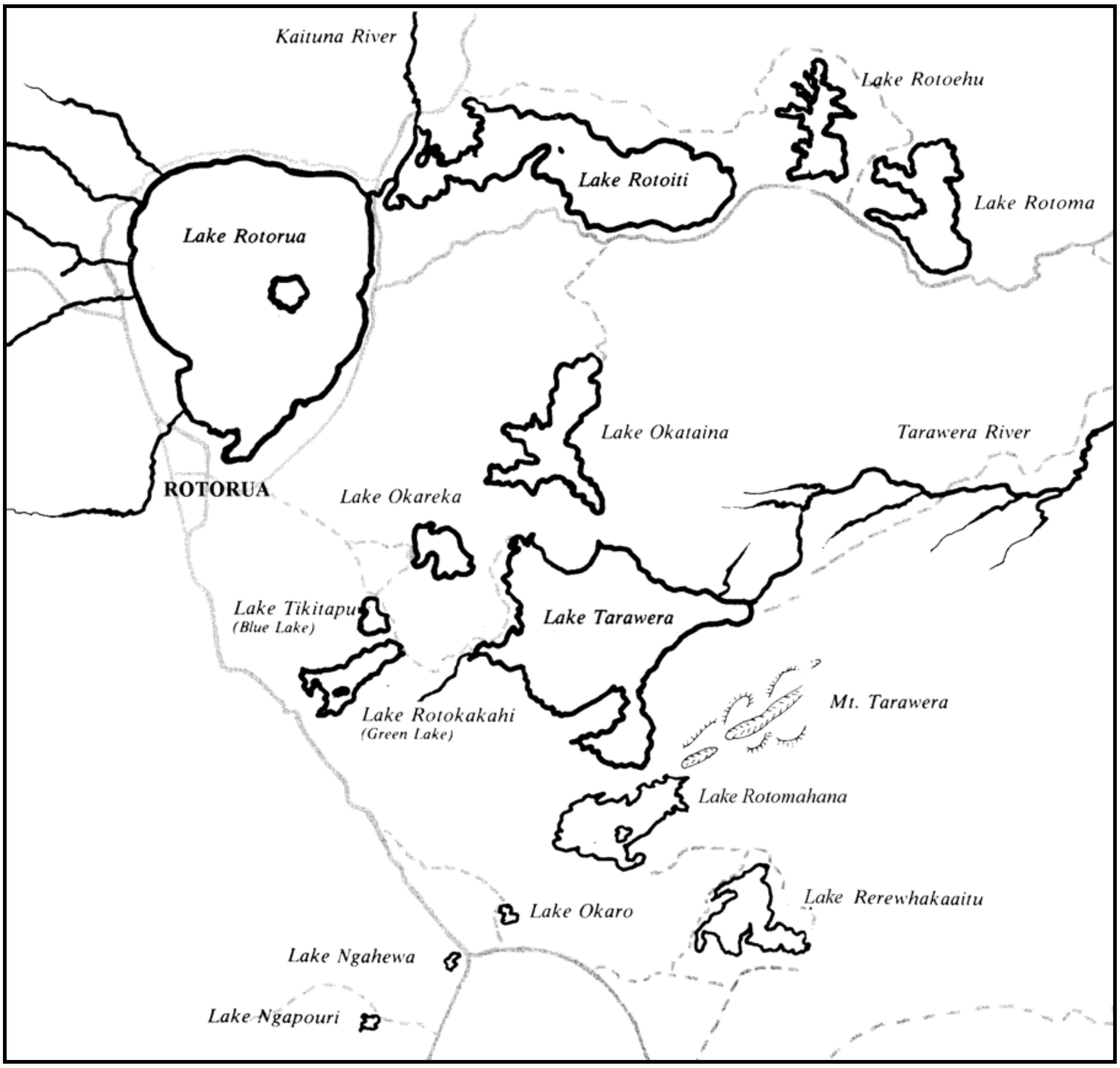
PROCEEDINGS AND REPORT

ROTORUA LAKES 2001

A symposium on Research Needs in the Rotorua Lakes



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ROTORUA LAKES 2001

A symposium on Research Needs of the Rotorua Lakes

22 – 23 March 2001
Rotorua, New Zealand

Jointly hosted by

LakesWater Quality Society (incorporation pending)
and
The Royal Society of New Zealand (Rotorua Branch)

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Editors' Note

Material for the Symposium Proceedings has been received in a variety of formats, from formal, referenced papers to computer 'Power Point' presentations. Two presentations were fully or partly transcribed from audio tapes by the editors. We have endeavoured to leave the material included in these Proceedings largely as it was received by us. We have corrected obvious minor errors, and imposed a uniform formatting on Paper titles, authors and their affiliations, but have not attempted to impose an overall uniform format, preferring to leave this to the authors' discretion.

Audience questions and presenter's answers have been included where available, but owing to taping problems, not all questions and answers are 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.

Please bear in mind that these Proceedings have been edited, proofed and assembled by volunteers, in their spare time.

Our thanks to Warren Webber and his team at the Foundation for Continuing Education, New Zealand Veterinary Association, Massey University, who have been responsible for printing and binding these Proceedings.

Nick and Elizabeth Miller, Ian McLean

Disclaimer: The Proceedings report the formal presentations and question sessions of the Symposium, which was designed to encourage open discussion amongst those managing, studying, or with an interest, in the Rotorua lakes. The information is not intended to substitute for official policy statements from parent organisations.

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ISSN

FOREWORD

The Symposium *Rotorua Lakes 2001* was organised by the LakesWater Quality Society and the Royal Society of NZ (Rotorua Branch). The LakesWater Quality Society, which under an earlier name is over 40 years old, initiated the Symposium for two reasons:

- public concern over a decline in water quality in some of these beautiful lakes, and especially the spread of blue-green algal (cyanobacterial) blooms;
- the limited amount of basic research being done into lakes (as opposed to applied research and monitoring).

The purpose of the Symposium was to identify research directions and priorities for the LakesWater Quality Society to actively promote. But the ultimate purpose is to preserve and enhance the water quality in the Rotorua lakes and beyond, and hence the objective is eventual action rather than research for research's sake.

I extend grateful thanks to all those who have prepared papers and to the voluntary committee who carried out the major task of organizing the Symposium.

We hope that those whose home is the land around the lakes - Maori and Pakeha - and who over the decades and centuries ahead will have the task of caring for these lakes will be able to look back at this Symposium as one of the foundation stones for their work.

Ian McLean

Chairman LWQS

August 2001

EXECUTIVE SUMMARY OF RESEARCH PRIORITIES

Topics considered by symposium registrants to have a high priority for research may be summarised under the following subject areas:

- Sediments – their impact on water quality;
- Internal/external nutrient loading models;
- Nutrient bioavailability;
- Cyanobacterial toxin development and reason for build-ups;
- Official response to toxin levels;
- Food webs and biota;
- Sustainable options for management;
- Remediation (rehabilitation of lakes);
- Plant and animal pest management.

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ORAL PAPERS

THE ANATOMY OF CYANOBACTERIAL BLOOMS: A FRAMEWORK FOR IDENTIFYING MANAGEMENT STRATEGIES AND INFORMATION NEEDS

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INTRODUCTION:

Controlling cyanobacterial blooms in freshwater supplies is a critical issue in many parts of the world. Research has indicated that an array of physical, chemical and biological factors influences the development of cyanobacterial blooms, but the relative importance of these factors differs between systems. Because of this variation, it is necessary to identify the environmental conditions responsible for the occurrence of blooms in particular aquatic systems so that appropriate control strategies can be applied. This requires an understanding of the biology of the cyanobacterial species causing problems and knowledge of the pertinent environmental conditions within a system. Because of the many interactions that influence the growth of cyanobacteria, identifying the environmental conditions responsible for enhancing the occurrence of blooms is not always straightforward. Often this analysis is made difficult by a lack of data to describe the various interactions, and inevitably different views develop as to what are the major causes. These opposing views can lead to vigorous scientific debate and critical experimental testing of alternative hypotheses. However, the development of alternative hypotheses, which is an important component of scientific debate, can result in confusion amongst the community who are ultimately paying for research and remedial works. A lack of understanding by the community of the complex issues being debated can lead to a loss of confidence and reduced support.

Recently in Australia, increased responsibility for managing river catchments has been given to catchment management groups consisting predominantly of community members. This delegation recognises that the landscape scale modifications necessary to improve water quality will require the support and resources of the community. This has placed a large responsibility on catchment management groups to identify and support appropriate research to address water quality problems within the catchment. One outcome of this change has been a requirement for researchers and catchment groups to liase more directly and more frequently. This has highlighted some persistent problems associated with developing effective and efficient communication between professional researchers and community members. There is a need to enhance communication without requiring community members to become scientists, but still enabling the complexity of the natural world to be conveyed. With respect to the issue at hand, there is a need to provide descriptions of the interactions between environmental conditions and the growth of cyanobacteria at various levels of complexity. These descriptions or ‘models’ are required to summarise and integrate continuing scientific investigations, to assist in communicating the current understanding of water quality issues to the community, and to help identify and explain management responses.

Models range in complexity from simple conceptual diagrams, through semi-quantitative decision support trees and empirical models, to dynamic process models. The development of models to describe nutrient cycling and aquatic foodwebs is not new and they have been widely applied in the scientific literature (De Angelis 1992). Predictive models describing processes in aquatic ecosystems (including models of phytoplankton biomass) must be based on appropriately scaled conceptual models that include the major pools and fluxes of the most important elements (Harris 1997). In this sense, conceptual models underpin scientific thought and contain the primary propositions of system function that are driving research. As such, they form an important foundation for communication between researchers as well as with the wider community. Conceptual models provide a means of integrating research findings and provide a framework for the discussion issues. No single model can capture all of the possible interactions that might occur within an aquatic system, and no single model will be suitable for all systems. However, the development of a series of conceptual models by researchers and community members, aimed at elucidating the processes responsible for water quality problems, can provide a basis for identifying and assessing likely causes.

Developing strategies to deal with cyanobacterial blooms requires knowledge of the environmental conditions suitable for bloom development, some basis for identifying which of these conditions are pertinent to the aquatic system of concern, and information to assess their relative importance. Management strategies then need to be assessed against the probability (or possibility) of altering these environmental condition and the likely success of restricting cyanobacterial growth. A necessary first step is agreement on the conditions influencing the development of cyanobacterial blooms. A broad conceptual model describing the influence of environmental conditions on phytoplankton growth will be used to identify key stressors responsible for the occurrence of cyanobacterial blooms and to illustrate some of the complex interactions that need to be considered (Figure 1). In practise it would be preferable to target such a model to a particular system using available knowledge and suppositions regarding system function, but the general model is suitable for illustrative purposes. Space does not allow for an exhaustive discussion of all issues, but this is unnecessary, as the diagram is meant to illustrate the type of outcome that would be developed through an interactive and iterative process.

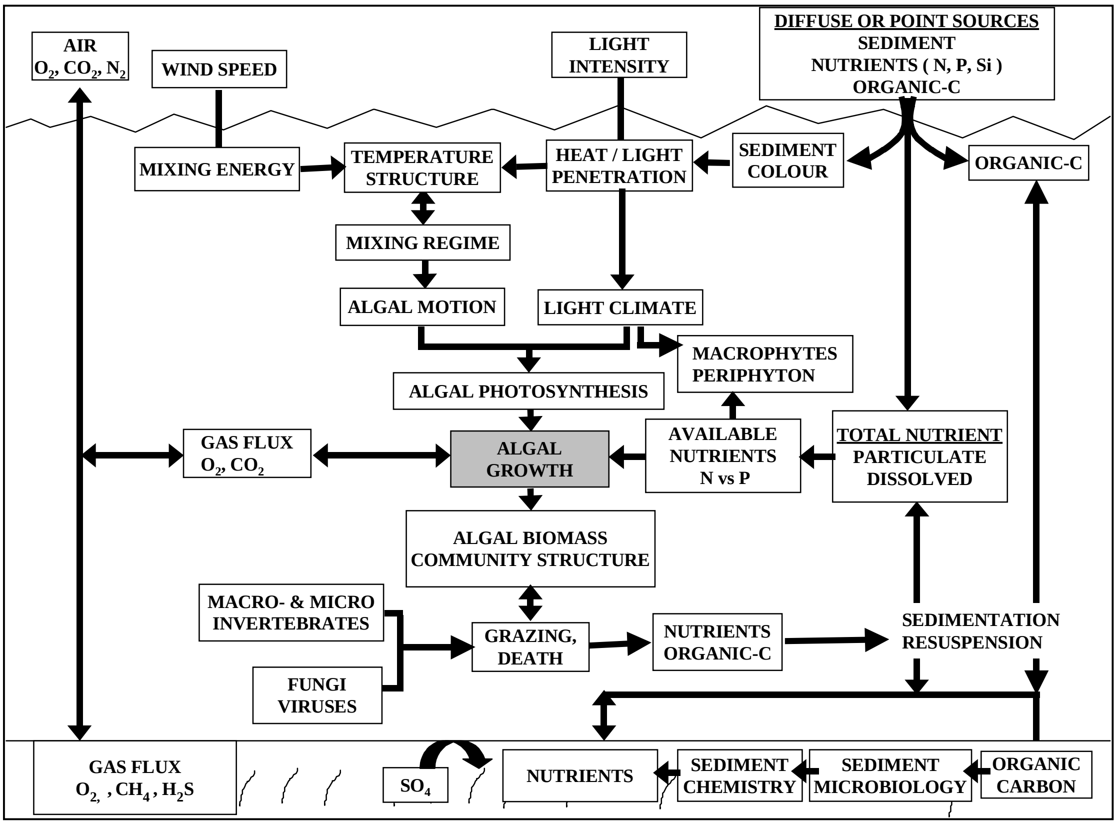

Figure 1. Conceptual diagram of the interactions between environmental conditions and phytoplankton growth.

If conceptual models are to be useful in integrating information and enhancing communication then relationships need to be quantified, but the underlying complexity of quantification should be simplified into indicators, or threshold levels that represent exceedance of required conditions. Such values may be simplifications of complex and dynamic interactions, but they are necessary to provide a sense of scale and to flag management targets. A generalised decision support tree is presented that describes the conditions leading to the development of particular cyanobacterial blooms and attempts to integrate and summarise information from the scientific literature by providing indicator values (Figure 2). These values will not be the same for all systems, firstly because of environmental differences and secondly because management targets may be re-defined in view of political and social constraints. The indicator values can be viewed as a series of hypothesis to be used as a framework for comparison with specific system measurements.

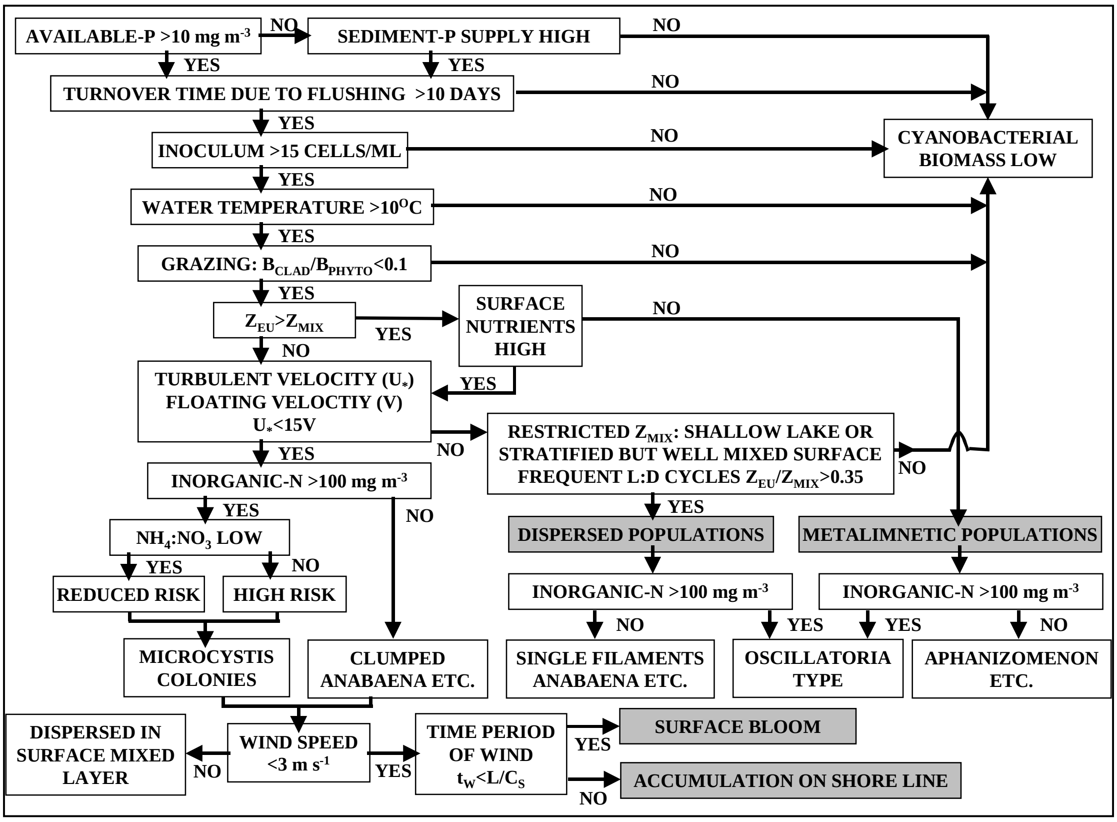

Figure 2. A decision support tree identifying environmental conditions leading to particular types of cyanobacterial blooms along with indicator threshold values for the interactions. Key: B_{clad} biomass of cladocerans, B_{phyto} biomass of phytoplankton, Z_{EU} euphotic depth, Z_{MIX} depth of mixing, u_* shear velocity, V floating or sinking velocity of phytoplankton, t_w time that the wind blows, L lake fetch, c_s current speed (Re-drawn from Oliver and Ganf 2000).

PHYSICAL INFLUENCES:

The physical structure of a lake water column is influenced predominantly by meteorological conditions. Vertical mixing is attributed to turbulence generated either by wind stress on the water surface, or to convective cooling due to fluctuations of temperature in the surface water (Imberger 1985; Spigel and Imberger 1987). The vertical penetration of mixing is resisted by the formation of a heated, buoyant surface layer (Imberger and Hamblin 1982, Reynolds 1990). The depth of the heated layer is a function of the intensity of the solar energy, its penetration into the water, the extent of heat capture by the water layers and the degree of mixing. If vertical mixing is not sufficient to redistribute the surface layer heating throughout the water column then temperature stratification will occur. In this situation, a warm surface mixed layer overlays cooler, weakly mixed layers.

Light intensity diminishes with depth due to absorption and scattering by dissolved compounds and particles within the water column (Kirk 1983). The depth at which light becomes insufficient to support phytoplankton photosynthesis is termed the euphotic depth (z_e), and in the dark layers below this level phytoplankton cells rely on energy stores to maintain their growth. Turbulent mixing in the water column acts to homogenise the vertical

distribution of phytoplankton by entraining slowly moving particles within the motion of the turbulence. If the depth of water mixing (z_{mix}) is greater than the euphotic depth then the motion will carry cells in and out of the light zone. The proportion of time that the cells spend in the light is then determined by the ratio of the euphotic depth to the mixing depth (z_e/z_{mix}). If the mixing depth is large, then the cells will spend a relatively short period of time in the light and growth will be restricted. To assess the impact of light climate on phytoplankton growth it is necessary to know the depths of the euphotic zone and the mixed layer. Phytoplankton growth is usually restricted when the z_e/z_{mix} ratio is less than about 0.3 (Talling 1957; Oliver *et al.* 2000).

The delivery of sediment and dissolved colour from the catchment can reduce light penetration and impact on phytoplankton growth and community composition (Kirk 1983). A reduction in light penetration can also be detrimental to the growth of macrophytes and to microalgae that grow attached to these plants and to the bottom sediments. Furthemore, water colour and transparency affects the amenity value of lakes (Davies-Colley *et al.* 1993). Despite these major influences, light penetration is still frequently measured using secchi disks. This technique is quick and easy but has considerable limitations. In particular, it is difficult to use such measurements in quantitative analyses of the underwater light field, especially when trying to attribute changes in light penetration to altered optical conditions resulting from material transported into the lake.

The influence that mixing has on the vertical distribution of phytoplankton is dependent on the intensity of turbulent mixing and the specific gravity of the cells. Most phytoplankton are heavier than water and sink, but if mixing is sufficiently intense to entrain the cells in the water motion then these populations can persist in the water column due to the constant homogenising of their vertical distribution (Smith 1982). In contrast, most bloom forming cyanobacteria contain gas-filled spaces (gas vesicles) that provide the cells with buoyancy so that losses due to sinking are small (Oliver 1994; Walsby 1994). This provides the cyanobacteria with a substantial advantage. When mixing intensity is sufficient to entrain the cyanobacteria in the water motion the population will be homogeneous throughout the mixed layer. However, when the mixing intensity is reduced the buoyant cells float towards the surface. The resultant improvement in light conditions can enhance their growth rate providing an additional advantage over other phytoplankton.

At times of extended stability buoyant cyanobacteria move to the water surface and form surface blooms. These can severely impact water quality, especially if the cyanobacteria are toxic. Surface blooms form when cells originally dispersed within the water column float upwards and concentrate at the surface. This concentrating effect has important implications for the management of surface blooms. If a cell concentration of 10,000 cells/ml is considered a problem and occurs in a surface bloom concentrated within a depth of 0.05m (5cm), but the cells were originally distributed over a mixed depth of 3m, then the original density of the population was only 160 cells/ml. This is a small population from which a substantial problem has arisen. This problem is further exacerbated if the surface bloom is transported across the lake by a breeze and accumulates against the shoreline. In this case the concentration factor is even greater and the bloom could have originated from an even smaller dispersed population. This demonstrates the difficulty of eliminating surface blooms. To do so requires that cyanobacterial numbers are reduced to near zero concentrations, a task that can be difficult to achieve.

In order to predict occurrences of surface blooms it is necessary to quantify the interplay between the intensity of turbulent mixing and the vertical distributions of phytoplankton populations. A function describing the extent of entrainment (Y) of cells within the water motion compares the sinking or floating velocity of the phytoplankton (v) with the velocity of the turbulent eddies (u) that mix the cells vertically (Humphries and Imberger 1982; Humphries and Lyne 1988).

$$Y = 15v/u$$

When Y is greater than 1 the sinking or floating velocity of the phytoplankton plays an increasing role in the population distribution and this begins to occur when the turbulent velocity falls to less than 15 times the phytoplankton velocity. Species of cyanobacteria in the genera *Anabaena* have flotation rates of the order of 4 m/d (0.00005 m/s). The velocity of the turbulent eddies necessary to mix these organisms can be calculated from the above equation. If it is assumed that the wind speed generating the turbulence is 1000 times the velocity of the turbulent eddies (Denman and Gargett 1983) then a wind speed of approximately 1 m/s is required and surface blooms will only occur at wind speeds less than this value. In contrast, colonies of cyanobacteria belonging to the genera *Microcystis* have flotation rates of 43 m/d or more and can move towards the surface even when wind speeds are of the order of 3 m/s (Oliver and Ganf 2000).

The currents generated by winds not only influence the vertical distribution of phytoplankton but also advect them from one location to another causing horizontal heterogeneity in the population (George and Edwards 1976; Webster and Hutchinson 1994). The surface current speed does not increase linearly with wind speed because of changes in the distribution of the energy between horizontal advection and vertical mixing. Below wind speeds of 3m/s the water surface is smooth and the vertical transfer of energy is small. Under these conditions a larger proportion of the wind energy is converted to horizontal water surface velocities. At wind speeds above 3m/s the vertical transfer of energy increases and surface current speeds are a smaller fraction of the wind speed. The relationship between surface current speed and wind speed shows a maximum current speed of 4.5 cm/s (162 m/h) at a wind speed of 3 m/s with current velocities decreasing either side (Oliver and Ganf 2000). Surface blooms occur at lower wind speeds and their transport to the downwind edges of a lake depends on the lake fetch, the wind speed and the length of time that the wind blows. However, even a wind speed of 1 m/s generates a surface current of 2.5 cm/s (90 m/h) so that surface accumulations occurring under these conditions are still quite quickly transported horizontally. It is only under very calm conditions or in relatively large lakes that surface blooms will be spread over the lake surface.

CHEMICAL INFLUENCES:

Materials that enter lakes from the catchment include dissolved and particulate organic and inorganic nutrients, organic debris and sediment (Figure 1). These materials can impact on nutrient cycles and may enhance the likelihood of cyanobacterial blooms.

Nutrients:

Of the many nutrients that phytoplankton require for growth, it is phosphorus and nitrogen that most frequently becomes limiting in inland waters (Hecky and Kilham 1988). When nutrient limitation controls phytoplankton production the potential maximum biomass is determined by the yield of the nutrient in shortest supply, that is the amount of cellular material that is produced per unit of the limiting nutrient. If nutrient enrichment of aquatic systems (eutrophication) is considered a major cause of phytoplankton blooms then an obvious management strategy is to try and reduce nutrient loads so that the potential maximum cell biomass is reduced. Nutrient reduction schemes generally involve large-scale modifications to point and non-point sources in the catchment and are often expensive. To obtain support for the implementation of such schemes it is necessary to predict the likelihood of their success and this requires establishing quantitative links between nutrients and phytoplankton concentrations. Two functions are of particular importance, the reliance of phytoplanton biomass on the limiting nutrient, and the minimum nutrient concentration that must be achieved to restrict substantial growth. The first enables prediction of the impact of a particular nutrient concentration, while the second indicates an extreme end of the nutrient range.

In freshwater ecosystems phosphorus is often in shortest supply and runs out first as the phytoplankton grow (Hecky and Kilham 1988). In such cases the quantity of phosphorus that is available to the phytoplankton will determine the maximum cell concentration that can form. This simple notion of a limiting nutrient controlling the potential phytoplankton biomass forms the basis of the well-known empirical relationships relating summer chlorophyll concentrations to preceding total phosphorus concentrations (Vollenweider 1968). In these chlorophyll-phosphorus models, the chlorophyll-a concentration is used as an estimate of the phytoplankton biomass and the total phosphorus concentration as a measure of the supply of phosphorus available to support cell growth. The total phosphorus concentration in the lake can then be compared with the phosphorus loads supplied by various inflows to develop a nutrient loading model. The linked models provide a means of identifying major nutrient contributors to the lake that can be targeted in management strategies to reduce phytoplankton concentrations.

Chlorophyll-a and total phosphorus concentrations have been correlated for a broad range of lakes providing relationships that are surprisingly congruent for a one-factor dependency. However, it is apparent that a single correlation does not adequately describe all situations (Figure 3). This is a major impediment to nutrient management, as a quantitative link between growth of phytoplankton and nutrient supply is required to set nutrient reduction targets. Part of the problem is that phosphorus models have been applied to lakes where phytoplankton growth is not phosphorus limited. Sas (1989) found that of 18 European lakes that had undergone phosphorus reductions 7 did not show a significant decline in the phytoplankton biomass. These lakes contained excess phosphorus in solution even when the maximum phytoplankton biomass was attained, indicating that the maximum was not dependent on the availability of phosphorus but was controlled by the availability of some other resource. In these situations, models based on the appropriate limiting resource might be expected to apply. In lakes that responded to phosphorus reductions Sas (1989) found that P-limitation did not occur until the concentration of unused filterable reactive phosphorus (an estimate of orthophosphate) fell below 10 mg m^{-3} for substantial periods of the growing season.

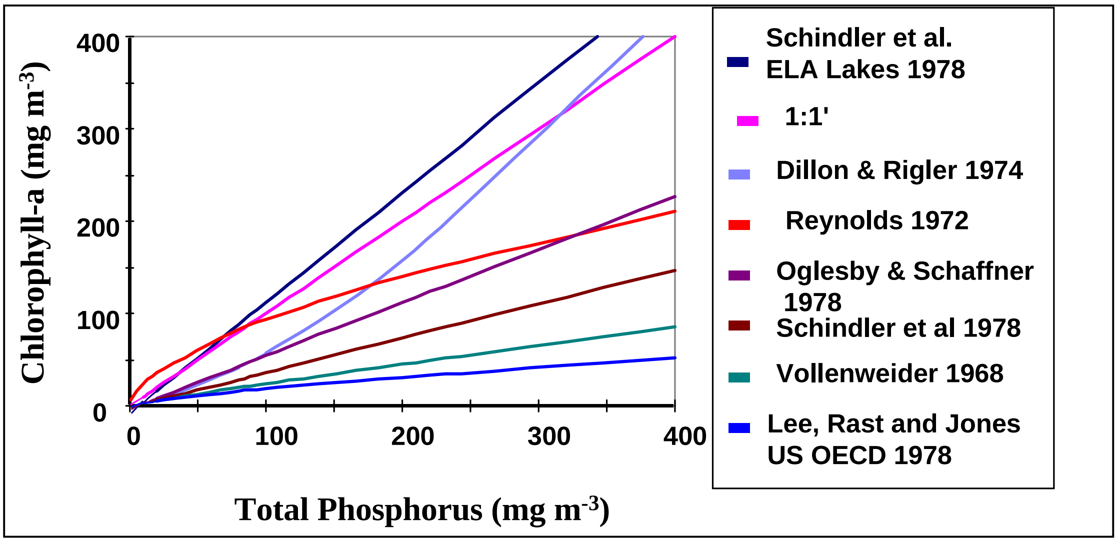

Figure 3. Relationships between chlorophyll-a concentration and total phosphorus concentration reported in major studies listed in the legend. The relationships are depicted on linear axes although in many cases correlations were determined using logarithms of concentrations. The legend lists the graphs in order from top to bottom in line with the 220 mgTP m^{-3} concentration mark on the bottom axis.

When analyses of phosphorus-chlorophyll models are restricted to lakes where phosphorus becomes limiting there is still a large variation in the correlations. In some of these cases the assumption that total phosphorus concentrations reliably and consistently estimate the phosphorus supply for the phytoplankton has been refuted. The total phosphorus concentration may be comprised of different forms of the nutrient, including dissolved orthophosphate, organic phosphorus, and phosphorus adsorbed to, or incorporated in particles. Phytoplankton can only directly utilise dissolved orthophosphate and the other forms of phosphorus must be transformed into orthophosphate to become available to the cells. Analyses of the various phosphorus forms is complicated by its particle reactivity, particularly in turbid waters where phosphorus is associated with a range of particles of different composition and size, and with varying degrees of reversibility (Froelich 1988). Attempts to measure the amount of phosphorus readily available for phytoplankton growth (including both dissolved ortho-phosphate and exchangeable phosphorus bound to particles) have generally involved complex chemical extraction procedures that are poorly linked to natural conditions (Bostrom *et al.* 1988). An alternative approach using strips of filter paper coated with iron oxyhydroxide is less intrusive and has shown some promise (Oliver 1993; Oliver *et al.* 1993; Sharpley 1993). The iron-coated filter paper strips rapidly adsorb dissolved phosphorus from solution causing the release from particles of exchangeable phosphorus to buffer the falling solution concentration. Adsorption of dissolved phosphorus by the iron-coated strips continues until all the particle-associated exchangeable phosphorus is removed into solution and adsorbed to the filter paper strips. The desorbable phosphorus (DP) measured using this technique corresponded with the phosphorus available to support phytoplankton growth measured using quantitative growth bioassays (Oliver 1993). The technique has been applied to a range of waters in the Murray Darling Basin in Australia and demonstrated that

desorbable (“available”) phosphorus can comprise between 20% to 100% of the total phosphorus concentration, with the unavailable fraction remaining associated with suspended inorganic particles. A conclusion from these measurements is that the same TP concentration can support different concentrations of phytoplankton biomass and that measurements of bioavailable nutrient concentrations are necessary to circumvent this variation. When the method was applied to eight reservoirs across Southern Australia, a single linear relationship between desorbable phosphorus and the maximum summer chlorophyll concentration was obtained (Figure 4). Of particular interest was the one-to-one ratio between phosphorus and chlorophyll concentrations, which cell composition studies suggest is the average ratio in phytoplankton (Reynolds 1984). These results indicate that bioavailable phosphorus measurements can standardise chlorophyll-phosphorus models so that a single relationship is applicable. This assumes of course that the total supply of phosphorus during the growing season is examined for its availability.

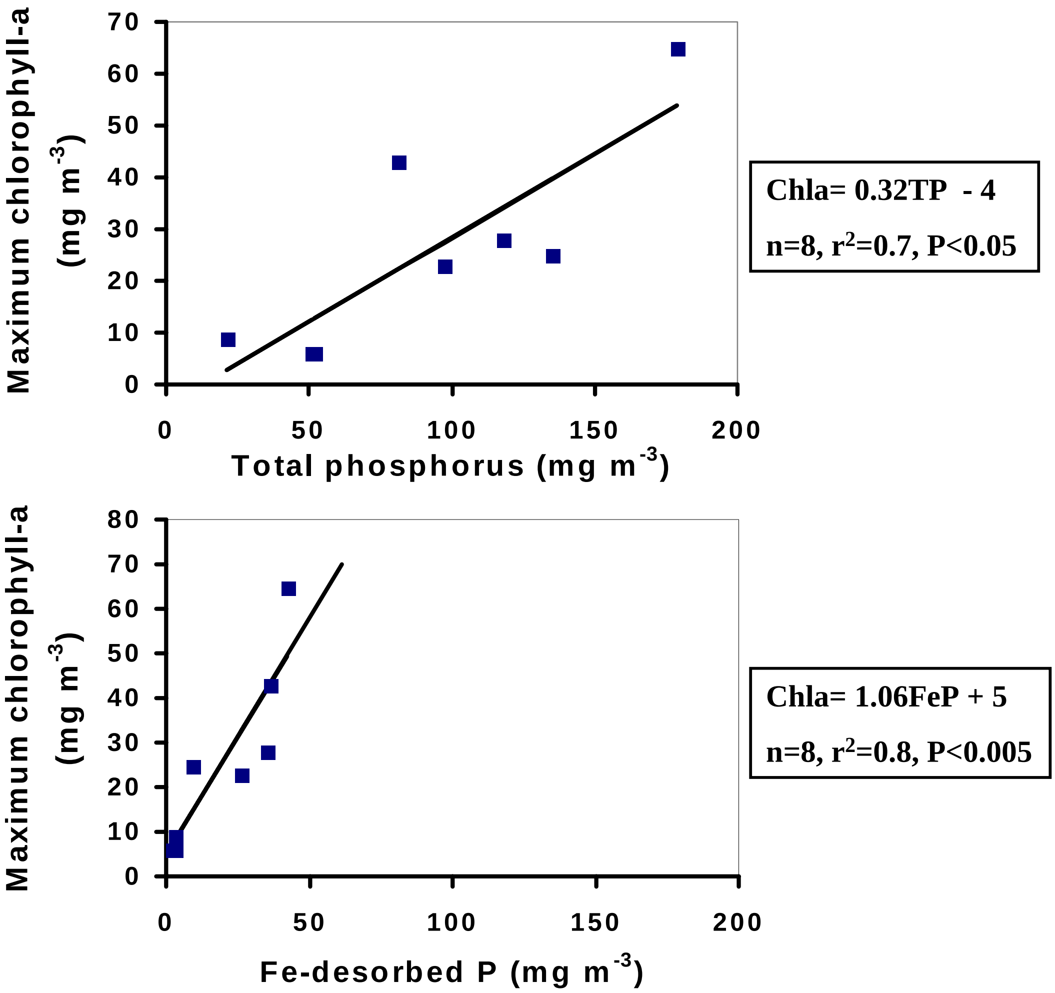

Figure 4. Data from eight reservoirs in south eastern Australia showing the relationship between the summer chlorophyll-a maximum and the concentration of total phosphorus (top) or bioavailable phosphorus (bottom) just prior to the start of the growing season. The “Fe-

desorbed P” is measured using iron-coated filter paper strips and estimates phytoplankton available phosphorus.

In lakes that are nitrogen limited (Elser *et al.* 1990; Wood and Oliver 1995) empirical chlorophyll-phosphorus models often still successfully predict the phytoplankton biomass maximum. This is because the initial nitrogen limitation favours the growth of nitrogen fixing species of cyanobacteria that utilise dissolved gaseous nitrogen and so continue to grow even when inorganic nitrogen is unavailable. In cases where the environmental conditions are suitable for these organisms, the phosphorus concentration is eventually reduced to limiting levels and determines their maximum biomass. A reduction in the phosphorus load to such systems can reduce the final biomass of nitrogen fixers that will develop. It can also reduce the likelihood of nitrogen limitation and so reduce the probability that nitrogen fixing cyanobacteria will appear. However, as these same cyanobacteria can occur when nitrogen is not limiting, their appearance in the phytoplankton community is not irrefutable evidence of nitrogen limitation. Nitrogen fixation becomes increasingly important as concentrations of total inorganic nitrogen fall below 50-100 mg/m^3 (Horne and Commins 1987).

The different forms of nitrogen appear to have an influence on the community structure of the phytoplankton. Blomqvist et al. (1994) noted from measurements on the oligotrophic, clear-water Lake Njupfatet and the mesotrophic Lake Erken that the development of cyanobacteria populations did not commence until nitrate was almost depleted. Based on results from a series of enclosure experiments enriched with either ammonium or nitrate, they postulated that non-nitrogen fixing cyanobacteria are favoured by ammonium, eukaryotic algae by nitrate-nitrogen and nitrogen fixing cyanobacteria by nitrogen deficiency. Although the occurrence of nitrogen fixing cyanobacteria in response to nitrogen deficiency is generally accepted, the suggestion of nitrate and ammonium being favoured by different organisms has not been well substantiated.

Oliver and Ganf (2000) reviewed laboratory studies pertinent to this hypothesis and suggested that a key component of the response was the influence of the light climate. In cultures of micro-algae kept under light limiting conditions growth on nitrate is equivalent to, or better than, growth on ammonium, (Syrett 1981, Thompson *et al.* 1989; Levasseur *et al.* 1993). In the cyanobacterium *Anacystis nidulans*, assimilation and growth on nitrate or ammonia is comparable if light is saturating (Guerrero and Lara 1987), but at light intensities half-saturating to photosynthesis nitrate assimilation is reduced while ammonium assimilation remains unchanged (Garcia-Gonzalez *et al.* 1992). Ward and Wetzel (1980) showed that the lowest light intensity at which growth of *Aphanizomenon flos-aquae*, *Microcystis aeruginosa* and *Anabaena flos-aquae* would occur was determined by the nitrogen source. Of the three sources tested (ammonia, nitrate and nitrogen gas) ammonia supported the highest growth rate under all light regimes.

These comparisons indicate a preference for NH_4^+ by cyanobacteria at low light intensities, but there is insufficient data to determine whether this enables them to dominate the micro-algae when ammonium is the major source of nitrogen. The results do not support the contention that micro-algae generally have a preference for nitrate, although under low light conditions the growth of some may be better on nitrate than ammonium. Importantly, it does seem that under sub-optimal light cyanobacteria growth is reduced when the nitrogen source

is nitrate, whereas growth rates of micro-algae are not affected. Rather than non-nitrogen fixing cyanobacteria being favoured by ammonium and eukaryotic algae by nitrate-nitrogen (Blomqvist *et al.* 1994) it would seem that the cyanobacteria may be disadvantaged by using nitrate-nitrogen under low light conditions (Oliver and Ganf 2000).

Organic carbon:

Oxygen depletion of the deeper water layers can occur in lakes with a high organic carbon supply to the sediments. The organic carbon can be delivered from the catchment as plant and waste material or it can be formed in the lake by aquatic plants. For example, the sedimentation of large phytoplankton populations can transfer a significant organic load to the bottom of a lake. The oxygen depletion is due to decomposition of the organic material by animals, bacteria and fungi. When oxygen is used more quickly than it can be re-supplied through the water column from the air, then anoxic conditions develop and the decomposers start to use alternative compounds to oxygen, including nitrate, iron oxides, sulphate and carbon dioxide. This shift has major repercussions for water quality and in particular results in the release of nutrients, including phosphorus, from the bottom sediments where they were sequestered. If these nutrients can be transported to the surface layers they will stimulate phytoplankton growth. Whether this occurs or not depends on the range of mixing processes and their timing.

In some lakes the internal supply of nutrients from the bottom sediments can exceed that arriving from the catchment. For example, in Chaffey Reservoir in north eastern NSW, the amount of phytoplankton that develops in the growing season is dependent on the amount of phosphorus released from the sediments into the anoxic deeper waters during the preceding year (Sherman *et al.* 2000). When the lake is fully mixed this phosphorus is distributed through the water column and governs the concentration in the surface layer when temperature stratification re-develops. It is this phosphorus that supports phytoplankton growth in the next growing season, especially in years when catchment inflows are reduced. The organic material driving the anoxic release of nutrients is the phytoplankton that grows during the summer and sediments to the bottom.

In contrast, nutrient release from sediments in some lakes is determined by the characteristics of the inflowing water. An example of this is Burrinjuck Reservoir near Canberra in the Australian Capital Territory. This lake receives a continuous flow of water, even during the dry summer, as a result of the discharge from a large sewage treatment plant. In this system the interaction of flow, nutrient content of the discharge and delivery of organic carbon to the narrow and relatively shallow receiving arms of the reservoir regulates phytoplankton growth (Lawrence *et al.* 2000). Historically nutrient concentrations were high in the reservoir because the sewage treatment works released large quantities, but upgrades to the STP reduced the phosphorus load and as a result cyanobacterial blooms in the lake were reduced. The occasional blooms that now occur in the lake are the result of high river flows delivering significant organic carbon concentrations in the form of periphyton and macro-algae to the reservoir. These plants grow in the river under moderate and low flows and capture nutrients in the stream, reducing the nutrient load to the reservoir. However, during high flows the plant material is sloughed from the river and transported to the reservoir where it is deposited in the shallow receiving arms. The breakdown of the organic material releases nutrients from the bottom sediments that stimulate the growth of cyanobacteria.

The impact of internal nutrient supplies from bottom sediments was also demonstrated in the large data set analysed by Sas (1989). Whereas in some lakes a reduction in the phosphorus load resulted in an immediate response in the phytoplankton biomass, the response in other lakes showed lag times of up to four years before significant reductions in biomass were achieved. The time lags reflected the magnitude of the sediment release of phosphorus. The lag time is not a necessarily a reflection of the period required to strip the sediments of phosphorus, although this depends on the sediment characteristics. Often it is a period required for reducing the supply of organic carbon that is generating phosphorus release from the sediments.

These studies indicate the importance of identifying whether sediments supply significant amounts of nutrients to the overlying water, and if so where the organic carbon that drives the nutrient release is derived. If phytoplankton form the major source of organic carbon then nutrient reduction strategies should eventually reduce this impact. However, if organic carbon is supplied from the catchment then a different strategy is required and the sources of organic carbon need to be identified and managed.

BIOLOGICAL INFLUENCES:

The community composition of the phytoplankton is impacted by a number of biological influences, two of these are grazing and competition with macrophytes and will be briefly discussed here. Others, such as fungal and viral infections are still poorly understood and will not be considered.

Zooplankton grazing:

Grazing can be a major loss factor modifying the biomass and community composition of phytoplankton. Gliwicz (1968) and Haney (1973) estimated that zooplankton communities could ingest 48-162% of their own biomass per day, and had daily community grazing rates that could process 10 to >100% of the water volume that they occupied. The major groups of animals present in the zooplankton community have diverse means of selecting, obtaining and ingesting food organisms (Reynolds 1994). However, although specialist protozoans and rotifers impact significantly on their particular food sources, it is the generalist feeders that often have the greatest effect on the phytoplankton. As concentrations of prey increase above certain thresholds, the grazing impact of the less selective filter feeding rotifers and cladocera becomes increasingly significant (Reynolds 1994). Of these generalists, it is *Daphnia* species that often have the greatest effect (Vanni and Temte 1990; Matveev and Matveeva 1997). Of particular relevance to water quality issues is the impact of grazers on populations of cyanobacteria.

In Lake Mendota, Wisconsin grazing impacted most on the phytoplankton community during spring while nutrient limitation was more severe in summer (Vanni and Temte 1990). This change was in part due to the replacement of the dominant edible phytoplankton species that occurred in spring by more resistant species in summer. *Daphnia* had the largest impact on the spring phytoplankton and was considered mainly responsible for the clear water phase. It was less effective on the large, inedible phytoplankton species that were dominant in summer, particularly cyanobacteria and the dinoflagellate *Ceratium*.

In Lakes Hume and Dartmouth, both man-made lakes located in south-eastern Australia, manipulations of the large cladocerans (*Daphnia* and *Diaphanosoma*) and the large copepod (*Boeckella*) had negative effects on the phytoplankton biomass, while smaller copepods (*Mesocyclops* and *Calamoecia*) had little impact or occasionally a positive effect (Matveev and Matveeva 1997). In both reservoirs the variation in *Daphnia carinata* alone could account for 50% of the variance in total phytoplankton biovolume. Colonies of *Microcystis* <50 µm diameter were grazed in feeding trials by both *Daphnia* and *Boeckella* without any suggestion of selectivity. Even when *Microcystis* dominated in enclosures grazing by *Daphnia* and *Boeckella* could reduce cell concentrations.

These studies are in general accord with many others that have found correlations between the abundance of zooplankton grazers and the timing of cyanobacterial blooms (Haney 1987). In general reduced grazing on cyanobacteria is associated with large size, high density and poor assimilability. The maximum size of food particles (y) taken in by *Daphnia* species is a function of the animals length (L) as described by Burns (1968).

$$y = 22L + 4.87$$

This indicates a maximum particle size of 49 µm for a large, 2 mm animal (Reynolds 1994). In general the optimum food sources are small planktonic algae whereas larger colonial and filamentous cyanobacteria have a depressive effect on filter feeding due to mechanical interference with the feeding apparatus (Reynolds 1994).

Burns (1987) summarised findings from enclosure experiments reported in the literature and concluded that in long term incubations dominated by large herbivores the more edible cyanobacteria showed an inverse relationship with grazer density. There appeared to be a threshold concentration of ca. 5×10^4 grazers m^{-2} above which filamentous cyanobacteria could not withstand grazing but large inedible colonies could (Lynch and Shapiro 1981). A similar result was reported by Ganf (1983) from a comparison of *Aphanizomenon flos-aquae,* which occured as large flakes and dominated in the presence of *Daphnia pulex*, with filamentous *Aphanizomenon elenkinii* that dominated only when *D. pulex* was absent. Reductions in the edible species required a threshold concentration of grazers of ca. 12 per litre.

It seems that zooplankton grazing can reduce the biomass of cyanobacterial populations provided they are present before the cyanobacteria attain a size larger than the animals can manage. If the phytoplankton species can reach a large size prior to substantial increases in the most effective grazers then the likelihood of control by grazing will be diminished. The grazing impact will therefore depend on the dynamics of the phytoplankton and zooplankton communities.

A number of indices have been suggested for assessing zooplankton grazing effects at the whole lake level (Reynolds 1994) including zooplankton number (Lynch and Shapiro 1981), total zooplankton biomass, and the ratio of biomass of zooplankton to phytoplankton. Matveev and Matveeva (1997) found in enclosure experiments that grazing was significant when the Cladocera/Phytoplankton biomass ratio was greater than 0.1, and showed that in both Lakes Hume and Dartmouth the clear water phases occurred when this ratio was exceeded, even when cyanobacteria were present.

Macrophyte competition:

In shallow lakes, or lakes with extensive shallows, macrophytes can have a substantial influence on the chemical, physical and biological conditions. At relatively low nutrient concentrations shallow lakes are generally characterised by abundant submerged macrophytes and clear water while at higher nutrient concentrations they are characterised by abundant phytoplankton and turbid water (Blindlow *et al.* 1993). These two conditions have been widely reported and are often considered as alternative stable states (Scheffer 1990). Light is a key factor controlling the occurrence and biomass of macrophytes and switching between states is often associated with changes in the availability of light, although direct evidence for this is not always well documented (Moss 1995). Reductions in light have been attributed to increases in water level, to alterations in turbidity or colour, and also to increased nutrient concentrations supporting larger phytoplankton and periphyton populations that shade underlying macrophytes. The presence of macrophytes creates conditions that are conducive to their maintenance. They reduce water movement and sediment re-suspension so reducing turbidity. They reduce nutrient concentrations either as a result of direct uptake or through modification of the bottom sediments and this inhibits phytoplankton growth. Dense plant beds offer shelter to invertebrates and their high densities increase grazing pressure on phytoplankton (Timms and Moss 1984). The presence or absence of plants can also influence fish populations (Blindow *et al.* 1995). Piscivores are less abundant in the turbid state and this decreases predation pressure on cyprinids. Cyprinids are thus abundant in the turbid state and assist in maintaining this state through sediment resuspension and efficient predation on zooplankton feeding on phytoplankton. Both processes increase nutrient concentration and reduce light availability in the water.

The influence of macrophytes on the functioning of aquatic ecosystems is complex, and perhaps this is why no simple, quantitative generalisations could be drawn from the literature to help assess the influence of macrophytes on phytoplankton blooms or on water quality in general. This is surprising considering the extent of the published literature on macrophytes, but I suspect that experienced researchers could develop useful indicator values for particular environments.

DECISION SUPPORT TREE:

The foregoing sections have described briefly the environmental conditions that influence phytoplankton populations and in particular the growth of cyanobacteria. These interactions have been summarised in a decision support tree that attempts to set general threshold levels indicative of the conditions needed to influence cyanobacterial blooms (Figure 2). Some of these interactions are more amenable to management than others and their relative importance will be system dependent. From a risk assessment stance all of these interactions (and others that have not been included) should be considered when assessing the causes for occurrences of cyanobacterial blooms. This is not an attempt to complicate what may seem a straightforward problem. Nutrient enrichment, a ubiquitous effect of human activity in water catchments, undoubtedly plays a major role in many cases and nutrient load reductions will be an obvious response. However, water resource managers are still faced with the difficulty of determining what should be reduced and by how much. Targets need to be set and complications addressed. In water supply reservoirs where water quality is the only issue and environmental considerations are secondary, a single nutrient reduction may be a successful

strategy. However, experience suggests that even in these situations a successful outcome cannot be guaranteed (Moss 1995). In lakes where environmental considerations are also important then the task is more difficult. There are important issues to be addressed, such as identifying the final mixture of nutrient forms that would be appropriate to the system, ensuring that alternative sources of nutrients do not negate the restoration, and assessing whether changes in plant and animal communities that have already occurred are reversible. These are just a few of the issues that need to be addressed when it becomes necessary to actively manage an aquatic ecosystem. There is also the stark reality that some changes are unlikely to be reversible in a time frame that has relevance to political and social desires. These need to be identified.

The purpose of the conceptual model is to provide an overview of these issues and an indication of their scale. It provides a framework for discussion and a basis for integrating information. The models are dynamic in the sense that threshold values are not reliable constants but instead represent hypotheses that are improved with further information and discussion. The aim is to provide values that are appropriate to a particular system and that can inform the decision-making process. Finally, a conceptual model is a tangible commodity that provides a reference point for ongoing discussions. It is one means of trying to enhance communication between the diverse groups who are involved in using and managing water resources.

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CYANOBACTERIAL BLOOMS IN ROTORUA LAKES

Dr Phil Shoemack
Medical Officer of Health, Pacific Health, TAURANGA

CYANOBACTERIA

- CHIEF PRIMARY PRODUCERS OF ORGANIC MATTER
- REQUIRE LIGHT, & NUTRIENTS
- CAPABLE OF NITROGEN FIXATION

CYANOBACTERIA

- FOUND IN ALL FRESHWATER
- BLOOMS INFLUENCED BY CLIMATIC CONDITIONS AND NUTRIENT LEVELS
- FLOATATION
- DISINTEGRATION OF BLOOM DEOXYGENATION
- SOME PRODUCE TOXINS

TOXINS

- COLOURLESS
- MAY BE POTENT FOR WEEKS
- STABLE, UNAFFECTED BY BOILING
- CANNOT FILTER OUT
- ? CHRONIC TOXICITY (AMES -VE)

HEPATOTOXINS

- LIPID SOLUBLE PEPTIDES
- GASTRO SYMPTOMS
- LIVER DAMAGE
- CAUSE HAEMORRHAGE + CIRCULATORY COLLAPSE
- DEATH CAN OCCUR WITHIN 24 HOURS

NEUROTOXINS

- WATER SOLUBLE ALKALOIDS
- DO NOT CONCENTRATE IN FAT OR MUSCLE
- CAUSE HEADACHE, MUSCLE TREMOR, PARALYSIS
- DEATH CAN OCCUR IN 5-30 MINUTES - FROM RESPIRATORY ARREST

ENDOTOXINS

- PHENOLICS
- CAUSE SKIN RASHES, EYE IRRITATION, ALLERGIC REACTIONS (WITH HAY FEVER, ASTHMA)

CYANOBACTERIA ALERT LEVELS

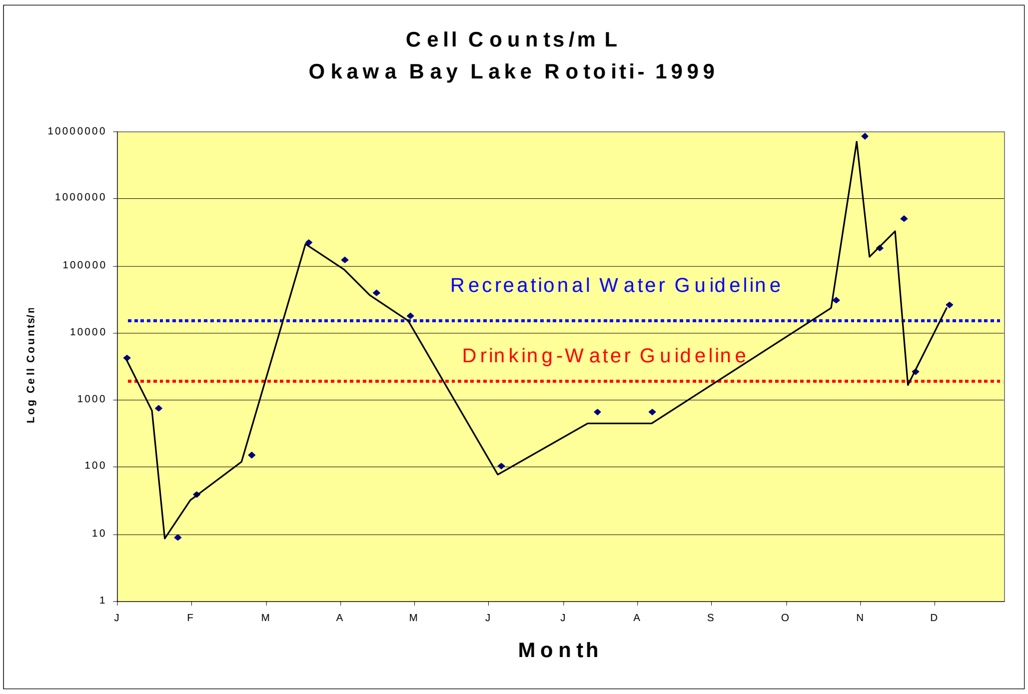
- 500-2000 CELLS/ML MONITOR
- OVER 2000 CELLS/ML STOP USE AS DRINKING WATER SOURCE
- OVER 15,000 CELLS/ML STOP ALL RECREATIONAL CONTACT

WATER TREATMENT

- <u>CHEMICAL</u> - COPPER SULPHATE, PHENOLICS
- <u>BIOLOGICAL</u> - SNAILS
- <u>MICROBES</u> ?
- ONLY REAL SOLUTION IS LONG TERM REMOVAL OF NUTRIENTS

ORGANISATIONAL RESPONSIBILITIES

- ENVIRONMENT BOP - SURVEILLANCE OF WATER QUALITY
- ROTORUA DISTRICT COUNCIL - WATER SUPPLIES, RECREATIONAL USE
- PUBLIC HEALTH - HEALTH ASPECTS/WARNINGS


Cell Counts/m L
Okawa Bay Lake Rotoiti- 1999
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Recreational Water Guideline
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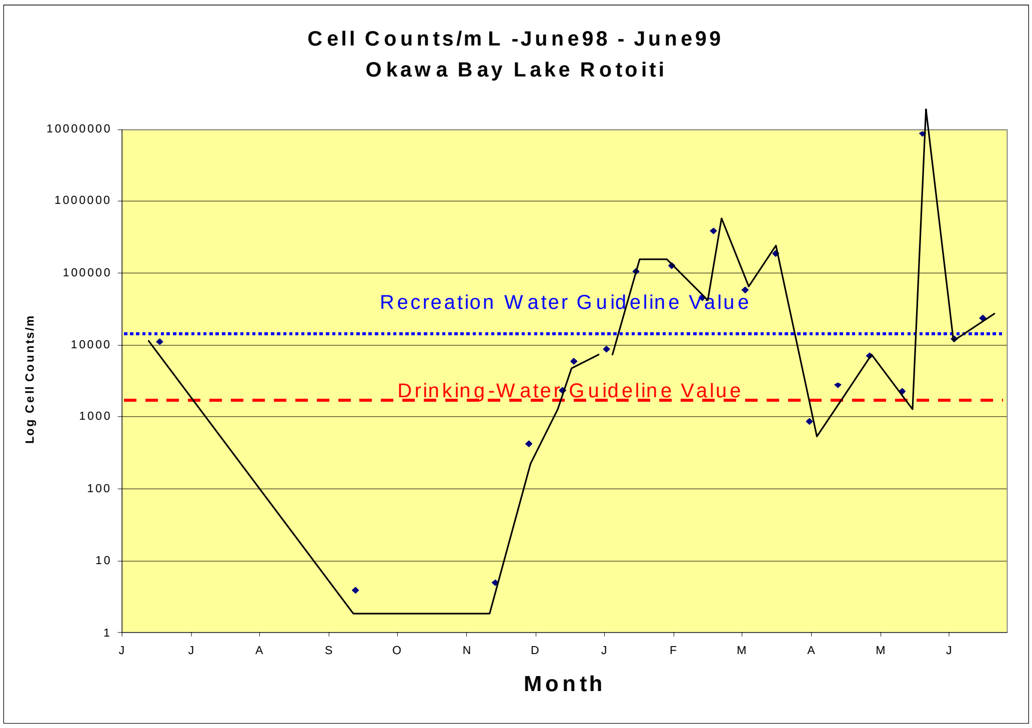
Cell Counts/m L -June98 - June99
Okawa Bay Lake Rotoiti
Log Cell Counts/m
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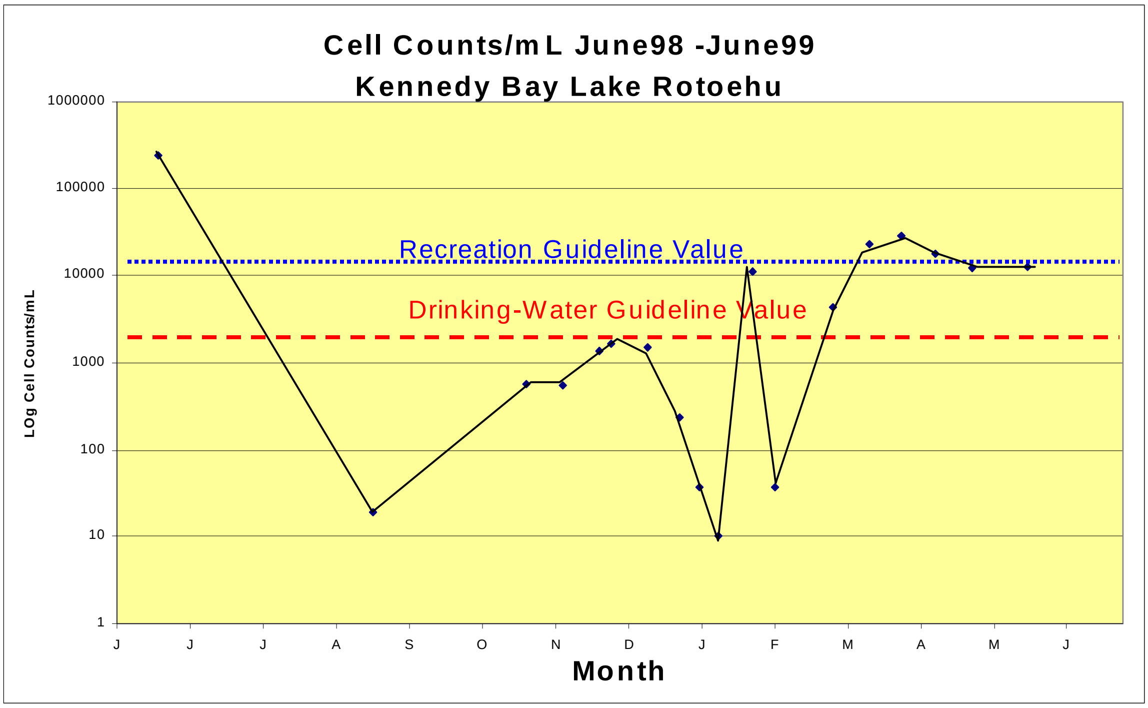


Questions

Unidentified speaker

Comment rather than a question – there's quite a lot of debate about these alert levels, in fact the World Health Organisation has put out or is about to put out some new guidelines which have been looked at by countries around the world who suffer these problems. ARMCANNZ (Agricultural Resource Management Council of Australia & NZ) have actually an algal manager, based in Australia, who has close links with the WHO in this debate about critical levels - they are doing work on all these matters. They will have an experiment underway shortly using volunteers and applying the material to skin.

Lindsay Brighouse

As a person who lives close by the lakes I assure you that the appearance of the notices has a devastating effect, not only on the people who live by the lakes but also out tourism economy in the district. It has come under close scrutiny and is one of the reasons why we are all sitting here today. Do you consider that our local medical fraternity is able to handle the symptoms that may come from this type of thing.?

Shoemack

At the beginning of summer I got in touch with all the GPs who live in the district to set up an informal surveillance system asking them to report to me any patients that they thought might have symptoms of problems of exposure to cyanobacteria. We explained to them the sort of things to look for.

Brighouse

Was there much came back from that at all?

Shoemack

No, I've only had two reports this summer of cases that may have been related.

Brighouse

It does appear from what you've related that these symptoms could well have come from something else?

Shoemack
That's right. That's what makes it all the more difficult.

Unidentified speaker
Phil, I just wonder whether you could talk a little about whether activated carbon has been considered as a water treatment technique or whether it's not really practical for the Rotorua lakes.

Shoemack
I'm not sure.

Unidentified speaker
I used to work with the Public Health Unit in Australia and I know that activated carbon was used as a filter in some areas particularly for reservoirs, however it is quite expensive.

Shoemack
Any other views?

Tim Charleson, RDC
I believe the Ministry of Health's view on this is that activated carbon isn't really a viable option mainly because of the large number of toxins that are around that need different types and it's very hard to evaluate the life of the activated carbon so essentially it's been dropped as a viable option.

Nick Miller, LWQS
Another problem is that all the active sites in the carbon are going to be busy adsorbing all sorts of other compounds than toxins and are going to get exhausted quite quickly.

Mary Stanton, Okawa Bay, Lake Rotoiti
This is not a question, but more a plea for health. We live in Mourea, we do not have a water supply and we are in an area where we are really affected by water quality. I am a permanent resident of Mourea and I've seen many of our people die at a dramatically increasing rate. Today we have a funeral, one of our locals, and when I look at the history of our people and their suffering I wonder whether this has a major impact on the health, the environment, and our people who live in Mourea / Okawa Bay and I do not like to see our children affected by water quality that is not regulated for our community. Kia Ora.

Unidentified speaker
Mr Chairman, I would like to make a comment too. The title of your talk is 'What colour do you want'. It seems from what I've heard that colour is not the problem, but something colourless is the problem. We seem to be spending a lot of time collecting data on cell numbers and cell types but are we collecting data that is not appropriate to decision-making about water quality and the health issues?

Shoemack
Are you suggesting we should do more work on the toxins?

Unidentified speaker
That's right, yes. So who monitors toxins.

Shoemack
Again, between EBOP and ourselves, each time we get the start of a new bloom, part of that sample is sent away for bioassay testing to see if it is toxin-producing. The difficulty with that is it only helps you if it comes back positive. If it comes back negative all you can say is that at that particular time that sample wasn't producing a toxin. It might have been an hour

later or a day later, or in the next bay, that's the difficulty. So every time you get one of these blooms you have to assume that it's capable of producing toxin, even though it might not have been doing so at the time you took the sample.

Dr Rod Oliver?
Just commenting on that, where studies have been done to look at toxicity of blooms over a period of time, or in a range of areas, on average something like 60% of blooms tend to be toxic, so it is a very difficult problem to deal with the toxicity and I think you have to assume that, as the speaker said, the blooms are going to be toxic because testing of them regularly enough is very expensive and very difficult at the moment.

Dr Robert Franich, Forest Research
The issues around measuring toxins on a regular basis and the cost of doing it, whether by bioassay or mass spectrometry, are something that this conference can think about and pursue further questions or comments about. It's a matter of actually getting the correct data for making the appropriate decisions at the time. Your Decision Support System (DSS) has got a lot of information that's been gathered about the environment, and the cell types and numbers but there's a piece of information missing – the chemical makeup of the toxins at the time. To my mind this is a very important piece of information that's missing out of that DSS. How we actually fund such a toxin-information-gathering system, who does it – is it a national or local issue – these are all questions.

ROTORUA LAKES BLUE GREEN ALGAE MONITORING

Thomas Wilding
Environment B·O·P, WHAKATANE

Abstract

Environment B·O·P has monitored blue-green algae in Lake Rotoehu since 1993, with Lakes Rotoiti and Rotorua monitored since 1997. Lake Rotoehu and Okawa Bay (a semi-enclosed bay off Lake Rotoiti) were most prone to blooms. Because Lake Rotorua is well mixed, owing to its long fetch, this lake experiences fewer blooms in spite of high nutrient levels. Lake Rotoehu has deteriorated since 1993 with increased intensity and duration of blooms. The likelihood of algal blooms was found to be highest during autumn and summer. Timing can be related to stratification and nutrient availability. Species of *Anabaena* were most commonly responsible for blooms (including *A. spiroides, A.circinalis, A. flos-aquae, A. solitaria*). Blooms of *Aphanizomenon flos-aquae* were recorded in Lake Rotoehu. *Microcystis* became the dominant alga in eutrophic Lake Rotoehu during autumn 1997 and was responsible for most of the blooms since. High concentrations of *Microcystis* first appeared in Okawa Bay (Lake Rotoiti) during autumn 1999 (displacing *Anabaena* spp.).

Toxicity testing was opportunistically undertaken. Samples were sent to ESR for mouse bioassays. To date 4 of the 19 samples (21%) have tested positive, compared to 40% of samples tested in Australia (where our health standards were derived).

The risk of lakes developing severe and persistent blue-green algae blooms was investigated. Lakes at risk are shallow, calm and have large areas of pastoral and urban land use. Lake Rerewhakaaitu is the only high-risk lake that hasn't already developed blue-green algae problems.

Introduction

Blue-green algae (Cyanobacteria) blooms have at times occurred in most of the Rotorua lakes. This is by no means a recent natural phenomena, but has only recently received attention as a potential health threat. The toxicity of blue-green blooms is well documented from lab tests and the death of livestock following ingestion (Baker and Humpage 1994). Since the occurrence of a toxic algal bloom on Lake Rotorua in 1997, Environment B·O·P has monitored the presence of blue-green algae in near-shore waters of Lakes Rotorua and Rotoiti. Monitoring of Lake Rotoehu began in 1993 after locals complained of taste and odour problems in the domestic water supply (Power & Donald 1993). Significant numbers of blue-green algae were detected forcing residents to find alternative water supplies.

Following on from overseas guidelines (New South Wales Blue-Green Algae Task Force) and policy adopted by Council in 1993, Environment B·O·P provides the relevant health authorities (Pacific Health) with results of the blue-green algae monitoring programme. Two 'alert triggers' are used for action by health authorities. At a cell concentration of >2,000 cells/ml potential toxicity problems can occur if water is taken for drinking purposes and at >15,000 cells/ml the water may be unsuitable for general contact recreation and stock

watering (Anon. 1993). To put these figures into perspective, surface scums and marked green discoloration of the water typically coincide with cell concentrations in the order of 30,000 to 100,000 cells/ml. To date, health warnings have been issued for Lakes Rotoehu, Rotoiti, Rotorua and Tarawera.

Methods

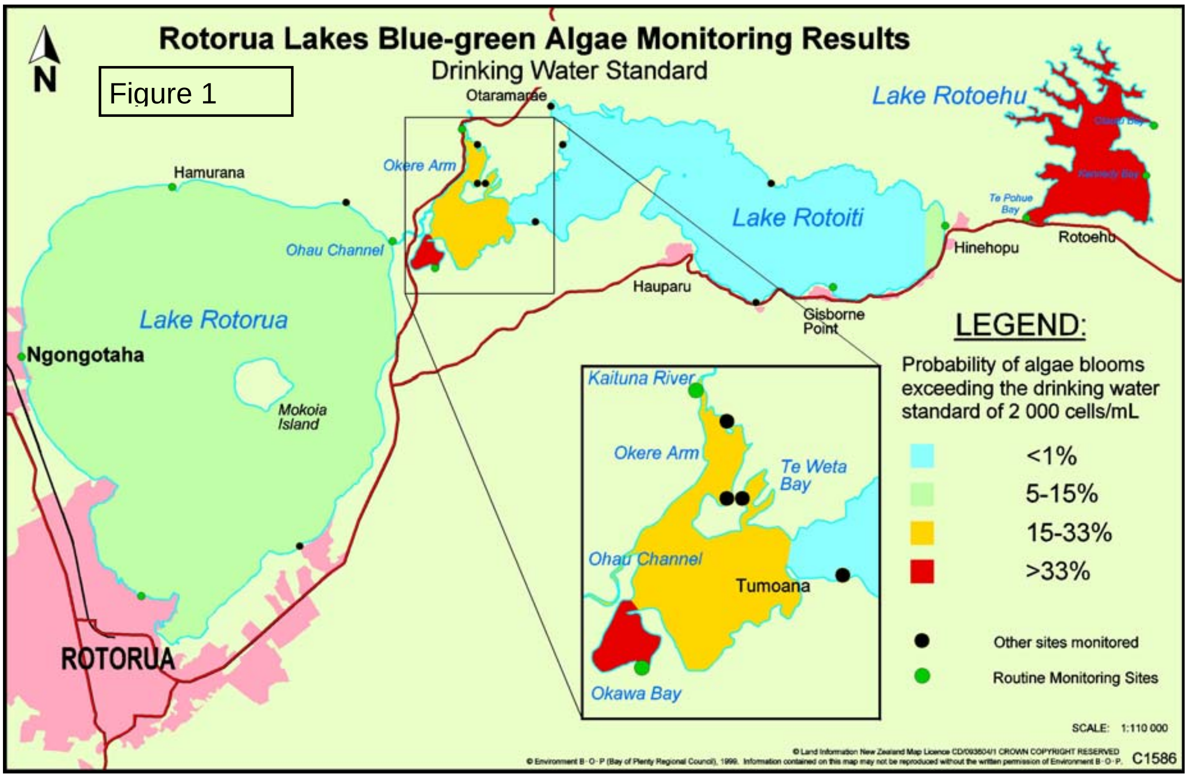
Water samples were collected fortnightly during summer and early autumn and less often during winter and spring. Sites were routinely monitored on Lakes Rotoehu, Rotoiti and Rotorua (Figure 1). Additional sites were sampled in response to local reports. Samples are collected from the shore, typically from a jetty or by wading out a short distance. Abundance is estimated using the Utermohl sedimentation technique (Utermohl 1958, Lund *et al.* 1958). A 10 ml subsample from each site is pipetted into a Utermohl (sedimentation) chamber with 2-4 drops of Lugol's iodine (preservative). This is left to settle overnight on a level plate. Algae are identified to species level using Etheredge and Pridmore (1987).

Samples are occasionally sent to Environmental Science and Research (ESR) to be tested for the presence of toxins. In early testing samples were concentrated by centrifugation, and the solid matter sonicated and filtered prior to being screened for toxicity using mouse bioassays. More recently (since early 1999) samples have been sonicated, filtered and freeze-dried prior to inoculation into the mice. This has enabled between 100-fold and 300-fold concentration of toxicity in all samples. The earlier method gave a 10-fold concentration.

Results

Spatial Trends
Spatial and temporal trend analysis made use of the summer and autumn data. This is when blooms were most likely to occur; more people visit the lakes; more samples were collected and these were collected routinely (at least fortnightly). The risk of algal blooms exceeding health standards (drinking water and contact recreation) was calculated for each monitoring site using data to May 1999 (Figure 1). For Lake Rotoiti correlations between routine monitoring sites and beaches occasionally sampled provided a better distinction of the 'risk boundaries' defined in colour.

Lake Rotoehu and Okawa Bay (Lake Rotoiti) experienced blooms more frequently and more severe than the other sites. The risk value for Lake Rotorua is the product of one severe bloom documented in 1997, which followed a period of unusually calm weather. Blooms on Rotorua have coincided with calm weather in the past (White *et al.* 1978).



In terms of aerial extent Lake Rotoiti is the most variable. Results from NERMN monitoring have already shown the lake can be divided between east and west in terms of water quality, because of the influence of Lake Rotorua and geothermal inflows (Deely 1995). The area west of Tumoana Point (Figure 1) is also shallower than the rest of the lake (10-15m versus 40-70m). Microalgae in shallower water bodies are known to reach a higher biomass for a given concentration of nutrients (Pridmore *et al.* 1985, Smith 1985). The blue-green results suggest Okawa Bay represents a third distinct water body, where blooms occur as often as Lake Rotoehu. Shallow calm conditions presumably contribute to blooms here. The 43 hectare bay is largely enclosed, reaching a depth of 6-8m. Hinehopu is distinguished from the main body of the lake because two blooms were detected here while none were observed at Gisborne Point. More recent sampling suggests a closer association between the two sites.

Significant algal blooms on Lake Okaro are well documented (Vincent & Dryden 1989), and from the algal community monitoring data it is assumed to represent a similar or greater level of risk than Lake Rotoehu (see Wilding 2000). A bloom was recorded on Lake Tarawera in December 1998. Sampling indicated this was confined to the Hotwater Beach area, where chemical weed control was undertaken a few weeks earlier. Blue-green blooms were documented on Lake Tarawera previously (Pridmore and Etheredge 1987). Because of the large volume of the lake and tendency for blue-green algae to accumulate on the shore, these isolated blooms do have the potential to be severe. Given that Tarawera is oligotrophic (low nutrient) such blooms are expected to occur infrequently.

Trends Over Time (year to year)
Rotoehu has shown a consistent upward trend between 1995 and 1999 (Figure 2). Algae concentrations in 1994 were as high as they reached in 1999. But only 4 samples were collected in 1994 so may not disprove a gradual decline in lake condition. This pattern reflects nutrient changes in the lake (Burns 2000). While there appears to be a trend at Gisborne Point/Hinehopu and Okere Arm (all on Lake Rotoiti) this may be an artefact of sampling duration. Blooms on Rotoiti often occur when stratification breaks down in late autumn. More sampling was undertaken during autumn in recent years, producing a higher median concentration.

Seasonal Trends
Seasonal patterns were clear for lakes Rotorua and Rotoiti (excluding Okawa Bay), with blooms most likely during autumn (March-May) followed by summer (December-February) and then winter (June-August), (Figure 3). Blue-green numbers were lowest during spring (September-November) for all lakes monitored. Lake Rotoehu and Okawa Bay (Lake Rotoiti) otherwise showed little seasonality with blooms likely during summer, autumn and winter.

Lake Rotoehu provides the longest running dataset and hence was used to further explore these trends in relation to water quality data (see Deely 1995 for water quality methods). Monthly averages of the two data sets are displayed in Figure 4. The heterocystous algae (principally *Anabaena* spp.) reach an early summer peak in response to increasing water temperatures and water column stability[1] . Presumably dissolved nutrients become the limiting factor as the algae exhaust epilimnetic supplies, and cell concentrations gradually drop off through the remaining summer months. The significant increase in DRP (dissolved reactive phosphorous) indicates nitrogen is the limiting factor at this time. This supports White's (*et al.* 1985) conclusion, finding Rotoehu to be nitrogen-limited during summer only. As water column stability decreases in autumn, DIN (dissolved inorganic nitrogen) supplies from the sediment are re-established and heterocystous algae numbers show a slight resurgence. *Microcystis* (not plotted) first bloomed in 1998 and subsequently established itself as the dominant taxon. For the first few years blooms occurred in autumn coinciding with the breakdown of stratification. Each year *Microcystis* has appeared earlier and disappeared later.

While there was less data available for Rotoiti, examination of available results suggest cell counts rise with the onset of stratification (summer); dropping off when the lake is most stable; with a resurgence as water column stability starts to break down again in late autumn.

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[1] The difference in dissolved oxygen concentrations between the bottom and surface waters, labeled "DO difn" was deemed the best indicator of water column stability in such shallow waters that rarely stratify in the strict sense of the word.

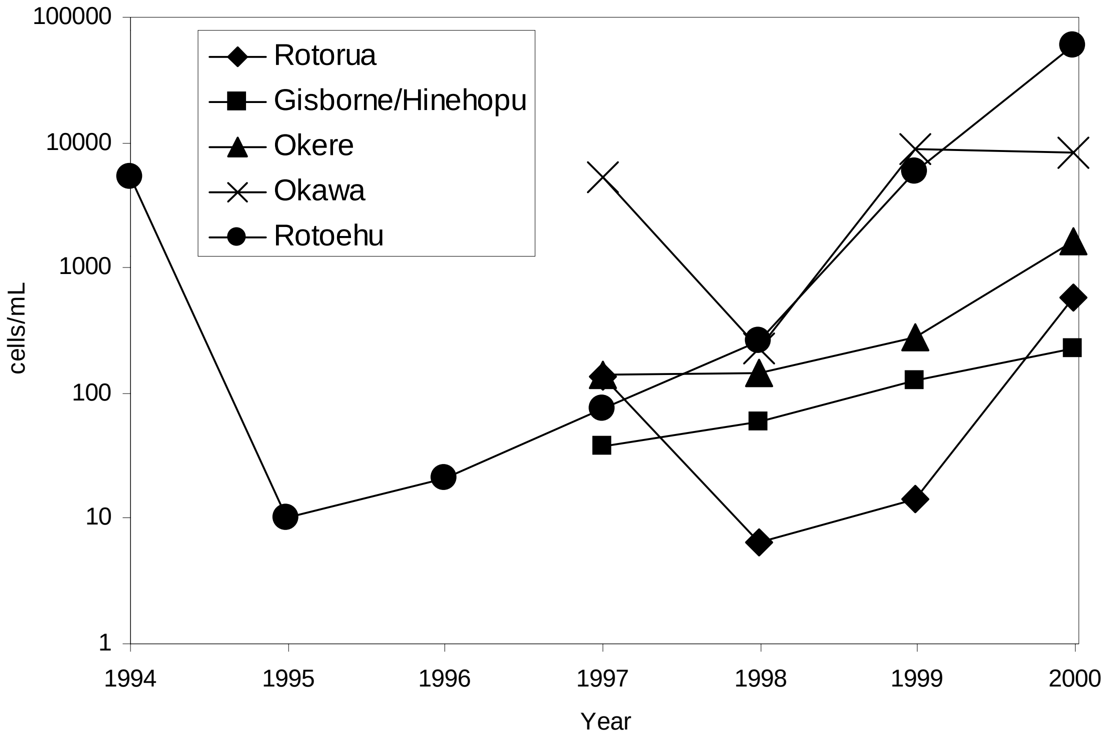

Figure 2 *Median blue-green algae concentrations for summer and autumn of each year (e.g. 98=Dec 1997 to May 1998). Gisborne Point, Hinehopu, Okawa Bay and Okere Arm are sites of Lake Rotoiti.*

Blue-Green Algal Taxa

Species of *Anabaena*, including A. *flos-aquae,* A. *circinalis* and A. *spiroides* var. *crassa* were the most widespread blue-green taxa, forming nuisance blooms on lakes Rotoehu, Rotorua and Rotoiti. *Aphanizomenon flos-aquae* was recorded at most sites during autumn. Numbers were typically low for Lake Rotoiti (range: 2-957 cells/ml) but contributed to Lake Rotoehu blooms in 1993 and 1999 (median 6204 cells/ml).

Microcystis aeruginosa has long been associated with the eutrophic Lake Okaro (Vincent and Dryden 1989). It was first noted in Lake Rotoehu in January 1997 and became the autumn dominant algae in 1998. Since then *Microcystis* was responsible for many severe blooms on the lake (up to 85,000,000 cells/ml). Each year *Microcystis* appears earlier and persists longer. Okawa Bay (Lake Rotoiti) experienced its first recorded *Microcystis* bloom during Autumn of 1999. This also affected many of the western bays on Lake Rotoiti during May (< 3 weeks).

Toxicity Testing
Of the 19 samples sent to ESR for toxicity testing, 4 (21%) screened positive. Samples collected from Lake Tarawera on 23 December 1998 were not found to be toxic, however a week earlier people water-skiing had displayed symptoms of toxin exposure (intense rash of the face, arms and torso) and a fish kill was noted.

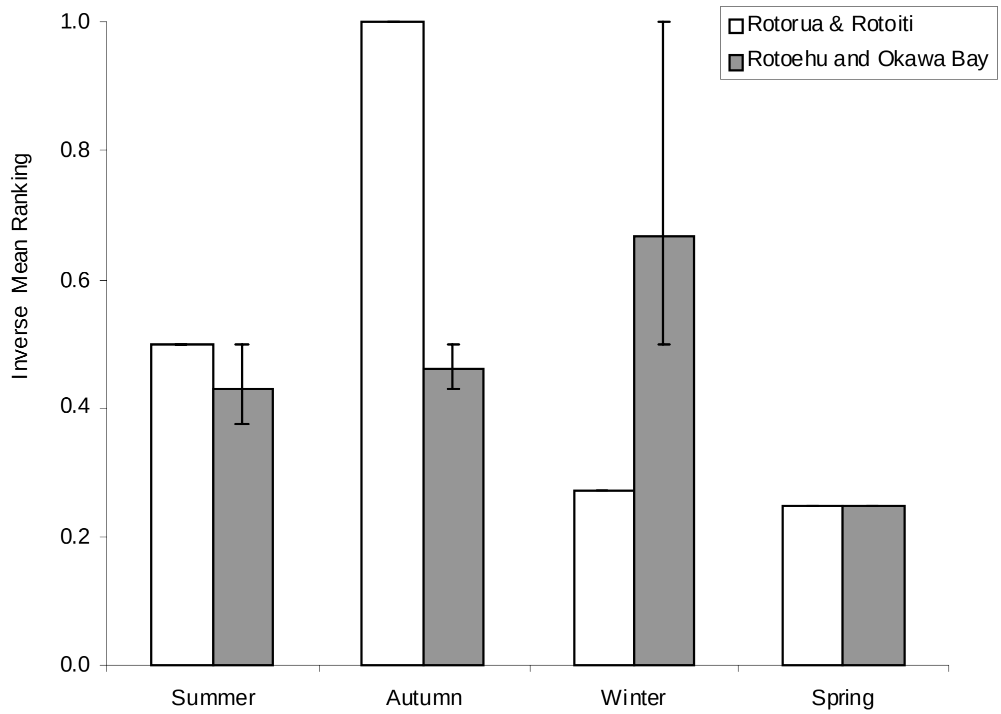

Figure 3 *Seasonal trends of blue-green algae for monitored lakes. The higher the 'inverse mean ranking' the greater the chance of algae blooms, (% exceedance and average cells/ml were ranked, then the two averaged). Error bars indicate the range of values across lakes.*

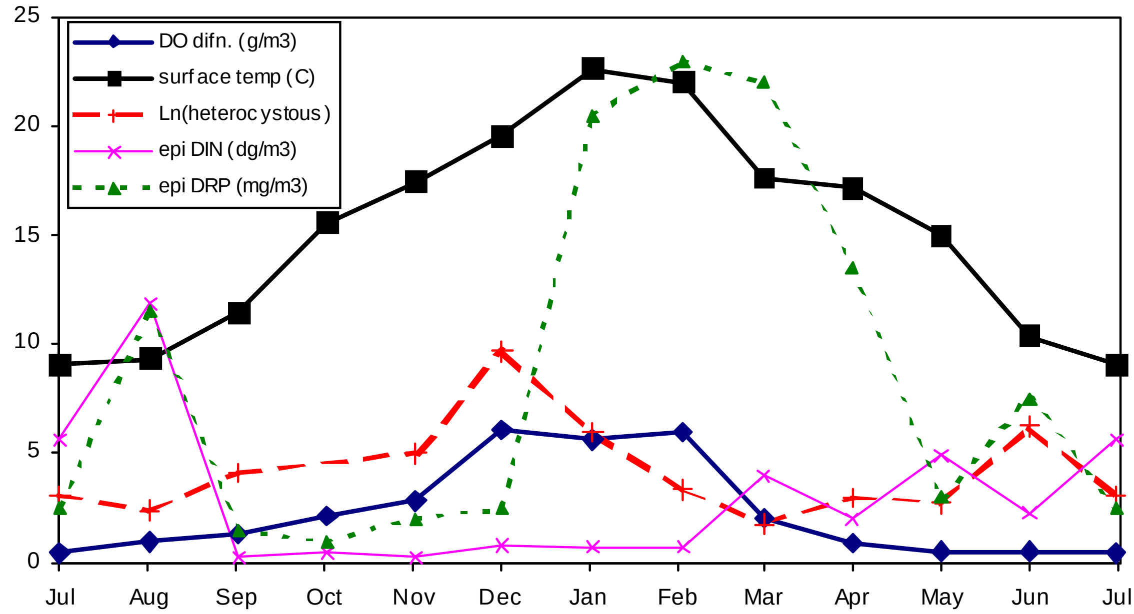

Figure 4 *Lake Rotoehu monthly medians for the period 1993-1999. Oxygen profiles and epilimnetic (surface sample) chemistry results from site 1. Dissolved oxygen concentration at the bottom of the lake was subtracted from surface values to give the DO difference. Heterocystous algae cell counts per ml are the sum of* Anabaena *species plus* Aphanizomenon *averaged across sites and log transformed. DIN = dissolved inorganic nitrogen; dg/m³ = g/m³ x 100; DRP = dissolved reactive phosphorus; epi = epilimnetic.*

Discussion

What Causes the Blooms?

A lot of scientific research has focussed on the causes of blue-green algae blooms, both in New Zealand and overseas. Much of this work has focussed on nitrogen – phosphorous ratios (TN:TP). As heterocystous blue-green algae can fix molecular nitrogen it is expected they can out-compete other algae when nitrogen levels are low and phosphorous is abundant. However many studies, both experimental and correlative have failed to confirm this, with generally high nutrient concentrations (both P and N) more often found to promote blue-green algae growth and dominance (Pick and Lean 1987, Vincent 1989).

High water column stability is also important (Reynolds *et al.* 1987). Blue-greens are particularly buoyant and can vary their position in the water column. During calm conditions other types of algae, such as diatoms gradually sink until they no longer receive sufficient light for growth. These sinking losses increase their dependence on water column mixing to re-circulate nutrients from the lake sediments. Concentration of blue-green algae near the surface cuts out light to underlying waters, further disadvantaging less buoyant species. Deoxygenation of the lake bed is thought to be better tolerated by the resting propagules of eutrophic species, particularly *Microcystis* (Reynolds 1984, p 325), so they have a head start over other species at the onset of the next growth season.

Shallow lakes are more susceptible to blooms (for a given nutrient concentration), as demonstrated by Smith (1985). A study of North Island lakes further concluded lakes could be divided into two groups of productivity, at a mean depth of approximately 11m (Pridmore *et al.* 1985). This is probably attributed to greater recycling of nutrients from the lakebed and greater time algae spend in the euphotic zone of shallow lakes, regardless of mixing times. Warm temperatures promote blue-green algae blooms, more so than for other types of algae. However, Roberts and Zohary (1987) concluded indirect heating effects, in particular stratification, were more important in controlling the occurrence of blooms. These authors suggested water temperatures below 15°C severely limit the growth of *Microcystis*, but found existing populations are able to persist through winter because of low loss rates. The lowest water temperatures and column stability occur during winter, according to the Rotoehu data (Figure 4) and that of Viner (1984) for other Rotorua lakes. Presumably the extraordinary buoyancy control of *Microcystis*, demonstrated by Walsby and McAllister (1987), is important to its survival at this time of year. Wind strength is greater during spring (Quayle 1984) and hence strong vertical mixing is assumed to be responsible for the low cell counts at this time.

The preferences of blue-green taxa can be distinguished. Heterocystous (N_2-fixing) blue-greens (*Anabaena*, *Aphanizomenon*) prefer high water column stability and intermediate nutrient levels, while non-heterocystous blue-greens (*Microcystis*) prefer intermediate stability and higher nutrient availability (Pick and Lean 1987, Vincent 1989).

State and Trends

Drawing together the sampling results with the aforementioned requirements of blue-green algae, conclusions can be drawn as to the state of the Rotorua lakes. Given the preferences of blue-green algae for high nutrients, the frequency of blooms (Figure 1) in part reflects trophic state. The implied eutrophic conditions of Okawa Bay and Lake Rotoehu are further supported by the presence of *Microcystis*, which has higher nutrient requirements than *Anabaena*. Additionally Pick and Lean (1987) state that as lakes become more eutrophic, blue-green blooms occur earlier in the year and last longer, as observed for Lake Rotoehu and Okawa Bay (Figure 3).

The higher incidence of blooms west of Tumoana Point on Lake Rotoiti probably reflects the shallow depth of this part of the lake, which increases productivity (10-15m, cf. 40-70m for the rest of lake), as well as the influence of high nutrient water from Lake Rotorua.

Lake Rotorua has comparable nutrient levels to Lake Rotoehu (Table 1), in spite of lower blue-green occurrence (Figure 1). Nitrogen (TKN) concentrations are on average lower, but it seems more likely water column stability is the limiting factor. Rotorua has a very long fetch and is well mixed as a consequence (Deely 1995). Blue-green algae (particularly *Anabaena* spp.) benefit from stable conditions (Reynolds *et al.* 1987), and in the past recorded blooms have coincided with prolonged calm weather (White *et al.* 1978).

Table 1 Geometric mean nutrient concentrations of Lake Rotoehu and Rotorua from surface samples (July 1992 to July 1998).

	DRP g/m3-P	TP g/m3-P	NH4 g/m3-N	TKN g/m3-N
Rotoehu 1	0.005	0.036	0.008	0.471
Rotorua 2	0.004	0.036	0.007	0.377

Increasing cell concentrations indicate a decline in condition of Lake Rotoehu, supported by a shift from *Anabaena* to *Microcystis* and more persistent blooms. This is consistent with increasing nutrients, but may simply reflect the gradual establishment of blue-green algae in the lake, having exceeded threshold nutrient requirements in 1993.

Toxicity

Of the blue-green samples tested, 21% were found to elicit a toxic response using mouse bioassy. Research on blooms of the Murray-Darling basin found 42% of samples to be toxic (Baker and Humpage 1994) - potentially twice the rate of toxicity. Australian water quality standards (2,000 cells/ml for drinking water; 15,000 cells/ml for contact recreation) may be too stringent for use in New Zealand, where our mild oceanic climate perhaps limits toxin production.

The number of samples tested in New Zealand is so far insufficient to allow a new standard to be set, and it is better to take a precautionary approach at this stage. However, more intensive research is clearly required on toxin production of blue-green algae in New Zealand.

Long Term Predictions

Because restoring lakes is difficult once they have become eutrophic, a preventative approach is critical. This necessitates predicting the susceptibility of lakes to eutrophication. Blue-green blooms are only one of many undesirable consequences of eutrophication, but impact severely on lake values such as aesthetics, recreation and water supply. Determining which lakes are most susceptible to developing such blooms would therefore assist in prioritisation of initiatives, such as riparian planting and controls on fertiliser use.

For the purposes of this report a basic comparison was made between lakes and their catchments to better understand the likelihood of developing persistent and severe blue-green algae blooms (Table 2). A suitable physical environment for blue-green growth would be shallow (Smith 1985) and calm (Reynolds *et al.* 1987), hence the inclusion of depth and fetch. Nutrient supply is largely determined by land use. Reports have shown the discharge of nutrients from native and exotic forest to be low (Macaskill *et al.* 1997), so we only consider pastoral and urban land use here.

The most susceptible lakes are shallow, calm (short fetch), and have large areas of pastoral and urban land use. The last column in Table 1 attempts to summarise this information to indicate the risk of developing blooms. Lakes considered high risk include Okaro, Rerewhakaaitu, Rotoehu and Okawa Bay. Lakes Okaro, Rotoehu and Okawa Bay have already lived up to this expectation. Rerewhakaaitu was the only shallow lake with reasonable water quality according to the last water quality report (Deely 1995). Data collected since then indicates a significant decline in lake condition. This decline is currently the focus of an Environment B·O·P project to identify nutrient sources.

Table 2 Lake and catchment characteristics that determine susceptibility to blue-green algae blooms. Depth and land use taken from Donald (1997). Mean depth for Lake Rotoiti west basin (west of Tumoana Point) & Okawa Bay estimated from bathymetry maps. Land use for Okawa Bay calculated using Mapinfo from 1996 aerial photography. Predicted long-term risk of establishing severe and persistent blue green algae blooms surmised.

	Mean depth	Fetch (km) 4 point mean	Depth:fetch (m/km)	% pasture & urban	Long-Term Risk
Okaro	12.1	0.7	18.6	88	High
Rerewhakaaitu	7	2.3	3	65	High
Rotoehu	8.2	3	2.7	34	High
Okawa Bay	5 (est.)	0.7	6.9	24	High
Rotoiti West	10 (est.)	2.2	4.6		Moderate-High
Rotorua	11	10	1.1	49	Moderate-High
Okareka	20	1.9	10.5	48	Moderate
Rotokakahi (Green)	17.5	1.9	9.1	21	Low-Moderate
Rotoiti East	31.5	5	6.3	17	Low-Moderate
Rotomahana	60	3.2	18.8	37	Low-Moderate
Tarawera	50	8	6.2	22	Low-Moderate
Okataina	39.4	2.9	13.7	8	Low
Rotoma	36.9	3.7	9.9	15	Low
Tikitapu (Blue)	18	1.3	13.7	3	Low

Lake Rotorua is shallow enough and receives runoff from an intensively developed catchment, but has the lowest depth to fetch ratio and is therefore expected to be too rough for blue-green blooms for most of the year. When it is calm and stratified the chances of severe blooms developing are high. Table 2 is misleading in regard of Lake Rotoiti, because it doesn't account for nutrient loading from Lake Rotorua. Adding the Rotoiti and Rotorua data, western Rotoiti (or at least Okere Arm) drains a catchment of 43% pasture and urban. Its shallow nature allows productive use of these nutrients. Probably the only factor preventing this area developing blooms like Rotoehu is the high flushing rate. This gives algae from

Rotorua and Rotoiti a head start over those species better suited to conditions in this part of the lake (i.e. blue-green algae).

Lake Okareka is relatively deep and therefore would require higher nutrient concentrations before developing blooms. For example, using equations from Pridmore (*et al.* 1985, eqn. 3), Okareka would need 1.5 times as much total phosphorus to produce the same algal concentrations as Lake Rotoehu (currently 0.2 x the TP of Rotoehu). Because a high percentage of the catchment is pastoral and significant contributions from septic tanks (McIntosh 1992), Okareka may simply take longer to reach this level. Lake Rotomahana is very deep, but its shallow and enclosed southern bay may experience blooms because of extensive land development.

Note that blooms may develop in isolated parts of a lake regardless of general lake condition, as demonstrated for Lake Rotoiti. Catchment development does not provide a direct indication of nutrient loading, but given that landuse intensity can change (e.g. drystock to dairy) this statistic is more appropriate for long-term predictions. The Rerewhakaaitu catchment has strongly phosphorus-binding soils so nutrient loading is more difficult to predict (see Wilding 2000). If development within a catchment were to increase (e.g. Lake Tarawera) then risk would increase accordingly.

Conclusions

Blue-green algae and eutrophication are clearly pressing issues for the Rotorua lakes. Monitoring has provided a clearer picture of where and when blooms occur with some insight into the causes. In achieving sustainable management we need to set our sights higher than restoration and instead aim for prevention. To be proactive we have to take what is learnt from the deterioration of systems such as Lake Rotoehu and apply it so the same does not happen elsewhere.

"*Anabaena and Microcystis are the two problem genera. All of the high risk lakes except Rerewhakaiitu have already established blue-green algae problems. The limited testing we've done so far – only 19 samples - does suggest lower than expected toxicity in those blooms.*"

"A few suggestions

- *We need a better understanding of the rate of toxicity in the blue-green algae blooms in NZ.*
- *In terms of research and management I think we need to head more towards preventative action in managing our lakes.*
- *From my limited experience the lakes don't always show a gradual decline in condition – they quite often reach a 'carrying capacity' and then turn over – that happened in Rotoehu and was quite dramatic.*
- *The small shallow lakes that you would expect to show the problems first have shown problems - the larger lakes may simply take a little longer.*
- *We need to look at what factors caused Lakes Okaro, Rotoehu and others to turn over and apply that knowledge to prevent other lakes developing the same problem."*

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TROPHIC LEVEL TRENDS IN 12 ROTORUA DISTRICT LAKES, 1990 TO 2000

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Introduction

A presentation of 24 overhead diagrams was made under the title shown above at the Rotorua Lakes Symposium 2001 on the 22nd March 2001. Twenty one of these diagrams are reproduced here along with some additional notes to form part of the published Proceedings of this Symposium.

Overheads shown as part of the presentation of 'Trophic Level Trends in 12 Rotorua District Lakes 1990 to 2000'

Overhead 1: Title, acknowledgements and accreditation

Trophic Level Trends in 12 Rotorua District Lakes

All Monitoring Data collected by ENVIRONMENT B·O·P

using the techniques of

Burns,Bowman and Bryers. 'Protocols for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs .'
issued by the New Zealand Ministry for the Environment

and

LAKEWATCH
a window into water quality

Trophic Level Assessment Technology

Notes to Overhead 1

The data analysed here are the monitoring data collected by Environment B.O.P in the course of their lakes monitoring programme. They kindly permitted Lakes Consulting to analyse their data and present the findings. The data analysis methods used here have been published by Burns, Rutherford and Clayton (1999). These methods have also been reproduced in a document issued by the New Zealand Ministry for the Environment (2000) entitled 'Protocol for Monitoring the Levels of New Zealand Lakes and Reservoirs' by N. Burns, Lakes Consulting, G. Bryers and E. Bowman of NIWA, Hamilton. The data analysis was done using the computer program 'LakeWatch' (LakeWatch Ltd. 2001).

Overhead 2: Values of variables associated with different trophic levels

Trophic Level Index
Annual average values for each level

Lake Type	Trophic Level	Chla	Secchi Depth	TP	TN
		(mg/m3)	(m)	(mg P/m3)	(mg N/m3)
Ultra-microtrophic	0.0 - 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	10.0 - 22
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 -15	1.8 - 4.1	22 - 46
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.0	4.1 - 9.0	46 - 99
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	99 - 213
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	213 - 458
Supertrophic	5.0 to 6.0	12 - 31.0	1.1 - 0.4	43 - 96	458 - 984
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>984

Notes to Overhead 2

Trophic level values are calculated for each of the key variables (TLx) using the appropriate equations for each year and the annual average value for each variable;

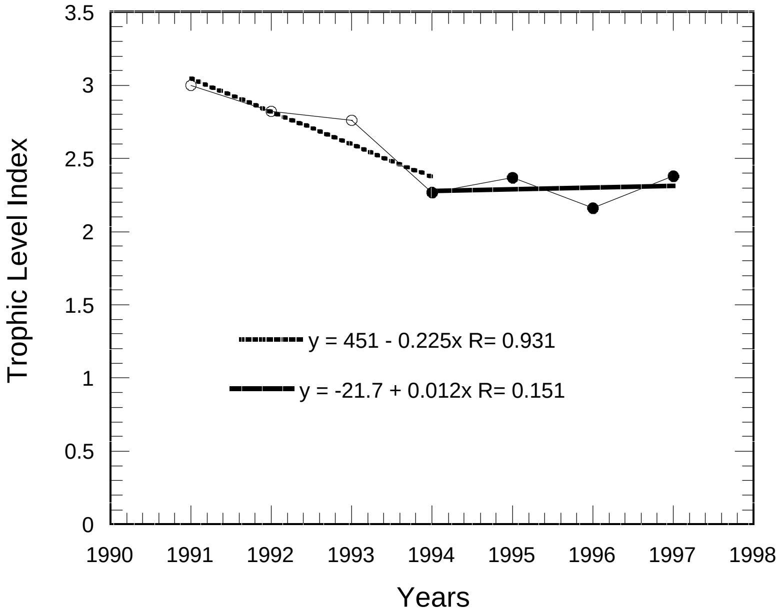
$$TLc = 2.22 + 2.54 \log(Chla)$$
$$TLs = 5.56 + 2.60 \log(1/SD - 1/40)$$
$$TLp = 0.218 + 2.92 \log(TP)$$
$$TLn = -3.61 + 3.01 \log(TN)$$

The TLI and its standard error is then calculated for each year;

$$TLI = \frac{1}{4} (TLc + TLs + TLp + TLn)$$

Overhead 3: TLI and temperature results for Lake Rotoma

Lake Rotoma - Av. TLI of 2.5 - oligotrophic



- TLI decreasing from 1991 to 1994 thereafter no real change
- Temperature increase since 1992 of 0.11^{o}C/yr

Note to Overhead 3

The TLI trend is calculated using an OLS regression on the TLI values vs. year. This value is then considered probable or not by use of the interpretation derived from the p-value of the PAC average. This technique is explained in the following two overheads.
"Lake Rotoma is the cleanest of the Rotorua lakes. For the first 4 years we had quite a drop in the trophic level, followed by a period when there was no real change. The temperature in this lake has increased since 1992, at a rate of 0.11^{o}C per year. All the temperatures in the Rotorua Lakes have risen since 1992, but at different rates."

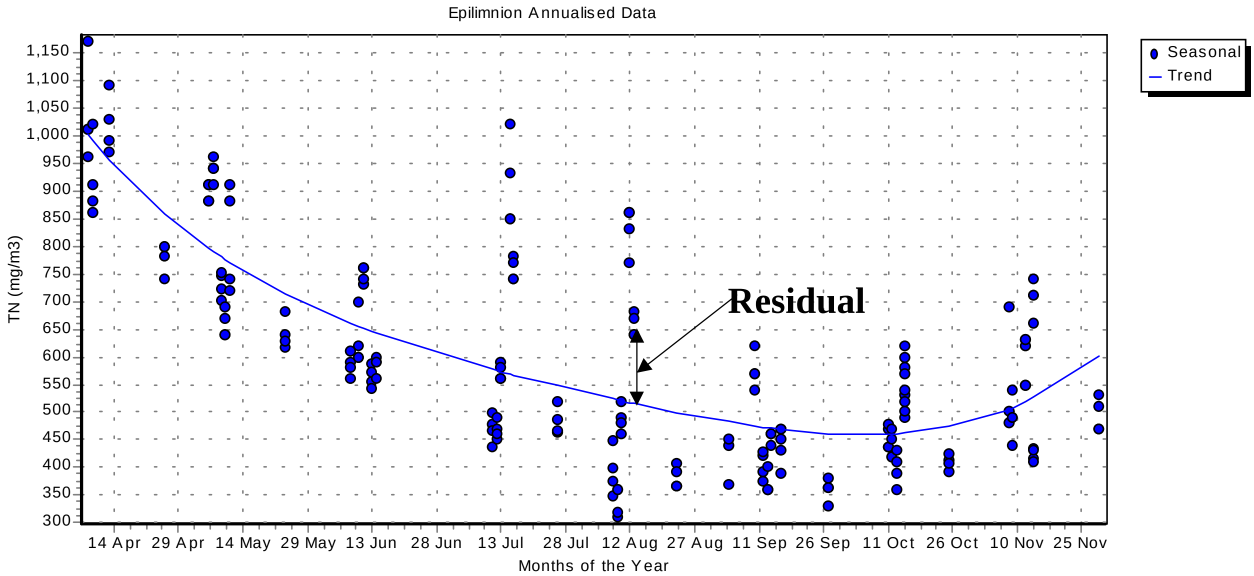
Overhead 4: Determination of deseasonalised residuals by the annualisation technique

Annualised data

Deseasonalising by Annualising.

Total Nitrogen (TN) data from Cannonsville Reservoir NY 1990 to 1994.

Distance of points from the fitted polynomial curve are the RESIDUAL values.



<u>Note to Overhead 4</u>

The complete data set for a variable is plotted against day and month of collection to obtain seasonal pattern of change. The year of collection is omitted. A polynomial curve is fitted to the data. Residuals are calculated as actual datum minus annualised curve-fit value for any day.

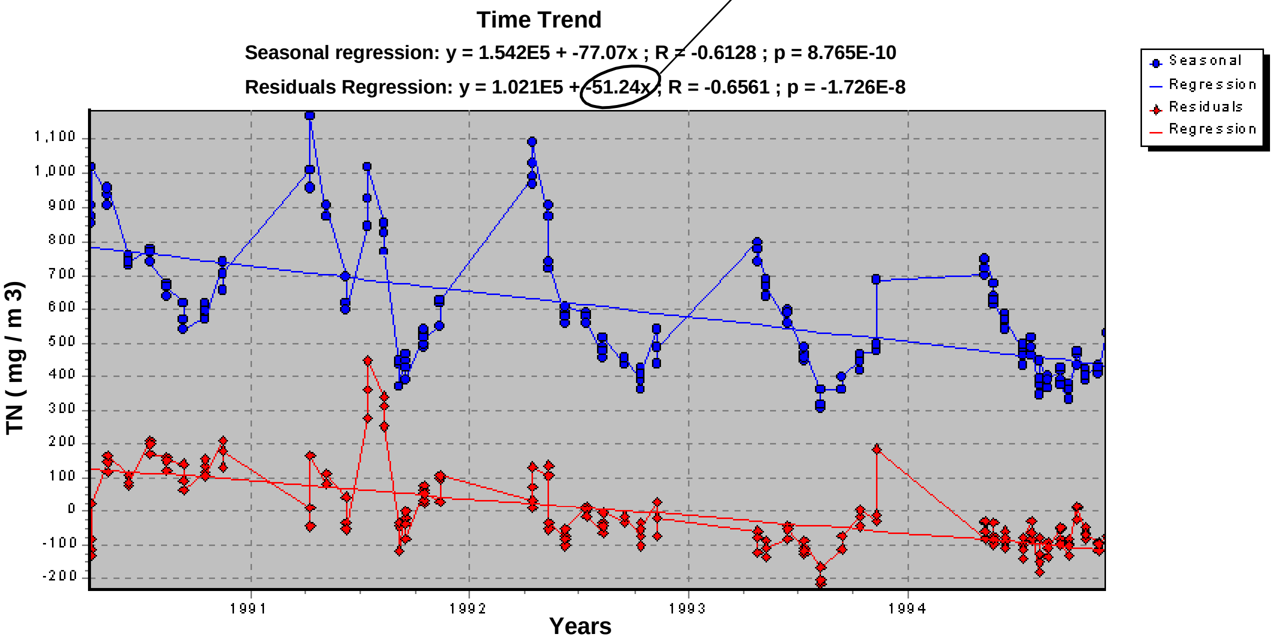
"There are two ways of quantifying change. One can put a regression line to the Trophic Level Index values (as in Figure 5 below) but experience has taught me that that's not a very reliable way of detecting change. Instead I've had to go to a more complex method of data analysis. Using data from Cannonsville Reservoir, New York, I've taken the Total Nitrogen data for 5 years and plotted it as though it comes just from one year and determined the annual pattern in that data by fitting a polynomial curve to it. The residual is the value between each individual data point and the fitted curve. These residual values are then used to determine percent annual change values and the regression line is fitted to the residuals. If the P value of the regression fit is taken as being less than 0.05 then it is considered to be significant and as it is plotted against years the slope of the line gives the change in the variable per year. (See below)

Overhead 5: Calculation of PAC values for a key variable

Calculating Percent Annual Change (PAC) values

If p-value to regression line fit is < 0.05 (< 5%) then trend is considered **SIGNIFICANT**. Thus for an analysis period, i.e. TN from 1990 to 1994**:**

$$PAC_{TN} = {}^{\text{Change per Year}}/_{\text{Av.Value of Variable}} = {}^{-51.24}/_{598} = -8.53\% \text{ per year}$$



<u>Notes to Overhead 5</u>

Plot trends

Ordinary least squares (OLS) regressions are done on actual and residual data against time. Slope of the regression line gives annual change in the data. P-values give significance level of regressions. A p-value of <0.05 is considered to give a significant trend. P-values of deseasonalised regressions are usually less those done with the actual data.

Percent Annual Change (PAC) calculated and tabulated

(a) Averages are calculated from the actual data for the four key variables for the period of analysis (chlorophyll a, secchi disc, total phosphorus, total nitrogen).
(b) The PAC value is calculated for each key variable.
Trend = slope of the residual regression.
Trend/average for period*100 = PAC.
If PAC trend not significant then PAC value is taken as 0.

Overhead 6: Interpretation of Average PAC value

Combining PAC values to obtain a trend

There are **4** Key Variables: **Chlorophyll *a*** (Chla) **Secchi Depth**(SD) **Total Phosphorus** (TP) **Total Nitrogen** (TN)

Concept - if there has been a change in trophic level in a lake, 3 or 4 of the key variables will indicate change

$$\text{Av. PAC value} = \frac{PAC_{(Chla)} + PAC_{(SD)} + PAC_{(TP)} + PAC_{(TN)}}{4}$$

Interpretation of p - value of Average PAC

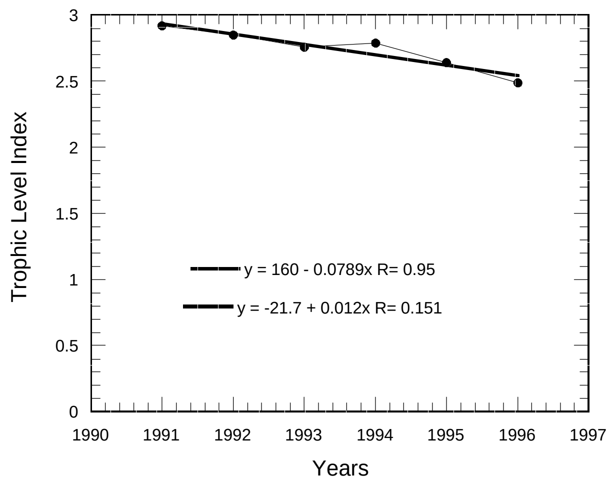
$P < 0.1$	**Definite** change
$0.1 < P < 0.2$	**Probable** change
$0.2 < P < 0.3$	**Possible** change
$0.3 < P$	**No** change

Note to Overhead 6

The p-value of the average PAC indicates the similarity or difference in the pattern of change in the four key variables. A low p-value for the PAC average indicates similarity of change in the key variables and this indicates a high probability of change.

Overhead 7: TLI and temperature results for Lake Tarawera

Lake Tarawera -Av. TLI of 2.7 - oligotrophic



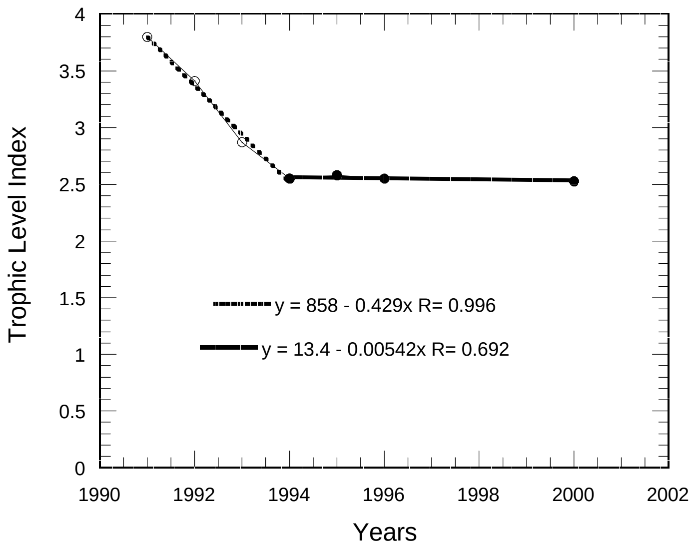
•PAC average p-value = 0.37 indicating no change. Need to see TLI value for 2001.

•Temperature increase since 1992 of 0.19^{o}C/yr

"*You can see there is a very nice trend line there – it looks as though there has definitely been a change- but the PAC value is 0.37 and in fact there's not been a change. None of the key variables has actually had a significant change. But what we really need now is the value for the year 2000 and if that value plots down the line further it would be significant, if it plots in the same range as those you would know it was just a temporary trend.*"

Overhead 8: TLI and temperature results for Lake Okataina

Lake Okataina - av. TLI of 2.9 -oligotrophic

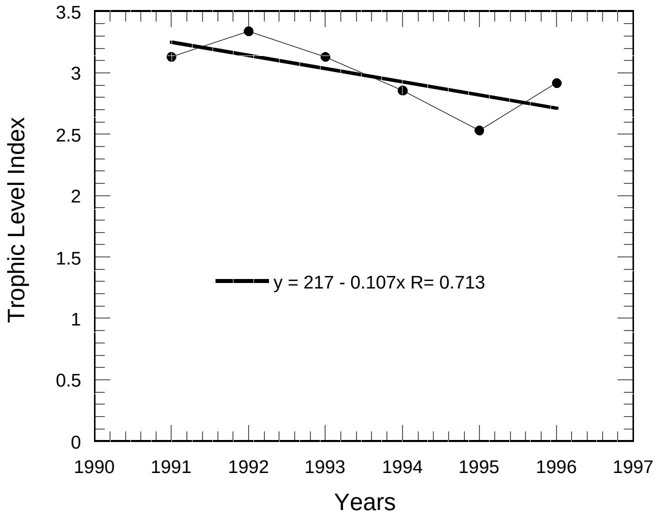


- TLI decreasing from 1991 to 1994 then no change.
- Temperature increase since 1992 of 0.13^{o}C/yr

"*A number of lakes had this change of really moving to lower trophic levels for the first 4 years from 1990 to 1994, and I haven't been able to figure out what is the cause of that – whether it is a water level change or sometimes you get changes at the startup of a lake monitoring programme.*"

Overhead 9: TLI and temperature results for Lake Tikitapu

Lake Tikitapu - av. TLI of 3.05 - mesotrophic

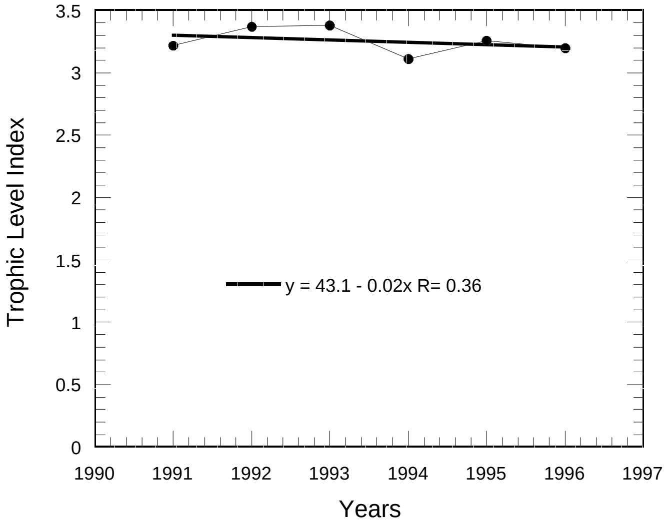


•PAC p-value = 0.43 indicates no trend with time - need values for 2001 to determine longer term trend.
•Temperature increase since 1992 of 0.49°C/yr

"Again, a seemingly downward trend, but the PAC value says no – it's just moving in a seemingly unpredictable way. Once again, if we get a value for the year 2000 we'll have a much firmer idea of what's happening in that lake."

Overhead 10: TLI and temperature results for Lake Rotokakahi

Lake Rotokakahi - av. TLI of 3.3 - mesotrophic



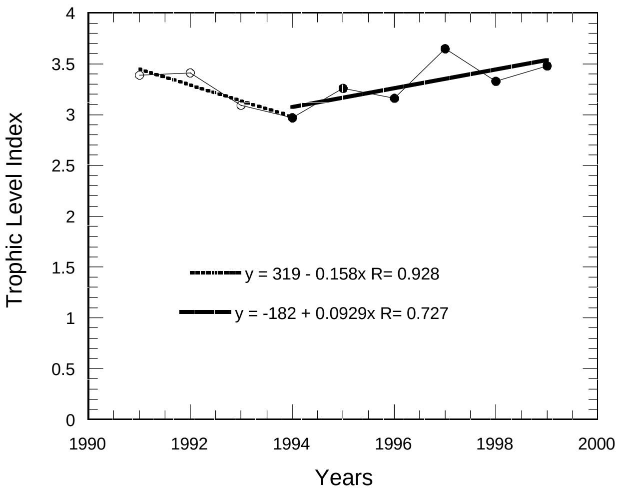
•PAC p-value of 0.37 indicates no change with time.

•Temperature increase since 1992 of 0.6°C/yr.

"*A very stable lake with a stable catchment and we can see – no change in that lake. But I might just point out, from 1992, a large temperature change per year.*"

Overhead 11: TLI and temperature results for Lake Okareka

Lake Okareka - TLI of 3.3 - mesotrophic



•Decreasing TLI 1991 to 1994 then TLI increases definitely from then to 1999 at 0.09 tli per year.

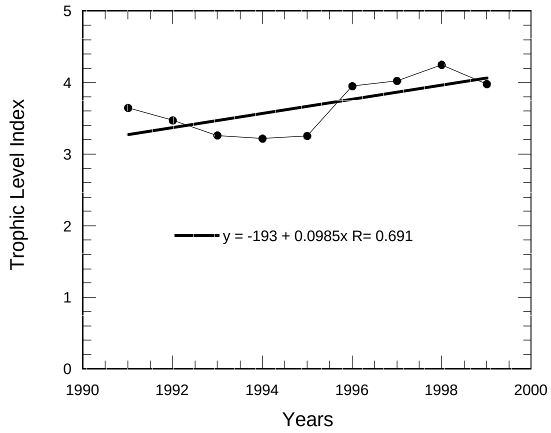
•Epilimnion temperature increasing by 0.24°C/yr from 1992 to 1999, as well as TP and TN. Hypolimnetic DO concentration decreased.

Note on Overhead 11

Temperature records exist for Lake Okareka from 1988 to 2000. The 1988-1992 temperature trend was –0.04 ^{o}C/yr in contrast to the trend of +0.24 ^{o}C/yr from 1993 to 1999. The cooling trend from 1988 to 1992 could have been associated with the effects of the Mt. Pinataubo eruption. The temperature rise from 1992 onwards probably contains two elements; a normal warming after a cooling period plus a smaller effect resulting from global warming. This lake warming effect is particularly dangerous for Lake Okareka because it induces more thermal stability to the lake and this lengthens the stratified period. The oxygen concentration in this lake used to reach very low values at the end of the stratified period when temperatures were lower but the lake seldom experienced anoxic regeneration of nutrients in its hypolimnion waters. Now however, with the longer period of stratification, hypolimnetic oxygen concentrations reach zero and anoxic regeneration of nutrients occurs. The lake is now in danger of entering a cycle of anoxic nutrient regeneration every year. Since this lake also receives nutrients from septic tank and agricultural runoff, these sources may have to be reduced to avert the consequences of the extra internal loading of nutrients.
"*I would just mention here, as you approach anoxia there is quite a complex interaction of the water with the sediments. First of all the nitrates lose their oxygen to the bacteria then, as it becomes more anoxic, you get a release of ammonia from the sediments and then if it goes more deeply anoxic you get the release of orthophosphorus. What's happening now is that the lengthened stratified period is causing the release of these nutrients from the bottom and the higher temperature causes the decomposition of the organic matter and the absorption of the oxygen to happen at a faster rate.*"

Overhead 12: TLI and temperature results for Lake Rerewhakaaitu

Lake Rerewhakaaitu - av. TLI of 3.6 - mesotrophic



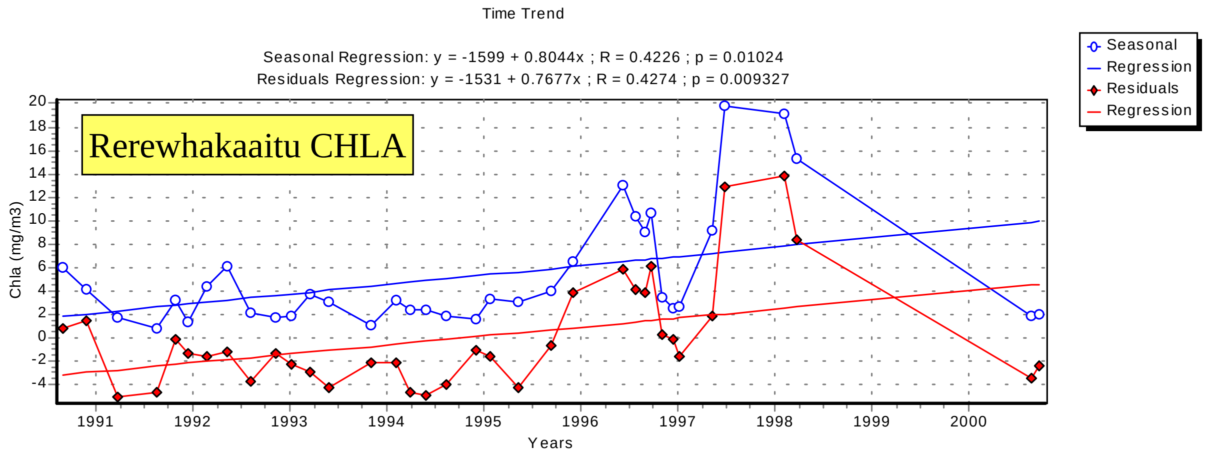
•PAC p-value = 0.39 indicates no change overall, but TLI elevated between1996 to 1999.
•Temperature increase since 1992 of 0.11^{o}C/yr
•Unstratified lake (14m deep - isothermal - similar to lake Rotorua.)

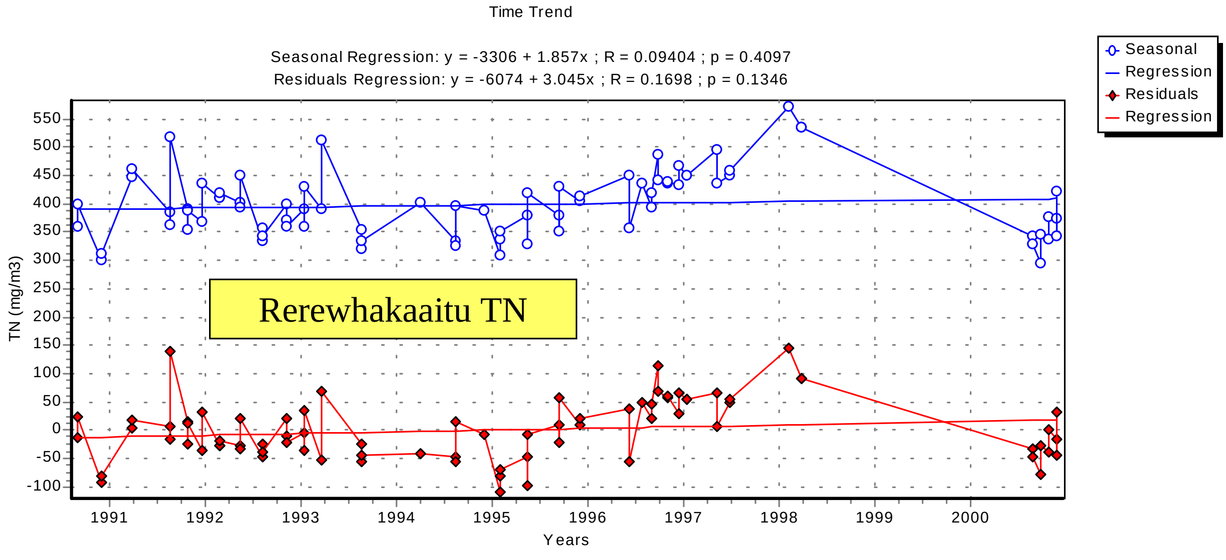
Notes on Overhead 12

Lakes Rerewhakaaitu and Rotorua are similar in that they are of similar depths and both are isothermal and relatively large. They both experienced large mid-winter regenerations of NH_4 during the calm winter of 1997. These nitrogen regenerations resulted in increases in chlorophyll concentrations and phytoplankton numbers. Nutrient regeneration episodes led to the changes that resulted in the higher TLI values in 1996 to 1999.

"It has demonstrated a phenomenon which I've really found in Lake Rotorua which was relatively unexpected – that is these mid-winter blooms. This is because (and you can see how the Total Nitrogen goes up in these periods) we've had a couple of unusually calm winters and the water in these unstratified lakes has sat there close to the bottom, undisturbed, and we've reached the stage where we've got ammonia release from the bottom sediments even if we haven't reached the phosphorus release and this pattern is even more obvious in Rotorua."

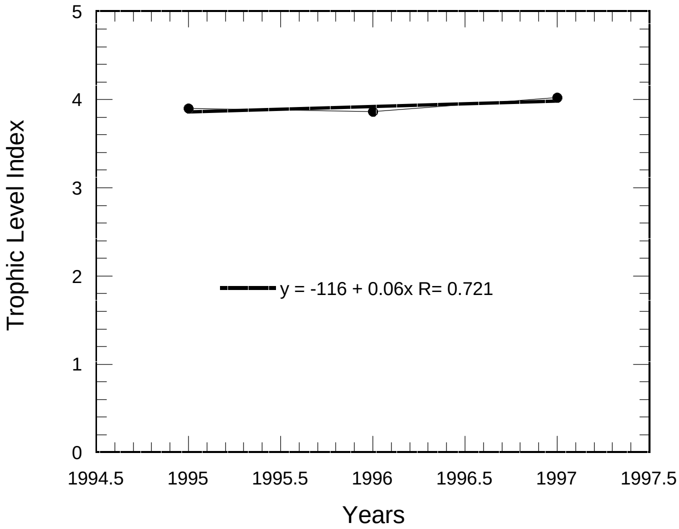
Overhead 13: Plots of chlorophyll *a* and total nitrogen, showing elevated levels of chlorophyll in the winters of 1996 and 1997





Overhead 14: TLI and temperature results for Lake Rotomahana

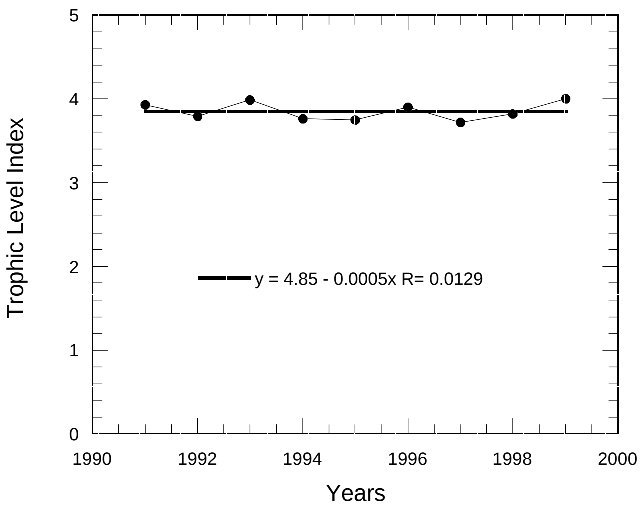
Lake Rotomahana - TLI of 3.9 - mesotrophic.



- Naturally enriched by geothermal waters.
- Temperature increase since 1992 of 0.07°C/yr

Overhead 15: TLI and temperature results for Lake Rotoiti showing the very stable, relatively high TLI values for this lake

Lake Rotoiti - TLI of 3.9 - Mesotrophic



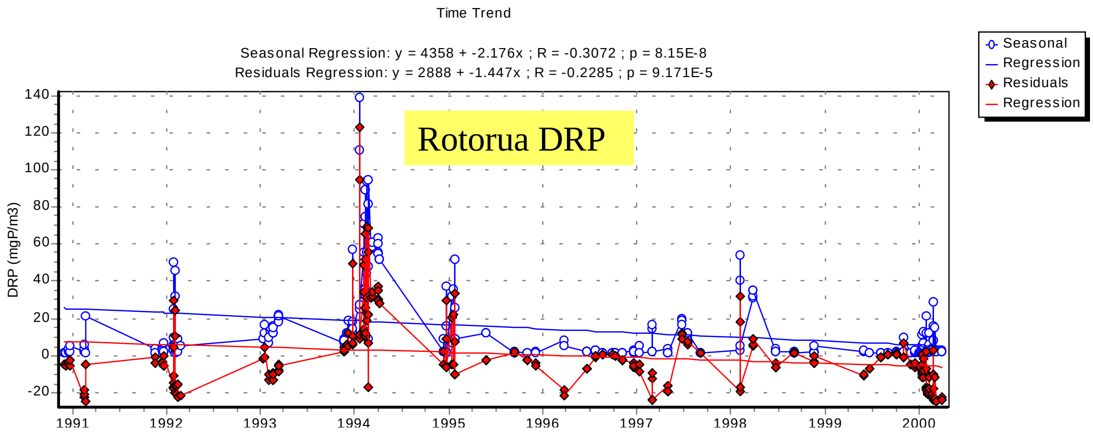
- PAC p-value of 0.39 gives a trend of no change with time.
- West (TLI=4.0), and East (TLI=3.8) stations when analysed individually give trend of no change with time.
- Temperature increase since 1992 0f 0.19°C/yr

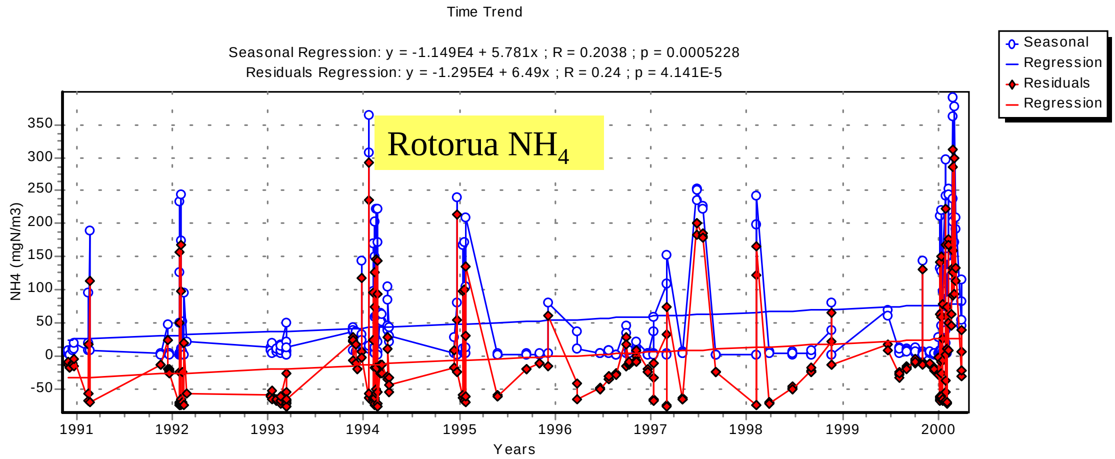
Note to Overhead 15

The water flowing from Lake Rotorua into Lake Rotoiti via the Ohau Channel frequently underflows the water in the west arm of Lake Rotoiti (Gibbs 1992) and then travels into the eastern basin of the lake. Thus much of the Lake Rotorua water flowing into Lake Rotoiti mixes into Lake Rotoiti. Thus the best means of improving the water quality of this lake is to improve the water quality of Lake Rotorua.

"*The one that many of you are interested in. Remarkably stable over the period – no real change. We analyse the west basin separately from the east basin and the west has a trophic level of 4.0 and the east a trophic level of 3.8. A 0.2 difference in trophic level is quite large – it makes quite a significant difference to the way a lake behaves*".

Overhead 16: Plots of dissolved reactive phosphorus (DRP) and ammonia (NH_4) in Lake Rotorua showing the high concentrations found in the water following periods of nutrient regeneration, resulting from anoxic conditions at the sediment-water interface. Note that the mid-winter regeneration of NH_4 in 1997 and lack of regeneration periods from March 1995 to December 1996.

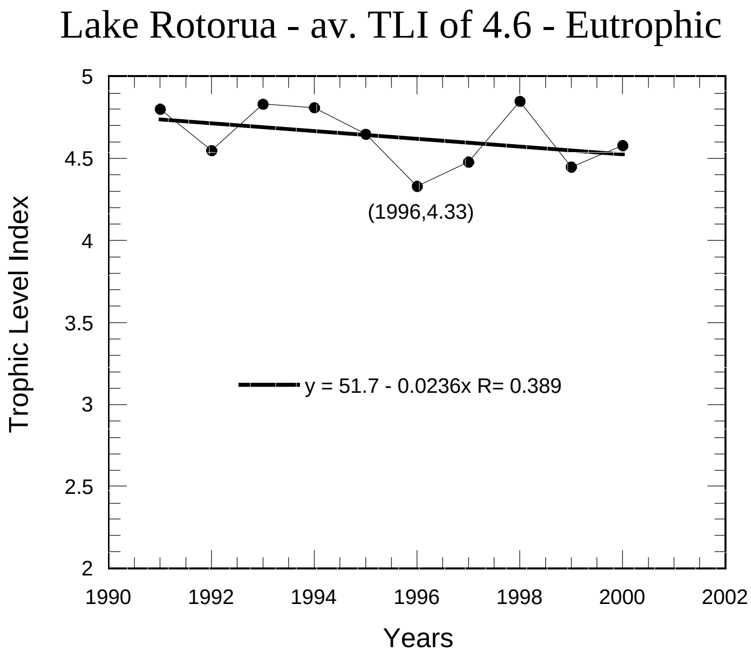




"*In the first 5 years of the decade there were quite a large number of anoxic conditions causing phosphorus release – you can see it by these high concentrations suddenly appearing in the water. But in the second half of the decade there was only one such release, in 1988.*"

"The pattern with ammonia is quite different. You have got the ammonia releases that accompany the phosphorus releases but you also have additional ammonia releases when there was no phosphorus release because the degree of anoxia was not as severe in the second half of the decade. One in particular, in mid-winter of 1997, was followed by another release of phosphorus in January of 1998. The effect of the phosphorus releases only in the first half of the decade is that the total phosphorus has trended downward over the decade in a significant manner. But the total nitrogen has trended upward and quite strongly so, in a significant manner, so we're getting really quite a contrary trend in our primary nutrients."

Overhead 17: TLI and temperature results for Lake Rotorua



Chla of 10mg/m^3 = TLc of 4.7 : SD of 2.5m = TLs of 4.5

TP of 20 mgP/m^3 = TLp of 4.0: TN of 300 mgN/M^3 = TLn of 3.9

Therefore proposed TLI for Lake Rotorua = 4.3

TLI trend is currently - 0.03 units/yr but PAC p-value =0.63

Temperature increase since 1992 = 0.13^{o}C/yr = 1.2^{o}C.

Note on Overhead 17

Rutherford et al. (1989) proposed values for the 4 key variables as water quality objectives for Lake Rotorua, following the removal of the sewage from the lake. These values are shown in Overhead 17 together with the trophic level values that can be calculated for each key variable using the equations for calculating trophic levels (see Overhead 2). The 4 values average out at 4.28 TLI units and thus the proposed water quality TLI objective for Lake Rotorua can be considered as 4.3. A TLI of 4.33 was calculated for 1996, a year when there were no nutrient regenerations. This indicates that the TLI objective of an average of 4.3 for Lake Rotorua is reasonable. The trend to higher lake temperatures

in the region, however, mitigates against attaining this objective consistently, because higher temperatures increase the stability of the lake water column and hence the occurrence of low oxygen conditions and nutrient regeneration. If global warming is going to result in a long term increase in the temperature of Lake Rotorua, the external loading of nutrients to Lake Rotorua may have to be decreased below current loadings to compensate for possible increased internal loadings to the lake.

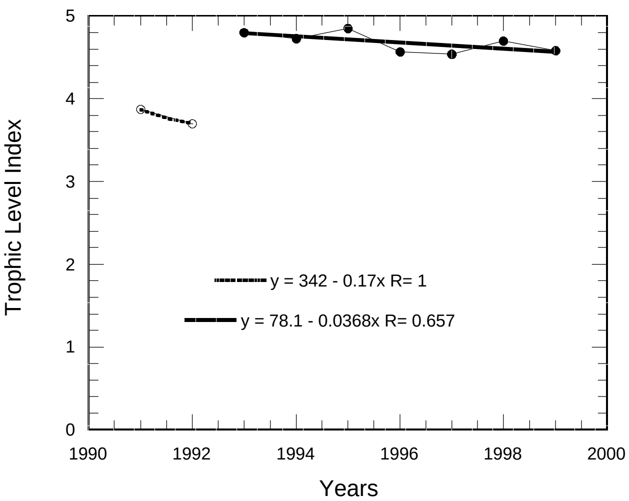
"*The trophic Index is at 4.6 now, which means it is quite a eutrophic lake, starting to get to be quite uncomfortable and unpleasant in its condition. Again we've had to rely on the PAC value to be our real guidance and you can see it's a very high value, 0.63, because we've got two of our primary key variables with opposing trends- that's the phosphorus going down and the nitrogen going up. But the line is nevertheless pointing down in a small decrease of –0.03 units per year.*

In 1989 Rutherford et al *published a paper on Lake Rotorua and they proposed levels for the key variables in that lake. For chlorophyll, the average was 10 mg.m^{-3} and because of the equations that I have between concentration and trophic level, I can calculate that the trophic level equivalent of 10 mg.m^{-3} of chlorophyll (i.e. the TLC) is 4.7. The desired level of Secchi depth is 2.5 metres which gives a TLS of 4.5, the Total Phosphorus of 20 mg, as being the objective for phosphorus, translates into a TLP of 4, and the objective of 300 mg for Nitrogen translates into a trophic level of 3.9. If we average those four values we get to the proposed Trophic Level Index value for Lake Rotorua being 4.3 and the interesting thing is that from 1995 to mid 1996 when there was no anoxic regenerations occurring for either phosphorus or nitrogen, the value of the TLI slipped down to 4.33 – relatively close to the objective value. If we could diminish these anoxic regenerations of nutrients in Lake Rotorua we would fairly rapidly come to the desired state for that lake."*

Overhead 18: TLI and temperature conditions in Lake Rotoehu

Note to Overhead 18

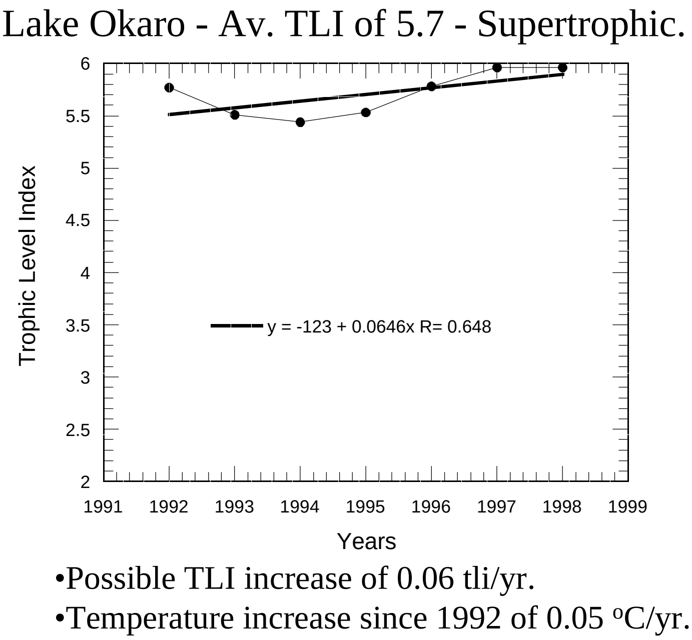
Lake Rotoehu - Av. TLI of 4.7 - eutrophic



- Large regeneration of DRP in 1993 - has set up a new regime of anoxic regeneration each summer. No change since 1993.
- Temperature increase since 1992 of 0.29 ^{o}C/yr

There was a large release of both NH_4 and DRP from the sediments of Lake Rotoehu to the water in 1993 that caused a phytoplankton bloom. The organic matter produced has apparently increased the oxygen uptake rate in the lake and this has led to a cycle of anoxic nutrient regeneration and phytoplankton blooms.

Overhead 19: TLI and temperature conditions in Lake Okaro



"*A whole trophic level unit higher than the previous one (Rotoehu) at 5.7, supertrophic, and it seems as if it might be even yet undergoing a further possible increase of 0.06 TLI units per year.*"

Overheads 20 and 21: The Conclusions and recommendations are self-explanatory

Conclusions

- Six lakes showed improvement from 1990 to 1993. All lakes have experienced temperature increases since 1992 of $0.17 \pm 0.12^{o}C$ on average. This has probably caused increased nutrient regenerations in Rerewhakaaitu, Rotoehu, Okareka and Rotorua.
- **Rotorua is possibly improving slowly.** It could take 10 years or more before it reaches its desired state - even longer if global warming continues to cause regeneration of NH_4. Consideration of decreasing external loads to the lake to compensate for increased internal loading may be necessary.
- The 7 acceptable, stable lakes are Rerewhakaaitu, Rotomahana, Rotokakahi,Tarawera, Okataina, Tikitapu, and Rotoma; with 2 lakes, **Rotoiti and Rotoehu, in *unsatisfactory*, stable condition.**
- **Okareka and Okaro appear to be deteriorating further.**

"We should be careful to do a study of the total and, as Rod also mentioned, and I think it's the key and has been missed by many limnologists in the past, we need to work on the bioavailable components of the nitrogen and the phosphorus, because they are what cause the problem.

"Okareka – quite a complex situation here, because the nutrient sources arise from the bottom when you have increased anoxia and increased warmth, but they also can arise from the leachate from septic tanks. We can't do anything about the climate, but we can, if necessary, do something about the leachate from the septic tanks. If the climate continues to cause more regeneration, we may have to consider reticulation as a means of containing the climate effect.
"Okaro is used quite extensively for waterskiing and with its Trophic Level it potentially could cause problems to the skiers. I think those two lakes (Rotoehu and Okaro) are in a state of heavy internal loading and it could be that we'll never be able to handle the situation by diminishing the external loading. What we need to do is compare the external with the internal loading and if the external loading is too small compared with the internal then we have to get into in-lake management procedure of handling the internal loading of those lakes if we hope to improve them."

What should be done?

- **Rotorua -** Future situation seems to be dependent on the climate. Nevertheless, there should be a study of total and bioavailable nitrogen and phosphorus inputs to the lake so that recommendations for external nutrient loading reductions can be made, if necessary. Currently, two indicative streams, the Puarenga and Ngongataha are being monitored.
- **Rotoiti -** Not much can be done as its condition depends on Lake Rotorua discharges. We need to continue monitoring this lake.
- **Okareka -** Check on the necessity to implement a reticulation scheme to decrease external nutrient loading. Diversion of sewage may be necessary to prevent the start a cycle of anoxic regeneration from the lake sediments resulting from the effects of global warming or increased loading of leachate from septic tanks.
- **Rotoehu and Okaro -** Carry out studies of bioavailable external nutrient supply to these lakes. From this information, determine whether the external loading is significant in terms of the current internal nutrient loads. If the external nutrient loads are small compared to the internal loads, then we need to investigate possible in-lake management strategies.

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PROCESS-ORIENTED LITTORAL AND WATERSHED FUNCTION

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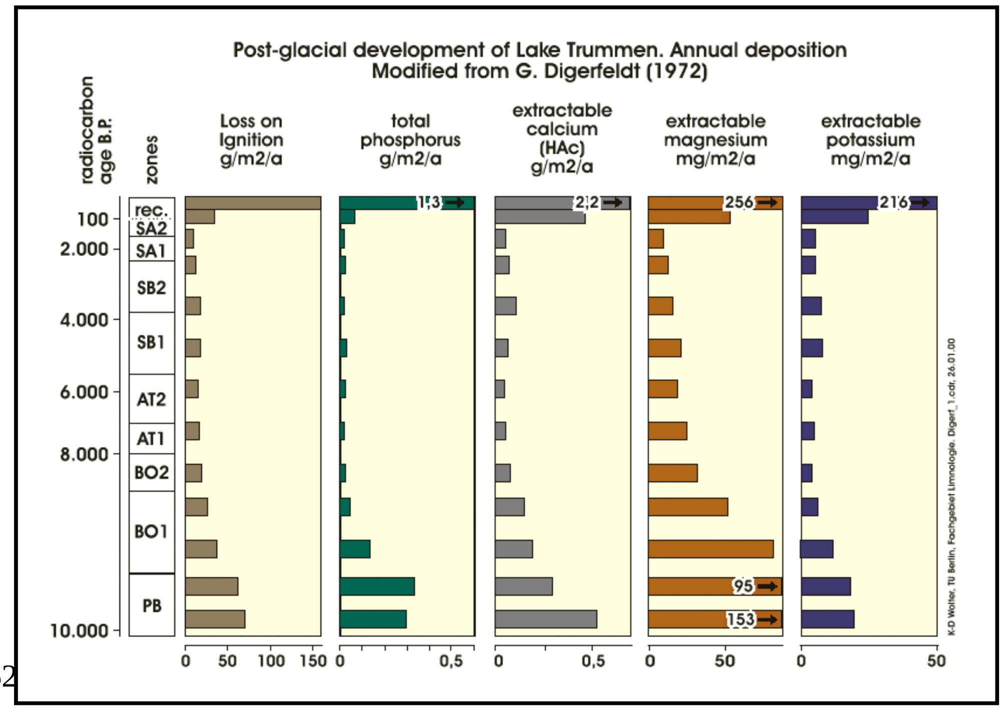
Editors' note: This material has been prepared directly from the tape transcript of Dr Ripl's paper. Any errors or omissions are the sole responsibility of the editors. Dr Ripl provided the graphics which we have placed in the text as appropriate.

In this lecture I will discuss how the ecosystem works, because I think we still have to understand how the parts of the system are put together.
I started off as a limnologist, did my studies in Sweden, and for 20 years I have been teaching in Germany. About 10 years ago I started to go into the catchments and talk with farmers and land managers to find out their troubles, and how the ecosystems and the links work together.

When I was studying in Sweden I had a colleague who was doing palaeobiology. He was taking cores in lakes and dating them to find out how the landscape had developed. This can be done by analysing the material flow from the landscape to the sea and by pollen analysis to find out how the various plants established in the catchment. He was studying a very small lake in southern Sweden of almost 1 km^2 in size and with a catchment of 15 km^2.
My colleague found from these cores that in the beginning, just after the glaciation, the material flows from the landscape were higher than some time later when vegetation had established. We found out that total yearly sedimentation rates were 2 – 3 mm in the beginning and after 3000 years the sedimentation rate had decreased to about 0.2 - 0.3 mm per year. It went down to 1/10 of the earlier level because Nature invented cyclic processes in the catchment. Nature developed from the *ecotone* (i.e. the borderline between water and the catchment) out into the landscape.

It took 3000 years to cover the landscape and to organise it in a very good way, and it was about that stage that there were minimum flows of material into this lake.

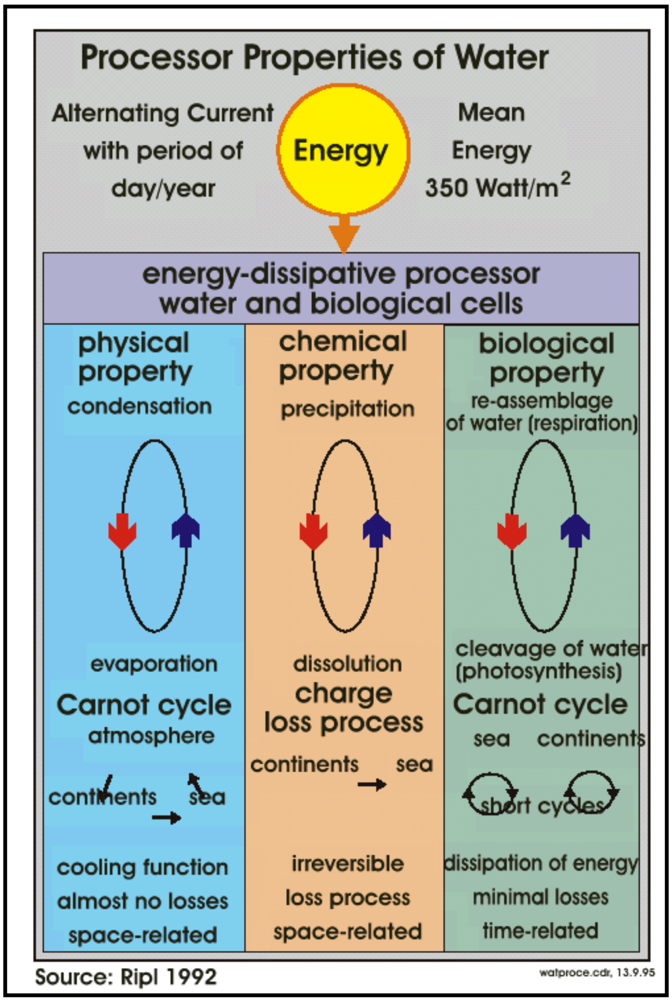
Figure 1



We could show this by measuring loss on ignition (i.e. the measure of carbon flows), to measure carbon entering the lake. Total phosphorus diminished to quite a large extent, and the extractable base cations calcium, magnesium, potassium - all plant-useable material - decreased to a large extent (*see Figure 1 above*). This went on until man introduced himself to Nature and he took on and managed the land. It seemed that just by clear cutting the forests there were tremendous flows of material out to the rivers and lakes. By this management these very nicely closed cycles were opened and irreversible material flow to the rivers and lakes occurred. This means that our lakes and rivers are mirrors of the human cultural activity on the land, and we can now see what happens if we do not know what are the linkages and how to manage the systems.

I and my colleagues developed a model of how the energy is processed in the catchments, both on a daily basis and as modulated by seasons. We found out the most important medium, water, which is spreading out energy in time and space - which we call *dissipative properties*. These are carried out by water. Thus water is the thermostatic fluid in our planet which is the damping factor that decreases the maximum temperature and increases the minimum temperature, so that all organisms thrive. (Figure 2).

Figure 2



But water has not only one property - to evaporate and to condense - it has also a second property. It is also a very weak acid, so that as the rain touches the earth it dissolves various materials and carries the dissolved matter to the lakes and through the lakes or the groundwater to the sea. In this way the landscape is aging.

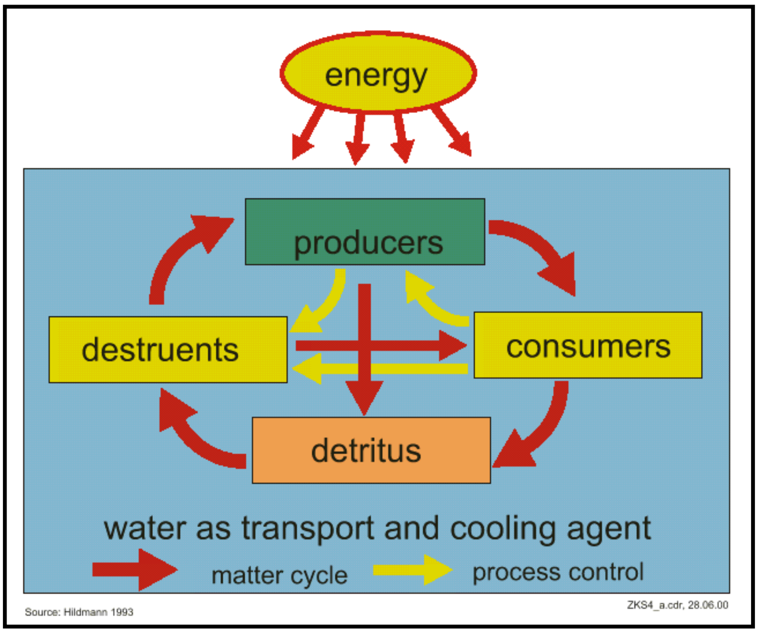
So landscape is not in perpetual motion: it is aging, and the phase during which vegetation and biota can visit the landscape is limited. By good management we can increase the cycle and by bad management we are reducing it, because on the soil surface we run out of the base cations and the nutrients. All the nitrogen and phosphorus you find in the lakes is missing from the catchments and its loss reduces the production from the land.

Also, Nature found out by evolution that within cells water has a third property: it disintegrates into hydrogen and oxygen.

The hydrogen is a reducing agent, forming an energy source (our carbohydrates) as sugars, detritus, organic matter etc., deposited underneath trees and plants.

We will now look at the basic circuitry - how ecological cells work. Let's take a tree. The tree gets energy and in Nature it serves as a pump and as a producer of organic matter in the leaves and all that is falling down from the tree. It is trying to serve other co-workers in this ecological cycle, so to speak, with energy and with nutrients and minerals, and at the same time pumping water by rapid transpiration. This producer is now getting stock from the soil. The soil in Nature is not just something upon which to maximise production, by irrigating and fertilising: the soil in nature is a dynamic interface between the geological substratum and the plant itself, and it should even help provide energy for the plant which is managing its domain.

Figure 3



So in this detritus small organisms - bacteria and fungi - are recycling and using this energy and by so using it are recycling phosphorus, nitrogen and base cations to the producers. It is a cycle. This cycle could not work if it did not have the food chain, because if the bacteria are to work all the time they need to have an opportunity to grow. If they do not grow they get inefficient, so that after a short time the cycle is not working any more. For this reason the consumers in this food chain are opening up the space all the time, recycling the bacteria, also recycling the producers (the plants) to open up the space and to keep the system growing in a very efficient way. Thus the losses from this domain are as low as possible and the cyclic processes are at a maximum, as you can see in this picture (Figure 3).

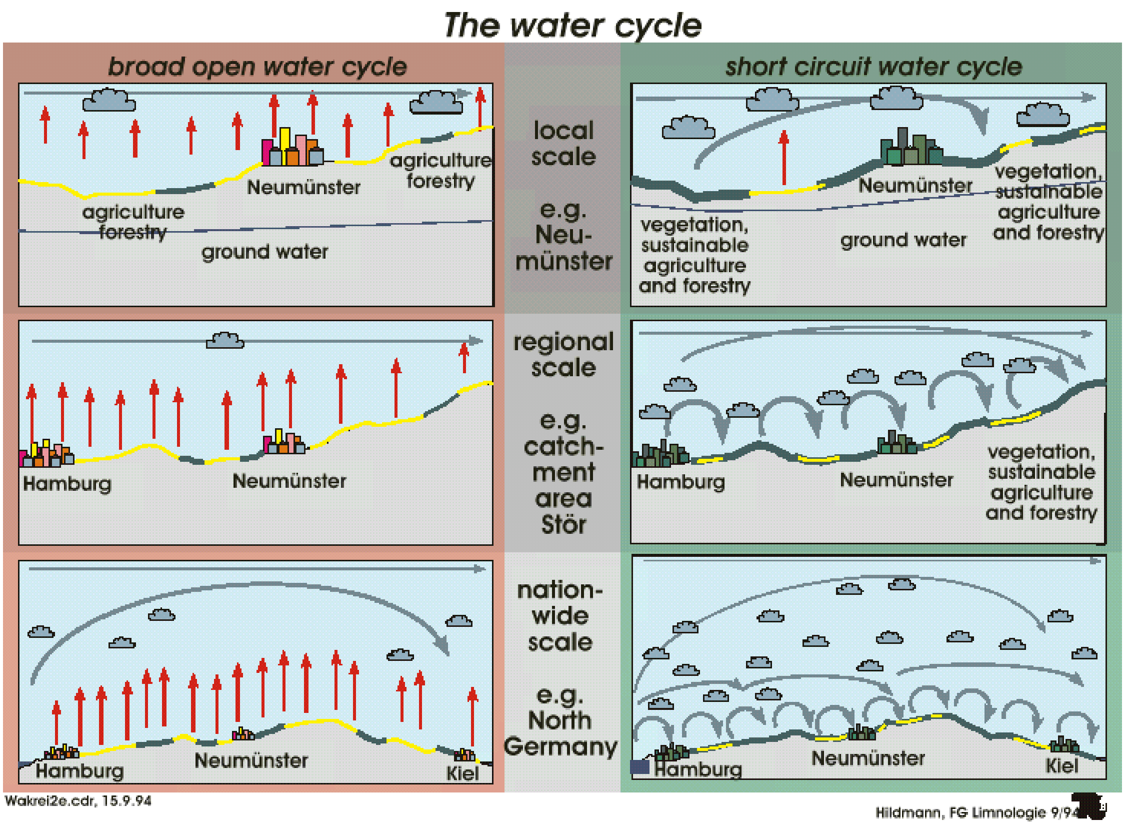
Now let us turn to self organisation. We can develop a model for the land zone and we can also develop a model for the water, especially the littorals or the riparian zones, where there is very high self-organisation. As you see (Figure 4 below), there can be a perfect cycle conducted by functionally defined things, with water (especially through its cooling of the transport medium) allowing the cycle to work. But it absolutely needs water.

We now examine the situation of a leaf of an aquatic plant in a very oligotrophic lake. I will explain why lakes are oligotrophic. In lakes the water, which is seeping into the lake via ground water and small tributaries, contains the mineralising CO_2 from the organic layers

which the organisms produce, and this CO_2 usually dissolves either iron or aluminium or calcium. All these three are control parameters for phosphorus, so the phosphorus is usually deposited after a very short time in the soil, or if it is carried over to the sea or to a river it is deposited there in the form of aluminium phosphate, iron phosphate or calcium phosphate (apatite). All these are controlled by the solubility of these phosphorus salts which is very low: in most cases below 10 micrograms / litre. For this reason lakes are oligotrophic when there is a highly developed countryside and a highly developed catchment.

Here is the problem: what is happening if there are limiting effects? Limited phosphorus? This limitation is regulating the energy partition in the organisms so there are parallel processes and other processes - the system has to wait until this limiting agent is liberated again. The course of growth in time and space is caused by limitations. The phosphorus limitation is now dealt with by organisms cooperating in teamwork, which is now recycling the phosphorus within the biofilm on top of this plant leaf. Here are organised bacteria, algae, small animals and larger animals in the food chain. All this that I have described is demonstrated on such a little leaf and all of it is working perfectly until somebody gets the idea of breaking up the cycles in the landscape, or we are using the water in such a way that when we flush our toilets into septic tanks the septic tanks don't receive any more of the iron or calcium or aluminium which control phosphorus.

Figure 4



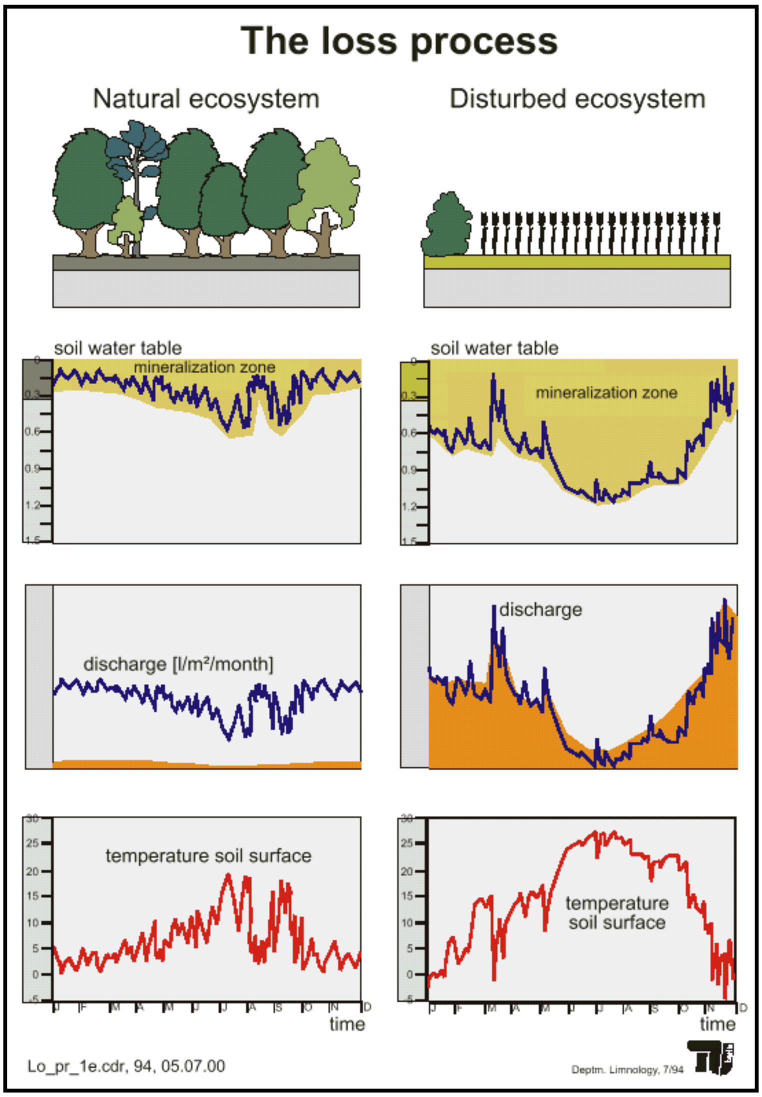
Instead there is food for bacteria and food for recycling, so that the processes and the oxygen demand in the lake are increasing. We also now get phosphorus in the lake; and as we put phosphorus in, there is a structure within which the organisms do not depend on each other any more. Each of these organisms could thrive quite as well alone and we get planktonic development and biofilms in the riparian and the littoral zones; this will decrease the structure because the algae will cause the light climate to decrease, and so the sub-aquatic vegetation will cease. [And we have this now in our catchment, so we can have a closed system there working together in good teamwork (– this is the right side, Figure 4). It is the more sustainable dissipative ecological unit (DEU), it is just the simple system in place]. The original system evaporated water more, and thus less water seeped directly to the sea. Water which is evaporated in short-circuited cycles is always cleaned: the same amount of water falls but it cycles rapidly. The rapidity of water cycling is what does the dissipative work, so it is a much better dissipative structure. Because the temperature is being damped by this, conditions are wet all the time, there is water vapour on top of the soil layer, acting as a filter and decreasing the long wave radiation. Molecules of the greenhouse gases will not be activated as long as there is a water vapour layer because water vapour is the best absorbant for this infra red radiation. This produces decomposers, consumers, detritus and water, as is shown earlier in Figure 3.

However, in an agricultural type of system which is reduced to a very high degree, we have a high net productivity. Net productivity means that almost nothing is recycled to the same place again: it is carried away with the harvest. Even the high net productivity has of course a high process density in the roots, otherwise it couldn’t be so effective. This now causes a big chemical loss of base cations and nutrients and so by increasing nett productivity, the sustainability of the system is being lost. So you can be sure that the better is the growth of, say, maize or corn, the more acidification effect you get on the land and in the topsoil the base cations and the nutrients are all depleted.

So growth is only possible if the system is opened up to the air, reducing the layer of detritus, which the original plants have built up, and thereby, by mineralising, getting heavy acids like sulphuric acid from the sulphur compounds and nitric acid from the nitrous compounds in the soil. These acids dissolve other stuff, weathering the material faster, leaving the insoluble material, and sorting out and flushing away the plant-useable material. It is very easy to see this in the landscape.

In Figure 5 are two entirely different situations. I will not talk too much about phosphorus and nitrogen. Notice the soil water table in Nature. A wetland or peatland of course can't be used for production or agriculture, but peatlands are still growing to a certain extent. They are producing soil for future agriculture, and by damping the water table in the soil so it is not getting so much oxygen in to it, it is becoming stable. This temperature chart is very even during summer and winter in a good system, through the temperature damping which is a very important effect. If there is no temperature damping and no overheated parts and no cool parts there is no potential for violent weather effects or for violent processes in this environment.

Figure 5



If energy is damped by water cycling you get very predictable conditions. I am now doing a study of virgin forest and Fig 5 shows how this virgin forest works. It works entirely differently from forestry. As can be seen in our disturbed system, there is a very deep mineralisation zone. It has been opened it up, wetlands have been drained to increase productivity and while this was feasible, at the same time there were increased material losses to the lakes and the eutrophication process advanced. And in the rivers we can see that in summer time the river discharge has almost disappeared. There is no water in summer time: except when there are high rainfalls and storm water. In Australia there are quite a lot of these almost dried-out rivers, with no temperature damping taking place.

So in summary: the system was initiated after glaciation in Europe, when the glaciers ceased and there was quite a high material flow, a long-distance water cycle between the seas and the landscape, and almost no temperature damping. The country developed without men, and various trees established, at first aggressive pioneer plants. When they got to the edge and became limited, this started a new phase in development, with diversification of the processes and improvement of the cycles. This was according to the rule that the most sustainable teamwork always had more energy left, and so it grew and the others shrank. In this way, efficiency was a framework for developing this highly organised ecosystem with everything in place. Believe me, all these plants and organisms are not put in random mode into the landscape – they are growing where they have the best dynamic conditions and the best energetic preconditions, so that they are highly organised in both time and space.

Now when there was temperature damping and closed cycles man was introduced. And in the beginning man did not think - he first did things, because he thought he was born to act and to manage this land. But he didn't understand the linkages, and so he replaced goats and gazelles

with cows. If on a slope a cow replaces a sheep or a gazelle, erosion is produced in a very high mode, and the erosion transports both solid and dissolved matter into the lakes and rivers.

Man planted, sometimes right on the tops of the hills. Maybe he had a house there and he thought that he shouldn't go so far to work, so he planted nearby. This was the most sensitive spot, because, from the hillside there are no cycles and if it is opened up everything is lost, so the hillside is the first to be depleted. This can be seen in Germany, where all our forests are now dying and we have bald hills, because there is no carrying capacity left in the system.

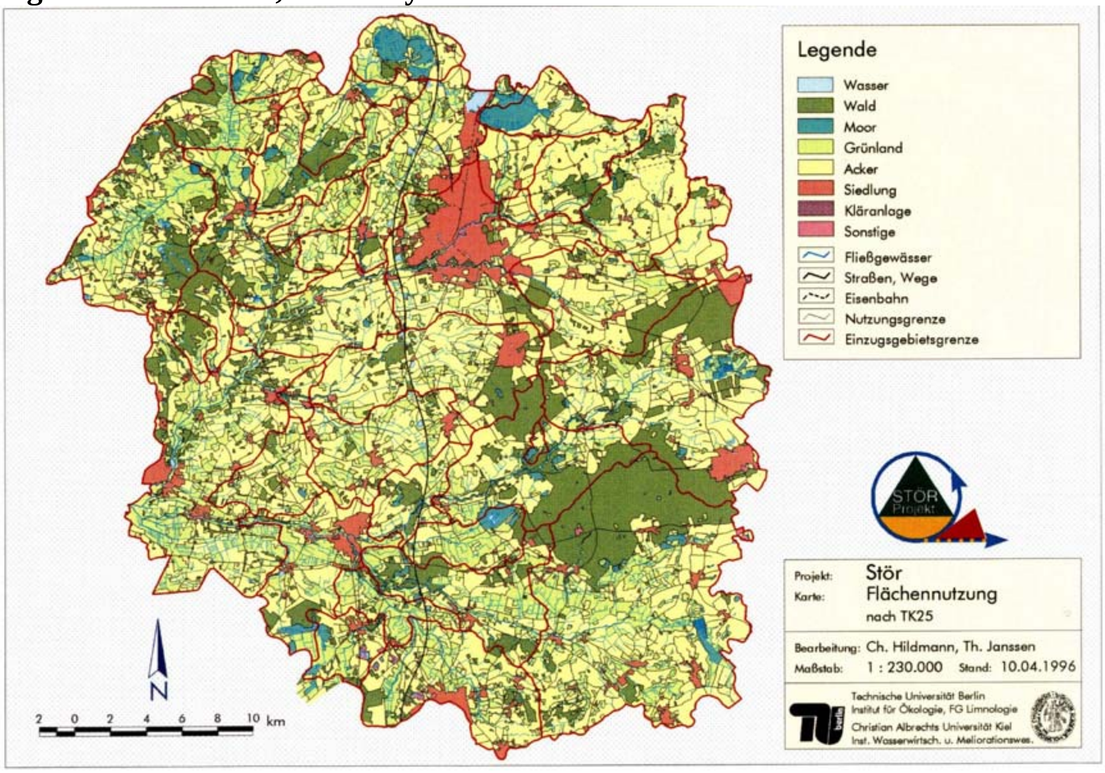
We are now victims of our markets, so that if we see that grapes or wheat is good on the market, we double the size of the field, and take away the trees and increase our operations. We have bigger and bigger machines to harvest, but we are losing the climate, the closed water cycle, and we are eutrophying everywhere. And finally, if we eradicate the biota there is no capacity - nothing left - to live on.

We also lose the water cycle because the dissipative structure includes it. Yesterday I heard from a Maori person that he wants to have (forest) canopy, and of course he should. You see the water cycle is taking place in the virgin forest, underneath the canopy, so that there is a local water cycle on a daily basis: a dissipation by evaporation in the daytime, and at night water coming back as dew. You probably couldn't measure it because dew is not as easily measured as the long range rainfall, which really puts something in your rain meter.
(Editors note: Fog has recently been shown to provide up to 50% of the annual water input to the coastal redwood forests of California)

The different landscapes are converting precipitation with different loss factors. The more evaporation there is, as in wetlands, woods and bogs, the less percolation is there through the soil. With percolation through the soil of course there is leaching, transportation to lakes, and the eutrophication process. Sandhills, fields, and meadows have high water losses, and cities as well - where the situation is a little different.

I shall now show what the landscapes were like. We did a study for five years on landscapes, and this is the actual land use map (below). The green things are forest, the pink areas are cities, and a lot of very fine blue lines show the drainage system which the farmers have made together with hydrologists to improve fertility in the landscape. All this peat soil has been mineralised - now sand is left. [*We are already short of all this, and this is now a good thing because you can see how we have randomised the landscape*.] To find out how this landscape functioned and what it looked like before man came in, take the topography and map a digital height model, with water raining on top, and the distribution of the streamlines can be seen. We see accelerating paths where the water is accelerating downhill and other paths where it is retained and retarded. In these retardation zones are light green areas, which were practically all initially wetlands where water was stored and where nature did an enormous job decoupling the flow of water from the flow of matter and increasing the retention on the land zone.

Figure 6 – Land Use, Germany



We have now done measurements and we could see that what we have achieved, at least in Europe - I'm sure it is very different in your country. We can see (Figure 6) the mean over the whole thousand square kilometres which we have here is more than 1000 kg / ha as dissolved material, running from the landscape in an irreversible way to the sea, and that we can see the blue markings show less than 30 % deviation down and the red markings show more than 30% deviation upwards.

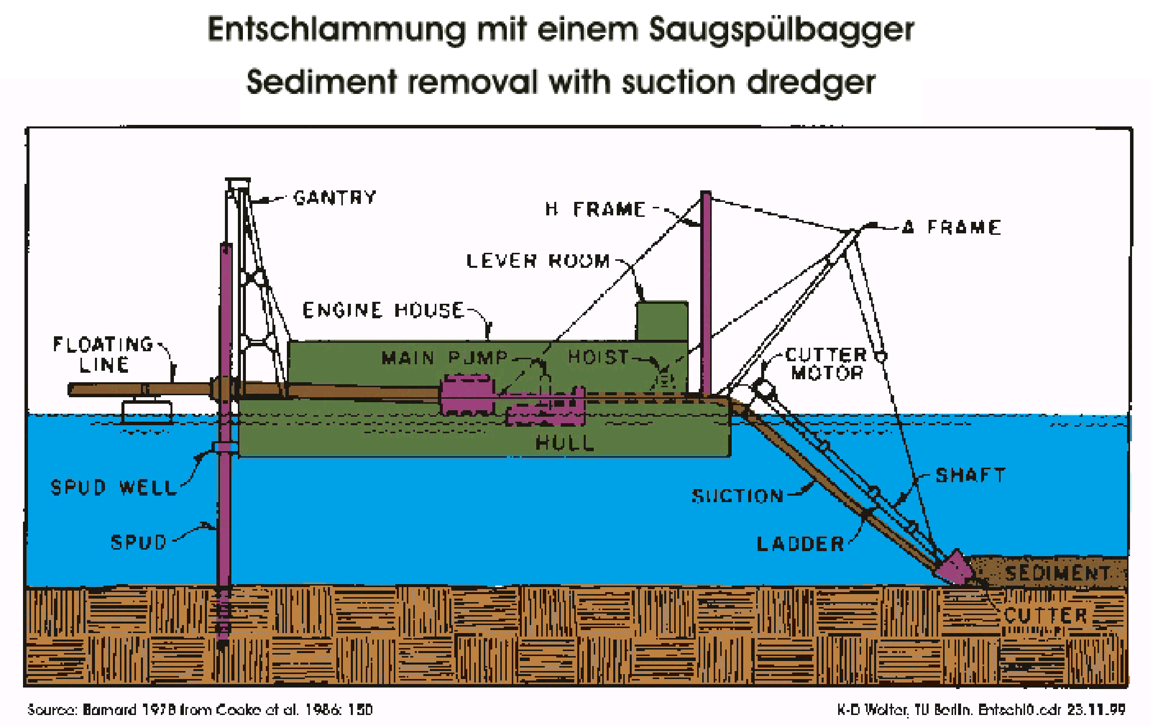
It can be seen that where the cities are located and where we have a lot of agriculture there is the lousiest cooling, but in the forested part there are excellent soils with clay and a very high water retaining capacity. Just what is happening now can be seen from a satellite. In May 1992, and from the satellite we can see the thermal signature, with hot spots where there is emission, the cool spots where we have the absorption. The hot spots generate turbulence in the air, blowing out the nice dust that has the highest concentration of toxins, residuals, and also heavy metals, which is now transported to the remaining wetlands because in the wetlands there is low pressure, a better cooling situation, and the air is descending.

It is not distributed in a random manner, so we couldn't just model this in a simple way. One can see the forests, and a region where there are good soils: and where there is agriculture of this type there is overheating. This was in springtime. In autumn, all of this part is depleted of water. There is no volatile water in the area any more so it is not cooled any more. As far as water goes, there are the forests with the clouds, because the clouds are attracted by the cooled areas and not by the hot areas. And so it can be seen now how these processes are distributed.

So to make the catchment better, better management is needed. For Nature, things must be done in the right place and at the right time, and not in a random manner. We require an adapted management and not management by brute force: just taking a larger tractor and increasing the growing area. Nature has very indispensable functions for Man. These indispensable functions are the services of Nature described above: the atmosphere's composition and distribution; the water cycle; soil fertility; and the vegetation cover. Action can only be taken by the land manager. In the future the land manager will also need to produce energy. You can be sure if we don't like nuclear energy we will have to go back to renewable energy, and renewable energy is an aerial function. And the return of used material is also a new thing for farmers. So the farmers should in the future move into an economic framework which makes it possible for them to carry out good management. For this better management, of course, we must pay.

Now to the internal processes. In lakes we have developed quite a lot of internal methods to do this. In the first one, which was used in 1968, when I did this study in lake Troman (where we had done the coring), we tried suction dredging. This involved just taking away the upper sediments from the lake and taking what was originally reducing and recycling phosphorus. First we had to do very thorough investigations to determine how the sediment was distributed, because if we took too little it would be no good, and if we took too much it was too expensive. So this was the problem we had in doing this (Figure 7).

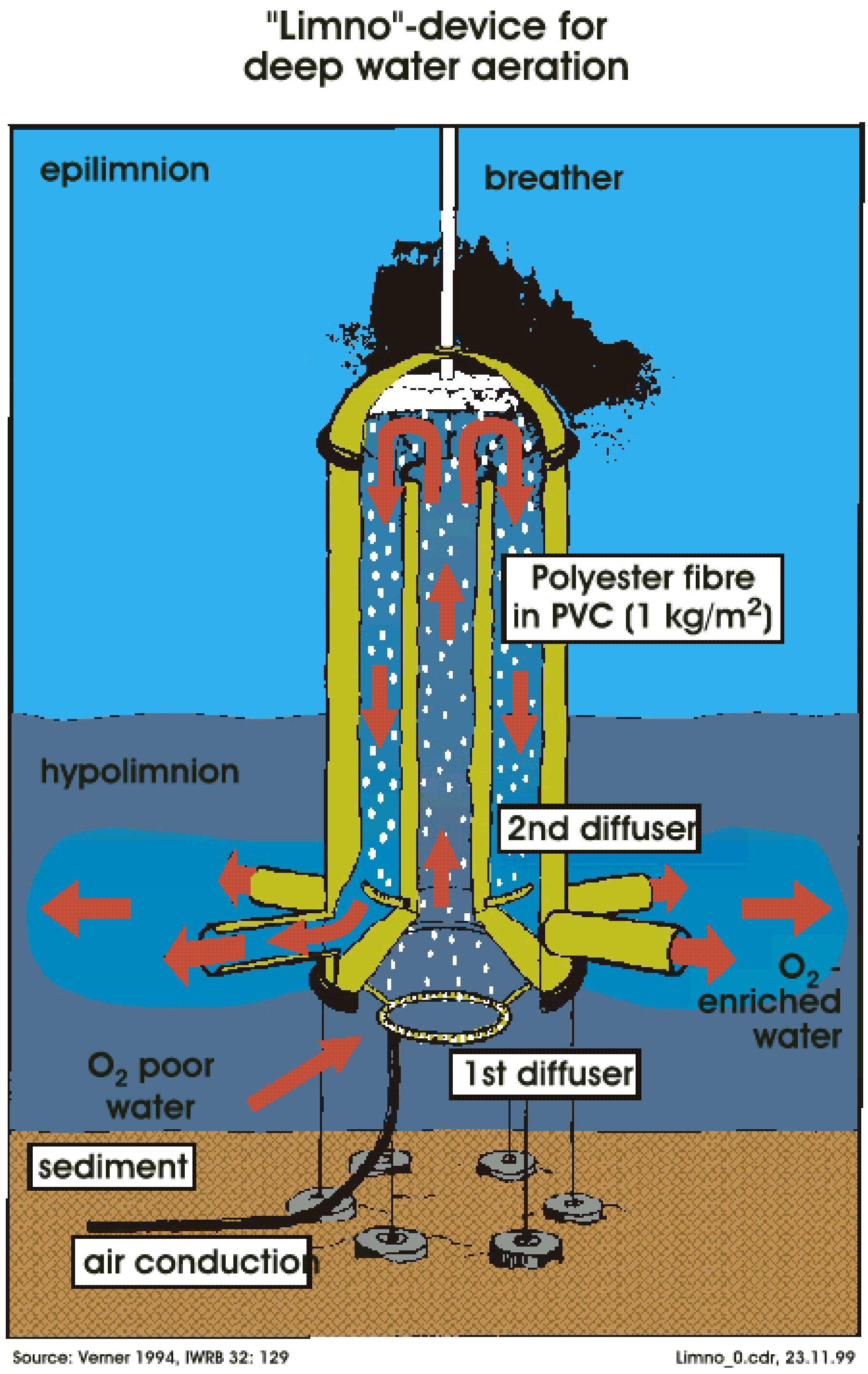
Figure 7



Another thing we developed, together with the firm Atlas-Copco, involved aerators for hypolimnetic aeration, getting down air into the lake (of course you could do it much more expensively with oxygen). By this aeration we could at least introduce oxygen, diminishing

the eutrophication problems in some ways and getting an enhanced lake habitat for the fish and getting benthic fauna on the bottom (Figure 8).

Figure 8



And we could do it by chemical means. I developed this method about 26 years ago, involving just adding a little iron as a redox buffer. There are a lot of reactions involved – for those who want to know more about this method I have some papers on the chemical processes and how this is carried out.

Figure 9

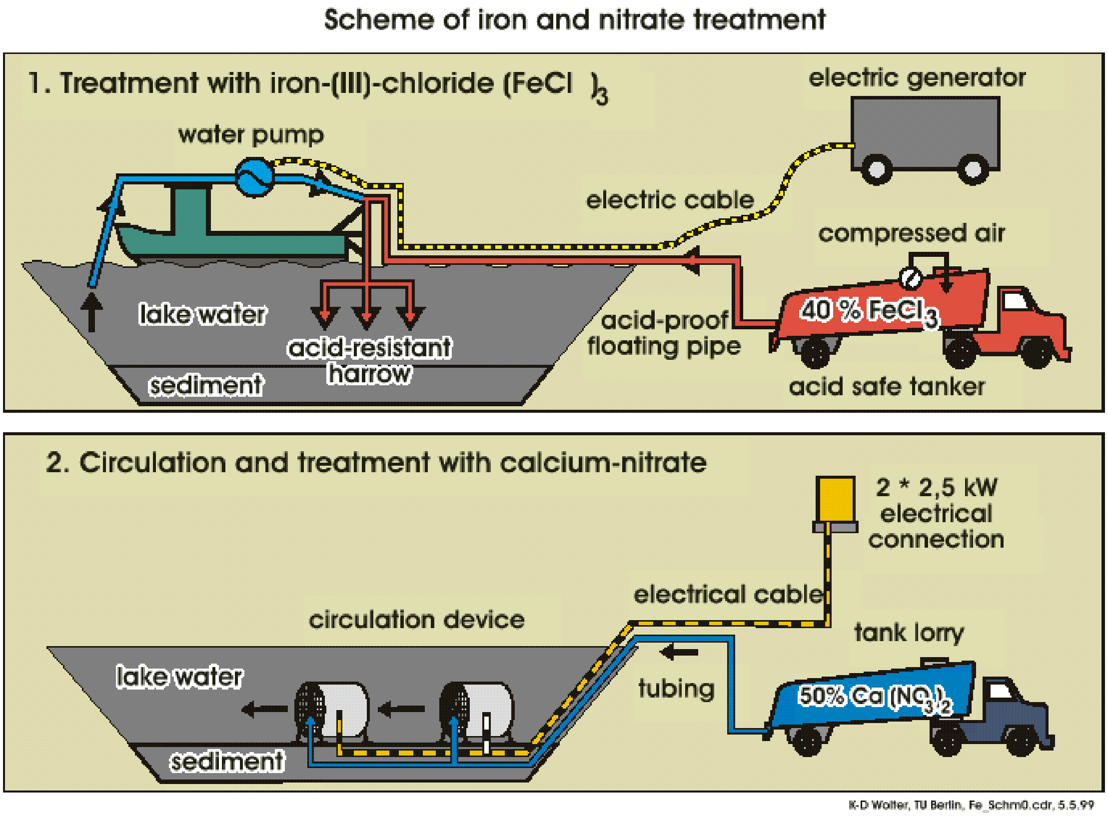
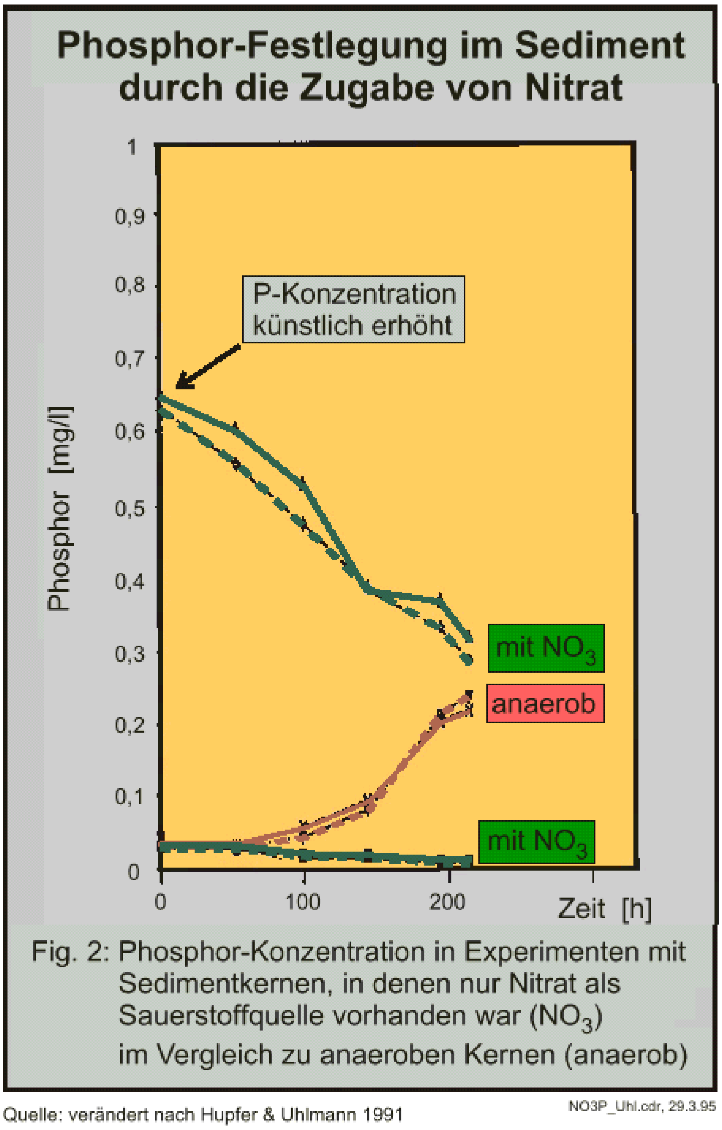


Figure 10 (below) shows another thing in Europe – the pattern of the nitrogen and phosphorus. Through monitoring we have found that in Europe the nitrate usually comes from the catchment in the high-rain winter phase, but it is produced in the summer when there is drying out and wetting continually - so there are decoupled conditions transporting nitrate. In winter time (January-February) is the nitrate peak and in summer time all this nitrate is first denitrified and used up in the lake. But in the catchment the nitrogen is mineralised and when the water table rises again it is transported into the lake.

Figure 10 – Phosphorus immobilisatiion in sediments by adding nitrate



Phosphorus is very different. It is recycling from the sediments, and so in summer, you could say in classical terms, there is nitrogen limitation, and in wintertime, there may be phosphorus limitation. So the system was highly productive. In the sediments the distribution of the processes is now such that with the temperature and with the load from plankton, there are different phases. Also during the seasons we found that the processes are moving up and down in the sediment (we did this also with diffusion cells). Methanogenesis in summertime goes quite high and the de-sulphurication is limited by the low occurrence of sulphate which is depleted totally. In the January - March period is the denitrification phase, so the nitrogen is very often removed, and the heavy load of sediments is already denitrified in the spring.

Figure 2: Phosphorus concentrations in an experiment with sediment cores, in which only nitrate was available as an oxygen source, compared with anaerobic cores. In the upper two lines P is artificially raised.

Figures 11-13 relate to these processes that are going on in the sediments.

Figure 11

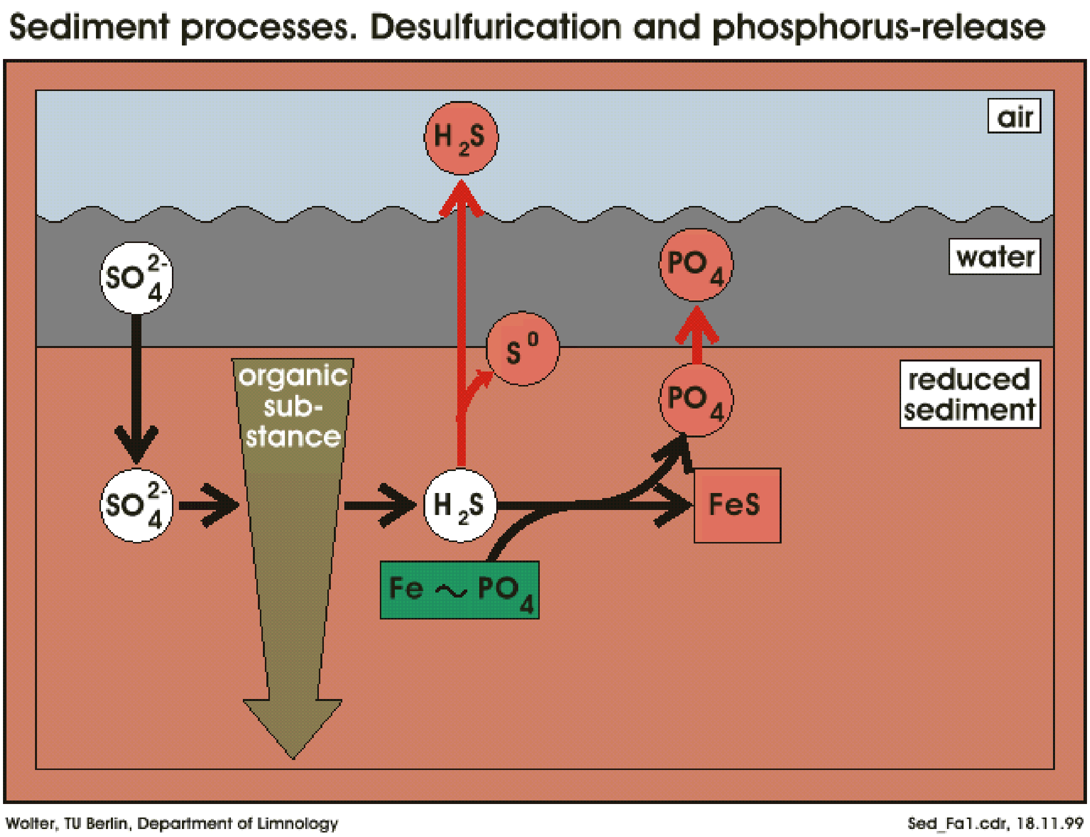


Figure 12

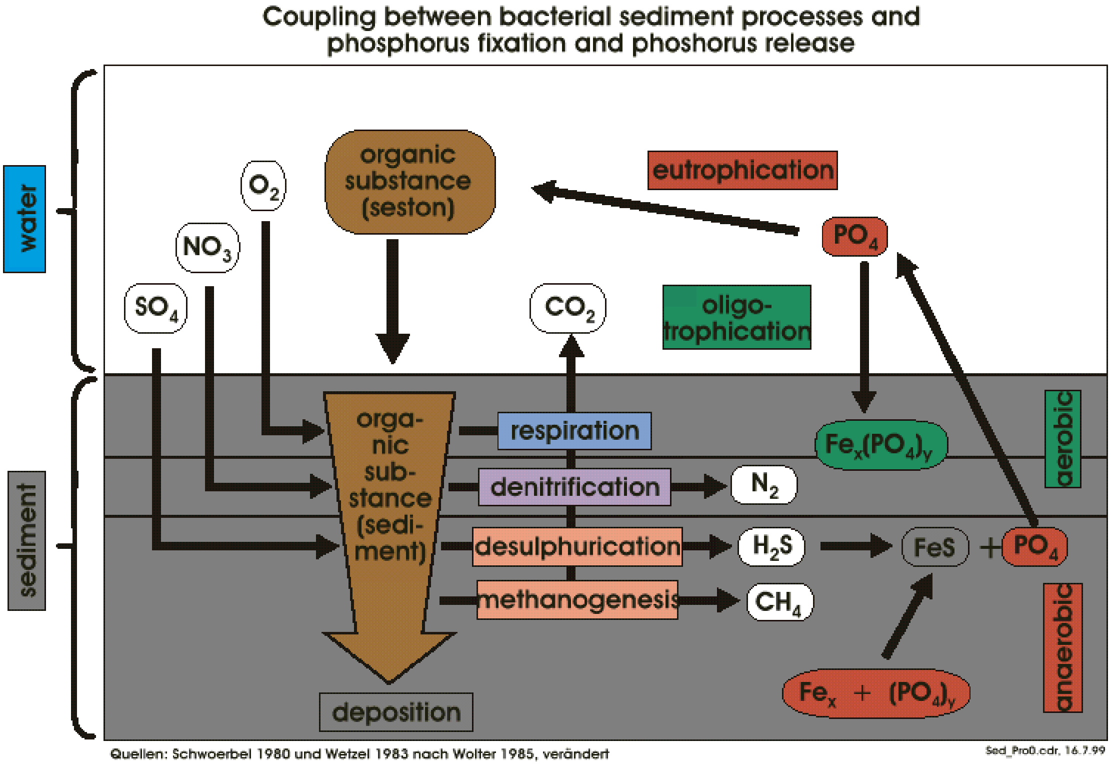
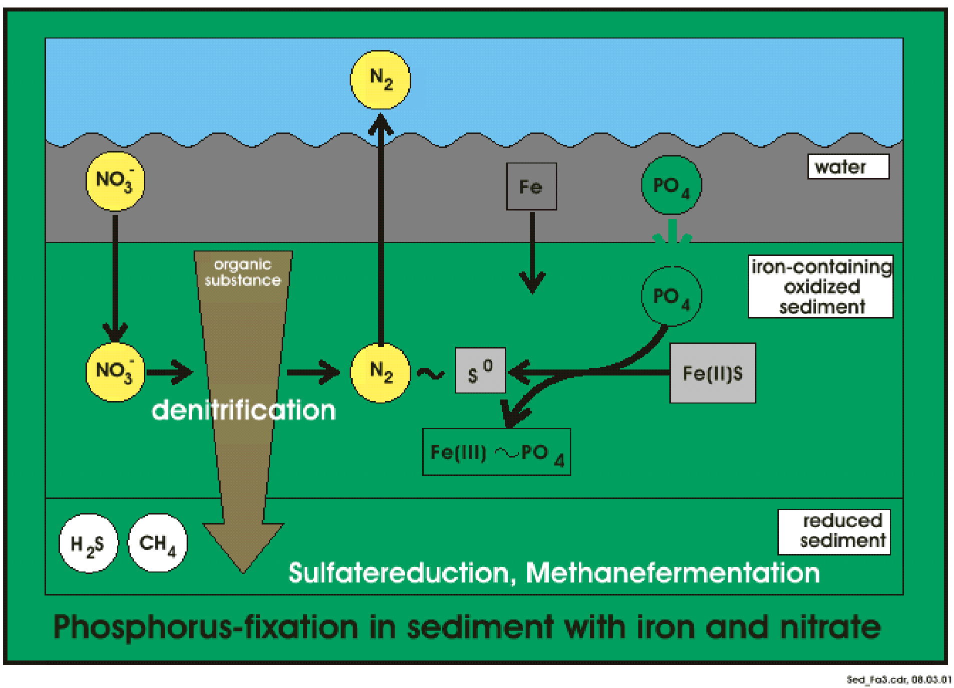


Figure 13



As discussed earlier, the whole German country of 121 catchments was examined. We analysed the material transport, the output from the catchments, and found that the mean is 1200 - 1300 kg/ha/yr in the whole republic of Germany. If we were now to do what the law says to us, that we should re-establish the equilibrium by putting back on top what we are losing by agriculture, we would have to put 650 kg of ground $CaCO_3$ per hectare, in a sensible way on the whole surface of Germany. This would be worth twice as much as our total farming. So you can see to what extent we have succeeded in Germany, and that this is about 100 times as much as Nature did.

We also register that this means we are losing in 100 years what Nature lost in about 10,000 years. For this reason it is very important to see eutrophication and lake restoration in an historical aspect, in a process aspect on the land zone and on the lake, rather than only monitoring lakes. I have some recommendations which are not mine alone.

So I will close now with some remarks from an American scientist who gives recommendations for clearing out ecological problems:

- It needs participation of professional scientists from the very beginning, because very often there are a lot of funny, queer things done in the landscape, not based on any science at all.
- Look on projects as if they were experiments. They are experiments. I could tell you of lake restoration projects with internal measures to about 80%, which do not work out well, they were just flops, using up a lot of money.
- Publish information in advance so that everyone can see what is going to happen.
- Define the time and spatial boundaries of a project system. One can't talk about system if it is not defined and confined in time and space so everybody knows what is meant.
- Use all the historical information available.
- Be careful with respect to unpredictable interactions.
- Be aware of cumulative effects.
- The planning should take into account the heterogeneity in time and space, so that you are not looking at some statistical parameters that are unevenly distributed. You have to grasp this heterogeneity first, otherwise perhaps you are doing the right thing in the wrong place and at the wrong time, and it will be a flop.
- Be prepared for uncertainties, and think in terms of probabilities, rather than trying to get the probability values of 1 or 0.1 or something like that. The probabilities are also distributed unevenly.

I thank you for your attention.

Will Esler – Session Chairman
Thank you very much Professor. It is very timely to be reminded that each landscape has a year zero. In Europe it's the glaciation, in Rotorua it's the last eruption. And also thank you for reminding us that good land management is essentially applied ecology, which is just another word for sound commonsense. So thank you for that.

ENVIRONMENT B·O·P'S LAKE MANAGEMENT PLANS – PRESENT AND FUTURE

John McIntosh
Manager Environmental Investigations, Environment B·O·P, WHAKATANE
(*John McIntosh was unable to deliver this paper, due to illness, and it was delivered on his behalf by Paul Dell, Group Manager Resource Management, EBOP*.)

Introduction

Environment B·O·P came into existence with the reform of local government in 1989 and the Resource Management Act became law in 1991. Enacting environmental management through regional plans has taken time because of the exacting nature of the legal process. However, policies have been developed outside of that process to enable continuing development of resources. An exception is the management of septic tanks where a regional plan has been drawn up for management purposes. Table 1 shows a number of environmental pressures that affect lakes where Environment B·O·P has established policies so that lake quality can be maintained. The policies will eventually be formalised in regional plans.

Table 1 *Methods Environment* B·O·P *uses for lake management.*

Environmental Pressure	**Management option**	**Comment**
Stream bank erosion	Riparian retirement	Most of Lake Rotorua streams have been retired from grazing. Work is progressing on other lakes.
Land erosion	Retirement from grazing	Planting in conservation species.
Stormwater	Resource consent	Comprehensive catchments consents being developed.
Sewage discharge	Resource consent	The major discharge at Rotorua has been diverted from the lake.
Septic tanks	Regional plan	Plan provisions are a basic measure; a higher level of treatment may be necessary at some lakes.
Agricultural discharges	Resource consent	Dairy shed policy encourages discharge of shed wastes to land.
Industrial discharges	Resource consent	In particular, the timber processing industry.
Nutrient run-off	Riparian retirement	Surface run-off can be reduced by plantings but a large pool of geologically derived nutrients is part of the natural baseflow.
Biodiversity threats	Exotic weed and pest control	Native biodiversity also encouraged.
Poor bathing quality	Water classification standards	In the Regional Water and Land Plan
Toxic algae	Monitoring	Monitoring is carried out over the summer and results considered by the Medical Officer of Health.

Environment B·O·P and their predecessor, the Bay of Plenty Catchment Board, have carried out riparian protection work around the Rotorua lakes, for three decades. There are still areas where retirement from grazing would be a benefit to the environment and there is a need for on-going maintenance. However, the procedures for carrying out this work are in place and continue to evolve.

Resource consents have been issued for activities based on negotiation between the resource users and the community. Policies have been developed in this process so that management is consistent e.g. a common dairy shed effluent disposal policy was developed for all lake catchments.

A programme of regional monitoring was initiated in 1989/90 and a number of research projects commissioned to build up the level of scientific knowledge of the regional environment. A lake-monitoring programme was begun which built on the lower intensity monitoring programmes of the past. The programme has been modified in the intervening years and is now based on the methods that were employed in NIWA's national lakes network. Dr Noel Burns has refined these methods and now advises Environment B·O·P on the lakes monitoring programme.

Objectives for lake quality

There have been lake quality objectives for some parts of the Rotorua lakes expressed as conditions of the old Water and Soil classifications in the Transitional Regional Plan. Where such a classification exists, this is a legal requirement to be taken account of, where discharges are proposed. Most of the classifications were for bathing quality waters. However, a lake could continue to develop poor overall quality while bathing quality was maintained.

There has also been an objective for the quality of Lake Rotorua. This was accepted in principle as a basis for resource consent conditions associated with removal of Rotorua city's treated sewage effluent from discharge to Lake Rotorua. Overall, there has not been a quality baseline for the lakes against which the accumulated effects of land development and land use changes could be judged and managed. Environment B·O·P wishes to establish such a baseline.

The first step in reaching this objective was taken with the classification of the Tarawera River catchment lakes (Tarawera, Rotomahana, Rotokakahi, Tikitapu, Okareka, Okataina, Okaro) in the Regional Plan for the Tarawera River Catchment. A baseline quality was set. The principle employed was that the quality of the lakes should not be reduced to a worse state than the current state. The baseline was therefore the quality of the lakes in 1994, when the Plan was released. This plan did not contain the mechanism for precisely measuring the state of the lake.

In formulating the Draft Regional Water and Land Plan, the balance of the Rotorua lakes are to be classified with a condition included that sets a baseline for lake quality. In this Plan the

quality is set using the Trophic Level Index (TLI) of Dr Noel Burns. This fills in the gap in the ‘Tarawera’ plan and sets the basis for lake management into the future. There are other narrative conditions of the classification as well but the TLI will really dictate our general catchment management.

Lakes Trophic Level

The Draft Regional Water and Land Plan has two lake classifications, Natural State and Managed State. Both have a condition that requires the TLI to be better than a specified value. Lake Rotoma is a Natural State (NS) lake. Six lakes of the ‘Tarawera’ group have also been classified as NS in the Regional Plan for the Tarawera River Catchment.

Experience has shown that the lakes respond slowly to changes in inputs. The decline in the quality of Lake Rotorua has been halted 10 years after diversion of sewage effluent. This was achieved with a major reduction in nutrient inputs of about 30% for total phosphorus and 15% for total nitrogen. Improvements are expected over the next decade and perhaps even over a greater time scale. The internal load at Lake Rotorua responds to climatic variation and is less predictable than external inflows. Summer monitoring of the dissolved oxygen depletion during periods of stratification has shown that the rate of depletion has decreased over the last ten years. This means that the period of time that the internal load can be released from the sediments has been reduced, assuming the frequency and duration of stratification events occurring has not increased. In the 1980s, nutrient release would occur about 5 to 6 days after one of Lake Rotorua’s intermittent stratification events was initiated. Now nutrient release can be delayed up to 10 to 20 days after a stratification event begins. Stratification events are generally short lived and last from a week to several weeks.

There are no big loads that can be easily targeted for diversion at the remaining lakes, should remediation of the lake be required. Table 2 indicates which of these lakes are under pressure because their quality is less than required by the Draft Regional Water and Land Plan.

Table 2 Baseline Trophic Level Index set in the Draft Regional Water and Land Plan compared to the current TLI.

Lake	Draft Regional Water and Land Plan TLI	Current TLI
Rotoma	2.3	2.3
Okataina	2.6	2.6
Tarawera	2.6	2.6
Tikitapu	2.7	2.7
Okareka	3.0	3.4
Rotokakahi	3.1	3.2
Rotoiti	3.5	3.9
Rerewhakaaitu	3.6	3.6
Rotomahana	3.9	3.8
Rotoehu	3.9	4.7
Rotorua	4.2	4.6
Okaro	5.0	5.7

The lakes with shading in Table 2 require nutrient reduction methods applied in the lake catchment to achieve the baseline quality. Note that a regional plan has a term of 10 years so the TLIs will be reviewed on that time scale.

Recent data indicates that Lake Okareka is in a state of decline. The lake has a large rural component and a community disposing of sewage to septic tanks. Rotorua District Council and Environment B·O·P have engaged NIWA to research nutrient sources within the catchment so that appropriate methods of nutrient reduction can be assessed.

Lake Okaro is a rural catchment with a large proportion of pastoral development. The available options for improving the lake quality in the long term involve a change from pastoral farming.

Lake Rotoehu is also a pastoral catchment, where riparian retirement is proceeding. A large dairy farm exists to the south of the lake and retirement works will be initiated along this shoreline this year. A small population live in this lake catchment so strategies for reducing rural inputs are the primary options for improving lake quality.

At Lake Rotorua the method of reducing the nutrient load has already been applied as discussed above. As Rotorua improves the effect will flow on to Lake Rotoiti.

Comments can be made to Environment B·O·P, regarding the TLIs and other aspects of the Draft Regional Water and Land Plan, up to Friday 6 April 2001. Various methods for sustaining and improving lake quality are included in the Plan. Another avenue for adopting methods of catchment management aimed at sustaining lake quality will be developed in the 'Strategy for the lakes of the Rotorua district'.

Lakes Strategy

This is an important vehicle for the ongoing integrated management of the lakes of the Rotorua district and has been developed in partnership with Rotorua District Council, Environment B·O·P and the Te Arawa Maori Trust Board. It aims to achieve joint management of a wide range of issues critical to the lakes' future. These encompass water quality, riparian and catchment management, recreation, rural/urban growth and iwi liaison and co-management. The Strategy was finalised in October 2000 and has involved a close liaison between the three parties, with public consultation and submissions used to gain feedback from stakeholder agencies and the community.

The Draft Regional Water & Land Plan will set the bottom line for lake quality but the day-to-day management of land use will be based on policy set in the Lakes Strategy. The progress of the Lakes Strategy has stalled for a number of years but the policy development is now set to progress.

The strategy sets key goals for protection, use, enjoyment and management of the Rotorua lakes.

The tasks that have been set under each goal are currently being achieved in various other initiatives. Lake water classifications in the Draft Regional Water & Land Plan (DRW&LP) have completed task 2 of the protection goals. Task 3, which involves prioritising lakeside and stream areas in need of retirement from grazing, is also at an advanced stage. There is still a debate regarding task 1, the prioritisation of causes of lake degradation. However, the classification of waters in the DRW&LP points strongly to the specific lakes in need of urgent action. At each lake a specific target is evident.

Dealing with task 1 involves gaining a clear understanding of nutrient export values for different land uses. This may need to be refined for specific locations in the lake catchment. The important outcome for lake management would be the refinement of a set of land-use model parameters. This would enable calculations to be carried out by district and regional council staff when a land use change was proposed to see if the lake nutrient status objectives would be met. Environment B·O·P is funding investigations to achieve this objective.

Making the system work

Environment B·O·P have set up a monitor/feedback system based on the lake classifications in the Draft Regional Water & Land Plan. Where the lake quality is found to be poorer than the required baseline quality then management intervention is needed. There will always be a choice of methods. Commonly, environmental controls are exercised through best management practices (BMPs), especially where it is difficult to apply 'end of system' standards or guidelines. To meet the needs of future lake management a comprehensive list of BMPs will be drawn up to offer options to compensate for nutrient export from every land use activity. Then when the TLI indicates action is required BMPs will be selected to curb nutrient inputs.

Summary

Actions have been taken and are continuing to be applied in land management with the objective of enhancing lake quality. Three lakes, in particular, stand out as requiring significant additional management input, i.e. Rotoehu, Okareka and Okaro. Riparian retirement works are in an advanced stage at Rotoehu. Studies (RDC, NIWA, Environment B·O·P) are under way at Okareka. Lake Okaro, because of its size and location, has become a lesser priority, but options for improvement will need to be addressed. Lake Rerewhakaaitu was targeted for a land-use study in Environment B·O·P's current financial year. This lake has the most intensively farmed catchment of the Rotorua lakes so the study will shed light on options for the continuation of this land-use.

Various factors and mixes of factors influence lake quality e.g. pastoral farming, sewage effluent disposal, septic tank effluent seepage. At each lake different factors tend to have dominant effects so the best solutions to poor lake quality may differ from lake to lake.

The extreme situation may require some significant change in both land-use type and land-use practice. It may be that within the context of the whole Bay of Plenty region, the Rotorua lakes are not the best place to carry out intensive agriculture. Other areas of the region are better suited. The trade off against lake quality may not be worth it to the region's economy.

On-going monitoring is critical to assess trends in lake quality and the success of interventive policies.

Revised version

NITROGEN: GUARDIAN OF LAKEWATER QUALITY?

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Abstract

Nitrogen (N) as well as phosphorus (P) is stripped from Rotorua sewage effluent, with the aim of avoiding excessive primary biomass in the lake, since the loadings of P are so high as to be conducive to excessive biomass levels. However, a literature survey involving the diverse group of Rotorua lakes has indicated that undue reduction of N inflows, which create or accentuated N-limited states, can lead to highly undesirable N-fixing cyanobacterial blooms (NFCB). Indications are that in the natural state these lakes had high water clarity, despite often high phosphorus (P) inputs, and in at least some cases high but stable N inputs. In addition to increased P inputs resulting from land-use changes, strongly accentuated fluctuations in N inputs, also resulting from these changes, may be a major cause of declines in water quality. While stable N-limited states can evidently exist, in the sense of not leading to NFCB, the requisite conditions for this are not fully known. Unless such conditions can be identified, and reliably imposed in the future, control of P loadings seems to be the only dependable way to assure high water quality.

Introduction

Current treatment of Rotorua sewage effluent is aimed at stripping both phosphorus (P) and nitrogen (N). This was prompted by worryingly high P loadings in the lake, with important natural P inflows that would be difficult to reduce, and a fear that removal of N limitation may lead to excessive levels of algal/cyanobacterial biomass. Such biomass levels greatly reduce water clarity, can include toxic components, and can cause considerable ecological disruption. When combined with lake stratification they can lead to anoxic states which are very undesirable in themselves and can then lead to ‘regeneration events’. Such events release nutrients from lakebed sediments, and these releases can include considerable P and ammonium N (although much of the N may disappear through associated denitrification), thereby exacerbating or at least perpetuating the original problem of excessive nutrient loadings. However, we critically examine the approach of limiting the N inputs. It can entail risks of favouring N-fixing species of cyanobacteria (‘blue-green algae’), which are highly undesirable if they form significant blooms. Also, if this approach fails to attack the strongly fluctuating components of N input, it may fail to address an important danger of high N inputs.

The examination is based on a literature review of past occurrences and timing in the various Rotorua lakes of N-fixing cyanaobacterial blooms (NCFB), in relation to seasonal variations in P and N loadings (Mylechreest 1988), taking special notice of features that naturally remove N and P differentially. The Rotorua lakes form a useful basis for comparative study, because while they represent a compact local group in an area with many common geological

features, they are still highly diverse. This diversity exists in: size, catchment area in relation to size, depth and other features of bed configuration, degree of shelter, geothermal inputs, density of human settlement and associated influences, and rural land use and associated vegetation. Thus, while this diversity prevents any facile generalisations across lakes, it offers a promising basis for generating and testing hypotheses concerning underlying mechanisms of lake function in the region.

Importantly, native-forest catchments on the central volcanic plateau, which are typically associated with high lake water clarity despite sometimes relatively high P loadings, can have high and relatively constant discharges of N (Cooper & Thomsen 1987; Cooper *et al.* 1988). This pattern is in at least some cases associated with large springs of very constant flow, resulting from very deep percolation, which have far from low contents of dissolved inorganic P and N, and tend to discharge into the lakes virtually unfiltered by wetlands. (There are also some large natural inputs of inorganic N from thermal fields). These may well be key features of the natural states of the lakes, although there is a frustrating lack of hard and direct information on the natural states and therefore on how the lakes functioned to retain natural clarity.

Conversion of catchments that were in native vegetation, largely forest, to other land uses has brought major changes. Pastoral farming has entailed heavy topdressings with superphosphate, especially in the early stages. This has been associated with increased inflows of P and erratic inflows of N (Cooper & Thomsen 1977: Cooper *et al.* 1988), although effective seepage dams would surely mitigate at least some of these effects. Also littoral wetlands were often lost and riparian strips were often eliminated. In any event, serious declines in water clarity have tended to be associated with conversion of catchments to pasture. Urban development has produced sewage effluent which, even after conventional treatment, contains high loadings of P and significant N, leading to the adoption of the land disposal system for stripping nutrients from sewage effluent. More scattered settlement has entailed use of septic tanks which, in pumice soils, release inorganic N readily but not P – provided they are functioning well.

The Wairua arm, Lake Tarawera

Conversion of land to pine plantations was thought to be comparatively benign for water quality. However, a surprise came in Lake Tarawera, which historically had very good water clarity, and where a trout-breeding experiment was being monitored (Mylechreest 1988). From 1985, blooms of N-fixing cyanobacteria (*Anabaena*) appeared in the Wairua arm, not just once, but in several successive winters. The trout growth was well below what was expected, pointing to lasting ecological impacts of the blooms. This occurred after almost all of the predominant inflow catchment had been planted in a short space of time with pines, and the canopy had started to close. The establishment of pine plantations has been associated with sharp falls in N release from catchments (Cooper & Thomsen 1987; cf Knight & Will 1977), so a strong, atypical N-limited state had evidently been created, which could account for these blooms. Such a degree of lock-up of N is evidently transient in the lifetime of a pine plantation, and as such is unlikely to affect whole catchments in normal circumstances, but it is an effect to watch for and counter if need be. While such blooms may be transient, their ecological impacts can be considerable, and prolonged.

Findings from literature review

The literature review (Mylechreest 1988), which had been prompted by the developments in Lake Tarawera, related to the Rotorua lakes in general, in the context of the wider limnological literature. While the evidence from the other lakes was less dramatic than in the Wairua arm of Lake Tarawera, it pointed to the noxious NFCB being favoured by N-limited states, which has become a classical tenet of limnology (e.g. Smith 1983). Of note was a pattern of *Anabaena* blooms occurring in Lake Rotoiti, not in winter but in summer, which could be related to winter inflows of N from Lake Rotorua favouring other types of phytoplankton. Lake Rotoma, which had the highest water quality and generally the most pronounced P limitation, has the feature of sand bars that enclose two lagoons at the mouths of pastoral catchments, and these bars could be expected to intercept P but not necessarily N. Also of interest was the case of Lake Okareka; its catchment has relatively dense settlement with heavy reliance on septic tanks which readily release inorganic N but not P if they are functioning. It had remained free of cyanobacterial blooms despite a far from low trophic level and a considerable plant biomass.

While interpretation is complicated by seasonal fluctuations in patterns of nutrient , there was a marked tendency for the Rotorua lakes of higher water quality to be P-limited rather than N-limited and free of cyanobacterial blooms in general. The phenomena reviewed have not all recurred during recent years, since some conditions have changed in the meantime. Also, the associated monitoring was generally less detailed than much of the more recent monitoring, and some of the analytical data less reliable. Nevertheless some of the phenomena were so marked that they surely cannot be disregarded.

Discussion

A N-limited state is believed to pose several dangers if it is allowed to become severe and persistent in the face of high P inputs. As already mentioned, it may lead to NFCB which, like cyanobacterial blooms in general, are toxic in themselves and can be ecologically disruptive even if their duration is brief. In extreme cases, they might lead to excessive biomass with its consequences, either directly or through relief of N limitation favouring other species of phytoplankton. In those situations moderate to high N levels could reflect trophic problems originating in high P, rather than being the root cause of trouble. Failing NFCB, a N-limited state may help P loadings to build up to levels at which a major influx of N will allow phytoplanktonic blooms to reach excessive biomass levels, with the attendant problems, which may contribute to bringing affected lakes to the point where they may not recover without intensive and very costly remediation.

A low N : P ratio at any one time is clearly not a sufficient condition for blooms of N-fixing cyanobacteria to develop (cf Smith 1983); various other conditions are entailed which can fluctuate in time, and these include exposure/wind velocities especially, which will affect mixing of lakewater, and also temperature, other nutrients temporarily becoming limiting, and historical availability of inoculum. But it is contended that any N : P ratio that represents a N-limited state is a precondition that favours the development of such blooms. If that

precondition can be denied, by reducing P loadings and/or by maintaining or even boosting N loadings, then at least the main risk of NFCB should be averted.

In any event, excessive P loadings must be avoided if at all possible, since they can lead in various ways to excessive primary biomass. However, since continuing high P inputs appear to be often geologically inevitable in the Rotorua area, this may be major challenge. Avoidable P inputs need to be reduced or eliminated, while any removal or immobilisation of P is likely to be an expensive and continuing task. In the area of underpinning research, to give better insights into the processes involved, there may be opportunities to use stable isotope analysis to apportion to contributions of 'geological' and fertiliser P to the P content of lakewater and lakebed sediments.

Adding N, or permitting avoidable N inputs, to mitigate a N-limited state may have a place in remediation. It is not unduly expensive or technically difficult. In the short term it can be expected to entail an increase in biomass, with some loss of water clarity. If P loadings are low enough to leave species composition rather than excessive phytoplanktonic biomass as the main hazard, there should be no serious risks. In such situations, inorganic N appears to be basically harmless, unless perhaps N loadings become so high as to threaten nitrate/nitrite toxicity in drinking water. However, if P loadings are high enough to allow excessive biomass, any N additions would need to circumscribed, even if at some remaining risk of NFCB. Yet partial relief of such N limitation may in some situations be safe and effective, with the benefit of eventually promoting sequestration of some P. However, since it would require judicious doses and timing, adding N would on present knowledge be very risky, except on a pilot scale in a water body where the values at stake are now minor, or where cheap correction can be assured. Any remedial measures, however, need be trialed sooner or later on actual lakes, initially on a pilot scale.

While major drops in P loadings may be readily tolerated if they are transient (prolonged and very severe P limitation will compromise all productivity), major fluctuations in N loadings appear to be inherently dangerous, for reasons given above (and they may reinvigorate existing NFCB). Factors of land use leading to both lock-up of N and/or large surges of N inflows are seen as needing further study, especially the latter which interact very unfavourably with high P loadings. Drying out of upper soil layers and consequent delays in recovery of soil wettability (as can often occur on pasture land), may be conducive to major releases of N before the deep percolation that allows prolonged and steady release is fully re-established. Pastoral land tends to accumulate high soil N, and build-ups of such N can occur in the summer, when evapotranspiration deficits can lead to drying of upper soil layers. In this connection, the observation that even rapid storm runoff can represent mainly displacement of existing soil moisture rather than direct run-off (Pearce *et al.* 1986; Sklash *et al.* 1986), may be highly relevant, since it could be conducive to major leaching of readily soluble N in such run-off. Such surges in N release from pastoral land, in contrast to steady release of considerable N from native forest, have been observed by Cooper *et al.* (1987). Brief periods of major releases of N occurring in this general way may at once be dangerous and yet hard to detect by routine monitoring. In this general connection, it is noteworthy that the pumice soils of the region, while inherently very permeable, can become highly resistant to rewetting when once the top layers have become very dry, a situation that may be exacerbated by surface compaction resulting from trampling by livestock. Major surges of N inflow, which may have

undesirable organic components, would be additionally favoured by loss of littoral wetlands and lack of riparian strips in gullies.

If strongly fluctuating inputs of N are undesirable that would have implications for the effectiveness of stripping N from sewage. Apart from being very expensive, this measure may have a significant limitation through attacking a stable source of N inflow, to which lake function may adjust more readily than to strongly fluctuating sources.

Concluding remarks

Restriction of P loadings to consistently below what allows undesirable levels of primary biomass is seen as the outcome of choice (persistently inadequate P for satisfactory productivity being discounted as any real hazard in the Rotorua lakes). If that is achieved, surplus inorganic N, relative to P, can be decidedly beneficial and should be at the worst essentially harmless. Failing adequate and reliable restriction of P loadings, optimal management of N inputs would depend on which is the more serious issue between excessive primary biomass production and the risk of NFCB. Ascertaining which is the more serious in a given water body, however, may be very difficult. There are evidently some situations where a N-limited state can, in the presence of considerable P loadings, be stable in the sense that the N limitation and consequent low biomass can persist indefinitely without giving way to NFCB. While windy weather and exposure, along with some other known factors, may militate against cyanobacterial blooms in the short term, we do not know the necessary conditions for long-term stability, let alone whether those conditions can be imposed and maintained after the various anthropogenic changes that have occurred in Rotorua lakes and their catchments. Yet without such knowledge, lake management that is not based on reliable containment of P loadings will rest on shaky foundations.

Acknowledgments

This contribution has been significantly revised in the light of the Symposium. Thanks are due to many individuals, including Prof. W. Ripl, Dr R. Oliver, Dr N. Burns and M. Gibbs for discussions, and to W.R, R.O., M.B., and Prof T. Northcote for commenting on a revised text. Final responsibility for the content, however, remains ours.

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TRACE ELEMENT FLUXES IN AND OUT OF LAKE ROTORUA: PROJECT OUTLINE

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Dr Joanne Deely (Department of Conservation) was unable to present this paper due to illness. It was presented on her behalf by Dr Chris Hendy (University of Waikato).

Objective

To determine the fluxes of nutrient elements and trace metals into and out of Lake Rotorua.

The concentration of any element in the water column of a lake is a consequence of the balance between the rate at which that material is added to the lake, and the rate at which it is removed. It is not possible to make sensible lake management decisions without quantifying and understanding the flow of materials in and out of the lake. We have put together a research program which attempts to achieve this for Lake Rotorua. We broadened the range of our study from just the nutrients of prime concern for the eutrophic status of the lake to include a range of trace elements which have the potential of reaching problem concentrations or which may shed light on processes occurring within the lake.

Key Questions

To what extent are trace element concentrations in sediments controlled by changes in fluxes into lakes or alternatively by diagenetic processes in the sediments?

How long will it take for Lake Rotorua to recover from past discharges of nutrients into the lake?

What options are there for lake management?

We are particularly interested in the sink that sediment accumulation provides for the removal of nutrients and trace elements from the water column and the potential that chemical and biological processes have for mobilising materials within the sediments and for returning them to solution with the lake.

As decaying organic matter from dead organisms rains down from the water column to become incorporated into the sediments decomposers such as bacteria and fungi utilise the oxygen in the surrounding waters to oxidise the carbon to carbon dioxide. Once the organic matter has become buried within the sediments the rate of supply of dissolved oxygen is severely limited and generally cannot keep pace with the needs of the decomposers. Under these conditions the decomposers reduce other chemical species such as nitrate to ammonia, sulphate to sulphide, ferric iron to ferrous iron, manganese dioxide to manganous etc. The sum total of all of these processes is termed 'diagenesis' or are termed as 'diagenetic processes'. This diagenesis drastically alters the chemistry of the pore waters in contact with the sediments allowing some elements which are insoluble and immobile in oxidising environments to become mobile and in so doing may be returned to the water column (as may be the case for phosphorus and nitrogen) or re-immobilised in the surface sediments (as may be the case for iron, manganese and many trace metals). This process is well known in the ocean where it results in the formation of manganese and phosphate nodules over large portions of the ocean floor, but has not been widely studied in lakes.

Traditionally, increasing concentrations of trace elements towards the top of sediments have been interpreted as evidence for increasing fluxes from the catchment and generally cited as evidence for anthropogenic pollution. We intend to evaluate the relative significance of depth dependant diagenetic processes to that of time dependant flux changes.

A side benefit of this study is that it should enable us to estimate the residence time for nutrients which are already in the lake system.

WHY ROTORUA?

An existing problem needs to be solved.

The presence of tephra layers gives sediment time horizons enabling time dependant processes to be distinguished from depth dependant processes.

The results are likely to be of global significance.

Lake Rotorua provides a good starting point for such a study for several reasons. It is a lake with a historic problem of eutrophication and a question of how to best manage the catchment to the trophic status to avoid problems caused by excessive macrophyte or phytoplankton growth.

Lake Rotorua has another feature which it shares with other Rotorua District lakes, but which is rare in the world as a whole. It lies in an area which has been subjected to a significant eruption of rhyolitic tephra (ash) about once every thousand years. As each eruption has its own characteristic mineral and trace chemical signature these provide time markers over the whole landscape including the lake sediments. Thus the sediments of Lake Rotorua, which at 235,000 years is probably the oldest lake in New Zealand, have built in time markers which will vary in depth depending on sedimentation rates. This should enable us to distinguish the effects of catchment flux changes from those of diagenetic processes.
The results of this study will be relevant to lakes anywhere in the world and therefore of interest to more than those who live in the catchment.

Pilot Study

Project for a selected group of 3rd year geochemistry/environmental chemistry students.

Field work to be carried out in April 2001

Report Due October 2001

We attempted to start this project with a M.Sc. Student last summer with the aid of funds from Environment Bay of Plenty and Department of Conservation, but were unable to compete with the mining industry. Instead we are starting a pilot study in April using a select group of 3rd year students who will carry this out as a research topic. Their report will be due in October of this year.

TOPICS

Representative catchments (soluble, suspended, bed load components)
Groundwater discharge (soluble)
Macrophyte sink
Sediment exchange (pore water, exchange, sinks)
Outflow (soluble)

In order to keep the project to manageable proportions we have broken the project down into a number of topics covering the main aspects of the trace element fluxes in and out of the lake. These are summarised on the slide. Representative catchments will be sampled for soluble, suspended and bed load components. A series of shallow ground water sampling wells will be inserted into the lake margin and these will be sampled for their soluble components. The lake water column and outflow through the Ohau Channel will be sampled at a number of locations, the soluble and suspended matter will be sampled and analysed, and macrophytes will be sampled and analysed for their trace element content. The lake sediment will be cored at about 8 locations with long piston cores taken to recover the sedimentary record and short cores for pore water analysis. The total and exchangeable trace element content of the sediments will be determined.

Follow up Proposal

A 3 year Marsden Fund project has been applied for which will support 3 M.Sc students to extend the scope and breadth of the project to include other significant lakes.
The study will examine the significance of catchment, lake depth and diagenesis versus sedimentation as controlling factors.

A follow up proposal has been made to the Marsden fund to enable us to extend the scope and breadth of this study to include other Rotorua Lakes.

Title: Trace Element Dynamics—Pollution or Redistribution?

Background: Decisions to undertake expensive remediation of natural waters are often made after observation of increasing concentrations of trace elements in the receiving water body sediments. Observed changes in the concentrations of trace metals with sediment depth are routinely assumed to reliably represent variations in the amount of each metal deposited on the sediment surface with time. *However, we suspect that diagenetic processes, including competitive adsorption and reduction and oxidation reactions, may so distort the concentration gradients of trace elements in sediments as to make their interpretation as indicators of catchment fluxes meaningless.* Such processes are ubiquitous and hence the problem should be a global concern.

Proposal: We propose to take advantage of two natural features which will enable us to distinguish between changes in catchment fluxes and diagenetic recycling as the driving agents of concentration gradient changes. In the Taupo Volcanic Zone there are many lakes of volcanic and hydrothermal origin. The lakes vary in catchments from unmodified native forest (e.g. L. Okataina), plantation forestry (e.g. L. Rotokakahi), rural/pastoral run off, urban/industrial, to predominantly geothermal (e.g. Lakes Rotowhero and Rotomahana). There are also many airfall tephra deposits with characteristic mineralogical and chemical composition. As the majority of the tephras have well established carbon-14 chronologies, there are distinctive components within the lake sediments which represent tightly constrained time horizons. We will take piston cores from a number of sites in a wide range of lakes. pH and Eh measurements will be made on the pore waters directly upon extrusion of the cores. We will use tephra chronology to determine sediment accumulation rates and we will use ICPOES and ICPMS of digested sediments to determine the trace element abundances. The texture, mineralogy and ion exchange capacities of the sediment will be measured. *We aim to produce a set of criteria to be followed in order to be certain that sediment concentration gradients are the result of input contamination.*

Anticipated Outcomes

Graduates with a good understanding of environmental chemistry

More effective management strategies for Volcanic Plateau lakes

Better understanding of the role of sediments in trace element fluxes

Outputs: We will produce three master's theses and one Ph. D. thesis. We aim to produce a set of criteria to be followed in order to be certain that sediment concentration gradients are the result of input contamination, which we will publish in a suitable international journal.

Development of Research Skills: This project will result in close cooperation between an environmental/geochemist, an environmental/analytical chemist and a environmental/physical chemist with established reputations at the University of Waikato with a research officer with environmental chemistry skills at the Department of Conservation (DOC). One Ph.D. student will develop skills in fresh water sediment diagenetic processes, and three M.Sc. Students will each produce theses on the trace element environmental/geochemistry of a contrasting lake,

enriching New Zealand’s skill base in environmental chemistry and leading to a better understanding of the significance of trace element behaviour in fresh water sediments. However it is important to realise that the Marsden Fund is heavily over extended, and that the current success rate for the granting of Marsden Fund contracts is 5 - 6%.

SHALLOW GROUNDWATER CHEMISTRY IN THE WHAKAREWAREWA FOREST AND ITS IMPLICATIONS FOR LAKE ROTORUA

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University of Waikato, HAMILTON

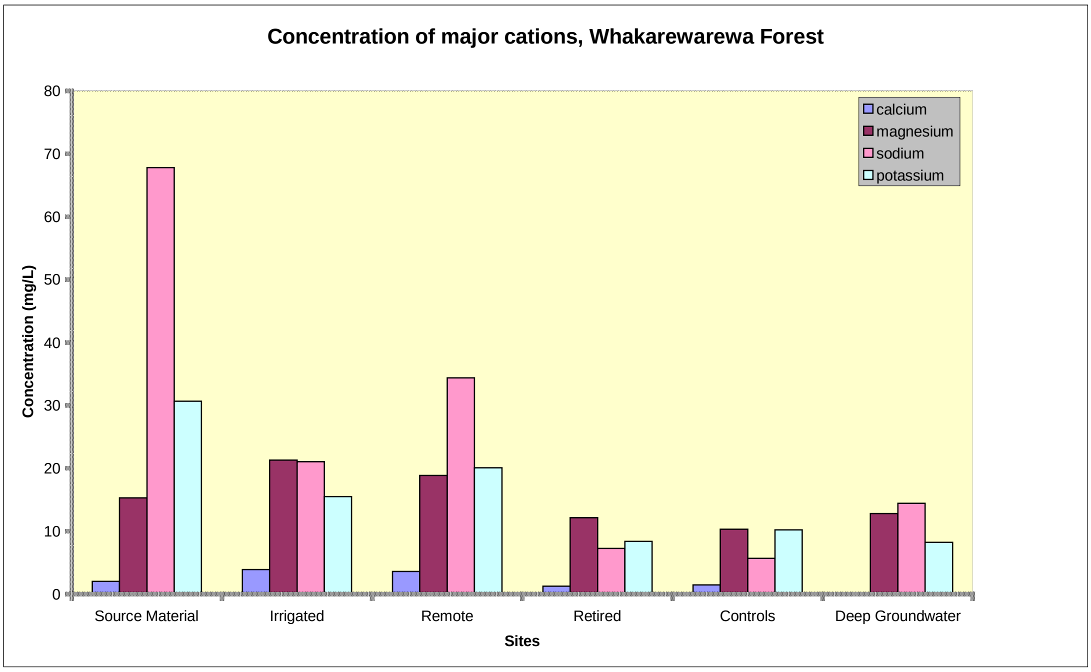
We have been collecting and analysing shallow groundwaters from a number of sites in the Whakarewarewa Forest. The sites can be divided into several types.

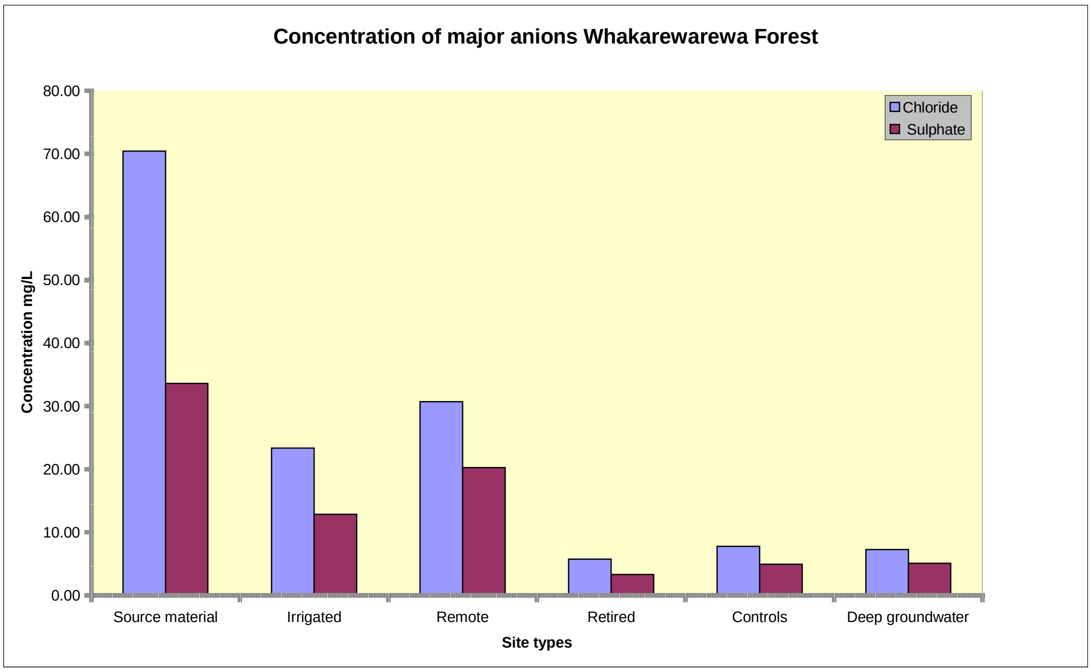
- (1) Source waters are those pumped from the Rotorua City Sewerage Treatment plant to a holding reservoir.
- (2) Irrigated sites are those beneath or adjacent to effluent irrigated blocks of forest.
- (3) Remote sites are those down slope or down stream from the irrigated sites and include wetlands and the Waipa Stream.
- (4) Control sites are located up slope or distal from the irrigated blocks and include sites in the Green Lake picnic area and a retired block.
- (5) Deep groundwater from two large springs discharging at higher altitude than the spray irrigated blocks. One of these is currently the source of drinking water for the eastern suburbs and the other (Hemo Springs) is a former water supply source.

Source Material

Rotorua City effluent is enriched in

- Sodium (Na),
- Chloride (Cl),
- Nitrogen (Nitrate- NO_3 and Ammonia-NH_3)
- Phosphate (PO_4)
- with smaller concentrations of Calcium (Ca), Magnesium (Mg) and Sulphate (SO_4)
- Geothermal waters are enriched in Sodium Chloride and Sulphate but have very low Calcium and Magnesium concentrations.


Concentration of major cations, Whakarewarewa Forest
Concentration (mg/L)
0
10
20
30
40
50
60
70
80
calcium
magnesium
sodium
potassium
Source Material
Irrigated
Remote
Retired
Controls
Deep Groundwater
Sites

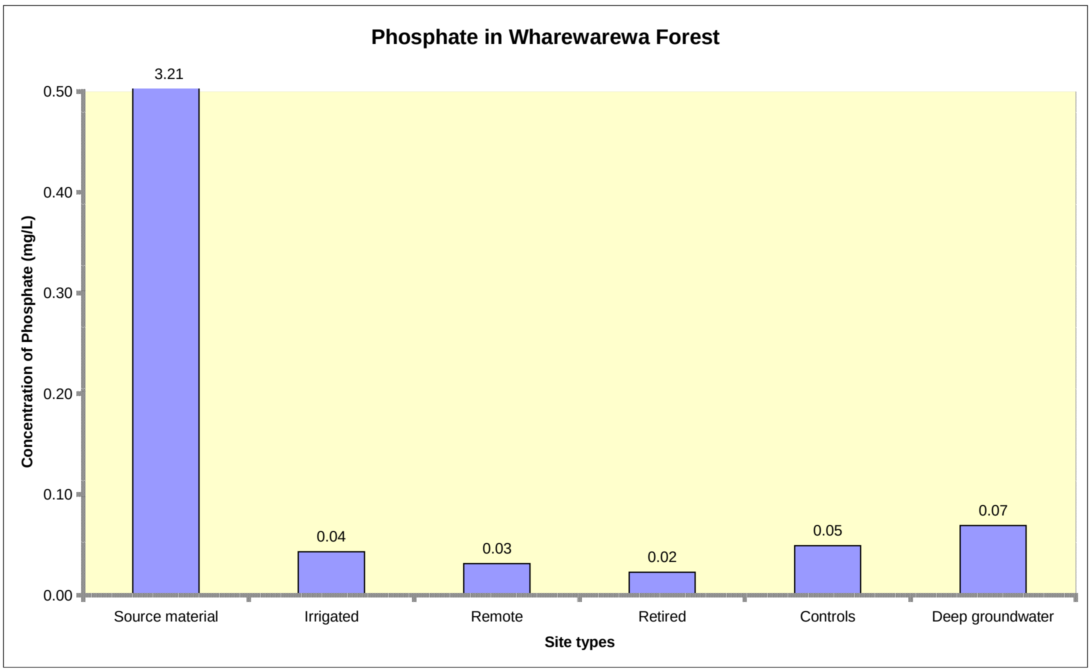

Concentration of major anions Whakarewarewa Forest
Concentration mg/L
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Chloride
Sulphate
Source material
Irrigated
Remote
Retired
Controls
Deep groundwater
Site types

Conservative Species

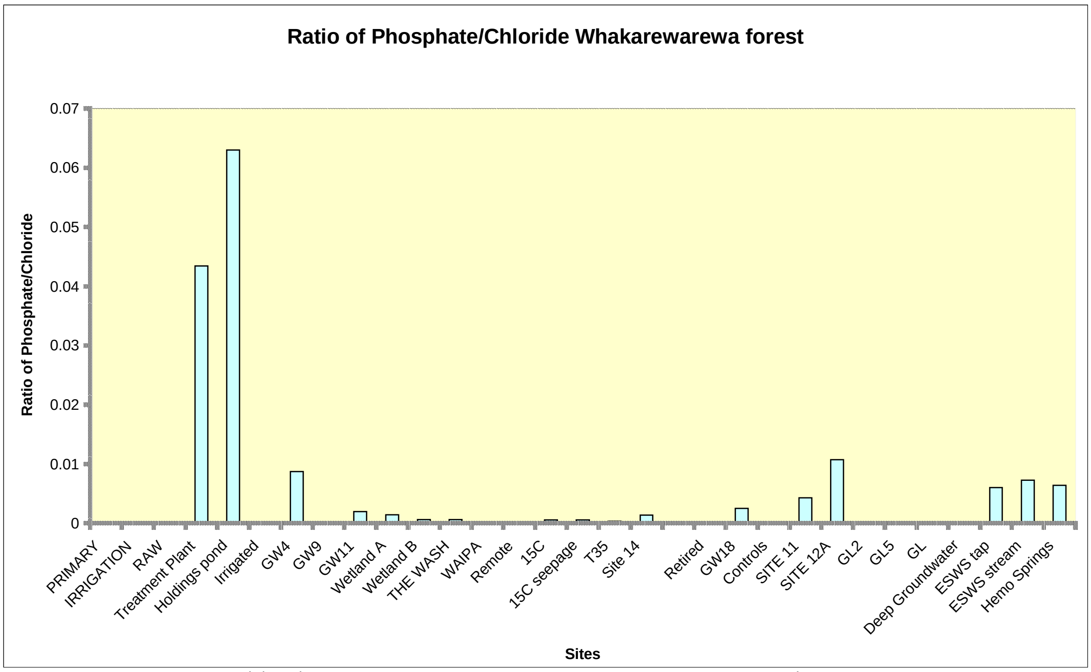
- Sodium and chloride have very little interaction will soils and tend to only change concentration by dilution with rainwater or enrichment through evaporation/ transpiration. The concentrations of the conservative species decrease progressively from source through to irrigated sites, but show little further dilution to remote sites. The effluent contribution can be seen by comparing the concentrations in the control sites with the remote and irrigated sites.
- The deep groundwaters are also enriched but have significantly lower calcium.

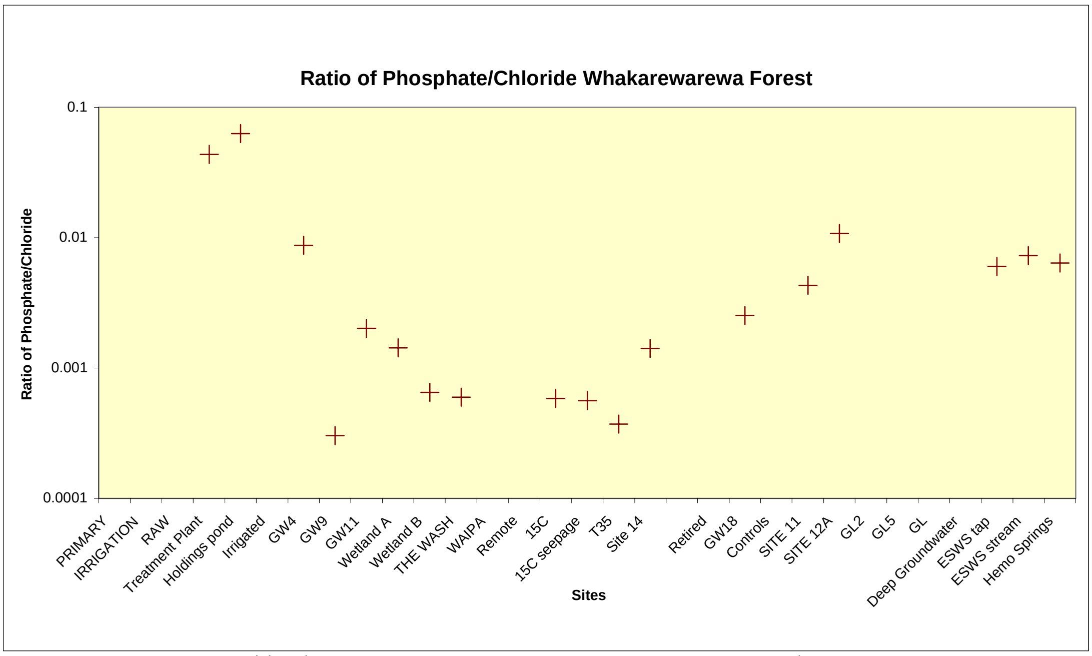
Adsorption and Plant uptake

- Limiting nutrients, usually phosphate and/or nitrogen species are generally taken up by plants (forest trees) to the limit of their requirements.
- Adsorption of phosphates onto allophanic surfaces (clays and weathered surfaces of ignimbrite, pumice etc.) will keep phosphate concentrations in a range of 0.03 to 0.1 mg/l (g/m^3)
- Phosphate is very rapidly removed from the effluent reducing its concentrations 100-fold to background levels.

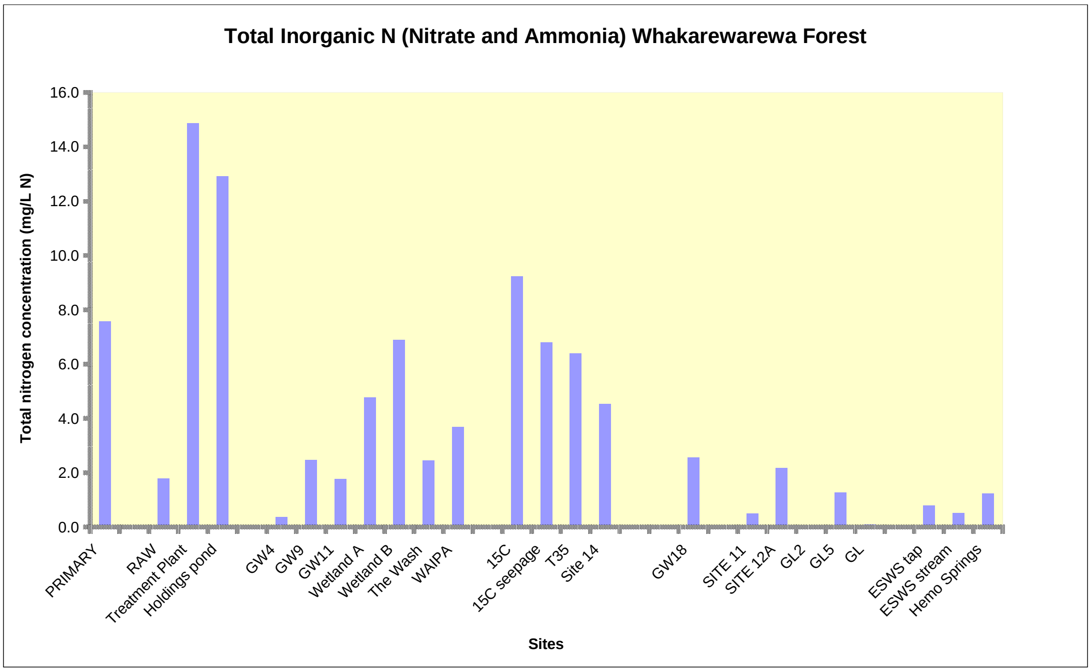


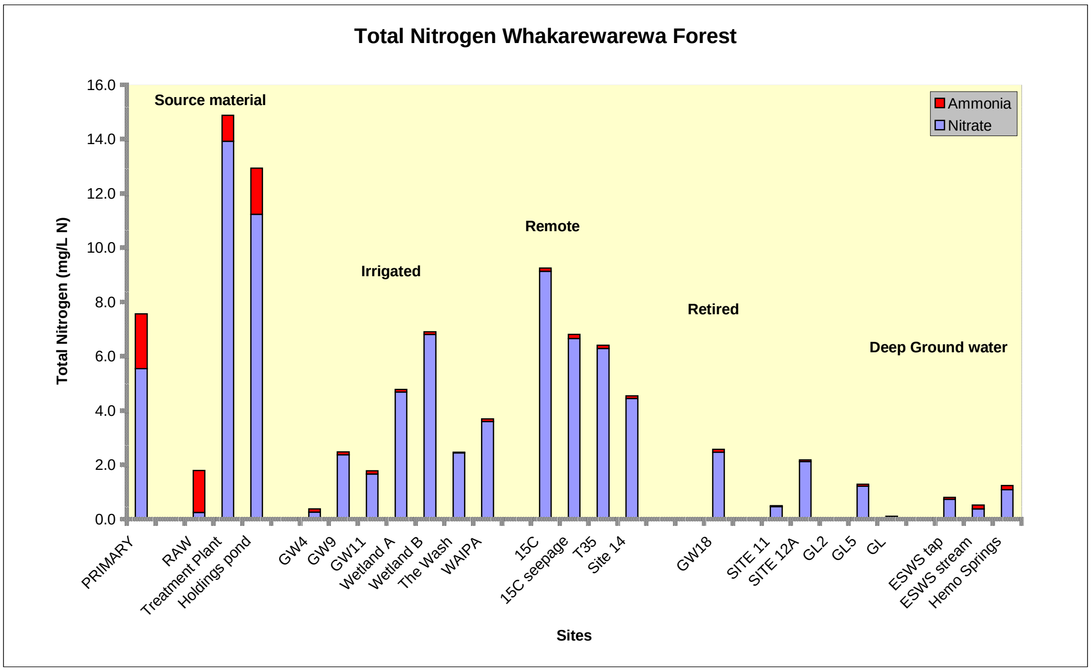
- Dividing the phosphate concentrations by the chloride concentrations should eliminate the effects of dilution by rainwater or concentration through evaporation/transpiration. This shows that the 100-fold decrease in phosphate concentrations to below the control concentrations is due to phosphate removal.





Nitrogen compounds (nitrate and ammonia) show a totally different pattern.



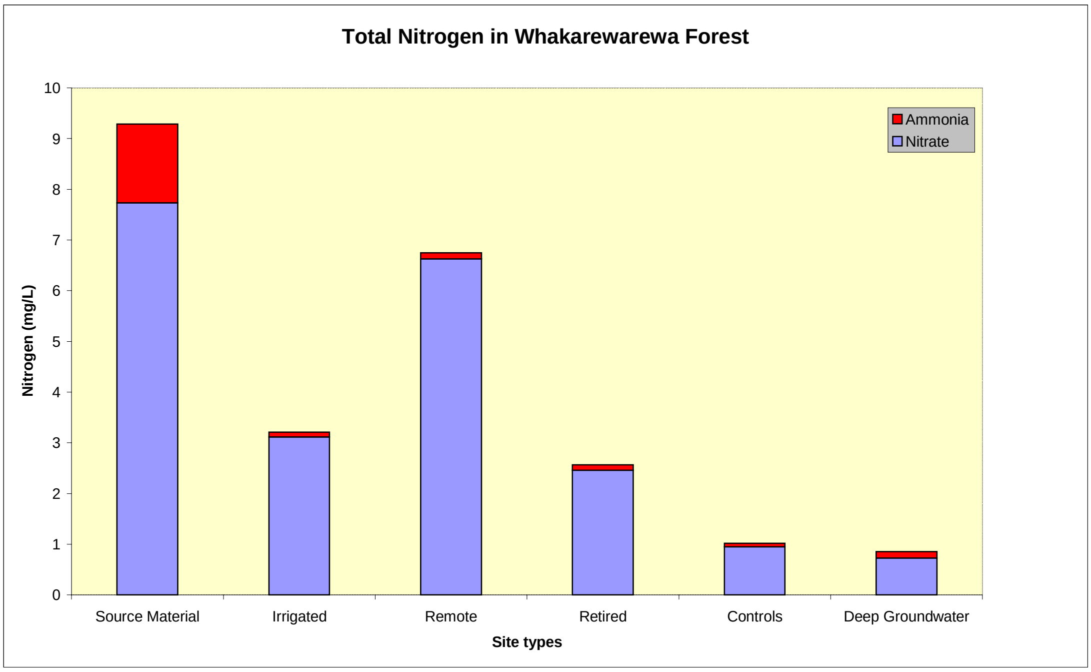


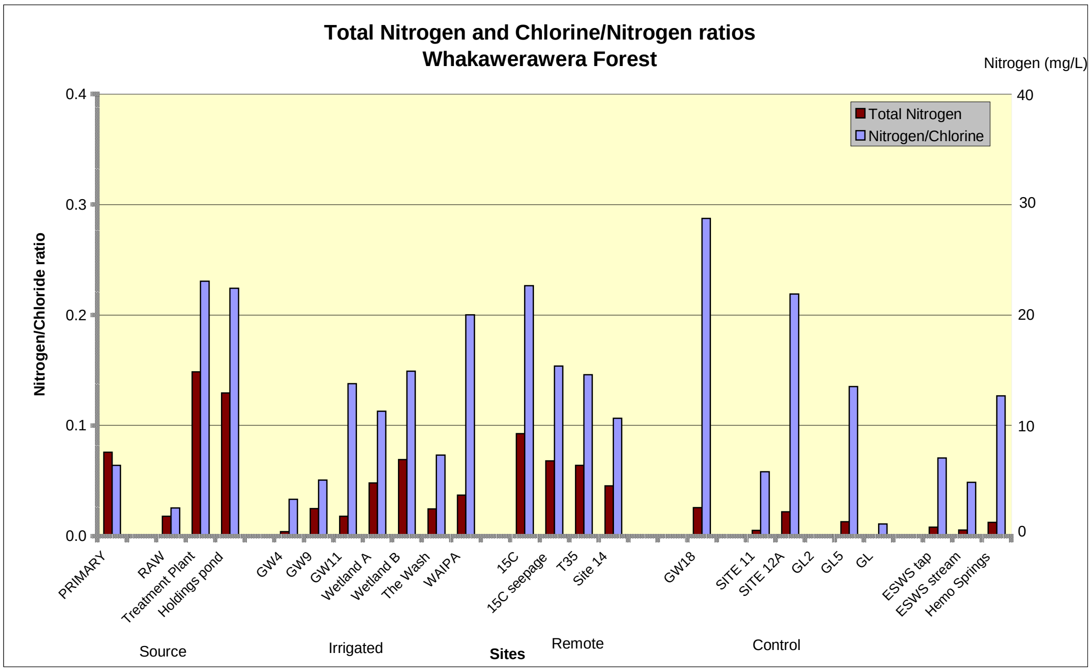
What happens to Nitrogen?

1. Ammonia is oxidised to nitrate

2. The reduction in total nitrogen concentrations is about double that of sodium and chloride, but shows a very similar pattern to that of sodium and chloride.

- Suggests that about half of the nitrogen is removed as the effluent passes through the vegetation/soil zone. The remainder behaves as a conservative species rather than a limiting nutrient.





Stable isotopes of Carbon

- Carbon has two natural stable isotopes
  - ^{12}C (98.9% natural abundance) and
  - ^{13}C (1.1% natural abundance)

- Small differences in the physical properties of the two isotopes result in measurable changes in the relative abundance of the isotopes in natural substances.

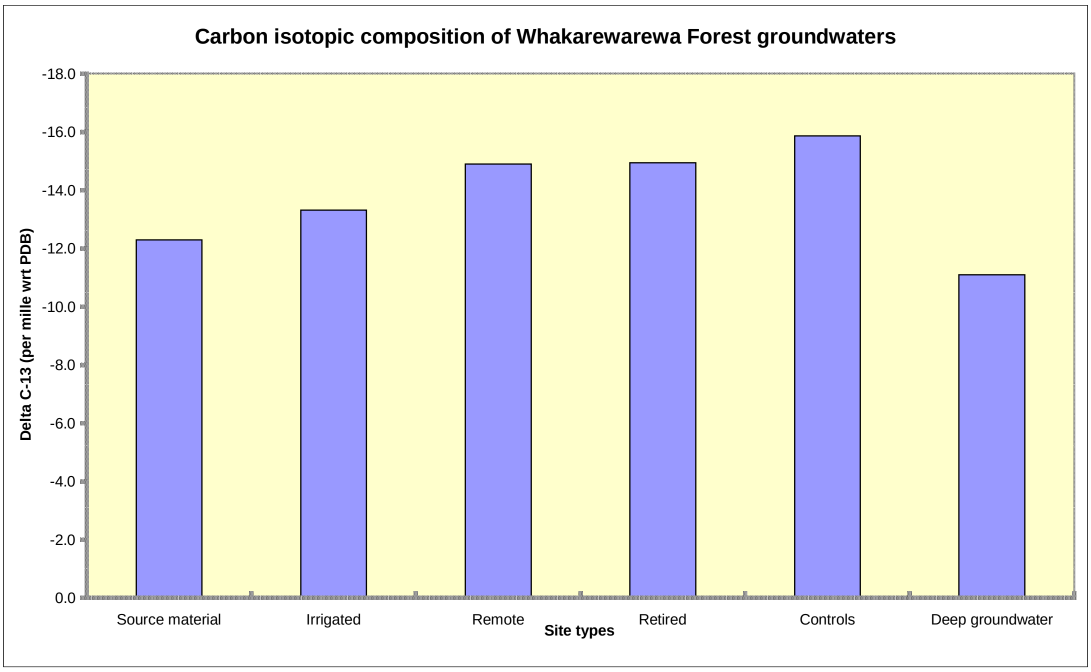
- Anaerobic fermentation of organic matter to methane and carbon dioxide results in a partial separation of ^{12}C from ^{13}C. The methane formed inherits 3% (30 per mille) less ^{13}C and the carbon dioxide 3% (30 per mille) more ^{13}C than the organic carbon.

- As this process occurs during sewerage transport and treatment, sewerage effluent contains bicarbonate which is significantly enriched in ^{13}C compared to that produced by forest soil respiration.

- Carbon isotope ratios are expressed as differences between the sample and an international standard (PDB)

so that

$$\delta^{13}C = 1000\,\left({}^{13}C/{}^{12}C_{(sample)} / {}^{13}C/{}^{12}C_{(standard)} - 1\right)$$



Carbon Isotope Story

- ^{13}C enriched bicarbonate from sewage effluent can be traced through irrigated sites to remote sites, but as the deep groundwaters are even more enriched in ^{13}C, carbon isotopes cannot be used to trace sub-surface contaminants.

Conclusions

1. Phosphate is very efficiently immobilised by Whakarewarewa forest soils/subsoils.

- Ammonia is oxidised to Nitrate.
- About half the nitrate is lost from the effluent but the remainder behaves conservatively and is lost to the drainage system.

3. Deep groundwater acquires some of the chemical characteristics of effluent as they pass through the complex mixture of volcanic and lake sediments that make up their aquifer.

4. It is likely that phosphate will eventually saturate the available adsorption capacity of the soil and shallow aquifer, allowing the forest to grow more vigorously and reduce the nitrate concentrations.

Questions

Kathy Horgan, Royal Society

What's the evidence that phosphate is limiting the growth of the trees – could it not be the high level of water put on the trees or something else?

CH

I'm not a tree scientist so I can't comment on the high water. I'm not saying that the trees are limited in their growth, what I am saying is that we are not seeing an increase in phosphate concentrations in the water beneath the trees. We are seeing an increase in the nitrogen concentration. So, I'm speculating that the phosphorus is being removed through absorption onto the clays rather than by the trees, allowing the nitrogen to pass on through.

Rowland Burdon, Royal Society

I'll attempt to answer Kathy Horgan's question. In this area phosphorus is typically not regarded as at all limiting for the growth of the trees. Nitrogen is to some extent. This is illustrated by the fact that on agroforestry ex-pasture sites where we have elevated nitrogen in the soil, particularly as the nitrate, we get greater diameter growth but in this sort of situation with the irrigation one can have some complications with tree health being affected through needle cast due to the humidity created by the irrigation. I wouldn't be certain about that but in any case I don't think it's a matter of phosphorus limiting the growth of the trees. The other thing is that the trees, through their mycorrhizal systems, do seem to be able to extract phosphorus very efficiently from the allophane, unlike a lot of pasture plants. There could be a complication that the amount of soil wetting could reduce the effectiveness of the mycorrhizal system but some of this could easily be checked by foliar analysis, looking at the percentages of these elements in the foliage.

Thomas Wilding, EBOP
Have you done any work to estimate how long before the soil would become saturated with phosphorus?
CH
No, we haven't looked at the soil itself, only the water underneath. It wouldn't be too hard to do that.

Jim Pringle, EBOP
It has been suggested by some Auckland scientific evidence that the trees could end up being as an inferior timber. I gather from some of the answers that have been given that possibly this is being looked at, but that has been inferred. Any comments?
Chairman.
Gertie Gielen of Forest Research has been doing some work on that and can address the matter.
Gertie Gielen
First of all we have done some phosphorus analysis of the tree foliage and we did not find any phosphorus deficiency. There are also some studies done on tree health and we did not find any tree health problems. We've done some tree quality studies on the retired plots, as mentioned by the speaker, and we found that the tree density could decrease by about 10% in the spray irrigated areas compared to the non-spray irrigated areas, but talking to the people who milled the trees, they did not find any visual differences to the wood.

LAKE EDGE WETLANDS AND THEIR IMPORTANCE TO THE ROTORUA LAKES

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ABSTRACT

In 1995, Environment Bay of Plenty commissioned a study to determine the role of lake edge wetlands in controlling the quality of ground water entering the lakes and hence their value in protecting lake water quality (Gibbs & Lusby 1996, Lusby *et al*.1998).

Most of the lakes in the Central Volcanic Plateau of the North Island of New Zealand, including the Rotorua lakes, have a natural abundance of the nutrient phosphorus, which means that phosphorus concentrations rarely restrict phytoplankton (free floating microscopic plants) growth. In contrast, nitrogen concentrations are often low and may restrict phytoplankton growth for much of the year. Sources of dissolved inorganic nitrogen (DIN) around the Rotorua lakes include geothermal, streams, storm water, and groundwater.

Although groundwater generally contributes only about 10% of the hydraulic load to a lake, the DIN concentrations in the groundwater may be 10 to 100 times greater than in the surface water inflows. This is because groundwater can receive nitrogen from septic tank effluent disposal, and infiltration of fertiliser and animal waste. A compounding factor is that groundwater is generally below the root zone of the plants that might remove that nitrogen. However, when the groundwater enters the lake it may pass through a marginal wetland on the lake edge, where nutrients including DIN can be removed by plant uptake and bacterial or microbial transformation processes can convert it into nitrogen gas, which is lost to the atmosphere. Where the groundwater passes into the lake through a beach, only minimal nutrient removal occurs.

A study of nine lake edge wetlands over a 2 year period was funded by Environment Bay of Plenty to determine the efficiency of wetlands for removing nitrogen from the groundwater moving through them to the lake. The results show that there is potentially a high level of DIN removal (up to 98%) within these wetlands.

INTRODUCTION

Most of the lakes in the Central Volcanic Plateau, including the Rotorua Lakes, have a high natural abundance of the nutrient phosphorus (P), mainly from geological sources in their waters, but little dissolved inorganic nitrogen (DIN). This means that, unlike northern hemisphere lakes where low P concentrations often restrict the growth of phytoplankton (free floating microscopic plants), in the Rotorua lakes P concentrations rarely restrict phytoplankton growth. Most of these lakes could support a much higher phytoplankton biomass with the addition of more DIN, i.e. they are sensitive to nitrogen (N). Whereas seasonal cycling of N from the lake sediments supplies some of that DIN which supports phytoplankton growth, the main sources of new DIN to lakes are from surface water inflows (rivers, storm drains, etc) and the shallow groundwater aquifer.

Although groundwater generally contributes only about 10% of the hydraulic load to a lake, the DIN concentrations in that groundwater may be 10 to 100 times greater than in the surface water

inflows. This is because the shallow groundwater aquifer can receive N from septic tank effluent disposal and infiltration of fertiliser and animal waste over a large area, and is generally below the root zone of the plants that might otherwise remove that N. Various estimates of the groundwater hydraulic contribution to the Rotorua lakes at this conference ranged from 40-60 % of the total inflow, and consequently the groundwater input is likely to be the largest source of new DIN to these lakes.

In the porous pumice catchments of the Rotorua lakes, groundwater always moves directly down-slope towards the open waters of the lake, but because of the hydraulic forces involved, most of the groundwater enters the lake through the beach at the lake edge. At this point the nutrients and other contaminants in the groundwater may be intercepted and removed in lake edge wetlands before they enter the open waters of the lake.

It has long been recognised that wetlands can remove substantial amounts of N and P from groundwater and waste water. However, while there were once large areas of natural wetlands around the shores of the Rotorua lakes, many of these have been cleared or drained to allow land development for housing and lake shore recreation, including bathing beaches. Although lake edge wetlands are sometimes considered aesthetically unpleasant, they are natural buffer zones and their removal can cause adverse effects on lake water quality.

This paper presents a summary of a two year study (Gibbs & Lusby 1995,1996; Lusby *et al*.1998) that examined nine natural lake edge wetlands to determine their efficiency as active buffer zones. The study objective was to determine the role of natural lake edge wetlands in controlling the quality of groundwater entering the lakes and hence their value in protecting lake water quality. Of particular interest was the mechanism by which N removal was achieved. The aim of this paper is to present a general overview of lake edge wetlands and their importance to the Rotorua lakes.

METHODS

Nine shoreline zones were selected on three Rotorua lakes: 2 sites at Lake Okareka (Fig. 1A); 2 sites at Lake Rotoma (Fig. 1B); and 5 sites at Lake Rotorua (Fig. 2) (Gibbs & Lusby 1995). Groundwater samples from the surface aquifer were extracted using the sampling penetrometer developed by John *et al.* (1977), filtered and analysed for DIN as nitrate plus nitrite nitrogen (NO_3-N) and ammoniacal nitrogen (NH_4-N), dissolved organic nitrogen (DON), and dissolved reactive phosphorus (DRP) using standard analytical methods (Lusby *et al.* 1998). Both DIN and DRP are biologically available and hence readily utilised for phytoplankton growth in the open waters of the lakes.

At each site, spatial sampling across the wetland area was used to estimate changes in nutrient concentrations as the groundwater flowed through these wetlands. Groundwater flow rates were variously estimated using salt tracer injection and by a direct inflow technique (Lock & John 1978).

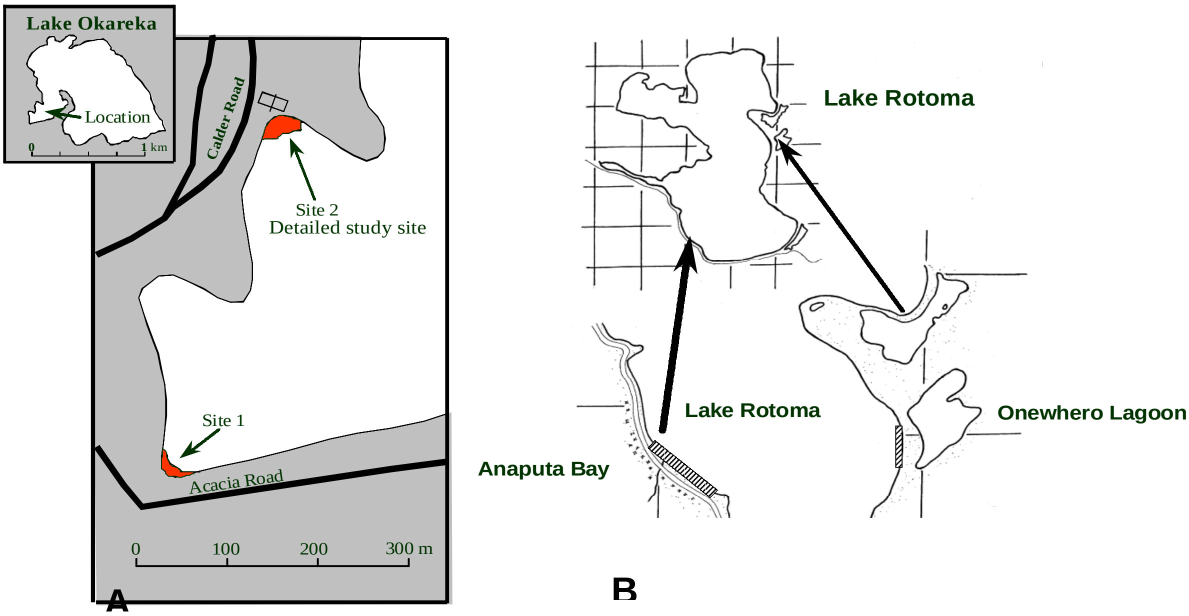

Fig. 1. Study sites at Lake Okareka (A), and Rotoma (B).

Lake Okareka site 1 has a clay capping over part of the wetland. Site 2 has a grass tennis court on land reclaimed from the wetland. This site is at the focus of about 30 houses all using septic tank disposal of domestic sewage. Lake Rotoma Onewhero Lagoon site has farmland catchment. Anaputa Bay site receives farm and forest derived groundwater, contaminated by septic tanks from a group of houses spread along the shoreline of the bay.

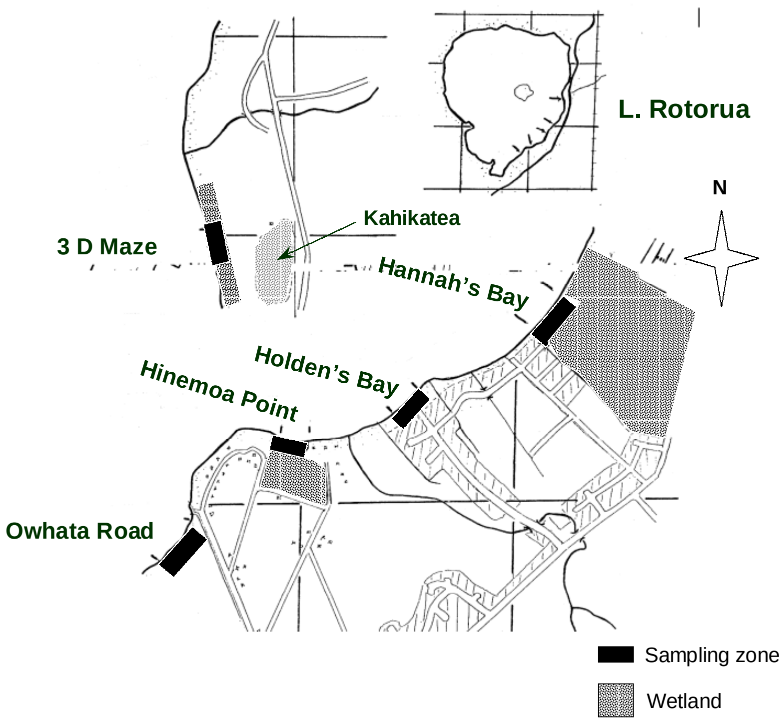

Fig. 2 The location of the 5 sampling sites around Lake Rotorua.

At Lake Okareka site 2 (Fig. 1A) a more detailed study (Lusby *et al.*1998) examined the *in-situ* processes involved in the removal of N and P from groundwater contaminated with septic tank effluent water as it moved towards the lake through a partially reclaimed wetland with a residual marginal wetland fringe at the lake edge. Laboratory studies used stable isotope techniques to examine plant uptake and recycling processes.

RESULTS AND DISCUSSION

Previous experience with DIN in groundwater from rural pumice catchments around Lake Taupo (John *et al.* 1978) has shown that DIN is usually in the form of NO_3-N and has an average concentration of about 1-2 g m^{-3}, increasing to >10 g m^{-3} where there was an influence from septic tanks. Around the Rotorua lakes, results from this study confirmed similar groundwater concentrations of DIN ranging from 0.5-2.5 g m^{-3} from farmland and up to 26 g m^{-3} from land under the influence of septic tanks (Table 1). Where that groundwater passed through a lake edge wetland, the DIN concentrations were substantially reduced, by up to 98%. However, where development, drainage or beach erosion had removed the vegetation between the catchment and the lake, DIN reductions were markedly less. At one site in front of farmland adjacent to Owhata Road on Lake Rotorua (Fig. 2), there was almost no DIN reduction (Table 1). At this latter site, the surface groundwater aquifer emerged in near-shore subsurface springs in the lake and experienced no apparent DIN reduction before entering the lake.

Table 1 Maximum ground water nitrogen concentrations at the lake edge sampling sites.

Lake	Location	NO_3-N (mg m^{-3})	NH_4-N (mg m^{-3})
Okareka 1	Acacia Rd	1650	620
Okareka 2	Calder Rd	65	2500
Rotoma 1	Onewhero Lagoon	181	338
Rotoma 2	Anaputa Bay	25830	35
Rotorua 1	3-D Maze	2300	146
Rotorua 2	Hannah's Bay	4540	526
Rotorua 3	Holden's Bay	2300	630
Rotorua 4	Hinemoa Point	7100	4330
Rotorua 5	Owhata Rd	6430	4330

Whereas drainage of these lake edge wetlands channelled the groundwater nutrients directly into the lake e.g. Holden's Bay (Fig. 2), at nearby Hannah's Bay (Fig. 2) the development of a beach on the lake shore with a grassed picnic area between the lake and the wetland caused little apparent reduction in the nutrient removal efficiency of the wetland. This indicates that it is possible to have managed development of the lake shore to accommodate both recreation and water quality management.

At Lake Rotoma, there was substantial DIN reduction where groundwater contaminated with septic tank effluent at Anaputa Bay (Fig. 1B) moved through a lake edge wetland consisting of reeds. However, where the reeds had been killed, there was little removal of the DIN and the reductions seen at the immediate lake edge could be attributed to dilution by lake water as the groundwater carried the effluent into the lake (Fig. 3). On the other side of Lake Rotoma, Onewhero Lagoon (Fig. 1B) probably intercepted the DIN from the farm catchment, as DIN concentrations in the groundwater between the lagoon and the lake were very low.

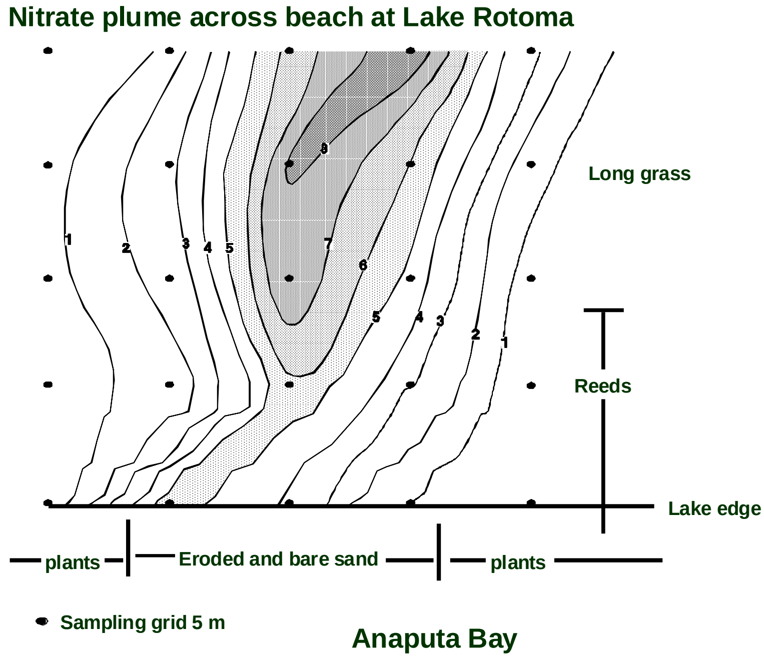

Fig. 3 Nitrate in the groundwater moving through the beach at Anaputa Bay, Lake Rotoma. Contours represent concentrations of nitrate-nitrogen in the shallow groundwater (darkest = highest concentration at > 8 g m^{-3}; outer contours = lowest at < 1 g m^{-3}). The groundwater flow moves from the top of the figure to the bottom down a narrow strip of bare ground (walking path) between tall grasses and reed beds.

Results from the detailed study of the Calder Road site at Lake Okareka (Fig. 1A, site 2) showed that where groundwater contaminated with septic tank effluent passed through the wetland, there was up to 90% removal of DRP (Fig. 4A) and up to 98% removal of DIN (Fig. 4B) from the groundwater before it reached the lake. Whereas the DRP removal appeared to be associated with adsorption onto the wetland soils, the DIN removal processes included uptake by plants and microbial transformations resulting in coupled nitrification-denitrification as the groundwater carried the DIN, as either NO_3-N or NH_4-N, through aerobic and anaerobic zones within the wetland. Nitrification converted the NH_4-N to NO_3-N in aerobic (oxygenated) zones. Denitrification converted the NO_3-N to N_2 gas, which is released to the atmosphere, where the NO_3-N passed into an anaerobic zone. These processes occurred throughout the wetland where there were pools of water overlying the decaying leaf litter between the plants and in the saturated highly organic sediments. Denitrification is the only process that permanently removes N from the groundwater.

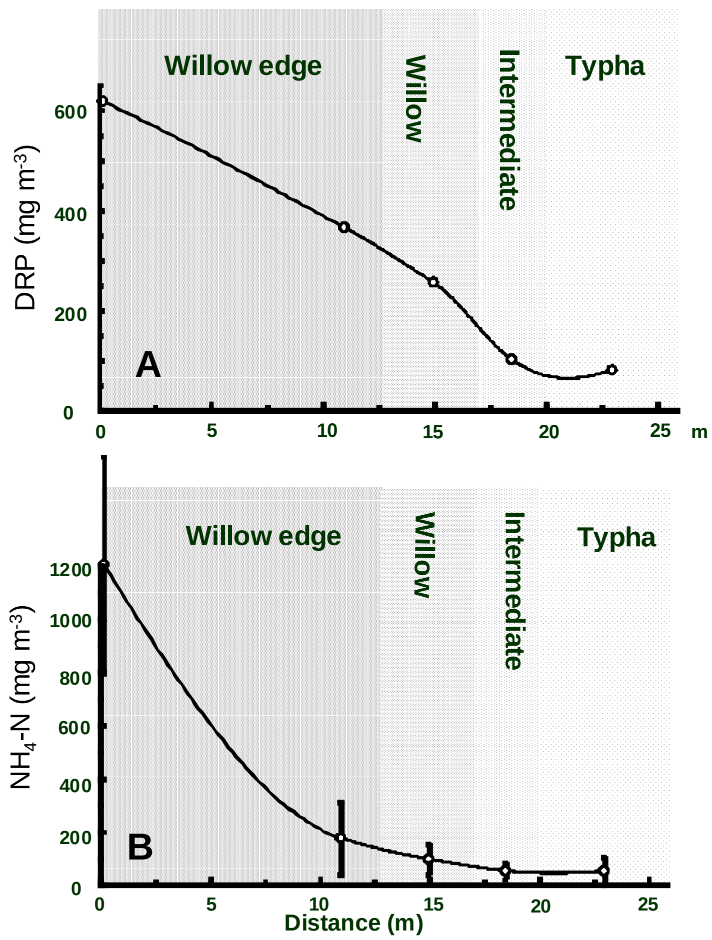

Fig. 4 Reduction in concentrations of DRP (A), and NH_4-N (B) as groundwater moves through a lake edge wetland towards the lake.

The stable isotope study determined that grey willow, *Salix cinerea*, could uptake DIN about 4 times faster than raupo, *Typha orientalis*, but both plants released the N back into the wetland as DON when the leaves fell in winter. The decomposing leaves, however, provided a carbon source to drive the microbial processes of nitrification and denitrification and hence they were an integral and very important part of the N removal process in the wetland (Lusby *et al.* 1998). From this study it was determined that a combination of factors help the wetland achieve the high nutrient removal efficiency observed. These factors include the mixture of wetland plants present, the decomposing leaves as a carbon source, and the requirement for aerobic and anaerobic zones within the wetland.

Examination of the chemical transformations of NO_3-N enriched groundwater passing through a reclaimed wetland (Table 2) indicated that the clay capping used caused an anaerobic zone in the groundwater, where NO_3-N was removed by denitrification. DON was also mineralised to NH_4-N providing up to 90% N reduction in the groundwater before it entered the lake edge

wetland. Further reductions occurred within the lake edge wetland via the processes described above.

Table 2 Nitrogen transformations in the groundwater through a reclaimed wetland capped with clay. (Concentrations in mg m^{-3}).

Compound	Upstream	Middle	Downstream	Wetland
NO_3-N	1650	7	3	2
NH_4-N	27	531	439	34
DON	685	170	194	204
TDN	2360	708	636	239

DON = dissolved organic nitrogen; TDN = total dissolved nitrogen

The apparently much higher water quality of the Rotorua lakes prior to European land settlement, development, and wetland drainage (Mylechreest & Burdon 2001), indicates that natural wetlands probably surrounded most of these lakes and prevented much of the nutrient loads draining from native forests from reaching the lake waters. The implication is that the removal of the natural lake edge wetlands played an important role in the deterioration of the water quality of these lakes.

CONCLUSIONS

The results from this study show that lake edge wetlands can remove up to 90% of the DRP and up to 98% of the DIN from groundwater entering the Rotorua lakes from their catchments. Consequently lake edge wetlands are very important to the Rotorua lakes as buffer zones protecting the water quality of these lakes.

Lake edge wetlands can be easily damaged, thus reducing their efficiency. Management strategies could be employed to allow a compromise between lake management and land development. While willow and raupo were shown to be highly effective in removing DIN from groundwater, there are other wetland plant species including native reeds that could perform the same role if willow and Raupo are deemed unsuitable lake edge vegetation.

FURTHER WORK

1. A study is needed to determine the best mix of wetland plants which would provide an efficient buffer zone that is aesthetically acceptable to the community.
2. A study is needed to determine the optimum dimensions for wetland buffer zones, and whether these can be reinstated in areas where they have been removed.
3. The possibility of intercepting contaminated groundwater from developed urban areas and redirecting this through adjacent constructed wetlands should be investigated as a management option for existing lake shore developments.

Questions

Mary Stanton Lake Rotoiti

Why have you chosen willow trees to sustain wetlands?

MG

In reality I haven't chosen willows. Our terms of reference were to look at the existing wetlands and determine how efficient they were and their ability to remove the nutrients or their role in protecting the waters of the lakes. The point that I make is that there are many plants which can be used to manage wetlands and the future work that could be done around the Rotorua lakes to enhance management would be to look at which plants are better, which plants are aesthetically and spiritually acceptable to the people so that we can maintain and manage the lakes' water quality.

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THE IMPACT OF EUTROPHICATION ON AQUATIC FOOD WEBS AS IT APPLIES TO THE ROTORUA LAKES

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Dr Julie Hall was unable to supply a full text paper in time for publication, due to pressure of work, so we have included the abstract that was originally printed in the Symposium Handbook, together with a heavily abridged tape transcript of her oral presentation.

ABSTRACT

The aquatic food web in the Rotorua lakes is composed of a wide range of organisms from bacteria to trout and includes many species of phytoplankton and zooplankton as well as small fish species such as smelt and bullies. The nutrient status of a lake is a key factor in determining the structure of the food web within that lake. In low nutrient, oligotrophic lakes the dominant phytoplankton species tend to be small and hence the food webs tend to be long and less efficient through to the production of fish. In contrast, in high nutrient, eutrophic lakes the dominant phytoplankton species are larger, the food webs shorter and more efficient. In some cases however some of the larger phytoplankton species present in the more eutrophic lakes may be toxic or not grazed by the zooplankton. This can result in a reduction of the flow of energy through the food web. When toxic species are present some zooplankton are able to migrate away. In other situations the presence of toxic phytoplankton species can result in a reduction in the growth and development of some zooplankton species. We know that potentially toxic phytoplankton species are frequently found in some Rotorua lakes but they do not always appear to be toxic to zooplankton. One key issue we do not understand is what stimulates these phytoplankton to become toxic and what impact this has on key zooplankton populations. We also need to be able to monitor the potential sublethal toxicity of these phytoplankton to assess what impact they may have on the food web.

The composition of the fish population in the lakes is also related to the nutrient status of the lakes. In oligotrophic lakes such as Okataina the forage fish populations tend to be dominated by smelt rather than bullies. Smelt are planktivorous fish, feeding primarily on zooplankton and are the preferred food source for trout. In more eutrophic lakes such as Rotorua the dominant small fish are bullies. Larval bullies are planktivorous like smelt but the adults are benthic feeders. One of the key links in the food web that is not well understood is the linkage between zooplankton and planktivorous fish and how this relationship may be impacted by toxic phytoplankton species. Conversely trout may exert top down effects on the zooplankton population with implications for the phytoplankton species composition in the lake.

FOOD WEBS

There was some initial discussion about various classes of organisms involved in food webs in New Zealand lakes, including phytoplankton, zooplankton, and larger organisms.

"I want to bring together some general knowledge and the small amount of data about food webs in the local Rotorua area and to present some unpublished data from my co-authors."

"Talking about food webs, this is a typical food web from an oligotrophic lake such as Tarawera or Rotoma. Looking at the proportions of the phytoplankton, we see that they are dominated by the picoplankton, the very small phytoplankton, and they are consumed by the microzooplankton which are then consumed by the mesozooplankton – we are starting to get quite a lot of steps in the food web – and then through into juvenile fish and adult fish. So this is a main pathway for energy and food through the system."

"If we go on to more eutrophic lakes, such as Rotorua, we see a change in the structure of the food web. The phytoplankton are dominated by the nanoplankton and microphytoplankton, with the main pathway being through the mesozooplankton and straight on to the fish. So we're seeing a much shorter more direct link between the phytoplankton and the fish."

"If we look at the phytoplankton – and what we are looking at here is the biological section which Rod Oliver talked about this morning – the things which are going to affect the phytoplankton species present are physical things like light, temperature, mixing, stability in the water column, nutrient concentrations and we've already talked about nitrogen and phosphorus being the key nutrients driving phytoplankton growth. And also the ratio of those two major nutrients. And we also have the interaction with the grazers, so there's a two-way interaction going on."

"We start looking at the mesozooplankton – they're grazers mainly of the nanophytoplankton and microphytoplankton – and we know that the grazing rates of these can be affected by the phytoplankton species present. There is a very good example of this – here are the results of an experiment carried out with Daphnia*. The limbs sweep through the water to bring food to the mouths. Here we're looking at the number of beats per minute, which relates to how quickly their limbs are beating and how much food they're consuming. Starting off in water that was uncontaminated at the start of the experiment and for the first few minutes, we then added filtered water that had had blue-green algae in it, so there were no algae in the water that was added, but the filtrates were present. You can see a significant impact – the rate of grazing dropped dramatically. After 20 minutes they were put back into uncontaminated water and you can see the grazing rates return to the previous levels. This is a method that has been used to evaluate the toxicity of some of the (cyanobacterial) toxins and certainly it starts to indicate that we are starting to get effects of the blue-green algae on the zooplankton. What we don't necessarily understand is the linkages between the species – some zooplankton species really aren't affected by blue-green algae –so we start to understand the very complex dynamics of the food webs."*

"The other thing with the mesozooplankton is that the growth and reproductive rates can also be affected by the phytoplankton species present. In another experiment conducted with Daphnia*, looking at the growth rate with the same amount of food present in each case, we have water from Rotongaio, Taupo, Okaro, Ngapouri, Rotoaira. They were fed a cultured phytoplankton, not a blue-green. It showed a significantly lower growth rate of* Daphnia *in water from the three lakes with blue-green algae present, compared with water from the other lakes. So we have an effect not just on the grazing rates but on the growth rates of these*

organisms as well. Again, quite species specific in terms of both the phytoplankton and the zooplankton present."

"Moving on to fish, we know that the food web leading to trout can differ greatly between lakes in the Rotorua Lakes area….. In addition to the food web in the water column, we also have the food web in the littoral zone, around the edge of the lake. Here we again start with algae but this is periphyton – algae which tends to stick to the rocks, the mud and the macrophytes. That's consumed by the snails, crayfish, other invertebrates, through to bullies and on to trout."

"What we do know about the lakes in this area is that in the oligotrophic lakes smelt tend to be the major prey of trout. In the more eutrophic lakes, bullies tend to be the major trout prey. We need to think about why this might be happening. This is data on what the trout might be eating, compared with (bottom axis) the clarity of the water as measured with a Secchi disk. As the water turbidity increases we see an increase in the number of bullies that are eaten and we see a decrease in the number of smelt that are eaten. We see different food webs and different prey that the trout are eating in different lakes. The question is why? Is it that in the more turbid lakes the trout can't see the smelt or is it to do with the number of bullies and smelt that are in the lakes? The indication from the data that has been collected is that it's the number of bullies and smelt that are present. The ratio of bullies to smelt decreases with increasing water quality. There seems to be quite a good relationship between what they're eating and what is actually present."

FUTURE RESEARCH

"We've really got very little data about the food web structures in the Rotorua lakes. We've talked a lot today about what's happening outside the lakes, the chemistry, but understanding what's happening in the food webs within the lakes, what's producing the trout and what the interactions are likely to be is very important. If we go through this (and this has already been mentioned today), what stimulates phytoplankton to become toxic? We know that some species can be present and not a toxic problem, that some species are more toxic than others. There are some indications that toxicity starts to occur after the population has peaked and the cells have started to degrade, but we don't know what those triggers are. That's one area for future research attention."

"What impacts do the phytoplankton have on the zooplankton population? We know toxins can be produced – what impact are they having? We have some evidence with Daphnia *and one type of blue-green that there is an interaction, but what happens in all those other interactions in the food webs in the various lakes?   Another area of importance because it is reflected in the rest of the food web."*

"How do we monitor the sub-lethal effects of phytoplankton toxins on the food web? These can be quite subtle effects – reduced grazing, reduced growth rates, reduced reproduction. If we start getting reduced reproduction of the zooplankton, then we start getting reduced production of smelt and bullies therefore reduced trout production. So we need to start looking at those sub-lethal effects and how they affect the rest of the food web."

"How does the phytoplankton species composition interact with the zooplankton species composition? We know that in some cases we get phytoplankton blooms –we know that there are some chemical controls affecting this, but what about the effect of the grazing of the zooplankton? Are they better able to graze some species than others? The species of zooplankton that are present may determine whether a bloom forms or doesn't form – you may get this two way interaction between the phytoplankton and the zooplankton – something that we speculate a lot about but don't know a lot about. And different phytoplankton species tend to be of different food quality, resulting in better growth rates in the zooplankton that eat them."

"If we move up the food web we start to look at the linkages between the zooplankton – what zooplankton species are present and the planktivorous fish (the larval smelt and bullies). Some of the mesozooplankton will also be taken by the trout, especially the smaller trout, so you start to look at those linkages. When we talk to the fisheries people they say that we know virtually nothing about those linkages and how they work."

"And then, finally, looking at top-down controls. If we look at the number of fish that are present, say trout, then how that impacts on the smelt and bullie population, and in turn how that affects the zooplankton population and in turn how that impacts on the phytoplankton population. So, what those top-down pressures are and how different species being present may affect that."

Questions

Professor Ripl – TU, Berlin

Well that was very interesting. The bacterioplankton I think was underestimated. If bacteria are sitting on a substrate at optimum conditions they will divide once in half an hour or an hour, and you have a phytoplankton of, say 100 microns diameter, but in one day the bacterial production is about 6 times as much as the production of this phytoplankton so this would mean that the main diet for the zooplankton and for the fish is channelled through the bacterioplankton. Early papers of Neuwerck showed that the phytoplankton would be quite depleted by the zooplankton if it was not channelled through the bacterioplankton. How would you comment on this?

JH

A number of things. The growth rates in the bacteria in the natural environment – and I've measured them in Lake Rotorua – are nowhere close (the generation time) to every half hour to twenty minutes. It's much closer to one to two days, even in a lake like Rotorua. So they are a very important part and when you start looking at food webs you see they tend to feed through the microzooplankton – they're too small for the mesozooplankton to consume so you tend to get a stronger flow of energy through that microbial part of the food web. But where you get into more eutrophic lakes the phytoplankton biomass is just so much higher that it's totally dominant and that energy flow does dominate.

Unidentified speaker

There's something interesting here. It appears that there is a lot of international research in this area and perhaps combining this local research together with the international research you might be able to advance your studies faster.

JH
I totally agree. The one thing we need to acknowledge in picking up information from lakes overseas is a key thing that has been brought out today – the majority of the lakes in the central North Island are nitrogen-limited. That is not the case in most lakes overseas – they tend overall to be phosphorus-limited so we're starting to get different interactions. I agree, we need to build and work with the data from overseas but we can't pick it up holus-bolus and use it in New Zealand. There needs to be a combination of the two, as you're suggesting.

Mary Stanton, Lake Rotoiti
The Ohau Channel has now got a weir going across it. The inanga (whitebait) have always gone into Lake Rotoiti and that gives you food for the trout but over the last ten years the amount of inanga has declined because they cannot get through the weir and we know that as locals – we've almost given up fishing for them because you have to wait all day to get a little cupful of them.
JH
What you're raising is a very important issue in food webs –what you are saying is that you have seen changes in one species within the food web and that's going to potentially impact both down the food web to the zooplankton and the phytoplankton and also up the food web to the fish, so it is an important part of the interaction.
Kim Young, DoC
In your methods did you separate out the smelt from the koaro in your diet analysis?
JH
I cannot answer that question – it was done by my colleague Dave Rowe, who is not here today, but you should certainly ask Dave about it.

WEED MANAGEMENT IN THE ROTORUA LAKES

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ABSTRACT

After 40 years of domination by exotic weed species within many of the Rotorua Lakes, changes in species composition, annual and seasonal weed abundance and invasive spread of weed species still continue. Interestingly, there has been an equally dynamic change in the legislation and allocation of management responsibilities for lake weeds. Subsequent to the Lands and Survey Department involvement, the Department of Conservation was made responsible for a period and more recently responsibility has been transferred to Land Information New Zealand (LINZ) who in turn have delegated weed management to various contractors on a tender basis.

The following recommendations should ensure better management is achieved:

- A Management Plan for aquatic plants in the Rotorua Lakes based on scientifically defensible management strategies, and appropriate stakeholders is urgently needed.
- A Water Weed Technical Committee should be established to address the broader issues of aquatic plants in the Rotorua Lakes and ensure wider agency, Iwi and public involvement. This committee should also have the role of co-ordinating the implementation of the Lakes Weed Management Plan.
- Any agency responsible for implementing the Weed Management Plan should ensure independent research findings and best management practices are adopted.
- An effective, region-wide aquatic plant monitoring and preventative weed management programme should be established to maintain a current record of the extent and spread of existing weed species and to enable effective containment or removal of new infestations.

INTRODUCTION

"I was looking in my diary last night to work out when I first started working on the Rotorua Lakes and I came to the horrible conclusion that I've been diving in these lakes now for 30 years. I know most of you don't think I look any older than 30 (laughter) *but it surprised me to realise that I am a veteran of these lakes and I have a very passionate interest in them. While saying that, I must acknowledge two people that are here today, particularly Vivienne Cassie, who would probably be the oldest person who worked longest on these lakes of anyone that's here and she's still, in retirement, working very effectively and volunteering her time and services. I think that's quite a remarkable performance – thank you Vivienne.* (Applause).

"And likewise Noel Burns who comes very close on her heels now, in retirement and he too is carrying on the good work on the Rotorua Lakes." (Applause).

"Research on weed control options for the Rotorua Lakes began in late 1959 when invasive weed species rose to prominence. Following the first major problems from shoreline stranding on Lake Rotorua the issue of responsibility for removal of the offensive accumulations of weed had to proceed through the court. The outcome of these hearings on

27.4.59 was that the former Lands and Survey Department were deemed responsible for managing the bed of crown-owned lakes."

"Aquatic weeds are notorious for straddling political boundaries of responsibilities and this has often resulted in confusion over who should pay and disagreement over when it is essential to control weeds. The current approach to management of water weeds in the Rotorua Lakes and elsewhere reflects the consequences of present management practices based on short-term subcontracting of responsibilities on a contestable basis. The resultant lack of management continuity and quest for cost savings presents a clear risk of leaning more strongly towards a reactive approach to weed management with little if any response to ecological issues, biodiversity strategies, research based decision making or accurate monitoring of control effectiveness or impacts."

"This photograph was taken seven years ago in Lake Rotoehu, and it comes of little surprise to me that Lake Rotoehu looks the way it does today. What is of particular concern to me is that four weeks ago, I was over in Lake Rotoma – clearly the crown of the crown jewels – it's the best lake of them all, it has the highest TLI and is the most oligotrophic of the lakes. Why are cattle still having access to our cleanest, most oligotrophic lake? I don't understand."

"Many of the Rotorua Lakes don't have natural outlets. It seems bizarre to me that we build houses and roads next to lakes that have never formed an outlet."

"I would like to point out one of the myths that many people actually have, that as you pump in more nutrients into a lake you get more weed problems. It's not really true. In actual fact as you put more nutrients into the water you get more algae, and as you get more algae you get less light available for macrophyte plant growth and over a period of time you end up with lakes like Lake Okaro, without macrophytes but lots of algae. Lake Rotorua is clearly an exceptional lake, mainly because of its extensive littoral shallow shelving zone - an ideal habitat for extensive weed beds and on top of that it does have a stable water level. The only thing mitigating against weed problems at the present time is that the water clarity is down a bit."

"Also you find that amenity areas, such as beaches and boat ramps, tend to be the very areas where weeds tend to grow – these areas are selected for their protection and shelter, and often make ideal areas for weed growth."

Aquatic habitats in New Zealand have undergone extensive modification in little more than a century following European settlement, deforestation and development of agriculture. Years of inadequate border control and on-site containment of aquatic weed species have lead to a broad spectrum of invasive species established throughout the country. Invasive weeds are implicated in the loss of biodiversity as they often form mono-specific stands to the exclusion of diverse native plant communities and to the detriment of ecological and utility values (Howard-Williams *et al.* 1987).

Concomitant with the changing status of aquatic vegetation in New Zealand lakes has been the dynamic change in legislation involved with managing natural resources that support aquatic plant growth as well as legislation specifically targeting problem weed species.

During this period of change and conflict resolution the Rotorua Lakes have always held a position of prominence, political significance and high recreational and tourist values on account of their tendency to reflect a wide diversity of weed and management problems.

HISTORY AND FUTURE OF WEED PROBLEMS

Not all the Rotorua Lakes have weed problems. There are various reasons for the absence of a weed problem, including excessive eutrophication (Lake Okaro), biotic disturbance (Lake Rotokawau), water chemistry (Lake Tikitapu), restricted boat access (Lakes Rotomahana and Rotokakahi) and steep shoreline morphology (much of Lake Tarawera).

Furthermore, not all water plants observable to the public are detrimental, although it is a common belief that they are a nuisance. Many desirable native plant species are found in New Zealand lakes and still remain in most of the Rotorua Lakes. Benefits of water plants arise from providing food and habitat for invertebrates and fish. Plants also help to keep the water clean and clear by trapping suspended sediments and other particles such as plankton.

The main problems with water plants are typically associated with introduced or exotic weed species that have a tendency to grow tall and dense, thereby interfering with recreational use of waterbodies (fishing, swimming and boating). Large weed beds also present a risk of significant shoreline strandings of abundant weed drift. The first clearly visible sign of aquatic weed problems in the Rotorua Lakes was during the late 1950s following the shoreline stranding of large quantities of *Elodea canadensis* and *Lagarosiphon major* (Chapman 1970). Lake Rotorua was particularly affected on account of its large shallow margins that provided an ideal habitat for extensive establishment and growth of these submerged water plants. Of these two weed species, *Lagarosiphon major* remains the most widespread and common weed in the Rotorua Lakes.

The most recent weed species to cause serious problems in the Rotorua Lakes have been *Ceratophyllum demersum* (hornwort) and *Egeria densa* (Coffey and Clayton 1988, Wells and Clayton 1991, Wells *et al.* 1997). These weeds are common in Lakes Rotorua, Rotoiti and Tarawera and *E. densa* has just recently been found in Lake Okareka (5.10.99) and Rerewhakaaitu (authors' observations).

Another 'weed' problem that came to prominence during the early 1990s was a filamentous net-forming alga commonly referred to as water net or *Hydrodictyon reticulatum* (Coffey and Miller 1988, Hawes *et al.* 1991). This once inconspicuous alga inhabited the culture ponds of a tropical fish and aquarium plant importer's premises. Within two years of its confirmed presence in New Zealand it spread to the Rotorua Lakes and from there, water currents, wildlife and boats facilitated rapid spread to other central North Island and coastal locations. Water net was particularly problematic in Lake Rotorua where it formed large floating rafts up to 200 ha in total and it had a major impact on boating activities, often damaging water cooling systems in outboard motors. Fortunately water net declined in abundance (due to management initiatives and natural causes) almost as quickly as it appeared and by mid 1990s it was relatively uncommon although it still persists in the Hawkes Bay region.

The decline of weed beds has been noted in areas or waterbodies with high nutrient enrichment, such as Okawa Bay and Te Weta Bay in Lake Rotoiti and in Lake Okaro. High levels of nutrient enrichment are typically associated with an abundant growth of phytoplankton algae, which in turn reduces water clarity and can prevent significant submerged plant growth. Abundant suspended algal growth has become an increasing familiar problem in the Rotorua Lakes, with sustained summer blooms even resulting in closure of some areas (Lake Rotoehu) to human contact. Periodic storm events and low water clarity within littoral margins have also been attributed to causing the collapse of some weed beds and vegetation decline in Lake Rotorua. After around 10 years there has been only low-density weed occurrence in this lake in comparison with previous growths.

After 40 years of domination by exotic weed species within many of the Rotorua Lakes, changes in species composition, annual and seasonal weed abundance and invasive spread of weed species still continue. Many water weed species still have the potential to invade and would have a major impact on the ecology and utility functions of these lakes. For example, *Hydrilla verticillata* occupies lakes in the Hawkes Bay and this weed species could have far reaching impacts on the vegetation of the Rotorua Lakes. Other major weed problems could also develop from species not yet recorded in New Zealand, such as *Myriophyllum spicatum* and *Trapa natans*, both of which present major management problems in temperate water bodies in the USA.

In North Auckland and Waikato lakes the aquatic vegetation has been severely impacted by swans (*Cygnus atratus*) and introduced fish species such as European (Koi) carp (*Cyprinus carpio*), brown bullhead catfish (*Ameiurus nebulosus*) and rudd (*Scardinius erythrophthalmus*). There is no evidence that these fish species have yet established in the Rotorua Lakes but their ever increasing distribution is a threat. NIWA has evidence that these fish are implicated in the collapse of aquatic vegetation and subsequent prevention of vegetation re-establishment. Any introduction of these fish species to the Rotorua Lakes is likely to have far reaching implications on the lake ecosystems.

HISTORY OF WEED MANAGEMENT

Research on weed control options for the Rotorua Lakes began in late 1959 when invasive weed species rose to prominence. Many conferences were held and research on these weeds began in earnest around this time. Local residents established a Weed Control Society, which has continued to this day under various names and has actively participated in weed removal programmes. The first attempts to respond to invasive weed problems were fuelled by the mistaken belief that eradication could be achieved if enough effort and money was put into their removal. Physical and chemical removal provided the main basis for control at this time. Control measures included a combination of local methods as well as overseas approaches. The potential use of grass carp as a weed control method has often been raised, however their non-selective feeding habit and their tendency to remove all aquatic vegetation has never been an acceptable option for management of aquatic vegetation within the Rotorua Lakes.

The aquarium and pond plant trade was responsible for bringing many undesirable species into the country and for their distribution to mostly private residences. In 1978, a Noxious

Plants Act was established. *Salvinia molesta* (salvinia) and *Eichhornia crassipes* (water hyacinth) were declared Class A weeds by an Order in Council, meaning they posed an intolerable national threat and they were to be eliminated at government expense. The most problematic of the submerged weed species (*Lagarosiphon*, *Egeria*, *Vallisneria*, *Hydrilla* and *Ceratophyllum*) were gazetted as Class B weeds in 1982, meaning they had to be prevented from propagation, sale and distribution. Under this same legislation, a number of Target species were declared (e.g., *Nuphar*, *Nymphoides*, *Hydrocleys*), meaning they were of such limited distribution or establishment that it was considered feasible to eradicate them. Until 1982, *Lagarosiphon*, *Egeria*, *Ceratophyllum* and *Elodea* were sold throughout the country within the aquarium trade and salvinia and water hyacinth were commonly distributed through the ornamental pond trade. Making the sale and distribution of all declared species illegal generally proved to be a cost effective and largely self-regulating means of reducing risk of spread. These regulations are still maintained under the Biosecurity Act (1998).

Curbing the large scale geographic distribution and spread of these weed species has been a national priority, however it has been the accidental escape from ornamental ponds, the deliberate release of unwanted aquarium plants and the recreational movement of boats and boat trailers that has been largely responsible for spread. For species that only reproduce asexually (most of the problematic submerged species), dispersal is largely dependent on human vectors. Johnstone *et al.* (1985) reported a high correlation between waterbodies with boat access facilities and the presence of weed infestations, with many weeds first observed in the vicinity of boat ramps. The public are largely aware of the risks of boats and trailers transferring weed species between waterbodies and most fishers and boat users would be familiar with the weed notices erected at most public boat ramps.

Following the first major problems from shoreline stranding on Lake Rotorua the issue of responsibility for removal of the offensive accumulations of weed had to proceed through the court. The outcome of these hearings on 27.4.59 was that the former Lands and Survey Department was deemed responsible for managing the bed of crown-owned lakes, which is where the weed growth originates. The former Department of Agriculture, and shortly thereafter also the DSIR, undertook research on various control options at the request of the Lands and Survey Department. Even the former Departments of Internal Affairs and Ministry of Works became involved with the development and testing of a weed harvester in the early 1960s. In 1963 the responsibility for weed control was vested with an inter-departmental committee chaired by the Conservator of Wildlife at Rotorua and responsible to the Commissioner of Crown Lands. The Lands and Survey Department managed the aquatic weed problems within the Rotorua Lakes between 1959 and 1988. During that time the prevailing philosophy was to treat the weed with the herbicide diquat and to target problematic growths based on public complaint. This resulted in areas of greatest public usage and those adjacent to residential property within Lakes Rotorua and Rotoiti being the most frequently and extensively controlled. Other lakes periodically controlled included Lakes Okataina, Tarawera, Rotoehu and Rotoma. Unfortunately records of quantities of diquat used or of areas treated were either not kept or have been lost. During the 1970s, research on alternative formulations of diquat led to a change from an aqueous to a gel formulation, which enabled more accurate herbicide placement (by penetrating thermally stratified water) and overcame any risk of aerial drift (Clayton, 1986).

In 1988, responsibility for the management of aquatic weeds was transferred to the Department of Conservation. This led to a greater ecological focus on weed management and a study was commissioned on the aquatic vegetation resources within all of the Rotorua Lakes (Clayton *et al.* 1990) and issues and options associated with alternative weed management approaches were considered (Clayton & Wells 1989). Based on this information, the Department of Conservation prepared a non-technical document requesting public input to the decision-making process for further management of these lakes (Froude & Richmond 1990). The Department of Conservation also adopted use of the gel formulation of diquat recommended by MAF (now NIWA), which enabled penetration of thermal density barriers in the water and better targeting of the nuisance vegetation. Application techniques were also revised with the development of high-pressure spray systems developed by NIWA, and the Department of Conservation contracted a hovercraft for application of the chemical. During this period accurate records were kept and reports prepared on the quantities of diquat used and the areas treated. Furthermore, the change in emphasis was noted from one of reaction to public complaint to a more ecological focus including an evaluation of alternative weed management strategies. For example, bottom lining was used with some success out from the Otaramarae boat ramp in Lake Rotoiti; suction dredging was trialed in the Okere Arm of Lake Rotoiti and in Lake Tarawera, and harvesting was evaluated using the Electricorp harvester in Lake Rotorua. Use of chemical control methods continued to be the most cost-effective option for control of large areas of weed beds, while alternative control methods or even abstinence of weed control was adopted in environmentally sensitive areas.

During the 1990s there was a concerted effort to meet the requirements of the Discharge Consent by investigating alternative weed control options, minimising ecological impact in sensitive areas and by undertaking pre-treatment assessment and post-impact monitoring. A regular annual report was prepared on weed control in the Rotorua Lakes (e.g., Wells *et al.* 2000) and a recent evaluation of potential long-term impacts from regular diquat application provided no evidence of chemical residue accumulation or barrier to biotic recovery at regularly treated sites (NIWA unpublished data).

In 1996 a newly formed department, Land Information New Zealand (LINZ), was given control of the management of weeds in unoccupied crown lands. During the first two years the Department of Conservation was subcontracted by LINZ to continue the management of the vegetation in the Rotorua Lakes with management advice and assistance provided from NIWA. After the Department of Conservation opted to discontinue this arrangement, LINZ Rotorua coordinated management of the weed control programme in the Rotorua Lakes with on-going technical and scientific assistance from NIWA. Subsequently LINZ downsized and tendered the work on a short-term contractual basis. Initially this was contracted to Mr A. Matthews (the former Rotorua LINZ employee coordinating the work) and in October 2000 Landward Consultants (Dr I. Johnstone) were appointed.

PRESENT MANAGEMENT

Since 1 July 1998, the management of aquatic weeds in the Rotorua Lakes has been administered by the Crown Property Contracts Group based in the LINZ National Office in Wellington, although this function was recently transferred to the LINZ office in Hamilton.

The Rotorua Lakes illustrates well one of the greatest problems that have confronted the effective management of aquatic weeds in New Zealand. After 40 years of sustained exposure to the presence of weeds, the harsh realities of often inadequate funding, on-going changes in legislation, government restructuring, divided and frequently changing management responsibilities, and an increased awareness of the limitations of control, have all helped to create a minimalist approach to weed management. Aquatic weeds are notorious for straddling political boundaries of responsibilities and this has often resulted in confusion over who should pay and disagreement over when it is essential to control weeds. Different agencies are often involved at different stages of the expression of a weed problem. For example, submerged weeds growing on the bed of a public lake are the responsibility of Central Government. If weeds interfere with surface navigation, mooring sites, ski lanes or boat ramps, then it is of concern to the Internal Affairs Harbour Master. If weeds become dislodged and stranded upon lakefronts, they become the responsibility of local or district authorities. It is not uncommon to involve Government Authorities (e.g., Department of Survey & Land Information, Department of Conservation), Regional Authorities, Local or District Authorities, various councils (e.g., Fish and Game Council), independent bodies (e.g., Lake Guardians) and local user representatives (e.g., boat, yacht and fish clubs), but often there has been poor communication between agencies. Another dimension to be considered now is the increasing involvement of Maori who have extensive claims before the courts for the return of previously confiscated land and associated waterbodies during Colonial rule in the late 1800's, but understandably they do not accept responsibility for the control of weeds introduced since European settlement. An on-going reluctance to accept responsibility for weed control (especially for weeds growing on the bed of public lakes) and the prevailing philosophy of 'end-user pays' have also contributed to a 'do nothing' attitude unless absolutely necessary.

The current approach to management of water weeds in the Rotorua Lakes and elsewhere (e.g., Lake Wanaka in the South Island) reflects the consequences of LINZ management *in abstentia* based on short-term subcontracting of responsibilities on a contestable basis. The resultant lack of practical management continuity and quest for cost savings presents a clear risk of leaning more strongly towards a reactive approach to weed management with little if any response to ecological issues, research-based decision-making or impact monitoring.

RECOMMENDATIONS

Prepare a Management Plan for Aquatic Plants in the Rotorua Lakes

The Bay of Plenty Region in particular, contains many nationally important water bodies and has a wide range of on-going and potentially new water plant management issues. This region has often been at the forefront of weed problems within New Zealand and it is

appropriate that relevant authorities take a lead in the establishment of a sound management approach, which is based on scientifically defensible management strategies, and politically sensitive representations.

The absence of a Lake Weed Management Plan can lead to major shortcomings with respect to effective and accountable management. A draft management plan should be prepared by LINZ beginning with an initial opportunity for the public to put forward the issues they think need to be addressed. Assistance should be provided from relevant authorities, which defines long-term (e.g., 20 years) management goals and objectives after careful consideration has been given to all the issues and options relating to weed management. The draft should then be peer reviewed and open for public scrutiny and comment. Following ratification of a final Management Plan all subsequent annual weed control decisions and control initiatives (i.e., implementation of the annual Lake Weed Management programme) using tax payer money can be seen to have gone through due process with appropriate accountability and compliance with the long-term Management Plan. This would avoid the potential risk of subcontractors making inappropriate decisions based on cost savings or short-term contract tenures without reference to long-term management goals and objectives.

"These are nationally important lakes. If a management plan is prepared then you can be assured that you have a means by which you can monitor and measure effective and accountable manegement."

Establish a Rotorua Lakes Weed Management Committee

A Water Net Technical Committee was established during the early 1990s to deal with the many management, research and public issues that arose at that time. This committee was particularly successful at addressing management concerns of key authorities, ensuring effective communication with user and interest groups and the public, as well as integrating current research knowledge and recommendations from research organizations. A similar group, such as a Water Weed Technical Committee, should be established to address the broader issues of aquatic plants in the Rotorua Lakes. It is suggested that it be comprised of representatives from LINZ, DoC, Environment BOP, Rotorua District Council, Eastern Region Fish and Game Council, Iwi and NIWA, with appropriate invitees included such as the LakesWater Quality Society. The primary purpose for establishing the Committee would be to ensure that relevant authorities with statutory responsibilities for the management of aquatic plants were more effective in coordinating the wide range of aquatic plant management issues in the region. A key objective of the Committee would be to help LINZ develop the Lake Weed Management Plan, ensure a representative overview of weed management issues were maintained and to act as a decision making body for implementing the annual Lake Weed Management programme.

A Water Weed Technical Committee would also help:
- provide a historical overview and continuity of knowledge
- establish prioritised treatment sites based on objective assessments of weediness, as well as technical, ecological and economic considerations
- ensure weed control contractors adopt effective, environmentally sound practices

- ensure appropriate pre- and post-control assessment and monitoring procedures are established for the Rotorua Lakes area.
- represent community interests
- provide open and accountable decision-making
- update Lake Weed Management Plan

One of the consequences of recent restructuring of the management responsibilities for aquatic weeds in the Rotorua lakes has been the loss of a resident person or group that is able to handle day-to-day issues, respond to and maintain a register of public complaints and inquiries, forward issues requiring further investigation or response to the appropriate authorities and coordinate management initiatives. Over the years it has proven important to have an informed official that is able to liaise with various Departments (e.g. DoC, Environment BOP, Rotorua DC, Chamber of Commerce), politically active organisations (such as Iwi and local ratepayers' associations) and other lake-user representatives, well-known public figures and the media, and represent any vested interests likely to be affected by long-term plans being prepared by the Lake Strategy Group of the District Council. The establishment of a Water Weed Technical Committee would help fulfil this role.

With the recent implementation of new legislation, it is apparent that there are some overlaps of responsibilities pertaining to management of aquatic weed problems, along with gaps in statutory commitments. Such matters could be resolved through consultation, clarification and collaboration by appropriate representatives of the Water Weed Technical Committee, while many other issues would also benefit by being coordinated through such a committee. The committee would also be the most appropriate forum for ensuring all parties likely to be affected by activities generated during implementation of the annual Lake Weed Management Plan are informed, and that any potentially sensitive issues (e.g. the suction dredging trial and deep water disposal in Lake Tarawera) are first approved by committee representatives reflecting a wide range of interests.

Each representative group would still have a distinctive role outside of the Technical Committee. For example, LINZ (as the current lake bed managers) could be expected to consult with Iwi, local Ratepayers Associations, Chamber of Commerce, other lake users representatives and the media to ensure that their perceptions and concerns have been taken into account and that correct information on management decisions is made available. Also as holder of the consent (discharge permit number 023763), LINZ would be required to forward an annual report and plan to Environment BOP of the areas treated, along with details of weed treatment and results. DoC would be expected to ensure implementation of any weed management plan for, and activities on, the Rotorua Lakes as a whole is compatible, and where possible in common, with the management of lakes in their reserves. DoC clearly has a vested interest in ensuring adjacent lakes do not pose an undue threat to the welfare of lakes under their own management. As a member nation to the International Biodiversity Convention, New Zealand management authorities also have a responsibility to develop biodiversity strategies, which would need to include management and prevention of impacts on biodiversity arising from invasive weed species. Similarly, Environment BOP is required to implement Plant Pest Management Strategies for their region under the Biosecurity Act and in this regard maintain an overview of weed management beyond just lakes. For example, Environment BOP have identified *Egeria densa* and *Lagarosiphon major* as 'High Risk Plant

Species' and are expected to maintain current knowledge on their distribution and monitor and protect uninfested waterbodies. Other weed species (*Hydrocleys nymphoides* - water poppy, *Nymphoides geminata* - marshwort, and *Vallisneria* spp. - eelgrass) are 'Regional Surveillance Pests' which have previously been removed from the region, but still require on-going surveillance. Some other aquatic weed species are still actively controlled, such as *Iris pseudacorus* (yellow flag) on Lake Tarawera, but other areas of infestation are not managed by any authority. Environment BOP is also responsible for policing a range of aquatic species that are banned for sale and distribution within the region. Rotorua District Council has a role in removing weed drift along lake shorelines. The role of NIWA within the Technical Committee would be primarily advisory and specific to the Rotorua Lakes issues. NIWA has long-term historical databases and knowledge on these lakes with a number of staff having 30 (or more) years ecological research and weed management experience. The NIWA role outside of this group is to evaluate environmental impacts from weed species, develop generic control techniques, and to contribute to the development of environmentally-sound weed management strategies. The supply of research knowledge and advice is consistent with NIWA responsibilities to ensure transfer of technical knowledge to end-users. The responsibility to work with industry and facilitate transfer of technical knowledge is supported through Public Good Science Funding.

Broader matters should also be considered by the committee, including issues such as the management options and potential impacts arising from restoration of degraded habitats, the selection and protection of representative areas with desirable native vegetation, the containment measures for problematic weeds species and the control of nuisance weed beds.

Incorporate research findings and adopt best management practices

LINZ as current managers of lake weed in the Rotorua Lakes have obligations under their discharge consent (discharge permit number 023763) requiring the grantee to adopt alternative control measures wherever practical and to ensure that best practical options are adopted for the control of aquatic weeds to minimize effects on receiving waters. Best Management Practices require compliance with OSH safety regulations when employing contractors, use of registered chemical applicators for applying herbicides to waterways, registered and certified divers with the Labour Department if used for pre- and post-impact inspection, and the use of any boats requires them to be certified under the Maritime Safety Authority with appropriate Safe Ship Management practices in place.

Research on the long-term environmental impact of using diquat for weed control has recently been investigated by NIWA, along with trials on alternative herbicides commonly used in the USA for submerged weed control. NIWA has an Experimental Use Permit and outdoor quarantine experimental research facilities enabling research on the effectiveness of Endothall on a wide range of weed species, including those most problematic in the Rotorua Lakes (Wells & Clayton 1993). Although diquat is a very effective herbicide and has formed the main basis for weed control in the Rotorua Lakes, it is essential that alternative, potentially more acceptable products also be considered. Research on the potential use of fluridone led to some highly relevant findings on the limitations of this product for weed control in New Zealand (Wells *et al.* 1986). Research on alternative formulations of diquat has already led to

results being incorporated into management practices with significant cost savings and environmental benefits (Clayton & Tanner 1988). Alternative weed control options such as rototilling and suction dredging have also been investigated and their usefulness assessed. Current research on the management of lake sediment seed banks also has relevance to management measures aimed to protect desirable native vegetation and minimise detrimental influences from invasive weed species. Any appropriate research knowledge relevant to the long-term sound management of the Rotorua Lakes needs to have a recognised and acceptable mechanism for incorporation to management strategies, and it is suggested that the establishment of a Lake Weed Management Committee would effectively enable this function to be fulfilled along with continuity of public and management interests.

Establish a regular surveillance programme

Establishment of an effective, region-wide aquatic plant monitoring and management programme should involve an integrated approach by all authorities having statutory responsibilities. Ideally this would form part of the Lake Weed Management Plan and provide the information to determine whether the goals and objectives of the plan were being met. Particular issues of concern relate to the potential for new aquatic weed species to invade the region, such as *Hydrilla verticillata*, which is established in the Hawkes Bay Region; or for even a variety of presently non-naturalised exotic species that are present in New Zealand (e.g. *Cabomba caroliniana*) and known to be problematic overseas, to become established. Even problematic weeds already within the region (e.g. *Ceratophyllum demersum* and *Egeria densa*) show evidence of continued spread, however there are inadequate surveillance measures in place to record the extend of spread or to enable effective containment or removal of new infestations.

Monitoring of coarse fish should be also incorporated into the aquatic plant monitoring programme as they are clearly a future management issue.

"What about future problems for these lakes? Last year a colleague and I undertook a contract to look at what species we've got in the country. We found that there were 179 new species of aquatic plants that were not yet naturalised or established in the wild – these are plants that are under cultivation through the nurseries or ornamental pond trade and aquarium trade. Of those, 65 species had never been previously recorded or known to be present in NZ. Last night, on the Internet, I read the news. There was a statement there that high compliance costs were deterring people from applying to import new organisms and could also be encouraging smuggling, according to the Environmental Risk Management Authority (ERMA). The Chief Executive, Basil Walker, told a Parliamentary select committee that the Authority has been surprised and concerned at the low number of applicants it had received over the last year for the release of new organisms. Smuggling of plants and seeds were of particular concern because they're difficult for border controls to detect. He said, in his view the Authority's prices were too high and it needed to do something about it. If you have very high prices you scare off legitimate players and encourage others to do things illegally and that's not in anyone's interest………So it really is a problem – 65 species not even known to be in the country and these guys just jokingly refer to it as a pocket trade."

Future research needs

"It has been over twelve years now since these lakes have actually been surveyed. It was only because I was doing some work with my colleagues just recently that we found Egeria *in Rerewhakaiitu and Okareka, but all these lakes need a comprehensive update and survey."*

One of the difficulties facing managers of water bodies is the limited range of environmental monitoring tools available for assessment of lake health and condition. Traditional methods have emphasised physico-chemical monitoring options, however these can be expensive and time consuming on account of the repetitive sampling required over different months and the high analytical costs for chemical levels. Aquatic plants have the advantage that they represent live biota within each water body and they integrate annual changes in ecological conditions and habitat suitability for aquatic life. The Ministry for the Environment is presently supporting the development of aquatic plant indices for the assessment of lake condition to produce Environmental Performance Indicators. This research by NIWA has just begun and also has the backing of various stakeholders such as the Environment BOP and Department of Conservation.

An update and review of current aquatic plant species in the Rotorua Lakes should be undertaken, with emphasis on uncommon native species (*Isoetes*, some charophytes) and identification of potential protection and management needs. There is also some urgency to identify and update the knowledge on the extent of invasive species within these lakes since it has been over 12 years since they were last surveyed.

Further research is recommended on identifying the nature of the impact of invasive weed species on seed banks (de Winton & Clayton 1996). Management measures for replenishing and protecting seed banks should be assessed.

Research should be undertaken on the likely future impact from coarse fish such as rudd, catfish and koi carp on aquatic vegetation in these lakes, since they are known to be now having a major detrimental impact on biodiversity and habitat quality in many Waikato lakes.

Research on herbicide options and application methods and evaluation of alternative weed control methods should continue so that weed management can continue to be more cost effective and environmentally acceptable.

"Aquatic disturbance is something that really concerns me. In the Waikato Lakes we've now seen eutrophication have a big impact, we've seen exotic weed species come in and have a huge impact, but now you go into the Waikato lakes and you're hard pressed to find any plants at all. All the submerged plants have gone. It wasn't just eutrophication, it wasn't just the effects of exotic weed species smothering out our native species, it's coarse fish. We've got rudd, perch, catfish, carp and they are having a devastating impact. I've dived on these lakes for many years - I was quite familiar with them, until I went back recently and the bottom of some of those lakes was like a moonscape. They had just been cratered out by the

impact of coarse fish and I think that's the next scourge that you have got to worry about in the Rotorua Lakes."

Questions

Cliff Lee (RDC Councillor)

You've mentioned the Water Net Technical Committee – I'm not sure that committee solved any problems at all. The committee worked well but the weed disappeared despite us I suspect. Have we any idea why these weeds come and then go without any noticeable change in the water quality or anything?

JC

I think you're right – if you form a committee the problem goes! (*Laughter*) I would also point out that different weeds have different reasons for appearing as well as disappearing and I do believe that the combination of input to the Water Net Technical Committee was effective at controlling some of the huge water net problems in front of the Rotorua foreshore. That was seen to be in combination with managing *Egeria* which acted as a support structure for the water net and in the control of *Egeria*, control of the actual habitat of the water net was achieved. So I do believe some good things came out of that integrated committee.

Professor Ripl

Do you have *Ctenopharyngodon idella* (the Chinese grass carp) in your lakes?

JC

Yes we do, but we would not recommend Chinese grass carp in the Rotorua Lakes – they have a place and are very effective at controlling weeds, but they are not effective if you are trying to manage and maintain a desirable level of plants. You either have all plants or you have no plants

Professor Ripl

I don't believe in this carp but I just wondered if you have got it.

JC

Yes we do have it and we use them quite selectively in some areas where we want to control weeds.

Kim Young, DoC

More a comment than a question – I would just like to thank John for raising the profile of pest fish in terms of maintaining the Rotorua Lakes, not just the aquatic weed beds but also the whole ecology of the lakes and their functioning processes as we want to maintain them now. So thank you John, it's the first time I've heard it articulated so well.

JC

Thank you Kim.

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MACROPHYTE MYSTERIES

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ABSTRACT

This paper explores some macrophyte mysteries that are relevant to the Rotorua lakes and lake eutrophication. Most research on macrophytes, especially introduced "weed" species, has focused on their control. This paper identifies aspects of the biology of aquatic macrophytes in New Zealand that have not been explored, including possible benefits of aquatic macrophytes, the relationship between macrophytes and lake health and ecology, possible causes of macrophyte population declines, and some observations on macrophyte invasions. The paper includes suggestions as to potential research directions.

INTRODUCTION

In New Zealand, many types of introduced submersed aquatic macrophytes have long been regarded as weeds, because they, like other weeds, interfere with human interests or activities.

Today, these macrophyte weeds dominate the aquatic vegetation in most of the Rotorua lakes. Although some species are thriving, for example *Ceratophyllum* in Lake Tarawera, others are now disappearing from several of the lakes. The rate of these declines, and their causes and effects, are undocumented.

The perceived weed status of introduced aquatic macrophytes has been the driving force behind virtually all investigations and research on these plants for over four decades. Indeed, in the many scientific papers that have been written, there are very few comments that would suggest that plants such as *Lagarosiphon major, Ceratophyllum demersum, Elodea canadensis*, *Egeria densa* and *Hydrilla verticillata* are anything less than a scourge of Biblical proportions inflicted on the lakes and rivers of our fair country. An early exception, which briefly notes possible beneficial effects, is the article by Vant (1987), a more recent one is that by Strickland *et al.* (2000).

It is not disputed that some of these plants have given recreational lake users headaches for some years, or that piles of weed thrown up by the waves onto the Rotorua foreshore are unsightly and smelly, or that in some situations these aquatic weed species can out-compete native turf-forming species. However, the one-dimensional perspective from which we have viewed these plants has left us with little knowledge of their ecological role or possible benefits they may provide.

Perhaps a more realistic view of these plants would be to consider their advantages as well as their drawbacks. These plants have filled an ecological niche in our lakes and rivers for some

time. Do we know how that niche fits into the ecosystem? What are the inputs and outputs of the weedbeds? How important are these weeds to overall lake ecology and health?

HEALTHY AND SICK LAKES AND THE MYSTERY OF MACROPHYTE DECLINES

Traditional science tells us that we can view lakes, on the basis of nutrient levels, as a successional series from nutrient poor (oligotrophic) to nutrient rich (eutrophic). That perspective is useful in a natural situation *with no human impact*. However, human activities can elevate nutrient levels in lakes (and rivers) far in excess of what might be expected to occur naturally. The ultimate result of human-related high nutrient input is a super-eutrophic lake, which is a sick lake.

For example, the water quality currently found in Lake Rotorua would never have developed naturally. Taking nitrogen as an example, the natural sources of nitrogen (in rain water from lightening and nitrogen-fixing organisms) are small (perhaps 0.1 kg/ha/year in pre-industrial rainwater). These natural sources could never have increased the nitrogen content in Lake Rotorua to current levels, especially since nitrogen is continually lost from lakes, either to the atmosphere (via the activities of denitrifying bacteria) or the sediments, a process that is particularly important in the Lake Rotorua nitrogen budget (White *et al*., 1978).

Therefore, it can be misleading to consider lakes like Rotorua as simply eutrophic, or even hyper-eutrophic, because that implies a possible natural state (see, for example, Reckhow & Chapra 1983, Table 8.11). It is potentially more useful to categorize the environmental status of lakes as simply either “healthy”, “at risk” or “sick”. The following table captures the essence of this concept.

LAKE STATUS

Healthy lake	**Sick Lake**
plenty of oxygen	no oxygen
macrophytes	no macrophytes
fish	no fish
high diversity and low levels of phytoplankton	blue-green algae and/or aquatic fungus
good for contact recreation	not good for contact recreation

Many qualifying "ifs", "buts" and "maybes" can, of course, be added to the table. For example, Lake Rotopounamu has a low diversity (Michaelis, 1983) and standing crop of macrophytes, not because it is "sick" but because the alkalinity is so low that carbon availability is virtually non-existent (pers. obs.). Thus, situations can exist where a lake is "healthy", but may not have a littoral zone filled with macrophytes. Alkalinity is a significant limnological determinant of macrophyte between-lake distribution patterns both for New Zealand (pers. obs.) and overseas (Vestergaard & Sand-Jensen, 2000), but it is a factor that has received little attention, in this context, in New Zealand.

Conceptually, it is the relationship between the nutrient status of a lake and the naturally available nutrients from its catchment that is important:

- *Healthy lake* (may be oligotrophic, mesotrophic or eutrophic; or, indeed, dystrophic): nutrient levels reflect only those available naturally from the catchment, excluding inputs related to human activities.
- *At risk lake*: nutrient levels are greater than the catchment can provide naturally.
- *Sick lake*: nutrient levels are greater than the catchment can provide naturally, and blue-green algal blooms are common.

Early European scientists postulated that the presence and abundance of macrophytes is directly related to a lake's nutrient status, as they had observed that nutrient rich lakes tended to have more macrophytes. These observations were linked to the eutrophication model of lake aging. It is possible that under natural conditions this relationship between nutrient status and macrophytes is accurate. However, human activities now affect all lakes, if only through airborne nitrogenous compounds from motor vehicles and sulphur compounds from the combustion of coal, so *healthy* (natural nutrient status only) lakes are unlikely to be found anywhere today.

Indeed, the changes in many European lakes have been dramatically opposite to what would be predicted on the basis that more nutrients mean more macrophytes. For example, Lake Alpnachersee, in Switzerland, has gone from a lake supporting a diverse macrophyte assemblage to a low diversity, narrow marginal band of macrophytes in 50 years (see HMSO, 1987).

What is observed, for many nutrient-rich lakes, is that macrophyte abundance declines as nutrient enrichment progresses.

It is interesting that although macrophytes (at least in New Zealand) appear to do best in lakes with low standing crops of phytoplankton, no study appears to have been published in the open literature clarifying the relationships between water quality and macrophyte decline, although Vant *et al.* (1986) explored the relationship between macrophyte depth limits and water clarity in a number of North Island lakes. It would be extremely interesting for this work, originally done in 1983/84, to be repeated, as several of the lakes studied now have no macrophytes, while the macrophyte depth limits in others, like Lake Rotorua, have decreased. (The major New Zealand study, since the work of Vant *et al*. (1986), on the relationship

between light levels and maximum macrophyte depth (Schwarz *et al.*, 2000) greatly clarifies this relationship, but does not provide up-dated maximum depths.)

Indeed, for want of a better explanation, macrophyte declines have been attributed to events like the "Wahine Storm" (the macrophytes in Lake Ellesmere) and "Cyclone Bola" (some lowland Waikato lakes).

The news media have reported various explanations. For example:

> *Lake Waikare:* "Waterweed is dying in Lake Waikare, near Huntly – and no one knows why...Waikato county councilors strenuously deny that the county council sprayed the weed...the lake had a history of "plant succession" he (P. Howard – Auckland Acclimatisation Society) said. The weed could be dying to make way for another species." (*NZ Herald*, 1977).
>
> *Lake Waahi:* "Fish and plants in Lake Waahi near Huntly power station, are dying and, according to a visiting university professor, chemical pollutants are to blame." (*NZ Herald*, 1983).
>
> *Lake Rotokauri:* "A 'dramatic die-off' of weed two years ago had changed the lake from aquatic plants to algae...Waikato District Council senior environmental planner Alan Turner said the lake had been deteriorating over several years (because)…lake levels were dropping…heavy grazing by ducks and swans…a gradual increase in farm run-off and urban stormwater had polluted the lake." (*Waikato Times*, 1999).

Sudden die-off of macrophytes has been hitting the headlines for a quarter of a century. Officials' comments have become more sophisticated, but where is the research that could help predict the future status of macrophytes in the Rotorua lakes? Vant (1987) suggested that for shallow lowland lakes, like Lake Whangape, macrophyte success is related to suspended and resuspended sediment. He proposed 5 $g.m^{-3}$ of sediment is roughly the maximum a macrophyte community can withstand. However, such sediment loadings from farming and mining activities would appear to have little relevance to the Rotorua lakes situation.

ADDITIONAL MACROPHYTE MYSTERIES

The following is a list of questions about macrophytes that appear to have received little scientific attention in New Zealand

- *What role do macrophytes play in the in-lake nitrogen cycle?*

Some research is available on the role of macrophytes in the nitrogen flux of New Zealand streams (Howard-Williams *et al.,* 1982).

- *What role do macrophytes play in the in-lake phosphorus cycle?*

- *What role do macrophytes play in the in-lake carbon cycle?*

One relatively recent New Zealand study suggests that macrophytes are "effectively dead ends for carbon flow up the food-web" (James *et al*., 1998). If this is true, macrophytes may be very important in reducing nutrient availability to a lake.

How important macrophyte biomass is to the dynamics of a lake ecosystem, whether as a "dead end" or as food for filter-feeders via the activities of bacteria which decompose dead plant matter, will depend on the turnover rate of the macrophytes (the turnover rate being the rate at which the standing crop is replaced). Curious as it may seem, there seem to be no estimates of turnover rate for submerged macrophytes, either native or introduced, under New Zealand conditions. Does the "dead end" relate to only one species? Cursory inspection of *Egeria* leaves reveals direct consumption, which appears to be denied by James *et al*. (1998).

It should be possible to model the role of each macrophyte species present in the carbon, nitrogen and phosphorus cycles of a lake. Such a model has recently been developed to test the effects of harvesting on *Potamogeton pecinatus* under South African conditions (Asaeda *et al.,* 2000).

- *Do macrophytes inhibit algal blooms?*

In areas of dense weed beds, phytoplankton levels are commonly observed to be less than in the open lake. Is this simply due to shading (under waterlily beds the water is usually crystal clear), or is it due to competition for nutrients, or is there some allelopathic interaction as seems likely (Nakai *et al.,* 1996; Nakai *et al.,* 1999)? It is not impossible that macrophytes release inhibitors that reduce growths on their leaves and also, concomitantly, reduce phytoplankton populations in their vicinity. Certainly, overseas studies have shown that macrophytes play a significant role in maintaining clear water (Small *et al.,* 1985; Meijer and Hosper, 1997; Perrow *et al*., 1997).

In contrast many seagrass species seem unable to control epiphytes colonizing their leaves by the production of allelopathic substances, but rather they depend on the constant production of new leaf material for survival (see, for example, Fong *et al*., 2000).

- *Do macrophytes create a useful habitat for animals and if so, how important is it?*

Harvest, by dropping a net, over one square metre of weed in Lake Karapiro, and the "catch" will be several kilograms of weed plus several small fish like bullies and goldfish. When diving, I have seen trout "patrolling" the edge of a weed bed. Perhaps the trout are looking for wayward small fish that inhabit the weed beds. Are weed beds a habitat that enhances trout productivity or are they just a refuge in which fish and other small animals can escape predators like trout and shags? There are few studies that have looked at the importance of submerged macrophytes to fish. Chisnall (1996) found that eels smaller than 400 mm preferred marginal habitat, which included macrophyte beds. On the other hand, Goldsmith *et al*. (1999) found that aquatic weed removal from streams in Southland (New Zealand) had no effect on the resident fish populations. Aquatic weed removal is, of course, different from

"natural" decline, and it is not clear that removal studies can predict the effects of decline events. The situation for the Rotorua lakes appears to be unknown.

The decline of macrophytes appears to cause dietary changes in fish (Hayes & Rutledge, 1991). Certain invertebrates are associated with macrophytes and decline when the macrophytes decline (Graynoth *et al.*, 1995).

Aquatic weeds are an important food of black swan (Sagar *et al*., 1995).

- *How do we know if macrophytes are healthy?*

Does the turnover rate decline when the plants are under stress? Does the root/shoot ratio change? How long does it take for the depth range of a macrophyte to be reduced in a lake where light is limiting – months? years? Macrophytes appear to be reasonably robust. Being perennials, they need to be able to survive a range of conditions. Is a decline in the health of the macrophytes a late signal rather than an early warning that undesirable changes are occurring in a lake's ecosystem? Evidence from Lake Coleridge suggests that vascular macrophytes respond quite slowly to changes in the light regime (Schwarz & Hawes, 1995).

- *What are the causes of macrophyte decline?*

Various macrophytes, both native and introduced, have declined in abundance in a variety of lakes. Do these lakes have anything in common? I note a few declines as follows:

Female *Elodea*: Historical records suggest that all *Elodea* in New Zealand, until about 1960, was female. In recent years in the North Island, I have been able to find only male *Elodea,* except at one site. In the South Island, female *Elodea* is still widespread except for the Nelson lakes, where only male plants can be found. Has the female plant been declining to be replaced by the male, or has the species simply changed its sex in some geographical areas?

Elodea: It is believed that *Elodea* was very abundant in the Waikato River and Lake Karapiro in the 1950s. Today, *Elodea* is virtually absent except for some cold-water sites.

Lagarosiphon: This species was the dominant macrophyte in the Waikato hydro-lakes in the 1960s. It is now a minor component of the macrophyte community in these lakes.

Egeria and *Lagarosiphon*: These species have virtually vanished from many of the lowland Waikato lakes where they were previously abundant.

Isoetes kirkii: The type locality for this plant is Lake Whangape, and in 1870 it formed a compact turf right across the bottom of the lake bed (Kirk, 1870). This plant has now completely vanished from its type habitat.

Myriophyllum robustum: This native milfoil has undergone such a rapid decline that it is now considered "endangered" in the North Island (de Lange, 1985).

(Waternet: Although this large freshwater alga is not a vascular plant, like the other macrophytes discussed, it has also undergone an unexplained decline. Over the course of a few years, it greatly expanded its range and then it essentially vanished very quickly from nearly all the sites it was occupying.)

Possible causes of declines of large freshwater plants include the following:

- Resuspended sediment due to wave action during storms.
- Sediment loading as a result of poor agricultural practices.
- Sediment loading as a result of mining.
- The foraging behaviour of rudd, catfish and koi carp.
- Inadequate light due to phytoplankton blooms.
- Toxins produced during phytoplankton blooms.
- Deoxygenation during phytoplankton blooms.
- Nutrient poisoning (nitrite/nitrate levels) – I have had macrophyte cultures die because the nutrient solutions were (accidentally) not dilute enough. Is it coincidence that many macrophyte declines have occurred post Motunui (inexpensive nitrogen fertilizer)?
- Interspecific competition – *Lagarosiphon* is usually thought to replace *Elodea*, and *Egeria* is, similarly, thought to usually replace *Lagarosiphon*. However, such species replacement is quite different to the overall loss of macrophytes noted in many lakes. [Such assumed species competition has never been tested.]
- Temperature – Macrophytes are sensitive to increased temperatures. Are some of the declines simply due to the water being too warm? If so, is temperature acting alone or is the problem a lack of oxygen at higher temperatures? How long can macrophytes survive, with little or no ambient oxygen? Evidence suggests, for those lakes for which we have data, that water temperatures are increasing. One aspect of global warming is that the nights do not cool as much. This could have a major influence on the heat budget of a lake. (It is of interest that although studies on the effects of hot water from Huntly Power Station were carried out for nearly 20 years, these studies were all related to animals [particularly fish]. Not one study was carried out on the effects of elevated temperatures on the health of the macrophytes. From overseas studies, we know that cooling water discharges can have devastating effects on seagrasses.)
- Declining vegetative "vigour" – The macrophytes under consideration are all clonal. There is no seed set in New Zealand for either *Egeria* or *Lagarosiphon*, as only one sex is present. Both male and female plants of *Elodea* are present in New Zealand, but they have never been reported from the same habitat while *Hydrilla*, although monecious, appears to not set seed under New Zealand conditions (Hofstra, *et al.*, 2000.) *Ceratophyllum* is also monecious, but, like *Hydrilla*, seed set has not been observed for New Zealand. An alternative possibility, that declining vegetative vigour is associated with an increased allocation of a plant's resources to flowering, has been explored by Johnstone (1982).
- Pollution – Industrial toxins may play a role in some circumstances.

- Decreasing pH, as a result of airborne sulphur compounds, from coal burning. An effect that could act directly or indirectly through shifting the CO_2, HCO_3, CO_3 equilibrium towards free CO_2.
- Boats – The physical effects of boats can be destructive to aquatic vegetation (Liddle & Scorgie, 1980). In Europe, the effects of two-stroke outboard emissions on aquatic fauna have been studied (Juttner *et al*., 1995), but not on macrophytes.
- Self-shading, a possible key mechanism that has not been explored.

Plant invasions and declines are usually depicted by plotting the population size against time. Such representations describe what happened, but not why. Assuming a living macrophyte is a "set point" in a cybernetic system, we need to look for the cause of positive feedback associated with a decline event (see, for example, Sutton & Harmon, 1973).

To determine whether macrophyte declines are to be welcomed or avoided, we need to know the effects of macrophyte decline on a lake's ecosystem. The classic seagrass decline in Europe in the 1930s was followed by a collapse of the fisheries, which depended on the seagrass beds for spawning. In comparison, the effects of macrophyte declines in freshwater lakes seem to be poorly understood.

Aspects of macrophyte biology may be related to strategies for avoiding natural declines. For example, in water more than about two metres deep, *Egeria* plants lie procumbent on the lakebed during winter whereas *Lagarosiphon* does not. Is this procumbent response a mechanism to prevent self-shading and decline, as appears to occur for *Lagarosiphon?*

- *How fast can a macrophyte invade a lake?*

Egeria: Both *Ceratophyllum* and *Egeria* were first recorded in Lake Tarawera in 1988. By 1993/94 *Ceratophyllum* was present at 52% of the sites sampled while *Egeria* was only present at 8% of the sites (Wells *et al.,* 1997). Today, *Ceratophyllum* is widely spread throughout the lake, while *Egeria* seems to have retreated to a few protected sites in Kotukutuku Bay (*pers. obs.*). It is possible some of the lake sediments are not conducive to its growth (de Winton, 1996). However, *Egeria* stem growth this summer (until early March) has been between 40 and 60 cm. This growth is not unusually low, suggesting nutrients are not the cause of *Egeria*'s lack of success in Lake Tarawera. What is the difference between these two species that has resulted in such vastly different invasion rates in Lake Tarawera?

As a working hypothesis, it seems likely that the barrier to invasion for *Egeria* is "category D" (see Appendix 1), this barrier being *Ceratophyllum*. This could be the case if *Ceratophyllum* has a longer growing season than *Egeria* in Lake Tarawera as a result of a lower light requirement for photosynthesis and the significantly higher minimum water temperature that is characteristic of Lake Tarawera compared with, for example, Lake Rotorua.

Lagarosiphon: In 1980 Dr Brian Coffey wrote about the “explosive” colonization and growth of *Lagarosiphon* in Lake Wanaka (Robertson & Blair, 1980). He suggested that *Lagarosiphon* had a potential doubling time of three months in Lake Wanaka. To know whether this is true or not one would need to know the reproductive potential, as a function of the frequency of branch loss, of *Lagarosiphon*. The absence of any definitive research on the reproductive potential of aquatic weeds, like *Lagarosiphon*, means that in situations where invasion, rather than decline, is still an issue for New Zealand lakes, “gestimates” still have to be made (Appendix 1). Of the three factors needed to understand a macrophyte invasion (Appendix 1), the reproductive potential of invading macrophytes remains a significant mystery.

PRACTICAL MYSTERIES

Some macrophyte mysteries are of practical significance. For example:

- Is there any practical means of controlling the rafts of *Ceratophyllum* that have been floating around Lake Tarawera in recent summers?

- Can a sick lake be helped by planting macrophytes? Rehabilitation of seagrass communities, by planting seagrasses, has proven difficult and expensive.

In New Zealand, retiring the margins of lakes to stop access by farm animals is a reasonably common strategy to improve lake health. In one case (Lake Tutira), a stream with a high phosphorus loading was diverted away from the lake. However, there do not seem to be any in-lake re-vegetation trials, although Dugdale and de Winton (1998) have investigated the potential of “reseeding” macrophyte-deficient lakes with characeans, and de Winton *et al.* (2000) have carried out extensive studies on the viability of seed banks in New Zealand lakes which could, given the right environmental conditions, contribute to the re-establishment of an aquatic macrophyte community.

CONCLUSIONS

Little appear to be known about the positive attributes of macrophytes, especially those considered to be “weeds”. Many mysteries still exist about macrophyte biology, including the role of macrophytes in lake ecology, interactions between macrophytes and other aquatic plants and animals, and what causes macrophytes to relatively quickly decline in abundance. For some species, practical methods of control remain a mystery; while the planting of others may be a way of improving the health of sick lakes.

Questions
Dr Rowland Burdon, Royal Society
Is it known what role the roots of macrophytes perform, if any significant one, in the mineral nutrient economy?

IJ
Certainly for the ones which we have here I'm not aware of any in-depth research. There's quite a lot of research on the roles of roots of waterlilies in pumping stuff from the roots up to the atmosphere, but in terms of what role the roots of *Egeria* or *Lagarosiphon* have, I'm unaware of any research in New Zealand on that.

Professor Ripl
I have some comments on what you have said. We have done some research on *Phragmites* expanding and going back and then dying off, and it showed that in nature all biota have a certain phase in which they can exist in a certain place. We have dynamic systems and we have growth, which is always much larger than respiration – you could say the production is much higher than the respiration. Once in a while we get the situation where we get the space filled up and this will be a shorter phase when we have eutrophic conditions than when we have oligotrophic conditions, where it will remain for a much longer time. From this point we get feed-back loops and there are various feed-backs. We can't exactly say the causes and consequences in cyclic processes because it's a matter of how we inspect the cycles and what position we take. Causes and consequences from classical science are not applicable for practical dynamic systems. Once in a while we get higher respiration and then we get the decline of each weed and then we get the succession to another weed and if this is going on all the time we get a rather stable system but if this process is synchronised we will get a very bumpy ecology in this place. So I think the questions always have to be put not just "Why" but 'Why, where and when" and this you will maybe find out in your place, but in another place it will be in another phase and you will get a different answer. So for this reason these general questions, in a living dynamic system, are not of significance.

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Appendix 1

LAGAROSIPHON INVASION: A LAKE WANAKA MYSTERY?

Ian Johnstone
North Island Manager, Landward Management Ltd

(Modified from information on the Lake Wanaka *Lagarosiphon* problem provided to the Lake Wanaka Guardians, March 2001).

Background

In the early 1970s, *Lagarosiphon* rapidly invaded certain parts of Lake Wanaka's shoreline. That invasion continued for about 2 years, a similar duration to the time *Lagarosiphon* took to invade almost all of the Clutha Arm of Lake Dunstan's shoreline. The patchy distribution of *Lagarosiphon* in Lake Wanaka today is very similar to that in the early 1970s. The mystery is, – why was the invasion of Lake Wanaka not complete – in other words, why, after 30 years, has *Lagarosiphon* not invaded most of Lake Wanaka's shoreline?

Lake Invasion by Vegetatively Reproducing Aquatic Plants

Lagarosiphon does not set seed in New Zealand because only female plants have been introduced into the country. For such plants that can spread only vegetatively to invade a lake, three requirements must be met:

(1) Someone or something puts them in the lake, for example by:

- A ride on a boat or boat trailer
- A ride on a poacher's net
- A ride in an aquarium which is emptied into a lake or stream
- Spillage from an ornamental pond
- Deliberate introduction

(Historically, birds have been suggested as a possible vector by which plants like *Lagarosiphon* could be introduced to a lake, but there is no direct or indirect evidence for this.)

(2) A viable plant fragment is dispersed to other sites within the lake:

The time taken to occupy all suitable habitats depends on the how many plant propagules are produced and what causes these propagules to move around a lake.

Branch-tagging experiments with *Lagarosiphon* (unpublished) showed that on average at least one branch or part of a branch was lost every 2 weeks. Each of these fragments could potentially produce a new plant. So if, say, 25 fragments are lost per plant per year, each of which can be dispersed beyond the parent plant and can produce a new plant, only

4,000 plants are needed to produce another 100,000 plants each year (if every fragment survived).

In contrast, my research on the waterlilly *Nymphaea alba*, which spreads by means of special banana-shaped propagules, showed that each plant produces perhaps half a dozen banana propagules per year, of which only one might be available for dispersal beyond the immediate colony.

The difference is substantial. *Lagarosiphon* occupied virtually the entire shoreline of the Clutha Arm of Lake Dunstan in less than two years, whereas *Nymphaea alba* has taken over 15 years to invade all suitable habitats in Lake Ohakuri, reflecting the low number of propagules it produces.

The difference is not due to the *mode* of in-lake dispersal, as the propagules of both species are transported by water currents.

(3) The habitat is suitable for plant establishment and growth:

Assuming *Lagarosiphon* arrived in Wanaka in the summer of 1970/71 (see Robertson & Blair, 1980), this plant has now been in the lake for approximately 30 years. With one or two exceptions, the sites occupied in the early 1970s, after about 2 years of dispersal (see Hughes & McColl, 1980), are the same today. Why has this plant not continued to establish nuisance growths around most of the lake shore?

Invasion of a site can occur only if the habitat at that site is suitable. The habitat may not be suitable for one of four reasons (see Figure 1):

A. It will not support plant growth.
B. It will not support the growth of certain species of plant.
C. The invader cannot compete against the existing vegetation without a “gap”.
D. The invader cannot compete against the existing vegetation.

The above four circumstances are essentially “barriers” that prevent invasion of a site. The barriers to *Lagarosiphon* invasion of sites in a lake like Wanaka are barriers A and B. *Lagarosiphon* will not invade deep parts of the lake below the photic zone (an A barrier). As well, *Lagarosiphon* will not invade beyond a certain depth limit due to light limitations, even though certain other species can (a B barrier). However, *Lagarosiphon* is absent from some of Lake Wanaka’s shores where other species of submerged macrophytes are present and light is obviously not the limiting factor. Research has shown that the level of wave action is critical to whether *Lagarosiphon* will become established at a shoreline site. *Lagarosiphon* will not establish where the fetch is greater than about 10 km, and forms nuisance growths only where the fetch is less than about 2.5 km (Howard-Williams & Davies, 1980). Lake Wanaka is about 47 km long and up to 12 km wide. Much of the shoreline of Lake Wanaka is, therefore, subject to a fetch that greatly exceeds that which can be tolerated by *Lagarosiphon.* Wave action is therefore a barrier, of the B category, to *Lagarosiphon* becoming established at shoreline sites.

Invasion Barriers

Scientists have often asked why a plant is a successful invader. The answer is that the environment meets the plant's requirements. This answer is not, however, particularly helpful. Instead, a more productive question might be, why is plant not a successful invader at a given site. The reason is that there are barriers to invasion. These barriers may be botanical or non-botanical and selective or non-selective. This concept is illustrated in Figure 1.

Barrier Selectivity

Barrier Type	Non-selective Change-dependent	Selective Species-dependent
Non-botanical	A	B
Botanical	C	D

Figure 1: Invasion barriers and invasion windows, where A, B, C and D are the four possible barriers to invasion. Invasion will occur only when one of these does not exist – in effect creating an "invasion window". (Modified from Johnstone, 1986)

A = no invasion possible (unless there is a non-botanical change)
B = invasion is habitat dependent
C = no invasion possible (unless there is a botanical change)
D = invasion species dependent

Some practical examples of the concepts in Figure 1 follow:

Invasion barrier type A: An example would be that part of the lakebed below the photic zone (which could, however, be invaded if the lake level dropped or water clarity improved).

Invasion barrier type B: An example would be that part of the lake bed where light limits the establishment of some (but not all) species of plants, or that part of the lake shore where waves limit the establishment of some (but not all) species.

Invasion barrier type C: An example would be that part of the lake bed occupied by a species capable of excluding the invader. This area could, however, be invaded if the

existing vegetation was disturbed to create a "gap"; an example being invasion by *Nitella* following *Lagarosiphon* control.

Invasion barrier type D: An example would be that part of a lakebed occupied by plant species which cannot exclude a particular invader, but could exclude another potential invader; an example being the exclusion of *Nitella*, but not *Lagarosiphon*, by *Isoetes*.

Summary

Lagarosiphon rapidly invaded parts of Lake Wanaka in the early 1970s. That invasion was very similar in duration to its invasion of Lake Dunstan, but with dramatically different results – almost all of the Clutha Arm of Lake Dunstan's shoreline was rapidly invaded by *Lagarosiphon*, whereas major areas of Lake Wanaka remained free of this weed. Thirty years later, these areas still have not been invaded, even though at first glance there appears to be no reason for this weed not establishing itself in these areas.

This situation can be explained as follows. After an initial invasion, which depends on (1) the plant entering the lake by some means, the duration and final pattern of spread depend on (2) the plant's reproductive and dispersal potential and (3) habitat suitability. The mystery as to why *Lagarosiphon* is still limited to sites in Lake Wanaka that it invaded in the early 1970s relates to the third invasion factor "habitat suitability". Habitat suitability for *Lagarosiphon* in Lake Wanaka relates to one of four potential invasion barriers. For shoreline sites, "barrier B", which in this case is wave action, is limiting invasion.

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CYANOBACTERIAL TOXINS

Neale R Towers
Toxinology and Food Safety, AgResearch, Ruakura Research Centre, Private Bag 3123, HAMILTON

"A year or two back when I heard that my colleague David Stirling has just bought himself a new mountain bike I was a little envious. But at the moment he has the broken elbow and the broken leg and I'm not quite so green with envy. The talk today will cover some of the aspects of immunoassays but I thought I should also cover some of the information on toxins, which David was to talk about."

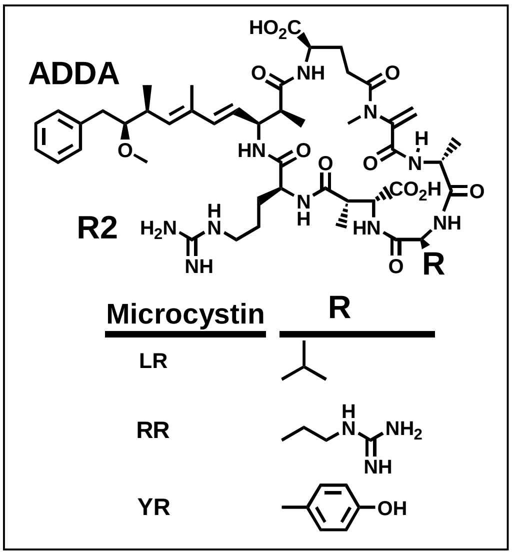
A major concern to lake users in recent years has been the occurrence of potentially toxic blooms of cyanobacteria and the effects of "closure" of the lakes for weeks or months on their enjoyment of the lake and on the tourism industry.

Cyanobacteria are known to have the potential to produce a range of toxins that have caused human and animal illness and death. The toxins fall into three classes: the neurotoxins which interfere with the nerve function; the hepatotoxins which result in liver dysfunction and disruption and the lipopolysaccharides which cause skin irritation on contact.

The chemical structures and modes of action of the toxins vary widely and this great diversity adds to the difficulties of health officers and analytical chemists who are trying to monitor the appearance of cyanobacterial blooms and determine whether the risks of toxicity are high enough to warrant distributing health warnings and "closing" a lake to recreational use and/or as a source of drinking water.

TOXINS

Microcystins and Nodularins



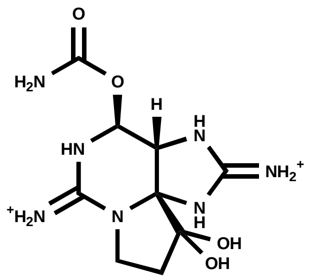
A highly variable group of toxins (more than 60 microcystins and 5 nodularins) – with most variation occurring in the regions of the molecule labelled R and R2 in the Figure. The side chain labelled ADDA occurs in most of these toxins.

Microcystins and nodularins are produced by several genera such as *Microcystus, Oscillatoria, Anabaena, Nostoc, Hapalosiphon,* and *Nodularia*. (Carmichael, 1997)

The microcystins are potent hepatotoxins (liver damaging toxins). Acute poisoning of humans and animals constitutes the most obvious problem from toxic cyanobacterial blooms in severe cases leading to death.*(Jochimsen et al., 1998; Pouria et al., 1998)*, In a recent incident, 60 patients of a haemodialysis unit in Caruaru, northeast Brazil, died of acute liver failure in February 1996 following acute exposure to toxin-

contaminated dialysis water prepared from cyanobacteria-containing lake-water (Pouria, *et al.*, 1998). In an earlier case involving a massive *Anabaena* and *Microcystis* bloom in Itaparica Dam, Brazil, the resulting contamination of drinking water with cyanobacterial toxins was responsible for 2000 cases of acute gastroenteritis and 88 deaths, most of which occurred in children (Teixeira, 1993). In contrast to the previously well-described acute intoxications, chronic exposure, although less-well defined, is of even greater concern — especially in view of the high incidence of primary liver cancer in China, which has been attributed to the tumor-promoting effects of chronic consumption of drinking water contaminated with cyanobacterial hepatotoxins (Harada *et al.*, 1996); (Ueno *et al.*, 1996a) (Yu *et al.*, 1998). As a result, there has been much interest in the microcystins from national and international safety committees, with increasing pressure for stricter regulatory guidelines.

Saxitoxins

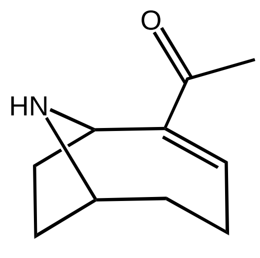


Saxitoxin

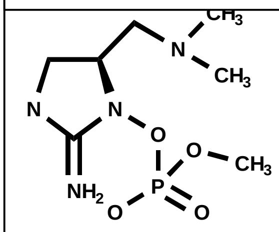
The saxitoxin family, a group of approximately 20 analogues of widely varying toxicity, are produced by various *Aphanizomenon, Anabaena circinalis,*and *Lyngbya wollei (*Falconer, 1999*;* Fitzgerald *et al.*, 1999; Humpage *et al.*, 1994*).* They are also known as the paralytic shellfish poisons (PSP) as they are produced by a number of marine microalgae and accumulated in shellfish. The PSP are neurotoxins that interfere with nerve signal transmission, and the symptoms of PSP intoxication are neurological and include numbness, tingling and burning of the lips and skin, giddiness, ataxia and fever. Severe poisoning may lead to general muscular incoordination, respiratory distress and death from paralysis of the respiratory muscles (Rodrigue *et al.*, 1990). No antidote is available, and treatment is symptomatic. Blooms of Saxitoxin-producing cyanobacteria have been associated with the death of wildlife and livestock. A very extensive bloom of 1000's of kilometres of the Darling River caused the deaths of many thousands of sheep and cattle. It is therefore important to prevent intoxication by monitoring cyanobacterial blooms for the presence of these toxins. Humpage has suggested a maximum concentration of 3 microgram saxitoxin/litre.

Anatoxin-A

Anatoxin-A and its several analogues are produced by species of *Anabaena, Oscillatoria, Aphanizomenon,*and *Microcystis* (Rapala *et al.*, 1993); (Park *et al.*, 1993); They are neurotoxins that block nerve signal transmission by mimicking the effect of acetylcholine. (Carmichael *et al.*, 1979). Anatoxin-a has been associated with the rapid deaths of dogs drinking bloom water or licking algal scum (Edwards *et al.*, 1992; Gunn *et al.*, 1992) and other instances of wild life death or ill-health (Oberemm *et al.*, 1999; Smith, 1996).



Anatoxin A

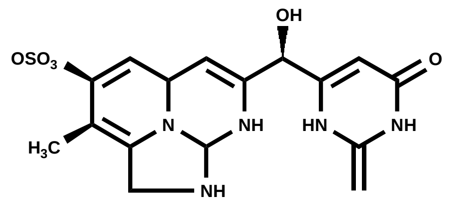


Anatoxin-A(s)

Anatoxin-A(s)

A second toxin type produced by *Anabaena*, but with a completely different chemical structure and biological mode of action, has unfortunately be given the name of anatoxin-A(s). Anatoxin-A(s) is also a neurotoxin blocking nerve signal transmission but in this case it acts as cholinesterase inhibitor (Mahmood and Carmichael, 1986). The presence of *Anabaena* blooms has been associated with the deaths of dogs and widelife (Mahmood, 1988; Onodera *et al.*, 1997)

Cylindrospermopsin



Cylindrospermopsin

Cylindrospermopsin is a toxin produced by *Cylindrospermopsis raciborskii* and *Umezakia natans* which causes widespread tissue injury, including damage to the gastrointestinal lining, liver, and kidneys. Initially thought likely to a problem only in the warmer waters of semi-tropical areas such as Queensland, it has been found in the cooler regions of Australia (Hawkins *et al.*, 1997) and recently in New Zealand (unpublished data, D Stirling, ESR, Wellington). Cylindrospermopsin accumulates in the tissues of farmed crayfish (Saker and Eaglesham, 1999) and is thought to have been the cause of cattle deaths in Queensland (Thomas *et al.*, 1998).

DETECTION METHODS

Potentially toxic blooms can be detected by microscopic examination of water samples for the presence of known toxin-producing species of cyanobacteria or by analysing for the presence of the toxins (Duy *et al.,* 2000). Basing health risk on cell counts of potentially toxic species is the most widely used technique adopted by water and health authorities, but suffers from the disadvantage of over-estimating the true risk as only about 20 percent of the samples from New Zealand blooms have been found to contain toxins. Management of the health risks would be better based on a system in which cyanobacterial cell counts were used to signal the need to initiate a programme of analysing for the presence of toxins in the water.

There are many and varied methods for detecting and quantifying the cyanobacterial toxins, but in general they fall into two classes (1) Bioassays that detect and measure the biological activity of the toxin and (2) chemical and immunochemical assays that detect and measure the presence of the toxins directly on the basis of their chemical and structural properties.

BIOASSAYS

(i) Mouse Bioassays

The most widely used bioassay is the “mouse bioassay” in which extract or concentrates of the bloom or water thought to contain the toxin are injected into the intestinal cavity of 3-5 mice which are then observed to see whether they show symptoms of toxicity and die. The assay has served health authorities well for many years in that it will detect the presence of most toxins even where the nature of the toxin is unknown. However, the bioassay has a number of drawbacks. It is not particularly sensitive and, like most bioassays is non-specific in that it can not identify a particular toxin and is thus not suitable for use in studies of the

toxin-producing dynamics of a developing and collapsing bloom, it is expensive because of the number of mice required and the length of the required observation period (up to 24 h) and there are serious animal ethics concerns over the use of mice in this way when alternative assay methods are available.

(ii) Alternative Bioassays

A large number of alternative bioassays (Torokne and Johan, 1999) using bacteria (Lahti *et al.*, 1995; Lawton *et al.*, 1990), yeasts, brine shrimp (Kiviranta *et al.*, 1991), mosquitoes (Kiviranta *et al.*, 1993), blow flies, desert locusts (McElhiney *et al.*, 1998), red blood cells (Carmichael *et al.*, 1981) or mammalian cell cultures have been developed as alternative to the mouse bioassay. They all have essentially the same principal as the mouse bioassay. Cultures extract or water concentrates are added to the medium in which the test organisms is growing (or in the case of the larger insects injected into the abdomen) and the test organism monitored for signs of toxicity or death. Some of the assays are easy to perform and require relatively unsophisticated inexpensive equipment and could therefore be adopted in many laboratories, although this is not the case for assays such as the neuroblastoma assay for PSP toxins (Manger *et al.*, 1993), using mammalian cell cultures, which require specialised laboratories and experienced technical staff.

The bioassays vary widely in their sensitivity and like the mouse bioassay, cannot identify which toxin in particular is present, only that something toxic is present. This lack of specificity can be considered an advantage when used to monitor safety as it is less likely that the presence of an unknown toxin will go undetected.

TOXIN DETECTION ASSAYS

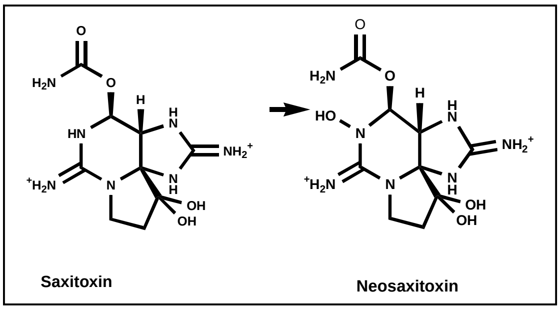
(i) Enzyme Inhibtion Assays

Assays based on the mode of action of the microcystin and nodularin toxins in inhibiting the activity of several common protein phosphatase enzymes (Holmes *et al.*, 1994) (Wirsing *et al.*, 1999) and of anatoxin-A(s) in inhibiting the activity of acetylcholinesterase (Henriksen *et al.*, 1997) have been widely used to detect these toxins. However as many other toxins, pesticides etc. have the same ability these assays are also non-specific in not being able to identify unequivocally the presence of microcystin or anatoxin-A(s).

(ii) Immunoassays

Immunoassays have been developed to PSP toxins (Huang *et al.*, 1996; Usleber *et al.*, 1995) and the microcystins (Chu *et al.*, 1990; Hirooka *et al.*, 1999; McDermott *et al.*, 1995; Nagata *et al.*, 1997). Immunoassays can be formatted as laboratory-based quantitative assays e.g. the ELISA, or as simple testkits (such as the home pregnancy diagnosis kit) that can be used in the field. Immunoassays are based on antibodies that have the ability to recognise and bind to specific toxins and analogues that have a very similar structure. Immunoassays have greater specificity than the mouse bioassays, *in vivo* bioassays, cytotoxicity assays and most receptor-binding assays as the antibody will only bind specifically to the toxin against which it was raised and to other compounds which contain the same, or very similar, epitopes. (The epitope is the region to which the antibody binds – good binding requires a high level of similarity in space-filling structure and electron charge distribution.) Antibody specificity provides both advantages and disadvantages with respect to other analytical methods.

Antibody specificity means that it is quite possible to determine concentrations of one toxin in the presence of many others. For example, saxitoxin may be determined in the presence of microcystin, which is not possible with the mouse bioassay or other cytotoxicity assays. But antibodies rarely have such narrow specificity that they bind a single compound or such broad specificity that they bind equally well to all members of a toxin group. This poses particular problems for the PSP toxin group as the anti-saxitoxin antibody used for the ELISA does not recognise neo-saxitoxin, one of the other more common toxins in the group, despite the great similarity in their structure (see arrowed difference in the figure) which could lead to a significant under-estimation of the toxin content of a bloom sample. This is much less of a problem for other toxin groups and ongoing research is directed at overcoming these problems – see below.



ELISA have particular advantages for use in routine screening of water samples for the presence of toxins in that the assays are simple, rapid, are suitable for use with large numbers of samples, use relative inexpensive equipment but are also highly sensitive. Assay development for a new toxin can be slow because of the prolonged period required to raise antibodies.

Assays for the immunoassays are quantitated by comparison to a standard curve prepared using a reference toxin and reported in "toxin equivalents".

HPLC and LC-MS
These acronyms stand for High Performance Liquid Chromatography and Liquid Chromatography - Mass Spectrometry. These are the reference methods used when it is necessary to determine absolutely which toxins are present. They generally require a greater 'clean-up" of sample extracts before the analysis step than bioassays and immunoassays and they detect only known toxins for which standards are available. Assay development can be rapid but the assays require specialised expensive equipment ($60,000-120,000 for HPLC; $350,000-600,000 for LC-MS). Where there are multiple toxin analogues these methods may under-estimate total toxicity(Edwards *et al.*, 1993; Harada *et al.*, 1988; James *et al.*, 1998; Lawton *et al.*, 1994; Watanabe *et al.*, 1997)

An improved ELISA for microcystin and nodularin toxins
In order to protect consumers from adverse effects of microcystins and nodularins, the World Health Organization (WHO) proposed a provisional upper limit for microcystin-LR (MC-LR) of 1 µg/L in drinking water (WHO, 1998), whereas Health Canada calculated a tolerable daily intake (TDI) of 0.013 µg/kg body weight/day of MC-LR (defined as a 60 kg adult consuming 1.5 L water per day, with an MC-LR content of 0.5 µg/L water) (Kuiper-Goodman, 1994). However, effective consumer protection requires the sensitive and efficient detection of the whole spectrum of cyanobacterial cyclic peptide toxin congeners, many of which are as toxic as MC-LR, and regulation should not be restricted to MC-LR alone. This, however, also requires that the present methods for cyclic peptide toxin analysis be able to quantify the

individual congeners with similar sensitivities and at concentrations well below the proposed limits (because the toxic effects of the various congeners are expected to be additive).

DISCUSSION

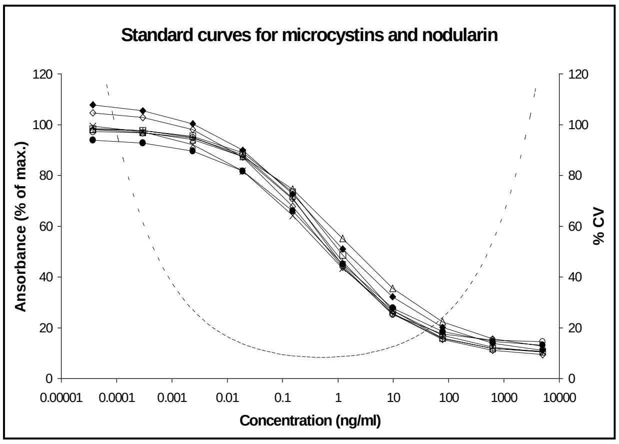
The mouse bioassay, routinely used to date, is able to detect toxicity irrespective of the toxin congeners present. However, it has several disadvantages: its sensitivity is quite low, so that it is of use only for the detection of toxin concentrations that could lead to acute intoxications; the intraperitoneal route of administration may not appropriately parallel natural exposures; and many animals and large samples are necessary. The other two widely employed methods, chromatographic detection e.g. HPLC, HPLC-MS (Harada *et al.*, 1988) and the protein phosphatase inhibition assay, (Holmes, *et al.,* 1994; Wirsing, *et al.*, 1999) offer excellent sensitivity but are expensive to perform and require highly skilled personnel. While chromatographic methods are capable of detecting and identifying single congeners, routine quantification of all known congeners is almost impossible because new analogues, especially of microcystins, continue to be discovered. Furthermore, chromatographic methods are ill-suited to the detection of toxicity arising from the presence of low levels of several congeners because the concentrations of the individual components may be below the limits of detection.

Because enzyme-linked immunosorbent assays (ELISAs) are quick, cheap, and easy to perform, ELISAs are ideal for the establishment of a screening program — provided that robust assays of sufficient sensitivity and, especially, universal cross-reactivity to the numerous toxin congeners, are available. The development of a broad-spectrum ELISA with high sensitivity and broad specificity for cyanobacterial cyclic peptide toxin congeners, and its validation for analysis of water, is the key to establishment of an efficient and cost-effective screening procedure.

Several groups have developed immunoassays for microcystins using monoclonal and polyclonal antibodies (An and Carmichael, 1994; Chu, *et al.*, 1990; McDermott, *et al.*, 1995; Nagata *et al.*, 1995; Saito *et al.*, 1994; Ueno *et al.*, 1996b). However, all of these antibodies were raised against a specific microcystin, and the assays therefore tend to be sensitive to a relatively narrow range of microcystin analogues. Such assays are not ideal for screening because of the possibility ELISA based on these antibodies may give false negatives when the samples primarily contain those members of the toxin family not recognised by the antibody.

To overcome this problem we have taken advantage of the fact that more than 80% known microcystins contain a side group known as of ADDA (4*E*,6*E*-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid) (see first Figure). In a collaborative programme involving chemists from the University of California (Davis) and toxicologists from the University of Konstanz, Germany, we have raised antibodies to this compound rather than to the complete toxin. These antibodies have been used to developed an ELISA based on these antibodies. While approximately 15% of the toxic microcystins contain a modified ADDA group and may not be detected by the ELISA, they are not common and if they go undetected would not significantly alter the ability of the ELISA to measure the total toxicity.

The assay has a limit of detection of 0.02–0.07 ng/mL (depending on which microcystins are present) that is much lower than the WHO-proposed guideline (1 µg/L) for drinking water, irrespective of the sample matrix (raw water, drinking water).



The assay is more sensitive than other available ELISAs, shows good cross-reactivity with all microcystin analogues tested to date, and has high cross-reactivity with nodularin – see Figure (the dashed curve indicates the concentration range where assay variation is less than 20%). The ELISA has the additional advantage over HPLC or LC-MS procedures in that it integrates the concentrations for the individual toxin analogues to give an estimate of total microcystin/nodularin hepatotoxin content to better predict potential toxicity. The assay is robust and quick (assays can be completed within 1 day of sample receipt), and can be used directly on crude water samples. It has been used successfully in the analysis of raw river and reservoir water, algal cultures, and algal bloom samples, and has been employed for the detection of microcystin contamination in rivers and lakes in New Zealand. The broad specificity, high sensitivity and robustness of the ELISA makes it suitable for use as a quick screening tool for the detection of microcystin and nodularin toxins in water samples, and in the analysis of components of the aquatic food chain.

Table
Cross-reactivities, limits of quantitation and working ranges of the ELISA for selected cyanobacterial cyclic peptide toxin congeners.

Toxin	I_{80} (Limit of Quantitation) (ng/mL)	Working range (ng/mL)	Molecular Weight	I_{50} (50% Inhibition of Binding) (nM)	Cross-reactivity relative to MC-LR (%)
MC-LR	0.05	0.05–7.50	995.2	0.61	100
MC-RR	0.06	0.06–26.26	1038	1.22	50
MC-YR	0.02	0.02–6.87	1045	0.37	167
MC-LW	0.03	0.03–8.33	1025	0.52	118
MC-LF	0.02	0.02–15.14	986.2	0.57	108
dmMC-LR	0.02	0.02–8.76	981.2	0.39	157
dmMC-RR	0.07	0.07–9.05	1024	0.77	80
Nodularin	0.06	0.06–4.5	825	0.61	100

Questions
Lindsay Brighouse, Lake Rotoiti
I see that in your last slide (not included in Proceedings), Okawa Bay (Lake Rotoiti) has a toxic reading and yet the whole lake was classed as toxic, and that is one of our problems – where we have a small isolated area but the whole lake is condemned. This is quite a major issue I believe, because Okawa Bay is really a small lake on its own. Also, I'm very curious about the machines that you've mentioned – if we had those machines here would we have had more accurate readings over the last two years? That's the LC-MS machine.
NT
Without doubt LC-MS is the gold standard reference method – I wouldn't have thought it would be the most appropraie way for doing routine monitoring though.
Lindsay Brighouse
Do those machines exist in New Zealand?
NT
Yes. ESR has one, used for commercial work, Cawthron Institute in Nelson has one used primarily for shellfish-toxin testing. Obviously the techniques are comparable, it's just a matter of setting up the methods. HortResearch at Ruakura is just establishing one and as part of our contract with them we will get some access as well. Waikato University, I think, is

about to buy one, I'm sure Auckland University has one – they are about. (*Comment from audience – "Forest Research are getting one."*)
I guess that anyone who has a good chemist and a good machine can set up for these assays, but the difficulty is the charge they have to make given the cost of the machine and the time that's involved – you might not want to pay several hundred dollars per sample for the analysis.

Lindsay Brighouse

These toxic issues – are they more likely to happen in a warmer climate?

NT

Pass. There have been toxic incidences in the South Island, also around Wellington. I think it probably will vary – in different areas with different climates you are probably going to have different toxins.

Unidentified speaker

I spent some time in Antarctica and worked out of Lake Chad. (*inaudible*)… Taylor camped by Lake Chad and drank the water flowing out of it. This water was flowing over a bed of *Nostoc*. As a result his whole party suffered from gastroenteritis, as did every other party that has camped at that site. The lake is frozen – it melts for just a few weeks each year so the water is essentially at zero degrees. Chad is the name of the toilet paper they used.

NT

It has to be said that our development of the mycrocystin assay was a joint programme between ourselves, the University of California (Davis) and the University of Konstanz in Germany. Professor Daniel Dietrich at Konstanz is one of the people who go to Antarctica to look at the blue-green algae because they are toxic.

Phil Shoemack, Medical Officer of Health, Pacific Health

Can I comment on whether we should be looking for toxins or cell counts. As the person who issues the Health Warnings when they're necessary it's probably appropriate that I make some comment here. You're quite right –the obvious health effect is due primarily to the presence or absence of toxins. The difficulty with only testing for toxins is that clearly the toxins can only be present if you've got some significant level of cyanobacteria to begin with. If there is not a significant bloom of cyanobacteria then *ipso facto* you're not going to get release of significant quantities of toxin. Just because you have a significant bloom of (cyano)bacteria somewhere doesn't necessarily mean that you will have toxins produced but you may have at any time that you've got a bloom. So to use toxicity testing as an indicator of whether you've got a health problem would mean that you would have to be testing for the toxin almost continuously, because even though you might sample today with a bioassay or whatever, and come up with a negative result for toxin, that only tells you what the state was at the time you did the test, not what it might be a few hours later. My understanding is that these (cyano)bacteria are capable at any time of producing these toxins so while there is a significant bloom there is that capacity for the toxins to be produced and hence the Health Warnings.

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THE SOCIAL AND ECONOMIC IMPORTANCE OF THE ROTORUA LAKES

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ABSTRACT:

The Rotorua lakes have shaped the history of this region as much as has the regional geothermal resources. While clearly important as a recreational and tourism-related resource the value of the lakes is shaped by all four of the usual value streams - direct consumptive, direct non-consumptive, indirect and existence/option. Relevance of these four types of value to the Rotorua lakes is briefly discussed.

The value of the lakes for recreation and tourism served as one of the major negotiating issues in negotiations between Te Arawa and government over the lakes. A 1922 agreement vested the beds of Lake Rotorua and 13 other lakes, along with the right to use their waters, with the Crown. The economic values associated with the lakes and their relationship with residents and visitors is explored.

Trout fishing, primarily in the lakes, is estimated to bring in some $25 to $35 million to the region annually. Survey work has indicated widespread willingness-to-pay to improve the quality of the water in Lake Rotorua, even when households do not use the lake. A commitment to a land-based wastewater treatment scheme for urban Rotorua also indicates the importance of this lake, and maintenance of its quality, to the local community.

INTRODUCTION:

There are a couple of major challenges being the penultimate speaker to any symposium that has been as intensive as this one. The first is to keep peoples' attention. It has been a full day with a large number of topics and papers. A paper on the social and economic importance of the Rotorua lakes at the end almost begs for a reaction of the 'for goodness sake, we've just spent a full day examining various aspects of the lakes and their health – we all know that they're important, so why bother' variety. So there is a real challenge to make the topic novel, interesting and relevant.

There is also a particular challenge in being an economist talking of these things. Some are bound to think of that Oscar Wilde crack about people who know the price for everything and the value of nothing. Wilde's comment was made about accountants, not economists, but following that line won't necessarily convince anyone about the need for economics and economists. I suspect there are probably some in this audience who are more than a little skeptical about any role for economic analysis when looking at the question of preserving the health of the lakes. So for those I hope that I can demonstrate that economics does have a role, if only in allowing them to show potential funders of preservation research how valuable this research actually might be.

WHERE VALUE ARISES:

The value of any asset comes from one (or more) of four basis sources. An asset may be valuable because it is consumed directly to provide some good or service we want – drinking water for example – and we can value it directly as being worth at least as much as the next cheapest way of supplying that particular good or service. However, we don't always consume assets in providing things that we want. A second way in which an asset may have value even though it isn't consumed in the production process it by being essential to it. It's a bit difficult to imagine being able to go sailing without a body of water to sail on, or to enjoy lake views without a lake. Economists, and I guess accountants too, have considerable experience in teasing out the total cost of providing some experience or good, subtracting from this the costs of those things used up in providing the good/experience and then inferring value to the other assets associated with producing the total package.

Next there are indirect use values, e.g. modification of the local climate, absorption and dispersal of land-based of pollution, (for example we used Lake Rotorua relatively directly for wastewater disposal from 1892 until 1991), as a habitat and for the protection of biodiversity. Finally there are option and existence values. People may value resources simply because having them allows for the option of using the resource at some time in the future. This is a bit of an insurance type value, like the nest egg squirreled away for the rainy day. Or the asset may be valued for the fact that it exists – in the way that we currently value much of this country's indigenous flora and fauna. There is no intention to make money from these species but there is a definite 'feel good' factor from knowing that they exist and a willingness to pay something to ensure that they continue to exist. Naturally these last values are some of the most difficult to measure but they need to be acknowledged and accounted for in determining stewardship of the lakes.

There is too much material for me to cover in the next 15 minutes. Instead I want to talk about one or two issues and values clearly associated with these. I intend to look at briefly at recreation and in particular recreational fishing and some material that I believe points to the fact that the option/existence value of the lakes is substantive. However, before doing so, and since this talk is supposed to be social as well as economic values I want to briefly mention the importance of the lakes to this region's history.

SOCIAL ISSUES:

The lakes are every bit as important in shaping the history of this region as the geothermal resource Without its lake (Roto) and the fact that it was the 2nd (rua) one would there even be a place called Rotorua?. Without Lake Rotorua and its island, Mokoia, this area could never have produced the love story celebrated in the names of the main streets of this town – or at least it couldn't have produced the love story in the way that it actually happened. That lake is essential to the story of Tutanekai and Hinemoa, as are lakes to a number of other stories from this region's history.

The lakes have been important in shaping the way people have interacted with one on a number of other occasions over the last 800 years. Don Stafford's (1967,1986, 1988) books

on the history of this region clearly reveal the social importance of the lakes to the history of the Waiariki region. However, I'm going to leave this aspect of the lakes at this point and turn to their recreational value.

RECREATIONAL VALUE:

Tourism is of vital importance to this city and region. For Rotorua something like 1 in 5 jobs, as compared to 1 in 12 for the country as a whole, is tourist related. The Bay of Plenty has some 1.4 million visitors in a year 2/3rds of whom visit the Rotorua District. One in ten of all visitors (local and international) visit the BOP. Rotorua alone accounts some 6.7 –6.8% of all New Zealand tourist numbers (Anon, 1999).

Many of these visitors spend some of their time here on or around the lakes of this region. (In the last week I've been stopped twice by international tourists – Scottish and American – while walking along Tutanekai Street and asked the way to the lake). Access to and use of the lakes was recognised as an important issue over 100 years ago. A 1922 agreement between Government and Te Arawa, an agreement which I understand is in fact being discussed again today by representatives of both Crown and Te Arawa, vested the rights of access and use of the waters of 12, (one source say 14[2]), of the Districts lakes in the Crown. In return Te Arawa as well as being confirmed in their customary use rights to these lakes were granted a number of (40) concessional trout fishing licences, and an annuity of £6000 pa (Stafford, 1988).

Its interesting to look at the annuity and what it was worth then and now. Since 1922 inflation in New Zealand, as measured by the change in the Consumers' Price Index, has been a mind blowing 3335%[3]. So £6000 in 1922 - $12,000 in dollar terms – had a purchasing power which is roughly equivalent to some $400,000 today. Thus back when New Zealand had a population of some 1.3 million, Rotorua's population was less than 8,899, which was the population recorded at the 1936 Census (Anon 1999), and fewer people visited the region in a year than the number visiting Rotorua on a good day, now the access and use value of the lakes was valued (in today's terms) at more than $400,000 per annum. (It is more than $400,000 because the settlement included not only the annuity but 40 discounted fishing licences as well as some other benefits that are not easy to quantify in monetary terms).

Now before I get myself into too much hot water over these numbers and what they all mean I should perhaps mention I'm giving them simply to establish that access to, and use of the lakes clearly has value – and that this fact has been well recognised for a long time. How much should be paid by whom, for what, and when, and how we wish to describe the use rights conferred by such payments are not something I want to get involved with here. However, some of the current concerns over the 1922 agreement simply highlight problems that can arise with long-term contracts and a changing value of money. There was an

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[2] In the section Te Arawa Heritage by Stanley Newton, of Ngati Pikiao (Rotoiti) pp59-60 in D.J. Shaw, M.A. Fletcher and D.J. Stack (1990) Rotorua Lakes:Rainbow Country 14 lakes are listed– Rotoma, Rotoehu, Rotoiti, Rotorua, Okataina, Okareka, Rerewhakaaitu, Rotomahana, Tarawera, Tikitapu, Ngahewa, Tuataeinganga,Opouri and Ngakaro - as being affected by the 1922 Rotorua Lakes legislation

[3] This comes from Statistics New Zealand's INFOS database and the quarterly CPI series from 1914 until the present.

alternative to the scheme approved by parliament back in 1922 and that provided for a lump sum payment of £120,000 instead of the annuity of £6,000. That £120,000 lump sum would in today's terms be equivalent to some $8 million.

Recognition of the recreational/tourism value of the lakes isn't confined to 78 year-old agreements. The tourism value of the lake is recognised explicitly in a number of more recent works such as one by Weber *et al*., (1992) looking at the benefits and costs of soil conservation in the Bay of Plenty. Part of the work looked at activities that occur on Lake Rotorua and how these might change with improved water quality. These authors surveyed 1089 households in the BOP getting 395 replies to a question on household use of Lake Rotorua for recreational activities. Of these households 27% (107 households) used Lake Rotorua, with, not suprisingly, the majority of the user households (53%) coming from within the Rotorua District.

Picnicking, Walking/Photography, Boating and Trolling, and Trout Angling were the most important uses. This was followed by swimming, other forms of motorised boating – water-skiing, sightseeing, sailing, canoeing and bird watching. Again because time is so short I'll just give you the results of the work in terms of willingness to pay to improve the water quality of Lake Rotorua.

As might be expected the general trend was that richer households were prepared to pay more However, some of you will also note that the general trend was disrupted by a small group of 'mean' punters with household incomes of just under $50,000.

Willingness-to-pay to Improve the Water Quality of Lake Rotorua (By Household Income)

	Mean Willingness-to pay $	Number of Households
Less than $5,000	0	1
$5,001 - $10,000	8.6	7
$10,001 - $15,000	9.5	22
$15,001 - $20,000	34.4	16
$20,001 - $25,000	9.3	19
$25,001 - $30,000	32.9	12
$30,001 - $35,000	22.4	11
$35,001 - $40,000	23.3	7
$40,001 - $45,000	70.1	9
$45,001 - $50,000	27.1	7
$50,001 - $55,000	48.7	8
$55,001 - $60,000	96.7	6
over $60,000	65.5	20
unknown	13.0	12

Source Weber *et al*. 1992.

The material can be analysed in other ways, for example by the location of the household. As one might predict this sort of analysis show Rotorua locals prepared to pay more for improved water quality in Lake Rotorua than people from out of town.

Willingness-to-pay to Improve the Water Quality of Lake Rotorua (By Location)

	Mean Willingness-to pay $	Number of Households
Rotorua	51.2	62
Tauranga	17.9	73
Whakatane	23.0	20
Unknown	60.0	2

Source Weber *et al.* 1992

Then there is the question as to whether only current users are prepared to pay for better water quality. Some might predict that the 'user pays' philosophy would have fully taken root and that if one was not a user then one wouldn't be prepared to pay. Well, as the next table shows the evidence isn't that way at all.

Willingness-to-pay to Improve the Water Quality of Lake Rotorua (By Current Use)

	Mean Willingness-to pay $	Number of Households
Household uses Lake Rotorua	40.4	53
Household does not use Lake Rotorua	27.9	97
Unknown	30.3	7

Source Weber *et al.* 1992

In summary the three tables show people are prepared to pay to keep the water quality up, perhaps as much as $2 to $3 million per annum for the region as a whole. (Note that this is only a value for Lake Rotorua alone). The work also shows that in general richer households are willing to pay more for improved water quality and that the closer one lives to this lake the more the household is prepared to pay. Lastly, as the third table reveals, there is evidence for an existence value for Lake Rotorua too. Those who don't use the lake are still willing to pay to maintain/enhance its quality. Moreover as the survey was a regional one the evidence is that existence value is a region wide value, not simply one confined to local Rotorua citizens.

Of course there is other evidence for this existence value too in the form of the city's wastewater/effluent purification project. Rotorua is one of the very few places in the world that having treated it wastewater then pumps it uphill for disposal on land disposal so as to improve/maintain the quality of its lake water. The system is substantially more expensive to build that the pipeline proposed as part of the Upper Kaituna Catchment Control Scheme – a scheme that in 1984 was ruled to be socially unacceptable by a Waitangi Tribunal finding. However, the in-forest treatment option had a capital cost that is perhaps $10 million to $16 million more than that of the cheapest alternative. It also has running costs that may be higher by as much as 100 percent over that of the cheapest alternative system. Not only do the costs of the Wastewater Disposal System demonstrate a willingness-to-pay to maintain the water

quality of the lake but by opting for a system that was less socially divisive than the alternatives it also indicates the social importance of Lake Rotorua too.

TROUT:

When beginning this talk I said that the value of the lakes for fishing was one topic that would be covered. Given the way that time is passing I had better get to this topic now. In 1986/87 anglers within the Rotorua Licence District spent $17.05 million on their sport. Some 78% of this related to fishing in the Rotorua lakes. In current dollar terms the total value of that expenditures would be just under $35 million and for the district as a whole,with the lakes-related component of the expenditure valued at some $21.9 million. That is not necessarily that far off the current mark – if anything it might be a bit low. Graham Andrews recently reported (Andrews, 2000) that the recreational trout fishing industry brings more than $25 million into this region.

The concern in the Andrews article relates to a possible liberalisation in trade in imported trout flesh. APR has in fact recently re-visited the question of the value of the trout fishery as part of work for the Ministry for the Environment on this topic (APR, 2000). Our estimate is that nationally the trout fishery is worth some $160 to $300 million with the most likely value in the $230 to $270 million range. The Rotorua lakes fishery accounts for some 30% of the total national figure – so we have an asset with a current value of around $70 million ($50 to $90 million).

Every year there are some 37,000 trout fishing licences are sold in the district – of which something like 40% of the total are sold to international visitors. Angling-related expenditures represents a bit less than 10% of Rotorua District tourism-related economic activity and it appears that in the last year (1999/2000) about 1% of international visitors to Rotorua fished the Lakes. Back in 1986/87 it was only about half this level (Shaw *et al.*, 1990).

In 1986/97 2.6% of the expenditure of international visitors who came to Rotorua was on angling activities in the Rotorua lakes. For domestic visitors the figures was 16.5%. Overall in 1986/87 the average spending per angler per day for all those fishing the Rotorua Lakes was approximately $86. In current dollar terms this would be around $142 per person per day. Back in 1986/87 the average angler spent some 7 days fishing per annum. Today they spend a bit less – about 6 - but if we apply the daily numbers to the total number of anglers then the total estimated expenditure is of the order of $32 million per annum.

Recreational fishing is obviously a big business and an important component of the local tourism economy. It also produces something of the order of 200 tonnes of fish per annum Attitudes towards the trout fishery have clearly changed since the early years of the last century when Wi Pere, the MP for Eastern Maori (1908) complained in Parliament on behalf of Arawa that their fishing rights had been disturbed by the introduction of exotic (trout) fish which were depleting stocks of native fish, for which they were required to obtain fishing licences for fish '*that are absolutely no good, because they are unpalatable*'.

OTHER VALUES:

I haven't even attempted to tackle things such as the value we clearly put on the lakes as a desirable place to live. When I began to prepare for this symposium I asked a principal of one local real estate agency about values of lakeside properties. He told me that I could expect to pay anything from 20 to 120% more for a lakeside property that was comparable in all other respects to one that wasn't lakeside. That would suggest that we value being lakeside rather highly. There is, I believe, more than enough data available for someone with the time to establish a pretty good estimate of the impact of being lakeside on property values – its just not going to be done here. There might even be sufficient information to allow one to begin to make some tentative estimates as to what deterioration in the water quality of a particular lake might mean in terms of changes to property values at that lake. However, that too is for the future.

CONCLUSION:

I believe though that I have established is that there is more than sufficient material already available showing that the Rotorua lakes, although not priceless, are of significant social and economic importance locally, regionally and nationally. To some of you it may be a bit of a sad commentary on the age that we always seem to need to put a monetary value on assets before they warrant proper stewardship. Be that as it may, in the case of the Rotorua lakes I believe that it is good to know that if such evidence is required then it can be found and that moreover it indicates that:

- the value is reasonably high,
- people know the lakes are valuable and, possibly even more importantly,
- they are prepared to pay to see that the existing values are both protected and maintained.

"That's probably quite important for those of you who are advocating more research, because the thing that also comes through from some of this work is that not only do people know that they are valuable but they are prepared to pay to protect, enhance and maintain the values that are currently associated with our lakes."

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SYMPOSIUM SUMMARY

Dr Robert Franich
Royal Society of New Zealand, Rotorua Branch

A quick overview of what has been heard – the natural science presentations, aspects of ecology, the physical aspects of lake systems, chemistry, nitrogen, phosphorus and micronutrients, organic carbon and sediments, all the biological and environmental aspects, the wetlands, the foreshore and all the quality aspects associated with those. The last presentation covered the social aspects, effects of lake environment on our city and urban environments, the leisure and sports activities built around our lakes, revenue from tourism, other economic aspects and also costs – maintenance and remediation costs.

One of the research opportunities identified is the development in the areas of fundamental science, both natural and social sciences and in the applied area we have heard of the monitoring and surveillance of the lake for toxins.

One of the most important outcomes of research is how that technology is transferred – we have heard comments about management plans for the lakes and using sound scientific data that results in sound management plans which cannot be refuted – this is one of the outcomes we have been looking for.

Thank you to all presenters for their excellent presentations which have given everybody a great deal to think about.

EVENING QUESTION SESSION

The day's presenters formed a panel. The questions and the replies have been abridged and abbreviated to remove the material extraneous to the matter under discussion. Names preceded by a question mark indicate that there is some doubt as to identity (this transcript was prepared from tape recordings). If we credit you with asking a question that you didn't ask, or missed your name, our apologies. Horizontal lines divide off each individual discussion topic.

Nick Miller, LWQS
Question to John Clayton. In your presentation, you advocated setting up an Aquatic Weed Management Plan, and suggested that LINZ were the organisation whose responsibility it would presumably be. Given our experience of them, do you think they have the resources, staff or will to do this?
Dr John Clayton, NIWA
If asked directly, based on the changes in management that I have seen take place in very recent times, I would have my doubts that they have the in-house capability to undertake any such review.

? Julie Hall, NIWA
What sort of variation in human population might be expected in the way people may react to a given dose of any toxin.
Dr Neale Towers, AgResearch
I can answer that, but not on the basis of any dosing given to humans – it's considered unethical these days (*laughter*). Given work done with animals there is quite a large variation between individuals. Some toxins that we work with in the agricultural area, at any given dose rate, range from apparently no effect at all to death. The same sort of range would be possible in human terms.

?Will Esler, Royal Society
Given staggering temperature increases in annual increments, the highest annual increases being on lakes closest to the linear vent zone associated with the Harahara volcanic complex – are the temperature rises attributable solely to global warming or is there a magmatic component which would presumably show up in the increased chloride flux in the lakes?
Dr Noel Burns, Lakes Consulting
Temperature increase has bothered me a bit – trying to understand it. Obviously increases of 0.2 degrees per year are unsustainable – we would have boiling lakes in 50 years. A good data record from Lake Okareka has been obtained from about 1987 through (and this also showed in a river study from NIWA) and it showed from 1987 – 1992 the temperatures dropped every year, I think something to do with Mount Pinatabo eruption when things went quite dark, so the temperatures we are seeing now are partly a reversal of previous cooling. Now we have the added component of climate change, maybe small but much more long-lived, and I don't know where its going to lead us.

?Rob Pikethley, Fish and Game
Question for Julie. We've noticed some serious changes in trout populations in Lake Rotorua in the past few years which are likely due in part to changes in algal communities. How far

away is the scientific community from being able to take climatic variables and conditions in the lake and predict what sort of algal bloom that is likely to cause, e.g. we get *Cyclotella* in winter time, blue-greens in summers?

Julie Hall, NIWA

A long way. The reason is complexity – because one is looking at temperature changes, seasonal variability, changes in nutrient concentrations from year to year, de-oxygenation and the biological interactions of top-down pressure, feed back from phytoplankton species. A very complex question and we are at this stage a long way from answering it.

Amanda Hunt, Environment BOP

Question for Chris Hendy. Relating to the Whakarewarewa Forest irrigation area, how confident can you be that the phosphorus will be taken up by the trees rather than entering the deep ground water when allophanic clay layers are saturated?

Dr Chris Hendy, University of Waikato

Can't be confident at all that the trees would take up all the extra phosphorus. My suggestion was that once saturation had occurred the phosphorus level in the soil waters would be raised and be more available to trees. Under those circumstances I think that you would start to see phosphorus leaking out through the groundwater aquifer system but you may also see a greater uptake of nitrogen at this stage, however I am not a tree expert. I know that pines are associated with mycorrhizal fungi that are very good at pulling phosphorus at low concentrations out of the allophane. The allophane is like an ion exchange system. So you are banking the phosphorus and you can pull it back again if you reduce the concentration in the water surrounding it.

Unidentified questioner

Question for Dr Ripl. Are you in a position to have a visionary look at the lakes around Rotorua? Can you give the layman of Rotorua any idea what might be in store for us and the lakes?

Professor Ripl, TU Berlin

In the lakes and the catchment we have highly dynamic systems, always changing and aging. We can now influence the phase length, however we have very few processes ruling this. One is the hydrological process – if we get a little more rain water in this country we will be exporting water vapour to the sea. Another is salination as experienced in Australia. Here you have a pristine landscape created by the volcanoes and this means it is quite young – much younger than in Europe or Australia.

In the lakes we have two biological processes, production and respiration. When the system is young production leads, you are accumulating organic substance in the catchment and you have good lakes because the catchment is structured better. If you are in the phase of destructuring the catchment, of course there will be a carry over from the catchment to the lakes and you will get a higher respiration, you are importing nutrients and organic matter into the lakes, the sedimentation will increase, and you could have a decrease in the lake size by having reeds and weeds in the shorelines or you could have a high sedimentation by sedimenting plankton, and the depth of the lakes will decrease. There is evidence that this can change sometimes so you can have a temporal eutrophication phase and then perhaps an oligotrophic phase and the sedimentation will decrease for a time.

If you have depleted your countryside and there are no nutrients or water cycle left the lakes will prevail and you will get less import from the sea and more export of the water vapour because the cooling system is damaged and eventually you will get saline lakes and in the end no carrying capacity left.

If looking at lakes management then we must also look at land management. This will increase the time phase and offer more sustainability. The land manager will be responsible for water, recycling, and producing energy, not only food. He should be advised how to do it best to get most sustainability for the local place.

Don Atkinson, Okawa Bay resident
Resident of Okawa Bay, which has been much talked about today.We frequently observe nutrients running across front lawns into the lake. A group of residents are pushing to see if they can get septic tanks converted to a sewage scheme for the area to take the nutrients away from the bay. Do the panel believe such a scheme would in time enhance the bay?
Max Gibbs, NIWA
If you remove nutrients from the septic tanks and sewage disposal systems from Okawa Bay and Mourea area you would improve the water quality in Okawa Bay. You already have large weed beds in the bay, possibly also leakage of geothermal nitrogen coming into the bottom of it from Ruahine Field. Anything that removes the nutrients, particularly nitrogen and phosphorus and also the bacteria associated with that, will improve the water quality of the bay.
Ian Johnstone, Landward Management Ltd. (responding to a comment from Ian McLean)
I was personally shocked to see how few aquatic weeds were in Okawa Bay, one wouldn't need to practice weed control for the next 500 years. It is sick enough that the weeds have reduced to a very narrow band around the edge of the bay. There are still characeans (*Nitella hookeri*) down on the bottom – how it's surviving there I don't know.

Warwick Silvester, University of Waikato
Question for Chris or Noel. The rate of sedimentation in the lakes is obviously an issue, particularly with respect to the regeneration of nutrients from the bottom and the rate at which we get immobilization at the bottom of the lake. Have we any sort of a feel for what proportion of nutrients comes from the bottom of the lakes and what is coming in from the inlets? It seems to me a critical question for the functioning of the lakes.
Noel Burns, Lakes Consulting
A report completed for Rotorua District Council showed that in **one** major anoxic event, about 40% of the year's external loading of nitrogen and 60 - 70% of the year's loading of phosphorus came up within one anoxic event. Ray Hoare did a study of loading to the lake, including Ohau Channel in 1984. At that time the export via the Ohau Channel was about 40 - 50% of incoming material. Now since the sewage treatment plant has come into being there is less input, but all these anoxic events we're having means that there is much greater export because the material comes out of the sediment, goes into the waters and goes out down the Channel,. and we're now up to about 70% export of the incoming material. While we're suffering from anoxic events we are to some extent clarifying the top layers of the sediment and that could in a number of years lead to some long term beneficial effects.

? Supplementary question –
With these anoxic events, it comes down the Ohau Channel and into Lake Rotoiti. Does that affect the quality there?
Noel Burns
If the water coming out of Lake Rotorua is colder than Lake Rotoiti, which often is the case, Ohau Channel water slides under the water in the west end and along the bottom of the lake to the east end and in fact incorporates itself fully into Lake Rotoiti.
Max Gibbs
The hydrodynamic coupling between Lakes Rotorua and Rotoiti is quite important. In 1980 the underlying current into Rotoiti is estimated to have displaced 25% of the volume of Rotoiti out of the lake. The nitrogen from Rotorua will be carried into Lake Rotoiti. At the same time, the water from Rotorua is fully oxygenated as it goes through the Ohau Channel so this underflowing density current carries oxygen into the bottom of that lake (Rotoiti). While it does that, it reduces the period of time when you have an anerobic release of the nutrients from the sediment, so in reality the water from Lake Rotorua, although it contains a lot of nitrogen, is beneficial to Lake Rotoiti. In the past it was detrimental because it was putting a huge load of nitrogen and phosphorus into the bottom of the lake, which otherwise wouldn't have got there. The two lakes should be considered as one when considering the water flow budget into the lake. Most of the water, for at least nine months of the year, that comes from the western basin of Rotoiti and down the Kaituna River has actually come from the eastern basin of Rotoiti and been displaced by water from Rotorua moving underneath and moving up and pushing it out. This may be why we have seen cyanophyte blooms in the western basin of Rotoiti and at the extreme eastern end of Rotoiti – the water from Rotorua carrying the cyanophytes has moved through under the lake and emerged at the other end, 14 kms away.
Nick Miller - supplementary question
So are you saying that in the past we got a nett loss from the deep water inflow but now we're getting a nett gain from it?
Max Gibbs
Yes
Unidentified questioner
Can I extend that question – what effect do you think that the Ohau Channel is having on Okawa Bay if any at all, given that it is going down to the other end of the lake?
Max Gibbs
From hydrodynamic study done, there is no direct linkage back from water in Ohau Channel directly into Okawa Bay. There may have been groundwater leakage through at one point near the entrance but the overall flow from Okawa Bay is out into the western basin of Rotoiti so there must be large groundwater springs driving that flow.

Okawa Bay resident
Question for Willy Ripl. At a recent meeting at Takeke Marae someone commented that nutrient inflow into lakes is not so good but our sea is nutrient deficient. What relevance does that comment have to our situation here?
Professor Ripl
Locally this has relevance but there are a variety of lakes and as there is currently destruction of these lakes it is better to keep this stuff in place by better management. There will be probably be local achievements and in the medium term they will help to improve the lake. So I think it's very important to look not only at nitrogen and phosphorus but also flows of

other materials, otherwise it's very difficult using just nitrogen and phosphorus budgets to identify the total processes contolling these lakes.

Jim Stanton, Lake Rotoiti
In 1997 or 1998 NIWA reported after weed spraying in Okawa Bay there had been a complete collapse of exotic weed growth and we are now seeing a regrowth of native species. Can you comment on what effect extensive weed spraying over a number of years has had on the weed collapse? Since you suggest that very little of the inflow from Rotorua is going into Okawa Bay, can you say what inputs from other directions apart from septic tanks are going into Okawa Bay.
Ian Johnstone
We really don't know why weed beds suddenly collapse.
John Clayton, NIWA
The lake (Okawa Bay) is small and does not have very good water circulation, is highly eutrophic and is very marginal in terms of maintaining itself in a long term macrophyte state. Often in smaller lakes macrophytes may collapse, algal growth will appear, then after some period of time water may clarify. It depends on a combination of wind mix, nutrients etc. After a good summer plants might re-establish and help to clarify and then you may get two or three years of weeds and then they may collapse again. Stuart Mitchell, Otago University, has studied small lakes down there and found that. When you have small lakes, high nutrient enrichment, poor water circulation, shallow water bottoms, these result in unstable states with an alternation between high turbidity from algal blooms and macrophyte domination. There's nothing magical or mysterious about it – it's well proven and demonstrated.

Okawa Bay resident
What might happen if the outcome from everyone's septic tanks was reduced, including a relatively large hotel?
Max Gibbs
That's a loaded question. I don't know the volume of water used in the bay. If you say an average household, 4 people, uses a cubic metre of water a day, multiply that by the number of houses around the bay, you'll get the flow of water into the bay. Normally in a lake the volume of water associated with septic tank discharge will be significantly less than the groundwater flow into the bay. My understanding is that Okawa Bay is a hydrothermal explosion crater. It doesn't receive direct water from Ohau Channel except possibly through groundwater infiltration through the sandspit. The crater itself may well be receiving water from the Ruahine field behind it, certainly the high hills there are going to provide a catchment for groundwater. I would speculate that if you remove the nutrients in the septic tank effluent and the volume of water associated with it you're going to reduce the flushing by 'x' percent. If the nitrogen and the phosphorus in the septic tank effluent was what was driving the biomass of phytoplankton in the Bay, you may reduce the biomass in the Bay but you would not flush it out as quickly. We don't know the flushing rate relative to the natural groundwater flow through the system and we don't know whether, if it is the Ruahine field that is putting the water in, whether that has a high ammonia content which is a natural high nitrogen source normally associated with geothermal fluids. There would be a change, but whether beneficial or otherwise is difficult to say.

Okawa Bay resident
You said septic tank inflow might represent up to 10% of the water inflow but up to 50% of the inflow of nitrogen, phosphorus etc? Someone said that.
Max Gibbs
In a normal lake, say Lake Taupo, about 10% of the water flow is attributable to groundwater and the rest is from rivers. However, one study in 1978 by Peter John and Maurice Block estimated 46% of the water into Rotorua was groundwater. There are no streams flowing into Okawa Bay which means that all water except that from septic tanks flowing into Okawa Bay is ground water which typically has 10-100 times the concentration of nitrogen that you would find in a stream and you find this generally throughout New Zealand. If Rotorua is receiving 50% of its water supply from groundwater relative to streams this means the groundwater is contributing 5 to 50 times as much nitrogen and nutrients into the lake as the streams are. In Okawa Bay you have 100% groundwater so everything is coming in from that point.
Noel Burns
It seems pretty straightforward. You've got a lot of groundwater coming in, a lot of dwellings, a big hotel, and all the nutrients from those will go into a very small shallow bay with high concentrations coming in, with a narrow neck, not much exchange of water with the wider lake – so you have stagnated, enriched water sitting there and the result is obvious.
Chris Hendy
In general terms, in an area with very rapid infiltration because of the ignimbrite and the pumiceous, loosely packed material on top, I would query the groundwater discharge measurements quoted so far - they may be an even larger proportion. Nitrogen inputs relate to what happens on top of land. Traditionally mostly farmland, with livestock farming. Cows in particular produce 10 times as much nitrogen as people do. At 1-2 cows per acre, none of which goes through a sewerage system. A little nitrogen is retained but most goes through. Most of the phosphorus stays behind so there is mostly nitrogen loading. (*Inaudible discussion with questioner*) Fertiliser use on gardens and lawns also may well exceed the septic tank discharges.

Lindsay Brighouse, LWQS
Question to Rod Oliver. One of the aims of this symposium was to bring us into the real world as regards scientific research – no reflection on our scientific friends here. (*Laughter*) As an Australasian cousin could you tell us how you've negotiated your findings and research world-wide. Is there any particular place in the world that has been of special value?
Rod Oliver, Murray-Darling Freshwater Research Centre, Australia
Like all scientists, I try to keep abreast of the literature, but you come to realise that your own systems are very individual and although there are general principles, many of which have been expounded today, these systems have their own idiosyncrasies, which you must come to grips with. Often these idiosyncracies are the most important points about how to control your system. We've had a long discussion now about incremental nutrient supplies into a closed lagoon. You can't really argue about this source or that one – in reality you need to be pulling back as much as you possibly can. Those generalities are well known. In the specifics of the case, things like turnover time, fertiliser use etc. are very specific to your own location. You can't get this from other places. They are important and must be known. The scientists here are well up with world literature.

? Mark James, NIWA
Can I ask a question, which follows on from what Rod was saying. It's a question for Rowland Burdon. It's the first time I've heard that putting increased nitrogen into a lake may improve it. Which nutrient is limiting – I agree that N/P ratios can influence community structures etc. It concerns me that you used Northern Hemisphere bioassays rather than ones done on these lakes where we know that if you add nitrogen to the water of these lakes, for much of the year, the algal biomass will go up. Why were you using Schindler's data rather than some local work?
Rowland Burdon
I was citing Schindler's study as quoting what Mylechreest has done, but regardless of that I think it is very significant that the Wairua Arm of Lake Tarawera did develop an *Anabaena* bloom when it became acutely nitrogen-limited. The question of what is nitrogen-limited or phosphorus-limited is not a straightforward one but there are situations in which nitrogen is applied to water bodies in order to head off cyanobacterial blooms. Nitrate can play another role in serving to protect the bottom layers against anoxic events because the first stage of reduction is converting nitrate to ammonia and then the next stage is release of ammonia and the other anaerobic processes which lead to regeneration from the sediments. If you have afforestation and you have a temporary plummetting in the levels of nitrogen flowing into the lakes then you may need to carry out remedial applications of nitrate. That is relatively cheap compared to some other treatments trying to remove nitrogen.
? Mark James
It might pay to look at the bioassay work that has been done on these lakes, and it might be very dangerous to add nitrogen unless you know what the ramifications are – it might be a very dangerous thing to promote around here.
Rowland Burdon
Certainly, but there are situations where it may be dangerous to prescribe severe limitation of nitrogen. The other question is the bioassays – were they done in the laboratory.
?
They were done in the field.

Noel Burns
Question for Rod Oliver. I was very interested in that bioavailability test of yours. I think we've all mislead ourselves with the nutrient budgets that we've done because the major component in the phosphorus input is the particulates and often only 30% of the particulate material ever becomes bioavailable. There are bioavailability tests where you use a sodium hydroxide extractant which gives you similar amounts to what algae will use but in this area the allophane clays negate the possibility of using the sodium hydroxide test. You now have this test based on ferric hydroxide. How do you think it might work here?
Rod Oliver
I should say that the technique comes from soil science literature – it is used widely in soil science, along with other adsorption/desorption techniques for availability. If your allophane clays are supplying phosphorus by desorption techniques because it's in equilibrium with the dissolved phosphorus concentration, then this technique should be quite useful.

Remaining few questions lost due to technical problems with sound recording equipment.

AN INDEPENDENT VIEW OF THE SYMPOSIUM PAPERS

Professor Warwick Silvester, who is acting as a rapporteur for this symposium, offers a summary of the first day's papers and discussion.

When I was asked to be a rapporteur for this meeting I was actually at Ohakune building a house and enjoying myself and I thought "I'ld much rather stay building this house" then I thought quickly again "No, it's a very interesting topic." It's one which I've been marginally involved in for longer than I would like to think. I also thought that it is extraordinarily timely that this should all be happening again for reasons that will become clear in just a moment.

I somewhat reinterpreted my role as rapporteur in two ways. one to summarise mwhat went on but also to give my personal view of where I saw the gaps – I think Elizabeth (Miller) did mention that in her request to me - I hope she did because I'm going to do it any rate. I've chosen to cut the cake differently to the matrix for good reason - I don't think anyone should pre-empt the matrix from the general discussion so I've cut the cake in an entirely different way as I see the needs that are required in further study of the lakes.

The subtitle of the Symposium was "Research Needs of the Rotorua Lakes" and a very apt and timely title I believe. First I will present a summary of what went on yesterday and then I will identify what I saw as some of the gaps and requirements for further research in this area.

It is fascinating that everything goes in cycles – there are sunspot cycles, then there are nutrient cycles, land and water cycles and also cycles in the way in which we approach problems.

There is a need to identify what outcomes we are interested in. Are we trying to preserve the lakes as they are now? Are we trying to arrest a downward decline? Or are we trying to restore them?

Let's not think we have something unique here. Lakes like this have been doing this forever and humans have been interfering with lake cycles forever, and although being in a geothermal area adds to the interest and complexity, the principles on which lakes operate – the water cycle, the nutrient cycles – are well known. Experience from overseas is very important and we must take and work on the experience from elsewhere.

Lakes are sinks. Things go into lakes and tend to stay there, they all have inlets and outlets and the more we can model that the more we can appreciate the extent to which they are sinks, as opposed to flow channels. Lakes are very different to rivers in the sense that things go in and may or may not go out.

We must get more linear data on the way in which the lakes are changing with time. The temperature rise promotes a fascinating study, the way in which land and riparian management affects the lakes and the role of wetlands in controlling inputs of nutrients into the lakes are areas of continuing study. Macrophytes, the scourge of the previous decade, seems to have gone away somewhat and a couple of contrasting papers have been heard

regarding their relationship with algae and coarse fish. Food webs, sediment and its role in recycling nutrients, and the sewage disposal were all covered by speakers.

I would like to list what I see as some of the research needs for the Rotorua lakes:

- Firstly, cyanobacteria and other phytoplankton organisms and their interactions
- Insects and midges and their movement in the food chain
- Indicator values and the limitation that they have in the bio-availability
- Linear studies on bio assays to give us trends on the way in which water bodies are acting
- Legislation and land use management
- Modelling of inputs and outputs
- Climate and temperature, something fascinating is going on here
- Coarse fish
- Sediments, they provide very important keys to the way in which lakes are operating
- Public perception. The public must be kept informed and on side
- Identify what is known and put it together
- Process versus synthesis
- Identify the funding sources

A rather idiosyncratic view and a personal one.

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POSTER PRESENTATIONS

Note: We received more applications to present oral papers than the prgramme allowed time for. Accordingly, some papers were presented as posters.
Abstracts only are presented for some posters

MICROALGAE IN ROTORUA LAKES AND THERMAL AREAS

Vivienne Cassie Cooper
Landcare Research, Private Bag 3127, HAMILTON

During the late 1960s and early 1970s, seasonal variations in composition and abundance of over 200 planktonic microalgal taxa were studied. Diatoms predominated, with green algae, dinoflagellates and blue-green cyanobacteria all present at different times of year, in different quantities. No blue-green blooms were observed during the sampling period.

In the early 1980s, more than 220 thermally associated microalgae were investigated in and around hot pools, fumaroles and outflow streams. Temperature and pH were among crucial factors in determining the nature of communities of cyanobacteria, diatoms and green algae. More research is needed on microalgae in fossil and subfossil deposits, to aid in our understanding of past limnological events in the region.

A FACILITY FOR ADVANCING EFFLUENT IRRIGATION RESEARCH: A "WHOLE SYSTEM" APPROACH USING SMALL FOREST PLOTS

Gerty Gielen, Mark Tomer
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ABSTRACT

A new research facility for effluent irrigation has been constructed in Whakarewarewa Forest, Rotorua. The purpose of this facility is to improve our understanding of nutrient movement and fate in different soil types when irrigated with effluent at various rates and degrees of pre-treatment. This will assist optimisation of design and operation of forested, effluent irrigated, land treatment systems. The facility features 12 treatments including two soil types (volcanic and sandy soil), three effluent types (fresh water, a biological nutrient removal effluent (BNR) and a 'secondary' effluent - primary effluent mixed with BNR to produce a nutrient rich effluent), irrigated at three rates (0, 30 and 60 mm/week). The facility was constructed between October 1998 and March 2000, trees were established in August 1999 and irrigation commenced on 18 July 2000.

Previously, effluent irrigation research conducted by ***Forest Research*** and collaborators has concentrated on the response of a given land treatment system, observing changes in soil, soil water, ground water, and tree growth and nutrition (e.g., Gielen *et al.* 2000; McLay *et al.* 2000; Thorn *et al.* 2000; Tomer *et al.* 2000). These studies have provided valuable knowledge on how ecosystems respond to effluent irrigation. However, it is difficult to assess how altering design may impact on the performance of a scheme and some alterations can not be studied in an operational setting.

This poster presents some preliminary observations from the facility. Concentrations of chloride in the leachate from the sandy soil changed due to effluent irrigation within 2 months of irrigation. At this early stage, nutrient concentrations in the leachate from the volcanic soil did not change due to effluent or fresh water irrigation. Trees grown on the volcanic soil, before and after irrigation commenced, were taller than trees grown on the sandy soil. The experiment is at an early stage and any results reported are preliminary only. Future research will address in more detail the nutrient movement and fate in different soil types when irrigated with effluent at various rates and degrees of pre-treatment.

ACKNOWLEDGEMENTS

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A STRATEGY FOR THE LAKES OF THE ROTORUA DISTRICT

Amanda Hunt
Resource planner, Environment B·O·P, on behalf of:
Environment B·O·P, Rotorua District Council, Te Arawa Maori Trust Board

1. Introduction

The strategy for the lakes of the Rotorua district aims to achieve integrated management of a wide range of issues critical to the lakes' future. It recognises that in the past there has been a lack of coordination between agencies and groups with responsibilities and concerns for the lakes, and aims to bring these parties together to work towards solutions.

The strategy has been developed in partnership over a number of years of close liaison between Rotorua District Council, Environment B·O·P and Te Arawa Maori Trust Board. Public consultation was used to obtain feedback from stakeholder agencies and the community, and identified a range of concerns and interests. Many of these groups will continue to be actively involved in working towards solutions for these issues. The strategy was finalised in October 2000. Project teams are now being established to work on specific issues.

The strategy identifies the principal issues affecting the lakes. It aims to bring together the relevant experts, government and non-government agencies, iwi representatives and community groups needed to ensure integrated management of the lakes. The strategy assesses priorities, identifies costs and benefits and monitors achievements.

2. Background

Till now, a number of organisations, including Environment B·O·P, Rotorua District Council and Te Arawa Maori Trust Board, have been working independently towards improving the management of the lakes of the Rotorua district. This strategy will co-ordinate the actions of these three organisations, together with those of other interested parties, such as the Department of Conservation, residents' and ratepayers' associations and individual hapu, to ensure that all the actions that promote sustainable management of the lakes are consistent and complementary and that the most important matters are addressed first.

The strategy was developed between 1998 and 2000, overseen by the Lakes Management Strategy Working Group, comprising the Chairman of Te Arawa Maori Trust Board, Chairman of Environment B·O·P and Mayor of Rotorua District Council. The strategy builds on over 30 years of lake research, intensive public interest and the April 1998 publication entitled *Towards a Te Arawa Lakes Management Strategy.*

From the submissions and public consultation we have developed this community vision:

The lakes of the Rotorua district and their catchments are preserved and protected for the use and enjoyment of present and future generations, while recognising and providing for the traditional relationship of Te Arawa with their ancestral lakes.

2.1 Aim of the Strategy

The strategy is not a statutory document under the Resource Management Act or any other Act. The aim is rather to identify and address the problems arising from a lack of co-ordination between many interests in management of the lakes and then to consider how the law and those concerned can work together to solve those problems as effectively and efficiently as possible. The Lakes Management Strategy is seen as being an ongoing process with regular review and accountability for achieving key goals that will make a difference and protect the lakes.

The strategy document focuses on identifying problems, the options for resolving them, the costs and benefits involved, agreeing on the best solutions, putting in place monitoring and reporting procedures for accountability and ensuring regular reviews of the effectiveness of each solution. It is therefore important that for each task the costs involved in achieving a particular solution, and the effectiveness of that solution, are identified in order that the community can ensure that it gets the best value for ratepayer funds committed to the lakes

3. Challenges and Goals

The strategy begins by establishing an overall vision for the lakes as a whole and a series of goals to be met on the way to achieving that vision. It also sets goals for each lake individually. It examines urban development, rural development, recreation, water quality, water quantity, plant and animal pests, natural hazards and the traditional relationship of Te Arawa with the lakes. Some issues are common to all of the lakes, while others apply to only some of them.

The initial public discussion document entitled *Towards a Te Arawa Lakes Strategy* identified a significant range of concerns and interests in the long-term welfare of the lakes.

A comparison of the vision with the current status of the lakes and their catchments reveals the policy gap and the issues to be addressed. We have identified options to address those issues, our preferred options and our recommended actions to implement those options.

3.1 Challenges

From community consultation, submissions and discussions, we have identified these challenges:

- A need to establish or maintain high quality lake, river and stream water.
- A need to agree on the impacts of lake water pollution, including the effects of on-site effluent treatment, wildlife, stormwater run-off and pastoral land uses.
- A need to maintain the quality of the land, including reserved areas and landscapes.
- A need to acknowledge the effects of urban and rural development on lake water quality and to plan future urban and rural development in accordance with the community vision and the principles of sustainable management.

- A need to manage recreational uses of the lakes and waterways, and to maintain access to them.

- A need to recognise and provide for the traditional relationships of Te Arawa as tangata whenua with the lakes, as set out in the Resource Management Act and taking account of the principles of the Treaty of Waitangi.

- A need to identify the costs and benefits of meeting the community vision and to decide on timing, priorities and sources of funding.

3.2 Goals of the Strategy

The goals of the strategy are addressed in terms of protection, use, enjoyment and management.

Protection

- Address the causes of water pollution.
- Deal with pollution from septic tanks.
- Determine the extent of pollution from storm water.
- Define and refine water quality standards.
- Examine the status and future of the catchment scheme for establishing stock-fenced, vegetated buffers along the banks of lakes and rivers.
- Address plant and animal pest problems.
- Identify present and future reserve areas.

Use

- Establish an urban development policy.
- Establish a rural development policy.

Enjoyment

- Develop a recreation strategy.
- Monitor and report on recreational activities.
- Define required esplanade areas for lake access.

Management

- Establish in partnership with Te Arawa a co-management framework that achieves the best integrated management.

- Establish meaningful and binding working relationships with the iwi/hapu and their ancestral lakes.

4. A Way Forward

To achieve these goals, the necessary tasks have been grouped together into six projects (see Figure 1. More detail on each task appears in Figure 2).

These tasks and projects will be worked through by project teams consisting of representatives of Environment B·O·P, Te Arawa Maori Trust Board, Rotorua District Council, and relevant government agencies and experts. The first of these teams has already been established.

Individuals and organisations with skills, expertise and interest have been invited to identify and participate in those tasks to which they felt they could best contribute. These groups and individuals will also have opportunities for input.

The project teams will report regularly on their progress to the Lakes Strategy Working Group. The Lakes Strategy Working Group will continue to manage and report on the strategic process outlined in this strategy. There is also a requirement to report on progress annually to the Rotorua community.

If the key goals are achieved, the community will be significantly closer to achieving its vision for the lakes of the Rotorua district.

Reference

Te Arawa Maori Trust Board, Environment B·O·P, Rotorua District Council (August 2000). *Strategy for the Lakes of the Rotorua District*

Lakes Management Strategy Projects

STRATEGY	*PROJECTS*	*TASKS*
LAKES MANAGEMENT STRATEGY	Project 1 WATER QUALITY	Task 1 Agreement on Sources of Lake Water Quality Degradation Task 2 Lake Water Quality
	Project 2 RIPARIAN PROTECTION	Task 3 Riparian Protection
	Project 3 RESERVES & RECREATION	Task 4 Reserves and Recreation Working Party Task 5 Identifying Reserve Requirements Task 6 Reserve Management Maintenance Task 10 Recreation Use of Lakes Task 11 Report on Harbourmaster Activities Task 12 Issues of Public Access to Waterways
	Project 4 URBAN/RURAL GROWTH MANAGEMENT	Task 7 Sustainable Urban Growth Model Task 8 Rotorua Urban Growth Capacity Task 9 Sustainable Rural Growth Model
	Project 5 CO-MANAGEMENT	Task 13 Holistic Management of the Lakes Task 14 Existing Legislation Co-Management Options Task 15 Te Arawa Waitangi Tribunal Lakes Claim Task 16 Indigenous Peoples Co-Management Options from World - Wide Assessment
	Project 6 IWI LIAISON	Task 17 Iwi Management Plans Task 18 Lakes Based Tangata Whenua and Community Co-peration

It is recognised that many of these projects and tasks are interlinked, and there will be opportunities for cross-fertilisation between them. It is also recognised that work on many of these projects is already underway. The strategy will allow efforts to be coordinated, gaps identified and work progressed.

Figure 2. Strategy Tasks

Task No. 1:	Reach agreement on the relative sources of water quality degradation for each lake.
Task No. 2:	Refine the water quality standards applying to each lake.
Task No. 3:	To identify all river and lake margins where grazing is no longer allowed and all areas that are yet to be declared unavailable for grazing
Task No. 4:	Establish a working party representative of all reserved land interests for the purposes of creating and over view database of reserved areas, advocacy, planning, policy, and costs and benefits of efficient and effective management of existing and future reserved areas.
Task No. 5:	Identify the need for and importance of reserved areas.
Task No. 6:	Identify the threats to maintenance of reserve areas
Task No. 7:	Create a sustainable urban growth model for the Rotorua district.
Task No. 8:	Review of the Rotorua urban area to determine its capacity to sustain urban settlement and maintain a quality urban environment.
Task No. 9:	Create a sustainable rural development model for the Rotorua district.
Task No. 10:	Establish a single working group on recreational use of the lake, representing statutory and other interests including Eastern Fish and 'Game Council, Anglers' Association, Te Arawa Maori Trust Board, sporting and recreation groups, canoe, walking groups and any other interested parties.
Task No. 11:	Preparation and presentation of an annual report on the harbourmaster's activities, including operations, effectiveness of bylaws, safety, public relations, regulatory matters and costs.
Task No. 12:	Prepare a schedule identifying all areas required for the protection of public access to the margins of all streams, river, and lakes in the district including a report on the methods and costs of protection.
Task No. 13:	Maintain development of a holistic approach to management of the lakes of the Rotorua district and their catchments while at all times maintaining the mauri (life force) of the lakes and the natural balance required to safeguard the life supporting capacity of the water and the associated ecosystems.
Task No. 14:	Identify and adopt co-management options that are consistent with the existing legislation.
Task No. 15:	Support the resolution of the Arawa Waitangi Tribunal lakes claim and all necessary consequential legislative amendments.
Task No. 16:	Investigate co-management single purpose models with indigenous peoples around the world and adopt the model that best provides for Te Arawa's traditional relationship with their ancestral lakes.
Task No. 17:	Provide for the preparation of iwi management plans that clearly identify all those matters required to be addressed in terms of the RMA, including but not restricted to: • How best the lakes can be managed to provide for their social, economic and cultural wellbeing; • How to recognise and provide for their relationship with their ancestral lands, water, sites, waahi tapu, and other taonga; • How to have particular regard to their role as kaitiaki;

	• How to take into account the principles of the treaty of Waitangi; • How best to consult, communicate and report to tangata whenua.

Task No. 18: Encourage tangata whenua to establish and link their interests in specific lakes, as well as in the lakes in general, with lakeshore community interests.

POLLEN DISPERSAL AND NUTRIENT INPUT INTO AQUATIC ECOSYSTEMS

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Introduction

Plants pollinated by wind produce an abundance of pollen, which improves the chance of compatible pollen reaching receptive ovules. Only a small percentage of this abundance becomes involved in pollination events. A certain proportion must land on water, and this is the component of the pollen cloud that interests us.

New Zealand is a long narrow set of islands lying across a predominant westerly airflow. This generates the image of a cloud of pollen exiting the eastern shores of New Zealand. We are aiming to develop a model that will tell us where this pollen goes.

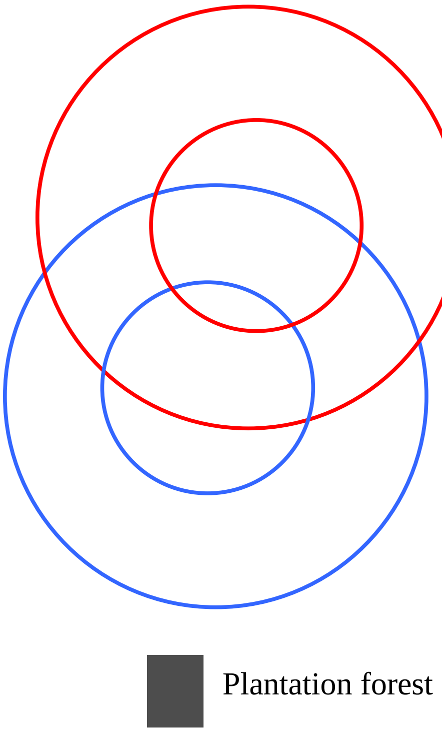
The pine forests to the east and north of Lake Taupo provide an opportunity to produce a small-scale model of aquatic pollen deposition. Plantation forests serve as a known source area of pollen - 91% from *Pinus radiata*.

There are currently 560,000 Ha of exotic forest in the Central North Island and almost all of these plantations are within 100km of both Taupo and Rotorua: both centres have about half of this area within 50km (Fig.1).

How much pollen do forests release?

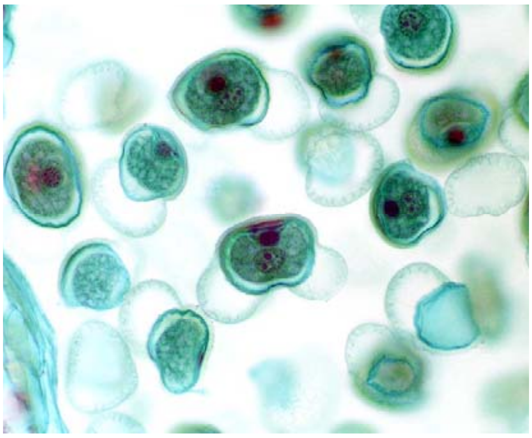
Versfeld and Donald (1991) calculated pollen produced by P. radiata *in the SW Cape of Southern Africa during a five year litterfall collection. The mean annual pollen production amounted to 28.30 kg/Ha. Will (1959) reported higher litter fall values in New Zealand, but did not report on pollen production.*

Because of this apparent discrepancy, an estimate of pollen production under New Zealand conditions is planned. The estimate will be made by counting male cones per tassel and tassels per tree. Combining a mass ratio of pollen to strobili with the count of strobili per tree, a record of trees per hectare (management regime) and hectares planted should give an accurate estimation of the amount of pollen produced by any forest source. Tree age and clone planted may also be significant.



After http://insights.nzforestry.co.nz /forestry%5Fregions%5Fcni.asp#

Figure 1. Exotic forests in the Central North Island. Circles indicate 50 and 100km distance from Taupo and Rotorua



http://www.wisc.edu/botit/img/bot/130/Gymnosperms/Coniferophyta%20Images/Pinus%20Images/Microsporangiate/

Figure 2. A: Cluster of male pine strobili. **B**: Microscopic view of pine pollen.

How much pollen reaches the lake?

Work done at Massey University researching New Zealand aero-allergens sampled pine pollen content of air over a period of 3 years. Table 1 shows the basic results of this sampling.

In August 2000 an abandoned sample at Taupo gave 30.2 grains/m^3 after 15 hours. This suggests that pollen levels reaching the lake could be consistently higher than those measured in Palmerston North, due to the large areas of forest planting near Taupo. In addition to the pollen deposited directly on the waters of Lake Taupo, a number of rivers flowing into the lake pass through pine plantations, and probably add to the total pollen input.

Sampling is planned for the 2001 season at Manawatu forestry sites and again at Taupo. This data will serve two roles: firstly to illuminate the amount of pollen reaching Lake Taupo and secondly, to supply information regarding pollen flight dynamics that can be used to create the model of pollen flight and destination from known sources for the marine component of the main study.

Table 1. Characteristics of the Pinus pollen season at Palmerston North

	1988	***1989***	***1990***
Starting date	*12/7/88*	*3/7/89*	*10/8/90*
Finishing date	*10/9/88*	*11/9/89*	*25/9/90*
Duration (days)	*62*	*40*	*47*
Total count	*1191*	*840*	*1614*
Maximum daily count (grain m^{-3})	*165*	*125*	*127*
#days count >10	*30*	*17*	*23*
#days count >100	*1*	*1*	*5*

after Fountain & Cornford (1991)

Figure 3: Pine pollen on water at AC Baths (Taupo) August 2000.

How much nutrient does pollen contribute to the lake?
Doskey and Ugoagwu (1989) report on atmospheric deposition of macronutrients into Crystal Lake, an oligotrophic lake in Northern Wisconsin. These workers measured inputs by Pinus *pollen and by wet deposition (precipitation).*

Table 2: Macronutrient fluxes by Pinus pollen deposition and atmospheric deposition for the Northern Wisconsin region.

Macronutrient	***Flux (mg/ m^2 /annum)***		
	Pinus pollen dry deposition		*Wet deposition*
	Total	*Water extractable*	
Carbon	*180-4000*	*-*	*-*
Nitrogen	*7.0-160*	*0.019-0.42**	*130-230**
Phosphorus	*1.0-23*	*0.56-13#*	*4.1#*
Sulphur	*0.84-19*	*0.49-11+*	*290-440+*
Potassium	*-*	*1.6-36*	*12019*

* NO_3^- # PO_4^{-3} + SO_4^{-2} after Doskey and Ugoagwu (1989)

Doskey and Ugoagwu report that the annual contribution of NO_3^- and SO_4^{-2} by pine pollen is insignificant next to anthropogenic sources of these substances. However, their data show that pollen may contribute about 45% and 20% of the external input of total P and K^+, respectively, to Crystal Lake and a significant proportion of organic carbon. They conclude that the brief input of pine pollen, for P especially, is likely to have a significant impact on the lake's nutrient dynamics, particularly with respect to phytoplankton growth.

A determination of the nutrient composition of P.radiata *pollen will be important in deciding the significance of the amount of pollen arriving at Lake Taupo. The behaviour of deposited pollen may also be a factor in establishing the role of pollen in lake nutrient levels. If the pollen sinks quickly, more nutrient may enter the water than if the pollen remains afloat and collects on the shore.*

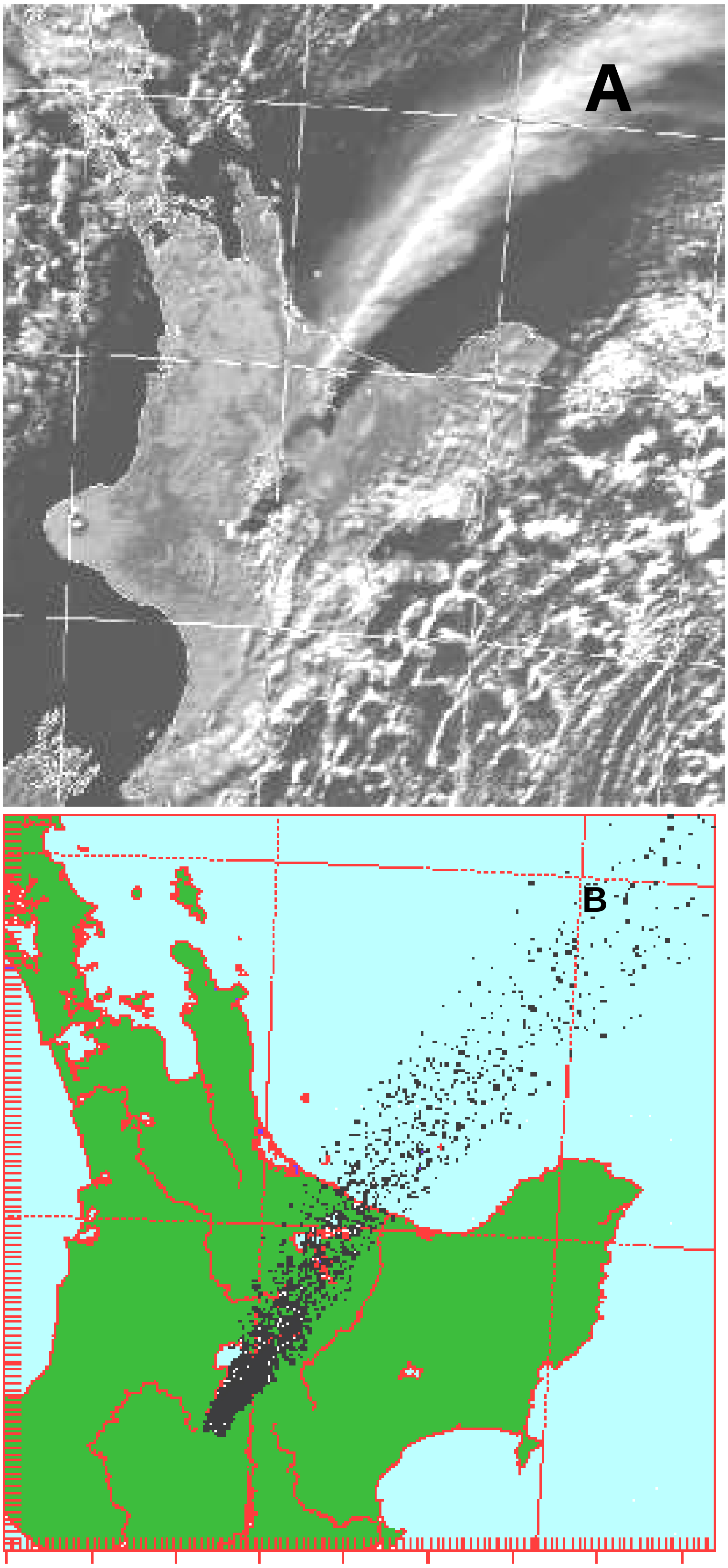


Figure 4. A: Image of Ruapehu eruption June 1995. B: HYPACT model of ash cloud

How significant is pollen nutrient to local food chains?

Pollen grains have an outer wall made of a material called sporopollenin. The exact structure of this material is not known, but it is very resistant to decomposition. This may make it possible to track the pathway of pollen grains through food chains, by looking at the contents of animals' stomachs. This will indicate if pollen is a direct contributor to animals in food chains.

Otherwise, pollen-sourced nutrients would be accelerating primary production (plant and algal growth). Currently, nitrogen levels in Lake Taupo are causing great concern (www.ew.govt.nz). The extra nitrogen is thought to be fuelling algal growth, which is depressing water clarity and has the potential to cause eutrophication if left unchecked. There are implications for aesthetics and recreation (and the business consequences of these) as well as health issues.

Conclusions

There are indications that pollen, and pollen from pine plantations in particular, may be a significant source of nutrient in aquatic ecosystems that are close to plantations. As more forests are planted, any impact can only increase and in areas already experiencing problems (such as Lake Rotorua) an increasing supply of nutrients will exacerbate current conditions. Although pine pollen is only an input of short duration, lasting about 2 months, the boost to primary production that may result from this input could be significant in terms of water clarity, amount of organic matter and oxygen depletion.

Research is planned to establish the significance of pine pollen inputs. If pine pollen is shown to have an important affect on lake nutrient levels, issues of control will then be raised. Perhaps the breeding of sterile trees that do not produce pollen would provide a viable solution to aerial deposition. There may also be a production spin-off if trees are not directing resources into reproductive activity.

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Forests and People/ Forestry in the Regions/ Central North Island
http://insights.nzforestry.co.nz

ROTORUA LAKES – SOME CONCERNS AND QUESTIONS

Nick Miller

LakesWater Quality Society, 91 Te Akau Road, R D 4, ROTORUA

The organising of this Symposium has been prompted by local concern about the state of a number of the Rotorua Lakes. During initial discussions, a number of questions have been formulated and these are outlined in this poster. This list is by no means exhaustive. A few references are attached. Answers may already exist for some of these questions – if so, we would like to know about them.

- Are lakes Rotorua and Rotoiti 'improving' or not? Opinions seem to vary.
- "The growth of bloom-forming cyanobacteria (blue-green algae, cyanophytes) in lakes and reservoirs has wide-ranging ecological and water management implications, but continues to be a subject of limnological controversy."[i] Is this still the case today?
- Sub-acute toxicity from cyanobacterial blooms – is it occurring?
- What contribution does L Rotorua make to the cyanobacterial problem in L Rotoiti?
- If L Rotorua could be prevented from stratifying (eg by the use of bubble plumes) what effects on Rotoiti? How much energy would be required and when?
- Does the oxygenating effect of the Ohau Channel underflow outweigh the nutrient load that it introduces to L Rotoiti? If not, what could be done?
- How important is the shallow area to the west of the Ohau Channel intake ?
- Climate change – what effects on the Ohau Channel underflow?
- Aquatic macrophytes – how to achieve diverse and adequate populations?
- What is the risk of macrophyte collapse in Rotorua and/or Rotoiti and other lakes in the district?
- What are the environmental effects of conifer and eucalypt forestry in the Rotorua Lakes watersheds? Has anyone really looked? Short-rotation eucalyptus plantings seem to be an environmental 'hot potato' overseas.
- The Mylchreest hypothesis – has it come to fruition? Time for a revisit?
- Cyanobacterial dominance – affected by macro and micronutrients in water. It is difficult to remove them from water – but is there anything we can add to affect algal dominance patterns?
- Arsenic may act as a phosphorus analogue in the environment – is it also released from sediments when the hypolimnion goes anoxic?
- Which lakes in the district would be suitable candidates for restoration trials?

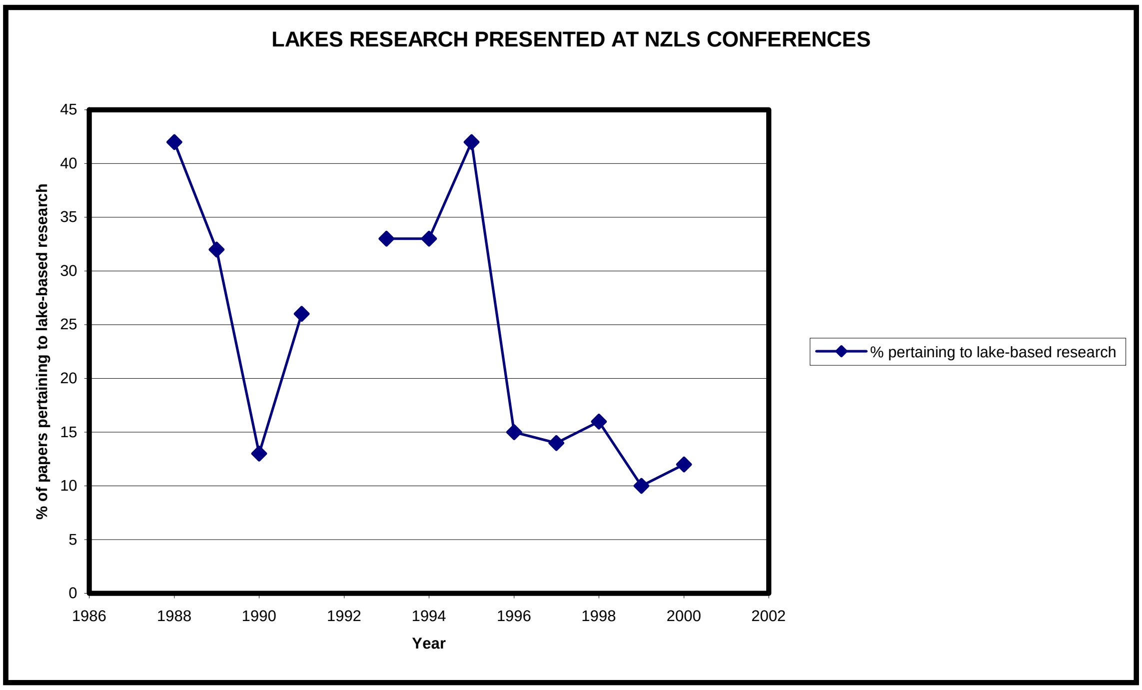
In addition an analysis of data collected from New Zealand Limnological Society Conferences over a number of years is presented. The variations in the percent of presentations pertaining to research on lakes is examined. (Below)

RESEARCH ON LAKES IN NEW ZEALAND
IS IT GETTING SUFFICIENT ATTENTION?

This data is taken from the abstracts of papers delivered at annual conferences of the New Zealand Limnological Society, as published in the annual *Newsletter* of the NZLS.

Year	Number of papers & posters	Number pertaining to lake-based research	% pertaining to lake-based research
1988	12	5	**42**
1989	41	13	**32**
1990	30	4	**13**
1991	35	9	**26**
1992	no data		
1993	34	11	**33**
1994	42	14	**33**
1995	41	17	**42**
1996	55	8	**15**
1997	71	10	**14**
1998	81	13	**16**
1999	122*	12*	**10**
2000	81	10	**12**

*Dual conference with Australians – NZ based papers only



EXPLORING THE LINKS BETWEEN LAKE ROTORUA'S TROUT FISHERY AND ALGAL COMMUNITIES

Rob Pitkethley
Fish and Game New Zealand, Eastern Region.

Abstract

Lake Rotorua attracts an estimated 41,000 angler visits per annum and is the third most popular lake fishery in New Zealand. Fish and Game New Zealand has been conducting random creel surveys of summer anglers on Rotorua since the 1997-98 summer. From the 1997-98 summer to the 1998-99 summer a dramatic decline in the rainbow trout fishery was detected. The average size of trout retained dropped from 488mm to 468mm and angler catch rates fell from 0.50 to 0.29 fish per hour. Angler satisfaction dropped from 95% in 1997-98 to 82% in 1998-99. An investigation of algal monitoring data shows the excellent fishery during 1997-98 followed a spring diatom *Cyclotella spp.* bloom, while the poor fishery during 1998-99 followed a *Kirchneriella lunaris* bloom. The possible links between the trout fishery and algal communities are discussed with the need for research into trophic interactions in Lake Rotorua.

Introduction

Fish and Game New Zealand is responsible for the management of the Lake Rotorua trout fishery which attracts an estimated 41,000 (95% C.I ± 16%) angler visits per annum (Unwin and Brown 1999). The Lake Rotorua trout fishery is a self sustaining fishery based mainly around summer angling for rainbow trout (*Oncorhynchus mykiss*). Trolling lures from boats is the most popular fishing method, although stream mouth fly-fishing and winter stream fishing contribute to the total angling effort. There is also a small amount of angler effort targeting large brown trout (*Salmo trutta*) in the lake margins and streams.

Periodic surveys of the angling on Lake Rotorua have been undertaken by past fishery managers but regular monitoring was only initiated in the 1997-98 summer. A creel survey of anglers fishing the lake over the 1978-79-80 seasons showed the average catch rate was 0.47 fish per hour and the average length of fish caught was 462mm (New Zealand Wildlife Service unpublished records). A postal survey of Rotorua Fishing District anglers after the 1986-87 season (Shaw, 1992) estimated that Lake Rotorua catch rates averaged 0.23 fish per hour although there were no estimates of the average size of the fish caught. In the 1997-98 summer Fish and Game New Zealand initiated a summer creel survey of anglers fishing on Lake Rotorua as part of a priority lake angler monitoring programme. These creel surveys have continued each summer.

Methods

Fish and Game New Zealand conducts roving creel surveys of anglers fishing Lake Rotorua from 1 November until 30 April each summer. The survey period is stratified into high use (weekend and holiday) and low use (mid week) periods and ten randomly

picked survey days are selected within each stratum. During sampling periods Fish and Game staff circle the lake in boats in a randomly selected direction and interview all anglers fishing from boats as they go. Angling also occurs at selected stream mouth sites, generally after dark, and these are also surveyed on a number of randomly selected days through the December to March period. Stream mouth fishing is primarily based around wading anglers and interviews are conducted on shore at the completion of fishing trips.

Angler interviews produce information on fishing effort, methods, catch and angler opinions (Figure 1). Fish retained by anglers are measured and weighed and anglers are asked a series of questions on their opinions of the fishery. Anglers are asked to rate the fishery compared to previous years and how satisfied they are with their current summer's fishing. Anglers are also asked what, if anything, detracts from their current summer's fishing on Lake Rotorua.

Figure 1. Data form for Fish and Game summer creel survey

Licence #__________ Hours fished _______ Method used __________

Completed trip ? ☐ Guided ? ☐ How many days a season do you fish this lake _____

Fish Kept ______ USRT _________ OSRT _________

Length (mm)	Weight (kg)	Maturity	Spp/Sex	Clips/tags	Other

Comparing this summer on this lake to the last three summers, how do you rate....

	excellent	good	average	poor	terrible	Don't know
Your CPUE....	5	4	3	2	1	☐
Size / condition of fish	5	4	3	2	1	☐

Does anything detract from your fishing experience ?_______________________

What is your current level of satisfaction with this summers fishing on this lake

Highly satisfied	satisfied	dissatisfied	strongly dissatisfied	don't know
4	3	2	1	

Catch rates were calculated from the number of fish kept plus the number of legal size fish returned (>350mm) divided by the hours fishing. Average catch rates are calculated from all anglers' individual catch rates, as this has been shown to be the best estimator when incomplete fishing trips are considered and when the objective is to produce a measure of angler satisfaction (Jones et. al. 1995). Anglers were asked to rate their opinions on the fishery on a 1 to 5 scale while angler satisfaction was

assessed on a 1 to 4 scale (Table 1). Angler detractions were grouped into simple categories by similar answer types.

Table 1. Rating scales used for assessing angler opinions.

Opinion \ Rating	**1**	**2**	**3**	**4**	**5**
Catch rate and fish size	Terrible	Poor	Average	Good	Excellent
Satisfaction	Strongly dissatisfied	Dissatisfied	Satisfied	Highly satisfied	

Creel survey data collected is entered into an MS® Access database and manipulated by MS® Excel. Statistical analysis is performed using SPSS SigmaStat® software and graphed with SPSS SigmaPlot©.

In addition to creel surveys a mark recapture programme known as "Datawatch" monitors annual growth of trout in Lake Rotorua. The datawatch programme involves releasing 1000 tagged fish annually into Lake Rotorua and anglers are encouraged to return details on fish lengths and weights by a reward scheme. This programme allows continual monitoring of the growth of age classes as they are caught over their life in the lake. Fish lengths are plotted at their time of recapture (days after release) and a Von Bertalanffy growth curve of the form $y = a(1 - e^{-bx})$ is fitted (Ricker 1975).

The Bay of Plenty Regional Council (EBOP) is responsible for algal monitoring in the Rotorua Lakes as part of their Regional Lakes Monitoring Network. The current algal monitoring programme has been developed since 1993 with changes in frequency and the intensity of sampling. Currently samples are taken from two sites monthly during the October to June period, and every two months during the winter months. Water chemistry information and samples are also collected with algal samples. A description of algal and water chemistry collection and analysis techniques is provided by Wilding (2000).

Results

Creel surveys of anglers fishing on Lake Rotorua showed significant changes in the fishery between the 1997-98 and 1998-99 summer seasons. The average angler catch rates (Figure 2) fell from 0.50 fish per hour to 0.29 fish per hour ($P = 0.03$). The average length of the fish retained (Figure 3) also decreased from 488mm to 468mm ($P = 0.29$) while average weights decreased significantly from 1.60 kg to 1.21 kg ($P = 0.04$).

Figure 2. Average catch rates of Lake Rotorua summer anglers.

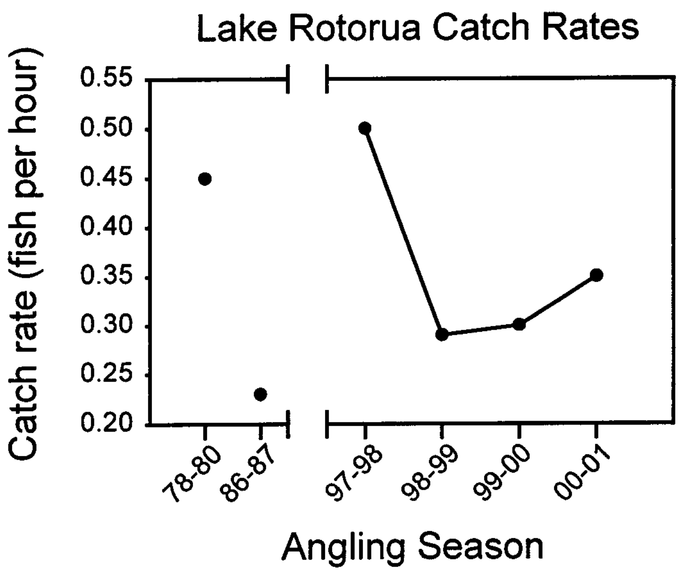
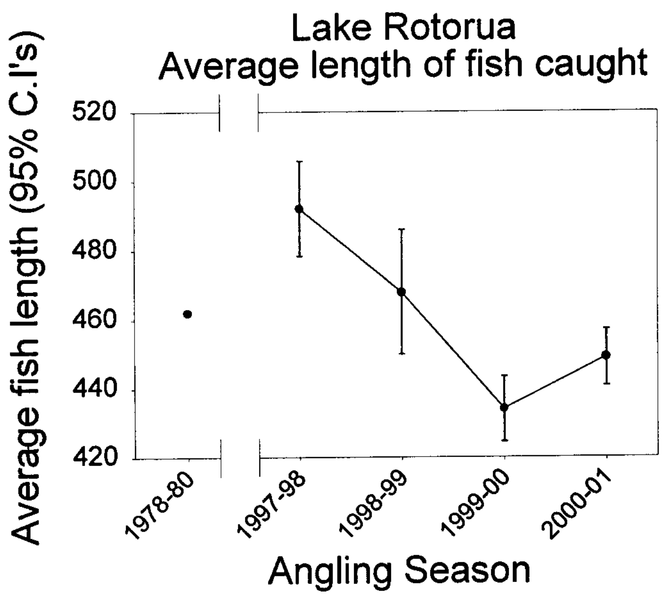


Figure 3. Average size of fish caught by Lake Rotorua summer anglers.



Anglers' perceptions on their catch rates and the size of the fish they were catching also showed a significant decline from the 1997-98 season to the 1998-99 season (Figure 4). The average rating given by anglers for their catch rate fell from 3.69 to 2.67 ($P<0.001$) while their average rating for fish size fell from 3.89 to 2.84 ($P<0.001$). The average rating value given for angler satisfaction fell from 3.32 to 2.84 ($P<0.001$). The number of anglers who said they were satisfied or highly satisfied with their fishing experience can also be used to express angler satisfaction and this fell from 95% in 1997-98 to 82% in 1998-99 (Figure 5).

Figure 4. Average angler perception on their catch rate and size of fish caught and satisfaction from Lake Rotorua summer creel surveys.

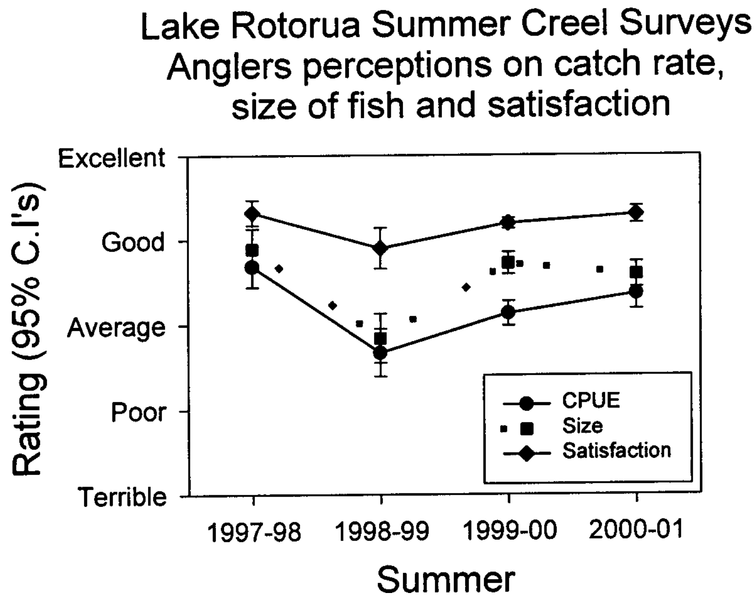
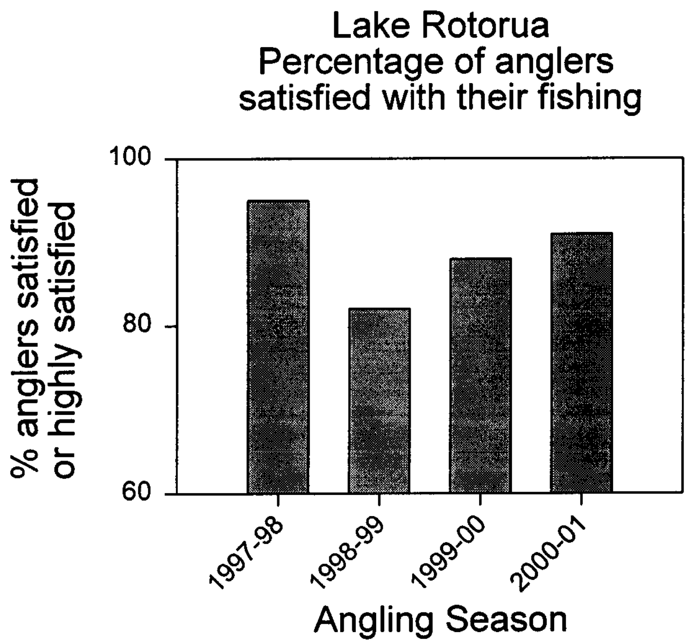


Figure five

Figure 5. Percentage of Lake Rotorua summer anglers satisfied or highly satisfied with their summers fishing.

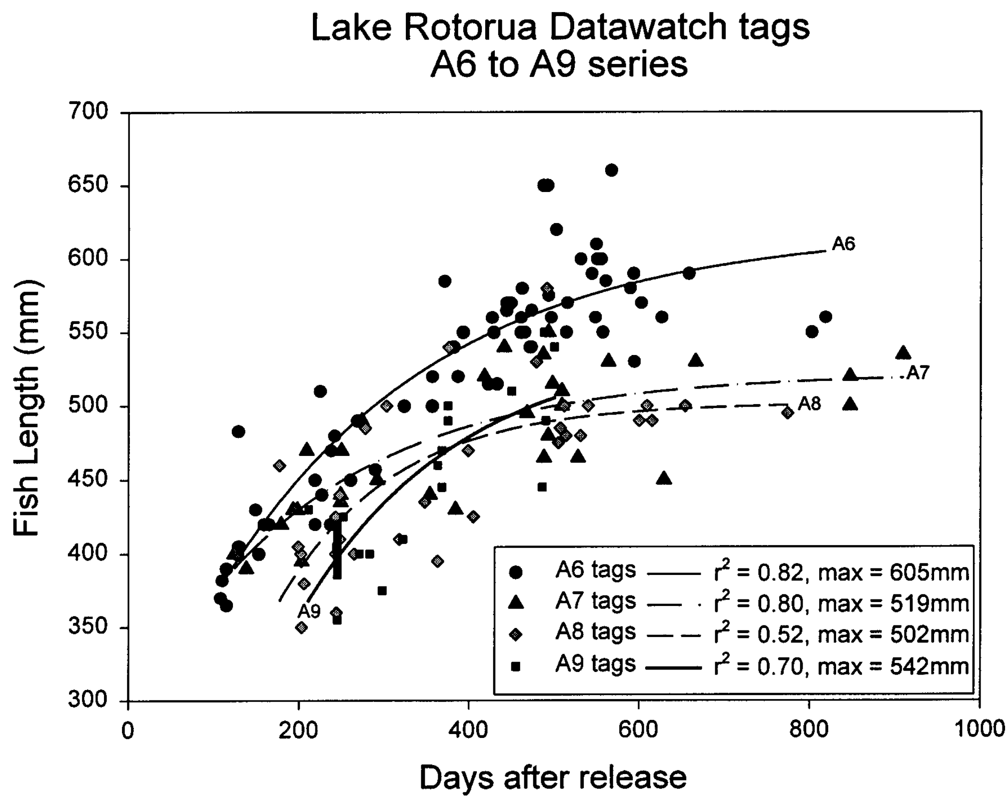


Since the 1998-99 season, fishing conditions appear to have reached the bottom of a trough and are now showing signs of improvement. The measured fish size in 1999-00 was lower than that of 1998-99, yet anglers perceived a significant improvement in fish size in the later summer. An analysis of the data showed that the 1999-00 catch contained a large number of well conditioned small fish compared to the previous summer. It has been noted that anglers often group size and condition together when considering fish quality so this may in part explain this discrepancy. Anglers also perceived a marked increase in catch rates while little change was measured from the survey data. With the perceived improvements in catch rate and fish size since 1998-99 we have seen a corresponding increase in the number of anglers who are either satisfied or highly satisfied with their fishing on Lake Rotorua.

Analysis of the datawatch tag information over the 1997-2000 period has also shown some marked changes in growth rates of hatchery released tagged fish in Lake Rotorua. Figure 6 shows growth curves for the tags that have been in the lake over the

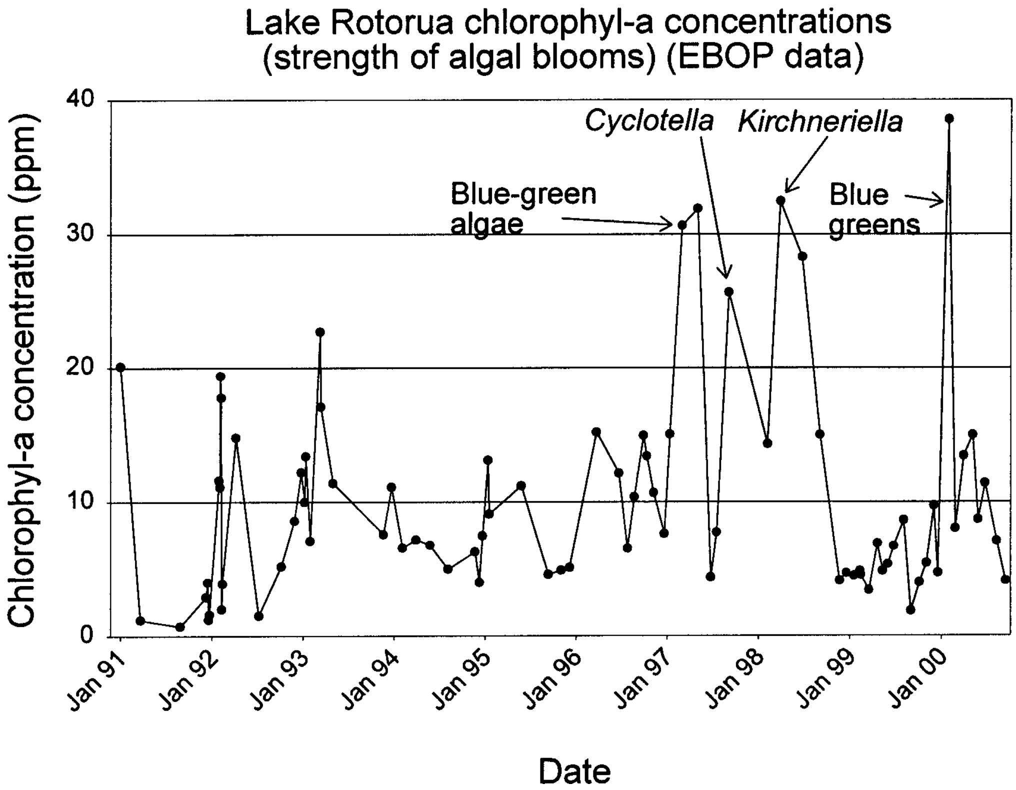
period of the creel survey monitoring. Tagged fish are released in September at a modal size of 180mm and generally start contributing to the fishery (>350mm) late in their first summer in the lake. The A6 tagged trout (released September 1996) showed high growth rates throughout their first and second year in the lake (1996-97 summer and 1997-98 summer). The A7 group appeared to reach legal size relatively early showing a strong sub legal sized growth rate, but then growth rate slowed considerably compared to the A6 group from the year before. The 1998 A8 tagged group arrived in the legal catch approximately 80 days after the A6 and A7 groups, and like the A7 group their growth was relatively poor compared to the A6 tags. The 1999 A9 released tags made a late start into the fishery but at this early stage are showing much higher growth rates than we have seen from the previous two years.

Figure 6. Lake Rotorua Datawatch tags from 1996 to 2000.



Chlorophyll a and algal monitoring by EBOP has shown a number of marked changes in algal concentrations and species composition over the late 1990's. Figure 7 shows that there have been major chlorophyll a peaks in February1997, August-September 1997, March-August 1998 and January 2000. These peaks have been principally due to algal blooms of Cyanobacta (blue-green algae), *Cyclotella spp, Kirchneriella lunaris* and Cyanobacta respectively (Wilding 2000).

Figure 7. EBOP Chlorophyll a monitoring.



The marked changes in the Lake Rotorua trout fishery appear to follow major changes in the dominant algal taxa present in the lake. From the limited historic records it appears that the angling over the 1997-98 summer was very good and this was endorsed by anecdotal comments from anglers. This time of large trout and high catch rates followed a period of high nutrient input, clear water and a *Cyclotella* algae bloom. *Cyclotella* are diatomaceous algae, and diatoms are known to be a major food source for larval smelt (McDowall 1990). Smelt spawn in Lake Rotorua in the early spring and with eggs hatching 8-10 days after spawning the juvenile smelt would be well timed to take advantage of a *Cyclotella* bloom. *Cyclotella* is also known to be an excellent algal food group for cladoceran zooplankton (J. D. Green, M. A. Chapman pers. comm.) which are in turn important for adult smelt. Spring zooplankton numbers are known to rise rapidly between August and October in Rotorua lakes (Chapman et. al. 1975) and the abundance of zooplankton after the *Cyclotella* bloom would also provide an excellent food supply for smelt in Lake Rotorua. Unfortunately little research has been conducted on the dynamics between algae, zooplankton and smelt, so it is not possible to conclusively link *Cyclotella* blooms to increased smelt production. Anecdotal reports from anglers stated that smelt numbers appeared to be

high during the 1997-98 spring but there is no data to verify this. Despite the lack of information on zooplankton and smelt, considering the timing of these events a spring *Cyclotella* bloom would have been very beneficial to smelt production from spring spawning, and this may very likely have been a major factor contributing to the success of the 1997-98 summer fishing season.

In the latter part of the 1997-98 summer the foam causing green alga *Kirchneriella lunaris* bloomed in the lake and this had a variety of direct effects. The decomposition of *Kirchneriella* resulted in much of Lake Rotorua becoming covered with a layer of unpleasant foam, and water clarity was reduced and stayed relatively low for an extended period. *Kirchneriella* is a relatively large alga that exists in colonies covered by a thick gelatinous sheath. Large sticky algae are difficult for zooplankton to feed on, and it is possible that *Kirchneriella* may even have inhibited the filtering nature of zooplankton feeding. Although research has not been done to investigate how this alga may have affected higher levels of the food chain, it is likely that the combined physical and trophic effects of *Kirchneriella* were detrimental to zooplankton communities and smelt population abundance. The decline in zooplankton and smelt abundance would lead to a decline in trout populations and therefore the *Kirchneriella* bloom is highly likely to have negatively effected trout populations.

The *Kirchneriella* bloom persisted on Lake Rotorua well into the 1998-99 summer and this is likely to have continued to suppress higher levels of productivity in Lake Rotorua. Chlorophyll a monitoring since the *Kirchneriella* bloom has indicated Lake Rotorua has had a relatively stable algal community despite some marked intense peaks of blue-green algae blooms during January 2000. This blue-green bloom was strongly noted by Rotorua anglers and 22% of anglers surveyed that year said the algal bloom detracted from their fishing experience. Surveys from the earlier and later summers shows that all detractions combined have never exceeded 20%.

Angler survey data from the 1999-00 summer showed a strong year class of young trout in the catch although the datawatch tags did not show trout growth was improving until the late summer-autumn period of 2000. The most recent data from the ongoing 2000-01 summer survey shows that catch rates and fish size is higher than the last two years so the fishery appears to be showing signs of recovery.

It looks as though this previously unusual sequence of events has had a complex effect on trout growth in Lake Rotorua. EBOP had surmised that the main driving factor for what has happened in the lake over the past few years has been due to extended calm and often warm conditions resulting in massive nutrient releases from lake sediments. The primary producers that have generally taken advantage of these conditions (blue-green algae and foam producing green algae) are not likely to be very good food for zooplankton, which in turn provide food for smelt. If smelt suffer due to a lack of food, trout are also going to suffer with poor growth and survival. However, if these nutrient pulses result in blooms of more favourable algae (eg *Cyclotella*) it is possible that beneficial effects on smelt, and in turn trout will be seen.

The sudden and dramatic changes in algae populations in Lake Rotorua appear to be capable of affecting higher trophic levels such as zooplankton, smelt and trout. The sequences of events that give rise to positive or negative changes to fishing success are complex and unclear. Obviously there is a need for research into dynamics between trout, smelt, zooplankton and algal communities. A more thorough understanding of these interactions will enable us to evaluate how changes in water quality effect fishing. Until these questions are answered Fish and Game New Zealand needs to watch for and evaluate similar patterns in Lake Rotorua so we can more accurately predict the likely effects on the trout fishery.

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IRON TREATMENT OF LAKE GROSS-GLIENICKER (GERMANY). A SUCCESSFUL RESTORATION

Klaus-Dieter Wolter & Wilhelm Ripl
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Lake Gross-Glienicker is situated in the Federal republic of Germany. It has surface area of 0.67 km^2, a mean depth of 6.5 m and a catchment area of approximately 20 km^2. The catchment area is mainly used for farming, forestry and settlements. Until the 1960's the lake had high water quality. Since the 1970's untreated sewage from military barracks was discharged into the lake. Secchi depth decreased to below 0.3 m and submerged vegetation disappeared. Hypolimnetic oxygen depletion occurred, with subsequent temporary smells of hydrogen sulphide and death of fish.

In 1992 a restoration concept for Lake Gross-Glienicker with the aim of improvement of water quality was developed by the authors. For this task experience from Sweden and restoration projects in Germany were used. Until 1992 partial dredging, hypolimnetic aeration as well as pumping water through a mobile phosphorus elimination plant were discusses as restoration measures. Because of the size of the lake, the low phosphorus binding capacity of the sediments and economical reasons these measures were regarded as ineffective.

A sediment/water treatment for in-lake phosphorus precipitation and increasing iron concentration in sediments was planned to improve water quality significantly. The treatment was carried out in autumn and winter 1992/1993 with 500g of Fe per square metre lake area. To decrease the formation of sulphide in the hypolimnion and in the iron-enriched sediments, iron treatment was combined with hypolimnetic aeration, which is operated during summer stratification.

After iron treatment total phosphorus concentration of lake water reached a minimum of 12 µg/l P (volume weighted mean) by co-precipitation with iron in mid March 1993. Since that time total phosphorus stabilised at a mean value of 38 µg/l P. Phytoplankton mass decreased markedly, and Secchi depth after treatment was practically always more than 2 m. Simultaneously, mean nitrogen concentrations decreased from 2.1 to less than 1.3 mg/l N, by coupled nitrification/denitrification at the sediment-water interface. After iron treatment the former vegetation-free littoral zones were slowly recolonised by *Elodea canadensis*, *Zannichellia* sp. and *Myriophyllum* sp.

In 1998, it was possible to reduce aeration. A further improvement of lake functionality can be expected along with the development of submersed macrophytes.

INVOLVING THE PUBLIC IN ENVIRONMENTAL MANAGEMENT OF LAKE TAUPO

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[1] School of Environmental and Marine Sciences, University of Auckland
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[3] Environment Waikato

Together with ecological concerns, community concerns are now recognised as being valuable components of environmental risk assessments[1]. Inclusion of community concerns can serve to provide for a sense of public ownership of an investigation by encouraging the community to participate in the setting of research objectives; to add legitimacy to management decisions; and to help determine intangible and often unique amenity values of a region.

Lake Taupo is one of the jewels in the New Zealand crown. Its water quality is currently considered to be excellent, with low nutrient concentrations, low levels of algae and high water clarity. However, on the basis of long-term monitoring, Environment Waikato has recently suggested that water quality in Lake Taupo may have deteriorated over the past 20 years and that the high quality status of the lake may be under threat from increased fluxes of nitrogen due to changes in land use in the catchment[2,3,4].

There have been several local and regional initiatives to protect Lake Taupo. At the local level, the need to protect Lake Taupo and its surrounds has been recognised by the Taupo community through the formation of the Lakes and Waterways Action Group, a volunteer citizens group formed in the spirit of the Agenda 21 principles of the Rio Earth Summit. A further local initiative has been the Lake Taupo Accord: an agreement entered into voluntarily by a number of signatory parties to protect and improve values of the lake identified as being important by the community at large. At the regional level, the regional council (Environment Waikato) have initiated a process that will result in a variation to the regional plan, specifically addressing the concerns in the Taupo catchment by seeking to reduce the quantity of nitrogen entering the lake[3]. Methods under consideration include voluntary changes to land use practices, financial incentives and regulation.

There have been many opportunities for public participation in these local and regional initiatives. However, the extent to which public participation in these processes has been effective in representing the full range of community views is not known. The aim of this study was to determine the attitudes, views and perceptions of Taupo District residents towards environmental issues relating specifically to Lake Taupo, for input into future environmental management of the lake. A subsidiary aim was to evaluate the level of awareness of the Lake Taupo Accord by the local community.

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2 Environment Waikato (November 1999) Lake Taupo: a national treasure. Water Fact Sheet Series 8.
3 Environment Waikato (October 2000) Issues and options for managing water quality in Lake Taupo.
4 Environment Waikato (Spring 2000) Protecting our lake. Envirocare Issue 25.

AN ELISA WITH BROAD SPECIFICITY FOR CYANOBACTERIAL HEPATOTOXINS

Ian Garthwaite, Christopher O. Miles, Kathryn M. Ross, Neale R. Towers
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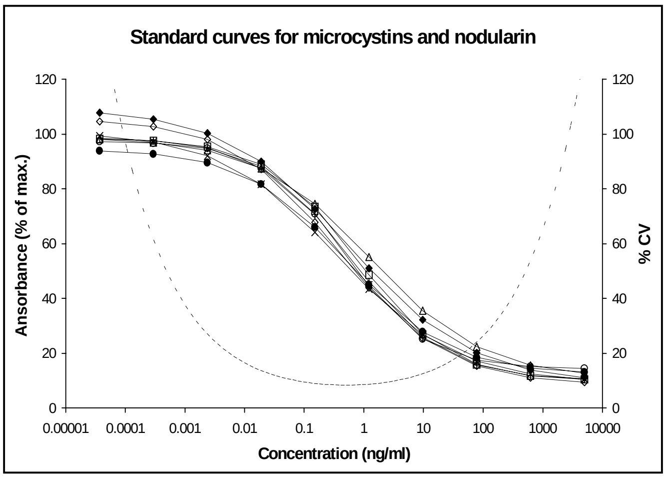
Cyanobacteria (blue-green algae) capable of producing hepatotoxins, e.g. *Microcystis spp.* are present in fresh water world-wide and have been major components of blooms in New Zealand. These algae produce toxins that cause severe liver necrosis at higher levels, while chronic exposure to lower levels may promote liver tumor formation. They are toxic to man, other mammals, to fish and to plants. Toxins produced include the microcystin (MC) heptapeptides (over 50 known variants) and the nodularin pentapeptide toxins (6 variants known). The large number of toxin variants makes it difficult to accurately determine the total potential toxicity of a water or algal sample using chemical analysis methods such as HPLC or LC-MS because the concentrations of the individual toxins may be below the limits of detection of these methods.

Antibodies raised against the ADDA moiety present in more than 80 percent of microcystins and nodularins were used to develop a competitive ELISA designed to detect most cyanobacterial hepatotoxins with equal sensitivity. The assay has a limit of detection of 0.02–0.07 ng/mL (depending on which congeners are present), lower than the WHO-proposed guideline (1 µg/L) for drinking water, irrespective of the sample matrix (raw water, drinking water, or pure toxin in PBS).

The assay is more sensitive than other available ELISAs, shows good cross-reactivity with all microcystin analogues tested to date, and has high cross-reactivity with nodularin – see Figure (the dashed curve indicates the concentration range where assay variation is less than 20%). Thus the ELISA integrates the concentrations for the individual toxin analogues to give an estimate of total microcystin/nodularin hepatotoxin content to better predict potential toxicity.The assay is robust and quick (assays can be completed within 1 day of sample receipt), and can be used directly on crude water samples. It has been used successfully in the analysis raw river and reservoir water, algal cultures, and algal bloom samples, and has been employed for the detection of microcystin contamination in rivers and lakes in New Zealand. The broad specificity, high sensitivity and robustness of the ELISA makes it suitable for use as a quick screening tool for the



detection of microcystin and nodularin toxins in water samples, and in the analysis of components of the aquatic food chain.

DETECTION, SCREENING AND MONITORING TESTS FOR EARLY DETECTION OF CYANOBACTERIAL TOXINS IN NEW ZEALAND AND AUSTRALIAN WATER BODIES

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Cyanobacterial water blooms are an increasing problem globally in reservoirs used for drinking water and in lakes and rivers used for recreation. A number of cyanobacteria species produce cyanotoxins such as hepatotoxins, which are primarily toxic to the liver (e.g. microcystins) and neurotoxins, which block various neuronal signal transmissions (e.g. anatoxin-a). Cyanotoxins constitute a threat to humans and animals consuming or coming into contact with them in drinking water supplies or by exposure during recreation.

At present the chemical and biological methods available for detection and quantification of cyanotoxins are too complex and costly for large scale or routine screening and biomonitoring of eutrophic water bodies. There are a number of instrumental methods (e.g. Liquid Chromatography/Mass Spectrometry) used that can quantify cyanotoxins but cannot detect their toxicity. The mouse bioassay (in which mice are intraperitoneally injected with toxins) is currently used worldwide and in New Zealand to determine bloom toxicity. However there is an increasing and urgent need for a more ethical and cost effective method.

This PhD study involves working with ecotoxicological testing kits known as Toxkits. These kits have been developed at the Laboratory for Biological Research in Aquatic Pollution at the University of Ghent in Belgium. In contrast to conventional ecotoxicological tests they are totally independent of the (costly) culturing/maintenance of stock's of the test species. The Toxkits use test organisms (eg. *Artemia salina, Daphnia magna)* in "immobilised" or "dormant" forms, which can be stored inexpensively for long periods of time without prejudice to the viability or sensitivity of the organisms. Toxkits are miniaturised kits containing all the materials to carry out several assays without sophisticated laboratory equipment. There are currently over 10 Toxkits available using a variety of organism such as ostracods, rotifers and cladocerans.

Because of their simplicity and low cost, these Toxkits are particularly suited for quantifying aquatic and terrestrial contaminants. One additional application of the Toxkits technology is the detection and quantification of the toxins produced by cyanobacteria. Initial studies by several laboratories in Central Europe have showed that some of the Toxkit organisms are sensitive to cyanotoxins. One of the kits, Thamnotoxkit, has been recommended by a number of laboratories as a pre-screening tool for cyanotoxin detection, and has been adopted in legislation in several countries of Central and Eastern Europe for this purpose.

Initially a whole range of Toxkit organisms will be subjected to samples of the four most common species of toxic cyanobacteria in New Zealand and Australia and also some pure toxins. Following this, more detailed investigations using the most sensitive species will look at how Toxkits can be applied to real world situations in New Zealand. Concurrent with this 'product testing' aspect of the study, will be an ecological survey of the upper and lower reservoirs in the Karori Sanctuary, Wellington. The lower reservoir is experiencing cyanobacterial blooms that potentially threaten wildlife. The study will reveal distribution patterns of cyanobacterial species within the reservoirs and determine levels of toxicity, thus forming an ideal circumstance for applying principles of risk assessment and risk management.

KARORI SANCTUARY - PROFILE OF A RESERVOIR WITH A CYANOBACTERIAL PROBLEM

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In 1992 a proposal was made to establish a secure native wildlife sanctuary in the Karori Reservoir Valley. It was proposed that the 252 ha valley be enclosed by a predator proof fence and developed as a premier conservation site with educational, research, recreational and tourism benefits. To accomplish this a 8.6 km predator-proof fence enclosing the valley has been constructed and an eradication program for all pest species was completed in 2000.

The Sanctuary contains two reservoirs both former water supplies of Wellington. The upper reservoir is shallow (8m) and lower reservoir is deeper (15m) and vertically stratified. Seven years ago a slight cyanobacterial bloom was noticed in the lower reservoir, with severe blooms being experienced in the summers of 1998/99 and 2000/01. The main species contributing to the bloom have been identified as *Anabaena spiroides* and *A. circinalis*, both species that can potentially produce cyanotoxins. Toxicity levels in the bloom are currently been assessed using mouse and other bioassays. The current cyanobacterial bloom poses a number of problems to The Sanctuary. It is currently preventing the release of several endangered bird species to the area. The area is shortly to be opened to the public, thus there is a possible human health risk, and there are problems related to the release of water downstream. The upper reservoir has never experienced a cyanobacteria bloom despite having the same water catchment and having cyanobacterial species present.

Over the next 14 months the two reservoirs will be sampled at regular intervals. Chemical analyses e.g.: total phosphorous, nitrogen, pH, water and air temperature will be monitored and compared to cyanobacterial species diversity, abundance and biomass in an attempt to explain possible causes of the bloom and reasons for the difference in abundance between the two reservoirs. Where possible, toxicity levels in the lakes will be monitored using LC/MS and Toxkits. Control and/or management solutions will also be investigated.

SYMPOSIUM SUMMARY AND CONCLUSIONS

Following the oral presentations on day one of the Symposium, a second day was spent in discussing research needs and priorities, with the registrants dividing into four groups. Each group then reported back to a full plenary session, the findings of which are summarised below.

Summary

This report sets out the purpose of the Symposium and the programme, comments briefly on papers delivered, summarises the research needs of the Rotorua lakes as expressed at the Symposium, and draws brief conclusions. Topics considered to have a high priority for research are summarised under the following subject areas:

- Sediments – their impact on water quality;
- Internal/external nutrient loading models;
- Nutrient bioavailability;
- Toxin development and reason for build-ups;
- Official response to toxin levels;
- Food webs and biota;
- Sustainable options for management;
- Remediation (rehabilitation of lakes);
- Plant and animal pest management.

A list of papers delivered at the Symposium and summary material from the workshop are shown as appendices.

Purpose of Symposium

The Rotorua Lakes 2001 Symposium, jointly hosted by the LakesWater Quality Society, formerly known as the Lake Weed Control Society, and the Royal Society of New Zealand (Rotorua Branch), was held on 22-23 March, 2001. The objective of the Symposium was to re-focus scientific attention primarily on the Rotorua lakes, but also on New Zealand lakes in general. It sought to present current world knowledge on cyanobacterial blooms, eutrophication and management (including the restoration of lake water quality), to sum up current knowledge about the many lakes in the Rotorua district, and to identify research priorities.

The Symposium was the first of its kind in New Zealand for over a decade, and the most comprehensive ever held on the Rotorua lakes.

Attendance and programme

Approximately 120 persons attended, representing Crown Research Institutes, government agencies, universities, local authorities, politicians, consultants and the interested public. Preceding the Symposium was a half-day field trip to three of the lakes. The Symposium opened with a formal mihi and karakia from Arapeta Tahana of Te Arawa, and then papers were presented, in oral or poster form. The second day was devoted to summing up the presentations, workshop discussions to determine research needs and priorities, and a plenary session reporting and collating the findings of the four workshop groups.

The presented papers were grouped into five general subject areas:

- Cyanobacteria and toxins;
- Eutrophication and bioavailability of nutrients;
- Sustainability and Management;
- Biota
- Economics

Papers at the symposium re-emphasised themes that have been central to the management of Rotorua lakes such as the significance to eutrophication of land use in the catchment; re-examined questions that have been around for decades such as the value of seeking to limit nitrogen inputs; and highlighted issues that have received relatively little past attention such as the nature and role of sediments, and detection and monitoring of cyanobacterial toxic blooms.

Keynote Speakers

The keynote speakers were Dr Rod Oliver of Australia, and Professor Wilhelm Ripl of Germany, both of whom emphasised systems rather than individual phenomena.

Dr Oliver has researched the ecology and physiology of micro-algae and cyanobacteria for 20 years. He has been involved in a wide range of projects investigating the influence of nutrients, light and physical mixing processes on blooms of cyanobacteria and microalgae. Included in this research has been the development of improved techniques for assessing nutrient and light limitation of algal growth, and investigations of methods for controlling blooms through nutrient reduction and enhanced water mixing.

Professor Ripl designed several lake restoration projects in Sweden before, in 1979, he was appointed Professor of Limnology at the Berlin Technical University and established a team of young limnologists working within the restoration sector of limnology. He has undertaken various international consultancies on water quality remediation. In recent years Prof. Ripl has stressed the importance of a comprehensive view of the landscape and has, in interdisciplinary projects, devoted much attention to restoration and management of whole catchment areas.

Research needs of the Rotorua lakes

The strong consensus of Symposium participants was that research in recent years has been inadequate and that there are significant issues needing research if the values of the lakes are to be preserved and improved. As important as the specific research proposals raised, were the comments giving background to the research needs. These included:

- There is little sense of a picture of how these lakes function, in either their natural or modified states.
- Water quality is the Number One issue, superseding lakeweed.
- Integration and ready availability of information is needed.

- There is a need to set realistic objectives for each lake.
- Lakes respond to what is happening in their catchments, and that must be linked to what is happening in the lakes.
- There is a need to understand lake processes.
- National lake research is limited, based in Christchurch, and only on a few lakes.
- Responsibilities for funding and implementing solutions to identified problems are not clear.
- An appropriate funding level is not established.
- Any review of long-term water quality data must allow for changing analytical methodology – in particular, the data on nutrients and metals collected in previous years is open to question.
- Those living and working with lakes need to accept that there is inherent uncertainty associated with lake systems.

Professor Silvester, the Symposium Rapporteur, considered it vital to get more time-series data on how the lakes are changing with time, and on how land and riparian management affect the lakes, particularly the input of nutrients into the lakes. He endorsed the keynote speakers' advice, that understanding the processes operating in the lake catchments is a prime goal.

A summary of subject areas with high priority for research, as chosen by at least three of the four Symposium workshop groups, is shown below. It must be emphasised that this list represents the major topics selected in a limited discussion time. Research on other topics may still be very desirable. A full list of the questions that were raised among the workshop groups is in the Appendix.

High-priority research topics put forward by the Symposium workshop groups:

Sediments	- physical information and nutrient fluxes between water and sediments; - sediment studies as support for catchment-level nutrient models for each lake; - significance of allophane-based sediments.
Internal/external nutrient models	- local effect of nutrients as opposed to total lake water quality; - rate of transport through groundwater; - information on peak loads and flows including potential limiting effects of minor elements.
Bioavailability	- availability and limitation for each lake; - comparison with earlier data to indicate changes.
Toxin development and reason for build-ups	- identification and response to toxin levels; - improving sampling procedures; - improvement of toxin detection.
Official response to toxin levels	- refinement of risk analysis.

Food webs and biota	- quantitative analysis of food web structure; - effects of eutrophication; - biomanipulation; - bioaccumulation of toxins; - interactions between algae and fish; - regular macrophyte surveys.
Plankton	- enhance monitoring programme to understand changes in plankton dominance and seek indicator organisms.
Trophic Level Index	- explore inclusion of biotic factor.
Water temperature rise	- check data against nutrient records.
Sustainable options for management	- monitoring to improve understanding and early detection of deterioration; - identify objectives for each lake; - investigate options for land use compatible with good water quality; - compare relative importance of nutrient inputs associated with residential and agriculture land use to water quality.
Remediation	- development and promotion of sustainable, acceptable wetlands; - monitoring long-term effectiveness of wetlands and treatment systems.
Pest management	- strategies and responsibilities for control of coarse fish and weeds; - possible integration with Plant & Animal Pest Control Strategy.

Additional proposals and comments associated with management of the lakes

- Collate and disseminate existing information.
- There is a need for a robust level of public consultation and involvement in setting priorities.
- Develop public education.
- Coordinate responsibility and planning among the authorities.
- Agreed outcomes should be incorporated into the Lakes Management Strategy.
- Achieve an effective interface of scientists with the Lakes Management Strategy.
- The implementation of the Resource Management Act must include proper assessment of the effects on the lakes of catchment proposals.

Action

While the Symposium was designed to help clarify research needs, and future research will allow remedial measures to be better targeted and more cost effective, some of the papers suggested ways in which knowledge already in existence could be applied now. Principles already applied in the upper part of the Kaituna catchment scheme, in the

diversion of Rotorua City wastewater away from the Lake, and the protection of littoral zones and riparian strips in Lakes Rotoehu were endorsed by leading scientists at the Symposium. Apparent decline in water quality in several lakes clearly shows that these principles need further application, drawing on existing basic research together with overseas experience including that in the restoration of lakes.

Conclusions from the Symposium

The response to the Symposium was far beyond the most hopeful expectations of the organisers, especially the degree of interest and participation of scientists, local authorities and interested members of the public.

The papers and discussion were of high quality and stimulated attention on eutrophication and knowledge of systems and processes affecting the Rotorua lakes.

On research needs, the role and nature of sediments was a new emphasis. The uncertainties regarding behaviour of cyanobacteria, monitoring of cyanobacterial levels, and the various authorities' response were of major interest to the public. Development of strategies for early detection and elimination of new plant and animal threats to the lakes was proposed. Overall, a systems approach was advocated, incorporating catchments and their land-use, and sediments, as well as what is happening in the water of the lakes.

The advocacy at the Symposium of a goal of restoration of at least some lakes, rather than just conservation of their present degraded state was an important proposal, and is worth prompt implementation through a pilot project in a small lake or enclosed bay. Overall, suggestions indicated the need for development of a coordinated approach to lake management and research, with public and scientific involvement in setting priorities.

The LakesWater Quality Society intends to follow up the findings of the Symposium in action and research, and encourages those working in or having influence in relevant fields to pursue opportunities to increase understanding of the lakes.

Together with the Royal Society of NZ (Rotorua Branch) it thanks all those who contributed to the success of the Symposium.

The Symposium Committee

Ian McLean	Chairman, LakesWater Quality Society
Robert Franich	President, Royal Society of New Zealand (Rotorua Branch)
Brentleigh Bond	LakesWater Quality Society
Lindsay Brighouse	LakesWater Quality Society
Rowland Burdon	Royal Society of New Zealand (Rotorua Branch)
Elizabeth Miller	LakesWater Quality Society
Nick Miller	LakesWater Quality Society
Warren Webber	LakesWater Quality Society

APPENDIX

ROTORUA LAKES 2001 SYMPOSIUM
WORKSHOP SUMMARIES TABLE

(Figure in brackets is priority rating given by group: 1,lowest; 5,highest.)

TOPIC **Sub-topic**	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**No of groups mentioning topic**
ALGAE					
Toxin development and reason for build-ups	Understand relationship between cyanobacteria stage of growth and toxin production (**4**)	Rate of toxicity development (**3**)	Better understanding of N/P ratio, and how levels affect cyanobacterial build-ups	Need to relate toxin production to environmental conditions	4
		Threshold biomass for rapid decline (**3**)			1
Identification of toxins			Adequate toxin information from Rotorua cyanobacteria	Develop simple tests for toxins, and appropriate local standards Min of Health working on cyanobacterial standards at present	2
Response to toxin levels	Better system of response to toxic algal blooms (**3**)		Cyanobacterial toxin detection: refinement of risk analysis and notification process.	Improve sampling programme and methods for cyanobacterial level detection	3
				Develop improved information on closure notices	1
Toxin removal			Investigate cleaning of cyanobacteria-infected waters		1
Plankton	Review and enhance plankton monitoring programme (**4**)				1
	Understand the changes in plankton dominance (**4**)			Are nutrients involved in algal problem or not?	2
	Encourage development of programme of indicator organisms (**2**)				1

EUTROPHICATION	Group 1	Group2	Group3	Group4	Mentions
Control		Process to limit or reverse accelerated eutrophication of the Rotorua Lakes (**5**)	.	How to manage reduction of nutrient loads	2
Internal/external nutrient loading models	Effects on local, as opposed to total lake water quality (effects of septic tanks, storm water etc) (**5**)	Rate of transport of nutrients through groundwater (**5**)	Internal/external nutrient loading models Input information for each lake, and relation to land use e.g. Are septic tanks the only significant source of nutrients? Are there effective alternatives? Natural inputs not fully understood	More on nutrient loads (inputs) and catchment sources, including residential vs. agricultural (relates to land use)	4
				Information on peak loads and peak flows into lakes (Long-term monitoring seldom captures these events)	1
Bio-availability	Bioassay programme to be restarted to repeat earlier work (**5**)	N & P bio-availability and limitation for each lake (**3**)	Bio-availability of nutrients in sediments (Bioassays)		3
			Do other elements have significant limiting effects e.g. Si?		1
Monitoring		Need monitoring for early detection to allow appropriate, efficacious management	Nutrient, algal and macrophyte surveys to compare with old data and check postulations Regular monitoring period to be determined	Integrated risk assessment approach for each lake? Identify what we want to achieve for each lake. What should we be monitoring? Paucity of current information	3
			Indicator values. Require nutrient and algal bioassays		1

Eutrophication (cont)	Group1	Group 2	Group 3	Group 4	Mentions
Sediments	Catchment level nutrient models for each lake to include role of sediments (**5+**)	Sediment studies to track historical events	Sediment studies – physical information	Significance of allophane-based sediments (pH sensitive rather than redox?)	4
			Nutrient fluxes between water and sediments	Investigate nutrients and organic materials implicated in release from sediments	2
TLI (Trophic Level Index)		Whether other components need to be recognised in TLI , e.g. biota, bacterial activity. Doesn't relate to land use, sediment or eutrophication sources (**4**)		TLI – how generally accepted? basis for expensive decisions. Should it include biota?	2
Temperature rise			Check relevance of recent water temperature data to nutrient budget for each lake.		1
LAND USE					
Sustainable options	Research options for sustainable land use in catchments. Includes public and private valuation and usage (**5**)		Investigate options for land use compatible with good water quality	What land use practises in general are sustainable in terms of maintaining water quality? (RMA requires 'no adverse effect') (Land use is major component of LMS	3
Agricultural vs. residential		Relative importance of residential and agricultural land use (main cause of eutrophication) in each catchment (refer also to Eutrophication, Internal/external nutrient loading models) (**5**)			1

Land Use (cont)	Group 1	Group 2	Group 3	Group 4	Mentions
Remediation	Development and promotion of sustainable, acceptable wetlands (**4**)		Remediation to improve or halt decline of lakewater quality e.g. retirement	Effectiveness of wetlands as filters, and wastewater/ stormwater treatment, including public health issues	3
Remediation monitoring			Monitor remediation effects long-term	In riparian protection strips, what happens outside saturation zones?	2
BIOTA					
Food webs	Quantitative analysis of food web (trophic) structure (**4**)	Effects of eutrophication on population structure; Time scale of effect; Food web interactions that cause change; how to reverse change - bio-manipulation		Food web connections, including bio-accumulation of toxins	3
				Interactions between algae and fish	1
Monitoring			Regular macrophyte surveys (see eutrophication section)	Current macrophyte surveys	2
				Have large changes in macrophyte dominance played a role in algal problems?	1
Management	Native fishery management (**3**)				1
Plant & animal pest management	Strategies and responsibilities for control of coarse fish and weeds (**5**)		Coarse fish watch to be initiated, possibly involving user groups.	Integration with Regional Plant & Animal Pest Management Strategy?	3
OTHER					
Information management				Coordinate, assimilate, collate & disseminate known information	1

Other (cont)	Group 1	Group 2	Group 3	Group 4	Mentions
Education	Public education on state of the lakes (via book?)	Improved education, knowledge transfer		Public education	3
Organisational relationships and responsibilities	Relationships between organizations, with respect to cooperation, planning, responsibility (**4**)		Agreed outcomes need to feed into Lakes Management Strategy, which includes understanding water quality. Process of interface of scientists with LMS to be addressed.		2
			RMA processes to consider and adequately assess effects on lakes of proposals in catchment		1
Public involvement				Robust level of public consultation and involvement in setting priorities	1
Funding				When a problem identified, who is responsible to find funding and action solution? Need to set out responsibilities (in L M S?)	1