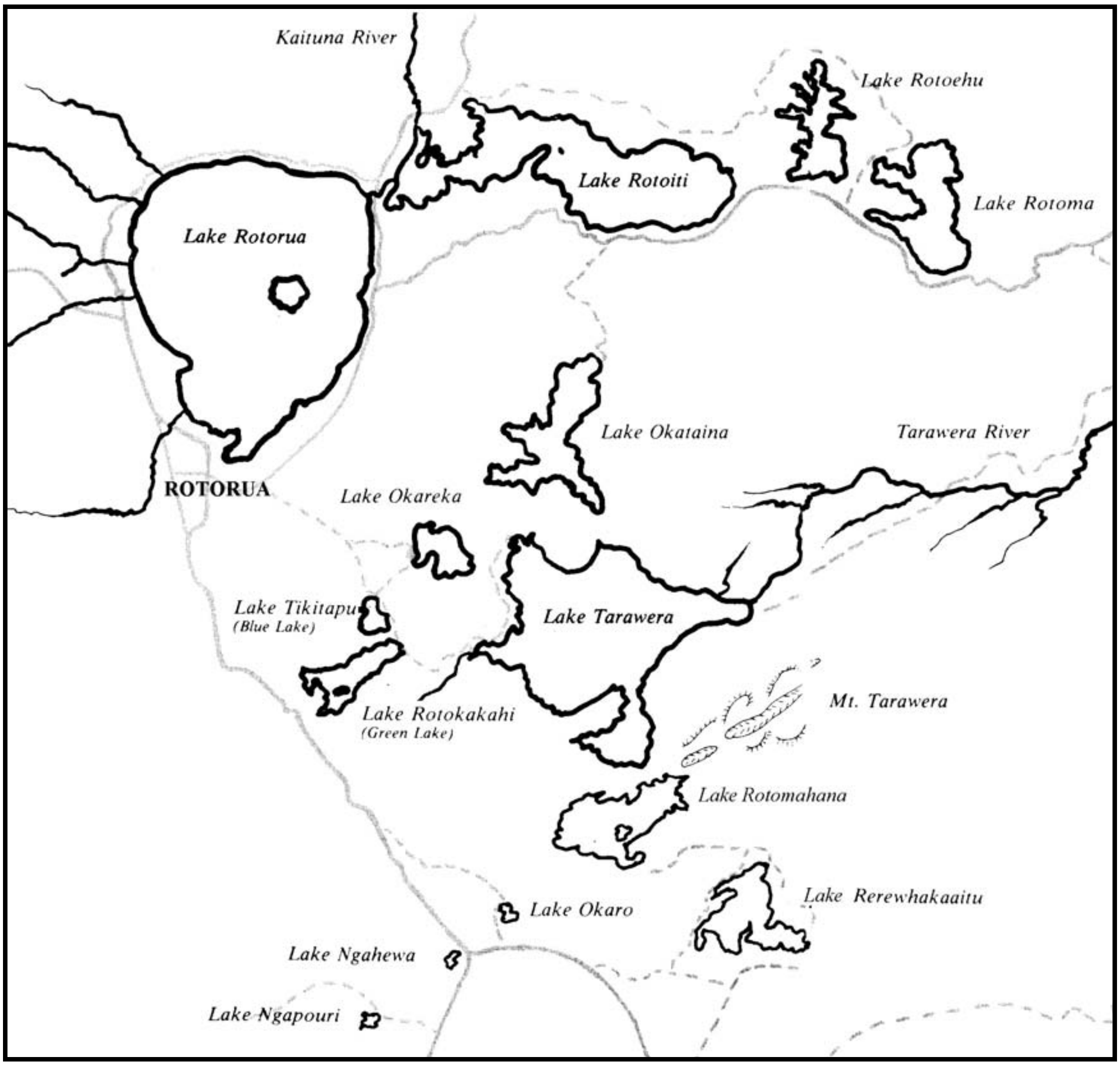
Proceedings

ROTORUA LAKES 2004
Restoring Lake Health - Nutrient Targets and Cyanobacteria



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Proceedings

ROTORUA LAKES 2004

Restoring Lake Health - Nutrient Targets and Cyanobacteria

16-17 September 2004
Park Heritage Hotel, Rotorua

Jointly hosted by

LakesWater Quality Society Inc.

and

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(Rotorua Branch)

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Editors' Note

Not all oral presentations were made available as formal written papers, in which case the edited tape transcript has been used, coupled with the supplied abstract. In some cases the PowerPoint files used in presentations were also unavailable, due to commercial sensitivities (a sad reflection on the current state of publicly funded science) and the edited transcript was amended accordingly, to delete references to graphics. Where graphics were available, not all slides were used, at the discretion of the editors. In such cases, the transcript may refer to slides that are not present. Colour printing has been used only where it significantly enhances the effect or comprehension of an illustration. Where there are multiple authors, presenting author's 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 in quotation marks 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.

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

Non-scientific readers have been provided with a scientific glossary, useful in understanding these Proceedings, at the end of this volume.

It was evident that some opinions shifted during the course of the Symposium, as is apparent in the transcript of the technical discussion, to which the readers' attention is particularly directed.

Nick and Elizabeth Miller

Published October 2005
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TABLE OF CONTENTS

To next page

Foreword – Rotorua Lakes 2004

Ian McLean
Chairman, LakesWater Quality Society Inc.

The Symposium ***Rotorua Lakes 2004*** was the fourth annual event of its kind hosted by the LakesWater Quality Society. Its focus was ***Restoring Lake Health - Nutrient Targets and Cyanobacteria.***

In previous years ***Rotorua Lakes 2001*** dealt with research needs, ***Rotorua Lakes 2002*** covered lakeside communities and sewerage, and ***Rotorua Lakes 2003*** focussed on practical management for good lake water quality. All were prompted by public concern over the decline in water quality in these beautiful lakes.

The summer and autumn of 2004 were a second season of record cyanobacterial blooms in Rotorua lakes, arising from past and present pollution with nitrogen and phosphorus compounds. The authorities had started to give urgency to action and much scientific work was being done.

As work to reduce the nutrients was planned, it became clear that the target levels for N and P, and just how fast each of N and P should be reduced, would determine how the money should best be spent. Huge sums were and are involved. The decisions will be of great financial importance to all levels of government. They will have major impacts on decisions affecting farmers, households and other landowners.

The purpose of the Symposium was to present up-to-date science on the role of N and P (and other nutrients) in the degradation on water quality. Unlike its predecessors it was more of a scientific event, but it still sought to share knowledge with land managers, local residents and public authority members and managers as well as scientists.

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

The Royal Society of New Zealand (Rotorua Branch) again joined in holding this Symposium. It was supported by a generous grant from *Dairy InSight* which was greatly appreciated.

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

Workshops and Symposia such as ***Rotorua Lakes 2004*** have a most useful purpose in 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 2003 Symposium encouraged a surge of interest in management of the catchments.

The value of ***Rotorua Lakes 2004*** will be measured by the practical action that it triggers. Already, Action Plans for several lakes are incorporating projects to reduce phosphorus rather than just concentrating on nitrogen.

ORAL PRESENTATIONS (in order of presentation)

Detecting, predicting and managing cyanobacteria in source water

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ABSTRACT

- There are three requirements for phytoplankton growth: a nutrient source, an adequate light supply and an inoculum from which the population can propagate.
- To successfully manage cyanobacteria there needs to be integrated management of the catchment, the water body and the treatment plant
- the cyanobacteria tend to dominate when the water-column is stratified. At Myponga Reservoir *Anabaena* populations grew when the surface mixed layer became shallow and the cells remained entrained near the surface.
- Artificial destratification is one of few available “in-lake” management options available to control cyanobacteria. However, techniques are still required to effectively disrupt the surface mixed layer which escapes entrainment by conventional bubble plume aerators.
- The internal nutrient load, which along with catchment sources of nutrients, contribute to the magnitude of the phytoplankton biomass can also be controlled with artificial destratification.
- Cyanobacterial and phytoplankton growth in reservoirs is determined by environmental conditions which vary at scales ranging from minutes to seasons and interannually.
- The limiting of light availability by artificial destratification and controlling nutrient sources remain the most sustainable strategies to control cyanobacteria.

INTRODUCTION

Cyanobacteria are notorious as indicators of degraded aquatic systems. The toxins produced by the cyanobacteria have been responsible for livestock (1) and human deaths (2) which has stimulated considerable public interest. However, recent research has shown that with appropriate treatment most toxins can be effectively removed from drinking water(3), significantly reducing the risk to consumers. Cyanobacteria also produce taste and odour compounds which are not easily removed during conventional

water treatment and compromise the quality of potable water. Even low numbers of cyanobacteria can produce concentrations of these compounds which exceed the taste threshold and attract customer complaints. The water industry has been active in seeking methods to control cyanobacteria, however, controlling to a level which ensures no taste and odour problems is difficult.

The aim of this paper is to describe the conditions which lead to cyanobacterial blooms and from this information identify means of predicting, detecting and managing cyanobacteria in source waters. The site used as a case study was Myponga Reservoir in South Australia (S 35º 24' 13" E 138º 25' 13"). The reservoir is 36m deep, has a volume of 26,000 ML and catchment area of 124 km^2. Landuse in the catchment is predominantly dairy and beef grazing. The reservoir is the site of a CRC Water Quality and Treatment study on artificial destratification using a bubble plume aerator and two surface mounted mechanical mixers are operated for six months each year. As part of this study two meteorological stations with thermistor chains have been permanently deployed in the reservoir to record physical data at 10 minute intervals (Figure 1).

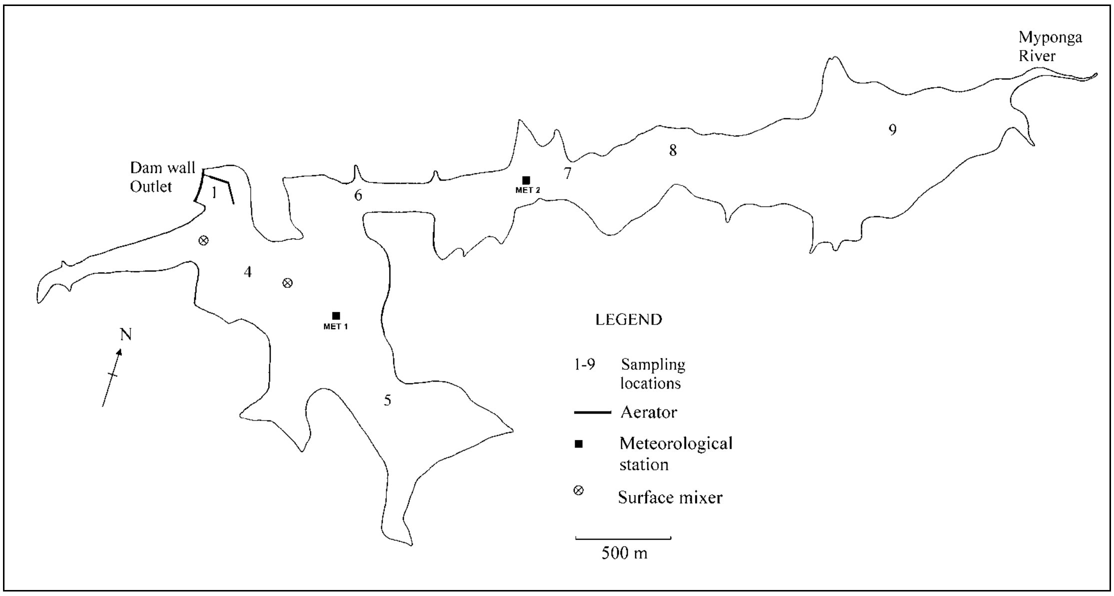


Figure 1. Myponga Reservoir showing sampling locations, mixer and aerator deployment and sites where meteorological stations are deployed.

PHYSICAL CONDITIONS FAVOURING CYANOBACTERIA

Cyanobacteria are an extremely well adapted group of photo-autotrophic organisms which dominate the freshwater phytoplankton community during stratified conditions. Whilst the cyanobacteria have existed on earth for more than 2.5 billion years (4), there is a general opinion that "cyanobacterial blooms" are increasing in frequency due to anthropogenic eutrophication (5) and the regulation of waterways with weirs and dams.

The success of the cyanobacteria is, in part, attributable to the gas vesicles which provide buoyancy (6,7,8). The ability to float into the illuminated surface water in stratified water-bodies provides a distinct advantage over other phytoplankton that rely entirely on turbulence to remain entrained. By floating upwards the cyanobacteria can significantly increase light capture and consequently increase productivity (9,10,11), nitrogen fixation (12) and growth (13).

The scum-forming cyanobacteria do particularly well when there is a shallow surface mixed layer, that is when stratification persists close to the water surface. An example of rapid *Anabaena* growth in a shallow surface layer occurred in Myponga Reservoir in January 2000. Myponga Reservoir is generally a well-mixed site and cyanobacterial concentrations are low. However, during summer the physical conditions can become suitable for *Anabaena circinalis* to grow rapidly. Myponga Reservoir was well-mixed in early January 2000, however, there was significant heating of the surface water between January 7 and January 21 (Figure 2). The result of this of this was that the diurnal surface layer remained shallow (Figure 3) and cyanobacteria were not entrained deep into the water column.

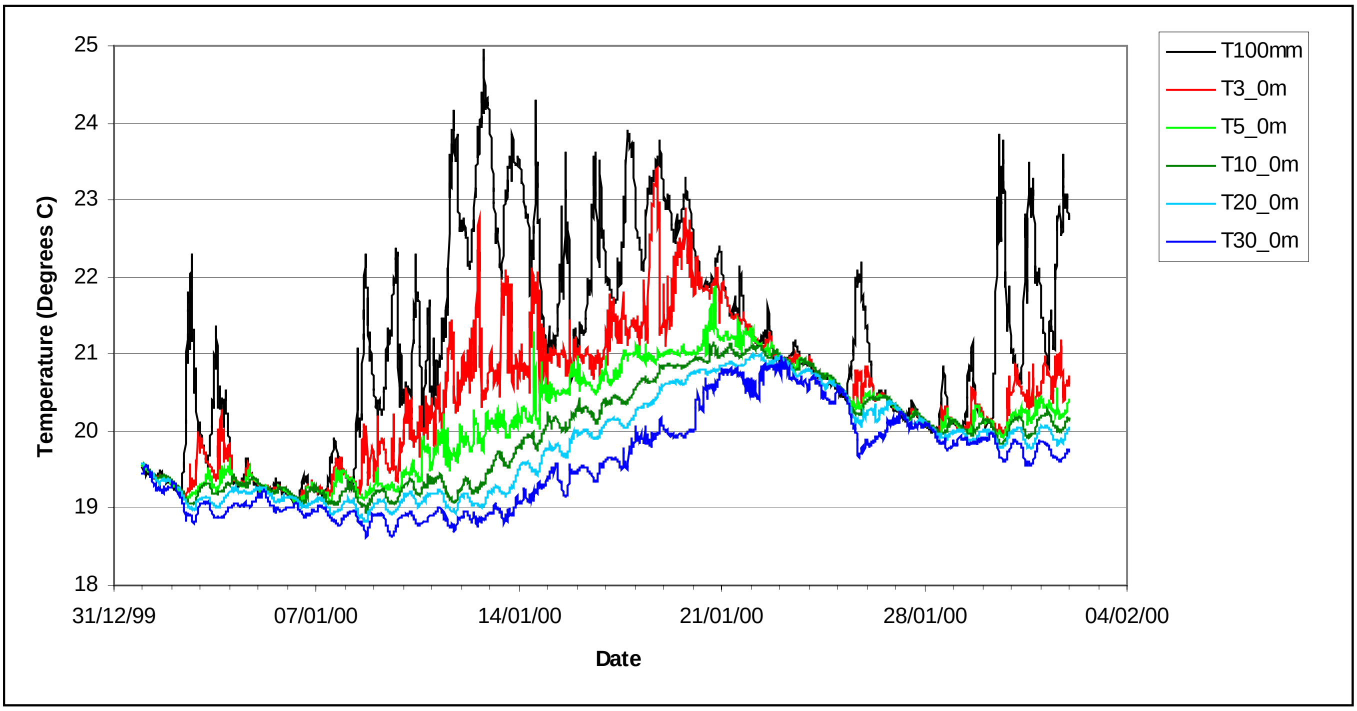


Figure 2. Temperature profile at Myponga Reservoir for January 2000

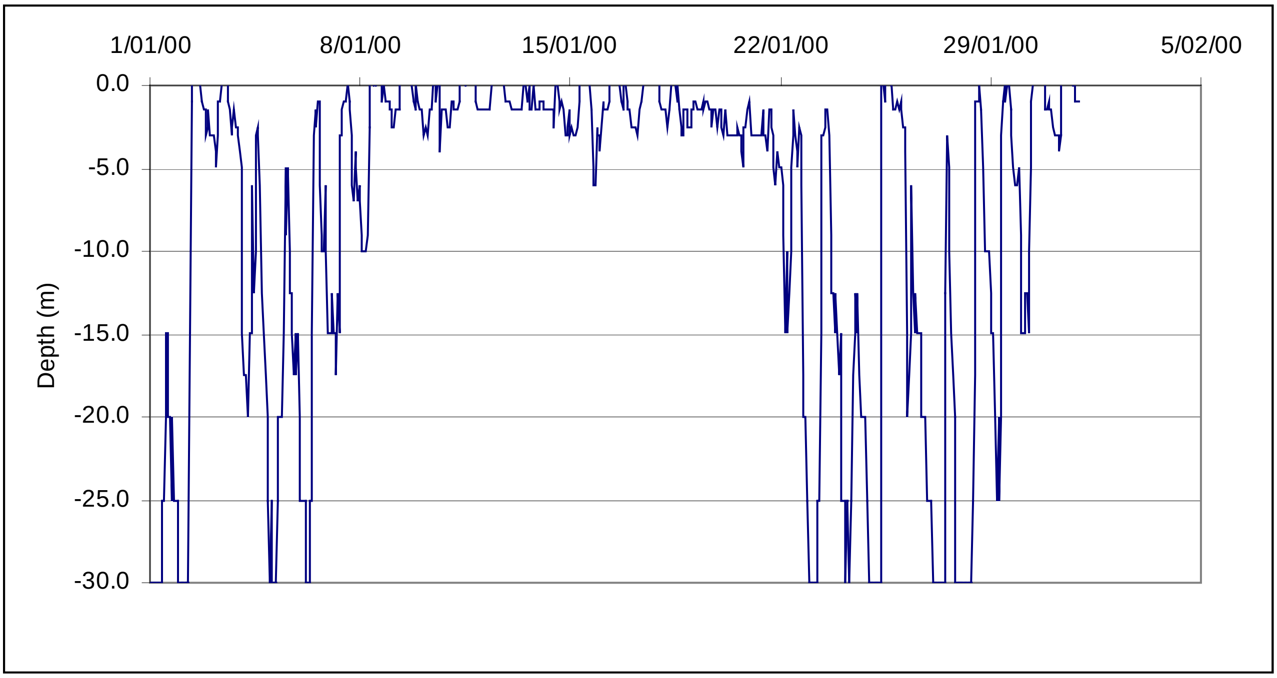


Figure 3. Depth of surface mixed layer, defined as the shallowest depth at which the temperature difference between two adjacent thermistors is 0.05 ºC or greater.

The euphotic depth in January was 3.6m (light attenuation coefficient: k_d=1.22) and nutrient concentrations were sufficiently high to support rapid growth rate and high yield: Ammonia – 0.027 mg L^{-1}, Filterable reactive phosphorus – 0.038 mg L^{-1}, Total phosphorus – 0.051 mg L^{-1}, Total Kjeldahl Nitrogen – 0.98 mg L^{-1}, Nitrate and nitrite – 0.131 mgL^{-1}. *Anabaena circinalis* was not detected on 14 December 1999, and was first recorded later in December, albeit at low numbers (Table 1). As the water column stratified, *A. circinalis* growth accelerated and by 10 January 2000 the highest recorded concentration was 3891. The mean growth rate between 4 January and 10 January was 0.36 day^{-1} and concentrations were high enough to present a geosmin (taste and odour) threat to the treatment plant.

In this case the *A.circinalis* population was controlled with a chemical algicide on 11 January 2000, however, in reservoirs where algicides are not used, early warning of cyanobacterial risks can enable treatment, such as activated carbon dosing, to be anticipated.

Table 1. *Anabaena circinalis* concentrations (cells mL^{-1}) at five locations at Myponga Reservoir. – signifies *A. circinalis* not detected in a 1mL, 10x concentrated sample.

Location	21/12/99	29/12/99	4/01/00	10/1/00	18/1/00	25/1/00
1	4	9	43	3891	45	2
4	-	-	-	2186	2	-
5	29	-	-	146	12	-
6	-	-	163	1470	30	-
7	-	-	459	448	8	-

Although there are two different destratifying systems in Myponga Reservoir, there is still strong persistent stratification in the surface layer as high nocturnal temperatures and low

wind speeds inhibit cooling. However, modelling studies have shown that the destratifiers have significantly reduced the period when *Anabaena* can grow. The phytoplankton biomass at Myponga Reservoir is dominated by green algae and diatoms, which rely on turbulence to remain entrained, and the conditions when cyanobacteria grow is narrowed to a brief period in summer each year (Figure 5).

CHEMICAL CONDITIONS FAVOURING CYANOBACTERIA

Nutrients can be limiting to cyanobacteria in two ways: they can limit the rate of growth and they can limit the maximum biomass or magnitude of the bloom. There is a common perception that cyanobacterial blooms are the result of eutrophication, however, the reality is that cyanobacteria can exceed problematic levels at concentrations barely above the detection limit. Concentrations of phosphorus less than 0.01 mgL^{-1} filterable reactive phosphorus are considered to be growth limiting (14) and 0.1 mgL^{-1} soluble inorganic nitrogen is considered the minimum concentration to maintain growth during the growing season (15). Higher concentrations support rapid growth and higher biomass.

The major nutrient sources are the catchment, the internal load derived from sediment release and atmospheric deposition. In some instances catchments are naturally high in phosphorus and consequently attempts to reduce phosphorus to limiting levels would be unsuccessful. In these cases alternative strategies to control algae should be sought.

The nutrient source which reservoir managers often do have the ability to control is the internal nutrient load or sediment-derived nutrient load. The internal nutrient load is most often controlled by oxygenation of the hypolimnion either by artificial destratification or by direct oxygen injection. In systems where the internal nutrient load contributes significantly to the total nutrient load, a reduction in nutrient release from sediment can significantly decrease the sustainable algal biomass (16).

In a typical phosphorus cycle, phosphorus is remobilised from sediment or decaying organic matter and entrained into the water column, where it is taken up by algae. From there the phosphorus is either passed on to higher levels of the food web or lost to the bottom as the algae sediment. In deep lakes the resolubilisation of P at the sediment is vertically separated from the algae and so each P molecule can only be accessed with entrainment from the hypolimnion to the epilimnion. In strongly stratified deep lakes this may happen only once or twice a year during significant ‘over-turn’ events. In contrast shallow lakes have the zone of P resolubilisation much closer to the zone of greatest productivity and a single molecule may be recycled a number of times during the growing season (17) and thereby sustain a high algal biomass for longer. This is why shallow lakes prove so much more difficult to restore than deep ones (17,18)

MANAGING CYANOBACTERIA IN SOURCE WATER

Cyanobacteria are difficult to manage once they have become established in a waterbody. Often copper based algicides are used, however, there are environmental issues concerning the addition of heavy metals to aquatic systems. The most environmentally sound method to control cyanobacterial growth in reservoir is to manipulate the environment to favour other phytoplankton over the cyanobacteria. Previous attempts have included manipulating the physical, chemical and biological components of the reservoir. Manipulation of catchment nutrient sources takes a number of years before any impact is observed. Manipulation of the biological environment to encourage grazing requires rigorous monitoring and is not applicable in some systems (19). On the other

hand manipulation of the physical environment is a practical means of changing the phytoplankton habitat and also can manipulate the internal nutrient load.

ARTIFICIAL DESTRATIFICATION

During stratification the hypolimnion is effectively separated from the atmosphere and becomes depleted of oxygen. This leads to reducing conditions at depth and contaminants such as iron, manganese and nutrients are released from sediment.

There are basically two types of artificial destratification systems available: bubble plume aerators and mechanical mixers. Both systems weaken stratification so that wind forcing can more readily break down stratification and mix the reservoir. Bubble plume aerators operate by pumping air through a diffuser hose near the bottom of the reservoir. As the small bubbles rise to the surface they entrain water such that the plume has a unique temperature and density and will plunge to the level of equivalent density and an intrusion will propagate at that depth. As the intrusion moves through the reservoir there is return flow above and below the intrusion, and these circulation cells facilitate exchange between the surface and the hypolimnion (Figure 4).

The role of bubble plume aerators is to weaken stratification and work synergistically with wind to mix the reservoir and to oxygenate the hypolimnion. To control contaminant resolubilisation the hypolimnion must receive sufficient oxygen to satisfy the sediment oxygen demand. Artificial destratification has been relatively successful at controlling the release of contaminants from sediments (20) but has been less successful in controlling cyanobacteria (21). The inability of destratifiers to mix the stratified surface layers, outside the immediate influence of the plume or mixer, has meant there is still a habitat for buoyant cyanobacteria to exploit (22).

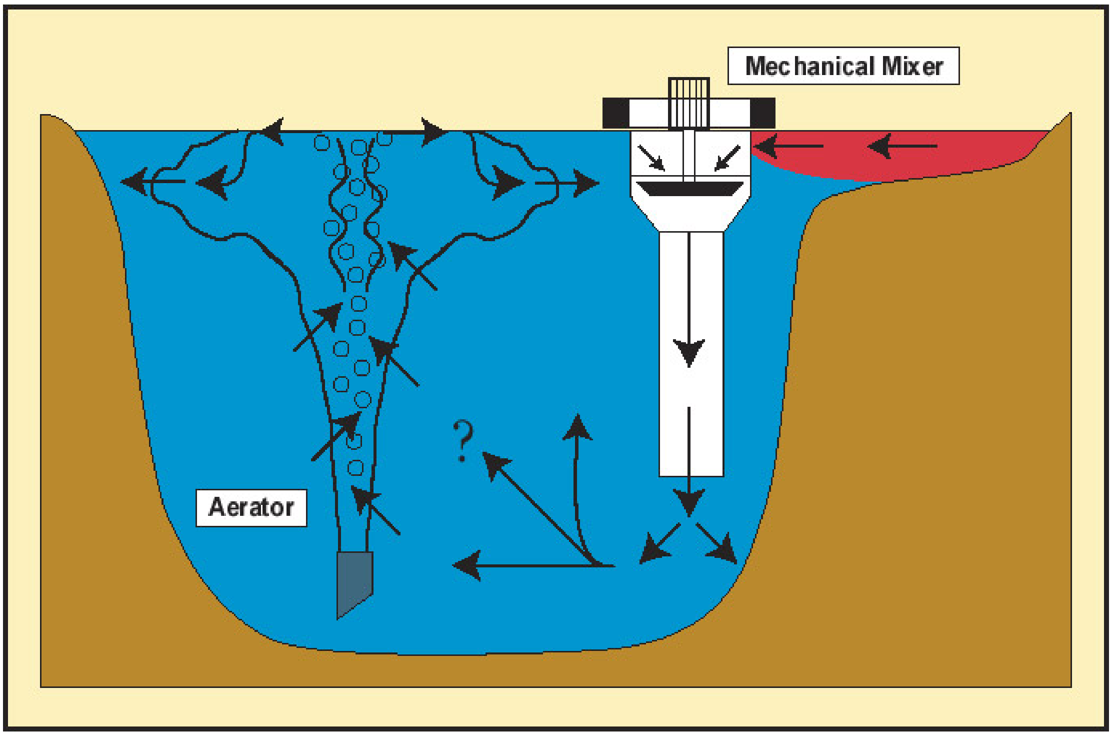


Figure 4. Surface mounted mechanical mixer .

The Phytoplankton Community

Current management at Myponga Reservoir includes both artificial destratification and chemical algicides to control cyanobacteria.

Although there are two different destratifying systems in Myponga Reservoir, there is still strong persistent stratification in the surface layer at particular times when high nocturnal temperatures and low wind speed inhibit cooling (Figure 2). However, modelling studies have shown that the destratifiers have significantly reduced the period over which *Anabaena* can grow. The phytoplankton biomass at Myponga Reservoir is dominated by green algae and diatoms, which rely on turbulence to remain entrained, and the conditions when cyanobacteria growth is narrowed to short periods each year (Figure 5).

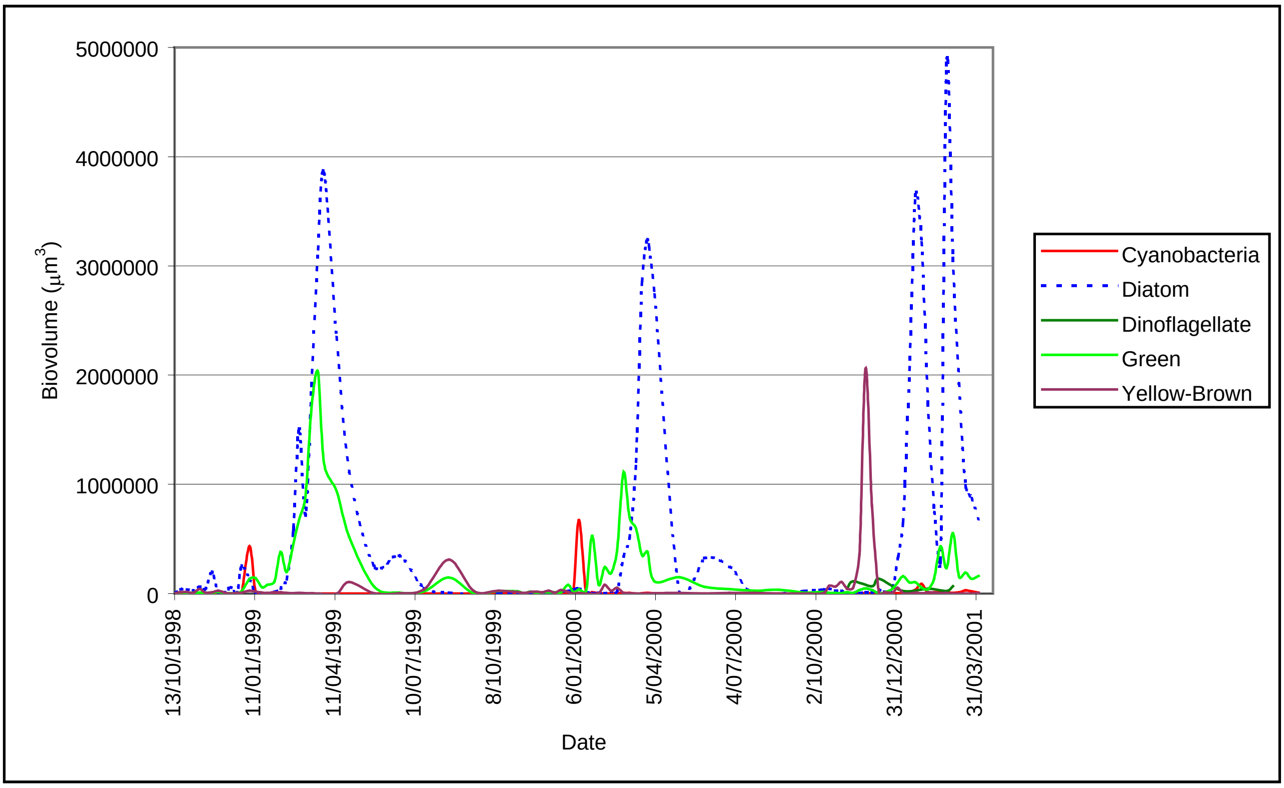


Figure 5. The relative abundance of the different phytoplankton groups in Myponga Reservoir.

Artificial destratification to control the nutrient load

Seasonal temperature stratification was evident at Myponga Reservoir during summer from 1984 until 1994. Since deployment of the aerator in 1994 isothermal conditions have been maintained at the sampling site (Figure 2). However, surface layer heating is evident at other sites in the reservoir outside of the immediate bubble plume which is consistent with other reservoirs where bubble plume aerators are operating (22, 16). Dissolved oxygen concentrations were below 4 mg L^{-1} for extended periods during 1992/93 and 1993/94 which provided conditions suitable for contaminant resolubilisation. Since aerator operation in 1994 the dissolved oxygen concentration at 30 m has been maintained above 4 mg L^{-1}.

Prior to 1994 the concentration of filterable reactive phosphorus (FRP) at 30 m depth was consistently higher than the surface concentrations during summer and autumn (Figure 7). This coincides with the periods of extreme temperature stratification and low dissolved oxygen in the hypolimnion. Filterable reactive phosphorus at 30 m depth reached a maximum concentration of 0.259 mg L^{-1} in April 1986. The vertical gradient in FRP concentration has decreased since deployment of the bubble plume aerator and the large flux events have been eliminated.

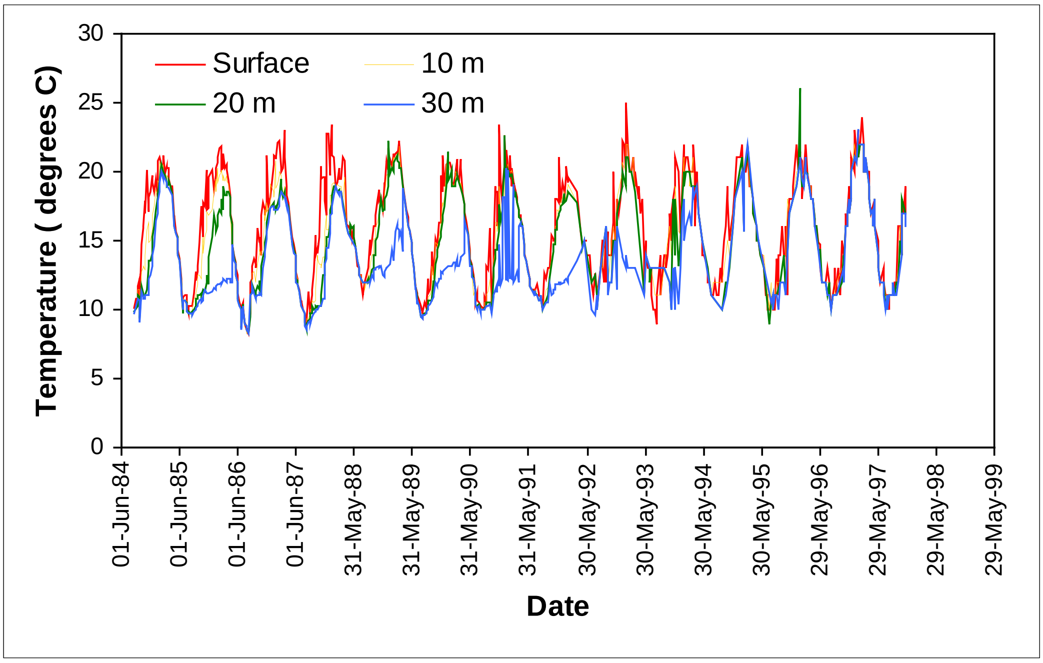


Figure 6. Temperature measured weekly at the surface, 10 m, 20 m and 30m depth adjacent to the offtake point at Myponga Reservoir. The aerator was installed in 1994.

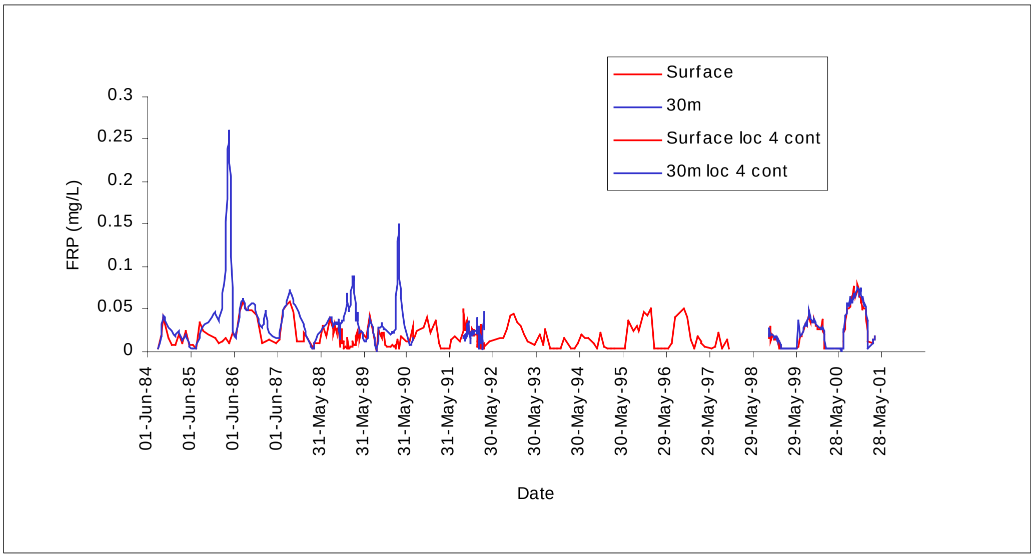


Figure 7. Filterable reactive phosphorus at the surface and 30 m at location 1 near the dam wall and from location 4 from October 1998. Aerator installation decreased the internal nutrient load and high concentrations in the hypolimnion were not observed following aerator deployment.

Relating nutrients to algal biomass

In Myponga Reservoir the nutrient loading from the catchment occurs predominantly during winter and early spring. The nutrient pool is not utilised immediately as phytoplankton growth is limited by cool water temperatures and grazing pressure. As water temperature increases the phytoplankton grow rapidly and chlorophyll a concentration increases with a concomitant decrease in FRP (Figure 8). FRP concentrations decrease to below the detection limit (0.005 mgL^{-1}) and the chlorophyll decreases some time later and the seasonal cycle is repeated.

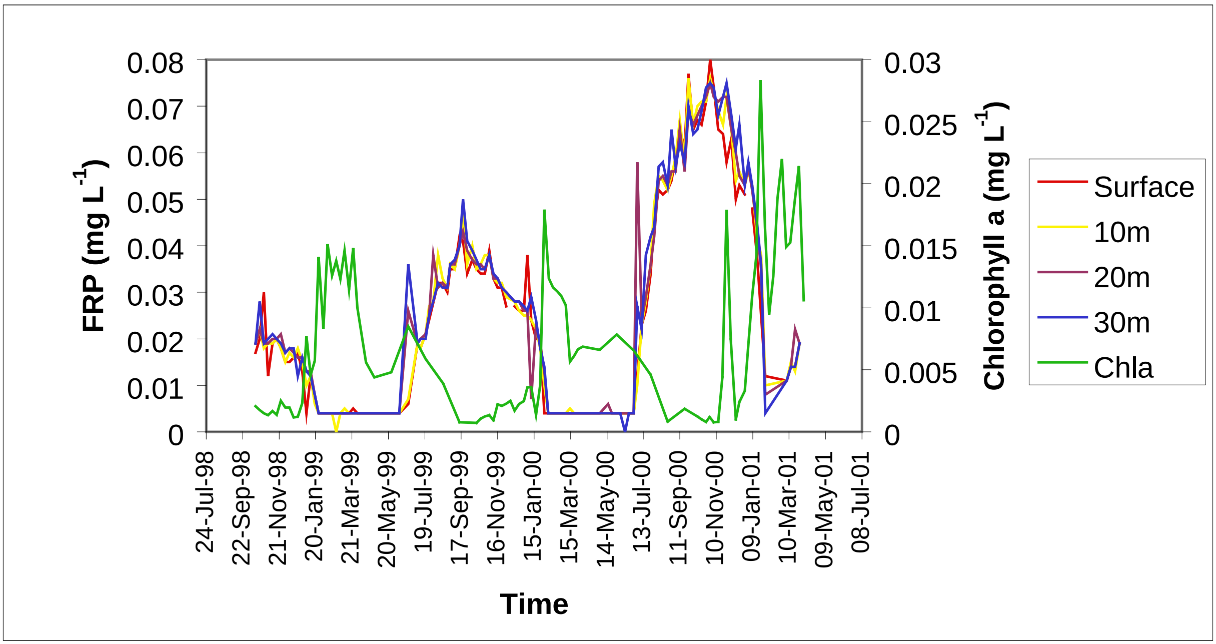


Figure 8. Filterable reactive phosphorus at four depths at location 4 and chlorophyll concentration integrated over the top 5m.

With the internal nutrient load controlled in Myponga Reservoir the input of nutrients is dominated by catchment sources. In Myponga Reservoir two tributaries contribute the majority of the nutrient load, but loading is both seasonally and interannually variable.

Rainfall in the Australian context is highly variable in space and time with significant seasonal and inter-annual variability. Inter-annual variability in rainfall patterns over eastern Australia are strongly influenced by "El Niño" events, which are characterised by sustained warming over a large part of central and eastern Pacific Ocean, and low rainfall on land. El Niño events are opposed by "La Nina" events that show essentially the opposite patterns of sea surface temperature and bring higher than average rainfall (23). Nicholls & Kariko (24) concluded that the El Niño-Southern Oscillation (ENSO) mostly effects the frequency and intensity of rainfall in Australia and exerts less influence upon the length of events.

Years of high mean annual SOI (Southern Oscillation Index) coincide with years of high flow volume in the Myponga catchment (Figure 9). Deviations from the trend are explained by variation within years. For example, in 1999 the mean annual SOI was influenced by strong positive values in January and December but were otherwise low, resulting in low flows. In 1992 the monthly mean SOI in May, August and September was slightly positive and all three months received higher than average rainfall. The low

flows found in 1988 were possibly due to the strong negative SOI values in the first half of the year remnant from the strong negative SOI values in 1987. 1984 and 1985 also had a number of winter months with negative SOI values.

We have seen that high flow results in high TP loads and reservoir concentrations. The result of a high maximum TP concentration in Myponga Reservoir results in a high chlorophyll *a* concentration (Figure 10). This figure show the relationship between the maximum annual TP concentration and the maximum chlorophyll *a* found in the following growth period in the years between 1985 and 2000. Two outlier years, 1988 and 1993, are excluded from the regression in figure 13. 1988 was unusual in that it had early rains and consequently there was 6 months between the TP and Chl *a* maxima. In 1993, hypolimnetic anoxia caused by thermal stratification, released higher than usual FRP concentrations from the sediments, sustaining high algal biomass and resulted in a high maximum chlorophyll *a* concentration. The operation of the bubble plume aeration system since 1994 has most likely prevented this situation from recurring (20).

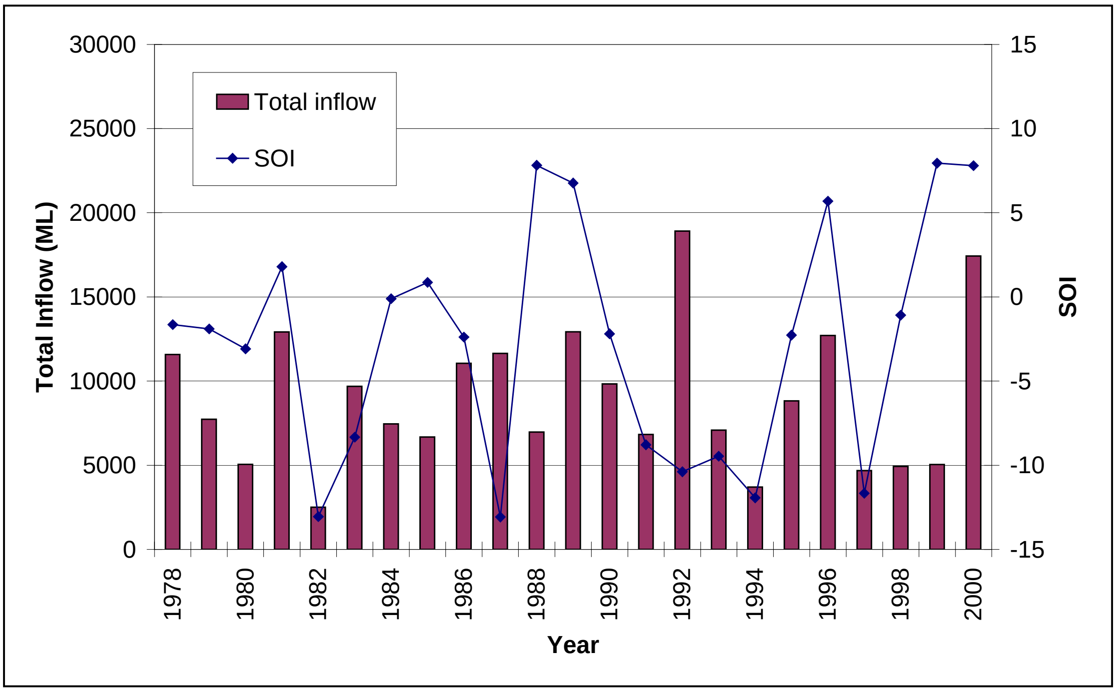


Figure 9. Relationship between annual mean Southern Oscillation Index and flow into Myponga Reservoir.

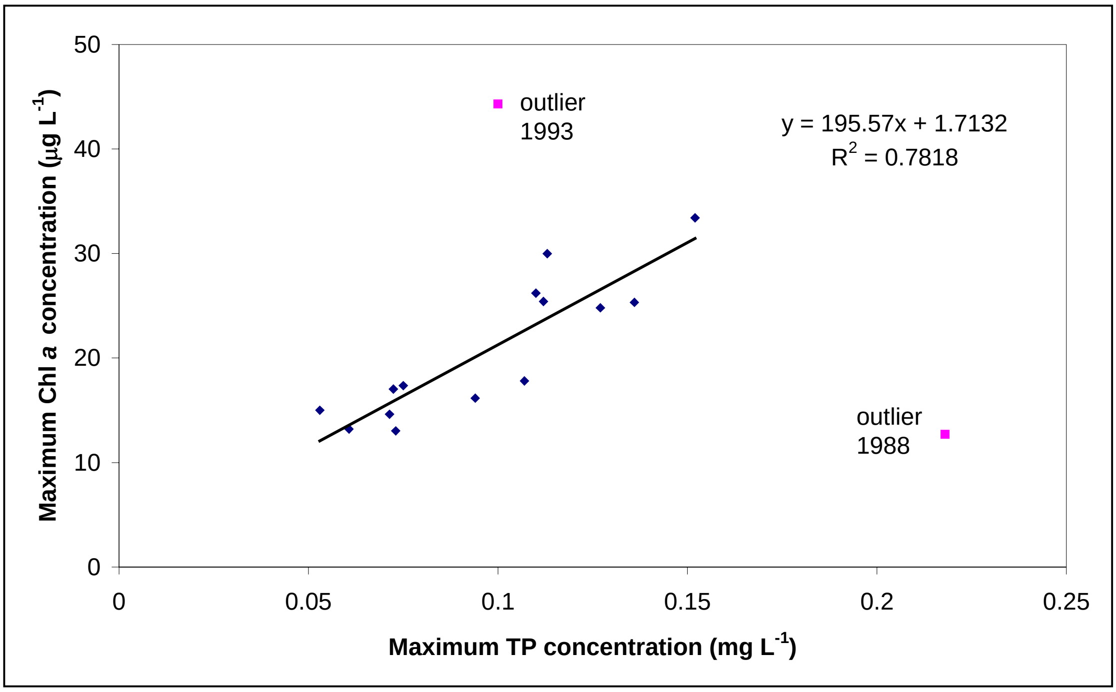


Figure 10. Relationship between maximum total phosphorus and maximum chlorophyll *a* in the following growing period.

DESTRATIFICATION AND CONTROL OF CYANOBACTERIAL GROWTH

Because weather and limnological conditions are never constant it is difficult to determine whether destratification has an impact on cyanobacterial growth without very extensive historical data sets. An alternative approach is to use numerical models to simulate the hydrodynamics and cyanobacterial growth. Dyresm-Caedym is a coupled hydrodynamic, water quality and algal growth model available as free-ware from the Centre for Water Research, The University of Western Australia (http://www.cwr.uwa.edu.au/). The modelling approach has been used in our studies to evaluate destratification in Myponga Reservoir. Meteorological variables measured at the stations on the reservoir were used for model inputs. Algal growth was simulated using equations describing nutrient and light limited growth of *Anabaena circinalis* and floating velocity. The model was used to evaluate the following scenarios:

No Mixing

Under natural conditions the model predicts that the water column at Myponga would remain stratified for approximately six months each year (Figure 11), which is corroborated by the historical data which identifies long periods of stratification (Figure 6). Temperature differences between the surface and 15m exceeding 5 ºC are not uncommon. During the periods of stratification conditions favour the cyanobacteria and when the surface mixed layer is sufficiently shallow they can grow rapidly (Figure 12) and reach concentration of approximately 8 µg L^{-1} Chla (~11,000 cells mL^{-1}).

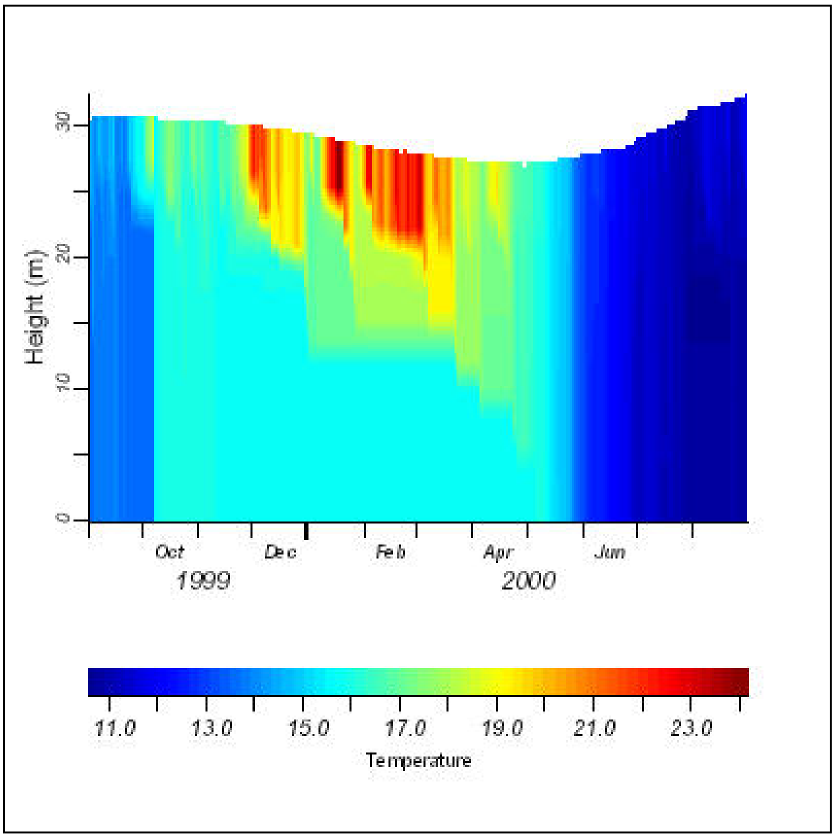


Figure 11. Simulated seasonal temperature structure at Myponga Reservoir with no artificial destratification

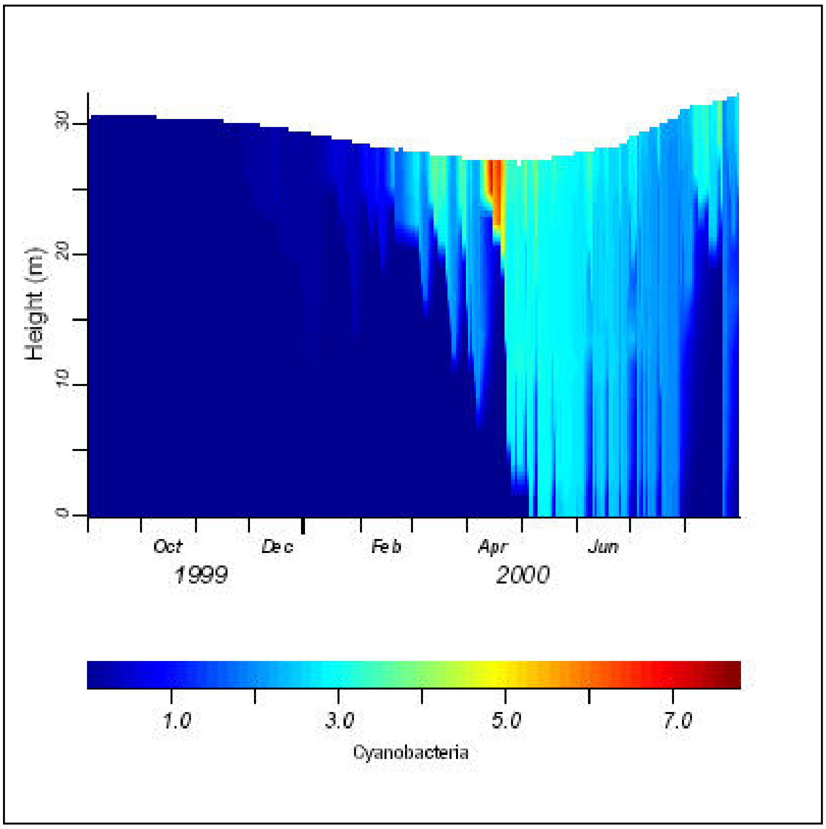


Figure 12. Simulated *Anabaena* concentrations in Myponga Reservoir with no artificial destratification. Units are Chla ($\mu g\ L^{-1}$) attributable to *Anabaena*.

Bubble plume aerator

Simulations over the same period (1999-2000) but with a bubble plume aerator operational shows there is a significant breakdown of the temperature stratification, however there are still periods during intense insolation when a shallow surface layer persists (Figure 13). The *Anabaena* concentration is also significantly reduced with the operation of artificial destratification. The maximum concentration of *Anabaena* chlorophyll *a* under destratified conditions is 2 µg L^{-1}, approximately 25% of the concentrations expected in the reservoir with no artificial destratification.

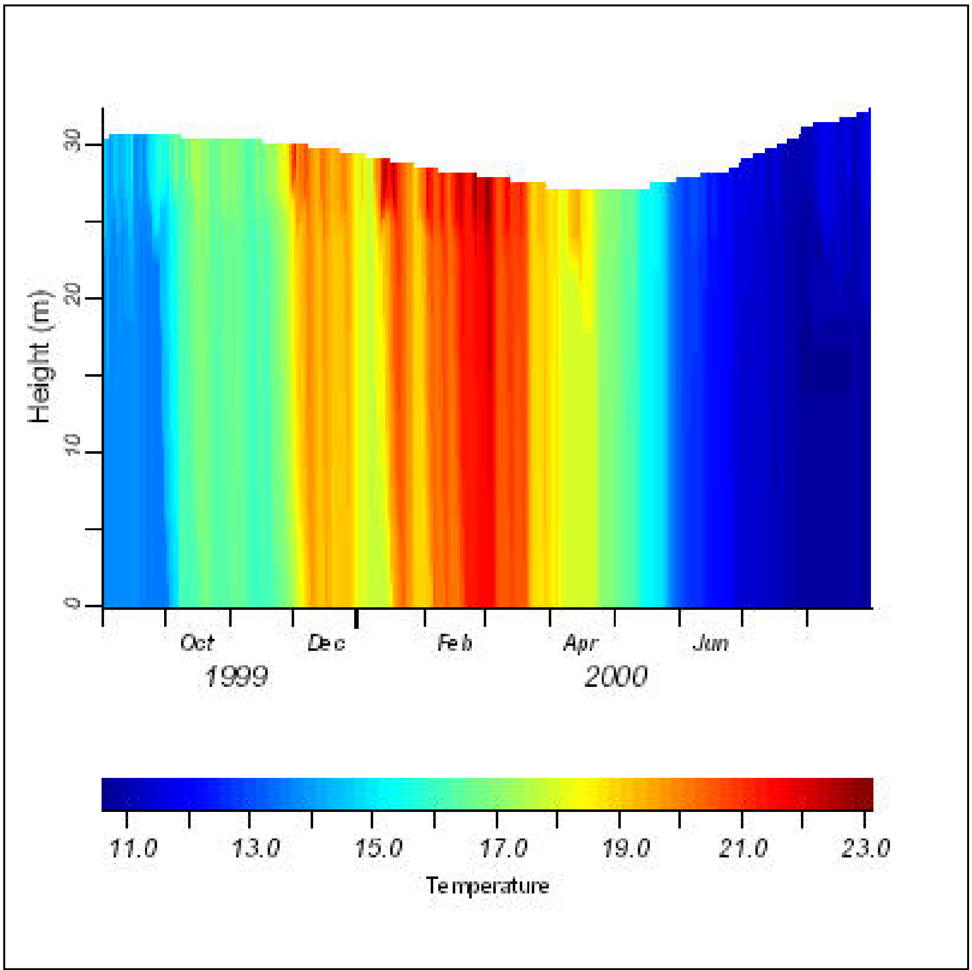


Figure 13. Simulated seasonal temperature structure at Myponga Reservoir with artificial destratification using a bubble plume aerator.

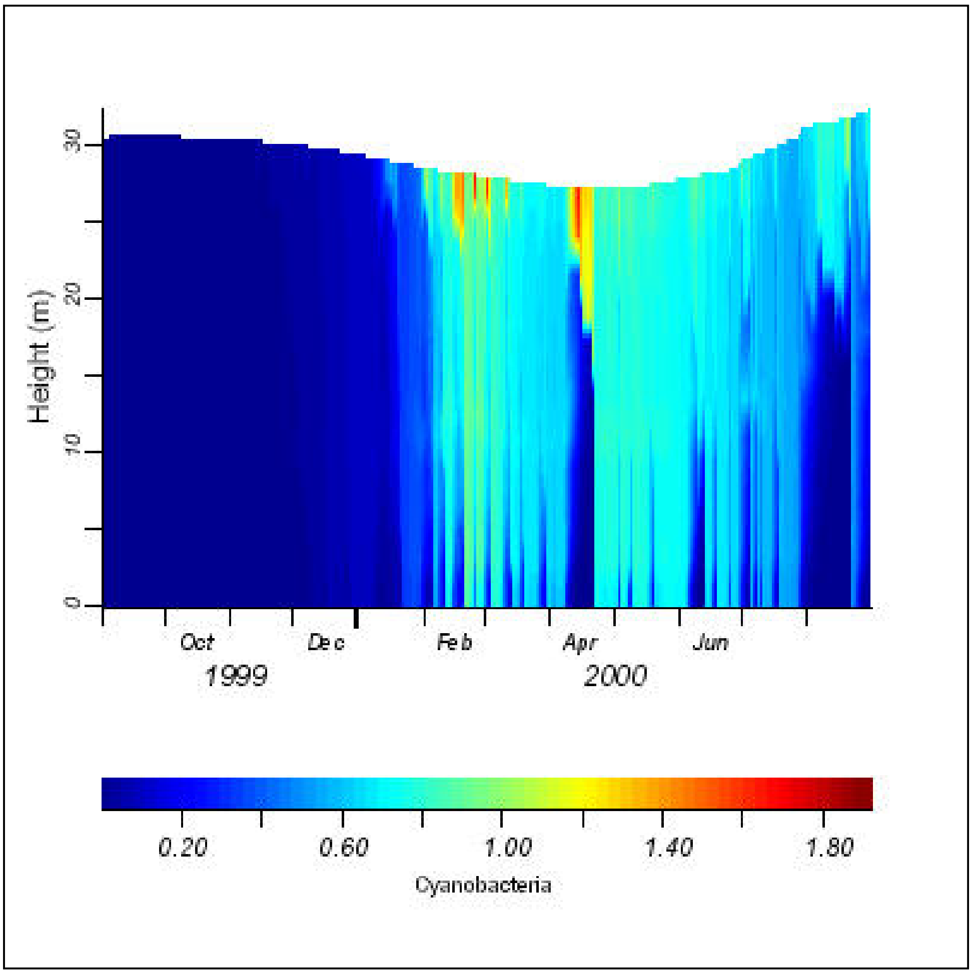


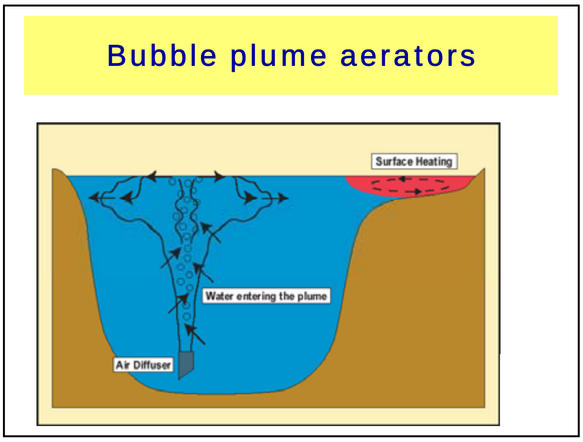
Figure 14. Simulated *Anabaena* concentrations in Myponga Reservoir with artificial destratification using a bubble plume aerator. Units are Chla (μg L^{-1}) attributable to *Anabaena*.

CONCLUSIONS

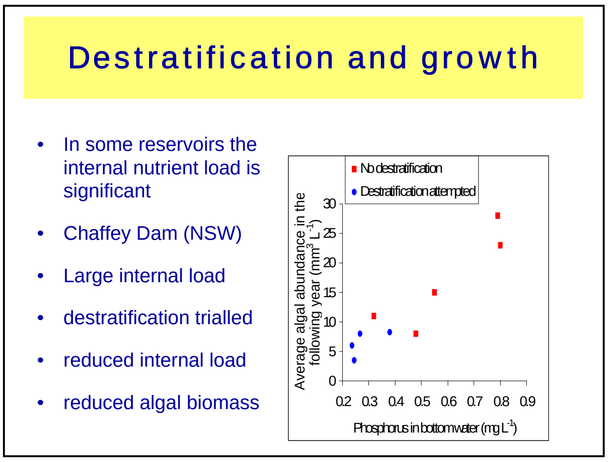
- Cyanobacterial and phytoplankton growth in reservoirs is determined by environmental conditions which vary at scales ranging from minutes to seasons and interannually.
- The growth of *Anabaena* is favoured by a shallow surface mixed layer where light availability is increased.
- Although *Anabaena* is problematic because it produces geosmin it is a small component of the total phytoplankton biomass in Myponga Reservoir.
- Annual nutrient loading to Myponga Reservoir is highly variable and determined by flood magnitude and strongly influenced by El Niño.
- The magnitude of the phytoplankton community is correlated to the nutrient load.
- Artificial destratification, and manipulation of the physical environment, is capable of significantly reducing the cyanobacterial concentration and the internal nutrient load.
- To successfully manage cyanobacteria there needs to be integrated management of the catchment, the water body and the treatment plant.
- The limiting of light availability by artificial destratification and controlling nutrient sources remain the most sustainable strategies to control cyanobacteria.

SELECTIONS FROM TRANSCRIPT

"Control of cyanobacteria is difficult and has plagued managers for 50 years or more. Within optically shallow water bodies, those where we have coloured water, there's the opportunity to manipulate the light environment in order to start controlling cyanobacterial growth. One of the best mechanisms we have for doing this is by setting up basin-scale circulation with a destratification device and these can be bubble plume aerators, but we also did some work at Myponga Reservoir looking at whether we can overcome some of the favoured buoyancy by sucking the buoyant colonies near the surface through a mechanical mixer and putting them down at depth. The whole aim of this was twofold – one is to put oxygen at depth as well so we start controlling sediment release of nutrients and the other is to mix the storage in order to light- limit the cyanobacteria.

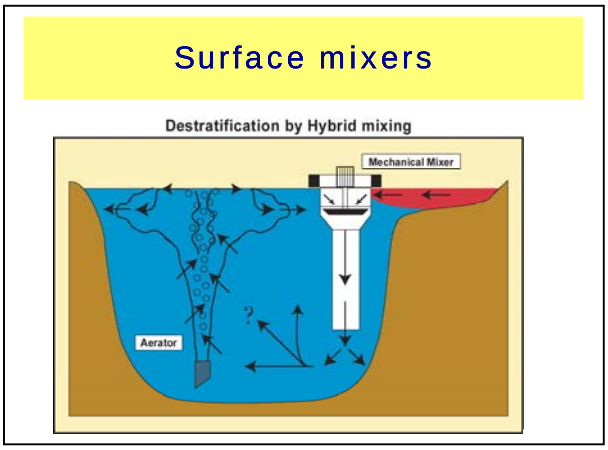


"Tthe way these bubble plume aerator devices work is aas an air diffuser, and we're putting in a series of fine bubbles into the water column. As these bubbles rise they expand and they entrain water from all depths within this water column. Now as we know, we're going to have different densities of water through here, so this entrained water at the surface has a density of its own which is the equivalent of the sum of all this water that it's entrained along the way. It's going to be denser than the surface water which is buoyant and so it plunges down into the water column and forms an intrusion which moves out through the reservoir. As this water moves out we need to replace that water and so we get these big circulation cells generated on either side of the intrusion. Now what this does is act to disrupt stratification, so when we get wind mixing operating on top of that, then we can push through the stratification and mix deeper into the water column. One of the problems we've found with artificial destratification though is that we still get surface heating. As we've seen in the previous slides, surface heating gives rise to Anabaena or Microcystis growth and if you've got buoyant cells they sit up in these little pockets and we're not entraining them within the flow in our aerator.



"But does it work? There is good evidence that we can control the internal nutrient load with an aerator because we only need to be able to control our dissolved oxygen to around about 3 mg/litre. There's a good chance we can put in enough energy and enough mixing and get enough atmospheric exchange into that reservoir in order to cope with the oxygen demand of the sediments and BOD. To illustrate that, here are some data from Chaffy Dam which is near Tamworth in New South Wales. In this system it stratifies for about 10 months of the year. There's a large internal nutrient load,

highly developed agricultural catchment and a long history of fertiliser application, so there’s a lot of phosphorus which is now tied up in sediment from historical land use. Again we see this linear relationship between phosphorus and the algal abundance, so as the reservoir turned over, this phosphorus in the bottom water became available for algal growth in the following year and not surprisingly, the more phosphorus you have the more phytoplankton you have. With the destratification attempted, what it acted to do was decrease the phosphorus in the bottom water because it kept oxygen in the hypolimnion and as that occurred, we got less phosphorus release and consequently lower algal abundance. In years without destratification we’re still getting a high algal abundance. The aerator didn’t control cyanobacterial growth, we still got Microcystis and Anabaena growing, but what we did see was a big reduction in yield and so the aim of controlling nutrients is to decrease our yield.



We set out to see whether we could use mechanical mixers to start light-limiting algae and overcome some of theadvantages provided by buoyancy and stratification. So the aim of this was to directly tackle the surface mix layer, the surface heating and pull down cells that were within that area and put them at depth. Unfortunately it wasn’t as successful as we’d hoped because what we’re working against is the intrinsic buoyancy of the surface layer. So as we deposited it at depth, it’s buoyant and because we’re not entraining any water along the way, when it gets to the bottom it’s still buoyant and it pops back up to the surface, so we had a lot of short-circuiting within the system.

“So although we do get some entrainment and a small intrusion, it's nowhere near the sort of mixing efficiency we saw with the aerator. This is what our mixers look like. They move around about 5000 litres/second. Under the water we have 10 blades rotating and there is a large draught tube. With the draught tube we’re putting water down to about 15 metres. Once we had a temperature difference of around about half a degree between where we were pulling water from at the surface and the bottom water, then our mixer wasn’t working anymore. So if we had basically an isothermal water column where you don’t need mixing, our mixer would work. Once we start getting stratification it started to fail.

In order to look at reservoir scale application of a device such as this or to get some idea about how nutrient reduction is going to affect a system, it's very difficult to go out and just take measurements because the reservoir is never the same. Each time you go out there the reservoir looks different, it's got different stratification behaviour, it's got different nutrients, it's got a different phytoplankton community and so what we did was use some models which were developed at the Centre for Water Research in order to start getting some estimate on how effectively these different mixing devices were working on destratification and how effectively they were controlling the Anabaena population. We tried a number of different scenarios looking at our aerator and our mixers. In the model Anabaena is represented as chlorophyll and so about 3 µg/litre of chlorophyll is about 4000 cells, just so you're aware in the following slides (shown in formal paper). If we had no mixing in Myponga Reservoir, this is what it would look like. So this is just a simulated period from winter through summer and winter again in 2000, and this is the surface of the reservoir and just the reservoir depth. We can see that as we get this intense heating which we have in our Mediterranean climate, we get stratification occurring and you'll note we're looking at around about 5 to 10 metres.

"So we have ideal conditions in Myponga with no mixing for Anabaena or Microcystis establishment. In fact what we see is that we're getting about 6 µg/litre, so 8000 to 12000 cells per ml of Anabaena occurring through summer and particularly into autumn when we start getting our low wind speeds and our nice calm stable weather. If we then put in our aerator and see how well that's operating, you can see we've disrupted all of this stratification, and the aerator's not that expensive – it's costing us to run about $30,000 a year for 6 months.

"So if we look at the benefits of that aerator, it's providing a lot for its $30,000. We can see it's mixing right to the bottom. There are still some periods where we can't cope and you can see we've got some shallow surface mixing which is what we saw with the surface mix layer examples before, but in general it's doing a good job of controlling Anabaena growth. Here we're down to about 2 µg/litre of chlorophyll attributable to Anabaena, so with the aerator alone we've reduced our population potential by about four times.

"If we look at the mixer alone, you can see quite clearly in this slide how it's not working. It's not pushing through that thermocline and giving us the sort of mixing we need. You can see we're not fully mixing through December and January and as a result, there are still lots of pockets within that reservoir where the Anabaena can grow and in fact our concentrations are up at around 5 ½ to 6 µg/litre of chlorophyll of Anabaena. So we've only reduced it against the no mixing scenario by about 2 µg/litre or 3000 cells per ml.

"If we have both systems working in tandem we do actually see some additional benefits. So we have our aerator working and our mixer working, we're seeing good mixing and we're also reducing our Anabaena population down to less than 1 µg/litre. So we've got an 8 times reduction with the two systems over what we'd have if we had no mixing at all. In the type of lakes I deal with in Australia the mixing will work. In the clear lakes there's less opportunity to cope with the light limitation issue or start light-limiting the cyanobacteria and so it really does come down to a nutrient control issue. So how do we apply what I've just told you to the New Zealand lakes? Well I guess there's nothing new in phytoplankton research, it's nutrients and inoculum."

QUESTIONS

Rowland Burdon, Royal Society of New Zealand: You mentioned the accumulation of phosphorus in the cyanobacteria, specifically mentioning the polyphosphates. Now I assume that luxury accumulation of phosphorus can tide the organisms over for quite a few cell divisions even if the available phosphorus in the water column disappears. Is it a special feature of cyanobacteria to be able to accumulate and continue using phosphorus and other nutrients in that sort of way?

J.B.: Yes, the cyanobacteria can go for quite a number of cell divisions. We've grown cells out to 23 days with no phosphate; we've loaded them up with phosphorus and then left them or put them in phosphorus-free media and let them grow. We were out to about 23 days and then we gave them another shot of phosphorus and they were able to recover. This is another feature of the adaptation to a resource-poor environment which has allowed the cyanobacteria to do this. Whether it's unique to the cyanobacteria, I am not absolutely sure. There may be some other species which can do it. I don't know whether there are any other algal physiologists who can give insight into whether some of the green algae or diatoms do that. I presume there is some potential for luxury uptake in some of the other species, however it may not be as extensive as with the cyanobacteria.

Charles Sturt, Rotorua District Council: Justin, you mentioned the aerators and in relation to your dam, what surface is each aerator able to service?

J.B.: Oh, the aerator at Myponga is probably one of the best operating aerators around and I'm not exactly sure of the surface area. It must be in the order of 8 square kilometres or something like that. We've detected that with the aerators in the main basin, that intrusion from the aerator travels right down the side arm. We've picked it up about 4 kilometres from where that aerator is actually working, and it's still high flow. And because you will lose velocity with that and you'll entrain a lot of other water, but you will generate that large circulation pattern. The influence of the aerator is also increased because of the other features of Myponga which enable basin exchange. There's the differential heating and cooling, and wind mixing as well driving basin exchange, so altogether we're doing a good job of mixing up that reservoir.

(inaudible) … what form of aeration will we require?

J.B.: It's a big ask to aerate a lake this big. What you have to remember is that you're trying to overcome heating by the sun and the sun's a pretty powerful thing and so we'd be fooling ourselves if we thought we could mix every reservoir or lake with an aerator device. David have you got any comment on an aerator for this type of system?

David Hamilton, University of Waikato: Well just to comment on the areas, Rotorua is 80 square kilometres approximately and Rotoiti is about 33 or 34 square kilometres and so it really becomes a trade between how much energy and how much cost we're going to need in order to achieve it. And going a little bit further, there have been a lot of unsuccessful applications where the efficiency and the amount of air that was supplied just simply wasn't enough, and that includes one application, I think, previously here in New Zealand where that was the case. Max (Gibbs) might have some other comments about that.

Noel Burns, Lakes Consulting: I was just wondering, another type of algae in the water column is the flagellates and they are also mobile by their swimming capability. Now it seems as if the blue-greens aren't competing for nutrients, is there another ecological adaptation that's helping the blue-greens not compete or why aren't the flagellates doing it as well?

J.B.: That's an interesting question. We often do see a succession between our flagellated algae and our cyanobacteria and we've seen them co-exist in some shallow lakes in Australia, in Adelaide. So we've seen paradigms in which you have flagellates here in your lakes co-existing with *Microcystis* in this lake as well. One feature of the cyanobacteria though is that they do tend to float to the surface if they have heaps of nutrients and it may be that they can shade some of these deep water maxima which the dinoflagellates tend to exist in. And so if you set up the right conditions for your cyanobacteria, they may actually be out-competing because they're using the light and then shading deeper populations.

*Simon Moran, West Coast Regional Counci*l: Just a question on the effect of the aerator itself, coming back to that. If it's covering 8 square kilometres, is there any effect on other uses of the lake that may work in the reservoir situation. If there's recreational use, etc. on the lake, is there any effect on that?

J.B.: No, the risk to recreational uses basically comes from pathogens and the cyanobacteria. With an aerator operating I can't see too many mechanisms where you're going to increase risk to recreational users.

Max Gibbs, NIWA: Just recently there have been some papers produced on the collapsing of gas vacuoles using high frequency waves, have you any comments on the use of this as a way of sinking cells.

J.B.: Yes there's a fair bit of interest in ultrasound nowadays and ultrasound does collapse gas vesicles, it's being able to apply the soundwave close enough and have enough power in your ultrasound device in order to cover a big enough area to have a big enough impact on your population. Within a tube if you've got a little sonicator, it's really easy to collapse gas vesicles and disrupt cells. Applying it to the field, we've now got a study going on. Mike Birch who is co-author on this paper has a study looking at a commercially available ultrasound device and seeing what impact that has. That's very preliminary at that stage, but there is a fair bit of interest world-wide. We're talking with Thames Water and some guys at Cranfield University are looking to get up a project on that as well.

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Time trends in water chemistry and future nutrient load in the Lake Rotorua area

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ABSTRACT
Declining water quality due to delayed impact of land-use intensification has prompted this investigation by Environment Bay of Plenty (EBOP), in accordance with the technical advisory group, for assessment of technical aspects of the lakes research. Hydrochemical and age dating measurements were made in the western Rotorua and northern Okareka lake catchments to assess the past and the current states, and future trends in water chemistry.

The volcanic aquifers in the Rotorua area have large water storage capacity and therefore have the potential to delay the impacts of land-use intensification on lake water quality. Because of the hidden nature of groundwater and it's long residence time in the aquifer, extensive groundwater contamination can occur unrecognised over long time periods. Progressively, the old pristine groundwater is being replaced by younger impacted water, which then starts discharging into the streams and lakes.

The hydrogeology of the Lake Rotorua area can be described as a permeable pumiceous surface tephra layer that allows easy penetration of rainwater recharge to deeper rhyolite and ignimbrite aquifers. These aquifers are essentially unconfined and yield high volumes of groundwater. The chemical signature reflects the volcanic origin of the aquifer lithology.

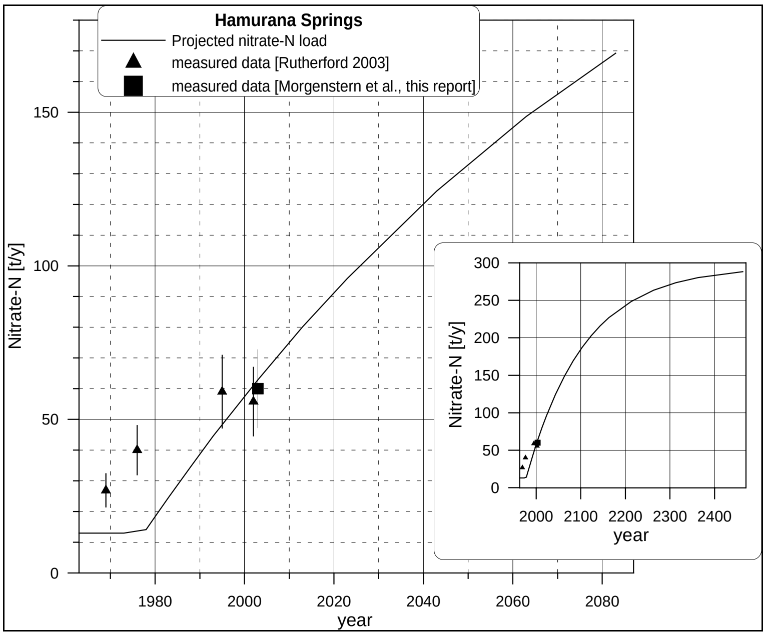
This study involved age dating of springs and groundwater wells to assess how long it takes for nutrient-enriched groundwater to travel from pastoral land to springs and streams, and to the lakes. Most of these groundwaters are relatively old, with mean residence times over 60 years.

Trends in hydrochemistry indicate that only three analytes, nitrate (NO_3-N), potassium (K) and sulphate (SO_4) are impacted by land-use intensification. These analytes all have increased concentration in young groundwaters.

Total Phosphorus is very low in young groundwater (<0.04 mg/L), but increases with age and with reducing young water fraction. Total Phosphorus is considerably higher in the oldest groundwater (1.3 mg/L). This demonstrates that phosphorus does not originate from land-use practises but is naturally leached from the volcanogenic aquifer material. Therefore, no changes in phosphorus loading to the lakes can be expected.

The nitrate concentration is significantly higher for water recharged after land-use intensification. The natural background level of NO_3-N (before land-use intensification) is assessed to be 0.15 mg/L, and the current recharge level to be 2.7 mg/L. Therefore, 94 % of the NO_3-N in the young groundwater is derived from the land-use in the catchment. This is an increase by a factor 18 above natural background.

The following loads of phosphate and nitrate were calculated from a mass budget for the five springs: The current phosphate load is 13 t/yr, and this is expected to stay constant because it is naturally occurring. However, the current load of nitrogen NO_3-N is 149 t/yr, and this is expected to increase to 476 t/yr once steady state is reached. The expected increase for Hamurana Springs, the main contributor, is shown below.



Dramatic increases in nutrient load are expected in the future for the large old water fractions. Land-use impacted water carrying high nitrogen loads (NO_3 is the major nitrogen component) will increasingly discharge into the lake as the old pristine water is depleted. The current total nitrogen concentration of Lake Rotorua is 0.45 mg/l. Some major springs already discharge water to the lake with 0.7-1.4 mg/L NO_3-N. These are expected to increase to about 3 mg/L. The nitrogen concentration in the lake is therefore expected to increase significantly.

TRANSCRIPT (edited, no graphics available)

Abrief outline, I will first talk a little bit about the problem and give a little bit of information on hydrogeology in the Rotorua area, then I will give some explanation of how we assess the age distribution in ground water. Because this is a very new development, I will have to spend a bit of time on it and also will have to become a little bit technical. Then I will demonstrate how we can get out time trends in ground water chemistry and lastly I will show how we can project future contamination releases from the ground water system.

The problem as we have heard already is that nutrients are the key for cyanobacteria growth and in the Lake Rotorua area we have degrading water quality because of increasing nutrient release from ground water systems. It's demonstrated **in** data from Russell Cort report. We clearly see that nitrate concentrations have risen over the decades now. The Rotorua catchment was developed in the 1940s and at that time there was not much impact on the groundwater quality, but only in the last decades the nitrate levels have risen considerably despite the fact that there was not much change in the catchment development.

So this strongly suggests there is a delayed impact of land use to the lake water quality and what we need to know now is what is the link between land use and lake water quality, and the link is clearly the ground water. Nutrients from land use enter the ground water system with rain and they travel with the ground water toward the lake. We have already done some isotope studies decades ago and we know that there are large time constants involved here. This means that the arrival of nutrients to the lake will be delayed by decades. Ground water distance is a key component in the understanding of transport of nutrients from farms to the lake, and the question is now how will this develop in future, so when will we reach a steady state and at what level with a steady state be reached? We need accurate age information on the water to assess these things.

The study aim was to assess the past and current state and the future trends in ground water and surface water quality, so what we did was basic hydrogeology. We have measured a whole suite of hydrochemistry, we have assessed the ground water age distribution and we have modelled the data into time trends for water quality. First to hydrogeology, the Lake Rotorua catchment consists of highly porous aquifers, of permeous and volcanic ashes. The data which I will present is mainly from the western part of Lake Rotorua which was an initial study that we did last year. There is more work currently going on which includes all major ground water and stream water flows around Lake Rotorua.

The cluster analysis shows here that in this area most of the waters have a very uniform chemistry and that means the time trends which I will present are not masked by different materials. The map shows clearly that the ground water flow is toward the lake and I want to demonstrate the problem. We have rain discharge into the ground water system and at some stage contamination happened or started, and this time the ground water travels towards the lake and also the contaminant plume will travel with the ground water. The problem here is if you are monitoring the chemistry or contaminants in surface and ground water, then if large time constraints are involved here, ground water contamination can happen over long periods of decades without recognising them, because what comes out here can still be old pristine ground water which is not yet contaminated, but over time this contaminant will build and the contaminant loads will increase in the future.

These are a few ground water models which are mixing model which means, sthat for a particular well, water which has very short travel distance gets into the well, but also water which has a very long travel distance, so that means any ground water is a mixture of different ages. A different model, more or less the upper extreme,. is a piston flow model, where only water with a very narrow age range occurs, because the water is more or less flowing along the piston flow, so that would be a groundwater with a very narrow recharge area or a river recharge ground water system. Fully mixed model, also called black box models, use piston flow system based on the two extremes which of course never happen in nature. In nature something will happen between the two extremes, that's why we are using a combination of the two models which is the exponential piston flow model and what we need to know now is what flow situation we have to apply to this area here, which means we need to eliminate the black box.

How can we do this? What we need is to put a tracer through the ground water system, a pulse-shaped tracer and by measuring the time delay on the output and the dispersion of a

pulse, we can accurately measure the age distribution of the water and also the mean residence time. There is such a tracer available which is Tritium. Tritium is naturally produced; we see tritium in the rainwater of New Zealand, and this shows us the natural level of tritium. In th*e* early 1960's we know that there was a nuclear weapon testing period and large amounts of tritium were released into the atmosphere by atmospheric test bombs, which increased the tritium concentration in rain significantly. Ssince the tests in the early 1960's, tritium concentrations have fallen. So we do have such a tracer available to illuminate the black box and the good thing is that this tracer is a hydrogen isotope, so it's an ideal tracer for the water cycle.

We need to have measure the output concentrations several times to accurately assess both unknowns. If we take the tritium concentration in rain and if we apply ground water models of different mixing, there is a residence time of 20 years for these curves here. For 20% mixing, 50% mixing and 80% mixing we have different outputs. For residence times of 40 years we would see different outputs and we can clearly see that if we have data in this time we can clearly measure the different age distributions. But of course we see that all the data are converging, that's why we need to look with high resolution here. So that means if you have enough accuracy then we still are able 30/40 years after the bomb time to assess accurately age distributions. So this was the theory - how does the tritium now move through ground water systems in reality? I will demonstrate a few data here from different New Zealand areas. This is Hutt Park aquifer in the Hutt Valley. We have a lot of data available here in the early 60s and we see a mixing model of only 50% mixing. This 3.5 year mean residence time can very accurately model the data, which means that the age distribution of this model does really reflect the real conditions. For some different wells, again in the Hutt Valley, we have data from the early 70's and from just around year 2000. Again we can very accurately assess the age distribution which would be for 25% mixing, with 21 year residence time. In a different well which is more on the margin, 45% mixing and 30 years.
Looking through a few more ground water systems shows that with a piston flow model you can get quite a good match with real flow situations throughout New Zealand. For a few wells from Napier, again, different mixing fractions and mean residence time in the range of 15-30 years and also one other water of 115 years. This is Hastings District Council; these are a few wells from Canterbury plains, a relatively young water of 22 years mean residence time. This already has a higher mixing fraction and one quite old water of 130 years. So we do now have a very accurate clue to establish not only the mean residence time of ground water, but also the mixing fraction. I presented this methodology last week in Paris at the International Conference of Isotopetology and I got confirmation there that there is a world-wide need for such accurate understanding of ground water flow situations.

By applying these methods now to the Rotorua area, we already have data here (this is mixed flow) and it shows that in the Rotorua area we have very high mix fractions, which means around 90%, so these are mostly confined ground water flow situations where we do expect less mixing which means more piston flow. But for the Rotorua area we have unconfined aquifers with high storage capacity, so they and the isotope data confirm very well that we do have high mixing fractions here. These are our first data from the Rotorua area. We have ground water mean residence times of 30 years up to 170 years in this area. Related young water fractions here show that young water means water which is younger than 40 years, and we chose 40 years as a time because we believed that 40

years ago was the major increase of development in the catchment. So that fraction tells us how much water could be already influenced by land use.

We see that there are waters with very little young water, which means these waters still reflect the original conditions of the pristine old ground water. I have demonstrated before in the Rotorua area we have a very narrow range of mixing fraction. That's why we can plot the data against mean residence time and what we see here is, this is sodium phosphate, silica and fluoride. So these species do quite clearly show an increase over time. Especially also important here is phosphate. Phosphate is very low in young waters but does increase in residence time, also the silica and fluoride. So that means all these species do not show increased levels in the young area, so that's why they are not anthropogenically influenced, they are not influenced by land use. These species are magnesium, calcium, carbonate and fluoride. They are nearly constant which means they are not significantly influenced by anthropogenic effects. Once they are able to enter the ground they equilibrate very quickly and do not show any change over time. But these others are the kind of species which do show an anthropogenic impact which means higher levels at a young age. They are potassium, nitrate and sulphate. What I did here was to plot the data with this young water fraction because there should be a linear relationship between young model fraction and the contaminant concentration and we do see such trends.

From these linear trends we can now establish the natural conditions which means the conditions for water not influenced by land use. The natural level for potassium would be about 1 mg/litre and by extrapolating to age zero we have about 4.5 mg/litre which is an increase of about 3.5. We can see clearly that phosphate is not anthropogenically influenced and shows very low concentrations at a young age, which means less than 0.04 mg/litre. With an increase in age, which means an increase in time of reaction, more and more phosphate is leached into the sea at levels up to 1.3 mg/litre. The last one is nitrate, the natural concentration is very low, 0.15 mg/litre, so the very young water which is getting into the ground has a concentration of about 2.7 mg/litre which is an increase by a factor of 18.

We can now use the age data to establish how much of the water is from a time before land use change and how much of it is from the time after that land use change, and then we can extrapolate into the future. From the sudden arrival of nutrients from the contamination plume we will see an increase over time and we can extrapolate this increase. The increase for the nitrate shows we will have quite a significant increase in the near future, which will level out in a few hundred years to about 200 mg/litre. Tthis is an ongoing project, and we are producing this data now for all the major ground water flows toward the lake.

So just to summarise, we have the hydrogeology here which is characterised by highly porous, deep and confined water and relative activeness. The hydrochemistry is characterised by lower calcium, magnesium and sulphate and higher phosphate and silica carbon situations in relation to other New Zealand aquifers. This is related to the aquifer unit and we can use the data to accurately assess the age information and age distribution on this aquifer. The impact of land use is delayed by decades and in general the ground waters have a residence time higher than 30 years. The nitrate, potassium and sulphate are elevated in young waters which means they are influenced by land use. The nitrate has a natural level of 0.15 mg/litre and the current level is 2.7, which means an increase

by a factor of 18. With more and more arrival of nitrate which is already in the ground, we will have to expect an increase of nitrate in the future which will be in the order of factor 2. Total phosphate in the young water is very low but in old water is high, which means it is not anthropogenically impacted which means we do not expect any change in the future.

QUESTIONS
Jim Gray, Tikitere Trust: Development in terms of optional land use is being investigated in the Taupo catchment, which is undergoing the same problems. I have a belief in mankind that everything has been put on this earth by the good Lord for the benefit of man, and I'm asking whether any research has ever been done on the algae and toxins to see whether there is commercial value, say. We may be sitting on a gold mine and don't know it.

Chair: Your question was to do with the commercial value of the algae? I think we might defer that question to the general discussion on Friday.

John Green, LWQS: What you're saying is that there's going to be an 18-fold increase of nitrates coming in from Hamurana Spring. Is it possible to be able to drill down into the aquifer and to be able to deposit another anti-chemical to neutralise the nitrate?

U.M: We are talking here about large volumes. For example the water storage capacity behind only Hamurana Spring is about 5 cubic kilometres, so we are talking here about dimensions where you can't really do anything. You also mentioned an increase by a factor of 18 – this factor is not (I just want to clarify here), we do not expect an increase in the lake water quality from now in future by a factor of 18, because a lot of contaminated water is already here so we do already see some. But the factor 18 is between the old, the very old pristine condition which was 0.15 mg/litre and now in the young water we see 2.7. So the extrapolated increase of nutrient loading toward the lake is in the order of factor 2.

Critical nutrients; nitrogen, phosphorus and algal growth in Lake Rotorua

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ABSTRACT
Nutrient enrichment has been implicated in significant changes in the water quality of the Rotorua lakes over the past 50 years, particularly Lake Rotorua itself. These undesirable changes can be summarised as an overall increase in phytoplankton biomass and a switch from a composition dominated by diatoms and green algae to one where proliferations of cyanobacteria (blue-green algae) are frequent. Attempts to reverse this decline by reducing the external loading of nutrients to the lake have had mixed success in meeting target in-lake concentration. During the 1990s, following sewage diversion, there were initial improvements in water clarity, nutrient and chlorophyll-a concentrations, but since 1995 the picture has deteriorated once more. Evidence has shown how a recent increase in the N loading from pastoral streams is compensating for much of the reduction in N loading achieved by sewage diversion.

In this presentation we review and summarise historical and recent information on the nutrient status of Lake Rotorua. We summarise the dynamics of nutrients in lakes, and compare these in lakes Rotorua and Taupo, highlighting the importance of internal loading in the latter.. We address the issue of N or P limitation, and the importance of N:P ratios. We note the importance of understanding the speciation of N and P in the lake, the difference between growth rate and yield limitation, the importance of nutrient availability relative to growth rate in understanding nutrient limitation. We argue that for N and P to become limiting the concentrations in lake water of dissolved reactive phosphorus and ammoniacal nitrogen needs to return to historical low levels, of 1-2 mg m^{-3}. We argue that nutrient concentrations in Lake Rotorua are at times now so high, that growth rates can be limited more by light than N or P. We review the physiology of algae and cyanobacteria and summarise how the environment of Lake Rotorua has shifted to favour performance of the latter over the former. Significant and sustained reductions in loads of both N and P appear to be required before the lake can begin to return to its historical quality. Our expectation is that, even so, internal stores of N and P are such that water quality improvement will be a decadal scale process.

TRANSCRIPT (edited, no graphics available)
It's nice to be here on behalf of the NIWA team This presentation is very much a joint effort, but cabinet responsibility doesn't apply and this is my personal view. I'm going to talk quite generally here as introduction to a lot of the talks which I think are going to come later in the session.

I'm going to focus on Lake Rotorua and I'm going to cover some of the ground that we've already heard this morning and you will hear similar concepts expressed in slightly different ways, which is sometimes helpful. You will also hear what may sound occasionally like differences of opinion, but don't worry about that, that's quite normal. My talk will focus around a series of key questions which I took out of the information that came prior to this meeting starting, and these key questions are here. A lot of talk

about nitrogen and phosphorus, about limitations of growth rate, about limitations on biomass. The issue of trace elements has bounced around a few times and I have some information to give you about that. I'll talk a bit about the internal load, again it's a very important topic that we need to discuss a lot and again, echoing some of the things we've already heard this morning, focus on why it is that cyanobacteria seem to be particularly prolific in these lake systems.

Before I go much further, I just want to explain why it is we get so hung up on nitrogen and phosphorus in the biological world and it's because a lot of the key biochemical compounds that make up organisms require significant amounts of nitrogen and phosphorus in their biochemical structure. Things like proteins which are the drivers of most processes in cells, require a lot of nitrogen. Nucleotides which are the energy currency of cells, require nitrogen and a lot of phosphorus in nucleic acids - that's DNA, RNA, those things that you have to have to be able to grow fast and reproduce. They all require a lot of nitrogen and phosphorus. So that's really just a background as to why it is we get hung up about it.

A corollary of that is that in algae, the ratios of those three elements are obviously going to vary according to the composition of those cells, but there's a large extent to which because those essential biochemical components are essential and they have finite bounds, those ratios only vary within a certain finite degree. Of course we've all heard about nitrogen and phosphorus accumulation in internal storage. When there's plenty of nitrogen and phosphorus around, all algae have got an ability of some sort to take them up and hang on to them for later use.

An other corollary of the previous slide is that if you're going to grow fast you need lots of enzymes, you need lots of nitrogen, you need lots of energy, you need lots of DNA and RNA, so you need lots of phosphorus. So if you're going to grow fast you need plenty of nitrogen and phosphorus. If you haven't got plenty of nitrogen and phosphorus you're going to grow slowly and that's just the way it is. If you're growing slowly because you've got low nutrients, you're probably going to have an abundance of carbon but low nitrogen or phosphorus concentrations. So these carbon, nitrogen and phosphorus ratios varying within those finite limits are indicative to some extent of the nutrient supply relative to the demands of growth. So they're informative and they're useful and they vary, but within finite limits.

Trace elements – we're talking about iron, molybdenum, manganese, magnesium – are also really important and they're essential parts of most cells. For instance iron is really important in the electron transport chains and you can't fix nitrogen without molybdenum and iron. Those trace elements are essential components, so they've got to be there as well as nitrogen and phosphorus.

So first key question: does nitrogen or phosphorus limit the growth rate? I'm going to focus on Lake Rotorua. Generally our perception is that growth rate is related to nutrient concentrations within the cells (and I stress that we're talking about the concentration within the cells), so that's those nitrogen and phosphates which are bound up in those biochemical components we just looked at. The typical sort of relationship that we get is a minimum concentration, a maximum growth rate, maximum nutrient- limited growth rates – so when nutrients are limiting these are the growth rates you can expect. A

minimum content of cells is the absolute smallest amount of nitrogen or phosphorus or something else that cells have to have just in order to keep themselves going.

There's a saturation rate above which you can have more that's going into the storage pool, but it's not going to allow you to grow any faster because at this stage your potential growth rate isn't being limited by the amount of nutrient your cells contain.

That's just a bit of background. A useful thing to know would be how much nutrient content we've got in our cells growing in Lake Rotorua relative to these critical values of saturation, where for any more phosphorus or nitrogen there will be no increase in growth or our minimum which determines our point at which no further growth can occur. That would be a useful thing to know. Can we actually get those sort of numbers for Lake Rotorua? It's an indirect approach and the approach that I'm going to use is some bioassay data from the early 1990s which is the best data I think that I know of for beginning to address those questions.

Justin talked a bit about bioassays, and essentially what we do with this type of approach is we take a sample of lake water and we might add nitrogen to it, we might add phosphorus to it or we might add nothing to it, in which case we have our control system. We do something to it for a few days, and the conditions that we apply during those few days is actually quite important to the outcome of the experiment. That's what makes bioassay experiments often quite difficult to interpret. But essentially we incubate them under what we hope are favourable conditions and if we find at the end of our incubation period that the part we don't add any phosphorus to has turned bright green, a lot of algal growth, it's an indicator that under those growth conditions shortage of phosphorus was unlikely to be limiting growth in these other treatments.

The sort of array that we have are these various combinations of treatments. Justin talked about those. We add nitrogen, we add phosphorus, we add nitrogen-phosphorus, sometimes we add nitrogen-phosphorus-trace elements because we're worried about this possibility, and then after 4 days we measure these various things within the experimental bottles. And the only thing that's ever been reported from these experiments is what happened after 4 days and the conclusion that was made was that most of the time nitrogen limited growth under the conditions that we applied.

But there's a lot more information in those experiments that I'm going to work you through and try and get some of these critical indicators off nitrogen and phosphorus sufficiency in cells within the lake. We're looking at nitrogen and phosphorus. PN is particulate nitrogen, that's essentially the nitrogen that's in the phytoplankton cells within the water sample, nitrate and ammonium. At the start of the experiment and in the control those nitrate and ammonium were at very low concentrations. There's also organic nitrogen which is a name that covers a multitude of things, but it's nitrogen that isn't any of those other things. It's not nitrate and it's not ammonium; what it is we don't really know.

We've got similar considerations for phosphorus. Particulate phosphorus in the cells, reactive phosphorus (almost the same as filterable reactive phosphorus), dissolved organic phosphorus too. After 4 days of incubation in the control situation nothing much happened. If we add nitrogen (representing the times of year that we've got all this extra nitrogen) as ammonium, that ammonium is very rapidly taken up over the first four

periods and it appears straight away in the phytoplankton in this particular fraction. So essentially we've got a direct transformation of ammonium through to phytoplankton. Phosphorus, the dissolved reactive phosphorus, has started to decrease slightly here and the particulate has gone up again, so we've transferred this phosphorus from dissolved reactive to particulate. We haven't touched the dissolved organic phosphorus and also we haven't touched the dissolved organic nitrogen.

What we can infer from those particular aspects of those experiments is that those field collected samples were taken straight from Rotorua. They contained dissolved reactive phosphorus at concentrations that can be taken up by those cells if they need it. The reason why I say that is because as soon as we added nitrogen, then the phosphorus was taken up, but if we didn't add nitrogen it just stayed, it wasn't used. It was available but wasn't used, and that's an important point. It suggests that our field-collected samples are full of phosphorus. They've got all the phosphorus they need at that time, but if there's nitrogen supplied then their internal pool goes down a little bit and they start taking up a bit more. Our field-collected samples take up dissolved inorganic nitrogen which is our ammonium and nitrate. They take them up very rapidly if it's supplied, but at the concentrations that were present in our field-collected samples they were at the limits of the amount they could take up. There was no more they could take up, they were already as supplied as they could get.

So another inference we can make from those data is that when we collected those samples the amount of dissolved inorganic nitrogen in the water was at the limit for uptake by those cells. Plenty of phosphorus, not so much nitrogen. If we add phosphorus to those same experiments, what you can see is that nothing really happens. The phosphorus that was present when we added nitrogen still stays there. We add more and it still pretty much stays there. It reinforces our view that those field- collected samples had plenty of phosphorus but they were a bit short of nitrogen. We know we've got ample phosphorus here, but we still haven't touched any of this nitrogen which is dissolved organic nitrogen, so once again that kind of leads us to the conclusion that the dissolved organic nitrogen is largely unavailable to phytoplankton growth.

So the really important parts are the particulates (nutrients) which are in the phytoplankton and the dissolved inorganic N and P which is the stuff that they can actually get their hands on when they need it. If we add nitrogen and phosphorus, and here I'm comparing the plus nitrogen plus phosphorus treatments, we get more of the same. Again we take up all of that nitrogen at pretty much the same rate and once again we take up all of the extra phosphorus we've added and it all gets converted to particulate nitrogen and particulate phosphorus. Just summarising some of those conclusions and looking at trying to get a handle on the important concentrations and targets and numbers that we need to keep in our minds for these lakes. When they have plenty of nitrogen they took up dissolved reactive phosphorus down to less than 2 mg/cubic metre of concentration.

So an inference from that is that in our field situation, if we've got dissolved reactive phosphorus of more than 2 mg/cubic metre then it's not unlikely that there's plenty of phosphorus available. When we apply phosphorus in excess the ammonium and the nitrate both went down to less than 3 mg/cubic metre. Our inference is that if you've got 5 mg/cubic metre or more of dissolved inorganic nitrogen the cells have got plenty, that's

well within their capability to take that stuff up. You will see where we're going with this shortly.

Using this data we can also look at the internal nitrogen and phosphorus concentrations inside the cells. What we're looking at here is the particulate phosphorus to particulate carbon ratio expressed as a percentage and what we're looking at here is the bio-assay response, the growth increase in terms of carbon increase over our 4 day period in response to giving these cells more phosphorus. What you can see basically is that there is no response. Number one is relative to the control, one means no change. So what we can say there is that if we've got a phosphorus to carbon ratio within our cells of 1 or more, then they've got plenty of phosphorus in their cells for growth. We can do a similar thing for nitrogen and we see a slightly different plan, We've got very much of an increase here, a break point of around about 10 to 12% nitrogen as a component of carbon and if we're above those critical numbers, then we can add nitrogen and we don't get an increase in growth. Below that number we add nitrogen and we do get an increase in growth. So these are beginning to home in on some of these critical numbers of concentrations and contents which are determining whether or not phosphorus is limiting under field conditions.

We can also go on to look at the relationships between external nutrient concentrations, dissolved reactive phosphorus concentration in this case and phosphorus content and storage. Here we're looking at the particulate phosphorus response to adding phosphorus. So what we're saying there is that if these cells are short of phosphorus. then when you give them some they'll take it up fast. And indeed what we find is that below a concentration of about 4 mg/cubic metre we begin to get in a situation where the cells would say, okay there's some phosphorus, thanks very much, I'll have some of that. Above that they've got plenty. Looking at the same deal in terms of ammonium it's not quite such a nice plot as the phosphorus, but here we're looking at the cells' tendency to take up nitrogen when it's offered in relation to how much is actually sitting outside the cells. And once again we're getting a situation where until we get down to quite a low concentrations, around about 5 or 6 mg/cubic metre, then we're not getting any real response from the cells to giving them more nitrogen. It's a similar situation for nitrate, a similar sort of concentration of 2-3 mg/cubic metre.

So what I'm going to suggest is that these give us a handle on what the critical nutrient concentrations are, both in the water and in the cells themselves. If we've got dissolved reactive phosphorus of more than 2 mg/cubic metre or inorganic nitrogen of more than 5, we've got a pretty healthy supply relative to the demands of growth under our growth conditions. If we've got 4 mg/cubic metre of dissolved reactive phosphorus, we have a concentration which is enough to support surplus phosphorus accumulation and with dissolve inorganic nitrogen, the same for nitrogen. Tfor the internal concentrations inside the cells, if we've got a particulate phosphorus to particulate carbon ratio of about 1 to 100 we've got plenty of phosphorus, phosphorus isn't limiting growth rate. Similarly for nitrogen – the indication is that if we've got a particulate nitrogen to particulate carbon ratio of 1 to 10, this is indicative of ample nitrogen.

Now the last inference here is that if phosphorus is limiting, because the internal concentration of phosphorus is low, the nitrogen-phosphorus ratio of the algal material, that's the particles, is going to be greater than about 10. If it's less than about 10, then we're probably expecting that nitrogen will be less available for growth than phosphorus

inside the cells. Kit Rutherford has assembled a whole lot of water quality data from Lake Rotorua and we've added a few more bits of data that we found.

Looking at when those critical concentrations over the period from 1967 through to 2003 were approached or met, there is a zone of criticality where within or above this zone we've probably got plenty of phosphorus to support growth and below it we're in the situation where we can expect there to be a limitation. This applies for DRP and for ammonium. So I'm suggesting that historically we were in a situation when DRP phosphorus was not infrequently at concentrations which were limiting to growth.

Certainly in the 80s and early 90s we never got to that stage, there was always plenty of phosphorus left in the water column. After the diversion of the sewage effluent in about 1991 we had a period when we dipped down nicely occasionally, but we still had plenty available at other times. In recent years it's a bit more difficult to say, but certainly the situation is that we've had low concentrations indicative of rapid uptake and potential limitation. We've also had high concentrations and the same applies to ammonium. Nitrate is similar. There's less nitrate available than ammonium, but we're getting an increase over the sewage years, then a decrease and perhaps a slight increase now.

What about those critical internal ratios, do they tell the same sort of story? I've plotted those ratios for the only period we've got good data for which was between 1988 and 1994. The green line marks the critical numbers and I've adjusted the scale such that all of the ratios have the same critical value. The red is phosphorus content relative to carbon. It's almost always higher than that critical ratio, so almost always we can expect phosphorus not to be exerting a strong limitation on the rate of growth. After 1991 nitrogen also it dipped down a little bit getting back into those nitrogen-limited conditions, but certainly during that 1980's period the nitrogen concentration was pretty high in those cells, at levels which we would associate with a healthy nitrogen content. The nitrogen to phosphorus ratio has always been low throughout that period, 5 to 6, which supports our view that this is an unusual situation in which nitrogen is often limiting as well as phosphorus, potentially.

One thing that often gets discussed, particularlyrelevant to of Uwe's recent talk about the increase in nitrate load to come, is whether we can engineer a situation where we take the lake to a phosphorus limited condition away from its current apparent prevalence of nitrogen limitation.

I would start out by saying that at the moment there's plenty of phosphorus available and it seems to be mostly in excess of growth requirements. What we need to do is to get that C : P ratio up well above 100 and our DRP concentration down to 1 mg/cubic metre or less, in order to achieve that phosphorus limitation. Based on a quick analysis of the total phosphorus/ dissolved reactive phosphorus relationships, we need to get our TP down to around about 20 mg/cubic metre or less in order to achieve phosphorus limitation which is basically a halving of the current condition that carries on to at least a halving of the phosphorus load in order to achieve that situation.

The next one I am going to talk about is nitrogen or phosphorus and biomass. Growth rate is subtly different to biomass and Justin's already talked about that. A lot of the preoccupation with biomass limitation dates back. The approach that they took then was a real leap forward in limnology because it was trying to look for the unified theory of

life, the world and everything in terms of lakes. They did a really good job at the time in linking the phosphorus loads with phosphorus concentrations, and phosphorus concentrations with chlorophyll production. But there have been a few problems with these sorts of relationships where they have many lakes and look at the phosphorus loads and the chlorophyll production. These are pretty good if you're quite careful about the lakes that you select.

One of the problems with Rotorua if we think about that one is that over time we have seen changes in total phosphorus, total nitrogen and chlorophyll and there are the mean annual concentrations of those variables. We can see that total nitrogen was increasing up through to the 80s and then levelled off a bit. Total phosphorus looks like it might slightly go down a bit, chlorophyll's following that sort of pattern, but if you look at the relationships between them, it's not great. Total nitrogen and chlorophyll, again it's not great it's a little bit unconvincing as a relationship.

So I want to take the focus slightly away from the classical load chlorophyll response and talk a bit about capacity limitation, which basically says that our biomass or our final yield of algae becomes resource limited when the availability of that resource is insufficient to maintain their growth.. It means that if you can't grow fast enough to counteract what you're losing somewhere else to grazers, to sedimentation, to outflow, then your biomass is not going to increase. Now our problem here is that when we looked at those nutrient situations, the picture that I was painting, based on data that we have, was that for most of the time phosphorus and for at least quite a lot of the time nitrogen, were unlikely to be constraining growth rate. So we haven't got a restriction to our growth rate imposed by those nutrients and yet this says that our nitrogen and phosphorus capacities weren't being met.

So there may well be something else that's kicking in here which confuses things. This is taken from one of Colin Reynolds' publications where he discusses the use and abuse of the OECD type of models. His suggestion, which is a totally logical one, is that a lot of the time where we have phosphorus yet it is limiting our capacity to grow, the type of relationship that we expect between phosphorus and chlorophyll holds really well, and as we increase phosphorus, that will be fine until we reach a stage where something else begins to limit our capacity. In this case it might be nitrogen, or it might be light, and so instead of taking the trajectory which would be our phosphorus-defined trajectory, we're taking our nitrogen-defined trajectory and our light-defined trajectory.

You can see that now we're beginning to get a lot of scatter around this overall phosphorus/chlorophyll line. So is it possible that we're in a situation where some of these wild card things are actually important in these lakes, and maybe one of those is the possibility of light-limited capacity? The problem is we don't have really good light data covering a long period of time in these lakes. What we do have is good data on the clarity of the lake and the chlorophyll concentration, so I measure our phytoplankton biomass.

What I hope you can see is that there's certainly a correspondence between changes in chlorophyll and changes in water clarity. Water clarity is expressed in a slightly odd way in that it's expressed along from a zero to minus 4, so down here we can see 3 metres into the lake,. up here we can see 2 metres into the lake. This is low clarity associated with higher biomass and high clarity associated with low biomass down here. What we're looking at is a potential density stand-off mechanism and I say that because the higher the

density of phytoplankton, the greater the degree of limitation of growth because the more phytoplankton there are and the darker the water is, the less light there is available for growth. So we're increasing our possibility of light (being a factor).

We don't have good light data and that's a problem, but we can use a bunch of relationships that are fairly well established to estimate how much light we're getting within the lake. The number to look at here really is this 10 to 15 metres and that's an approximation of the mixed water column depth to which eukaryotic phytoplankton occur. And we mustn't forget that we don't have problems just with cyanobacteria, we have problems with proliferation of other algae as well, We think that eucaryotic phytoplankton (that's non-cyanobacteria), can sustain themselves to a depth of about 10 to 15 metres in Lake Rotorua. So a suggestion there is that certainly for the eucaryotic phytoplankton we could be put in a situation where light is potentially a factor influencing growth rate, because of the high biomass of phytoplankton. Some species of Cyanobacteria can handle much lower light intensities, and the critical max depth for them may be closer to 30 metres. So with the situation there don't look on it as a factor that can't affect cyanobacteria, but look on it as being another factor which is promoting cyanobacteria relative to other types of phytoplankton.

Carbon dioxide – that's an interesting one. We think of carbon dioxide as being universally available. It comes from the air, we breathe it in and we breathe even more of it out. And lakes exchanging gases with atmosphere usually have got plenty of carbon dioxide, but it's not always the case and Rotorua is unusual.There's about a quarter of the dissolved carbon in Rotorua than there is in Lake Taupo for instance. The reason for that, Mike Timperley our chemist assures me, is that the acidity of the geothermal water is actually titrating a lot of the carbonate out of the water, so the sulphuric acid that's coming in via geothermal inputs is largely responsible for the low carbon concentration. I notice concentrations are close to concentrations overseas that have been found limiting to photosynthesis. Maybe the university is going to tell us later on in the next two days, whether those have been repeated recently in the Rotorua district and if so, I would be really interested to hear about them. Look on this next point not so much as a reason why it's a growth limiting factor, but there's another reason why cyanobacteria can out perform other algae - it's pretty well known that they have mechanisms for concentrating carbon dioxide within their cells so that they can actually perform really well at low external concentrations.

Trace elements are key components of bio-chemical systems but they are really hard to measure in a way that is actually meaningful, because often you can have a higher concentration in a fresh water system but it is all tightly bound up with those dissolved organic materials that are floating around, so you can measure it but it might not be available. The best thing I could offer are the results of the bio-assay experiments which show what happens to growth over time if we add nitrogen and phosphorus and what happens (very little) if we add trace elements as well. So I suspect that trace elements may be something that could bear a further look at, but they don't really wave themselves as a massive red flag at the moment.

, Justin talked really well about the internal load so I'm not going to go on about that a great deal, but I want to stress that of the nutrients that enter the lake, nutrients that enter Lake Rotorua for instance – only about 20 to 30% of those that come in ever go out via the Ohau Channel. The rest of it stays in the sediment and some of it get degassed.

Nitrogen gets degassed into the atmosphere as nitrogen gas. It enters the sediments and once it's in there it's freely available to return to the water column and promote more growth, which may then settle out again, so it can actually go through that cycle in the lake many times. This is the problem of internal loading, which is one of those things that tends to delay response to load reduction because of that big pool sitting inside which keeps coming in and going out of the sediment.

What I want to stress here is that there are two types of sediment release. There's sediment release that occurs under oxic conditions, when there is oxygen present and what that tends to do is generate ammonium, for instance, within the sediments, but in the oxygenated surface layer of sediments that's largely converted to nitrate which then goes into the water column. So we're getting nitrate and we're getting phosphorus released through the bacterial and protozoan breakdown reactions and they are released into the water column as nitrate and dissolved reactive phosphorus. Because they're the product of cellular material, the ratios of these two are often very close to the ratios in that cellular material.

I'll give you an example of that from Lake Taupo which is always oxic, always oxic release. Here after stratification in August, nitrate increases very quickly and DRP is increasing. Also almost all of the dissolved inorganic nitrogen that's accumulating over time in this oxygenated deep water layer is nitrate, and the relationship between the nitrogen production and the phosphorus production is around about 5 : 1. It's pretty consistent with the kind of ratio that we see in biological materials.

When we get anoxic situations we have the possibility of chemical release of phosphorus into the anoxic water. We get primarily ammonium being released as opposed to nitrogen. There's no oxygen to form nitrate so the products of anoxic sediment release are ammonium and lots of dissolved reactive phosphorus not necessarily in those bio-chemical ratios.

So what we would suggest is that accumulation of phosphorus and ammonium in the water column, less so nitrate, is certainly an indicator that these are products of internal cycling. In Rotorua again, over a period from 1980 through to 2000, there was a lot of phosphorus, a lot of ammonium, less nitrate than ammonium. Nitrate, remember, is coming from oxic sediments, ammonium is coming from anoxic sediments. The relationship between ammonium release and phosphorus is anything but that kind of nice tight bio-chemical sort of ratio and in fact this is one of those famous log log scales. There's an old ecological adage, if you don't get a straight line with a log log scale then your data has something terribly wrong, but there's no straight line in this example at all. So there's no relationship there between the phosphorus concentration and the ammonium concentration.

Summarising quickly on that internal loading issue: The presence of lots of reduced species, particularly ammonium, is indicative of recycling processes associated with anoxia much of the time. We suspect that the sediment quality in Rotorua is really low at the moment. It's quite likely that the surface is always close to or at anoxia and therefore we're getting a lot of this internal loading occurring. I would suggest that we may actually be considerably underestimating that load.. It was particularly high during the 1980s and early 90s according to the ammonium concentrations that we saw.

Why is it that cyanobacteria are proliferating? Justin again did a really good job of highlighting some of the reasons why cyanobacteria proliferate under natural conditions. It's really important in the Rotorua case because we quite often stand up here and say there's evidence that things are getting better. Looking at the annual cycle of chlorophyll concentration, by taking all the numbers we've got between 1960 and 1970 and expressing them as their fraction of a year, we get a a late summer biomass maximum deoxygenation. A classical sigmoid cycle fits this curve. In 1970 to '80 the curve goes a bit higher, with higher concentrations, but it was in the 80s and 90s that things got really wild and there were really huge concentrations of chlorophyll happening in summer and in winter. We looked at the 90s to the recent data and it seemed like it was getting better, particularly after the sewage diversion. It's quite hard to show those sort of data and yet the perception is, and it's the absolutely right perception, that the water quality is really bad. A lot of that revolves around the fact that we've had a major shift from a diatom of green-dominated phytoplankton community in the early years through to the prevalence of cyanobacteria, despite the fact that our concentrations of these nutrients and our light conditions in these lakes haven't really changed all that much.

Theses are the sorts of conditions in Rotorua that are really conducive to cyanobacterial dominance. When wee have a large amount of material in the water column it gives us those low average irradiance in the mixed water column. This light is green and low amounts of green light is something which favours cyanobacteria over other types of algae. We have got low DIC (dissolved inorganic carbon) and cyanobacteria are better at using that than other types of algae. We've got plenty of phosphorus, we've got a small amount of nitrogen. Cyanobacteria in some cases have that potential to fix nitrogen. Nitrogen fixation isn't the absolute kind of answer to growth in the high biomass conditions because it requires a lot of light as well. It's one of those light- requiring things and so it's not a panacea but it helps.

Cyanobacteria tend to have a higher ability to take up ammonium than other types of algae which often are better than cyanobacteria at taking up nitrate, but there really isn't any nitrate there. We've got a relatively shallow lake with sediments, and other deep reserves are in close proximity, and the possibility of cyanobacteria to move up and down in the water column potentially gives them access to that. Over the years we've built up a lovely inoculum of *Anabaena* and *Microcystis* in most of the lakes now, the inoculum is there, it's ready to go. And they like warm temperatures and the temperatures of Rotorua do get pretty warm. And it's probably a combination of all of these factors together, along with this issue of histeresis.

There was a really good review done quite recently by someone at Heinzstraten and some people from Europe, and they highlighted the probability that there are two sets of factors that affect cyanobacterial dominance. There are those that promote cyanobacterial growth in the first place and there are those attributes which sustain them once they are established. And those promoters of growth are these things like warm summer temperatures, the presence of a good inoculum and nitrogen and phosphorus available in plentiful supply. They promote the initiation of a bloom.

The resistance of cyanobacteria to grazing and their ability to avoid sedimentation, unlike other types of phytoplankton, are attributes that promote cyanobacteria becoming dominant over other types of phytoplankton. They also have the ability to tolerate low dissolved inorganic carbon and low light in the thick soupy scums, and their ability to

move around. These are factors that sustain dominance once it has been established. The nitrogen to phosphorus ratio is often associated with cyanobacteria, but it's more often associated a high biomass situation, which is usually due to a nutrient enrichment. Usually we enrich water more with phosphorus than with nitrogen, and so nutrient-rich waters throughout the world on average have a lower nitrogen to phosphorus ratio, because we usually put more phosphorus in sewers than we do nitrogen.

On a global scale it's true that thick soupy water is often associated with low nitrogen to phosphorus ratios and cyanobacteria are often associated with thick soupy water. So nitrogen to phosphorus ratio is a useful and meaningful thing, but I think it's really easy to overplay the significance of it. Things like the ability to move around and the ability to avoid grazing are probably at least as important in the cyanobacterial story. And I think one thing that we also tend to forget a little bit for the lakes of this district is the extent to which the whole eco-system has been pushed and shoved around over the years. If we think what these systems would have been based on a hundred years ago, there would have been no trout and there would have been no smelt, we'd have had a koura and koaro dominated system. Whereas now we've got a system that's dominated by smelt and by trout, and the impact that's had on the grazing dynamics over that time is something which I think we can only really speculate on. We've also seen the invasion of many species of exotic weeds and all sorts of attempts to control those using different methods.

So where to from here, how can we see light at the end of the tunnel? I think that as we said time and time again, the only solution is to reduce the amount of nitrogen and phosphorus going into these systems. The recent attempt to reduce nutrient loads through the sewage diversion, and it was a successful attempt, did show a response in terms of water quality, but now we've got a problem because the stream loads are increasing to counteract all the benefits that were gained from that, certainly for nitrogen. Patience is a virtue and it's a necessity too. The world's understanding of solving lake problems shows that nothing happens in a hurry and these whole ecosystems have been changed. You're not just turning off a tap and stopping something growing, you're pushing the whole eco-system in a direction in which you would prefer it to be, when in fact it wants to be different to that.

So these things take time and there's no overnight solution. Histeresis is this property whereby if you change something by taking an action and then you take the reverse action, it doesn't automatically come back along the same path that it starting out going along. In eco-systems there's a lot of resistance to change and any expectations that by reducing the phosphorus and nitrogen load back to what it was in the 1960s we will see the reverse pattern of changes to what have seen since then - they probably are not going to be seen out. But ultimately we will end up with a situation of improvement if we do manage to reduce the nitrogen and phosphorus in the water. It would be really useful to know a little bit more about that and hopefully we'll hear some of that over the next couple of days.

On climate, we often think a little about climate change and how that might affect the situation. In many ways stratification and warm water are really good if you're a cyanobacterium. We've looked at temperature records from quite a lot of lakes in the central North Island now and there really isn't a consistent strong signal of warming of water or any increase in stratification. So at the moment, any climate change effect has been really subtle. My final point is that cyanobacteria have been here maybe 3 billion

years and they are always going to be here. I would suggest it's going to be on timescales of a decade that we're looking at responses here. We can expect improvement but the risk of cyanobacterial blooms is not something that's going to go away overnight with management actions. Thank you very much.

QUESTIONS

Jim Gray, Tikitere Trust: I have this horrible feeling of guilt when I look at perhaps the human contribution. But the question is how much of this is a natural phenomenon, what percentage of this is part of the normal evolution of lakes moving towards wetlands and eventually moving towards dry land. Effectively we've heard a lot of comment in respect to what is happening, but if this is a natural phenomenon, it may be that our contribution is trying to push it uphill. And I'd like your comments on that, Sir.

I.H: What we are referring to here is that there's long been a view going around, I think, of natural eutrophication. The concept is that every lake from its moment of inception is doomed and eventually it's going to fill in with sediments and as it gets shallower and richer in sediments, then it's slowly going to become more and more nutrient-rich and it's going to turn ultimately into a wetland, but perhaps by way of a very different lake to what it started out with. My response to that is that there is a strong element of truth in that, but it's the time-scales that I think we need to keep in mind, in that there are natural eutrophication processes over thousands and thousands of years and of course every exact situation is different. But my opinion would be that the changes that we've seen over periods of decades in the Rotorua lakes are not consistent with the time-scales of natural change, so I would say we should stick our hands up and say that almost all of the change that we've seen is a consequence of land use and exotic species introduction.

Ian McLean, LWQS: Does the change in algal species that you mention over the last 10 years make any difference to the results of the N & P limitation in the early 90s. The second question is this: if in fact there is a very great difference between the technical feasibility and cost of reducing nitrogen as against phosphorus, it is possible to reduce the incidence of cyanobacteria by reducing phosphorus alone?

I.H.: I was concentrating so hard on the second question I might have almost forgotten what the first question was, but I'll start with the second question. Is it a realistic scenario to control cyanobacterial growth through phosphorus control? Ultimately I guess 'yes' is the answer to that. Approximately then the situation is unusual for Lake Rotorua which has a high natural phosphorus loading. An awful lot of the literature and understanding of lake restoration and lakes issues is based on lakes where most of the phosphorus has come from anthropogenic sources and it's relatively straightforward to identify and get rid of it. The situation is different here because the natural loading of phosphorus is high and I suspect that to get to a phosphorus-limited situation we would have to reduce the phosphorus loading to less than what it would be under natural conditions. You can imagine what that means. It means that we will need to start removing phosphorus from natural waterways to concentrations which are less than they were before any land use change occurred. If that's technically and economically feasible that's a good approach. I would still hesitate to put all my eggs in that one basket though. Just targeting phosphorus during the short term would be relatively ineffective because of the huge amount of phosphorus that's currently sitting in the sediments and is potentially available for release. So it will take a very long time to actually flush that material out. Also I just have a natural caution about focusing on just one nutrient which historically hasn't really

been limiting in this situation, whereas another one potentially was. So the answer to your question is, maybe, yes it would take a lot of thinking about and the implications in terms of what you would need to do to achieve that are not trivial. On the first question, when those essays were done we had a really nice mixture of data on cyanobacteria and so what we were looking at was the response over different times of the year. We were looking at cyanobacteria dominance particularly during late summer, whereas during the winter period (and these experiments covered several years) we were looking at diatoms and green algae. One of the remarkable things, and I hope you would have got it from some of those plots, was that the responses were very consistent and that made us believe that the inferences that we made were applicable across the whole range of different types of phytoplankton groups. That sounds a little bit surprising, but that's what it was, that's what happened. So the experiments were done with a whole range of different phytoplankton communities from diatom- and green-dominated cyanobacteria and the same inferences were coming out from all the different treatments that we made.

The trophic level index - a state of the lake indicator

John McIntosh

Environment Bay of Plenty

ABSTRACT
State of the environment indicators are becoming an integral part of triple bottom line reporting to complement economic and social indicators. The Ministry for the Environment initiated a programme to develop national environmental indicators and selected the Trophic Level Index (TLI) as <u>one</u> indicator of lake quality.

In developing policy for lake management, Environment Bay of Plenty needed a precise measure of lake quality as a trigger to initiate an action mode for application of remedial measures. Initial attempts, in 1996, at formulating such a policy for the Tarawera group of lakes in the Regional Plan for the Tarawera River Catchment proved difficult. The TLI (Burns, 2000) provided a tool custom made for the task.

Consulting the public in 1994 for the “Tarawera Plan” the message had been “We want the lakes to remain as they are now and not deteriorate. But there are some that need improving.” The same message came through in public consultation for the “Water and Land Plan”. Thus the quality of the lakes in 1994 became the baseline objective for most of the lakes to be consistent between the plans. Lake Rotorua had it is own objective based on its quality in the 1960s. An objective was set for Lake Rotoiti equivalent to the same baseline. Rotoehu and Okaro also varied from the 1994 baseline.

The TLI is not an ecological state, contamination state or toxicity indicator. However, the state of the lake as expressed by its trophic level is the most relevant indicator that Environment Bay of Plenty can use to relate to nuisance algal blooms. Ecological state, such as aquatic plant dynamics, can be monitored by LakeSPI (submerged plant index) and monitoring programmes can detect contamination events. The TLI is a versatile index. Targets for lake remediation have been calculated from its components. Other monitoring is needed to build up a full picture of the environmental quality of a lake but the linear scale of the TLI makes it suitable to use as an easily understood policy tool.

The TLI is calculated annually from monthly measurements. Five lakes currently exceed the baseline TLI. They are Okareka, Okaro, Rotoehu, Rotoiti and Rotorua. Several others are moving towards this status. Lake Okareka’s action plan process makes an interesting case study. The “Water and Land Plan” contains other triggers so taking action to remediate lakes is not limited to changes in the TLI alone.

A large monitoring programme is carried out by Environment Bay of Plenty to track changes in various aspects of lake quality. This allows looking back to show how the lakes are changing. A relationship is now established with the University of Waikato to carry out fundamental lake research using the Rotorua lakes and the other New Zealand lakes on which to base studies. A predictive capability will develop though lake modelling to translate current land use changes to future changes in lake quality. Research providers perform specific scientific studies to ensure that management actions will be effective and are carried out appropriately.

TRANSCRIPT

Kia ora, good morning.
I'm talking today about the trophic level index, a state of the lake indicator. Initially I'll focus a little bit on the state and what it means. That means how a lake is now and how it's changed in the recent past. We're not really talking about predictive capacity, but I'll talk a little bit about how we might in the future work to get some predictive capacity. I'll then talk about the trophic level index, how it's derived and how we use it in the lake. And then how it's used in our policy in the proposed regional water and land plan. And then I've got some plots of the TLI's in five of our lakes from about 1991, just to show you how it's changed in those lakes.

There's a model for environmental reporting that we use in our state of the environment report which is a pressure state response model, with the state up front, how the lake is now or how any environment is. We'll talk about the lakes, and how they have changed over the recent past. Then there are the pressures - what is happening in the environment that is changing the state. And the response - what we're doing, as a community not just ourselves as a council, to counter those pressures. So that's the model we use for our state of the environment reporting.

- **Whole lake monitoring**
- **Algal blooms at lake edge**
- **Bacterial quality at lake edge**
- **Aquatic plants**
- **University of Waikato research**
- **CRI consultant research**

So the state of the lake monitoring that Environment Bay of Plenty does, that's what I've called their whole lake monitoring and I'll talk a little bit more about that in the future. There's the algal bloom monitoring predominantly at the lake edge, although some of the samples are in the middle of the lake but the effect of the algal blooms is at the edge of the lake. We have a programme that starts in about November and goes weekly until the blooms end, that's at the lake edge. There's also bacterial quality monitoring at the lake edge and those two really refer to recreational quality. So that's what they are dealing with, effects on human health. There is aquatic plant monitoring, we're really starting that. Aquatic plants are a biological system that really responds differently to the algae in the lake, so it's good to have a bit of a monitoring system looking at what's happening there.

We've also now got a few more strings to the bow with our relationship with the University of Waikato and the Chair in Lakes Restoration and Management, David Hamilton. And through that and through our association with research contracts with the CRI's and other researchers, we do work which could be called state of the lake. We have the ability now to look at that predictive capacity and develop that through modelling and David Hamilton perhaps will be showing you some of that work tomorrow. So it gives us the ability in the future to not just look at the state as it is now and how it's changed over the recent past, but look at what's going to happen in the future based on the changes in the catchment. Whole lake monitoring, it takes place in the middle of the lake where the lake is generally, I would say

Whole lake monitoring

- **Profile dissolved oxygen**
- **Profile temperature**
- **Nitrogen and phosphorus**
- **Chlorophyll *a***
- **Algal species**

Basic parameters for determining changes in a lake

homogeneous - I think Justin used that term. Even when it's stratified, the levels that it's stratified at are relatively homogeneous.

So we have sites out in the middle of the lake where we measure dissolved oxygen and temperature profiles, measure the nutrients, nitrogen and phosphorus, chlorophyll A as a surrogate for algal biomass, and we also take samples for algal species determination. So these are the basic parameters for determining changes in the lake water.

Burns, Rutherford, Clayton (1999)
'A monitoring and classification system for New Zealand lakes and reservoirs'
Burns, Bowman and Bryers (2000)
'Protocols for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs .'
New Zealand Ministry for the Environment

The trophic level index was developed by Burns, Rutherford and Clayton. There is a trophic state index which is used in the northern hemisphere and so Burns, Rutherford and Clayton have devised the trophic level index as a classification system for New Zealand lakes. It's based on information from lakes across New Zealand. Burns Bowman and Byers then developed protocols for monitoring the trophic levels of New Zealand lakes. So that's the "how, when and what".

The objective there was to standardise the monitoring of lakes across New Zealand for the development of the Ministry for the Environment's national indicator. That was adopted by the Ministry for the Environment as the indicator for lakes. There are not many regions in the country that actually do this kind of monitoring. I think the lakes across New Zealand are very poorly monitored, so we are perhaps the only region that's picked this up to any great extent.

Trophic Level Index (TLI)

An annual measure.

Calculated from monthly records of :

- **Total nitrogen**
- **Total phosphorus**
- **Secchi disc clarity**
- **Chlorophyll *a***

The trophic level index is an annual measure, so we get one data point for the year calculated from monthly records. In the lake year we go winter to winter, it's a June to June year, although theoretically we have all the data so you could calculate it on any of those 12 periods. The data that goes into the trophic level index is total nitrogen, total phosphorus, Secchi disk clarity and the chlorophyll *a*. The written paper deals with how that is done and has the equations for those calculations. So the TLI is used as a monitoring tool on the lakes. We also use the TLI as a policy tool in our Regional Water and Land Plan.

TLI used as a policy tool in Regional Water & Land Plan

Has a linear scale

Easily understood

Responds to changes in a lake

One of the things about the trophic level index is that it has a linear scale that goes from 1 to 7. It's easily understood by the community. You can see that if your lake went from 3.5 to 3.7 that's a change. There's an analysis that goes along with it that comments on the significance of that change, so it may still indicate a stable situation in the lake.

We see in some of the graphs that some of the lakes definitely have changed and you will have noted those changes. The comment there does respond to changes in the lake. I'll explain just a little bit about the policy and the Regional Water and Land Plan as they refer to the lakes. There's an objective there where a base line quality is set for all the Rotorua lakes. That was based on the 1994 quality of the lakes. The reason for 1994 was that we were doing the public consultation at that stage for the Tarawera plan of the Tarawera system. The people were telling us was they were happy with the way the lakes were at the present time, they didn't want them to deteriorate, but there were some that needed improving. That was the message.

Regional Water & Land Plan

Lakes have a baseline TLI (objective 10)

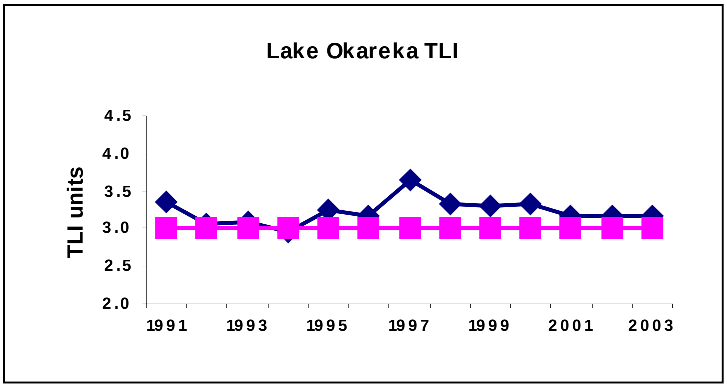
Objective to maintain or improve

If baseline is exceeded - this triggers certain policies (method 35)

Rule structure (rule 11)

When we came to the Water and Land Plan we needed to maintain consistency with those policies, so we adopted that 1994 base line and people were basically saying the same thing – they didn't want the lakes to deteriorate and there were definitely lakes they wanted improved. That objective is to maintain or improve, so it doesn't say that we get there and sit there, it also expresses that we could improve them. This policy says that the base line TLI shall be maintained or improved and that there should be no net increase in nitrogen or phosphorus in the Rotorua lakes catchments. Now if that base line is exceeded, this triggers certain policies. I've noted there the method 35, which is really the action plan process and a lot of you will be involved in that.

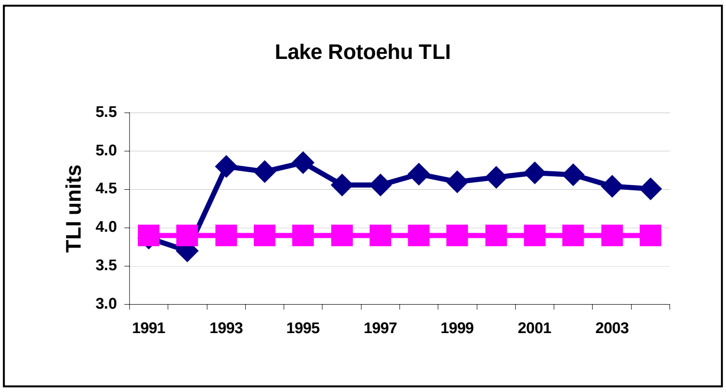
So that's a community-based process, where we determine a target to bring the lake back to its objective TLI and then we think about the methods and strategise on how we might use those methods to bring the quality of the lake back to its base line. There's a also a rule structure to firm up that no net increase in nutrients from land use in the catchment. When this policy came in we had five lakes that already exceeded their base line quality, so we've got action plans in progress on those five lakes. The method 35 also directs us to do a risk assessment on all the other lakes by 2005. That will look at the threats to exceeding that base line TLI and then prioritise action plans for all the lakes.



This looks at Lake Okareka from 1991 with trophic level units along the y axis, on a scale from 2 to 4.5. So the base line TLI was set at 3 based on the 1994 level, so when this policy was developed this was one of the lakes that exceeded its TLI. It's a lake that doesn't really suffer any problems, but what we were finding was the bottom waters were becoming increasingly anoxic and there were releases of nutrient from the sediment. Looking into the future we would be

experiencing problems, so it still fitted into this model, we needed to do something to improve it.

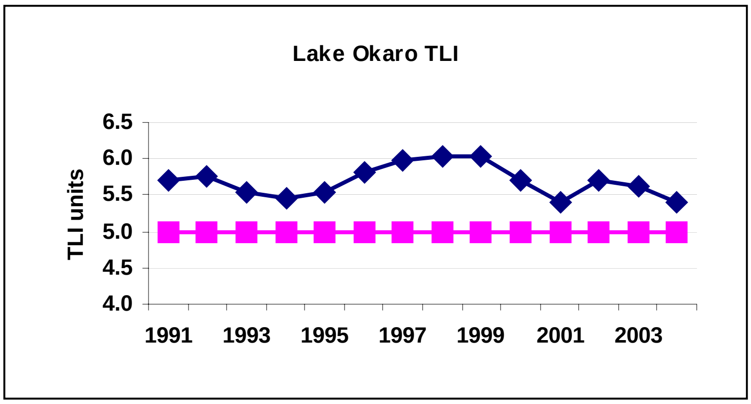
The target TLI is subtracted from the current TLI or the nitrogen or phosphorus component of the lake. The difference shows that, we've got a load of nitrogen and phosphorus that had to be reduced in the lake. We had consultants who then modelled back from that in-lake concentration to what that means and what flows into the lake, and those results became the target and the ratio of nitrogen to phosphorus was taken from that advice. The Lake Okareka action plan has gone right through to a completed action plan and the main action is the reticulation of sewage in that catchment. We're also examining creation of constructive wetlands and retirement of lands and perhaps change of land use on some land.



Lake Rotoehu is one of the five lakes that exceeded the TLI immediately. In 1994 we were already in this poor state with algal blooms, so the base line was set at an earlier period. One of the members of our working party on that lake said that he noted (this is during a period of falling lake level), that the lake in front of his place fell 14 vertical feet over that 1993/94 period.

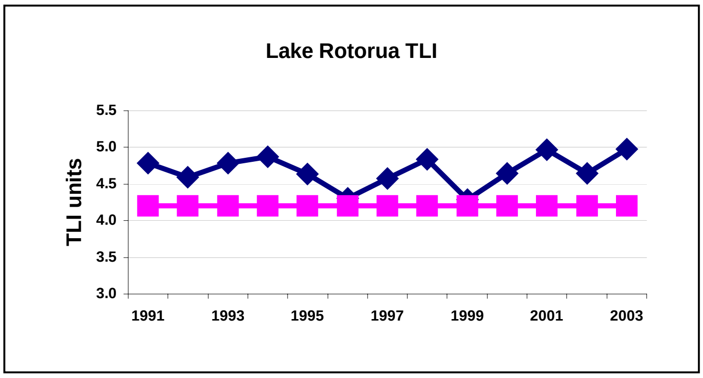
So there was a big decrease in lake level and the same climatic conditions. I don't know if the decrease in lake level necessarily caused the problem, but the climatic conditions certainly did. It had this huge bloom of algae. The nutrient level in the lake in that period was about double what it had been in the early 90s. What we virtually had since then was one event of blue-green algal blooms. They subside in the winter of course, that's the normal occurrence. But it was virtually one event from there for 10 years. I actually have the 2004 data point there, I twisted some arms and got that. I expected that to be lower because this year we didn't have the blue-green algal blooms. Going back to 2003, the phosphorus level in the lake in 2003 had actually come back to the level it was in an earlier period, but the nitrogen was still elevated. Now with not having the blue-green algal blooms I expected phosphorus to be lower, but we had a big release of phosphorus from the sediment over this period, so the phosphorus in the lake was again elevated, while the nitrogen had decreased not quite to the desired level but getting closer. So it seems counter-intuitive that we didn't get the blue-green algal blooms, but we didn't.

So another concept that comes out of this is one of threshold and it seems to be that where there are lakes that have the blue-green algal blooms, the nutrient content, the TLI exceeds a threshold. When we get into the situation where we're having the blue-green algal blooms, and if we can bring it down below that threshold, then we won't get the problems. I think in terms of us reaching our base line we are not necessarily going to get all the way, so we need to still do more work to get it below the base line.

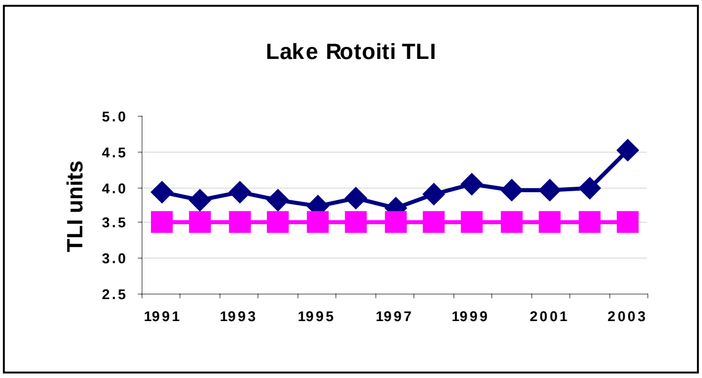


Lake Okaro is the worst of our lakes in terms of its quality. We struggled with where to set our base line, so we just went for less than what it was, and we've set the base line at 5. If we can do better than that, we certainly will be trying. There's an action plan group for Lake Okaro and the main action we are undertaking here is constructed wetlands, intercepting the run-off into the lake. It comes in at quite a concentrated little area and those of you on the field trip last year would have noted that.

The landowner has given us land for the wetland and the Rotorua District Council have given us some of the lakeside land. There's land available there to strip nitrogen and perhaps capture some phosphorus from the water running into the lake. That's the major action that we are taking. There will be some retirement of streams and there are some smaller areas up in the catchment that will also be either retired or maybe enhanced as wetlands. We had an alum trial on the lake over this period, so we've looked at the effects of applying alum to a lake. The intention was to apply it over an extended period of time – 10 years, so we didn't intend to clean it up in one hit. We now have several other products that are becoming available and you'll hear talk of those as well, that's a developing field.



The TLI for Lake Rotorua was set during negotiations over the sewage diversion, so NIWA scientists examined the data. They considered that back in the 1960s the lake was in a good condition, we didn't have blue-green algal blooms and the quality they suggested as a base line for the lake we converted to a TLI. The sewage was taken out of the lake just prior to this, about 1990 perhaps, and the lake has really struggled to get back here, but it has occasionally got close to that target. There are years where there have been less or no releases of nutrients from the sediment, but every other year we seem to have a bit of recharge from the sediment. The last data point is for 2003 and I think judging by the way the lake was this year, 2004 is going to be higher. Over this period the nitrogen that was taken out in the sewage has really been replaced by the diffuse run-off from the catchment. The phosphorus however has been permanently reduced, so that was a good outcome, but the nitrogen load has been replaced from the catchment. So I think the prognosis for Rotorua in the coming years is not good and I wouldn't give advice for people to organise recreational events over the coming summers on Rotorua.



The base line for Rotoiti was set with equivalency for Rotorua, so it's probably based on 1970s quality. The TLI has never been below that since 1991 and in 2003 the event that you are all aware of pushed it up even further. In terms of the actions there we are considering the diversion of the Ohau Channel, based on the target we've calculated. So it's a worst case scenario, but diversion of the Ohau Channel will achieve a reduction of that order.

<u>Other lakes</u>

TLI set at 1994

Some will exceed the baseline

Method 35 (2005) - evaluate the risk

- prioritise development of action plans

For the other lakes, the TLIs were set in 1994 and it's 10 years on, so some of them will be exceeding their TLI. So in terms of method 35, we'll be evaluating the risk on all the lakes and prioritising the development of action plans. So that's an explanationof the use of the TLI for our monitoring and in our policy. Thank you.

QUESTIONS

Rowland Burdon, Royal Society of NZ: John, you mentioned that you feel that there are threshold effects operating above which you have real problems. That, I think, calls into question whether it is appropriate to have the TLI as a linear scale. Would you like to comment on that or would Noel want to comment on it?

J.M.: Well I think what I can comment on, Rowland, is that the TLI is set in terms of what people said they wanted and I think that it was a reasonable request that they wanted the lakes to remain as they are. So the TLI sets that moment in time and says this is the base line. It's not set at a level that will stop algal blooms from forming. We're fortunate that the threshold above which we get blue-green algal blooms will be above that base line. So I don't think a linear scale or lack of a linear scale really has too much to do with it.

John Green, LakesWater Quality Society: I notice that you had a TLI for Rotorua of 4.2 and for Rotoiti we've got 3.5. 85% of our problems come from Rotorua and I find it very hard to understand that when more polluted water is brought into a less polluted environment that our TLI is struck at 3.5. We might as well strike it at 4.2 because there's absolutely no way we can avoid that polluted water coming into our lake.

J.M.: Well 3.5 is a better quality lake than 4.2 and Rotoiti will always be slightly better than Rotorua on a calibration system, because Rotoiti has its own cleaner water coming in from the catchment. I'ld just go back to our record that people wanted (well I guess for Rotoiti they didn't) a better quality for Rotoiti than 4.2 because we can virtually beat that

at the moment and we've got a situation there where we've got extreme problems. So I think there's always going to be a difference in value. Rotorua is going to be up here and Rotoiti down there.

J.G.: In that case, why not change Rotorua to 3.5 and then we'll all be happy.

J.M.: It's not a case of juggling numbers, it's a case of what's reasonable. What we're trying to do is to go back to a situation that existed previously. We're not creating a number that has no meaning. The TLI number has meaning, and for Rotorua it expresses how it was in the 60s, while Rotoiti expresses how it was in the 70s, so that's what we're trying to do. You can't just create different numbers if they're not meaningful. All those numbers have some meaning.

Phytoplankton composition and biomass along vertical gradients

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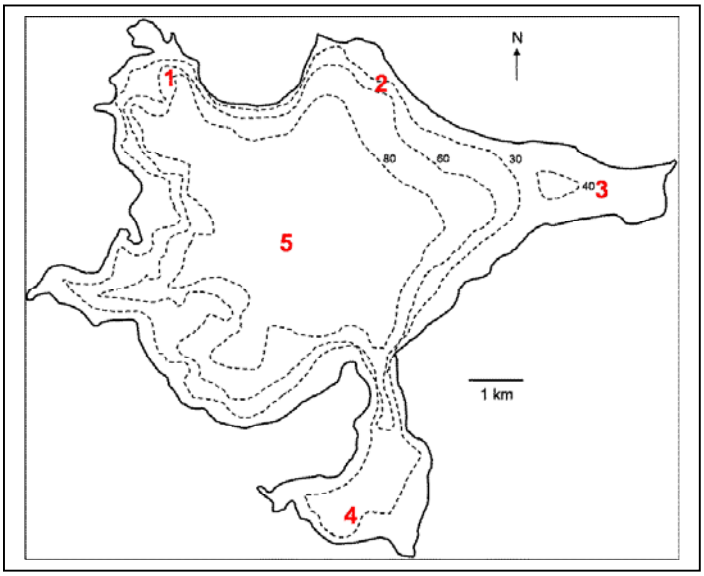
INTRODUCTION

We examined factors controlling the vertical distribution of phytoplankton in Lake Tarawera which has a deep chlorophyll maximum (DCM) during the summer months. The DCM is a subsurface, deep layer of phytoplankton. Our objectives were to quantify the spatial and temporal variations in phytoplankton biomass. The interactions between rates of turbulent diffusion, sedimentation and net population growth were determined to investigate the phenomenon of formation and maintenance of the DCM at discrete depths.

METHODS

Lake Tarawera has an area of 41.6km^2, and maximum depth 87.5m. Sampling stations were established in four major lake embayments and one mid-lake station. Depths of the embayment stations were 30-50m and the mid-lake station was 87m.

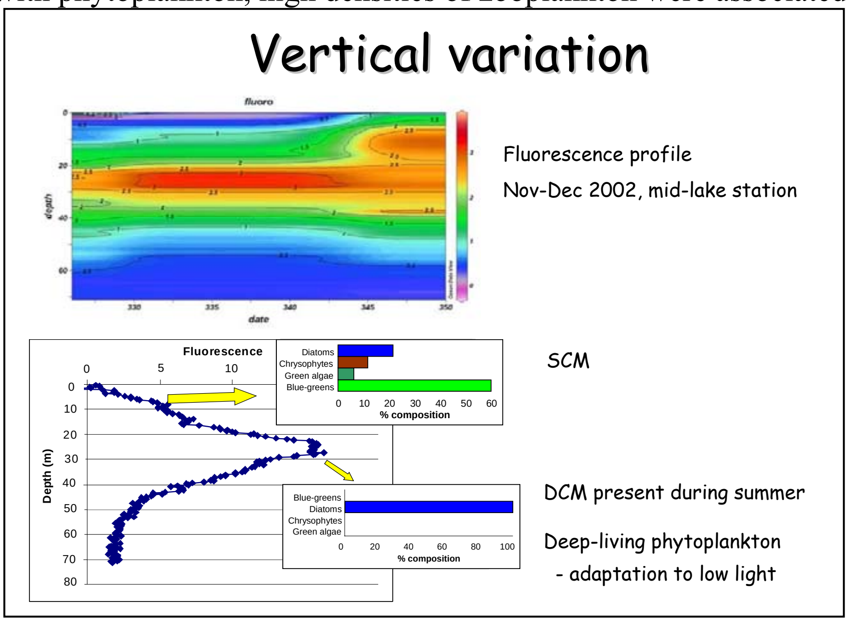
Stations were sampled once a week over 3 weeks in November 2002 (late spring) and February 2003 (late summer), followed by twice daily for one week during December 2002 and March, July and November 2003. A Seabird Electronics (SBE) 19plus Seacat Profiler was used to resolve the depth (z) distribution of chlorophyll-fluorescence, temperature, density (ρ) and photosynthetically available radiation (PAR). Chlorophyll-fluorescence was calibrated against acetone-extracted chlorophyll *a* extracts (Axler & Owen 1994) collected simultaneously with the fluorescence measurements. Depth-integrated samples of the surface mixed layer were collected for determination of chlorophyll *a* and for phytoplankton enumeration. Discrete samples of the DCM, located from the fluorometric profiles, were collected with a diaphragm pump. Thermocline and metalimnion depths were defined according to Hoare and Spigel (1987) and averaging to 1m was used. The position of the thermocline depth is where $d\rho/dz$ = maximum.



Phytoplankton samples were preserved with 2% Lugol's iodine. Cell counts were conducted using the sedimentation technique of Utermöhl (1958), and algal biomass was approximated using the closest geometrical shape for each algal unit (Hillebrand et al. 1999). Zooplankton samples were filtered on-board through a 45µm mesh-net and preserved with 10% formalin. Subsamples of 5 mL were placed in an open-top perspex counting tray (50 mm x 80 mm) and were enumerated using a Leica MZ12 microscope at 50x magnification. Successive samples were counted until >200 individuals were counted.

RESULTS/CONCLUSIONS

The DCM was dominated by diatoms, including *Stephanodiscus* spp., *Cyclotella* spp., *Aulacoseira granulata* var. *angustissima*, *Asterionella formosa*, and *Fragilaria crotonensis*. *Stephanodiscus* cf. *alpinus* had the highest density of any species recorded at the DCM. The presence of diatoms indicates DCM formation is likely to be due to physical factors (i.e., sinking of diatoms cells and interactions with lake mixing). Along with phytoplankton, high densities of zooplankton were associated with the DCM. The zooplankton assemblage at the DCM was dominated by the copepod *Boeckella* sp., followed by cladocerans *Ceriodaphnia* sp. and *Bosmina* sp. Several species of rotifers were also recorded. The deep-living phytoplankton may form an important part of the lake food chain in the lake, with zooplankton grazing on the DCM, which in turn may provide a food source for higher trophic levels and potentially impact on the fisheries in the lake.



The DCM developed between 25-35m during Nov-Dec 2002 (Fig. 1) at approximately 1% of surface irradiance. The depth was closely related with the depth of the thermocline (Ryan et al., 2004), suggesting that basin-scale seiching contributed to most of the DCM displacement. The thermocline may act as a physical barrier to sinking cells, with the dense underlying water slowing the velocity of non-motile phytoplankton such as diatoms. In Lake Tarawera low mixing at the DCM (vertical diffusion coefficient, Kz ~ $10^{-6} m^2 s^{-1}$), coupled with low sedimentation and high growth rates, allowed the establishment of a DCM during summer. However during winter, growth could not concentrate cells sufficiently to offset the increase in mixing rates (Kz ~ $10^{-3} m^2 s^{-1}$), leading to the breakdown of the DCM. The results to-date indicate that maintenance of the DCM peak in Lake Tarawera may be attributed to active *in situ* growth by diatoms adapted to low light. The light levels in the DCM are within the range where DCM formation is observed in other lakes and in the ocean.

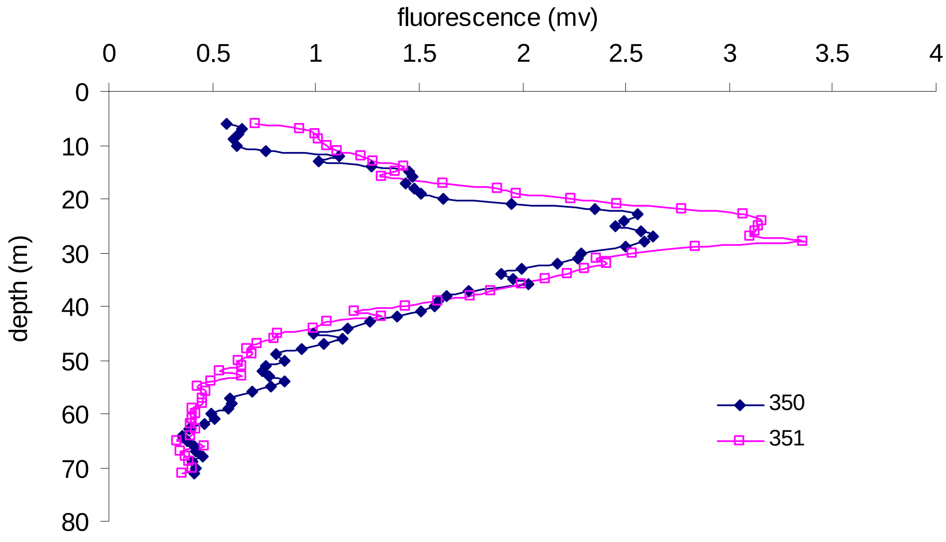
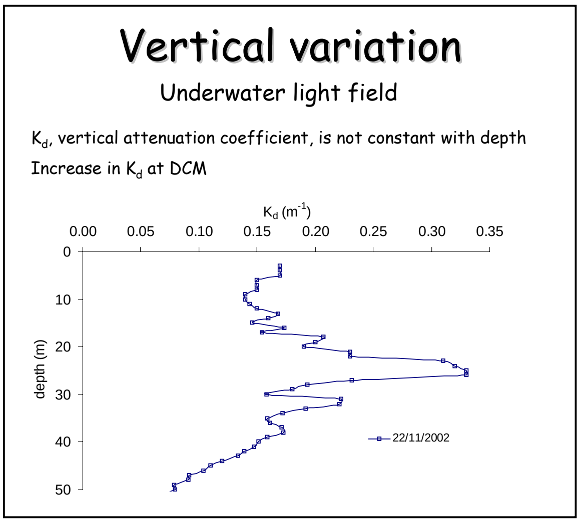
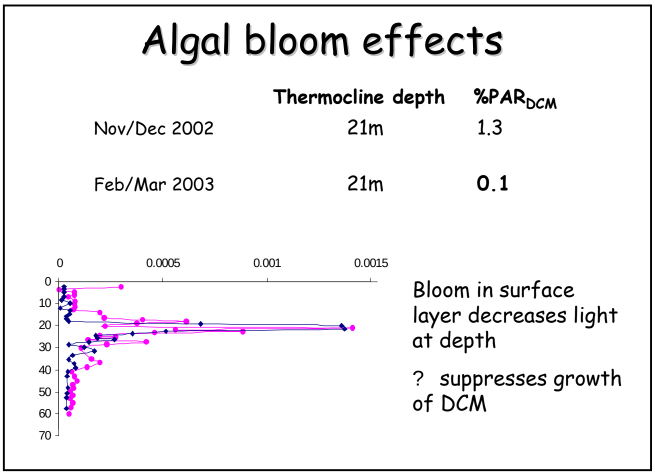


Figure 1. Profiles of chlorophyll-fluorescence, used as an indicator of phytoplankton biomass, showing the distribution of the phytoplankton. Days 350-351 are 16-17 December 2002.





A surface algal bloom of *Anabaena* cf. *lemmermanni* in the summer of 2003 increased the rate of attenuation of light with depth, and the light available at the depth of the DCM was reduced from 1.4 % to < 0.1 % of the surface irradiance (Table 1). The surface bloom shaded the phytoplankton to such an extent that it appeared to suppress phytoplankton growth in deeper layers of the lake, resulting in loss of the DCM. Increased nutrient inputs to oligotrophic Rotorua lakes which have a DCM may differentially stimulate phytoplankton growth in the surface, potentially leading to blooms, while reducing light to phytoplankton that constitute the DCM. This may become more apparent during calm summer stratified conditions, in which the deep-living algae could be replaced by buoyant cyanobacteria.

Table 1. Light climate at the DCM in Lake Tarawera.
%PAR - % Photosynthetically Available Radiation. K_d – extinction coefficient for light.

	$\%PAR_{DCM}$	$K_d(m^{-1})$
Nov/Dec 2002	1.4	0.11
Feb/Mar 2003	0.1	0.14

The relevance of the negatively buoyant (sinking) diatoms in Lake Tarawera is that they play a key role in several biogeochemical processes. They may sequester nutrients from the upper water column and deposit these nutrients in the bottom sediments or in deep water layers. The permanent loss of the diatom DCM in deeper Rotorua lakes may lead to higher nutrient levels in the surface waters during winter, which may provide a nutrient source for the over-wintering blooms.

QUESTIONS
Brendon Hicks, University of Waikato (session chair): I had a hard time understanding how these little creatures actually maintain themselves, how they know where the optimum place is.

E.R.: They're falling down to the thermocline and at that thermocline there's a strong density gradient and they are actually getting trapped in that density gradient. At that gradient there's actually high eddies trapping them there too, so they're getting entrained there, blocked between two different layers. I didn't really go into the lake physics, but that's what's happening. They are heavy and they should sink, but they get trapped in the density gradient.

Rod Stace, Lake Okareka: Given that Lake Tarawera has low levels of nutrient and algal blooms are a symptom of high levels of nutrients generally, how do you account for the fact that blooms occur on Lake Tarawera.

E.R.: I think we've really got to relate the algal blooms to the lake physics. In Lake Tarawera there's strong diurnal stratification. That is, during the day there is strong sunlight, it's a big stable lake, and you can set up a top layer of about 10 metres of stable water and that's enough for the algae. The algae are throughout the whole water column, but during the day we set up the strong diurnal stratification and the algae all get trapped in this layer, so it looks like it's actually quite a large surface bloom. However you notice how in the winter even now there are green lumps of algae in Tarawera but they're quite well spread. However in summer they actually increase their buoyancy and come up to the surface and get entrained. So that's one of the dangers with blue-green algae. You can't just look at nutrients, you've also got to look at the lake physics.

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Land based factors associated with blooms of cyanobacteria

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ABSTRACT

During the last decade there has been a significant rise in observations of blooms of the toxic cyanobacterium *Lyngbya majuscula* along the east coast of Queensland, Australia. Whether the increase in cyanobacterial abundance is a biological indicator of widespread water quality degradation or also a function of other environmental change is unknown. A bioassay approach was used to assesses the potential for runoff from various land uses to stimulate productivity of *L. majuscula*. In Moreton Bay, *L. majuscula* productivity was significantly ($p<0.05$) stimulated by soil extracts, which were high in phosphorus, iron and organic carbon. Productivity of *L. majuscula* from the Great Barrier Reef was also significantly ($p<0.05$) elevated by iron and phosphorus rich extracts, in this case seabird guano adjacent to the bloom site. Hence, it is possible that other *L. majuscula* blooms are a result of similar stimulating factors (iron, phosphorus and organic carbon), delivered through different mechanisms.

Keywords: Lyngbya majuscula, bioassay, nutrients, land use, organic carbon, iron

INTRODUCTION

Lyngbya majuscula (Gomont) is a toxic, filamentous marine cyanobacterium (family Oscillatoriaceae), previously cited in the literature as *Microcoleus lyngbyaceus* (Kützing) (Diaz et al., 1990; Speziale and Dyck, 1992). *Lyngbya majuscula* grows on solid or sandy substrates or epiphytically on seagrass, macroalgae and corals in the coastal zones of many sub-tropical and tropical oceans. Since the early 1990's, nuisance blooms of this toxic cyanobacterium have been observed seasonally in Moreton Bay, Queensland, Australia (Dennison et al., 1999).

In Moreton Bay, *L. majuscula* blooms typically begin in the summer (December/January) and expand rapidly over the following two-three months to an area on a kilometre square scale (10-30 km^2) (Dennison et al., 1999; O'Neil and Dennison, 2004). This is often followed by a rapid population collapse, possibly aided by viruses specific to *L. majuscula* (Hewson et al., 2001). During this cycle *L. majuscula* has been observed to begin growing from the sediment below the seagrass canopy. As the 'bloom' develops this benthic mat is able to grow sufficiently to overtop the seagrass species creating a blanketing effect that can turn the sediment and bottom water anoxic (pers. obs.). Often after periods of high light, warm temperatures and calm weather, bubbles from rapid

photosynthesis by the *L. majuscula* are trapped within the filament matrix and cause the *L. majuscula* to eventually float to the waters surface to form large surface aggregations. This stage may provide a dispersal mechanism for *L. majuscula*, enabling it to spread to other regions.

The environmental consequences of *L. majuscula* blooms are still being investigated. Seagrass loss and altered marine plant community structure have been the most significant documented impacts of *L. majuscula* bloom events to date (Watkinson, in press). Economically, *L. majuscula* blooms within Moreton Bay have had significant impacts on both commercial fish catches (Dennison et al., 1999) and local communities through lost tourism and beach clean up of *L. majuscula* bloom material washed up on beaches. *Lyngbya majuscula* can also produce a suite of toxins which cause severe skin and eye irritation as well as asthma-like symptoms in humans (Osborne et al., 2001).

In general, marine plants within Moreton Bay are nitrogen limited (O'Donohue and Dennison, 1997; Udy and Dennison, 1997). Nitrogen-limited systems often favour prokaryotic nitrogen-fixers such as cyanobacteria. In the absence of nitrogen limitation, phosphorus can be the limiting nutrient for cyanobacteria growth (Martin and Gordon, 1988) with blooms of cyanobacteria often related to phosphorus loadings from the surrounding environment (Reigman and Mur, 1986; Paerl et al., 1987; Seitzinger, 1991). However, where there is sufficient phosphorus available, biologically available iron often becomes a significant limiting factor of biological growth in oceanic systems (Martin and Gordon 1988; Martin et al., 1990**)** as well as coastal and estuarine ecosystems (Hutchins and Bruland 1998; Hutchins et al., 1998)**.** Cyanobacteria have a high demand for iron (Paerl et al., 1994; Trick et al., 1995) and phosphorus (Paerl et al., 1987; Sanudo-Wilhelmy et al., 2001) for both photosynthesis and nitrogen fixation. Elevated iron concentrations in laboratory studies have: increased productivity and phycocyanin production in *Oscillatoria tenius* (Trick et al., 1995), increased nitrogen fixation in *Trichodesmium sp.* (Rueter et al., 1990) and increased toxin production by *Microcystis aeruginosa* (Utkilen and Gjolme, 1995).

Iron is often limiting to marine organisms (Anderson and Morel, 1982), as insoluble ferric iron (Fe(III)) oxides and hydroxy oxides are the thermodynamically preferred forms of iron at seawater pH, with soluble free Fe(II) undergoing rapid oxidation and subsequent precipitation of the ferric form (Byrne and Kester, 1976). Cyanobacteria are unable to take up and utilize these oxides of iron directly. However, in the presence of organic ligands that complex with the soluble iron, oxidation and precipitation is generally decreased making iron more persistent in the dissolved phase in seawater, and hence more bioavailable (Emmenegger et al., 1998; Santana-Casiano et al., 2000). Following reductive processes (e.g. photo-reduction) to break these organic ligand – iron complexes (Waite and Morel, 1984; Wells and Mayer, 1991; Voelker et al., 1997), phytoplankton and cyanobacteria are able to take up the soluble iron directly from the water column (Anderson and Morel, 1982). Therefore, the level of bioavailable iron in seawater can fluctuate greatly depending on the presence of natural complexing agents such as organic carbon. Parallel studies investigating the role these organic-rich compounds have as a transport mechanism for bio-available iron to reach the bloom sites from terrestrial sources, are currently under way (Rose and Waite, 2003).

The aim of the current study was to assess potential stimulating factors associated with *L. majuscula* blooms. Two case studies are presented, Deception Bay (NW Moreton Bay) and Hardy Reef (central Great Barrier Reef). Although there are many interactive factors

in bloom development, this project sought to identify key processes that may help explain recent increases of this noxious cyanobacterium.

METHODS

Study Sites

The two sites chosen for this study are geographically disparate (Figs. 1, 2) with very different hydrology and water quality, both have experienced blooms of *Lyngbya majuscula*. The first site is Deception Bay (27º05'S, 153º09'E), a relatively shallow region (<5 m) with extensive seagrass beds in the north-western section of Moreton Bay. It is adjacent to a large estuarine passage (Pumicestone Passage) draining a large catchment, dominated (approximately 37%; Pointon et al., 2003) by exotic pine plantations (*Pinus elliotii*). Hardy Reef, a mid shelf reef in the central portion of the Great Barrier Reef approximately 80 km off the coast of Mackay, Queensland (19°44'S, 149°10'E), was the second site. This area has negligible terrestrial influence. Blooms of *L. majuscula* occur in the shallow (<5 m) benthos of the coral reef lagoon, epiphytically on calcareous macroalgae (e.g. *Penicillus* sp.) and corals (particularly *Acropora* sp.). Despite the significant differences between the sites, both have experienced extensive blooms of *L. majuscula* over the past 5-10 years.

Deception Bay Case Study

A biological assay (bioassay) technique was developed using soil extracts from eight representative land use types (*Melaleuca* forest, mangrove forest, cleared and intact exotic pine plantation, canal development, iron rich creek (Shirley Creek), marine sediment (Sandstone Point) and coffee rock) within the Pumicestone catchment. These soil extracts were produced to simulate the compounds that these soils would yield during natural runoff events. *Lyngbya majuscula* was incubated in dilutions of these extracts in seawater to determine physiological effects.

Bioassays were undertaken to investigate the effect of extracts from different land uses on *L. majuscula* productivity. Three replicate one-litre glass beakers (acid washed) were filled with 900 ml of seawater from the Deception Bay bloom area and 100 ml of the various soil extracts (90x300 mm soil cores extracted with natural rainwater from each of the eight land uses above). One hundred ml of rainwater was added to the seawater control to ensure consistent salinity. This dilution was based on previous salinity monitoring of the bloom region that indicated a 10% decrease in salinity prior to bloom initiation (Watkinson, in press). Between 4 and 6 cm^3 of *L. majuscula* collected from Moreton Bay was incubated in these beakers for 48 hours under 50% shadecloth at 25 °C ± 2 °C. After 48 hours of incubation a WALZ Diving Pulse Amplitude Modulated (PAM) fluorometer was used to measure *L. majuscula* photosynthetic capacity. Rapid light curves (White and Critchley, 1999) were used to assess the photosynthetic status of *L. majuscula*. Soil extracts were analysed for total and soluble iron, pH, dissolved and total organic carbon and dissolved inorganic nutrient analysis (Table 1).

Pumicestone Passage Water Sampling

Water samples were collected from 47 sites throughout the Pumicestone Passage (Fig. 3) during a prolonged *El Nino* driven drought (7th February 2002) and, one year later at the onset of the first rain event following the prolonged dry season (26th February 2003). Water samples (25 ml) were collected for iron analysis at each site, using a sterile syringe. The samples were filtered through 0.45 µm polycarbonate filters (Ministart) into polyethylene bottles, each containing two drops of 32% hydrochloric acid (HCl). Samples

were analysed for iron using inductively coupled plasma atomic emission spectrometry (ICP-AES). Water samples (200 ml) were also taken at each site for dissolved organic carbon (DOC) analysis. The samples were filtered through 0.45 μm polycarbonate filters (Ministart) into polyethylene bottles. Samples were maintained at 4 ºC and purged with nitrogen to remove CO_2 (Khan, 2002) prior to analysis on a TOC auto sampler (Beckman).

Hardy Reef Case Study

Guano was collected from the helicopter pad adjacent to a *L. majuscula* bloom at the Hardy Reef Lagoon on the Great Barrier Reef in February 2002. The guano was oven dried at 80 °C for 24 hours on flat Pyrex watch glasses. Any fish bones and feathers were removed and the dried guano was homogenised using a mortar and pestle. A water extract was prepared by adding 13 g of the ground guano to two L of deionised water (to simulate rainwater leaching of guano from the helicopter pad). After shaking, the cloudy suspension was allowed to settle for 30 mins. The supernatant was then decanted off and filtered through 0.45 μm polycarbonate filters (Ministart). The resulting solution was analysed for phosphorus and soluble iron (as above). *L. majuscula* was also collected from this site and kept in seawater in an aerated tank until used for bioassay analyses.

Using a similar methodology to the Deception Bay case study above, bioassays were conducted using the guano extract. Sub-samples of the guano extract were added at three different volumes (0.1, 1.0 and 10 ml) to 900 ml of filtered (0.45 μm) seawater in one litre acid-washed beakers. Deionised water was added to make the final volume added to the seawater up to 100 ml. Deionised water (100 ml) was added to the seawater control to ensure consistent salinity. Between 4-6 cm^3 of *L. majuscula* collected from Hardy Reef was rinsed in seawater and added to each of the solutions. The beakers were incubated in natural sunlight with 50% shade cloth for three days at constant temperature (25 °C ± 2 °C).

In the Hardy Reef bioassay, *L. majuscula* productivity was measured using ^{14}C-bicarbonate radioisotope uptake (Parsons et al., 1984). After incubation for three days a sub-sample of *L. majuscula* biomass was added to 25 ml polycarbonate vials containing the same concentration of guano and seawater as originally in the treatments at the start of the incubation period. A dark control was included to account for respiration. Aqueous ^{14}C bicarbonate (final activity 4 μCi) was added to samples, which were then incubated for 2 hours under 50% shade cloth in natural light and maintained at a constant temperature (25 °C ± 2 °C). Samples were then filtered onto pre-weighed 12 μm polycarbonate filters using vacuum filtration. These samples were then rinsed with filtered seawater and 10% HCl to remove any residual unincorporated ^{14}C-bicarbonate and with 6% (w/v) isotonic ammonium formate to remove any salt. They were then dried (60 ^{o}C) and weighed (± 0.0001 g). The samples were placed in scintillation vials and 4 mL of Beckman (Ready Safe) liquid scintillation fluid was added. Radioactivity was determined using a scintillation counter (Packard Tricarb 1600). Productivity (mg C g_{dw}^{-1} h^{-1}) was calculated according to Parsons et al., (1984).

Statistical Analysis

Cochran's test was used to check for homogeneity of variance. One-way analysis of variance (ANOVA) was used to test difference in means between treatments. A post-hoc Tukeys test was used to assess which treatments were significantly different ($p<0.05$).

Linear regression analysis was used to elucidate the relationship between organic carbon and iron.

RESULTS

The first significant bloom of *L. majuscula* to be positively identified in Queensland waters and become a focus of research efforts into its causes (Dennison et al., 1999) was from Deception Bay (Moreton Bay) in 1996 (Fig. 2). Other observations of *L. majuscula* blooms have since been made in other regions of Moreton Bay; Eastern Banks (2000), Adams Beach (2001), Horseshoe Bay (2001) and Wellington Point (2002) (Fig. 2). More recently *L. majuscula* has been observed at a number of locations throughout coastal Queensland. These sites are geographically and environmentally disparate. In southern Queensland *L. majuscula* was observed growing on coffee rock and seagrass substrates in Hervey Bay (1999) and Fraser Island (1999). In central Queensland *L. majuscula* was observed on seagrass substrates in Shoalwater Bay (2002) and Whitsunday Islands (2001), coral substrates on Hardy Reef (2001) and Scawfell Island (2004) and both coral and seagrass substrates in the Keppel Islands (2002). In northern Queensland *L. majuscula* was observed on seagrass substrates at Hinchinbrook Island (2001) and coral substrates at Cape Kimberly (2003) (Fig. 1).

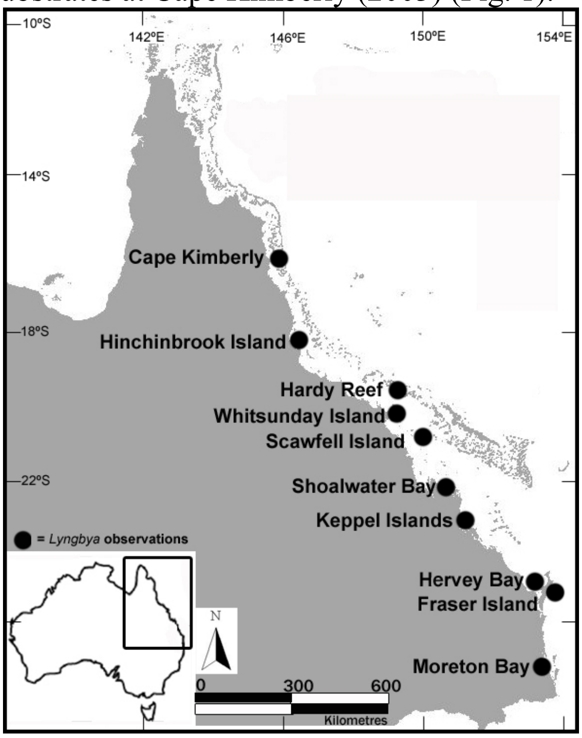


Figure 1: Location of 'significant' observations of *Lyngbya majuscula* in coastal waters of Queensland, Australia over the last ten years.

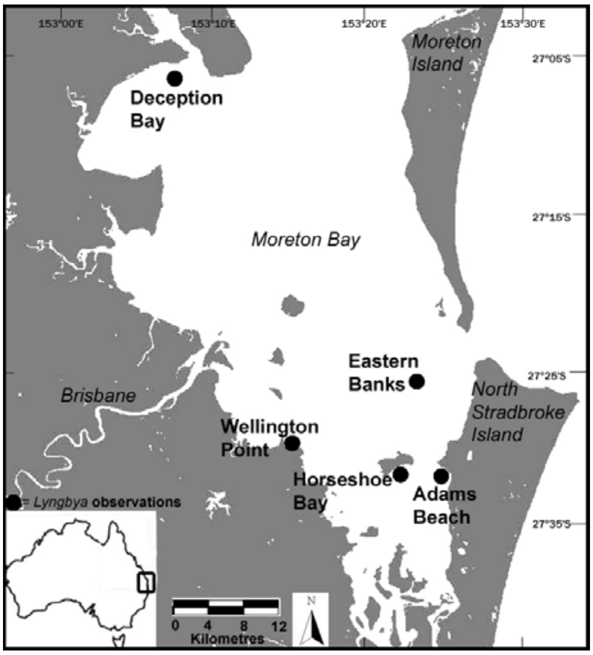


Figure 2: Location of *Lyngbya majuscula* blooms in Moreton Bay over the last ten years.

Deception Bay Case Study

Chemical Parameters of Soil Extracts

The chemical composition of the extracts derived from the eight soil types were diverse (Table 1). This diversity is a function of both soil type and land use at the sites. The three forested soil extracts (cleared pine, intact pine and *Melaleuca*) all contained substantially more dissolved organic carbon than the other sites. Different land uses within these forests also showed variation, with the extract from the cleared pine site yielding higher dissolved organic carbon values than the extract derived from soils under native *Melaleuca* forest.

Table 1: Chemical parameters of soil and guano extracts; pH, free reactive phosphorus ($[PO_4]$), dissolved organic carbon (DOC), total organic carbon (TOC), soluble iron ($Fe_{(Sol)}$), total iron ($Fe_{(tot)}$), ration of soluble:total iron ($Fe_{(sol)}:Fe_{(tot)}$), *nd=no data*.

Extract	pH	$[PO_4]$ (μM)	DOC mg/L	$Fe_{(sol)}$ mg/L	$Fe_{(tot)}$ mg/L	$Fe_{(sol)}:Fe_{(tot)}$
Cleared Pine	3.9	6.7	62.9	0.57	1.1	0.50
Intact Pine	3.3	9.5	35.8	0.12	1.0	0.12
Melaleuca	4.3	0.3	59.1	0.43	2.8	0.15
Mangrove	6.1	<0.01	4.1	0.16	3.5	0.05
Shirley Creek	5.9	0.2	5.3	0.05	43.0	<0.01
Sandstone Point	6.8	0.1	2.1	<0.01	1.0	<0.01
Canal Development	3.7	0.1	4.7	0.15	3.3	0.05
Coffee Rock	6.6	<0.01	28.6	0.2	6.1	0.03
Guano	*n.d.*	1.9	*n.d.*	0.16	*n.d.*	*n.d.*

The soil extracts can be categorised into two distinct groups based on pH (Table 1). The three forested sites (cleared pine, intact pine and *Melaleuca*) and the canal development all yielded highly acidic extracts ranging from pH 3.3 - 4.3. The remainder of the sites yielded less acidic extracts of pH 5.9 - 6.8.

Large variations were found in the concentration of filterable reactive phosphorus (FRP) within the extracts, with the extracts from the cleared and intact pine extracts having the highest concentrations (6.7 and 9.5 μM P respectively). The remaining extracts contained negligible FRP (between 0.05 - 0.3 μM P) (Table 1).

Large variations in the concentration of total iron (Fe_{tot}) occurred between the extracts, with Shirley Creek yielding the highest concentration (43 mg l^{-1} Fe_{tot}) and the other sites ranging between 0.99 mg l^{-1} (intact pine) and 6.1mg l^{-1} (coffee rock) (Table 1). However, the concentration of soluble iron (Fe_{sol}) did not follow this trend. The extract from Shirley Creek yielded only 0.05 mg l^{-1} of Fe_{sol}, whilst the cleared pine extract contained 0.57 mg l^{-1} Fe_{sol}. When the proportion of soluble:total iron is considered, the three forested sites (cleared pine, intact pine and *Melaleuca*) had high proportions of dissolved iron, 0.50, 0.12 and 0.12 respectively. While, other extracts had much lower ratios of soluble:total iron (between 0 and 0.05). In addition, the high ratios of soluble iron in the forested sites also correlated with the dissolved organic carbon content of the extracts (Fig. 4, R^2 = 0.78).

Pumicestone Passage Organic Carbon Monitoring
As expected, the concentration of dissolved organic carbon (DOC) was significantly greater during the wet period than during the dry period (p>0.001) (Fig. 3). As expected, concentrations of dissolved organic carbon were highest closer to catchment inputs (tributaries to the passage and the mouth of coastal creeks). A strong correlation (R^2=0.90) was evident between dissolved iron concentration and dissolved organic carbon concentration of water samples collected from Pumicestone Passage during the wet period (Fig. 4). A similar correlation (R^2=0.78) existed between DOC and dissolved iron present in the soil extracts used in *L. majuscula* bioassays.

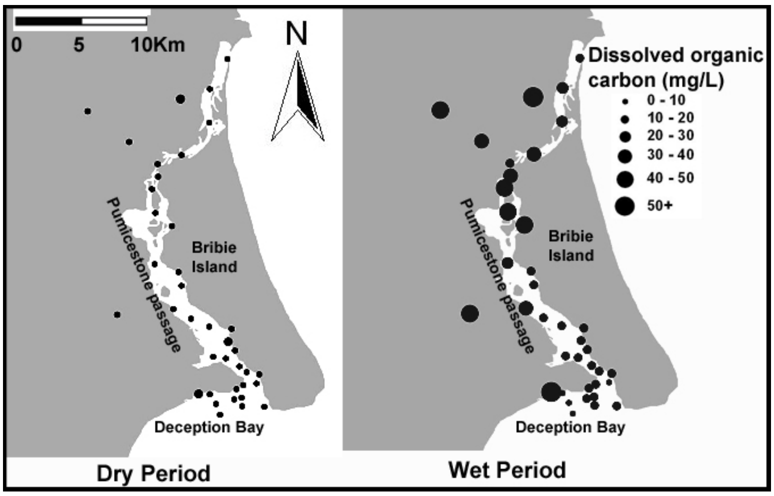


Figure 3: Dissolved organic carbon measured in Pumicestone Passage and Deception Bay during a dry (Feb 2002) and wet (Feb 2003) period.

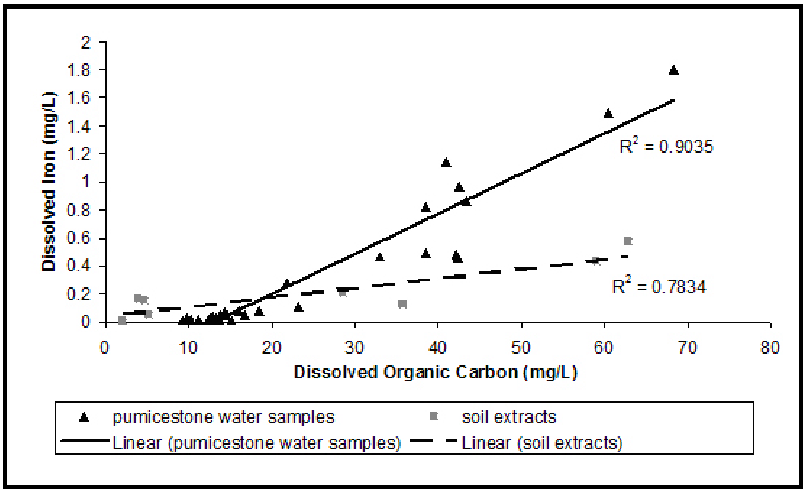


Figure 4: Correlation between dissolved organic carbon (DOC) and dissolved iron within the eight soil extracts (dashed line; boxes) and Pumicestone Passage water samples following rainfall (solid line; triangles).

Photosynthetic Capacity

Lyngbya majuscula incubated in dilutions of soil extracts from major land use sites within the Pumicestone Passage showed various electron transport rates. The *L. majuscula* in the seawater control had an electron transport rate of 189 µmol electrons m^{-2} s^{-1} (Fig. 5). The electron transport rate in response to the cleared pine extract was over twice that of the control (381 µmol electrons m^{-2} s^{-1}) ($p<0.001$), intact pine showed a 33% increase (252 µmol electrons m^{-2} s^{-1}) ($p<0.05$) and the combination of Sandstone Point and cleared pine extracts caused a 74% (329 electrons µmol m^{-2} s^{-1}) elevation ($p<0.05$) (Fig. 5). Depressed electron transport rates (compared to the control) occurred in *L. majuscula* in response to mangrove, Shirley Creek, canal development and coffee rock extracts, although not significantly ($p>0.05$).

Hardy Reef Case Study

The guano extracts contained high levels of phosphorus (1.89 μM) and dissolved iron (0.16 mg l^{-1}) (Table 1). The photosynthetic rate of *L. majuscula* increased incrementally with increasing applications of guano extract (volumes of 0.1, 1.0, 10 ml in a final volume of 1.0 l) (Fig. 6). The highest application rate (10 ml in 1.0 l) containing 1.6 μg l^{-1} of dissolved iron caused a significant ($p<0.05$) increase in *L. majuscula* productivity. Both carbon uptake and electron transport rate of *L. majuscula* were elevated incrementally with increasing concentrations of guano extract.

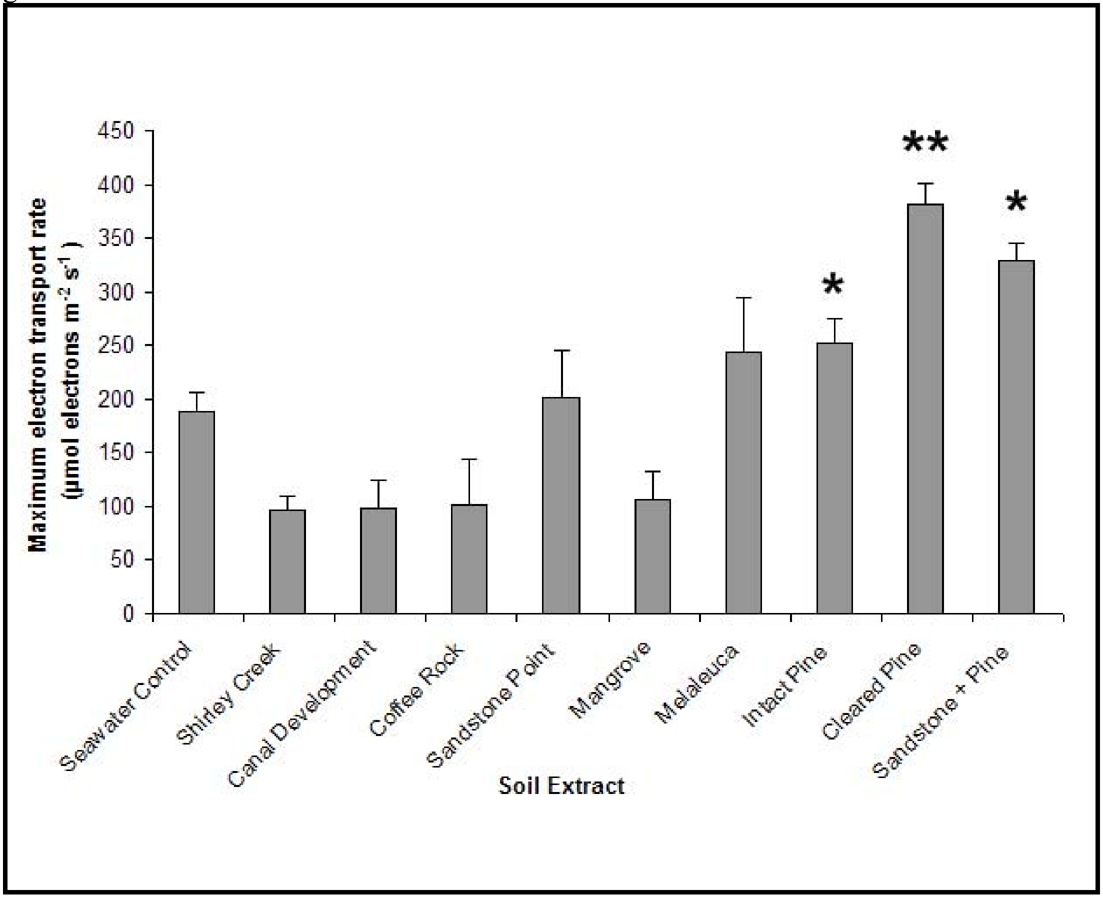


Figure 5: Photosynthetic capacity of *Lyngbya majuscula* incubated in dilutions of soil extracts from major land types within the Pumicestone Passage. (*=p<0.05, **=p<0.001 significant difference from control ANOVA F=11.01)

DISCUSSION

It is difficult to assess the historical extent of *L. majuscula* in Queensland coastal waters. Prior to 1996 there is no mention in the literature of significant blooms of *L. majuscula* in Queensland. However, oral history suggests blooms of a non-toxic filamentous algae occurred in Moreton Bay seasonally since at least the early 1900's (Buchanan Heritage Services, 2003). Since 1996, *L. majuscula* has been observed growing in significant quantities in at least thirteen locations in Queensland (Fig. 1). Whether the increase in cyanobacterial abundance is solely a biological indicator of widespread water quality degradation or also a function of other environmental change including increased observation, is unknown. However, strong anecdotal evidence suggests that at two sites (Hardy Reef and Deception Bay) there have been significant increases in extent and frequency of *L. majuscula* blooms in recent years.

In Deception Bay, it is hypothesised that altered runoff dynamics due to changes in land use within the catchment may have contributed to increases in *L. majuscula* blooms. Runoff during rain events introduce iron, phosphorus and dissolved organics to the coastal zone, which have been shown in other regions to stimulate algal blooms (Bennet et al., 1986; Mallin et al., 1991, 1993). The Pumicestone Passage catchment, which is adjacent to Deception Bay, contains a diversity of horticultural, residential and natural land uses. The dominant land use within the catchment is exotic pine plantations (*Pinus elliotii*) (37%), a large amount of which has been clear-felled in the last decade (Pointon et al., 2003) due to contingency clearing following a large bushfire. This current study has assessed the potential for these land uses within the Pumicestone Passage catchment to be the source of substances stimulating blooms of *L. majuscula* in Deception Bay.

Large variability occurred in the chemical composition of soil extracts derived from the different land uses. Due to the high capacity for forests to fix atmospheric carbon the cleared pine, intact pine and *Melaleuca* forest soils yielded higher organic carbon than un-forested sites. However, differences between forests were more complex. Total organic carbon was higher under the pine forests compared to the *Melaleuca* forests. Similar differences were observed during a twelve-week leaching study in Germany, where pine plantations yielded twice the organic carbon as that of a natural oak forest, and four times that of grasslands (Khomutova et al., 2000). These differences are probably a product of the lower C:N ratio and higher surface area: volume ratio of pine litter enabling rapid microbial incorporation into the soil.

In the current study, there was a positive correlation between the concentration of soluble iron and organic matter contained in the different soil extracts and field measurements within Pumicestone Passage (Fig. 4). Previous studies have shown that organic carbon from both terrestrial and marine sources is able to form a complex with Fe(II) or Fe(III) (Theis and Singer, 1974; Koenings and Hooper, 1976). Extracts without high concentrations of organic material, such as Shirley Creek, had very high total iron concentrations of which negligible amounts were present in the soluble phase. In comparison, organic rich extracts did not necessarily have high total iron content, but a higher proportion of the total iron was in the soluble phase. The coffee rock extract was the only exception to this trend; having high dissolved organic carbon with negligible iron present in the soluble phase. This is probably due to the difference in the specific organic compounds between the forested soils and coffee rock extracts. Specific organic types have differing abilities to complex iron (Hutchins et al., 1999; Rose and Waite, 2003). Parallel studies have indicated that the organics within the pine extracts are able to complex the iron 240 times the rate of the organics in the coffee rock extract (Rose, unpublished data). Thus, not only are pine forests yielding more organic rich material into Deception Bay, this leached material is able to complex iron more effectively than organics from the native vegetation. Despite this, the strong correlation between dissolved organic carbon (DOC) and soluble iron at all sites throughout Pumicestone Passage (Fig. 4) suggests that the concentration of organics is an important factor affecting iron solubility in the water body rather than the actual source of the organics. Therefore, management actions that control/reduce the input of organics to waterways are likely to help reduce the severity of *L. majuscula* blooms in the Deception Bay region.

The main focus of this study was to investigate how the soil extracts (from different land uses) affected physiological parameters of *L. majuscula*. A significant increase in photosynthetic capacity of *L. majuscula* occurred in response to extracts from cleared

($p<0.001$) and intact ($p<0.05$) pine forests. Both the cleared and intact pine extracts can be distinctly separated from the others by their high phosphorus concentrations (6.7 and 9.5 µM respectively). It is unlikely that the elevated photosynthetic rates observed in response to these extracts are a result of phosphorus alone, as the cleared pine extract caused a significantly higher ($p<0.05$) photosynthetic response compared with that of the intact pine extract, yet had a substantially lower phosphorus concentration. The cleared pine, however, did contain soluble iron concentrations four-fold those of the intact pine extracts. It appears, based on these results, that a threshold concentration of phosphorus may be required for elevation of the photosynthetic capacity of *L. majuscula*. The magnitude of this elevation however, may be related to soluble iron concentration rather than phosphorus concentration. This pattern is reinforced by the results obtained from *L. majuscula* treated with the other extracts. The *Melaleuca*, mangrove, canal development and coffee rock extracts all contained significantly higher soluble iron concentrations than the intact pine extract, yet, unlike the intact pine, the extracts from these soils contained low phosphorus concentrations, and hence lacked a significant photosynthetic response ($p>0.05$). These results indicate that a combination of iron and phosphorus is required to increase the photosynthetic capacity of *L. majuscula*. These results are consistent with other studies of cyanobacteria and plankton species in which interactions between iron and phosphorus were required for elevations in photosynthetic rates (Lovstad and Krogstad, 2001; Clasen and Bernhard, 1974).

Hardy Reef

A floating helicopter pad was built within the Hardy Reef lagoon in 1999 to support commercial tourism operations to visit a small heart-shaped ‘microatoll’ within the lagoon. Prior to the helicopter pad being built, tourist operators had not reported *L. majuscula* blooms in thirty years of daily visits to the area (P. Bull Whitsunday Air, pers. comm.). However, within one year of the helicopter pad being built in 1999, a bloom of *L. majuscula* occurred around the perimeter. Blooms also occurred in the following years 2000, 2001 and 2002 (D. Haynes, Great Barrier Reef Marine Park Authority, pers. comm). Incubation of *L. majuscula* in dilutions of guano extract collected from the Hardy Reef helicopter pad caused significant ($p<0.05$) increases in *L. majuscula* productivity. The extract made from guano contained exceptionally high concentrations of phosphorus and high concentrations of dissolved iron compared to levels found in marine waters. These results, in conjunction with strong anecdotal evidence lend support towards the hypothesis that guano in this location is the nutrient source that has caused *L. majuscula* blooms at Hardy Reef.

Stimulation of *L. majuscula* by guano has previously been observed. In the 1980s a guano ship was wrecked off the coast of the Bahamas and guano washed out of a damaged hull of the ship into the surrounding water (pers. obs.). A substantial bloom of *L. majuscula* (identified as *Microcoleus* sp. at the time) formed around the shipwreck suggesting that the input of a cocktail of nutrients into the marine environment can stimulate a *L. majuscula* bloom under various environmental conditions.

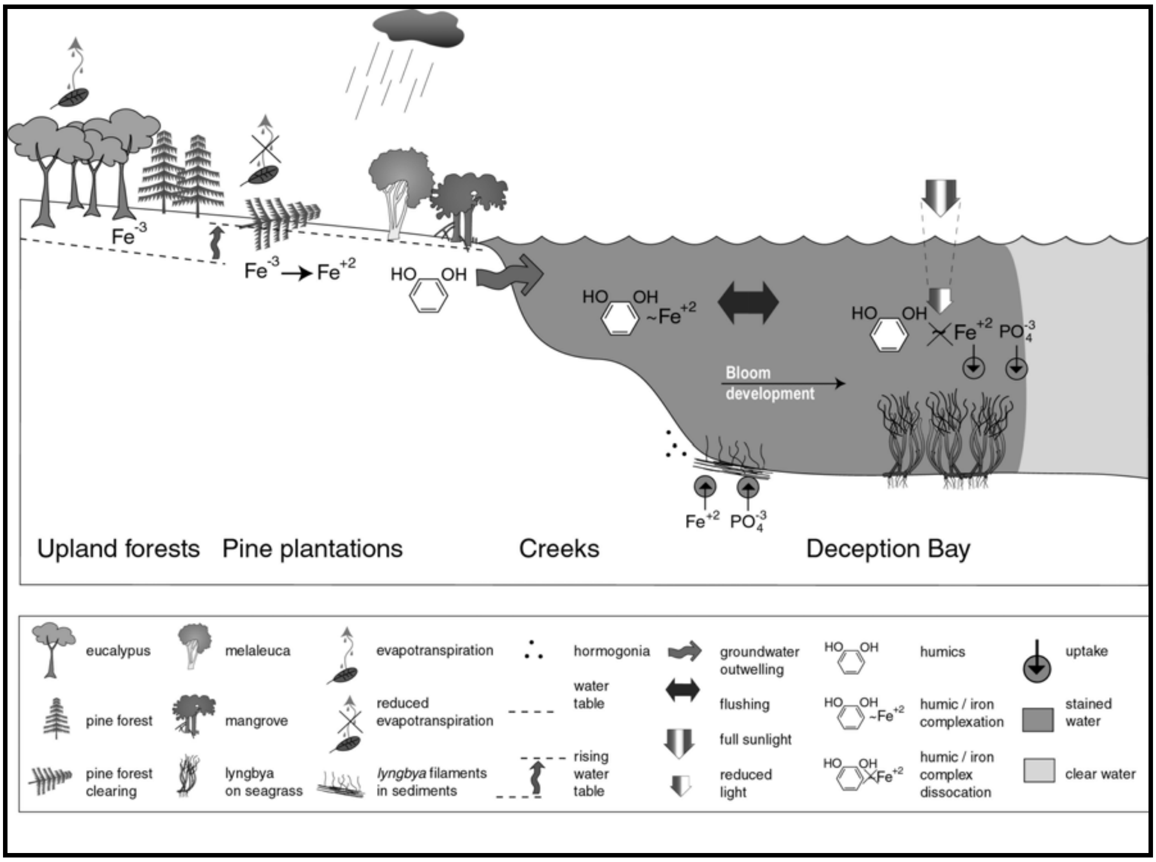


Figure 7: Conceptual diagram of Deception Bay area showing release of organics and iron from disturbed catchment following rainfall. These iron-organic complexes are transported through the estuary to the shallow seagrass beds of Deception Bay. This bioavailble iron combined with existing phosphorus stimulates growth of *Lyngbya majuscula* in bloom proportions.

The combination of factors required for blooms of *L. majuscula* to occur based on our observations include the following: high concentrations of organics, phosphorus and bioavailable iron in the water column, warm waters, high light availability and relatively shallow substrate. It is hypothesised that increases in dissolved organics in the Deception Bay water column provides a transport mechanism for iron and phosphorus to reach *L. majuscula* in a bioavailable form (Fig. 7). Likewise the input of phosphorus and bioavailable iron from guano appears to promote *L. majuscula* growth on Hardy Reef. These results are likely to have relevance to other observations of *L. majuscula* throughout Queensland coastal waters.

In many cases worldwide, estuarine algal blooms have been linked to terrestrial run-off, following periods of heavy rainfall (Bennet et al., 1986; Mallin et al., 1991, 1993). More specifically, phytoplankton blooms have been attributed to the increases of dissolved organic matter following rainfall (Heil, 1996). Similarly, other blooms of cyanobacteria have been linked with terrestrial organics providing a source of bioavailable iron (Emmenegger et al., 1998). Other *L. majuscula* bloom areas in the world may potentially have similar organic sources. Bamboo and sword-grass trash is seasonally flushed into coastal waters of Guam during the summer months of the *L. majuscula* blooms (Matson, 1991) although this link has not yet been specifically tested. The recent seasonal blooms of *L. majuscula* in Florida (USA) are in the proximity of large freshwater *Melaleuca* swamps which yield similar dark stained waters to those observed in this study (Burns pers. comm.). Red tides (dinoflagellate blooms) in Florida have also been linked with dissolved organics in the water column (Ingle and Martin, 1971).

Anthropogenic manipulation of coastal forests can alter the organic carbon and iron balance and, in turn, impact on the ecological integrity of the marine system. Based on relationships between catchments and estuarine iron dynamics, Kawaguchi et al., (1994) have proposed bio-available iron as an indicator of upstream catchment health. The present study highlights the importance of considering both organic carbon and soluble iron concentrations, in addition to the "usual" inorganic nutrient parameters such as nitrogen and phosphorus, in any water quality monitoring program that aims to assess impacts of water quality changes on marine ecosystem health. While this study has not investigated all of the significant *L. majuscula* bloom locations in Queensland (Fig. 1) the stimulating factors (dissolved organics, iron and phosphorus) may be the same, yet delivered through different transport mechanisms, as is the case between the two disparate sites of Deception Bay and Hardy Reef.

In conclusion, changes in catchment land use or seabird distributions that lead to alterations in inputs of dissolved organics, iron and phosphorus can lead to proliferation of noxious blooms of cyanobacteria. The changes can be rather subtle, but have broad ecological impacts. It is only by ascertaining the underlying causal mechanism of bloom stimulation that we can formulate effective management responses.

Acknowledgments
This work has been funded through an Australian Research Council Linkage Grant (LP0219352) in conjunction with Healthy waterways Partnership, Brisbane, Department of Primary Industries Forestry, Queensland and Whitsunday Air. Thanks to P. Moody and D. Waite for assistance with soil and iron chemistry respectively. Nutrient analysis was carried out by D. Wruck. Thanks also to T. Lukondeh, A. Rose, T. Salmon, A. Goldizen, A. Watkinson, C. Collier, K. Arthur, C. Roelfsema and all at MarBot for field and technical assistance.

PARTIAL TRANSCRIPT (edited). *The Editors felt that there was sufficient additional material of interest here to justify adding this partial transcript to the formal paper.*

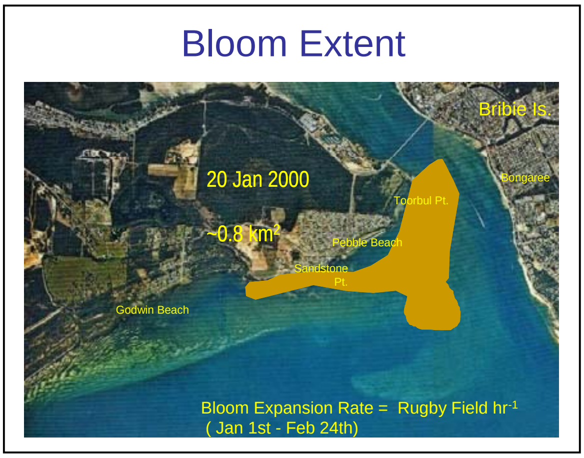
Thank you for this opportunity to present this work to you. The work I'm going to present is the culmination of about 6 to 8 years of research into very extensive blooms of a marine species of cyanobacteria which are occurring along the east coast of Australia. I am sure you are starting to get the impression of what a complex challenge managing and beginning to understand these blooms is. It can only occur through the great inter-linkages between scientists, between managers, between industry and of course between community. And that's the beautiful thing about today, that we all come from one of those groups.

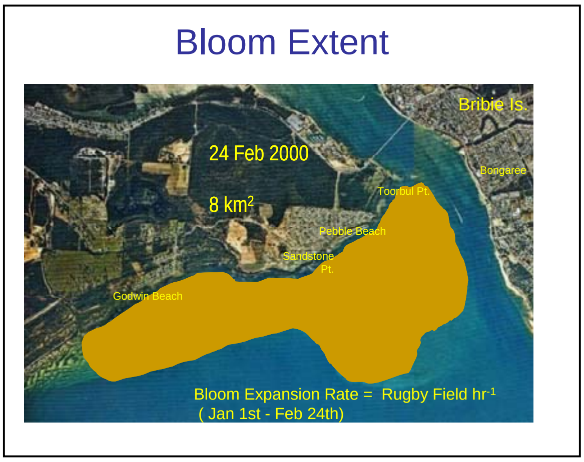
This research that we've been involved in reflects that. We've amassed a fairly large inter-disciplinary team to look at understanding and potentially managing these blooms of cyanobacteria which we are experiencing in Australia. We have Judith O'Neill who is a cyanobacterial expert from the University of Maryland in the US; David Waite and Treadwell Lukondeh who are both marine iron chemists. We have soil scientists, catchment hydrologists, we have marine ecologists, we have remote-sensing experts, as well as the more pure algal physiologists and molecular biologists. So I'm a fairly small part of this large team and I'm going to try and whip through a fairly large amount of the work that we've been involved in over the last few years.

The organism we work on is *Lyngbya majuscula* which is a cyanobacteria, with a filamentous growth form, so it's not a single celled organism like *Anabaena* and

Microcystis. This is a filamentous cyanobacteria with long sheets of filaments which can occur from about 2 cm up to about 30 cm. In a buoyant scenario these filaments grow rapidly and form large bent thick mats of cyanobacteria which occur along the bottom of our shallow estuarine and marine environments. It occurs in a number of habitats. One of the other interesting things about this organism is that it is very toxic, its primary toxins are dermatotoxins. The other interesting factor about this cyanobacteria, as well as some others, is that it's capable of fixing nitrogen, which gives it a great advantage over other traditional green algal species.

The blooms we've been working on are occurring in Moreton Bay which is the largest bay in Queensland, also the largest in the world. Moreton Bay is adjacent to the capital of Brisbane. It's a large semi-enclosed marine environment with a catchment to bay ratio of 16 : 1. So the catchment of this bay is 16 times the size of the bay itself. There's higher pressure with the City of Brisbane of 1 ½ million people, and a lot of agricultural influences in that catchment, it's generally a highly disturbed area. Within the bay we have two major bloom regions of *Lyngbya majuscula*. One is in Deception Bay in the northern region, another is in the eastern part of Moreton Bay in the fairly pristine area of the eastern banks. The work I'll present today is mainly focused around the Deception Bay region, as this has been where the blooms are occurring to the highest population densities, it has been the one of most public concern. These blooms out here, although fairly large in scale, are removed from any human population densities. They are in a very pristine environment and there hasn't been much public pressure to understand those blooms as yet, but certainly as far as the environment is concerned they are fairly important.



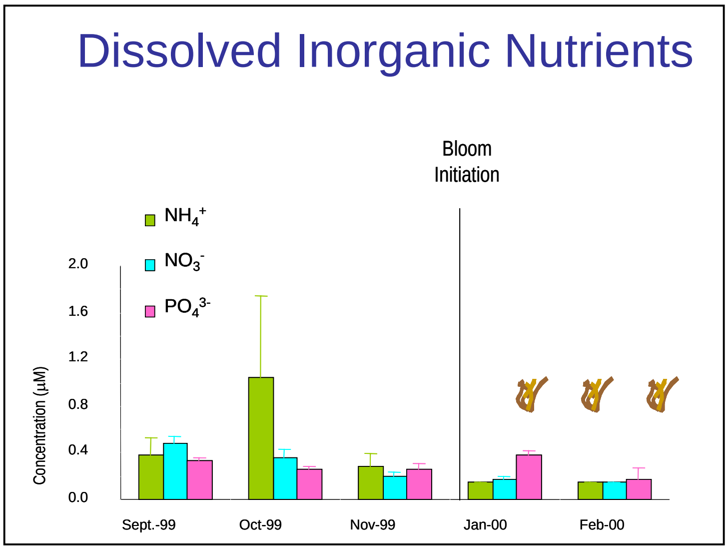


In mapping of one of the larger blooms which occurred back in 2000, as the water warms up we see small patches of this filamentous cyanobacteria occurring on the bottom, growing physically attached to the sea grass, covering initially about 1 square kilometre. After 2 weeks we see rapid expansion and up to 8 square kilometres by mid-February. So for you Kiwis to understand that sort of rate, we're talking about one rugby field per hour of aerial expansion of this *Lyngbya* bloom.

So there were very rapid expansion rates within a matter of 3 to 4 weeks over the summer months. And that's aerial expansion. These blooms can reach anywhere between 1 foot and 4 foot in depth, so we have enormous biomass of this cyanobacteria growing in these shallow marine environments.

As far as the science goes, we've really taken the catchment-wide approach with the understanding that what's occurring in this catchment is affecting the estuarine

environment and is affecting the marine environment and potentially leading to blooms of *Lyngbya*. We've been looking at interactions between the catchment, the estuary and the bloom, and the physiology of the *Lyngbya*. I'm going to step you through each of these regions that we've been looking at and show you a sample of data.



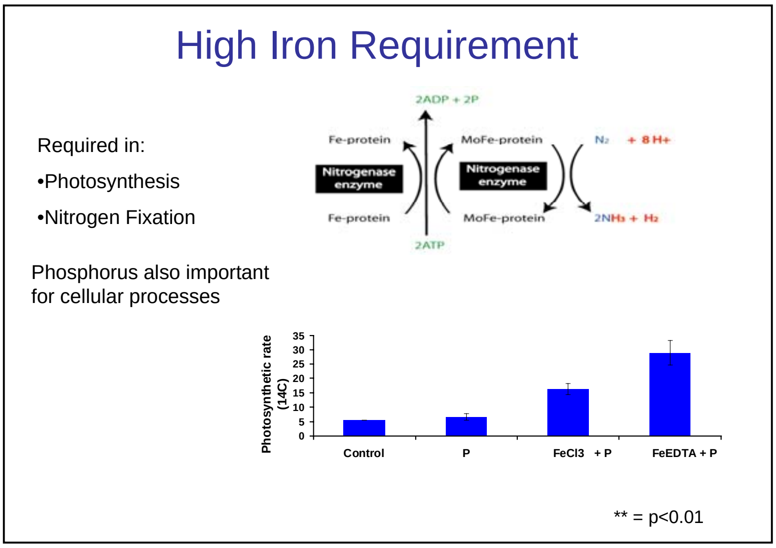
Obviously initially, with a lot of the work from the freshwater environment where cyanobacterial blooms have been occurring for a longer period, we instantly look towards nitrogen and phosphorus. If we look here at dissolved nitrate, ammonium and phosphorus levels within the waters surrounding the bloom site in Deception Bay, we observe these levels are very low. Half a micromolar for most of the elements, with no indication of any increases in these nutrients prior to or following *Lyngbya* bloom events. So given these very low concentrations, and in fact this is a very pristine environment, there wasn't a lot of evidence to suggest that nitrogen and phosphorus were important elements from the water column to promote these blooms.

If we look at monitoring of nitrates from across Moreton Bay, we observed the light blooms between zero and 1 micromolar moving up to the darker colours 10 plus micromolar. We observed that the two regions, eastern banks and Deception Bay where we've been experiencing these cyanobacterial blooms, have very low concentrations of nitrates, of ammonium and of phosphates. (*Illustration unsatisfactory for use*)

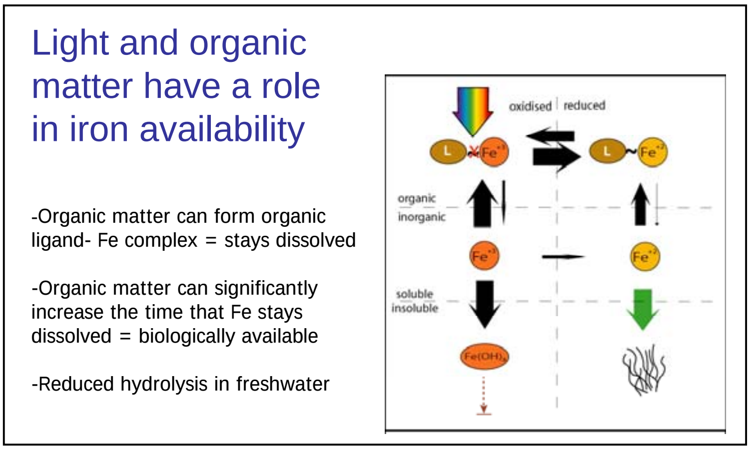
We weren't observing any blooms surrounding these plumes of higher nutrient areas, so there really wasn't any indication that N or P was responsible in stimulating these blooms that suddenly occurred about 5 years ago.
A look towards the catchment and one thing that did stand out was fairly high concentrations of iron, both in the water column and in the sediments. The iron levels in this region of Moreton Bay are far and above that experienced in the other more polluted N & P areas. You can see this image here from one of the creeks (*illustration unsatisfactory for use*)

entering the bloom site, there are very iron-rich sediments. If we look to the literature as Ian Hawes alluded to earlier, we understand that the cyanobacteria have been around for 3 ½ billion years. Back when these organisms evolved, there was no oxygen in the environment but there was a lot of iron available. This was a very iron-rich stage in the earth's history, and also very low nitrogen and phosphorus stages. So these organisms developed a method of fixing their own nitrogen using iron. So the nitrogen fixation process which cyanobacteria utilise to access unavailable atmospheric nitrogen relies heavily on iron to form the sub-units for that enzyme. In conjunction with that, iron is critical in the synthetic pathways of the ferrotoxin electron-shuttling enzymes.

So we understand that iron is critical for cyanobacterial physiology. Some evidence from around the world in the marine environment has indicated that iron-rich Saharan dusts have been responsible for stimulating blooms of cyanobacteria and phytoplankton in the Atlantic Ocean. So they're talking about large scale continental movement of iron-rich dusts stimulating blooms in the open ocean. In laboratory studies we conducted on *Lyngbya* from Deception Bay, measuring photosynthetic rate of the organism, we observed that the addition of phosphorus and also nitrogen had very little impact on photo-synthetic rate, with fairly small insignificant increases. If we add phosphorus in conjunction with inorganically-bound iron, we see significant 3 to 4 fold elevations in the photosynthetic ability of these organisms. This is based on laboratory bioassays carried out in a similar way to those Ian presented earlier.



So the addition of iron enables more fixation of nitrogen, enables higher photosynthetic rates and heads a higher growth rate. Now if we start to look a bit at iron chemistry, and we work very closely with one of the leading iron chemists in Australia, we understand that iron in sea water exists in one of two form: as ferrous iron, the reduced form; or ferric iron, the oxidised form. Generally speaking *Lyngbya* and most other phytoplankton and cyanobacteria are able to use ferrous iron and uptake it into their cells.

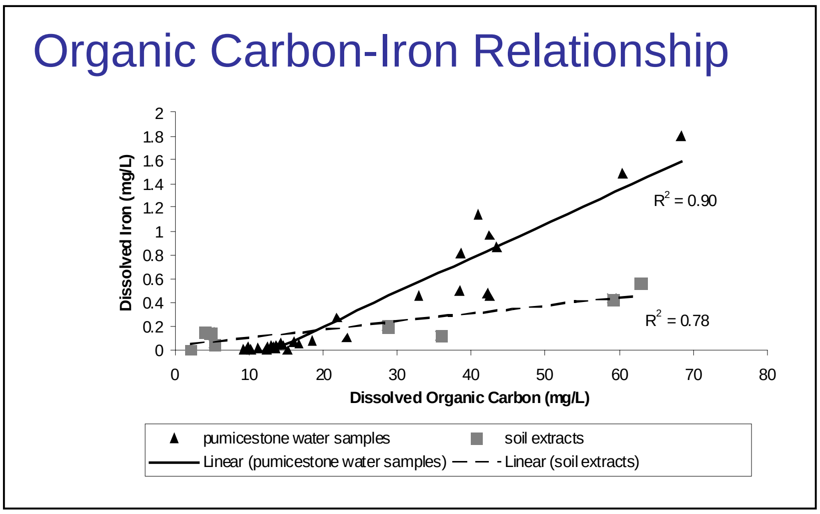


Unfortunately in sea water and with the oxygen-rich environment that cyanobacteria are now exposed to, ferrous iron undergoes rapid oxidation to become ferric iron and then

rapid hydrolysis to become ferric hydroxide precipitates. So all you need to understand is that basically the form of iron that *Lyngbya* and other cyanobacteria enjoy is rapidly oxidised and hydrolysed to become unavailable in sediments. So generally speaking this ferrous iron, this available iron, is only available in concentrations between 2 and 5 nanomolar in sea water. These are very low concentrations and it's generally considered to be the limiting nutrient of cyanobacteria in these low-iron environments such as sea water. The chemistry gets a little bit more complicated if we introduce an organic ligand, an organic molecule or an organic carbon molecule into the equation. In the presence of these organic molecules we observe that both ferrous and ferric iron can become complexed and bound. This enables these species of iron to bond in a dissolved phase in the water column, so if we add organics into the sea water, instead of rapid oxidation and hydrolysis we have complexation which is maintaining the iron in a soluble and hence available form in the sea water. So we understand that organics are critical in maintaining a high concentration of iron in sea water. In the fresh water environment their story is a little bit more complicated and we don't see as much of this hydrolysis occurring and so generally speaking in the fresh water environment iron is more available than in sea water.

We looked for potential sources of these organic molecules and we saw that there are very high concentrations of this organic-rich organic carbon water flowing out of the catchment. This is the humic or tannin stained water that we observed throughout coastal Australia. So these organic-rich waters were potentially having a fairly major role in the iron chemistry of this estuary and of the bloom site. In some monitoring conducted we set up about 45 monitoring stations throughout the bloom site in the catchment and observed dissolved organic carbon concentrations in the water column during a fairly dry period. We observed that between 2 and 5 mg/litre of organic carbon is distributed throughout the catchment. These are fairly low levels.

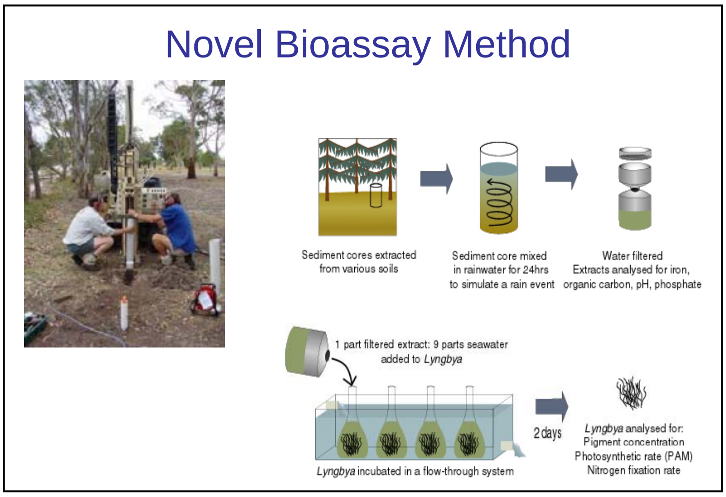
However following rainfall, a significant rainfall event, we see these concentrations increased by a factor of 3 to 4. So we're now seeing in the upper reaches of the catchment something like 40 or 50 mg/litre of organic carbon. This is transferred down to the bloom site where we have increases of two to threefold in the organic carbon concentrations in that sea water following a rainfall event. So this was potentially fairly interesting as a

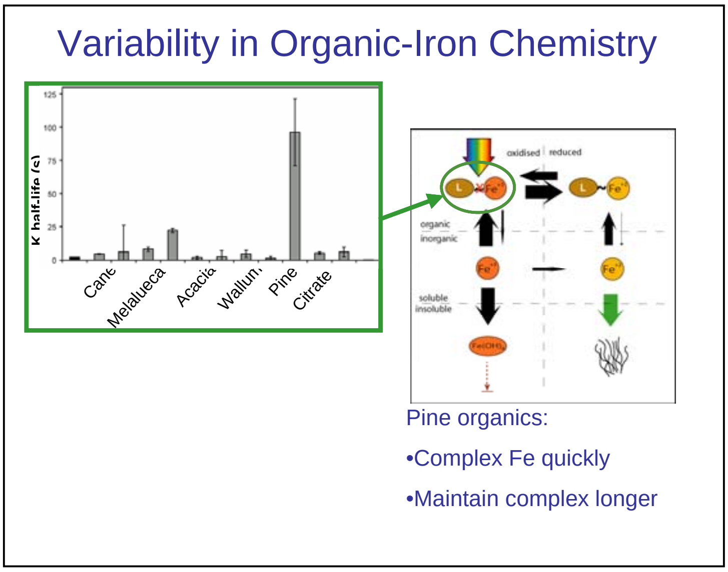


promoter of the bloom, given the importance these organic carbon molecules have in regulating the iron chemistry of the sea water. If we look at the correlation between dissolved organic carbon and dissolved available ferrous iron, we observe that in Pumicestone Passage a fairly linear relationship with increased organic carbon causing increases in dissolved available iron, as represented in the chemical diagram I put up earlier. So, we understand that organics are important and we know that there are significant sources of organics through the catchment. We are interested in how these different sources of organics, organics from different parts of the catchment, could potentially act differently as far as complexation of the iron goes. So we're interested in whether organics from pine trees, from eucalypt trees, from grasses, how those different organics specifically reacted with iron.

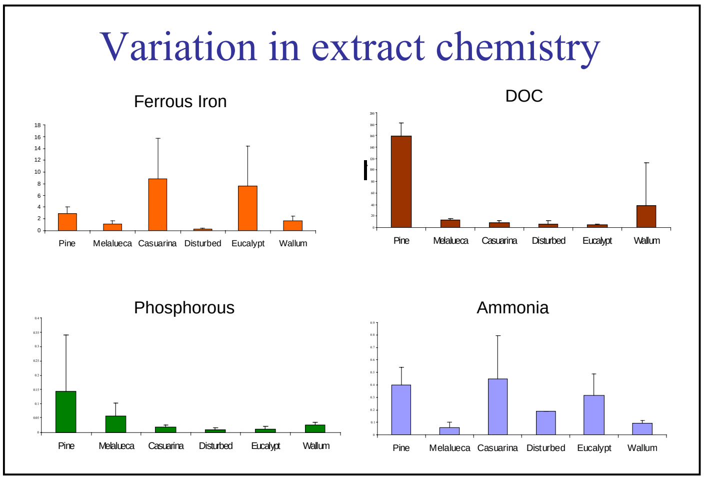
We observed that the organic carbon coming off the exotic pine plantations within the Deception Bay catchment had a far greater ability to complex the ferric iron and maintain it in the soluble phase. With other organic species, although this process still occurred, it occurred at a much slower rate. So the hydrolysis process generally out-competes the complexation in these other species. In the pine organics however, we observe very rapid complexation and very strong organic iron bonding, maintaining its iron in a soluble phase. This was quite interesting from the potential ramifications of the iron in the *Lyngbya* bloom area.

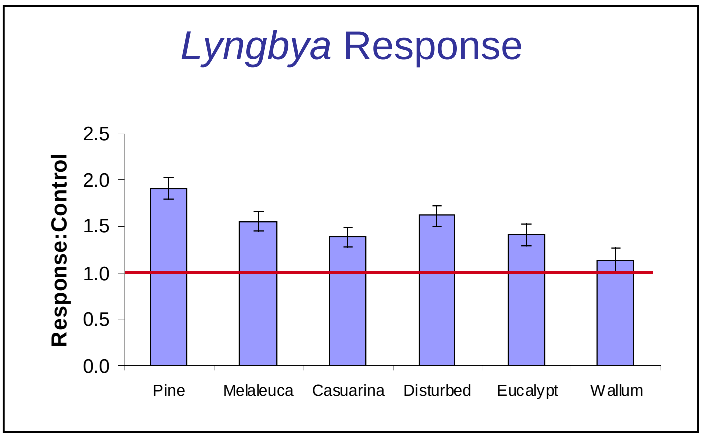
So how did these catchment processes and different catchment land use types relate to the biology and physiology of the *Lyngbya*? We used a fairly rapid, coarse approach to this collecting ground water samples from about 50 to 60 sites across this catchment from a range of different land use types, so these were replicated fairly heavily. We collected from disturbed or recently cleared areas, we collected from exotic pine plantation areas, from native eucalypt, native melaleuca, casuarina and wallum. The methodology was basically inserting shallow piezometers about 3 to 5 metres in with a hydraulic probe. The ground water was then extracted and analysed for its chemical composition and also was used to conduct bioassays. We heard Ian Hawes talk this morning about the bioassays they were conducting in the laboratory with *Anabaena* and *Microcystis*, adding different concentrations of nitrogen and phosphorus and monitoring the response. In these bioassays we've actually





added small concentrations of the groundwater extracted from different land use types throughout the catchment. *Lyngbya* is placed in small glass chambers, a dilution of groundwater is added and the response of the *Lyngbya* is monitored over a 24/48 hour period.



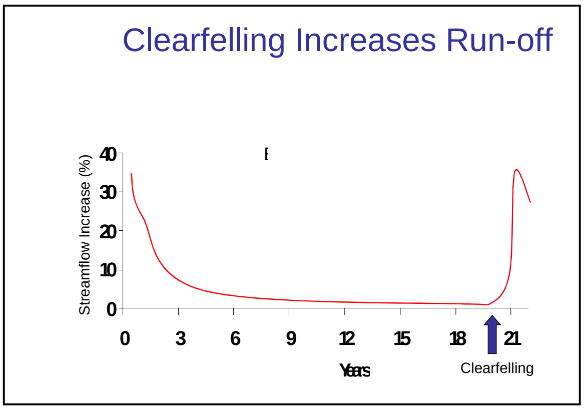


We know the impacts of nitrogen, phosphorus and iron, but we wanted to look at the impact of the cumulative effect of that cocktail of nutrients derived from these various land use types. We observed high variability in ferrous iron, in dissolved organic carbon, in phosphorus and in ammonia concentrations between these different land use types. Wwe were really interested in the cumulative effect of these at different concentrations and how *Lyngbya* reacted to that. The table shows the *Lyngbya* photosynthetic rate as a ratio to the control, with 1.0 being the same photosynthetic rate as the control which was pure sea water, 2.0 being twice that of the control. We observed that across the majority of these different land use types there was a significant increase in photosynthetic rate of *Lyngbya* when groun water from exotic pine plantations, melaleuca areas and disturbed regions were added, with the pine groundwater extract showing the most significant response to photosynthetic rate of *Lyngbya* in the laboratory.

These results were fairly compelling given that we knew from laboratory work the importance of iron in *Lyngbya* growth. We knew from laboratory work the importance of dissolved organic carbon from these exotic pine plantation species on regulating iron concentrations in sea water. So it was interesting to actually observe this effect and make the connection between catchment and the physiology of the *Lyngbya* grown in the laboratory. If we look at the land use regime in this catchment, we observe exotic plantations of *Pinus elliotii*. These are mono cultures similar to what's occurring in the New Zealand region. Approximately 37% of this entire Deception Bay catchment is under exotic pine plantation management which is a fairly high concentration. There are very small urban residential areas in this region, but generally this catchment is rural and considered fairly pristine.

In 1995 we had an extensive bush fire which moved through this region of the catchment. Following that bush fire the managers of these forests were very keen to try and salvage what timber they could, so a large amount of the catchment was clear-felled beyond what

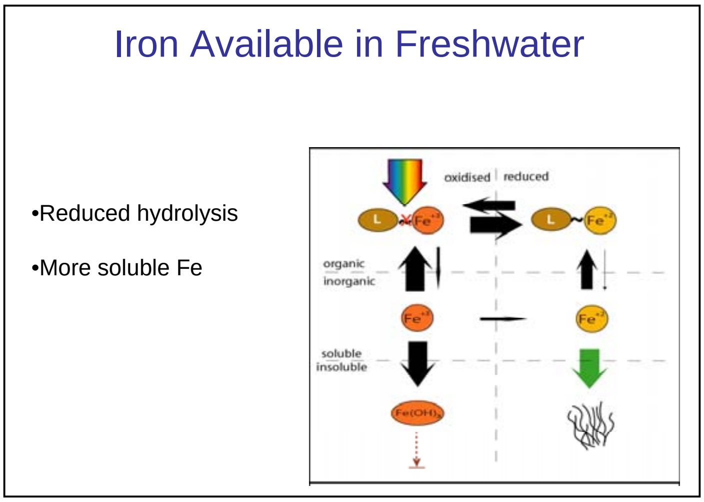
would normally occur. So in the years leading up to the *Lyngbya* blooms, which started in approximately 1996, we had significant catchment disturbance with approximately 10% of the catchment cleared during a very short space of time. This clear-felling is complete clear-felling, it's not selective and so effectively these areas were completely removed of all vegetation in this very short space of time. So this is obviously fairly coincidental with the timing of these very large blooms of cyanobacteria which were occurring at the bottom of this catchment.



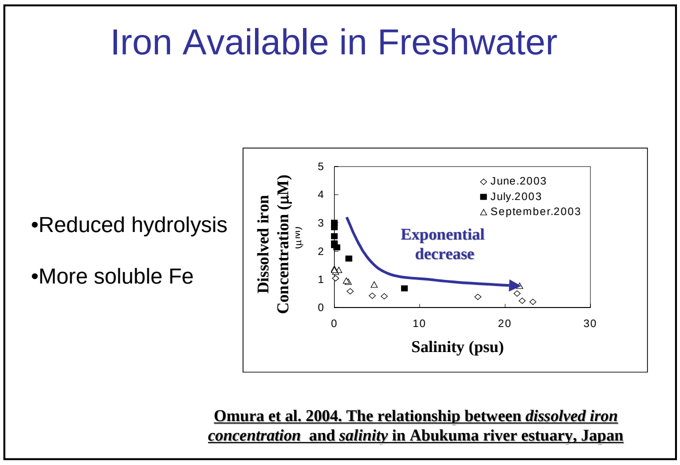
We observed that after plantations were initially cleared there was approximately a 30 to 40% increase in the water yield of that catchment. So if the entire catchment is cleared, 30 to 40% higher loading of water will be yielded from that catchment. Following a 20-year rotation, if that catchment is clear-felled again we see another spike in catchment water yield. Generally speaking, looking at the effects of plantations on catchment water quality, there doesn't seem to be an effect on water quality. The nitrogen, phosphorus and, dissolved organic carbon loads coming off plantation catchments don't appear to be any higher than other catchments, but it's this significant increase in the quantity and the loads of those concentrations that really seems to have the impact. In the 3 to 5 years following a clear-felling event, we see a significant increase in the amount of water and obviously the nutrients that it brings with it coming off that catchment.

So, taking us back to this original schematic diagram, we've observed that in the years leading up to these blooms we saw significant changes in the catchment land use type with large scale clear-felling. We understand that these organics from this land use are very effective in stimulating the growth and photosynthetic capacity of cyanobacteria, we understand that organics from pine in particular have a great affinity for iron and are able to complex it in this available dissolved phase in the sea water. We understand that this iron is able to reach the bloom site and is then able to be utilised by *Lyngbya* in its ferrous form and we observe from laboratory studies that iron is a critical nutrient in stimulating *Lyngbya* productivity. So although there's clearly some missing links, we've started to piece together the different interactions which are occurring through this catchment, the estuary and at the bloom site itself.

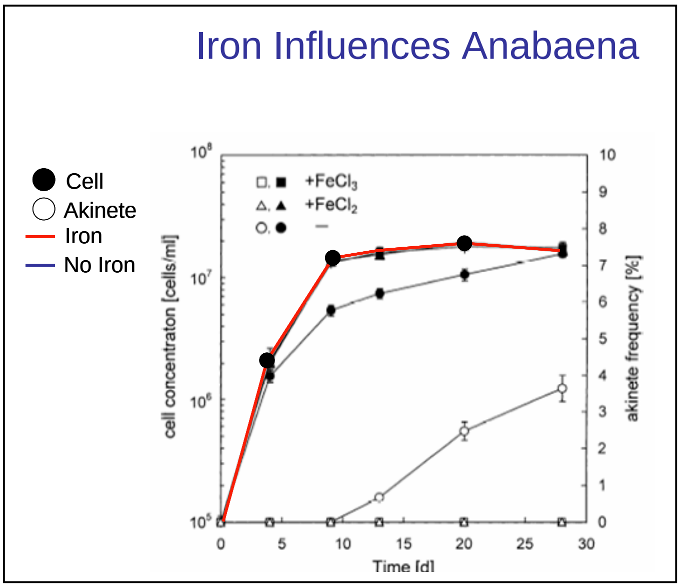
Significant missing links at present are the influence of shallow and deep ground water and the inputs of nutrients. We still need further understanding of the exact transport mechanisms and the time involved for these organic iron complexes to get from the catchment down to the bloom site. We also know very little about the life cycle of *Lyngbya*. What sort of resting structures it has, how does it survive over winter?



So how does all this work relate to what's happening here in Rotorua? Well obviously it's fairly challenging, but in Rotorua there are certainly some parallels with what we observe in Queensland. We have a fairly disturbed catchment, I guess the significant change here is the high N & P loading of the catchments which we've heard about this morning. So what's the role of iron in these environments? Well it's hard to say. I guess the big thing is that in fresh water environments this hydrolysis effect occurs to a much lesser extent, generally speaking in fresh water environments we have higher concentrations of available iron than in the marine system. Hence iron, generally speaking, becomes less limiting to a fresh water organism, because most of it is present in this soluble or complexed stage. In fact some data suggests that iron is so abundant in fresh water that the addition of organic carbon molecules can actually lock the iron up and prevent uptake to the cyanobacteria in the fresh water system.



But basically there's very limited knowledge and understanding of these processes in the environment. We observed some field data here from Japan. We notice that in these lower salinity regions we have an exponential increase in the concentration of available ferrous iron. So certainly in these fresh water lake environments we have a much higher concentration of iron than in the marine system. So potentially it's a less limiting trace element.



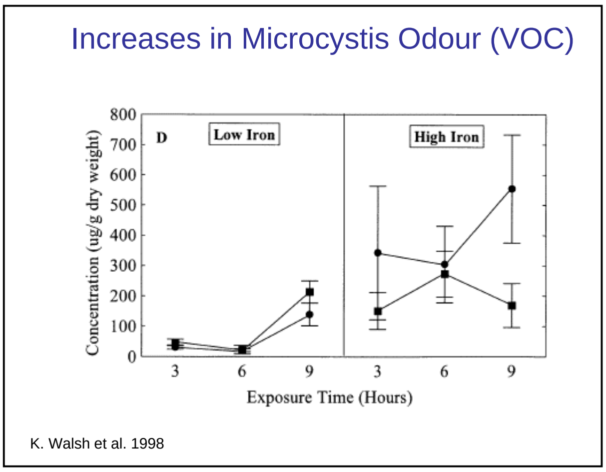
There is some limited data that our group has started to collect on iron acquisition system of *Anabaena* and also *Microcystis*. From the preliminary data it suggests that particularly *Anabaena* has specialised enzymatic processes which are designed to access iron. So the fact that there are these specialised processes indicate that iron is a fairly important nutrient for *Anabaena*, for it to go to the

trouble of developing these specialised enzymatic processes.

There's also some data coming out of Europe which suggests that in *Microcystis* the toxin compounds themselves may act as an iron-binding agent internally within the cells, maintaining iron availability within the cells. So there's a lot of debate over what actual role the toxins in cyanobacteria play and there's some evidence to suggest that one of the roles they play is to act as an organic molecule able to bind that ferrous available iron, maintaining its availability. Increases in cell counts of *Anabaena* have been observed, with the addition of iron in a laboratory bioassay study.

Likewise if we look at akinetes which are the resting or dormant stage in the *Anabaena* life cycle, we observe that akinete formation is significantly increased in low iron environments. The formation of a resting structure such as an akinete indicates that the organism is shutting down and is becoming dormant. So the fact that in iron-limited conditions *Anabaena* elevates its akinete production indicates that iron may be important in regulating its life cycle.

Another piece of data on *Microcystis* is that we've noticed in high iron-rich solutions is that there's an elevation in the volatile odour compounds produced by *Microcystis*, so there is some initial data that those odour compounds could be regulated by iron concentration within the water in which the organism is growing. So is iron important? We understand that there is potential in *Anabaena* for iron to regulate life cycle stages. There is some evidence that *Anabaena* growth can be elevated under elevated iron concentrations. There is evidence to suggest that the volatile odour compounds within *Microcystis* may be regulated by concentration of iron in the lake. And there's also some limited knowledge on the importance of toxins as an iron-binding agent. But there are obvious missing links in this, and the big questions are what really are the iron requirements of species such as *Anabaena* and *Microcystis*, which you experience here.



Missing Links

Iron requirements of freshwater cyanobacteria sp.

Inputs of dissolved iron in Rotorua lakes

Sources and role of organics

The data Ian Hawes presented this morning indicates that potentially there is a fairly low requirement for iron, the iron present in the environment is sufficient, so this is obviously a fairly large question mark. What are the concentrations in these lakes? There doesn't seem to be any actual data on the available ferrous iron concentrations within these lakes, so it's obviously a fairly major interest. And more importantly, what are the sources and role of organics in regulating iron chemistry of these lakes? Are the similar catchment-scale processes involving exotic pine plantations as important in these lake systems as they are in the estuarine marine environment that we experience in Australia. What are the sources, what are the concentrations of organic

carbon coming into these lakes? I guess that's all I've got initially for you, but what I'm really interested in doing is just opening your eyes to the possibilities of these other trace metals and other nutrients that can be important in regulating blooms. Obviously these are very complex problems and it requires us to really draw on as many different skills and disciplines as possible to attempt to manage and mitigate these blooms. Thank you very much.

QUESTIONS

Will Esler, Royal Society of New Zealand, session chair: I'll just make a comment first. In the Rotorua lake sediments there's a band of Mayor Island Tefra that's very high in iron, it's about 5% iron and so it's about 5 times more than any of the local tephras. And just above that layer the diatoms are huge, they are about 20 times the normal size, so maybe there's a connection there.

Chris Hendy, University of Waikato: Simon, can I just add a bit of local information. We've been looking at the pore waters in the sediments and in the ground waters around the lakes and we actually find a lot of iron, but we're talking about dealing with a thousand times the concentrations you are dealing with, they're up into the half a million range in the pore waters. But also a very large amount of manganese and I wonder if you have any thoughts as to any role that manganese might play as well.

S.A.: We haven't done any experiments on manganese itself, we have worked with molybdenum. It appears that molybdenum is definitely important in nitrogen fixation and likewise with iron, but the concentrations in the environment that we work in are not limiting, there's plenty of manganese. As far as the pore water goes, that's something we've been very interested in as well. In an estuarine environment we have about a thousand times the concentration of iron in the pore water compared to the surface water. So the anoxic pore water environment is perfect for maintaining iron in that sort of ferrous state, which is the state that cyanobacteria prefer. In sea water however, due to the oxic conditions of the water that we experience, that pore water is not able to enter the water column and as soon as it is released from the sediments it immediately hydrolyses and precipitates and becomes unavailable in the sediment waters. Obviously in a lake environment with potential anoxic hypolimnion areas, if that pore water is able to escape from the sediments into an anoxic anaerobic water column, then those high concentrations will be maintained in the water column and directly available to the cyanobacteria. So I think pore water is certainly critical in this lake environment.

Raewyn Saville, Rotorua resident: Has the clear-felled area been replanted? If so, do you have the opportunity to measure the nutrients in the run-off and whether it's been reducing as the trees grow?

S.A.: Yes a very interesting question. As I mentioned, these blooms started occurring in about 1996 and this was following that large scale clear-felling we saw after the bush fire in 1995. And that data I showed said that after about 5 to 6 years the effect of clear-felling started to reduce. So, yes the obvious question is are these nutrients, and hence the blooms, decreasing now? The blooms certainly haven't decreased and as far as the nutrients go, our monitoring programmes have been fairly basic in measuring what comes off into the creeks and rivers, and that's highly dependent on recent rainfall events. With

the 5 years of data that we have, we can't detect any long-term trends as yet, but obviously it's certainly hopeful.

Rowland Burdon, Royal Society of NZ: What you have told us in connection with the pines I find extremely interesting in connection with a tale that I recounted I think two symposia ago about third hand information, but it related to the Wairua arm of Lake Tarawera, which rates as pretty oligotrophic. The main catchment was planted up pretty well all at once in *Pinus radiata* and a few years after that planting when canopy closure had occurred, there was a real choke off in the nitrogen inflows and for several winters there were *Anabaena* blooms, despite the relatively low trophic state. Well, a classical explanation would be that the nitrogen-limited state that resulted would have favoured the *Anabaena*, but one wonders whether there might in fact be an influence of the pine in the catchment on inflows of organic iron. Clearly a great deal will depend on whether iron is in fact limiting for cyanobacteria in these lakes. With the high phosphorus levels I understand that it tends to get to a state where ferric iron and phosphorus precipitate each other, but would you like to comment on that?

S.A.: I think that's very interesting. Obviously the reduction in nitrogen and the increase in iron are inter-related. Generally cyanobacteria would prefer to uptake ammonium, it's a much easier process and doesn't involve the fairly expensive creation of the nitrogen-fixation chemicals. So in a higher nitrogen environment cyanobacteria generally have a lower need for iron because the nitrogen-fixation process is shut off, they simply take the nitrogen out of the environment. When that nitrogen is decreased like you mentioned in the Tarawera catchment, suddenly the need for iron is elevated because they can use this iron to create nitrogen-fixation enzymes and make their own nitrogen. So the crux of the story is if there is enough iron available, then nitrogen becomes less limiting because the nitrogen fixation process can occur. So certainly in that environment if the introduction of *Pinus* species were to cause decreasing nitrogen in conjunction with increasing organic available iron, that's the perfect situation for nitrogen-fixing cyanobacteria such as *Anabaena* to occur. I think that story is certainly interesting, but really without some more work it would be hard to pin that down. It's interesting that you mention *Anabaena* was the blooming species. I understand it has much higher nitrogen-fixation rates than *Microcystis*. I'm not sure if anyone has been measuring nitrogen-fixation in these lakes, but certainly we see very high rates of nitrogen-fixation by the *Lyngbya* that we're working on. And that's actually an input of nitrogen into the system. So the blooms every year are equivalent to about three large sewage treatment plants with the amount of nitrogen they're fixing out of the atmosphere and inputting into the system.

Jan Sprosen, AgResearch: I'm interested in the toxin side of things. Have you done much work on that? Do you know when toxin has been produced and what may be the reasons for that, any iron influences or the nutrient influences on that?

S.A.: The blooms we're working on in Moreton Bay show very variable toxin production rates. Generally speaking, at the start of the bloom toxins are very low and the toxic concentrations in the tissue are very low. Towards the peak and towards the end of the bloom is really when toxin production is ramped up, so we see five to tenfold increases in toxin production towards the end of the bloom compared to at the start. As to why that occurs, it's one of our interests and there's certainly a theory that the nutrient environment in which the organism is living is determining the toxin production. That data I showed on the potential for these toxins to be an iron-binding agent is very interesting. Obviously

towards the end of the bloom iron becomes more limiting, so potentially they are ramping up toxin production to access more of that iron. But a definite answer we haven't been able to get yet.

Mary Stanton, Te Arawa Iwi: I'm very interested in what you have spoken about regarding pine trees. Can you tell me does pollen have any effect on our water quality when you're dealing with nitrogen, phosphate and iron? Because looking at management around our lakes, pine trees are not naturally from New Zealand, they came from Canada where there are gigantic rivers to push out the flow that you get from the pollen. I'm interested to know whether pollen has any effect on our water quality. Our trees around here are being felled and we are going into second rotation and when I look at the date spans of the worst times our water quality is affected, I cannot help but think is there something to do with pollen? It is air pollution and surely it must affect the ground and water quality.

S.A.: I can't comment on pollen specifically, it's not something we've ever considered. I think the relationship with pine is fascinating but as far as the pollen, I can't see any specific role that would be playing, but certainly the organic debris following clear-felling and the leaves and the branches and whatnot that are left behind greatly elevates the organic carbon concentration in the soil and that's the real impact we see, rather than from pollen.

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Assessment of phosphorus loss risks from agricultural soils in Rotorua Lakes catchments

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BACKGROUND

Phosphorus (P) has been implicated in the eutrophication of some of the Rotorua lakes and agriculture is one of the possible sources for this. Fertiliser application to pasture land and grazing produces a build-up of the phosphorus content of soils. It is well known that phosphorus added as fertilizers can be retained in the topsoil, especially where the soils are highly phosphorus retentive. However, the sandy nature of many of the Rotorua soils, and low phosphorus retention by some of the soil horizons may allow leaching of phosphorus down the soil profile, and eventually into groundwater.

AIMS

This project aims to identify the potential extent of P movement down the profile of a range of Rotorua soils under pasture located in the catchments of lakes Rotorua, Tarawera, Rerewhakaaitu and Rotoiti. We did this by:

1. Measuring the P retention properties of soil samples taken from these soils at depths between 0 and 1.5 m;

2. Measuring Olsen P values in these soils samples.

Olsen P values of subsoils which have not been exposed to fertiliser or waste P inputs are very low (Perrott et al. 1999) and can provide a very sensitive indicator of phosphorus movement down the profile. The P retention and Olsen P measurements enabled us to assess the ability of the topsoils to retain P in their surface layers and identify situations where previous movement of P down the profile has occurred.

MATERIAL AND METHODS

The predominant pastoral land use in the catchments, especially closer to lakes, is sheep/beef and dairying followed by beef/bull or beef grazing and this was reflected in our sampling regime (Table 1). We sampled 17 farms from the Lake Rotorua catchment, four each from Lake Tarawera and Rerewhakaaitu catchments and 2 samples from Lake Rotoiti catchments. Twenty eight sites were selected for sampling based on soil type and P retention information. Further information is given in Table 1.

An area of 25 m^2 was sampled from each sampling site. Sampling was from 0 - 150 cm depth. Three deep cores (0 – 150 cm) were collected from each site using a motored mechanical auger. Each deep core sample was divided into the following depths: 0-10, 10-20, 20-40, 40-70, 70-100 and 100-150 cm.

Soils were sieved (4 mm) and air-dried (35°C). Olsen P (Olsen et al. 1954) and P retention capacity (Saunders and Williams 1965) (also known as anion storage capacity - ASC) measurements of these soils were made on the air-dried samples. Total organic carbon (C) (by combustion method using a Leco furnace), total nitrogen (N) and total phosphorus (P) were measured on the 0 – 10 and 10 – 20 cm samples.

RESULTS AND DISCUSSION

Land use and Olsen P in surface soils

Dairying needs to maintain high levels of soil fertility to sustain the high dry matter production necessary for economically sustainable dairy farming and is therefore the most fertilized pastoral agriculture in the area. For dairy farms located on pumice soils the targeted Olsen P values for near maximum production in the top surface (0-7.5 cm) is between 35-45 µg P ml^{-1} soil (Roberts and Morton, 1999). In this study we sampled at 0-10 cm instead of 0 – 7.5 cm. Consequently, we expect dilution with soils from below 7.5 cm giving lower Olsen P values than if sampled at the standard 0 – 7.5 cm used for soil fertility estimation. Using the targeted values as the basis for optimum level of Olsen P in surface soils, survey results show that 66% of the sites sampled from dairy farms had Olsen P values greater than the targeted levels (Table 2). Considering the effect of the dilution factor due to greater depth of soil sampling we suggest that most of the dairy farms sampled in this study would have greater Olsen P values than required for the near maximum production. A possible exception to this is on very coarse soils from Tarawera/Matahira gravels where previous research suggests optimum Olsen P for near maximum production is approximately 50-60 µg P ml^{-1} soil. Two of the dairy sites located on these soils showed values of 61 and 66 µg P ml^{-1} soil (sites 27-28).

The Sheep/beef farms that were sampled had appropriate Olsen P levels for meeting the herbage production demand of this type of land use. The values ranged between 10-25 µg P ml^{-1} soil. These values are consistent with those reported by Wheeler et al. (2004). These workers analysed over 240,000 data from a commercial laboratory and concluded that mean value of Olsen P in pumice soils that are grazed by sheep/beef was 20 µg P ml^{-1} soil.

Because of the smaller number of the samples from other land uses (2-4 farms), we cannot draw any conclusions on the range of Olsen P values existing on other land use sites. However, 2 dairy run-off farms (sites 14 and 15) sampled showed higher levels of Olsen P than expected (51 and 73 µg P ml^{-1} soil), even for dairy farms. For comparison purposes, two sites in maize paddocks were included. These showed medium to high levels of Olsen P values (27, 33 µg P ml^{-1} soil) in the surface soils.

Anion Storage Capacity (ASC)

Table 5 shows the ASC results for each site. We can classify ASC values into high (> 70%), medium (30-69%), and low (< 30%) categories. Only five sites namely 7, 8, 9, 13 and 23 had high levels of ASC throughout the soil profile. Therefore these sites have a potential to accumulate large amounts of fertiliser P in the soil profile and consequently pose no threat to groundwater pollution through P leaching. Seven of the sampled sites (4, 6, 16, 17, 19, 22 and 25) had medium ASC values throughout their profiles. These sites

have the potential to accumulate significant amounts of P throughout the profile. If P leaching from surface soils occurs when P accumulation exceeds the P storage capacity within the top soils, then the leached P will be adsorbed in the lower horizons. We expect that these sites would contribute very little P to groundwater through leaching.

There were four sites which had low ASC values throughout the profile (12, 24, 27, and 28). Because of their poor P retentive capacity, movement of fertiliser P to lower horizon in these sites is most likely to occur. There were a few sites which had combination of high-medium, medium- high, low-medium or low-high or high-medium-low levels of ASC values at different depths of the profile (sites 2, 3, 5, 10-12, 14-15, 18, 20-22 and 26). Variations of ASC values in these profiles were dependent on the presence of ash layers at specific depth. The risk of P leaching to groundwater from these sites would depend on the distribution of high or low P retentive capacity of soil layers with in the soil profile, as well as agricultural P inputs.

Olsen P distribution with depth

Soil samples from lower depths from each site were also analysed for Olsen P to determine if there was any detectable movement of soluble forms of P from surface soil to lower profiles. These results are presented in Table 6.

Perrott et al. (1999) found that the natural background level of Olsen P in pumice subsoils is generally around 1 or 2 µg P ml^{-1} soil. With the current set of sites the data in Table 6 suggests natural background Olsen P values of <5 µg ml^{-1} soil. Therefore, Olsen P values >5 µg P ml^{-1} soil in the lower horizons would indicate movement of fertiliser P from surface soil down to lower horizons. Some of the sites have medium-lower ASC values (e.g. sites 1, 4, 10, 19 and 26) but Olsen P values in the lower horizons are either equal of less than 5 µg P ml^{-1}. However, this does not necessarily mean that leaching of P is not occurring. It could be that lower horizons, which have low ASC values, are unable to retain much of the soluble P and hence allow soluble P to move to ground water. This aspect needs to be evaluated in further studies.

The Olsen P values for sites 3, 11, 14, 15, 17, 18, 20, 21, 24, 27 and 28 clearly showed signs of movement of soluble fertiliser P to lower horizons. There is therefore potential at these sites for P leaching to groundwater and then possibly to the surrounding lakes. These movements are generally well correlated with ASC capacity of soils, the lower the ASC capacity of the soil, the higher the movement of the soluble P to lower profiles. The extent of movement of P to lower horizons would depend on the amounts of cumulative application of fertiliser P over time, utilisation efficiency of fertiliser P, ASC capacity of soil, amounts of rainfall and groundwater table. Our survey results show that over third (36%) of the sites sampled from the pastoral sites located in the lakes Rotorua, Tarawera and Rerewhakaaitu and Rotoiti catchments have the potential to contribute P to groundwater.

Total P accumulation

It is difficult to make any comments on the rate of accumulation of P in soils as total P due to lack of any historical data of total P from any of the sites that were sampled. The amounts of total P in the surface soils varied considerably ranging from 430 to 2100 µg P g^{-1}soil (Table 3). These values provide a snap shot of the total P level in soils around the

lake catchments. Any loss of surface soil due to erosion or runoff would contribute significant amounts of total P to surrounding lakes. The amounts of total P in the surface layer of these pastoral soils appeared to be considerably higher when compared to a forestry site planted in 1990 on Whakarewarewa sandy loam which had 307 µg P g^{-1} soil of total P (Perrott et al. 1999). This clearly shows accumulation of fertiliser and dung P in the pastoral soils. If we use the total P values at the forestry site as a benchmark which could have inherently a low level of total P, it would appear that some of the pastoral sites that we have sampled have accumulated up to 7 fold higher amounts of total P. These values are also 2-5 times higher than those reported by Perrott et al. (1989) for undeveloped yellow-brown pumice soils. Higher total P values in these pastoral sites are due to sustained topdressing with P fertiliser which in turn would result in a greater return of dung from grazing animals and plant litter helping to build the total organic matter which also contains significant amounts of P.

Total C, N and P

Total organic C and total N were also determined in the surface samples to assess the quality of soil organic matter in the surface soil. Results are shown in Table 3. The minimum and maximum values have been highlighted in the table. There was a wide range of total organic C and total N in these soils. Also there was a wide spread of ratios between these two nutrients in soils but most of the soils had C:N ratio between 11:1 and 14:1. This is also reflected in Fig. 1 which shows good correlation between total organic C and total N in soils. There was relatively poor correlation between total organic C and total P and between total N and total P (Fig. 1). This is understandable as total P is not entirely present in the soil organic matter. Soil parent material may also plays a significant role in the total P concentrations in soils as some soils have parent materials which are rich in apatite.

CONCLUSIONS

Based on the increased P levels with depth in some soils coupled with low anion sorption capacity of soils, there are some pastoral sites where soluble P either from fertilisers or mineralised from soil organic matter has moved down to lower profiles. In some case movement is detectable beyond 100 cm depth. Our study shows that contamination risk of P movement to groundwater from pastoral sites through leaching may be occurring particularly in soils that have low ASC values. This could be examined further by assessing P concentrations in groundwater in different areas/catchments and different P histories and soil characteristics.

QUESTIONS

Chris Hendy, University of Waikato: I would like to know just what your concentrations are even under the high ASC soils in the soluble phosphorus at depth. The reason for asking is that even one microgram of phosphorus per millilitre in the ground water is quite a high concentration to see going into a lake. And if this is being achieved underneath those soils, it could be quite an important source of higher phosphorus.

A.G.: Typically the levels of Olsen P in high ASC soils which we have measured ranged between 1 to 3 maximum. The Olsen P determination also measures a very small fraction

of organic P as well if there is any, so it's not like a water extract situation, it's slightly more.

Name not recorded: Could you show us on the screen the soil map and could you point out where the troublesome soils are on that map please?

A.G.: These, out of 28 sites, are the 7 sites which showed greater amounts than 5 mcg of phosphorus per ml (volume-based measurement for Olsen P). So it shows that we need to really know a little bit more about this, so that we can manage things better. Typically phosphorus leaching is not something which is an upper concern, but because being a porous soil which we have got here, we need to be aware of it.

Name not recorded: Now am I right in saying that site 11 up there is Wairenga Dairy Farm, a very large dairy farm, is that correct? Because they put on a lot of fertiliser and if there's a problem it may be shared with other dairy farms in the Rotorua area. Thank you very much Dr Ghani.

*Charles Sturt, Rotorua District Counci*l: Can you go back to that map please, of your phosphorus survey. We have a major problem and some of the other papers have highlighted it, with the Hamurana and Taniwha Springs, with the levels of contamination that is coming through the spring system and the gentleman who is chairing the meeting said there are some major dairy farms. Was that site at Te Wairenga Road and the other one up Oturua Road? Are they in close proximity to those springs in terms of the water and the flow on effects? Because there is double the rainfall up there that there is in the city, so I just wondered if you had taken that into account when you did your phosphorus counts.

A.G.: I would like to pass that down to Martin (Hawke) to explain the relative locations, in terms of what we have measured at the time. How this relates to the movement of water at those depths, perhaps we can extrapolate from the paper which was presented earlier on.

Martin Hawke: No neither of these sites were anywhere near the springs. The one at Oturoa Road was where the sharp bend is, on a lifestyle block. The one in Wairenga Station was well to the right of Hamurana and to all the facilities there. We certainly didn't connect those to the springs at all.

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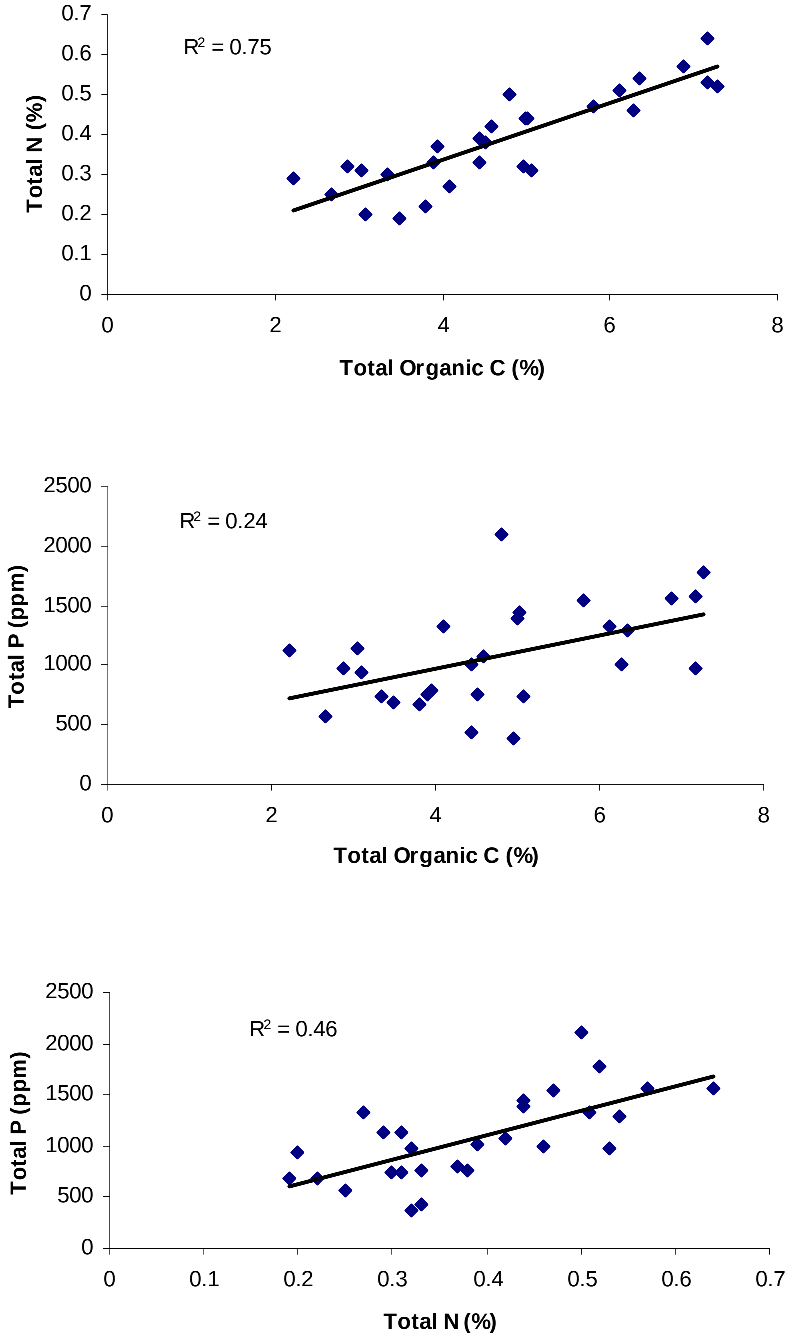

Figure 1: Correlations between total organic C, total N and total P in surface soils.

Table 1. Some details of the pastoral sites that were sampled from the lakes in Rotorua area.

Site No.	Farmers detail	GPS Location	Land use	Distance (km)	Soil type	Soil Grouping	Lakes
1	Wharenui Stn, Gee Rd., NWTL	E 2800261, N 6335592	Dairy	2	Rotomahana shallow sandy loam	Recent on YBP	Rotorua
2	Wharenui Stn, Gee Rd., NWTL	E 2801973, N 6336175	Dairy	2.5	Rotomahana shallow sandy loam	Recent on YBP	Rotorua
3	Wharenui Stn, Gee Rd., NWTL	E 2800973, N 6337434	Dairy	1	Te Ngae loamy sand	Recent	Rotorua
4	Tony Carr, Te Ngae Rd	E 2802025, N 6339485	Bull beef	0.5	Te Ngae loamy sand	Recent	Rotorua
5	Tony Carr, Te Ngae Rd	E 2801766, N 6339266	Bull beef	0.5	Te Ngae loamy sand	Recent	Rotorua
6	Ngongotaha Stn., NWTL	E 2791796, N 6341150	Sheep/beef	1	Ngakuru Sandy loam	YBL	Rotorua
7	Ngongotaha Stn., NWTL	E 2790142, N 6340880	Sheep/beef	2.5	Ngakuru Sandy loam	YBL	Rotorua
8	Bill Gibbs, Dalbeth Rd	E 2789495, N 6344750	Dairy runoff/Dry stock	3.5	Oropi Hill soil	YBP on YBL	Rotorua
9	Peter Schweizer, Central Rd	E 2789786, N 6348802	Dairy	4.5	Oropi Sand	YBP on YBL	Rotorua
10	Barry Russell, Te Waeranga Rd	E 2795661, N 6349148	Sheep/beef	2.5	Oropi Sand	YBP on YBL	Rotorua
11	Waeranga Stn, Mourea	E 2801872, N 6347221	Dairy	1.5	Oropi Sand	YBP on YBL	Rotorua
12	Waeranga Stn, Mourea	E 2802326, N 6345976	Dairy runoff/Dry stock	0.5	Waiowhiro sand/Utahina peaty loam	Gley/organic	Rot/Rotoiti
13	Tihiotonga Stn, Otonga Rd., NWTL	E 2793129, N 6331484	Sheep/beef	4.5	Ngakuru Sandy loam	YBL	Rotorua
14	E. Wilcox, Owhata	E 2797998, N 6335545	Dairy runoff/Dry stock	0.5	Waiowhiro sand	Gley	Rotorua
15	Hinemoa Pt(B. Cornwell)	E 2798609, N 6336656	Dairy runoff/Dry stock	0.5	Ngakuru Sandy loam	YBL	Rotorua
16	Tony Carr, Te Ngae Rd	E 2803478, N 6339127	Sheep/beef	2	Rotoiti loamy sand	Recent on YBP	Rotorua
17	Trust, Te Ngae Junction	E 2801798, N 6341437	Maize	0.5	Te Ngae loamy sand	Recent	Rotorua
18	Trust, Te Ngae Junction	E 2801661, N 6341147	Maize	<0.5	Waiowhiro sand	Gley	Rotorua
19	Tikitere, AgR	E 2802832, N 6344153	Bull beef	0.5	Rotoiti loamy sand	Recent on YBP	Rotoiti
20	Crater Farm, NWTL	E 2806187, N 6332192	Deer	1	Rotomahana sandy loam	Recent from Mud	Tarawera
21	Crater Farm, NWTL	E 2806635, N 6332332	Deer	1	Rotomahana sandy loam	Recent from Mud	Tarawera
22	J. Ford, Highlands Stn	E 2804028, N 6322542	Sheep/beef	6.5	Rotomahana hill soil	Recent from Mud	Tarawera
23	J. Ford, Highlands Stn	E 2802069, N 6322289	Bull beef	5	Rotomahana sandy loam	Recent from Mud	Tarawera
24	Rainbow Farm, Fairy Springs Rd	E 2792883, N 6339100	Dairy runoff/Dry stock	1	Waiowhiro sand/Utahina peaty loam	Gley/organic	Rotorua
25	C.Sutton, Yankee Rd, Rerewhakaaitu	E 2814085, N 6312498	Dairy	1	Te Rere shallow sand	Kaharoa Ash-YBP	Rerewkakaaitu
26	J.Mascall, Yankee Rd, "	E 2814631, N 6313621	Dairy	0.5	Te Rere shallow sand	Kaharoa Ash-YBP	Rerewkakaaitu
27	S.Marshall, Ash Pit Rd, "	E 2819521, N 6316556	Dairy	0.5	Matahina gravel	Recent, from Tarawera Ash	Rerewkakaaitu
28	B.Osbourne, Ngamotu Rd, "	E 2820104, N 6317193	Dairy	1	Matahina gravel	Recent, from Tarawera Ash	Rerewkakaaitu

Table 2: Olsen P levels in the surface (0-10 cm) soils. Values exceeding the maximum targeted levels recommended for dairy farms are bolded.

Site No.	**Land use**	**Olsen P (μg P ml^{-1} soil)**
1	Dairy	**53**
2	Dairy	42
3	Dairy	**51**
4	Bull beef	**47**
5	Bull beef	19
6	Sheep/beef	11
7	Sheep/beef	12
8	Dairy runoff/Dry stock	10
9	Dairy	22
10	Sheep/beef	21
11	Dairy	**78**
12	Dairy runoff/Dry stock	16
13	Sheep/beef	24
14	Dairy runoff/Dry stock	**73**
15	Dairy runoff/Dry stock	**51**
16	Sheep/beef	29
17	Maize	27
18	Maize	33
19	Bull beef	11
20	Deer	11
21	Deer	24
22	Sheep/beef	14
23	Bull beef	31
24	Dairy runoff/Dry stock	18
25	Dairy	40
26	Dairy	**61**
27	Dairy	**61**
28	Dairy	**66**

Table 3: Some chemical characteristics of surface soils (0-10 cm depth) collected from 28 pastoral sites in Rotorua lakes catchments. Maximum and minimum values have been highlighted.

Site No.	Total Organic Carbon (%)	Total Nitrogen (%)	Total Phosphorus (PPM)	C:N ratio	N:P ratio	C:P ratio
1	5.81	0.47	1550	12 : 1	303 : 1	3749 : 1
2	5.02	0.44	1450	11 : 1	303 : 1	3462 : 1
3	3.09	**0.20**	945	15 : 1	211 : 1	3269 : 1
4	4.99	0.44	1385	11 : 1	317 : 1	3602 : 1
5	2.87	0.32	975	9 : 1	328 : 1	**2943 : 1**
6	4.44	0.39	1010	11 : 1	386 : 1	4396 : 1
7	6.87	0.57	1555	12 : 1	366 : 1	4418 : 1
8	7.17	**0.64**	1570	11 : 1	407 : 1	4566 : 1
9	7.16	0.53	975	14 : 1	543 : 1	7343 : 1
10	3.80	0.22	675	17 : 1	325 : 1	5629 : 1
11	3.49	0.19	690	**18 : 1**	275 : 1	5057: 1
12	4.44	0.33	430	13 : 1	767 : 1	10325 : 1
13	**7.28**	0.52	1785	14 : 1	291 : 1	4078 : 1
14	4.80	0.50	**2100**	10 : 1	238 : 1	2285 : 1
15	4.09	0.27	1325	15 : 1	**203 : 1**	3086 : 1
16	3.95	0.37	795	11 : 1	465 : 1	4968 : 1
17	4.52	0.38	755	12 : 1	503 : 1	5986 : 1
18	6.28	0.46	1000	14 : 1	460 : 1	6280 : 1
19	4.96	0.32	**380**	15 : 1	**842 : 1**	**13052 : 1**
20	2.67	0.25	565	10 : 1	442 : 1	4725 : 1
21	3.90	0.33	760	12 : 1	434 : 1	5131 : 1
22	3.35	0.30	745	11 : 1	402 : 1	4496 : 1
23	6.35	0.54	1295	12 : 1	416 : 1	4903 : 1
24	6.11	0.51	1320	12 : 1	409 : 1	4628 : 1
25	4.59	0.42	1080	11 : 1	388 : 1	4250 : 1
26	5.07	0.31	745	16 : 1	416 : 1	6805 : 1
27	3.04	0.31	1140	10 : 1	272 : 1	2667 : 1
28	**2.21**	0.29	1130	**8 : 1**	257 : 1	1956 : 1

Table 4: Distribution of percent anion storage capacity (ASC) in soils at various depths.

Soil depth (cm)	Site numbers and % ASC in soils																											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
0-10	42	41	13	38	35	58	77	82	76	25	27	37	66	45	34	35	40	40	44	27	22	36	57	21	43	34	15	17
10-20	46	44	7	39	24	41	81	84	84	33	24	25	50	39	39	38	40	34	30	28	36	28	57	28	41	40	11	14
20-40	59	59	25	50	34	40	76	71	95	79	52	12	78	62	23	44	37	28	36	13	15	14	60	10	46	48	9	4
40-70	64	80	47	66	65	50	66	63	86	65	83	26	81	36	17	66	60	46	61	19	51	48	71	12	33	36	10	3
70-100	55	61	62	51	79	61	70	85	83	53	55	*	80	21	36	67	59	23	63	41	46	63	70	2	48	30	6	5
100-150	41	55	50	35	72	57	79	91	77	45	47	*	81	16	55	57	47	16	48	42	51	54	73	10	44	25	7	1

Table 5: Distribution of Olsen P (µg P ml^{-1} soil) levels in soils at various depths.

Soil depth (cm)	Site numbers and Olsen P (µg P ml^{-1} soil)																											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
0-10	53	42	51	47	19	11	12	10	22	21	78	6	24	73	51	29	27	33	11	11	24	14	31	18	40	61	61	66
10-20	17	15	23	15	8	6	6	3	2	13	54	3	9	89	59	10	14	19	17	3	14	3	14	6	8	15	67	49
20-40	5	6	6	6	4	4	3	2	1	3	20	3	3	29	24	5	3	11	8	4	10	3	5	3	3	3	35	26
40-70	3	3	4	3	3	3	3	2	1	2	3	3	3	8	14	2	3	8	3	4	4	3	2	4	1	1	23	14
70-100	3	3	4	3	3	3	2	1	1	3	4	*	2	10	8	2	4	5	3	11	4	2	2	4	1	1	13	11
100-150	4	5	5	3	2	4	2	1	1	3	5	*	2	11	9	2	7	8	3	10	3	1	2	5	1	2	15	9

Microcystins in Rainbow Trout, Freshwater Mussels and Phytoplankton in Lakes Rotoiti and Rotoehu

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ABSTRACT

Cyanobacteria in water bodies can produce cyanotoxins. A range of cyanotoxins has been found in the Rotorua Lakes and at times microcystin concentrations in Lakes Rotoiti and Rotoehu have reached levels that are potentially dangerous to humans involved in recreational activity on or in these lakes.

Microcystins are known to accumulate in freshwater organisms. In this study we investigated the accumulation of microcystins in rainbow trout (*Oncorhynchus mykiss*) and freshwater mussels (*Hydridella menziesi*) in Lakes Rotoehu and Rotoiti. The study involved using both trout that had access to the entire lake and hatchery trout added to an enclosure in Lake Rotoiti where microcystin levels in the water and cell counts could be closely monitored. Microcystins in water samples, trout liver, trout muscle tissue and in the mussels were analysed using the ADDA-ELISA method.

A maximum microcystin level in the water samples of 760 $\mu g\ l^{-1}$ was recorded in Te Weta Bay, Lake Rotoiti, in March 2004. The ELISA results also confirmed the presence of microcystins in trout liver and muscle tissue, and in freshwater mussels. The Total Daily Intake for microcystins intake recommended by the World Health Organisation for human consumption is 0.04 $\mu g\ kg^{-1}\ day^{-1}$. A 70 kg human consuming 300 g of trout muscle tissue from Lakes Rotoiti and Rotoehu would have exceeded this level in 50% - 71% of the samples. Health problems could result if more than 300 g of trout muscle tissue was consumed on a regular basis over an extended period.

Key words
microcystins, cyanobacteria, rainbow trout, freshwater mussels, Lake Rotoiti, Lake Rotoehu

1. INTRODUCTION

Cyanobacteria (blue-green algae) in waterbodies can produce cyanotoxins, which are hazardous to humans exposed to them through recreational activities, or via ingestion of contaminated drinking water and food.

Cyanotoxins include the cyclic peptides (microcystin and nodularin), the alkaloids (cylindrospermopsin, anatoxins and saxitoxins) and lipopolysaccharides (LPS). Table 1 (adapted from Chorus and Bartram (1999)) presents the known cyanotoxins, the primary toxicological target in mammals, and examples of the cyanobacterial genera that produce each toxin.

Toxin Group and Toxin	**Primary Target in Mammals**	**Cyanobacterial Genera**
Cyclic Peptides		
Microcystins	Liver	*Microcystis, Anabaena, Planktothrix, Nostoc, Hapalosiphon, Anabaenopsis*
Nodularin	Liver	*Nodularia*
Alkaloids		
Anatoxin-a	Nerve synapse	*Anabaena, Planktothrix, Aphanizomenon*
Anatoxin-a(S)	Nerve synapse	*Anabaena*
Cylindrospermopsins	Liver	*Cylindrospermopsis, Aphanizomenon, Umezakia*
Saxitoxins	Nerve axons	*Anabaena, Aphanizomenon, Lyngbya, Cylindrospermopsis*
Lipopolysaccharides (LPS)		
	Potential irritant; any exposed tissue	All

Table 1. **Summary of Cyanotoxins**

Cyanotoxins have been found in a number of the Rotorua lakes (Table 2). Microcystins are the most common cyanotoxin in the Rotorua Lakes. In Lakes Rotoiti and Rotoehu microcystin levels have at times reached concentrations that could be hazardous to humans involved in recreational activity on or in the lakes (Wood, 2003). Microcystins are cyclic heptapeptides, which block protein phosphatase 1 and 2a (MacKintosh et al., 1990). Although humans are unlikely to be exposed to a lethal acute dose of microcystins, there is now sufficient evidence to show that there is risk from chronic exposure, particularly if there is long-term frequent contact. A number of studies have demonstrated that microcystins can cause an increased liver tumour promotion action and long-term liver damage (Falconer and Humpage, 1996; Ueno et al., 1996).

Lake	Toxins detected
Ngahewa	Microcystin
Ngapouri	Microcystin, Saxitoxin
Okaro	Microcystin
Rotoehu	Microcystin, Anatoxin-a, Saxitoxin
Rotoiti	Microcystin, Saxitoxin
Rotorua	Microcystin

Table 2. Rotorua lakes where cyanotoxins have been found and the types of cyanotoxins known to occur in the each lake

The first objective of the present study was to investigate the variation in microcystin levels during a bloom event. Lakes Rotoiti and Rotoehu were chosen for the study because they are known to contain microcystins and regularly experience cyanobacterial blooms. Microcystin levels, and composition and abundance of cyanobacteria species were monitored weekly in both lakes (Nov - May) and daily in the enclosure on Lake Rotoiti during a three week period.

Microcystins are known to accumulate in freshwater organisms including fish (Ernst et al., 2001; Magalhaes et al., 2003). Traditionally microcystins were thought to accumulate mostly in livers of freshwater fish and that the risks to humans consuming gutted fish would be low. Current advice given in the Bay of Plenty district to people eating fish from areas experiencing cyanobacterial blooms is to gut them. However, recent studies (Mohamed et al., 2003; Vasconcelos, 1999) have also detected microcystins in the muscle tissue of fish, indicating that consumption of animals containing microcystins might adversely affect human health.

A Daily Tolerable Intake (TDI) value of 0.04 μg kg^{-1} day^{-1} has been proposed as a provisional guideline value by the World Health Organisation (Chorus and Bartram, 1999) for total microcystins. TDI is defined as the acceptable amount of a potentially toxic substance that can be consumed daily during a life period.

The rainbow trout (*Oncorhynchus mykiss*) is a species that is of particular importance to recreational fishers and to tourism in the Rotorua lakes. A further objective of this project was to assess whether microcystins accumulate in trout in the lakes, which organs accumulate microcystins, and if present whether microcystins could reach levels that would be hazardous for human consumption.

A final objective of this study was to establish whether significant levels of microcystins accumulate in the native freshwater mussel (*Hydridella menziesi*), and if they do accumulate, how concentrations of microcystin changes with exposure time.

2. METHODS

2.1 Field Methods

2.1.1 Phytoplankton
Water samples (400 ml) were collected weekly as part of the Environment Bay of Plenty (ENVBOP) algae monitoring program. Sample collection began on the 14-11-03 and finished on 02-05-04. Samples were collected from Te Weta Bay, Okawa Bay, and Hinehopu (Lake Rotoiti) and Kennedy Bay, Otautu Bay and Te Pohue (Lake Rotoehu).

A 50 ml subsample was taken and preserved using Lugol's Iodine and stored in the dark. The remaining 350 ml was frozen at –20°C immediately for later microcystin analysis.

During the enclosure experiment, water samples were collected at the centre of the enclosure bay and processed as described above. Samples were collected daily at 10 am (surface only) and at 3 pm (surface, 1 m, 2 m and 3 m depths).

2.1.2 Rainbow Trout
The study involved using both trout that had access to the entire lake and hatchery trout added to an enclosure in Lake Rotoiti where microcystin levels in the water could be monitored closely.

Each month from November 2003 to April 2004, up to five trout which had access to the entire lake were caught by local fishing guides in both Lakes Rotoiti and Rotoehu.

A large scale mesocosm type enclosure was set up in an arm of Te Weta Bay, Lake Rotoiti in March 2004. In the enclosure experiment 80, two-year-old rainbow trout from the Fish and Game New Zealand Rainbow Valley hatchery were released into the enclosure on 08-03-04. Each trout was tagged by clipping one of the pectoral fins before release. Up to five of the released trout were caught every two to three days over a 21 day period. Before releasing the trout into the enclosure three trout were retained to check background microcystin levels. A total of 28 released trout were caught. In addition, three "wild" trout that were in the enclosure area prior to installing the net were captured.
Necropsy was performed and liver, kidney, gut and muscle tissue removed. Approximately 5 g of trout muscle tissue was taken from each trout and combined into a pooled sample. Each liver was halved with one half combined in a pooled sample and the remaining half retained for individual analysis (not carried out in this study). Samples were stored at -80 °C until extracted for ELISA analysis as described in Section 2.2.1.

2.1.3 Mussel Cage Experiments
Approximately 130 freshwater mussels were collected from sediment in Lake Rotoma (free of microcystins) at a depth of approximately 10 m. Mussels were transported in buckets containing Lake Rotoma water to the study site in Lake Rotoiti.

Ten mussels were killed immediately and kept frozen at -80°C until microcystin analysis was carried out. These mussels were used to determine if there was any baseline microcystins present. The remaining 120 were placed in plastic cages suspended from buoys 300 mm below the surface in the centre of the enclosure bay about 20 m from the net.

Ten mussels were collected every 2-3 days over a period of 21 days. They were frozen shortly after collection and then halved. They were then pooled into two sets each containing

ten halves and stored at -80°C until microcystin analysis was carried out as described in Section 2.2.1. The remaining pooled mussels were retained for individual analysis (not carried out in this project) or for use as backup samples.

2.2 Laboratory Methods

2.2.1 Microcystin analysis

The total microcystin content of the samples (phytoplankton and organisms) was analysed with a competitive indirect ELISA using the methods of Fischer et al. (2001). This ELISA uses antibodies raised to the ADDA moiety that is present in most (>80%) of the known toxic penta- and heptapeptide toxin congeners.

For phytoplankton, 2 ml sub-samples were freeze-thawed twice, centrifuged at 10 000 g for 2 min and the supernatant used for the ELISA assay. This gives a measure of the total microcystin present in the lake water.

Trout muscle tissue and liver, and freshwater mussels were homogenised in 75% methanol/water. The homogenate and solvent was centrifuged and the supernatant recovered and washed with hexane. The aqueous phase was retained and processed by solid phase extraction. The toxin-containing fraction was then eluted with 80% methanol/water and was diluted in assay buffer (PBS) and analysed by ELISA. For some samples it was necessary to dilute extracts 1:50 to overcome matrix effects. All trout and mussel samples were analysed out by the Toxinology Laboratory at AgResearch, Hamilton, New Zealand.

2.2.2 Phytoplankton

The preserved sub-samples were used for species identification and enumeration of cyanobacteria species. Enumeration and identification were carried out using an inverted Olympus microscope and Utermöhl settling chambers (Utermöhl, 1958).

2.2.3 Trout

An assessment of stomach contents was performed on each trout. The stomachs were opened and the contents were identified into one of the following groups; plant material, molluscs, insects, fish, pebbles and unidentifiable organic material. The stomach contents were blotted dry and wet weight of each category was recorded and a percentage composition of stomach contents calculated for each trout. An average stomach contents for each pooled sample was then calculated.

3.0 RESULTS

3.1 Weekly Phytoplankton Samples

The variations in microcystin levels at the six locations sampled on a weekly basis are shown in Figure 1.

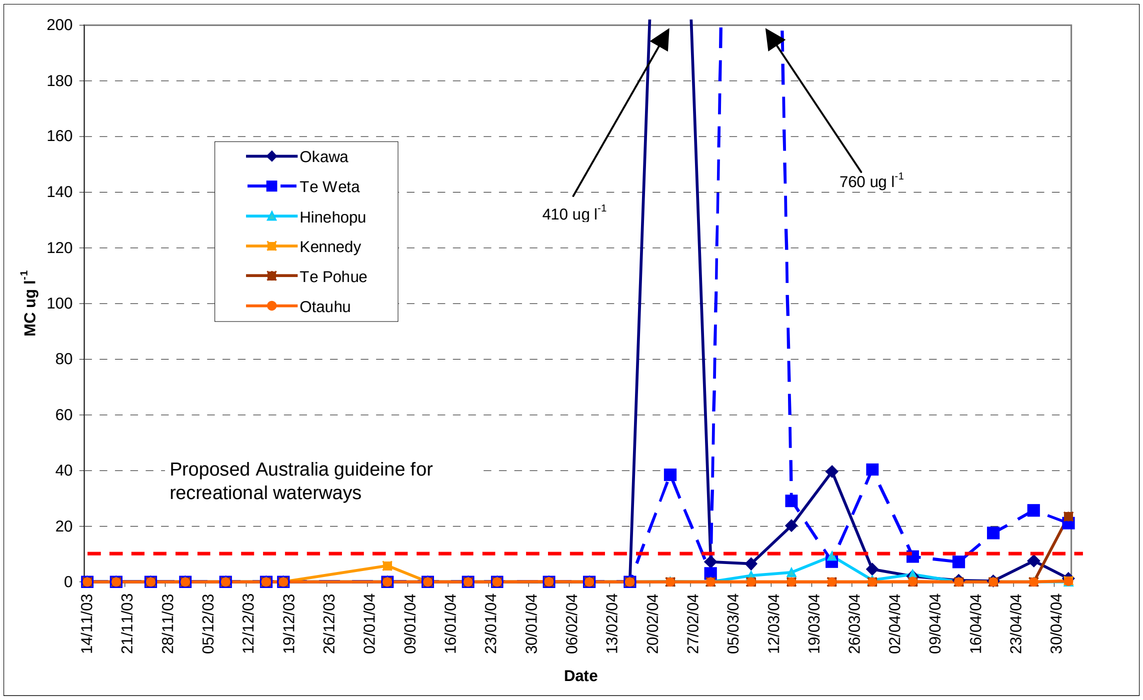

Figure 1. Microcystin levels in weekly samples - Lakes Rotoiti & Rotoehu.

Generally no or very low (<1 µg l^{-1}) microcystins levels were detected at the three sampling locations at Lake Rotoehu (Kennedy Bay, Te Pohue Bay and Otauhu Bay). This corresponded with low levels of cyanobacteria at these locations. On the two occasions that significant levels of microcystins were detected (Kennedy Bay, 05-01-04– 5.8 µg l^{-1} and Te Pohue Bay, 02-05-04 – 23.5 µg l^{-1}) these corresponded with an increase in the *Microcystis panniformis* cell counts.

Microcystins were absent from Lake Rotoiti samples until 23-02-04 when they were detected in both the Te Weta Bay and Okawa Bay sites. Okawa Bay had very high levels of microcystins - 410 µg l^{-1}. This corresponded with a high cell count of *Microcystis aeruginosa* (940 000 cells ml^{-1}). Microcystins continued to be recorded at Okawa Bay until the conclusion of sampling. On two other occasions (15-03-2004 and 26-03-2004), the levels were above the proposed Australian recreational guideline (8 µg l^{-1}) for microcystins (National Health and Medical Research Council, 2004). The sample from Te Weta Bay on 08-03-04 recorded the highest levels of the study, 760 µg l^{-1}. This corresponded with a level of 430 000 cells $ml^{-1}$of *Microcystis* spp. Levels in Te Weta Bay remained elevated during the study with samples regularly being above the proposed Australian guideline. Microcystin levels at Hinehopu remained generally low with only the sample from the 22-03-04 recording a level above the proposed Australian guideline (9.3 µg l^{-1}). This also corresponded with an increase in *Microcystis* spp.

3.2 Rainbow Trout Samples

3.2.1 Lake Rotoehu

Microcystins were found in liver and muscle tissue samples in all monthly samples from November 2003 to April 2004 (Figure 2). Microcystin levels were always higher in liver than in muscle tissue. Highest levels of 27.57 μg kg^{-1} for muscle tissue and 78.92 μg kg^{-1} for liver were recorded in November 2003. The amount of microcystin decreased between December 2003 and March 2004 before increasing again in April 2004.

The average weekly water microcystin levels from the three sampling sites is plotted for each month (Figure 2). Microcystin levels were zero or very low in the water during the study period. Thus there is no apparent correlation between microcystin levels in the water and microcystin levels in trout samples.

An estimated daily intake (EDI) was calculated using an adult human weight 70 kg and ingestion of 300 g of trout muscle tissue. The EDI values for the monthly samples from Lake Rotoehu are shown in Figure 3. The TDI of 04 μg kg^{-1} day^{-1} value suggested by the WHO (Chorus and Bartram, 1999) is also shown on the graph. The EDI in the tissue exceeds this guideline in the samples from November and December 2003 and April 2004. The TDI value is not relevant to the liver samples as the liver of trout is not usually consumed.

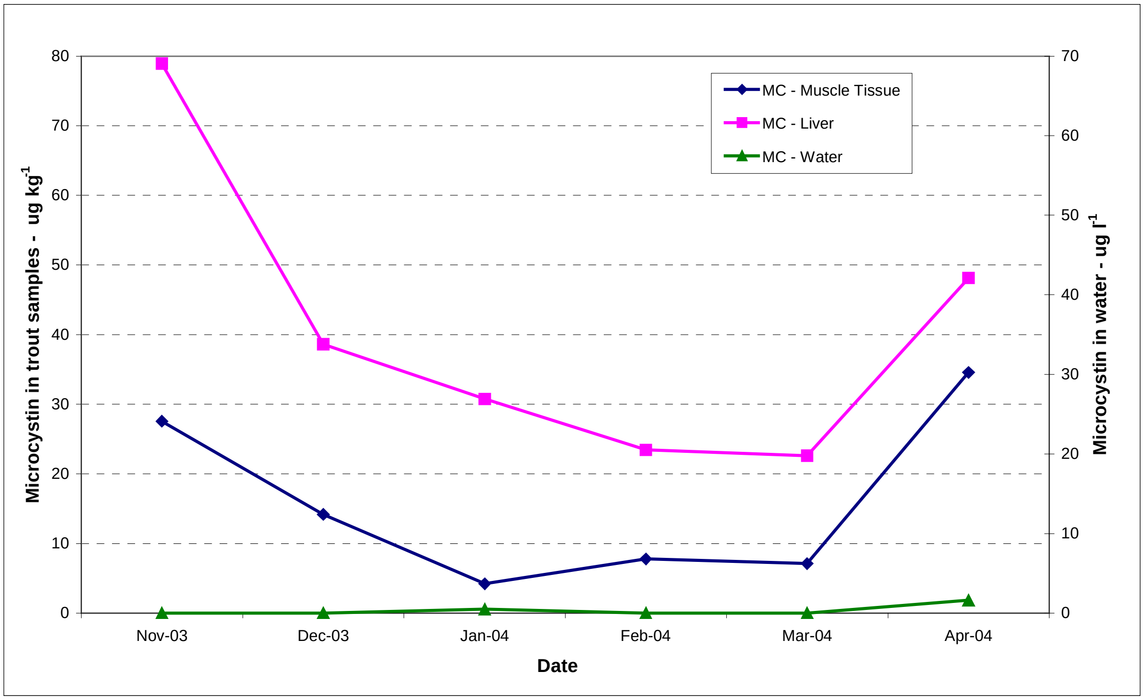

Figure 2. Microcystin levels in rainbow trout (*Oncorhynchus mykiss)* muscle tissue and liver, and in the monthly water samples from Lake Rotoehu. The water microcystin level is an average of weekly samples at three locations in lake**.**

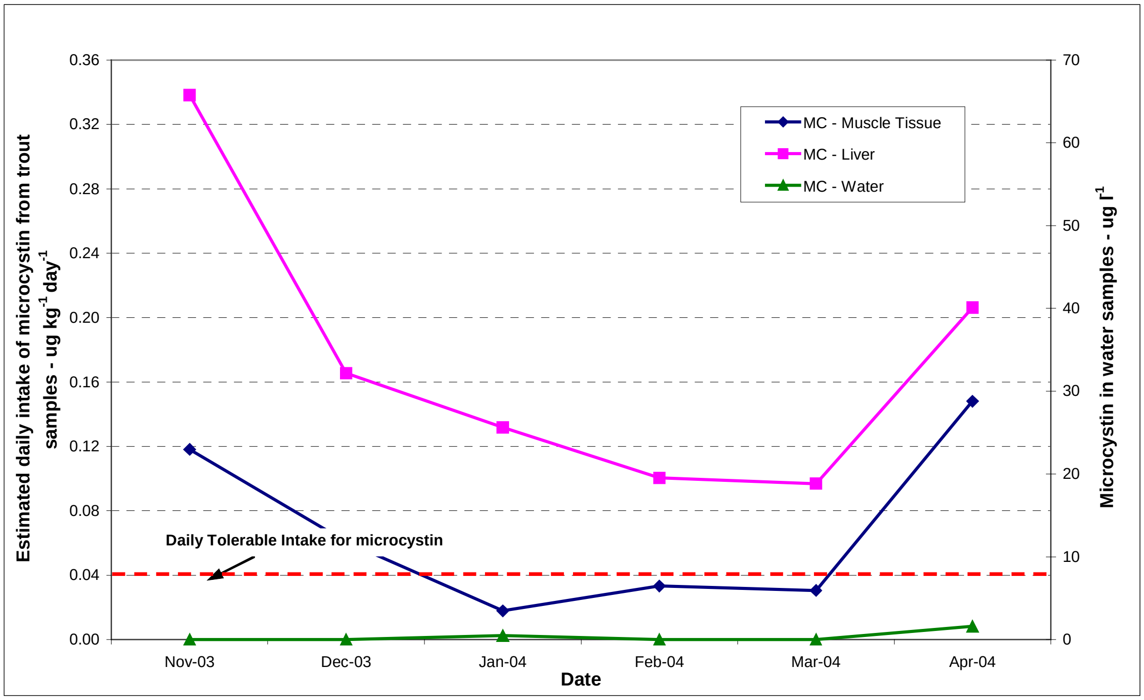

Figure 3. Estimated human daily intake of microcystin from Lake Rotoehu based on a 70 kg person ingesting a 300 g serving of rainbow trout *(Oncorhynchus mykiss)*. The water microcystin level is an average of weekly samples at three locations in Lake Rotoehu.

3.2.2 Lake Rotoiti

Microcystins were detected in all trout muscle tissue and liver samples in the trout received monthly Lake Rotoiti (Figure 4). Levels in the muscle tissue samples did not vary greatly 8.0 µg kg^{-1} (March, 2004) to 12.3 µg kg^{-1} (February, 2004).

Microcystin levels varied more widely in liver samples with peaks recorded in December 2003 (44.5 µg kg^{-1}) and February 2004 (46.4 µg kg^{-1}).

No microcystins were recorded weekly in the water samples until February 2004 (Figure 4). The highest average was recorded in March 2004 (62.5 µg l^{-1}). Water levels do not appear to correlate with the changes in the microcystin levels in the trout.

Figure 5 shows the EDI for Lake Rotoiti trout. On three occasions (December 2003, February and April 2004) microcystin levels in muscle tissue were just above the TDI.

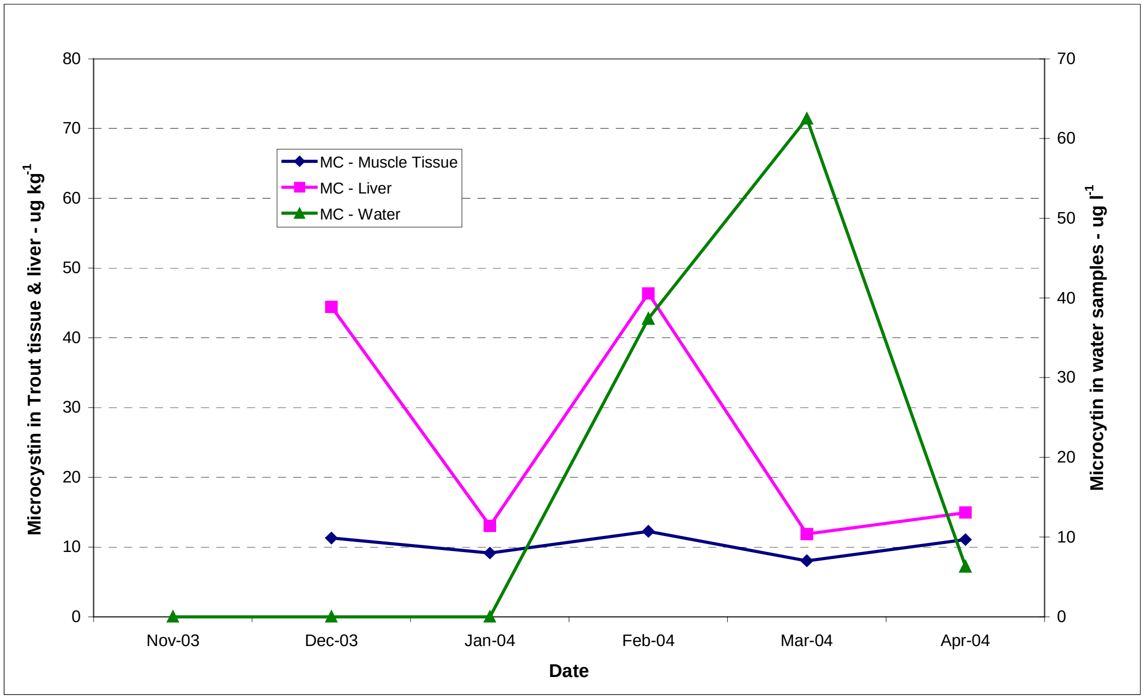

Figure 4. Microcystin levels in rainbow trout (*Oncorhynchus mykiss)* muscle tissue and liver, and in the monthly water samples from Lake Rotoiti. The water microcystin level is an average of weekly samples at three locations in lake**.**

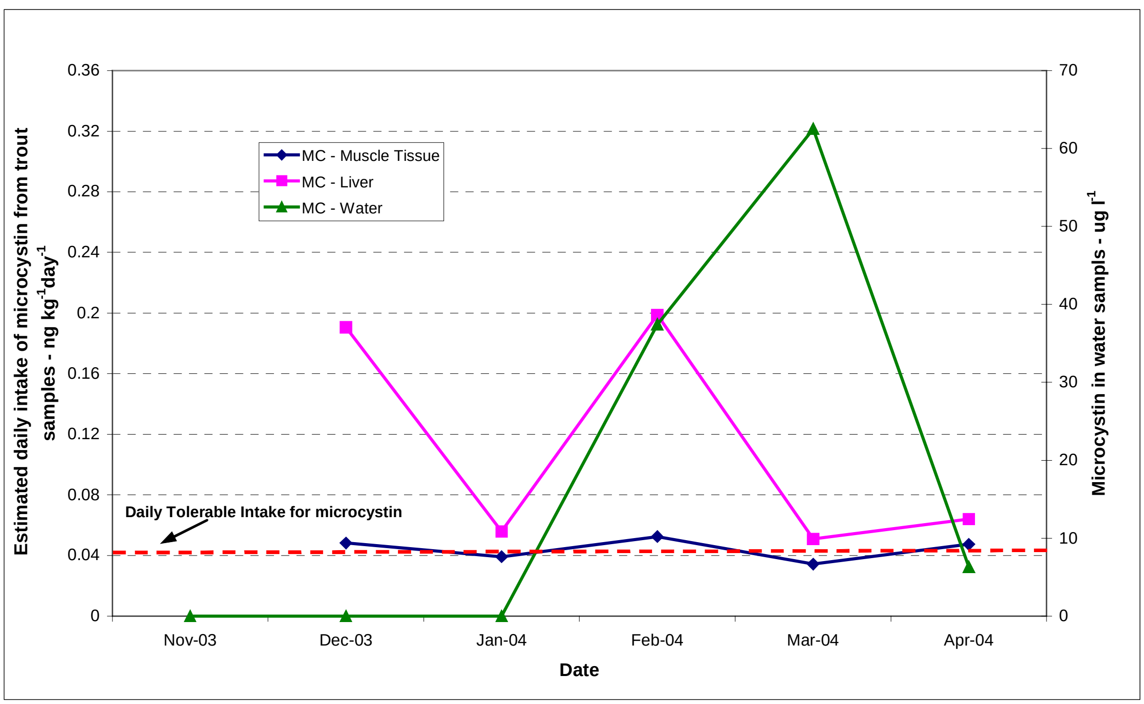

Figure 5. Estimated human daily intake of microcystin from Lake Rotoiti based on a 70 kg person ingesting a 300 g serving of rainbow trout *(Oncorhynchus mykiss)*. The water microcystin level is an average of weekly samples at three locations in Lake Rotoiti.

3.3 Enclosure Experiment

3.3.1 Water Microcystin Levels and Cell Counts

Average microcystin levels in the five samples from each day were calculated. Figure 6 shows the plot of this average together with the average of the total cyanobacteria cell counts per day. The proposed recreational Australian guideline of 8 μg l^{-1} (National Health and Medical Research Council, 2004) and the ENVBOP guideline for issuing a health alert (15 000 cells ml^{-1}) are shown as dotted lines (Figure 6). On the 18 to 19-03-04 the cell counts exceeded the ENVBOP health alert but on these days microcystin levels were below the proposed Australian guideline. On six days, the microcystin levels exceeded the proposed Australian guideline but on these occasions the cell counts were below the ENVBOP health alert. There was no clear correlation between microcystin level and cell counts.

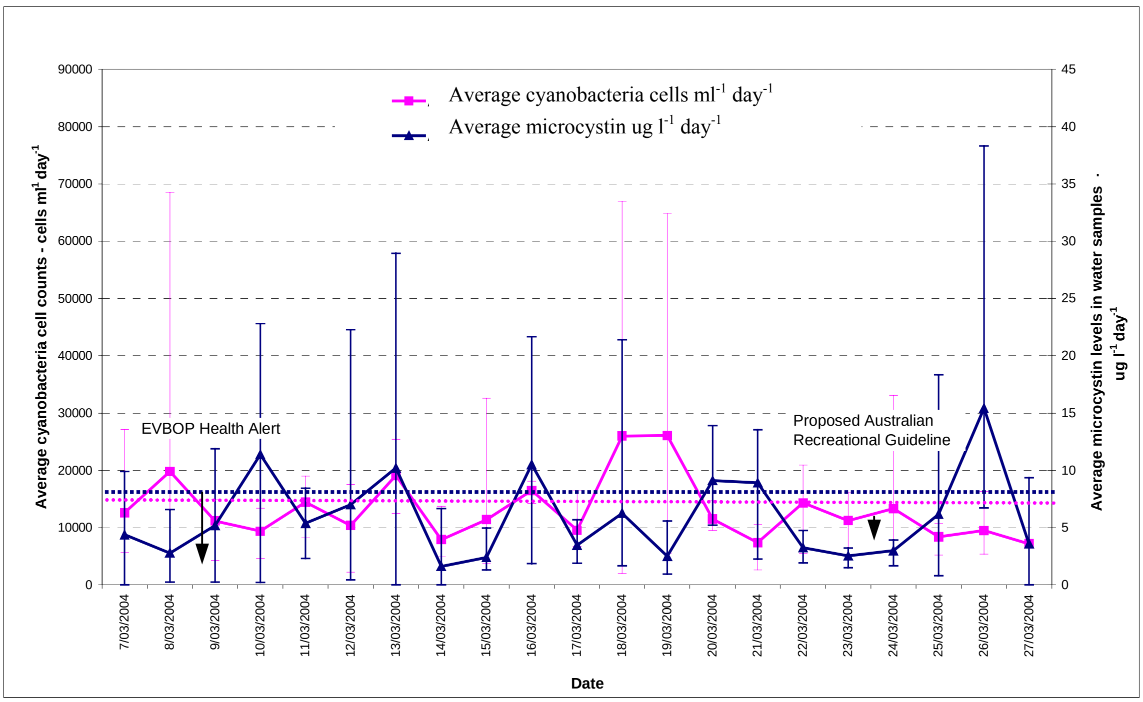

Figure 6. Average cyanobacteria cell counts per day and average microcystin levels per day during enclosure experiment. Error bars show maximum and minimum values for each day.

3.3.2 Microcystin Levels in Rainbow Trout Samples

Of the 80 trout released into the enclosure 28 were recaptured. Three "wild" trout were also caught in this area.

No microcystins were found in the three trout from the hatchery (08-03-2004 – Figure 7) retained to check for background levels of microcystins. Microcystins were found in all muscle tissue and liver samples from trout caught during the enclosure experiment. Microcystin levels in trout samples are plotted together with the average smoothed microcystin levels in the water samples (Figure 7). Water microcystin levels shown are the

average of microcystin levels in five daily samples smoothed using the following formula; Smoothed Value = (microcystin on day)/2 + (microcystin previous day)/4 + (microcystin next day)/4. Microcystin levels were also analysed for two of the three "wild" trout caught in the enclosure experiment (Figure 7). Levels in the "wild" trout do not differ markedly from those found in enclosure trout caught on similar dates.

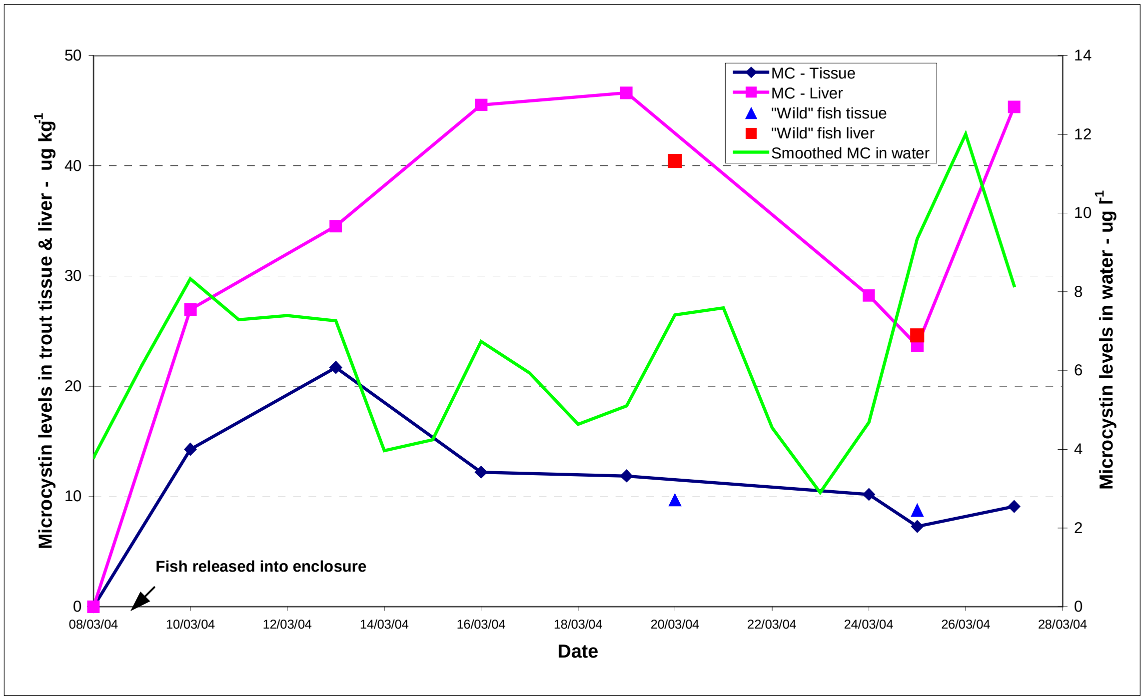

Figure 7. Microcystin levels in rainbow trout (*Oncorhynchus mykiss*) and in water samples from enclosure experiment. Microcystin levels are an average of five samples per day. Only two of the three "wild" trout were analysed for microcystins.

Microcystin levels in liver were always higher than those recorded in muscle tissue samples. For days 1 to 11 the microcystin levels in liver increased to a maximum value of 46.6 µg kg^{-1}. From days 12 to 18 the microcystin levels decreased to 23.7 µg kg^{-1}, before increasing again to 45.4 µg kg^{-1} in the final sample (day 21). Microcystin levels in muscle tissue increased from days 1 to 5 to a maximum of 22.7 µg kg^{-1}. Levels then decreased and remained between 7.3 µg kg^{-1} and 12.2 µg kg^{-1} for the duration of the enclosure experiment.

There was no clear correlation between microcystin levels in the water and those in the trout muscle tissue and liver samples. However, lower microcystin levels in the water and the sudden rise between 23-03-04 – 26-03-04 was possibly the cause of the fall and rise in liver microcystin values over the period 23-03-04 - 27-03-04.

Figure 8 shows the EDI for enclosure trout. Five of the seven muscle tissue samples were above the TDI for microcystin

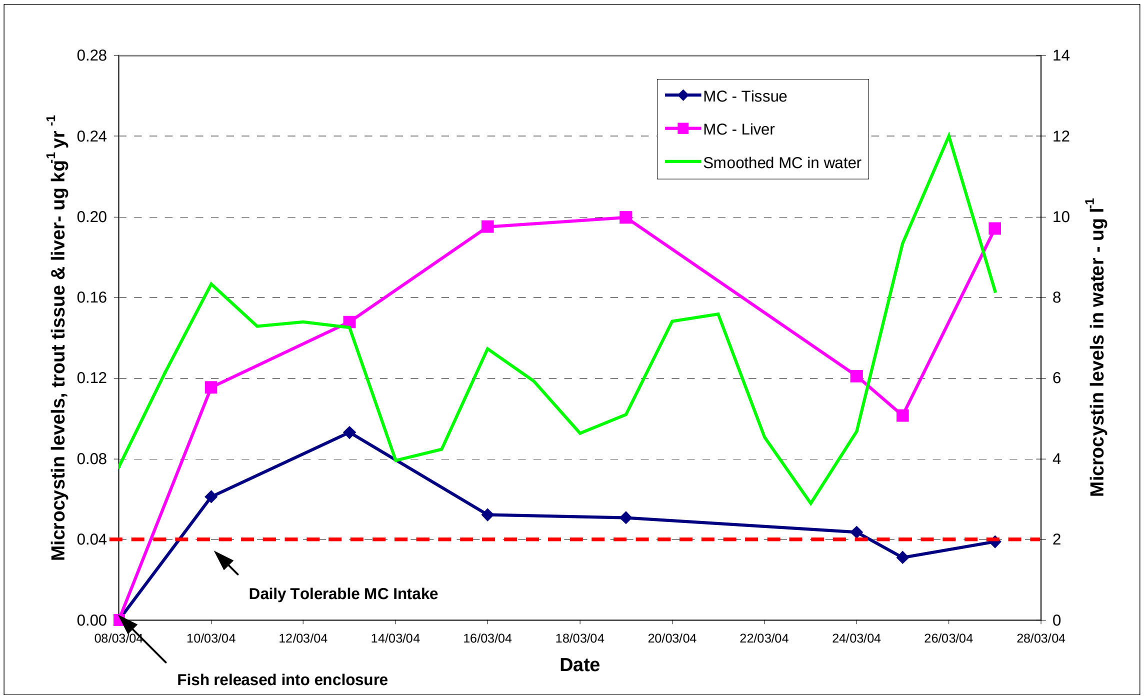

Figure 8. Estimated human daily intake of microcystin from enclosure experiment based on a 70 kg person ingesting a 300 g serving of rainbow trout *(Oncorhynchus mykiss)*. The water microcystin level is an average of 5 samples per day.

3.4 Trout Stomach Contents

Stomach contents of the Lakes Rotoehu and Rotoiti trout were varied (Figures 9 & 10). However, in all monthly samples over 40% of the diet was fish. The majority of these fish were smelt (*Retropinna retropinna*), with bullies (*Gobiomorphus* spp.) identified in some samples. Molluscs, mainly the gastropod snail, *Physa acuta,* made up a large component of the Lake Rotoehu trout's diet in some months.

Percentage composition of stomach contents of trout from the enclosure experiment is shown in Figure 11. For days 1 to 11 of the enclosure a large portion of the trouts diet was made up of insects. The dominant insect was the water boatman (*Corixidae* sp.). Smelt and bullies were absent or only present as a small proportion of the stomach contents. After 16 days, trout diet contained large quantities (30-60%) of fish. Both smelt (*Retropinna retropinna*) and bully (*Gobiomorphus* spp.) were identified. Stomach contents of three "wild" trout are also shown in Figure 11. Fish (including goldfish, smelt and bullies) made up 58% of the stomach content of these trout.

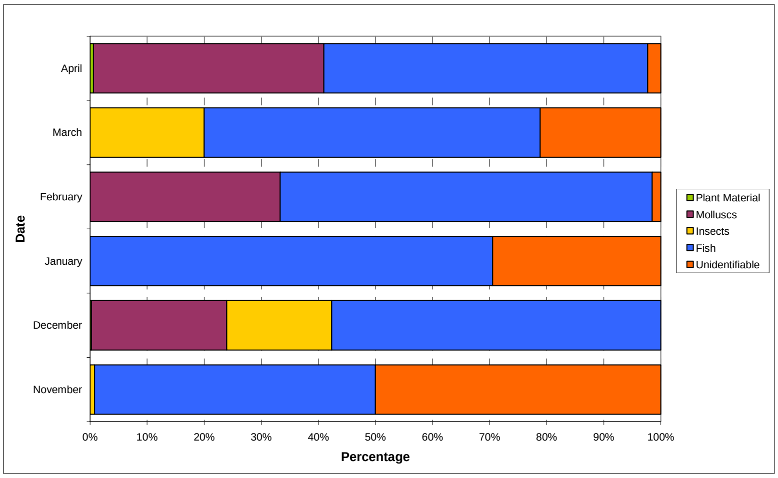

Figure 9. Percentage composition by weight of organic material in stomach contents of Lake Rotoehu rainbow trout (*Oncorhynchus mykiss*).

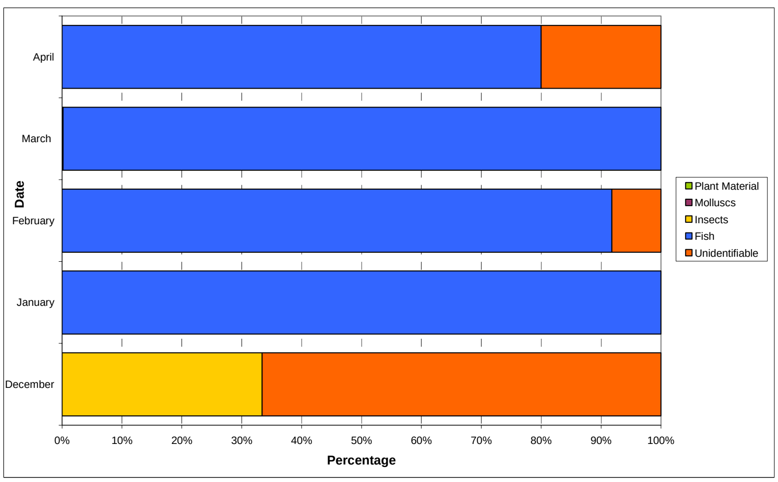

Figure 10. Percentage composition by weight of organic material in stomach contents of Lake Rotoiti rainbow trout (*Oncorhynchus mykiss*).

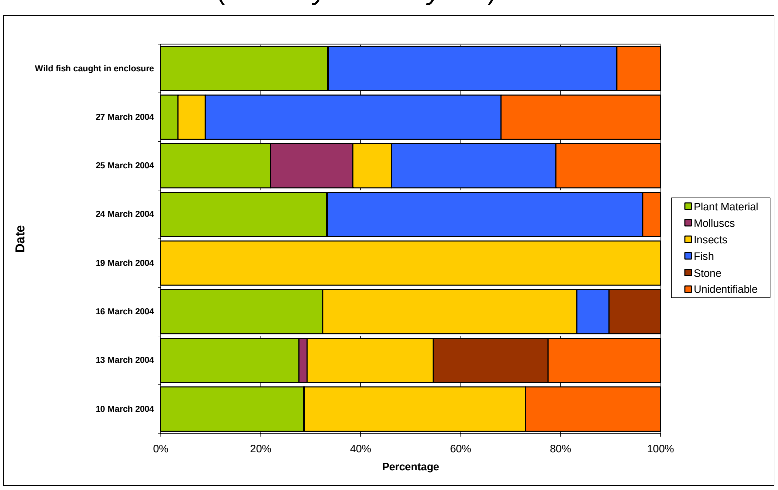

Figure 11. Percentage composition by weight of stomach content of enclosure and "wild" rainbow trout *(Oncorhynchus mykiss).*

3.5 Microcystin Levels in Mussels

Microcystin levels measured in the enclosure mussels are plotted in Figure 12 together with a smoothed surface water microcystin level. The smoothed surface water microcystin level was calculated by taking the average am and pm surface samples for each day and applying the smoothing formulae given in Section 3.3.2. Only surface samples were used as the mussels were positioned just below the surface.

After four days in the enclosure the mussels began to accumulate microcystins. Initially this accumulation was gradual with only 4.5 µg kg^{-1} recorded after five days and 4.6 µg kg^{-1} after seven days. Over the next two days microcystin levels in the mussels increased dramatically to reach a peak of 65.1 µg kg^{-1}. Microcystin levels in the water were much lower than those in mussels. With the exception of the first six days, the increase and decrease in microcystin levels in mussels tracked a similar trend in surface microcystin water levels with a two day delay.

Figure 12. Microcystin levels in freshwater mussels *(Hydridella menziesi)* and water during enclosure experiment.

4. DISCUSSION

4.1 Cell Counts, Species and Toxins

The microcystin levels in Lake Rotoiti have at times reached levels that could be hazardous to humans participating in recreational activities on or in the lake. When *Microcystis* species cell concentrations are very high, microcystin levels are also likely to be high. However, total cyanobacteria cell counts were found to be a poor indicator of microcystin levels in the water samples and testing for microcystins as part of the regular phytoplankton monitoring programme is suggested.

4.2 Accumulation of Microcystins in Trout

Our results confirm that microcystins accumulate and persist in both muscle tissue and liver of rainbow trout in Lakes Rotoiti and Rotoehu. In the enclosure microcystin appeared to accumulate readily in these tissues following the initial ingestion of contaminated food sources. However, our results showed that levels in both liver and muscle tissue reached a peak after 5 to 10 days and then levelled off, or dropped slightly, with more prolonged exposure. The microcystin levels in monthly muscle tissue samples from trout in Lake Rotoiti were reasonably constant over a six month period and were at about the same level as in the enclosure trout after the initial 10 days in the enclosure. In Lake Rotoehu, the monthly levels in the muscle tissue were more variable but the average level was similar to the Rotoiti trout in spite of the microcystin level in the water being very low over the six month period. These results suggested that levels in muscle tissue were not strongly affected by the presence of the observed bloom or short periods of high microcystin levels in the water.

Monthly levels of microcystin in the liver of the trout in the enclosure and from Lake Rotoiti were more variable than in the muscle tissue, and results appeared to mirror the changes in the water microcystin levels. However, there was no indication of this trend in the monthly samples from Lake Rotoehu where the liver levels were high at times when water microcystin levels were low. For these samples, a decrease and increase of liver levels followed a similar trend in muscle tissue levels indicating that the food source (presumably contaminated) maybe a more relevant factor than the water microcystin levels.

Presence of microcystins in liver and muscle tissue when cyanobacterial levels in the water are low may indicate concentration of microcystins in food web. This study showed that accumulation and variation of the microcystin levels in the trout (both liver and muscle tissue) depends on a complex interaction between levels in the water and food web. A need for further monitoring of microcystins in trout muscle tissue and in the food web is indicated.

4.3 Human Risk

Our results confirm that microcystins do accumulate and persist in the muscle tissue and liver of rainbow trout in Lakes Rotoiti and Rotoehu. The results illustrate that there is a potential human health risk from the consumption of trout muscle tissue, as 50% (Rotoehu), 60% (Rotoiti) and 71% (enclosure) of the muscle tissue samples were above the Total Daily Intake (TDI) of 0.04 $\mu g\ kg^{-1} day^{-1}$ recommended by the WHO (calculations based on a 70 kg person eating 300 g per day). Using the levels found in the muscle tissue of the trout sampled in this study and ignoring the issue of covalently bound microcystins (described in Section 4.4) the

health risk to humans from microcystins consumed while eating trout muscle tissue from Lakes Rotoiti and Rotoehu is very low because trout is not usually consumed every day.

Using the results of this study a 70 kg person can safely eat a 300 g serving of trout every 3.6 days. This calculation used a muscle tissue concentration of 34.5 µg kg^{-1}, (which was the highest value recorded in the muscle tissue during this study – Rotoehu, April 2004), the TDI of 0.04 µg kg^{-1} day^{-1} (WHO), a 70 kg human and a trout meal size of 300 g. If 70 kg humans eat trout at less than this rate, they will consume microcystin levels below the WHO standards and there is probably no need for concern. The TDI is a recommended limit for a healthy adult. Children, elderly and sensitive individuals may be at a higher risk from the ingestion of microcystins. The microcystin levels are significantly higher in the trout liver but the current advice given by Fish and Game New Zealand and local district health boards to gut and thoroughly wash the fish before eating would substantially reduce any potential health risks.

4. 4 Covalently Bound Microcystin

In our study we have only investigated and reported levels of free ADDA-containing microcystins in the trout and mussels. It is likely that our samples will also contain covalently bound microcystins. Covalent binding of microcystins can occur within a matter of hours. It involves the formation of a covalent linkage between the microcystins and PP-1 and PP-2A enzymes with the result of a secondary *in vitro* interaction (Craig et al., 1996; MacKintosh et al., 1995; Runnegar et al., 1995).

Few studies have addressed the issue of covalently bound microcystins in freshwater organisms. The levels of covalently bound microcystin (Table 3) vary dramatically and depend on the study species, types of toxin used, methodology used to test for covalent microcystins, the method of administration to the organism and the length of time following administration that the microcystins were measured.

Species	**Reference**	**Percentage of total microcystin detected that is Covalently bound**
Atlantic Salmon	Williams *et al.* (1997a)	76%
Mussel - *Mytilus edulis*	Williams *et al.* (1997b)	99.9%
Rainbow trout - (*Oncorhynchus mykiss*)	Tencalla & Dietrich (1997)	63%
Cypress Island Dungeness Crab Larvae	Williams *et al.* (1997a)	Covalently bound microcystin 10,000 x higher than free mircrosytin
Zebra mussel - *Dreissena polymorpha*	Pires *et al.* (2004)	38%

Table 3. Summary of published studies recording levels of covalently bound microcystins in freshwater organisms.

In a study on Zebra mussels (Pires et al., 2004) that investigated both free and covalently bound microcystins it was found that in the first week of exposure only low amounts of covalently bound microcystins could be detected. In the second week the amounts of covalently bound microcystins increased dramatically and accounted for approximately 62% of the total microcystin burden. Similarly, Williams *et al.* (1997) found that in the marine mussel (*Mytilus edulis*) almost all the microcystins present existed as a covalent complex after 3 days. These results may explain why the microcystin levels in the enclosure trout decreased after five days in the tissue and 12 days in the liver. Over time more of the microcystins may have became covalently bound and we were not able to extract and detect them.

We strongly recommend that future studies should assess the amount of covalently bound microcystins in the Rotoiti and Rotoehu rainbow trout and attempt to establish whether the total microcystin burden in the trout is a potential health risk to humans consuming the trout.

4.5 Freshwater Mussels

Hydridella menziesi accumulated microcystins rapidly and levels in the mussels were always higher than those in the water. However because mussels rapidly remove the microcystins from their tissue these organisms will be poor indicators of microcystin levels at any one location over an extended period of time. They may however be useful as early warning organisms when low levels of microcystins occur in a water body. While *H. menziesi is* not commonly consumed by most New Zealanders, some Maori regard them as a traditional food source and thus consumption may pose a potential health risk.

5. RECOMMENDATIONS

Our recommendations for further study and for actions that can be taken to reduce the impact of the toxins on human health are as follows:

- Monitor microcystin levels and the species composition of blooms in Lakes Rotoiti and Rotoehu.
- Inform the public of potential dangers.
- Test for microcystin as part of the regular phytoplankton monitoring programme.
- Establish unambiguously which species are responsible for the synthesis and release of microcystins.
- Investigate the fate of microcystins in water column and sediment.
- Monitor rainbow trout over time to track microcystin levels in muscle tissue during periods of both cyanobacterial bloom and low cell counts.
- Investigate microcystin levels and feeding patterns of organisms ingested by trout.
- Provide clear, unambiguous health information to enable the public to make informed decisions regarding consumption of trout (the quantities that can be safely eaten should be given) based on the best information available at the time the health information is issued.

- Develop methods to analyse for covalently bound microcystins and to assess their toxicity and bioavailability. Until this work is completed guidelines for safe levels of trout consumption cannot be stated precisely.
- Issue warnings concerning consumption of freshwater mussels.
- Conduct controlled studies investigating the value of *H. menziesi* in monitoring programmes.

6.0 ACKNOWLEDGEMENTS

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- Ross Price and Phil Shoemack (BOP district health) for their suggestions.
- Andrew Lang – Rotorua District Council (Harbour Master) – field assistance.
- Rob Pitkethley – Eastern Region Fish and Game – advice and field assistance.
- Eastern Region Fish and Game – field assistance and supply of fish.
- Greg Tuuta and Jim Koller – collection of monthly fish samples.
- Elizabeth and Nick Miller – field assistance.
- Beth and John Wood – field assistance.
- Paul and Gill Taylor – field assistance.
- Environment BOP staff – field assistance.

QUESTIONS

Anaru Rangiheuea, Chairman, Te Arawa Trust: When you sample the trout, did they look any different, those that were affected or have smells about them? I've had reports about some of the fish caught in Rotoiti have shown that sort of appearance and smell and they don't last as long as fish taken from other clean lakes. Did you notice any of that in your samples?

S.W.: I think that it's quite hard for me to comment on that, because I haven't necessarily compared them to trout from another environment. In terms of the toxins I don't think the toxins necessarily had much effect on the trout, the levels required to kill the trout are quite high, but you are talking more about the effect of taste and odour compounds in the trout?

Rob Pitkethley, Eastern Region Fish & Game: With regard to Anaru's question, we haven't had negative comments from anglers about the fish themselves. We've had certainly a lot of negative comments about trying to fish on the lake when it is in that condition. So, I can't answer you directly on that one, except just to say that we haven't heard anything. The other thing to point out probably is that when this work came out we talked to the Medical Officers

of Health about it, not being health experts ourselves, and they've pointed out that the current practice on not eating liver (which most people don't) is going to be sufficient in terms of the warning they're giving at the moment.

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Advanced on-site domestic wastewater treatment system for nitrogen reduction at Lake Rotoiti lakeside property

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Paul Scholes *Environmental Scientist Environment Bay of Plenty*
Peter Gearing *Environmental Scientist URS New Zealand*

ABSTRACT
Property occupiers all need to do their best to reduce nutrient inputs into the Rotorua Lakes, particularly sewage effluents discharged to ground water from on-site septic tanks. The Environment Bay of Plenty On-Site Effluent Treatment Regional Plan sets out proposals for advanced On-site Effluent Treatment systems. This paper describes such a system installed earlier this year at Gisborne Point, Rotoiti. The chemistry of nitrification/denitrification, initial test results, maintenance requirements and costs are described.

TRANSCRIPT (edited)
This has been an exciting programme. We've been very lucky to have the cooperation of quite a number of people and organisations. I have to make apologies for Paul Scholes of Environment Bay of Plenty, he is overseas on annual leave at the moment. Paul has been very helpful in collecting samples, taking readings, and he helped write the section on the chemistry which I'll describe shortly. Peter Gearing is my other co-author. Peter's main responsibility has been in the design of the irrigation field and Peter is quite a specialist in that area. I would also like to acknowledge Devan Blue from Tauranga. They provided the plant and Adrian Heugerbrelk, who is here with us this afternoon, will be able to answer any questions from anybody. Also Matt Riddell from Ecogent in Auckland, they are environmental engineers and they were responsible for a lot of the detailed design.

We are very lucky to have a property at Lake Rotoiti, but there is a problem. Undersized septic tanks are a real problem and ours was 1.3 cubic metres; we required 2.7. The new system has 11.3 cubic metres. Traditional effluent systems were inadequate. We've heard horrible stories about people not knowing where their septic tanks were, sometimes using old 44 gallon drums for septic tanks, so definitely there's a need for improvement and Environment Bay of Plenty and Rotorua District Council have been addressing that. Nutrients discharging into the ground water are a real problem and traditional septic tanks don't deal with that problem. They are very good at settling it out and distributing the effluent out, but they don't remove nutrients very well and the irrigation systems are not particularly good. They contaminate the ground water and the lakes and that has been our concern. There have been dramatic increases in algal growth and we feel partly responsible for that, so we're endeavouring to address that problem.

We are disturbed that the lake water quality has reduced. We're all part of the problem and we feel that our responsibility is to try and do something about it.

Environment Bay of Plenty have produced an excellent document called the On-Site Effluent Treatment Regional Plan. People were invited to comment on this, comments closed on the 30th July. We certainly congratulate Environment Bay of Plenty on producing it. We see I-

as a very important step in improving the water quality in the Rotorua lakes region. The objective of this plan is to address the issues related to the adverse effects caused by the discharge of effluent from on-site effluent treatment systems into the environment. If accepted, by the 1st December 2010 this will require that all property owners discharging waste water within 200 metres of the lakeshore either have to apply for a consent to discharge the effluent or alternatively, they have to treat the domestic effluent through an advanced on-site treatment system, reducing the total nitrogen concentration in the discharge to a maximum of 15 grams per cubic metre measured as nitrogen. Our system hasn't quite reached the 15 grams yet, but it's very close to it.

The Environment Bay of Plenty Plan will require that the effluent must be applied either by sub-surface drip irrigation lines at 100 to 200mm deep, which is much shallower than the traditional septic tank trench system, or in a surface drip irrigation line covered with an inert material such as bark to a minimum depth of 100mm. We have in our system two areas, one in a shrubbery area where the drip irrigation is actually 50mm below the surface, but also covered with compost material, and the other one in the lawn area buried to 150mm depth.

The plan sets out in quite a lot of detail the influence of soil types, rainfall and evapotranspiration on the effluent disposal systems. The plan contains a wealth of information on the conditions within the Environment Bay of Plenty region. It's not just limited to the Rotorua lakes, it's the whole Bay of Plenty. Advanced on-site treatment systems are increasingly being required in other environmentally sensitive places around New Zealand, so it's not just Rotorua that has this problem, it's also beach places and other areas in the South Island.

I would also like to mention On Site NewZ, a group coordinated by Ian Gunn, who is really the leading person in New Zealand as far as waste water treatment is concerned. He was formerly a senior lecturer in the Dept. of Civil Engineering at Auckland University, he's now an Honorary Research Fellow and he produces a regular newsletter called On Site NewZ and he's also produced a leaflet which I understand is available from Rotorua District Council. On Site NewZ is a regular newsletter providing information about domestic waste water treatment systems and in particular the household treatment of waste water. Ian has written a very good paper in the latest Water and Wastes in New Zealand, this is the magazine of the New Zealand Water and Waste Association, in which he describes the historical development of advanced on-site water treatment systems. I can recommend that to anybody who wants to know a little bit more about these systems.

The chemistry related to these systems is very important. What we're endeavouring to do is to reduce the nitrogen levels. The old household septic tank is very poor at removing nutrients and because the effluent drains are usually located at 400 to500 mm below the surface, they miss out on the topsoil and the root growth within that topsoil which is a very important part of reducing nitrogen levels in the effluent. There are many people who provide advanced waste treatment systems but quite a number of them haven't been fully tested and the system that we have installed is being tested. We've had regular testing by Environment Bay of Plenty and we've been very pleased with the results.

These systems have more storage capacity to achieve better separation of the solids from the sewage and they incorporate an aerobic nitrification process, so there's aeration putting air in to convert the nitrogen in the sewage into nitrites and then to nitrates and then to remove the nitrogen as nitrogen gas. There's an anoxic, anaerobic stage to add the denitrification and they deliver a vastly improved effluent to the disposal field. There are filters that will remove any solids and make sure that the effluent after being treated in quite good for distribution in the effluent field. The addition of nitrogen to a septic tank is highly variable. In our particular case, because it's a holiday bach we are down there for a week or a weekend and then we go away, so it's even more variable and the system is on and off. So this is quite a demanding situation and of course different people have different habits, so the amount of nitrogen which is going into the system is going to vary.

Nitrification

occurs as organic nitrogen and ammonia in the raw sewage components enter the tank(s) and are converted to nitrite (NO_2) and then to nitrate (NO_3).

Aeration

in the treatment will aid this process as microbes in the system use oxygen to decompose large organic molecules producing nitrate and other compounds.

Nitrification is quite a complex issue, particularly for a simple property owner like me, not versed in lots of chemistry. The nitrogen occurs in the sewage as nitrogen and ammonia in the raw sewage components, it enters the tanks where it's converted by aeration into nitrite first and then to nitrate, with the addition of oxygen from the aeration. Aeration in the treatment aids this process as the microbes in the system use oxygen to decompose large organic molecules producing nitrate and other compounds. The whole process is biological and the growth of bacteria and other microbes to assist this process takes a while to be achieved. The variants that occur in biological processes are certainly an issue in this process.

Denitrification

will occur at ambient temperatures in anoxic conditions and in the presence of a degradable carbon source such as sewage.

Denitrification is the microbial reduction of nitrate to nitrogen gas occuring in association with the decomposition of organic matter.

Denitrification will occur at ambient temperatures in anoxic conditions and in the presence of degradable nitrogen source such as sewage. So we're aiming with the NO_3 to minimise the amount of effluent that goes out into the effluent disposal system. In order to do that it is necessary to denitrify the nitrates in an anoxic environment and so there is a special tank which is anaerobic, short of oxygen, where the microbes grow on plastic floating disks and they help to perform this denitrification process. Denitrification is the microbial reduction of nitrate to nitrogen gas which occurs in association with the decomposition of organic matter and the denitrification organisms are present in large populations in the soils and around plant growth. We're actually removing some nitrogen from the system as nitrogen gas that can escape to the atmosphere. Removal will occur in the disposal field. The irrigation lines are up at a high level, where the root growth and topsoil is very good at removing nitrates as well, preventing it getting down into the ground water and causing the

problems that we're all aware of. The denitrification is dependent on the carbon to nitrogen ratio, the supply of nitrate and the wet and dry conditions in the disposal field.

The system is designed to remove as much as possible in the plant itself. In the tanks the nitrate can be reduced to nitrogen gas which is discharged to the atmosphere, but it can also be taken up by the plants. The nitrate is highly mobile in ground water and leaching of nitrate is likely to occur especially in saturated ground conditions. A traditional septic tank doesn't remove that nitrate that goes into the effluent system and down into the ground. The advanced systems remove that nitrate before it gets there, anything that's left is discharged into the topsoil layers and so there's a very good chance that very little will get down.

In short
the whole treatment system should
maximise the processes designed
to remove nitrogen from wastewater.

By combining
nitrification with denitrification
nitrogen is mostly removed
to the atmosphere in gaseous form.

Our bach at Gisborne Point has been in my wife's family for the last 80 years and we hope it will continue this way, as it's a delightful place for holidays. Our old septic tank was less than half the required size and we had until 1st December this year to upgrade it, and that applied also to a lot of other properties on Gisborne Point. The professionals involved as I mentioned earlier were very helpful in guiding us to the appropriate solutions in this case.

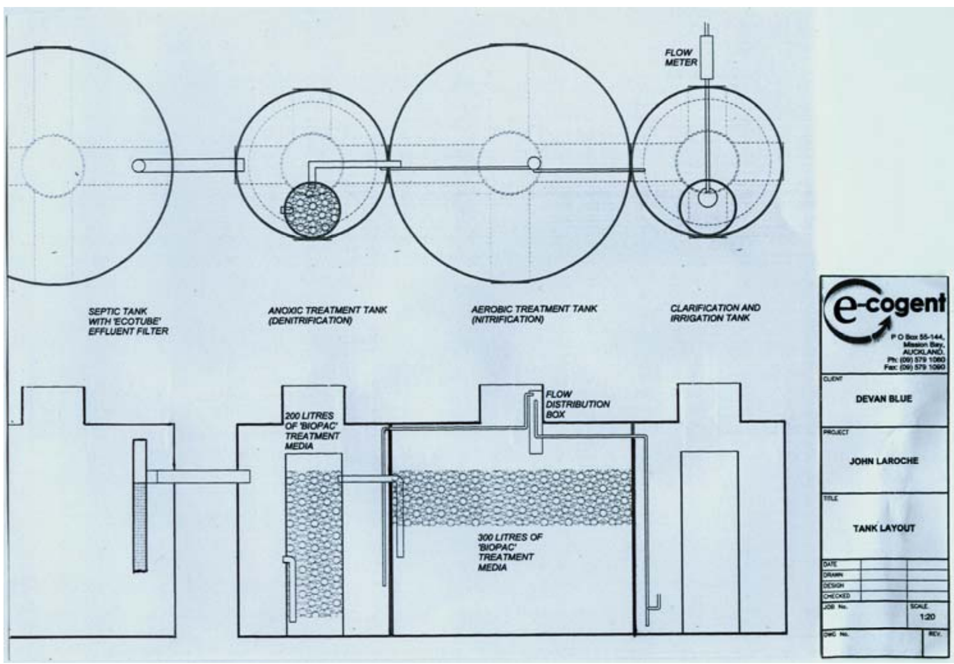
This is a plan of our system (*below*) which has been designed for an average use by 6 people. The plan shows the waste water pipes to the treatment plant system and two irrigation areas. One is the lawn irrigation area which is out on the eastern side of the property and at the back of the property there's a shrubbery irrigation area where the irrigation lines are laid mainly within shrubs and ground planting. Each has a groundwater sample point. All the effluent going out to the irrigation system is measured through a flow meter, so we're able to measure the total quantity of effluent going out and there's a valve system so that we can use either both irrigation systems or just one if we choose.

As-built plan

This (*below*) is the elevation of the tanks supplied by Devan Blue from Tauranga and engineered by Ecogent in Auckland. The basic system is that there is a primary septic tank where the effluent comes in. Originally we were going to use our old septic tank, however the earthquakes that we've had just recently could well have fractured it although I don't think there were any leaks in it as far as I am aware. We got Devan Blue to bring an extra larger tank in.

After the outlet of the primary settling tank there is a filter unit which is cleaned at 6 monthly intervals, so you just lift it up and wash it out. Then there is the first anoxic treatment tank which is where the denitrification occurs with floating plastic disks in that tank on which the bacteria grow. The third tank is the aeration tank with a little air blower which blows air down into it, which bubbles up and allows the conversion of the nitrogen to nitrite and then to nitrate. That then flows to the final tank after which there is a recirculation system from the final tank back to the anox tank where the denitrification takes place. Then finally from the last tank there's a small chamber with a submersible pump which pumps out through the flow meter to the irrigation system.

Ecogent drawing of system



When building the tank, there was a 2 metre deep excavation, the tanks arrived shortly after the excavator had started. All four tanks were on one truck. They were all prefabricated with everything inside. We expected that it would take probably about 3 days to put it in, but the digger arrived at 7 o'clock in the morning and by midday everything was installed and the backfilling was completed here. So it really was very quick and very efficient to install it.

My wife has what we call our mushroom garden planted it up with various shrubs and we feel it's quite attractive, we don't think it's unattractive having these tops of the septic tanks system or the advance treatment system there. The irrigation system is designed for a maximum loading of 690 litres a day and to date less than 300 mm have been going out the waste flow system which incorporates the drip irrigationand drip emitters There is sustained

release herbicide to prevent root growth clogging up any of the emitters and the plastic lines have also got a herbicide inside and an anti-microbial liner to prevent bacterial slime building up.

Working with Environment Bay of Plenty, we've put in test sample pits. In the lawn you can see the lines where the drip irrigation is below and so it really is being taken up in the lawn area. There are sample pits, approximately 500 mm below the surface, plastic sheets to collect any effluent from the sample lines. We put in some peat gravel on top to collect any effluent that went down, there's a tube in the centre which collects the sample and we put a little submersible pump down to collect it. My wife when she was doing the garden area around the tanks managed to put a fork through one of the drip irrigation lines, but it was very easy to see and very quickly repaired because they are the same as standard garden hose and so it was all back in the system very quickly.

Analyses of Initial Test Results

Position	Test No	Collect Date	BOD 5 day g/m3	Ammonia g/m3-N	NO2; g/m3-N	NO3; g/m3-N	Kjeldahl Nitrogen g/m3-N	Faecal Coliforms n/100ml
First Tank - inflow	1	30/06/2004	168	69			57.8	240000
First Tank - inflow	2	28/07/2004		89.1	0.01	0.13	98.0	150000
First Tank - inflow	3	11/08/2004		47.8	0.03	0.01	102.8	90000
Last Tank - outflow	1	30/06/2004	14	47.8			79.2	3500
Last Tank - outflow	2	28/07/2004		44.4	14.4	0.01	57.0	1000
Last Tank - outflow	3	11/08/2004		23.8	33.5	0.05	17.6	510
Shrubbery sample Pt	1	30/06/2004	1.3	0.01	After rain		3.97	6
Shrubbery sample Pt	2	28/07/2004	no sample					
Shrubbery sample Pt	3	11/08/2004	no sample					
Lawn Sample Pt	1	30/06/2004	no sample					
Lawn Sample Pt	2	28/07/2004	no sample					
Lawn Sample Pt	3	11/08/2004	After rain	0.06			1.8	
Groundwater	1	30/06/2004	0.7	0.01			1.71	0.5
Groundwater	2	28/07/2004		0.02	0.006	0.638	1.05	0.5
Groundwater	3	11/08/2004		0.03	0.1	0.069	0.53	6

This table shows the analyses of the results (*left*). The whole system is working extremely well. A little bit of maintenance is required, they're not completely maintenance free. As to the cost benefits of the system, the total installed cost of it was between $13,000 and $14,000. A fully sewered system according to Environment Bay of Plenty and Rotorua District Council in their report on Okareka, between $17,000 and $20,000 per household. Suitable treatment plants would have to be found for putting in a bulk system and maintenance would need to be covered by rates. Thank you.

QUESTIONS

Chair: It's a real pleasure to meet such an enthusiast for domestic waste water treatment. Paul Dell, I'm wondering if there is space on EBOP's website for enthusiasts such as John to post details of their successful systems.

Paul Dell, EBOP: No problem at all.

Rowland Burdon, Royal Society of N.Z.: What herbicide is used to keep appreciative plant roots at bay?

J. La R.: I'm sorry I'm not sure. I might have to call on Peter Gearing to answer that. Peter are you aware of that?
(*inaudible*) … Research Institute and basically is a very immobile form of release. It's a gaseous form which adheres very strongly to the soil particles, no further than 20 mm from each individual. The active ingredient is Trifluoralin and it is impregnated into the plastic.

Modified Zeolites for Phosphorus Removal

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ABSTRACT

Eutrophication is a condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of phytoplankton. The deterioration of the Rotorua lakes has focussed attention on potential remedial technologies to reverse lake eutrophication. One such option is the chemical treatment of lakes in order to remove nutrients and/or remediate sediments that are an internal source of such nutrients. A nutrient stripping media based on the chemical modification of two abundant and indigenous New Zealand natural minerals, zeolite and pumice, was developed in this study. Modified zeolite and pumice were investigated for their ability to adsorb phosphorus and /or nitrogen from aqueous solutions. Batch incubation studies with nutrients were performed at laboratory scale with artificial and natural lake waters.

Modified zeolite and pumice samples with different treatment processes and conditions were employed to understand the effect of various factors on phosphorus removal capacity. Results showed that modified zeolite and pumice exhibited substantially higher phosphorus removal capability than that of natural zeolite and pumice. Trials were conducted to compare modified media and two commercial remediation products: *Phoslock*™ and *Baraclear*™. Modified zeolite and *Baraclear* showed the best performance for nutrient reduction in water, though all media have the ability to achieve greater than 95% phosphate removal if sufficient dose is applied.

The binding of phosphate appears to be largely irreversible under natural pH and temperature conditions for all media tested. Unexpectedly, all media tested also had the ability to remove more than half of the nitrate present. The media developed in this study, and commercially available media, all have potential as remedial tools for the Rotorua Lakes. In this first step, the ability to removed dissolved nutrients was established. It was concluded that, to be successful, such treatments should have the ability to limit nutrient release from sediment. Thus, it is recommended that this be the next objective for study. In parallel with this, studies should examine the relative risks associated with the materials including toxicity and turbidity in local lake systems.

1.0 INTRODUCTION

Eutrophication represents a serious problem for many water bodies around the world and the eutrophication of the Rotorua lakes has recently received considerable attention. Phosphorus and nitrogen serve as the key nutrients, affecting the amount of algal and weed growth. A difficulty associated with the treatment of phosphorus in water is that the majority of the phosphorus (50-90%) is concentrated at the sediment-water interface. Current application techniques involving alum, primarily treat the phosphorus closer to the surface of the body of water, and rarely reach the targeted problem areas in need of treatment (Griffith, et al. 1973). The success of alum treatment is dependent on nearly instantaneous adsorption of phosphorus. As a result, this technique may not perform as effectively in a number of water systems, especially high energy and deep systems, or in systems that require more than just instantaneous phosphorus adsorption. In the former case, alum is flushed from the target waters before it can perform; in the later case, the alum is poorly utilised in application. The alum can also leave an unwanted white cloud in the water for an extended period of time. There are also toxicity and human health concerns with regard to dissolved aluminium in water. In response to the need for nutrient removal and sediment remediation, several patented modifications of clay-based minerals have been developed including *Phoslock*™ based on lanthanum and *Baraclear*™ based on aluminium.

In addition to testing commercially available media for nutrient removal, this study was focussed on developing a remediation material from zeolite/pumice which will assist in reducing internal recycling of sediment nutrient stores in estuarine and freshwater systems. Zeolite and pumice are abundant New Zealand minerals. Natural pumice possesses a porous structure, which contributes to its large specific surface area. The large proportion of free silica sites at the grain surface results in a negatively-charged surface. Zeolite has a skeleton structure that allows ions and molecules to reside and move within the overall framework. The structure contains open channels that allow water and ions to travel into and out of the crystal structure.

Due to these properties, zeolite is widely used in water and sewage purification, ammonia and heavy metals removal, ion exchange in radioactive wastewater treatment, removal of oil pollution from water, and adsorption of other components from liquid and gaseous phases (Colella, 1999; Piaskowski et al., 2000). However, the removal of anionic nutrients by use of natural zeolite or pumice has not been reported, possibly due to the limitation of the negatively charged surface. The present study was carried out to evaluate the enhanced phosphate removal capability of natural zeolite and pumice modified with aluminium-based substances. Due to the higher isoelectric point (net positive charge) of the modified surfaces, the treated zeolite and pumice can also play a role in coagulating and settling suspended dirt particles, bacteria and many microorganisms that possess negatively-charged surfaces in natural water.

2.0 OBJECTIVES OF THE STUDY

- Develop a rapid laboratory method to assess the efficacy of mineral-based nutrient removal media
- Compare the performance of commercially available nutrient removal media with that of modified zeolite and pumice for the removal of dissolved reactive phosphorus
- Examine the ability of media to remove nitrate
- Compare relative dose, reaction time and pH sensitivity of the media tested
- Test nutrient removal in a nutrient rich sample of surface water from the Rotorua Lakes area

3.0 MATERIALS AND METHODS

3.1 Materials

Zeolite used in this study was supplied by New Zealand Natural Zeolite Ltd. The chemical compositions and some important physical characteristics are summarised in Table 1.

Table 1. Chemical composition and physical characteristics of zeolite

Component	SiO_2	Al_2O_3	K_2O	CaO	Na_2O
Weight %	71.54	18.44	2.66	1.75	1.74
Exchange capacity	Slurry conductivity	Slurry pH	Absorbencies		
			Water	Oil	Ammonia gas
80-100 meq/100g	233 S/cm	5-6 for 20 % w/v	60-90% by weight	75% by weight	50-130 meq/100g

**Data provide by NZ Natural Zeolite Ltd.*

Pumice used in this study was supplied by Works Filter Systems Ltd. The chemical compositions are summarised in Table 2. The fraction of particles passing a UK standard No. 24 sieve, was collected to obtain pumice particles in the size range of approximately 177 to 290 µm diameter (24 to 60 mesh). Two patented commercial products, *Phoslock* and *Baraclear* were chosen in this study to compare with modified media. *Phoslock* is a lanthanum amended bentonite clay, whereas *Baraclear* is aluminium amended clay. Both formulations are sold as pellets that rapidly swell and dissociate into a suspension when added to water. A photograph of the commercial products in comparison to zeolite is shown in Figure 1.

Figure 1. Media tested in this study, from left to right, treated zeolite, *Phoslock*, and *Baraclear*.

As natural raw zeolite and pumice contain various extractable materials, which can affect the adsorption, 0.1 M HCl was used to pre-treat the mineral substrate to remove these residual inorganic salts. The particle size distribution of *Phoslock*, *Baraclear* and acid washed zeolite are shown in Figure 2.

Table 2. Chemical composition of pumice

Composite	SiO_2	AlO_2	Na_2O	Fe_2O_3	K_2O	CaO	MgO	TiO_2	MnO
Weight (%)	71.02	12.83	4.02	2.88	2.67	1.56	0.32	0.27	0.11

Composite	Nb	Zr	Y	Sr	Rb	Ca	Cr	As	Ba	Pb	Th
(ppm)	7	183	29	137	106	15	10	21	682	17	13

**Data obtained from Geoscience Laboratory in Sudbury, Ontario, Canada. Oxide measured in weight %., Heavy metals measured in ppm.*

Potassium dihydrogen phosphate (KH_2PO_4) was used as the source of phosphorus, and potassium nitrate (KNO_3) was used as the source of nitrogen throughout the bench experiments. Stock solutions at various concentrations and pH were prepared by dissolving the desired amount of KH_2PO_4 and KNO_3 into distilled water. Dilutions were prepared by adding distilled water to the stock solution to achieve the required concentration. Lake Okaro

water was used for the case study. The raw water was passed through a phytoplankton net (44 μm mesh) to remove all particles and suspended algae.

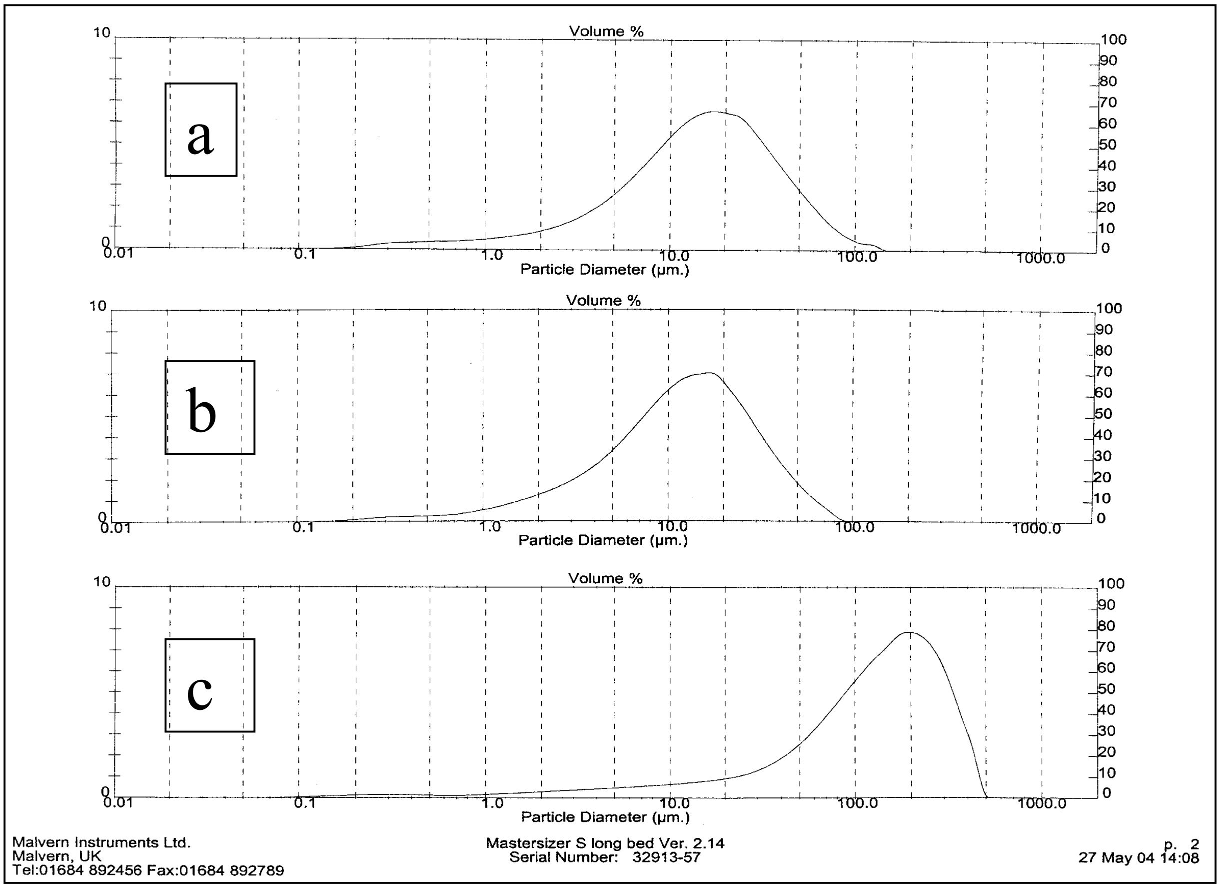


Figure 2. Particle size distribution of a) *Phoslock*, b) *Baraclear*, and c) Zeolite

3.2 Methods

A method was developed to rapidly measure the binding efficiency of mineral media at the laboratory scale. Adsorption experiments were carried out by shaking the media with 50 mL of known nutrients in solution. Measured quantities of media were added to the solutions in sealed tubes and the resultant suspensions were agitated for varying periods of time. A temperature-controlled shaker bath was used to keep the temperature at a constant 25^{o}C. All adsorption experiments were performed at the natural pH of the phosphate solution, except those in which the effects of pH of the solution were investigated. The pH of these solutions was adjusted with 0.1 M HCl or 0.1 M NaOH using a pH meter.

At the end of the adsorption period, the supernatant was transferred to a 50 mL centrifuge tube and centrifuged at 2000 RCF for 10 minutes. The supernatant was aspirated out to determine the concentration of the residual nutrients.

Dissolved reactive phosphorus (DRP) and nitrate were measured with a Skalar autoanalyser. The amounts of phosphate/nitrate adsorbed were calculated from the concentrations in solution before and after adsorption.
Three modification processes were used to treat raw zeolite and pumice. Products are referred to as Z-1, Z-2, Z-3 and PM-1, PM-2, PM-3 (Z represents zeolite; PM represents pumice), respectively. A series of experiments were carried out with the commercially available media and the modified pumice and zeolite. The purpose of these experiments was to:

- Examine the phosphate binding potential of the modified zeolite and pumice in order to determine if these mineral treatments had potential for remedial tools
- Examine the nitrate removal potential of media that showed good phosphate removal ability
- Compare the ability of the commercial products and modified zeolite or pumice to remove DRP
- Study the rate of phosphate removal and the impacts of initial phosphate concentration on this rate
- Determine impacts of pH on phosphate removal
- Examine the ability of the various media to remove nutrients from water flowing into Lake Okaro

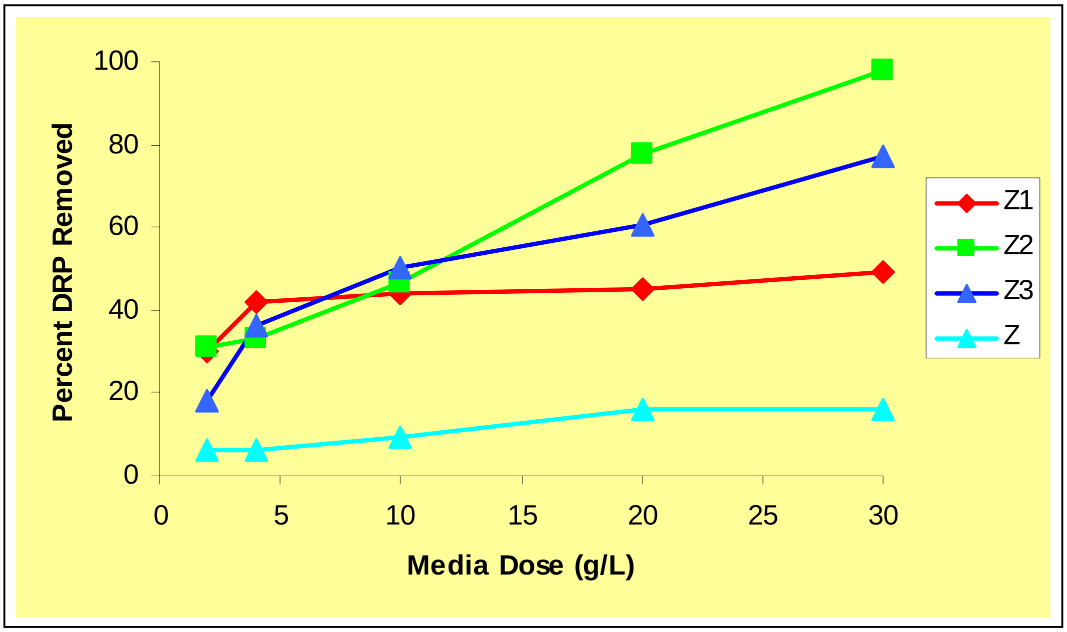
4.0 RESULTS

4.1 Adsorption capacity of modified zeolite and pumice for DRP

In order to examine the adsorption capacity of modified and natural zeolite and pumice, media were incubated with high concentrations of phosphate. Concentrations used were in the order of 100 mg/L, 100-fold higher than would usually be found in surface waters. For all forms of modified zeolite and pumice, chemical modification led to increased binding of phosphate as compared to the unmodified material (Figure 3).

The Z-2 modification process produced the highest adsorption capacity with both pumice and zeolite. The adsorption ability for the modified zeolite was superior to that of pumice. However, as the pumice used in this study was coarser than zeolite, this was likely a function of increased surface area per unit weight of zeolite. Adsorption isotherms for experiments are shown in Appendix 3.

Experimental results indicated that both pumice and zeolite modified with the Z-2 process demonstrate very high capacity for phosphate, binding up to 90% of the phosphate ions at the highest concentration of media. As the Z-2 modified zeolite provided the best phosphate adsorption, this media was used for all subsequent experiments and comparisons.



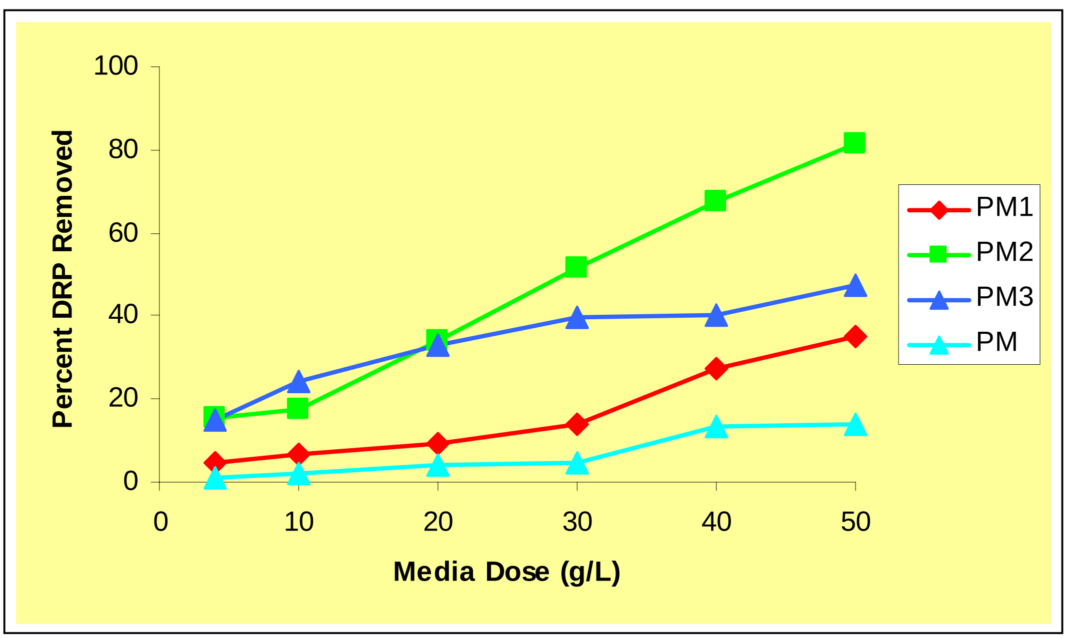


Figure 3. Binding capacity of modified zeolite (top) and pumice (bottom)

4.2 Adsorption capacity for oxidised nitrogen species (NO_x)

The Z-2 modified zeolite demonstrated high capacity to bind nitrate ions. Figure 4 shows adsorption of nitrate by the media at a range of nitrate concentrations. At the highest concentration of 1000 mg/L the media was still able to bind 98% of the nitrate in solution.

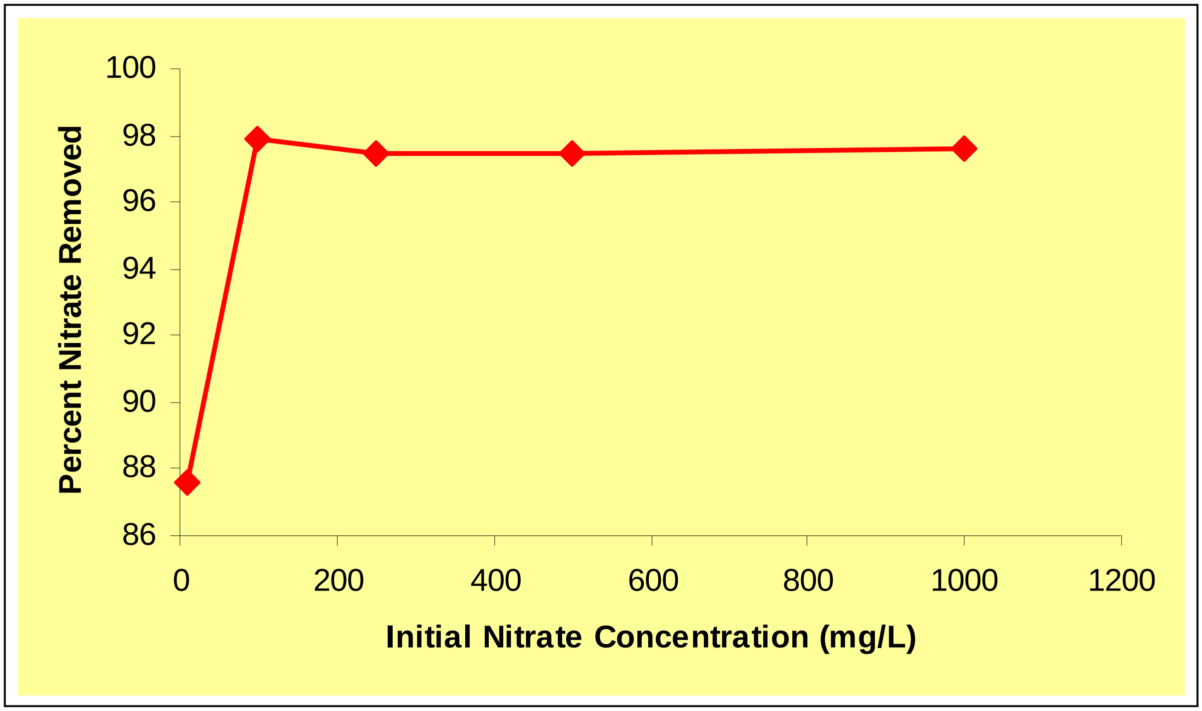


Figure 4. Binding of nitrate to Z-2 modified zeolite.

4.3 Adsorption rate of DRP on Z-2 modified zeolite and effect of pH

The binding of phosphate to Z-2 modified zeolite was rapid, with steady-state condition being reached in approximately two hours (Figure 5). The binding appeared to follow a first-order kinetic model (Appendix 3). There was a modest increase in binding with lower pH. The effect of initial phosphate concentration on adsorption was also examined using 5, 50, and 500 mg/L of DRP starting concentration (Figure 6). Kinetics experiments indicated that adsorption of the phosphate was rapid, and only minor differences in binding efficiency occurred with different starting concentrations. Phosphate removal was in excess of 84% for all concentrations tested.

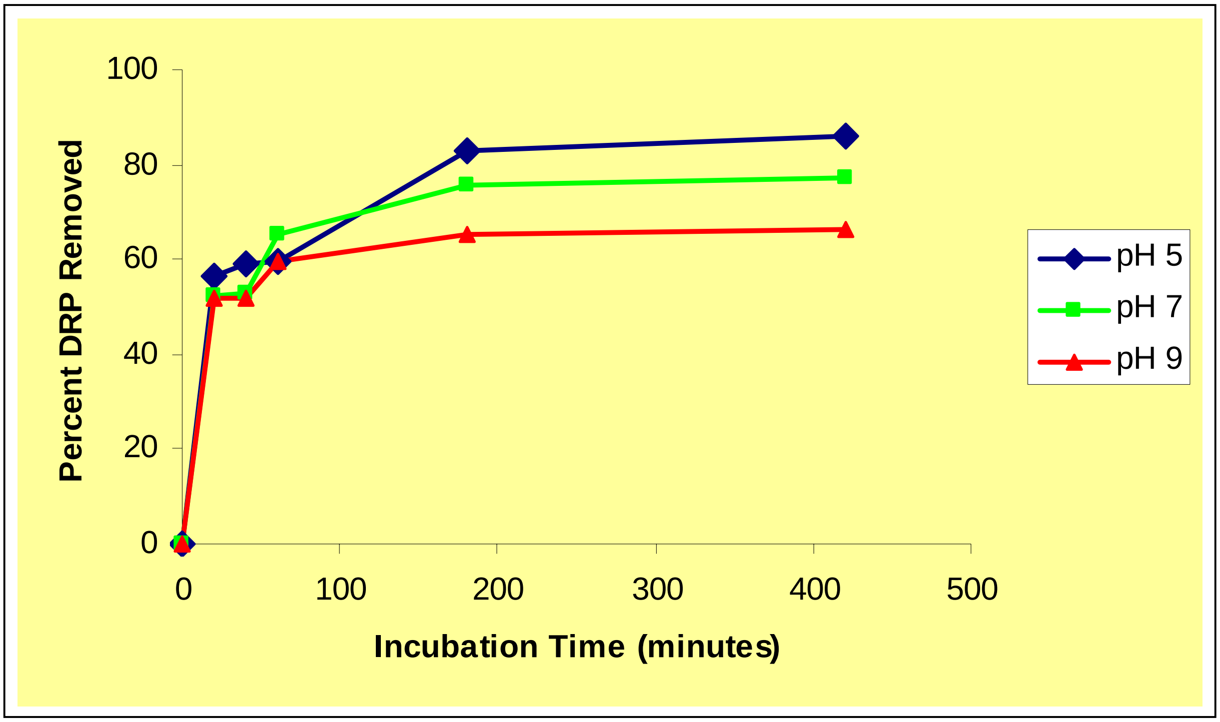


Figure 5. Binding kinetics of phosphate to Z-2 modified zeolite.

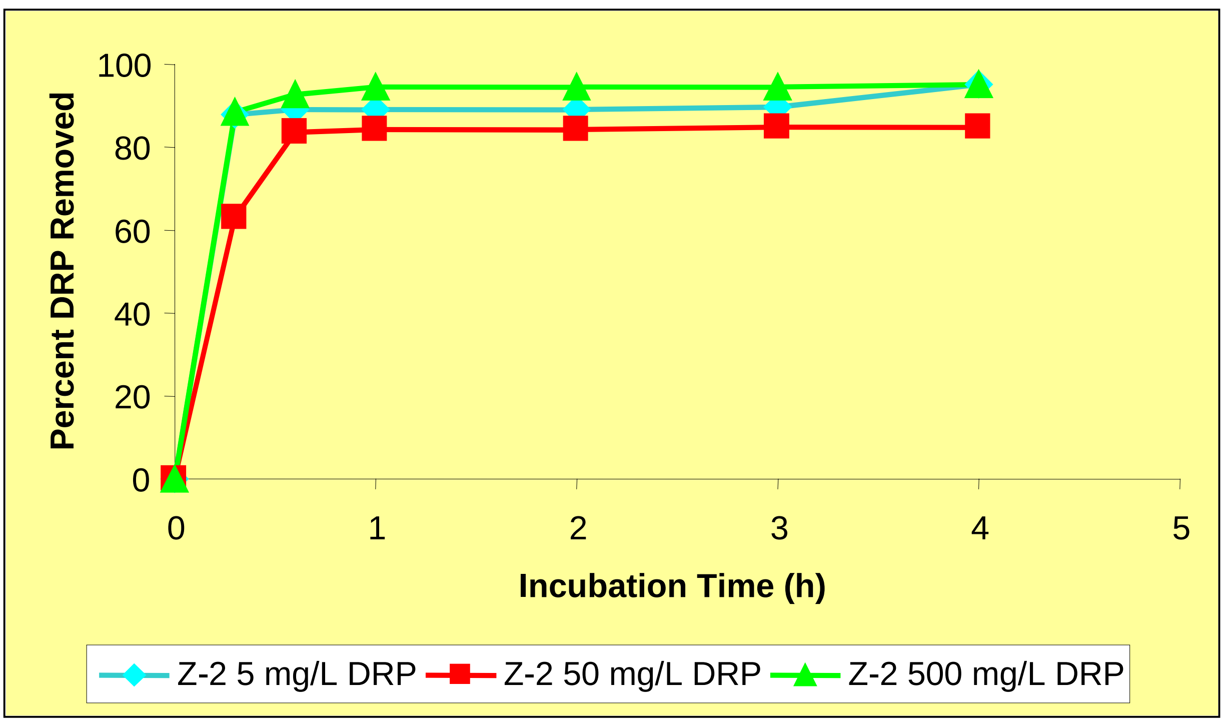


Figure 6. Adsorption kinetics of Z-2 with varying starting concentrations of phosphate.

4.4 Comparison of Z-2 zeolite with commercially available adsorbents

The Z-2 modified zeolite was compared directly with *Phoslock* at a variety of pH and incubation times. Initial phosphate concentrations were in the order of 50 mg/L. *Phoslock* demonstrated similar kinetics to Z-2 with maximum phosphate binding occurring within 1-2 hours. *Phoslock* was not as sensitive to pH as Z-2 with only a marginal increase in phosphate binding occurring at pH 5.0 (Table 3). Overall, Z-2 had a slightly improved efficiency for the binding of phosphate as compared to *Phoslock*, ranging from 6-10% higher binding efficiency. The greatest difference in binding occurred at pH 5.0. However, all treatments of both *Phoslock* and Z-2 performed very well and exceeded 83% phosphate binding.

Table 3. Comparison of the efficacy of Z-2 and Phoslock for the removal of DRP.

Media	Percentage of phosphorus removal		
	pH		
	5.01	7.05	9.72
Z-2	95.5	92.6	89.1
Phoslock	85.3	84.5	83.7

4.5 Phosphate binding reversal from Z-2 and *Phoslock*

This experiment was carried out in order to assess if phosphate could be re-released from the binding media. For the first stage, 1 g media was dispersed in a concentrated phosphorus solution, shaken for 6 hrs and settled for 12 hrs to reach equilibrium. As phosphate re-release was expected to be minor, very high phosphate concentrations (in excess of 1.5 g/L) were used so that the media would be saturated with phosphate and the phosphate released would be measurable. The sample was filtered through a 0.2 μm filter, the media added to 100 mL distilled water, shaken for a further 6 hr, and settled overnight (12 hrs). The residual in the solution represented the reversibly bound phosphorus. Table 4 shows the level of the reversed bound phosphate in *Phoslock,* and Z-2.

The Z-2 media showed the lowest rate of reversal, in the order of 1% whereas *Phoslock* had rates of reversal approaching 3%. Both media appear to bind phosphate irreversibly using the present methods. It is likely that the rates of reversal indicated are not representative of true reversal of binding. Due to the high levels of phosphate used in this experiment, it may have been difficult to rinse off all phosphate solution associated with the media, so these results may represent carry-over, not reversal of binding. However, the experiment demonstrates that significant re-release does not take place with either media.

Table 4. Percent of reversibly bound phosphorus

Percentage of reversal				
media	Initial concentration (mg/L)			
	6000	4500	3000	1500
Phoslock	2.26	2.79	2.94	3.29
Z-2	1.15	1.00	1.24	1.70

4.6 Lake Okaro Surface Water Case Study

Lake Okaro has the poorest water quality of the Rotorua lakes. The Trophic Level Index in 2003 was reported to be 5.61 and the average total phosphorus and nitrogen were 0.122 mg/L and 1.25 mg/L, respectively (Scholes 2004). In this study, a sample was taken from the inflow creek to the north-west of Lake Okaro, draining farmland. This sample had initial DRP and NO_x-N concentration of 0.185 mg/L and 1.520 mg/L, respectively. Modified zeolite Z-2, Z-3 and two commercial products, *Phoslock* and *Baraclear,* were selected as the adsorbents. All adsorbents were tested at media concentration of 1, 4, 10 and 20 g/L.

Both *Phoslock* and *Baraclear* are clay based pellets and disperse very quickly in water to form a suspension. Treated zeolite also forms a suspension upon agitation, but this suspension settles within minutes as opposed to hours for the clay-based particles (Figure 7). The relative charge, or isoelectric point, was also determined for the various media tested and is shown in Table 5.

Table 5. Isoelectric points of the media tested and untreated zeolite.

	Baraclear	*Phoslock*	Zeolite	Z-2	Z-3
Isoelectric Point	5.45	3.29	4.02	7.71	6.93

The Z-2 treated zeolite and *Baraclear* demonstrated the highest efficiency for DRP removal from Lake Okaro water as both were able to exceed 90% removal efficiency (Figure 8). This was followed by Z-3 treated zeolite then *Phoslock*. From the relationships obtained, *Phoslock* would require much higher doses to achieve the same removal efficiency as *Baraclear* and Z-2. The use of Lake Okaro water resulted in a reduction of phosphate removal efficiency as compared to that seen with lab water sample spiked with phosphate and the reasons for this loss of efficiency are unknown.

Figure 7. Treated zeolite, *Baraclear*, and *Phoslock* suspensions in water.

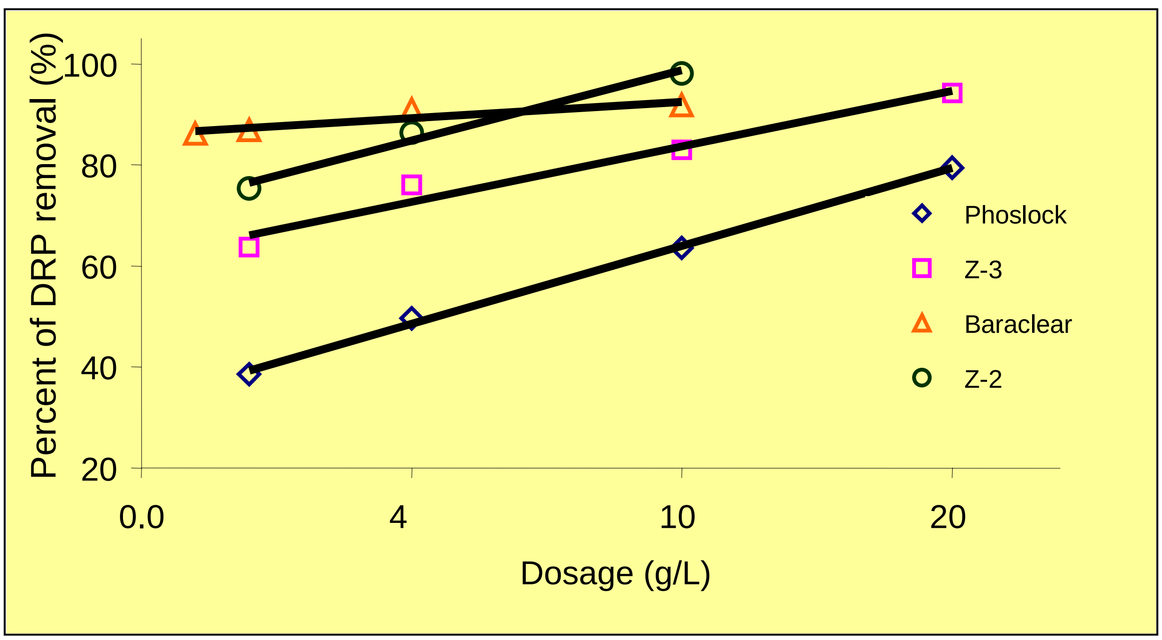


Figure 8. Removal of DRP from Lake Okaro water with treated zeolite and commercially available adsorbents.

Based on the binding data illustrated in Figure 7, the dosage of media required to remove 95% of DRP from Lake Okaro water was calculated and is shown in Table 6. The Z-2 treated media requires the lowest dose to obtain 95% DRP removal. However, due to differences in slope, *Baraclear* can obtain greater than 80% removal at lower doses than Z-2.

Table 6. Optimal dosage for 95% removal of DRP.

	Media			
	Z-2	Z-3	*Phoslock*	*Baraclear*
Dosage (g/L) (95% DRP removed)	17.4	30.4	40	27.6

The removal of nitrate/nitrite was also assessed for Lake Okaro water. All media tested had the ability to remove about half of the nitrite/nitrate nitrogen, irrespective of media dose (Table 7). It was not determined if the binding of these nitrogen species was irreversible.

Table 7. Removal of NOx species from Lake Okaro water.

	Percent of NOx removal (%)			
Dosage (g/L)	Z-3	Z-2	*Phoslock*	*Baraclear*
4	50.04	44.88	50.73	49.75
10	51.47	49.53	51.15	53.69
20	52.27	53.98	52.27	60.79

5.0 DISCUSSION

This research demonstrated that a variety of nutrient-adsorbing media have excellent potential for the removal of DRP from surface water. Those media using aluminium amendments of minerals, namely Z-2 treated zeolite and *Baraclear* showed the greatest performance for the removal of phosphate. Of the treated zeolite, Z-2 had the highest relative charge, explaining the superior performance for complexing phosphate. Unexpectedly, all media tested also showed the ability to complex a significant amount of the nitrate/nitrite nitrogen in surface water. *Phoslock* showed less affinity for phosphate as compared to the aluminium-based media tested. As lanthanum phosphate is even less soluble than aluminium phosphate, this was unexpected but may be related to the strong negative charge of *Phoslock* particles in solution. This discussion will focus specifically on the potential and strategies for remediation of the Rotorua Lakes, particularly the use of nutrient-adsorbing material.

All aquatic plants require exogenous nitrogen and phosphate. As phytoplankton all fix carbon from the atmosphere, one or the other of these two macronutrients generally limits the growth of algal blooms. Each lake has a nitrogen to phosphorus ratio (N:P) that defines the relative abundance of these nutrients. There have been many substantial reviews discussing the impact of N:P ratios on phytoplankton populations (Smith, 1983; Aleya et at., 1994; Takamura et al., 1992; Zohary et al., 1992; Fujimoto et al., 1997) that suggest that bloom-forming cyanobacteria tended to dominate in lakes where the N:P mass ratio is low. Thus, when nitrogen is the limiting factor in growth, cyanobacteria may be favoured due to their

ability to fix gaseous nitrogen from the atmosphere. This conclusion has led to the so-called "N:P rule" that increasing the mass ratios above 29 will reduce the proportion of cyanobacteria as a fraction of the total algal biomass. However, some researchers (Trimbee et al., 1987; Sheffer et al., 1997) hold the reverse view. They have recognised that even when such a response is observed, it may be due to the increasing P concentrations rather than a decrease in the N:P ratio. Paerl et al. (2001) suggested that the "N:P rule" is less applicable to highly eutrophic systems when both N and P loading are very large and N and P inputs may exceed the assimilative capacity of the phytoplankton. The understanding is further complicated by seasonal variation in N:P ratios and the availability of inorganic forms of N and P from the total nitrogen and phosphorus pool.

In the Rotorua Lakes Water Quality report (Scholes, 2004, Table 8), the majority of lakes in the Rotorua district have N:P ratios lower than 29, indicating that phosphorus is overabundant. Further analysis of these data show that, on the basis of N:P ratios, the five most eutrophic lakes cluster out from the five least eutrophic lakes, with the more eutrophic lakes having lower N:P ratios. However, there are also very tight correlations between both TP and TN and algal productivity as measured by Chlorophyll a. One striking observation is that those two lakes with the highest N:P ratio, Tikitapu and Rerewhakaaitu, are very dominated by green algae (Wilding, 2000) and are not known to demonstrate blue-green algae blooms. Rerewhakaaitu in particular is interesting due to the relatively high component of pastoral land surrounding the lake. It has been suggested that the allophanic soils surrounding the lake effectively complex phosphorus and prevent it from entering the lake (Fish, 1978). We have also noted that biota from these two very different lakes appear to be particularly depleted in the ^{15}N stable isotope of nitrogen as compared to the other lakes (C. McBride, unpublished data), further suggesting that phosphorus limitation is having significant effects on the ecology and fate of nutrients in those lakes.

Evidence from overseas, and from the Rotorua Lakes suggests that in the first instance, increasing the nitrogen to phosphorus ratio through intensive management of phosphorus inputs may be the best way to reduce harmful blue-green algae blooms in the lakes most affected. To force a reduction in overall productivity, more substantial phosphorus and nitrogen removal would have to be achieved. Sas et al. (1989) and Seip et al. (1992) suggested that if DRP was < 10 µg/L either on average over the entire growing season or absolutely during at least half of the growing season, then phytoplankton growth may be assumed to be P-limited during the growing season. Similarly, the threshold value below that where N-limitation occurred was assumed to be 100 µg/L inorganic nitrogen.

In some cases, nitrogen reduction will be more difficult to realise in the short term due to the high solubility of nitrate salts. For example, in the well-known case of Lake Taupo, ground water nitrogen inputs are significant, and due to the long groundwater residence time, these inputs will continue for decades regardless of any other measures taken. Work done on groundwater inputs into the Rotorua Lakes indicates that future nitrogen input may be substantial, particularly in Lake Rotorua given the large catchment size (Morganstern et al., 2004). Removing nitrogen will certainly reduce overall productivity, but low N:P ratio will continue to favour blue-green algal blooms.

Table 8. Nutrient and biological data for Rotorua lakes (from Scholes, 2004)

Lake	Chlorophyll a	Secchi Depth	TP	TN	TN:TP
Okaro	32.76	1.61	122.6	1250.5	10.2
Rotorua	14.77	2.48	43.8	426.2	9.7
Rotoehu	12.04	2.34	36.5	456.0	12.4
Rotoiti	7.27	4.96	23.1	276.8	11.9
Okareka	4.49	6.89	6.1	224.6	36.8
Rotomahana	5.08	4.24	24.8	221.9	8.9
Rerewhakaaitu	5.31	4.97	7.4	379.8	51.1
Rotoma	1.49	10.86	3.2	135.1	41.0
Okataina	2.13	9.2	6.1	123.1	20.0
Tarawera	1.58	7.98	7.0	112.9	15.9
Tikitapu	2.04	6.01	3.8	195.5	51.1

Some phosphate salts, unlike nitrate, are highly insoluble and phosphorus in unimpacted aquatic systems is naturally derived only from the weathering of minerals or internal recycling. As phosphate is rapidly tied up in soils, it generally does not enter groundwater via land-use practices in significant amounts (though there can be significant natural source in groundwater). The success of the Rotorua land application of municipal sewage scheme in removing phosphorus is an excellent example of this. For this reason, anthropogenic sources of phosphorus from agricultural activities and erosion, or enriched natural sources can more easily be limited in the short to medium term than nitrogen sources. One potential usage for phosphorus adsorbing media may be to treat surface water or effluent inputs where substantial phosphorus sources are known to exist.

As lakes become eutrophic, internal nutrient cycling from anaerobic sediments becomes more substantial. The total mass of phosphorus in a lake water column is relatively small as compared to the phosphorus stored in sediment. Thus, though removal of nutrients from the water column may have short-term benefits, longer-term benefits can only be realised through reduction of nutrient cycling from the sediments. A study with alum introduction in a lake in France demonstrated that removal of nutrients from the water column had limited benefits (Van Hullenbusch et al., 2002) and these results appeared to be mirrored by the Lake Okaro alum application trial.

Another method that has been tested for over 50 years for the reduction of trophic status has been lake aeration. Though many efforts have failed, the introduction of pure oxygen directly into the hypolimnion in a deep eutrophic lake resulted in a reduction of TP in the hypolimnion by 50% accompanied by a 55% drop in chlorophyll a. This caused the lake to revert from eutrophic to mesotrophic (Prepas et al., 1997). Though such methods have the potential to reduce nutrient recycling, they are costly. Similarly, lake dredging approaches

also have the potential for lake improvement, but are also very costly. Biomanipulation, or removal of biomass has been another means suggested of reducing overall nutrient loadings.

The greatest utility for nutrient adsorbing media in lake remediation is their ability to treat sediment and reduce nutrient release rather than just remove nutrients from the water column. In the case of *Phoslock*, bentonite clays form a nearly impermeable barrier over the sediment in combination with the ability to precipitate DRP. The treated zeolite tested in this report also has the potential to act in a similar fashion, though sediment capping would be expected to be more permeable as compared to *Phoslock*. Whereas clay particles are by definition colloidal, the zeolite can be obtained in any particle size. Different particle size may have different uses, for example larger particles may be more suitable to effluent treatment columns or batch removal of nutrients, whereas finer particles may be more suitable for nutrient removal from water bodies. Lake treatment with such media has the potential to provide a solution at a lower relative cost as compared to other methods of lake treatment. However, there are risks of such treatment including the release of metals into the environment, such as aluminium that is used for amendment of media. The re-suspension of fine particles during lake mixing, resulting in high turbidity on an ongoing basis is also a risk. This latter risk may be significant for a large shallow lake such as Lake Rotorua. The use of larger particle size may reduce this risk.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The modified zeolite and pumice have been demonstrated to substantially reduce phosphorus in both artificial and natural waters under batch-test conditions. The results indicate that the modified zeolite performed better than modified pumice, probably due to finer particle size. The adsorption capacity is pH dependent and increased with decreasing pH, but the modified media can still work very effectively over a wide pH range. The nutrients were strongly bound to the modified media, and phosphorus was mostly irreversibly bound under the test conditions used. The modified media were more effective in phosphorus removal than nitrogen removal in natural surface water. The modification process for zeolite and pumice is simple and economic and could be made locally. The reaction kinetics data presented could be used for designing substrates to treat natural water or effluents for the removal of phosphorus on a large scale.

During the progress of the work a number of aspects requiring further investigation were identified:

- The potential for the reduction in internal nutrient recycling through sediment remediation is the most critical question. In the first instance, this should be examined in water/sediment column experiments.
- Mesocosm (limnocorral) trials would be required to validate the performance of the various media in a site impacted by eutrophication. This should be performed in collaboration with limnologists in order to examine the impacts on productivity and pelagic algal and zooplankton communities.
- The environmental risk of the substances in question should be addressed with studies to examine the fate of metals on the media under various environmental conditions

including pH. The use of a number of toxicity bioassays at different trophic levels should accompany examination of the fate of metals.

- An engineering model should be established to examine the relationship between particle size, depth of capping and lake energy in order to determine the risk of media re-suspension.
- As research proceeds, and effective doses for the different outcomes (nutrient removal from water vs. sediment capping) are determined, a cost model should be developed for fabrication of modified zeolite in comparison to commercially available adsorbents.

EXERPT FROM TRANSCRIPT (edited)

"All of the inorganic media showed potential to bind nutrients in the water, although some of them aren't really designed to do that. Phoslock in particular is designed largely as a sediment capping approach and we haven't examined that yet, so all we've looked at is binding and water. Alum has the same potential to do it in water with a lower cost, so we haven't invented anything that's going to be more economic or new that we can't do with alum.

"The question is, what's the best economically feasible strategy to reverse increases in trophic status in the lakes? I have taken the liberty of having a play with some of EBOP's data, the original reason that I did this was to try and explain some of the things that we've seen with our food web stable isotope study that Chris McBride and Brendon Hicks and I are all involved in.

"Not surprisingly, if you look at the EBOP data of total nitrogen and total phosphorus versus chlorophyll A, which represents primary productivity and Secchi depth for clarity, you get quite a good relationship. So the nitrogen and phosphorus question is quite a big one. That doesn't tell us very much new, just that the nitrogen and phosphorus sources in the lakes are strongly associated with each other. When you're polluting with nitrogen, you're generally polluting with phosphorus as well. So it doesn't really tell us much about whether nitrogen or phosphorus is important. This is no way disagrees with what Ian Hayes said earlier this morning about total nitrogen and total phosphorus in Lake Rotorua.

"If you could actually look at a narrower range of data, you wouldn't see much of a relationship because there are a lot of other things happening and a lot of other variability, but when you look at it across a wide range of total nitrogen and total phosphorus concentrations, you see the relationship. And just as Ian said, when you pollute with nutrients, you tend to pollute more with phosphorus than you do with nitrogen. That's why there's over 2 orders of magnitude difference in total phosphorus and only about one order of magnitude difference in total nitrogen.

"So the nitrogen to phosphorus ratio becomes fairly important, and we do see a relationship there, which may just mean that clean lakes naturally have a high nitrogen to phosphorus ratio, it doesn't indicate any causality, but there's an association there. From the other EBOP data, it's been known for quite a long time that particularly Lake Rerewhakaaitu and Lake Tikitapu are not known to have cyanobacterial blooms of any significance at all, in fact Tikitapu is probably not known to have cyanobacteria at all. They are very, very different

lakes. One is very oligotrophic so that's understandable, but one is mesotrophic and these both have a nitrogen to phosphorus ratio of 50:1, which are your highest nitrogen to phosphorus ratios.

“So the Rotorua lakes themselves do show that it is potentially possible to limit cyanobacterial growth with the nitrogen to phosphorus ratio. As we heard this morning, iron might make a difference as well. Interestingly we just found out that our Z2 media also binds colour from Paper Mill effluent, that's another thing that we're trying to apply it to. Previous to today I saw no relationship between pine trees and this data, but now I do because a lot of the coloured molecules are the same organic polyphenolic molecules that are in pulp and paper effluent, creating the colour. So that what was being talked about this morning, that may increase the availability of iron, there's an interesting parallel there. Certainly there's a lot of literature on this and I've been looking at it.

“In very eutrophic systems neither nitrogen or phosphorus is limiting, light limitation you heard of that already this morning, therefore only very substantial removal will achieve improvement, and it may take a long time. P limitation has been known to limit blue-greens, although even in the international literature it's still a controversial subject. So in some cases by driving up the N to P ratio it may be possible to reduce blue-greens, but perhaps with little overall impact on algae productivity. Lakes like Okareka, which has a total nitrogen/total phosphorus of about 30, may just be on the borderline, so it's a lake where intensive phosphorus management may actually be useful. I don't know that it necessarily would in some of the other more severely impacted lakes for a long time.

“Targeting nitrogen alone could even favour blue-greens, though it will reduce overall productivity. The severity may be less, but you may still get blue-greens. Ther arees 14 Rotorua lakes, every single one of them is different and a different strategy has to be applied and that's self-evident.

“In terms of our media, phosphorus removal can be achieved most economically with alum. I've looked quite a lot at the literature, but alum has a bit of an Achilles heel, with the concerns about aluminium and human health, but also if you have relatively clean, clear waters with low levels of nutrients that you are removing, flocculation and settling are very, very difficult with alum. But it can work, it's even been used as a sediment remediation technique. Certainly I'm seeing a pattern that whether you use alum, whether you use dredging of sediments, whether you use hypolimnion oxygenation, they all seem to me as I'm starting to look at the literature, to be more effective where external inputs are not that substantial compared to the internal inputs of nutrients.

“So for lakes with very high internal inputs, those methods can be very, very effective and have been throughout the world. Where they haven't been is perhaps in a case like Lake Okaro, where you have a very significant external input and the effect is long-lived, so some people have seen alum improvements for 7 years and some people haven't seen any.

“Just finishing up, mineral media may have longer term benefits at reducing internal nutrient recycling and indeed, both our zeolite and the Phoslock may have applications for capping the nutrients and reducing that internal load, and that's something we'd like to look at.

Porous media such as zeolite have another application, as a permeable reactive barrier, which can be as simple as a hole in the ground loaded with treated zeolite into which you put effluent to tie up phosphate. Certainly media such as zeolite and Phoslock may be more suitable to water treatment where rapid settling and recycling of material is required. Rapid settling of zeolite can be a big advantage engineering wise to allow you to use it for reducing internal loading and capping nutrients.

QUESTIONS

John La Roche, LakesWater Quality Society: With the precipitation of the phosphorus and other substances to the bottom, did you look at what the effects of them sitting as sediments on the bottom would be? I am concerned that on the bottom where you get anoxic conditions the pH could be lowered and maybe some things that have been precipitated with alum could come out of solution and be just as much of a problem as they were before.

Mike van den Heuvel: It's possible and it's something we've looked at, though not completely. Certainly our lanthanum bound phosphate molecule is not coming to come off at all with any pH really, it's very, very insoluble. It's a difficulty with using iron, which also can be used, and it will also be affected by redox conditions. We don't expect aluminium to be affected. The interesting thing about Z2 is that nothing, including aluminium, comes off at acidic pH, we have actually subsequently tested that. We were more interested in whether aluminium comes off at acidic pH because of the health issues and it doesn't at all with the Z2 media.

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The effects of bottom water anoxia on the chemistry of Lake Rotoiti sediments

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ABSTRACT
Analyses of dissolved oxygen in the water column of Lake Rotoiti over the past 40 years show progressive development of anoxic bottom waters that reflect increasing oxygen demand from decomposition of organic matter. Decreases in redox potential at the sediment/water interface result in reduction of insoluble ferric (Fe^{III}) and manganese (Mn^{IV}) compounds to soluble ferrous (Fe^{II}) and manganese (Mn^{II} and Mn^{III}) states. These reductions have resulted in release of phosphorus and other trace elements from the sediments to the pore waters, with diffusion transporting these ions through the interface to the lake waters.

Development of anoxic bottom waters has likely resulted in greatly enhanced recycling of phosphorus and nitrogen compounds back into the water column, further enhancing eutrophication. Sediment cores from Lake Rotoiti show up to 600 mm of seston has accumulated following the Tarawera eruption of 1886. Development of anoxic sediments has occurred recently as the seston from 60m water depth shows that the upper 100 mm was deposited under reducing conditions, whereas the seston below 100 mm was deposited under oxidising conditions.

Sediment pore water samples taken at 10mm intervals have been analysed to determine concentration gradients of reactive phosphorus, inorganic nitrogen species, iron, manganese, zinc, arsenic and other trace metals. Fluxes of these ions from the sediments to the water column are being determined using their concentration gradients through the sediment/water interface and applying Fick's Law. Analyses of Lake Rotoiti sediment composition shows that the potential supply rate of phosphorus from the bottom sediments could dominate all other sources and remediation will therefore have to involve reductions of this flux.

Keywords: anoxic, eutrophication, trace metals, pore water, sediments

TAPE TRANSCRIPT (edited, not all graphics shown)

I have to thank all the previous speakers because they have done a very great speech and a lot of introduction to my topic. At the beginning of my Masters we decided to determine the nutrient and trace element levels in the water column and in the sediment pore water of Lake Rotoiti, also to assess the fluxes of nutrients and trace elements between the water column

and sediments of Lake Rotoiti and to look at the effect of the eutrophication and the bottom water anoxia and fluxes of nutrients and trace metals at the water sediment surface.

ELEMENTS ANALYSED

	LAKE WATER	DRY SEDIMENTS	PORE WATER
NUTRIENTS Nitrogen (FIA, AA)	√ NO_3^-/NH_4^+		√ NO_3^-/NH_4^+
NUTRIENTS Phosphorus (FIA, AA)	√ TDP,PO_4^{3-}	√ TP	√ TDP,PO_4^{3-}
TRACE ELEMENTS * (ICP-AES)	√	√	√
ANIONS – Cl^-, HCO_3^-	√		√

(*) **As, Cd, Cu, Zn, Ca, Sr, Al, Fe, S, Mg, Mn, K, Na**

For the elements analysed, they vary in the way we analysed due to the available instruments that we had at Waikato University, so some parts have been analysed on lake water only and some only on the sediments and pore water. The trace elements we looked at were arsenic, cadmium, copper, zinc, calcium, strontium, aluminium, iron, sulphur, magnesium, manganese, sodium and potassium. They are all as totals and no speciation was done.

We all know by now where Lake Rotoiti is and its link to Lake Rotorua through the Ohau Channel and these are the characteristics of Lake Rotoiti. We can almost consider that there are two lakes in one lake, because we have a very shallow area in the western side and then we have a deeper part in the western side. The average depths are 50 metres in the western basin and 60 metres in the eastern side, with the deepest site at 125 metres. We have a different sort of catchment area around Lake Rotoiti with pasture, lake, native forest, lowland scrub, exotic forest, sand dune and tussock.

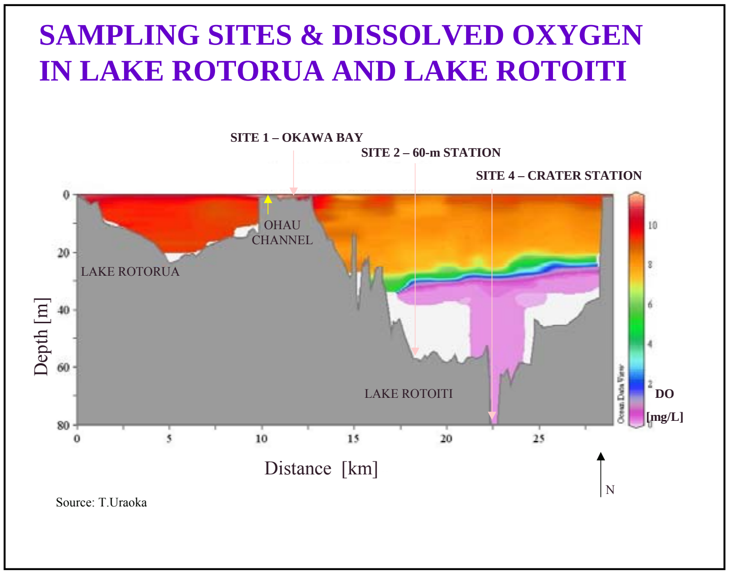
LAKE ROTOITI CHARACTERISTICS

Lake Area	**33.48 km²**
Catchment Area	**120.56 km²**
Maximum Depth	**124.5 m**
Average Depth (Western Basin)	**15 m**
Average Depth (Eastern Basin)	**60 m**
Urban Area	**5 km²**

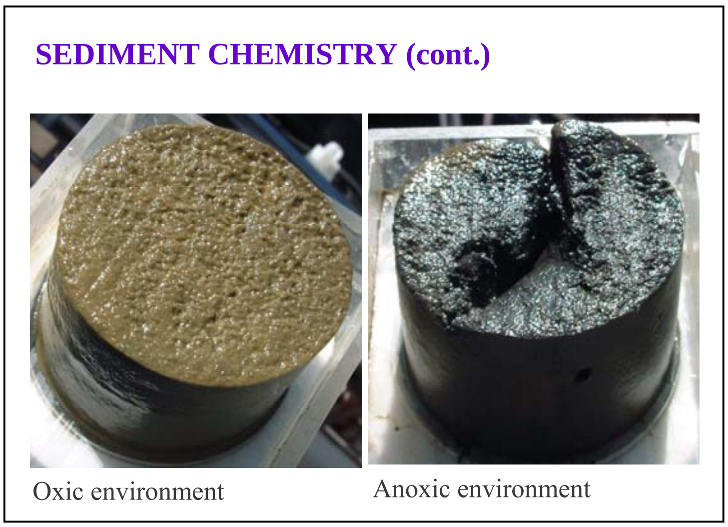
	Catchment Land Cover %
Pasture	**32**
Lake	**28**
Native Forest	**23**
Lowland Scrub	**10**
Exotic Forest	**5**
Sand Dune	**1**
Tussock	**1**

Sampling sites as shown in the diagram (*next page*); site 1 was in Okawa Bay, site 2 was at a 60 metre depth and site 4 was at the 125 metre depth, just in front of Gisborne Point. We had two other sites at 20 metres, but we haven't been able to actually get any gravity cores there, so after the first three trials we gave it up and we carried on only with these three sites. In this picture you can see on the background the colourful patterns showing the dissolved oxygen levels, so you can compare how it changed from Rotorua lake where it's well mixed

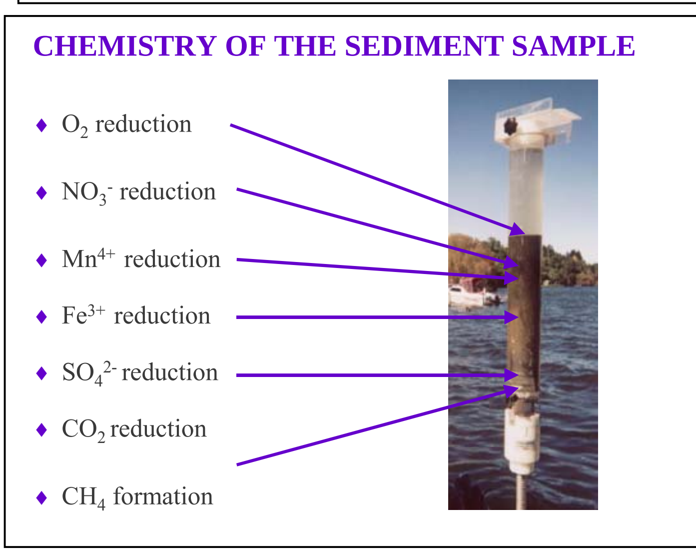
in to Rotoiti where it gets stratified and there is no oxygen in the bottom water. The times I have been sampling are July, September, November, January and March. We've been using Seabird CTD for our physical measurement and we've been using a Schindler trap for our lake water sampling and a gravity corer to sample the top sediments of the bottom of the lake.



These are two examples of how the sediment samples look. The one in an oxic environment you can see is a light colour and in the anoxic environment it's very dark and sometimes you can get a strong smell of sulphide coming out. These top sediments are formed actually by all the particulate matter falling on the bottom of the lake. As they settle on the top of the other, so the pressure builds up and you have the water being squeezed out of the core of the sediments. It's a bit like, for analogy, when you are making wine and you have the grapes, you put them all together and then you put maybe a child walking on those grapes and you make the wine. So that's a bit the same.



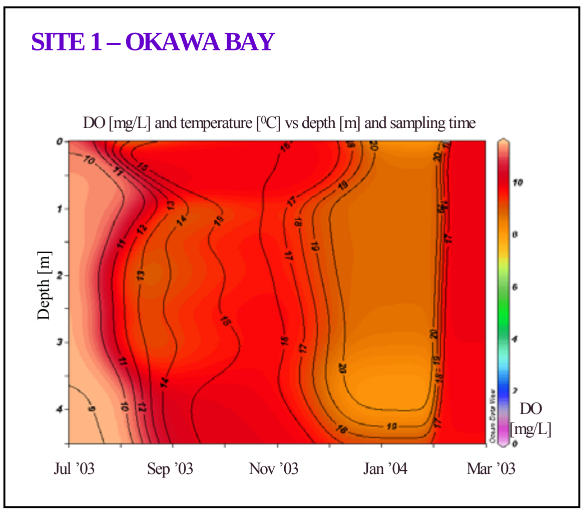
As the layers build up they consolidate more and more and they become hard sediment and bed rock. The chemistry of my samples we can roughly subdivide. If we have some oxygen, nitrate and manganese reduction, iron reduction, sulphate reduction and then we have CO_2 and methane at the bottom.

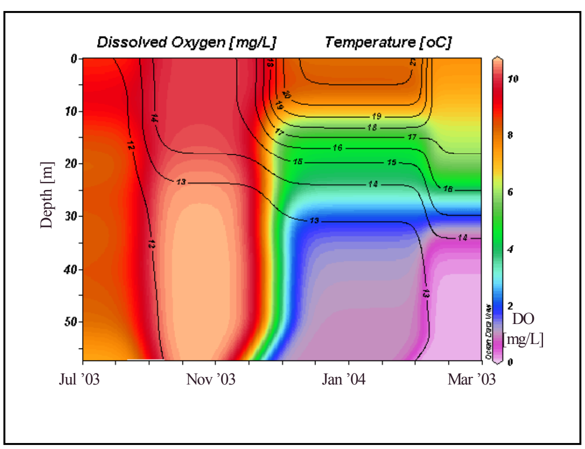


Why this topic?

- Uncertainty about fate and flux of metals in the bottom sediments of Lake Rotoiti
- Lake ecosystems are more vulnerable to metal pollution compared to other inland water ecosystems
- Eutrophication of Lake Rotoiti over past 50 years has resulted in progressive anoxia during summer stratification, leading to possible enrichment of sediments
- When bottom water anoxia occurs the deposited sediments reverts from being a nett sink for contaminants to releasing those elements back into the water column
- It is important to know the concentration of trace elements because of their role in bioaccumulation and food chain amplification

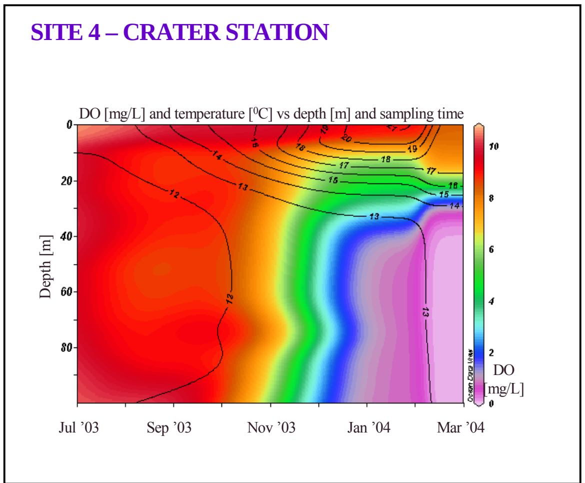
Because of the recent problems with Lake Rotoiti, I took a sample from the lake water of Okawa Bay when it had an algae bloom with *Anabaena planktonica* the predominant species. I chose these pictures (*not shown*) because you can see on the background the part of the landscape being harvested (r*eferring to forestry clearfelling*) and there are more parts around Rotoiti that have been harvested, which will just increase the erosion and leaching of nutrients to the lake water.



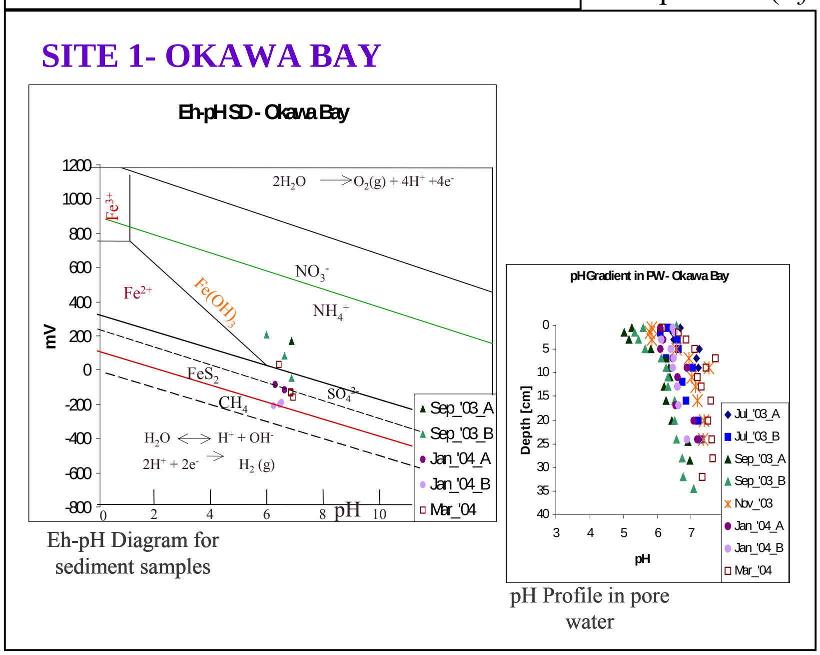


These graphs are a way to represent the dissolved oxygen (that is the coloured part) and the temperature (the lines), versus the depth where I've been sampling and the time I've been sampling. The sampling time has been every 2 months starting with July last year. So you can see that in Okawa Bay(*left*) most of the time it's well mixed and we didn't have episodes of anoxia when I was sampling.

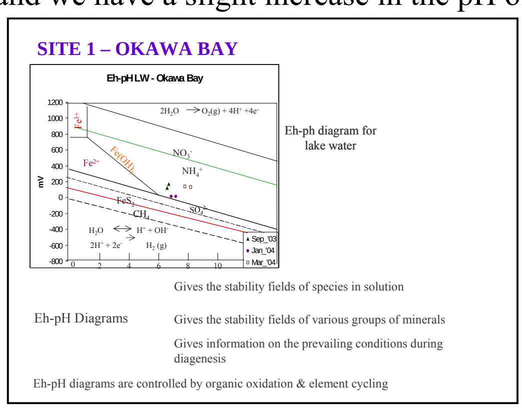
It is a different story as we get to deeper water levels. We have a 60 metre point almost at the edge between eastern and western sides and you can see in wintertime that the water is well mixed and the temperature is similar from the top down to the bottom water(*left*). As we get to summer and the top water starts warming up, we have the density gradient and the oxygen starts to be missing from the bottom waters.



We can see the same story for the Crater (*left*). We call it the crater station because it's a very narrow hole and previously was supposed to be a crater, it's 125 metres deep. Again in the winter months, very well mixed and as we start getting towards summer it is increasingly getting anoxic. Last summer it wasn't a very hot summer, but we still had this stratification in the lake.



The Okawa Bay diagram looks very complicated (*left*), but actually it gives a lot of information. It's an eH/pH diagram, so what we've done is to measure, in fresh samples, the redox capacity then measure the pH of the samples and then they are plotted, one on X, one on the Y axis. It gives the stability fields of species in solution, also of various group of minerals and it gives you great information about the diagenesis conditions, which are controlled by organic and element cycling. This is in sediment and the first samples as we can see the lighter colours are the summer samples, so compared with the winter samples are more anoxic. This is a slide with the pH values of my pore water (*right of diagram*), so that's a very nice correlation, I mean they are all more or less same, no big variation. At 60 metres I didn't collect a lake water sample, so it is only the sediment and as you can see we're getting towards a more anoxic environment as we're going down this plot, and we have a slight increase in the pH of the pore water.

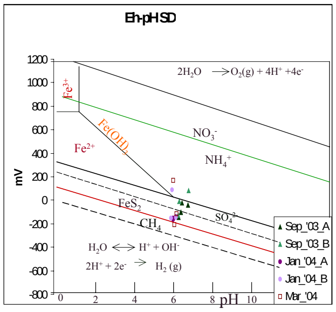


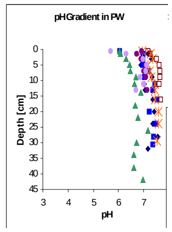
This is the lake water (*left*) from Okawa Bay and my samples tell us that the environment is already getting a bit anoxic here.

For the element analyses of my samples, I'm going to present only some of the elements that I have been doing and from only one spot, otherwise we'll be here until midnight (*all of next 2 pages*). The total phosphorus in sediments shows a very beautiful regression with an R square of 0.9, that is very good. But the very high values indicate that it's all in the top sediments. The depth of my core is constant. It has been sliced every 2cm, so there has been no variable depth. At the top of sediments we have a huge amount of phosphate that is ready to go back into the water. In an anoxic environment we have iron that goes from Fe^{3+} to Fe^{2+} and we heard that it becomes very soluble and will release all this phosphate. This is the total phosphorus in our pore water. In this case seasonal trends are not very accentuated as we're going to see for other elements. For sulphur values are pretty close for all the sampling times. In this case we start seeing in pore water a division between winter samples and summer samples.

We can see from the eH/pH diagrams that the values are also changing, they are getting more anoxic. The iron is compact more or less like sulphur, but in the pore water again we have the sulphur and this case we start with November samples getting close to zero. For manganese we've seen a very similar trend as for the phosphate. Again we have a regression line with an R square of 0.93 and these values are all in the top sediments, so all are ready to go back in the lake water. For manganese in pore water we see from November it is already getting closer to the detection limit of the instruments. The last element that I'll introduce here is the aluminium in sediments and then pore water and this strange behaviour from aluminium that we didn't expect. If someone has any suggestion for this we would be interested, however in summer we got almost to the detection limit of the instrument.

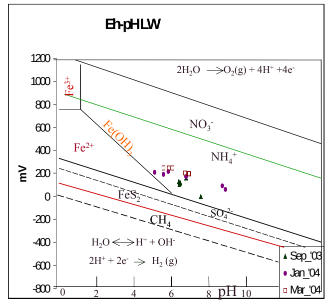
SITE 2 – 60-m STATION



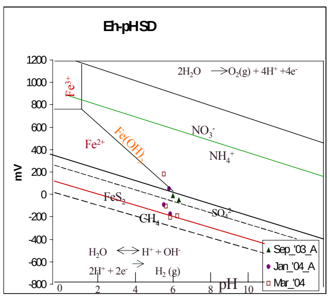


Eh-pH diagram for sediment samples

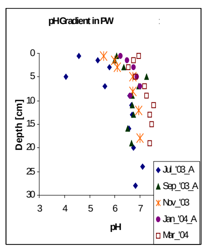
SITE 4 – CRATER SPOT



SITE 4 – CRATER STATION

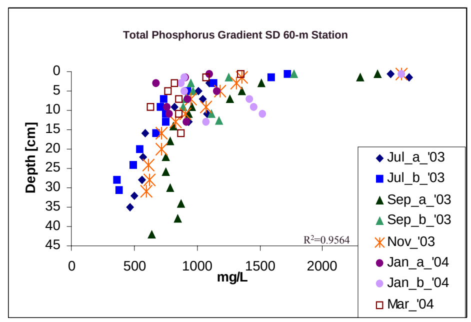


Eh-pH Diagram for sediment samples



pH Profile in pore water

ELEMENT ANALYSIS



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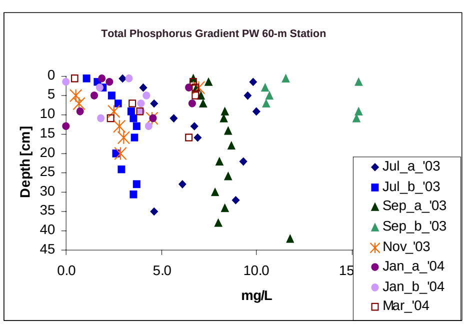

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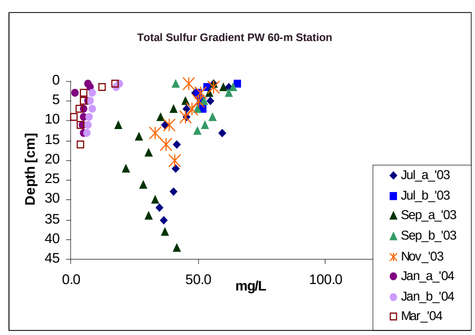

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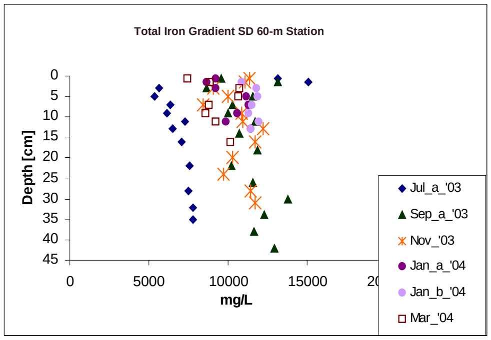

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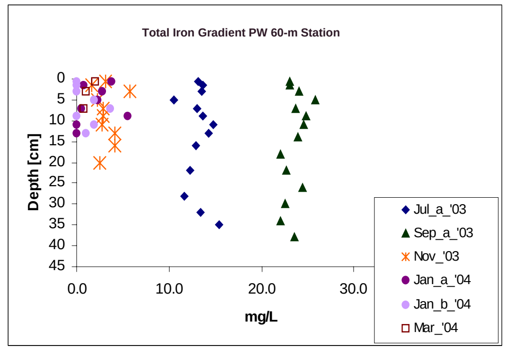

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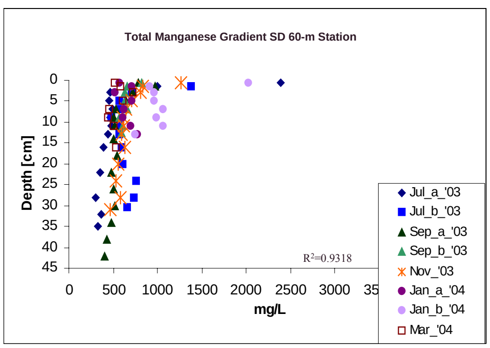

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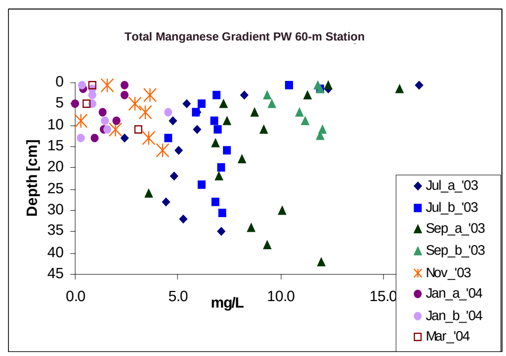

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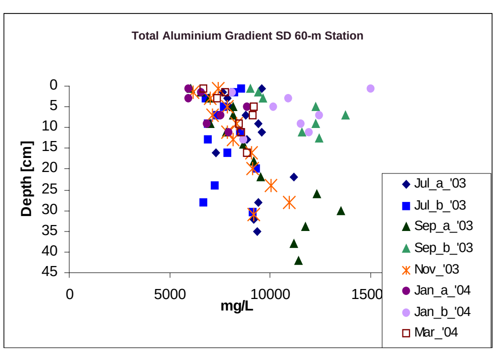

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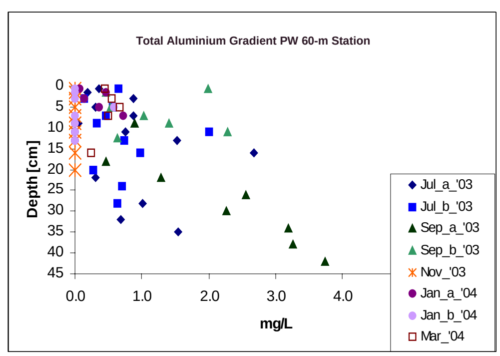

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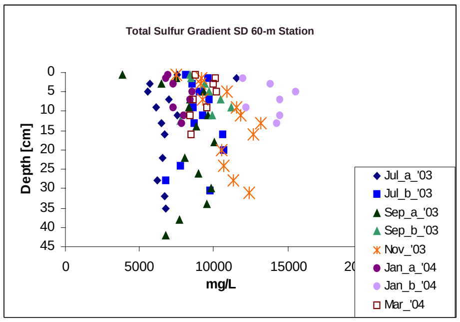

I would like to thank Environment Bay of Plenty for sponsoring this research, the chemistry department and Professor Chris Hendy, the boatmaster during the sampling sessions, Annie the technician in chemistry for being patient with all my requests, and Alison for the instruments.

KEY POINTS

Sediment composition

- Changes in refractory elements (e.g. Al) reflect variations in ratios of seston to clastic sediments as organic matter is broken down;
- Elements associated with the organic fraction show an inverse trend to Al;
- Elements mobilised by reduction and immobilized by oxidation have peak concentrations near the surface and reflect seasonal variations in redox (e.g. Mn, Fe, P)

KEY POINTS (cont.)

Pore water composition

- Soluble reduced/insoluble oxidised species (e.g Fe, Mn) increase in concentration with depth. These species show expected seasonal trends except when overridden by sulfide precipitation
- Insoluble reduced/soluble oxidised species (e.g. S) decrease with depth in the sediment.

Deciphering causal mechanisms of variability in phytoplankton biomass and succession in the Rotorua Lakes

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ABSTRACT

The biological response of several Rotorua lakes to increases in nutrient inputs is reasonably clear and may be exemplified by lakes Rotoiti and Okaro. The hypolimnion becomes anoxic during seasonal thermal stratification, there is an increase in phytoplankton biomass, and cyanobacteria generally dominate the phytoplankton assemblage, with loss of the deep chlorophyll maximum when the lakes stratify. These eutrophic lakes tend to have low nitrogen to phosphorus mass ratios, partly in response to an increase in denitrification which acts as a sink for nitrogen and is promoted by anoxia of the hypolimnion. Variations in phytoplankton biomass and species composition caused by other mechanisms, however, tend to be more subtle and often produce outcomes that are difficult to resolve against the inherent background variability. For example, while there are no significant long-term changes to water temperature in the Rotorua lakes, El Niño-Southern Oscillation (ENSO) events may have important short-term effects on surface water temperature and vertical stratification, and may influence cyanobacterial populations, which thrive under calm, warm conditions. Furthermore, when there is high lake-wide biomass of buoyant cyanobacteria, there is potential for very large amplification of populations in bays and sheltered areas of a lake, particularly in the presence of on-shore winds. These considerations mean that good long-term time series data at several stations on large lakes, in combination with detailed understanding of phytoplankton dynamics, are essential to more accurately predict how lakes will respond biologically to management of nutrient loads.

INTRODUCTION

The proliferation of cyanobacteria (blue-green algae) results from complex interactions amongst vertical stratification, water temperature, nutrient supply and light availability, all of which influence cell growth rates, and losses (e.g. grazing, viral attack, flushing). Thermal stratification in impoundments can be expected to favour buoyancy regulating cyanobacteria that optimise light capture to out-compete other phytoplankton that tend to be negatively buoyant and sediment out of the water column under stratified conditions. Many of the larger, colony-forming or filamentous cyanobacteria that are commonly associated with blooms have relatively slow rates of growth compared with other phytoplankton (Reynolds, 1997). However, replication rates of cyanobacteria tend to increase more rapidly with increases in temperature than those commonly observed in other phytoplankton (Robson and Hamilton, 2004). Thermal stratification is likely to be more pronounced in summer, especially when there are low winds. Therefore any long-term change in climate that increases water temperature and intensity of stratification may favour increases in cyanobacteria biomass (Weyhenmeyer et al. 1999).

Cyanobacteria possess a number of other potentially advantageous features that enable them to form water blooms which, in some cases, may be nearly mono-specific. Some cyanobacteria have the capacity to fix atmospheric nitrogen, i.e., as dissolved N_2 in the water column. *Anabaena* is a well known genus that is capable of nitrogen fixation, while *Microcystis*, a similarly prolific genus, has no such capacity. The 2002-3 bloom of *Anabaena planktonica* in Lake Rotoiti was found, using the acetylene reduction measurement technique (Turner and Bergerson 1980), to be nitrogen-fixing (author's unpublished data). The eutrophic, low total nitrogen to total phosphorus ratios and very low dissolved inorganic nitrogen concentrations in surface waters of Lake Rotoiti are likely precursors to nitrogen fixation. Similar conditions exist in Lake Okaro (Hamilton, 2003), where *Anabaena* species often form large blooms. Many lakes of the Central Volcanic Plateau of the North Island, including Lake Taupo, are nitrogen limited (White et al., 1985; Lean et al., 1987) and are therefore susceptible to blooms of nitrogen-fixing cyanobacteria with increases in trophic status.

One of the most important features of cyanobacteria is their ability to regulate depth in the water column. Physiological changes, in response to changing environmental conditions, alter cell buoyancy in cyanobacteria, behaviour that is commonly referred to as 'buoyancy regulation' (Reynolds, 1984). Buoyancy regulation may provide a means of overcoming the vertical separation between light (at the surface) and nutrients (at depth) 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 the high surface light intensities that would otherwise damage cells or inhibit photosynthesis.

Buoyancy regulation can occur through three mechanisms that may operate together or independently. Collapse of gas vesicles, air-filled structures that normally provide buoyancy, is one mechanism (Reynolds and Walsby, 1975), but this process may occur infrequently in natural populations. Regulation of gas vesicle synthesis (Kromkamp et al., 1986) may provide medium-term (several days to weeks) changes in the buoyancy of cells. Regulation of cell ballast is the mechanism responsible for the frequently observed pattern of cyanobacterial populations accumulating near the surface during early morning and then sinking away from the surface later in the day (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. This mechanism, more than any other, is responsible for the physiologically induced diurnal periodicity of cyanobacterial blooms (Wallace et al., 2000). Changes in buoyancy may also be expressed to a greater or lesser extent by the accumulation of cells into colonies. According to Stokes' Law, the rate of upward or downward movement of a particle varies under quiescent conditions as the square of the particle diameter. Thus individual cells of the genus *Microcystis*, which are around 5 μm in diameter but agglomerate into colonies often to 1mm in diameter, could increase their rate of migration by 40,000 fold through colony formation.

The position of cyanobacteria cells or colonies in the water column depends on both the buoyancy of the cells or colonies and on water motion. Water motion in the surface waters of lakes is most strongly influenced by wind. Strong winds create turbulence and, depending on the size and shape of the cyanobacteria and the control that a species has over buoyancy (Reynolds, 1984), will mix the organism to homogeneous levels. The depth to which this occurs may encompass the entire water column or it may be to an intermediate depth commonly dictated by the vertical stratification of temperature. Most moderate to large-sized lakes in New Zealand are monomictic. Thermal stratification is most intense through summer to autumn; the period when cyanobacterial blooms most commonly occur. More intense periods of thermal stratification in the surface waters, commonly associated with light winds and strong radiation inputs, create quiescent conditions that allow buoyancy of cyanobacterial cells to be fully expressed. This phenomenon is referred to as 'telescoping' by the eminent phytoplankton ecologist Colin Reynolds and results in bloom formation. In very simple terms it may be compared with adding polystyrene balls to a washing machine; the polystyrene balls will only float and accumulate at the surface of the tub when the washing machine is no longer mixing (i.e. no-wind or light-wind situation). The more polystyrene balls (equivalent to the lake-wide phytoplankton biomass), the greater is the rate of accumulation (i.e. bloom size). In reality blooms may be blown onto leeward shores of lakes, particularly where there are 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.

Many cyanobacteria have other physiological features that also influence their losses. They are often not a preferred food source for grazers, 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).

The objective of this paper was to present some of the temporal and spatial variability of phytoplankton populations in lakes Rotorua and Rotoiti, and examine some of the causal mechanisms of variability. While it is difficult to make definitive “cause and effect” statements about the factors that drive variability, the analysis does provide new insights into the relatively slow-growing nature of cyanobacteria and how blooms result mostly from a redistribution of cells rather than a growth phenomenon *per se.*

METHODS

The Rotorua lakes were formed and modified at intervals up to 140,000 years B.P. by a series of volcanic eruptions which produced explosion craters or damming of drainage basins by lava flows (Lowe and Green, 1986). Twelve Rotorua lakes are sampled routinely as part of the State of the Environment monitoring programme conducted by Environment Bay of Plenty (Scholes, 2004). Data from this programme are supplemented here with past measurements in polymictic Lake Rotorua ($A=79km^2$, $\bar{z}=10m$) and monomictic Lake Rotoiti ($A=33.5\ km^2$, $\bar{z}=33$ m), which are archived in the National Institute of Water and Atmospheric Sciences lake data base. BioFish™ measurements have been conducted across

lakes Rotorua and Rotoiti, to provide estimates of chlorophyll *a* fluorescence, with data presented as 'curtains' through one axis of the lakes. Climate data were obtained from Rotorua Airport meteorological station. Monthly values of the Southern Oscillation Index (SOI) were obtained from the Bureau of Meteorology, Australia. The SOI is used to explain predominant weather trends; when it is consistently positive (La Niña), the New Zealand climate tends to be warmer and winds are lower than when it is consistently negative (El Niño), a state characterised by cooler, windy conditions.

RESULTS

Long-term trends

Time of year explained 92% and 94% of the variation in surface water temperature measurements for Lake Rotorua (n=944, years 1967-2003) and Lake Rotoiti (n=90, years 1990-2003), respectively, using a 6th order polynomial regression equation. The residuals from each regression gave a non-significant ($p>0.05$) linear trend through time in the two lakes; the slope was small in Lake Rotorua (-0.0051^{o}C yr^{-1}) but of greater magnitude and positive in Lake Rotoiti (0.078^{o}C yr^{-1}). The latter result was influenced by cool surface temperatures during a predominantly El Niño phase (negative SOI values) in the early part of the time series from 1991 to 1995, and warm temperatures during a strong La Niña phase (positive SOI values) later on, from 1999 to 2002 (Fig. 1a). It can be surmised that there is no evidence of a significant warming or cooling trend for surface waters of Lake Rotorua over the 35-year sample period, while for Lake Rotoiti a longer record with several El Niño-Southern Oscillation (ENSO) events will assist in removing bias associated with the relatively short duration of sampling. For the case of Lake Rotorua, however, an analogy can be drawn to a study by Gerten and Adrian (2001), who observed that frequently circulating polymictic lakes are least susceptible to the North Atlantic Oscillation (NAO) influence, followed by shallow and then deep dimictic lakes.

Relationships between the polynomial regression residuals and SOI values for the corresponding month of sampling were not significant ($p>0.05$) for both lakes, but there was some general visual correspondence over the time series of a 5-sample running mean of the residual temperatures and 5-month running mean SOI values (Fig. 1). Brief anomalous periods (e.g., 1976-77, 1989, 1997-98 in Lake Rotorua and 1997-98 in Lake Rotoiti) confounded the establishment of statistically significant relationships between the residual temperatures and SOI values. Similarly, the relationship between mean wind speed or air temperature at Rotorua Airport averaged over periods of days to months, and SOI values was not significant ($p>0.05$), though visual interpretation again indicated a general inverse behaviour between wind speed and SOI values (i.e., high mean wind speeds and low SOI values and vice-versa).

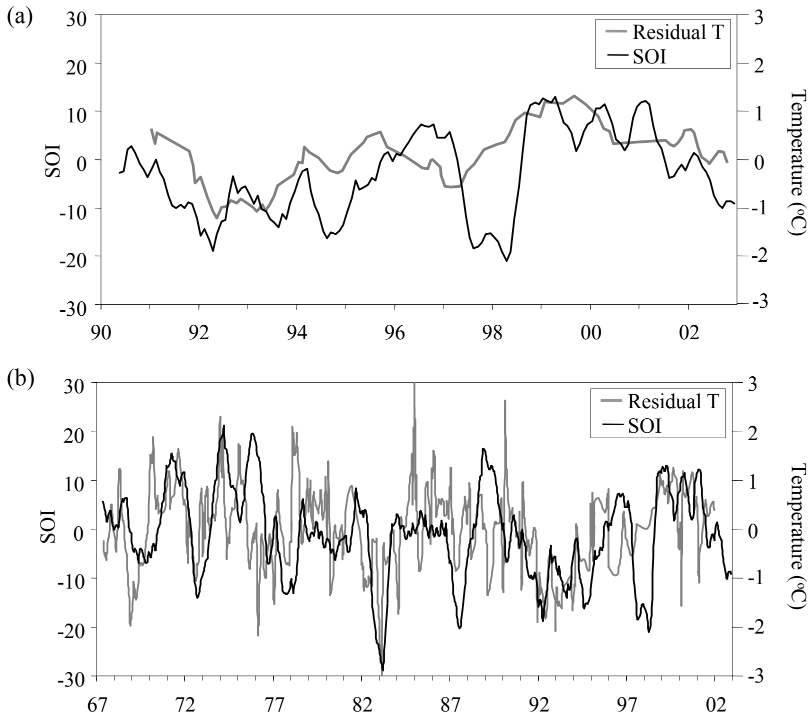

Figure 1. Time series of 5-sample running mean of the residual temperatures derived from a polynomial regression between time of year and surface water temperatures, and 5-month running mean SOI value for (a) Lake Rotoiti and (b) Lake Rotorua.

Relationships between monthly SOI values and corresponding phytoplankton biomass and trophic state, as indicated by the Trophic Level Index (Burns et al., 2000), were examined in lakes Rotoiti and Rotorua, but there was no evidence of any relationship, either statistically or qualitatively. In summary, there is no evidence for a long-term climatic trend as evidenced by consistent changes in surface water temperature nor do changes in trophic state in lakes Rotoiti and Rotorua appear to be related to any long-term climatic trend. One should not rule out the possibility, however, that specific ENSO events may create short-term variations in lake mixing and temperature that will influence conditions that may differentially favour or hinder cyanobacterial growth (Hamilton et al., in press).

Trends in nutrient concentrations

In this analysis comparison is made of inorganic nutrient concentrations in Lake Rotoiti in 1981-2 and in 2002-3. For surface waters, concentrations of filterable reactive phosphorus (FRP) are almost indistinguishable for the two periods 1981-2 and 2002-3, and are very close to detection limits in the period 1.2 to 1.4 (around February to May). By contrast, FRP concentrations are around 20 mg m^{-3} higher in bottom waters (around 60m depth) in 2002-3 compared with 1981-2 (Figure 2). It may be argued that concentrations of FRP in bottom waters are not immediately available to phytoplankton in surface waters, though it is now recognised that boundary layer mixing at the thermocline (MacIntyre et al., 1999) creates an important 'pump' that supports nutrient transfer to surface waters. In addition, Lake Rotoiti

has an active internal wave environment (authors' unpublished data) that enhances boundary layer mixing as well as substantial stirring of the hypolimnion from geothermal heating (Gibbs, 1992). Any inorganic phosphorus that is transferred to the surface waters in the period of February to May, when phytoplankton biomass is generally high, can be expected to be rapidly taken up by phytoplankton and will therefore not be detectable as an increase in FRP.

For brevity, concentrations of inorganic nitrogen are examined only for surface waters for the two periods 1981-2 and 2002-3. There appears to be very little difference in both ammonium and nitrate concentrations between the two periods, though perhaps a greater variability of both nutrient species in 1981-2 (Fig. 3). The transition to a higher rate of supply of phosphorus between 1981-2 and 2002-3, with little apparent change in dissolved inorganic nitrogen concentrations, could be conducive to the relatively high rates of nitrogen fixation that were recorded in Lake Rotoiti in the latter period.

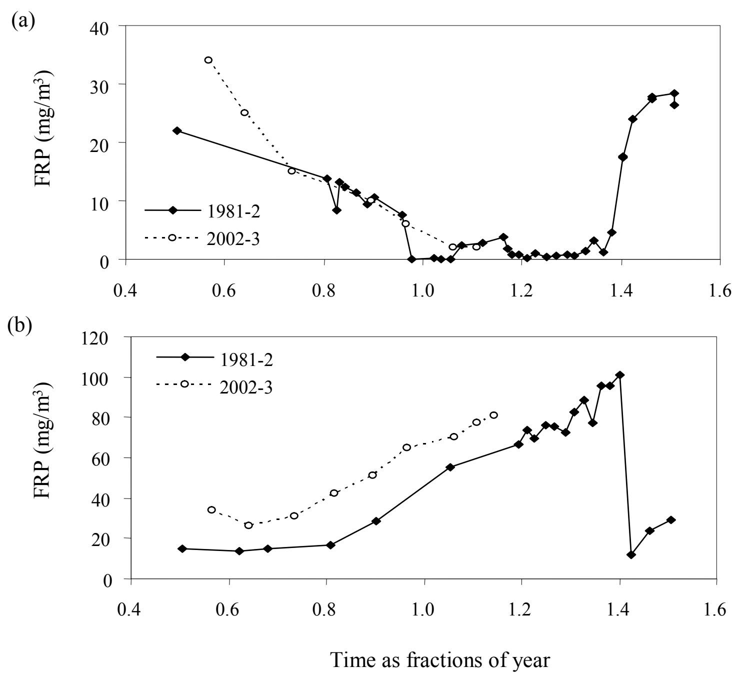

Figure 2. Concentrations of filterable reactive phosphorus (FRP) as a function of time of year for Lake Rotoiti: (a) surface water and (b) bottom waters (approximately 60-m).

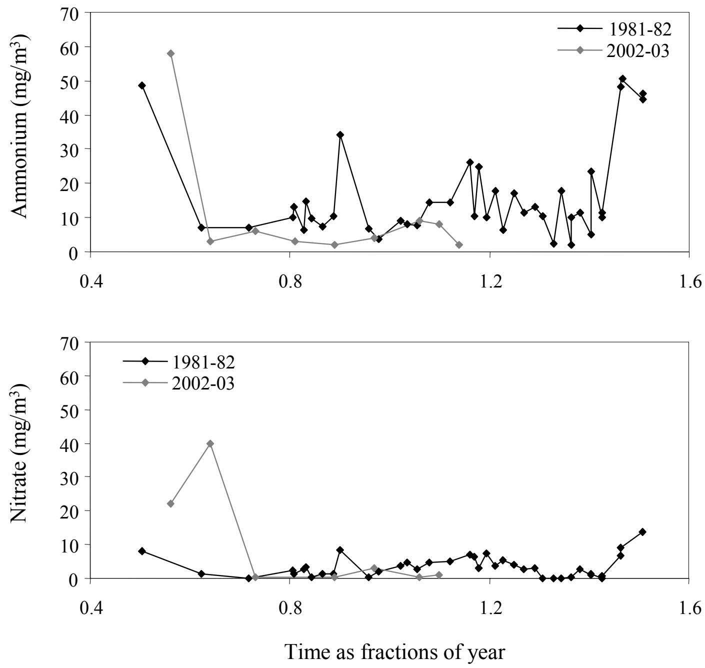

Figure 3. Concentrations of (a) ammonium and (b) nitrate as a function of time of year for surface waters of Lake Rotoiti.

Spatial variations in chlorophyll fluorescence

An example is provided in Fig. 4 of spatial variations in phytoplankton biomass in Lake Rotoiti on 25 February 2004, obtained from a BioFish transect from the Kaituna outlet through to Okawa Bay and then proceeding eastward to the far end of the lake at Hinehopu. This transect was typical of several obtained during intensive monitoring of Lake Rotoiti in the first half of 2004. Variations in chlorophyll fluorescence in surface waters, and in bays in particular, were contributed predominantly by cyanobacteria. Ryan et al. (in press) have shown that horizontal variations in phytoplankton biomass in Lake Tarawera are small in deeper waters, where biomass is generally dominated by diatoms, compared with surface waters where different stations may exhibit very large variations in biomass and the dominant phytoplankton group is cyanobacteria. The data for Lake Rotoiti reinforce the concept that cyanobacterial cells may readily be blown into bays by on-shore winds, while the limited fetch from off-shore winds tends to confine populations within the bays. This concept is further supported below by the analysis of phytoplankton growth rates in Lake Rotorua, which included some of the data presented in Fig. 5.

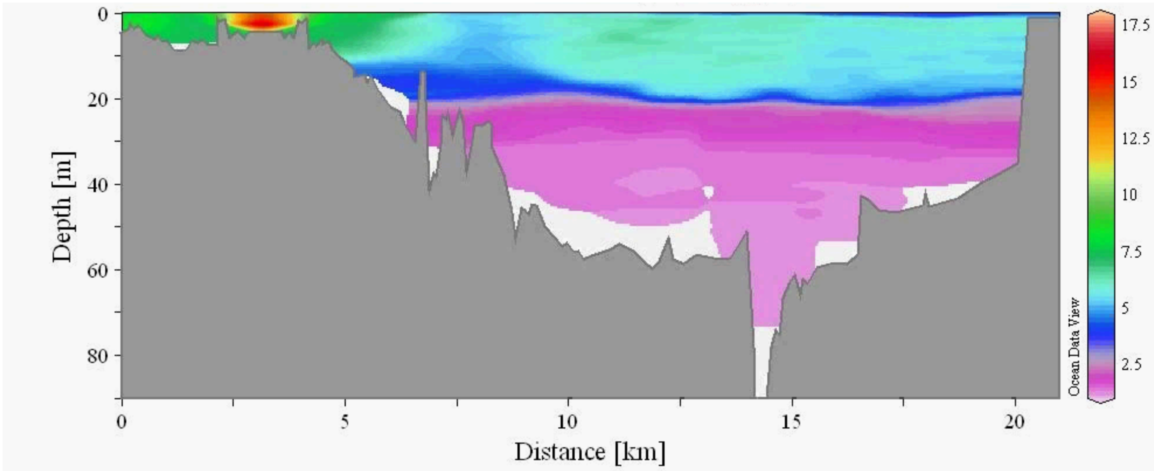

Figure 4. BioFish transect of chlorophyll fluorescence in Lake Rotoiti on 25 February 2004. The uppermost part of the grey shaded area represents the bottom of the lake. The colours represent chlorophyll fluorescence values, with the scale on the right-hand side equating approximately to µg chlorophyll *a* L^{-1}. The transect includes the Kaituna arm (0-2 km) through to Okawa Bay (2-4 km) and then proceeds approximately eastward to the Hinehopu end of the lake around 21km.

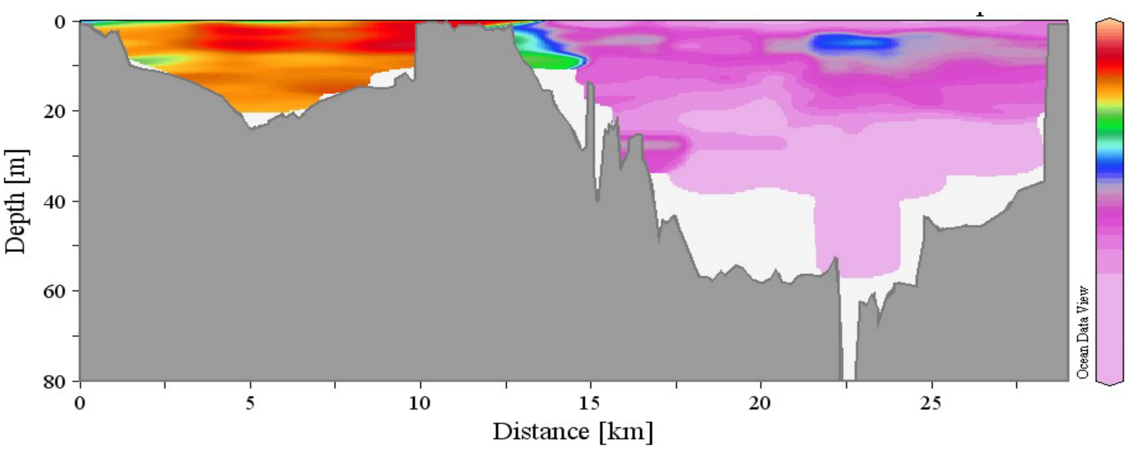

Figure 5. Bio-fish transect of chlorophyll fluorescence in Lake Rotorua (0-10km), Ohau Channel (10-13km) and and Lake Rotoiti (13-30km) on 14 April 2004. The uppermost part of the grey shaded area represents the bottom of the lakes. The colours represent chlorophyll fluorescence values, with the scale on the right-hand side equating approximately to µg chlorophyll *a* L^{-1}. The transect proceeded approximately east from Ngongotaha to Hinehopu.

In contrast to the fluorescence transects through shallow regions of Lake Rotoiti (Fig. 4), the transects through Lake Rotorua (e.g. Fig. 5) showed remarkably little lake-wide variation in the period from March to June 2004, suggesting that accumulations of cyanobacteria in Lake Rotorua may only occur in very localised regions of the shoreline. The relatively homogeneous nature of the distributions in Lake Rotorua, both vertically and horizontally, suggest that a combined vertically and horizontally integrated chlorophyll fluorescence (i.e., effectively a 'mass'), can be used to decipher temporal variations in lake-wide phytoplankton concentrations. The variations in this value were small through time and never exceeded 0.04 per day. Effectively, this means that the maximum rate of growth of phytoplankton never exceeded 4% per day in Lake Rotorua over the period March to June 2004, when there were major blooms of cyanobacteria that forced recreational closures of parts of the shoreline (M. Bloxham, Environment BOP, pers. comm.). This finding may contradict visual observations of rapid 'waxing and waning' of cyanobacterial populations, but largely reflects the fact that the blooms are primarily a response to water transport processes that physically redistribute populations into discrete areas of a lake. Where the lake has relatively shallow, enclosed embayments (e.g. Rotoiti) the cyanobacterial populations are not as transient and may persist for relatively long periods of time as long as the lake-wide population is elevated. These observations support Reynolds' (1984, 1997) observations that cyanobacteria are predominantly a slow-growing group of phytoplankton that may 'telescope' to the water surface under favourable (i.e. calm) conditions.

ACKNOWLEDGEMENTS

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QUESTIONS

Raewyn Saville, Hamurana: For the last 16 years I have been watching the lake and the various rivers that I have lived alongside. You say that you've got temperature anomalies while you've been watching the water over the last 2 years. Have you factored in apart from El Niño and La Niña the manual raising and lowering of Lake Rotorua and Lake Rotoiti? Around about the beginning of November every year Lake Rotorua loses about a metre of water for some reason best known to Environment BOP. It stays low, we will have a bloom in early January in Lake Rotorua if we have the weather pattern where it was hot and fine and we had the north northwester swinging some wind. If we get a lot of rain the temperature is possibly less and the lake is topped up by the rain and then we don't have a bloom at all. We also don't have the north-northwest swinging wind under those circumstances. My question is with the dropping of Lake Rotorua and Lake Rotoiti manually, that obviously makes Lake Rotorua much shallower plus Te Weta Bay, plus Okawa Bay which allows the light to penetrate far deeper into the sediment levels and exacerbates the opportunity for *Anabaena* to become a blue-green algae bloom. We then have the wind which picks up the floating blooms and takes it through the Channel and into the various bays where they are low and suffering, so the bloom just continues. Surely if the lake was kept at a higher level there would be less of a problem?

David Hamilton: Well I guess the question you are asking is one that's asked right throughout the world, what difference do water levels make? In deeper lakes probably not a whole lot of difference on water quality, but you do mention things such as Okawa Bay. It is possible that if you drop the level in Okawa Bay you will decrease the volume and potentially bring about a greater amount of light and a greater availability of nutrients for phytoplankton, that's something that I hadn't actually considered and it's a good point.

Cr. Cliff Lee, Rotorua District Council: For the Ohau Channel diversion, is the seiche and the gradient (of the) seiche showing that there will be any detectable pressure between the two sides of that barrier?

D.H.: If you considered a diversion of the Ohau Channel and you ran it across from Ohau of course towards Kaituna, you'd need to consider very carefully

1) where you put it, and at what depth you put it, and
2) what the impact of internal waves would be, because a flimsy structure would tear apart with the strength of those internal waves.

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Nutrient limitation experiments in Lake Rotorua, Summer 2004

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Abstract
Phytoplankton nutrient limitation was examined in Lake Rotorua during 2004 using three 4 to 5-day *in-situ* incubation experiments. Samples were spiked with NH_4-N (to 10mg/l), PO_4 (to 1mg/l) or with both nutrients. A control containing no added nutrients was used for comparison. Phytoplankton responses to nutrient additions were determined using chlorophyll-*a* concentration, and changes in cell density and species composition. The results indicate phytoplankton production in Lake Rotorua may be co-limited by N and P, although variations in light and mixing regimes during the sample periods complicated our ability to isolate the role of nutrient limitation.

Introduction
Lake Rotorua has experienced frequent cyanobacterial blooms over the summer months. For example, blooms in March 2004 reached cell densities greater then 200 000 cells/ml (Burger, unpublished data 2004). While earlier studies have examined phytoplankton nutrient limitation in this lake (e.g. White and Payne, 1978), their methods have focused largely on assessing growth limitation by measuring changes in nutrient concentration. The experiments did not take into account individual species responses and community structure. We therefore conducted three *in-situ* bioassay experiments to assess phytoplankton nutrient limitation in Lake Rotorua over the summer (Jan-Feb) of 2004, by examining phytoplankton species and community responses to the nutrient additions.

Methods
Field Methods
In-situ incubations were carried out at a central lake site (depth 20m) on three separate occasions in summer 2004 (23 January, 30 January and 9 February). On each sampling occasion, 4 to 5-day *in-situ* incubations were performed in 3-litre polycarbonate bottles using unfiltered lake water. Replicate bottles were spiked with growth saturating levels of NH_4-N (to 10mg/l), PO_4 (to 1mg/l) or both nutrients, and incubated at the lake surface and at a depth of five metres depth. Control bottles containing no added nutrients were also incubated at both depths. Initial (before incubation) water samples were collected and preserved in Lugols iodine for phytoplankton enumeration with additional samples immediately filtered and frozen for dissolved nutrients (NH_4-N, NO_2-N, NO_3-N and PO_4) and for analysis of chlorophyll-*a*, in duplicate. These analysis were repeated for each bottle after the incubation period.

Climate data (wind speed and direction, rainfall and light) were obtained from Rotorua Airport climate station. Lake temperatures, used to assess stratification, were obtained from Odyssey (Dataflow Systems Ltd) temperature loggers deployed at two-metre depth intervals at the same site that the incubations were conducted.

Phytoplankton enumeration

Phytoplankton cells were enumerated at 100x magnification using the Utermohl sedimentation technique (Utermohl 1958). Depending on cell densities, 3 to 7 ml aliquots were settled for 36 hours in a settling chamber prior to counting. As colonial cyanobacteria species have a tendency to clump together, possibly leading to high count variability, counts were repeated for each sample. For multi-celled filamentous species (*Anabaena planktonica*, *Anabaena circinalis*, *Aulacoseira granulata* var., and *Fragilaria crotonensis*), the average number of cells per trichome was calculated per sample and total cell densities then approximated by multiplying this factor by the number of trichomes present in the sample (Ryan *et al.* 2003). Densities of colonial species (*Chlorokybus* sp., *Microcystis aeruginosa*, *Spaerocystis* sp.) were calculated similarly using the average number of cells per colony in each sample. Species were identified according to Baker and Fabbro (1999) and John *et al.* (2002), and were verified by Eloise Ryan (University of Waikato).

Results

The incubations conducted at 5-m depth are considered to provide a true representation of light climate in the water column as this depth approximates to one-half of the mean depth of Lake Rotorua. Only results for the 5-m samples are presented here.

Cell densities

Cyanobacteria were the most dominant taxonomic group in the lake, representing nearly 70% of all phytoplankton cells (Table 1). *Anabaena planktonica* was the dominant species, representing 63% of the total cell count. The second largest group was the green algae, which was dominated by *Chlorokybus* and *Spaerocystis* species, and collectively represented 30% of the total cell count. The diatoms and other groups represented less than 1.5% of the total count.

Table 1: Phytoplankton community composition

Order	Species	% composition	% by group
Cyanobacteria	*Anabaena planktonica*	65.33	**68.9**
	Microcystis aeruginosa	3.59	
	Anabaena circinalis	0.00	
	Planktothrix sp.	0.00	
Green algae	*Chlorokybus* sp.	27.88	**29.8**
	Spaerocystis sp.	1.87	
Diatoms	*Aulacoseira granulata* var.	0.77	**1.3**
	Cocconeis placentula	0.00	
	Fragilaria crotonensis	0.00	
Desmidiales	*Staurastrum* spp.	0.09	
Dinoflagellates	*Peridinium* small (gymnoid)	0.46	
Euglenoides	*Trachelomonas volvocina*	0.00	
Volvocales	*Eudorina* sp.	0.00	

Response to nutrient additions.

Changes in chlorophyll-*a* concentration and phytoplankton cell densities between each treatment and the control were used to determine responses to nutrient additions. Chlorophyll-*a* concentration was generally higher than that of the control in all treatments (Fig. 1), although it is unclear whether N or P stimulated the greatest response as results for these two nutrients are not statistically significant ($P > 0.05$).

A. planktonica and *M. aeruginosa* cell densities increased in all treatments and during all periods (Fig. 2). *A. planktonica* appeared to respond more to P for periods 2 and 3 while *M. aeruginosa* appeared to respond more to N for periods 1 and 3. Differences between P and N treatments were not statistically significant, indicating possible co-limitation of phytoplankton growth for both nutrients. P and N combined generally had the greatest effect on growth. Green algae (*Chlorokybus* and *Spaerocystis* spp.) responded to P more than N for all periods.

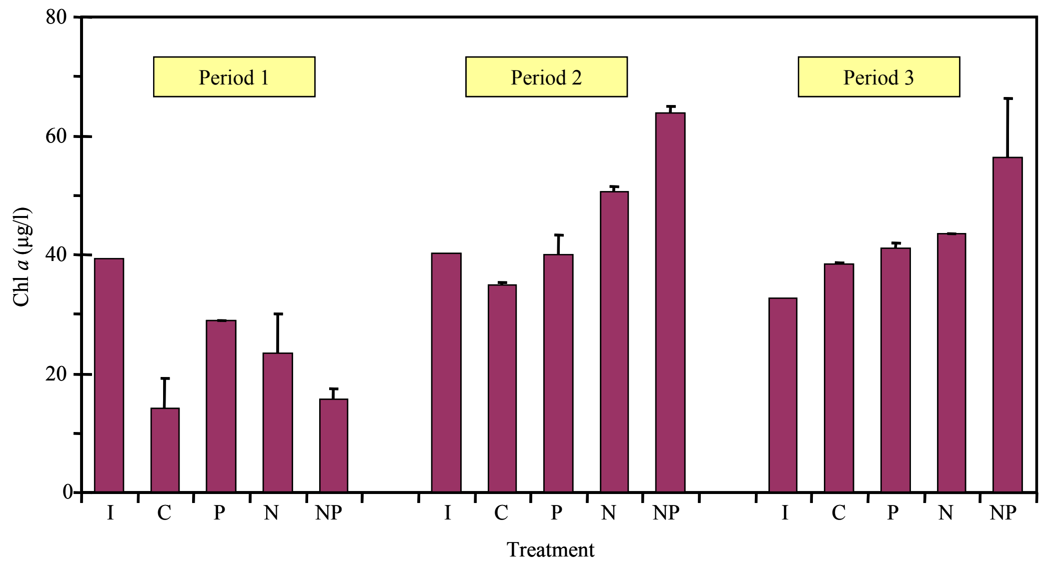

Figure 1: Chlorophyll *a* concentrations in each treatment, periods 1-3 (23 January, 30 January and 9 February, 2004). I = initial concentration, C = control, P = phosphorus addition, N = ammonium addition, and NP = both phosphorus and ammonium addition.

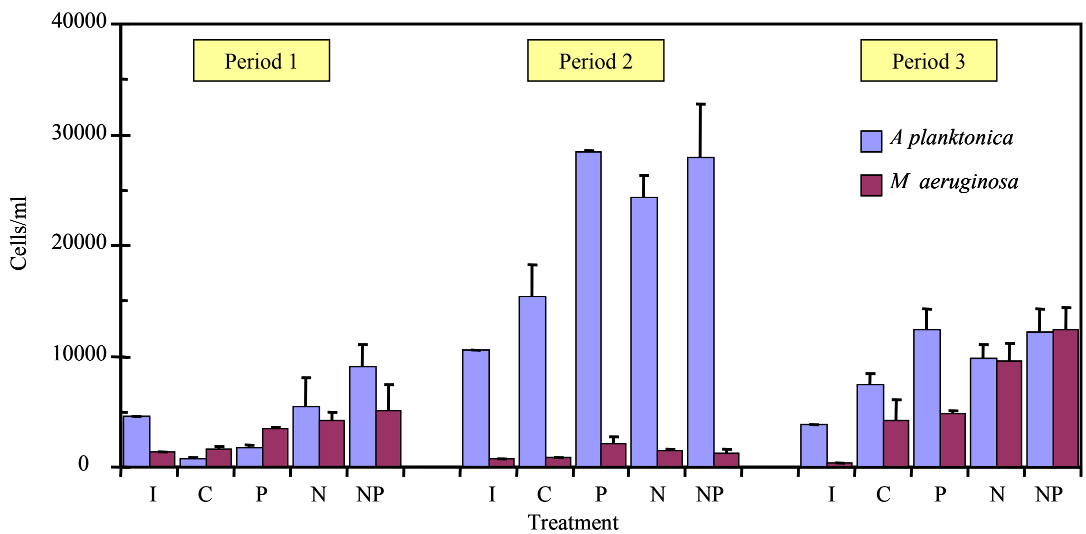

Figure 2: *A. planktonica* and *M. aeruginosa* cell densities in each treatment, periods 1-3 (23 January, 30 January and 9 February, 2004). I = initial concentration, C = control, P = phosphorus addition, N = ammonium addition, and NP = both phosphorus and ammonium addition.

Conclusions

Phytoplankton responded to both N and P additions during all incubation periods, with N and P combined giving the greatest response. Differences between N and P in individual additions were not significant for cyanobacteria, indicating possible co-limitation of both

nutrients. However, certain species may respond differently at different times. For example, *A. planktonica* appeared to respond more to P while *M. aeruginosa* appeared to respond more to N. Green algae (*Chlorokybus* and *Spaerocystis* spp.) demonstrated a clear response to P rather than N for all periods.

Several results for nutrient additions are variable and suggest that other factors may also be important in limiting algal growth rates in Lake Rotorua. For example, the luxury uptake of phosphorus by phytoplankton cells prior to the experiments may have provided them with sufficient intra-cellular P stores to utilise in the case of the control. Some cyanobacteria, such as *A. planktonica*, also have the ability to fix atmospheric nitrogen using specialised heterocyst cells during periods of N limitation. *A. planktonica* was common in Lake Rotorua and were found to contain heterocysts.

Preliminary analysis of the surface incubations, which were conducted concurrently with the 5-m incubations, indicates that light and self-shading may also be important in regulating growth through the water column. Dissolved inorganic carbon limitation may also have been important given the low inorganic carbon levels in Lake Rotorua and the potential of the high phytoplankton biomass to deplete inorganic carbon over the 4-5 day incubation period.

Nutrient concentrations in Lake Rotorua during summer months are often at levels that could saturate growth. Thus, nutrient loading to this lake must be reduced substantially in order to exert major controls on phytoplankton biomass. Simultaneous reduction of both N and P is likely to reduce biomass, including cyanobacterial populations. If loads are not reduced, a combination of low light condition, low N:P ratios and high nutrient levels could favour invasive cyanobacteria species such as *Cylindrospermopsis raciborskii* in Lake Rotorua.

QUESTIONS

Raewyn Saville, Hamurana: Is it true that in phosphorus-limited lakes the addition of nitrate alone will have little or no effect on algal growth, but if phosphorus is added plant growth will increase until it out-strips the supply for nitrate, and then when nitrate becomes limiting, the nitrogen fixing blue-green algae will take over?

David Burger: I think in terms of the situation in Lake Rotorua, blue-green algae have already taken over. The key point that I wanted to make is that the nutrient concentrations are high and we're going to have this biomass in the lake for some time to come yet unless we reduce the nutrient load, whether it's nitrogen or phosphorus.

Raewyn Saville: The lake nearest to its natural state that we have in this area is Lake Okataina. For example, the nitrate:phosphate ratio is about 28 N:1 P and is our healthiest lake.

David Burger: Nitrogen and phosphorus ratios are something that we certainly need to look at and that's something that we'll be focusing a lot more on in this. With this talk we are really interested in looking at the differences between the phytoplankton species, how they responded differently, and that the ratios appear to be different for those species in terms of what they're taking up.

John Green, LWQS: Are there trace elements in which these (cyano)bacteria cannot live? Is there an antidote that will actually kill them, so that if there is a certain level of it then cannot survive?

*David Burge*r: I'm not sure about actually killing the cyanobacteria, but there are certainly trace elements which could limit the population growth, but because phosphate and ammonium are so high in the lakes anyway, it’s going to be a long time before these trace elements will be important.

Sally Brock, LWQS: I’d just like you to comment please on lakes with higher TLI’s than Lake Rotoiti such as Rerewhakaaitu. They have high N:P ratios and they don’t bloom. Lake Rotoiti has a low N:P but with a lower TLI does bloom. Have you got a comment please?

David Burger: In terms of the TLI’s or the nutrient ratios?

Sally Brock: On the fact that Rerewhakaaitu has a higher TLI than Lake Rotoiti and doesn’t bloom. Is it because of its high NP ratio?

David Burger: Well one thing to remember is the dynamics of the lake. David Hamilton mentioned in the previous talk the dynamics such as wind and stratification in calm conditions which are just as important for promoting cyanobacterial dominance as actual nutrient ratios. So the nutrients are there anyway, but it’s other conditions that we also need to really look at in terms of the dynamics of the lakes and we are not sure of those in terms of the different lakes there.

Rick Vallance, Session Chair: We need a big hoover in Okawa Bay.

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Phoslock™: an effective technology for permanent P reduction from water bodies under a wide range of environmental conditions

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Abstract
The performance of a new modified bentonite product— Phoslock®— in reducing the filterable reactive phosphorus (FRP) concentrations of different types of water bodies is illustrated through a number of small and large scale laboratory as well as field trials. In most cases, Phoslock® removed more than 97% of the FRP within 24–36 hours. Moreover, it is shown that the FRP reduction can occur under a wide range of pH dissolved organic carbon and salinity. The subsequent effects of the FRP reduction in improving the quality of an estuarine water sample are also demonstrated in a preliminary large scale laboratory study. This study showed that the concentration of chlorophyll-a, an indication of the biomass content of the water sample, was significantly reduced and the pH of the treated water returned closer to the neutral level within days of Phoslock® application. Furthermore, additional benefits in the appearance of the water sample were observed within the same period.

1. Introduction

The role of phosphorus in the eutrophication process has been known since the 1960s [1]. During the last decade, the significance of FRP reduction from the water column and the sediment P release control in preventing algal blooms has been recognised [2]. In order to control the P level in water bodies, a number of chemical methods, such as alum or ferric chloride have been used over the last few decades. However, many scientific studies have demonstrated significant limitations associated with these methods, including the re-release of the sorbed P when physiochemical characteristics of the water body, such as its alkalinity or redox conditions are changed.

Given the recognised role of the FRP in phytoplankton activity and the limitations of the currently used chemical methods, a novel technology involving the use a modified clay product— Phoslock®— was developed by CSIRO and Waters and Rivers Commission in the mid 1990s. Since then, Phoslock® has been demonstrated to reduce the FRP concentration of the water column and prevent the release of the sediment P under a wide range of chemical conditions (pH, salinity and redox), with a negligible environmental impact [3].

The removal of FRP by Phoslock® is due to the reaction of the specific sites of the product — created by incorporation of a rare earth element during its manufacturing process— with the phosphate anion, forming a highly stable mineral. The stability of rare earth-anion complexes is noted by their high solubility products [4]. As the rare earth element is locked into the clay structure, it can either react with the phosphate anion in the water body or stay within the clay structure under a wide range of physiochemical conditions.

In this work, the effectiveness of Phoslock® in FRP reduction is illustrated through a number of laboratory and field trials. The subsequent effects of the FRP reduction on the quality of an estuarine water sample are then examined by monitoring its chlorophyll-a concentration and pH during a preliminary large scale laboratory study. In addition, the light absorbance spectra of the treated and untreated samples were used to compare the effects of Phoslock® treatment on the visual appearance of the water.

2. Methods

2.1 Laboratory and field trials

Evaluation of FRP reduction of wastewater samples by Phoslock® in small scale laboratory trials, were determined by CSIRO [3]. In the case of natural water samples, the FRP reduction evaluation was carried out by adding the appropriate amount of Phoslock® granules at the ratio of 200 grams per gram of initial FRP content to 2 L of unfiltered test solution. This was done by adding the accurately weighted amount of granules to a small volume of water in a 100 mL Nalgene centrifuge tube. The content of the tube was then transferred into the test solution after 20–30 seconds of mixing by a laboratory grade vortex mixer. The beaker content was then mixed for approximately 30 seconds by magnetic stirrer initially. It was then left unstirred for 24 hrs, before taking a sub-sample for the final FRP determination.

The large scale laboratory trials were performed in two 20 L Perspex reactors (1 m long with an 8 cm ID), using one reactor for the Phoslock® treatment and leaving the other one without any treatment. Each reactor was surrounded by three day-light spectrum light tubes and an IKA overhead stirrer. The lights were controlled by a timer to simulate the diurnal lighting cycle. After filling the reactors with the site water, they were left overnight for temperature equilibration. On the following day, Phoslock® granules were added at a rate of 200 g per m^2 to one of reactors, using the above-mentioned granule-to-slurry method. The contents of both reactors were then left stirring at a gentle speed throughout the trial.

In the case of Phoslock® application in a fresh water pond in China, sufficient amount of the slurry was added to produce a 1 mm capping on the bottom sediment at the beginning of the trial [5]. On the other hand, in Vasse River three applications were carried out over the trial period [6].

2.2 Analytical methods

Samples were collected and analysed for both soluble and total nutrient and chlorophyll-a, in accordance with the American Public Health Association Standard (APHA 1998).

In order to compare the absorbance spectra of the untreated and Phoslock® treated water samples, a small volume of water from each reactor was removed and filtered through a 0.22 μm syringe filter to remove the suspended matter. Using a double beam Jasco V-550 spectrophotometer and a 1 cm cell, the absorbance spectrum of each filtered sample in the range of 200–900 nm was then obtained.

3. Results and discussions

3.1 Factors influencing the performance of Phoslock®

To assess the performance of Phoslock® under various environmental conditions, numerous laboratory investigations have been carried out by Douglas *et al.* [3]. The effects of a few physiochemical parameters on the P uptake of Phoslock® are summarised in this section.

Effects of pH and Dissolved Organic Carbon (DOC): Figure 1 illustrates the effect of pH on the P uptake capacity of Phoslock® in presence and absence of humic acid. In absence of DOC it is also found that Phoslock® can remove >99% of the FRP, with the first 80% of it being removed after the first 1 hour, in its optimum performance pH range of 6–8. However, when the solution pH is raised above 9, only 40% of the FRP is removed after first hour and after 24 hrs 60% of the remainder is removed. The observed decline is due to the formation of the hydroxyl species of the lanthanum ions [3]. In examining the kinetics of the P uptake at pH 9, Douglas *et al.* further comment that if the observed rate of the P uptake were to continue, 99% of the phosphorus load could be removed in less than 4 days.

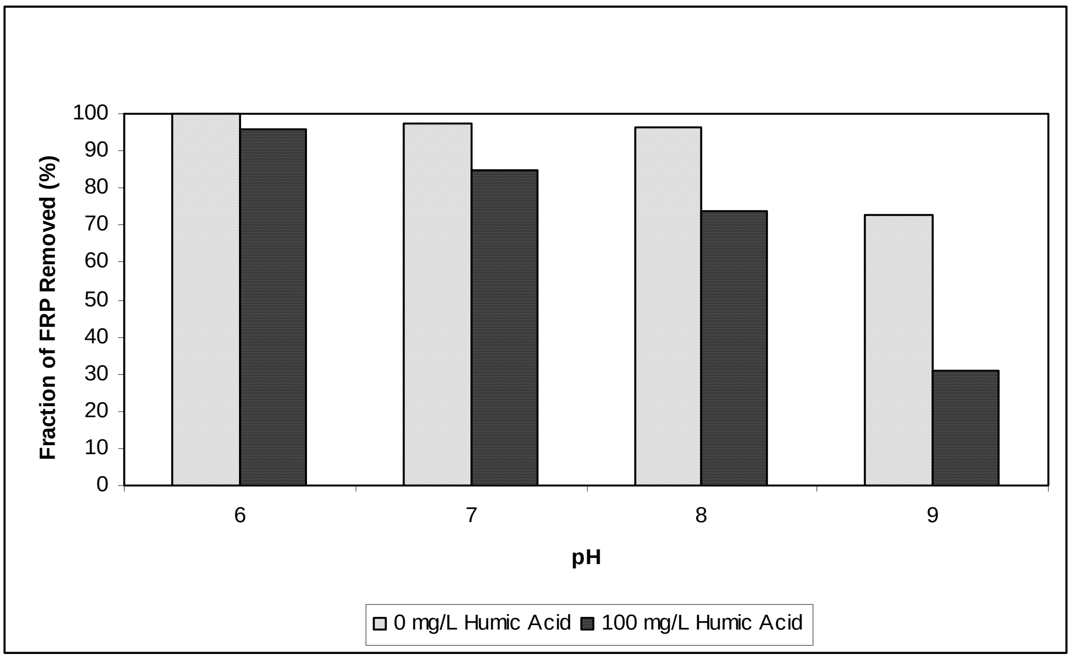

Figure 1. Variation of FRP removal with the solution pH

On the other hand, presence of 100 mg/L of humic acid is found to lower the P uptake capacity, as shown in Figure 1, with the effect being most distinct at pH 9 [3]. According to Douglas *et al.* the kinetic study of the P uptake at pH 9 showed that P uptake appeared to continue after 24 hrs. The authors suggest that if the study were to continue, quantitative removal would have occurred after nine days.

Effect of salinity: Investigation of the effect of salinity on the P uptake of Phoslock® was carried out by determining the P uptake of Phoslock®at various salinities. Figure 2, showing the fraction of FRP that is removed at the extremes of salinity range, illustrates that at a salinity that is close to that of the sea water, the uptake of Phoslock® is increased by about 5% [3].

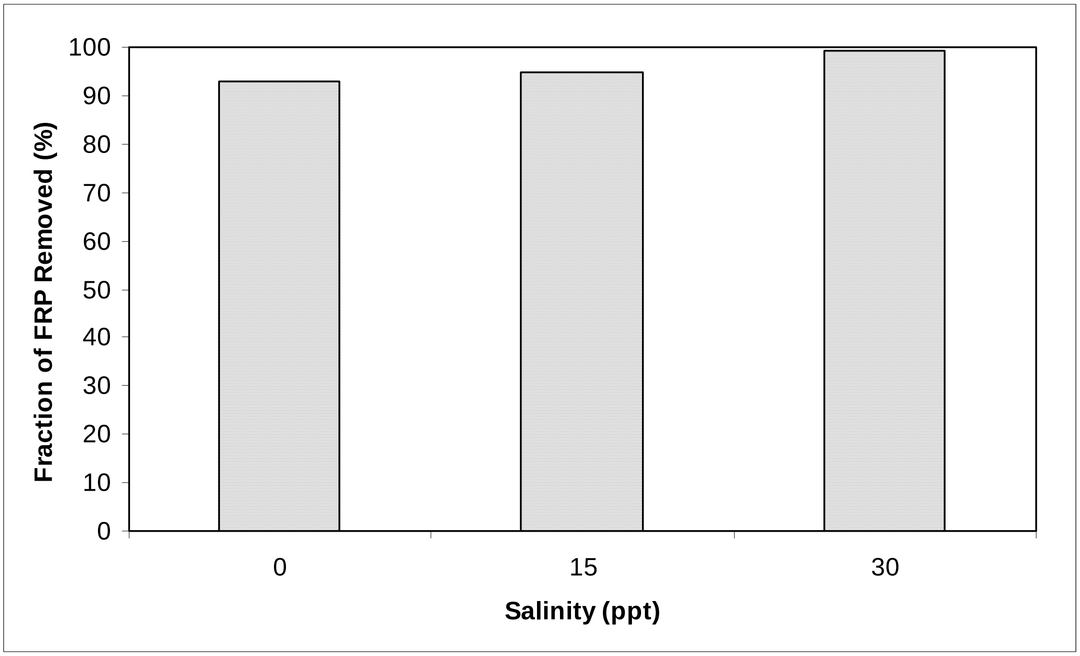

Figure 2. Comparison of the effect of salinity on the performance of Phoslock®

3.2 Performance of Phoslock® in P uptake

Table 1 shows a compilation of the FRP reduction data from a diverse number of natural and wastewater samples, obtained in small laboratory trials over the last few years. This table shows that in most cases, Phoslock® removed more than 97% of the FRP content of the water samples.

Table 1. Summary of the small scale laboratory trials

Water Type	**FRP Concentration (mg/L)**		**Fraction Removed (%)**
Natural waters:	**Initial**	**Final**	
Reverse osmosis treated Water	1.00	0.005	>99
Golf Course Pond (QLD)	0.65	0.01	98.5
Oxley Creek (1)	0.21	0.003	98.6
Oxley Creek (2)	0.52	<0.01	>98
Stanwell Dam (QLD)	0.655	0.048	93
Wastewaters:			
Subjaco STP	1.13	<0.005	>99
Denmark STP	3.49	<0.005	>99
Northam STP	2.41	0.005	>99
Piggery abattoir	5.32	0.008	>99
Cooling tower	0.907	<0.005	>99
Constructed wetland	0.092	<0.005	97
Winery effluent	1.18	0.021	98
Aquaculture	0.087	<0.005	97
Cheese effluent	35.9	0.068	89

In addition to the numerous small scale laboratory studies, the remarkable ability of Phoslock® in reducing FRP levels has also been demonstrated in a number of field applications, such as fresh water ponds in China and sewage treatment holding lagoons in Australia. Among these applications, the drastic lowering of the FRP level in a fresh water pond in Kunming, China [5] and the Vasse River in Western Australia are shown in figures 1 and 2, respectively. Both figures show that in comparison to the untreated or the control section, the FRP level was lowered substantially for a considerable length of time, as a result of the Phoslock® treatment.

In both cases, the slurry form of Phoslock® was used. In the case of the Vasse River trial, to both remove the P from the water column and prevent the re-release of the sediment P, a sufficient amount of Phoslock® was added to produce a 0.5 mm sediment capping with two other applications in response to seasonal events with the intention of applying a 1 mm thickness over the summer period [6]. The treated areas were historically the worse part of the river for blooms and the untreated area was upstream.

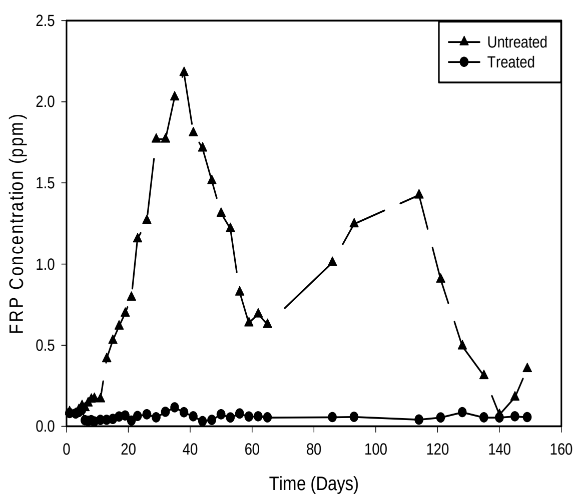

Figure 3. The variation of FRP in Kunming (China) application

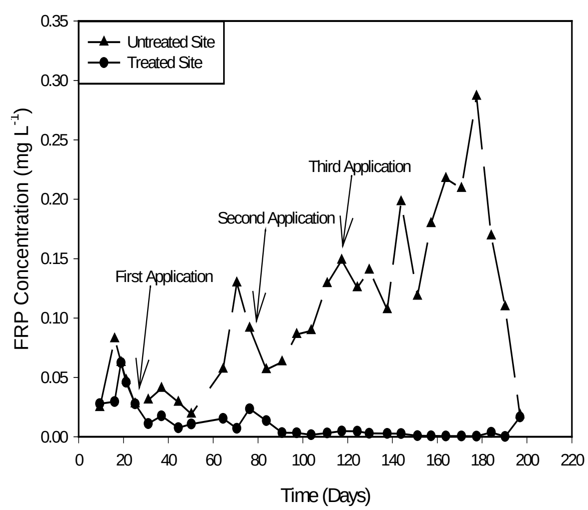

Figure 4. The variation of FRP in Vasse River, Western Australia [6]

3.3 Effect of Phoslock® application on the water quality

The effects of Phoslock® application on the water quality was studied in a preliminary large scale laboratory trial, where the variation of a few physiochemical parameters of an estuarine water sample was measured with time. A summary of the initial physiochemical characteristics of the water, determined in the laboratory prior to the addition of Phoslock®, is given in Table 2. Following the initial determinations, Phoslock® was added at the rate 200 g/ m^2, similar to a typical commercial application rate.

Table 2. Summary of the physiochemical characteristics of the water sample

Chemical Characteristics	Value
pH	7.50
Conductivity (mS/cm)	27.6
Salinity (g L^{-1})	12.6
Total organic carbon (ppm)	8.6

Figures 5 shows the effect of Phoslock® application on the FRP level of the treated sample throughout the trial, while Figure 6 shows the reduction of the total P content of the treated water after one day. It can be seen that the FRP concentration of the treated water was reduced to below 0.01 ppm after the first 24 hrs. In addition, Figure 6 shows an 83% reduction in the total phosphorus level during the same time period.

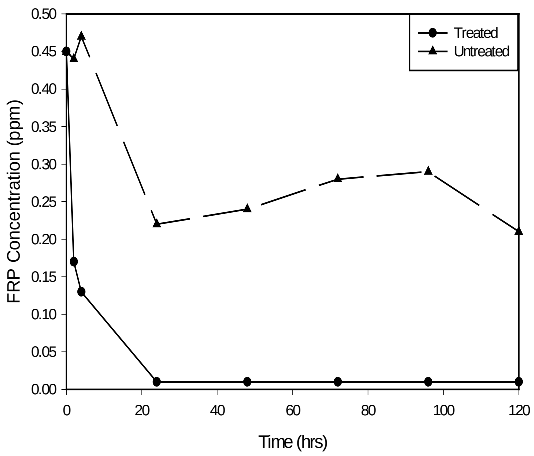

Figure 5. Variation of the FRP in untreated and treated water samples

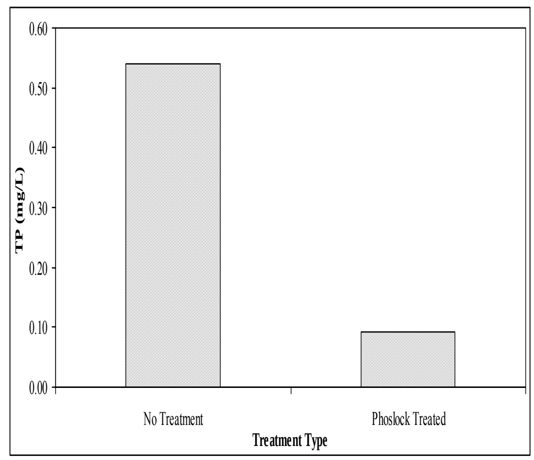

Figure 6. TP concentrations of the untreated and treated water samples

The effect of the FRP reduction on the biomass content of the water was monitored by measuring the chlorophyll-a level of the untreated and treated water samples throughout the trial (Figure 7). This Figure shows that the chlorophyll-a level of the treated water increased to approximately 60 µg/L 48 hrs after the application. It then decreased to below detection levels. The observed increase could have been due to the presence of residual P in the biomass and the increase in water clarity and hence an improved light penetration after Phoslock® application. On the other hand, the chlorophyll-a level of the untreated water sample increased to well above 125 µg/L within the same period. It then decreased before another further increase to a value of 75µg/L by the end of the trial.

In the case of the Vasse River application, described earlier, the extent of phytoplankton growth was also lower in the treated area. Furthermore, unlike the untreated area, there was no nitrogen fixing cyanobacteria in the treated area [6].

Comparison of the variation of chlorophyll-a and pH with time in figures 7 and 8 shows that as the phytoplankton activity of the treated water increased in the first 48 hrs, its pH also increased as well. However, with a drop in the phytoplankton activity, the pH also dropped to near neutral values rapidly. A similar trend is also observed in the untreated sample, except

that the pH remained high, as the phytoplankton activity of untreated water also remained high as well.

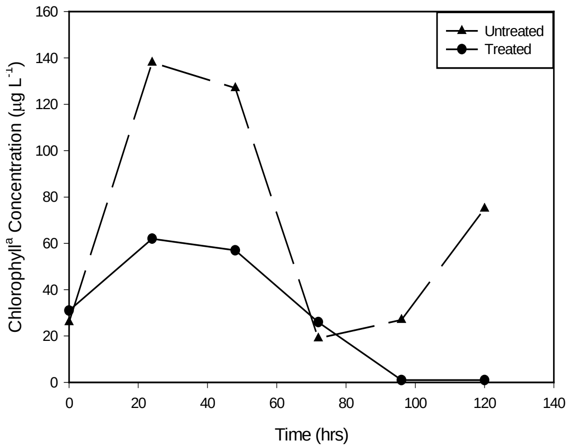

Figure 7. Variation of chlorophyll-a levels in untreated and treated reactors

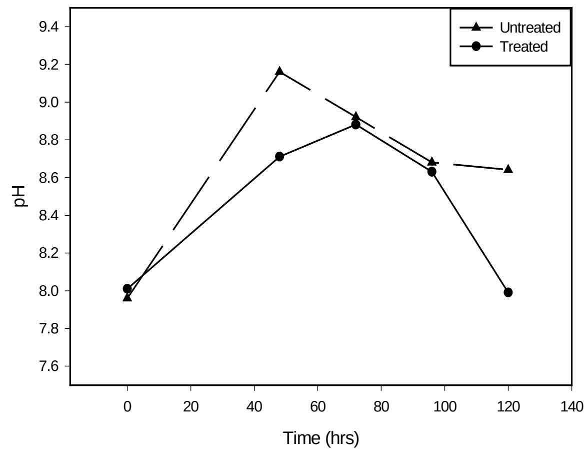

Figure 8. Variation of pH in the untreated and treated reactors

The effect of lowering the biomass level was apparent in the comparison of the visual appearances of the untreated and treated water samples. This was done by comparing the absorbance spectra of the filtered water samples, five days after the application of Phoslock® (Figure 9). This Figure shows that throughout the spectral range, the absorbance of the untreated water is approximately 0.05 units higher than the treated sample. In addition, the absorbance of the treated water fell to about zero in between the 450–900 nm range, indicating a distinct improvement in the transparency of the treated water.

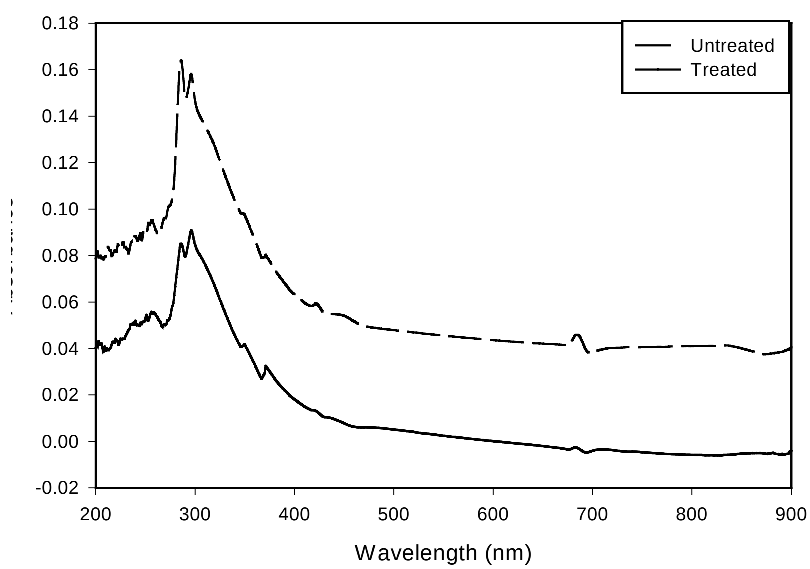

Figure 9. The absorbance spectra of the treated and the untreated water samples

Conclusion
This work shows that Phoslock® is an effective tool in reducing the FRP levels of a variety of water bodies, including fresh, estuarine and different types of wastewaters. It was also demonstrated that the P uptake can occur under a wide range of physiochemical conditions, such as the pH, DOC content and salinity. It is also illustrated that the subsequent reduction of FRP levels could lead to lower levels of biomass and a pH that is closer to the neutral level. In addition, further advantages, such as improved appearance of the water body were also observed.

The ability of Phoslock® to perform under a wide range of environmental conditions, together with the low solubility of the rare earth-phosphate complexes [4] indicates that this technology can offer a long-term solution in removal of the water column P and prevention of the re-release of the sediment P.

This is the first time since the recognition of the significance of the role of phosphorus in algal growth in the 1960s that a technology can offer a long-term solution for P control, without the adverse environmental impacts of the conventional chemical methods that are currently in use for P control.

Acknowledgments
In addition, the author wishes to thank Dr. David Garman for his valuable suggestions on the manuscript, Dr. Sun Peishi for providing the data of the fresh pond study in China and Mr. Luke Mathews for technical assistance.

QUESTIONS
Rowland Burdon, Royal Society of NZ: My question is, what would the stability of Phoslock be under the conditions of a geothermal event. One of the things is that Lake Rotoiti, which is one of the lakes in the worst trouble, has some very large geothermal vents in its bed. That also applies to a lesser extent under Lake Rotoehu which is also in trouble. In those geothermal vents the temperatures would probably be very high at those depths and the chemical conditions could be pretty extreme. I understand to that lanthanum if it is converted into a soluble form can be pretty toxic. At the same time it may be that the areas occupied by those geothermal vents would not be enough to matter too much, but I think this question does need to be asked.

F.H.: Good question. From what I understand, with a geothermal vent the temperature is quite high. In fact some initial trials have shown the lanthanum in the clay structure becomes even more stable under high temperatures. So when heated to about 400 or 500 degrees you get no leaching.

Rowland Burdon: And the low pH? I think pH would be very low indeed in some of those vents but I 'm not certain'

F.H.: There could be leaching under very low pH, but if there are other things such as arsenic and phosphate it can still complex with those. It's been shown that if the thermo-dynamics are suitable it can react with very low concentrations of phosphate. But as far as temperature goes there are no problems, in fact it makes it more stable.

Brentleigh Bond, LWQS: I wonder if you could give me some idea of the relative costs of trying to limit cyanobacterial blooms by the removal of phosphorus, as opposed to achieving the same result by the removal of nitrogen?

F.H.: Well, the key is that most of the studies have shown that phosphorus was thought to be the key element. And if you remove nitrogen, then there's still the nitrogen fixing, we want to favour the growth of those. Phoslock is a long-term solution. The cost should not be compared with conventional methods such as alum or ferric chloride. As far as actual cost goes it's not something that can easily be discussed right now.

Chris Hendy, University of Waikato: My interest is very similar to the last question, but rather than cost, what is the quantity required to remove phosphorus from a lake like Rotorua which has approximately 10 metres water depth per square kilometre of lake?

F.H.: To be effective, a number of things come into it. It's difficult just to give a magic number. It's the re-release of the phosphate from sediments that is important, but in most applications we found that if there's around 1mm capping, it stops the re-release for a very long time. However, it is important to have an idea of the re-release per day before a final quantity is given. Usually in most fresh waters the quantity that is required for the capping outweighs what is required to remove what's in the water column.
(Tape change)
??: … and if you are applying it to say the Rotorua lake, after it is saturated how will you remove it?

F.H.: It becomes part of the natural sediment. Lanthanum phosphate. Bentonite is basically the carrier for it and it's a naturally-found mineral, lanthanum phosphates can easily be found in nature. There's nothing artificial about it, it just becomes part of the sediment. In addition, I forgot to add something to the last question, that approximately 200 grams gives usually 1mm capping per square metre.

Terry Beckett, Lake Tarawera Ratepayers: Assuming that the product works and would work in the Rotorua lakes and assuming that it costs an amount that we could afford, do you actually guarantee results?

F.H.: Well the results speak for themselves, it's not a personal guarantee that I stand here and promise it works. The best way to judge it is to look back at its achievement. For example, on purpose I wanted to include the results from the Chinese trial. They are seeing organisms, fish and plants that they haven't seen for over 20 or 30 years. So really the guarantee comes from the results it has achieved so far.

Nick Miller, LWQS: I understand from what you say that apart from binding phosphate you're also binding arsenates, molybdates and selenates. You mentioning molybdenum is interesting, perhaps, in that we know the importance of molybdenum in cyanobacterial nitrogen fixation. If it'll bind those it will also presumably bind sulphate. An earlier question mentioned geothermal inflows to some of our lakes which in some cases are quite considerable and often sulphate-bearing, Some of our lakes under some conditions might have quite high sulphate concentrations. Would that be expected to bind competitively perhaps with the lanthanum and would we need to adjust your dosage rates accordingly?

F.H.: The thing is by the time it has descended and has capped it, from what I understand with a geothermal vent, it takes quite a length of time before it goes into it, I mean it's not an immediate thing. By that time it has already done its job, so it's already saturated with phosphate, so what happens as far as the sulphate goes would become, I guess, irrelevant to the water quality.

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This presentation incorporates two distinct papers.

Land application of treated municipal wastewater is becoming common in New Zealand because of government regulations, Maori cultural beliefs, and economic and environmental benefits. Forested land has become the main contender for such application because of restrictions on other land uses.

A large lysimeter research facility (LLRF) was constructed in Whakarewarewa Forest, Rotorua, New Zealand, to develop an understanding of wastewater irrigation issues in forest ecosystems. The facility had 36 plots (21 volcanic soil and 15 sand dune soil) each 5 x 5m, and with 9 trees in each plot. Secondary and tertiary effluents were irrigated over a 3-year period at 0, 30 and 60 mm/week. This paper reports nutrient leaching, especially nitrate and phosphate, from two different soil types under various irrigation regimes.

In general, for both soils, nitrate leaching from secondary wastewater irrigated plots was greater than from the tertiary wastewater irrigated and the control plots. As expected, with higher irrigation rates more nitrate leaching occurred. Also, more nitrate was leached from the volcanic ash soil than from the sandy soil which could be due to contributions from the native volcanic soil. Generally, wastewater irrigation did not result in phosphate leaching from the volcanic soil. In the sandy soil, although P concentrations were initially low, they increased with time, with concentrations up to 4 g m^{-3}.

The final results of the leaching of these nutrients in relation to soil storage and plant uptake will be presented.

TRANSCRIPT (edited, graphics not available)
This paper is given by the waste management team at Forest Research and it comes under the Centre for Sustainable Forest Management. In this presentation I'll give you some introduction about waste water and the land application of waste water and give the objective of this actual presentation, then give some information on our research, experimental design, results and conclusions.

Then I will discuss one of the projects which is close to my heart and which I have been thinking about for a number of years, and I will give the basic concept of it and how it can be used as an educational team, especially for our school children (*see following paper*).

As we all know, large quantities of waste water are produced not only here, but world-wide. Most of this waste water is treated either primary, secondary or tertiary and the treated water is discharged onto the receiving environment. A number of years ago most of the treated water was discharged to receiving water bodies such as lakes, rivers and oceans. But we know that even such treated water will have some contaminants, some nutrients which may affect the water quality. No wonder this is one of the reasons why

Rotorua changed from discharging to the lake to Whakarewarewa Forest which we are doing experiments on.

In recent years land application became popular, especially in New Zealand because of the Resource Management Act 1991. We all very well respect our Maori cultural values, so that's one of the aspects and it is also due to the New Zealand Waste Strategy which was published by Ministry for the Environment in 2002. Land application is a good idea but at the same time in New Zealand it cannot be applied to all the land. For example, the dairy industry doesn't, it pollutes anyway. They don't apply human waste onto dairy farms because they like to maintain their international market share. So which land would be better?

Coming from Forest Research I would say it's the forest land. There are a number of environmental, economic and social advantages. For example, it reduces the risk of food chain contamination, meets water and nutrient demands, it requires very low intensive management, enhances forest production and naturally there are multiple uses of such products such as pulping, energy, etc. There are two objectives in this part of the presentation. The first one is to share the latest nutrient leaching results from our experiment. We will be concentrating only on nitrogen and phosphorus which is more interesting to the people here. This is one of the plots we have been using for our experiment (*all not shown*), is 5 metres x 5 metres in area, there are 9 trees at about 9 metres and we have 4-week samplers to collect the draining water. This is because most of the roots are in the first one metre of soil so any nutrients which are coming below that will be going into the ground water or surface water. So we placed these about 1 metre and collected the samples of the leachates.

The main aim of this experiment is to study the effects of waste water type, the irrigation rate, soil type, on the tree and the leaching of nutrients. I'll be discussing only the leaching part in this particular talk. This is the experimental plot we had. We had 36 forested lysimeter type plots as I mentioned earlier, 5 metres x 5 metres. Of the 36 of them, 21 contained the volcanic soil. It is intact, that means there is no disturbance now, so it is native to the experimental site at Whakarewarewa. The remaining 15 plots contained sand dune soil. You can see it is very bright coloured, it is sand from Papamoa Beach. So we dug holes and replaced the soil with the sand.

We have three effluent types here, the first one is BNR effluent, BNR stands for Biological Nutrient Removal. This is the process which takes place at our treatment plant in Rotorua and the resulting effluent is irrigated in Whaka Forest. The second one is secondary effluent, we don't have secondary effluent here. What we did was take 50% of the primary effluent, mixed with BNR and made a secondary effluent. The reason is to compare different effluent types. The third one is water, that's the drinking water which is being supplied.

As in any experiment, especially in long-term experiments, there are a number of aspects we look at. For example, we look at the quality of area to effluent because we want to know what is going into the soil, this is for our modelling purposes. The second one is to collect what is coming out of the site, so we were mentioning quality of leachates. We want to see how fast it moves and where it stores and how much comes out, so we looked at the soil/water dynamics. Of course the changes in soil we need to know, so soil chemistry and nitrogen pools were also measured. Finally the tree got a nutrient uptake.

I will be concentrating, as I said earlier, only on the quality of leachates, the nitrogen and phosphorus.

This is for our volcanic soil, this Y axis gives the concentration which is ppm, parts per million. You can see that the unfilled square is for secondary which is supplied at 60 ml per week. The second one is the secondary 30 ml per week. We don't apply secondary effluent into Whaka, so let's not worry about the concentrations here. Initially, the first 6 months it took time for it to settle down, but then we can see that the concentrations which are coming from our BNR which is being applied, is much lower even than the control, which is very surprising. So we need to resolve that one and we'll be doing more work on it. I'll compare the other one and discuss on this.

This is for a sandy soil. You can see that the patterns are almost similar, that more leaching happened from secondary effluent than the tertiary effluent. The other thing is you get more leaching from volcanic soil than sandy soil. This is because soil by itself contributes towards leaching, a number of processes take place especially during the early autumn period and nitrates do leach from that one. Whereas in sandy soils it is from the beach and we don't have the background for enough content to leach. In terms of phosphate, the good news is the volcanic soil doesn't leach anything. I think this is a particular contamination. The sandy soil you can see that in the first 1 ½ years it is very low.

This is the control plot, I think it clearly shows it has contamination. We hadn't noticed it, but definitely this is the contamination part. That's the only explanation we can give. But after 1 ½ years you can see whether it is a tertiary or a secondary, the more you apply, the more it got leached. For example, in terms of phosphate the BNR value is 3.6, that is what is being applied. You are getting up to that one now. Whereas in terms of secondary effluent it is 5.4 parts per million, we are coming closer to it, at least 90% of it. So sandy soils leach more and this because of the soil make up, it is the allophane and non-allophane. So the conclusions from here in this study that secondary effluent area to grass leached more nitrate than the BNR one.

This conclusion we need not worry about, because we don't apply any secondary effluent in Whaka Forest. More nitrate was leached from volcanic ash soil than the sandy soil. This is purely, I think, the contribution from the native soil. Effluent irrigation did not result in phosphate leaching from the volcanic site. In sandy soil the peak concentrations increased with time, reaching up to 4 parts per million, nearly 90% of what we applied. Now, this is the research that we have done, this is what I am going to discuss (*next paper*).

DREAM project as an educational tool

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DREAM (Drainage and Reuse of Effluents for Agricultural Management) is a simple, low-cost, and holistic approach to reduce/remove contaminants from effluent to produce "clean, useable" water for agricultural management. It is a "package" that combines the concepts of land-based effluent irrigation, intensive cropping /phytoremediation, water harvesting, permeable reactive barriers, and an artificial recharge of groundwater (Figure 1).

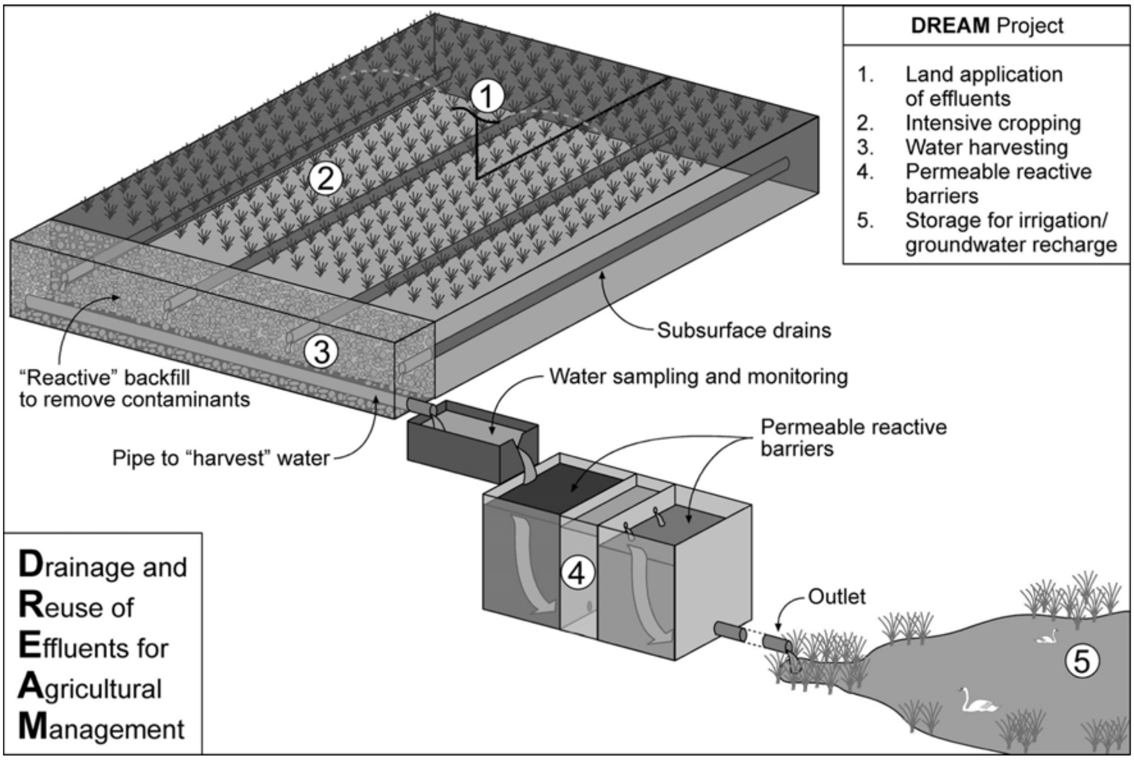


Figure 1: Different components of a DREAM project

In this paper, the basic concept of DREAM project and its use as an educational tool will be explained. DREAM project offer opportunities for students to understand and get the hands on experience of the concepts of land treatment of wastewater, technology to remove various contaminants either through plants (phytoremediation) or using low cost materials (reactive barriers), and collection of water to reuse (water harvesting).

Educating students on reuse of wastewater is important, as water is becoming one of the precious commodities on earth. This is because, in future, countries will compete not for oil or land, but for water.

TRANSCRIPT

Now I am going to shift to our dream project. We have a number of observations we have made, we expect to produce a special issue on this particular experimental site, the results will be published on different topics, the facility and gender trends, nutrient leaching, tree growth and nutrient uptake, soil (we have Hailong Wang here today who will be writing that one), soil/water modelling and nutrient modelling (HortResearch people will be writing that) and the final one is by Sarah, one of Warwick Silvester's students, and she will be writing on N^{15}.

Coming to the Dream project, why did I name this DREAM? This is because I have had this idea since my PHD days about 10 or 12 years ago. The DREAM stands for Drainage and Reuse of Effluent for Agricultural Management. It still is a dream because it hasn't come to reality, but things have started to change. It is a simple low cost and holistic approach, it removes contaminants from effluent and produces clean usable water for our agriculture and our forestry management. The DREAM, this is the conceptual diagram. It has got 5 components in it. If you look at each component, thousands of papers of research has been done, but putting them together as a package this is what this is all about. We have land application of effluent here, the second is intensive cropping, the third is water harvesting, the fourth one is reactive barriers and the fifth one is the storage of clean water. I'll just briefly give the concepts, the background, about each component, then I'll try to put them together and show how we can use this as an educational tool.

The objective of the land treatment is to utilise the properties of the soil/plant system to assimulate waste components without affecting the soil environment. In our DREAM project the effluent is supplied onto the land and sub-surface drains are installed to collect excess water. This is similar to the experimental site I was working on for my PhD at Massey University, Palmerston North.

The second component is the intensive cropping or phytoremediation. We all know soil/plant systems can renovate effluent by removing nutrients and organic matter. If the effluent is a good one, if it is rich in nutrients, then of course we will use cropping as the preferred option, but I always would use phytoremediation. What is phytoremediation? It is the process by which the plants take up the nasty things like contaminants. Phytoremediation is a technology which is rapidly developing, it is very environmentally friendly and cost-effective.

The third component is water harvesting. Water harvesting is the process by which you collect and store water during the wet season and use it during the dry season, so collect it in a wet area and use it in a dry area. This is the process. In our project we have water harvesting, with water being collected by an appropriate sub-surface draining system.

The fourth component is permeable reactive barriers. It is an innovative and low cost technology for the institute clean up of ground water pollution. It can be used to remove water-borne organic as well as inorganic contaminants. This is done either by mobilising the contaminant within the area by absorption or precipitation or by transforming it from very toxic to less toxic. A number of research has shown there are different materials to cover. For example yesterday we heard from Mike van den Heuval about the zeolite, and this morning, Phoslock. There are materials which can trap particulates. For example with nitrate, to remove nitrate we used a process, microbial denitrification, using organic materials such as sawdust. You might have seen a presentation by LandCare Research,

and especially Louie Schipper, who works on this one. Secondly for phosphate we have Phoslock, or you can use simple limestone through the process of precipitation. For heavy metals you can absorb metals like chromium using modified clays, peat moss. Likewise we can look into the acid mine drainage, organic contaminants, etc.

The final one is the water storage. The excess water from the drainage system is collected and stored in ponds. It can be either used for irrigation or for ground water recharge. So this is how the system works. We are hoping that we will soon be having a system in Forest Research and they are going to the local government for extra financial support for us. A number of invitations have come for this project and very soon I will be going to Japan to work on this. No matter how much research we do, unless it is taken up by the public it is going to be a waste of time. So who do we educate, we need to educate especially the school children, on the use of these wastes, which we should consider as resources. Thank you very much.

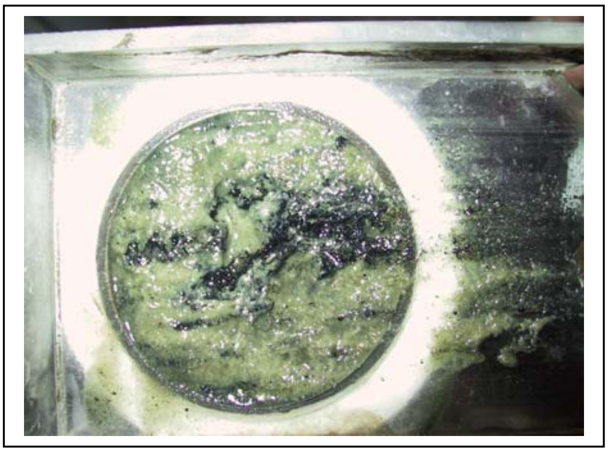
How sediments influence the eutrophication of Rotorua lakes

Dr Chris Hendy
University of Waikato

TRANSCRIPT
Good morning. I want to talk about some work that we've been doing at the University over the past 4 years. A little different to much of the research that has been carried on in the lakes, but still very pertinent to the lakes. My problem arose out of teaching. I had the need to teach environmental chemistry and for the last 4 years I have been taking a third year class of 8 to 10 students to Rotorua each year. We spent a week doing field work, collecting samples and then spent much of the rest of the year analysing the material collected and analysing those results to present in the form of the posters you see out in the foyer. From this work some interesting aspects of the chemistry of the sediments has arisen, so I want to just take you through this without interfering with the paper which Rossana Untaru presented yesterday.

We have worked on this group of six lakes, Rotorua in 2001 was the initial study, then the next year three smaller lakes, Tikitapu, Okareka and Okataina, really set the ball rolling. We were fortunate enough to be working on Rotoiti at the time it crashed and that provided another new insight in Tarawera this year. So Okareka, Tikitapu and of course Lake Tarawera, you'll all be familiar with those.

The aspect I want to draw your attantion to is Seston. Now seston is the light fluffy material that accumulates on the bottoms of the lakes. It's a soupy mixture with a density very close to that of water and it's made up of a combination of washed in materials, silt and clays, and the organic debris from dying organisms. As this falls to the bottom of the lake it plays a very important part in removing material from the lake, especially the nutrients and adsorbed material such as trace elements, and much of this is assisted by the adsorption of trace elements onto the surfaces of the seston, rather than a chemical reaction itself. In particular we look at manganese and iron as these adsorption agents.

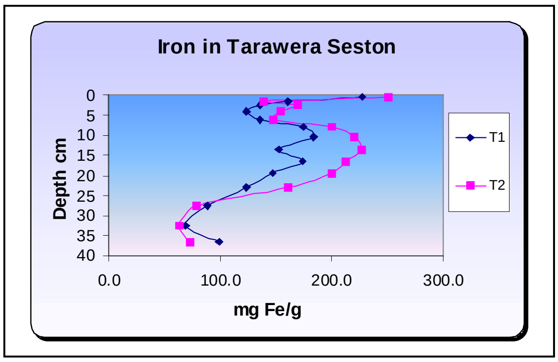


This process works because the water from which the seston is falling contains dissolved oxygen and while it contains dissolved oxygen in sufficient quantities, the iron and the manganese remain in an oxidised state which is a rather sticky state providing the binding agent between the solid material that's falling and the phosphate, the arsenate and other trace elements that are adsorbed onto those solids. That's what it looks like (*left*). This is seston caught out of Lake Tarawera, this is a lake that doesn't go anoxic in the bottom. This is the top of a core, we're actually looking down the top of the core barrel.

We have a surface, that surface in itself is not going to do very much unless we have the binding agents and those binding agents could be aluminium, they could be iron, they could be manganese. In the case of the iron and the manganese they have to be in their

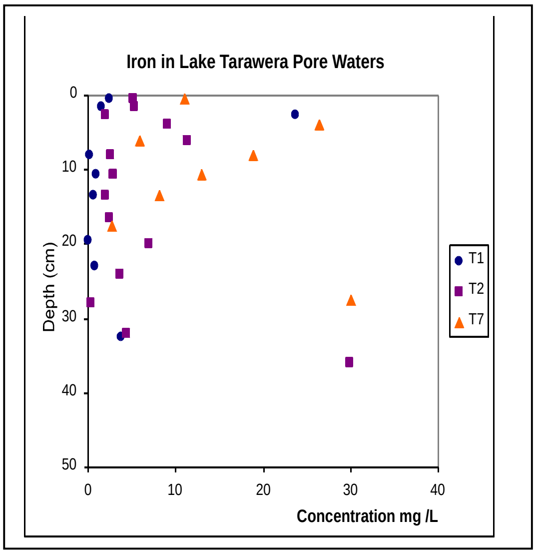
oxidised state and they provide the link between the anions such a phosphate and arsenate and that surface.

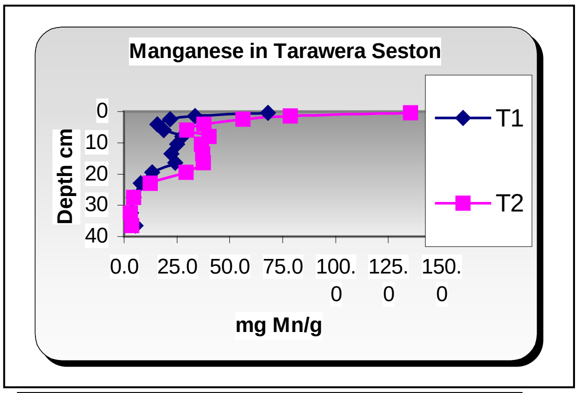
Now the problem arises that as the lakes become more eutrophic the accumulation rate of this falling organic matter to the seston will eventually exceed the total dissolved oxygen in the water into which they are falling. As the micro-organisms break down that organic matter, they first utilise the dissolved oxygen and then when that's run out they start to reduce the manganese and the iron. When that happens the iron and the manganese become soluble, released into the pore waters and the adsorbed materials that they are holding are let go. Once they are let go they are free to move with the water and through the water and back into the bottom of the lake. Now in a lake that is oxygenated, as they approach the bottom waters, they are approaching a zone in which there's oxygen and once more the iron and the manganese will start to oxidise and readsorb the nutrients, the phosphate, the arsenate and other trace elements.



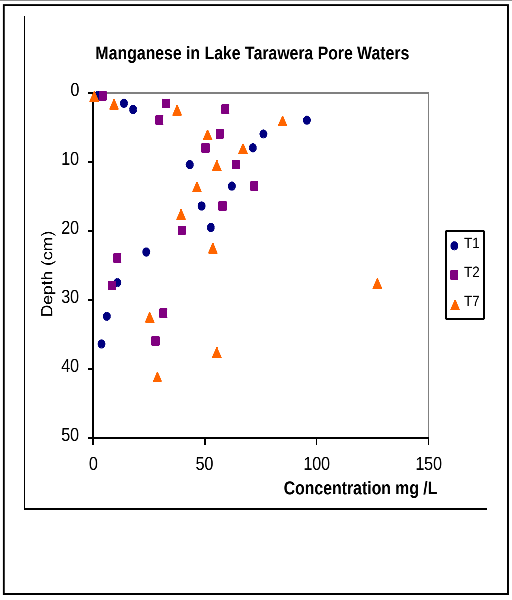
So if we look in Lake Tarawera which is a good example of this, here are the concentrations in the seston itself. Thirty cm down we're into the Tarawera eruptive material, so that's going to be anomalous. From here on upwards, this is the material that has accumulated in the last 100 years. Geochemists have been sampling lake cores for decades and seeing profiles like this, and up until very recently they have looked at these and have said, "Ah there's been a sudden rapid increase in the amount of that material going into the lake." But that, I think, is actually wrong. What is happening is that the material in the seston is being remobilised and materials are moving up, striking the oxygen in the lake and re-precipitating.

We can see this if we look at the concentration in the waters within these same cores. If we look at the pore waters in the same material (*left*), we can see what is happening to the iron and whereas we see very high iron concentrations in the seston at the top, we find very low concentrations in the pore waters and higher concentrations in the zone from 10 to 20 cm below the surface. Here we see the pore water concentrations(*left*), so the iron is being released in the zone roughly 10 cm down and reoxidised higher up to re-precipitate.



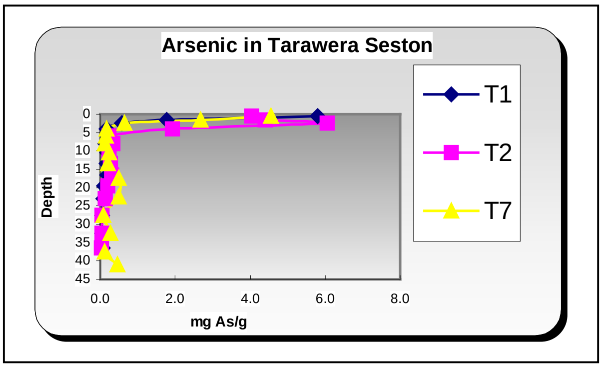


Here's the same thing for manganese, peaking in the top 2 or 3 cm in the seston(*left*), but in the pore waters the peak is 5 to 15 cm down and these are quite high concentrations (*below left*). Concentrations are up to typically 70 mg/litre which is a very high concentration for manganese, but disappearing to zero right at the surface of the lake where it's oxidised.

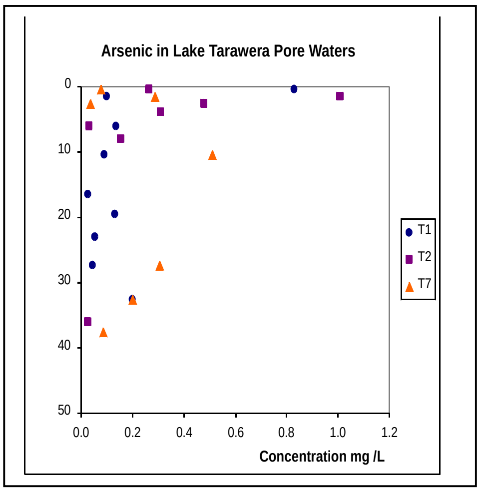


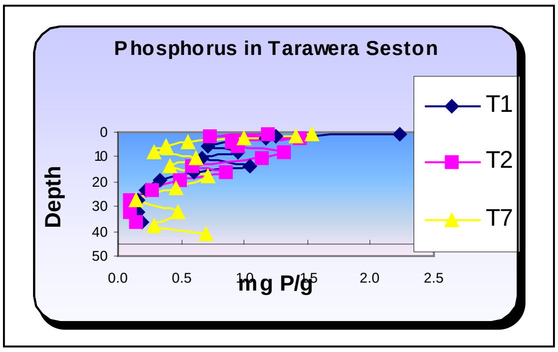
As it does this it's bringing up with it arsenate and phosphate and these two curves are very similar, there's the arsenic re-precipitating (*below left*), it's being redissolved down here, moved and re-precipitated there and you can see it going through the water column, dropping off right at the surface(*bottom left*).

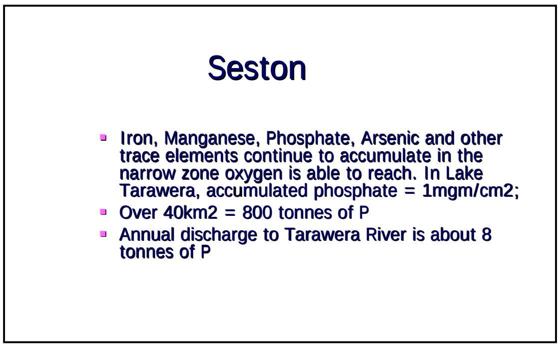
The phosphate is doing the same thing. Right at the very top in the pore waters there are concentration gradients like this and those gradients are the driving force driving these ions out of the seston and into the overlying lake (*next page*). From the slope of those and once we know how fast materials can diffuse through this material, we can calculate the rate at this these trace elements and nutrients are being re-released back into the lake. So the iron, the manganese, the phosphate and the arsenic continue to accumulate in that intermediate zone where the seston meets the lake, and in Tarawera that accumulation has given a total of about 1 mg/square cm.



Now that doesn't sound very much, but if you multiply that up by the area of the lake, that's 800 tonnes of phosphorus. Compare that to what's flowing out of the lake which is about 8 tonnes per year. This is now a rather substantial number and the worry is what happens next?

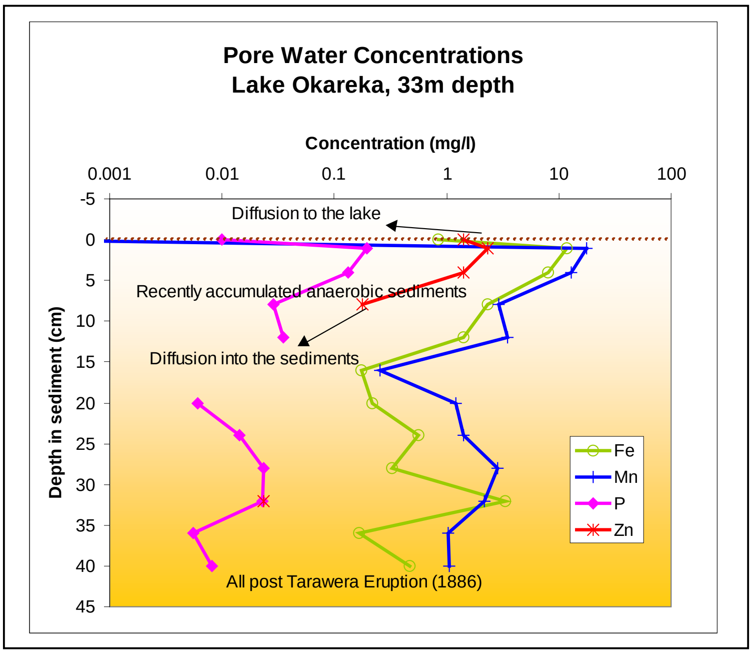






If we get to a state where the bottom waters of the lake run out of oxygen, and in fact all they have to do is go below about 3 mg/litre of oxygen, the manganese is reduced and there's lower oxygen concentration, the iron is reduced as well and this phosphorus will be available to come back into the lake.

When those surface waters cool and the lake turns over, the material is carried up into the light and massive eutrophication will then happen. We've now seen this happen. It's happening to a smaller extent in the three small lakes we talked about. Tikitapu stratifies in the summertime and once it stratifies the oxygen levels in the bottom waters drop off to essentially zero, so the bottom part of Tikitapu is now doing this.



Okataina does the same thing, there's stratification at around about 30 metres water depth and in the late summer/early autumn period the bottom waters also become anoxic and here also iron is reduced and phosphorus escapes.

Sampling these, here's the technique used. This is the seston corer (*not shown*), it's a little gravity corer that is dropped onto the bottom of the lake, brought up to the surface, a bung is put in the bottom and then this whole device assembled on a screw and the bung is forced up through the tube and we scrape of the seston layer by layer and sample the seston and the pore waters contained within it. Once we've got this material we can separate the solids from the fluids by centrifuging it and then analyse those fluids. We've only got a few millilitres, so if you get things wrong you've lost it forever, and this is what we find (*above left*). Here's a lake that goes anoxic and you can see the concentrations in the pore water right to within 1cm from the bottom of the lake and there everything is now diffusing into the lake.

From this, in the case of Lake Rotoiti, we now find that there is more phosphorus coming back into the lake from the bottom in the period of anoxia, than there is transported into the lake from Rotorua. The abundance of the trace elements increases towards the top as it's diffusing upwards and being reduced and then the concentrations are lost right at the

Pore Water Chemistry

- The abundance of trace elements (iron, manganese, phosphorus and zinc) in the pore waters of the Lake Okareka core are shown above. Concentrations rise steadily towards the top of the core, where they exhibit a sharp decrease towards the bottom waters. This is the result of diffusion of all of the trace elements into the bottom waters.
- The rates at which the trace elements are transported to the lake can be estimated from the slope of this diffusion gradient. Similar but much less steep diffusion gradients were observed in Lakes Tikitapu and Okataina.

very top by diffusion into the lake water. The rates at which this happened can be calculated from the diffusion gradient once you know the permeability of that material. The problem we've got is that once these lakes become sufficiently eutrophic to have anoxic bottom waters, then the rate at which the nutrients are put back into the lake accelerates enormously and eutrophication then becomes very difficult and very expensive to control.

So the first message, the most important message of all is that this process should be prevented. The process will continue until you either wash the nutrients out of the lake, you seal the nutrients below something else, you prevent the bottom waters from becoming anoxic so they lock up chemically naturally within the lake, or you remove the sediments completely. I want to thank a number of organisations for helping in this work. Initially we had a lot of assistance from the Department of Conservation while Jo Deely was there and subsequently. We've also had assistance from Environment Bay of Plenty, particularly in providing boat access, and assistance within the University from various other peoples to do this. So thank you very much.

QUESTIONS

Noel Burns, Lakes Consulting: A question that has always bothered me for a long time, is about when you get the iron and manganese dissolving back into the water and releasing the phosphorus and the ammonium back up as well. It stays in solution because the water is anoxic, but then in the autumn you get the remixing and that iron and manganese that's in the water becomes oxidised, re-precipitates in the water column and at that point they should scavenge out the manganese so trapping the phosphate that they released. In fact I see this happening in Lake Pupuke where the lowest phosphorus concentration is the month after the highest, because of the precipitated iron and manganese. What happens in these lakes here? What happens in Lake Rotoiti? Because you've got a huge release of iron and manganese into those bottom waters which get mixed up into the surface waters.

C.H.: If I can attempt to answer that, our work on Rotoiti didn't see sudden peaks in re-precipitated phosphate, iron or manganese at that time, but we were only successfully sampling in four sites. Many other sites where we tried to sample we kept bouncing off the bottom and Max Gibbs who has run a camera along the bottom, says a lot of it is covered with manganese nodules. So it's possible that the process is occurring in these manganese nodules, but we haven't had the opportunity of sampling them to know.

Economic aspects of the lakes situation

Brian Bell
Nimmo-Bell & Co Ltd., Wellington

Abstract

This paper summarizes the findings of economic analysis on the impact of the Plan Variation to reduce nitrogen inflow into lakes Rotorua and Rotoiti. The work was undertaken for Environment Bay of Plenty by Nimmo-Bell and evaluated a number of land use change options for the Rotorua Lakes district. Specifically it looked at the cost benefit and opportunity cost of land use change scenarios and the potential cost of the proposed restrictions and changing land-use to land owners in Rotorua and Rotoiti catchments.

The analysis was widened to assess the potential impact on the local economy associated with a change in land use to improve lake water quality. The national inter-industry tables were regionalised to assess the multiplier effects through the local economy. Impacts on tourism were also factored in to highlight the potential opportunity cost of not applying restrictions. A survey of the willingness to pay to improve lake water quality was also undertaken using the contingent valuation method. This showed how much local people use the lakes and value the lakes.

In looking ahead, the paper discusses some of the important issues relating to assessing the economic impacts of changing water quality. A framework including real option analysis is offered to assess economic impacts when uncertainty is high and the lags in the system may exceed 100 years.

Introduction

Good morning ladies and gentlemen, it's certainly a pleasure to be here. I would like to acknowledge the organizers for inviting me to the symposium and to acknowledge the financial support of Environment Bay of Plenty who funded the research. I'm going to be talking about the economic evaluation of policy changes to improve water quality and the talk is going to be broken down into four parts. Firstly, I am going to look at the implications of the policy changes from a landowner point of view, then go on to look at what are the wider implications of these changes to the community at large. Then I will look at some results of a survey we did in the district and the wider Bay of Plenty looking at what people thought about the deterioration in the quality of the lakes and what they would be willing to pay to improve that situation. And lastly I will look at some of the issues that need to be addressed in the economics of water quality and provide a framework about how you'd go about future work in the area.

Implications for landowners

First of all, implications for landowners. We used a financial modelling approach to evaluate economic loss to landowners through three key value drivers (Nimmo-Bell, 2004a). Firstly, what would happen to the income from present land use? Secondly, what

would be the implications of changing land use? And thirdly what implications are there about restrictions on the ability to benefit from productivity gains in the future?

We considered six scenarios for Lake Rotorua and three for Lake Rotoiti. We looked at what would be the situation without policy change under two scenarios. Firstly a moderate land use change, in other words if the policy wasn't put in place, what would happen to land use over the next 15 years under moderate assumptions of growth. And then we looked at what would be a more substantive change in land use. Then we compared that with the policy where the intention is to put a cap on nutrient output across the whole of the catchment and then look to see what would occur if we had to take out 150 tonnes, 200 tonnes and 250 tonnes of nitrogen over the whole catchment. The implications for the landowners is the difference between the 'with the policy' and the 'without the policy' situations.

When we looked at moderate land use change and a nutrient cap, we found that the net present value of the loss of benefit to landowners was about $31 million. That's discounting back the future returns, the difference in income stream between having the policy and not having the policy. And if you then move to more and more restrictions under moderate land use change that rises to about $78 million. If you're looking at a substantial land use change, then it gets up to about $90 million. That's the present value of the economic loss that would be suffered by landowners with the policy. The reason to do this work is to estimate the burden being put on landowners, and if that burden was to be shared, the quantum of it. If we're looking at sharing burden, maybe you could look at three major groups who are involved here. There's the landowners themselves, there are people in the district who benefit from the flow-on effects from the economic activity that is undertaken by farmers and then you could look at the overall implications to New Zealand as a whole - the taxpayers.

So the conclusions from this part of the study were that first of all there is likely to be quite a large impact on landowners economically. The actual loss they would suffer would depend on things like how accurately we got the land use changes in our analysis. Because we're looking into the future obviously that's an unknown. We have to make certain assumptions which could change substantially. Secondly, the form of the restrictions that are actually put into place has a big bearing on the economic loss. Thirdly, where the nitrogen reductions are sought, whether we take dairy land out of production and put it into forestry or take sheep and beef land and put it into forestry is a major issue. How that is actually implemented would have a big implication on the cost as well. Lastly, how landowners respond to this policy. Whether they respond positively or if a good dialogue cannot be established and a stone wall goes up between the landowners and the community and the policy makers. Landowners might dig their toes in and try and minimise the changes they have to make. So all these things affect what would be the actual economic loss. It is a dynamic environment and substantial change can be expected.

The next stage of the study was to look at what would be the impacts on the wider district and the region.

Impacts on the wider district and the region

Here we were looking at the changes in output, household income, value added and employment (Nimmo-Bell, 2004b). We considered the impacts from farming and forestry and also tourism, because we wanted to have some measure of what is the opportunity cost of not trying to fix up the lakes. And the tourism sector is the one we could attempt to quantify. The data we used here was based on the National Inter-Industry Tables which are a set of input-output tables that break down all the economic activity that is undertaken in New Zealand. We then regionalise to the specific attributes of Rotorua and use multiplier analysis to assess the impacts. Now, in terms of the economic benefit, firstly there's the direct effects of the actual economic activity itself like farmers producing meat and wool and dairy products. But then there's a second round of benefits as farmers spend money on supporting businesses, going to the stock firm and spending money there, the processing that goes on and so on. So that's an indirect effect from that direct farming activity and that's part of the second round of multipliers that the community benefits from. And then there's a third round where you have induced effects as householders spend more money and that money is re-spent in the community.

So what we're trying to do here is assess the wider implications of a restriction on land use that would result in less economic activity in the region. The results of this study were very interesting. To get an idea of the quantum of change that would be necessary for what we're talking about here, we looked at the economic effect on Rotorua if all the dairy land was converted into forestry. The reason to do that is because forestry has a lower nitrogen output than dairying. Based on the input-output data this would be a similar effect in terms of economic loss to a 10% decline in tourist numbers, assuming that the deterioration of the lakes caused that 10% decline in tourism. If you had the 250 tonne nitrogen reduction to be taken out of the catchment, that would require 93% of all the dairying land to be converted into forestry and that would be equivalent to a saving in tourism numbers of about 7%.

Now we couldn't find anyone who would actually put a figure on what would happen to tourism numbers, so we had to fall back on this approach of saying what if? But it does give you an idea of the sort of trade-offs that may be required. And the conclusions from this part of the study are that changing land use to improve water quality has substantial economic implications for all of us in the region. If we capitalise the annual loss to the district and the region, then depending on the assumptions, it's of the order of about $500 million to around $1.3 billion to the region. That really sets the outer and the higher end of the impacts that could be suffered and the challenge is how can we implement a policy to reduce that figure, that would be effective?

Value of the Lakes

Now I'll move on to the third part of what I want to talk about and that is a willingness to pay survey we did of 1,000 households in Rotorua district, Bay of Plenty region and also a sub-sample of trout anglers from Auckland (Nimmo-Bell, 2004c). The Auckland anglers form a big proportion of the trout angling population here and make a substantial economic commitment to coming down from Auckland to fish the lakes. We sought all their views on lake water quality and we tried to estimate the value that they put on the lakes and improving water quality.

Views about water quality. Both Lakes Rotorua and Rotoiti have poor water quality and they blamed it on septic tank sewerage, farming, industry and city sewerage. When we asked them who should pay to fix that up, half the residents said that the Government and the polluters should pay, where the polluter is obviously the source of the nutrient going into the lakes. There was also another interesting view that made it clear that there was a need for education and awareness to overcome some misconceptions about what is happening. The one that really cames to mind is a view amongst a lot of people in the district that city sewerage is still a contributor to nutrients going into the lakes.

What did people think were important? First of all passive attributes, just the lakes being there, were ahead of active use of the lakes. Secondly, algal blooms have affected directly more than half of the respondents in terms of their use of the lakes.

We also looked at the revenues forgone from Auckland anglers coming down to the lakes - they represent about 27% of total anglers of the lakes. The value that would be lost by having the blooms worked out to about $800,000 a year, just through their direct travel, their equipment and so on and the amount of money they spent when they were fishing. So that's a significant amount of money for this relatively small group.

Going back to the presence of the blooms and their effect on use, we see here that in Rotorua 69% of the respondents said yes it did affect their use, 20% said no and 11% were unsure. It's interesting that when we went wider to the rest of the Bay of Plenty, there was not much difference really. The table below shows how the use of the lakes is affected by algal blooms.

Change in usage of HH affected by algal blooms

	Additional Days w/o blooms (median)	With blooms Number of days usage (average)	Without blooms Number of days usage (average)	% change (average)
Swimming	20	17	40	128
Wind sailing	15	3	27	756
Picnicking	12	18	30	70
Motorised boating	10	17	34	97
Trout angling	10	19	38	104
Walking	10	29	38	31
Scenic driving	8	15	33	124
Yachting	8	8	14	71
Jet Skiing	5	3	11	282
Gathering traditional food	4	6	49	687
Kayak/rowing	3	17	25	44
Bird watching	2	12	54	362
Shooting	2	3	5	60

If we just have a look down the left-hand column there, these are activities ranked in order of the median use in terms of additional numbers of days use without algal blooms. The median is where half the population is on one side and half the population is on the other side. Swimming is most important, followed by windsailing, picnicking, motorised boating, trout angling, walking, scenic driving, yachting, jet ski, gathering traditional food, kayaking, rowing, bird watching and shooting in that order. If we have a look at the next column, the average number of days varies quite significantly from the median. If we compare that to 'with' blooms and 'without' blooms, you can see the percentage change in the final column. So for swimming the difference between 'with' blooms and 'without' blooms is a 128% difference in usage.

Willingness to pay

We asked people through a stratified process, one question for each group within the sample about whether they would be prepared to pay a certain amount in extra rates to clean up the lakes. The amount went from $5, $15, $45, $135 and $405. But we only asked a proportion of the population each amount for that question. What we found was that within Rotorua district the willingness to pay was about $91 per annum with less than half the respondents said they would be willing to pay the increase. If we could say we could fix this problem, that's how much they would be prepared to pay each year in increased rates. When we broadened that out to the whole region, it dropped substantially to about $12 and the weighted average for the whole region was $32. If we took that on aggregate, that would add another $2.8 million to the rates that people would be prepared to pay to fix this problem. Very interestingly, the anglers said they would be prepared to pay significantly more. In fact 62% of them said they would be prepared to pay $245 a year if they could have good clean lakes to fish in.

In the open ended question at the end of the survey we asked them just to state whatever they wanted to. The key themes that came out of that were first of all Environment Bay of Plenty didn't seem to be doing its job and the second thing was to get on and do something. So there was a very clear message there.

Framework for future analysis

If we have a look at the framework for future analysis, the key thing is the delay in receiving economic impacts. There's the delay between the time that the nutrient enters the ground water to the time that it gets to the lakes. And here we're looking at huge time frames from a few years to over 150 years (GNS, 2004), so that has big implications for how you analyse the implications about doing something.

Secondly, that we're expecting (from what the scientists tell us) that there's going to be a big increase in nitrogen coming into the lakes.

Thirdly, that land use does not significantly affect the level of phosphorus going into the lakes. So our work is focused on nitrogen, and Environment Bay of Plenty are doing other things about the phosphorus situation.

The next thing is that depending on who you are and where you fit in the system, you have a different viewpoint about the lakes and how it affects you and I'll talk about that a little bit more soon. We don't know a lot about what is going on underground yet and

there's a lot more work to be done, so there's uncertainty there and if there's uncertainty we need to be able to look at options. We don't want to get locked into one line of moving forward. The last thing I want to say is that economic spill overs can be both positive and negative and we need to be very aware of that.

Cost Benefit Analysis

The way we analyse this is the accepted methodology of cost benefit analysis. The results of this are very dependent on what the discount rate is. The discount rate is the factor by which we decrease future costs and benefits to get it back to a present value — because of the fact that a dollar in the hand today is worth more than a dollar that's out in the future. The discount rate depends on people's time value for money. How much they regard a dollar today compared to a dollar in the future, their attitudes towards risk and what is their required rate of return for a particular economic activity they're undertaking. So we'll have a look at some discount rates here.

If you were going into a green fields sort of operation, maybe buying a dairy farm, you might be looking for a return of about 20%. If you're currently in an economic activity and you know what the risks are, you might only require a return of 8%. If you are involved in allocating industry-good type money to do research, you might require a lower rate of return again. And then there is the question of what is society's time preference rate. What are the trade-offs that we as a society are willing to make today for some future benefit or cost. Generally, I think most economists would say that it is the growth of GDP that is the rate of time preference of people today. So that's about 3% that we're achieving in New Zealand.

But what about future generations? How do we take them into account? There are two schools of thought here, one says that there shouldn't be any discount rate because future generations have as much right as we have to resources. The other view is that future generations are going to be much richer than us. If you think about our parents, our grandparents and our great grandparents and think about the lifestyles they had and what we have. We're much better off than they were in most ways and I think this school of thought says that future generations are going to be far better off than us so we shouldn't take them into account too much at all. So there's this big conundrum about discount rates.

To illustrate the effect of discount rates on the way people think I've set up a table showing how a landowner would view income today, in 25 years and in 100 years. Then I've contrasted this same income with that of the community over the same period - today, 25 years and in 100 years. We assume the landowner discount rate is 8% and the community discount rate is 3%. Now assume the economic farm surplus from dairying is $1500 per hectare today. From the landowner's point of view $1500 today is worth $219 in 25 years time and only $0.70 in 100 years. Looking at it from community's discount rate of 3% this same $1,500 is worth $716 in 25 years time and $78 in 100 years time.

Value foregone

	Community			Land Owner		
Discount rate	3%			8%		
Mean residency (years)	0	25	100	0	25	100
EFS Sheep & Beef/ha	$300	$143	$16	$300	$44	$0.1
EFS Intensive Dairying/ha	$1,500	$716	$78	$1,500	$219	$0.7

So stopping that 70 kg of nitrogen on an intensively-farmed dairy unit in 25 years time has revenue foregone to the land owner of $219 while to the community that is worth $716. One hundred years out the difference is even more stark. From the community's point of view that $1500 has a value of $78 but the landowner regards it as virtually worthless. This means that from a commercial point of view landowners have a much shorter time horizon than that of the community. Given this difference in the view about future benefits particularly when they are a long way off there is bound to be a divergence of views about how to deal with long-term problems. It puts the focus on having policies that are able to adapt to changing circumstances. This is very important when the costs of the policies are large and new technology comes along that can reduce nitrogen. The income foregone is very high for landowners in comparison to that of the community.

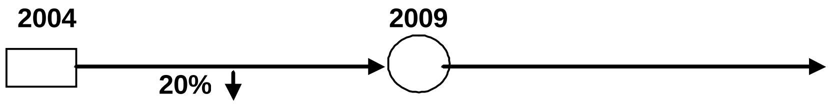
The implications of this are firstly that removing land from putting nitrogen into the system that has a short time frame is much better than trying to remove the nitrogen where it's going to take a long time frame to get into the lake. You get a bigger bang for your buck if you aim for the land where you know that the return period is short.

I would now like to talk about alternatives to cost benefit analysis through what's called real option analysis and then finish by looking at spill over effects.

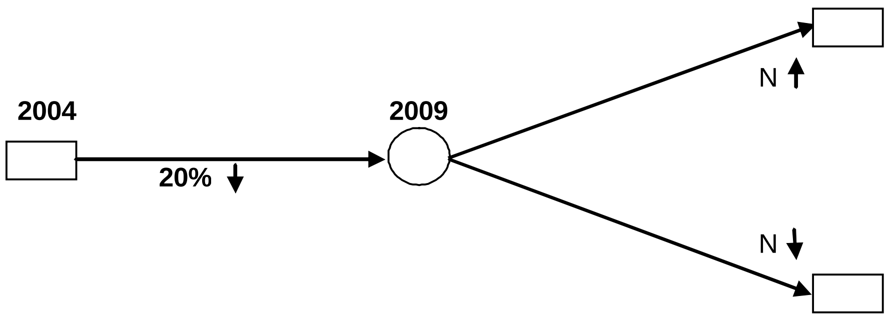
Real option analysis

Real option analysis allows for the fact that things do not progress linearly but there are usually key milestone points in a project where there are options to do something different. Standard cost benefit analysis does not take this into account. A relatively new technique called real option analysis can take these options into account in the analysis (Faulkner, 1996). It generally means that the benefit/cost ratio rises because we take into account the fact that if things go wrong we can stop the project and therefore limit the downside cost. On the other hand if things go better than expected we can put more resources into a project and therefore the benefit/cost ratio goes up.

Cost Benefit Analysis



Real Options



In the diagram I make the point that under standard cost benefit analysis we go forward in a straight line. Under real options after a five-year review we have a decision point where if the nitrogen levels are still high then we might need to take more drastic action. However, if nitrogen levels are falling (possibly due to successful application of R&D) then we may be able to take less drastic action. When this is incorporated into the analysis there can be a significant difference in the outcome compared to standard cost benefit analysis. Real options incorporate the value of flexibility.

We should recognise that the community gets spill over benefits from the economic activity of farmers. Farmers get the direct benefits of their economic activity. The community gets the indirect benefits on spending by supporting businesses as the money spent by farmers is used on goods that are supplied to them, and then the induced effects as money that goes into pay packets is spent by households buying more goods. The analysis of these spill over benefits and costs needs to be taken into account when comparing the existing scenario and making a policy change that restricts this economic activity for the benefit of the environment.

Another benefit of using real option analysis is that it can draw attention to the benefits of delaying action, particularly where there is major uncertainty. "…the greater the uncertainty and the longer the remaining life of the project, the more incentive there is to delay." (Brealey and Myers, 1988, p498).

A major problem with the draft policy is that implementing it is expected to result in inequities – between land activities (livestock versus forestry) and between intensive and extensive land use (dairy versus low productivity sheep and beef). If a delay of one or two years meant that the results of R&D could show that the policy could be modified to reduce these inequities then the benefits of delay could far outweigh the social cost of

community friction. This is not just theory. There is a new technology based around nitrate inhibitors that is very exciting for landowners and for the community at large because it has the potential of reducing nitrogen inflow into the ground water by around 60%. This is three times the desired level at this stage. The product is being tested in the catchments now and looks very promising, not only for water quality, but also for greenhouse gas emissions and it delivers a positive economic benefit through additional grass growth (Cameron *et al*, 2004).

A market solution in a regulatory environment

A market solution to the nitrogen problem is to allow trading of nitrogen credits (MAF, 2004). This will allow those landowners that can reduce nitrogen to trade the reduction in nitrogen that they are able to achieve with a person who wishes to increase nitrogen output. The trade will ensure that overall impact is zero and just as important that the economic outcome is better than if there is no trade. This market can only operate within a regulatory environment, and this is where the regional Council has a very important function (and a statutory responsibility). The key attributes of a trading system are that there are good information flows about the market, that it provides incentives to change activities in the direction that is desired and that it produces the maximum benefits to the community.

Conclusion

Let me conclude. Under uncertain outcomes we need to have policies that are flexible. The worst outcome would be for councils to adopt policies that are too prescriptive. This would leave landowners with very little incentive or ability to adapt their operations to produce desired environmental outcomes while remaining economically viable. Thus the benefits of their activities for the rest of the community could be lost as well.

A further most important point is that policies need to be able to incorporate technological change as it occurs. Real option analysis could quantify the net benefit of incorporating new technology (nitrate inhibitors) and reduce the cost of implementing a socially risky policy, while still maintaining progress on the environment.

The last point I would like to make is that it is very important that landowners have incentives to change. In an environment that is uncertain where there are big information gaps it is very important to ensure people are able to change in the right direction. I hope that these points give some thought to you as members of the community about a more open view on going forward - one that can produce a win for the environment and a win for us in terms of our ability to keep viable and thriving land use activities and a cohesive community.

Thank you very much.

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Why we decided to host this symposium

Nick Miller

LakesWater Quality Society, Analytical & Environmental Consultants, Rotorua

Good afternoon everyone.
My apologies for the rather bland title of this paper – it sounds rather along the lines of "What I did on my holidays".

As a consultant working on the fringes of limnology, I feel a certain diffidence in making this presentation, on behalf of the LakesWater Quality Society. The LWQS wanted to make sure that a full range of viewpoints was represented in the discussion of N and P targets, and to air some issues that are not included in the main focus of research on the lakes. Here I am going to discuss the lakes from the viewpoint of a biologist who strayed into analytical chemistry some 17 years ago, who also happens to live beside Lake Rotoiti.

As most of you will be aware, this occasion is the fourth such scientific gathering hosted by the Society, in cooperation with the Rotorua Branch of the Royal Society of New Zealand. Two of these gatherings have been organised in response to direct approaches from local government agencies. However, both the Rotorua Lakes 2001 Symposium and this year's event have been direct results of initiatives of the LakesWater Quality Society.

So what business do we have in "interfering" in matters of such grave import? And why have we decided to organise this event, on our own resources?

To answer the first question, when our 2001 Symposium was first announced, a friend of mine in NIWA emailed me mentioning that some of his colleagues were wondering why we were hosting such an event, with the unspoken implication that we were "meddling" in matters that were none of our business. Here is part of my email reply to him.

"We're merely representing the poor so-and-so's that have to drink water potentially contaminated with algal toxins and refrain from swimming in the stuff during the successive public health closures that have been posted in the last few years.

"As far as status and authority go - that is determined by the people that attend, what they have to say, and what is decided and acted upon at the outcome. We (the LWQS and Royal Society) are acting as facilitators to channel concern, funding and action into what is emerging as a major issue in this region. Someone had to do it, and we are representing the people most concerned. When the LWQS sent out a newsletter regarding our interest in lake water quality our financial membership rose virtually overnight from c. 20 to >200. 'Nuff said!"

(The response I got from my NIWA friend was short and to the point – "Well said!")

This photograph shows, better than any words, why local residents were concerned.

Te Weta Bay, Lake Rotoiti, February 2003.

At the time the photo was taken, the waterway shown was the source of the domestic water supply for a number of households. I expect it still is, for some of them.

Many of us remember the time when at least the Eastern end of Rotoiti was beautifully clear, and you could see the sandy lake bed several metres down. To those who use the lakes the deterioration has been very obvious.

Here is a popular tourist spot, the Manupirua Hot Pools, at Lake Rotoiti, in March 2003. The popular activity there was sitting in hot water and then jumping into the lake to cool off again. As you can imagine the second part of that activity is not so popular as it used to be, but people still do it which makes one a little concerned. I think I have shown enough on our reasons for concern.

The Society has, unfortunately, been right about the lakes situation. For several years now, we have been endeavouring to bring home, to various levels of government, the potential seriousness of the problem. We have made numerous representations as to the need for urgent action, often in the face of contrary advice from officials. In the end, we

proved to be correct that the lakes were deteriorating and thankfully the officials shifted their stance. They are still doing so, as the situation evolves. Indeed we all have to shift our stance and our views as the situation evolves. We undertake the work involved in setting up such a Symposium, publishing Proceedings etc., because we think it may be valuable and someone should do it.- we do not do it because we like running such events.

Our first Symposium, in 2001, was hailed as being 'very timely' and it served to reveal how many gaps there were in our knowledge of the Rotorua lakes. A direct result of this symposium was that John Keaney, the Chairman of Environment BOP at the time, was so fired up that he went back to Whakatane and persuaded his Council to establish and fund the Chair in Lake Management and Restoration at the University of Waikato. The residents of the Rotorua lakes region should be forever grateful to John for this initiative. The incumbent of this Chair, plus some of his students, have made presentations at this symposium. Another direct outcome of that 2001 symposium has been a great flowering of research work on the Rotorua lakes. We predicted at the time that research contracts would flow from the symposium, and they have.

As to why we are hosting this Symposium, we are doing it on behalf of the interested public and various sector groups. We also feel there are still uncertainties out there and the rest of this presentation will address this matter. Rather than reporting on research, as others here today are doing, I will be posing questions that we would really like to see answered and making some observations. I will be discussing nutrients and their measurement, concentrating on phosphorus, and then stormwater and the potential impacts of forestry – all topics which are closely interwoven.

NUTRIENTS

There has been much debate, over some decades, as to whether nitrogen or phosphorus were the limiting nutrients in the Rotorua lakes, as far as algal and cyanobacterial growth is concerned. For example, reports have been appearing on nutrient enrichment studies and bioassays on Lake Rotorua waters since at least the year 1978[1]. In general, these reports conclude that nitrogen is the probable limiting nutrient. For example, a 1988 [2] report discusses the findings of seven such papers and comments "The algae of Lake Rotorua have never been found to exhibit a 'demand for phosphorus'".

A number of studies have been made on various Rotorua lakes, over some decades. These experiments have often been made using in-lake enclosures, to which selected nutrients are added. In general the conclusions have been that P-limitation does nor occur, though the responses to addition of P were described in one often-quoted study as "mixed".

> "Possible phosphorus limitation
> Seven out of eight criteria indicated potential phosphorus limitation for samples taken from Lake Waikaremoana.
> ….none of the samples indicated shortage of phosphorus in samples from Lake Rotoiti. The samples from Lakes Okataina and Tarawera produced mixed responses."
>
> Payne *et al* 1988

This contrasts somewhat with overseas experience where “phosphorus is often a key element in regulating algal biomass” [3].
During the Rotorua lakes 2003 Symposium Dr Kit Rutherford commented :

> “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.”
> Dr Kit Rutherford, NIWA
> *Rotorua Lakes 2003 Symposium*

It appeared that scientific opinion was by no means unanimous or certain on the question.

In January 2004 Environment BOP released a document titled:
‘A Statement of the Significance of Phosphorus and Nitrogen in the Management of Lakes Rotorua/Rotoiti’, which was prepared by a Technical Advisory Group.

Paragraph 14 read:

> “Reduction of nitrogen and phosphorus inputs should be undertaken concurrently.”

Which we thought was promising.

However, Paragraph 16 read:

> “The collective view is that nitrogen is driving phytoplankton productivity and therefore needs to be targeted if the community is to see water quality improvements in the medium term (10 — 20 years). Dependent on actions taken for Lake Rotoiti, improvements in that lake could occur more quickly.”

This statement did give our Society some concern, not because we could see any strong scientific evidence to contradict it, but because we considered that, once adopted as official policy, it might tend to become dogma. It is this paragraph that probably lead to the conception of this Symposium. We felt that such a critical issue deserved public debate, rather than discussion behind closed doors.

Papers presented yesterday and today by researchers from both NIWA and the University of Waikato strongly suggest that the picture is still clouded, and that it is far too early to be dogmatic as to which nutrient should be regarded as most critical if, indeed, any nutrient can. In addition, the overall expectation has been that phosphorus inputs (other than those due to internal recycling from the sediments) can be expected to remain relatively constant, due to the ability of local soils to retain phosphorus. However, yesterday Dr Ghani from AgResearch served us warning that such complacency may be unwise. These and other papers, in my opinion, amply justify the presenting of this

Symposium, and here I feel I do need to make the point very strongly, because there have been some impressions to the contrary, that the Symposium was not conceived in order to knock over some particular view on whether nitrogen or phosphorus was most important. We merely felt that it needed a good and vigorous public debate and scrutiny. I would comment however that if it turns out that nitrogen is the major critical and limiting nutrient, then based on the evidence we have heard from GNS about its ever-increasing inflows into the Rotorua lakes, inflows that we're not probably going to be able to do much to halt, possibly it might turn out to be, shall I say, less impossible to undertake work that might end up resulting in our making phosphorus the limiting nutrient. There might be sound economic drivers towards that.

I now want to talk about **phosphorus** for a few minutes. At last year's Rotorua Lakes Symposium, Dr Bill Vant from Environment Waikato made this comment, at the end of his presentation about Lake Taupo and its cyanobacterial problem:

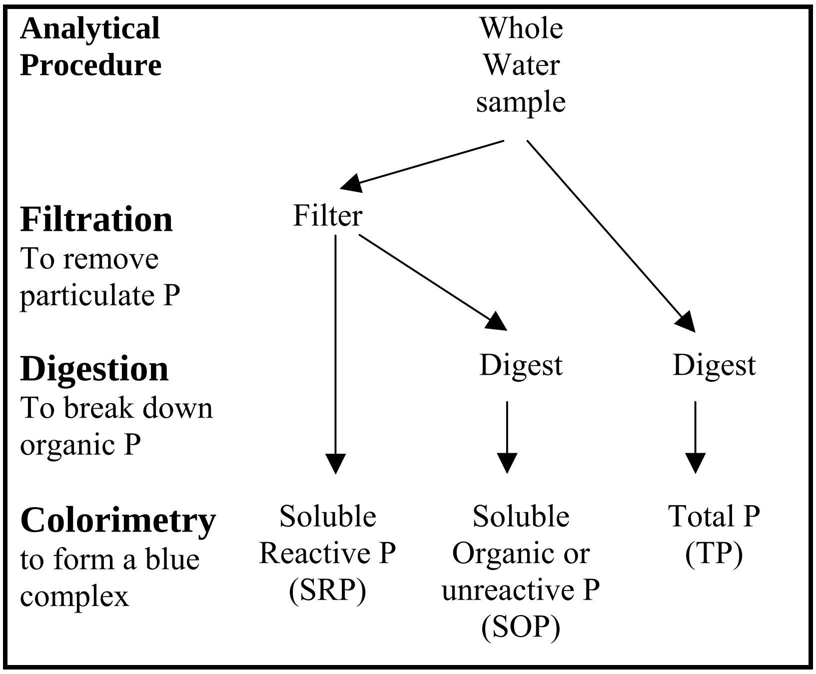
> "And, by the way, we can never find dissolved phosphorus in the water at Lake Taupo when we look for it. There just doesn't seem to be any there for any luxury uptake."
> Dr Bill Vant
> *Rotorua Lakes 2003 Symposium*

Speaking from personal experience, for some fourteen years I have owned and operated an Ion Chromatograph, which is an instrument used for accurately and sensitively detecting a variety of ions, including all of the major ionic plant nutrients, in water. I have often been struck by how difficult it is, using this technique, to detect 'phosphate', (generally regarded as the main bioavailable form of phosphorus) as the orthophosphate ion, even in waters which the literature tells me are well-endowed with phosphorus.

I have seen the element phosphorus referred to as 'remarkable and paradoxical' and it certainly has some extraordinary chemical behaviours. However, when we are talking about it in its limnological context we generally just dismiss it as "another major nutrient". It is a vital element for life, with roles in cellular energy metabolism, genetic material and many other functions.

Phosphorus occurs as a huge range of different chemical compounds in the environment. The analysis and measurement of phosphorus compounds in water is a problematical business. There are many factors which can affect the final result.

Here is the usual, traditional method for analysing the various forms of phosphorus in natural waters (*next page*). The final stage relies on the formation of a blue complex, known as phosphomolybdenum blue.



Some of the factors which can give varying results in phosphorus analysis include :

- Sampling and sample storage
- Filtration media and procedures
- Sample digestion methods and procedures
- The colorimetric procedure
- Varying proportions of complex phosphates (polyphosphates) or colloidal P.

Obviously, any alterations in the various analytical procedures may result in changes in the final concentrations that you may obtain in the final results.

Digestion methods (where organically-bound phosphorus is broken down or ‘digested’ to simpler inorganic forms) have changed over the years, but the various digestion procedures are generally regarded as giving similar results. The filtration step usually utilises a 0.45 µm membrane filter, which excludes most particulates but does not exclude some colloidal phosphorus.

For many decades the final stage of phosphorus analysis in natural waters has been a colorimetric procedure based upon the formation of a complex compound known as phosphomolybdenum blue. The concentration of this coloured complex is directly proportional to the concentration of phosphorus compounds that will react with molybdenum to form the blue complex. Phosphorus compounds are known as reactive or unreactive depending on whether they form this complex. Phosphorus compounds that are described as soluble and reactive are generally regarded as being the forms readily available for uptake by plants, algae and cyanobacteria. They are often referred to as ‘phosphate’. Frequently phosphate’ is regarded as being equivalent to the orthophosphate ion.

Orthophosphate is generally present at low concentrations in most natural waters and is very rapidly cycled due to biological and chemical activity. Orthophosphate may undergo polymerisation processes and occur as ‘condensed’ phosphates or polyphosphates, such as pyrophosphate (also known as diphosphate ($P_2O_7^{4-}$)),

triphosphate ($P_3O_{10}^{5-}$) and a whole series of linear chain compounds of increasing length, together with ring compounds (metaphosphates) such as trimetaphosphoric acid ($H_3P_3O_9$). Pyrophosphate is believed to have played a major role in the energy metabolism of early life on Earth [4]. These polymeric phosphate species play a major role in the complexation of metal ions in natural waters, are readily hydrolysed, and form a major reservoir of readily available phosphorus in natural waters [5]. These hydrolysis reactions are catalysed by algae and other organisms, and they also occur in the standard colorimetric determination of 'soluble reactive phosphorus', leading to the overestimation of orthophosphate [6]. A number of low-molecular-weight phosphate esters also occur and are similarly labile. Various colloidal organic compounds of phosphorus which will pass through a 0.45µm filter also exist. Any or all of these may be referred to as 'phosphate' by various authors.

So what is 'phosphate' and have we been measuring it accurately?

A recent paper [7] described research carried out on 58 Canadian lakes using a new steady-state mass balance procedure [8] for measuring phosphorus as the phosphate ion (PO_4^{3-}), which is generally regarded as the bioavailable form. This procedure measures the uptake and release rates of radiolabelled phosphorus and uses these rates to calculate dissolved phosphate concentrations. The authors reported that phosphate concentrations can be 2 to 3 orders of magnitude lower than estimated with current conventional techniques. They estimated that phosphate concentrations in these lakes (which ranged from clear nutrient-poor lakes to turbid nutrient-rich ones) range from 27 to 885 picomolar. The lakes studied varied widely in characteristics, from soft to hard, shallow to deep, and with varying biotic communities.

Other research, carried out in the Sargasso Sea (North Atlantic) and using a new chemical technique [9], reported phosphate concentrations in the picomolar range, 2 orders of magnitude lower than previous measurements.

Both papers point out that dissolved bioavailable phosphorus, in the form of phosphate, limits the growth of phytoplankton in temperate lakes and some oceanic areas, and that much remains to be learned about phosphorus budgets in lakes and other waterways, particularly if nutrient studies have been based on apparent phosphate levels that have been significantly overestimated.

The problem derives from the fact that the traditional analysis for what is known as soluble reactive phosphorus (SRP) actually analyses for a number of forms of phosphorus, plus other non-phosphorus compounds such as arsenate and silica (which can be compensated for with varying degrees of success).

A further complication is that the phosphomolybdenum blue procedure has also changed over the years, to eliminate various interferences from those other elements such as arsenic or silicon. Each change in procedure changes the reaction conditions under which the blue complex is formed, and also causes varying degrees of hydrolysis of the various polyphosphates referred to earlier. All of this means that data collected over the past decades may not be directly comparable. Very often, research papers or reports do not give sufficient information on the analytical methodology to allow us to factor in these variations when assessing the data.

So when we are talking about bioavailable phosphorus, as examined in different studies, we may in fact be comparing apples and oranges, depending on who carried out the analyses and how and when they were done. In addition, different organisms have differing abilities to take up and utilise polyphosphates or organically-bound phosphorus. Orthophosphate, the most common ionic form, is known to be immediately bioavailable. However, other forms may be bioavailable to a greater or lesser extent, possibly depending on the organisms involved. For example, the unicellular algae *Chlamydomonas reinhardtii* was shown to be able to utilise all size fractions of organic phosphorus compounds, including the large colloidal phosphorus fraction (0.2 – 0.45 μm) which made up 58% of the algae-available phosphorus in the Perth (Western Australia) wetland where the trials were conducted [10]. *C. reinhardtii* is known to produce phosphatases and it is believed that these rendered organic phosphorus bioavailable. Orthophosphate was shown to provide only 10% of the algae-available phosphorus.

So when we discuss ‘phosphate’ or ‘SRP’ or even ‘TP’ we are discussing a variable, hard-to-measure set of rather vague entities, and it is important not to get too definite in any conclusions we may come to. When we examine the results of nutrient enrichment experiments, whether carried out in bottles or in-lake enclosures, we should again bear in mind that we do not really know for certain what forms of phosphorus are present, how long for, or how bioavailable they really are to the organisms we are interested in. We should also keep in mind that water samples for phosphorus analysis should never be stored in plastic bottles, due to the strong ability of phosphates to be adsorbed onto the walls of such bottles. It is interesting to consider whether this effect also occurs in the polyethylene enclosures so often used in in-lake nutrient bioassays.

I should also mention that, to a lesser extent, these problems also apply to nitrogen compounds in the aquatic environment, but we won’t go down that byway!

Also we should consider the possible role of other nutrients in stimulating cyanobacterial blooms. Lake Rotoiti residents have commented to me that “the blooms have appeared once they started clearing the pine trees”.

This photo was taken a couple of years ago in the Rotoiti catchment, quite close to the lake. A paper delivered at last year’s Rotorua Lakes Symposium examined the increased losses of N and P to streams, following logging, and suggested that although such increases occur, they are of relatively short duration. However, there are other nutrients that may be involved. An interesting paper passed on to me by Susie Wood lead to an invitation to Simon Albert to deliver a paper at this Symposium. I certainly found his presentation yesterday, on organic carbon and iron, thought-provoking. To be sure, his work has been carried out in a marine environment, but nutrients in aquatic environments have generally similar behaviours and effects in fresh water or salt.

Finally, **stormwater**.
A paper delivered at last year's Symposium examined the effects of urban stormwater runoff on Lake Rotorua, and concluded that the effects were minor, with stormwater discharges contributing about 2% and 5% of the total catchment input of N and P respectively. I wonder whether we can afford to ignore even those inputs, considering the state of Lakes Rotorua and Rotoiti? The nutrients N and P, as well as heavy metals, were examined.

Here is a photograph taken, from my bathroom window, a few weeks ago, during the early stages of the rainstorm event that caused such problems in the Bay of Plenty. It appears washed out because it was shot through moderately heavy rain, during a brief break in the downpour. If you look closely you can see the plume of discoloured water flowing out into the lake, and the torrent of water cascading down the bank beside the shoreline. One of our committee members very intrepidly ventured out onto the lake during this event and reported similar scenes right around the shores of Rotoiti. I hope the canopy of her boat is reasonably watertight!

It would have been interesting to sample the site at which this photograph was taken, during this rain event. How much sediment, nutrients and organic carbon, in a variety of forms, would have entered the lake? Such rainstorm events happen every few years in this District and it may or may not have been a coincidence that the bloom which initiated the first closure of all of Rotoiti commenced just a few days after a similar rainstorm.

One problem is that field workers are, naturally, reluctant to carry out field sampling in such conditions. Instead of taking photographs I should have been out collecting water samples, but I was preoccupied by an imminent departure for Taranaki, to attend a funeral. At least we missed the subsequent earthquakes! I will finish up by quoting Dr Jake Peters, of the US Geological Survey, from his keynote address from last year's Symposium.
"I feel that it is a good idea for folks to listen to even the most hair-brained ideas. These 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."

QUESTIONS
Ann Green, a local resident of Rotoiti: I did want to ask one question. With Phoslock if we threw it into our lake to get rid of the phosphorus, what happens to a lake without phosphorus?

N.M.: A lake totally without phosphorus would be a most improbable thing, but if such a thing was possible there would basically be virtually no biological productivity in it. It would be to all intents and purposes very nearly a dead lake, so although phosphorus is a curse, it is also a blessing.

A.G.: So can there be repercussions if you put Phoslock in and remove the phosphorus?

N.M.: I would be very surprised if Phoslock or any other material was capable of reducing the concentrations of phosphorus to such low levels that really severe repercussions as I've just described occurred, but other people might have a different view on that.

Unknown: We could always just not top dress the farms and just top dress the lakes instead.

N.M.: In years gone by that happened.

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DISCUSSION: THE SCIENCE AND ECONOMICS

Ian McLean, LWQS: Ladies and Gentlemen, I wish to record our thanks and yours to a few people. First of all to Dairy Insight for their generous sponsorship, to Margaret Winslade who was on the front desk, to Sally Brock who sat silently on the stage for one and a half days, thank you Sally. To Deirdre of Dynamics who have done a great job with all the technical gear, to Wade Tozer who's looked after the audio tapes, to Mark, Colin and Nick the roving microphones, Richard Wilson who's been liaising on the catering, to those who I thanked the other day – Elizabeth Miller, Nick Miller and Brentleigh Bond, and also thanks to the Hotel. I hope you all enjoyed their hospitality, it's certainly great to run a Symposium in this hotel. So would you express your thanks to all these people please. It's now my pleasure to introduce Campbell Johnstone who is a member of the Committee of LakesWater Quality Society and also Chair of Lake Okareka Ratepayers' Association and who will be chair for the sessions this afternoon. Thank you Campbell.

Campbell Johnstone, Chair: Thank you Ian. The first part of this afternoon's session up until afternoon tea anyway is designed for the opportunity to ask questions of the presenters that you were unable to ask because a) there were too many questions or b) the presenters used their fully allocated period time thus avoiding the opportunity to answer your questions. There were a couple this morning so I'll open it to the floor and we'll keep it reasonably free running, but if it gets out of hand then I will call you to order. So does anyone have any questions to start with? You may choose to direct it to one of the presenters or you can leave it open and we have somebody answer it.

Brentleigh Bond, LWQS: In a report produced by Kit Rutherford in October 2003 I read the statement that a high TN:TP ratio is desirable to make it more likely maximum phytoplankton biomass remains low and that diatoms and greens predominate over blue-greens. Now presumably to get a high TN:TP ratio we've got one of two things we can do. We can chuck in nitrogen or we can reduce phosphorus. But if we can achieve the higher ratio and we can replace blue-greens with diatoms and greens, we've possibly got a solution to the fish problem we heard about yesterday and we're not going to have health warnings around the lakes. Is there any relevance in attacking phosphorus first to change that ratio? Perhaps I should direct that question to Dr Ian Hawes who I believe spoke for Kit Rutherford.

Ian Hawes, NIWA: I'll just say a few words about nitrogen and phosphorus ratios because they've come up a lot. In the limnological world you can divide us into the round ends and the square ends on the issue of nitrogen to phosphorus ratios because there's a strong school of thought which says that the ratio is only significant when the nutrients become limiting. And by that I mean that if you've got 100 phosphorus and 1000 nitrogen you've got a ratio of 10 : 1. If you've got 1 phosphorus and 10 nitrogen you've got a ratio of 10 : 1. But when you've only got 1 phosphorus, then phosphorus can become limiting, but if you've got 100 phosphorus then it's not going to become limiting. The first thing you have to consider is the concentration and the situation that you'll end up with if you try and increase your N to P ratio by adding nitrogen and not worrying too much about phosphorus. But let's take that one to its most ridiculous extent and you're not limiting anything at all. You're going to end up with a situation where nutrients aren't limiting and light will become limiting and under those conditions you will almost certainly get cyanobacteria growing, because cyanobacteria just ultimately take over those really thick soupy environments except in very weird places like sewage pond effluents where you

would get greens, but I'm sure we wouldn't want a sewage pond effluent-type situation. So the nitrogen to phosphorus ratio is something that is important to bear in mind, but only once you get to the situation where those nutrients are limiting. And if you have a low nitrogen to phosphorus ratio and a low phosphorus, then you will probably tend to favour those algae which can fix their own nitrogen by nitrogen fixation. These are cyanobacteria and some diatoms but not many. But if you have a low nitrogen to phosphorus ratio but a good supply of phosphorus, then if you're adding more nitrogen that certainly won't help. So nitrogen to phosphorus ratios are slightly mischievous because most people would probably agree that if the phosphorus isn't limiting at all and the nitrogen is, then you can favour cyanobacteria, but it's the concentrations that are available that is really the critical thing.

Bill Vant, Environment Waikato: I just want to add to what Ian said. When somebody says a high ratio or a low ratio, then that presupposes that we know what the normal ratio is. Now there's a thing that chemists talk about called the Redfield number and it describes in a typical organism the ratio of the carbon, nitrogen, phosphorus and oxygen. But from what I understand, the weird world isn't that simple and in lakes you can have some lakes with a nitrogen to phosphorus ratio of maybe 8 and that's normal, through to a range of maybe 15 and that's normal too. So I suspect Limnologists would say ratios of 20 are high and ratios of 3 are low, but between 8 and 15 they are normal. And some of the changes that people are talking about are going well if we double the amount of nitrogen, for example we might change the ratio from 8 normal to 15 or 16 which is also normal. Nature isn't plastic. Organisms vary, there is no magic ratio.

Warwick Silvester, University of Waikato: If I may add just one more comment. We've got to realise that not all cyanobacteria fix nitrogen, some of the worst ones don't and they fill another niche which of course is filled when you get high nutrient concentrations and that's what Ian was alluding to. The cyanobacteria start filling that niche as the nutrient concentration gets up and so *Microcystis* which doesn't fix nitrogen is a very important organism and is one of the worst bloom-forming organisms that we've had.

Chair: Does that sufficiently answer your question, Brentleigh? Then let's keep going and see if we can get the answer. I think the crux of Brentleigh's question was do we focus in on P to start with to get the ball rolling?

John McIntosh, EBOP: In terms of whether we should or we shouldn't this is not what I'm addressing, but there's a lot of research coming together at the moment on phosphorus adsorbance. We've had the paper from Forest Research yesterday and we've had one from Fouad on Phoslock. There is also other bench testing being done by URS the engineering firm, looking at various adsorbance. We're bringing those together and that will eventually come out through the focus group and the Rotorua/Rotoiti Working Party. We expect to put up proposals and trials looking at removing phosphorus from the inputs to Lake Rotorua, possibly treating the lake, but the first trial will be looking at removing phosphorus in the inputs to Rotorua. I just want to add the quote that Nick put up about the collective view that nitrogen is driving photo-synthetic productivity, etc. The comment that came after that, I believe, was that it's only worthwhile attacking phosphorus if you intend to drive it down to a limiting nutrient. So that comment was made there somewhere and that is an avenue of investigation, anyway, Brentleigh.

Brentleigh Bond: In my mind the statement that's contained in that October 2003 report still remains, that it is desirable to get a TN:TP ratio to change to the diatoms and greens, rather than blue-greens. The statement is there in the book, it stands. Frankly I haven't heard the answer to that.

David Hamilton, University of Waikato: I think the situation where you have a lot of phosphorus and low nitrogen, and I think that Ian, Warwick and Bill have hit on it, is you greatly increase the likelihood of getting cyanobacterial blooms and that's where phosphorus is essentially no longer limiting and where you have eutrophic type conditions. But having said that, if you have a fairly balanced type of situation or maybe you have a slightly nitrogen-limited situation and you say "well, we're not going to worry about nitrogen any more and we'll let the ground water aquifer and the nitrate seep through and we'll just focus on phosphorus" - you do run the risk of getting a flip in the system and that's what I tried to demonstrate this morning.

Anybody who has been on Rotoiti also through 2002/2003 would know that lakes don't behave in a linear fashion, they often go through long periods of quite prolonged "no response" or "little response" to a forcing and then a sudden flip. In shallow lakes it's called alternative stable states and in fact it probably applies to Rotorua, which went through a weed-dominated clear water phase through to a relatively turbid and no-weed-dominated phase. So I think that we shouldn't take the focus away from nitrogen when we're not sure. Wwe've shown that at some times and in some spaces, nitrogen is limited and at other times it's phosphorus and the balance is quite clearly. In many of the Rotorua lakes it's very hard to decipher, which David Burger's work pointed to this morning. If you take the pressure off one, you're simply reducing your ability to control the system. To go back to Justin Brooke's talk yesterday morning, he said you want multiple actions to give yourself every opportunity to control the biomass and if you simply take the focus off one, that to me is providing an opportunity.

Noel Burns, Lakes Consulting: I knew both Rick Pridmore and Eddie White and it was about 10 years ago that we had to knock some heads together and decide whether it was nitrogen or phosphorus which they wanted to see removed from these lakes, and in the end they said both, you have to take out both. I also gave a talk here about 2 years ago when I looked at the characteristics of nitrogen and phosphorus in these 12 lakes. You've got 4 of the lakes which are strongly phosphorus-limited such as Okareka, Tikitapu and Rerewhakaaitu, and you've got 4 which are strongly nitrogen-limited and they are Rotorua, Rotoiti, … there are about 4. The 4 which are nitrogen and phosphorus-limited are about imbalance. What I found in those 4 with the nitrogen and phosphorus imbalance was that the chlorophyll wasn't high, the trophic level TLc, which is chlorophyll, was about the same as the TLn and the TLp. What seems to happen in the lakes is that in the springtime the algae use up the phosphorus first and then in the autumn they begin to use up the nitrate. So you switch from the one type of algae to the other and neither algae gets a dominant position, but if you have a lake like Rotoiti which is strongly nitrogen limited, nitrogen-efficient algae are always the ones that are there, active, and they become very good at using their nitrogen. You find the TLn is very much lower than the TLc. In other words they create quite a lot of chlorophyll for the nitrogen and if you look at the phosphorus-limited lakes like Okareka, the TLc is about 3.8 and the TLp is about 2.8, so again in that phosphorus-limited system the algae become very efficient at using the phosphorus in creating chlorophyll. So really what I think you need to do is bring down both, keep reasonably close to that N to P ratio of 10, but always

favour phosphorus-limitation rather than nitrogen, but only slightly. And the most important thing is as Ian was saying, is to get the concentration down so that your trophic level is, I think, under 3.8. It seems to me if you get TLIs over 3.8 you're really going into the danger zone.

Sally Brock, LWQS: You say to get the TLI down below 3.8 because then you reduce the amount of blooms in the lake and yet we have lakes like Rerewhakaaitu which have quite high TLIs and no evidence of algal blooms. I'd like to know the difference between Rotoiti and Rerewhakaaitu, because remember we're going to be doing an Action Plan which is solely on nutrient inflow into the lake and yet we've got a highly nutrient-enriched lake like Rerewhakaaitu which doesn't experience the nuisance blooms. In comparison, for Rotoiti which is less nutrient rich, we're trying to reduce the amount of nutrients going into that lake to reduce the algal blooms. So I can't understand the relationship.

Noel Burns: Rotoiti is actually stratified and Rerewhakaaitu usually isn't. I think that makes quite a bit of difference. The other thing is that Rotoiti is nitrogen-limited and Rerewhakaaitu is phosphorus-limited, and the phosphorus limitation restrains the blue-greens. The fact that its shallow and, I think, that the wind can actually mix Rerewhakaaitu all the way to the bottom nearly all the time, gives the diatoms an ecological advantage over the blue-greens, because the blue-greens like the stability. They like to sit at the surface and go down to the thermocline where you've got nutrient leaking up from the hypolimnion into the thermocline and they absorb that and then they go back up into the light. Whereas the diatoms in a stratified condition just sink down and get into the thermocline and they get trapped there and never come back up because they're not vertically mobile, and so the blue-greens out-compete them in a stratified situation. In a thermal situation I think the diatoms are more efficient at using light. You're getting the circulation from the wind, the water in the surface is often going down, we get these spirals of circulation as you move down wind and that means the diatoms come up, get a dose of light which they use very efficiently and then go back down into the dock. They are more efficient at using that occasional exposure to light than the blue-greens are and so they out-compete them that way.

Sally Brock: So if we're just talking about shallow lakes then, liken it to a lake like Rotorua, because we've got highly nutrient-rich lakes that aren't being closed because of algal blooms and we have less nutrient-rich lakes that are being closed to nuisance algal blooms. So compare Rerewhakaaitu to Lake Rotorua which has that same mixing effect.

John McIntosh: The target TLI for Rerewhakaaitu is 3.6 and the target TLI for Rotoiti is 3.5 so they're very similar, but the current quality of Rerewhakaaitu gives a TLI of 3.3 and the current quality of Rotoiti gives a TLI of 4.3. So Rerewhakaaitu is not nutrified at all, in fact it has a reasonable quality and the reason is because it's highly phosphorus-limiting. The farmers have their own group there and the big issue for them is to not let more phosphorus go in to the lake. The indications with the little stream at the moment are that the phosphorus is increasing. So that's an issue for them. They are dealing with it before they get any bad problems.

Sally Brock: And it's just a silly question, but can you make a lake phosphate-limiting to stop the blue-green algae?

John McIntosh: Well, I think we going to look at those possibilities, but it could be very costly so then you'll have to sit down and do the cost benefit analysis as well. But for Rotorua we will certainly put that on the table to be discussed.

Noel Burns: The current Rotorua TLI is 4.9, a very big difference you see. The water quality is definitely being reflected in the TLI. The lakes which have a poor perception of water quality also do have the high TLI.

Richard Wilson, Lake Rotoiti Ratepayers' Association: My question firstly is to Brian Bell and secondly to John Cronin and perhaps a representative from Rotorua District Council. In light of Susie Wood's report that says that there is a potential human health risk from the consumption of trout tissue on Lake Rotoiti, would Nimmo Bell do further analyses as to the economic aspects of this to the Rotorua economy? Secondly, would Environment Bay of Plenty or Rotorua District Council fund this?

Brian Bell: Certainly this is something that can be analysed, so the answer is always yes.

John Cronin, Chairman, EBOP: With regard to funding, that's an issue we'll take back to the new Council because we haven't considered that. I haven't read the report so I can't give you an answer on that at this forum.

Mary Stanton, Iwi Te Arawa: I know the water quality in our lakes is deteriorating so much that I would like to cry, but I will save my tears and move forward. We have to be positive for our people around the lakes, Maori and Pakeha, friends and our children who will benefit long-term. We need to look at our water supplies. The15 years we have been waiting has been a long time. We find where the water (source) is closer to the waterways along the Ohau Channel in particular and the Mourea Bridge, people are using muddy water. This is a health issue we have to be aware of. I ask any of our scientists do you believe that we should be deprived of water?

Another question I would like to bring forward to the public arena is policy changes. There was a time when because of the cost the Government subsidised our treatment plants. My father Stan Newton blessed the treatment plant in Rotorua in 1991. He knew and all our Maori people knew the lake so well and they tried to save the lakes because they were our food basket and just imagine your food basket being destroyed. We are going to have a sewage treatment plant for Okawa Bay and Mourea and I believe the first lot of turf is being turned over next Wednesday and it's going to cost us, people who own properties, far too much money. Why should we carry that burden when we are trying to save the lakes, it's a problem for everybody and we need a subsidised treatment plant for Okawa Bay and Mourea, then we should move beyond that particular area to serve all our 14 lakes. I believe that's the best possible solution. We must face the fact that it's money that is the biggest problem. Kia ora.

Chair: So the first part of the question was to some of the scientists about water quality. I think the answer, Mary, is no, nobody wishes to accept that, but somebody may wish to answer on my behalf.

Ian Hawes: I think I probably speak for all of the people involved in lake sciences that our passion is lake environments and none of us want to see them go downhill in any way. In fact the reason why we're in this job is to come up with robust and reasonable

solutions to try and improve things or at least do what we can. So I think nobody considers the situation which has evolved from the social setting that we're working in now to be what we really want.

Chair: In terms of the second part of your question Mary requesting policy changes, who would you direct that question to please. Is it an RDC question or an EBOP question. If you could be specific then we can get an answer for you.

Mary Stanton: I will direct it to John McIntosh. Thank you.

John McIntosh: The policy is in our regional water and land plan that deals with quality of the rivers, the lakes, the Ohau Channel and we have set standards for those water bodies. The standard that we've set for Rotorua is a better quality than it is now and that's really what the work is going for. The water flowing through the Ohau Channel is Lake Rotorua water so the objective is to improve that water flowing through there. I don't think we need a policy change. I suppose that's what people have been gingering us up on is to get along with it, but things are moving at a reasonable pace now, I would think.

Rowland Burdon, Royal Society of New Zealand: The question I would like to revisit is that of the relative importance of fluctuations in inputs of these nutrients as distinct from absolute inputs over a period of time. In the past before land development I think one feature of the hydrology of this area would have been the very considerable constancy of inflow seasonally and perhaps from year to year, both in terms of the volume of water and the amount of nutrients. It would seem, although we do not have good documentation, that all the lake systems here handled that very well despite amounts of nutrients that are really pretty high by world standards. But land development started, then there were big changes in inputs. Certainly there was the superphosphate and there were some undoubtedly huge but poorly documented pulses of phosphorus getting into some of the lakes. I think that's probably much less of an issue now but it's probably not totally disappeared. Perhaps now the issue could be more a matter of pulses of nitrogen inflows in the short-term after high intensity rains following drought periods and if one has lakes with high phosphorus loadings, nitrogen-limited at the time, some of those pulses might destabilise the situation. So I just wonder if any of the speakers or anybody else would like to respond to that one.

Chair: Okay so that's about the importance of fluctuations of the important nutrients.

David Hamilton: I think you make a very valid point and it's a point that I've picked up in discussions recently and which in fact has been picked up by Environment Bay of Plenty also. It's a new look at storm flows and concentrations of nutrients coming in on storm flows and I think that work is actually work in progress through Kit Rutherford and others at the moment. I asked some colleagues about this and their response was that any phosphorus that comes in whether it's with sediments or whether it's dissolved, is potentially available. With the way that the lakes are with some of them going into anoxia, then you simply liberate that phosphorus and it becomes available again. So I think it's an absolutely valid point that any phosphorus that comes in whether it be particulate or dissolved is potentially available.

John Green, LWQS: Could I address this to John McIntosh please. As a Rotoiti resident and an observer along with a lot of my colleagues at the lake, we have witnessed from

time to time aerial topdressing in which the pilot has headed towards the lake while dropping and we've seen superphosphate going straight into the lake, and I could give many many examples of that. I even witnessed that last week while watching the pilots go over the farm down by Honeymoon Bay and there is no doubt in my mind that the fertiliser was heading to the lake. Could we please have a policy change on fertilising around the lake edge and also could you please address what fertilisers the farmers are putting on, to try and get a formula or mix which obviously is beneficial for farming, but also beneficial for nutrient release into the lake. Thank you.

John McIntosh: I wonder if Ruth would like to answer on the policy on fertiliser?

Ruth Feist, Environment Bay of Plenty: I'm an environmental planner so, I guess, thank you John for passing that question on to me. We are aware of the aerial topdressing issue. At the moment aerial topdressing is controlled by rules in our regional air plan, which is operative but we will be reviewing those rules particularly for the concern with the lakes.

John Green: When will you be reviewing them?

Ruth Feist: To be honest I'm not too sure of the exact date for those but we have got a review of the air plan and we're just in the initial stages of that, so it will be within the next year.

John Green: Could I also ask that when you're doing that review, could you please work with Federated Farmers or whoever to get a formula mix which is mandatory for the farmers when they are fertilising near the lake. Because you can get slow release fertilisers, there are so many different types of fertilisers and mixes. Farmers are still putting cobalt in their mixes. It seems to me that we should get a scientific focus to actually agree what is the best formula for applying in and around the lakes.

Ruth Feist: Certainly I think the application of fertiliser, the timing, the volumes are something that is involved with defining what best management practices are for rural land uses and addressing the effects of fertiliser use in also about reducing the costs to farmers, so they are not putting on so much fertiliser that it's just leaching through. So yes, it would be something that we develop through best management practices and give that information to the farmers and landowners in the catchments.

Max Gibbs, NIWA: Can I pass a further comment on the issue of topdressing. It's not just near lakes, it's also alongside streams. Farming practice and common sense dictate that you shouldn't actually have the downstream side of your wind drift of fertiliser and so forth going across a waterway. I've studied lakes and watched the effect of superphosphate going in just as wind drift. The little things on the back of a quad bike are spraying pellets out across the field and a great cloud of white dust goes across. Phosphorus levels in one lake went up from around about 5 ppb up to over 350 ppb in a single pass. Those are the sort of problems that you've got. They can get into rivers, they can get into the streams and many of us think that topdressing is a great way because it covers a large area. Unfortunately it's very unspecific and it will get into streams as well, so perhaps a bit of common sense in the way fertiliser is applied is also in order.

John McIntosh: Within the Rotorua/Rotoiti action plan process, Environment Bay of Plenty intend to form a land use technical advisory group, much in the way we had the

lake technical advisory group and we will also get them talking, so that would be something that could go on the table. And already, as you might be aware, there are companies promoting alternative fertilisers and they feel they're not getting a good hearing with them. So we can get a technical advisory group to look at all those alternatives, evaluate them and make that public.

Nick Miller: Can I put in a comment here as a resident. I think it would be a reasonable observation to say that in the last 2 or 3 years in particular the level of topdressing around Lake Rotoiti has increased quite significantly, and whether it's people making hay while the sun still shines, as it were, I don't quite know. And following on John Green's comments, I live just across Te Weta Bay from him and I don't think John was in residence at the time, but I recall quite vividly just a few months ago after one topdressing run, seeing fine material drifting down across his property and straight into the bay. So I certainly would agree with and endorse his remarks.

Chair: Perhaps some representatives of Federated Farmers can take some of those comments on board.

Robin Ford, Regional Councillor: Just an answer to Mary's concern. We have recently approved a considerable amount of money that will go a long way to alleviating her concerns, so we hope that helps Mary and all her other residents.

Sally Brock: I'm going to be a bit of a mischief-maker and go back to this P versus N query. I asked Noel how you make a lake phosphate-limiting and he said you cut off the supply of phosphate. So I now refer that back to my good friend Brentleigh's question. If we cut off the supply of phosphate into a lake like Rotoiti, can we make it phosphate-limiting to reduce the cyanobacteria blooms?

Noel Burns: This problem is actually world-wide and it's even more intense in America than it is here, because so many of their lakes are in really bad condition and most of the American lakes are phosphorus-limited. It's this problem that we're increasing the number of humans all the time, we're increasing land use, we're increasing the intensity of land use and we're just continually increasing the supply of phosphorus to water. So we have to go back, for example, to the Lake Rotoiti situation, where you've got Lake Rotorua supplying a lot of the phosphorus, so you would have to try and diminish first of all the supply of phosphorus to Lake Rotorua, which is not an easy situation but it's being tackled. That means all this land use, conversion of pasture to forestry, improving the way the treatment plant in the forest works, being much more careful about the storm water drainage from the city of Rotorua. Each one of these things is going to cost a lot of money.

Then when you've got that done, because Lake Rotorua has got higher phosphorus content than Lake Rotoiti, I think you do still want to take the safety precaution of diverting as much of that Lake Rotorua water down the Kaituna River, which means building quite a strong structure to get the water to go straight down the river rather than all the way down to the far end of the lake. Even when you've done that, you've then got the problem of what to do about all the phosphorus which you've regenerated from the bottom which is now cycling annually through the lake system. And it's going to take 20 years to diminish that recycling phosphorus. So it's easily said, cut down on phosphorus, but it's difficult and expensive when it comes to the reality.

Chris Hendy, University of Waikato: If I could just add a little bit to the last answer and address the problem of phosphorus in the bottom of the lakes, say Rotoiti in particular. The problem is that we may actually be getting worse rather than getting better. Even if you were to turn off completely the phosphorus supply into Rotoiti, as the eutrophication has raised the level to which the bottom waters have become anoxic, both the area extent and the fraction of the year that it is anoxic were actually increasing the feedback from the bottom of those lakes. To get that out would in my opinion take a lot more than 20 years. I haven't done the calculation, but it's only a very short period of the year in which you effectively flush that water and you've got a large volume with only a small throughput. So if you really want to get that phosphorus out you may have to look at alternative ways of doing it, such as either removal from the lake by precipitation or removal of the sediment from the bottom or capping of the sediment. Those options probably will have to occur if you want a solution in less than perhaps a century.

John McIntosh: I don't think we necessarily have to wait a century. The modelling work that David Hamilton's doing at NIWA will provide answers on what the effect of that diversion will be and then they'll be able to tell us what the likely time frame is for improvements in the lake and then we'll be able to assess whether more actions need to be taken.

Bob Martin, RDC Councillor: My question is pretty straightforward and goes to the scientists. Radiata tree pollen, what elements does it contain? Does it contain nitrogen or phosphates? What elements please.

Warwick Silvester: N to P ratios again. It contains both nitrogen and phosphorus and this question has been raised many times. Let's equate pollen with cyanobacteria because it does exactly the same thing, gives us the same impression. Cyanobacteria float to the surface and then get blown in to the beach and we have this enormous concentration. Pollen does exactly the same, it hits a puddle, runs to the edge and we see this yellow scum and we think there's an enormous amount of pollen out there. There is not an enormous amount, but it appears to be an enormous amount. In terms of the total nitrogen cycling of an ecosystem, the amount of nutrients (and there's nitrogen and phosphorus in pollen), is in fact quite small compared with the annual turnover of nitrogen and phosphorus. The impression that we get is of a very large problem and when we see it floating on the lake, and accumulating at the edge of the lake. I'm actually trying to get some numbers to really quantify this. I've been asked to do that. I haven't got those numbers yet. I've got some preliminary numbers which indicate it is within the range of measurement error rather than as a significant amount. It's very much like the cyanobacteria in some ways because it does accumulate by floating and by moving sideways.

Bob Martin: I hadn't actually finished my question. The other one is the fact that as farmers, we are quite aware that when we put phosphate on we get growth of what I'll call the good weeds, grass, etc. and when we stop fertilising we get the rogue weeds. Now Brentleigh asked the question which basically was that if we got rid of the phosphate in our lakes, would we have the rogue algae starting to perform. Is that what you're trying to tell me? I can give you a situation where I have got one property that has not had fertiliser for 20 years and I've got another property that we've fertilised to the stage of about 300 kgs per hectare. What I am seeing now is that the property with the 20 year

lapse of fertiliser or phosphate has actually reverted back into some real rogue-type weeds. Would that same situation apply within the lake?

Rowland Burdon: I'd like to return to the previous question following on from Professor Silvester's response concerning the pollen nutrient inputs from pollen, particularly of *Pinus radiata*. This issue of the inputs resulting from pollen dispersal is something that has been the subject of more than one grant application for research and it just hasn't been funded. I certainly agree that it is something that needs to be addressed. If Warwick is happy to address it as a gentleman of leisure these days, then good on him. I would add also that if we get on to genetically-engineering pines, one of the things that we would certainly want to do would be to stop them producing pollen. There would be various reasons that would be in the interests of containment of genetically-engineered material which is a very sensitive issue with the public. And the other things is that we would be producing trees that would focus more than ever on making wood, not love.

Chair: Thank you, a valid point. We still require an answer to the second question.

David Hamilton: I guess I'll give a quick answer, that in low-nutrient environments we see fairly bio-diverse environments, we see a mixture of phytoplankton species and zoo plankton species in general. By comparison, in highly eutrophic systems which have high nutrients, one or two species dominate and I guess that's what this forum is about, because typically those species are cyanobacteria.

Ian McLean, LWQS: Can I say I've got great sympathy for Tim Bennetts, because Tim's the guy who is going to be persuading Treasury to write a cheque out. He is persuading his Minister and he's going to get a lot of help from Steve Chadwick and we'll be very grateful for that. I think he's got problems. He knows now one of the numbers, the size of the number in the cheque, a very tentative one from Brian Bell, about $90 million for the change in land use to get rid of 250 tonnes of nitrogen, more or less. So that's the size of the number for nitrogen. There is no size of a number for phosphorus yet emerged. What Treasury is going to be asking him when he fills in the number, is how much of a bang for our buck are we getting with phosphorus and how much for nitrogen. How much do we do of each? And I've got to say with, great respect to some of the scientists who've answered today in this session and who've told us about the problems, that that approach won't get one dollar out of Treasury. To talk of the complexity of the situation, of the delays of all the troubles, that won't get one dollar out of Treasury. So my question is to the scientists, who is doing the modelling work which will enable a reasonable specification, a reasonably confident specification of the effect of reducing nitrogen and phosphorus by different amounts, rather than generalities? Who is doing that work? Is it being funded at the moment? Is there a dynamic model which is currently being run which can produce those answers, so Tim can write the numbers on his cheque and persuade Treasury to countersign it?

David Hamilton: Thank you Ian and that model is the one that I presented this morning. Underpinning that model of course is the best possible data and it's a combination of using all of the information that's available, pulling it together, trying to understand it and using it in that modelling package. There's a phrase that the modellers use which is garbage in and garbage out. We need good information, we need as much information as possible in order that we can refine the predictions and give quantitative answers to the sort of question you just raised.

Chair: What level of risk or probability would you look to take the modelling work forward to, to be able to put it into a commercial model for funding a grant?

David Hamilton: The types of models that we use, the ecosystem models, are a bit like the global climate change models, there are uncertainties in them. What a lot of those people who use those global climate change models are doing continuously is to try and refine the uncertainties. At the moment, as you know, there is enough uncertainty for people to still say that it is the solar flares that are causing climatic variability and potentially warming. So that's very much the same with the type of lake ecosystem models that are being used. They have inherent variabilities, but they are the best available tool. They capture the physics in general very well, they capture the chemistry generally pretty well and they capture the biological variables with less certainty. That just illustrates exactly where the science is, that we are still trying to quantify how different species interact. Remember we're dealing with systems that have 200/250 different species interacting at any one given point in time in that lake.

In that regard we also don't know how invasive species are going to impact and they are an event that we can't necessarily model with any certainty. We know that invasive weeds came and caused problems in Lake Rotorua through the 60s and 70s and likewise in terms of algal species we've got species such as *Cylindrospermopsis*, a new blue-green that's started turning up in some of the Waikato lakes. And that's another species that, for example, in Lake Rotorua could potentially be a very real problem. When *Anabaena planktonica* came in about 2 years ago, particularly into Lake Rotoiti, Vivienne Cassie Cooper, who many of you will probably know, and who is one of the most experienced phytoplankton taxonomists said she thought it was a weed, she hadn't seen it particularly before and so we don't know.

Again it's another one of those things that we're right at the boundaries of and some of the certainties are good with physics, less so with chemistry and a little bit less so with biology. But we have to use these tools, they are the best in the world that we've got and they are the ones that are going to take us forward to guide a lot of the management decisions. In that regard, what we try to do is to predict from past data as accurately as possible and get the model to essentially be calibrated to that past data. We then run a series of scenarios and those scenarios might be such things as taking away the Ohau Channel, use of flocculants, destratification or oxygenation, a variety of different things that are going to be used to actually test what's going to guide the best management decision forward.

GENERAL DISCUSSION

Campbell Johnstone, Chair: To open this last session, it is an open forum as you've been advised and I think that comments on the quote that Nick left you with just prior to lunch would sum up this session succinctly, so I will repeat it and it is from Dr Jake Peters. "I feel that it is a good idea for folk to listen to even the most hare-brained ideas. These ideas might lead to the right solution. We may have preconceived ideas on how things work, but they may not be right ones." So with that I open the ultimate session of this symposium and ask for questions please.

Richard Wilson: My question is to John La Roche. I listened with great interest to your presentation yesterday about your advanced on-site domestic waste water treatment system. I do understand that you are a special case and I acknowledge that, but don't you think that sewerage schemes are going to be better for everyone than your on-site domestic waste water treatment system, which regardless of how good it is, will leach some nutrients into the lake?

John La Roche, Rotoiti resident: Thank you, Richard. We don't consider that we're a special system, a special case. We offered to put in the system as a trial working with Environment Bay of Plenty so that tests could be taken. The results from our trials would indicate that we can achieve very similar results to what would be achieved from a treatment plant attached to a piped sewerage system and I also don't think that everywhere around the lakes is going to get a piped sewerage system. So hopefully what we are doing will provide some sort of information and a model for people who will not be able to get piped sewerage. We do realise that there's a possibility of a piped sewerage system coming in at Gisborne Point where we are. Just where that will leave us we're not too sure at the moment, but we're certainly keen to continue with the experiment and to provide whatever information we can to anybody who's interested in systems similar to what we've put in.

Terry Beckett, Lake Tarawera Ratepayers' Association: I'm not sure who I should address this question to, but it's related to Lake Okataina which seems to me to be a bit of an enigma. There the situation is that we have deoxygenation below the thermocline in a lake that is apparently pristine and has never had any direct inputs of N and P or whatever around it, other than possibly from the small habitation at one end.

John McIntosh: In Okataina, what's happened there that's caused poor water quality in the past is the fluctuation in lake level. The lake level has fluctuated 4 or 5 metres at times and the poor quality resulted as the lake filled again, because it goes down fairly slowly but it fills rapidly and I presume it was the nutrient that was entrained into the water that was around that 4 metres of shoreline going back into the water, causing the quality to get worse for short periods. It does almost go to anoxia in the bottom waters, there's a small part that does go anoxic. Perhaps someone would like to talk about that. Noel?

*Noel Burn*s: I had a monitoring programme for 4 years on Lake Okataina as part of the New Zealand lake monitoring programme and we did notice that occasionally it was only the bottom 1 or 2 metres that would run low in oxygen and it was because some of the algae had settled down I think and made a coating on the bottom. So I particularly asked the field people to sample that bottom water and analyse it. And while it was low in

oxygen, it never had the regenerated phosphorus in it, because when you have a lake that goes anoxic you've got to actually drop the electrochemical potential down quite low to get the release of the phosphorus. The anoxia was never that severe, because it was getting a small amount of oxygen coming in from the water above. So at the moment I think it's just a natural phenomenon that's probably been happening for most of the past.

David Hamilton: I'm actually going to contradict you a little bit Noel because the most recent data shows quite clearly that Okataina has become slightly more anoxic in the bottom waters and that, to me, is a complete anomaly. I really can't explain it, I've thrown up some ideas and obviously John just mentioned the water levels which I haven't really considered before, but there is a very consistent trend from 1970 through to 80s/90s and the zone of anoxia has basically extended fairly consistently through on a decadal-type sequence. So there's considerably more anoxia in those bottom waters now than that there was in the past. If anybody's got any ideas, then it's a case for the wacky ideas because it's got me baffled.

Mary Stanton: For restoring lake health, would our wetlands help to restore our lakes? I am interested in bio-diversity, I have a great interest in native trees and I say that by looking at our wetlands we have natural plants which could help with nutrients. We have the raupo, we have the wiwi, and if you have a close look at the roots of the raupo they are like a sponge and they take in huge amounts of nutrients. As our grandparents always said, these plants were put there for a purpose, to cleanse the lakes. I have seen the lakes deteriorate, I have seen housing move in and development and population increase, and a lot of people who have moved into the foreshore line, in particular around Okawa Bay and Lake Rotoiti. They don't regard these natural plants as anything other than weeds and they pull them out and I think we've got something in there that is natural, costs nothing and it should be looked at. Also, get rid of willow trees because they're a pest, they're a noxious weed and the twigs break off and move down the waterways. They are actually saturating our swamp lands. So Environment Bay of Plenty, if you want to look at sustainable water quality, I ask the question do you believe that swamp lands should be taken more notice of? .

John McIntosh: That's a good question, and for the lakes that we've prepared action plans for, it has been one of the strategies to construct wetlands to intercept the inflowing waters to the lakes to clean them up. But we also have environmental plans that we have had for a long time looked at restoring wetlands for bio-diversity reasons. The wetland at the mouth of the Ohau Channel, there is work going in there, there are negotiation between our staff and the Iwi to clear the willows out of there, because it is a big valuable wetland. So it is certainly part of our bio-diversity strategy, but it's also part of our strategy for cleaning up the lakes. We're interested if anyone thinks there is an area that would be suitable for regenerating as a wetland; we will certainly be looking for places.

Robin Sinclair, LakesWater Quality Society: I've got wacky question number 1. I'll give a little bit of background to it before I put the question. In 1940 the Lands & Survey Department and also the development system here in Rotorua started developing land on the volcanic plateau. The reason that they did this was they found that there was a problem with cattle sickness and to overcome the cattle sickness they then had to put trace elements into the fertiliser that they put on. So from the time of 1940 and continuing right through until today, the trace elements, in particular cobalt along with others, have actually been added to the total area of the volcanic plateau. Now my question is, and

most probably Ian Hawes might be able to answer this for us, that some of these trace elements are essential for the growth of blue-green algae and would it be that if we looked at the increase in the amount of cobalt and these trace elements from 1940 through until today, which must have gone into our water system, could they be and would they be something that makes the blue-green algae grow and if you could then isolate these out of the system, would it actually restrict the growth of blue-green algae?

Warwick Silvester: Yes, it's very true that cobalt was put on to fight bush sickness. Cobalt is a micro-element which is not required for any plant growth except for legumes which produce haemoglobin. Cobalt is required to produce haemoglobin in animals. The only plants that produce it are legumes. It is not required and lots of experiments have been done to try and show cobalt as an essential element. It only has one essentiality in plants that we know of. The other possibility of course is molybdenum but molybdenum has been put on in only very small traces. There does not seem to be any significant molybdenum deficiency across most of New Zealand and that is one that is required for the nitrogen-fixing enzyme as well as for nitrate reduction. So a good question which as far as I'm concerned has a simple answer. I don't think there's any relationship other than the fact that there was a timing relationship.

Chris Hendy: I want to add a little to Mary's suggestion about the raupo which of course is often used as a plant for cleaning up waters going into wetlands. The problem is that it is often in competition with beach shorelines which are also rather valued. I wonder whether some thought could be given to construction of a combination of wetland containing plants such as raupo with a beach on the lake side of this. That would certainly intercept ground water flowing into the lake which carries a lot of phosphorus with it. I'd like to make one further wacky suggestion. This is another alternative to the sewerage problem and that is to consider putting holding tanks on the outlets of septic tanks and have these holding tanks collected on a regular basis, as opposed to having them connected to a permanent pipe pumping system back to our treatment plant.

Nick Miller: Can I comment further on the raupo matter. Raupo is sometimes proposed for use in artificial wetlands and so on which are being used for water treatment, but it has one problem. In areas like Rotorua with cold winters it's more or less deciduous and it tends to shut down much of its biological activity in the winter. Also it tends to form a monoculture which is not looked on with favour. There are other native aquatic plant species that are more effective.

Martin Hawke, Bay of Plenty Farm & Pastoral Research: Just an observation on Okataina and it really comes from a lot of the evidence we've heard about the age of the water that's coming through into the lakes. This is something that is before my time, but the area run by the Education Trust was farmed. Now I don't know how well it was farmed or how many animals were on it or how much fertiliser went on it, but they say it's a pristine catchment. But there was an area that was farmed that we've all forgotten about. Is that taken into account in terms of what might happen 30 or 40 years further on and if that's the case, something might be happening from that now?

Anaru Rangiheuea, Chairman, Te Arawa Maori Trust Board: I have a strong interest in Okataina and I am Chairman of the Okataina Scenic Board. I manage the reserves right around the lake in conjunction with DOC. We have made a commitment not to establish any more developments around the lake that would create any effect on the quality of the

water. I am very worried about the comment made by David that he doesn't have any answers, because I don't want Okataina to be isolated and just left because no one has an answer. I want answers to be found for all our lakes including Okataina. The only part that I have concerns about is the farming activity on the southern side of the lake which may have some run-off that could get into the lake. But I am doing my best to ensure that that lake remains pristine for all the generations to come and that's the commitment that I am making for that lake, even to the effect of reducing boating activities and I mean speed boating activities, so that you can go and enjoy that lake on holidays at any time that you want to do so.

There was a farm down there where the Education Trust was. It was a small Maori farm with probably about 25 cows and I don't think they would have been in the activity of fertilising that much because some of us didn't and some of us couldn't afford it, but it was an activity carried out by one of our whanau at that time before they moved back into town. They cleared that and also they grew crops out there, a lot of potatoes were out in front of the lodge as you might know. So that's all I want to say about Okataina. I want it to remain clean and I hope that David and other scientists can find answers to that to help me keep it clean as well.

Noel Burns: When I first gave my comment on Lake Okataina it was on the basis of 1992-1996 information and David being the professor he is, spoke about the modern information. I've just checked it in the EBOP data and the oxygen in Okataina has decreased, the chlorophyll has increased a bit and the Secchi depth has diminished a bit. So there is something happening, but as John mentioned the lake level in that lake varies considerably and it's gone up by 2 metres since 1995 to the present. It means you're getting water invading fresh shoreline and it can extract a certain amount of phosphorus from the shoreline which was previously not exposed to the water. So while the lake is getting worse, it might just be part of a natural cycle and it does mean that there needs to be careful monitoring and possibly some careful observation of the lake.

Anaru Rangiheuea: I remember a time when the lake went down and exposed a lot of the bones that had come out from burial grounds under the lake and we had to go down and pick them up and remove them and bury them somewhere else. So it fluctuates, we know it comes up and I know the jetties from time to time are covered in water, but it's something I guess to make us work and think more.

John McIntosh: On Lake Okataina, we're not forgetting about any lakes and you might remember I mentioned yesterday that the method in the Water and Land Plan is that we have to do a risk assessment on all the other 5 lakes and prioritise when we do an action plan for every lake. So there's no question about forgetting any lake.

Rowland Burdon: Concerning the hypothesis that level fluctuations may have something to do with the situation in lake developments in Lake Okataina, what about the case of Lake Rotoma which certainly has fluctuated very considerably in level in recent years and yet I understand there have been no real water quality problems reported in that lake.

John McIntosh: Are you going to put forward the evidence for that Rowland?

Rowland Burdon: Well, what I've seen driving past Lake Rotoma is that there have been times when there has been a considerable breadth of shoreline that at one stage was quite

well-vegetated and it's since been completely covered with water. I certainly don't have hard figures on the level fluctuations in Rotoma, but I think one can be very sure that they have been considerable.

Chair: I think there's no doubt about that, but John may well just provide you with the answer to your observations and if the water quality is deteriorating in Rotoma …

John McIntosh: Rotoma, according to our TLI, is on a declining phase and it would perhaps trigger an action plan according to the method of the plan, but one will be done in any case on that lake. It does fluctuate perhaps as much or almost as much as Okataina and it doesn't appear to have bad results.

Tai Eru, Ngati Pikiao: I'd just like to comment that I notice that there are no tests taken with Rotokakahi, the Green Lake, and Anaru over here is one of the major people in that area. My grandmother once told me "when the frogs don't croak or make a noise, the lake is dead." I'll follow up with my cousin Mary down there with the raupo (*Typha orientalis* Ed.) and paupau (tall lake rush, *Schoenoplectus validus* Ed.). If you drove to Rotokakahi, there's an abundance of it there and frogs are singing every morning. In my little establishment down at Lake Tahapua which is just off Honeymoon Bay, we actually restricted stock from going in for the last 4 years and the raupo and paupau has come back in abundance. But we have this dreaded things that fly around called Canada Geese and the swans, and they tiko everywhere, they drop their faeces, they eat so much grass and I wonder how much of that is a problem to our lakes?

John McIntosh: With Lake Rotokakahe we did sample in the early days, perhaps in the 1980s, with permission and then when we came in in the 90s as a Regional Council to sample, the owners asked that we didn't go on the lake. So what we've been doing is sampling the outlet to the lake as a surrogate, because that's the surface water of the lake, we do that. I talked to Anaru during one of our meetings and he said to put a request in to him and he would consider it, so Anaru did offer and perhaps we could follow that up Anaru?

Anaru Rangiheuea: I took the moment specifically to look at the ground cover around the side of Rotokakahi and make recommendations when the trees come down that they weren't to be replanted any closer than 200 metres from the shore. That's what they came on to look at, not to test the water or anything else. But before that I've gone out several times with Dr Peter Mylchreest for other reasons I guess, for the development of fish species, but I am happy to entertain the idea of people if they want to come on it. It will be a help to us, it will be a help to the Rotokakahi Scenic Board to have the information that's coming through now, especially at this time when everybody is concerned. Rotokakahi is one that could be under stress. We've got farms around it, we've got all sorts of trees, but that's what I went out for, about 3 or 4 months ago, I took the boat out just to do that. And it's important, I guess, to look at how close the trees, especially *Pinus radiata* and all the others, to our lakes now, so that when they come back with their recommendations, they don't plant close to the lake anymore.

Brian Bell, Nimmo Bell Ltd.: I would just like to return to the question that John Green put earlier in the afternoon about optimum fertiliser applications. Part of the policy of capping N coming out of farms will be in auditing of the amount of nitrogen coming from farms and that will require nutrient budgeting. By the very fact of nutrient budgeting and

targeting nutrients, I am sure there will be a reduction in nutrient use. Doug Edmeades, who is a freelance soil scientist, did some research where he monitored about 5 dairy farms, I think. On every one they were applying more than the optimum amount of fertiliser, so I think that will have an impact. That capping is something that is in the policy and I understand will be reviewed in 5 years. I still don't think we know very much about the science of this at all. Maybe what we're seeing now is a spike of nutrients coming into the lakes that had happened right at the beginning when this land was first brought into farming. That's one view of this and it may go down in a few years, again it may keep going up. So the important thing I think is to be flexible in terms of the policy so that we don't shut off options when we don't know what the science really is.

Nick Miller: This question is for Justin Brookes and then for anyone else who cares to comment. When Justin was talking yesterday about aeration in Lake Myponga I was impressed at how far the effects of that spread out from the aerator, 700 metres if I remember rightly. Now, there's a proposal afoot at the moment to oxygenate the hypolimnion of Lake Rotoiti which will be quite an expensive exercise, I imagine. I'd be interested in comments from people as to the possible relative effectiveness of aeration, in other words destratifying the lake by bubbling air through it, or oxygenating the hypolimnion. Perhaps in particular the cost benefit analysis and so on.

Mike van den Heuvel, Forest Research: I can't say that I know the relative costs of the oxygenation, but it doesn't matter whether you do oxygenation or whether you do capping or any of the other approaches. Unless you reduce that external nutrient loading your effects are going to be very short-lived. So you can reduce the internal nutrient loading, but if you continue externally putting nutrients in you're going to create the same situation again, so there's no easy quick fix.

John La Roche: Aeration of water supply lakes is quite common. In Auckland all the water supply lakes for the regional water supply are aerated when required. There's regular chemical testing on the lakes and when it is found that there is a thermocline in the lakes, then aeration is put into operation. So it's not a new process and there's certainly a lot of experience in the country with that.

Max Gibbs, NIWA: The situation in Rotoiti is quite interesting because instead of having an air gun in the bottom of the lake, we have in fact got a hot water jet. This is the geothermal crater in the bottom of the lake. The evidence is that it's producing vertical mixing, stirring the hypolimnion and keeping it mixed. It's associated with the bubble field, the bubbles go through the thermocline but they don't break it up. The geothermal heat associated with that rising plume is insufficient to break down the thermocline as it comes up. The amount of energy involved in getting an aeration system which could disrupt the strength of the thermocline in Rotoiti is going to be rather colossal, and somebody worked out that it would take a small nuclear reactor to provide the power to actually drive the breakdown of that thermocline. So there is a cost efficiency, a benefit to doing these things and I don't think it's going to be very cost-effective to do this one.

Mike van den Heuvel: With oxygenation it's not required to break the thermocline, it's performed very successfully in Canada with oxygen injection directly into the hypolimnion, without breaking the stratification at all. They managed 50% reduction in internal total phosphorus loading and the lake went from eutrophic to mesotrophic, but it

was a lake with very high internal loading rates and very low external loading rates so it was quite successful.

John McIntosh: Just on the oxygenation, we have actually costed out to oxygenate Lake Rotoiti. We've had some engineering consultants looking at different means of oxygenating it, so we do have a document. Perhaps seeing as there is a lot of interest it could be released, although generally we don't release reports until they've been through the Council, so if you do want that report we could let you have a look.

David Hamilton: I guess what we did was to calculate the amount of oxygen that would be required in order to provide the consultants with the feasibility of what they were able to do. And the estimates were that about 45 to 50 tonnes per day would be required to oxygenate Lake Rotoiti, hopefully going down quite quickly to maybe 20/25 tonnes per day after a little while, that's during the stratified season. So in very approximate terms I think that was about two tankers per day coming from Auckland to provide oxygen for Lake Rotoiti.

Meriana Thompson, Rotorua resident: As a matter of interest can I just have a show of hands of how many people actually live around Rotorua. I'm very impressed with the amount of research that's been presented over the last couple of days. I'm also aware that maybe there's more being done around Lake Rotorua that we haven't been made aware of and that's my prime concern. Because clearly a lot of the problems at Rotoiti are being caused by Lake Rotorua, so I have a question regarding the research being done about Lake Rotorua. Is any of the research factoring in what used to happen prior to the town's water supply being drawn from the 4 or 5 natural springs around the lake? What is the volume of water that used to flow from those springs into the lake in what we as Tangata Whenua believe was a flushing system that circulated the water, destratified the waters of the lakes and help to push that water into the Ohau Channel and on into the Kaituna River. Is there research being done along those lines?

David Hamilton: Offhand I don't know how much is actually taken out for water supply, but that's certainly quite readily testable in terms of the modelling which is simply to run a scenario in which we put back all the water and take out the water and compare the two of them.

Sally Brock: David Hamilton, with regard to oxygenation of Lake Rotoiti to prevent it deoxygenating in the bottom waters, has the modelling been completed on the benefits of that once, and if the diversion goes ahead? By benefits I mean the prevention of the release of nutrients from the bottom layer, because that occurs only when you get deoxygenation of the bottom of the lake, you get release of the nutrients. By stopping the phosphorus coming through the Ohau Channel with the diversion and then if you oxygenate the lake, is there any science that is available now to tell us what the benefits to Lake Rotoiti in the short-term would be?

David Hamilton: In very approximately terms there's about 20 tonnes of phosphorus that is released from the bottom sediments during the period of stratification. Some phosphorus release occurs naturally, it doesn't matter whether it's anoxic or not, but it would appear that a lot of that phosphorus is indeed released from anoxic regeneration. I think that John might be able to comment better on what is coming through the Ohau Channel, but it's about 20 tonnes in very approximate figures through the Ohau Channel,

perhaps 25. I guess if you oxygenated, if you had the money to oxygenate and divert, you'd have a very high probability of success because you're hitting those two major nutrient sources in one go.

Robin Sinclair: On Lake Rotoiti this time, I'd like to comment on Susie Wood's presentation yesterday. The outcome of this, as we saw in this morning's paper, is an extremely would-be negative situation as far as Rotorua and the Rotorua lakes are concerned, in as much as it has portrayed a picture of poisoned fish or fish that are likely to be subject to poisoning a human being. I note that the fish that were actually analysed in this particular test came from a controlled area, an area which I understand and have seen to be very, very high in the blue-green algae. I have also questioned Susie about a control as far as the tests were concerned and the control that they used were fish from the Ngongataha hatchery which in fact has absolutely pristine water and of course the result of the test on the control was totally negative as far as the toxins were concerned.

My concern is, and it may be able to be passed on to the faculty and Massey University, is that fish should actually be taken from a broader spectrum of Lake Rotoiti and maybe Lake Rotorua and a comparison made of the toxin contents of these, so that we would get a better picture of what is actually the norm for the Rotorua lakes, especially Lake Rotoiti, rather than dealing with a specific test control. Rotorua needs some good news, they don't need too much of the bad news, so therefore if there is a significant difference between that controlled area and the fish that we would expect to catch in Lake Rotoiti, then I think it ought to be made public.

Chair: Is Susie here? No, well perhaps the funders can take on board that request and put it in for further funding which she may seek to achieve.

Vance Fulton: When there is an algal bloom, do the fish migrate away from that bloom area, so are they still going to be exposed to the concentrations of the cyanobacteria? Maybe Rob might be able to answer that.

Rob Pitkethley, Eastern Region Fish & Game: With regard to the experiment that was done in Rotoiti, what wasn't stated yesterday was that the fish that were held in the enclosure were actually based upon an absolute worst case scenario. They were confined behind a net in a bay where any decent living trout shouldn't probably stay, so that was a point that didn't come through yesterday. There were some fish taken from the main body of the lake itself that did have elevated levels of microcystins in them. And again what wasn't expressed quite as well yesterday was that those guidelines are set on the assumption that someone would eat trout every day for the rest of their life, and I don't know too many people who actually do that. So there were those points that we'd like to bring in. In answer to Vance there, trout generally wouldn't like a still warm area of the lake that has an incredibly high algal bloom, so the uptake of toxins in that sort of area are perhaps a little over-inflated compared to what might be happening in a realistic and wild situation.

Anaru Rangiheuea: I'm quite concerned about the press release that's come out, it's quite negative and I'm worried about the impact that is going to have on us. We need to have some response to that because knowing our news media they've picked up on anything in the last 8 months and continue to. It could affect the tourist industry in some manner if this got across to other places. I think that someone from here needs to make a response

to that or even to report how we are moving forward and not backward like that has stated.

Chair: Is the press reporter here?!

Steve Smith, Eastern region Fish and Game: *(tape change)* … but we don't want to scare people from enjoying the opportunities that remain and from our point of view I think the key thing is we need to inform the public what to expect if they want to fish Rotoiti. Come in the spring or come in the winter, don't come in February or March. We were heartened by the Medical Officer of Health who was very clear in stating they didn't believe there were any pubic health concerns through eating fish. So until they change that point of view, and it's their responsibility, we'll certainly not be telling people to stay away from the Rotorua lakes and I think everyone should be doing the same.

Ron Marsden, LakesWater Quality Society: I've been hearing today about the amount of energy, equals cost, that's required to do anything to artificially stimulate the lakes. I wonder why we don't look at the natural forces, the energy that perhaps to take the Ohau Channel as the example, that is seething through there at the moment. Why can't we harness that energy to aerate or oxygenate Lake Rotoiti, to turn some form of mechanical device which will introduce oxygen into the water and then distribute it. My question is, is it feasible at the Ohau Channel outlet to strip the P and N and then use the natural force of the weight of the water that goes through there to help put oxygen back into the water?

Max Gibbs: There are one or two fundamentals about generating electricity for energy-producing mechanistic devices from flowing water. One is that you have to have a head. The head between Rotorua and Rotoiti is not particularly large, the build-up in back pressure there might actually be detrimental to Mourea if that was implemented. We would have to effectively raise the level of Rotorua or else drop the entire level of Rotoiti to achieve the head that you need. Modelling might be quite useful on that. The possibility of stripping nutrients out of the Channel was the other part of your question. We've had a number of people talk about Phoslock or the equivalent zeolite - aluminium treated zeolite. People have come to me with ideas of using gabion bags, there were iron pellets. SteelServe in Auckland have a product which apparently works for removing phosphorus. It's possible you could do that, it would block the channel because you would no longer have a navigable system going through it. What it wouldn't do is remove the nitrogen and if we come back to a question that was raised very early on by our member over the far side, about would it be useful to remove phosphorus now? I think it would be useful to remove nutrients now. The whole point of the exercise here is to restore the lakes.

I'm going to throw a wacky idea at you. Rotorua is the cause of the problem in Rotoiti. The water from Rotorua has for hundreds of years gone into Rotoiti, then during the seasonal cycle goes down the Kaituna River to the sea. This cycle has changed because the nutrient loading in Rotorua has gone up, therefore the nutrient loading in Rotoiti has gone up, so one follows the other. We can see that in the TLI index that Environment Bay of Plenty have been telling you about. If you're going to clean up Rotorua you have to get rid of something like 250 tonnes of nitrogen a year to start to improve it and you've got to get rid of about 30 tonnes of phosphorus out of Rotorua. It's got to go somewhere and next door is Rotoiti, so it's got to go into Rotoiti under the present system. To

manage Rotorua to get that clean, are we going to sacrifice Rotoiti or are we going to do a package deal which looks at both lakes?

Perhaps the answer is there that what we're dealing with at the moment is developing a model which will look at what comes out of Rotorua, how it reacts with Rotoiti and how we can manage that flow to reduce the loading on both lakes. Part of it is that there is a hydraulic residence time in these things. We've mentioned springs and the possibility of the flushing rate in Lake Rotorua being affected by the extraction of water. The extraction of water from the springs is a very minute amount of the actual water budget on the lake. A lot of it actually goes back into the catchment and is recirculated and comes down back into the lake, so we don't lose water from the system. The flushing of the nutrients that get into Rotoiti from Rotorua are affected by the differential of the water from Rotorua flowing under the lake and pushing out Rotoiti water.

So you've got a possibility there if we deflect the Ohau Channel down to the Kaituna, of changing the residence time of water that's lifting Rotoiti and that has to be modelled to make sure that we are not creating a worse mess by taking a short-term measure for deflecting the nutrients out. A far cry from the original question can we generate energy to oxygenate the lake, but the oxygenation has been considered, it's been modelled, the energy one I think perhaps that should also be included in the model. I think people have actually thought about it and looked at it.

John Green: I'm not an expert on this but if you haven't got a head at the Ohau Channel, you've got a head at the Kaituna end.

Nick Miller: I understand plans are being dusted off on that one. That's called the Okere Falls Power Scheme.

Mary Stanton: I was born on the Ohau Channel and I just about slept on it, because my bedroom was from here to where John is. So during my journey of life I have seen many things happen on the Ohau Channel. It was a swamp land when I was a baby and then they decided to straighten the Ohau Channel because the belief was that by straightening it, it was going to increase the flow. So everything went ahead and my Dad said very good, I have agreed with this plan because it will take our children out of the swamp land. We were suffering rheumatic fever, but we enjoyed it because you listened to the frogs wake you up in the morning, you had the bird life, you had native plants, everything was just so joyful and natural and the water was crystal clear. It was a paradise to live in. Anyway along came the big machinery and they ploughed through the Ohau Channel and things changed very quickly. There were piles of what was the lining of the Ohau Channel as shingle on the bottom, a terrible mistake. When they took that shingle off the Ohau Channel, in came the mud and after the mud came the weeds. That became the end of that era of was a fishing paradise to our family and our neighbours. The bird life disappeared, then they went and pushed all the shingle and everything else, the mud, you name it, where the tennis courts at Mourea are and it became like a parkland.

As my father put it, it had it's benefits and it had its disadvantages, because no longer were his children living in the swamps. Quite often we had to row the boat to get down to the main road because of the flooding. So it took us away from the swamp lands. He said it would be our generation, the children who would experience the after effects. Today we are experiencing just that. Now when people are talking about the change, there may

be places, there may be times you may have to do it, but my strong opinion is hold on to your shingle and the sand that made the swamp lands, that created the bottom of your lakes. Once you take that away you will never get it back again. And after that, perhaps your lakes will be polluted.

Chair: Okay it's now 4.15 and I'm going to call this session to a halt. Thank you very much for the questions, the observations and thank you very much to the scientists, professors, learned friends and also members of the community who provided a contribution. There has been commendation during the last two days of people who have participated in this and delivered much in the way of science, but perhaps I as a member of the community and an interested party in the lakes region wish to pass gratitude and ask those that are in attendance from the various universities to pass our gratitude to your supporting colleagues, many of whom you recognised during your discussions and speeches by name, but for us their contribution was obviously just as great as your own in your attendance. So please take that back when you return to work on Monday. The last speaker today is Professor Warwick Silvester. Warwick is a former head of department at the Department of Biological Sciences at the University of Waikato. He currently works on a part-time basis. He's familiar with some of our committee members from his days at University of Auckland. He has a wide range of research interests, but is perhaps particularly happy when studying biological denitrification. Professor Silvester, it’s over to you to provide a personal view on this symposium. Thank you.

SUMMARY BY PROFESSOR WARWICK SILVESTER

I'm glad it was put on the programme as a personal view because that's what it's got to be. Attempting to objectively summarise what's been going on the last two days is pretty well impossible. I want to start off in the way I started off the last time I did this, by giving a few little quotations that came through that in some way encapsulate many of the scientific approaches that have had to be made. Things like "Histeresis is a fact of life," there's some great truth in that. "Blooms will continue." "Patience is a necessity." Thank you for that one Ian and again Ian, "Climate is a wild card, how wild it is too." And a couple of my own: "The average never occurs" and that's an interesting one for biologists. And then "Biology is chaotic and also idiosyncratic." So some of those things underline where we've been in the last two days.

I want to remind you what we set out to look at, our nutrient targets and cyanobacteria. We've strayed a fair way outside of that, I'll try and keep within it if I can, but I think I'll also stray. I've made 7 major points, so I've got about 1 ½ minutes for each. First of all, the history of this meeting, this is the fourth meeting, this is the fourth time I have stood up here and attempted to summarise. I've found it a very interesting evolution over those 3 years and I'll allude to that as we go along. One of the most important aspects that has been an undercurrent was the change from that first meeting when there was significant political tension between the various authorities and some of their staff. One could feel this palpable jockeying for position in tension that had been created by this big problem that came in between people. I have noticed that as we have gone through the last 3 years and in this now our fourth symposium, that has virtually been cast aside because we've all come to agree there is a problem, we're not going to solve that problem by hitting each other, we're going to solve it by getting together. I believe there's been a very distinct change in attitude regarding that. It may also be significant that it's about time for the elections as well and that's a good thing too.

Some of this relationship-building, of course, has evolved some very important players in it and I want to make mention of the Lakes Water Quality Society and Environment BOP, because they have been two of the major players in setting up this forum and continuing the research forward. I want to give justice to both of those groups for the way in which, despite the tensions that have been and perhaps still are between them, because they're looking at things from a slightly different point of view, the way in which they've worked together and co-operated to produce forums such as this and to move forward rather than fight standing in the one place. And I want particularly to mention people like Ian McLean and his team and Paul Dell and his team in both of those arenas.

Now moving forward and discussing some of these things here, cyanobacteria, we've heard a lot about them in the meeting and I have to thank the Australians for coming over and telling us about cyanobacteria. There have been some very useful insights that you've given us and we appreciate that. I was particularly interested in the *Lyngbya* situation because

a) that's added a new name to our group of cyanobacteria that we've heard about and
b) the iron situation.

The cyanobacteria, we were told, have 3½ billion years of evolution and what an amazing group of organisms have evolved over that period of time, adapted to virtually every environment on this planet. They are without doubt the most widely distributed of any group of organisms and their adaptation to the environment has helped them colonise the aquatic environment so extraordinarily well. They have these attributes of floatation,

affinity for nutrients, production of toxins, nitrogen fixation, carbon fixation, all encapsulated in the cell which is only about 15 thousanths of a millimetre across. One of those cells can do all of those things and there are no other cells on the planet that can do that, none.

Cyanobacteria are so well adapted to the environment and if we think we can fight them, think again! Eventually they will win, but in the meantime we're going to win and we've learnt a lot about the possibilities of, at least in the short-term, keeping up with that battle.

Water age, a fascinating paper on water age which puts us in the picture as to the battle that we're looking at. The fact that the Hamurana water has a mean residence time of 145 years and currently only 18% of the water coming out of those springs is in fact recent water, is a very significant finding. Also, the fact that there are 5 cubic kilometres of water in the Hamurana Spring catchment waiting to come out. I did a quick calculation while I was sitting down there. If that water has in it the current concentration of the pristine water, it's got 150 tonnes of nitrogen waiting for us, which in fact is 30 truckloads of urea, and that's pristine water. But if that water becomes enriched to the extent that the recent ground water is enriched, it actually has got 15,000 tonnes of nitrogen which is 1000 truckloads of urea waiting to come out and hit us.

So we're up against a big problem. If you start quantifying that there are enormous problems and I was faced with that when David gave me the quick calculation of how much nitrogen is contained in the water underneath the Canterbury Plains. You do that sum, it's actually unbelievably staggering and it's all waiting to come out, albeit perhaps rather slowly but it's building all the time. Of course the phosphorus that's coming out is not going to increase with time because that seems to be part of the background, but the nitrogen is going to go on, so perhaps the nitrogen/phosphorus ratio is going to take care of itself in not too long. Now the vexed question of bioassays and N:P ratio that we keep on coming back to. To me the overlying conclusion that we come to all the time is first of all, as Ian so nicely put, that N:P ratios of themselves do not have any biological meaning of themselves. It is the concentration of nutrient elements which is important.

So I'd just like to say that from a personal point of view I'd like to get away from always considering N:P ratios. They of themselves have no biological significance. The concentrations of those two elements do and that's what we should be looking at. And of course the conclusion we have from the bioassays, both the older ones and the more recent ones that David Burger mentioned, is that we're actually sitting in the middle of a nitrogen/phosphorus limitation. Sometimes it's one and sometimes it's the other and unlike the northern hemisphere where all this literature has come from, we're not concerned with an acute phosphorus deficiency or a response to phosphorus, we've got both here in reasonable quantities roughly equating to the 10 ratio. I like the point that Nick made that phosphorus is absorbed so rapidly by cells that sometimes we never see it and sometimes the concentration of phosphorus in water is the result of what's happened, not a measure of what might happen in the future. A lot of that phosphorus has entered cells and we've heard that many cyanobacterial cells can live for 20 or 30 days on their stored phosphorus, which is quite a number of generations of cell growth.

Now we come to what for me is the high point of this conference and I put this in a historical context. We have moved in the last few years from being jigsaw modellers to being three-dimensional, physiological modellers and I think the papers that were

presented first of all by Eloise and then by David, illustrate the way in which we are now able to get this enormous amount of information in a three-dimensional, that's time and space, context and put it together in realistic physiological and dynamic models. This really has blown me away and I think many of you as well. The ability to gather enormous quantities of data and compute that and then present it in the models that we have seen, I think are leading us to an enormous and better understanding of the situation. Just compare what we did 30 years ago when I did a little limnology where you'd go out with a thermometer and drop it down, you might get 10 measurements and then move to another place and get 10. Now you can get 10,000 in a day and put them together in a dynamic model. It's like comparing a jigsaw with a very complex engine, there's an infinite difference.

So we are now developing this dynamic understanding of the way in which these lakes move. And I would just like to emphasise yet again, and this perhaps is a prejudice of mine, that the principles that underline this have not changed and our understanding of those principles has hardly changed. What we've been able to do is to put them together to express what each lake is doing, because each lake is different but the principles on which they operate remain the same. I was intrigued about the DCM the Deep Chlorophyll Maximum, because I first heard of the Deep Chlorophyll Maximum, I think it was on Lake Tahoe where the first finding of this deep chlorophyll layer was. They dropped probes down and they found chlorophyll down there, tiny wee organisms. In those days they were called LRGT's Little Round Green Things, because no one knew what they were. They discovered them in the 1960s and suddenly this deep chlorophyll layer became the centre of a lot of interest.

Then I just want to refer to low tech/hi tech, a fascinating group of papers on how we can actually do some hands on management of nutrients. I want to talk about John La Roche's paper and his wonderful enthusiasm for that. Unfortunately we didn't get to the numbers, so I asked him for the numbers and he gave them to me and sure enough, that system of his is rapidly getting towards the planned output and reducing the nitrogen content very significantly. Of course we had the other technology approach which is locking phosphorus up using either Phoslock or zeolite, so we have on the horizon some technological possibilities for actually manipulating nutrients. The economics of them, of course, at the moment, doesn't look particularly bright, however for tactical management particularly perhaps of small water bodies, there is some possibility there.

And then finally some of the management and economic situations. As we were looking at some of the possibilities I just put together a little scenario which helped me understand the sorts of ways of managing the lake and this is my approach to Powerpoint today. There are three places which we can actually start to manage this whole system and thinking about those and thinking about the emphases that we've been given, I think it's important for us to realise that if we start manipulating catchment use, we're talking about a 10 to 100 year time-frame in which that manipulation is going to have significant downstream effects. If we start manipulating the outputs into the lakes, then we're talking about a 1 to 20 year range of time over which that will have some effect. If we look at in-lake manipulations we're talking from a 0 to 10 year, perhaps an immediate effect by capping or by oxygenation up to a 10-year effect. So in considering the way in which we might start managing the lake systems, we need to bear this in mind and think about what that means in terms of the whole management scenario.

Finally I'm going to finish because the sun is shining, the kowhai is flowering, the pine is producing pollen and all things are happening out there and it's shortly time to go home. I just want to finish with something perhaps a bit more light-hearted and that's to talk about modelling, because there's an interesting model I'd like someone to actually work on here. This is the model of this meeting or the model of what some people have to be doing regarding this. This is a model of the way in which different agencies (and I've left the number off of course) and their interactions that have to be coped with. I've put EBOP in the centre, sorry about that EBOP but it does seem that you're in the big gun and we've got LakesWater Quality Society here and various interactions, Royal Society, District Council, Central Government, Ministry of Energy, Federated Farmers, CRIs, University and Tourism Rotorua. I think it would be wonderful if someone could model all these interactions and give us a social science interaction model for the way in which that works.

But let me just finish off by saying that I want to give a tribute to Paul Dell, he's in Wellington doing a lot of this stuff today actually. He's the one that has to handle all these interactions and I think the way in which things are moving ahead is a tribute to the way in which he is handling many of these things and I believe we are making excellent progress. Also I want to give a tribute again to LakesWater Quality Society, to Ian, Nick, Elizabeth, Brentleigh and that crew for this conference, which again has been enormously successful in really opening up some of these issues and allowing you to question them. Thank you very much.

Chair: Thank you very much Professor Silvester for that enlightening address and it may well stay on the whiteboard for some time. I welcome Ian McLean, Chairman of the LakesWater Quality Society, back to the lectern, to bring the symposium to a conclusion.

Ian McLean, Chairman, LWQS: Thank you, Campbell, for chairing that session so competently. I should say toWarwick that Brentleigh Bond tried to use Microsoft Chart or some such programme to map all these things and his machine blew up, it just couldn't handle it, it couldn't handle the complexity. I'll be very brief. Again thank you to all for participating. Special thanks to our two Aussies for coming over, Simon and Justin, we appreciate it very much. Thanks to everybody who has made this Symposium successful and thank you for something else, thank you all for loving the lakes and being willing to spend some of your time looking after them. On behalf of the lakes, thank you.

POSTER PRESENTIONS (listed in alphabetical order of presenters)

Editors' note. Many of these were supplied in Acrobat (pdf) format, and some graphics did not convert satisfactorily to Word format. In such cases the graphics have been omitted.

The role of fish and invertebrates in distributing trace elements in Lake Tarawera

Robert Bagnall & Chris Hendy
University of Waikato

INTRODUCTION

The fauna native to Lake Tarawera is a potential mechanism for super-concentration and transfer of elements, both spatially and from one medium to another. The mobility of the studied species allows for redistribution of elements to other areas of the lake bed, as well as the recycling of nutrients though the food chain and removal though death and decay. This can occur in forms where the environment is unable to re-release the elements, such as deep sediments, or in shells and carapaces. The most significant exchange of elements is probably that of removal of large amounts bound up in game fish such as trout, which feed on the studied species. This report on elemental concentrations present in limnological fauna has been created as part of the greater effort to understand the fluxes of elements within the Tarawera basin.

The species studied consisted of the major native fauna which were accessible, and present in the greatest concentrations per biomass. The common smelt (*Retropinna retropinna*), transferred to the lake as a source of trout food feeds on small insects and crustaceans, and is very motile in its habitat, roving in large schools in open water throughout the lake (see Fig. 1). The common bully (*Gobiomorphus cotidianus*) was another species transferred from ocean-accessible habitats to the land-locked lake. Also a source of trout food, this species grazes on all manner of insects, crustaceans, fish and insects. The common bully is found throughout a wide range of habitats, though it is uncertain as to the extent of its migration (see Fig. 1).

The freshwater mussel (*Hyridella menziesi*) spends its adult life slowly moving through the sediments as a detritus feeder, making it ideal as a gauge for an average composition of the elements present in the organic sediment.

The mussel is also found to inhabit most of the lake. The freshwater crayfish, or koura (*Paranephrops planifrons*) is the largest benthic organism, and lives for perhaps the longest of all the fauna present in the lake. Koura feed on all manner of detritus, and rove across the whole lake basin.

METHODS

The twenty one samples collected in April 2004 were from six sites across the lake (see Fig. 2). They were gathered with the use of a seine net for the pelagic species (see Fig. 3), whilst the benthic organisms were gathered by hand. Species were separated and frozen for future analysis at the laboratory. There the benthic organisms were separated into

flesh and shell, and all were freeze-dried using liquid nitrogen. After weighing the samples were digested in *aqua regia* and filtered for later analysis of elements. AES, ICP-OES and colorimetry were used to determine the concentration of elements within each sample.

DISCUSSION

Smelt, Bullies and Koura generally show similar concentrations of particular elements, with high levels of sodium, potassium, phosphorus, sulphur and calcium (see Fig. 4, Fig. 5, Fig. 7). The Mussels bore particularly high levels of sodium, manganese, phosphorus, sulphur and calcium (see Fig. 6). Their concentrations of arsenic, cadmium and iron were higher than those of other species, especially in the mussel flesh.

A site of note is Hot Water Beach (HWB), which is characterized by geothermal activity, with geothermal spring waters running into and extruding below the lake surface at multiple points over the area. Within this area, those species more localized in distribution were found to have very high concentrations of certain trace elements (see Fig. 4-7).

In particular, the bully and koura carapace (shell) concentrations of arsenic, cadmium, iron, magnesium, manganese, phosphorus, sulphur and zinc were all much higher than at other sites and from those other species' concentrations on site.

Overall, the elements most strongly concentrated were calcium, magnesium, phosphorus, potassium and sulphur in all samples. All elements have been super-concentrated in the flesh and shell of the Lake Tarawera fauna, and will continue to be biomagnified to the top consumer. This poses a problem if toxic elements such as arsenic are consumed via trout or koura (the two common food sources) in quantities that would result in poisoning to humans.

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Restoration, enhancement, and construction of freshwater wetlands

Sarah Beadel, Willie Shaw, Andy Garrick

www.wildlands.co.nz
Wildland Consultants Ltd

ABSTRACT

Freshwater wetlands are multi-functional and multi-purpose ecosystems – including habitats for indigenous plants and fauna, sediment removal, nutrient capture, and many human uses. Wetlands have been heavily reduced and are now nationally and regionally threatened ecosystems and habitats. Healthy wetlands should be an integral component of sustainable land management. Restoration and construction of new wetlands is not a new phenomenon, but is becoming increasingly important and is being done on larger scales.

Wildlands have undertaken many wetland projects, on large and small scales, including ecological surveys, restoration planning, physical works, planting, weed and pest control (including predators), monitoring, and project management. Soundly-based wetland restoration requires careful integrated planning, utilising a range of technical disciplines. Practical experience over many years has led to the development of cost-effective methods and implementation.

Trace element distribution in Lake Tarawera sediment

Michelle Carmine & Chris Hendy
University of Waikato

1. Aim

a) To characterise the distribution of trace elements present in Lake Tarawera sediment
b) To understand the reasons behind the sediment distribution

2. Introduction

Lake Tarawera formed 5000 years ago from lava flows originating from Mount Tarawera and Haroharo. The maximum depth of the lake is 87.5 m with a surface area of 41.6 km^2. The lake is considered to be a good quality oligotrophic lake. Five other lakes drain into Lake Tarawera, along with geothermal inputs. Recent research has shown that the lake water quality has been declining. The nitrogen and phosphorus levels are increasing, which is very concerning for the future of Lake Tarawera.

3. Method

Four cores of sediment were collected off the Environment Bay of Plenty boat using a piston corer at water depths of:
80m (core 3)
60m (core 4)
45m (core 6)
20m (core 5)

The cores were then split and described with small samples taken from along each core..
After drying the samples were digested using Aqua-regia, filtered, then analysed using:
1CP-OES for As, Ca, Mg, Mn, Cd, Fe, P, S, Zn
AAS for K& Na

4. Results

The clastic sediment in Lake Tarawera is considerably more uniform than in other Rotorua lakes, thanks to the overwhelming impact of the Tarawera Eruption. The initial phase of the eruption has not been captured in the 1 m piston cores, but at the base of the cores, the high iron and magnesium content reflects a basaltic character of the eruption. The bulk of the sediment consists of Rotomahana mud, with higher arsenic and sulphur content. This sediment is made up of layers of alternating mud and sand, possibly being reworked in the lake during the eruption, as well as rapid erosion following the eruption.

5. Discussion

The chemical composition of the sediments is quite different to the chemical composition of the lake. A layer of seston, which acts as a buffer layer, separates the water column from the sediments. The buffering effect of the seston means that the underlying sediment has little influence on the water quality.

6. Conclusion

a) The sediment from the cores sampled are made up entirely of material from the Mount Tarawera eruption in 1886
b) The trace element distributions found indicate that the sediment is basaltic in nature
c) High sulphur and arsenic levels at shallow depth within the core indicate these sediments are derived from the Rotomahana Mud
d) The sediments are not having an effect on the water quality of Lake Tarawera

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Concentrations and distribution of major and minor trace elements in Lake Tarawera

Shane Carter & Chris Hendy
University of Waikato

Introduction
As part of an element accounting project of Lake Tarawera the various inputs and outputs (streams, ground waters, geothermal), the lake bed (seston) and suspended matter including biota were analysed. The lake water concentrations can then be used as a measure of concentration of these inputs. At the interface of the lake waters and the seston we would expect to see results of elemental exchange equilibrium.

The analyses of the water column may also show any stratification events and plots of any input plumes, such as geothermal inputs from ‘Hot Water Beach’. From previous studies of other Rotorua lakes it has been shown that some elements have a greater tendency for mobility in solution, whilst others are more mobile in suspension. Therefore the results of this investigation can be utilised to determine trends in other areas and as a basis for the total lake budget.

Method
Water column samples were taken along a line running from Hot Water Beach, north through the main lake. At each site a tube was run from the surface to the lake bed, allowing sampling down the water column. All the samples were filtered to 0.2 μm to remove suspended matter for independent analysis.

AAS (atomic absorbtion spectroscopy), ICP-OES (inductively coupled plasma optical emission spectroscopy) and UV/Vis spectrophotometry methods were used to analyse the prepared water column samples.

The depths at each of the sites varied but in many cases the concentrations of the elements followed trends. This allowed for combined site averaging as a percentage of depth to be used.

Results
- There is some stripping of phosphate from the surface by biota and also indications of mineralization in the bottom waters.
- Site 1 and 2 show increases in the bottom waters from geothermal inputs. This can be seen as a plume flowing out from the southern arm through these sites, becoming diluted in the main lake.
- Fe, Mn, P, Zn show no real increase with depth. Mn, Fe, Zn all show some redox effects in the bottom waters. Phosphorus (P) shows an increase in concentration at the surface i.e. from the presence of biota.
- Arsenic (As) shows an increase, peaking at 50 metres, indicative of geothermal inputs.
- Both potassium (K) and sodium (Na) are conservative in behaviour and show little concentration changes until the bottom waters and the lake bed.

- S, Ca, Mg are also conservative in their behaviour. There is little change in concentration until the bottom where there is a slight increase as part of the exchange equilibrium with the lake bed.

Discussion

- P, Mn and Fe have much lower concentrations than the inflow waters (1%, 0.1% and 1% respectively) and are being actively removed.
- Na, K, Ca, Mg and S have lake water concentrations that are averages of the inflows. For example, sodium, which is 10 times the concentration of non-geothermal streams but 1/10 that of geothermal streams.
- It is interesting that the large quantities of phosphorus seen entering the lake water have not resulted in either algal blooms or a build up in lake water concentration.

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The significance of ground water to nutrient/trace element influx into Lake Tarawera

David Cornes & Chris Hendy
University of Waikato

INTRODUCTION

The aim of this research is to determine the contribution of nutrients through groundwater to the budget at Lake Tarawera. The different land uses around the lake are characteristic of the different trace elements entering the lake. As surrounding landscapes are composed of porous ignimbrite, a large proportion of drainage occurs through groundwater flow. Eutrophication is a natural process of lakes but it is accelerated by human activities.

METHODS

- To sample the representative groundwaters surrounding Lake Tarawera catchment:
  - Insert groundwater piezometers.
  - Abstract groundwater sample.

- Collect sample(s) in flask and measure pH in field.

Laboratory Analysis

- Centrifuge samples and filter through Millipore filters.
- Add 1 mL HCL to preserve.

Analysis

- Elements - Na. K, were analysed on the Auto-Analyser.
- Elements – Fe, Mg, Ca, Mn, P, S, As, Cd were analysed by ICP-OES.
- Nitrogen and phosphorus are not reduced to pure elements therefore analysed as $P0_4$, NO_3 and NH_4. These were done by colorimetry.

RESULTS

- Ground water samples collected around the lake indicate two types -geothermal and non-geothermal. Geothermal groundwaters - high sodium, sulphur, phosphate, arsenic and manganese.
- Non-geothermal groundwaters – low sodium, sulphur, some high phosphate and nitrate, high manganese (unusual) plus iron in reducing waters.

Is this natural? Could be agricultural, septic tanks or even gardens….

CONCLUSION

High levels of phosphate ~1 mg/L in residential/rural shallow groundwater are alarming and likely to lead to eutrophication of Lake Tarawera. Research into the cause of these high phosphates., and comparisons between unmodified shallow groundwater (i.e. bush areas around the lake) and urban influenced ground water needs to be undertaken.

Why is there so much Manganese?

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Trace element uptake of aquatic macrophytes in Lake Tarawera

Alison Leslie & Chris Hendy
University of Waikato

1. Abstract
Macrophytes play an important role in removing manganese, phosphorus and arsenic from L. Tarawera's water column to the lake sediments.

2. Introduction
A number of trace elements (especially phosphorus, arsenic and manganese) enter the lake at higher concentrations than they leave. Native macrophytes have been largely displaced by exotic species such as *Ceratophyllum demersum* and *Lagarosiphon major* which have been introduced accidentally. Lake Tarawera supports a thriving community of macrophytes in contrast to Lake Rotorua, where they have been displaced by phytoplankton. This poster attempts to quantify the role played by the macrophytes of Lake Tarawera in removing trace elements from solution.

3. Methods
- Samples collected from various points around the lake.
- Samples were bagged, labelled with site and date then placed in a chilly bin to await transport back to the lab.
- In the lab the samples were separated by species, weighed and dried.
- Following this they were digested using aqua regia, diluted to 100 ml and analysed using the ICP.

4. Results
The most common species sampled were *Egeria*, *Lagarosiphon*, *Ceratophyllum* and *Myriophyllum*. Manganese was found to be very high in most samples, with many over 500 mg/kg. The macrophytes are also a reservoir of phosphorus with results of 3000 – 4000 mg/kg being common. This is around two orders of magnitude higher than in suspended matter, and around four orders of magnitude higher than in lake water. Arsenic concentrations were also around four orders of magnitude higher than in lake water.

5. Discussion
Very large concentrations of manganese, arsenic and phosphorus were found compared to the background level indicating that they are very efficient at the removal of these elements from the lake water and sediments. This is an important mechanisms in the cycling of nutrients within the lake as the macrophytes remove nutrients from the sediments and water column, only to return those nutrients to the sediments as seston upon death.

One sample (33) had very high levels of some trace elements with zinc, iron, phosphorus, sulphur and cadmium well above most other samples. However the other elements in this sample were within the normal range. These elements are common in environmental pollution (such as urban runoff) and this sample was taken from a suburban area. Thus, it is considered more likely that the high values returned are due to environmental contamination rather than the mishandling of the sample. The sample may also have suffered from environmental flocculation.

6. Conclusion

Macrophytes play an important role in nutrient cycling in Lake Tarawera, particularly for arsenic, phosphorus and manganese, removing these elements from the water column and returning them to the sediments upon death.

7. Acknowledgments

Many thanks to Tristan Leslie, Chris Hendy, Annie Barker, Jacob Croall, Sarah Milicich, Steve Cameron and the EBOP Harbour Master Team for all their help.

The exchange of elements between sediments and lake waters in Lake Tarawera

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1. Introduction

The overall aim of this project was to quantify the fluxes of trace elements and nutrients in and out of Lake Tarawera. Water samples were collected from inflows, outflows, lake water and ground water and included geothermal springs and areas of the lake that were influenced by seepages of geothermal water.
Cores were extruded from the sediment and seston, biotic samples were collected which included fish, invertebrates and macrophytes (algae and water weed).
A fine floc of organic matter and silt settles to the bottom of the lake as seston. While oxygenated, iron and manganese act as adsorbers, binding phosphate, arsenate and other trace elements. When deprived of oxygen the iron and manganese may be reduced releasing the phosphorus etc.

2. Field and laboratory methods

Seston samples were collected using a gravity corer from the top 45cm of the bottom sediments in the lake bed. Seston was extruded in centimetre segments and pore water samples were obtained by centrifuging
in the laboratory. Cores T. 1 and 12 were taken at a lake depth of 85m and T.7 at 39m.

- Pore water samples were filtered using a 0.45 μm Millipore filter and preserved using l ml HCL.
- Analysis of pore water was for a range of trace elements and nutrients using AAS: Na and K, Colorimetry: NO_3^- and NH_4^+, 1CP-OES: As, Cd, S, Fe, Mn, Mg, P and Zn.
- pH and Eh were measured from the seston *in situ*.

3. Results

Concentrations of ammonia are typically 10 mg/L. Deep water core ammonia rises to the sediment surface and shallow water core ammonia decreases to the sediment surface. Concentrations of nitrate are generally low. Phosphate is high and decreases at the surface. Arsenic shows a similar pattern but at lower concentration.
Iron and manganese are low at the sediment-lake water interface but rise in concentration, peaking at 5 - 15cm below the surface.
There is a slight increase in sodium and potassium concentrations with increasing depth. Magnesium and sulphur show similar patterns with greater concentrations in the shallow water core.

4. Discussion

The solution of iron and manganese oxides, between five and twenty centimetre depth, is releasing phosphate and ammonia which diffuse toward the lake and is reprecipitating within the top few centimetres of the seston column (see seston poster). Manganese is dominant over the iron due to an unspecified parameter. The conservative elements (Mg, Na, K, and S) show peaks in concentrations between 5 & 10cm depth and exhibit a typical diffusion gradient to the sediment-lake water interface and are diffusing back into the lake.

5. Conclusions

As the seston is buried, bacterial degradation reduces iron and manganese to soluble ferrous, and manganous states and results in arsenate, phosphate and ammonia remobilisation. Near the sediment-lake interface. the iron and manganese are reoxidised, and phosphate and arsenate are readsorbed (a little is lost by diffusion to the lake).

These will continue to accumulate in the upper 10cm of the sediment so long as the overlying water remains oxygenated. If the bottom waters ever become anoxic, the accumulated phosphate (and other elements) will be released back into the lake causing serious eutrophication.

6. Acknowledgements

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Geothermal Sources of Ammonia in Lakes Rotorua and Rotoiti; A Stable Isotope Study

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The Tikitere geothermal field releases high quantities of ammonium-derived nitrogen each year which drains through various stream channels into both Lakes Rotorua and Rotoiti. Research done at Hells Gate and the surrounding geothermal area shows that geothermal source waters contain as much as 200mgL^{-1} of ammonia N, with normal geothermal source ammonia being in the range of 50mgL^{-1}. In-stream dilution further reduces this concentration to 2mgL^{-1}.

The N isotope enrichment in source waters ranges from -9.5‰ to +7‰ with no consistent pattern in isotopic signatures. The isotopic signals associated with stream dilution range from -2‰ to +4‰ which is within the isotopic ranges of the source waters. The large isotopic range of the source waters makes it difficult to assign an isotopic value to ammonia derived from this geothermal field and thus determine the extent of ammonia exports from the geothermal field into Lakes Rotorua and Rotoiti.

The Significance of Geothermal Activity to Nutrient/Trace Element Influx into Lake Tarawera

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University of Waikato

1. Introduction

Lake Tarawera is oligotrophic but has experienced blue-green algal blooms. This paper evaluates the significance of geothermal discharges to the quality of the lake water and especially the nutrient budget of the lake.

2. The setting

The geology of the surrounding area influences the chemical and physical processes of Lake Tarawera which lies within the south-western section of the Haroharo Caldera. The Tarawera eruption in 1886 blocked the outflow of the Tarawera River, resulting in a lake level rise of approximately 12 m, as well as modifying the southern shore.

Numerous geothermal springs enter the lake on the southern shore between Rapatu Bay and Wairua Stream, and are associated with the Paeroa fault.

3. Methods

19 samples were collected from various springs and seepage areas located at Te Rata Bay and from Wairua Stream in April 2004. Samples were analysed for pH and Ca, Mg, As, P, Fe, Mn, S and Zn by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Na and K were analysed by Atomic Emission Spectrometry (AES), ammoniun and phosphate by Colorimetry and nitrate by autoanalyser.

4. The Geothermal Contribution

Geothermal springs emerge at the southern end of Lake Tarawera. Sodium analyses indicate that geothermal water contributes 5 – 10% of the flow (~$0.5m^3.sec^{-1}$), thus the trace element loadings are:-
Phosphorus, about 20 tonnes/year
Nitrogen, about 7 tonnes/year
Arsenic, about 12 tonnes/year
Manganese, about 17 tonnes/year

In addition to trace elements, the geothermal springs contribute about 5200 tonnes of sodium and 1100 tonnes of sulphur per year. Although not measured, the geothermal springs are also probably the most significant source of silica to the lake.

Calculated annual flux of Chemical Species into Lake Tarawera from all geothermal sources based on an assumed $0.5m^3.sec^{-1}$ discharge.

SPECIES	TONNES PER YEAR
Ammonium (N)	6
Arsenic	12
Iron	3
Magnesium	165
Manganese	17
Nitrate (N)	1
Phosphorus	19
Potassium	450
Sodium	5,200
Sulphur	1,100
Zinc	0

5. Significance of Geothermal Discharge

The Geothermal springs had high pH and high sodium indicating core geothermal water. To account for the sodium in Lake Tarawera, they must contribute 5% - 10% of the water in the lake. They contain significant concentrations of sulphur, arsenic, ammonia and phosphate, influenced by the underlying geology. The phosphate concentration would have led to eventual eutrophication of L. Tarawera, but is now overshadowed by shallow ground water sources, which are accelerating the decline in water quality.

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Lake Okaro Alum Trial

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Lake Okaro has recurrent blue-green algal blooms and is considered to have the poorest water quality amongst the lakes of the Rotorua region. It is classified as hyper-trophic. With declines in water quality of several Rotorua lakes, Environment Bay of Plenty (EBOP) trialled flocculation with aluminium sulphate at a dose rate of $5 g/m^3$ ($0.45 g/m^3$ aluminium) based on the epilimnion volume of the lake. The principal aim of this trial was to reduce phosphorus in the epilimnion through adsorption by aluminium hydroxide, produced by a series of reactions following aluminium sulphate application. As heterocyst-bearing blue-green algae such as *Anabaena* sp. are capable of fixing atmospheric nitrogen, reducing phosphorus concentrations to the point where phosphorus limits growth has the potential to reduce problematic *Anabaena* blooms.

The lake was stratified throughout the sampling period (2 December, 2003 to 13 January, 2004) and dissolved reactive phosphorus concentrations were high in the presence of an anoxic hypolimnion. Surface pH exceeded 8 throughout the sampling period, including the time of alum application.

A bloom dominated by *Anaebaena spiroides* was present at the time of the application, and dosage of the aluminium sulphate was low compared with applications elsewhere in the world. From 12 to 22 December, 2003, the TN:TP mass ratio in the epilimnion increased from 12:1 to 34:1, but this resulted mostly from an increase in ammonium concentrations rather than a reduction in phosphorus *per se*. There was no immediate impact of the aluminium sulphate application on the density or biomass of *Anabaena spiroides; Staurastrum* sp. was the dominant species in the presence of low phytoplankton biomass while *Anabaena* sp. dominated when biomass was higher.

Analysis of Stream Inflows entering Lake Tarawera

Lisa Pearson & Chris Hendy
University of Waikato

1. Introduction

This study is part of a group effort with Chemistry-304 students at the University of Waikato to understand the budget of nutrients and trace elements for Lake Tarawera. This poster examines the role of the stream inflows into the lake. It is essentially a snap-shot of the lake's condition as of the 20^{th} to the 23^{rd} of April 2004.

2. Background Information

Lake Tarawera is a large deep lake located within the south-western section of the Haroharo Caldera, where it was formed and held back lava flows from the Haroharo and Tarawera volcanoes. The lake level was raised approximately 10 metres following the Mount Tarawera eruption in 1886, which blocked the outflow to the Tarawera River. Geothermal springs enter the lake on the southern and northern shores.

Indirectly the catchment includes five other lakes within the Lake Tarawera 'system'. Lake Rotokakahi (Green Lake) drains into Lake Tarawera via the Te Wairoa Stream. Lake Okareka does also via the Waitangi Spring. Lake Rotomahana has an artificial overflow to Lake Tarawera that operates only during high lake levels, There are no surface outlets from Lakes Tikitapu (Blue Lake) or Okataina. However, subsurface flows from these lakes, and from Lake Rotomahana, are believed to drain into Lake Tarawera. The annual drainage of Lake Tarawera is about 10% of the lake volume.

3. Catchment information

Catchment Usage

Tarawera Catchment Area		14,494 ha
Lake Area		4165 ha
Land Cover-	- Indigenous forest/scrub	60.1 %
	- Exotic forest	15.4%
	- Pasture	21.1 %
	- Wetlands	0.0%
	- Urban development	0.7%

Sample Sites ......

Sample 1. Kotukutuku Bay - Te Wairoa Stream
Sample 2. Kotukutuku Bay - Orchard Park Waterfall
Sample 3. Kotukutuku Bay - Pipe at Landing jetty
Sample 4. Kotukutuku Bay - Inflow through rocks
Sample 5. Kotukutuku Bay - Small stream
Sample 6. Waitangi Bay - Waitangi Spring
Sample 7. Te Karamea Bay - Spawning Stream 1
Sample 8. Te Karamea Bay - Stagnant Drain
Sample 9. Te Karamea Bay - Spawning Stream 2
Sample 10. Te Karamea Bay - Stream at bridge
Sample 11. Hot Water Beach
Sample 12. Twin Stream 1
Sample 13. Twin Stream 2
Sample 14. Te Tapahoro Bay - Tarawera River Outlet

4. Methods

Field work

The water samples were collected from as many streams, inflows and springs (other than geothermal) that enter Lake Tarawera as possible. Two samples from each water source were taken.

- Rinse both the 250 ml bottles with stream water before taking sample.
- Take sample by holding the bottle underwater and flood-filling the bottles.
- Gauge inflow, if possible, using a Pygmy meter (Velocity-Area method).
- Store sample in an ice bucket for transport back to the lab.

Lab work

- Measure pH and dissolved oxygen (D.O.).
- Filtered through acid-cleaned Millipore filters to remove all suspended sediment.
- Preserve sample using 1 ml HCL. For a blank use deionised water preserved with 1 ml HCL.
- Analyse using the following methods:
  - AAS: Na and K
  - ICP-OES: As, Cd, S, Ca, Fe, Mg, Mn, P and Zn
  - Colorimetry: N and NH_4^+

5. Results and discussion

The pH of the water leaving the lake, via the Tarawera River, is higher than the stream inflows into the lake (Geothermal springs not included). Sample 11 taken from Hot Water Beach has the highest pH due to the geothermal influences in the area.

The streams are predominantly rainwater fed therefore low in all major elements. Geothermal influences are the major sources for sodium, sulphur, calcium and potassium entering the lake.

The dominant elements flowing through the lake system are sodium and sulphur. The gauged streams provided only a small fraction of the total flux of water and trace elements through the lake. Significant sources remain unaccounted for.

The dissolved oxygen (D.O.) level of the water entering the lake is between 80 - 90 % which is as expected for surface waters. Sample 8 has a lower D.O. because the water was stagnant in a drain.

In the minor elements an increase in iron and manganese are noticed in water passing through a wetland before entering the lake. A higher level of phosphate is observed entering in Sample 2 without a geothermal influence.

6. Conclusion

Geothermal Springs account for approximately 9% of water entering Lake Tarawera. As shown by samples 11, 12 and 13 they have a major influence on the amount of sodium, sulphur and calcium entering the lake. They are also a significant source of phosphorus.

The wetlands that samples 8 and 9 flow through have a higher amount of iron and manganese due to the anoxic reducing conditions.

In general the stream waters tend to be lower in phosphorus than the groundwater but higher than the lake. Phosphorus is being removed from the lake by plant uptake from the riparian zone and the water column.

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The Significance of Seston as a Sink for Nutrients and Trace Elements in Lake Tarawera

Louise Stewart & Chris Hendy
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Introduction

Lake Tarawera is an oligotrophic lake that is unique in the Rotorua lakes for experiencing blue-green algal blooms which have been noted since the 1950s. Environment Bay of Plenty annual data (Gibbons-Davies 2003) suggests that Lake Tarawera is balanced with respect to nitrogen and phosphorus. This project examines the role of seston as a source and sink for nutrients and other trace elements.

Seston

Seston is organic debris lying on the sediment at the lake floor as a semi-solid layer beneath the overlying water. It is composed of dying algae, animal excreta and silt that have descended through the water column. Bacterial and fungal activity metabolises seston organic matter, consuming oxygen, releasing phosphorus and nitrogen and creating a reducing zone.

Methods

Seston core samples were obtained from three sites on the lake. A seston corer was dropped and used to extract seston samples. Back on shore the cores were extruded into measured intervals, bagged, marked and returned to the laboratory. The pore waters were separated from the seston by centrifugation. The seston was dried, ground, weighed and digested with *aqua regia* and subsequently analysed for As, Mg, Mn, Fe, S, Zn and P by ICP-OES (Inductively Coupled Plasma - Optical Emission Spectroscopy) and K and Na by AES (Atomic Emission Spectrometry.

Results

Analyses of the seston show two pronounced trends:

1. Phosphorus and arsenic peak in the upper 5cm of all seston cores. This is accompanied by peaks of iron and manganese at the same levels and results from consumption of oxygen by bacteria etc. producing reducing conditions below 10 cm depth. Iron and manganese are reduced from insoluble oxide phases to mobile Fe^{2+} and Mn^{2+}. This in turn releases the adsorbed phosphate and arsenate. As the pore waters migrate upwards they encounter the oxygenated lake waters causing iron and manganese to reprecipitate and readsorb phosphate and arsenate.

2. Deeper in the cores is a transition to Rotomahana mud from the last phase of the Tarawera eruption. This can be seen in the increasing concentration of magnesium.

N.B. There was an increased abundance of sulphur in the seston from the core site nearest Hot Water beach.

Conclusion
Iron and manganese oxidation in the upper 20 cm of Lake Tarawera's sediment column is remobilising phosphorus and arsenic but retaining both within the sediment. This situation will remain as long as the bottom waters do not become anoxic. With a total of approximately 400 tonnes of phosphorus, such a release would cause a dramatic decrease in water quality and trophic status.

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The Significance of Suspended Solids to the Nutrient & Trace Element Budgets in Lake Tarawera

Kim Sullivan & Chris Hendy
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INTRODUCTION
This project assesses the significance of suspended matter as a reservoir and for the transport of trace elements into Lake Tarawera and was carried out as part of a group investigation (CHEM 304). Samples of lake, stream and geothermal water were collected in April 2004.

BACKGROUND INFORMATION
Rotorua's Lakes are stunningly beautiful. However, over the past decades they have been under increasing pressure from human activities. The problem is too many nutrients (mainly nitrogen and phosphorus). which encourage algal growth and lead to deterioration of the water quality. Decreasing dissolved oxygen suggests that Lake Tarawera is also deteriorating.

Lake Tarawera formed 5000 years ago, following the eruption of Mount Tarawera. It has a maximum depth of 87.5 m and an average depth of 50 m. Its surface area is 41.6 km^2 and it has a catchment area of 144.9 km^2. Five other lakes drain into Lake Tarawera, as well as geothermal inputs. The surface outflow from the lake is via the Tarawera River.

METHODS
Fieldwork

- samples were collected into 250 m1 bottles
- samples were then stored in an ice bucket/fridge until transported back to the lab

Labwork

- samples were filtered and filter papers retained
- filter papers were weighed and then digested using aqua regia digestion methods
- solutions were made up using diluted distilled water and analysed for As, Ca, Cd, Fe, Mg, P, S and Zn by ICP-OES; Na and K by AES; and PO_4^{2-} by Colorimetry

RESULTS

1. The contribution of suspended matter to the trace element content of Lake Tarawera is small compared to their abundance in the water column. There appears to be a higher concentration of sodium in suspended matter in the lake than in the streams.

2. The suspended matter in the streams is a minor source of transport for trace elements.

3. Excluding iron, suspended matter in the geothermal springs is also a minor source of transport for trace elements. The concentration of suspended major elements (sodium and potassium) in geothermal water appears to be higher than that of the lake and stream water.

4. The phosphorus content of the suspended matter is considerably lower than in macrophytes. The phosphorus content leaving via the Tarawera river is considerably lower than that entering the lake.

CONCLUSIONS
The results show that the suspended matter in the lake water, the stream water, and the geothermal water is a minor source of transport of trace and major elements. This contrasts with results obtained from Rotorua and Rotoiti Lakes, where the suspended matter plays a large part in the transport of nutrient material. Phosphorus does not leave the lake as suspended matter.

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New Tools for Monitoring Water Quality of the Rotorua Lakes

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We present data collected with a Bio-Fish, a remote-controlled probe that oscillates from the surface down to 60 m depth as it is towed behind a boat. A 10-km lake transect can be measured in one hour. The probe measures variables such as temperature, conductivity, dissolved oxygen, light and chlorophyll fluorescence. The information collected with the probe is initially examined in real time via an on-board computer. Extensive post-processing is used to present graphical images of the data over entire lakes basins. For lakes Rotorua and Rotoiti the Bio-Fish has been used to measure basin-scale changes as well as details of the Ohau Channel inflow to Lake Rotoiti. The data clearly demonstrate the important influence of the Ohau Channel inflow on the dynamics of Lake Rotoiti. The Bio-Fish monitoring has recently been extended to lakes Okareka, Rotoehu and Rotoma. Major horizontal variations in conductivity, dissolved oxygen and chlorophyll fluorescence occur in all of these lakes.

Groundwater in the Lake Rotorua Catchment.

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The load of nitrogen to Lake Rotorua, from the catchment via streams, has increased over the past few decades (Rutherford 2003), due to increasing concentrations of nitrogen in stream baseflow. Groundwater supports flow in many streams in the catchment. Many streams are spring-fed and many streams have a baseflow supported by groundwater flow; groundwater also discharges directly to Lake Rotorua. The time scales of response of surface water to land use change, often many decades (Morgenstern et al., 2004), is controlled by the groundwater system because water flows in the Lake Rotorua catchment are commonly through the groundwater system.

Therefore, an understanding of the groundwater system is important to the understanding of nutrient discharges to Lake Rotorua. Groundwater is also an important source of drinking water in the catchment as most of the major springs are used for water supply.

Aquifers composed of ignimbrite are common in the Lake Rotorua catchment and the Mamaku Ignimbrite, erupted from Rotorua approximately 220,000 years ago, is the thickest ignimbrite with over 1km of pumice and ash within the Rotorua caldera. Huka Group sediments are fine volcanic ash and diatomaceous silts up to 40m thick that surround Lake Rotorua.

A water balance study of the western Mamaku Plateau estimates 52% of rainfall is recharged to groundwater (Dell 1982). The areas and locations of 10 spring catchments are calculated using this estimate of rainfall recharge, a detailed rainfall model and a map of groundwater levels in the Lake Rotorua catchment derived from approximately 700 regional groundwater level measurements. Hamurana Springs has the largest catchment of the springs in the area, at approximately 80 km^2.

The Lake Rotorua catchment is divided into 13 ‘major’ groundwater subcatchments, including spring catchments, for the purposes of: 1) estimating the groundwater flux, 2) assessing groundwater quality and 3) establishing the land catchments of the various groundwater systems. These subcatchments include springs and three geothermal systems and are a total of 506 km^2 in area, which is approximately 75 km^2 larger than the surface catchment because the catchment of Hamurana Springs extends beyond the surface catchment boundary.

Groundwater flux in all groundwater subcatchments is estimated as 15.8 $m^3 s^{-1}$ and the subcatchments of Hamurana Springs and Taniwha Springs have the largest groundwater flow. Groundwater flow in subcatchments where groundwater discharges directly to Lake Rotorua, and in sections of surface water catchments located between surface water recording sites and Lake Rotorua, is an estimated maximum of 3.3 $m^3 s^{-1}$. This flow potentially contributes a significant nutrient flux to the lake yet is unmeasured by surface water recording sites.

Nutrients from groundwater, and from the Tikitere/Taheke geothermal field and Rotorua geothermal field, travel into Lake Rotorua directly or via springs and streams. Nutrients in groundwater include phosphorus, nitrate (the most common form of nitrogen in groundwater) and ammonia. Rotorua groundwater has a relatively high concentration of phosphorus, compared with other parts of New Zealand, as well as being relatively high in K, F and SiO_2 (Morgenstern et al., 2004) because of the chemical composition of the ignimbrite and rhyolite aquifers.

Nitrate concentrations in groundwater are generally less than 2 g m^{-3} in volcanic lithologies in the Environment Bay of Plenty region. Grinsted and Wilson (1978) reported nitrate concentrations in the range 1 to 5 g m^{-3} around Lake Rotorua. They concluded that agricultural practices around the lake were impacting on nitrate concentrations in groundwater because concentrations of nitrate in shallow groundwater near the lake were typically higher, at around 2 g m^{-3}, than concentrations of nitrate in groundwater underneath the forested Mamaku Plateau of around 0.5 g m^{-3}.

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GLOSSARY

This short glossary is intended as a guide to technical terms for those attendees who are not involved in science. Not all the technical words that you will hear can be expected to be listed below, but we have done our best!

UNITS

Abbreviation	**Expressed as**	**Full name**
mg	1×10^{-3} g	milligram (1/1000 gram)
µg	1×10^{-6} g	microgram (1/1000,000 gram)
ng	1×10^{-9} g	nanogram (1/1000,000,000 gram)

Abbreviation	**Equivalent to**
ppm (parts per million)	1 mg per litre (1 mg/l or 1 $mg.l^{-1}$)
	or 1 g per cubic metre (1 g/m^3 or 1 $g.m^{-3}$)

Algae
Primitive plants, often almost invisible to the naked eye. The term algae often also refers to microscopic plants that are suspended in the water of lakes or the sea (also known as phytoplankton). Excessive quantities of these can result in algal blooms.

Algal biomass
The amounts of algae present in the water. The concentration of chlorophyll-a is the most widely used method to measure and describe algal biomass.

Allophane
A clay-like soil material, derived from volcanic ash, common in the central North Island. Very effective at retaining phosphate and other ions.

Ammonia
Ammonia (NH_3 as ammonia or NH_4^+ as the ammonium ion) is the form of nitrogen that is easiest for plants to take up. It may be released from the sediment of lakes during periods when the dissolved oxygen concentrations in the bottom waters are low.

Anatoxin
Cyanobacterial toxins, originally isolated from *Anabaena*. These are neurotoxins. Note that some cyanobacteria may produce more than one type of toxin.

Anthropogenic
Derived from human activity.

Benthic
Organisms or processes associated with the benthos (see below).

Benthos
The bottom or bottom sediments of a lake, pond, stream, etc. (in the broadest sense).

C-13 or ^{13}C
A non-radioactive isotope of the element carbon. Uncommon in the natural environment.

Clarity
Often determined in lakes using a secchi disc (a disk painted in contrasting black and white ‘pie wedges’). This gives a measure of the vertical distance that objects can be seen from the surface of the lake.

Chlorophyll-a
Often abbreviated to Chl-a. Chlorophyll-a is the major plant pigment responsible for photosynthesis. It is used to give an indirect measure of the amount of algal biomass in the water.
Cyanobacteria (cyanophyta)
'Blue-green algae'. Generally not regarded as algae (see above) these days, but are very primitive, usually microscopic, organisms that may sometimes produce powerful toxins. Common genera of cyanobacteria in the Rotorua lakes include *Anabaena*, *Aphanizomenon* and *Microcystis*.
Diatoms
Unicellular microalgae with silica shells, often very elaborate.
Dinoflagellates
Unicellular microalgae with two flagella for locomotion.
Dissolved reactive phosphorus
Phosphorus is an important plant nutrient. Dissolved reactive phosphorus is often measured in water as it stimulates the growth of algae.
Epilimnion
The upper, warmer, and circulating layer of a stratified lake. Generally high in dissolved oxygen. To clarify this in your mind, remember that a **hypo**dermic needle goes **below** your **epi**dermis.
Eutrophic
Eutrophic lakes have a high concentration of nutrients. This results in high algal biomass that in turn gives poor water clarity.
Eutrophication
Lakes develop from an oligotrophic state (high water quality) to a more eutrophic state (lower water quality) over geological time. Eutrophication is thought to be a natural part of lake development but the rate is increased by human activities which increase the input of nutrients, specifically phosphorus and nitrogen.
Hepatotoxins
Toxins that attack the liver.
Hypolimnion
The cool and relatively undisturbed lower layer of a stratified lake. Often deficient in dissolved oxygen.
Ignimbrite
A rock formed by the welding together of semi-molten particles during a pyroclastic flow from a volcanic eruption.
Lanthanum
A metallic element, uncommon in nature, which is generally regarded as one of the 'rare earth' elements, although, strictly speaking, it is not.
Limnology
Limnology is the study of surface freshwaters, their chemistry, interaction with land and air, and of the freshwater communities which they support.
Littoral
The interface zone between land and water (also used as an adjective).
Lysimeter
A device used for studying water and/or nutrients in soils.
Macrophyte
Macroscopic (i.e. larger than microscopic) plants. Aquatic macrophytes are water plants.

Mesotrophic
The water quality of mesotrophic lakes is intermediate between oligotrophic and eutrophic lakes.
Microalgae
Algae not identifiable without the aid of a microscope.
Microcystin
Cyanobacterial toxins, originally isolated from *Microcystis*. These are hepatotoxins.
Neurotoxins
Toxins that attack the central nervous system.
Nitrate
Nitrate ($N0_3^-$) is a form of nitrogen readily available for plant growth.
Nitrogen
A major plant nutrient, occurring in various chemical compounds. Often abbreviated as "N".
Nodularin
Cyanobacterial toxins, originally isolated from *Nodularia*. These are hepatotoxins.
Oligotrophic
Oligotrophic lakes have a low concentration of nutrients. This results in low algal biomass and high water clarity.
Periphyton
Algae or algae-like organisms growing attached to submerged surfaces.
Phosphorus
A major plant nutrient, occurring in various chemical compounds. Often abbreviated as "P".
Phytoplankton
Very small plants or plant-like organisms living freely suspended in water.
Planktivorous
Feeding on plankton.
Plankton
Microscopic (usually) organisms living freely suspended in water.
Redox potential
Reduction-oxidation potential, a measure of the electron activity in water etc., much influenced by oxygen availability.
Rhyolite
Volcanic magma that is high in silica and prone to explosive eruptions that form calderas.
Saxitoxin
Algal toxins, originally isolated from marine 'red tide' organisms, but more recently isolated from the Cyanobacterial genus *Anabaena*. They cause paralytic shellfish poisoning and are neurotoxins.
Seston
Organic debris lying on the sediment at the lake floor as a semi-solid layer beneath the overlying water.
Stratification
In lakes usually applies to thermal stratification, in which warming of the surface waters leads to the formation of three layers of water, warm, sharply cooling, and cold (as seen from the surface down).
Thermocline
The layer (usually narrow) of water between the epilimnion and the hypolimnion is known as the metalimnion, where the temperature changes rapidly over a short distance in

a stratified lake. This sharp temperature gradient is called the Thermocline. Also known as the discontinuity layer.

Total Kjeldahl nitrogen

A measure of ammonia + organic nitrogen.

Total phosphorus

Total phosphorus includes dissolved forms, phosphorus adsorbed to particles and phosphorus in algal cells. Total phosphorus can be used to define the trophic state of lakes.

Toxins

Poisonous compounds or elements.

Trophic state

Trophic state describes the productivity of lakes. It may be determined using single measures of water quality (e.g. algal biomass, clarity and nutrients) or a combination of measures.

Water column

The full depth of a body of water, from surface to bottom.

Zeolites

A group of aluminosilicate minerals which act as natural ion-exchange materials.

Zooplankton

Very small animal (non-plant) organisms living freely suspended in water.

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