of photographs of those urban streams, the Utuhina and the Mangakakahi, and this is the outlet of the CBD area to Lake Rotorua (*not shown*). Some key characteristics of the urban scene: the streams that flow through Rotorua city have a very high base flow, as I'm sure most of the local residents are aware of, and that's because they are spring-fed streams. And because of that high base flow they do have quite high environmental qualities, much higher than is typical for urban streams and certainly much higher than those of, for example, a place like Auckland which has a very much lower base flow in the summer. So they're not just urban drains. Another obvious characteristic of the area is the geothermal influence, and there were some real challenges for us in trying to separate the effects of stormwater on the lake from the effects of the geothermal influences.

Mangakakahi

Utuhina

The District Council has already obtained consents for stormwater discharges from the CBD area and as part of that process they put in place some quite comprehensive stormwater treatment devices, mainly in the way of ponds at a cost to the ratepayers of many hundreds of thousands of dollars. One of the key questions that RDC needed to answer while seeking these comprehensive permits was: "What other treatment might be required elsewhere in the city?" So the key question that we were asked to answer was, "What are the effects on the receiving environment of the stormwater discharges?" Because you need to know that to answer the first question.

RDC S/W sampling & analysis

- 3 - 4 storms
- flow-weighted composite sampling
- Results fairly consistent
- EMC痴used to derive annual loads
- 3 catchments (res., comm., indus.)

The District Council themselves undertook quite a large range of stormwater sampling and analysis. They took three catchments in the city – one residential, one commercial and one industrial. They managed to capture between 3 and 4 storms at each of those catchments, and during the storms they carried out flow-weighted composite sampling. The results between those different sample events were fairly consistent, which was a good result. They then used the Event Mean Concentrations (EMC's) from those storms to derive annual loads of contaminants on the streams and on Lake Rotorua, essentially using average annual rainfall and making some assessments of the degree of run-off that was expected.

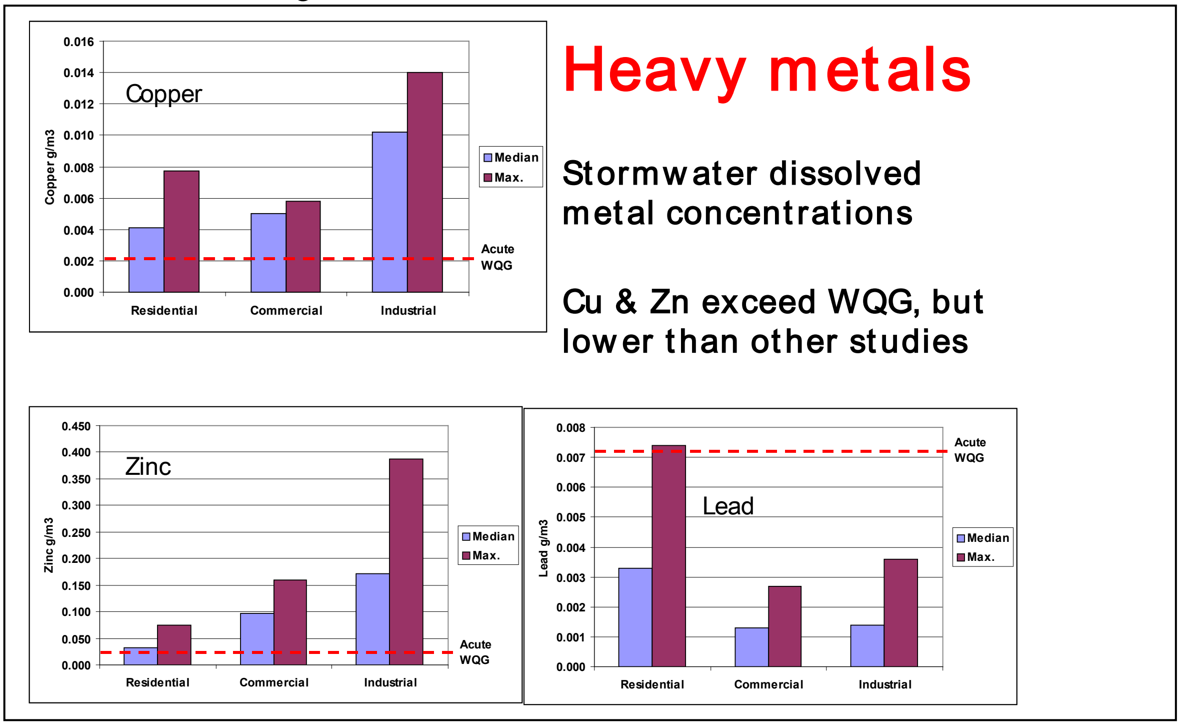
Nutrients:
Rotorua City vs other sources

	TN (t/yr)	TP (t/yr)
Rotorua City	10	2.3
Whole land Catchment (Burns 1999)	504	42

City contributes ~2% of TN & 5% of TP
(c.f. City occupies 13% of catchment)

So, just addressing nutrients and comparing nutrients from Rotorua city stormwater with other sources: RDC's calculations on annual loads for Rotorua city came up with the figures of 10 tons per year total nitrogen, and 2.3 tons per year of total phosphorus. We've compared those figures against the estimates made by Noel Burns in his report of 1999 on inputs from the whole land catchment (this does not include rainfall that's fallen onto the lake or processes within the lake). His figures were 504 tons per year of nitrogen and 42 tons per year of phosphorus. So the city contributes something in the order of 2% of the total nitrogen and in the order of 5% of the total phosphorus to the lake. An interesting comparison to make is that the city occupies about 13% of the catchment area, so on a per hectare basis the input of both nitrogen and phosphorus is less from the city than it is from the rural catchment.

I'm now going to go through the work we did on heavy metals. Again, these are some results of stormwater sampling that the District Council undertook. These are the dissolved metal concentrations for copper, zinc and lead (*next page*). We've got three different catchment types, residential, commercial and industrial. The red dotted line at the bottom is the acute water quality guideline, so you can see there for both copper and zinc, all those concentrations exceed the acute water quality guidelines. Interestingly for lead, almost all the samples were below the water quality guidelines, and that's almost certainly due to the removal of lead from petrol a number of years ago. I should point out that these results for the copper and zinc, although they exceeded the water quality guidelines, were actually significantly lower than most other studies that have been done on stormwater, including studies within New Zealand.



We also undertook some toxicity testing. We used three New Zealand native organisms and did some whole effluent toxicity testing using stormwater taken from Rotorua city. I haven't got time to go into the details of the work, but the results essentially supported the comparison of the stormwater concentrations with the water quality guidelines. They showed that the native algae was slightly more sensitive than the water quality guidelines would suggest, but the water flea and amphipod were less sensitive. So there's quite a

Toxicity testing

- Use NZ native organisms
- Used 3 organisms (algae, water flea & amphipod)
- Results supported WQG comparisons (algae more sensitive, water flea & amphipods less sensitive)

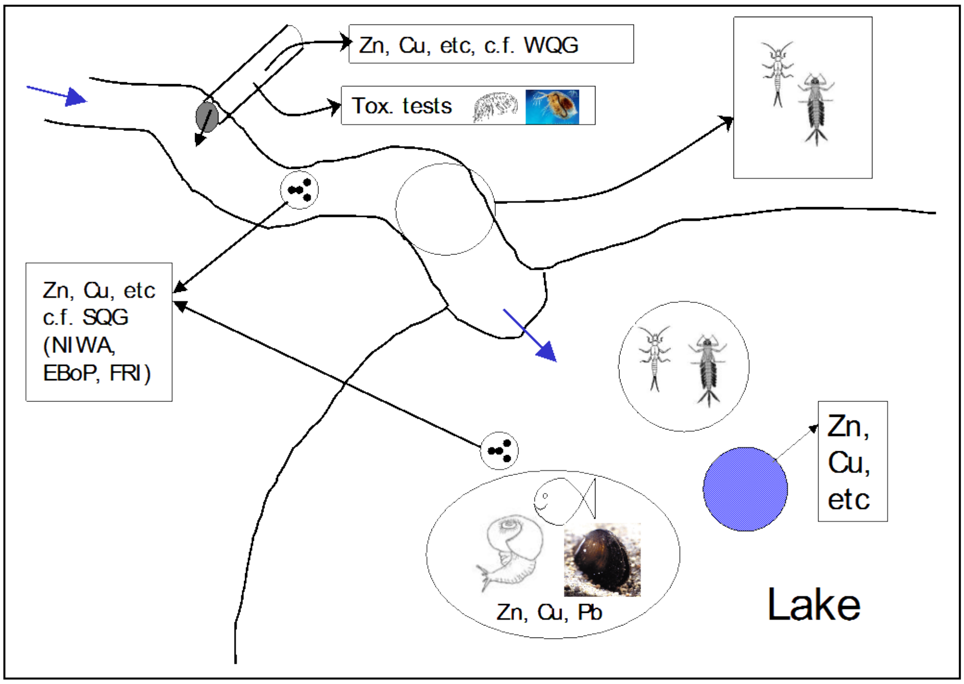
Next step?

- Require 10 to 20-fold dilution to meet WQG
- Dilution not available
  - ⇒ effects???
  - ⇒ treatment required? Where? ($$$?)
- Receiving environment investigations req塯
- Multiple investigations to provide 層eight of evidence

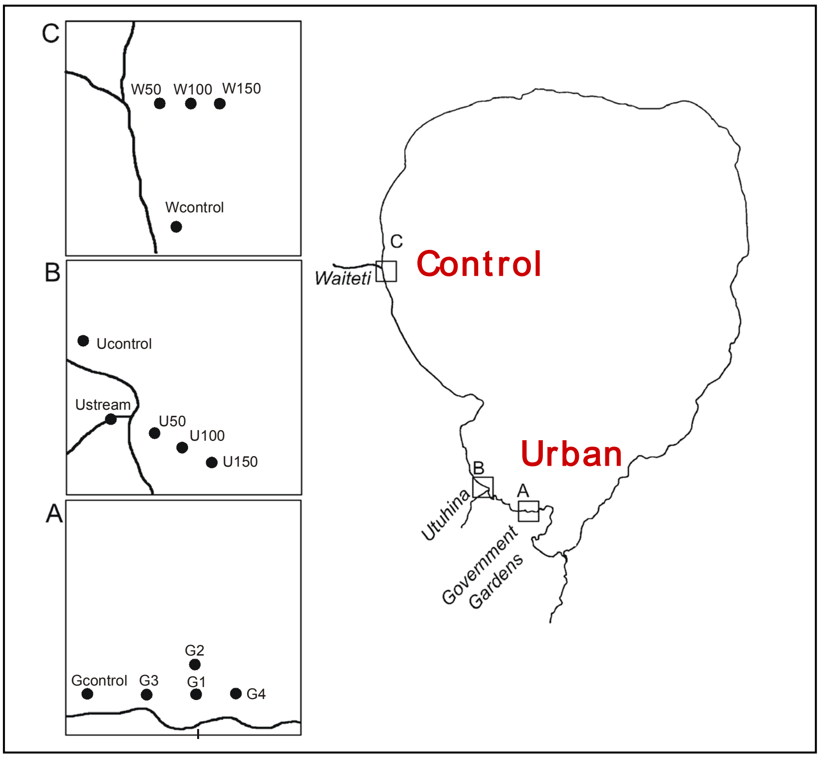
good agreement between those two lines of investigation.

From these two lines of investigations, this seemed to imply that we would need between 10- and 20-fold dilution of the stormwater in the urban streams to meet the water quality guidelines. That amount of dilution, even with those high base flows, isn't available. So that would suggest that we might expect to see some impact on the receiving environment and on the animals living in the receiving environment, and perhaps some sort of treatment would be required. So what we recommended to the District Council was that we go the next step to see if we could actually measure some effects in the receiving environment.

We undertook a multitude of investigations to try and answer that question, so that we didn't have to rely on one particular line of investigation. So it's a weight of evidence approach, like the Police use.

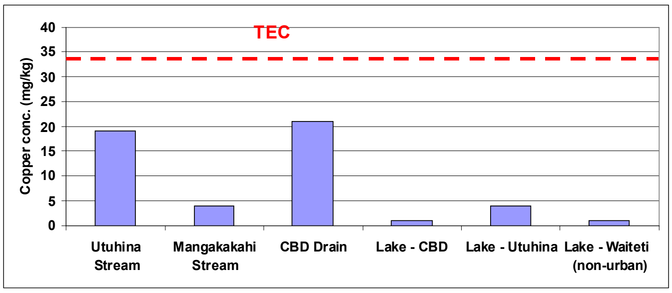


I'll just use this schematic diagram to illustrate our approach. We've got the lake down here and this is a typical urban stream and a stormwater pipe discharging into it. We've already got the results of the contaminant concentrations in the stormwater, comparing those concentrations with water quality guidelines. We've also got the toxicity testing results.



We then looked at results of sediment analyses for heavy metals. This is work that was done by Environment Bay of Plenty and also Forest Research, and similarly we looked at sediments in the lake. We looked at macroinvertebrates living in the urban streams and also in the lake, and we also undertook some bio-accumulation tests on freshwater mussels, snails and fish in the lake. And finally we also looked at the lakewater itself, to look at the heavy metal concentrations in the lakewater. We had two impact sites near Rotorua city, one at the outlet of the Utuhina Stream and one near the CBD discharge near the Government Gardens, and then we had a control site at the Waiteti Stream which is a rural stream.

Stream & lake sediment quality



Sediment copper concentrations (maxima)

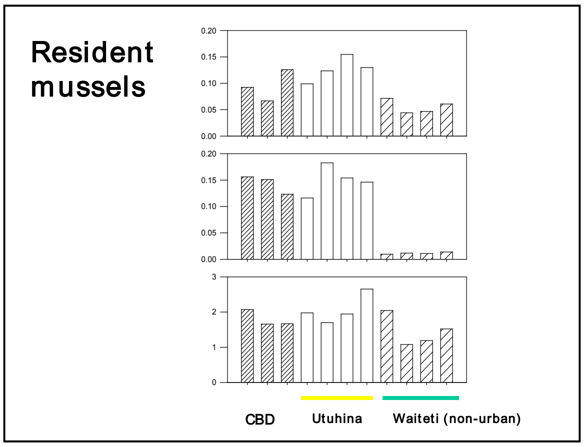
First of all the sediment quality in the stream and the lake. These are the copper concentrations, the maximum values we obtained. The dotted line at the top is the Threshold Effects Concentration, which is very conservative. So we can detect a signal of copper in the Utuhina Stream and the CBD drain, but very low concentrations in the other samples – well below Threshold Effects Concentrations.

Survey of biota

- Slight impact on stream invertebrates
- Lake invertebrates results mixed - difficult to pick up a 'signal'

These are the macroinvertebrates results. I don't have time to go into detail on those studies, but essentially only a very slight impact was measurable on the stream invertebrates. The results for the lake invertebrates were quite mixed, but it was very difficult to pick up any sort of a signal that could be attributed to stormwater.

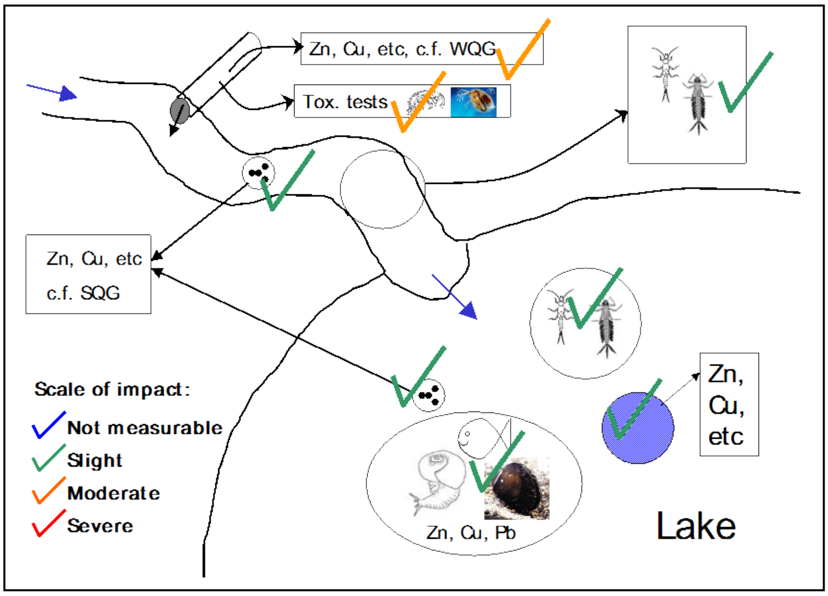
The metal bioaccumulation studies were carried out for animals living in the lake - we looked at resident mussels and bullies, (mussels and bullies taken directly from the lake). We also had some caged experiments where we put mussels and snails in cages and then dropped them into the lake for a number of days. I've only got time to talk about the results for resident mussels here, so this graph shows copper, lead and zinc concentrations in the mussels. These bars on the left are for the CBD site, these clear ones in the middle are the Utuhina Stream site and the ones on the right hand side are for the control site near the Waiteti Stream. So I guess if we look hard at the copper and zinc concentrations, the top and bottom graphs, there is perhaps a slight impact observable for the copper and zinc. It’s interesting to compare these with the lead concentrations. Mussels are quite long-lived animals, they live for a number of decades, and what’s apparent is that there has been a build-up of lead in those mussels over time, even though we are now measuring low concentrations of lead in the stormwater.



Bioaccumulation results (lake)

- Slightly higher levels at urban sites for:
  - Resident mussels
  - Bullies
  - Caged snails
- No effect on caged mussels

So in summary, if I use a qualitative scale of impact down at the bottom left-hand corner there of the blue arrow indicating no measurable effects, going through red meaning severe effects. For the initial tests we did on stormwater concentrations of zinc and copper in the toxicity testing, we might conclude that there’s the potential for moderate effects. For all the other studies in the receiving environment the results all indicated, at worst, only slight impacts.



So in conclusion, going right back to the nutrient data, the contribution from Rotorua city to Lake Rotorua is that only about 2% of the nitrogen and 5% of the phosphorus inputs to the lake are derived from the city. The contribution proportionally in comparison between the city and the rural area is less from the city area on a per hectare basis. And

Conclusions

- Nutrient contributions:
  - Fairly small contribution
  - Contribution proportionally less than rural catchment
- Metals:
  - Some impact on urban streams, but no significant loss of values
  - Only weak stormwater "signals" detectable in lake

looking at the metals, we picked up some impact on urban streams, but there wasn't any significant loss of environmental values and we could only pick up very weak stormwater signals in the lake.

I'd just like to acknowledge both the funding from Rotorua District Council for our work and also obviously our use of the considerable amount of their data in the study.

QUESTIONS

Sally Brock, LWQS: Are you saying that this test was basically based on the fact that you were putting stormwater into urban streams that had not had that 10- to 20-fold dilution to meet the World Quality Guideline?

D.R.: What I'm saying is that the stormwater, to meet the water quality guidelines, the stormwater would need to be diluted 10 to 20 times via the water in the stream, by the flow in the stream.

S.B.: And that was the basis of the results was it, after that 10- to 20-fold dilution?

D.R.: No the stormwater sampling showing those elevated levels above the water quality guidelines, that was the sampling of the stormwater itself. So that's not sampling in the stream. So the concentrations in the stream would be less than that.

S.B.: Why would you put stormwater into urban streams that do not meet the World Quality Guidelines?

D.R.: That's the existing situation.

(*Subsequent explanatory note by David Ray: During question time I misunderstood the question from Sally Brock. Sally correctly pointed out that the copper and zinc concentrations in Rotorua's stormwater were 10 to 20 times higher than the water quality guidelines for the receiving waters. However, I should point out that those water quality guideline are very conservative (that is, they are designed to be "on the safe side"). Exceedance of the guidelines does not mean that there will be adverse effects on animals living in the receiving environment. As I showed in my presentation, our investigations into animals in the receiving environment indicated that any impacts on animals in the receiving environment were, at worst, slight.*)

Rossana Untaru, Waikato University: I was just wondering if you've tried to do a similar research on Rotoiti stormwater to see what's getting into the lake, seeing that it has a lot of problems.

D.R.: No we haven't done a study there, no.

R.U.: Are they planning to do anything similar?

D.R.: Not that I'm aware of, you'd need to ask someone from the District Council that question.

Ian McLean, LWQS.: The figure of 5% phosphorus intake into Lake Rotorua coming from the stormwater has been interpreted in reports within Rotorua District Council and in their documents to mean that that means it's okay. Now was that a fair conclusion from your report and what's the logic that says because it's a lower concentration per hectare than from rural land and it's because only 5%, then it's okay. Would you draw that conclusion?

D.R.: Well I think that's a fair question and I think it's a judgment decision. I guess my response is that the objective we should have is to limit all inputs of nutrients to the lake. My understanding of the position of the District Council is that, whatever we do with the lake is going to cost money, so let's make sure that the money is best spent, that we get the "best bang for the buck", if you like. Does it make more sense to spend money on treating stormwater or is it better to spend the money elsewhere. I'm certainly not advocating that the nutrients in the stormwater don't matter.

Chris Hendy, University of Waikato: I note that you didn't include the Puarenga Stream in your study, which is the one that flows right past the Hotel here and which is probably the largest one flowing through Rotorua city and also includes both the Waipa Mill and Waipa Forest drainage system. Was there any reason for this?

D.R.: We were looking solely at the stormwater inputs to the stream. We weren't measuring what was actually in the streams, because obviously you want to see what's being contributed from the city. If we took samples from the stream, obviously some of that would be derived from outside the city catchment, so we're trying to clarify the situation in terms of what the inputs are from the city.

C.H.: Does this imply there were no inputs from the city into Puarenga?

D.R.: I'm not entirely sure about that.

C.H.: The sewage works and the composting plant and everything are right on its shores.

Use of constructed and restored wetlands to reduce lake nutrient loadings in agricultural catchments

Chris C. Tanner and Long M. Nguyen, *NIWA, P O Box 11-115, Hamilton*
John McIntosh, *Environment Bay of Plenty, Whakatane*

ABSTRACT
Diffuse runoff from agricultural catchments commonly contributes a major proportion of the nutrient loads to surface and ground waters entering New Zealand lakes. Interception of this diffuse runoff in riparian buffers and natural, restored or constructed wetlands can complement good grazing, fertiliser and effluent application, irrigation and drainage management practices to reduce rates of nutrient inputs. Riparian and wetland buffers can also reduce inputs of other contaminants (e.g. faecal microbes and pesticides) and enhance the habitat, biodiversity, cultural and aesthetic quality of agricultural landscapes around lakes.

The results of recent New Zealand trials investigating constructed wetland treatment of nitrate-rich subsurface drainage from dairy pastures show constructed wetlands can substantially reduce nitrogen export via drainage systems. However, removal efficiency varies during establishment and maturation of the wetlands, and in response to variations in seasonal temperature, rainfall, evapotranspiration, irrigation, and resultant run-off characteristics.

In addition to these factors, the potential role of wetlands in reducing nutrient loads to lakes depends on the relative importance of different hydrological pathways (e.g. surface or subsurface flow) in the contributing catchment, and the particular form in which the nutrient is transported. General principles and performance attributes of constructed wetland treatment systems are discussed, and their potential role in reducing diffuse nutrient loads explored using local examples.

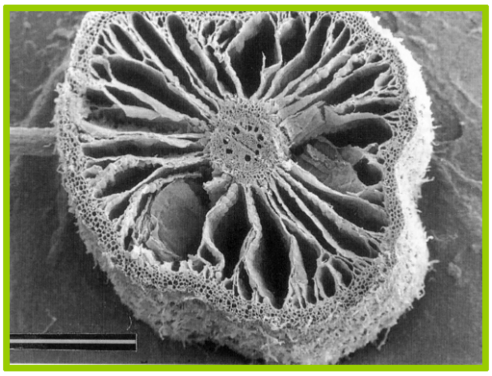
(*Tape transcript*)
We're now going to move from urban stormwater into the rural landscape and what we usually call run-off, and looking at constructed wetlands there – just for a change from lakes. I've been lucky enough to start working recently with Environment Bay of Plenty on looking at how wetlands might be used in some of the lake catchments around here. Today I'm going to talk to you a little bit about how wetlands function to improve water quality and how they might be used to control the nutrient loads from agricultural land. In particular I'm going to concentrate on just nitrogen, particularly nitrate, removal and give a few results from New Zealand trials and other agricultural settings, and then look at how we might incorporate constructed and restored wetlands in lake catchments.

Wetlands are really the kidneys of the landscape and as such, they intercept run-off, they can buffer flows, by both reducing flooding downstream and sustaining base flow during dry periods. They can be effective trappers of sediment and they can attenuate nutrients and a whole range of other contaminants. So how do they do this?

Pretty simple things, wetlands. They're big shallow water bodies, basically, Water enters them, spreads out and slows down, promoting sedimentation. Also, there's a lot of dense aquatic vegetation growing in them, all with sticky biofilms or slimes on their surfaces. These tend to trap sediments and enhance their sedimentation and retention capacity.

There’s close contact between water, sediments, plants and these microbial biofilms of slimes, which makes them biochemical hot spots for exchanges and transformations or nutrients. Wetlands are also known to have very high plant productivity –they’re well supplied with water, often with nutrients as well. A lot of this organic matter gets returned into the wetland as organic forms which accumulate in the sediments.

The plants that grow in these systems have special adaptations –basically a ventilation system so they can get oxygen to their roots growing in the muds below the water surface. If you look at a cross-section through the stem of most wetland plants you can see they have large air spaces within them (*see left*). Air can diffuse down through these stems, and in some cases it can even travel as a mass flow down through them, into their roots. As a result of this, oxygenated zones are created around the roots, which can be important in terms of bacterial decomposition and transformation processes.



This mosaic of aerobic (oxygen present), anoxic (oxygen absent) and anaerobic (reduced) conditions can promote nutrient transformations in the sediments, particularly nitrification and denitrification that are important in nitrogen removal. These plant ventilation systems also allow other respiratory gases like carbon dioxide and methane and nitrogen to be vented out to the atmosphere.

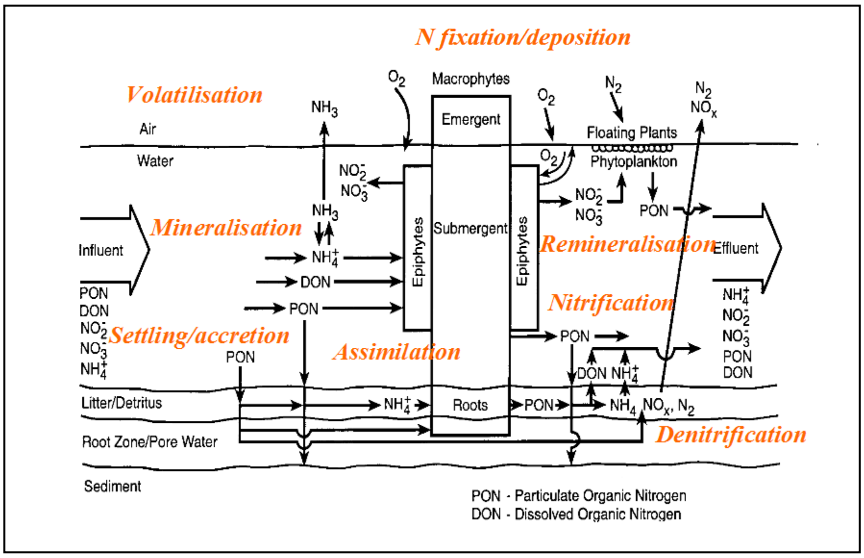
So how can wetlands be used in agricultural landscapes? Firstly, we think they’ve got potential in these situations because they’re relatively passive low-maintenance systems. They don’t require continual day-to-day management and once you've got them established, they sit there quietly doing their job. They are low-cost relative to other options, and sustainable if designed and built properly. There are also a lot of secondary benefits in terms of wildlife habitat and bio-diversity, for example, and aesthetic enhancement of the landscape.

There are two main options for using wetlands in this way– one is to use existing or restored remnant natural wetlands for this function. The other option is to specially construct wetlands. The advantage of this is you can construct them where you want and you may be able to optimise their function as a treatment system.

So let’s just look at a real situation. This is a constructed wetland that we’ve been involved with building and studying over a number of years. This one’s in Northland on a dairy farm.

It receives sub-surface drainage from about 4 ½ hectares of pasture. It firstly enters the wetland-fringed pond that stores the high flows and moderates flow into the second stage, which is a shallow marsh. After about 8 months growth, aquatic grasses had established a dense vegetation across much of the wetland, but after a couple of years native rushes and sedges become the dominant vegetation.

Nitrogen occurs in a range of forms and is subject to a myriad of, mainly biological, transformations. I've tried to simplify this down. The main forms that you find in water are organic nitrogen, much of which can be particulate, and then the dissolved species, ammonia and nitrate.



The organic particulate nitrogen can be removed by sedimentation fairly simply, accumulating in the bottom of the wetland. Plants can take up the dissolved forms of nitrogen and incorporate them into organic matter that eventually gets returned to the sediments in plant litter. We have to remember that nitrogen accumulating in litter and accreted sediments isn't locked in there. There are continuing exchanges with the overlying water and so, for example, if a wetland has periods with no flow and is subject to periods of wetting and drying, there may be some mineralisation leading to release of stored nutrients.

At high pH ammonia can be volatilised from the water surface. This basically means that it is gassed off to the atmosphere. Denitrification, which is generally the main mechanism of nitrogen removal, occurs where nitrate is converted by bacteria to nitrogen gases that are released to the atmosphere. These are the main mechanisms of gaseous emission and are really the key sustainable mechanisms that operate in wetlands to remove nitrogen.

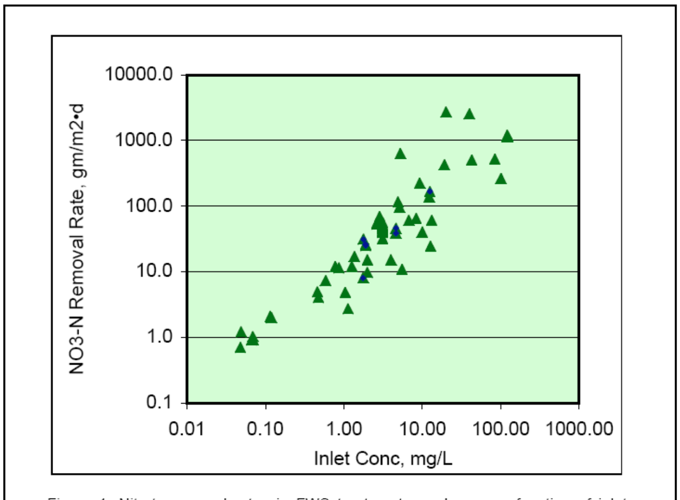
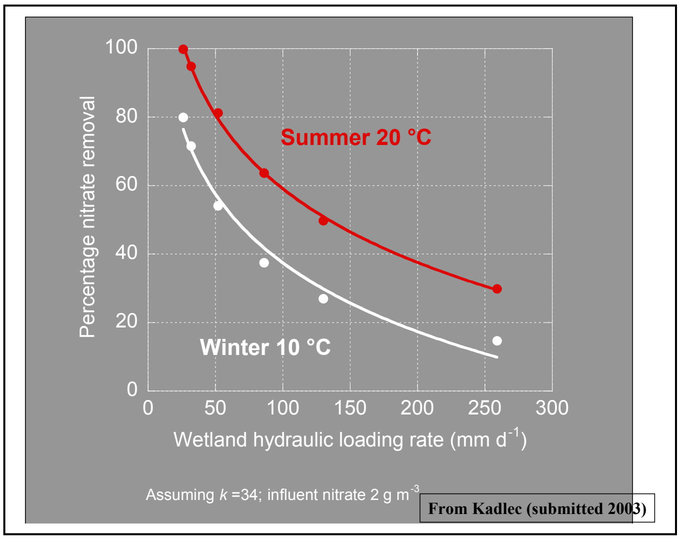


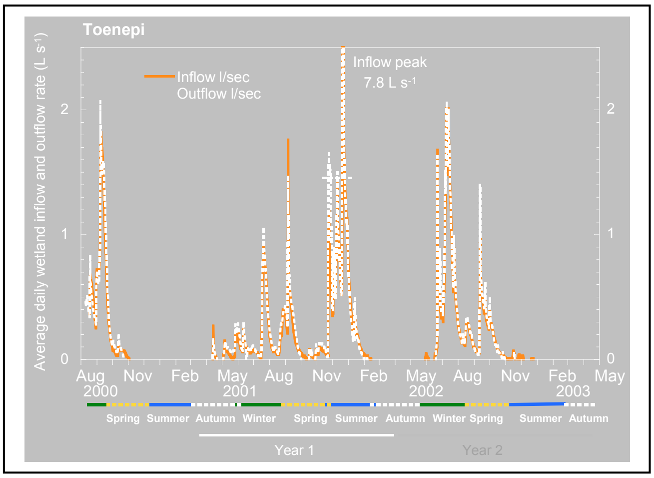
Figure 1. Nitrate removal rates in FWS treatment marshes as a function of inlet concentration. Each point represents the entire dataset for one wetland, typically spanning 1 – 4 years. Data are from project operating records and published papers.

Let's now look at some data for actual constructed wetlands treating nitrate rich water. You'll see on the bottom axis here (*left*) we've got inlet concentration and on the vertical axis, nitrate removal rate in grams per metre squared per day. We see that there's a pretty good relationship there between the concentration of nitrates going in and the actual removal rate, and that's been used along with other information about the hydraulic efficiency of each of those wetlands to develop performance models.

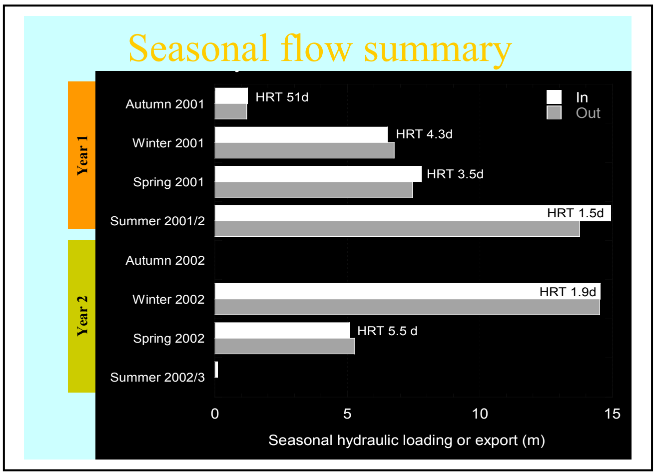


These show us that at low hydraulic loading rates the removal is quite high, and as we start to put more and more on them their efficiency decreases, as you might expect. You'll also see we've got two different relationships shown here, with markedly higher rates during the summer than winter.

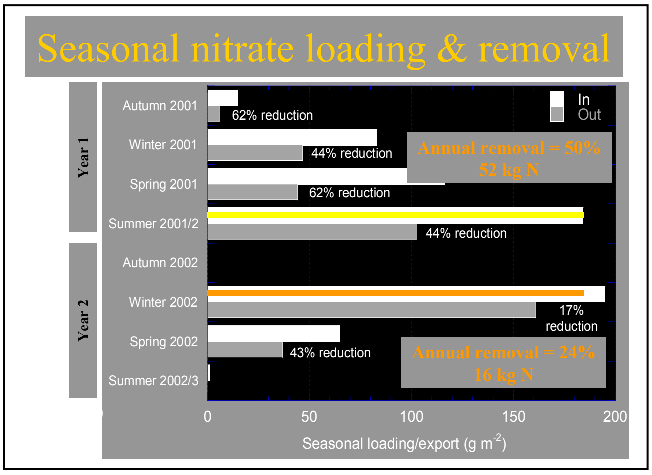
We're going to look now at another example of a constructed wetland that we've been studying for a little while and this is in the Waikato, again treating dairy farm drainage. Again this is a two-part system where water accumulates during high flows in the first stage and then it's released to the second stage. This is a long linear system. The advantage here is that it sits along the farmers fence line out of the way, although it is not quite as aesthetically pleasing as the more naturally shaped one we saw previously.



This figure shows the flows into the wetland from the drainage system over a number of years and you can see that they are very peaked, very flashy sort of flows, and there's also dry periods when there are no flows at all, usually during summer.

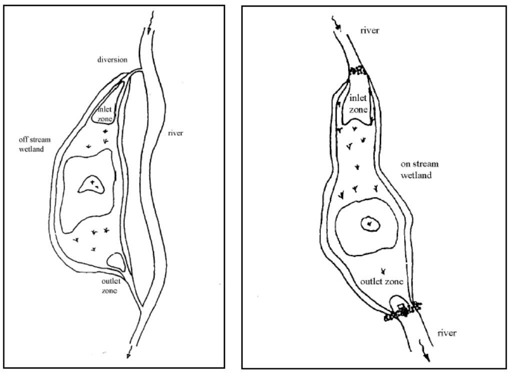


I've tried to summarise the complexity of the this over two years. During year 1 (at the top) we see we've got rainfall mostly occurring in summer. The second year we had a much drier year with no drainage in summer and very high flow into the wetland during winter. The seasonal loadings and removal rates are shown by the grey lines.



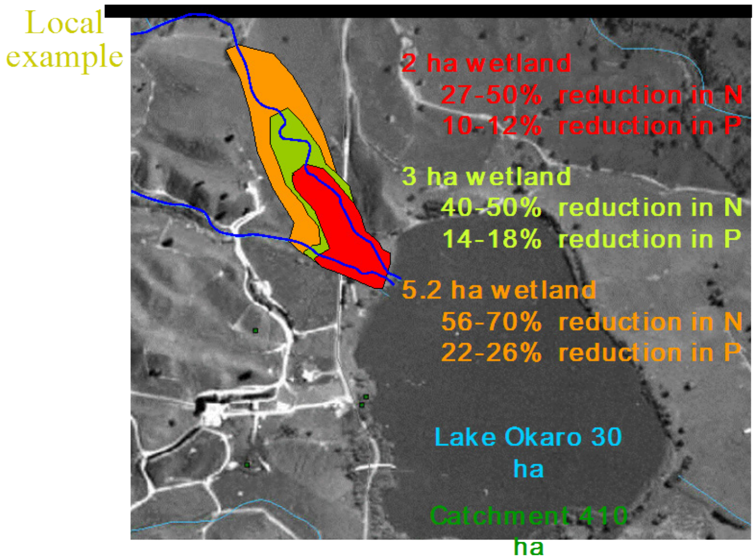
If you just look here at the summer and winter data for these two periods, the actual loading of nitrate into them over that period was quite similar, but in summer it removed 44% of the nitrogen and in winter it only removed 17%. That's the basic temperature effect of the flow arriving in different seasons. So in the first year we got 50% nitrate removal which was 52 kgs of nitrogen. In the second year we had less nitrogen being loaded, but we only removed 24% removal, representing 16 kg of nitrogen. So the performance of these systems is a little complex in that it is affected by when water enters them and in what sort of quantities.

If we're looking at using constructed wetlands in agricultural landscapes, there are a couple of different approaches to how we might use them. One is to have multiple small upstream wetlands (these might be existing wetland areas) dotted around the landscape. The advantage here is that wetlands are situated where the loads have been generated. The other option is to have fewer, larger downstream wetlands that treat drainage from larger areas. Under varying scenarios one or other can be more or less efficient. Generally in terms of cost, the single downstream wetland usually comes out cheaper.



A: off-stream wetland b: on stream wetland

Another thing we need to think about if we're using wetlands, is do we have then on-stream or off-stream. The off-stream wetlands as shown on the left-hand side are usually seen as the best option. Flow can be diverted from the river into a wetland constructed parallel with the main stream. That way very high flows can be diverted down the old stream channel, safeguarding the wetland from flooding damage. You could also retain some residual flow down the stream channel as well. In-stream systems can be a cheaper option, and sometimes where you're constrained by the shape of valley that you're working in, the only available option. The disadvantage here is that system can silt up very quickly. It usually needs some sort of inlet pond zone that can be cleared out if there's a high sediment load, and it can also be washed out during very high flows.



Coming back a little bit more to somewhere local –Lake Okaro which we visited on the field-trip yesterday. Lake Okaro has a surface area of ~32 hectares and the catchment is about 410 hectares. The stream in the top left-hand side of the photo, that is the major input to the lake from the catchment. If we constructed a 2 hectare wetland there, we'd remove about somewhere between 27 and 50% of the nitrogen (that's the winter/summer range) and 10–12% of the phosphorus. If we went a bit bigger to 3 hectares, we'd be able to get up to 40–50% nitrogen reduction and if we go up to 5 hectares this would increase to 56–70% reduction. So this gives you some sort of context about what sort of wetland area you might need to achieve those sort of targets. I'm not saying that this is happening or that's what we should actually do, it's just a theoretical example for a real situation.

So, I think wetlands are part of the tool kit, they're not going to solve the problems themselves. They really need to be linked together with other types of good catchment management, but they have got application for reduction of nutrient inputs and they should be taken into account. Their performance is relatively good for nitrate removal and they are also good at removing particulates and the associated nutrients.

To evaluate their performance we need to look at them more than just one year, because it varies from year to year, depending on climatic variability and flow regimes. Particularly with constructed wetlands, there's also a range of options available to optimise their performance. I mean things like improving the efficiency of water flows through them and trying to promote better denitrification by carbon supplements, things like that. In the end, to make them more usable, we really need practical guidelines that farmers and lake managers can use, both to cost these systems and to evaluate their performance and where best to use them. Thank you.

QUESTIONS

Colin Curry: I'm a resident down at Hinehopu. How important is it to keep the access stream providing the run-off from the wetland clean. Does it have an impact if it gets blocked up or overgrown and doesn't flow. What impact does it have on the usefulness of the wetland.

C.T.: In general the longer water spends in the wetland, the more treatment will occur. So in some ways the blockages could perhaps give it a longer treatment time. A lot of wetlands are modified, so they are channelised, which is an attempt to try to get water to move through them more quickly, which often means that a large part of a wetland isn't really coming into contact with that water at all, so it can't do anything. So one of the things in terms of trying to design a wetland for water quality performance is actually to get the water to spread out through the wetland, rather than rip through it through the channel.

Martin Evans, URS New Zealand: Chris, the basis for the removal rates for nitrogen, were those based on field testing, that's the first question. And related to that is have you noticed any improvement if they are actually managed by harvesting in terms of nitrogen removal?

C.T.: I should have emphasised when we had the diagram up there of all the different ways that nitrogen can be removed. Most people think that because there's lots of plants in wetlands, that the plants take up the nutrients and that's the most important way that they are removed. In actual fact it's probably only about 20% of the removal occurs by plant uptake. Most of it occurs by denitrification, by the bacteria converting the nitrate into nitrogen gas and emitting them to the atmosphere. So the plants, their most important role is to produce organic carbon, organic matter that falls back in the wetlands, that supplies these microbes that denitrify it.

Rob Pitkethley, Eastern Region Fish & Game: There are a lot of places around the lakes and Rotorua in particular, where there's a nice land/water interface where there's grass right down the water's edge and things like that. Is there work done or information available on how to better manage those interface zones? They're not actually wetlands as such, there's not standing water there, but to sort out issues like septic tanks running through the water and lawn fertiliser and stuff like that. Are there areas of work that have been done on how to better manage those interfaces?
Are they sort of more like riparian zones?

C.T.: Yes, more so, even Council reserves that run right down to the lake edge.
I do think there is a lot of knowledge about how riparian zones work and how to better manage them. I don't know if there is a guideline that can really help you there. But yes, I would be pleased to talk to you about that a bit more afterwards.

Riparian protection in the Rotorua Lakes catchment

Colin Stace and **Vance Fulton**
Environment Bay of Plenty

ABSTRACT
Riparian protection is a recognised tool for modifying the impact of pastoral land use on water quality of streams. Concern over deteriorating water quality prompted an extensive study of the trophic status of Lakes Rotorua and Rotoiti in the late 1960's, which emphasised a need to reduce phosphorus inflow to Lake Rotorua. In 1975 the Upper Kaituna Catchment Control Scheme was proposed, focusing on disposal of sewage from Rotorua City, lake control structures and soil conservation works with a specific emphasis on riparian buffer zones.

Under the Scheme extensive riparian protection works were implemented between 1978 and 1992 covering the grater part of most permanent watercourses in the Rotorua basin. Over 500 kilometres of protection fencing was built and around 4,000 hectares of riparian margin and LUC class VII terrain was retired from pastoral land use. Monitoring of one of the ten major catchments that drain into Lake Rotorua was carried out in the late 1980's, comparing data with that collected before riparian protection works were implemented.

Riparian protection was found to give some significant benefits for water quality. The incidence of stream bank erosion fell from 30% of channel length affected to just 4% while sediment export from the catchment declined by 85%. Export of particulate N and P was reduced by 33%, yet total P declined by 25% and there was little change in overall N loading because reduction in particulate N was offset by an increase in nitrate levels. The specific reason for this was unclear but may have related to a decline in denitrification as a result of wet soil zones being de-watered and shaded by riparian vegetation.

Environment Bay of Plenty continues to implement riparian protection, along with erosion control works and protection of natural areas on private land. Throughout the twelve major lake catchments in the Rotorua district programmes are currently in progress involving 540 hectares of protected stream margin and unstable terrain, along with 4,000 metres of lakeshore. A further 260 hectares and 3,600 metres of lakeshore are under negotiation with landowners.

These works are delivered through a property plan policy (Environmental Programmes) supported by grant rate assistance for activities such as fencing and revegetation planting. In August 2000 grant rates were extended to plant and animal pest control for riparian buffers, while significant natural areas and wetlands were also included in the policy. Currently, a nutrient runoff control component is being developed for incorporation in the Environment Programme approach, involving methods such as on- farm nutrient budgeting, interception structures and constructed wetlands. Through the lakes action plan process other initiators are being developed, such as mechanisms to encourage conversion of pastoral land use to forestry.

(*Tape transcript*)

Colin Stace
Thank you. Now riparian management is a recognised tool for protecting water quality, particularly in pastoral catchment areas, and locally we have a 25 year history of such work particularly around Lake Rotorua. Much of this work was done under what was called the Kaituna Catchment Control Scheme, which was developed in 1975. That scheme was developed after a 3 year study of lake water quality in Rotorua and Rotoiti, carried out by the Ministry of Agriculture and Fisheries in the late 1960s. The author of that study was Dr Gordon Fish and it was published in 1975. The study produced certain implications for catchment protection work. Fish noted that pastoral catchments as you might suppose tended to flood more frequently than forestry catchments. Flood waters derived from over land flow tended to be relatively high in nutrients. He thought that most of the phosphorus entering Lake Rotorua did so as a result of flooding and erosion events, and he suggested for any permanent beneficial effect on Lake Rotorua, input of phosphorus should be reduced by at least 50%. So the Kaituna Scheme was developed in 1975, it had a number of components in it. The principal proposal was to actually pipe city sewerage directly to the Kaituna River. Of course that didn't happen and nowadays it goes up to Whakarewarewa Forest. There are other works such as flood control and lake level control of structures and then there was a catchment protection component aimed at erosion control and riparian protection works.

Kaituna Catchment Control Scheme Riparian Protection Works

- 217 property plans
- 540 km fencing
- 4,000 ha retired
- 400,000 revegetation plants
- 260,000 woodlot trees
- 70 stream crossings
- 30 runoff control structures
- **Cost: $4.7 million**

Now here are some of the key outcomes of that programme. Between 1977 and 1994, during that time there were 217 different farm properties involved, 540 kilometres of fencing was built mainly around riparian and stream bank areas. About 4000 hectares retired, quite a few revegetation plants and wood lot trees, but if you do the division you'll see that it's actually a relatively low density of planting. Quite a few areas were simply left to revert for various reasons and I'll enlarge on that in a minute. There were a number of stream crossings that went in to get livestock out of stream beds and also there were a number of erosion control structures that were built. Not necessarily on stream banks, but on areas where large scale erosion was taking place and generating quite large sediment discharge. Total cost of the scheme in 1980 dollars was $4.7 million.

Riparian Protection, Ngongotaha Stream

Now just to give you a quick look at some of sort of works that came out of the scheme. This is riparian retirement or riparian protection works in the lower reaches of the Ngongotaha Stream valley. The main channel of the stream running through here and there's a tributary stream that comes in from this side here. The protected margin there

varies between about 5 and 10 metres on average and landowner preference at that time was to go for wood lot species, so we've got *Pinus radiata* in here, we've got some *Acacia melanoxylon* in here and *Acacia dealbata* in that area there. Not our favoured choice these days.

Narrow areas are not very good for growing timber trees really, their quality is degraded by edge effects and of course those planted on the stream banks eventually fall in and then we have to go and pull them out. So we don't really encourage wood lot development in riparian zones these days. Now in a situation like this where we've got a wide valley floor, it's pretty easy to fence, but when we get into hill country situations it's not quite so simple, you catch really build a viable fence across a steep slope, and in these situations it's necessary to take the fence lines up adjoining spurs or ridges.

Riparian Protection, Hill Country Stream

Areas like this were quite large and it would have been fairly expensive to undertake. Also at that time we had problems with sourcing large numbers of native plants in the early '80s, so areas like that were simply left to revert and after 15-20 years it doesn't look too bad, but initially those areas tended to fill up with gorse for example. You might notice the landowners taking the opportunity there to extend the area into a wood lot as well.

Erosion caused by Uncontrolled Runoff

Now as well as stream bank protection works, we also paid some attention to erosion events which were generating a lot of sediment. In this particular situation it's happened under high intensity storm conditions where flow has been concentrated in a swale and been behaving itself, but then it's come across a track bench which had no water controls on it. It's headed downhill, it's built up velocity and gained quite a bit of energy and as a result it's actually scoured out a lot of material. Now this is fluvial erosion, it's caused by running water. Once that material is in suspension, it's moving quite rapidly and it's moving to the nearest water courses it can find, which depends a bit on the duration of the storm. These sorts of events can actually cause quite a lot of sedimentation in channels.

This is a more typical situation (*next page*). This is a gully head formation and these typically form a lateral line off permanent stream channels. These can start off quite small, but get very big. What happens of course if flow coming down the swale drops off the edge, when there's heavy flow that scours the plunge pool at the bottom of the vertical face. That vertical face loses lateral support and drops in and the process just proceeds in stages like that. These can get very large in a very short space of time. We're controlling

Gully Head Erosion

them for three reasons, first of all there's that sediment discharge and that has a direct impact on water quality, because we know sediment is one of the main transport mechanisms for phosphorus. The landowner has obvious concerns about these situations, because they see parts of their farm disappearing before their eyes. And just the sedimentation that takes place in channels is a problem as well. It leads to increased flooding in the lower reaches of the stream and also throughout the length of the stream, sediment deposits displace flow against stream banks and cause a whole suite of secondary erosion throughout the length of the channel. In this case you can see the fixes where we're installing a detention dam there, which actually controls the rate of flow through a pipe over that feature, and it has since stabilised.

Now, how effective was the Kaituna Scheme? Well in the late 1980s the Environment Bay of Plenty commissioned a study which was undertaken by the DSIR, to examine the effect on water quality which could be attributed to the works. The study catchment chosen was the Ngongotaha Stream, which was a handy site to do it because there was quite a body of data that had been collected 10 years previously by the Ministry of Works & Development before the actual catchment protection works went in. Now as you might imagine, there were definite benefits to catchment protection, sedimentation was decreased significantly along with stream bank erosion, particular N & P was reduced by 33%, but total P overall was a 25% reduction. Their study didn't find a net significant reduction in total N, because they found between the mid 70s and late 80s there was actually about a 40 to 50% increase in nitrate concentration and base flow entering the stream. That's largely put down to intensification or changes in land use, but the authors also speculated that riparian vegetation may have been implicated and that it may have inhibited the denitrification mechanism in wet soils adjoining the channel, through dewatering and shading. It wasn't something they actually pursued in their study, it was simply an idea they put out there and I don't think it's been investigated since as such.

Ngongotaha Stream Study

Key Findings

- Incidence of streambank erosion decrease by 87%
- Volume of sediment entering Lake Rotorua decreased by 85%
- Volume of particular N & P reduced by 33%
- Total P reduced by 25%
- Total N reduction offset by higher nitrate
  - Dewatering/shading by riparian vegetation
  - Intensification of land use
- Overall, riparian retirements in Kaituna Scheme
  - Reducing N 8-9%
  - Reducing P 15-20%

Now overall, they rated the scheme with a modelling exercise and that was on the basis of 80% of the channels in the Lake Rotorua catchment being in protection works of some sort. And their model said that the scheme would give an 8 to 9% reduction in N entering Lake Rotorua and about a 15 to 20% reduction in phosphorus.

Well following the Kaituna Scheme, Environment Bay of Plenty policy has been to continue with a policy of protection for riparian areas, and here's pretty much where we

Protection Status of Rotorua Lakes September 2003

Protection Status	Lake											
	Rotorua	Rotoehu	Rotoiti	Rotoma	Okatina	Okareka	Tarawera	Tikitapu	Rotokakahi	Rotomahana	Okaro	Rerewhakaaitu
Stream Channel (m)												
Under Agreement	149,870	4,420	3,540	0	0	1,650	4,850	0	0	12,910	0	560
Under Negotiation	0	580	1,380	0	0	120	380	0	0	0	0	0
No Livestock Access	185,010	20,740	31,210	12,300	48,400	2,530	115,170	2,070	1,390	55,700	1,410	1,550
Other	41,650	250	13,460	0	2,400	0	6,390	0	0	8,810	3,570	5,280
Total	376,530	25,990	49,590	12,300	50,800	4,300	126,790	2,070	1,390	77,420	4,980	7,390
Percentage Protected	89%	99%	73%	100%	95%	100%	95%	100%	100%	89%	28%	29%
Lake Margin (m)												
Under Agreement	360	18,300	760	0	0	0	0	0	0	10,990	0	0
Under Negotiation	1,090	9,430	2,010	360	0	80	0	0	0	0	0	0
No Livestock Access	37,860	11,220	50,150	23,040	29,100	10,480	47,390	5,120	15,150	18,100	1,350	21,860
Other	5,380	400	4,200	1,350	0	0	0	0	470	0	850	0
Total	44,690	39,350	57,120	24,750	29,100	10,560	47,390	5,120	15,620	29,090	2,200	21,860
Percentage Protected	88%	99%	93%	95%	100%	100%	100%	100%	97%	100%	61%	100%

are up to at the moment (*next page*). We've got stream channels, lake margin lengths. You'll see there are four classes there, we actually amalgamated these classes off about 10 different classes in the GIS layout. So it warrants a little bit of explanation. Under agreement, refers to situations where we have a programme of landowners and those programmes are protected by a formal legal agreement which says areas of stock exclusion will remain like that, etc. Those are programmes that are either completed or are in progress at the moment. Under negotiation, means that we are dealing with situations where we have had approaches from landowners who are willing to do work, and we've taken those negotiations some way down the track. We have agreement in principle, we're just working out the details of works and costings. No livestock access, refer to all non-pastoral land uses we've identified and those are areas like reserves, including road reserve, residential areas, other uses like resorts or golf courses and areas where stock physically don't have any access because of barriers like cliffs or something similar. The class other, is basically areas which are exposed to livestock grazing, however it's conditional. It includes areas where we know there is currently regular livestock access, but it also includes areas where we know there is only intermittent livestock access, and in fact we've included areas in there which don't appear to be grazed at all at the moment, but they certainly don't fit into any of those other classes.

Now just to qualify that a little bit, if we take Lake Rotoiti for example, we've got about 13 kms of stream channel rated as other. Now 98% of that is intermittent access, it's on forestry leased blocks. And about three quarters of that is in short rotation eucalyptus which gets grazed probably 3 to 4 times a year. And the other 25% is on a forestry leased block with a partial margin which doesn't appear to be grazed at all, but I'm sure it is from time to time. Similarly on the lakefront for Lake Rotoiti we've got 4,200 metres, that's on a single property in the south-west corner of the lake. It's actually one of these forestry leased properties. It does have a certain amount of fencing on it, but we don't have it under agreement and we don't have it under negotiation, so we can't put it in any other class but Other, but it's certainly not in regular grazing at the moment.

The same conditions apply actually to what we have under negotiation. 2010 metres on Rotoiti, most of that's on the northern side of the lake. Of that, 900 metres is regular stock access and works are actually progressing on that at the moment as a matter of fact, as of last week. 500 of those 900 metres have now been fenced, but I can't put it in under

agreement, because we haven't completed the agreement with the landowner. The balance of about 1100 metres is an intermittent stock access.

Just a couple of other things to note, at Lake Okaro we've put the entire lake margin under no livestock access. That's because the entire lake margin falls within a District Reserve, however that reserve is not fully fenced at the moment, there's about 800 metres which are currently being negotiated between the Council and the adjoining landowners for position of a boundary fence.

Lake Rerewhakaaitu, we've got about 5.2 km of stream listed as Other. There's only one permanent stream on Lake Rerewhakaaitu in the south-west corner and in fact most of that is fenced. It was done during the late 60's, early 70's as soil conservation retirement work. It's not under an agreement, but by goodwill most of the current landowners don't graze it. In practice it sits in the no livestock access, but it's not under an agreement and we don't know what future landowners are going to do, so we don't sort of count it as being in the bag as it were. Now we've delivered these works through a property plan approach, known as the environmental programme, that's an integrated farm plan style of programme involving soil and water values, as well as basic bio-diversity values. So we develop a programme of works which is supported by grant rates, with additional financial support from the District Council.

Streambank Damage by Livestock

Primary target for us is stream bank protection and you can see from this photograph it's pretty obvious what effect stock access has in terms of sedimentation. Al lot of exposed loose soil there is washed away by rainfall, it's washed away by floods and of course stock directly in the water contribute to the contamination as well.

Protected Stream Environment

Compare that with an area that's been retired for a while. You can see by the water clarity and the rocky substrate that we've got a definite improvement in water quality, but it's not just about that, there's a whole environment here. There's an in stream habitat that's now been enhanced, as well as a riparian environment as well. So programmes involve such things as plant and pest animal control works and if there's a structure like a crossing involved, there's issues like fish passage as well.

Now this is the basics of the riparian protection work. A good quality of fencing and our preferred option nowadays is revegetation with hardy colonising native shrub species. The fence line is worth a comment, that's a 9 wire post and batten fence. 25 years of experience has shown us that electric fences aren't really an option. Once stock are excluded from these areas, a body of vegetation develops which has contact with the fences. And an electric fence is only that – once its voltage drops or ceases altogether, stock will get through it. These are fences are reliable and they last a long time, and that's our preferred option. Native plants are going in there at about 1100 stems per hectare, that's 3 metres by 3 metres.

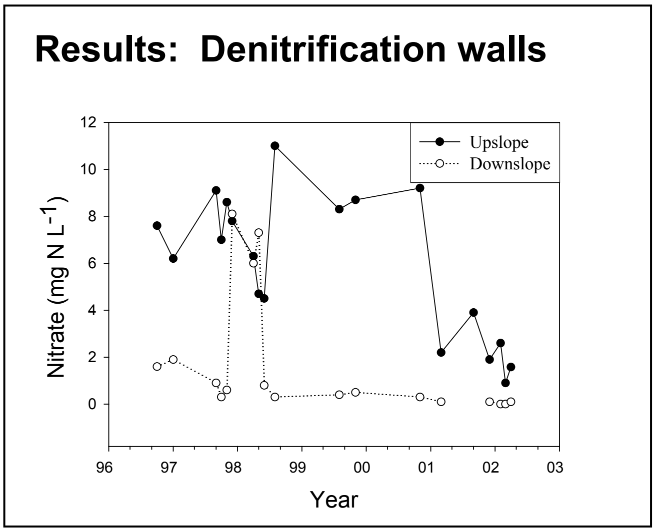
So for about 7 years we're going to have quite a lot of grass cover on that site, which is ideal for interception of overland flow. However on sites where we might have a slightly higher objective in terms of bio-diversity protection, we bump that planting rate up – not to the restoration standard of 10,000 stems per hectare because it's simply unaffordable for landowners, but up to about 2,500 stems per hectare. And we have a core range of about 8 to 15 species we use, which we find do establish quickly and develop ground spread very quickly. Now in addition to that, we are introducing to our environmental programmes another range of activities, which are specifically designed to provide on farm management options for control of nutrient run-off. We've taken on a new staff member for that purpose, Mr Vance Fulton, and I'll hand over to Vance at this point, just to give you a quick run-down on those options.

Vance Fulton
Thank you. As Colin's just said, the environmental programme's approach has been currently expanded to include a nutrient loss component. The methods include assessment of on farm nutrients, loading to the environment, constructed wetlands, interception structures and retirement or forestation of low productivity pasture.

With respect to the assessment of on farm nutrients, Environment BOP has engaged NIWA to produce a computer model specifically tailored to the Rotorua lakes catchment. This model is called NPLAS which stands for Nitrogen and Phosphorus Lake Assessment System, and will be used to determine nutrient loading to the environment from existing land uses and also used to predict what will be the loading from a change in land use. For example, on dairy farms we can assess what will be the implications if they put a feed lot on and feed these animals from that, rather than have them out in the pasture. For example, what will happen if we retire 10 hectares of pasture and put it into pine trees?

In appropriate locations, wetlands will be used. The use of interception structures such as denitrification walls (*next page*) is a new concept and Landcare Research, who have been trialling our sites for the last 6 years with sawdust walls have been getting very good results. This shows a very marked drop-off in nitrate levels down the slope of the denitrification wall (*below left*).

There needs to be a clarification.
They trialled another site and there were very permeable soils. The groundwater preferentially bypassed the denitrification wall, so there needs to be cautious as to where you actually place them, but they are a very effective tool in the appropriate location.



It is anticipated that over the next few years a number of other materials will be trialled in nutrient walls and interception structures. At the moment New Zealand Natural Zeolites are looking at trialling modified pumice and zealite for this purpose, and I think there are some other organisations who are looking at the same sort of thing.

Another option is the retirement of low productivity pasture. Here is a classic example of a steep hillside which is pretty poor production. Economically they are much more valuable to the property owner if that was converted to a wood lot. There's also slopes that are prone to erosion and rapid run-off, so actually converting that into forestry would be a significant reduction potential of phosphorus loss from the property.

QUESTIONS

Chayne Zinsli, Carter Holt Harvey Forests: Some information came out a while ago that the cost of restructuring planting is around $10,000 per hectare. Most restoration plantings fail normally in the first 5 years because of failure to maintain that restoration planting. I was interested to know what the sort of cost of the programme that EBOP's put in place is and how they deal with that maintenance issue.

Colin Stace: Our current revegetation model, this is at about 2,000 stems per hectare say, runs at about $7,000-$8,000 – it just depends a bit on the stock type. We try to use larger grade stock as much as possible, that's PB3, PB2 grade stock. We will use a little bit of Root Trainer stock, but only for fairly vigorous species or weedy species if you like, like manuka and karamu. And in programmes, we support our programmes with a grant rate and we programme in initial weed control, spot release in the first season and two spot releases in the second season. Now usually on a friendly site, because most riparian sites give us reasonably good growth, using our preferred list of species we'll get plants up to maybe 1200mm high by the end of the second season. At that stage we figure that they're pretty right, they don't need too much more annual weed control. But the other part of the programme we now include an environmental programme is site preparation, particularly brushweed control. Around here blackberry is our real nemesis. So we have a separate programme which means the site is properly prepared before we go in with

revegetation works. The cost of that can vary, if you do a lot of mechanical work such as logs and willow and rubbish like that to get out of the way, you can be spending $5,000-$7,000 per hectare. Or if it's just spraying, you’d get that done for under $1,000 per hectare.

The Rotorua Lakes protection and restoration action programme – evaluating options

Paul Dell: *Environment Bay of Plenty Lakes Project Coordinator – The Rotorua Lakes Protection & Restoration Action Programme*
John McIntosh: *Environment Bay of Plenty Manager Environmental Investigations*

ABSTRACT

Development of a programme to ensure success for the Rotorua Lakes Protection and Restoration Action Plan has been a very fluid process which has hopefully resulted in the critical components being identified.

Often when faced with an environmental problem the immediate focus is on the science and engineering to identify a solution(s).

If we are to see physical actions to protect and restore the Rotorua Lakes, the following modules of work must be linked from the outset. These are:

- Completed Research and Monitoring	- Ongoing Research and Monitoring
- Action Plans	- Funding
- Works	- Best Management Practices (BMPs)
- Education	- Regulations

It is the Action Plan process where the community will consider the science, the options, application of BMPs funding and use of regulations to achieve the long-term water quality goal for various lakes.

As part of the Lake Okareka Action Plan development the working group has developed a broad evaluation system to allow different options to be considered .

The evaluation system was developed using the results of detailed SWOT analysis undertaken by the group.

The initial evaluation has identified eight criteria against which options can be evaluated. The intention is that the criteria explain the strengths and weaknesses of the various options.

The criteria identified in rank order:

- Is the option proven
- What % of N target can option achieve
- What is the level of risk of implementing the option
- What % of P target can option achieve
- What is the time for reduction in nutrient impacts
- What is the cost per tonne of nutrient removed
- Will the option impact other values (+ve/-ve)
- Will it adversely/positively impact another catchment.

While people may debate some of the detail of the evaluations, hopefully the criteria will ensure we focus on what is important.

BACKGROUND

In 2002 Environment Bay of Plenty, Rotorua District Council and the Te Arawa Maori Trust Board adopted a "Strategy for the Lakes of the Rotorua District". This document, while not statutory was seen as crucial to ensuring a coordinated approach is taken in the long term planning and management for the Rotorua Lakes and their catchments (Figure 1). Each of the lakes and associated catchments are different and will require different management regimes (Table 1, Figure 2, *next page*)

The strategy identified a number of goals and tasks that needed to be addressed for the long-term management of the lakes. The goals were separated into four categories: protection goals, use goals, enjoyment goals and management goals.

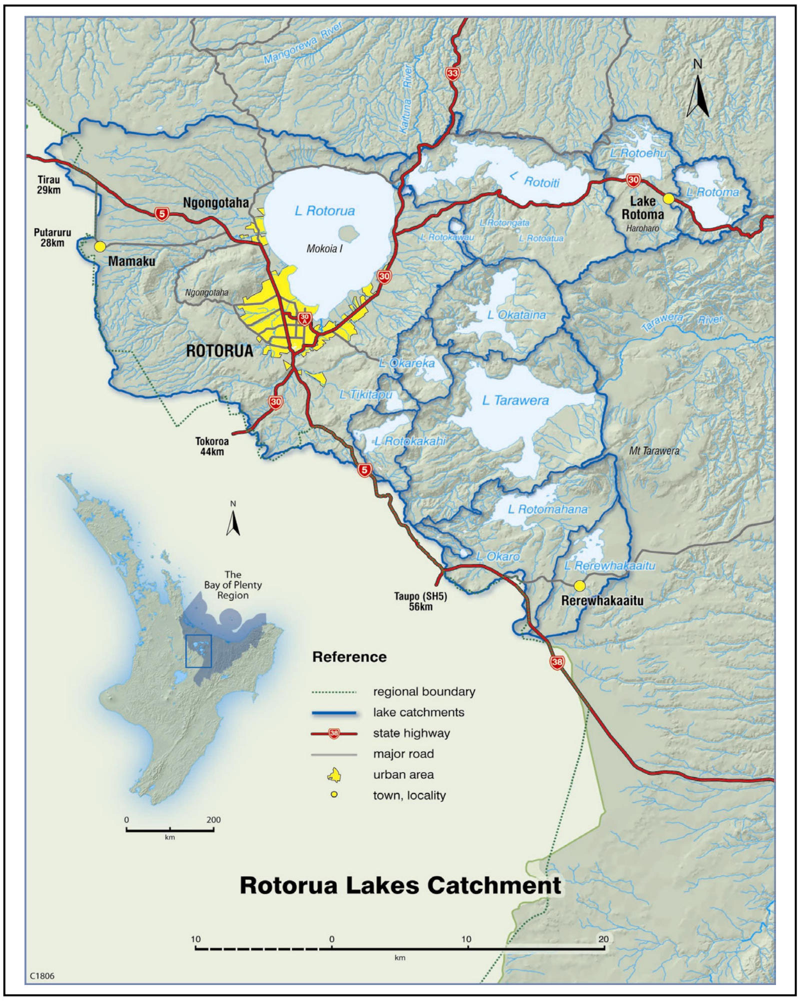


Figure 1

From a management perspective seven projects were identified that the various goals and tasks could be linked to: These are

- Water Quality
- Catchment/Riparian Protection
- Reserves and recreation
- Urban/Rural Growth Management
- Water Recreation
- Co-management
- Iwi Liaison

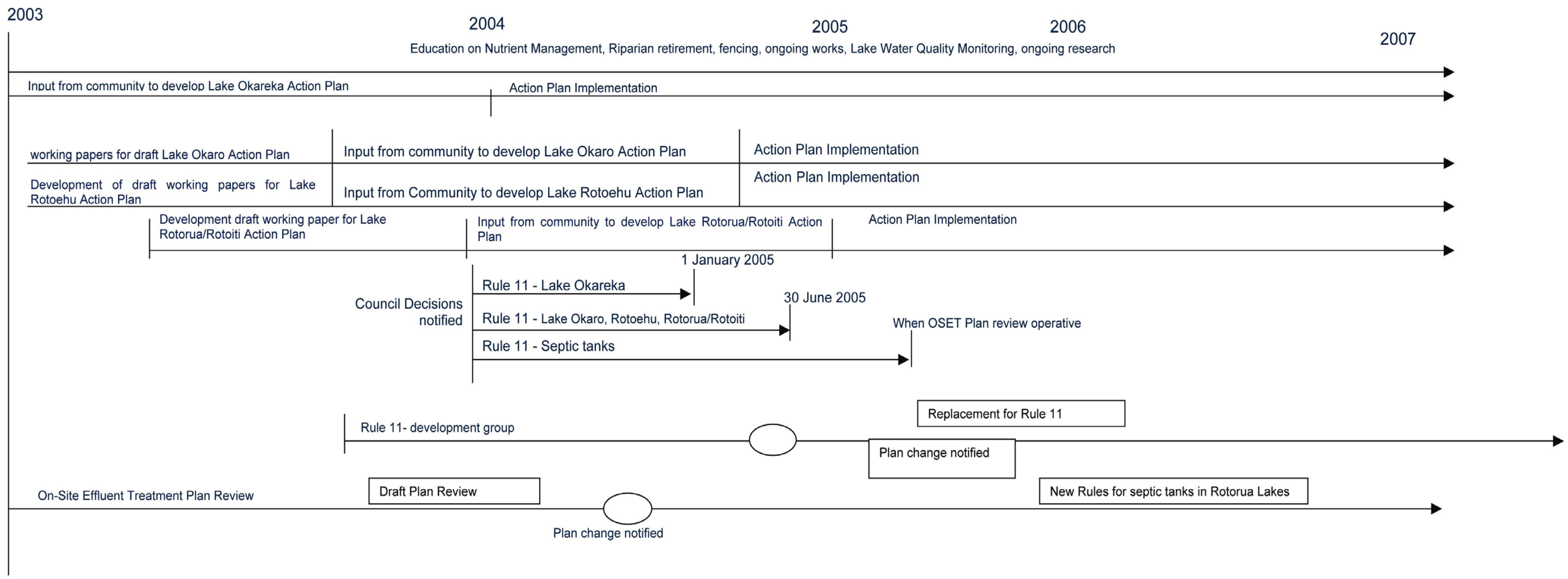
Table 1
General Lake Statistics (1997)

Lake	Catchment Area	Lake Area	Max Depth (M)	Mean Depth (M)	Age (x 1000 yrs)	% Pasture	% Indigenous Forest/Scrub	% Exotic Forest	% Urban	% Clarities	Trophic Status
Okaro	4.1	0.3	18	12	0.8	95	4	1	-	1.5	EUT
Rotorua	507.8	80.8	45	11	140	52	25	14	9	2.4	EUT
Rotoehu	56.7	8.0	14	8	8.5	40	30	30	-	2.5	EUT
Rotoiti	118.6	34.6	94	31	8.5	23	43	31	1	5.0	MESO
Okareka	18.7	3.4	34	20	19	56	38	3	3	7.9	MESO
Rerewhakaaitu	38.2	5.8	16	7	0.7	77	6	15	-	5.9	MESO
Rotomahana	86.0	9.0	125	60	111	42	43	14	-	4.2	MESO
Rotokakahi	18.7	4.5	32	17	13.3	27	26	47	-	6.8	MESO
Tarawera	144.9	41.6	88	50	5	22	60	16	1	8.5	OLIGO
Tikitapu	5.7	1.5	28	18	13.3	3	79	18	-	6.4	OLIGO
Okataina	56.8	11.0	78	39	7	9	85	6	-	8.9	OLIGO
Rotoma	29.1	11.0	83	37	8.5	23	40	32	1	10.6	OLIGO

Figure 2

Timeline for Action Plan Preparation

Figure 3.5a Lake Water Quality Management Timetable (updated July 2003)



The water quality project has been seen as being a priority project where much of the current work is focussed. It is also considered that the water quality project will drive the outcomes in many of the other projects.

A Rotorua Lakes Strategy Joint Committee comprising members of the three coordinating bodies has been established to overview implementation of the strategy.

Running almost concurrently with this process in 2002, Environment Bay of Plenty released the "Proposed Regional Water and Land Plan" which set out a proposed framework for managing the water and land resources of the Bay of Plenty Region.

The plan set water quality standards for the lakes, described as "managed state" or "natural state". The "managed state" classification recognised that certain lakes were affected by human activity and may have degraded quality. The "natural state" classification was to ensure that the lake quality is not altered by discharges and are protected in their existing high quality.

A Trophic Level Index was also set for each lake (Table 2). The Trophic Level Index is a numeric system for the monitoring of lake quality adopted by Ministry for the Environment. It is determined using measurements of chlorophyll, secchi depth, total phosphorus and total nitrogen. The TLI value integrates measures of key nutrients and algal production over a year, giving an indication of the overall quality of a lake. The TLI number increases as water quality decreases. It is seen as a simple means of indicating to the community the state of a lake.

The plan also specifies that where the 3-year moving average TLI for a lake exceeds its designated TLI by 0.2 for 2 years, then an Action Plan must be developed for the lake.

It will be noted in Table 2 that the top 5 lakes exceed their target TLI by 0.2 or more. Action Plans are being developed for these five lakes at this time. The timeline for the preparation of these plans is challenging but achievable if everyone works together (Figure 2).

Table 2
Trophic Level Indices (TLI) – Current and Management Target

Lake	**TLI in Objective 10**	**Current TLI (at 2001)**
Okaro	5.0	5.7
Rotorua	4.2	4.6
Rotoehu	3.9	4.5
Rotoiti	3.5	3.9
Okareka	3.0	3.3
Rerewhakaaitu	3.6	3.6
Rotomahana	3.9	3.8
Rotokakahi	3.3	3.3
Tarawera	2.7	2.8
Tikitapu	2.7	2.8
Okataina	2.6	2.6
Rotoma	2.3	2.3

At present the working party is close to completing the Proposed Lake Okareka Catchment Action which will be released to the community for comment. Working papers have been prepared for both Lake Rotoehu and Okaro and documentation for the Lake Rotorua/Rotoiti Action Plan is programmed to be available by the end of 2003.

THE ROTORUA LAKES PROTECTION & RESTORATION ACTION PROGRAMME

Historically much science has been undertaken into the quality of the Rotorua Lakes. However, if there is to be action to protect and restore the quality of the Rotorua Lakes it is essential that many other components of work and not just science are brought together.

Figure 3 (*below*) outlines the Rotorua Lakes Restoration and Protection Programme that has evolved over the last twelve months. The programme is focussed primarily on the Water Quality Project of the strategy. It will be noted that the nine project work areas cover everything from science to funding, from works to regulation and education to process. Every one of these work streams is critical to the long-term protection and restoration of the lakes.

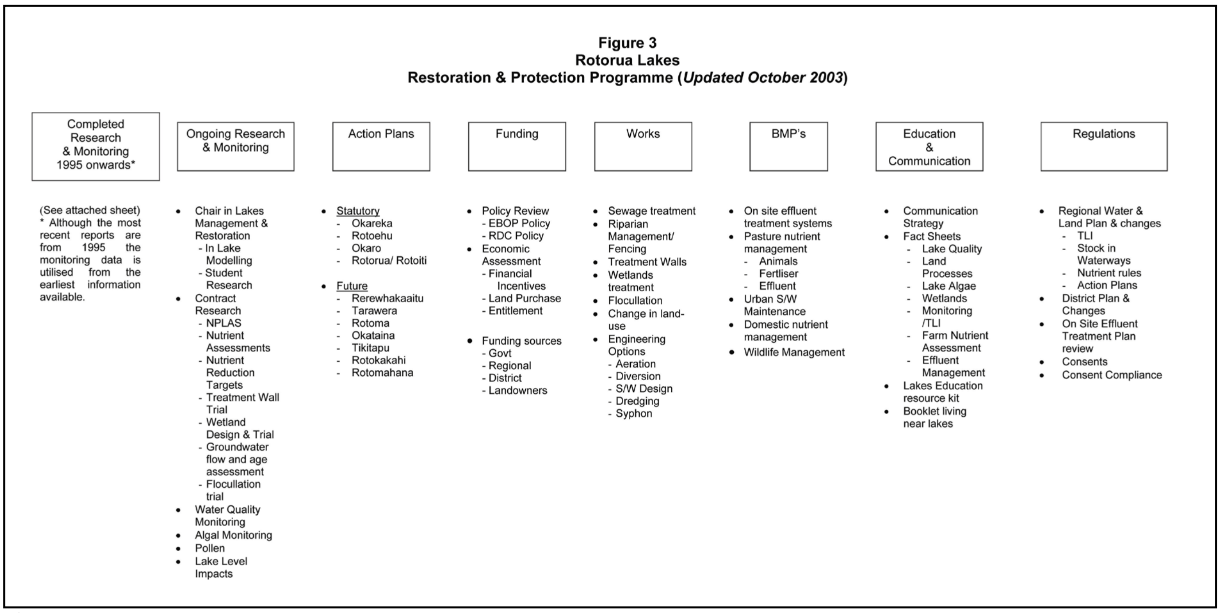


Figure 3

The programme is regularly updated as new issues arise. The development of Action Plans for the lakes is seen as the process to be used to determine with the community the actions to achieve the water quality targets.

ACTION PLAN DEVELOPMENT

The proposed Water and Land Plan identified the requirement to have a process by which the necessary actions to protect and restore a lakes water quality can be determined. Method 35 of the proposed Plan states:
"Develop and implement action plans in conjunction with appropriate parties to determine the measures necessary to improve water quality where a lake exceeds its Trophic Level Index. Measures to address the effects of existing land use include, but are not limited to:

(a) Riparian Retirement
(b) Land Acquisition

(c) Review of existing discharge consents in the catchment
(d) Education on nutrient export programmes and budgets."

Action Plans will include fair and equitable provisions to address effects on existing land uses where it is necessary to restrict land use to maintain or improve water quality.
The role of the Action Plan is to work with the community to:

- Reach agreement on the overall existing nutrient budget for a Lake Catchment.
- To determine what level of nutrient inputs is sustainable with respect to achieving the TLI.
- To identify the nutrient reduction targets for Nitrogen and Phosphorus.
- To determine what actions are to be taken to achieve the reduction targets.

One of the most critical and probably most difficult aspects is to reach consensus on the scientific information and its application to resolving the Lake Water Quality problem.

PROPOSED LAKE OKAREKA CATCHMENT ACTION PLAN
It was decided to undertake development of a proposed Lake Okareka Catchment Action Plan as the majority of the information was known, the issues in the catchment were considered to be less complex than those of other catchments and it was seen as a good opportunity to develop and assess how the Action Plan process would evolve.

Although the process is still evolving much has been learnt with respect to the needs of the community and how to work with the community to achieve "buy in". As already commented on, one constraint is "time" or to be precise the lack of it. However the community has demanded urgency and we must all do our best to meet this expectation.

Early in the process the working party discussed a range of options to reduce the lakes nutrient load. A SWOT analysis was undertaken for each of the options considered worthy of evaluation.

From the SWOT analysis a draft evaluation system to help assess the options was developed. This draft system was then further refined by a focus group consisting of working party members and council staff. The refined draft was referred back to the full working party and following their comments the focus group is still fine-tuning the evaluation system but the overall concept is fairly well developed. The criteria and assessed weightings are presented in Table 3 (*next page*).

Evaluation of Nutrient Reduction Options

Criteria (in rank order)	Weighting
Is the option proven	3
% N target the option can achieve	2.5
% P target the option can achieve	2.5
What is the level of risk in implementing the option	2
What is the cost per tonne of dominant nutrient removed	2
What is the time for reduction in nutrient impacts	1
Will the option impact other values	1
Will it adversely/positively impact another catchment	1

The following is more detail of each of the criteria

Is the Option Proven

This criteria reflects how tried and proven a given option is. For example while the design of sewage schemes is well-proven other emerging technologies have only had limited field trails with variable success.

(ii) &(iii) What % N or P target can option achieve

These criteria are important in "adding up" the nutrient tonnages to be removed relative to the target.

What is the level of risk in implementing the Option

This criteria recognised that some options can be implemented with greater certainty while others require consents, property owners co-operation, community support.

What is the cost per tonne of dominant nutrient removed

This criteria is about cost/benefit of an option. Some options can be of low value but remove very little nutrient. More detailed work is being done on this.

What is the time reduction in nutrient impacts

This evaluates the estimated time for the majority of nutrient reduction to the lake to occur.

Will the option impact other values (+ve/-ve)

Although this was subjective it helps identify other values: e.g. Impact on landscape, biodiversity, fishery.

Will it adversely/positively impact another catchment

This criteria recognised that some options could impact on another catchment e.g. discharging nutrient-laden water.

The focus group who have developed the evaluation system have concluded that:

- The evaluation system gave a broad framework which would allow variations within and between options to be evaluated.
- The system is flexible enough to allow comparisons between different options.
- The system has identified the relevant criteria that define the explanatory aspects of a particular option.
- The scoring is no longer relevant once the priorities are identified and detailed evaluation completed.
- As used to date the system has identified more favourable and less favourable clusters.

At this point in time the working party is close to identifying the agreed actions for the catchment.

SUMMARY

Development of a programme to ensure success for the Protection and Restoration of the Rotorua Lakes has been a very fluid process which will hopefully ensure the critical components are identified.

All components of the programme are critical to the success of this work.

It is the Action Plan process where the community will consider the science, the options, applications of BMPs, funding and use of regulations to achieve the long-term water quality goal for the various lakes.
Action plans are currently programmed for lakes Okareka, Rotoehu, Okaro, Rotorua and Rotoiti.

As part of the Lake Okareka Action Plan development, an evaluation system comprising a number of criteria has been developed to allow the different options to reduce nutrients to be assessed.

The initial evaluation has identified eight criteria against which options can be evaluated. The intention is that the criteria explain the strengths and weaknesses of the various options.

QUESTIONS

Bruce Thorrold, Dexcel: Paul, in that graph of the lakes you highlighted the five that weren't meeting the trophic index. Given the warning signals that Bill Vant and Kit Rutherford talked about this morning, what plans if any do you have for pre-emptive action on the seven, I guess it must be, that are meeting their trophic index targets?

P.D.: I think David Hamilton covered some of that and we're actually doing monitoring

and looking at the lakes. I think the science and a lot of the work we're doing on those crucial ones right now, and you've seen a compressed time-line, will flow through into those other lakes quite quickly. I would expect there will be action plans on the table for all of the lakes in a fairly reasonable time-line. So we're not just focusing on the five and saying that's it, we're saying these are the urgent ones, but we're not losing track of those other ones. There's a lot of work going on and David's work on some of the ones that aren't heavily developed are showing some warning signs too, so we should give regard to that.

Kepa Morgan, University of Auckland: You've just mentioned action plans and I guess the concern for the tangata whenua is, in what context are those action plans going to be drafted and whose input is going to be incorporated in terms of how they come together?

P.D.: In the whole process of the action plan, if you look at Okareka and right through from the strategy at the top end, Iwi are identified as an important player in the whole process, so they would be part of working through the process, putting their values on the table, putting their issues and working through it. So we see that as a core part of any work and we'll have to determine whether that is going to be at hapu level or, depending on what lake catchment we're in, who the relevant people are and how that consultation process will take place.

Options to manage nutrient inputs

John McIntosh
Environment Bay of Plenty

INTRODUCTION

Environment Bay of Plenty's policies relating to lake quality are developed in the Proposed Regional Water & Land Plan (RW&LP), released in February 2002. Submissions on the document closed in May 2002 and the final version will be released in February 2004. The Proposed Plan was based on submissions received on the Draft Plan. The policy development was therefore based on public consultation relating to the previous two years. In fact lake policy related back to the policy developed in the Regional Plan for the Tarawera River Catchment and the eight of the Rotorua lakes in the headwaters of this catchment. So the basis of Environment Bay of Plenty's lake policy was developed in the process beginning in the early 1990s.

Since 1993 certain areas of the Rotorua lakes have been subject to annual blue-green algal blooms. In addition to that the Rotorua lakes have experienced a number of unusual events in recent times e.g. the waternet invasion, the foam algae and in early 2003 algal blooms across the whole of Lake Rotoiti. This last event resulted in a concerted call for action from the public. The response has been enabled by enacting the policy developed in the RW&LP. Method 35 of the Plan is the principal method dealing with lake quality issues and calls for the development and implementation of action plans for lakes that do not meet the baseline quality of the RW&LP.

A baseline quality was set in the Plan as a Trophic Level Index (TLI) for each lake. The level at which it was set was an outcome of the public consultation process where people said that the lakes should not get worse than they were now and some should be improved. The TLI index combines total nitrogen, total phosphorus, chlorophyll *a* and secchi disc clarity into a numerical guideline. Five lakes, Rotorua. Rotoiti, Okaro, Okareka and Rotoehu already exceeded the baseline quality so a period of 2 years was set, in the Draft Plan, for the implementation of action plans for these five lakes. The event on Rotoiti last summer resulted in that timeline being shortened.

NUTRIENT MANAGEMENT

Nitrogen and phosphorus are the primary limiting nutrients for biological communities in the lakes and management of lake quality involves managing the supply of these two nutrients to the lakes. A lot of energy has been consumed arguing the merits of limiting one or the other of nitrogen and phosphorus in certain lakes. The general consensus has always come down to management of both. Blue-green algal blooms are associated with the more eutrophic lakes which have nutrients re-cycled from the sediments in release events when the bottom waters are anoxic or low in oxygen. Such events supply nitrogen and phosphorus in a low N:P ratio, which favours blue-greens as they can 'fix' their own nitrogen from air dissolved in the lake water. Predominantly, these lakes are ones which stratify intermittently. The only lake that has blue-green algal blooms and does not have sediment release events is Lake Tarawera. However, Tarawera has a large inflow of geothermally sourced water from the Rotomahana catchment that has a low N:P ratio (White & Cooper, 1991), which could explain the occurrence of blooms in this lake.

Of the five lakes that exceed the TLI baseline of the RW&LP, four experience some degree of nuisance from blue-green algal blooms.

OPTIONS FOR NUTRIENT MANAGEMENT

Two basic strategies are proposed – land management and direct intervention.

LAND MANAGEMENT

Riparian Retirement
Environment Bay of Plenty and its predecessor organisation employed riparian retirement as a tool to control erosion and to limit nutrient inflow to lakes. Large areas of stream banks and lakeside verges have been fenced and retired from grazing. Some areas remain to be completed. This has resulted in a huge infrastructure of land where management in the future can be targeted at nutrient reduction methods as well as other issues such as biodiversity. Development of such methods is a challenge for the future and Environment Bay of Plenty has initiated the process by appointing a Land Management Officer- Lake Quality for the purpose of investigating and implementing nutrient control measures.

The land retirement, that's another one of our main tools. I won't add any more to what's been said, except to say that around these Rotorua lakes we have a huge infrastructure of retired lands, with the fencing in and the vegetation there. We've heard from Kit's presentation that it's not particularly effective at the moment, so I think the challenge for us in the future, and Vance will probably be leading the forefront there, is looking at ways that we can enhance those areas to get better nutrient reduction.

Pasture to Forest
Conversion of pastoral land use to forest reduces the export of nitrogen and phosphorus. In the Lake Okareka Action Plan process the economics of land use change is being investigated. Also different mechanisms to achieve afforestation will be advanced.

Wetland Construction
A project is currently being funded by Environment Bay of Plenty in the design of constructed wetlands at lakes Rotoehu, Okaro and Okareka.

Lake edge wetlands of rushes and raupo are also important areas where nitrogen is stripped from water flowing into lakes. More of these areas can be established and the preservation of existing areas will be promoted.

More wetland construction shown there at Lake Okareka, with some of the water from the stream coming in at the bottom. It's been piped into these wetlands. Also the edge has been retired and one of the things to look at here is that lake edge riparian area. The rushes

have presumably been grazed back from the shoreline before it was retired, and so hopefully along that shoreline they will re-establish and we can give them a hand by planting more. And in this catchment Max Gibbs did a study in 1994 or thereabouts, looking at the riparian wetlands further round the catchment, and they were very effective in reducing the nitrogen going into the lake. So this will be an added benefit of that lake edge retirement.

Sewage Treatment

Nutrient reduction can be achieved by community schemes or by advanced systems for individual properties. At Lake Okareka, a community scheme of some sort is a probable solution to reducing the nutrient load on the lake.

Best Management Practices (BMPs)

An underlying principle that will be advocated is that of efficiency of land use i.e. that for any land use the most nutrient-conservative method of carrying out an activity that is consistent with the general objectives of the land use should be chosen. Best Management Practices (BMPs) will be developed with the community. BMPs are seen as being environmentally responsible but not as methods of achieving the major nutrient reduction targets for action plans.

DIRECT INTERVENTION

There are long delays in the effects of land management working through to lake quality improvement. To get a more rapid response that the public demands, more direct methods are proposed.

Phosphorus Precipitation

A trial is planned to be carried out in Lake Okaro, once approvals are obtained, to treat the lake with alum to precipitate out phosphorus. Another product, Phoslock, which is a bentonite clay and lanthanum mix will also be trialled in the future. Lake Okaro is used for water sports and reduction in the phosphorus levels in the water should make the lake less likely to suffer blue-green algal blooms.

In addition to the above two products a host of proprietary products are currently marketed where the marketers claim benefits for water quality. Few have been tested on a lake-size scale. Other products are being developed, some of which use locally- based raw materials. Environment Bay of Plenty will encourage the testing of some of these.

When we were on our field trip with Jake Peters, Del Bottcher and David Hamilton before the symposium, we stopped at Hamurana Springs and we also talked there about treating that high phosphorus input using alum with a regular dosing station. And I think we worked out that about 6 tons of phosphorus a year goes into Rotorua from that source alone. It would be as a one-off hit, and it would be possible to reduce the phosphorus by quite a large amount, so there was a good discussion at that site.

Treatment Wall

The objective of a treatment wall is to intercept nutrient-laden groundwater with a carbon source through which the groundwater flows. The carbon promotes denitrification and lowers the level of dissolved nitrogen in the subsurface flow.

This is looking further along that Lake Okareka shoreline from the Lake Tarawera end. What you see are those pieces of land jutting out into the lake. They are actually the outwash fans from the high plateau of the Playnes' farm, and in our action plan working party it was suggested that we should be looking at treatment walls along this edge here. So we did some initial investigations and the groundwater does flow quite shallow region just along that edge. It possibly could be more effective enhancing that edge with the riparian wetland vegetation, although it's an exposed shoreline. So that might be another option there

Oxygenation

A large number of businesses in New Zealand have technologies that can be used to inject oxygen into hypolimnetic (lake bottom) waters. These are being compiled predominantly for the purpose of renovation of Lake Rotoiti. The action plan process for that lake will evaluate the findings.

One of the direct intervention methods that we've looked at, and we're trying to get some documentation on, so that when we go to the Rotorua/Rotoiti working party at the beginning of next year, we will be able to put costs on the table and look at feasibility of, is oxygenating. That would involve a piece of plant somewhere along the shoreline. Perhaps you might put it on a raft, you might have trucks carrying liquid oxygen, so there are a lot of issues that would concern people about that. But it could be effective in oxygenating the bottom waters of Rotoiti, and I think we heard Max saying that phosphorus releases begin when the dissolved oxygen drops down to 6 parts per million, so it does take a lot of oxygen. A little bit would be a waste of time really, you would need to oxygenate the whole of the hypolimnion of Rotoiti to be effective.

Stream Diversion

Investigations are being undertaken to determine the effects on Lake Rotoiti of diverting the Ohau Channel flow from entering the main body of Rotoiti i.e. the eastern basin. Rotorua water provides a large load of nutrients to the eastern basin, however, the Ohau Channel water provides oxygen and it also reduces the retention time of water in the eastern basin.

Diversion options would be to direct the flow into Okawa Bay or to prevent the

Ohau Channel under-flowing to the east with some form of barrier ie direct the Ohau Channel flow towards Okere Falls.

Another prospect has been proposed by Max Gibbs, NIWA. This is, that the intake to the Ohau Channel be extended further out into Lake Rotorua to avoid the re-suspended sediment in the shallow zone near the inlet being transported down the Channel. The nutrients and BOD (biochemical oxygen demand) would then be excluded from Lake Rotoiti.

Hypolimnetic Discharge

This has been proposed for Lake Okareka and also raised as a method of remediation of Lake Rotoiti. At Lake Okareka, the outlet discharges through pipes below the surface of the lake. If the pipes were extended to the bottom of the lake, the discharge would be sourced from the lake bottom waters. When nutrients are released from the bottom sediments, they could be discharged before mixing into the main body of lake water and so would not contribute to the biological productivity of the lake. This would be akin to diverting an inflow of nutrients to the lake.

At Lake Okareka it has been calculated that this method would be effective in reaching part of the phosphorus target for nutrient reduction but have little effect on reaching the nitrogen target. It would also be possible to treat the water before it was discharged to Lake Tarawera.

People have also raised this in phoning us up about Lake Rotoiti. The situation at Lake Rotoiti is a lot more extreme. You would need a huge pipe work and there would be a big load of material that I don't think people would readily like to see discharged into the top of the Kaituna. So the issues with Rotoiti are several orders of magnitude greater than at Okareka.

CONCLUSION

There are options available to enable nutrient management in the catchments of the Rotorua lakes. The actions require the process outlined by Paul Dell in the previous paper to be completed. Some of the proposed actions will require the public process of RMA resource consents as well. However, as time progresses direct intervention methods will become more widely tested and will be available to be used at short notice. The Action Plan process will determine the gains in nutrient reduction that can be made through land management. The limitations will also be highlighted. There should therefore be optimism that the Rotorua lakes will be managed to meet the aspirations of the community. This should be tempered by the knowledge that the lakes are a natural ecosystem with numerous communities of organisms responding to the particular conditions that apply at any given time. What we might call 'unusual events' such as waternet invasion, foam algae or perhaps algal blooms across the whole of Lake Rotoiti,

will occur from time to time and will have to be managed. Sometimes that will involve warnings and avoiding contact with the water.

REFERENCES

White E and Cooper A B 1991: A desk study of the nutrient load on Lake Tarawera, with an assessment of prospects for lake water quality management by manipulation of land use or point nutrient sources. February 1991. Prepared for: Director, Science and Research Conservation Sciences Centre, Department of Conservation.

OPEN FORUM

Chair. The format this afternoon will be that this is a general forum for all of the afternoon. Effectively there are three parts to it:
To start off with there will be questions specific for Paul Dell and John McIntosh, because there wasn't the opportunity for them to respond to your questions during their session.
Once those questions are exhausted, we will move seamlessly to questions on any matters whatsoever, except policy.
And the third part of the session, which will be after the afternoon tea break, we will have members of the Lakes Strategy Joint Committee here from the Rotorua District Council and Environment Bay of Plenty to answer questions on policy, to discuss policy, to hear what you have to say on policy.

After that Professor Silvester will sum up and the meeting will be closed by the Right Honourable Paul East QC. So that's the pattern for the afternoon. I have three requests to make please. Firstly, please be courteous as I know you will be, secondly – please keep to the point and thirdly, please be brief. There isn't time for long speeches and everyone to have their say. So we'll start the first part now – and it's questions specifically to Paul Dell and John McIntosh on their presentation please. If you could say your name and affiliation when you rise please.

Bruce Thorrold, Dexcel. Paul, in that graph of the lakes you highlighted the five that weren't meeting the trophic index. Given the warning signals that Bill Vant and Kit Rutherford talked about this morning, what plans if any do you have for pre-emptive action on the seven, I guess it must be, that are meeting their trophic index targets?

Paul Dell, EBOP. I think David Hamilton covered some of that and we're doing monitoring and looking at the lakes. I think the science and a lot of the work we're doing on those crucial ones right now, and you've seen a compressed time line, will flow through into those other lakes quite quickly. So I would expect there will be action plans on the table for all of the lakes in a fairly reasonable time line. So we're not just focusing on the five and saying that's it, we're saying these are the urgent ones, but we're not losing track of those other ones. There's a lot of work going on and David's work on some of the ones that aren't heavily developed are showing some warning signs too, so we should give regard to that.

Kepa Morgan, University of Auckland. You've just mentioned action plans and I guess the concern for the tangata whenua is, in what context are those action plans going to be drafted and whose input is going to be incorporated in terms of how they come together?

P.D. The whole process of the action plan is, if you look at Okareka and right through from the strategy at the top end, Iwi are identified as an important player in the whole process, so they would be part of working through the process, putting their values on the table, putting their issues and working through it. So we see that as a core part of any work and we'll have to determine; is that going to be at hapu level or, depending on what lake catchment we're in, who the relevant people are and how that consultation process will take place.

Ian McLean, Chair: We're now in general forum and the floor is open for questions,

expressions of opinion (briefly) and for general reactions. The floor is yours.

Paul East, LWQS: Could I ask a question from a lay perspective, it seems that one of the contributing factors to the problems we're facing, that we don't know the answer to from a scientific point of view, is whether the oxygenated waters of Rotorua are beneficial or otherwise to Lake Rotoiti. And work, as I understand it, is going ahead at pace on that issue, so that we can ascertain whether it's best to divert the waters in their entirety or not. But that leaves the question of the nutrient enrichment of Rotoiti's waters through the Ohau Channel. Is there a potential for some sort of biological stripping or some other sort of action that can take place to reduce the nutrient enrichment of those waters before they reach Rotoiti?

Chair: I wonder if perhaps we might ask Del Bottcher to respond to that, if he would care to.

Del Bottcher, Soil & Water Engineering Technology Inc.: I guess I received that question because we build really big systems. I think if we were to do a stripping, it would be a pretty major undertaking to do that. I'm not saying it couldn't be done, but just from the quantity of water and the location I would think it would be somewhat difficult to construct a facility of that nature that would be effective enough to take out the materials. Biological stripping takes even more retention time and when you start talking retention time for reactions, you're talking fairly large storage units in order to do that. If you considered perhaps using a portion of Rotoiti as a treatment arm – I know that suggestion probably has a lack of appeal – but that has happened and we've done that. There were certain sections of the lake system that would be taken off and in some respects sacrificed for the betterment of the rest of the lake. But I haven't had the opportunity to really look through it.

Max Gibbs, NIWA: John McIntosh referred in his presentation to the option of introducing wings out into Rotorua. The preliminary data that looks at the transported nutrients through the Ohau Channel would suggest that weather moves 80% of the nutrients. This could be avoided simply by moving the intake of the water going through the Ohau Channel to a minimum of 200 metres offshore. In other words, the way the wash zone resuspends the inshore nutrients which are currently going down the Ohau Channel, might be avoided by going offshore. There would be some other side-effects to this, possibly, silt that would need to be dredged or some other action needed, but that is a possibility that could be useful to do.

Nick Miller, LWQS: Can I comment further there? Max is probably too polite to say this, but I know he recommended that option in a report he wrote quite a number of years ago. Perhaps it's a pity that report wasn't read more carefully.

Kepa Morgan, University of Auckland: Del Bottcher suggested what I believe a lot of residents of Rotoiti believe to be one of the fundamental causes of the problems that we have out there. In terms of looking for a solution to the high nutrient load coming from Rotorua, your suggestion was to use an arm of Rotoiti. Rotoiti people actually believe that it had a serious impact when they opened up the Ohau Channel to avoid flooding of Rotorua properties. Just after that they realised that they had levels of Rotorua that were too low, as I understand it. They also wanted to protect the farmers out at the coast from flooding, so they put the flood gates at Okere. That then meant that they had to raise the

levels of Lake Rotoiti, so that Rotorua could have the lake levels that they desired, but not have the fluctuations and storm events that cause flooding. So my perception and I'm sure it's that of many others who live at Rotoiti, is that Rotoiti has borne the brunt of those engineering efforts to try and improve the lot for Rotorua. And what happens is, if you get a fresh in the Rotorua catchment, pretty much it goes straight into Rotoiti, because it's got a larger capacity to hold that water and because of that, we basically just pick up all the problems from Rotorua. So I'd be interested in anybody commenting on that – why haven't we actually looked at what happened in terms of that system when Ohau Channel was opened and when those head water gates were put in at Okere?

Don Atkinson, Okawa Bay: I just had an idea floating around in my mind and I'd like to test it amongst the participants here, and that is for the District Council to in actual fact encourage in our rural areas a change to an organic lifestyle planting situation, and effectively allow and encourage sub-division effectively. And that would allow higher producing properties to migrate through to a lifestyle-type property and an organic regime. I can see that significantly reducing fertiliser use, allowing people to move from a high agricultural base to a probably more profitable base (capital-wise as far as selling the property goes, so they get all of their money out) and also allow a significant reduction in nutrients.

J*ake Peters, USGS*: Well if you put less fertiliser on or you don't fix as much nitrogen in a landscape, then less is going to end up in groundwater and moving out of there. I think that's what all of the agricultural research is showing, so if you go to organic farming – is that something that is more effective at retaining the nutrients? So far from what I've seen in the US it is, but in terms of production and other issues, I can't really comment , because you're talking about the economics of that change and the change in the lifestyle to the people who are affected. So that's a management issue and a policy issue.

Chair: What about the other part of it, shifting to urban with large lots?

Jake Peters: Shifting to urban – well, from what we just saw from the stormwater issue, that seems to be relatively benign. Maybe not for other contaminants, but certainly for nitrogen and phosphorus. So maybe that's a reasonable alternative, but that also has knock-on effects because it increases traffic, increases a lot of other things in the basin that have negative consequences in terms of run-off, such as increased imperviousness and associated increases in sediment loads. You have to be designing run-off systems as well to handle that. So there are a lot of factors that when you change your land use, you have to consider.

Paul Dell, EBOP: Just to touch on the economic aspects that Don's raised, the focus groups have been working in Lake Okareka to look at the very aspect of it. If you take for example change of land use, what does that mean – not just in terms of the person who may sell land and get the capital value, as Don says, and do something else. But there are multipliers into the economy and so we are trying to make sure that any decision we make, we have the full information to determine that if you do move away from a particular land base to another land style, what that means in terms of, for example, the economy of the district, the economy of the region in terms of contributing to the bigger GDP. So that has to come into the picture as well.

Councillor Brian Riesterer, Environment Bay of Plenty: It takes a councillor to have a

bit of a view on this, but I think that one of the big issues that Paul raised before when he gave his presentation was the plans that were being made and issues that are going to need to be raised for Rotorua and Rotoiti. And Kepa just brought up what I consider to be a major issue on those two lakes and that is that basically the people of Rotoiti feel that they're sucking the raw end of the sausage from the people of Rotorua. And that is simply because all of Rotorua's nutrients are being transported to Rotoiti. And I'm really interested in understanding, as a Councillor, how the Regional Council and Rotorua District Council are going to get two diverse communities together to make a combined action plan on the Rotorua/Rotoiti issue. If some people could come up with some real wisdom (maybe Jake Peters had the best piece of wisdom of all, right at the beginning, when he said he wanted us to take over some of the American lawyers), then maybe we should really seriously examine the law issue as well and stay away from making objections to the land plan. Thank you, I'll stop there.

Chair: Well now, that's quite a talk there from a Councillor. Thank you Brian.

Graham Ross, LWQS: Just a comment on the organic side of suggestions. It was very interesting reading recently in one of our agricultural journals, where England have been financing growers to go organic and they had to sign up for 5 years. For the first grower to sign, the 5 years are up and he's gone straight back to ordinary agriculture, because financially he cannot survive. And the article was stating this was probably true of all those who've gone into that type of farming.

I think we ought to get a bit of clarification from Councillor Riesterer as to which side of the objections to the water and land plan he believes we should withdraw?

Brian Riesterer: I don't have any comment really. I mean Paul Dell got up this morning and explained it to everyone in this room. Let's focus on the nitrogen and phosphorus. If we don't focus on that, we're going to lose the plot. If we decide that our answer to it is objecting and protesting and doing all of that, we will lose the plot. Paul put the issue in front of everyone in this room - keep the focus there – that is the issue.

Chris Hendy, University of Waikato: I didn't get the opportunity to talk before, but I would like to spend 5 minutes. I shall be very brief, but what I want to talk about is the phosphorus and the nitrogen – the phosphorus in particular, that's sitting at the bottom of the lakes and what happens to it, particularly in Lakes Rotorua and Rotoiti.

Rotorua, being shallow and a bit windswept, turns over very frequently and doesn't develop a very pronounced oxygen minimum for very long. This keeps the sediments with oxygen in them at the top, which prevents the iron and manganese from releasing the phosphates. They act like a glue and hold the phosphates to the sediments. So the phosphorus that's falling out of the lake to the bottom is largely still there.

Rotoiti, on the other hand is deeper and more sheltered. If the algae are falling to the bottom and stripping the oxygen out, that has the consequence that the iron and manganese, which are attaching the phosphate to the particulates, let go and the phosphorus that's been taken to the bottom is on its way back up into the lake again. That's going to happen in every lake where the lake becomes stratified and where bottom waters become anaerobic. We're seeing that happening in Okaro, Tikitapu and Okataina

and I expect we'll see another later on here.

Unfortunately, once that starts to happen you are releasing a larger quantity of phosphate into bottom waters than you've carried in that year from all the run-off water. So when that water turns over at the end of the summer/autumn period, it comes back to the surface, it then sets up again an even bigger eutrophication than the year before.

My own interpretation is that's what's happening in Rotoiti at the moment. We've gone through a phase where we could conceivably have cut the nutrients off in Rotoiti by diverting the outflow from Rotorua, to a situation now where it would be very dangerous to do so, because you're also cutting off the flow of water carrying out some of the surface nutrients. So I'd be very wary about letting Rotoiti go it alone at this stage or we might then find we've got a permanent bloom happening in the lake. There are some lakes in which this hasn't happened and I think that we should focus part of our attention to making sure that this never happens, and Rotoma would be a prime example. So I would give a higher priority to keeping what we've already got, before the next priority of trying to recover loss.

Chair: Thank you very much, Chris and that's well said. We'll quote you directly in the next submissions that we as a Society make on the Annual Plan for Environment Bay of Plenty.

Colin Curry, Rotoiti: I'd like to reinforce the comments made about Rotoiti. For the first time our lake turned green, fluorescent green. The impact of that, of course, is that my wife and my children got very upset and people will tend to ask questions of why this has happened. So therefore, anyone who thinks that the resources that are getting applied to whatever the solution may or may not be, please bear in mind that if a reasonable amount of resources don't come to Rotoiti, then we will have to do things to make sure we get it. So, the focus should be very much on a joint effort, but at the moment I would have to say that the wetlands, the bushlands, the roads, the public access to Rotoiti, is a very poor relation to the other lakes and I don't know why that is, but I would be very happy to change it. Thank you.

Chair: If it's a question of the public provision of facilities, we can deal with that in the second part of this forum.

Robin Sinclair, LWQS: This question actually dates back to 1982. In 1982 the scientists looked very carefully at the situation of the Ohau Channel and its discharge into Lake Rotoiti. The reason, that they looked at that, as we were told this morning, is that we've some very high nutrient values. They also at that particular time considered diverting the bottom end of the Ohau Channel so that the overflow actually went down the Okere arm, so avoiding it going under the warmer waters of Lake Rotoiti and down to the eastern end of Rotoiti. That was 21 years ago. My first question is, if it had been diverted then and we had not received that nutrient until today, would Lake Rotoiti be in the same condition as it is now?

Chair: Well this is an 'if' question. Who have we got amongst our scientists who is prepared to answer it? Max, you gave a paper on this subject.

Max Gibbs: Thank you. It is all speculation. If it had been diverted at that time, the

prediction was that we'd get worse very quickly for the first few years and then it would gradually improve. The getting worse for the first few years would make what you saw last summer look like clean water, unless you oxygenated the bottom of the lake. So there has to be more than just one action, you can't just simply divert the water, you have to divert the water and replace the oxygen. Now if you'd done that 20 years ago, which was feasible by the same engineering processes that we know today, it's very likely that the lake would have been well on its way to recovery at the moment. A little bit of procrastination I'm afraid.

Kepa Morgan: What if we removed the head water gates at Okere and reinstated the flow restrictions that used to exist at Ohau Channel? The engineers should be able to tell us, from Environment Bay of Plenty?

Jeff Jones, Environment Bay of Plenty: When the scheme was designed, there were a lot of issues that needed to be considered by the Rotorua community, not the least of which was the level of the lakes. There was just as much noise coming from Rotorua as we're hearing now about the quality of the lake, about the quantity of it – i.e. the level of it. We had just gone through a period of extreme rainfall in the mid '60s, and those of who were around in those days will remember that the road around Lake Rotoma actually had to be lifted because it was being flooded, and this wasn't flooding on a periodic basis, the lake level was rising. Now you can contrast this to the situation in Lake Rotoma a couple of years ago when the lake level dropped so low that the island in the middle that everybody believed was there came out of it. Those were issues that had to be considered. The structure at Okere and the structures that we have constructed at the front end of the Ohau Channel are to control lake levels within the limits set by the Resource Consent that the Regional Council holds.

When I first came here, which happened to be in 1982, the resource consent that was authorised in those days said that we had to maintain those two lakes between levels plus or minus about half a metre. We're now trying to maintain them between levels plus or minus three hundred millimetres, because that's what the community wanted. And I would be happy to show Kepa the objections both for and against the latest resource consent, where some people wanted the levels to be let go and others wanted them tighter. There are people like the tourism operators who need to have a sufficient level in Lake Rotorua so that they can land their float planes and they can get those other boats out onto the lake. On the other hand, there are concerns about high levels affecting septic tanks in the communities in and around the lakes.

That's why the control structures are there, they enable us to manage the outflow from the lakes, because as Colin Stace pointed out this morning, those works are part of a comprehensive catchment control scheme, which considers the flooding in the lower reaches of the river at the same time. That's why they are there. The initial decisions were made in the late '70s when the scheme was approved – approved not only by the local people, but also by central Government. The level aspect of them has been reconsidered several times when resource consents were renewed and each time it's been a community consultation process. There are other issues to be considered and in terms of the work that was done on the Ohau Channel, that was done a little ahead of the Kaituna Catchment Control Scheme and was to avoid flooding to the Ngati Pikiao land in and around the Ohau Channel, which used to occur quite regularly and there was concern. That work was done before I arrived on the scene, in order to satisfy the communities of

Ngati Pikiao, at that stage represented to us by the late Stan Newton.

Councillor Karen Summerhays, Environment Bay of Plenty: My comment is just a general one to help us move forward, I think. I learnt that as a baby you have no responsibility and as an adult you have full responsibility. And the thing that stops you getting there is if you fall into the chasm of blame. And you know, I think we're all here with the right intention, but we need to move forward. We could sit here all day blaming everybody else for the past actions, but really we just need to go forward. Kia ora.

David Ray, NIWA: I spent the first 17 years of my life growing up in the great town of Kawerau and I spent many happy times at Lake Rotoma. I would just like to support the comment that was made by the person on the front row there about Environment Bay of Plenty addressing that beautiful lake. One of the things I feel very concerned about is Paul Champion's presentation yesterday about the state of the submerged vegetation. It seems almost inevitable to me that the great native vegetation we've got in that lake at the moment is going to be taken over by exotics. So if we want to preserve that lake the way it is, do we need to take some drastic action, I mean are we going to get serious about it? One option that sprang to my mind, which I'm sure would be very unpopular, is to ban all boats from the lake. But how serious are we going to be about preserving the vegetation in that lake?

Del Bottcher: Banning boats and recreation - it has occurred, but it's only occurred in very small lakes where all the property owners made that decision themselves. In larger lakes it hasn't been very successful to do that, because of the public access. One thing that has been implemented, for exotic weed control, is that some lakes have actually set up what I guess you'd call boat police. If you enter there, you're actually inspected to make sure that your boat is clean, that you're not carrying anything from another area, and they've done that. But for the most part I think it's going to be extremely difficult to stop that kind of thing, because of the public outcry that you're going to get when you start shutting down access.

Paul Champion, NIWA: There are several examples in New Zealand of lakes with limited access. Probably a very pertinent one is Lake Tutira in Hawkes Bay, which is the main recreational lake with the weed *Hydrilla*, the one that I warned about in the talk yesterday. No motorised boats are allowed on that lake, so in that way you can put a row boat on there, a lot of kayakers use it, but no motorised boats. All of the locals support this, as we found out to our distress when we were actually doing a survey of *Hydrilla* on the lake with a motorised boat, and we had people from DoC and from the Regional Council and District Council, all heading over the hill to see us. So, it can work. Another point I would make is that the spread of weeds is independent, and I said this yesterday, it's independent of the eutrophication issues, but you can't forget it. You can't say "Oh well if we manage nutrients, we won't have these weed problems". Tarawera, which has got very good lakewater quality, has got the worst current weed in the district, to the detriment of the habitat in that lake. .

Brian Riesterer: I was just going to say exactly the same thing. I'm also on the Conservation Board for Waikaremoana, which is a lake that is actually under a management plan, that's the Urewera Park Plan, so that if weeds became an issue in the Waikaremoana lake, the bylaw would prevent boats on it. It's in the plan and has been accepted by the community about that particular issue.

Daphne Le Valliant, Rotoiti: I just want Jeff Jones to actually answer Kepa Morgan's question, that is what would happen if the flood gates were removed?

Jeff Jones: I can't be at all precise, because that would require some modelling. But I can tell you that indicatively the lake levels would fluctuate up and down the way they used to and in a manner that was unacceptable to the community in the 1970s. That's why they wanted change and that's why it was incorporated as part of the Kaituna Catchment Control Scheme. We would not be able to manage the flood peak going down the Kaituna River and that would have some impact on the lower Kaituna river works. Right now, if a whole-of-catchment rainstorm hits, we are able to let the flood peak from the Mangorewa Stream go down first and then just hold back the flood peak (we're talking about hours) from the Rotorua part of the catchment. That's what would happen.

The community have told us what they wanted in the past, and this is in the distant past when the scheme was first designed, and that was on the basis of the standards that existed around those times. But that's what they wanted. Now these various structures all have resource consents and I have no doubt when the resource consents expire and we have to reapply for them, if the community's needs or perceptions have changed at the time we come to renew them, then I'm sure it will be before an independent hearings committee, because the Council generally doesn't hear its own resource consent applications at the joints hearings committees, who are independent people. We will consider all of those issues from all sides of the argument and a decision will be made accordingly.

Chris Sutton, Federated Farmers: I think the issue should really be deferred to the policy part after afternoon tea, because as I said in my presentation, I can't see how Rotoiti can get better while there is bad water going into it from Rotorua. No matter what you do in Rotoiti, if you're going to have 4.6 TLI entering 3.9 you haven't got a chance. I'd ask them what they are going to do or how they feel that's going to work.

Chair: Can I just say, speaking as a former politician, that politics is about the art of the possible. And I don't believe that the people around Rotoiti really can expect us who live round Rotorua to hold our water indefinitely. Next question please.

Fenella Playne: I'm a landowner at Lake Okareka. You will have seen the photographs of the wetland and from what I've learned in the last couple of days, I have a question mark over whether these streams shouldn't be going through it, because quite frankly, I'm a lot more interested in the water quality than I am in the trout. I know Fish & Game are here and I would actually like to ask them to stop releasing fingerlings. I can easily go fishing at Tarawera and I would much prefer the lake water quality, so that all those little bugs which all you scientists know a lot more about than I do, could oxygenate the water instead of the trout eating them. By the same token, I'd like all the motor vessels, all the boats with motors on the back, completely off the lake, so we just have yachts and kayaks and wakas. Thank you very much.

Rob Pitkethley, Eastern Fish & Game: Thank you Fenella. Yes, interesting concept and actually Okareka was part of a long-term trial to try and clean up the lake using trout. Given that the trout eat the smelt, the smelt eat the zooplankton and the zooplankton eat the algae – the assumption a long time ago was that if we absolutely filled the lake up

with trout, they would eat the smelt, which would allow for a zooplankton bloom which would then clean up all the algae and clear up the lake. No, it's not working and it never did work, because over the 15 to 20 years that the programme was running, there were some major changes in lake water quality overriding the experimental design. So I don't honestly think that taking all the trout out of Okareka is going to fix the problem. No more fingerlings - well again like many of these issues there are people who would be rather disappointed if we stopped releasing fingerlings. It's all part of meeting the community's expectations, so there is a balance to listen to.

Chair: Thank you. Trout 1, Bugs 1.

Ron Marsden, LWQS: Could I ask our American friends what was the basic reason for prohibiting the size of outboard motors to below 10 horsepower on a lot of the American lakes?

Del Bottcher: We've implemented noise ordinances in many areas and we have wake problems with wave action. I think that they're probably related, I couldn't say specifically, but I think they're related. Now they're even to the point where EPA is now trying to implement the ban on 2-cycle engines, period. So even motors will be 4-cycle and much quieter with less oil in the water, etc.

R.M.: Was it mainly a pollution problem or a noise problem?

D.B.: It was primarily a neighbour nuisance problem that drove most of regulations stopping motorised vehicles and a lot of this got stimulated very quickly when jet-skis were introduced.

Chair: I recognise that sitting right at the back is Steve Chadwick MP, Member of Parliament for Rotorua. Welcome Steve.

Steve Chadwick, M.P.: Kia ora. Thank you Ian and congratulations to the Lakes Water Quality Society. Sorry I wasn't with you yesterday, but for today I don't know if we've had discussion on where we're going forward in terms of the role of the Ministry for Environment. Has that been discussed Ian?

Chair: It hasn't. Can we discuss that in the next policy section and we'll make a note of that. Thank you.

Stephen Colson, Planning Manager, Rotorua District Council: I just wanted to make a little point about boats, because people may not be aware that we have actually taken a little initiative, a little step on this issue with Lake Okataina. In fact, controls have been brought in on Okataina to manage things like helicopter and heli-skiing and water-skiing and all those types of activities, to try and start down the track of that being perhaps our first quiet lake. Along with those controls, noise measures as fitting in with our normal bylaw of going (less than) 5 knots within 200 metres of all our shorelines. Other people do observe those little controls, then it does get a lot quieter for those who are enjoying the lakeshore. So those are two little steps along a path that we might travel in the future.

Kim Young, Department of Conservation: Kia ora, thank you Ian. I have a comment and a technical question for, perhaps, Professor David Hamilton and some of his colleagues

that might be able to help me out here. The comment is that I sat through the last Lakes Water Quality Symposium and the Workshop subsequent and this one as well. The one thing that I find that we often miss is considering these lakes as actual ecosystems, the lacustrine ecosystems that support not only our recreational, spiritual and cultural aspirations, but also whole lacustrine aquatic fauna and flora as well, that contribute to those values that we hold dear as New Zealanders. The de-oxygenation of the hypolimnion in the lakes is not just an issue for lake water quality. It is also a removal of an entire component of habitat that the lacustrine system provides. That's incredibly important for the whole operation of a lake ecosystem to provide the habitat values in their entirety. The technical question that I had to ask, perhaps Professor David Hamilton can help me out here: in the restoration of a lake like Lake Okareka to the TLI desired value, will that remove the deoxygenation process that's occurring in the lake over the summer period, and that reduction in TLI – is it a linear process in terms of the deoxygenation process?

David Hamilton, University of Waikato: I think that what we do need to do, and I think Environment Bay of Plenty is aware of this also, is to more closely connect the TLI with the deoxygenation. Part of the reason why I haven't looked at long-term trends is because the phytoplankton part of it, the chlorophyll that's included in the TLI and in fact water transparency are inherently variable. Most sampling programmes around the world, including the current sampling programmes in the lakes around here, don't actually observe changes on the time scale that changes actually occur, which can be in the order of days and even within a day in the case of blue-green algae, which happen to move up and down the water column. For that reason I have stayed deliberately clear of making predictions through a 10-year phase and I believe there are inherent issues with trying to make predictions within that phase.

It's part of the reason why I've looked back to the 1950s, through the 1970s and towards the current status. The trends there are very clear with oxygen, which happens to integrate with the season, as opposed to integrating within a day or a couple of days, which is the case with the highly variable phytoplankton concentrations. As for the role of oxygen, what I've looked at is primarily nutrients, because they are the most critical issue and we're all aware of that for all of these catchments. There are undoubtedly major impacts in terms of aquatic life and biota, particularly that which depends on oxygen in the region that's becoming deoxygenated. Again, to emphasis the point that Chris may have made, but which I think I made pretty clear yesterday also, the lakes that are critically threatened really include Okataina which is an unusual case, Okareka, Tikitapu and Rotokakahi. Those are the lakes where oxygen levels in the bottom waters are disappearing right at the end of summer and where there is a small threat at the moment to aquatic life in those systems.

Kim Young: I don't really have anything else that I wanted to progress, except to say that I'm not sure that the participants are convinced that restoration to the TLI value that's being sought for a lot of the lakes will automatically restore the oxygenation of the hypolimnion.

Dr Rowland Burdon, Royal Society: I would like to know if any of the speakers would want to comment on the role and the fate of freshwater mussels. This is a matter which has been publicised quite recently by Robert McDowall. On one hand mussels would seem to be very vulnerable to deoxygenation events in the lake beds, but on the other

hand it has been postulated that they may, in fact, perform an important role as filter feeders in cleaning up the lakes and clarifying the water.

Chair: Who's the authority on mussels please? Rowland, I'm very sorry but despite the vast assemblage of knowledge here …..

Anon: You'll know if they're not cooked properly!

David Hamilton: Stuart Mitchell who was actually the supervisor on my PhD did some work and found in Lake Tuakatoto that freshwater mussels there filter the water column about the equivalent of once every 2 days. If you look to international examples, there have been invasive species in San Francisco Bay and also the case of the Great Lakes in particular, where filtration rates are up to once every 3 or 4 days. I think that we can't discount the role of using some of the freshwater mussels in that filtration process, although with large lakes it's unlikely that they'd be acting on that sort of time scale.

Nick Miller: I think a paper was presented to a LimSoc Conference 10 years or so ago on that topic. I'll see if I can find the abstract for you. (*Shown in box below*)

Freshwater mussels for control of eutrophication? Studies in a shallow South Island lake.
Shaun Ogilvie, Department of Zoology, University of Otago, Dunedin.

Lake Tuakitoto (South Otago) has high dissolved nutrient levels as a result of its agricultural catchment. Chlorophyll *a* concentrations in the lake are, however, not nearly as high as predicted from such nutrient levels. An hypothesis explaining this anomaly is that freshwater mussels in the lake, by means of filtration activity, are keeping algal populations well below potential levels. As a preliminary step in testing this hypothesis data on population densities in the lake were combined with measurements of filtration rates in the laboratory to calculate the daily volume of water filtered in the lake. It was found that mussels in Lake Tuakitoto filter a substantial volume of water, as will be discussed. These findings have led to more in-depth work, including observations of rhythmic filtration activity and the manipulation of mussels in the field using enclosures.
From: *New Zealand Limnological Society Newsletter* No. **29** October 1993.

Richard Wilson, Otaramarae, Lake Rotoiti: Stephen Colson, you mentioned about Lake Okataina, your lake restrictions there. Has the Rotorua District Council got any plans to toughen up on boats on the Rotorua Lakes, who overnight empty out toilets on board.

Chair: I think we'll put this in the next session, Richard, if you don't mind, because it's really a policy question. Thank you. That's the end of this session.

LAKES STRATEGY JOINT COMMITTEE FORUM

Panel members:
John Cronin, *Chair, Environment BOP*
Jeff Jones, *Chief Executive, Environment BOP*
Grahame Hall, *Mayor, Rotorua District Council*
Paul Sampson, *District Engineer, RDC*
Neil Oppatt, *Councillor*, *RDC*
Anaru Rangiheuea, *Chairman, Te Arawa Maori Trust Board*

Ian McLean, Chair: This is for questions relating to policy or other matters too.

Can I also present an apology from Te Arawa. As you may be aware, Te Arawa are involved with two very important series of treaty claims. They're doing them concurrently and today is the date of the last of the hui consultation for one of the claims, so it's unfortunate that the Te Arawa members of the Joint Standing Committee are not able to be here. However, we are fortunate to have Arnaru Rangiheuea here who will be able to present Te Arawa's viewpoint generally as we come through. Kia ora.

Chris Sutton, Federated Farmers: The question is, how can Rotoiti with a TLI target of 3.5 ever reach that target, when a lot of the water coming into Rotoiti is coming from Rotorua with a target TLI of 4.2. How do you believe that you can reach Rotoiti, there's a chance for reaching its TLI of 3.5?

Paul Dell, EBOP: I think the reality is that we have the two lakes, Rotorua and Rotoiti, and clearly Rotorua has a big impact on Rotoiti, but we know that a lot of the flow from Rotorua goes to the eastern arm and also to the western arm. So we've said the environmental bottom line that we think is going to be achievable, and there is a reality check in there that goes right back to the early work by Kit Rutherford. Then we're going to have to ask what mixer mechanisms are we going to use? We've heard Max talk of some examples today of maybe extending some form of wings into Lake Rotorua. Having got those goals of water quality, we then have to sit down and ask how we can achieve them. And it's not just necessarily a case of saying because that's water quality is that and that is that - the two will conflict. It may not necessarily be the case at all.

C.S.: I don't believe you answered the question, because if 4.2 is going into 3.5 … One would think that the water quality of Rotorua would have to improve above that of Rotoiti for Rotoiti to improve. What are we doing?

Thomas Wilding, NIWA: An important component of the TLI reflects the productivity of the lake. If you have two lakes with the same nutrient levels, for example Rotoiti and Rotorua, the shallower lake will always be more productive, if you have exactly the same nutrients in the two lakes. Rotoiti will always be less productive, because it is deeper.

Kit Rutherford, NIWA: I'm just putting the same thing in mathematical terms, there's not a linear relationship, it's not a matter of taking the two TLI's and adding them together in a linear fashion. As Max has told us, roughly 60% of the outflow is mixing into the basin.

And when you deconstruct Noel Burns' trophic lake index and you do the mass balance calculations on each of the nutrients, those two numbers are not necessarily inconsistent.

Chair: Steve Chadwick, can we have your question that we held over?

Steve Chadwick, M.P for Rotorua: I just wondered if it was useful to talk about Government's commitment in 2 minutes?

The Minister for the Environment has encouraged the Chief Executive, Barry Carbon, into Rotorua, and we had a very constructive meeting on the 27th September which was about an introduction of Dr Bruce Hamilton. That was first, to the only people that we could manage to gather together on that day. He's going to come back and spend considerable time in the district meeting all of the groups with an interest in the Rotorua lakes collective, focussing mainly on 5 lakes. I'm sure all the interest groups, including the action groups and those with wonderful ideas outside of the box and the science knowledge, such as Fenella's (Playne) fabulous ideas - it would be really interesting to put all those into that ring. He's then going to go away, and we'll await the report that's coming through in March next year. I know that you've had the Commissioner for the Environment reporting as well. Then we're putting together what other things we could contribute to the EBOP and the RDC integrated action plan. So that's just a little potted view of our commitment and we'll be working through Barry Carbon and Dr Bruce Hamilton. Thank you.

Richard Wilson, Lake Rotoiti Residents' and Ratepayers' Assn.: My question to John Cronin – Lakes restoration is going to cost an awful lot of money, is Environment Bay of Plenty going to spend some of their considerable nest egg on lakes restoration, especially as not a lot has been spent over many years? We were told there's been a big problem and if not, why not? Thank you.

John Cronin: I think the necessary funds will be sorted out by Environment Bay of Plenty from its normal budget rounds. When you talk about a considerable nest egg of Environment Bay of Plenty, you're really talking about a fund that the Council has put together to use interest to build up a fund so that the expenditure of our Council doesn't need to come direct from the ratepayers. And if we dive heavily into the capital of that fund, that would make considerable rate increases. However, we are looking to use those funds for leverage to do just the things like development that you are talking about.

Sally Brock, LWQS: It's my understanding that the Ministry for the Environment had got involved primarily to look at the crisis at Rotorua/Rotoiti, as well as looking at the other three lakes. But we've seen lots of information, lots of presentations about data that's been collected over the last 30 to 40 years. My question to you is, why has it taken so long. We've spent years looking at this data, while our lake is turning green. The community now demands action. We've got septic tank seepage still and we've cows still standing in the lake. So I'd like to ask our learned friends, when are we going to actually put that data into action?

Grahame Hall, RDC: Actually there has been a lot of action, something like $170 million dollars has been spent on the lakes over recent years. There is a lot still to be done and I can say that now, I think, almost two of the lakes are totally fenced off. There is a lot of physical work going on within the lakes district and to look after the lakes and lake water

quality. There is still a lot to do. We heard some really good presentations over the last couple of days on some of the work that has been undertaken. These have made it quite clear that new research has shown that certain things done back 10 years ago or even less than that, may have been able to be done a little bit better. So I accept that we might not have done everything that we could have done, I think we can all stand up and say that. We are doing a lot and there has been a lot done to date, but you can look forward to a lot more physical work being done – you'll be able to see the drains being laid for the Mourea/Okawa Bay sewerage scheme in a very short time and then you'll see the Lake Okareka one following almost straight away.

Mark Collet, Lake Okareka Residents' & Ratepayers' Assn.: We have a second issue which has been circling round this one of lake water quality and that is lake water use. We put fish in the lake for fishing, we put boats on the lake for recreation and we want to make sure Lake Rotorua is deep enough so that we can run a restaurant boat out on Lake Rotorua. We all want changes in these things too and this is part of the planning system, and I would like to ask Neil Oppatt if he could comment on that.

Neil Oppatt, RDC: I would like to answer Sally's question. I can't see how anybody could sit here for the last 2 days and say that nothing's happened. I mean, clearly Lake Rotoiti's problems is a Lake Rotorua problem, and what we can see is that substantial work has been done on that and the goal was to try and stop those nutrients getting into Lake Rotoiti. As far as seeing hard things done at Lake Rotoiti, this Council, RDC, has approved the pipeline, has approved the direct funding – it approved the funding 2 or 3 years ago. That work is going to happen and really, you get to the point where you ask, how long can you keep looking back without trying to look forward. And really what we've learnt from the Lake Okareka Action Plan process is that it's pretty much what Paul Dell said earlier today and that is, we've got to focus on what's important.

What's important is reducing the targeted P and N, and that's where the focus should be. And it's really important that those people that take part in those action groups come along with that objective and aren't going to spend most of the time looking backwards, because really all it does is slow down the whole process, and what we're aiming to do is try and get these works happening as quickly as possible. But, you know, even when you look at the Mourea and Okawa Bay sewerage system, the reality is that's a minute amount of nutrients going into the lake, compared to what's coming via Lake Rotorua.

Just going back to what Mark asked, there is a process to do with determining what the lakes can be used for. The lakes are zoned, they have their own zoning, and that process takes place about every 10 years when we review our district plan. That's the opportunity for people who believe that maybe a change in lake use should happen. So if you look at the last round or the last annual plan, there were submissions asking for quiet lakes. There were submissions for banning motorised boats on Lake Okareka, but the reality is that when all the submissions were heard, on balance the vast majority of the community wanted to see motor boats kept on that lake. At the end of the day, what we know through the Lake Okareka Action Plan process is that we don't need to ban motor boats on that lake to achieve our phosphorus and nitrogen reduction targets.

Ian Johnstone, Landward Management: 35 years ago Lake Pupuke was in a terrible, terrible state. It was so bad you couldn't go swimming in it. It had constant blue-green algal blooms in it. I just wonder if the Joint Standing Committee has a policy of talking

to the North Shore City Council and the Auckland Regional Council who have done a really amazing job on Lake Pupuke and have turned it from a lake that you could not have contact recreation in, to a lake which has now got really beautiful water in and people are encouraged to use it.

Jeff Jones, EBOP: Ian, as I think has been demonstrated over the last 2 days by the number of references that various speakers from independent scientific organisations have made to "I'm doing this work for Environment Bay of Plenty," we are using the same organisations who advise the Auckland Regional Council and the North Shore City Council on Lake Pupuke to advise us on this. Granted some of them have got different names now as a result of government restructuring. We will leave no stone unturned to find solutions.

W*ayne Bettjeman, Ministry for the Environment*: I just want to clarify a few things that Steve Chadwick said about what we believe Bruce Hamilton will be coming up with. Firstly, he has been over here a few weeks ago to have a preliminary look, to talk to a few people and he's now gone away because he's got commitments in Western Australia, but he'll be coming back later on this month for about 3 weeks to extensively talk to people mostly in the Rotorua/Rotoiti area, rather than all the catchments around. He just won't have time for that, I would suspect. However, we don't know what his itinerary is yet. And the report that he'll have done will be done, we are hoping, by the end of November. In other words a short report.

All he is doing is looking at the information that's here and he's giving it a fresh look and perhaps there's something, particularly in the short-term, that he knows about that perhaps could be suggested as part of the solution. Now the thing is, he has had success and he's also been instrumental in his experiences in algal blooms, so that's really why Barry Carbon, our Chief Executive, who knows Bruce's background, is pleased to have him here just to have that fresh look. The Ministry is here for a start getting used to and getting up to speed with what the issues are around here, and this conference has been absolutely superb over the last 2 days. Now the second thing that some of you might know, is that Barry Carbon has said that we do have funds available through the Sustainable Management Fund to assist community ideas and so on, particularly in the Rotorua/Rotoiti area. We were talking on Wednesday afternoon on what sort of project that might have been, working with a number of estate holders, and we're meeting again next Wednesday on that, and we hope to have some ideas to go forward and discuss with the community. This whole thing will have to be a community-led and -driven project, and we'll look and see what can come off it. There's no guarantee, so it might be that, in fact, it's not appropriate and no one can work together and so on, but we'll just see what comes off that. That's all I have to say. Thanks.

Kepa Morgan: Well I just heard the previous answer from the front there and there was reference made to the research that's been going on and sort of saying to Sally that it was incorrect to challenge that and ask why hadn't things happened earlier. I want to back Sally up, because no amount of research is going to change the management decisions made by the politicians unless they want to change the way things happen. And it really frustrates me – you can pour all the money you like into research and you can understand the problem until the cows come home. But if the politicians are not going to make some decisions that actually protect the rights of everybody, instead of favouring the rights of one group over another, we'll be sitting here in 20 years time talking about Rotoiti in

exactly the same way we are now. And the politicians, by the way, know full well that Ngati Pikiao have been opposed to those headwater gates since they were put in.

Grahame Hall: Thank you Kepa and I agree with you totally. That's why the politicians are making decisions and that's why they are getting on with on it. Can I just say one thing though, I think in fairness we have had a little bit of a delay and I was speaking to Paul Dell before about one of the delays that we had. We decided it had to be a joint venture between EBOP, Rotorua District Council and Te Arawa. However, it took something like 18 months, nearly 2 years for Te Arawa to come on board. That's not a criticism, it is far better to get Te Arawa there sitting around the table where they can make a decision than rush it through and say, "Well we're not going to do anything, we're going to go ahead and do things by ourselves". So we're now on track, we're now moving forward, we are making decisions. It has taken a while, but I think we're looking forward, rather than looking back.

Kepa Morgan: Okay, if you go back to the group that existed, I think, before the Lakes Water Quality Society, there was a meeting held at Forest Research Institute in 1995. At that meeting we had two busloads of kaumatua from Te Arawa there and it was put forward to the group that was there, scientists, politicians and Te Arawa, that we would form a management committee for the lakes. Now what happened was it was going to be evenly proportioned between tangata whenua and the Councils, ratepayers associations and so on. And the people who were there will back me up - the nominations for positions started, there were to be 10 positions each, the Rotoiti Ratepayers Association nominated me, the Chairman adjourned the meeting for lunch saying we would continue after lunch, and never re-adjourned that meeting. Now that could have been the committee that you're talking about Grahame, it could have been set up 10 years ago. But that was wiped by the Chairman at the time.

Rod Stace, Lake Okareka Ratepayers & Residents Association: I have a planning issue to ask about. It is I think generally accepted that septic tanks, no matter how well designed and how well they function, put nutrients into the groundwater which end up in the lake. And this is obviously a factor with the condition of Lake Okareka. How is it that the District Council through its own variation to the District Plan still has provision for urban type development or extensions to settlements on septic tanks – no requirement for reticulated sewerage?

Paul Sampson, RDC: My understanding is that at the time that the District Plan went through, there was a requirement in there to comply with the Environment BOP on site effluent plan, and I guess that is why it is where it is today. As has been mentioned here already, that plan is under review and also with the action plan, at the end of the action plan process, it is proposed to look at both the District Plans and Regional Plans and see how they tie in with that output. So my anticipation is the actions plans will result in some changes. I don't know what they are, but obviously that's one that will need to be addressed.

Nick Miller, LWQS: I have a concern, partly scientific in nature, but it also strongly infringes on policy, and that's the heavy reliance on the use of the trophic level index (TLI). As human beings we love to put numbers beside things, it makes life much easier and perhaps administrative people particularly love this. I'm a lakeside resident, I have at least some comprehension of the science behind the use of the TLI, but I have great

difficulty in reading TLIs that tell me that Lake Rotoiti is remaining stable, when I see how it has behaved over recent years. I'm well aware, having read the original paper about the TLI, that the authors of that index made it very plain in their paper that they would like to introduce a component looking at what was actually living in the water, in the way of algae, in particular. But they could not afford to do the necessary statistical work at the time. The usual story, you know. And I would like to pass the comment that if you want to use an index that will be readily accepted by the general public, perhaps you need to spend those extra bucks to get it up to actually recognising what is happening out on those lakes.

Ian McLean, LWQS: I have one last question and the question really arises from what Brian Riesterer said, and it is addressed to the Councillors: Brian said "If you want things to get on withdraw your objections". Now that's being a bit more direct than Brian said. There is a suspicion around that much of the work is intended to be top down rather than bottom up, and that the community are going to be involved, but the community aren't really going to have any say, and that the community should actually not make objections. Can you give us some assurance that you really want the community to come in, in partnership, rather than as rubber stamps please?

Grahame Hall, RDC: If you feel you need a policy issue, Ian, I can just say that we as a Council represent as many people as we can possibly can and if people come to us and say we have some concerns about the basis for this policy because it'll affect us here, here, here and here, then we have an obligation to have a look at it. Not necessarily object, but maybe put a submission in or have a look so that we can say that there are people who come to us, we've given it some thought, we're representing your views. But the bigger picture is, of course, that what we do want is to move forward as quickly as we possibly can do.

John Cronin, EBOP: As far as Environment Bay of Plenty is concerned, there will be community involvement right through.

Chair: Thank you very much for those assurances.

Well that brings this session to a close. We have two final important parts of the Symposium. Could I invite members of the Strategy Joint Committee to move back to the body of the hall, and invite both Professor Silvester and Paul East to come up please.

SYMPOSIUM SUMMARY, CLOSING ADDRESS

Professor Warwick Silvester, University of Waikato

I've been building the notes and studiously not asking questions, because I didn't want to divert myself from trying to summarise two days' proceedings. It's never an easy job, but actually has been easier this time than I had anticipated. Two years ago I summarised the events of the 2001 Symposium and I found that a fascinating exercise. I'd just like to talk about a few things that happened then and have happened since then – very encouraging things.

And I'd certainly like to emphasise the positive, because it was on that occasion that we started talking about the possible funding of a Chair in Lakes Management and Restoration. I give a lot of credit to Environment Bay of Plenty for the enormously forward-thinking, positive action that they took in doing that. I of course talk from a personal point of view because he's at the same institution that I'm at, the University of Waikato, but it has very far-reaching consequences for all of us and certainly within this area. Also, I congratulate Environment BOP Council and also Jeff Jones and Paul Dell who were really instrumental in doing all the groundwork and the busy work in getting that position put in place and in having it funded.

Of course we went out and we did a worldwide search for the best person for this position and we found him, a former New Zealander who was in Perth, Western Australia. We brought him over here and he's been here just over a year. The amount of work that's done and the value added that this position has made to this problem has been quite enormous, and I salute Environment BOP for that.

One of the very tangible outcomes of that, of course, was the fact that at the last symposium there were 2 papers by University of Waikato, this year 17 papers here from the University of Waikato. Hooray for us, and hooray for David particularly. Also comparing with last time, the quality of the papers seems to have gone way up. It's not all PowerPoint, there's more to it than just PowerPoint, but there have been some wonderful dredgings through of old data and bringing it together and focusing on the problem, and I think this has been an excellent conference, every bit up to the same standard as the Workshop last year, which I praised enormously at the time because that Workshop was a wonderfully focused and very productive occasion for all of us.

Another thing that I've noticed in this Symposium was the lack of confrontation, because I felt it in that first one – didn't we all? There was a tension there. It was used by some people in a positive way, but there also was an undercurrent of tension, and things were being worked on that many of us didn't know about. It doesn't seem to be here today and it seems that we are now doing what we said we were going to do, **working together for the good of the lakes**. It was really happening and I have a feeling when people speak that those tensions have now gone, we've now gone beyond that to looking at the welfare of the lake, - the catchments, the lakes and all of those things. Thankfully we seem to have got over that.

Now I did anticipate some things that were going to happen, so I put a few slides together. What I'm going to show in the next slides encapsulates a lot of what's happened in the last few days and a lot of what we know about the lakes. You know about this phenomenon. What happens there is a microcosm of what's happened in the lake, enrichment. You see enrichment every spring in the paddocks when the grass has been

eaten down in the winter and suddenly those paddocks that haven't been fertilised do this sort of thing. You get these great mounds of grass coming up. That's where the cows urinated of course, and that's a nitrogen phenomenon – it might be a P phenomenon as well (well it's certainly a pee phenomenon!).

This is a microcosm of what we're talking about in two ways. First of all it is where

much of the nitrogen is coming from in the system. It's not the amount of nitrogen, it's the concentration of nitrogen that we're concerned about. So the second law of thermodynamics is taken, a lot of nitrogen put on in concentrated areas as fertiliser, into cows and out the other end. So it's not the amount, it's the way in which it's been concentrated. We have to explore thermodynamic ways of actually redistributing it, going back down the thermodynamic cline.

This is another story to tell and it's to do with lake enrichment of course, because this is what lakes are doing. We see it every day on the grassland, but lakes are doing exactly the same and they respond in very much the same way. The same way the clover responds, because it's got its own source of nitrogen. Here's clover growing on the

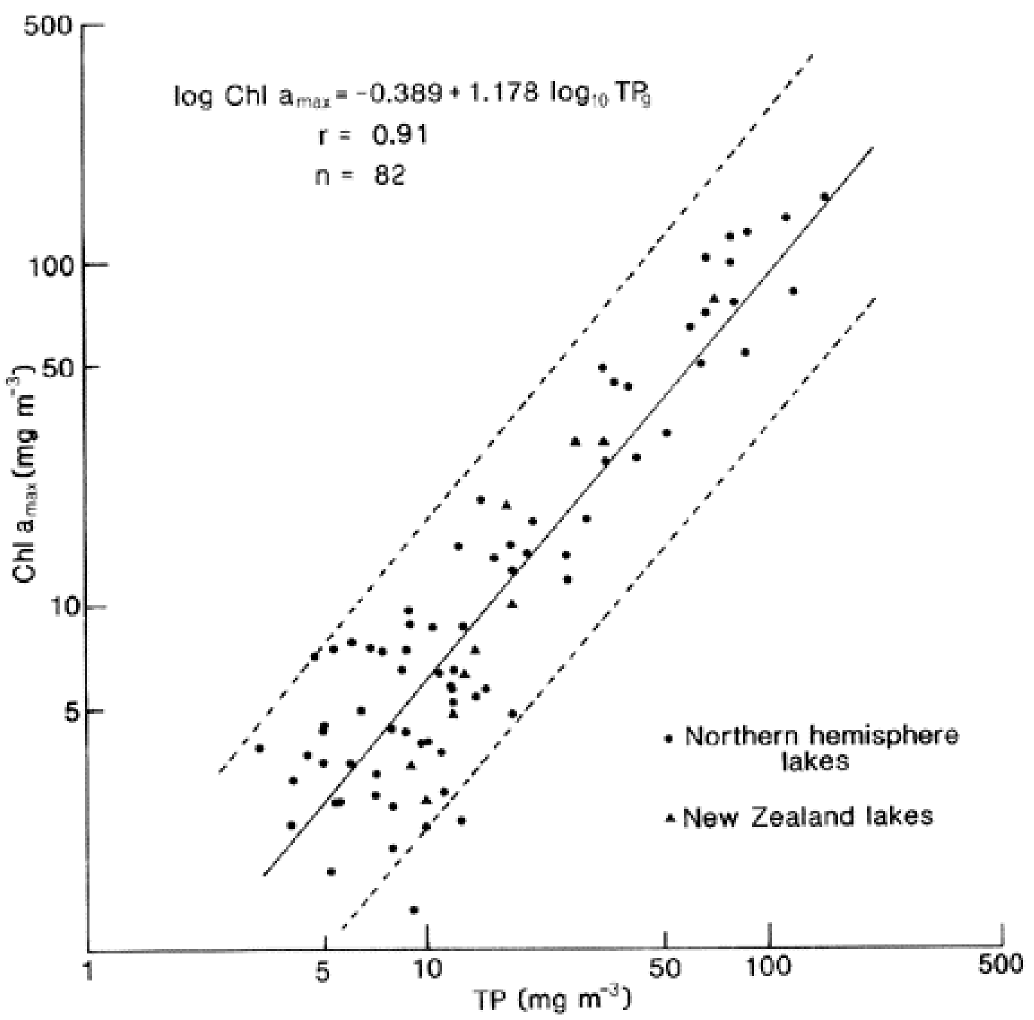
roadside and it grows wonderfully well when it can provide its own nitrogen. And these plants out here, there's no clover there, they don't like it at all. So I think, just trying to encapsulate what so many people have said today, we are talking about processes within the community which tend to bring the nutrients together and push them out a pipe or into systems and re-concentrate and redistribute them into places where they weren't before, in concentrations that they weren't in before. So we get away from the fact that there's too much nitrogen. There's too much concentration of nitrogen or phosphorus or whatever.

The linkages between nutrient input and lake quality are inescapable.

The linkages between catchment development and nutrient release, while less direct, are similarly inescapable.

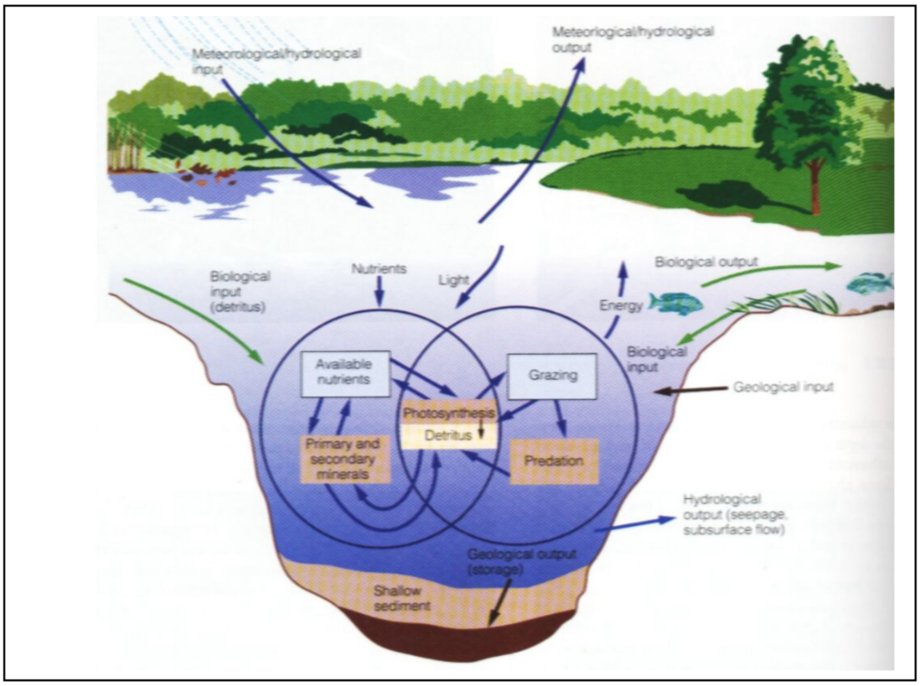
We had some excellent examples of the science behind what's going on. I remember very much at the first conference, I was constrained to say that the basic science behind the way lakes operate is well-known, the basic science is a well-known phenomenon. A lot of people were talking about the details of the way a lake operates and while that may be true, we mustn't get away from the fact that these systems operate on very good basic biological principles. And in fact there's good physics behind it as well, that's how they operate.

The linkage between nutrients and lake quality



This is work that has gone on for the last 30 to 50 years. You go back to some of the early textbooks, which show that if nutrients increase (it is total phosphorus on this occasion), within reasonable boundaries, the amount of chlorophyll goes up. That is,

algae start to bloom. So we get increase in biomass with increase in nutrients. There's no escaping this – it happens, and it's our challenge, of course, to understand this, work with it and mitigate it.

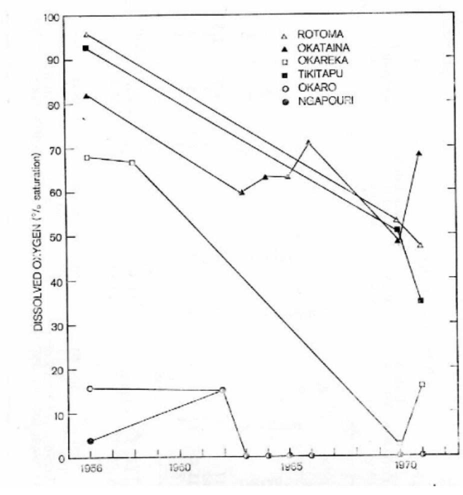


I think above all, within the basic science, we are now coming to grips with the fact that there are two parts of the system, and we must be careful not to concentrate on one to the exclusion of the other. Within lakes we have the circulation process in which a lot of nutrients stored in here are being brought back up and re-utilised. A number of papers have talked about this and the fact that particularly, in say Rotoiti, there's so much of this going on that let's ignore what's coming in because that's small in respect to this. Don't ignore what's coming in – we mustn't. So we've got inputs into the lake, and we've got recycling and it's like so many things, if you work on one – you tend to ignore the other. We mustn't. The amount coming in, and I remember talking about this last time, is the material which primes this pump.

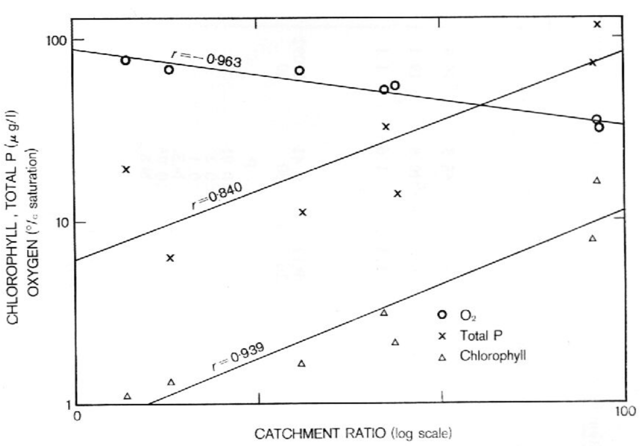
It's this material here which continues to prime this pump. Even though this is small with respect to what's going on here, we must not forget that controlling this must be one of the very important aims of lake management, as well of course as an attempt to control this. It's probably, in the context of deep lakes, much easier to control this to a certain extent than this one here. Of course there are outputs from lakes as well. But really this is what's originally causing it, this is what's generating it – both are very important. We must not forget that both are very important. And this brings us to the thing we call the internal load. The internal load is an extremely important part of driving the system and it's that hidden bit that we often don't see.

Chris (Hendy) gave us a good example of the amount of phosphorus which is caught up in the sediments, which tends to be regenerated in many of these lakes. I just want to talk a little bit about history, because several papers actually talked about history - some of the longer term cultural history of this country, others more recent. And so many people have said, that we've heard all this before and we don't do anything about it.

Rob McColl in 1974 showed the decline of DO in six lakes over the period 1956-1972.



This takes us back to Rob McColl who did some very very interesting work, some seminal work, in fact, and showed that for a variety of lakes the oxygen concentration had been declining for a long time. So this is dissolved oxygen and they've been declining over the period, and we're talking about 1956 to 1970, this is way back. The writing was on the wall for a number of these lakes for a long time.



He also did this very interesting bit of work, in case we forget, the catchment ratio. This is the conversion of a catchment from zero development, say in forest, to 100% developed, and a number of things were shown to happen. These are for the Rotorua lakes. The dissolved oxygen level drops, the total phosphorus goes up, the total chlorophyll goes up, so the relationship between catchment development and lake trophic status has been well-known for a long time. We can go on reinventing this wheel and of course all of our new students will want to reinvent this wheel again.

Now we come to blue-green algae – we've heard a lot about blue-green algae as indicators of the status of the lake. They are part of the natural progression of all bodies of water. Just like we see the movement of wetlands being infilled, blue-green algae are a symptom of the status of a lake, just as the water plants are. I seemed to be saying not long ago that when we had the lakes full of water plants, we moaned about the problems that they were creating for us. We didn't know how lucky we were, because we had clear water then. It's like so many things in life, we tend to look at the negative. But it wasn't until we had the blue-green algae that we realised just how lucky we were. Those of you who have got lakes which have just got macrophytes in, just treasure them for a while.

There are several mentions of local studies and I think this is really one of the very bright rays of hope, the way in which local communities are now taking charge of the problem - owning the problem I heard many people say - and using, at the community level, the information that's been generated to work on a number of issues in their own catchment. Lake Kapoia and Lake Rerewhakaaitu are just wonderful examples of local community action, taking the opportunity to work cooperatively together and using scientific information to work on their own catchment areas.

Getting back to the problem of nutrient concentration, where there is too much nutrient concentrated in particular areas. There are some good thermodynamic principles to be applied here and the one shown very well by Jim Crush and his team is that there are some plants that can actually redistribute these nutrients very well. You can take the very concentrated nutrients in your effluent stream and use them to grow plants and to redistribute those nutrients widely again, to what we call 'immobilise' them. But to immobilise nutrients like nitrogen and phosphorus you need carbon.

You can capture carbon by photosynthesis and all plants do that, Jim showed very nicely how some of the grasses can do this very much more effectively. In fact, much more effectively, I have to say, than the pine example that I showed you data on. The grasses are much better storers of nutrients than many trees are. They have a much lower nutrient use efficiency than the trees do, and plants with low nutrient use efficiency actually immobilise large amounts of nutrients very effectively. I think increasing use of plants like that could have a great advantage.

Urban stormwater was an interesting one. I was waiting to hear how bad urban stormwater was, and I guess many people were. And I was delighted to hear from David (Ray) that it wasn't as bad as we thought it was, for the nutrients that are causing most of the eutrophication. I was a bit worried about some of the copper levels that were going up, then I thought, hey, blue-green algae hate copper, in fact copper is one of the best things to kill blue-green algae. So maybe there's an answer in there somewhere. However the copper levels did seem to be getting up a little bit in some of those sediments.

Then there was the emphasis on our poorest lakes. There was a nice statement about that right at the end from Chris Hendy. The work that's going ahead at the moment does emphasise the poorest lakes but let's not forget the better lakes, because while our backs are turned and we're working hard on these bad lakes, the better ones over there are all doing their thing. We must actually distribute our effort across all of the lakes, but there maybe a good argument for spending more time on the poorest lakes. I think there's a balance here that we should be very concerned about.

To wrap up, what I've done is actually capture a series of quotes. I'm not going to put names against them and I've paraphrased some of them. I think they do summarise some of the things that have been said that are quite I think definitive, and some of them are a bit controversial, but never mind. You may recognise the people that said them.

"Rule 11 made people sit up a little."
"Keep out of the Courts."
"Focus on your P" or "Go P some place else."
"The collective paradigm must mature."
"Where do the fish go?"
"What comes after the blue-green algae?"
"When BMPs are part of FESLM you get a TNM."
"This had green swales."
"and from the potty will grow the pot."
And then on ZB news this morning, "Central government will have to cough".
"Let's learn from others' successes and failures."
"Share the burden of change."

"Let's not fall into the chasm of blame."
"The power of the process."
"The community wants urgency."
This is a good one, about septic tanks, "Not necessarily embrace me or the programme."
'Use an arm of Rotoiti as a treatment pond."
And finally, "If we litigate, we lose."

Thank you.

Chair. Thank you very much Warwick, and thank you for your contribution over the years to this work.

I will now call on Paul East to give the closing address and then Anaru Rangiheuea will close the conference for us.

Rt. Hon. Paul East, QC.
Mr Chairman, Ladies and Gentlemen. By any measure this Symposium has been an outstanding success, with 240 attendees, and I think over the last 2 days all of us, both scientists and laypersons, leave a good deal better informed than when we arrived. Ian, I was particularly pleased that earlier in the day your leadership was acknowledged, because you have been at the forefront with regard to this issue. You have energised many of us and indeed Central, Local and Regional Government to apply renewed attention to these issues that we have been facing over the last two days.

I can remember in 1968 when a visiting United States environmental scientist referred to Lake Rotorua as "an unflushed toilet." The local reaction was one of outrage. Not at the evident deterioration of Lake Rotorua, but at the fact that some overseas expert would come here and make such critical comments. And what was highlighted then was the tension that exists with issues like this. We need to publicly recognise the seriousness of the problem that we deal with. And then there's a tension because that conflicts with the economic interests of our region, where we are so dependent on tourism, the visitor infrastructure and all the associated businesses that flow from it. And this has been an issue since the 1960s.

I can remember as a very young City Councillor and Deputy Mayor the debates we had at the Council Chamber through the 1970s about the lake issue. Some of them have been traversed over the last two days. We didn't make as much progress as we should have, but there has been acknowledgment that this local authority was the first in the country to undertake nutrient stripping and we had a long and involved scientific debate involving experts from Sweden, who said that we should continue to strip and discharge into Lake Rotorua.

There were those of us who wanted it out of the catchment area and the original plan was to pipe it to the Kaituna pipeline. The late Stan Newton has been mentioned already here during the course of this Symposium. It was his leadership that saw this issue taken to the Waitangi Tribunal and a new solution was found, to pump the sewage into the Whakarewarewa Forest. I must say that many of us were pleased with that result and in fact I suspect there are even more and more people lining up as strong supporters of the Waitangi Tribunal, because a lot of us know that these lakes are held in stewardship by the Crown under the agreement of 1922 and that Te Arawa can quite rightly expect the

Crown and all its agents, including Central and Local Government, to keep the water quality in the pristine condition that it was in 1922. It isn't and there may well be some remedies available if it isn't restored to that pristine condition.

I put that to you simply, that it's an acknowledgment that we haven't done as well as we should have, but as somebody said earlier, casting blame doesn't get us much further. We implemented the Kaituna Catchment Commission Scheme. It was the largest environment scheme in the country. It was the last environmental scheme to qualify for the Central Government Subsidy. We thought with its three parts, the control of the lake levels, the retirement of a good deal of land and planting, and the pumping of the sewage, we thought out of the catchment area, many of our problems were solved.

Well, we relaxed with an air of self-satisfaction. We were in fact lulled into a false sense of security, because over the last two days it's been graphically brought home to us how serious the issues are. And of course it was a major wake-up call for all of us when we had Lake Rotoiti, a major lake in New Zealand, closed in its entirety for over 5 weeks last summer because of the toxic nature of the water. And that can only rightly be described as a national environmental disaster. David Hamilton showed us his graphs which clearly demonstrate how serious the deterioration has been over the last 50 years. They paint a very depressing picture.

But after the last two days I leave here with more optimism than when I arrived, because we have made progress. We have now gone past denying that there's a problem. We've gone past a pessimistic attitude that says no action we take can fix it, and we've gone past the slogan, the fob off: well, there's no quick fix. We have a renewed resolution to take action and this will be a very real test of leadership at a local, regional and central level. Because we have identified the contributing factors to the deterioration of our lakes. We've identified almost every one of them, perhaps with the exception of whether the oxygenation from Lake Rotorua to Rotoiti is beneficial or otherwise. But we can say we have identified the contributing factors.

So we are past the arguments over what the contribution is plagued by, nitrogen or phosphorus. We have been given some wise and cautionary advice not to panic, but to thoroughly assess all likely results before taking action. But I come back to the point that we know the contributing factors and now there are some very tough decisions ahead, not the least those relating to land use. As one of your speakers put it to you earlier today, no one volunteers to go broke. But there is going to be some hardship, there is going to be some sacrifice and there's going to be some considerable expense.

But the most important factor required will be leadership, so that we are all prepared to sign up and take responsibility for the solution. These lakes are national treasures and our problem will only be addressed with the continued recognition that this is an issue of major national importance. Now if there was to be some form of resolution from this gathering today (and I've seen 240 people here and every one of them wanting to see some action taken). If there was to be some sort of resolution from this Symposium, my guess is that it would be along these sort of lines

"That the Symposium recognises the critical condition of the Rotorua lakes, acknowledges that the contributing factors have been identified, seeks that the present state of urgency continues and that local, central and regional Government ensure

remedial measures are implemented as quickly as possible”.

Thank you very much.

Chair. Thank you Paul for that, and Paul has in his summing up suggested some words which he feels might be a conclusion to this meeting. I wonder if those present would be in accordance with what he has proposed. A show of hands please. Well that’s overwhelmingly carried. Thank you very much.

Can I now ask Anaru to close the Symposium, please.

Anaru Rangiheuea, Te Arawa.
Thank you Ian, for sponsoring our conference and thank you for the summing up. Te Arawa had a very important part in the whole issue of lake management strategy, as you know. And I must thank Kepa for his presentation on my behalf. It’s a lot to understand the way there is the spirit of water. Water is the life blood of my people, it sustains life, it cleanses the outer body, it cleanses the inner body and we used it for baptism, and we still do. And we treat that water sacredly. I will not allow people to be buried in the lakeshore area without knowing, and from time to time we have asked a tapu to be placed on the lake because the people have drowned in the waters. I placed that at a particular time in Tarawera, and the Tarawera residents have acknowledged that and so have the District Council and the local people. So it’s very important for me to say thank you for the Symposium, thanks for the information and to the high-powered people here – let’s get all our heads together. Te Arawa is pleased to work with the two bodies to set out policies for the management of our lakes. You mentioned 1922. Naturally Te Arawa would like to see the lakes back in that state, and so we will all pledge ourselves like this meeting has today, to conduct ourselves so that our lakes will be in a better position than they are today. Thank you. Let me close the meeting.

POSTER PRESENTATIONS
In alphabetical order of presenters

Settling dynamics of diatoms responsible for winter blooms in Central North Island lakes

Amanda Baldwin[1], David Hamilton[1] and Ian Hawes[2]
[1]*Centre for Biodiversity and Ecology Research, University of Waikato, Hamilton*
[2]*NIWA, P O Box 11115, Hamilton*

This poster describes proposed research on diatom settling dynamics in lakes of the central North Island. Winter diatom blooms, usually of *Aulacoseira* sp*.,* do occur in other lakes around the world, but in temperate regions the winter biomass peak appears to be unique to New Zealand. Sedimentation appears to be a major factor in regulating the dynamics of these blooms, and plays a major role in the translocation of nutrients within these lakes. Modelling has been used to successfully elucidate processes related to phytoplankton dynamics and to generate and evaluate management scenarios for many large lakes (e.g. Lake Taupo: Spigel *et al.* 2001). These models have had limited success in simulating the winter diatom bloom that is typical of large New Zealand lakes such as Taupo and Tarawera, and it appears that this is at least partly due to the inability of models to capture the sedimentation process.

This study will provide information on aspects of winter phytoplankton dynamics, in particular sedimentation rates that are lacking or inadequately formulated in existing models. Settling rates are believed to be influenced by various environmental factors, including: small scale turbulence, large scale mixing, physiological state, water clarity and ambient light conditions. In this study settling rates of diatoms will be measured *in situ* using a combination of novel underwater video-microscopy techniques and *in situ* measurements of particle sedimentation rates. These will be combined with direct measurements of water column turbulence and spatial variability of algae (captured in both vertical and horizontal directions using a towed BIO-FISH to measure chlorophyll fluorescence). Combined with taxonomic assessments and production estimates, this will provide a comprehensive picture of variations in phytoplankton biomass and settling characteristics in the lakes. Previous studies of diatom settlement have inferred settling rates from experimental columns that are isolated from the lake, with cells therefore subject to different environmental conditions.
The deep lakes that are likely to be included in this investigation will include Tarawera, Rotoiti and Taupo.

Reference
Spigel, R.; Howard-Williams, C.; James, M.; Gibbs, M. 2001. A coupled hydrodynamic-ecosystem study of Lake Taupo: A preliminary model. NIWA Client Report: CHC01/52 31p.

Carbon dioxide recycling in Lake Rotoiti

Hayden Bosgra & Chris Hendy.
Chemistry Department, University of Waikato, Hamilton

Samples of aerobic surface waters, anoxic bottom waters and typical inflowing waters collected in April 2003 have been analysed for their carbon isotopic composition. This shown that despite the strongly reducing conditions encountered in the deep waters and their sediments, anaerobic fermentation of bottom sediments has not become a significant source of carbon dioxide to the bottom waters, however remineralisation of falling organic matter and seston contributes about 20% of the dissolved inorganic carbon (DIC) to the bottom waters.

Cyanobacteria: toxic algae explained

D. F. Burger; E. F. Ryan and D. P. Hamilton

Centre for Biodiversity and Ecology Research, University of Waikato, Private Bag 3105, Hamilton, New Zealand.

INTRODUCTION

Cyanobacteria (blue-green algae) are primitive prokaryotic organisms yet contain the photosynthetic pigment chlorophyll, thereby taking on some of the features of plants (hence reference to blue-green algae). Cyanobacteria grow as solitary cells or as colonies or filaments (Fig. 1). They possess a number of potentially advantageous features that enable them to form water blooms. These features include heterocysts, which are cells specialised for nitrogen fixation, and air-filled structures known as gas vacuoles to provide buoyancy.

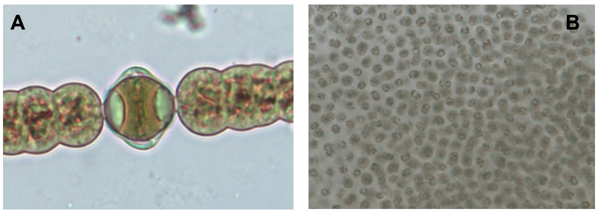


Figure 1. (A) Individual cells of *Anabaena planktonica* (magnification 400X) and (B) *Microcystis* colony (200X).

BLOOM FORMATION

The mechanisms driving cyanobacteria algal bloom formation are complex (Fig. 2). One of the most important features of cyanobacteria is ability to regulate depth in the water column. Physiological changes, in response to changing environmental conditions, alter cell buoyancy in cyanobacteria. Buoyancy regulation may provide a means of overcoming the vertical separation between light (near the surface) and nutrients (near the bottom) that often occurs in stratified lakes (Ganf and Oliver, 1982). Buoyancy regulation may also allow access to high light near the water surface while providing a means of migrating downwards to lower light to avoid photoinhibition resulting from high light intensities at the water surface that would otherwise damage cells or inhibit photosynthesis.

There are three mechanisms of buoyancy regulation, these can either occur together or independently. One of the mechanisms relates to the collapse of gas vacuoles, air-filled structures that normally provide buoyancy (Walsby, 1971; Dinsdale and Walsby, 1972; Reynolds and Walsby, 1975), but this process may occur infrequently in natural populations. Regulation of gas vesicle synthesis (Walsby, 1970, 1971; Utkilen *et al*., 1985; Kromkamp *et al*., 1986) may provide medium-term (several days to weeks) changes in the buoyancy of cells.

The most frequently observed pattern of cyanobacterial migration is caused by regulation of the cell ballast, whereby cyanobacteria accumulate near the surface during the night and early morning and then sink away from the surface during late morning and afternoon (Van Rijn and Shilo, 1985; Wallace and Hamilton, 1999, 2000). This process occurs through accumulation of photosynthetically-fixed carbohydrate in the cell during

the day, increasing cell density, followed by depletion of the carbohydrate through the night, often resulting in highly buoyant cells by sunrise.

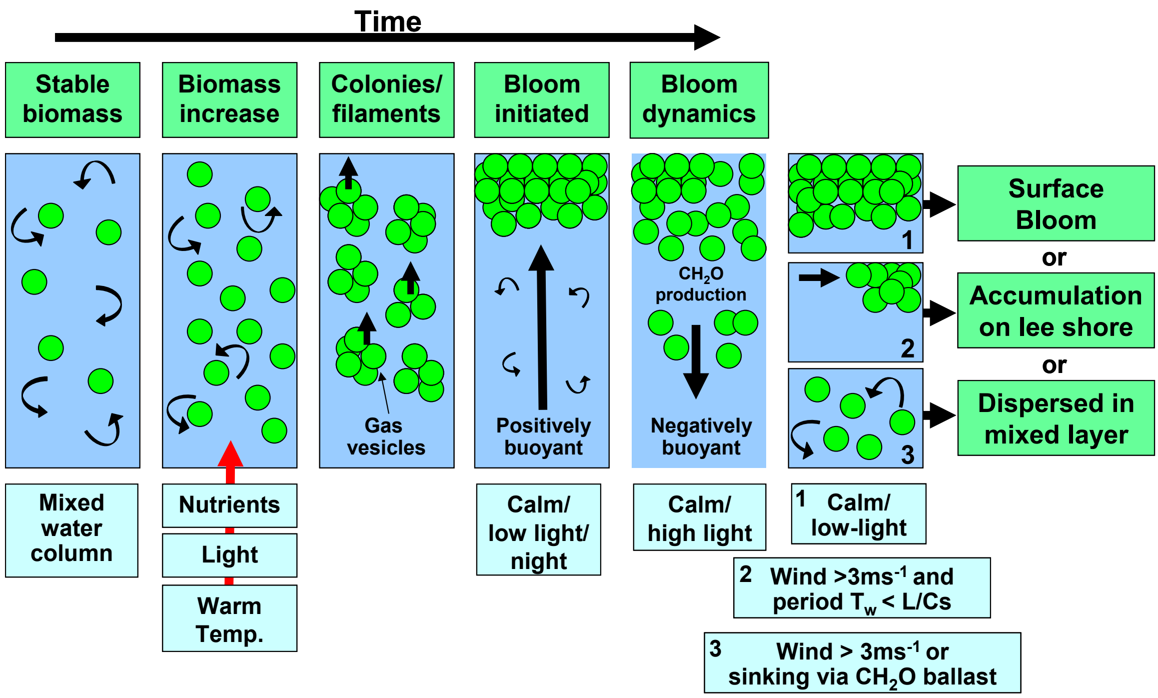


Figure 2. **Mechanisms of bloom formation.** Key tw - time that wind blows, L - lake fetch, Cs - surface current speed. CH2O is carbohydrate.

The position of cyanobacteria cells or colonies in the water column depends on both the buoyancy of the cyanobacteria and water motion. Most moderate to large-sized lakes in New Zealand are monomictic, i.e., they mix fully throughout the depth of the water column for some period during cooler months of the year. In summer these lakes thermally stratify; the period when cyanobacterial blooms most commonly occur. During periods of strong thermal stratification cyanobacterial cells may congregate at the water surface. This phenomenon is referred to as 'telescoping' Reynolds (1997). In addition, blooms may be pushed onto the leeward shores, particularly embayments, by light winds that do not disrupt the vertical stratification and associated expression of buoyancy (Hamilton, 2001; Robson and Hamilton, 2003). This magnification of cells on the leeward shore may lead to huge accumulations or scums of cyanobacteria.

Cyanobacteria have other well documented, potentially advantageous features that can enhance bloom formation. Many cyanobacteria thrive in summer with high water temperatures, much more so than other algae. Some cyanobacteria have the capacity to fix atmospheric nitrogen (N_2) when this nutrient is directly limiting growth, and incorporate it into plant tissue as part of the cellular requirements for growth. Many lakes of the Central Volcanic Plateau of the North Island, including Lake Taupo (White *et al.*, 1985; Lean *et al.*, 1987), have been found to be nitrogen limited. Many cyanobacteria are not preferred as a food source for grazers, often resulting in limited 'top-down' control of populations. The reduced grazing may be associated with large size (of colonies), high cell densities, production of allelopathic compounds and poor assimilation by grazers Oliver and Ganf, 2000).

TOXIN PRODUCTION AND HUMAN HEALTH EFFECTS

Cyanobacteria are often responsible for taste and odour problems in water supplies as a result of geosmin production. Geosmin levels as low as 1-2 parts per trillion produce earthy-musty off-tastes in drinking waters. Certain species have the ability to release a range of natural toxins, including hepatoxins, neurotoxins and endotoxins, under particular environmental conditions. These include several taxonomic groups found in the Rotorua lakes. The presence and concentration of toxins and level of concentration is unpredictable and cannot be accurately determined for all species and blooms. Contact with contaminated water may lead to ill health.

During the summer of 2002-03 there were widespread and prolific blooms of cyanobacteria in the Rotorua lakes. Rotorua lakes closed to the public at some time during 2002-03 included Rotoehu, Rotoiti, Rotorua, Tarawera and Okaro. Potentially toxic blue-green algae species causing Rotorua lake closures included *Anabaena planktonica, Anabaena circinalis, Anabaena spiroides, Microcystis aeruginosa, Anabaena* cf. *lemmermanni* and *Aphanizomenon flos-aquae.*

Potential human health effects following contact with toxin-affected water include: skin rashes and irritation, eye and ear irritation, vomiting and gastroenteritis, mouth ulcers, liver problems and fevers.

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Benthic-pelagic coupling of nutrients in Lake Rotorua

D.F. Burger[1], D.P. Hamilton[1], C.A Pilditch[1], J.A. Hall[2] & M.M Gibbs[2]

[1] Centre for Biodiversity and Ecology Research, University of Waikato, Private Bag 3105, Hamilton, New Zealand. E-mail dfb@waikato.ac.nz
[2] NIWA, PO Box 11115, Hamilton, New Zealand.

ABSTRACT

Nutrient fluxes and the mechanisms inducing nutrient release across the sediment-water interface were highlighted as priority lake research issues by the Rotorua Lakes Symposium in 2001. Nutrient concentration and trophic status in Lake Rotorua remain high despite attempts to reduce external nutrient loads in recent years. Internal nutrient fluxes from bottom sediments and their importance to nutrient cycling in this lake, however, are largely unknown. In this study lake stratification and deoxygenation patterns were determined at a 20-m deep site for one year from November 2002 using in-situ temperature and oxygen sensors. Weekly sampling of the water column between January and April 2003 was carried out at this site to quantify changes in water column nutrient concentrations. Concentration of total phosphorus (TP) and total nitrogen (TN) beneath the thermocline were used to assess the mass of nutrients released to the water column during deoxygenation. Approximately 24 tonnes of TP and 308 tonnes of TN were released from the lake sediments during two stratification-deoxygenation periods in the summer of 2002-03. Further research will quantify sediment nutrient fluxes and sedimentation rates using in-situ benthic chambers and sedimentation traps. A nutrient budget and model for the whole lake will then be developed.

INTRODUCTION

Nutrient release across the sediment-water interface may contribute a significant fraction of the total nutrient requirements for primary production in aquatic habitats. In shallow lakes, internal nutrient cycling may sustain high nutrient concentrations regardless of external nutrient input (Marsden, 1989; Anderson and Ring, 1999; Burns, 2001). Sediment nutrient fluxes are closely related to temperature and oxygen concentrations (Schroeder *et al.*,1992; Anderson and Ring, 1999).

Climate, particularly solar radiation and wind, influences lake thermal stratification and mixing processes. During stratification, the surface waters become isolated from the bottom waters and the hypolimnion becomes deoxygenated. As deoxygenation occurs, the oxidised microzone at the sediment-water interface becomes anoxic, which reduces the adsorptive capacity of the sediments for phosphate (PO_4) and may increase the release of ammonium (NH_4) into the water column. These nutrients accumulate in the hypolimnion until mixed throughout the water column following breakdown in stratification.

There has been little change in nutrient concentrations and trophic status of Lake Rotorua during the last two decades despite external nutrient load reductions through Rotorua City sewage diversion in 1991 (Burns, 2001). Previous predictions of lake water quality (Rutherford *et al.*, 1996; 1989) indicated that internal nutrient loads and subsequent flux rates across the sediment-water interface form an important component of the nutrient cycle in this lake. It is essential that these fluxes are quantified in order to make predictions about if, or when, positive responses to external load reductions will become evident. The objective of this research is to examine nutrient fluxes across the

sediment water interface during stratification and deoxygenation events in Lake Rotorua. A further objective is to understand how release events affect algal productivity, as shown conceptually in Fig. 1.

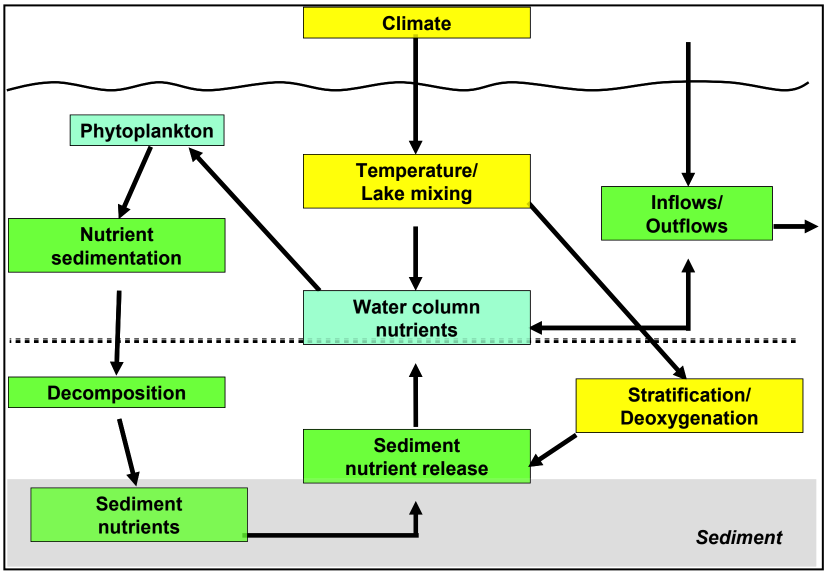

Figure 1. Influences on sediment-water interactions.

METHODS

Stratification and deoxygenation regimes are being determined in Lake Rotorua for a year period from November 2002. Temperature loggers have been deployed at 2-meter depth intervals and oxygen probes at 15 and 19-meter depths at a central 20-m deep site to record every 10 minutes during this time. Weekly sampling of the water column between January and April 2003 was carried out at this site to quantify changes in nitrogen (NH_4 NO_3 and TN) and phosphorus (PO_4 and TP) concentration during deoxygenation events. Sampling frequency was increased during periods of calm weather when there was an increased likelihood of stratification. Water column profiles were taken of temperature, dissolved oxygen and chlorophyll florescence and water samples were collected for nutrient analysis at 0-8, 12, 15.5 and 19-meter depths. Algal samples were collected from the surface mixed layer (0-8 meters) to assess changes in biomass and species composition during this time.

RESULTS

Lake Rotorua is a polymictic lake, showing distinct thermal stratification for several days or weeks on three occasions over summer 2002/03 (Fig. 2, Fig. 3 C). Stratification was accompanied by a decline in dissolved oxygen concentrations in the hypolimnion, with concentrations reduced to < 4mg/l during two such events. The decline in dissolved oxygen resulted in a net release of nutrients from the lake sediments. The rate of release and total load were quantified from the change in mass of TN and TP beneath the thermocline (Fig. 3 B, C). A total of 24 tonnes TP and 308 tonnes TN were released from the sediments during two deoxygenation periods (Table 1). Each nutrient release pulse was immediately followed by an increase in biomass of cyanobacteria (Fig. 3 D).

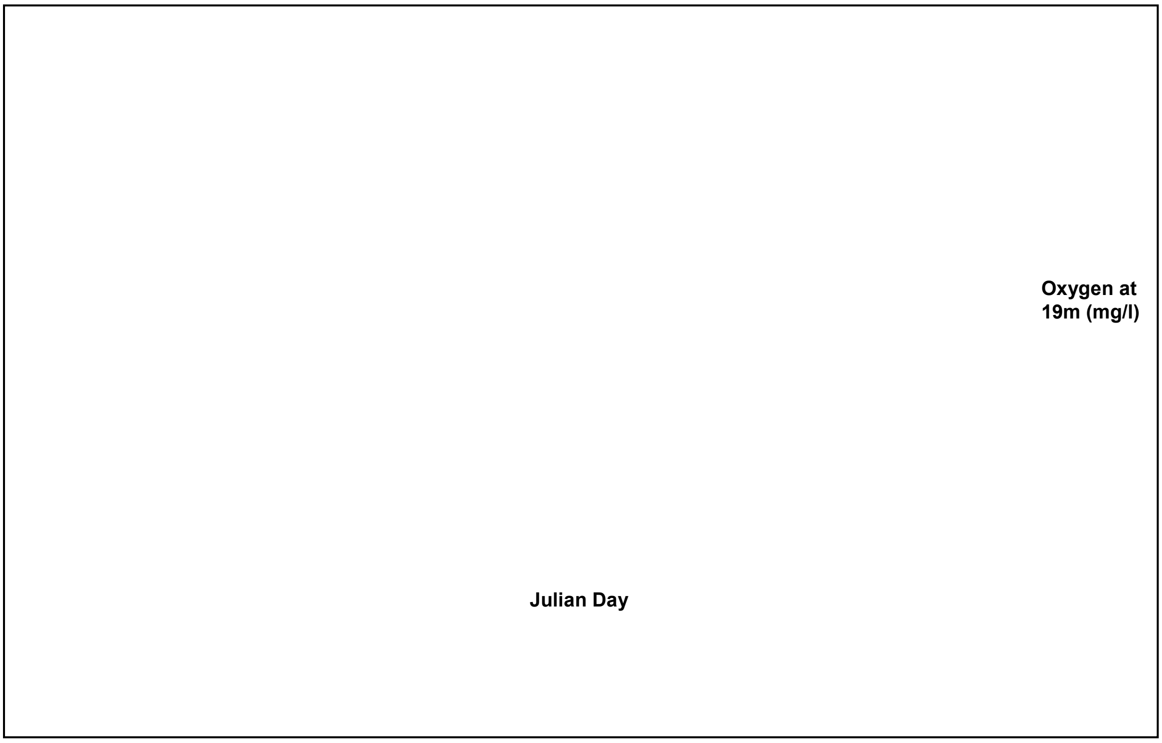

Figure 2. Contour of temperature in Lake Rotorua at central site (20-m depth) and time series of dissolved oxygen concentration at 19m.

Table 1. Sediment nutrient release during two stratification periods.

	Stratification Period	**Duration (Days)**	**Release Rate (tonnes/day)**	**Total (tonnes)**	**Total Release (Tonnes)**
TP	29 Jan-7 Feb	9.0	0.9	8.4	**23.8**
	10 Feb- 19 Feb	8.9	1.7	15.5	
TN	29 Jan-7 Feb	9.0	18.2	164.2	**307.7**
	10 Feb- 19 Feb	8.9	16.2	143.5	

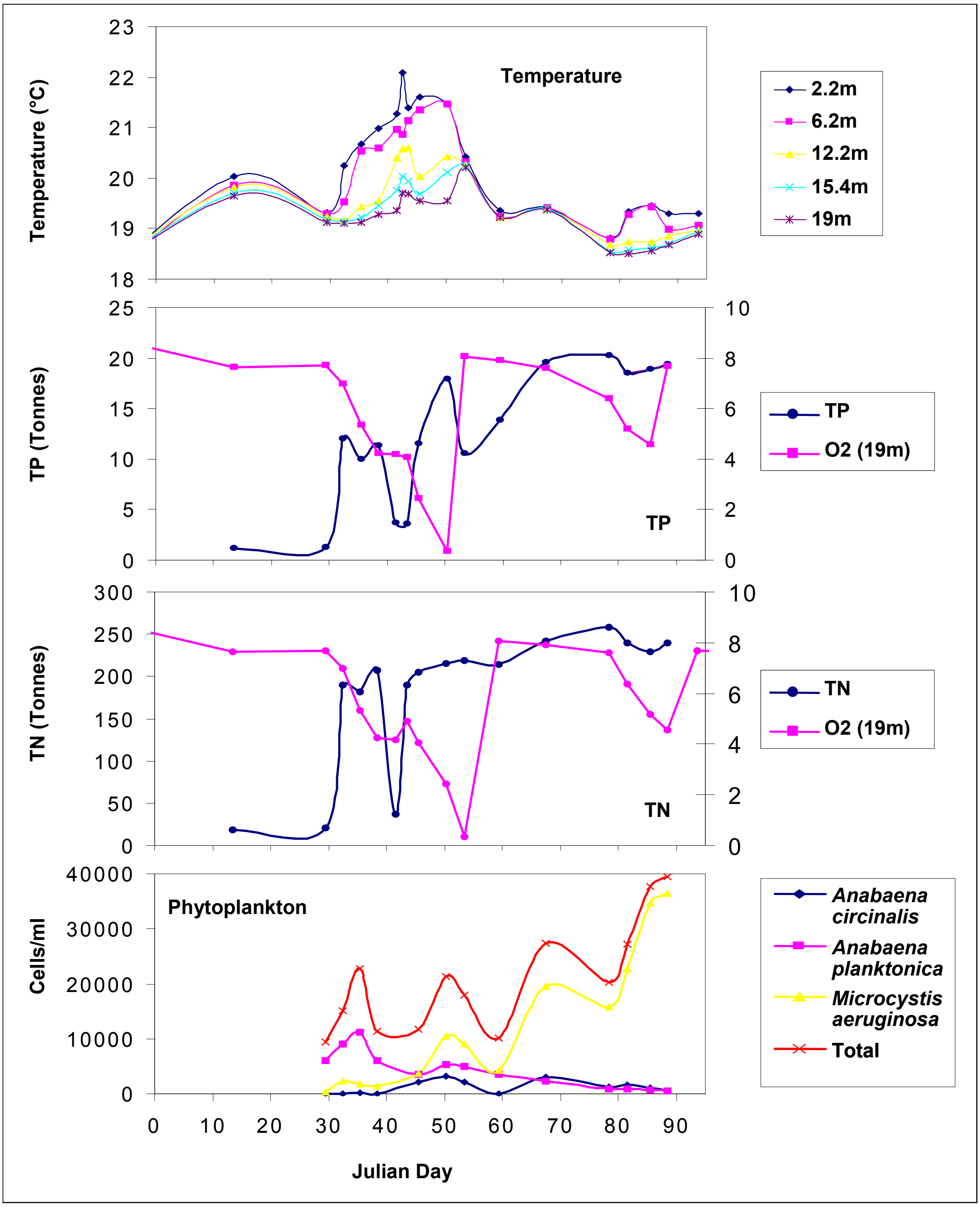

Figure 3. (A) Temperature, (B) TP and (C) TN below the thermocline and (D) phytoplankton concentration, central site lake site (20-m depth), Jan-April 2003.

DISCUSSION

Nutrient fluxes from the bottom sediments of Lake Rotorua are an important load of nutrients to the lake. Furthermore, there were large increases in densities of blue-green algal following these events, which led to the closure of several shore regions of this lake. While the lake became stratified on only three occasions during the 2002/03 summer, greater stratification frequency and duration, as recorded in previous years for this lake, will lead to a much greater release of nutrients from the bottom sediments. Donovan and Donovan (2003) estimate total nitrogen and phosphorus inputs from external sources to Lake Rotorua are 542 and 73 tonnes respectively. Nutrients released internally from the lake sediments in this study account for 56% of the external load for TN and 32% for TP, however, these figures are a conservative measure as only two stratification events are considered and resuspension of nutrients ignored. Benefits of major reductions in external nutrient load are therefore hindered by high internal loads.

Ongoing research to quantify seasonal variations in sediment nutrient release rates are being carried out with in-situ benthic chambers. Nutrient sedimentation rates are also being assessed using sedimentation traps aligned at different depths in the water column. Collectively, with nutrient inflow and outflow concentrations, a nutrient budget and model for the whole lake will be developed.

ACKNOWLEDGMENTS

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Transport of phosphorus and other trace elements by suspended matter in Lake Rotoiti

Karina Brooks & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

The role of suspended matter in transporting nutrients and trace elements within Lake Rotoiti has been investigated by analysis of material filtered from water samples collected in April 2003. The results indicate that transport of P, Zn, As, Fe and Mn in suspension is more significant than transport in solution. Major elements such as Na, K, Ca, Mg tend to be more mobile in solution. The role of suspended material as a transport mechanism is important as it is this material which ultimately ends up as sediment and can be recycled when bottom waters become anoxic.

Distribution of major and trace elements in Lake Rotoiti waters

Terri Chan & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

Samples of Lake Rotoiti waters taken in April 2003 have been analysed for major and trace element concentrations. While surface waters had pHs of about 7.1, the pH dropped with increasing depth, especially below the thermocline (30m) reaching 6.20 at 90m. No significant changes were observed in sodium, potassium, iron or manganese concentrations, but calcium and magnesium concentrations decreased with depth while zinc increased. This suggests that zinc is being remobilised from the sediments into the bottom waters while the alkali earth ions are being absorbed by the sediments.

Riparian attenuation of faecal microbes

Andrea Donnison and Colleen Ross, *AgResearch, Ruakura Research Centre*;
Rob Collins, *National Institute of Water and Atmosphere (NIWA), Hamilton*;
Malcolm McLeod, *Landcare Research, Hamilton*

Riparian margins are widely used to prevent nutrient enrichment of rivers, streams and lakes but it is not known whether they are similarly effective at intercepting faecal microbes washed downslope in overland flow. Non-point source faecal microbial contamination of waterways is of concern; particularly in rural areas and a range of strategies is needed to reduce this impact. To assess the ability of riparian strips to attenuate faecal microbes, we carried out a series of experiments in which we flushed liquid farm dairy effluent down sloping (10-15°) grass plots (downslope length 5 m or 1 m, width 2 m) on moderately well drained Hamilton clay loam soil. We collected the water that flowed over and out of the lower end of the plots, and measured two types of bacteria, the widely used faecal contamination indicator *E. coli* and the pathogen *Campylobacter jejuni*.

We found there was a rapid first flush of both types of bacteria but that their concentrations in the outflow decreased by 100 fold or more over the following hour. The concentration of bacteria in the outflow was not affected by the height of the grass. However, the downslope plot length affected the outflow of water, and the timing and magnitude of peak bacterial concentration: outflow, and the time to peak concentration were faster, and the magnitude of peak concentration higher, upon the shorter (1 m) plots.

This finding raises implications for the optimal size of riparian buffer strips. Five to twelve days after effluent application we watered the plots again to generate surface flow and found that we did not re-mobilise significant numbers of bacteria. We consider that this was due to adhesion of bacteria to particles and die-off in the soil. We also flushed cow pats rather than effluent down the plots. Although there was the same overall pattern of a rapid first flush of both bacteria, the bacterial concentrations were lower using cowpats than for parallel experiments using liquid farm dairy effluent.

We plan to carry further experiments on plots on different soil types over the next few months and produce a document for MAF Policy that includes preliminary guidelines for interception of faecal microorganisms through riparian management.

Lake plants speak out on lake condition

Tracey Edwards and John Clayton

Aquatic plants are valuable indicators of lake health. They are easy to measure and they integrate long-term climatic and environmental influences. LakeSPI (Lake Submerged Plant Indicators) is a new tool that uses information based on aquatic plant measurements taken from within lakes in order to generate a score indicating lake condition. LakeSPI creates a native and an invasive plant condition index and it is these scores that are integrated to create an overall lake condition index. The LakeSPI method can also be applied to historical lake vegetation survey data to generate a score reflecting former condition, which can then be compared to present day vegetation status.

Five Rotorua lakes (Rotorua, Rotoiti, Rotoehu, Okareka and Okaro) were selected at the request of Environment Bay of Plenty to carry out a LakeSPI analysis. To do this we applied our LakeSPI method to historical full lake vegetation surveys carried out on these five lakes in the 1980s. Next we selected five sites within each of these five lakes, based on historical records, and then we resurveyed these sites in October 2003 using the LakeSPI method.

LakeSPI results highlight that while lakes Rotoiti and Okareka have continued to decline in lake condition; lakes Rotoehu and Okaro have remained in a stable yet degraded state since the 1980's. On the other hand, Lake Rotorua has shown some small improvement, largely on account of its high exposure that helps to minimise weed impact and can enhance water quality features. Earlier findings showed that all five lakes underwent a major decline from their pre-invasive condition in the early 1900s, however their decline since the 1980s has been minimal in comparison. This is largely because invasive weed species have had a major impact during the 1960s to 1980s, while water quality deterioration has been a long term and progressive influence. Despite this, it was clear that all five lakes are now dominated by invasive weed species, native vegetation has been largely displaced, former deep water charophyte communities (as can still be found in Lake Rotoma) have all but disappeared, and the health of remaining aquatic vegetation is clearly compromised by smothering growths of filamentous blue-green algae. These benthic and epiphytic growths are a natural corollary of advancing eutrophication and provide the subsurface equivalence to surface blue-green algal blooms being experienced with increasing frequency in these lakes. Such growths are a harbinger of total macrophyte collapse as has been experienced in many Waikato lakes.

Despite the Rotorua lakes showing varying degrees of degradation they have the potential to get much worse! Protection of these lakes is far more feasible and cost effective than attempting to restore them once they become excessively degraded or devegatated. Many of the Rotorua lakes still have significant native plant communities and biodiversity values that deserve more rigorous protection.

For more information on aquatic plants in the Rotorua lakes see 'Rotorua Lakes: Plants tell the tale' in this symposium proceedings. For more general information on aquatic plants and their management, refer to: www.niwa.co.nz/rc/prog/aquaticplants.

LakeSPI surveys will continue to provide meaningful baseline information for assessing the influence of current and future management activities on the Rotorua lakes. For more

information on the LakeSPI method, refer to: www.niwa.co.nz/ncwr/lakespi, or feel free to contact the authors.

Days of our lakes: the life and times of Rotorua and Rotoiti

Will Esler
Department of Earth Sciences and Waikato Radiocarbon Dating Laboratory, University of Waikato, Private Bag 3105, Hamilton. will.e@clear.net.nz

INTRODUCTION

Ongoing PhD fieldwork by the author suggests that the history of Lakes Rotorua and Rotoiti is much more complex than previously thought. Lake Rotorua has drained underground and probably dried up several times.

EARLY HISTORY OF LAKE ROTORUA

Lake Rotorua first formed soon after the caldera-forming eruption of Mamaku Ignimbrite 220,000 years ago. The caldera subsided about 1.2 km during and just after this eruption. It was partly backfilled with ignimbrite and degassed magma remnants erupted as Ngongotaha and Pukehangi lavas. Early lake sediments are found in Paradise Valley, the Utuhina, and in geothermal boreholes. Early diatomite is interlayered with local volcanic material.

HUKA GROUP

A series of major lakes between Taupo and Rotorua more than 220,000 to about 80,000 years ago were probably at times continuous. Sediments of this age belong in the "Huka Group". Faulting, tilting, and ryegrass make old lakes very hard to map. Lake level in the Rotorua Basin rose to well over 360m above sea level (asl). There are much higher possible terrace remnants, but no convincing outcrops. Towards the end of the long period of stability, volcanism between Waimangu and Hinemoa Point abruptly moved sedimentation from diatoms to glass silt. Apparent lake-level varied a lot at this time, although perhaps the earth moved as much as the water. The foundering of the Tikitere Graben between Lakes Rotorua and Rotoiti and the formation of Mokoia Island roughly 80,000 years ago was spelt the end of the biggest Rotorua-Taupo lakes. This northern spillway drained Lake Rotorua to below 220m asl. This era lasted long enough for several metres of peat to build up 60 metres below Rotorua City.

ROTOITI IGNIMBRITE

Rotoiti Ignimbrite eruptions took place 50-60,000 years ago. The first explosion involved lots of water; a big lake somewhere around Lake Okataina got used up very suddenly. The result was wide dispersion of much very fine tephra; the Rotoehu Ash. Rotoiti Ignimbrite then covered all the Rotorua Basin. It flowed around but not over Mt Ngongotaha. Rotoiti Ignimbrite blocked the Tikitere Graben, causing a plumbing crisis. The Earthquake Flat Ignimbrite erupted soon after. This deposit blocked the south end of the Lake Rotorua catchment which would otherwise have soon overflowed into the Ohakuri or Atiamuri catchments, potentially forming a smaller version of the old giant lake. As it happens, a separate lake did re-form further south, about 40m lower than Lake Rotorua. Lake Rotorua rose sharply for a brief spell at around 400m, then fell and stabilised at ca. 380m asl, 100 metres above present, for the next 15,000 years or so. Lake Rotorua extended well south of the Hemo Gorge after the Earthquake Flat Ignimbrite

eruption. The southern arm of the lake was about 38km^2; a little larger than present Lake Rotoiti, but mostly very shallow. Some oozings would have gone south, but not a major stream. “Southern drainage” of Lake Rotorua is a myth. Drainage was underground during this period; and/or into the Hururu stream on the Waerenga block where lake sediments are found at high level beyond the northern catchment boundary of Lake Rotorua. The high lake extended a little east of the Ruahine Springs in the Tikitere area. The Rotoiti Ignimbrite dam had its crest near the Manupirua Springs.

PULLING THE PLUG

Between 40-35,000 years ago, after the Tahuna eruption at Taupo, Lake Rotorua drained to below its present level, leaving intact the Rotoiti Ignimbrite dam at Tikitere. The lake water drained underground and probably emerged from ENE fissures in the Okere/Kaituna valley. Tutea’s Cave seems to have been formed next to an outlet similar to the present Tarawera Falls.

SOCK IN THE PLUGHOLE

Lake level remained low until about 35,000 years ago when a major lobe of the Mangaone Tephra pyroclastic flow travelled west from the OVC and blocked the plughole. This ‘Mangaone Ignimbrite’ overwhelmed and carbonised a forest; now charred logs in the Microsilica quarry at Tikitere. The ignimbrite is about 10m thick at Hells Gate where it forms Te-mimi-o-kakahi waterfall, and 40m thick nearby. Lake Rotorua level rose to about 340m asl and paused. Most of the eastern and northeastern Rotorua Basin “lake” terraces are in fact alluvial fans silicified by vigorous geothermal activity at this time. Lake level gradually rose to its former height of 380m asl only briefly before falling again, probably by overtopping the catchment divide in the Okere Falls area.

The main break-out flood was down the Kaituna; not to the Rotoiti Basin, and certainly not to the south. Lake level paused at ca.330m for a brief period, and then fell again to a little above present level 28,000 years ago. The overflow soon abandoned the Kaituna and drained through the present Rotoiti basin into the Haroharo Caldera and ultimately the Tarawera River. A major hydrothermal explosion at Wharetata Bay seems to be linked with this unusual diversion that was the end of the Rotoiti Ignimbrite dam. Lake Rotorua fell to an unknown depth below present for 18,000 years. It probably drained underground again, as it seems not to have eroded a deep channel into the Rotoiti Basin.

LAKE ROTOITI

Geophysical data collected before the recent accumulation of gassy acoustically opaque sediments suggest that Lake Rotoiti might have formed 22,000 years ago by partial blockage of the river into the Haroharo Caldera by lavas of the Te Rere eruptive episode. Further eruptions 9000 years ago conclusively impounded Lake Rotoiti, which seems to have then spilled westward into the drained Rotorua Basin. This event drowned a mature mixed podocarp-broadleaf forest by >20m. Exposed highly organic lake sediments with well-preserved plant fragments suggest the new Lake Rotorua remained anoxic for centuries. Later rise and re-occupation of the Okere Falls outlet allowed flushing. Lake Rotoiti and Rotorua were joined as a single lake a few metres above present level at this time. Differential uplift has since tilted the floor of the Rotorua Basin northward, giving the impression of a former 14-16m higher lake level. Lake Rotorua then had a much

longer and more convoluted shoreline than at present, with five small islands in the City area; Kawaha, Koutu, Pukeroa, Owhatiura, and Owhata (Hinemoa). We will need long cores from both lakes to confirm this scenario, as seismic probing might now need to be of trout-killing intensity to penetrate the lake beds.

SEPARATION OF THE LAKES

Lake Rotoiti separated from Lake Rotorua within the last few thousand years either by lowering due to erosion at the Okere Falls or by longshore drift forming the Mourea isthmus. Work is underway to clarify this.

THE FUTURE

Lake Rotoiti is *geologically* vulnerable to sudden draining through fault fissures, but not more so than the other Rotorua Lakes. The Rotoehu Ash layer ensures it is perched well above the water table north of the lake. Lake Rotoiti may already have a minor plughole, known as Pararaki, in the northeastern end of the basin. Lake level could potentially fall many metres. This would probably cause a significant hydrothermal explosion in the Tikitere and/or Taheke geothermal fields, and inject a lot of 'fertile' water into the Pongakawa aquifer.

A more likely geological event is another in the series of small to medium-sized eruptions in the Okataina Volcanic Centre (OVC). Typical OVC eruptions 'instantaneously' seal or at least refresh nearby lake beds with tephra. This has happened many times to Rotoiti, most recently in 1886, but not for 5,000 years to Lake Rotorua; because the prevailing wind pushes most tephra towards Kawerau. Our guilty lakebed secrets will be eventually swept under the mat.

Pore water chemistry and the contribution of seston diagenesis to the nutrient supply to Lake Rotoiti

Andrew Fitchett & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

As part of a group investigation into the flux of nutrients and trace elements through Lake Rotoiti seston cores were collected in April 2003. Pore waters extracted from sections of these cores taken at regular intervals down core have been analysed and the fluxes to the lake bottom waters calculated from the concentration gradients.

The contribution of groundwater to the loss of nutrients and trace elements into Lake Rotoiti

Nicola Foran & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

As part of a group project to determine the trace element fluxes through Lake Rotoiti, the contribution to the nutrient and trace element budget to the lake through the discharge of ground waters has been assessed by insertion of piezometer tubes into the shallow groundwater systems within the esplanade strip. The results of analyses of groundwater samples taken from these in April 2003 are discussed.

Eutrophication and early diagenesis: a geochemical timebomb in New Zealand lakes

Chris Hendy, Adam Berry, Michelle Caird, Rachel Cooke, Jacob Croall, Katrina Daysh, Sarah Milicich, Janine Sedgwick, Rossana Untaru
Chemistry Department, University of Waikato, Private Bag 3105, Hamilton.

Nutrients and many other trace elements discharged into Rotorua lakes are largely removed from solution to the sediments, where there are effectively immobilized as long as the sediments remain in contact with oxidizing waters. Where lakes can remain stratified for a significant fraction of the year, the continual rain of organic debris from the surface waters to the deep waters gradually consumes the dissolved oxygen of the deep waters. As the nutrient loading to such lakes increases, dissolved oxygen is completely removed forcing the bottom waters to become anoxic. Anoxic bottom waters lead to reduction of other oxidized species including ferric to ferrous mobilizing not only the iron, but also most other absorbed trace elements, including phosphorus. Analysis of the budget of trace elements in three Rotorua lakes (Tikitapu, Okareka and Okataina) in April 2002 showed that the diffusion of the remobilized phosphorus and other trace elements across the lake/sediment interface greatly exceeds the flux of these species from all other sources. This will lead to rapidly increasing eutrophication of the lakes, which may take many decades to centuries to reverse. Studies initiated in 2003 indicate that the effect in Lake Rotoiti may be even more significant than in Tikitapu, Okareka and Okataina. Conservation of lake water quality will require that the input of nutrients be kept below that which can lead to bottom water anoxia.

Clastic sedimentation in Lake Rotoiti

Erica Hofstee & Chris Hendy
Chemistry Department, University of Waikato, P O Box 3105, Hamilton

Analysis of sediments deposited in lakes provide both a record of changing inputs into the lake and a measure of chemical and physical processes (diagenesis) occurring at the base of the lakes. In most lakes the lack of well defined time markers in the sediments make it difficult to separate the two processes, but in the Rotorua lakes the all pervasive presence of tephra provides well defined time markers. As part of a senior undergraduate integrated study of trace element fluxes through Lake Rotoiti, six soft sediment cores were taken. The major tephra identified was the Kaharoa, 1305 AD, which erupted from Mt Tarawera, and contributed about up to 1m of sediment to the lake. Thin deposits of 2-5cm of the 1886 Tarawera tephra cover this. Diatom ooze separates the two tephra, covers the Tarawera, and is in turn covered by 200 - 600 mm of seston. Each significant layer within the cores has been sampled and digested for trace element analysis to determine the maximum potential for trace element flux from sediment to lake water. The results of Mg, Ca, Sr, Mn, Fe, Cu, Zn, P, S, Cd, As, Na, and K analyses will be presented.

Food webs in the Rotorua lakes: a stable isotope study

Chris McBride, Brendan J. Hicks
Centre for Biodiversity and Ecology Research, Department of Biological Sciences, University of Waikato, Private Bag 3105, Hamilton
cgmcbride55@hotmail.com
b.hicks@waikato.ac.nz

Michael van den Heuvel
Forest Research, Private Bag 3020, Rotorua
Mike.VandenHeuvel@ForestResearch.co.nz

The study sampled rainbow trout, bullies, common smelt, freshwater crayfish, plankton, macrophytes, and benthic invertebrates in the 14 lakes of the Rotorua Lakes District. Dried and weighed samples were analysed by the Waikato Stable Isotope Unit, University of Waikato, for their stable isotope ratios of carbon and nitrogen. These values were compared to the lake morphometry and nutrient status.

In a more detailed comparison, limnetic samples will be compared to littoral samples in three lakes that span the range from oligotrophic to eutrophic status. Eutrophic lakes have typically shown less isotopic discrimination between the stable isotopes of carbon than oligotrophic lakes (McCabe 1985). We predict that isotopic ratios will be related to trophic status, and that bullies will be a more important food source for the trout in eutrophic lakes than in oligotrophic lakes, where smelt will be the primary food.

Reference

McCabe, B. 1985. The dynamics of 13C in several New Zealand lakes. D.Phil. thesis, University of Waikato, Hamilton

Rotorua Lakes water quality research: a bibliography to 2002

Claire E. Miller
*Victoria University of Wellington**
cmiller@wave.co.nz

The Rotorua Lakes have been described as the Jewels in the Crown of the Rotorua District. They play a large role in the economy, environment, culture, recreation and tourism potential of the area. However, since human settlement in the region, the water quality and ecology of the lakes has deteriorated. Introductions of exotic flora and fauna, combined with the impact of a large population in the lake catchments, have increased the problem.

Over the last half century, concern over the water quality of the lakes has grown, and many studies on the subject have been undertaken. This selective annotated bibliography seeks to identify and locate the reports and publications produced from this research, providing a solution to the lack of bibliographic information on the topic. The primary aim of this bibliography is to provide information for researchers on what studies have already been carried out, and to present a chronological view of the perceived problems in the lakes.

The bibliography contains four hundred entries, arranged chronologically by author, and indexed by subject, author and organisation. The primary format of the bibliography is digital, as this provides advanced retrieval features and the ability to easily update the study, but it is also supported by a paper-based format for easy reference for those who prefer it.

*Now at AgResearch, Ruakura Research Centre, Hamilton

Some sample records

23.
Lands and Survey Department. 1965: Weed in Rotorua Lakes. Unpublished report, Lands and Survey Department. 3 pp.
These notes contain a description of the existing weed situation in the Rotorua lakes, from owners of properties on the lake shores affected, to the trials conducted and the results. Recommendations were to make a reduction in the sewage and fertilizer inputs, continue testing of chemical poisons, and to undertake further research. It was considered that to rid the lakes of weed entirely might cause algal blooms, and create problems for fish and waterbirds.
Location: WSU.

137.
Hatton, C.; Larcombe, M.F.; Donovan, W.F.; Thomson, M.R. 1975: Ecology of Ohau Channel. Unpublished report, Bioresearches Ltd. Auckland. 7 pp.
The physical and biological conditions in the Ohau Channel, between Lakes Rotorua and Rotoiti, are summarised. The report comments on the uses made of the Channel, and what species of flora and fauna can be found there. Both short-term and long-term changes are described. As an appendix it contains "A brief report on conditions existing in parts of Lake Rotorua, the Ohau Channel, and Lake Rotoiti - January 1975". This was undertaken in response to press reports of an extensive algal bloom in Lake Rotorua, and observations were made with regard to water colour, zooplankton, and algae colonies at various locations in Lakes Rotorua and Rotoiti, and in the Ohau Channel.
Location: WKRG.

269.
Vincent, W.F.; Spigel, R.H.; Gibbs, M.M.; Payne, G.W.; Dryden, S.J.; May, L.M.; Wood, P.; Pickmere, S.E.; Davies, J.; Shakespeare, B. 1986: The impact of the Ohau Channel outflow from Lake Rotorua on Lake Rotoiti. Taupo Research Laboratory, Department of Scientific and Industrial Research, File Report 92. 6 pp.
Details are provided of a series of measurements in Lake Rotoiti and the Ohau Channel over 1985-1986. The study sought to define the physical processes, and determined that during winter the Ohau Channel penetrates into the lake's eastern basin as a bottom current, while during summer the diurnal cycle of the Ohau Channel's heating and cooling controls whether it flows into the main body of the lake or down the Okere Arm. Management options for the Ohau Channel are considered.
Location: WKRG.

Copies of this bibliography, in either print or CD-ROM format, are available from the LakesWater Quality Society Inc.

Off to the chemist's: some thoughts on symptom relief for sick lakes

Nick Miller
LWQS

ABSTRACT
The causes of the current water quality problems in some of the Rotorua Lakes are briefly listed, together with the most obvious symptoms, which include:

- Deoxygenation of the bottom waters (leading to additional nutrient release)
- Significant or severe cyanobacterial blooms
- Loss of biological diversity

It is acknowledged that action is now being taken to address the causes, however this may require a long time scale to be effective. Action to reduce the severity of the symptoms is also required, and is now being considered. An examination is made of some potential techniques to treat these symptoms, which include:

- Stopping the lake from stratifying
- Injecting air or oxygen into the hypolimnion of a stratified lake
- Removing water from the hypolimnion of a stratified lake
- Controlling or eliminating cyanobacterial blooms

Some of the practical aspects of these technologies are briefly considered, together with the pros and cons of each approach.

THE PATIENTS

- Lake Rotorua – on critical list
- Lake Rotoiti – on critical list
- Lake Okaro – on critical list
- Lake Rotoehu – on critical list, signs of recovery?
- Lake Okareka – some worrying symptoms
- Lake Tarawera - some worrying symptoms

THE DIAGNOSIS

- Advanced eutrophication, due to excessive inputs and organic matter over many decades
- Land use changes
- Too much human activity in the catchments?

We recognise the cause, and the authorities are starting to apply a cure, but this will take years (decades?) to accomplish. Can we also address the symptoms?

THE SYMPTOMS

- Deoxygenation of the bottom waters (leading to additional nutrient releas)
- Significant or sever cyanobacterial blooms
- Loss of biological diversity

While we await a cure, we also need to control the symptoms. MfE and EBOP are starting to look at this also.

WHAT SYMPTOM RELIEF IS POSSIBLE?

- Prevent deoxygenation of the bottom waters
- Control or eliminate cyanobacterial blooms
- Application of these remedies would also help with the third symptom

CONTROL OR ELIMINATION OF CYANOBACTERIAL BLOOMS

- Environmental manipulation
  Difficult to arrange on a whole-lake scale, many uncertainties
- Chemical control
  Environmental implications, excessive and ongoing cost on a whole-lake scale
- Biotic control. Some aquatic macrophytes release control factors, as does barley straw.
  Environmental implications, impractical on a whole-lake scale
- Use of ultrasonic irradiation – controls by damage to algal vacuoles and other effects
  Significant capital cost
  Results may be inconsistent
  Offers of low-cost trials

HOW TO PREVENT DEOXYGENATION?
We can:

- Stop the lake from stratifying

Or we can:

- Inject air or oxygen into the hypolimnion of a stratified lake

Or we can:

- Remove water from the hypolimnion of a stratified lake

HOW TO REMOVE WATER FROM THE HYPOLIMNION?

- In the case of Rotiti, the proposed (currently dormant? Kaituna Power Scheme could be used
- In the case of Okareka, a submerged inlet to the overflow could be used

TO STOP STRATIFICATION

- Our lakes stratify because heat from the sun (and maybe a little geothermal input) causes a layer of warm water (the epilimnion) to form on the surface, with the cold lower layer (hypolimnion) having very little water exchange with the lake surface, hence the deoxygenation.
- In effect, the lake is acting as a giant heat engine
- It is possible to destratify a lake using plumes of air bubbles, or circulating pumps or propellers

BUT

- In a lake the size of Rotoiti this would take very large amounts of energy

HOW TO REOXYGENATE A HYPOLIMNION: OPTION 1

Bubble air through it – compressors plus a distribution network plus power supplies. Impellors may be needed for horizontal distribution.

- High capital costs, cheap raw material
- Inefficient – much energy wasted compressing nitrogen
- Possible nitrogen supersaturation?
- Areas of reduced buoyancy above bubble plumes – safety hazard to swimmers?

HOW TO REOXYGENATE A HYPOLIMNION: OPTION 2

Inject pure oxygen into it – oxygen supply plus compressors plus a distribution network plus power supplies. Impellors may be needed for adequate horizontal distribution.

- Oxygen as LOX or compressed gas or a peroxide. High capital cost, high supply cost.
- Oxygen generated on site (pressure-swing adsorption). High capital cost, medium running cost.
- In lake electrolytic or electrodialytic production of oxygen.
  Inefficiencies due to low-conductivity electrolyte (lake water)
  High capital cost, fairly low running cost

The influence of geothermal waters to the composition of Lake Rotoiti

Stacey O'Driscoll & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

The south-western shores of Lake Rotoiti, North Island New Zealand, are influenced by geothermal activity, generated by Tikitere Geothermal Field. As part of an integrated undergraduate project in practical environmental chemistry to determine the flux of trace elements through Lake Rotoiti, geothermal water samples were obtained from specific sites along the shoreline from Manupirua Hot Pools to Te Rei Bay and analysed for a combination of major and trace elements (calcium, magnesium, sodium, potassium, zinc, manganese, iron, cadmium, sulphur, chromium, copper and arsenic, plus nutrient species nitrate, phosphate and ammonium). The geothermal waters contribute significant sodium, potassium, ammonia, sulphate and arsenic to the lake.

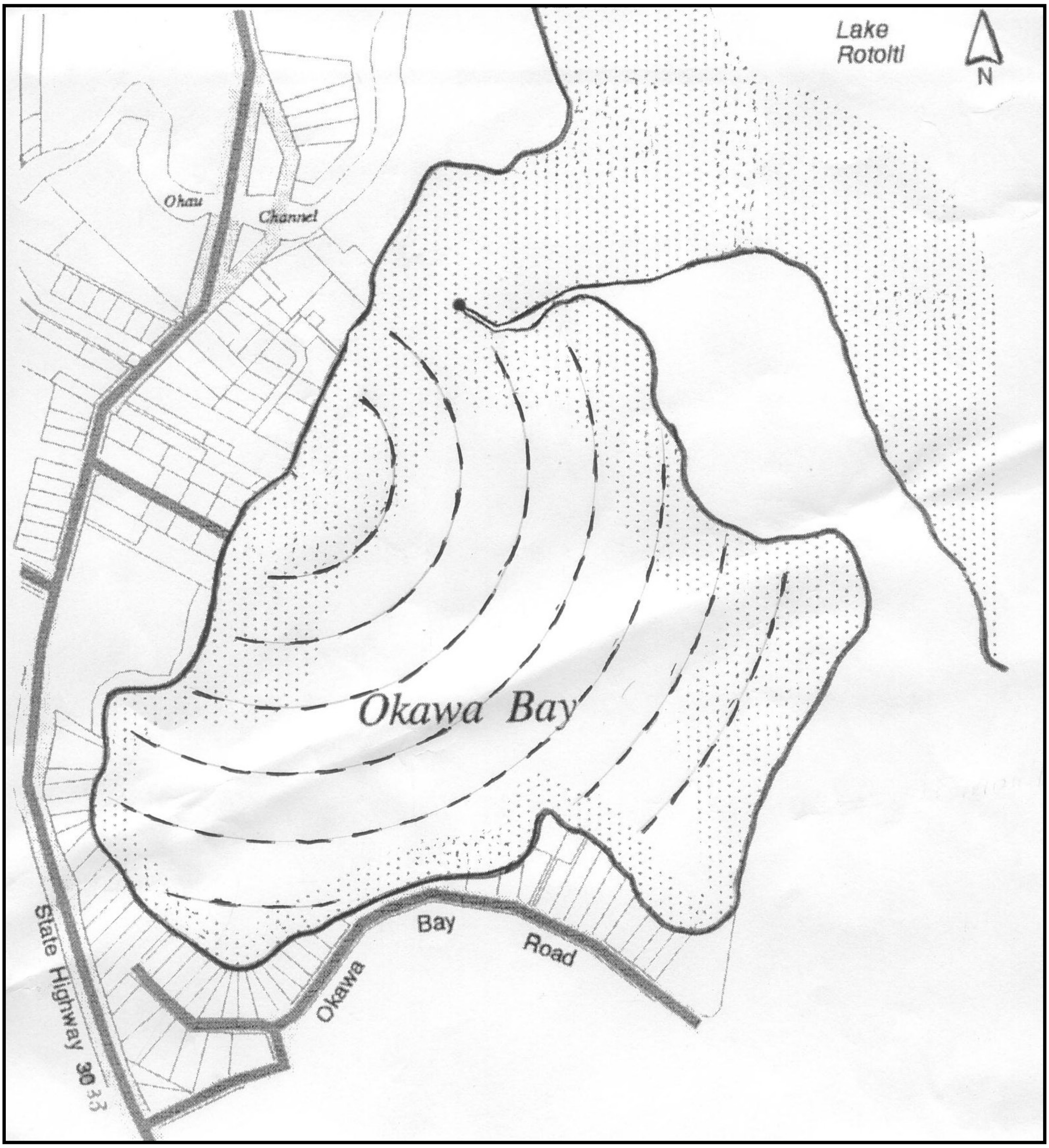
Considering Okawa Bay as the worst hit body of water: a suggested remedy

Don Penn
Okawa Bay, P O Box 7042, Te Ngae, Rotorua

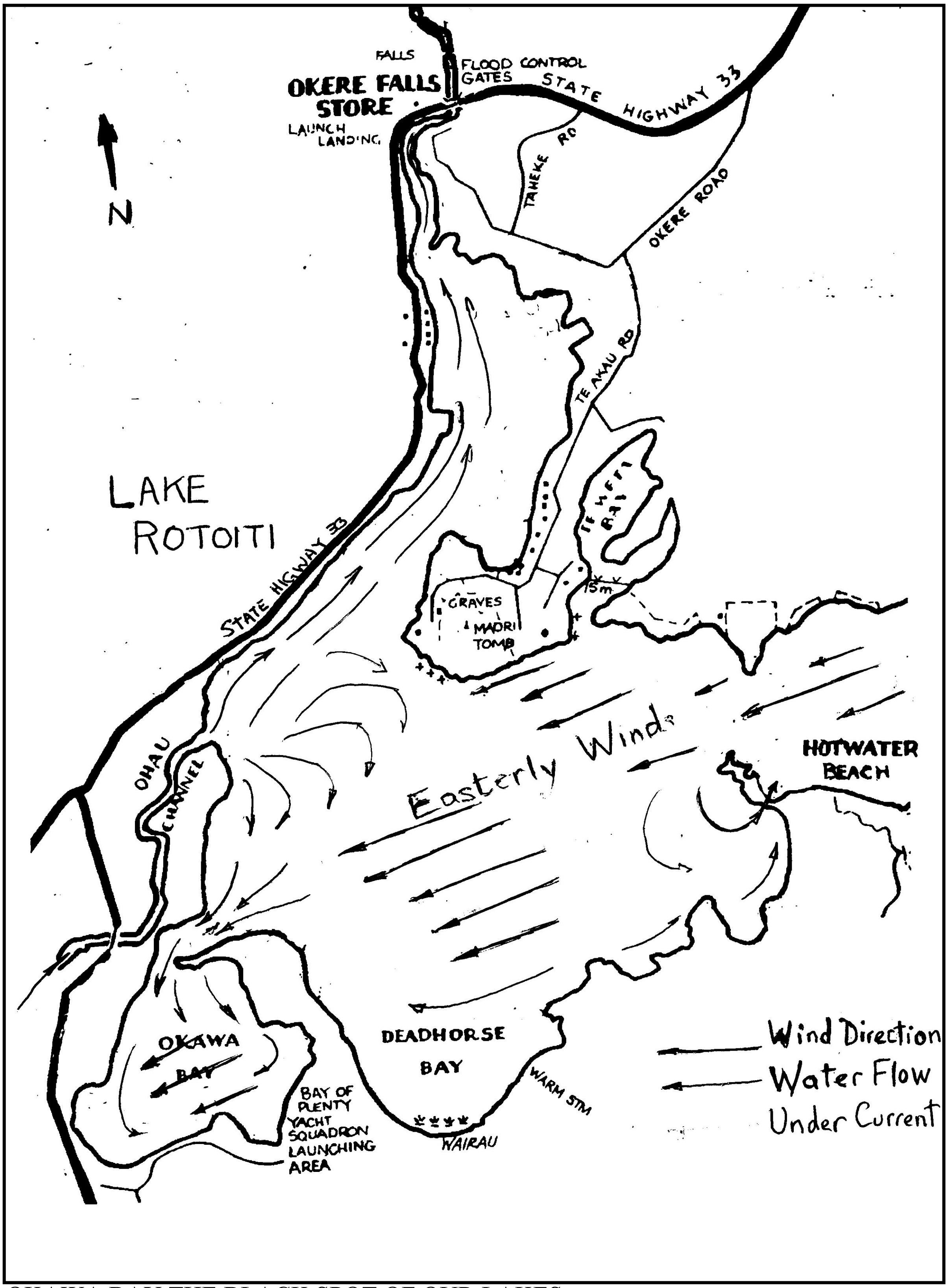
ABSTRACT
A pipeline is proposed, drawing lake water 'down hill' from Okawa Bay to the Kaituna River beyond the control gates and road bridge. The inlet at Okawa Bay would be fed by 3 inlets set in a large triangle drawing water from about 1 metre above lake bed. In the centre of the triangle is an aerator dispensing oxygen to the lake bed, and stirring up nutrients in solution and suspension at low density. The whole structure is floating and able to be swung around to cover Okawa Bay and Deadhorse (Wairau) Bay in a grid pattern. The outlet would be monitored for flow and nutrient content so that maximum improvement in nutrient removal from the Bay can be achieved, without causing problems elsewhere. This will tend to reduce the settlement of nutrients in Rotoiti from the Ohau Channel/Kaituna flow.

Siphon systems
The advantage of a siphon is that you can choose where you place the inlet, and where you place the outlet, and providing it is going down hill it will flow, and keep flowing without further attention. A relatively low cost installation that will give free running costs indefinitely.

With proper consideration to fall and pipe diameter, a moderate flow running for 24 hours a day achieves large quantities. Okawa Bay is an obvious first choice because of its current black image, its small area, and proximity to the lake exit, making it easier to fix.



- Suggested grid lines with 78 lay points for sweeping Okawa Bay with aeration pontoon.
- Simple relocation at intervals.
- Pontoon can be drawn back, then pipeline is long enough to sweep beadhorse Bay.
- More pontoons reduce recovery time.
- Greater depth requires different system with long air hoses fitted lances or flailing tubes.
- Syphon lifts water from any depth.



OKAWA BAY THE BLACK SPOT OF OUR LAKES
WHY?

There are no farm run offs into Okawa Bay. Of 22 tons of nutrients added to Okawa Bay per annum septic tanks account for just 2.4 tons

Consider the following:

- The Ohau Channel flow is loaded with nutrients from Lake Rotorua. The bulk of this bad water goes straight down the Kaituna. Some is side tracked into Lake Rotoiti.

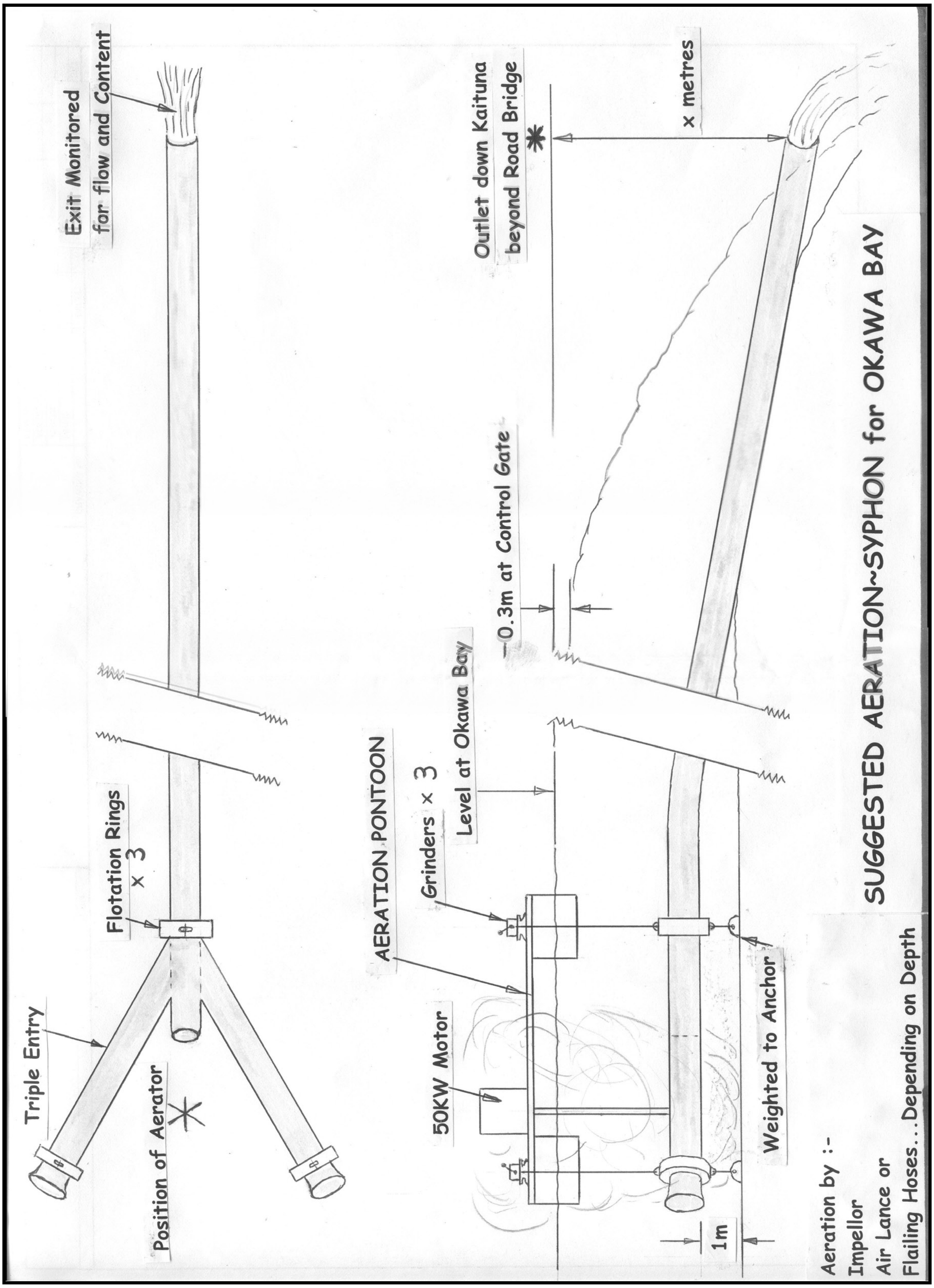
- The Ohau Channel flow slows down as it broadens out into Lake Rotoiti, and deposits large quantities of nutrients etc. into Deadhorse (Wairau) Bay and beyond.

- Lake Rotoiti has become a large settling pond for nutrients. 75% of which came from Lake Rotorua, via the Ohau Channel.

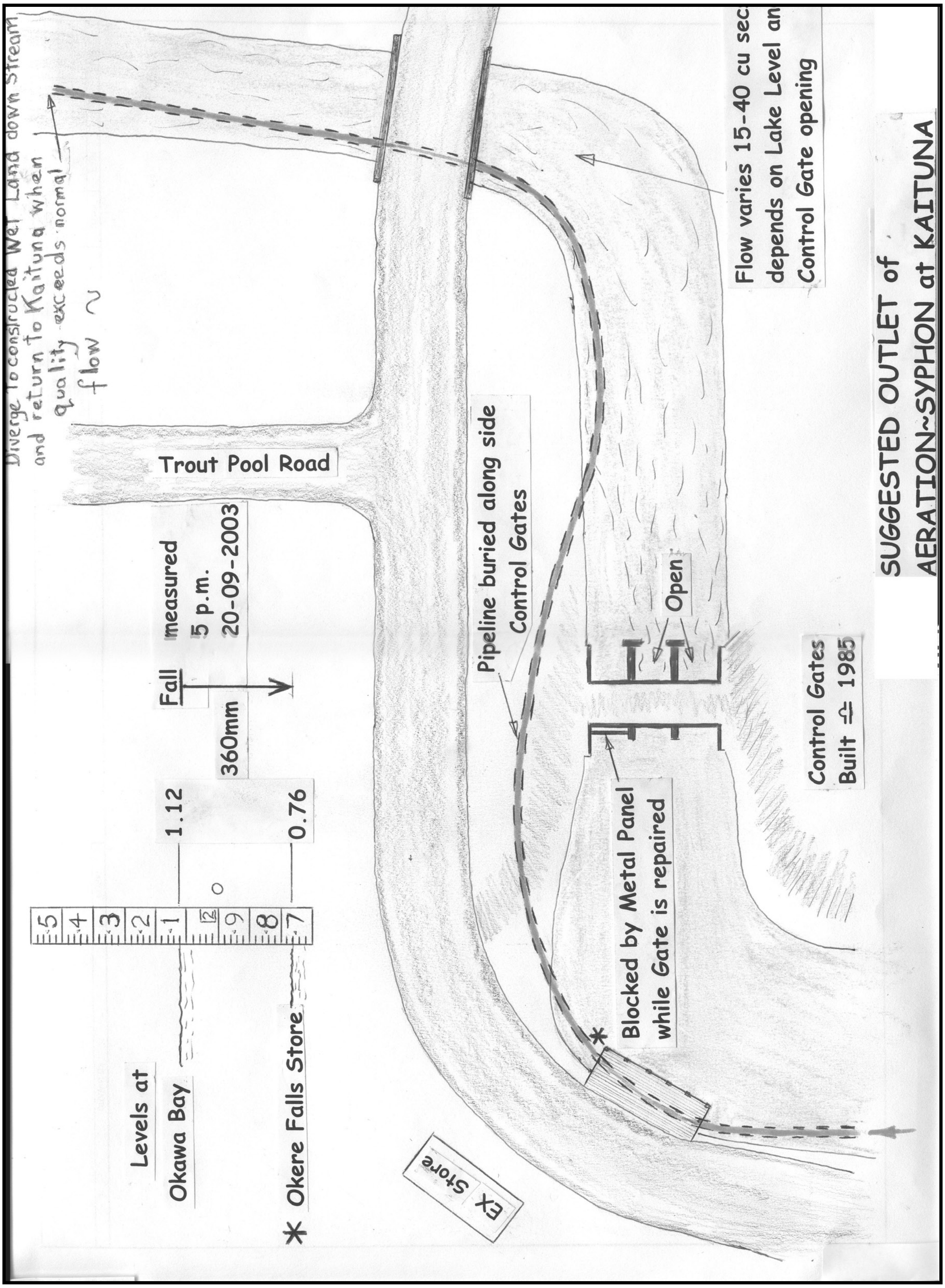
- When easterly winds occur, low grade water flows of up to 5 cusecs enter Okawa Bay from Deadhorse (Wairau) Bay.

- Because there is no escape from Okawa Bay. this added water is contained (other than slippage) and settles extra nutrients to the bed of Okawa Bay until the wind eases. This reduces the quality of the Okawa Bay water to lower than the surrounding average.

- This beyond average build up of nutrients has been occurring for decades, and it is due to lack of flushing or any attempts made to encourage water flow in the bay.



Triple Entry
Flotation Rings x 3
Exit Monitored for flow and Content
Position of Aerator
50KW Motor
AERATION PONTOON
Grinders x 3
Level at Okawa Bay
0.3m at Control Gate
Outlet down Kaituna beyond Road Bridge
x metres
1m
Weighted to Anchor
Aeration by :-
Impellor
Air Lance or
Flailing Hoses...Depending on Depth
SUGGESTED AERATION~SYPHON for OKAWA BAY


Diverge to constructed Wet Land down Stream
and return to Kaituna when
quality exceeds normal
flow ~
Trout Pool Road
Fall measured
5 p.m.
20-09-2003
360mm
1.12
0.76
Levels at
Okawa Bay
* Okere Falls Store
EX Store
Pipeline buried along side
Control Gates
Open
Blocked by Metal Panel
while Gate is repaired
Control Gates
Built ≙ 1985
Flow varies 15-40 cu sec
depends on Lake Level an
Control Gate opening
SUGGESTED OUTLET of
AERATION~SYPHON at KAITUNA

Controlling of some algae using ultrasound

David Powell
Auburn Industries, Pukekohe, South Auckland

ABSTRACT

Approximately six years ago, a new product was released into the horticultural market in the Netherlands for the control of algae by non-chemical means. The method is using ultrasound waves to kill algae. Now thousands of these units are being used around the world for the control of algae. Applications include, drinking water lakes, horticultural water re-use reservoirs, oxidation ponds, cooling water reservoirs, fish farms and swimming pools.

From the 3 years of experience gained in New Zealand and Australia we know the product does work, but not in every case. Some algae are hard to kill and some water bodies are difficult to treat for various reasons. The positive outcome is that when it does work, 1 Aquasonic unit can treat 1.5 hectares of water while only consuming 60 watts of power.

THE EQUIPMENT

The auburn algae controller consists of an electronic control cabinet, connected by a 12 volt cable to a transducer which emits sound wave pulses through the water. The transducer is mounted on floats for larger applications.

NEW ZEALAND TRIAL

The New Zealand Trial (Acknowledgements to Rodney District Council)
Over the past 18 months an independent trial has been conducted by Rodney District Council at their Helensville reservoir comparing fortnightly then weekly, water temperature and algae concentrations pre and post the installation of an Aburn Algae Controller.

Summary Results (detailed overleaf)
In summary, when comparing the warmest periods of the year for year 2000 (pre-installation) to year 2001 (post installation) we are pleased to report the following reductions in algae concentrations:

CERATIUM	75% REDUCTION
TRACHELOMONAS	80% REDUCTION
ANABAENA	100%REDUCTION

The Site

The Helensville Dam No. 1 reservoir is a lake surrounded by native vegetation and fed by a stream. It measures approximately 100 x 150m and ranges in depth from shallow edges to 9m in the centre. Vegetation grows right to the water line where water tolerant plants are also abundant. Water is gravity fed via a submerged pipe to a pump house located 130m away.

The Trial Set Up

The closest power source was the pump shed located 130m away. This was chosen as the best location for the control cabinet for the purposes of this trial and a 12 volt heavy core twin wire was taken from there up the hill to the lake. The floats were positioned in one corner of the pond to maximise the effect of the ultra-sonic transducer with its range of 150m.

Regular fortnightly data recording water temperature and algae concentration (Ceratium, Trachlemonas and Anabaena) were available from 25th February 2000.

The unit was installed 18 October, 2000 and readings of algae concentrations and water temperature were then taken at weekly intervals to provide a comparison with the previous summer. In mid February 2001 in response to an appearance of Anabaena it was decided to move the power source closer to the Transducer thus minimizing any signal loss occurring over the 130m cable.

The Results

The main problem algae the previous summer had been bluegreen algae (Anabaena sp.), (see Graph 1.) which can cause the water to give offensive odour and taste when the cells die. In Feb– March 2000 Anabaena levels peaked at 60,000 cells/L with a water temperature high of 21.2C.

During our trial period, water temperatures peaked at 24C in Dec-Jan 2001. In early February Anabaena concentration levels rose to 8,800. Cells/L. Further to consultation with the manufacturer it was concluded that the power supply should be moved closer to the transducer. Once this change was made no further Anabaena was detected in the pond over the remainder of the summer. Other algae (Graph 2) also show a major reduction in concentration.

In Summary

These results point towards the Aburn Algae Controller providing an efficient and effective method of controlling the levels of some algae found in New Zealand lakes, ponds or reservoirs during the warmer months. Having trialed the product in local conditions, Aburn Industries is confident in offering this product with a full money back guarantee.

The algae controllers come in 4 standard sizes (25 sqm – 15000 sqm coverage). Larger lakes can be protected by installing multiple units. Our study indicates that it is advisable to locate the control box as close to the transducer as possible. Solar power is also an option.

Our thanks to **Rodney District Council** and **Works Infrastructure Ltd– Silverdale** for making this trial possible.

Distribution of major and trace elements in Lake Rotoiti biota

Lynette Ralph & Chris Hendy
Chemistry Department, University of Waikato, Hamilton

ABSTRACT
The significance of plants and animals in the transfer of trace elements in and out of Lake Rotoiti has been assessed. Samples of fish, macrophytes and molluscs were collected from various sites around the shore of the lake during April 2003. These have been dried and digested before analysing with AES and ICPOES.

Factors controlling phytoplankton composition and biomass in the Rotorua Lakes: the deep chlorophyll maximum

E. F. Ryan [1], D. P. Hamilton[1], U. V. Cassie Cooper[1] & J. A. Hall[2]
[1]*Centre for Biodiversity and Ecology Research, University of Waikato, Private Bag 3105, Hamilton.*
[2]*NIWA, PO Box 1115, Hamilton.*

ABSTRACT

The Deep Chlorophyll Maximum (DCM) is a subsurface, deep layer of phytoplankton. In stratified lakes with high water transparency it can be very important in terms of primary production for the lakes. The objective of this study is to investigate the role of mixing, light and nutrients in the vertical distribution of phytoplankton in Lakes Tarawera, Tikitapu and Okareka. Each of these three lakes has a deep chlorophyll maximum (DCM). The DCM is situated at depths between 11-19 m in Lakes Tikitapu and Okareka and 29 – 32 m in Lake Tarawera. Differences between the surface and subsurface communities are also being described in each lake as different species contribute to the DCM. In Lakes Tikitapu and Okareka the DCM is composed mostly of dinoflagellates (*Peridinium* spp.). Continuous profiling over each day was necessary to capture vertical migrations by *Peridinium* in response to vertical variations in nutrient and light. The DCM in Lake Tarawera was comprised mostly of diatoms, which suggests that it was formed by physical factors (i.e. sinking of diatoms cells interacting with lake mixing) rather than biological factors (i.e. vertical migration) as was found in Lakes Tikitapu and Okareka. Carbon-13 uptake and nutrient spiking experiments have been carried out *in-situ* to determine phytoplankton growth rates and nutrient requirements. The results indicate that phytoplankton in the DCM from Lake Tarawera are primarily light limited and have adequate supply of nutrients, while those from the DCM in Lakes Okareka and Tikitapu are primarily nutrient limited. Our study is continuing with an investigation of the hypothesis that the breakdown of the winter DCM in Lake Tarawera leads to the annual peak phytoplankton biomass as found in large lakes during winter. The classical paradigm of phytoplankton seasonality in temperate monomictic lakes suggests that light, temperature and mixing regimes cannot support net phytoplankton growth in winter. We hypothesise that the deepening of the thermocline as has been observed in Lake Taupo during winter with entrainment of nutrients from depth, may lead to the large winter phytoplankton biomass.

INTRODUCTION

In aquatic systems, phytoplankton are frequently situated in the upper surface layer of the water column where there is considered to be adequate light to support growth. In Lakes Tarawera, Tikitapu and Okareka, however, chlorophyll maxima are sub-surface (11 – 39m) with lower concentrations in the surface mixed layer. A deep chlorophyll maximum has been observed in various aquatic systems and can be important in terms of their primary productivity (Steele & Yentsch, 1960; Fee, 1976; Abbott *et al*., 1984; Barbiero & Tuchman, 2001).

Several processes in the physical environment may lead to the formation of a deep chlorophyll maximum (DCM). Changes in vertical mixing affect diffusion, nutrient supply rates, and changes in light availability at the DCM. The main biological processes

are *in situ* growth or sinking of phytoplankton, and the other physiological and behavioural adaptations of the phytoplankton (Fee, 1976; Kiefer *et al*., 1972; Shortreed & Stockner, 1990). However, the biological processes are classically a response to the physical conditions, so monitoring the combined effect of these processes in necessary. High stability prevents mixing of cells over depth and allows them to collect within discrete layers. The phytoplankton may then adapt to temperature, nutrients and light levels at these depths.

Where deep chlorophyll layers develop, the relative importance of nutrient limitation is not well understood, and reviews of phytoplankton nutrient limitation have not even addressed these populations (e.g., Downing *et al*., 1999). Phytoplankton in these layers are thought to be primarily light or temperature limited, with adequate supplies of nutrients diffusing into the photic zone from deeper strata. However, some studies have indicated that the phytoplankton in some deep layers can be nitrogen or phosphorus limited (LeBrasseur *et al*., 1978; Schindler *et a*l., 1980). Where nutrient concentrations play a role in determining DCM extent and position, uptake by the algae themselves will alter nutrient profiles, thus effecting changes in vertical chlorophyll distribution over time (Barbiero & McNair, 1996). This highlights the issue of lag time response of phytoplankton to environmental variables. To build in lag times of phytoplankton response to environmental variables measured at the same time, environmental variables will be examined over a period of time inversely proportional to the species growth rate.

There have been a number of phototrophic organisms, including small and large flagellates, coccoid and filamentous forms, and colonies, observed in relatively deep layers conforming to depth maxima in lakes and in the ocean. There have been few in-depth taxonomic studies aimed at enumerating the full species composition of the vertical communities, concurrent with ecological studies in order to provide a link between taxonomy and phytoplankton physiology.

The first objective of this study is to resolve the factors of DCM formation in the three lakes. We hypothesise that the DCM depth coincides with the depth where phytoplankton growth rates peak. If *in situ* growth is a major process involved in maintaining the DCM, the cell growth rates may be reduced by nutrient limitation at levels above the DCM and at levels below the DCM by light limitation, resulting in a relative growth rate maximum at the DCM.

We are also investigating the temporal trends in the lakes, with regard to the effect of mixing regimes on DCM and lake productivity. The breakdown of the winter DCM in Lake Tarawera may lead to the annual peak phytoplankton biomass. The classical paradigm of phytoplankton seasonality in temperate monomictic lakes suggests that light, temperature and mixing regimes cannot support net phytoplankton growth in winter. We hypothesise that the deepening of the thermocline during winter with entrainment of nutrients from depth, may lead to the large winter phytoplankton biomass.

METHODS

Lake sampling started in November 2002 and the lakes were sampled intensively in December 2002, and February, March and August 2003. A Seabird CTD-profiler was used to resolve the vertical distribution of chlorophyll-fluorescence, dissolved oxygen, conductivity, temperature, photosynthetically available radiation (PAR) and beam

transmittance. Samples were collected for dissolved and total nutrients, phytoplankton and zooplankton enumeration, and *in-vitro* chlorophyll to the depth of the surface mixed layer and discretely at the DCM. As the DCM in Lakes Tikitapu and Okareka comprises mostly flagellated species, it was necessary to sample these lakes continuously throughout the day and night to observe vertical migrations of DCM species.

Thermistor chains were deployed in the lakes, recording at 5 minute intervals, in order to examine time series of metalimnion displacement by internal waves. Photosynthetic irradiance sensors were positioned just under the lake surface and at the depth of the euphotic zone to measure photosynthetically available radiation.

^{13}C and nutrient spiking experiments on the SCM and DCM phytoplankton were carried out *in-situ* to determine phytoplankton growth rates and nutrient responses. The phytoplankton at the SCM and DCM were spiked with saturating levels of nitrate, phosphate and a ratio both of these nutrients, and were incubated at different depths to also quantify the interaction of light on biomass and chlorophyll *a* concentrations.

RESULTS

The predominant species in the DCM in Lake Tarawera were non-motile, therefore the behavioural mechanisms leading to concentrations in a layer can be disregarded. Physical factors, particularly sinking, subsequent accumulation in layers of uniform density, and internal waves can account for the DCM dynamics observed during the summer months. The recruitment of deep phytoplankton from surface waters may be an important feature of the DCM in deep oligotrophic lakes. Interestingly, there is a lag-time in Tarawera, as the DCM species composition in this lake changed from diatoms to the same dinoflagellate species recorded in Tikitapu and Okareka four months earlier. This study also showed the importance of embayment effects in Lake Tarawera, as the DCM depths in the embayments were different to those of the central lake. Internal wave amplitudes of 1-2m were reflected in corresponding movements of the DCM in Tarawera.

In Lakes Tikitapu and Okareka, the DCM did not form as a result of settling out of the dominant forms of phytoplankton in the SCM. Here the DCM species were flagellated. *In situ* growth and migration may play an important role in the DCM formation in these lakes, and downward migration may be a strategy for motile phytoplankton, such as dinoflagellates, to escape inhibiting irradiances near the surface and utilise higher nutrient concentrations with depth.

The light climate at the DCM was similar for all three lakes. The three study lakes have low diffuse attenuation coefficients of photosynthetically available radiation ($K_{d\ PAR}$), and the DCM in each lake situated in a relatively narrow band corresponding to 1.3 – 2.7 % of surface PAR irradiance.

The results from the in-situ growth experiments indicate that phytoplankton in the DCM from Lake Tarawera are primarily light limited and have adequate supply of nutrients. Those from the DCM in Lakes Okareka and Tikitapu are primarily nutrient limited. Downward migrations by the dinoflagellates may be a strategy to exploit nutrient-rich water at depth.

A surface chlorophyll maximum (SCM), particularly a bloom, suppresses algal growth in

deeper layers of the lakes. High surface biomass increases the rate of attenuation of light with depth, and in productive waters may do so to such an extent that by self-shading phytoplankton in the SCM become significant in limiting light for the DCM. In the summer of 2003 there was a rapid shift from a DCM to a SCM in Lake Tarawera (Fig. 1), due to the light limitation at the DCM associated with a bloom of *Anabaena* spp. At the peak of the bloom the light climate at the DCM was reduced from 1.3 % to < 0.1% of surface irradiance, which inhibited growth for the deep-living phytoplankton.

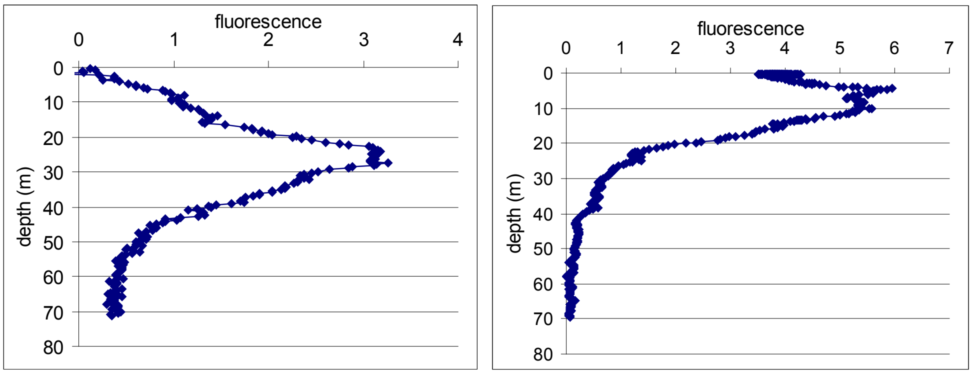


Figure1. Comparison of profiles of fluorescence (arbitrary units) for November 2002 before the bloom (left) and March 2003 (right) during the bloom.

Aulacoseira spp., *Stephanodiscus* spp. and *Cyclotella* spp. are diatom species that dominate the winter productivity of some deep New Zealand lakes. This phenomenon violates classical paradigms of phytoplankton seasonality in temperate monomictic lakes, which suggest that light, temperature and mixing regime cannot support net phytoplankton growth in winter. During winter 2003 the deepening of the thermocline with entrainment of nutrients from depth, led to a large winter phytoplankton biomass of diatoms. High densities of diatoms, including *Stephanodiscus alpinus* (>500 cells/ml), *Aulacoseira granulata* (>200 cells/ml) and *Asterionella formosa* were recorded. These diatoms may have important ecosystem-level effects through sedimentation of nutrients and transfer of biomass to higher trophic levels resulting from preferential grazing. High densities of zooplankton, including copepods, cladocerans and large rotifers, were associated with the DCM in all of the three study lakes. This may have important implications for food webs in lakes with a DCM as much of the food source for higher trophic levels such as fish may arise from the DCM phytoplankton.

CONCLUSIONS

The DCM supports a large biomass of phytoplankton and is important in the primary productivity in stratified lakes with high transparency. If there is continued nutrient enrichment in the Rotorua lakes with associated algal blooms leading to a decrease in water clarity, there may be loss of the DCM. This could have significant effects for the food webs in the lakes, with potential impacts on fisheries.

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Synchronous blooms of *Anabaena planktonica* in North Island, New Zealand

E.F. Ryan[1]; D. P. Hamilton[1]; D. F. Burger[1]; B. O'Brien[1] and W. N. Vant[2]
[1]*Department of Biological Sciences, University of Waikato, Private Bag 3105, Hamilton.*
[2]*Environment Waikato, PO Box 4010, Hamilton, New Zealand.*

ABSTRACT

Anabaena planktonica is a blue-green alga that in summer (Jan.-Mar.) 2003 has been both widespread and prolific in lakes and rivers over a wide area of the Central Volcanic Plateau (CVP) of North Island, New Zealand. Blooms (> 15,000 cells/ml) were recorded in five hydro-electric lakes of the Waikato River, shallow (z_{max} < 5m) Waikato peat lakes and also in Lakes Rotoiti and Rotorua, volcanic lakes from the Rotorua region. *A. planktonica* has been recorded occasionally in New Zealand lakes but never previously at the densities observed in 2003. The largest bloom of >120,000 cells/ml occurred in Okawa Bay in Lake Rotoiti where active fixation of atmospheric nitrogen was measured with acetylene reduction. *A. planktonica* appears to have been dominant in systems where there was nitrogen limitation leading to N-fixation, adequate phosphorus supply and vertical stratification of temperature, though the reasons for the synchronous growth and dominance of *A. planktonica* across a wide geographical area still require further elucidation. *A. planktonica*, which has been occasionally recorded in NZ water bodies (previously recorded as *A. solitaria*) but not at the densities recorded in 2003.

METHODS

Water samples from the Waikato River were taken from 7 January to 6 May 2003 as part of an intensive monitoring program. The hydro-lakes were generally monitored daily to weekly during the bloom period. The Rotorua and Waikato shallow lakes were monitored weekly or fortnightly during summer 2003, depending on their level of recreational use, but sampling frequency was increased when high densities of cyanobacteria were recorded. The samples were collected from surface waters (depth = 0.2m). Phytoplankton were preserved with Lugol's iodine and cell counts were conducted using the sedimentation technique of Utermöhl (1958). Phytoplankton were identified to species level when possible and *A. planktonica* was identified using the guide of Baker & Fabbro (2002). For *A. planktonica* the average number of cells per trichome was calculated for each sample and cell densities were then approximated by multiplying this factor by the number of trichomes counted and adjusting for the sample volume. The resolution of this technique was < 10 cells/ml for individual species.

RESULTS

Nitrogen Fixation
Anabaena planktonica has the potentially advantageous feature over some other algal species of being able to fix atmospheric nitrogen. Light microscopy analyses of *A. planktonica* samples from the Waikato River samples, Waikato peat lakes and Lakes Rotoiti and Rotorua consistently showed the presence of nitrogen-fixing heterocyst cells in high numbers relative to vegetative cells. Heterocytes allow the capacity for nitrogen fixation when this nutrient is directly limiting growth, and provide a competitive

advantage when there are low ambient concentrations of inorganic nitrogen. Measurements of nitrogen fixation using the acetylene-block technique (Turner & Gibson, 1980) in Lake Rotoiti (Silvester pers com. 2003) demonstrated fixation of atmospheric nitrogen by *A. planktonica* during the bloom phase. The ability of *A. planktonica* to fix nitrogen may be particularly advantageous if its geographical range in New Zealand is extended, due to nitrogen limitation in many Central Volcanic Plateau lakes (White et al. 1985).

Monospecific Blooms
The phytoplankton community in Lake Rotoiti was at times monospecific, dominated by *A. planktonica*, palpably out-competing all other phytoplankton. The reduced light climate created by self-shading due to the high densities of *A. planktonica* cells in Lake Rotoiti does not appear to have strongly influenced the bloom intensity.

Flow Regimes
High densities of *A. planktonica* in the Waikato River may be related to low water flows. A low-flow system may increase thermal stratification in the hydro-electric dams which could be an advantageous to buoyancy regulating cyanobacteria that optimise light capture to out-compete other phytoplankton that tend to sediment out of the water column under stratified conditions. The growth of *Anabaena* and other cyanobacteria has been linked to low discharge in turbid rivers (Sherman et al. 1998; Mitrovic et al. 2003). Discharge influences the downstream translocation of phytoplankton, the mixing of phytoplankton cells through the vertical light gradient and can also affect the physicochemical environment within a river by influencing the development of thermal stratification. Mitrovic et al. (2003) found that the dominance of *Anabaena* in the Barwon-Darling River, Australia, was most likely the result of the physical and chemical state of the water column rather than high water temperatures. The high stability of the water column allowed the buoyant *Anabaena* to accumulate in surface water where it received higher light intensities than non-buoyant species.

High densities of *A. planktonica* were not recorded in the Waikato River compared with the Rotorua lakes. The rate of flushing and associated turbulence may have been sufficiently high that the biomass did not reach its growth potential for the available nutrient supply. The lower stability in the Waikato River may have restricted the phytoplankton from the surface layers and the higher overall light levels.

Water Supply Problems
Hamilton City Council found that the *A. planktonica* bloom was responsible for taste and odour problems as a result of geosmin production and that there was potential for release of saxitoxins into the water supply to Hamilton (population 120,000). Geosmin levels as low as 1-2 part per trillion produce earthy-musty off-tastes in drinking waters. Testing showed that microcystins and anatoxins, toxin compounds with a proven association to *Anabaena*, were not above acceptable limits (EW unpublished data).

CONCLUSIONS

The synchronous proliferation and dominance of *A. planktonica* in North Island lakes has not previously been recorded. N-fixation is likely to have contributed to its predominance over non nitrogen-fixing algae. Thermal stratification also appears to have played a key role in the success of *A. planktonica* in the CVP region in the summer of 2003.

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Measurement of microcystin hepatoxins by ELISA

Jan Sprosen, Lyn Briggs, Christopher Miles
Toxinology Group, AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand

ABSTRACT
Microcystins and nodularins are cyclic toxin peptides that are produced by cyanobacteria (blue-green algae). These toxins are harmful to man, other mammals, birds and fish and can cause death. Acute exposure causes liver damage while chronic exposure may cause promotion of liver tumours.

A competitive ELISA has been developed at AgResearch using polyclonal antibodies against the ADDA moiety which is present in over 80% of the known microcystin variants and in nodularins. The assay has broad specificity and the limit of quantitation for microcystin-LR is 50 ng/L, well below the WHO provisional upper limit of 1000 ng/L in drinking water. Extracts from contaminated animal body fluids and tissues can also be analysed for microcystins and metabolites with this assay.

The ELISA provides a rapid, quantitative, screening method for microcystin and nodularin contamination in rivers, lakes and reservoir water, and the methodology has been successfully incorporated into a commercial screening service provided at AgResearch. Protection of consumer health by analysis of water for supply authorities, and avoidance of product contamination by screening intake water for manufacturers, are examples of the benefits obtained from the ELISA method.

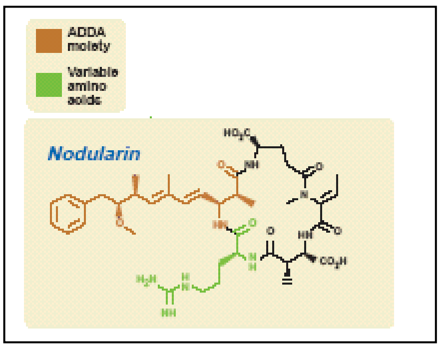
METHOD

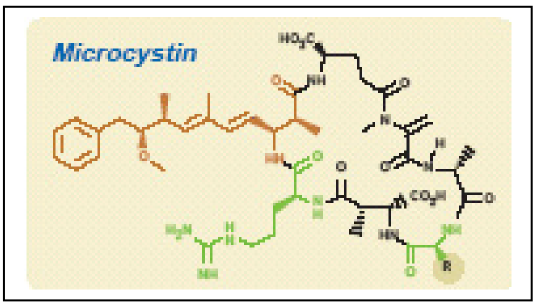
The competition ELISA

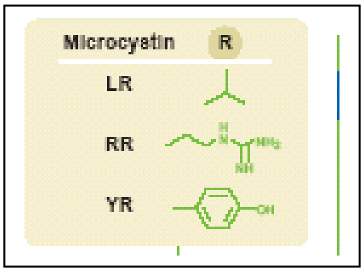
The assay is an indirect competitive ELISA with competition between toxin pecific antibodies binding to toxin-protein conjugates immobilised on the ELISA plate or binding to microcystins present in the sample.

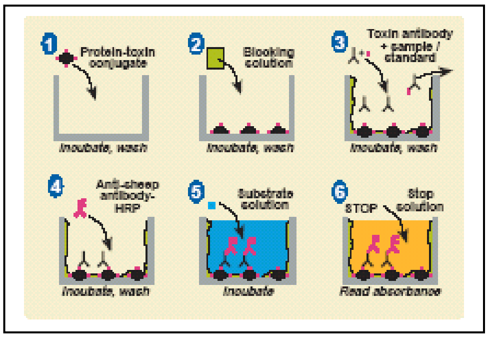
Added anti-sheep antibody-HRP reagent binds to any specific antibody remaining after washing and this is detected by reaction with HRP substrate. The coloured product is measured spectrometrically.

Inhibition of colour development, i.e. reduced binding of specific antibody to the plate coater, indicates high toxin content in the sample.

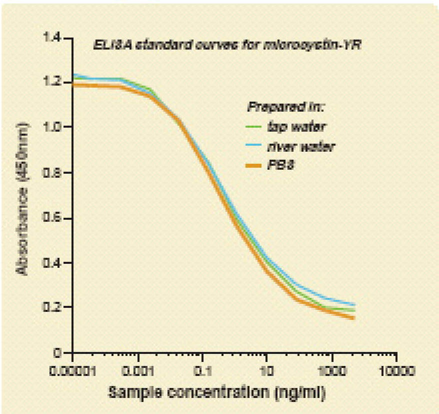








Aqueous samples cause negligible matrix effects



Assay sensitivity for microcystin-LR

Limit of quantitation	50 ng/L
Working range	50-7500 ng/L

Cross reactivities of microcystin variants in the ELISA

Toxin variant	Cross-reactivity* relative to MC-LR (%)
microcystin-LR	100
microcystin-RR	60
microcystin-YR	167
microcystin-LW	118
microcystin-LF	108
3-desmethylmicrocystin-LR	157
3-desmethylmicrocystin-RR	80
nodularin	100

*% cross-reactivity = (I_{50} microcystin-LR/ I_{50} variant) x 100, where I_{50} is the molar concentration of compound giving 50% inhibition of the antibody binding to the coating antigen

Benefits of ELISA analysis

- Sample analysis for water supply authorities provides protection to consumer health.
- Farm water supply analysis provides protection for stock animals.
- Analysis of intake water for manufacturers avoids product contamination.
- Quality control testing of algae-based products ensures safe foods.
- Analysis of tissue and body fluids from wildlife can provide links to freshwater toxins for unexplained deaths.

Summary

- The ELISA provides a rapid, quantitative screening method for microcystins and nodularins in contaminated rivers, lakes and reservoir water.
- Sample treatment or concentration is not required.
- The ELISA has broad cross-reactivity – detects all ADDA-containing microcystin variants and nodularin.
- The assay is very sensitive – the limit of quantitation for microcystin-LR is 50 ng/L compared to the WHO provisional upper limit of 1000 ng/L in drinking water.
- Extracts from contaminated animal body fluids and tissues can be analysed.
- The assay has been successfully incorporated into a commercial screening service provided by AgResearch.

ACKNOWLEDGMENTS
The microcystin ELISA was developed at AgResearch, Hamilton, New Zealand in collaboration with the Department of Environmental Toxicology, University of Konstanz, Germany and the Department of Chemistry, University of California, Irvine, USA.

ELISA DEVELOPMENT REFERENCE

Fischer, W. J.; Garthwaite, I.; Miles, C. O.; Ross, K. M.; Aggen, J. B.; Chamberlin, A. R.; Towers, N. R.; Dietrich, D. R. Congener- Independent Immunoassay for Microcystins and Nodularins. *Environ. Sci. Technol.* 2001, *35*, 4849- 4856.

Bottom water anoxia, ion composition and eutrophication of Lake Rotoiti

Rossana Untaru[1], David Hamilton [2] , Chris Hendy [1]
[1]*Chemistry Department,* [2] *Department of Biological Sciences,*
University of Waikato Private Bag 3105 Hamilton, New Zealand

INTRODUCTION

Lake Rotoiti undergoes seasonal thermal stratification. Organic matter formed in the surface waters sediments into bottom waters and uses oxygen during aerobic breakdown. Over the past 40 years increasing deposition of organic matter has made the bottom waters severely anoxic. Nitrogen and phosphorus in the organic matter are recycled into ammonium and phosphate and returned to the water column each winter when the lake 'turns over'.

DIAGENESIS

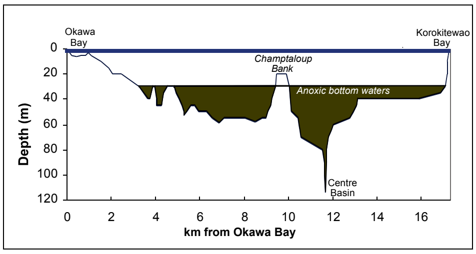


Figure 2 Profile of Lake Rotoiti showing anoxic (shaded) region in April 2003

Sedimentation of organic matter to the lake bed removes trace elements and macronutrients. So long as bottom waters remain oxygenated trace elements are mostly hound to the sediments. When the bottom waters become anoxic. trace elements, including iron and manganese, arc reduced and released in dissolved form. The return of phosphorus and nitrogen to the water phase has the potential to greatly increase eutrophication of Lake Rotoiti. Figure 2 (left) shows the bathymetry of Lake Rotoiti, indicating where anoxia occurs currently, at the end of the stratified period.

PROJECT AIM

This project sets out to evaluate the importance of the sediments as a source of eutrophication of Lake Rotoiti by assessing nutrient and trace metals levels in lake water, pore water and seston. Nutrient and trace metal fluxes from bottom sediments into lake water, and especially she rate of phosphates release from bottom sediments is quantified for oxic and anoxic conditions.

METHODS

The project involves sampling the water column and taking sediment cores from 5 sites (Figure 3) in July 2003, September 2003, November 2003, January 2004 and March 2004.

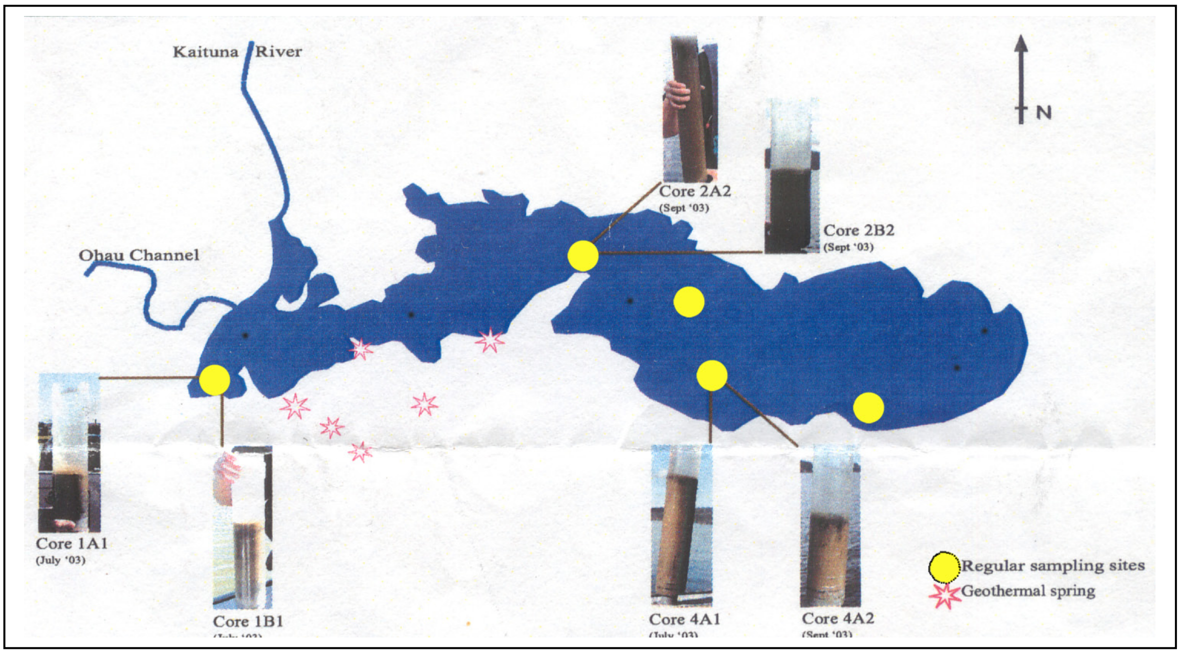


Figure 3

Water sampling is carried out with a Schindler's trap, a CTD is used for physical measurements, and a gravity corer is used for seston sampling (Figure 4, *not shown*).

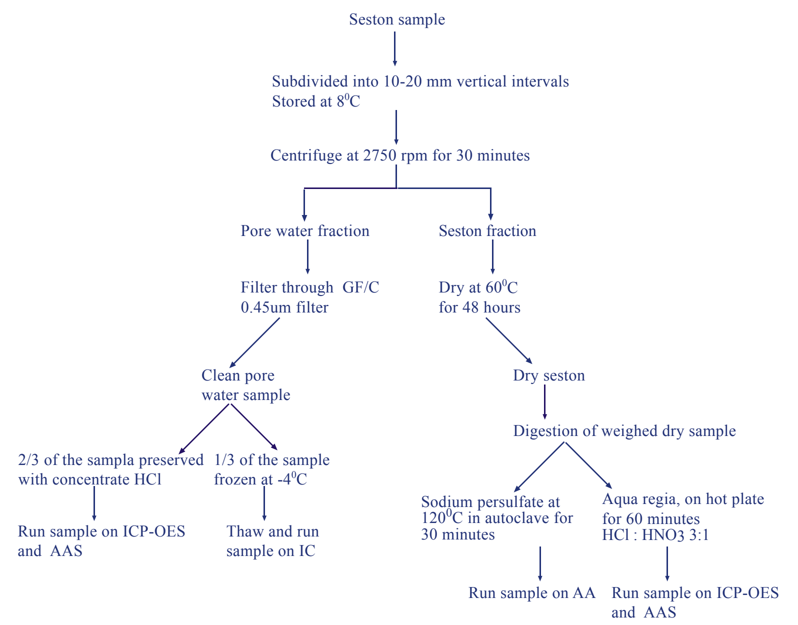


Figure 5: Preparation and preservation of seston samples

The preparation and preservation of the samples (Figure 5, *left*) is followed by analysis by using ICP-OES for detection of Al, As, Ca, Cd, Cu, Fe, Mg, Mn, 5, Sr, and Zn; IC for detection of NO_3, Cl, F, PO_4, and SO_4 on lake water and pore water, AA for detection of total N on digested samples, and AAS for detection of Na and K.

LAKE ROTOITI BACKGROUND

Lake Rotoiti is located in the Taupo Volcanic Zone, North Island, New Zealand. The lake formed about 9000 years ago after damming the eastern drainage from Lake Rotorua by volcanic events (Gibbs, 1992). Lake Rotoiti is a monomictic lake that can now be considered to be eutrophic. The inflow into the lake is from permanent and geothermal springs, and via Ohau Channel water from Lake Rotorua. The geothermal discharges are

in the south and west regions of the lake. A number of springs also appear to discharge directly into the bottom of the lake (Priscu, 1986). The main outflow is via Kaituna River.

Lake Rotoiti has a surface area of 33 km^2 and a catchment area of 120 km^2 including areas of bush (~71 km^2), pasture (~40 kin^2), and urban (~ 5 km^2) (EBOP, 2003). The lake can be sub-divided into a western basin with shallow waters (average depth ~15 m) surrounded by low density housing, low intensity farming and exotic forestry, and a deep eastern basin (average depth ~ 60 m) surrounded mostly by native and exotic forests.

Soils in the catchment are dominated by tephra, allophanic and diatomaceous earths. Major tephras are Tarawera (105 years BP), Kaharoa (770 years BP) and Taupo (1850 years BP) (Pickrill, 1993).

DISCUSSION

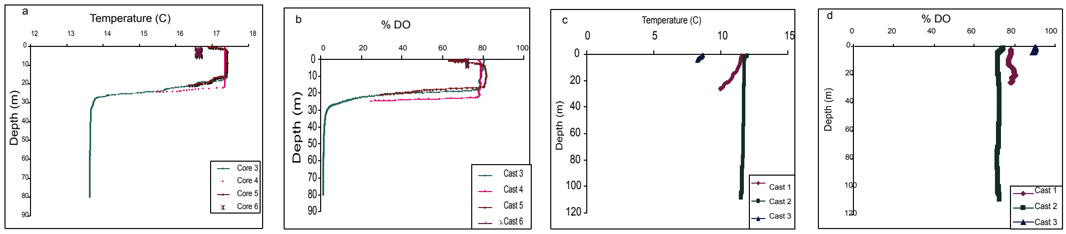


Figure 6 Temperature and dissolved oxygen profile in summer (a and b) and winter (c and d)

Lake Rotoiti stratifies into warm surface and cold bottom waters on an annual cycle (Figure 6). Organic matter accumulates in the bottom as a sediment layer, providing a reservoir of trace elements including phosphorus. As increasing eutrophication has made bottom waters anoxic the potential for recycling of trace elements has increased. This research will determine the release of trace elements from the sediments and changes in concentration of bottom waters.

Analyses of digested seston from the lake (e.g. Figure 7, *next page*) show that at least 50 tomes of phosphorus per km^2 are available for release to bottom waters.

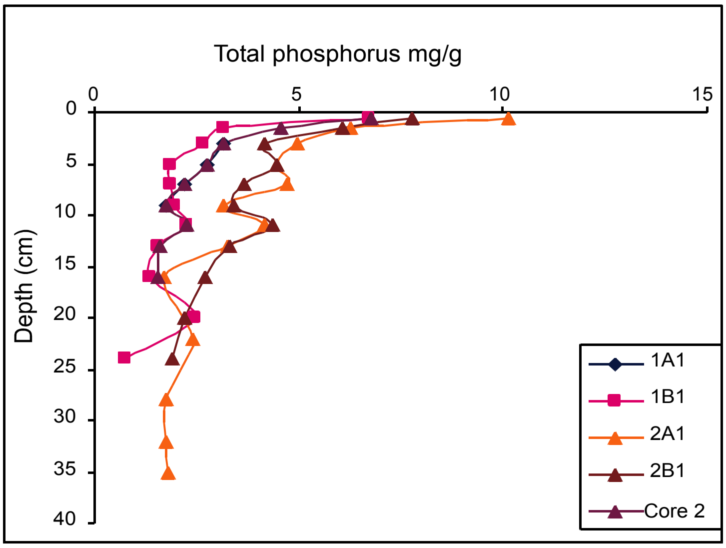


Figure 7
Concentration of phosphorus in July cores

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Efficiency of land treatment in removing nitrogen and phosphorus from sewage effluent

Hailong Wang, Gujja Magesan, John Lavery, Loretta Garrett, Stephen Pearce and Tim Payn

Forest Research, Private Bag 3020, Rotorua

Treated sewage effluent from Rotorua wastewater treatment plant has been applied to Whakarewarewa forest since 1991 in order to reduce nutrient loading to Lake Rotorua. Although the land treatment system effectively removes phosphorus from the effluent, effluent derived nitrogen has leached out of the forest and entered the Waipa stream in recent years due to lower than expected treatment efficiency of wetlands within the forest.

To better understand and manage nutrient movement after effluent irrigation in forest ecosystems, Forest Research has constructed a large lysimeter research facility (LLRF) in Whakarewarewa Forest, Rotorua. This facility is used to model and predict the mobility of effluent derived nitrogen and phosphorus and other nutrients in two contrasting soil types: undisturbed native volcanic soil and sand. These soils received a weekly application of secondary and tertiary effluent at three loading rates of 0, 30 and 60 mm/week through a drip irrigation system. Nutrient movement has been monitored using leachate collected weekly from passive capillary wick samplers. In collaboration with HortResearch, we used Soil-Plant-Atmosphere System Model (SPASMO) to predict the fate and mobility of effluent constituents.

Tree growth data, foliage and soil samples were collected and analysed annually. Effluent irrigation had no effect on tree growth in the volcanic soil, but significantly increased growth in the sand. This can be explained by the natural high nitrogen content in the volcanic soil and lack of nutrients in the sand. Irrigation with effluent has resulted in leaching of nitrate from both soils, but nitrate leaching from the sand was much less than the volcanic soil, because a larger proportion of nitrogen being taken up by the tree crop in the sand plots. Considerable amounts of effluent derived phosphorus leached from the sand due to a lack of clay minerals to immobilise the phosphorus, whereas no phosphorus was leached from the volcanic soil. Therefore, application to a forest plantation in a volcanic soil is an effective way to remove phosphorus from sewage effluent. Currently data are being analysed and modelled. More information will be available in the near future.

ACKNOWLEDGEMENTS

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OVERSEER® nutrient budget 2 model – a decision support tool to investigate on-farm management effects on water quality as affected by N and P

D M Wheeler[1], S F Ledgard[1], R M Monaghan[2]
[1] *AgResearch, Ruakura Research Centre, PB 3123, Hamilton*
[2] *AgResearch, Invermay Research Centre, PB 50034, Mosgiel*
david.wheeler@agresearch.co.nz

Nutrient budgets are useful tools for assessing the sustainability of nutrient flows within a farm and for highlighting potential negative environmental impacts of nutrient use. The OVERSEER® nutrient budgets model is a farm based decision support model to help users develop nutrient budgets, and to determine maintenance fertiliser requirements. It covers all pastoral farming (dairy, sheep, beef, deer), a wide range of arable crops and vegetables, apples and kiwifruit.

A new version of this model has improvements in the nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) models, and the addition of nutrient budgets for calcium (Ca), magnesium (Mg), sodium (Na) and hydrogen (potential acidity, used to generate maintenance lime requirements). The model has been validated against available field trial results.

OVERSEER® nutrient budgets model contains nutrient databases for fertilisers, supplements and animal products. Additional interpretation and mitigation information has also been added to the model based on meetings and feedback from farmer groups and consultants. The Code of Practice for Fertiliser Use and information from the 'Use of Fertiliser' booklets has also been added as a reference for best management practices.

In developing the new version of the model, end-user surveys and meetings were held. These identified the desire for different levels of complexity, information on interpretation and mitigation options, the ability to compare scenarios, associated estimates of maintenance fertiliser nutrient requirements, and access to data needed to parameterise the model. These requirements have been designed into the new version.

OVERSEER® nutrient budgets model can be used to develop nutrient budgets and associated indexes, and these can be interpreted to assess the likely impact of individual farm operations on water quality. The model can then be used to develop mitigation strategies, and compare the effect of these different strategies and the current farm operation on the environmental impacts.

Combining nutrient budgets and maintenance fertiliser recommendations into a single model allows the user to assess some of the interactions that may occur. Typically these interactions revolve around maintaining farm production, reducing costs by optimising fertiliser inputs, optimising production per kg nutrient used and increasing water quality by reducing N and losses to ground and surface waters.

Nutrient use efficiency is a whole farm management issue, and can be impacted on by issues such as optimising the fertiliser program, the efficient collection and use of effluent, supplement inputs, animal health, animal genetics, and general farm management.

OVERSEER® nutrient budgets model is increasing being used as a key model in catchment studies and in finding integrated solutions to reduce N and P inputs into receiving waters. This typically involves linking OVERSEER® nutrient budgets model with a farm systems management model such as Stockpol or UDDER to determine the costs and feasibility of management changes. If this process is linked to a participatory user-group process then it can highlight previous unthought of management changes that may either enhance or reduce the effect of initial management changes on the N and P outputs into the environment. This can then be linked to information on managing critical sources and a GIS/indexing system to look at catchment management, and to optimise the size of the reduction in N and P for the effort (time and money) spend. This approach is been employed in the Taupo catchment study (see other papers, this symposium), and in a dairy catchment study using catchments in both Islands.

The model is available free at http://www.agresearch.co.nz/overseerweb

Leaky lakes and nutrient fluxes at Rerewhakaaitu

P. White, R. Reeves, T. Tait, D. Gordon
Institute of Geological and Nuclear Sciences

ABSTRACT

Lake Rerewhakaaitu is a shallow Lake (<15 metres in depth) and has mainly agricultural land use catchment. There has been increasing intensification of agricultural land use since the 1970's. The results of a lake catchment study by McIntosh et al (2001 in Environment Report 2001/15) concluded that there was potential for increased nutrient loading to Lake Rerewhakaaitu as a result of agricultural land use in the catchment.

The geohydrology of the Lake Rerewhakaaitu catchment is examined to calculate surface water / groundwater, water and nutrient fluxes in order to assist with future management decisions effecting the catchment. Analyses of geological, water quality, water quantity and land use information in the Lake Rerewhakaaitu catchment shows that:

- The groundwater flow must be considered in Lake Rerewhakaaitu water balance calculations.
- Water will generally flow out of the lake to groundwater because groundwater levels are generally below the level of the lake. The lake water probably discharges into the Rangitaiki Ignimbrite Aquifer and this water travels west, south and east of the lake.
- The Rangitaiki Ignimbrite Aquifer is the most important aquifer in the area and most wells are in this aquifer.
- Impacts of land use on groundwater quality and stream water quality were observed.
- The nitrogen concentrations in streams are tending to increase over time but nitrogen levels observed in the lake are significantly less than levels predicted by simple nitrogen flux models and therefore denitrification processes are likely to be occurring within the lake catchment.

Toxic cyanobacteria in New Zealand waterbodies

Susie Wood [1,2]
1. Institute of Food, Nutrition and Human Health, Massey University, PO Box 756, Wellington
2. School of Biological Sciences, PO BOX 600, Victoria University
S.Wood@Massey.ac.nz

INTRODUCTION

Cyanobacteria (blue-green algae) are a group of photosynthetic prokaryotic organisms. When environmental and hydrological conditions are favourable cyanobacteria cells can multiple and form what are known as water or algal blooms. Cyanobacteria occur naturally, but an increase in nutrients from deforestation, agriculture and urbanisation has lead to the eutrophication of many water bodies, which in turn has lead to the proliferation of cyanobacteria. Cyanobacteria can also grow on the bottom substrates of waterbodies sometimes forming coherent mats (benthic cyanobacteria). During low flow periods the cyanobacteria may become detached and form thick floating mats.

There are approximately 2000 cyanobacteria species world-wide and more than 50 are known to have toxin-producing strains. These natural toxins, known as cyanotoxins, are a threat to humans and animals consuming them in drinking water supplies or by contact with them during recreational activities. The mechanisms of toxicity of cyanotoxins are very diverse, ranging from hepatotoxic and neurotoxic, to dermatotoxic. Some cyanotoxins have also been shown to have a liver tumour promoting action when ingested in low doses over extended periods.

Bloom forming cyanobacteria have become increasingly prevalent in a variety of New Zealand waterways[3] and it seems likely that this trend will continue as land modification increases. Public awareness of the potential problems is also growing. However until recently, information on the toxin content and taxonomy of New Zealand toxin producing cyanobacteria species has been sparse[1,4].

Table 1. Summary of Cyanotoxins:

Toxin Group and Toxin	Primary Target in Mammals	Cyanobacterial Genera
Cyclic Peptides		
Microcystins	Liver	*Microcystis, Anabaena, Planktothrix (Oscillatoria), Nostoc, Hapalosiphon Anabaenopsis, Pseudanabaena, Synechocystis*
Nodularin	Liver	
Alkaloids		
Anatoxin-a	Nerve synapse	*Anabaena, Planktothrix (Oscillatoria), Aphanizomenon, Raphidiopsis*
Anatoxin-a(S)	Nerve synapse	
Cylindrospermopsins	Liver	*Cylindrospermopsis, Aphanizomenon Umezakia, Raphidiopsis*
Saxitoxins	Nerve axons	
Lipopolysaccharides (LPS)		
	Potential irritant; any exposed tissue	All

AIMS & METHODS OF THIS PROJECT:

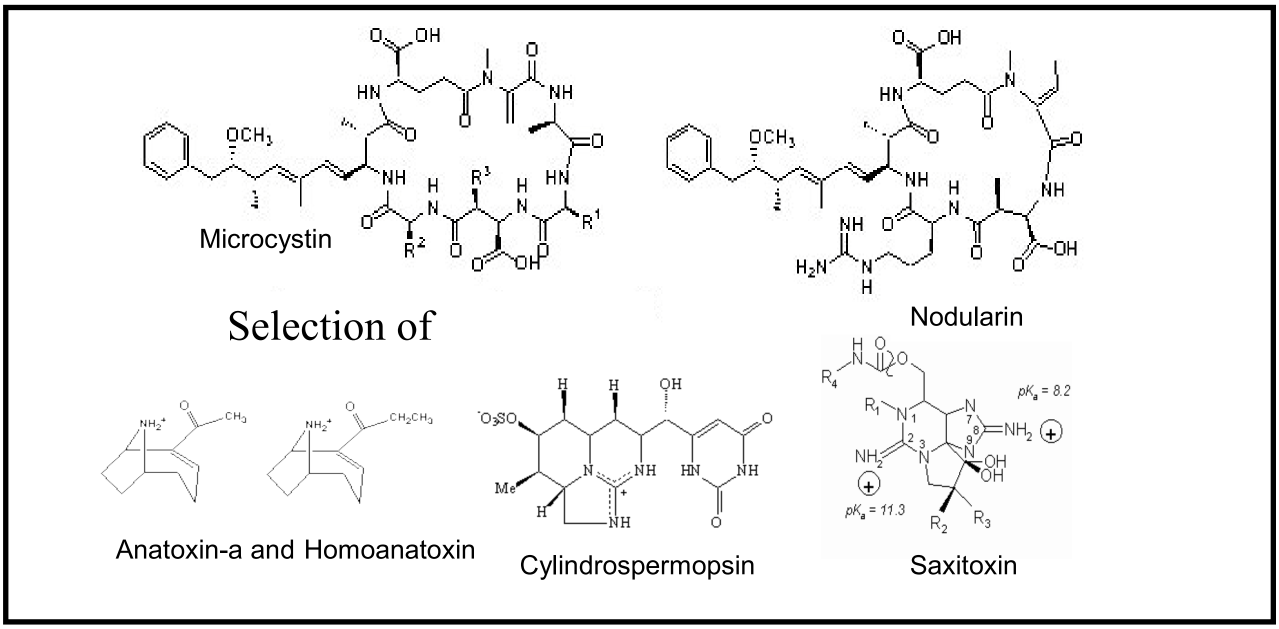
To establish:

- Which cyanotoxins are present in New Zealand?
- What species in New Zealand produce cyanotoxins?
- How widely distributed cyanotoxins are in New Zealand?
- What concentration levels of cyanotoxins exist in New Zealand waterbodies?
- How cyanobacteria species and cyanotoxin levels change during a bloom?
- If microcystins bioaccumulate in freshwater organisms?

Water/bloom samples were collected or received from around New Zealand during the summers of 2001-2003.

Cyanobacteria taxonomy and enumeration was carried out using an inverted microscope.

A variety of chemical and immunological methods were used to determine which cyanotoxins were present in the samples. These included; ELISA's, HPLC, LC/MS and neuroblastoma assays.



RESULTS: CYANOTOXINS & THEIR DISTRIBUTION IN NEW ZEALAND

Anatoxin - a

Anatoxin-a is a nicotinic agonist that binds to nicotinic acetylcholine receptors. A high dose of anatoxin-a can lead to rapid death from paralysis and asphyxiation.

There are many reports worldwide of animal deaths from this toxin. Degradation products of anatoxin-a have been found in one cyanobacteria sample in New Zealand following the rapid deaths of several dogs after ingesting benthic mats[2]. During this study HPLC-FLD was used to analyse over 50 samples containing genera known to produce anatoxin-a. Samples from the Karori Reservoir (Wgtn), Lake Henly (Masterton) and Lake Rotoehu (Rotorua) were found to contain anatoxin-a. Spiking experiments were performed to confirm the presence of the toxin in these samples.

This is the first time anatoxin-a has been identified in New Zealand and the first indications that planktonic species in New Zealand produce anatoxin-a. Further work is required to confirm the species responsible for production of this toxin.

Microcystins & Nodularins

Nodularins and microcystins are cyclic peptides. Microcystins' and nodularins' primary target is the liver. Microcystins and nodularins inhibit protein phosphatase 1 and 2A and ingestion may lead to an increase human health risk of carcinogenesis and tumor growth promotion of the liver. During this study microcystins were identified in over 40 waterbodies. Table 2 shows areas where microcystins reach levels that pose a health risk to humans involved in recreational activity on or in the water. The World Health Organisation guideline recommends a guideline value of 1μg/L of microcystins for drinking water.

Table 2: Examples of micrcystin levels in new Zealand Waterbodies

Waterbody	Location	Max MC Level μg/L
Lake Watawa	Horowhenua	42 000
Lake Horowhenua	Horowhenua	23 000
Neuman Pond	Horowhenua	9 000
Lake Dudding	Horowhenua	2 000
Lake Wiritoa	Horowhenua	1 000
Lake Hakanoa	Waikato	425
Lake Ngaroto	Waikato	420
Lake Rotoiti	Rotorua	350
Lake Rotoehu	Rotorua	25

Cylindrospermopsin

Cylindrospermopsin (CYN) is a hepatotoxic alkaloid. CYN's primary target is the liver, although recent studies have also found it to be carcinogenic and genotoxic. CYN is a inhibitor of protein synthesis.

CYN was first discovered in New Zealand in 1999[4]. However the organism responsible for its production was not identified. CYN is known to be produced by four cyanobacteria species, but most commonly *Cylindrospermopsis raciborskii*. During this study a bloom of *C. raciborskii* was discovered in a Lake Waahi (Waikato). Liquid chromatography-mass spectrometry and liquid chromatography-tandem mass spectrometry were used to confirm the presence of the cyanotoxins CYN and deoxy-cylindrospermopsin (do-CYN)[5].

Since the identification of *C. raciborskii* in Lake Waahi it has now been found in three other Waikato lakes. *C. raciborskii* is now a species of concern in recreational, stock drinking, and potable waterbodies in New Zealand.

Saxitoxins

Saxitoxins are toxins that act on the sodium ion channels of the excitable membranes of the nerves, which leads to paralysis, respiratory depression and respiratory failure. In this study over 120 samples were tested for saxitoxins using an ELISA. Many of the samples returned low level positives. A neuroblastoma assay is been used to confirm these results. There is still a lot of work required to establish which cyanobacteria species produce saxitoxins, which saxitoxins analogues are being produced and at what levels these are present in New Zealand waterbodies.

New Toxin Producing Species in New Zealand
This study has lead to the identification of several toxin producing species which have not previously been found in New Zealand. Cyanobacteria taxonomy has traditionally relied on morphological features to distinguish between species. Recently developed molecular techniques will be used in this study to confirm the identification of these species.

For example: *Cylindrospermopsis raciborskii* - molecular techniques such as PCR may be able to be used to quickly establish if this species is present in a sample and if cylindrospermopsin is been produced.

Aphanizomenon issatschenkoi was identified in a Waikato lake. However a lack of heterocytes meant this identification was ambiguous. A comparison of 16S rRNA is currently underway and it is hoped that this may help in confirming the identification of this microcystin producing species.

Cyanotoxins a health risk in New Zealand? A case study……

Lake Horowhenua - Jan 2003, Scum Sample - 23 000 µg/L (MC)

- Amount of scum that could be a lethal dose to a 10kg toddler
- LD_{50} of Microcystin (MC)= 5 mg/kg (oral administration) = 2.2L of lake Horowhenua Water
- Amount of scum that could cause health impairment in a 10kg toddler
- NOAEL & LOAEL of MC = 0.04 µg/kg = 0.02mL of Lake Horowhenua Water

Benthic Cyanobacteria
Little is known about the toxin production and potential health risks of New Zealand's benthic cyanobacteria species[2]. A number of samples tested in this study were found to contain microcytsins eg: Detached benthic mats in the Hutt River (Wgtn) were found to contain low levels of microcystin and a thick mat of a benthic species - *Nostoc commune*, along the shore of Lake Taupo in April 2003 was found to contain 175 µg/g FDW.

CONCLUSIONS:
- New Zealand waterbodies will continue to become eutrophic, thus it is likely that incidences of cyanobacterial blooms will increase.
- New Zealand cyanobacteria are now known to produce the cyanotoxins: microcystins, nodularins, anatoxin-a, cylindrospermopsin and saxitoxins.
- Microcystins are the most common cyanotoxin in New Zealand. However data on other cyanotoxins is still too patchy to fully understand their distribution.
- Cyanotoxins can reach levels that pose a health risk to humans and animals. There is a need to improve public knowledge of the potential dangers.

We are just beginning to understand toxic producing cyanobacteria in New Zealand There is a need for further research into cyanobacteria at a; species, toxin and ecosystem level.

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- Anna Crowe- Cawthron Institute for assistance with cyanobacteria taxonomy
- Dr Penny Truman - ESR (Kenepuru) for carrying out neuroblastoma assays
- The present work is partly funded by a research grant from the Lakes Water Quality Society, Rotorua.

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LIST OF REGISTRANTS AS AT 8 OCTOBER 2003 – late registrants appended at end of list

Name Tag	Institution	E mail
Phil Alley	Department of Conservation	palley@doc.govt.nz
Geoff Angell	Aqua-Ag Ltd	aqua-ag@xtra.co.nz
Dianne Atkinson	Mourea-Okawa Bay Group	donald.atkinson@xtra.co.nz
Don Atkinson	Mourea-Okawa Bay Group	donald.atkinson@xtra.co.nz
Ron Bailey	LWQS	baileyfarms@xtra.co.nz
Brenda Baillie	Forest Research	brenda.baillie@forestresearch.co.nz
Amanda Baldwin	University of Waikato	abb5@waikato.ac.nz
Greg Barkle	Lincoln Environmental	barkle@lvlham.lincoln.ac.nz
Helen Beaumont	Parliamentary Commissioner for the Environment	helen@pce.govt.nz
Andrew Bell	Rotorua District Council	andy.bell@rdc.govt.nz
Mark Bellingham	Massey University	m.bellingham@massey.ac.nz
Wayne Bettjeman	Ministry for the Environment	martyn.pinckard@mfe.govt.nz
Jose Beya	University of Waikato	jbeya@ing.uchile.cl
Matthew Bloxham	Environment BOP	matthew@envbop.govt.nz
Brentleigh Bond	LWQS	grahamb@clear.net.nz
Del Bottcher	Soil and Water Engineering Technology, Inc	dbottcher@swet.com
Bill Bourke	SteelServ Ltd	bbourke@heckettmultiserv.com
Eddie Bowman	NIWA	e.bowman@niwa.co.nz
Lyn Briggs	AgResearch	lyn.briggs@agresearch.co.nz
Sally Brock	LWQS	te-pohutukawa@paradise.net.nz
Jo-Marie Brown	NZ Herald	jo-marie_brown@nzherald.co.nz
Rowland Burdon	Royal Society of NZ	rowland.burdon@forestresearch.co.nz
David Burger	University of Waikato	dfb@waikato.ac.nz
Noel Burns	Lakes Consulting	lakescon@xtra.co.nz
Neil Callaghan	Lake Tarawera Ratepayers	neil@buildingcompliance.co.nz
Debbie Care	AgResearch	debbie.care@agresearch.co.nz
Vivienne Cassie Cooper	University of Waikato	cassie-cooperv@landcareresearch.co.nz
Paul Champion	NIWA	
Bill Cleghorn	Environment BOP	bill.cleghorn@cgj.co.nz
Mark Collet	Lake Okareka Residents and Ratepayers Assn.	colletm@wave.co.nz
Stephen Colson	Rotorua District Council	stephen.colson@rdc.govt.nz
Sherilyn Coney	LWQS	sconey@xtra.co.nz
Steven Cornelius	Waipa District Council	scor@waipadc.govt.nz
Mark Cosgrove	Advocates for Tongariro River	cosgrove@reap.org.nz
Ana Cotter	Environment BOP	ana@envbop.govt.nz
John Cronin	Environment BOP	
Jim Crush	AgResearch	jim.crush@agresearch.co.nz
Colin Currie	Hamilton	colin.currie@xtra.co.nz
Michel Dedual	Department of Conservation	mdedual@doc.govt.nz
Paul Dell	Environment BOP	pauld@envbop.govt.nz
Murray Dench	Te Awamutu	dpds@xtra.co.nz
Sam Denford	Rotorua	
Mary deWinton	NIWA	

Peter Dine	Rotorua District Council	peter.dine@rdc.govt.nz
Andrea Donnison	AgResearch	andrea.donnison@agresearch.co.nz
Wayne Donovan	BioResearches	wdonovan@bioresearches.co.nz
Roly Earp	LWQS	
Nick Edgar	NZ Landcare Trust	nick@landcare.org.nz
Dr. Edmeades	agKnowledge Ltd	doug.edmeads@agknowledge.co.nz
Tracey Edwards	NIWA	t.edwards@niwa.co.nz
Will Esler	Waikato University	will.e@clear.net.nz
Nic Etheridge	Department of Conservation	netheridge@doc.govt.nz
Marc Fauvel	Rotorua District Council	marc.fauvel@rdc.govt.nz
Ruth Feist	Environment BOP	ruth@envbop.govt.nz
Andrew Fenton	LWQS	afenton@enternet.co.nz
Mary Fenton	LWQS	afenton@enternet.co.nz
Owen Firth	LWQS	
Joan Fitzgerald	AgResearch	joan.fitzgerald@agresearch.co.nz
Robin Ford	Environment BOP	
Peter Franz	Page Macrae Engineering	peterf@oxypure.co.nz
Vance Fulton	Environment BOP	vance@envbop.govt.nz
Sven Furstenberg	Page Macrae Engineering	svenf@oxypure.co.nz
Helen Gear	Foundation for Research, Science and Technology	helen.gear@frst.govt.nz
Eru George	Lakes District Health Board	eru.george@lakesdhb.govt.nz
Max Gibbs	NIWA	m.gibbs@niwa.co.nz
John Gibbs	Department of Conservation	jgibbs@doc.govt.nz
Dougall Gordon	Environment BOP	dougall@envbop.govt.nz
Tawiri Hakopa	Taupo	
Geraldine Hale	LWQS	ghale@xtra.co.nz
Grahame W Hall	Rotorua District Council	grahame.hall@rdc.govt.nz
Ruth Hamill	Whakatane	ruthhamill@xtra.co.nz
David Hamilton	University of Waikato	d.hamilton@waikato.ac.nz
Lars Hansen	Forest Research	lars.hansen@forestresearch.co.nz
Martin Hawke	AgResearch	martin.hawke@agresearch.co.nz
Roger Hill	LWQS	roger.hill@hill-labs.co.nz
Kathy Horgan	Royal Society of NZ	kathy.horgan @forestresearch.co.nz
Gerard Horgan	MAF	horgang@maf.govt.nz
Kevin Hutchinson	Department of Conservation	khutchinson@doc.govt.nz
Chris Ingle	West Coast Regional Council	ci@wcrc.govt.nz
John Jackman	LWQS	
Mark James	NIWA	m.james@niwa.co.nz
Ian Johnstone	Landward Management	ian@landward.co.nz
Ray Jones	LWQS	
Jeff Jones	Environment BOP	jeff@envbop.govt.nz
Martin Kear	AgResearch	martin.kear@agresearch.co.nz
Leith Knowles	Forest Research	leith.knowles@forestresearch.co.nz
Jim Koller	Rotorua Professional Trout Fishing Guides Assn	j&c.koller@xtra.co.nz
Ian Kusabs	Fisheries Consultant	ikusabs@xtra.co.nz
Sue La Roche	LWQS	johnwfs@clear.net.nz
John La Roche	LWQS	johnwfs@clear.net.nz
Garry Law	Environmental Defence Society	glaw@lawas.co.nz

Daphne Le Vaillant	Rotorua	
Shane Lodge	Fonterra	shane.lodge@fonterra.com
Bob Longhurst	AgResearch	bob.longhurst@agresearch.co.nz
Joan Lusk	LWQS	
Ham Lusk	LWQS	
Christeen MacKenzie	Department of Conservation	cmackenzie@doc.govt.nz
Glenn MacLean	Department of Conservation	gmaclean@doc.govt.nz
Greg Manzano	Rotorua District Council	greg.manzano@rdc.govt.nz
Ron Marsden	LWQS	gladehse@clear.net.nz
David Marshall	Department of Conservation	dmarshall@doc.govt.nz
Fleur Matheson	NIWA	
Colin Maunder	TMC	colin.maunder@tmclimited.co.nz
Trevor Maxwell	Rotorua District Council	tracey.may@rdc.govt.nz
Gifford McFadden	Federated Farmers	g.r.mcfadden@clear.net.nz
Alec McGowan	AgResearch	alec.mcgowan@agresearch.co.nz
John McIntosh	Environment BOP	johnmc@envbop.govt.nz
Lachlan McKenzie	Federated Farmers	
Ian McLean	LWQS	imclean@ihug.co.nz
Karlov McLeod	Department of Conservation	kmcleod@doc.govt.nz
Andrew McRae	Radio New Zealand	amcrae@rnz.co.nz
Elizabeth Miller	LWQS	elizabeth.miller@forestresearch.co.nz
Nick Miller	LWQS	millern@wave.co.nz
Ross Monaghan	AgResearch	ross.monaghan@agresearch.co.nz
Lynne Moore	Fert Research	lynne.moore@fertresearch.org.nz
Kepa Morgan	University of Auckland	k.morgan@auckland.ac.nz
Wayne Morrison	Rotorua	
Sandy Morrison	Rotorua	
David Murphy	NZ Forest Managers Ltd	david@nzfm.co.nz
Bob Murray	NIWA	r.murray@niwa.co.nz
Graeme Natusch	Tumoana Residents Assn	
Janet Newbury	Mourea	janetnewbury@yahoo.co.uk
Norm Ngapo	Waiora Soil Conservation	norm@waiorasoilcon.co.nz
Shirley Nichols	AgResearch	shirley.nichols@agresearch.co.nz
Mike O'Connor	AgResearch	mike.oconnor@agresearch.co.nz
Peter O'Flaherty	Agriculture NZ	peteroflaherty@wrightson.co.nz
Neil Oppatt	Rotorua District Council	tracey.may@rdc.govt.nz
Leigh Overton	Queenstown Lakes District Council	ceo@qldc.govt.nz
Keith Owen	Department of Conservation	kowen@doc.govt.nz
Jon Palmer	Environment Waikato	jon.palmer@ew.govt.nz
Stephen Park	Environment BOP	stephen@envbop.govt.nz
Bob Parker	Agriculture New Zealand	bobparker@clear.net.nz
Jamie Paterson	Federated Farmers	chrisjam@xtra.co.nz
Don Penn	LWQS	donken@ihug.co.nz
Jake Peters	U.S. Geological Survey	nepeters@usgs.gov
Rob Pitkethley	Fish & Game New Zealand	rpitkethley@erfgc.co.nz
Fenella Playne	LWQS	fplayne@xtra.co.nz
John Quinn	NIWA	j.quinn@niwa.co.nz
Anaru Rangiheuea	Putauaki Land Trust	
David Ray	NIWA	d.ray@niwa.co.nz
Robert Reeves	Geological & Nuclear Sciences	r.reeves@gns.cri.nz

Bryan Riesterer	Environment BOP	bryan.riesterer@clear.net.nz
Kathie Rittson-Thomas	LWQS	kathie.r-t@xtra.co.nz
Jeanette Robertson	LWQS	
Colleen Ross	AgResearch	colleen.ross@agresearch.co.nz
Berys Ross	LWQS	
Grahame Ross	LWQS	
Eloise Ryan	University of Waikato	efr@waikato.ac.nz
Paul Sampson	Rotorua District Council	paul.sampson@rdc.govt.nz
Bill Scapens	Tauranga	
Herwi Scheltus	Department of Conservation	hscheltus@doc.govt.nz
Louis Schipper	Landcare Research	schipperl@landcareresearch.co.nz
Jock Schoeller	Mourea-Okawa Bay Group	switch@xtra.co.nz
Paul Scholes	Environment BOP	pauls@envbop.govt.nz
Glenys Searancke	Rotorua District Council	g.g.searancke@xtra.co.nz
Phil Shoemack	BOP District Health Board	phil.shoemack@bopdhb.govt.nz
Warwick Silvester	University of Waikato	w.silvester@waikato.ac.nz
Robin Sinclair	Mourea-Okawa Bay Group	robinph@xtra.co.nz
Peter Singleton	Environment Waikato	peter.singleton@ew.govt.nz
Jack Smith	LWQS	j.g.smith@xtra.co.nz
Jan Sprosen	AgResearch	jan.sprosen@agresearch.co.nz
Rod Stace	Lake Okareka Residents and Ratepayers Assn.	rod.stace@xtra.co.nz
Jim Stanton	Lake Rotoiti Residents and Ratepayers Assn.	
Roland Stenger	Lincoln Environmental	stenger@lvlham.lincoln.ac.nz
David Stirling	ESR	david.stirling@esr.cri.nz
Hannah Stone	Daily Post	hannah_stone@dailypost.co.nz
Peter Storey	Lake Tarawera Ratepayers	nztroutfisher@clear.net.nz
Karen Summerhays	Environment BOP	ksummerhays@xtra.co.nz
Chris Sutton	LWQS	crisanda@xtra.co.nz
Tamara Tait	Geological & Nuclear Sciences	t.tait@gns.cri.nz
Chris Tanner	NIWA	c.tanner@niwa.co.nz
Bruce Thorrold	Dexcel	bruce.thorrold@dexcel.co.nz
Clive Tozer	Environment BOP	clive@envbop.govt.nz
Rossana Untaru	University of Waikato	ru1@waikato.ac.nz
Rick Vallance	Ngati Whakaue Tribal Lands	richard@ngatiwhakaue.iwi.nz
Mark Venman	Department of Conservation	mvenman@doc.govt.nz
Nina von Westernhagen	University of Waikato	v_westernhagen@yahoo.de
Helen Wallace	LWQS	grantw@electropar.co.nz
Grant Wallace	LWQS	grantw@electropar.co.nz
Hailong Wang	Forest Research	hailong.wang@forestresearch.co.nz
David Wheeler	AgResearch	david.wheeler@agresearch.co.nz
Kate Wilkins	University of Waikato	kate1444@hotmail.com
Colin Williams	LWQS	
Gavin Williamson	Fletcher Challenge Forests	gavin.williamson@fcf.co.nz
Richard Wilson	Lake Rotoiti Residents and Ratepayers Assn.	
Kevin Winters	Rotorua District Council	tracey.may@rdc.govt.nz

Susie Wood	Massey University	s.wood@massey.ac.nz
Neil Woods	Timber Management Company	neil.woods@tmclimited.co.nz
Kim Young	Department of Conservation	kyoung@doc.govt.nz
Additional Registrations	**(Not sorted into main list)**	**Not all available for late registrants**
Hayden Bosgra	University of Waikato	
Karina Brooks	University of Waikato	
Warwick Catto	Ballance Agri-Nutrients	
Steve Chadwick	MP for Rotorua	
Terri Chan	University of Waikato	
Cr. Neil Clarke	Environment Waikato	
Rt Hon Paul East, QC	East Brewster	
Andrew Fitchett	University of Waikato	
Nicola Foran	University of Waikato	
Ray Gosling	Lake Rotoiti Realty	
Frank Graham	Rotorua Chamber of Commerce	Rotorua Chamber of Commerce
Dr. Chris Hendy	University of Waikato	chendy@waikato.ac.nz
Pamela Heron	University of Waikato	
Erica Hofstee	**University of Waikato**	ehh1@waikato.ac.nz
David Horgan	Massey University	david.horgan.3@uni.massey.ac.nz
Andrew Hosken	University of Waikato	
Andrew Land	Rotorua District Council	
Christopher McBride	University of Waikato	
Carola McCarthy	Integrated Treatment Systems	Integrated Treatment Systems
Mike McVicker	Rotorua Chamber of Commerce	Rotorua Chamber of Commerce
Ed Mercer	Carter Holt Harvey Forests	
Stacey O'Driscoll	University of Waikato	
Fred Openshaw	Summit Quinphos	
Peter Pavlovich	Integrated Treatment Systems	
Ross Price	Public Health	
Lynette Ralph	University of Waikato	
Dr. Kit Rutherford	NIWA	k.rutherford@niwa.co.nz
Gary Searle	Integrated Treatment Systems	
Annaka Simpson	District Health Board	
Colin Stace	Environment BOP	colin@envbop.govt.nz
Arapeta Tahana	Chairman, Te Arawa Trust Board	
Bill Vant	Environment Waikato	bill.vant@ew.govt.nz
P White	GNS	
Chayne Zinsli	Carter Holt Harvey Forests	