A REVIEW OF SHORT-TERM MANAGEMENT OPTIONS FOR LAKES ROTORUA AND ROTOITI

A REPORT FOR THE NEW ZEALAND MINISTRY FOR THE ENVIRONMENT, DECEMBER 2003

Prepared by
Dr Bruce Hamilton
Principal Consultant
Hamilton Integrated Management

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CONTENTS

FIGURES AND TABLES

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ABOUT THE AUTHOR

Bruce has worked for 28 years in the Western Australian Government, primarily in environmental and natural resource management. He also has a strong interest in organisational management, with an emphasis on people and community participation.

In 14 years from 1972 with the Environmental Protection Authority, Bruce pioneered programmes in coastal management, environmental planning, strategic control of air pollution and hazardous chemicals, and was strongly involved in the early years of environmental impact assessment in Australia. Bruce led the final phase and implementation of the Peel-Harvey Management Strategy, one of the biggest successful estuarine rescues in the world.

In the following nine years, he was the CEO of the Waterways Commission, and established the Swan River Trust (including the Swan River Management Strategy and new legislation for the Trust), three new waterways management authorities and numerous management programmes for rivers and estuaries. As part of this work, Bruce negotiated and established the Swan Canning Clean Up programme and led the establishment of integrated catchment management in the Metropolitan Region (now the Swan Region). Part of this work included leadership of several waterways studies and implementation of successful management measures.

This work continued in 1996 when Bruce joined the Water and Rivers Commission as the Director of Resource Investigations. During this period Bruce worked with community people in the 'NRM Regions' and government officers to develop a 'framework' for natural resource management in Western Australia. This is now being progressively implemented.

Since 1999, Bruce has been a private consultant working in natural resource management, environmental management and organisational management. During this time he has played a leadership role in developing several regional natural resource management strategies, been a member of the Western Australian Government Taskforce to review salinity, developed a strategic and operational framework for Greening Australia, carried out a number of organisational reviews and has recently been appointed to the Board of the Swan River Trust.

Bruce's main skills are linking focused scientific research to good management outcomes in natural systems and bringing people together to achieve common objectives. He enjoys working with people to improve the environment we live in and improve our use and management of the earth's precious natural resources.

Contact:
Dr Bruce Hamilton
31 John Street
Gooseberry Hill, WA 6076, Australia
Phone:00 61 8 9293 3197
Mobile:0419 946 545
Email: hamilton@webace.com.au

EXECUTIVE SUMMARY

Purpose and methodology

Dr Bruce Hamilton was engaged to evaluate the range of current, proposed and potential actions to manage the short-term symptoms and causes of water quality problems in Lakes Rotorua and Rotoiti and provide a written report to the Secretary for the Environment. This work follows considerable concern about large blooms of blue-green algae, particularly in Lake Rotoiti over the summer of 2002-2003.

The work was undertaken by working closely with management, technical and scientific staff in Environment Bay of Plenty (EBOP), Rotorua District Council (RDC), the University of Waikato, the National Institute of Water and Atmospheric Research and officers from relevant central government agencies. In addition, a series of meetings with local community and industry groups was organised by Paul Dell from EBOP (Group Manager Regulation and Resource Management and Lakes Project Manager), and these provided valuable advice and information.

Most of the recommendations for both vital short-term investigations and short-term management measures are set out in detail in section 7, while all of the recommendations have been summarised together for ease of reference after this Executive Summary. The numbers of two recommendations that arise before section 7 are noted in the Executive Summary below while the remainder are noted against a summary of the discussion from section 7 in the last part of the Executive Summary.

Sources of information and context for the recommendations

Nearly all of the information on which this report is based was obtained directly from EBOP, and people and organisations working for EBOP. In the former case, the staff and management of EBOP were extraordinarily generous in providing information and assisting the author. In the latter case, special thanks are due to a number of talented scientists from the National Institute for Water and Atmospheric Research and Professor David Hamilton from the University of Waikato.

EBOP has done and is doing a large amount of work on the Rotorua lakes, including Lakes Rotorua and Rotoiti, and it was a privilege for the author to work with the very professional team from EBOP. In this context, a number of the recommendations in this report are already underway, or have begun to be investigated, or have been implemented since the report was written.

Accordingly, it is difficult to separate those recommendations that are entirely new, so the author’s intention is to support work that is already being done by EBOP and provide an ‘adaptive management’ and ‘systems’ context to assist EBOP in its further management initiatives and working with the community.

EBOP is to be commended on its leadership and overall approach to managing the Rotorua lakes and this excellent approach is summarised in the body of the report. EBOP is also to be commended for the way it has partnered with the Maori people at the highest levels and with the RDC, which has an important role to play in the management of the Rotorua Lakes.

Significance of the Rotorua Lakes

Rotorua is the most visited tourist destination in New Zealand and the lakes are a focal point for tourists and locals for recreation and trout fishing. Lakes Rotorua and Rotoiti are especially important being the two biggest lakes with the most settlement around them. Lake Rotoiti is famous for the large ‘trophy’ trout that are caught and is a favourite place for holiday homes.

Thus, the blue-green algal blooms, which closed Lake Rotoiti for several weeks in early 2003, were seen as a real indication that the lake was in trouble and many local people called for an urgent response from the ‘authorities’. There is no doubt that these lakes are very important for New Zealand and are of national significance.

Leadership and responsibility for lakes management – Environment Bay of Plenty and Rotorua District Council

Environment Bay of Plenty (EBOP) is one of 16 regional councils in New Zealand charged with integrated management of land and water resources under the Resource Management Act 1991. Rotorua District Council (RDC) is the local government body for the Rotorua district where the lakes are situated. These two bodies together have the responsibility for management of the lakes with EBOP providing overall leadership and coordination.

EBOP has taken a strategic approach to its leadership role, establishing a series of policies and plans which set out the basis for protection and management of the Rotorua lakes. These are briefly summarised below and set out in more detail in the body of the report.

1) The **Proposed Regional Water and Land Plan** sets out how EBOP will collaboratively manage the land and water resources of the region. It addresses issues relating to the adverse environmental effects of the use and development of land, water and geothermal resources that are within the scope of EBOP’s functions and responsibilities under the Resource Management Act 1991.

   Considerable attention is paid to the strong relationship that the Maori people have with the land and the concepts of kaitiakitanga (guardianship) and mauri (life force or spirit). This is important because the Maori people need to be fully involved in all stages of the investigations and implementation of any management measures.

   The Water and Land Plan sets Trophic Level Index (TLI) targets for each lake, which are a useful measure of the trophic status (level of nutrient enrichment and plant growth) for the lakes. Each TLI target provides a good goal for the community to work together and aim for. The current TLI levels and targets for each lake are shown in Appendix 2.

2) The next level of policy and planning is for the Rotorua lakes as a whole and is contained in the **Strategy for the Lakes of the Rotorua district - *‘Te Kaupapa mo Nga Taonga o Rotorua’* (Protecting the Jewels in the Crown of the Lakes of the Rotorua district).** This important document, which was developed and adopted by EBOP, RDC and the Te Arawa Maori Trust Board, sets out a vision, goals and priorities for protection and restoration of the Rotorua lakes.

   The vision for the lakes is:

   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.

Fourteen key goals are set under the headings of Protection, Use, Enjoyment and Management Goals, and the Strategy contains a 'Schedule of Tasks' for each goal.

Overall coordination and direction for the Strategy is vested in the Lakes Strategy Joint Committee comprising the Chair of the Te Arawa Maori Trust Board, the Chair of Environment Bay of Plenty and the Mayor of RDC, plus a further representative from each of the three organisations. This key body ensures all of the work is done cost effectively and collaboratively. Paul Dell from EBOP has been appointed as the Coordinator.

3) Implementation is being coordinated through the **Rotorua Lakes Restoration and Protection Programme**, which is shown in Figure 2 in the report. This brings together the large number of elements that are being undertaken, from ongoing research to education and communication. Currently, it is a 'work in progress' as work is added and changed, but it would be useful if the Rotorua Lakes Restoration and Protection Programme was documented to show the practical side of EBOP's overall approach and how the community, the research organisations and government are working together. (**Recommendation 1**)

4) **Lake Action Plans** are the next step where the current TLI exceeds the target TLI. These Action Plans bring the community together to identify the preferred management options. Each Action Plan defines the existing catchment nutrient budget, determines what level of nutrient inputs are sustainable, identifies agreed nutrient reduction targets and determines actions to achieve the agreed targets.

   Lakes Rotorua and Rotoiti will have a single Action Plan because of the way they are inextricably linked by the Ohau Channel.

5) Tracking the health of the Rotorua lakes is through EBOP's '**Water Quality Monitoring Programme'**, which started in 1990 and builds on previous monitoring and studies that began in the late 1960s. The results of the programme to 2002 are summarised in a valuable document, Rotorua Lakes Water Quality 2002 (Ref 3), which shows the different parameters that have been measured, including oxygen levels, total phosphorus and nitrogen, chlorophyll *a*, algal species in the lakes, and nutrient loads and concentrations from the catchments. **Lake Quality Indicators**, including the TLI and oxygen levels, are used to report on the health of the lakes each year, but additional water quality indicators that are more closely linked to the processes causing algal blooms would be useful to complement the longer-term health indicators. (**Recommendation 2**)

The condition of Lakes Rotorua and Rotoiti

Appendix 2 shows that the five worst lakes according to their TLI are Okaro, Rotorua, Rotoehu, Rotoiti and Okareka and these are EBOP's priority for action. Professor David Hamilton, who holds the EBOP chair of Lakes Management and Restoration at Waikato University, has analysed all of the historical data and classified the lakes into four categories based on mixing regimes and dissolved oxygen as shown in Table 2 in the report.

This analysis has shown that there has been a steady decline over the last 30 to 40 years in a number of the lakes as shown by the depletion of oxygen in the bottom layers. Lakes Okaro and Rotoiti are the worst but Lake Rotorua is also in poor condition, and because it is shallower, it contributes significant inputs of nutrients to Lake Rotoiti during periods of stratification and destratification over summer.

Thus it is not surprising that both Lakes Rotorua and Rotoiti are suffering problems and that Lake Rotoiti is showing the greatest signs of stress.

Whole systems, understanding and adaptive management

Appendix 3 is a foldout diagram, which attempts to portray a whole systems approach by showing the way the inputs of nutrients and other materials from a catchment interact in Lake Rotorua and are carried through the Ohau Channel to Lake Rotoiti. While this report is primarily about short-term management measures to tackle the blue-green algal blooms, it is important to first look at how the whole system works and whether there is enough understanding of the various interactions to move to management.

Appendix 3 shows that two levels of understanding are needed; an understanding of the processes in the catchments that cause the nutrient inputs to the lakes and an understanding of the processes in the lakes that mobilise the nutrients and cause the algal blooms. This does not mean that every process has to be understood in great detail, but rather that there is enough understanding to give confidence that management measures can be trialled and tested.

This process of **adaptive management** is a powerful way to work and move forward. In the case of Lakes Rotorua and Rotoiti, there are aspects where the understanding is good enough to begin trialling management options, while in other cases there are critical gaps in understanding where short-term investigations are needed before it is safe to begin management.

The discussion and recommendations in section 7 cover both aspects and clearly identify where urgent studies are required and where short-term management measures can begin.

A short history of monitoring and investigations

There have been studies and monitoring of Lakes Rotorua and Rotoiti since the late 1960s when problems of algal growth first emerged. All of this work has been elegantly brought together in a paper being prepared for EBOP by Dr Kit Rutherford from NIWA, on 'Lake Rotorua Nutrient Targets' (Ref 4). The author is grateful to Dr Rutherford and EBOP for making the draft report available as it helped identify many of the key management issues.

Section 6 in this report sets out a summary of the investigations from the late 1960s to the present, including the historical catchment target loads that have been set for total phosphorus and total nitrogen. The latter are set out in Table 3 and more fully in Appendix 4, which is a detailed foldout table of the 'Rotorua Nutrient Inputs and Water Quality – Loads and Targets' adapted from two tables in Dr Rutherford's draft report.

From this work a number of 'key issues for management' are identified and these are detailed in section 6 and briefly listed below:

- determining whether the Rotorua Land Treatment Site (RLTS), where the treated sewage is sprayed, can continue to strip nutrients so they do not leak into Lake Rotorua

- support for connecting a number of smaller urban areas around the lakes to reticulated sewage where septic tanks are leaking nutrients into the lakes

- continuing the work begun by EBOP to define a suite of water quality indicators that can be used to measure the impact of management measures on lakes water quality, and the frequency and severity of algal blooms

- the need to more accurately characterise the nutrient inputs in the Lake Rotorua catchment streams to identify possible 'point' sources that could be reduced by appropriate management measures in the short to medium term

- the need to better understand the relationship between deeper groundwater, which emerges as springs, and the land uses in the recharge areas. A concerning trend is that while riparian retirement and catchment revegetation has reduced particulate nutrients, soluble nitrogen in the form of nitrate in deeper older groundwater (50 to 70 years old) has increased, negating the gains made by diverting the treated sewage to the RLTS. Work has begun to test younger groundwater to determine if the upward nitrate trend is continuing

- clarification of whether storm-flows, which only contribute 10% of the nutrients, cause algal blooms by introducing relatively large 'slugs' of nutrients at times of the year which favour undesirable algal blooms

- further work on the total nutrient loads and concentrations in the lakes when blooms are likely to occur to determine the N:P ratio, because if this is less than about 22:1, blue-green nitrogen fixing and blue-green non-nitrogen fixing blooms will be favoured

- further investigations to determine the size and role of internal nutrient loads in both lakes, which could be at least as high as half the external nutrient loads. This is particularly important at those times of the year that the blue-green algal blooms occur

- further urgent investigations to better understand where the Ohau Channel flows in Lake Rotoiti, as it has both a beneficial role in supplying oxygenated water and an adverse role in bringing large amounts of nutrients into Lake Rotoiti, especially into the surface waters in summer when blue-green algal blooms are favoured. This work will be critical for any management measures

- a better understanding of the dynamics and succession of algal blooms to aid in the introduction of algal risk prediction and short-term cosmetic management measures.

Recommendations for short-term management measures and vital investigations

Detailed discussion and recommendations for short-term management and vital investigations to support short-term management are set out in section 7. A full summary of the recommendations follows this Executive Summary. A summary of the key issues that lead to the recommendations and the recommendation number is set out below.

The recommendations are split into short-term understanding and then short-term management, firstly for the catchments and then for the lakes. Finally there is a sub-section on 'other management issues and options', which do not readily fall into the earlier sub-sections.

Understanding the catchments

EBOP and RDC accept that there are key aspects to better understand catchment processes to move to the short-term management options that are summarised below.

1) Quantifying the nutrient sources in the catchments and relating them as far as possible to land uses and point sources. Some of the inputs are 'natural point sources' like some of the springs, which have relatively high phosphorus levels and at least one geothermal input, with a high soluble nitrogen level. Identifying these inputs will lead to short-term management measures that can be applied using existing technologies and methods. (**Recommendation 3)**

2) Monitoring the catchments to quantify nutrient inputs from different land uses and land types, and to measure the results of often expensive management measures. Using the monitoring results and other information to build simple catchment models that can be used to work with landowners to show how they contribute to nutrient reductions across the catchment and how their management efforts are working. (**Recommendations 4 & 5)**

3) Quantifying the levels of nutrients in the deeper groundwater, especially nitrate levels, that appear to be rapidly increasing, is an important step for management. Monitoring of the deeper groundwater, where it emerges as springs, has shown it is aged between 50 to 70 years, so that the high nitrate concentrations are due to land uses and land-use changes that occurred 50 to 70 years ago. EBOP has begun work to measure nutrient levels in younger groundwater and it is important to continue this work as the deeper groundwater could be the most significant source of nutrients for the foreseeable future. (**Recommendation 6**)

4) Understanding the role that storm flows have in promoting 'event driven' algal blooms as they may trigger undesirable blooms at certain times of the year. If this is the case, short-term management measures could be put in place relatively quickly. (**Recommendation 7**)

Short-term catchment management options

5) EBOP has been investigating materials like alum for stripping nutrients from catchment inputs and has imported a quantity of a new efficient material for stripping phosphorus, Phoslock ™, from Western Australia. EBOP should continue this work and consider forming a closer working relationship with the Western Australian Department for the Environment, which is conducting similar trials. A number of local soils may also be useful for nutrient stripping and as a substrate for the rare earth used in Phoslock. (**Recommendations 8 & 9**)

6) Several springs that enter streams in the Lake Rotorua catchments have relatively high concentrations of phosphorus and these are essentially natural point sources of nutrients. Hence, there is an opportunity to manage them in the short-term to strip phosphorus using the type of materials discussed for the previous recommendations. (**Recommendation 10**)

7) At least one geothermal input has a relatively high level of soluble nitrogen by the time it enters the Waiohewa stream and EBOP and RDC are considering diversion to the reticulated sewerage when it is extended. This is good short-term management option and should be pursued as a priority. (**Recommendation 11**)

8) Diversion of the treated sewage from Rotorua to the Rotorua Land Treatment Site in 1991 was initially successful in reducing nutrients in Lake Rotorua, but intensive spraying subsequently caused leakage of nutrients via the Puarenga Stream. Changes to the spraying regime appear to have initially been effective in stopping the leakage but resilience needs to be built into the system to cope with future increases in loads. Also, as this is a relatively cost-effective method of removing nutrients from Lake Rotorua, the load targets for phosphorus and nitrogen should be reduced to zero. (**Recommendations 12, 13, 14 &15**)

9) Previous studies and monitoring have shown that 90% of the catchment flows come in stream base-flows, bringing with them the majority of the nutrients. EBOP has characterised the high nutrient input streams so that short- and medium-term opportunities for wetland stripping of nutrients can be identified. (**Recommendation 16**)

10) Once point sources of nutrients have been identified and prioritized, 'Best Management Practices' (BMPs) can be identified and applied to particular point sources like dairy sheds. EBOP is already applying BMPs and with better identification of point sources, they can be prioritised for short-term management. (**Recommendation 17**)

Understanding the links between the catchments and the lakes – nitrogen and phosphorous loads and the N:P ratio

11) Current estimates of the annual catchment nutrient loads to Lake Rotorua are 35 tonnes of total phosphorus (compared to a target of 37 tonnes) and 692 tonnes of total nitrogen (compared to a target of 435 tonnes). These figures do not include septic tank inputs and internal loadings in the lakes, and as stated earlier, the N:P ratio in the lakes is also important in determining what type of blooms occur. Therefore, it is believed more work needs to be done to clarify the relationships between catchment nutrient loads and lake nutrient dynamics, to set a range of targets for nutrients entering the lakes and in the lake waters. The aim for these targets is to minimise unwanted algal blooms and focus both short-term and longer-term management measures. (**Recommendations 18 & 19**)

12) As discussed earlier, the nitrogen to phosphorus ratio (N:P ratio) is critical in determining the types of algae that will bloom. The priority for Lakes Rotorua and Rotoiti, at least for the next few years, will be to eliminate toxic blue-green algal blooms and therefore the in-lake N:P ratio should be kept above 22:1 if possible, especially over late spring, summer and autumn. Therefore, short-term investigations should focus on ways to manipulate the N:P ratio, by both reductions in catchment nutrient inputs and in-lake management to change the ratio to greater than 22:1. (**Recommendation 20**)

Understanding the lakes

13) A major issue for short-term management is to determine the role of internal lake nutrient loads in promoting algal blooms. In Rotorua, these loads could be at least half the catchment loads and they occur at the worst time of the year for blue-green algal blooms, caused by stratification and destratification events during summer. Equally important is a better understanding of how soluble and particulate nutrients are mobilised in Lake Rotorua and transported through the Ohau Channel into Lake Rotoiti. Information from short-term intensive monitoring to build on work already done could then be used for hydrodynamic modelling to quantify the transport and fate of these nutrients. This work is critical to underpin

management options involving diversion of the Ohau Channel. (**Recommendations 21 & 22**)

14) It is well known that there are a number of geothermal inputs into Lake Rotoiti but their contributions of nutrients and energy and how they modify transport processes and residence times are not well known. A better understanding of these 'hot' inputs is vital for short-term management measures involving diversion of the Ohau Channel or in-lake management measures like oxygenation. (**Recommendation 23**)

15) While algae samples have been collected monthly and there is a more regular sampling programme for blue-green algae, little is known about the succession and cycling of phytoplankton in Lakes Rotorua and Rotoiti. In other systems this knowledge has often been vital in testing management options, and data to develop the necessary understanding is collected by monitoring at weekly or fortnightly intervals. It would be wrong to be prescriptive for Rotorua and Rotoiti, but it is important that EBOP considers more frequent monitoring, especially during periods when blue-green algal blooms are expected. (**Recommendation 24**)

16) A critical issue that has already been mentioned is the role of the Ohau Channel in transporting nutrients into Lake Rotoiti. One of the main management options for Lake Rotoiti could be whole or partial diversion of the Ohau Channel, but unfortunately there is not enough information on the hydrodynamics and circulation patterns in Lake Rotoiti to confidently make management recommendations. Therefore, short-term investigations and hydrodynamic modelling are vital and discussions indicate suitable models can be developed in 6 to 12 months. (**Recommendation 25**)

Short-term lake management options

17) A significant source of nutrients that flow into Lake Rotoiti through the Ohau Channel come from resuspended sediments, especially when the wind is in the western quarter. An earlier recommendation was to carry out investigations and modelling to better understand how these resuspension events interact with internal nutrient loadings from stratification and destratification, but this should not stop short-term management to trap the resuspended material. EBOP and RDC are investigating the construction of groynes each side of the entrance to the Ohau Channel and this work should be strongly supported. Initially, the groynes should not be built out to the deeper water in Lake Rotorua until the flow of water (and nutrients) from the deeper water is better understood, but this could be done at a later date. (**Recommendation 26**)

18) Clearly diversion of the Ohau Channel will be a significant short-term management option, including the possibility of using part of the flow to flush Okawa Bay, but as stated earlier, some short-term investigations are vital to provide the level of understanding necessary to trial preferred diversions. But, this must not stop parallel engineering investigations into the best diversion techniques for trialling as soon as possible. Monitoring and investigations can then continue as the trials proceed to give the best ongoing management options, a truly adaptive approach. (**Recommendations 27 & 28**)

19) EBOP is planning to trial nutrient stripping with alum in Lake Okaro in the near future and is also considering oxygenation trials. Phoslock could also prove beneficial with, and without, oxygenation. It is likely that direct oxygenation of Rotorua over the short periods when it is stratified and longer-term oxygenation of

Lake Rotoiti in combination with diversion of the Ohau Channel will prove beneficial for both lakes. Therefore, it is important that EBOP continues, and is supported in carrying out trials of nutrient stripping materials and oxygenation to develop these important management tools. (**Recommendations 29 & 30**)

20) Cosmetic measures have been used to trap and remove algal blooms in other parts of the world by using floating booms to concentrate the blooms and 'sucker' trucks to remove dense concentrations. Booms may also be able to contain a bloom in an embayment. While such measures do not stop blooms, they can be used to remove or trap dense accumulations and show the community that some action is being taken. (**Recommendation 31**)

21) Herbicides are already being used in the Rotorua Lakes to control nuisance build-up of invasive aquatic 'weeds' and in other places to selectively control aquatic weed infestations. Herbicides have also been used to kill blue-green blooms in farm dams, but it is a big step to use herbicides to control blue-green blooms in natural systems. Nevertheless, herbicides as a control measure could be investigated, particularly 'Roundup' which has a short half life in water bodies. (**Recommendation 32**)

22) It is often valuable to predict when certain types of algal blooms may occur, to warn the public and to prepare any management measures that may be appropriate. From discussions with NIWA, it appears that a longer-term prediction - say three months ahead - could be made using NIWA's climate models and, shorter-term predictions - say ten days or less - could be made based on more frequent monitoring and shorter-term weather forecasts. EBOP should investigate whether such a capacity would be worthwhile. (**Recommendation 33**)

Other management issues and options

In addition to the recommendations made above, there were a few issues that did not fit simply into catchment or lake management to tackle short-term management of algal blooms and these issues are summarised below together with recommendations.

23) It became apparent during meetings and discussions that there is a significant amount of work on management of lakes occurring in New Zealand. EBOP is aware of the extensive work on Lake Taupo and has established a working relationship with Environment Waikato. 'Cross regional cooperation and learning' should reduce the cost of investigations and the trialling of management options and should be pursued wherever possible. (**Recommendation 34**)

24) Another issue that became apparent in discussions is the apparent lack of consistent coordination of the research and science that underpins lakes management. This is not to belittle the very good work that EBOP is doing, but it is apparent that some of the science could be better coordinated towards focused management outcomes. It is not for the author to say how this should be done, but it would be useful for EBOP to consider this aspect as part of its overall leadership role. (**Recommendation 35**)

25) Trout fishing is a very important part of the tourist attractions of the Rotorua district and the economy. Unfortunately, the problems in Lake Rotoiti appear to be having an adverse effect on the trout fishery, with the average size of fish falling over the last few years. Fish and Game New Zealand are working with the University of Waikato and EBOP to investigate the reasons for the decline,

including how the food webs may be changing. While this work is not directly applicable to this report it should continue to be supported, as it is one of the 'public faces' of the health of the lakes. (**Recommendation 36**)

26) Consideration of the broader ecosystem health of the lakes is also not directly part of this report, but it must be the ultimate aim of any management. Some very good work has been done on developing broader ecosystem health indicators, based on the health of native aquatic plants and the degree of impact by invasive weed species. EBOP has been supporting this work and the development of broader ecosystem indicators and targets complements the TLI and other water quality targets. (**Recommendation 37**)

Priority recommendations

All of the recommendations in this report should be considered by EBOP for short-term (1 to 2 years) and medium-term (2 to 4 years) management measures, recognising that many management options will require resource consent approvals that may delay their implementation.

In this context, some recommendations are considered to be of a higher priority for either direct implementation of management measures or for urgent studies to improve understanding of the lakes that will lead to short-term management measures. These 'high priority' recommendations are reproduced below, in addition to being in the full Summary of Recommendations.

Recommendation 3: That as far as practicable, monitoring should be extended into the catchments and sub-catchments with the highest nutrient inputs to characterise any 'point' sources that may become a priority for management.

Recommendation 10: That EBOP urgently investigate options to strip phosphorus from streams that have high levels of phosphorus coming from springs and other sources, starting with the Waingaehe, Hamurana and Awahou streams.

Recommendation 11: That EBOP and RDC divert the flow from the Tikitere geothermal field to the Rotorua District Sewage Treatment Plant as a high priority.

Recommendation 12: That EBOP and RDC establish a zero target for nutrient inputs from the Rotorua Land Treatment Site to Lake Rotorua.

Recommendation 16: That EBOP identifies opportunities for constructed and enhanced natural wetlands to strip nutrients in the catchments and on the foreshores of Lake Rotorua and, as a high priority, construct or enhance such wetlands where there are opportunities to intercept high nutrient level base-flows.

Recommendation 18: That EBOP continues to support investigations that are aimed at clarifying the relationships between catchment and internal lake nutrient loads, lakes water quality and algal blooms.

Recommendation 20: That EBOP focuses as a priority in the short-term on studies and investigations leading to management measures that reduce lake total nitrogen and lake total phosphorus concentrations and produce a high N:P ratio of 20-22:1 or greater in Lakes Rotorua and Rotoiti, especially during the late spring, summer and autumn period.

Recommendation 21: That EBOP focuses in the short-term on monitoring of the stratification and destratification, and sediment resuspension events over the most common meteorological conditions in Lake Rotorua, including concurrent monitoring of the Ohau Channel to provide critical data for management.

Recommendation 22: That EBOP uses the data collected from implementation of Recommendation 21 to interactively carry out hydrodynamic modelling to quantify the quantities and timing of nutrients and phytoplankton transport through the Ohau Channel into Lake Rotoiti.

Recommendation 25: That EBOP continues to pursue as a high priority further monitoring and hydrodynamic modelling of the flow of the Ohau Channel into Lake Rotoiti as the basis for short-term management decisions on manipulation of this flow to improve the health of the lake and reduce or eliminate blue-green blooms.

Recommendation 26: That EBOP and RDC initiate engineering design and construction of temporary groynes on either side of the entrance of the Ohau Channel to minimise transportation of suspended material into Lake Rotoiti. Permanent structures can be constructed when the best configuration to minimise transport of suspended material is determined.

Recommendation 27: That EBOP and RDC begin engineering investigations and designs for trial structures to divert the Ohau Channel to the Kaituna and/or Okawa Bay as soon as possible, and interactively with the monitoring and modelling work that has been recommended in Recommendations 24 and 25, so that work on trial structures can begin as soon as resource consent approvals have been obtained.

Recommendation 28: That EBOP builds temporary structures to test the favoured options for diversion of the Ohau Channel to the Kaituna River and/or Okawa Bay when resource consent approvals have been obtained, and monitor the trials to further refine the hydrodynamic models for the channel flows and the western end of Lake Rotoiti before building any more permanent diversion structures.

Recommendation 29: That EBOP continues trials with nutrient stripping materials such as Alum and Phoslock and begins trials with direct oxygenation separately and in combination, to determine the best methods of using these methods to reduce nitrogen and phosphorus in the lakes and manipulate the N:P Ratio.

Recommendation 30: That the use of oxygenation and nutrient stripping materials be built into the modelling proposed in Recommendation 27 so as to inform any trials and help predict the best options for using these management methods individually and together in Lakes Rotorua and Rotoiti.

Recommendation 31: That EBOP and RDC investigate the use of oil pollution booms to contain and concentrate the worst algal blooms, and the use of 'suction trucks' to remove the worst of the accumulations.

SUMMARY OF RECOMMENDATIONS

Recommendation 1: That the Rotorua Lakes Restoration and Protection Programme is written up as a brief document to explain how all of the elements, from Research and Monitoring to Regulations, are brought together to produce and implement the best management options through Lakes Action Plans.

Recommendation 2: That Environment Bay of Plenty (EBOP) considers developing supplementary Lake Quality Indicators to focus on the factors that cause algal problems in the Rotorua Lakes that will complement the Trophic Level Index.

Recommendation 3: That as far as practicable, monitoring should be extended into the catchments and sub-catchments with the highest nutrient inputs to characterise any 'point' sources that may become a priority for management.

Recommendation 4: EBOP should work with the Western Australian Department of the Environment to investigate the use of its catchment monitoring system in the Lake Rotorua Catchments to measure the efficacy of catchment management measures.

Recommendation 5: EBOP should consider developing a simple catchment model that can be cooperatively used by landowners and community groups to see how nutrients move through their catchments as an aid to understanding how they can be managed.

Recommendation 6: EBOP should consider carrying out hydrogeological investigations to determine the chemistry of the younger deeper groundwater and use this and other information to develop a 'mid-level catchment model', to enable land managers to estimate how proposed land use changes and/or mitigation measures will modify nutrient concentrations in the deeper groundwater.

Recommendation 7: EBOP and Rotorua District Council (RDC) should carry out more detailed monitoring of storm-flows into Lake Rotorua, especially in the late spring, summer, autumn period to determine if these 'events' are initiating or prolonging blue-green blooms.

Recommendation 8: That EBOP approaches the Western Australian Department of the Environment to form a partnership to jointly trial and develop Phoslock for nutrient stripping in catchments and water bodies, separately and in conjunction with other nutrient management methods.

Recommendation 9: EBOP should investigate the use of Allaphanic soils and related clays for use in stripping phosphorus and as a substrate for preparation of Phoslock.

Recommendation 10: That EBOP urgently investigate options to strip phosphorus from streams that have high levels of phosphorus coming from springs and other sources, starting with the Waingaehe, Hamurana and Awahou streams.

Recommendation 11: That EBOP and RDC divert the flow from the Tikitere geothermal field to the Rotorua District Sewage Treatment Plant as a high priority.

Recommendation 12: That EBOP and RDC establish a zero target for nutrient inputs from the Rotorua Land Treatment Site to Lake Rotorua.

Recommendation 13: Repeat studies of the nutrient stripping processes and pathways at the Rotorua Land Treatment Site should be undertaken under the new spray regime to determine the nutrient stripping effectiveness.

Recommendation 14: Wetlands within and below the Rotorua Land Treatment Site should be modified if necessary to strip any residual nutrients 'leaking' from the spray irrigation areas.

Recommendation 15: The RDC should continue to monitor nutrient levels above and below the Rotorua Land Treatment Site to measure its efficiency at stripping nutrients as spray volumes are increased to cope with increasing population.

Recommendation 16: That EBOP identifies opportunities for constructed and enhanced natural wetlands to strip nutrients in the catchments and on the foreshores of Lake Rotorua and, as a high priority, construct or enhance such wetlands where there are opportunities to intercept high nutrient level base-flows.

Recommendation 17: EBOP and RDC could consider the use of certified and contractually managed Alternative Treatment Units with nutrient stripping capacity in nutrient sensitive areas where reticulated sewerage is too costly or too difficult.

Recommendation 18: That EBOP continues to support investigations that are aimed at clarifying the relationships between catchment and internal lake nutrient loads, lakes water quality and algal blooms.

Recommendation 19: That EBOP focuses in the short-term on investigations that will set clear targets for:

- ***An annual total catchment load for Lake Rotorua for phosphorus and nitrogen that builds in capacity for future development around the lake.***
- ***Annual catchment phosphorus and nitrogen load targets for each of the main Lake Rotorua catchments.***
- ***Internal lake phosphorus and nitrogen load targets for Lakes Rotorua and Rotoiti.***
- ***Annual average stream phosphorus and nitrogen concentration targets for each of the nine Lake Rotorua catchments.***
- ***Annual average lake water quality phosphorus and nitrogen concentration targets for Lakes Rotorua and Rotoiti.***

Recommendation 20: That EBOP focuses as a priority in the short-term on studies and investigations leading to management measures that reduce lake total nitrogen and lake total phosphorus concentrations and produce a high N:P ratio of 20-22:1 or greater in Lakes Rotorua and Rotoiti, especially during the late spring, summer and autumn period.

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Recommendation 22: That EBOP uses the data collected from implementation of Recommendation 21 to interactively carry out hydrodynamic modelling to quantify the quantities and timing of nutrients and phytoplankton transport through the Ohau Channel into Lake Rotoiti.

Recommendation 23: That EBOP initiates studies to characterise the geothermal inputs to Lake Rotoiti, especially to determine if they contribute nutrients and how they interact with other hydrodynamic processes to cause algal blooms.

Recommendation 24: EBOP should work with NIWA and Professor David Hamilton to establish a more frequent monitoring regime for Lakes Rotorua and Rotoiti to gain a better understanding of the processes that cause algal blooms, especially blue-green blooms, as a basis for management measures that will best eliminate or reduce them.

Recommendation 25: That EBOP continues to pursue as a high priority further monitoring and hydrodynamic modelling of the flow of the Ohau Channel into Lake Rotoiti as the basis for short-term management decisions on manipulation of this flow to improve the health of the lake and reduce or eliminate blue-green blooms.

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Recommendation 30: That the use of oxygenation and nutrient stripping materials be built into the modelling proposed in Recommendation 27 so as to inform any trials and help predict the best options for using these management methods individually and together in Lakes Rotorua and Rotoiti.

Recommendation 31: That EBOP and RDC investigate the use of oil pollution booms to contain and concentrate the worst algal blooms, and the use of 'suction trucks' to remove the worst of the accumulations.

Recommendation 32: That EBOP and the RDC, in liaison with the appropriate authorities, investigate the potential use of herbicides to control blue-green algal blooms.

Recommendation 33: That EBOP considers working with NIWA to develop an algal bloom risk prediction capacity for both longer periods (three months) and shorter periods (10 days or less).

Recommendation 34: That EBOP continues to work with Environment Waikato, and other organisations carrying out lake investigations, to share information and contribute to joint studies and management trials where appropriate.

Recommendation 35: That EBOP considers ways of better coordinating and focusing the scientific investigations that will underpin the preferred short- and longer-term management measures.

Recommendation 36: That EBOP continues to work with Fish and Game New Zealand and the University of Waikato to support investigations into the impact of the decline of Lakes Rotorua and Rotoiti on the trout fishery.

Recommendation 37: That EBOP works with other organisations, such as the Department of Conservation and the Ministry for the Environment, to develop readily measurable lake ecosystem health indicators as an aid to measure the success of short- and longer-term management measures.

A REVIEW OF SHORT-TERM MANAGEMENT OPTIONS FOR LAKES ROTORUA AND ROTOITI

1 PURPOSE AND METHODOLOGY

Dr Hamilton was engaged to evaluate the range of current, proposed and potential actions to manage the short-term symptoms and causes of water quality problems, particularly in Lakes Rotorua and Rotoiti, and provide a written report to the Secretary for the Environment. This work follows considerable concern about relatively large blooms of toxic blue-green algae which closed Lake Rotoiti from around 20 January to 15 March 2003. Only a few bays were closed in Lake Rotorua, but this was still enough to add to the community concern.

The work was undertaken by liaising closely with management, technical and scientific staff in Environment Bay of Plenty (EBOP), Rotorua District Council (RDC), University of Waikato, the National Institute of Water and Atmospheric Research and relevant central government agencies. Valuable advice and information was obtained through this methodology, which enabled this report to be written.

A number of the recommendations in the report were underway or being considered, or have begun to be implemented during preparation of the report. This occurred in part because of the close working relationship that was developed between the author and officers from EBOP, especially Paul Dell, the Lakes Project Coordinator.

As a result, it is difficult to say which recommendations are entirely new and, accordingly, it is not the author’s intention to try and separate each recommendation into a category of ‘newness’. Rather, it is intended that this report and its recommendations support and extend EBOP’s excellent approach to management of Lakes Rotorua and Rotoiti, and introduce the concepts of ‘adaptive management’ and a ‘systems’ approach.

2 WELCOME TO ROTORUA

Rotorua is the most visited tourist destination (1.2 million visitors per year) in New Zealand and its lakes are prized for recreation and fishing. Lake Rotoiti is said to be the second most important lake for trout fishing, and is important for trophy fishing. The district is 2708 square kilometres with a population of around 69,000 (European 65%, Maori 30% and other 5%).

Rotorua has a mild climate with an average summer temperature of 24.7 and an average winter temperature of 12.5 degrees Celsius respectively. The rainfall is an average of 1421 millimetres annually with the wettest months in June, July and August.

The city and district of Rotorua take their name from the lake that dominates them. Rotorua is a Maori word that means second lake (roto: lake and rua: two). The full name given to the lake is Rotorua-nui-a-kahu, the Big or Great Second Lake of Kahu. It was the second lake to be discovered by Ihenga who named it after his father-in-law, Kahu-mata-momoe.

The countryside around Lake Rotorua was originally settled around AD 1350 by the descendants of the Polynesian voyagers, who came to New Zealand from the traditional homeland of Hawaiki, in a canoe called ‘Te Arawa’. Their principal settlements were at Ohinemutu and Whakarewarewa.

With European settlement Rotorua became a destination for visitors wanting to relax and improve their health in the mineral waters that 'bubbled' from the ground, although these benefits were well known to the first settlers. Now, host to some of the world's most incredible earth forces, Rotorua boasts an array of 'icon' experiences, which together encapsulate the spirit of this remarkable country.

With the Europeans came more intensive agriculture and much of the area around the lakes now boasts some of the most productive and efficient sheep and dairy farming in the world. Sadly, it is this intensification of land uses, together with urban, and tourist development, that is now causing the problems for the lakes that is the focus of this report.

Even so, there is still enveloping warmth, an undeniable spirit and a deep sense of history that comes from the Maori experiences and their close relationship with the land and the lakes. This sensation, called *manaakitanga,* is both a challenge and a responsibility for all of us. It charges us with guardianship over the land, the lakes, the treasures, and all of the people.

3 LEADERSHIP AND RESPONSIBILITY FOR LAKES MANAGEMENT – ENVIRONMENT BAY OF PLENTY AND ROTORUA DISTRICT COUNCIL

New Zealand is a leader in natural resource management having recognised early, by world standards, that effective management of our precious natural resources (land, soils, water, lakes, rivers, estuaries, oceans, vegetation and animals) needs a coordinated and integrated approach. Through its Resource Management Act, New Zealand has established a number of processes to achieve this approach, including the establishment of 16 regional councils to achieve integration at the regional level.

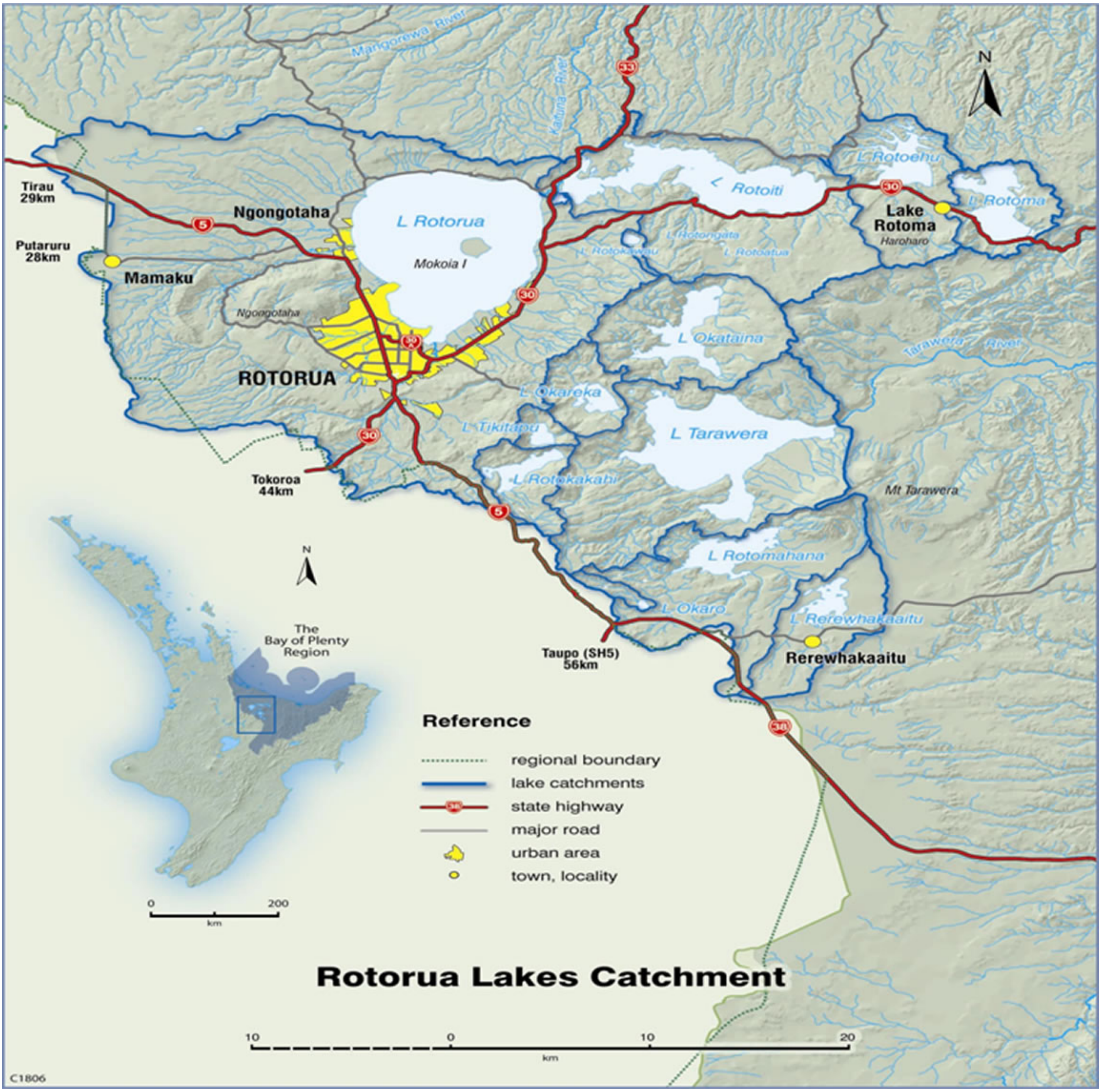
Environment Bay of Plenty (EBOP) is the council charged with overall water quality and catchment management of the Rotorua Lakes as part of its broader role in sustainably managing all of the natural resources in the Bay of Plenty region. The Rotorua District Council (RDC) plays an important role in land use planning and management, including certain specific aspects such as sewerage and urban storm-water management.

3.1 Regional Management Framework – The Proposed Regional Water and Land Plan

Management of the Rotorua Lakes, and especially Lakes Rotorua and Rotoiti, come under the Regional Water and Land Plan. This is nearly completed after an extensive public consultation period although the decisions of the Council will still be open to appeal. This comprehensive plan covers management of land and water resources under the Resource Management Act 1991, including:

- Land and Water Integration
- Discharges to Water and Land
- Beds of Rivers, Streams and Lakes
- Geothermal Resources
- Wetlands
- Regional Rules
- Financial Contributions
- Information to be Submitted with resource consent Applications
- Anticipated Environmental Results
- Cross Boundary Issues
- Plan Review Process.

Figure 1. Rotorua Lakes and Their Catchments



The Proposed Regional Water and Land Plan (the Water and Land Plan) covers all the area in the Bay of Plenty Regional Council boundary, excluding the coastal marine area, the areas covered by the Operative Rotorua Geothermal Regional Plan and the proposed Regional Plan for the Tarawera River Catchment, which is shortly to be made operative. The Water and Land Plan covers land (including soil), water (including rivers, streams, lakes, wetlands, modified watercourses and groundwater) and geothermal resources in the Bay of Plenty. It addresses issues relating to the adverse environmental effects of the use and development of land, water and geothermal resources that are within the Scope of EBOP's functions and responsibilities under the Resource Management Act 1991.

The Purpose of the Plan is to achieve the following aims:

a) promote the sustainable management of land, water and geothermal resources

b) achieve the integrated management of land and water resources

c) maintain or improve environmental quality in the Bay of Plenty Region

d) protect existing high quality environment and resources

e) protect sensitive receiving environments

f) sustain the life-supporting capacity of soil, water and ecosystems

g) maintain or enhance the heritage values of land, water and geothermal resources

h) establish appropriate environmental standards to achieve c) to f)

i) address the adverse environmental effects of the use and development of land, water and geothermal resources

j) take a permissive approach to the use and development of land, water and geothermal resources where it is consistent with a) to g).

The links between the identified Values and Environmental Standards are set out in a useful figure on page 4 of the Proposed Plan.

Considerable attention is paid to the strong relationship of the Maori people to the land and waters and the concepts of kaitiakitanga and mauri. section 2 of the Proposed Plan begins with a quote of the Maori aphorism, "Mankind perishes, the land remains eternal", as this epitomises Maori beliefs on kaitiakitanga or guardianship of the land and its resources.

Broadly speaking kaitiakitanga involves a wide set of practices based on a world and regional environmental view that includes the ideas and principles of:

- guardianship
- care
- wise management
- that the condition of the natural resources indicates the state of their own mauri
- maintenance of the spiritual and cultural aspects of the natural resources
- protection, enhancement and restoration of the mauri
- appropriate development of resources where necessary.

As mentioned earlier, mauri is the life force present in all animate and inanimate objects. It binds one resource to every other element in a natural order, both physical and spiritual, and pervades and influences all that we do.

Thus the Regional Land and Water Plan will contain an iwi and pakeha view of integrated natural resource and ecosystem management, which is consistent with, and embraces the best approaches in the world. These deeply held views and proposed approaches in the Land and Water Plan provide a very good framework for consideration of how the Rotorua Lakes can be better protected, restored and managed.

While the Proposed Land and Water Plan goes into considerable detail on the methods and processes that are proposed to be used, it is important to now set the specific context for protection and restoration of the Rotorua Lakes.

3.2 Strategy for the lakes of the Rotorua district – '*Te Kaupapa mo Nga Taonga o Rotorua'* (Protecting the Jewels in the Crown of the Lakes of the Rotorua district)

This important document, which was developed and adopted by Environment Bay of Plenty, Rotorua District Council and the Te Arawa Maori Trust Board, sets out a Vision, Goals and Priorities for protection and restoration of the beautiful Rotorua Lakes. It was preceded by a public discussion document entitled *Towards a Te Arawa Lakes Strategy,* which identified a significant range of concerns and interests in the long-term welfare of the lakes. To quote from the Forward:

"This strategy is not a statutory document under either the Resource Management Act or the Local Government Act or any other Act. Our aim is rather to identify and address the problems arising from a lack of coordination 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 effectively and efficiently as possible. We see the Lakes Management Strategy as being an ongoing process with regular review and accountability for achieving key goals that will make a difference and protect the lakes.

We acknowledge that various authorities are carrying out a variety of ongoing activities aimed at protecting the lakes. However, we believe that there is a pressing need to unite efforts and resources to achieve sustainable lake and catchment management, so that this and future generations can continue to use and enjoy the lakes. For the most effective use of community resources, we believe that it is essential to establish and maintain an overview group with a mandate to ensure accountability and action. We seek not only to identify what needs to be done but also to identify the costs involved and that the greatest benefit can be achieved for each dollar spent in meeting these goals."

The **Vision** for the lakes is:

"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."

Fourteen **key goals** are set out:

Protection

1) address the causes of lake water pollution

2) deal with pollution from septic tanks

3) determine the extent of pollution from storm-water runoff

4) define and refine lake water quality standards

5) examine the status and future of the catchment bank protection scheme

6) address plant and animal pest problems

7) determine present and future reserve areas

Use

8) establish an urban development policy

9) establish a rural development policy

Enjoyment

10) develop a recreation strategy

11) monitor and report on recreation activities

12) define esplanade reserve areas to ensure public access to each lake

Management Goals

13) establish in partnership with Te Arawa a co-management framework that achieves the best integrated management

14) establish meaningful and binding working relationships with the iwi/hapu and their ancestral lakes.

The aspects covered in the Strategy as set out in the 'Parts' are:

I. Establishing a Community Vision

II. The Elements of the Vision

III. Key Goals to Achieve the Vision

IV. Targeting Lake Priorities

V. Meeting the Costs

VI. Ensuring Accountability

VII. Putting it All Together

Appendix A contains a 'Schedule of Tasks' for each of the 14 Key Goals. Appendix B provides a summary for each of the lakes covering a description of the lake and its catchment, a vision for the lake and its catchment, issues facing the lake, possible options for addressing the issues, analysis of options and recommended actions. It was useful to review these sections for Lakes Rotorua and Rotoiti in the light of this report.

Overall coordination and direction for the Strategy is vested in the Lakes Strategy Joint Committee, comprising the Chair of the Te Arawa Maori Trust Board, the Chair of Environment Bay of Plenty and the Mayor of Rotorua District Council plus a further representative from each of the three organisations. This is a key body bringing the three responsible stakeholders and organisations together to ensure all of the work is done cost effectively and to achieve the goals that have been set. Paul Dell of Environment Bay of Plenty has been appointed as the Coordinator for implementation of the strategy by the three organisations.

The management structure provides for direct involvement of the Maori people at the highest level and this will be important in view of the special relationship that the Te Arawa have with the lands surrounding the lakes and the lakes themselves. It will be especially important in the early identification of sites that will be affected by management measures that are significant for Te Arawa.

3.3 Rotorua Lakes Restoration and Protection Programme

As can be seen from sections 3.1 and 3.2, there is a strong strategic, legal and policy framework in place for protection, restoration and management of the Rotorua lakes. A more detailed programme for all of the supporting information and processes that will be needed is currently being developed and has been well summarised in papers presented by Paul Dell and John McIntosh at the Rotorua Lakes 2003 Symposium held in Rotorua on 9-10 October 2003 (Refs 1 & 2).

These papers summarise the overall approach through the Strategy for the Lakes of the Rotorua district and the Water and Land Plan. As well as the aspects of these two documents summarised above, the following aspects are important:

The Strategy identifies seven key projects:

- Water quality
- Catchment and riparian protection
- Reserves and recreation
- Urban and rural growth management
- Water recreation
- Co-management
- Iwi liaison

The Water and Land Plan sets Trophic Level Index (TLI) targets for each lake. The TLI, which is discussed further below, integrates measures of key nutrients and algal production over a year through averaging of the following measurements:

- Chorophyll a, which is a measure of the density of micro algae or phytoplankton blooms
- Seechi Disc Depth, which is a measure of water clarity
- Total Phosphorus, which is a measure of the nutrient phosphorus in its various forms that may be available for plant and algae growth
- Total Nitrogen, which is a measure of the nutrient nitrogen in its various forms that may be available for plant and algae growth.

The TLI is a useful measure of the trophic status (level of nutrient enrichment and plant growth) for each lake and provides a good target for the community. It is not such a good indicator for overall ecosystem health or to understand the causes of particular events, such as the blue-green algal blooms in Lakes Rotorua and Rotoiti last summer. EBOP clearly understands these distinctions and is taking them into account in the development of Lake Action Plans and implementation of the agreed management options.

In this context, the Rotorua Lakes Restoration and Protection programme has not been fully documented as it is a 'work in progress'. It is well summarised in Figure 2 on page 15, which is taken from the Dell paper (Ref 1). As can be seen from Figure 2 there are a large number of elements that need to be brought together to implement the Water and Land Plan and the 'Lakes Strategy', including:

1) reviews of **completed research and monitoring** to identify information that improves the understanding of processes in the catchments and lakes, that in turn will lead to viable management options

2) **ongoing research and monitoring** that is targeted towards understanding key processes and supporting the best management options

3) **action plans** for each lake that will set out the best management options for implementation

4) identification of the **funding** requirements, including economic analyses to determine the most cost-effective approaches and negotiations to determine the best sources of funding

5) identification of the **works** that will be needed to implement the best management options, including the investigations to determine how to best implement them

6) identification of the **'best management practices'** that can be used to reduce or eliminate nutrient inputs from the various land uses and practices in the catchments, and how these can best be implemented in collaboration with landowners and managers

7) **education and communication** to keep the community fully informed and appropriately involved at all stages

8) use of **regulations** as part of a 'toolbox' of management options to complement and strengthen the management approach when appropriate and needed.

While all of the work that makes up the Rotorua Lakes Restoration and Protection programme is evolving over time, it would be useful to write the programme up as a document that explains the purpose of each element, how each element builds on and implements the Water and Land Plan and Lakes Strategy, how each element is being done, who is involved and how all of the elements are brought together in the action plans.

Recommendation 1: That the Rotorua Lakes Restoration and Protection programme is written up as a brief document to explain how all of the elements, from research and monitoring to regulations, are brought together to produce and implement the best management options through lakes action plans.

3.4 Lake action plans

A key step in implementing the Water and Land Plan and Lakes Strategy for the lakes of the Rotorua district is the development in close consultation with all stakeholders, of action plans for each lake where the current TLI exceeds the target TLI. These are typically preceded by 'Draft Working Papers', to set out the issues and options and then a process, including a full SWOT analysis with the community, to identify the preferred management options. The result is the lake action plan, which is then progressively implemented.

Each action plan will:

- define the existing Catchment Nutrient Budget
- determine what level of nutrient inputs is sustainable
- identify agreed nutrient reduction targets
- determine actions to achieve the agreed targets.

These processes are led by a working party made up of local stakeholders and representatives of relevant organisations. Perhaps the most advanced action plan is that for Lake Okareka where four main management options have been identified:

1) reticulated sewerage to eliminate nutrient inputs from septic tanks

2) retirement and revegetation of stream and lake foreshores to reduce nutrient inputs and improve ecosystem health

3) use of enhanced natural wetlands and artificial wetlands to reduce nutrient and sediment inputs

4) ‘in lake’ treatments such as dosing with alum and oxygenation to reduce the internal availability of nutrients and frequency of low oxygen conditions.

These action plans will be an important step involving all of the key stakeholders, including the community, in identifying and then implementing the best management options for each lake.

A single action plan for Lakes Rotorua and Rotoiti is being developed, because of the way they are strongly linked by the Ohau Channel, and should be ready early in 2004.

Figure 2. Rotorua Lakes Restoration & Protection Programme (*Updated October 2003*)

Completed Research & Monitoring 1995 onwards*

(See attached sheet)

* Although the most recent reports are from 1995 the monitoring data is utilised from the earliest information available.

Ongoing Research & Monitoring

- Chair in Lakes Management & Restoration
  - In Lake Modelling
  - Student Research
- Contract Research
  - NPLAS
  - Nutrient Assessments
  - Nutrient Reduction Targets
  - Treatment Wall Trial
  - Wetland Design & Trial
  - Groundwater flow and age assessment
  - Flocullation trial
- Water Quality Monitoring
- Algal Monitoring
- Pollen
- Lake Level Impacts

Action Plans

- **Statutory**
  - Okareka
  - Rotoehu
  - Okaro
  - Rotorua/Rotoiti
- **Future**
  - Rerewhakaaitu
  - Tarawera
  - Rotoma
  - Okataina
  - Tikitapu
  - Rotokakahi
  - Rotomahana

Funding

- Policy Review
  - EBOP Policy
  - RDC Policy
- Economic Assessment
  - Financial Incentives
  - Land Purchase
  - Entitlement
- Funding sources
  - Govt
  - Regional
  - District
  - Landowners

Works

- Sewage treatment
- Riparian Management/
- Fencing
- Treatment Walls
- Wetlands treatment
- Flocullation
- Change in land-use
- Engineering Options
  - Aeration
  - Diversion
  - S/W Design
  - Dredging
  - Syphon

BMP's

- On site effluent treatment systems
- Pasture nutrient management
  - Animals
  - Fertliser
  - Effluent
- Urban S/W
- Maintenance
- Domestic nutrient management
- Wildlife Management

Education & Communication

- Communication Strategy
- Fact Sheets
  - Lake Quality
  - Land Processes
  - Lake Algae
  - Wetlands
  - Monitoring /TLI
  - Farm Nutrient Assessment
  - Effluent Management
- Lakes Education resource kit
- Booklet living near lakes

Regulations

- Regional Water & Land Plan & changes
  - TLI
  - Stock in
  - Waterways
  - Nutrient rules
  - Action Plans
- District Plan & Changes
- On Site Effluent Treatment Plan review
- Consents
- Consent Compliance

3.5 Lakes water quality – Environment Bay of Plenty strategic and policy approach

While section 6 provides a fuller summary of the historical monitoring and investigations that have been carried out in Lakes Rotorua and Rotoiti, it is important to first summarise the basis that EBOP uses to set water quality targets. This is well done in EBOP's publication, *Rotorua Lakes Water Quality 2002* (Ref 3), which is briefly summarised here.

The introduction of the Executive Summary of the report usefully sets out the basis for EBOP's monitoring, which has been undertaken since 1990, and how this leads to the targets set for each lake. This is reproduced below:

"The Natural Environment Regional Monitoring Network (NERMN) is Environment Bay of Plenty's programme for general 'state of the environment' monitoring. The programme is divided into modules with lake monitoring budgeted as a separate module. Lake monitoring results are reported annually because of their relevance to lake management issues.

The major thrust in reporting the lakes results is calculation of an annual figure for the Trophic Level Index (TLI). This is composed of four interrelated factors that come together and form a sensitive indicator of lake water quality. The four factors are total phosphorus, total nitrogen, Secchi disc depth (clarity) and chlorophyll a (amount of algae).

In the Proposed Regional Water and Land Plan (PRW&LP), the TLI has been used as one method of assessing lake quality in the classification of waters. A baseline quality has been set for each lake at a specific TLI level. A trigger has been proposed using the baseline, so that land management options for reducing nutrient inputs can be evaluated when a lake is definitely deteriorating."

EBOP also considers the Percent Annual Change, which is the average annual rate of change of the Secchi depth, Chorophyll *a*, total nitrogen, total phosphorus and the oxygen depletion rate (HVOD). Both measures have been used to document changes in all of the lakes as set out in Tables 1 and 2 in *Rotorua Lakes Water Quality 2002*, which are reproduced as Appendix 1 and 2 in this report. The shaded area in Table 2 in Appendix 2 shows the lakes that are most severely degraded and are priorities for development of action plans.

Table 1 shows the annual average TLI values and Water and Land Plan Targets for Lakes Rotorua and Rotoiti as presented at the Rotorua Lakes 2003 Symposium (Ref 3).

Table 1. Current and Management Target Trophic Level Indices for Lakes Rotorua and Rotoiti

Lake	TLI in Objective 10	Current TLI (at 2002)
Rotorua	**4.2**	**4.6**
Rotoiti	**3.5**	**3.9**

As can be seen in Appendices 1 and 2, no overall trend has been detected in the TLI over the reporting periods. But the *Rotorua Lakes Water Quality 2002* document also provides graphical summaries of the Secchi disc, Chorophyll *a*, total nitrogen and total phosphorus concentrations for all of the monthly monitoring from 1990 to

2002. This is valuable data and even a cursory examination shows a number of cause and effect relationships between the four parameters.

Cause and effect relationships, especially between nitrogen, phosphorus and Chlorophyll *a*, are important because they indicate 'events' that have caused particular algal blooms. An understanding of these events is vital if targeted management measures are to be put in place and this is discussed further in section 6.

EBOP is aware that the TLI measurements are just one way of representing the condition of the lakes and are to be commended on the detailed monitoring it is doing and reporting. Another useful method for characterising the state of the Rotorua lakes has been developed by Professor David Hamilton of Waikato University and this is summarised below.

3.6 Anoxia as a measure of lake health

Professor David Hamilton, who holds the Environment BOP Chair in Lakes Management and Restoration, has analysed all of the available data on the Rotorua lakes (paper in production) and developed four categories based on mixing regimes and dissolved oxygen. Professor Hamilton's work is presented in this section as it is part of EBOP's strategic approach to managing and restoring the lakes, including the creation of the Waikato University Chair to carry out key research to support the development of management options.

The four categories and the lakes that fall into these categories are shown in Table 2.

Professor Hamilton's analysis, as shown in Table 2, clearly shows that Lakes Okaro and Rotoiti are degraded and that conditions in them, especially from late spring through to autumn, are likely to cause algal blooms and stress fish and other aquatic fauna. Lake Rotorua is a shallower lake that is eutrophic and, during periods of stratification, significant amounts of nutrients are released from the sediments and become available for algal blooms. Professor Hamilton is leading other studies that will aid in lakes management and these are discussed further in section 7.

Table 2. Classification of the Rotorua lakes according to their mixing regimes and levels of dissolved oxygen

ROTORUA LAKES CATEGORY	LAKES WITHIN CATEGORIES
Lakes that undergo seasonal stratification of temperature and moderate levels of oxygen depletion. These lakes show trends of reduced levels of oxygen in the bottom waters compared to previous years.	**Okareka** **Tikitapu** **Okataina**
Lakes that show a strong seasonal stratification of temperature but where oxygen levels in bottom waters rarely decline below 50% of saturation. These lakes have remained relatively stable through time, especially with respect to the duration and extent of seasonal decline in oxygen.	**Tarawera** **Rotoma** **Rotomohana**
Lakes that are strongly stratified but undergo severe seasonal decline in oxygen to the extent that the entire bottom layer (hypolimnion) is anoxic early in the stratified period. These lakes are eutrophic and were originally well oxygenated over the full year but have suffered severe declines in oxygen in their bottom waters over the last 30 to 40 years.	**Okaro** **Rotoiti**
Lakes that are shallower that do not stratify seasonally but rather, intermittently, on time scales of a few hours to several days. These lakes are mesotrophic to eutrophic and the deoxygenation events contribute significant inputs of nitrogen and phosphate to the water column, that over a year are likely to exceed those arising from point and diffuse sources in the catchments.	**Rotorua** **Rotoehu** **Rerewhakaaitu**

3.7 Lake quality indicators

While the TLI is a useful indicator for targeting overall lakes water quality, it has limitations and, as identified by EBOP, needs to be supplemented by other measures to present a full picture of the condition of the lakes and hence the priorities for management. Based on Professor Hamilton's recent work and consideration of other factors such as the concentrations of nutrients coming from the catchments and broader ecosystem health, it would be desirable to have additional 'lake quality indicators' to represent the key factors that affect lake quality. Such indicators could include shorter-term concentrations of nutrients in the water column at critical times for algal blooms and the N:P Ratio.

Initially, any indicators that are developed should focus on the factors that cause algal problems in the lakes, but consideration should be given in the near future to broader ecosystem indicators.

Recommendation 2: That Environment Bay of Plenty (EBOP) considers developing supplementary lake quality indicators to focus on the factors that cause algal problems in the Rotorua Lakes that will complement the Trophic Level Index.

4 WHOLE SYSTEMS UNDERSTANDING AND ADAPTIVE MANAGEMENT

Even though the focus of this report is to recommend on short-term management options to address the symptoms of algal blooms in Lakes Rotorua and Rotoiti, it is important to place this work in the context of a 'whole systems' approach. This is because in complex natural systems many factors interact with each other and it is important to understand how changing one aspect could affect another aspect.

Equally it is important to look at all of the issues and processes in a system, even when considering just 'short-term' aspects so that any short-term management measures that are being considered are placed in the range and sequence of all of the proposed management measures.

It is also vital to understand all of the elements and interactions of the system that will be important for management. There are many examples around the world where incomplete understanding has led to costly and environmentally damaging mistakes.

Finally, it is important to get in and manage those issues that can be managed in the short-term because there is enough understanding to provide confidence that the proposed management will succeed. These three important principles or processes are discussed in more detail below in relation to the problems in Lakes Rotorua and Rotoiti.

4.1 Whole systems and understanding

Appendix 3 is a foldout graphic which shows a 'whole system' approach for Lakes Rotorua and Rotoiti. This diagram and the processes that interact between and within the lakes and the catchments lead to both the understanding that is necessary for management, and the prioritising of management options over the short (1 to 2 years), medium (2 to 4 years) and longer term (more than 4 years). In particular, they lead to the recommendations for short-term studies where there are critical gaps in understanding and the recommendations for short- and medium-term management measures that are set out in section 7.

Lakes Rotorua and Rotoiti are closely interconnected by the Ohau Channel and some 50% to 80% of the nutrients going into Lake Rotoiti come from Lake Rotorua. Lake Rotoiti's catchments are relatively small and there are relatively low levels of intensive land use, whereas Lake Rotorua has nine major catchments with significantly more intensive land uses. Thus for short- and medium-term management measures the focus needs to be on Lake Rotorua and its catchments.

Appendix 3 shows that two levels of understanding are needed; an understanding of the processes in the catchments that cause the nutrient inputs to the lakes and an understanding of the processes in the lakes that mobilise the nutrients and cause the algal blooms. These processes are discussed in more detail in section 7 as they lead to the specific recommendations in that section.

Research and investigations are normally tailored to provide the level of understanding necessary to trial or implement management options. The role of the responsible manager is to ensure that limited public funds are focused and used wisely to produce the required level of understanding, and EBOP is doing a good job in this respect, although a recommendation for some fine tuning is made in section 7.

Whether or not further research is done to more completely understand particular systems is a matter for negotiation and availability of funding. Often management specific applied research is carried out as part of a larger package of broader research, with multiple funding to develop a much fuller understanding of the system. This is valuable and can lead to better goals and targets for parts of the system, but the prime concern of the manager will always be to understand the system enough to sustainably manage it for agreed goals and outcomes.

4.2 Adaptive management

Adaptive management is a process by which understanding of systems is iteratively used to apply and test management approaches until the best set of management options is reached. It is based on the principle that in most cases there will never (within reasonable costs and timeframes) be a 'complete' understanding of complex systems and that it is much better to build understanding by a combination of targeted investigations and adaptive trials of management approaches. Or, to put it crudely, it is very much the 'suck it and see' approach, but never jumping so far ahead that real problems occur.

In the case of Lakes Rotorua and Rotoiti, the steps for adaptive management could be:

1) **Understanding** – do we know enough to understand a process or set of processes – within reason?

2) **Management** – do we have enough confidence to test some management options and measure how they perform?

3) **Trial Management** – where we carry out larger scale trials and measure the effects and responses

4) **Sustainable Management** – when the agreed management option is implemented, but is then monitored and fine-tuned if necessary.

Using this process and agreeing on the best management options over time as adequate understanding is developed, will result in a sequence of management decisions and implementation of agreed management measures over the short, medium and longer term.

The recommendations in this report for short-term management options to tackle the symptoms of the recent algal blooms must be seen in this context as part of a whole system approach, and not just a knee-jerk reaction to a problem over one summer. It is also vital that short-term management options are not seen as an excuse for delaying or avoiding longer term and possibly harder measures that need to be undertaken to restore and manage the lakes to agreed water quality and ecological standards.

5 A SHORT HISTORY OF MONITORING AND INVESTIGATIONS AND THE IMPLICATIONS FOR MANAGEMENT

This summary of monitoring and investigations in Lakes Rotorua and Rotoiti is largely taken from a more extensive draft paper on ‘Lake Rotorua Nutrient Load Targets’. This is being prepared for EBOP by Dr Kit Rutherford who is based at NIWA in Hamilton (Ref 4). This important paper refers to a large number of references, which are not cited in this report, covering work from the late 1960s up until the present.

It is important to summarise this work as it sets the scene for the recommendations covering gaps in understanding and the recommendations for short-term management options in section 7.

5.1 A list of monitoring and investigations

During the 1970s it was recognised that water quality was deteriorating in Lake Rotorua as a result of increased nutrient loads, mainly from the discharge of secondary treated sewage into the lake and catchment inputs from streams draining pasture and other land uses. The resulting water quality problems included: excessive growth of large invasive exotic plants (macrophytes) which smothered the native water plants; unwanted blooms of microscopic algae (phytoplankton) which reduced water clarity and were sometimes toxic; de-oxygenation during summer stratification leading to more frequent periods of anoxia; and more frequent releases of nutrients from the lake bed.

Public concerns led to a number of studies and management actions, which are listed below:

1) Fish studied water quality and measured stream nutrient loads from 1968 to 1970.

2) Taupo Research Laboratory (DSIR) conducted bioassay studies to determine nutrient limitation and measured ‘internal loads’ and lake quality during the 1970s and 1980s.

3) Lake water quality was monitored from the mid 1970s by Fisheries Research Division (MAF), Taupo Research Laboratory, Hamilton Science Centre and EBOP.

4) RDC has consistently monitored nutrient inputs from the Rotorua sewage treatment plant.

5) Hoare conducted detailed stream nutrient load studies in 1976-1977.

6) During the 1970s and 1980s, several catchment management measures were implemented through the Upper Kaituna Catchment Control Scheme to reduce nutrient inputs to Lake Rotorua.

7) Williamson *et al* undertook a detailed study of flows and nutrient concentrations in the Ngongotaha catchment from 1987 to 1989 to assess the effectiveness of riparian retirement undertaken as part of the Kaituna Catchment Control Scheme.

8) Vincent, Gibbs and Spigel have studied the effects of the flow from the Ohau Channel into Lake Rotoiti in the 1980s.

9) Aquatic weed problems have been studied by the Aquatic Weeds section of MAF (now part of NIWA, Hamilton).

10) More recently Rutherford *et al* have investigated the use of artificial and natural wetlands to strip nutrients.

11) Rutherford, Elliot *et al* have also developed land use and catchment models to characterise nutrient losses from individual land uses and catchments, and this work is continuing.

It can be seen from this brief list that a large amount of work has been done to understand the processes that are causing the nutrient enrichment and algal problems in Lakes Rotorua and Rotoiti. This provides a firm foundation for the current work that EBOP is doing and many of the management measures that are now being contemplated.

5.2 Historical lake and nutrient targets

EBOP adopted lake water quality targets in the 1980s based, in the case of Lake Rotorua, on the acceptance that the water quality in the 1960s did not give rise to significant public concern. At the same time, the decision was made to divert treated sewage away from the lake as it was contributing 50% and 25% of the total (sewage plus catchment) load of total phosphorus (TP) and total nitrogen (TN) respectively.

The nutrient targets that were set are shown in Table 3 with the assumption that the catchment nutrient loads would remain steady.

Table 3. Total Phosphorus and Total Nitrogen Annual Load Targets for Lake Rotorua 1985

Nutrient Sources	Total Phosphorus Target (Tonnes P per Year)	Total Nitrogen Target (Tonnes N per year)
Sewage Loads	3.0	30.0
Catchment Loads	34.0	405.0
Total Target Loads	**37.0**	**435.0**

As well as absolute targets, it is important to consider the N:P ratio as this can determine the type of algal blooms that can occur. Current thinking (Professor David Hamilton pers comm) is that this ratio should be greater than 22:1 in the water body to prevent N limitation and the formation of nitrogen fixing blue-green algal blooms. This can be compared to an N:P ratio of about 1:12 for the catchment load targets in Table 3. The current N:P ratio in the lakes and its significance is discussed later.

These load targets are for both nitrogen and phosphorus and as discussed later it is important for both of these nutrients to be reduced, as well as managing the N:P ratio. This is because in phosphorus-limited systems - and at various times during the year even in nitrogen-limited systems - other algae blooms such as diatoms and dinoflagellates can occur and cause problems like reduced water clarity.

Targets for the Trophic Level Index have already been discussed in section 3.5 and are 4.2 for Lake Rotorua and 3.5 for Lake Rotoiti.

5.3 Key issues for management

A number of key issues for management arise from the monitoring and investigations that have been undertaken for Lakes Rotorua and Rotoiti and these are summarised below.

Sewage disposal

Since 1991, sewage disposal has been by spray irrigation on pine forest in the Whakarewarewa Forest at the headwaters of the Waipa Stream. Monitoring of the stream since 1992 showed that N and P levels gradually rose to about 4 tonnes per year of total P and about 55 tonnes per year of total N in late 2001, exceeding the targets in Table 3.

It was originally intended that wetlands in the spray irrigation area would strip nutrients, but it appears that the spraying was too intense in each sub-area and the residence times too short in the wetlands for the nutrient stripping to be effective. Changes to the spray irrigation to reduce the time of application in each sub-area to 160 minutes appear to have markedly reduced the inputs of P and N into the Waipa Stream and hence into Lake Rotorua.

The implications for short-term management are discussed in section 7.

Septic tanks

Many lakeside settlements and holiday homes have septic tanks that have been shown to leach nutrients via groundwater into the lakes. This can cause localised nutrient enrichment and problems in some bays and lakeside areas.

These problems have been recognised by EBOP and RDC and priority areas will be connected to reticulated sewerage for treatment.

Lake water quality

As noted in section 3.5 and as shown in Kit Rutherford's paper (Ref 4), the TLI for Lake Rotorua does not show an overall increasing or decreasing trend from 1970 to 2002. It has not changed significantly since 1970, although some short-term variations can be seen with changes in sewage disposal and a long period of stratification in the lake over the summer of 1969-70. This is in contrast to public perceptions that water quality is steadily decreasing and indications that lake total nitrogen and total phosphorous concentrations are steadily increasing. On the other hand, David Hamilton's analysis of the long-term monitoring data using anoxia as an indicator does show a decreasing trend in water quality over a period of 50 years, especially in Lake Rotoiti.

Stream nutrient concentrations

Williamson *et al* showed in 1996 that the Kaituna Catchment Control Scheme had resulted in a decrease in total P and particulate N, but that total N had not changed because of an increase in soluble N (nitrate). This trend is supported by the monitoring of streams in the other Lake Rotorua catchments from the late 1960s to 2003, although as Rutherford points out (Ref 4), some caution must be observed in comparing the data from the various studies.

The overall conclusion from Rutherford's analysis is that stream nitrate concentrations in eight of the nine Lake Rotorua catchments have steadily increased, while total P concentrations have remained relatively steady. This increase of nitrate relates predominantly to base-flow, which a number of studies have shown contributes approximately 90% of the flow and a large proportion of the nutrient inputs to Lake Rotorua. Rainfall and stream-flow variations have been considered but further work may be needed to fully quantify the variations in the nutrient concentrations they cause.

Table 4 taken from Rutherford shows the stream names, monitoring sites, codes and base-flows for each of the nine catchments.

Table 4. Stream names, codes and mean base-flow

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

[a]1.79 m3/s over the whole study 1976-78

The Waiohewa is a ‘hot’ stream receiving geothermal flow from the Tikitere geothermal field. It has historically been characterised by high ammonium concentrations that are progressively oxidised to nitrate between Tikitere and the lake, and provides an opportunity for short-term management which is discussed in section 7.

Springs flowing into the Waingaehe, Hamurana and Awahou Streams have relatively high concentrations of phosphorus and also provide opportunities for short-term management, but similar springs flow into most of the other main streams. Hamurana is especially significant for short-term management as it contributes nearly 25% of the total phosphorus load.

Rutherford’s draft report shows that phosphorus loads have not varied significantly over the period of monitoring, but that there are relatively high Dissolved Reactive Phosphorus loads in the Waingaehe, Hamurana and Awahou streams. This form of phosphorus is readily available for algal growth and reductions in concentrations in these streams provide opportunities for short-term management.

Rutherford's draft report also shows the high ammonium concentrations in the Puarenga Stream, which have been discussed earlier, and the increasing trend in nitrate in all but the Waiohewa Stream, which is of real concern and has significant management implications.

Groundwater and its relationship to nutrient concentrations

Groundwater plays a dominant role in transporting nutrients from the catchments into the lakes, mostly via supply to the streams. Some of the volcanic soils are quite porous, so that water flows off land uses like dairying and can move down into the soil from recharge areas into relatively deep aquifers. These often reappear years later as springs flowing into streams or directly into lakes.

Aging of these deep groundwater flows shows they are up to 50 to 70 years old, indicating that the high nitrate concentrations in the streams have come from changes in land uses 50 to 70 years ago. EBOP is undertaking work to identify younger groundwater to determine the nitrate concentration trend for more recent land-use changes. This is important work that has significant implications for the medium- and longer-term management measures that focus on changing or modifying existing land uses.

Shallow groundwater generally flows laterally to the nearest stream and can also carry nutrients, especially nitrate. Together, these two groundwater flows provide nearly all of the stream base-flows and hence a significant fraction of the total nutrient inputs to the two lakes.

Storm-flows

While storm-flows appear to only contribute about 10% of the total flows and are more difficult to manage than base-flows, they may be important in causing algal blooms because of a relatively large input of nutrients over a short period. Subsequent weather conditions, especially in late spring, summer and autumn with sunshine and low wind speeds, could cause algal blooms including toxic blue-greens.

These 'event' driven blooms are common in other water bodies around the world and may occur in Lakes Rotorua and Rotoiti, but there is not enough information to determine if this is the case. Storm-flows may also be comparatively important in transporting sediment-bound phosphorus to the lakes.

Catchment nutrient loads, lake water quality and the N:P ratio

Rutherford (Ref 4) has used data from a number of the studies and the trends in the nitrate concentrations to estimate nutrient loads to Lake Rotorua.

Rutherford's draft report clearly shows the increasing trend in total nitrogen and a steady trend in total phosphorus. The former is concerning and has significant implications for management. The latter must not be ignored as it will be important to reduce both phosphorus and nitrogen.

The total load of nitrogen is about 700 tonnes per year and that of phosphorus is about 35 tonnes per year. This produces an N:P ratio for catchment inputs of about 20:1, although this is somewhat artificial as it is the ratio of N:P in the water column when an algal bloom occurs that is important.

Rutherford (Ref 4) elegantly analyses the effect of nutrient concentrations on lake water quality, particularly chlorophyll *a* and observes that some of the variations from model predictions could be due to factors other than catchment inputs, such as internal nutrient loads and nutrient cycling.

Rutherford has a figure in his draft report showing the ratio of annual average total N to total P in Lake Rotorua from 1970 to 2002. The N:P ratio is around 10 although there are some higher values from 1996 to 1999. As noted earlier, the N:P ratio in the water column at the time of an algal bloom may be more important than an annual average.

The difference between the catchment inputs may reflect inflows that have not been gauged but is more likely to reflect preferential loss of nitrogen from the lake, presumably through denitrification of oxidised nitrogen. This is important as it suggests that the denitrification process may play a key role in the proportion of blue-green algal blooms.

Internal nutrient loads

Internal nutrient loads may be similarly as important to algal blooms as external loads, especially over the summer period when stratification of Lake Rotorua happens and blue-green blooms are more likely to occur. In an average year, Lake Rotorua stratifies for periods of two to 10 days on several occasions each summer, although in the unusually calm and hot summer of 1969-70, it stratified for 20 to 40 days. Lake Rotorua is generally well mixed for the remainder of the year being relatively shallow (20 metres in the deeper basin with a mean depth of 8.9 metres) when compared to Lake Rotoiti (40 to 90 metres with a mean depth of 33 metres). The fold-out diagram in Appendix 3 shows these differences in depth along a transect of both lakes.

Lake Rotoiti is strongly stratified from about November to March and, as discussed earlier, the bottom layers are severely de-oxygenated (anoxic). During these stratification events, nutrients, particularly phosphorus, are released from the sediments and may become available for algae growth. This aspect is not well understood, particularly as to the amount of nutrients that may move out of the hypolimnion to become available for algal growth. This is a key question that needs further understanding for both short- and longer-term management.

In Lake Rotorua the nutrients and algae can be transported through the Ohau Channel into Lake Rotoiti and add to the nutrients and algae already in that system.

Rutherford (Ref 4) has graphed the data for internal loads in Lake Rotorua from the existing monitoring data, which on limited data, suggests annual average loads of total phosphorus in the range of 10 to 15 tonnes and of total nitrogen of around 150 tonnes. Rutherford estimates that the internal loads will continue to supply nutrients for at least 20 years even if the external loads were reduced to the targets.

Professor Hamilton and a PhD student have been carrying out further work on this important topic and believe the internal loads could be considerably higher in Lake Rotorua perhaps around one half of the external loads. In other work, Professor Hamilton has shown that a significant fraction of the soluble nitrogen released from the lake bed in Lake Rotoiti is denitrified and lost from the system, thus lowering the N:P ratio.

Rutherford (Ref 4) reports the ratio of N:P from internal loads in Lake Rotorua as 4-5:1, which is quite low when compared to the ratio of about 22:1 to minimise or eliminate blue-green blooms. When coupled with the denitrification occurring in Lake Rotoiti, there is a clear disposition towards N limitation and nitrogen-fixing algal blooms in Lake Rotoiti over summer.

A better understanding of these processes is essential for management of algal blooms and this is discussed further in section 7.

The Ohau Channel and flows into Lake Rotoiti

It has already been stated that Lake Rotoiti is closely linked to Lake Rotorua with greater than 70% of the nutrients, along with sediments and algae, flowing through each year. Some work has been done on the fate of these flows as noted at the beginning of this section, but more work is needed to reach the necessary understanding to trial management options involving diversion of the channel.

Work by Vincent, Gibbs and Spigel, particularly in 1981-82, has shown that in winter (for approximately two-thirds of the year) the colder Lake Rotorua water flows into the bottom of Lake Rotoiti bringing oxygen, nutrients and particulates. It is believed that this winter ‘underflow’ has a benefit by bringing oxygen-rich water into the bottom waters of Rotoiti, particularly when the lake is stratified in spring and autumn, and therefore that any diversion during this period should be very carefully considered.

In summer, the limited evidence (primarily the studies using dye tracers in 1981-82) is that the warmer ‘overflow’ predominantly flows into the western arm of Lake Rotoiti and into the Kaituna River. More recent ideas are that there may be other warmer water flows into the surface layers (interflows) of Lake Rotoiti with concurrent transport of nutrients and algae at the best times for blue-green algal blooms (Max Gibbs, Noel Burns and Paul Scholes – *pers comm).*

A further complication is that the Ohau inflow is generally two to three degrees Celsius warmer when Lake Rotorua stratifies and hence is likely to be a surface overflow rather than an interflow.

Diversion and/or management of the Ohau Channel is a management option that has been considered for a number of years, but the lack of an adequate understanding of the processes discussed above is a major block to any trials.

Algal dynamics and succession

Rutherford’s report (Ref 4) and the *Rotorua Lakes Water Quality 2002* report both show considerable variations in chlorophyll *a* levels in Lakes Rotorua and Rotoiti. Some of the variations can be explained by the sewage diversion and increases in catchment nitrate loads, but other peaks are clearly related to shorter-term events (like stratification and destratification episodes) causing nutrient peaks in Lake Rotorua, which may be transported to Lake Rotoiti.

Depending on the time of the year and the weather conditions, these ‘events’ will provide opportunities for particular algae to bloom. In summer, especially in Lake Rotoiti, the result may be toxic blue-green algal blooms. These event-driven algal blooms are common in other parts of the world and effectively managing them requires an understanding of the events and processes that cause them.

In turn, this usually requires detailed monitoring of the processes and the succession of algae that bloom over the seasons. More intensive studies may also be needed to understand particular processes or interactions. So, for example, the blue-green algal blooms may have started from bottom sediment spores or living cells carried from Lake Rotorua, which bloomed in the western end of Lake Rotoiti and were then transported to the eastern end of the lake by wind or water currents.

Unfortunately, there is not adequate monitoring data to determine what happened, although there is good anecdotal evidence that the main blooms started in the western end of Lake Rotoiti. A better understanding of these processes is needed to focus management measures, but even with the existing knowledge some cosmetic management measures could be trialled.

6 RECOMMENDATIONS FOR SHORT-TERM MANAGEMENT MEASURES AND BETTER SYSTEMS UNDERSTANDING

In a number of cases, there is enough information available to start investigating management options now, although in most cases there will need to be engineering evaluations and design. In other cases, there is not enough information available to support short-term management options and recommendations are made for urgent monitoring and investigations to fill critical information gaps.

Based on the detailed discussions and information provided to the author, there are a number of short-term and medium-term (one to four years) management options that can be implemented, some within one to two years and some, which will depend on further vital information in two to four years. There are also some cosmetic management measures that can be implemented if further blue-green blooms occur.

Most of the recommended management measures support the ideas and directions that are already being pursued by EBOP and RDC. Hopefully, this report will help prioritise and programme these management measures and any new ones that are recommended. It should also be noted that a number of management measures will require formal resource consents and that these processes will lengthen the time in which they can be implemented.

6.1 A whole systems approach

Appendix 3 is a fold-out diagram which shows Lakes Rotorua and Rotoiti in cross section and an idealised catchment flowing into Lake Rotorua. Processes by which nutrients flow from the catchment into the lake are shown as well as the processes by which the nutrients cycle within the lakes and become available for macrophyte and phytoplankton growth.

It is important to consider and understand all of these processes in so far as they lead to the most cost-effective and efficient management measures. Building understanding and implementing management measures should be adaptive, so as sufficient understanding is gained, management measures are trialled and then implemented.

Each stage is a learning process where understanding and management is improved. Management of complex natural systems can never be left with the expectation that it will work ‘forever’. Even when successful and resilient management is implemented, it must be monitored and fine-tuned if needed. If significant changes occur in the natural system, through climate or other influencing processes, larger changes or alterations to management may be needed.

Taking a whole-systems approach also helps all of the stakeholders and partners see their part, when they need to be involved and why certain things are being done at different times. In particular, the various stages of moving to management, including when studies need to be done to improve understanding, can be set into a 'project management' and time sequence.

This helps all stakeholders understand that some things can be done relatively quickly but that other things will take a while because they are more complex or difficult. The more organised amongst us can prepare flow charts and Gant charts to show the sequencing and timing of the different steps to reach agreed goals, outputs, targets and outcomes.

It is this context into which the recommendations for short-term understanding and management fit. The recommendations are divided up into understanding and managing the catchments, and understanding and managing the lakes.

6.2 Understanding the catchments

Understanding the nutrient sources

As discussed earlier, considerable work in the form of monitoring and investigations has been done on Lakes Rotorua and Rotoiti over the last 35 years. Even so, there is still an incomplete understanding of some key processes, including a more detailed understanding of particular nutrient sources.

It is clear that there are a number of springs that contribute relatively high levels of phosphorus and/or nitrogen from various land uses and natural sources. At least three springs contribute significant loads of phosphorus, namely Waingaehe, Hamurana and Awahou. As well, there are geothermal inputs that contribute significant amounts of nutrients, such as the Tikitere geothermal field.

There will be other specific sources of nutrients such as leakage from the sewage spray irrigation area, septic tanks and dairy sheds. All of these nutrient sources should be characterised so that those that are 'point sources' are identified. These will be the easiest to tackle as opposed to the more diffuse sources such as fertiliser leakage and nutrients coming from grazing stock.

A general rule in catchment management is to tackle the easiest and highest level nutrient sources first.

Recommendation 3: That as far as practicable, monitoring should be extended into the catchments and sub-catchments with the highest nutrient inputs to characterise any 'point' sources that may become a priority for management.

Monitoring and modelling the catchments

Catchment monitoring can be expensive, but it is generally much less expensive than implementation of management measures. It is therefore important to have monitoring systems in place that show with statistical validity and good confidence levels whether the management measures are working or not, especially in the catchments and sub-catchments that are contributing the most nutrients. These type of monitoring systems also allow shorter-term targets to be set that communities can see are being achieved and which can then be celebrated. Such a monitoring system has been developed by the Western Australian Department of the Environment in partnership with the US Geological Survey and should be tested for its suitability in the Lake Rotorua catchments.

Recommendation 4: EBOP should work with the Western Australian Department of the Environment to investigate the use of its catchment monitoring system in the Lake Rotorua Catchments to measure the efficacy of catchment management measures.

Catchment modelling can be useful in transferring understanding of catchment processes between similar land uses and land types, and in calculating nutrient losses from various land uses where the processes are well understood and the nutrient losses have been accurately calibrated. They can be used at different scales from a single farm to sub-catchments to full catchments, and if used well, can save considerable resources and time.

NIWA has developed a good model for nutrient loss management at the farm level for the Rotorua lakes, and has developed sub-catchment and catchment models for other situations. NIWA (Ref 5) is also involved in a project to develop 'a new catchment model for use by non-specialists'.

Recommendation 5: EBOP should consider developing a simple catchment model that can be cooperatively used by landowners and community groups to see how nutrients move through their catchments as a aid to understanding how they can be managed.

Another very important issue for catchment management in the Lake Rotorua catchments is the increasing levels of nitrate in most of the streams coming from deeper groundwater that is 50 to 70 years old. It is not clear, with more recent changes in land use, whether these concentrations will continue to increase or reach a plateau. Equally, if changes are made to reduce nitrate losses, it is not clear how quickly stream concentrations will decrease and what the new equilibrium concentrations will be.

While consideration of this aspect is not strictly to do with short-term management, it is seen as so important that some comment should be made. While EBOP has started work on aging younger groundwater in streams it would be useful to build on work that is being done for Lake Taupo to develop a 'mid-level catchment model'. This 'model' should be relatively simple and would enable managers to estimate how land-use changes in the past have affected stream nutrient concentrations (a reality check) and how proposed land-use changes and/or mitigation measures will affect them in the future.

A parallel benefit would be that some hydrogeological work would need to be done to check the age and chemistry of the deeper groundwater to calibrate the model. This would be of considerable benefit in its own right as it would throw light on the issue of nitrate concentrations (and other nutrient concentrations) in the younger groundwater.

Recommendation 6: EBOP should consider carrying out hydrogeological investigations to determine the chemistry of the younger and deeper groundwater and use this and other information to develop a 'mid-level catchment model', to enable land managers to estimate how proposed land-use changes and/or mitigation measures will modify nutrient concentrations in the deeper groundwater.

Storm-flows

While storm-flows do not carry as much of the nutrient load to the lakes as the stream base-flows they can carry significant quantities of nutrients over short periods.

Work in Western Australia has shown that the heaviest nutrient and carbon loads are typically found at the beginning of a stormflow and during summer and autumn periods when there is little rainfall and flow in streams and drains. These summer-autumn ‘events’ often cause algal blooms, with the severity depending on the exact nature of the event.

No clear patterns of nutrient inputs have been determined for storm-flows into Lake Rotorua although there have been several studies that have considered storm-flows. Therefore, it is not clear if storm-flows, especially in late spring, summer and autumn cause algal blooms, but they may play a role along with internal loads of nutrients, in causing particular blooms. It may be important to clarify whether storm-flows during these times have any causative role in initiating or prolonging the blue-green blooms.

If this is the case, there are a number of well-proven management measures, such as stormflow diversions and wetland detention basins, that may be used to manage these events, and EBOP and RDC have considerable experience with these types of measures.

Recommendation 7: EBOP and RDC should carry out more detailed monitoring of storm-flows into Lake Rotorua, especially in the late spring, summer, autumn period to determine if these ‘events’ are initiating or prolonging blue-green blooms.

6.3 Short-term catchment management options

Tools for nutrient management – Phoslock and other ‘benign’ nutrient stripping materials

There are a number of tools for reducing nutrients that will have application in the catchments and in the lakes. These include the use of alum, calcium carbonate, and various minerals to absorb or modify nutrients. EBOP is trialling a number of these substances. This is to be applauded and should be continued to add to the number of tools in the ‘nutrient management toolbox’.

Another useful material that has been developed in a partnership between the Western Australian Department of the Environment and the CSIRO is Phoslock, a patented, modified clay that irreversibly absorbs phosphorus in virtually all natural situations, and requires relatively small quantities to be effective. EBOP has already obtained small quantities of Phoslock and is proposing to trial it when the Environmental Risk Management Authority (ERMA) approval has been granted and resource consents obtained.

Trials in Western Australia in freshwater systems have proved promising and when used in conjunction with oxygenation, Phoslock has changed some N limited systems to P limited and eliminated blue-green blooms. It therefore seems appropriate for EBOP to form a closer partnership with the Western Australian Department of Environment to conduct joint trials and exchange information and ideas. Phoslock in various forms could be used to cost-effectively strip phosphorus in stream base-flows, springs and artificial and enhanced wetlands.

Recommendation 8: That EBOP approaches the Western Australian Department of the Environment to form a partnership to jointly trial and develop Phoslock for nutrient stripping in catchments and water bodies, separately and in conjunction with other nutrient management methods.

A number of allophanic soils in the Rotorua area are similar to the bentonite clays used as the substrate for Phoslock and have strong phosphorus retention characteristics. These soils should be tested for use in wetlands and other situations (along with other benign materials for phosphorus stripping) tested for their suitability as a substrate for the rare earth used in Phoslock.

Care should be taken with the use of such materials that release of nutrients does not occur under anoxic conditions. EBOP is already testing these types of materials and recommendation 10 supports continuation of this work as a key measure for short- and longer-term management.

Recommendation 9: EBOP should investigate the use of allophanic soils and related clays for use in stripping phosphorus and as a substrate for preparation of Phoslock. Work should continue on the use of other benign materials such as alum.

High phosphorus springs

As noted earlier, a number of deep groundwater springs contain elevated levels of phosphorus, which enter Lake Rotorua in a number of the main streams. These are, in effect, 'natural point sources' and an earlier recommendation was that all of the deep groundwater springs should be characterised as to their nutrient inputs.

Three streams in particular contribute higher levels of phosphorus from the springs that enter them: Waingaehe, Hamurana and Awahou. It is understood that EBOP is considering phosphorus stripping from these streams and this should be treated as a high priority short-term management measure.

Recommendation 10: That EBOP urgently investigate options to strip phosphorus from streams that have high levels of phosphorus coming from springs and other sources, starting with the Waingaehe, Hamurana and Awahou streams.

Geothermal nutrient inputs

Geothermal waters enter both the catchments and the waters of Lakes Rotorua and Rotoiti and could add significant amounts of nutrients. An earlier recommendation was that the catchment geothermal flows be characterised to quantify their nutrient inputs. As noted earlier, the Tikitere geothermal field injects about 30 tonnes of nitrogen, mainly as nitrate, into Lake Rotorua via the Waiohewa stream. It is understood that EBOP and RDC intend to divert this flow into the reticulated sewerage when it is extended. This will quickly and easily reduce a significant source of nitrogen and should be implemented as a high priority.

Recommendation 11: That EBOP and RDC divert the flow from the Tikitere geothermal field to the Rotorua District Sewage Treatment Plant if practicable, or to some other suitable location such as the Kaituna River if acceptable.

Rotorua Land (Sewage) Treatment Site (RLTS)

As noted earlier, changes to the spray irrigation of treated sewage onto pines in the Whakarewarewa Forest appear to have initially been effective in reducing nutrient inputs to Lake Rotorua via the Puarenga Stream. However, it is not known what effect increased volumes of effluent from increasing populations and extension of the reticulated sewerage scheme will have.

Previous NIWA work at the Rotorua Land Treatment Site (RLTS) under the higher spray regime showed springs formed and the short soil-water contact times and preferential pathways through the wetlands markedly reduced the nutrient stripping capacity, especially removal via denitrification. NIWA has also done work (Refs 6 & 7) to show how the RLTS and other wetlands could be made more efficient at nutrient stripping simply and at relatively low cost.

The RLTS is a good way to reduce nutrients entering Lake Rotorua and, given the likely relatively low cost of nutrient removal, load targets of zero should be set for nitrogen (N) and phosphorus (P), rather than the existing targets of three tonnes of total P per year and 30 tonnes of total N per year. Repeat studies should be done of the nutrient stripping processes under the new spray regime and, if necessary, the wetlands within and downstream of the RLTS should be modified to increase their nutrient stripping capacity.

Recommendation 12: That EBOP and RDC establish a zero target for nutrient inputs from the RLTS to Lake Rotorua.

Recommendation 13: Repeat studies of the nutrient stripping processes and pathways at the Rotorua Land Treatment Site should be undertaken under the new spray regime to determine the nutrient stripping effectiveness.

Recommendation 14: Wetlands within and below the Rotorua Land Treatment Site should be modified if necessary to strip any residual nutrients 'leaking' from the spray irrigation areas.

Recommendation 15: The RDC should continue to monitor nutrient levels above and below the Rotorua Land Treatment Site to measure its efficiency at stripping nutrients, particularly if spray volumes are increased to cope with increasing population or inputs from newly reticulated areas.

Wetlands and stream base-flows

Previous work, as discussed earlier, has shown that stream base-flows carry about 90% of the nutrients into Lake Rotorua. NIWA, in work for EBOP, has studied the use of constructed and 'enhanced' natural wetlands to strip nutrients (see, for example, Ref 8) and has developed methodologies for using these wetlands in the catchments of the Rotorua lakes. An earlier recommendation was that all of the catchment nutrient inputs be characterised and prioritised for management.

All opportunities to use wetland stripping in the Lake Rotorua catchments should be identified, especially where there are streams with high nutrient base-flows. As EBOP has identified the streams entering Lake Rotorua that have high levels of nutrients, a further step for short- and medium-term management is to identify the best opportunities for wetland stripping.

Recommendation 16: That EBOP identifies opportunities for constructed and enhanced natural wetlands to strip nutrients in the catchments and on the foreshores of Lake Rotorua and, as a high priority, construct or enhance such wetlands where there are opportunities to intercept high nutrient level base-flows.

Best management practices for point sources

An earlier recommendation covered the need to characterise the higher nutrient sources in the catchments, especially 'point sources'. Another recommendation was the use of constructed and enhanced natural wetlands to strip nutrients from the base-flow in streams with high nutrient loads. There are a number of 'Best Management Practices' (BMPs) for stripping nutrients from other point sources such as dairy sheds and piggeries. In the longer term, such BMPs will need to be used for diffuse sources such as pasture and stock and EBOP is already using a number of BMPs such as riparian retirement.

In the short-term useful reductions of nutrients may be achieved by the use of proven BMPs for smaller point sources. A particular BMP that is widely used in Australia for sites that are difficult or too costly to provide sewage reticulation are Alternative Treatment Units (ATUs) to replace septic tanks and leach drains. Where nutrients are a problem, nutrient stripping modules are added to the ATU.

Compliance is guaranteed by certification and registration of particular ATU systems by state authorities, and approvals and management contracts through local government authorities for installation and maintenance. These ATUs should not be seen as replacement for reticulated sewage in the areas already identified by EBOP and RDC but they could be considered in sensitive areas where reticulated sewage is too costly or too difficult.

Recommendation 17: EBOP and RDC could consider the use of certified and contractually managed Alternative Treatment Units with nutrient stripping capacity in nutrient sensitive areas where reticulated sewerage is too costly or too difficult.

6.4 Understanding the links between the catchments and the lakes – nitrogen and phosphorus loads and the N:P ratio

Nitrogen and phosphorus loads and targets, and the concept of resilience

Work by NIWA for EBOP by Rutherford (Ref 4) has summarised previous studies and produced target loads for nitrogen and phosphorus from the catchments of Lake Rotorua. Two of Rutherford's tables have been combined in Table 5 in this report and this table is reproduced as a fold out in Appendix 4 for ease of reference. In summary, Rutherford estimates that the 2002 annual catchment input is 35 tonnes of phosphorus (compared to a target of 37 tonnes) and 692 tonnes of nitrogen (compared to a target of 435 tonnes).

However, this does not include raw sewage, presumably from septic tanks and internal loads in Lake Rotorua, which Professor Hamilton estimates could be at least half of the catchment loads. It also assumes that the inevitable growth around the lakes will not contribute any more nutrients so that little or no resilience (or capacity for the systems to cope with change) is built into the targets. Further, it does not take into account the processes and internal loads in Lake Rotoiti which add to the loads from Lake Rotorua to produce problems like the blue-green blooms.

It must be said however, that Dr Rutherford's paper that has kindly been made available for this report, is a draft and his conclusions and recommendations could change. Nevertheless, further work should be done to improve the understanding of the relationship of the Lake Rotorua catchment and internal nutrient loads to Lake Rotoiti's nutrient concentrations over the year, but especially over the late spring, summer and autumn period when blue-green blooms appear. This is discussed further in the next sections and specific recommendations are made.

Even without this fuller understanding of the processes that cause algal blooms in the lakes the approach in the short-term should be to reduce both phosphorus and nitrogen, so that interim catchment targets below those in Table 5 should be set. It is hard without the necessary further studies that are recommended in this report to set firm figures, but a 25% reduction for both nutrients should not cause any problems in the short-term.

Recommendation 18: That EBOP continues to support investigations that are aimed at clarifying the relationships between catchment and internal lake nutrient loads, lakes water quality and algal blooms.

Recommendation 19: That EBOP focuses in the short-term on investigations that will set clear targets for:

- ***an annual total catchment load for Lake Rotorua for phosphorus and nitrogen that builds in capacity for future development around the lake***
- ***annual catchment phosphorus and nitrogen load targets for each of the main Lake Rotorua catchments***
- ***internal lake phosphorus and nitrogen load targets for Lakes Rotorua and Rotoiti***
- ***annual average stream phosphorus and nitrogen concentration targets for each of the nine Lake Rotorua catchments***
- ***annual average lake water quality phosphorus and nitrogen concentration targets for Lakes Rotorua and Rotoiti.***

The nitrogen to phosphorus ratio

As discussed earlier, the ratio of nitrogen to phosphorus (N:P ratio) is critical in determining the types of algae that will bloom in most types of water bodies, from oceans to estuaries, rivers and freshwater lakes. Current thinking is that the N:P ratio should be above about 22:1 to prevent blue-green booms.

This is because below this ratio the system becomes ‘nitrogen limited’ and phytoplankton, like blue-green algae that can fix nitrogen from the air, are therefore favoured. Furthermore, most species of blue-greens are more efficient at utilising nitrogen, hence even non nitrogen-fixers such as Microcystis are favoured at low N:P ratios.

If the ratio is greater than 22:1 there is more than adequate nitrogen and the system becomes phosphorus limited. This favours phytoplankton that are less efficient at utilising nitrogen, typically diatoms and green algae. Some of these algae can also cause severe problems, so just shifting a system from nitrogen limited to phosphorus limited is not always the best solution, although it must initially be a priority in Lakes Rotorua and Rotoiti.

The situation in many water bodies becomes more complex because they can ‘flip’ from being nitrogen limited to phosphorus limited during a year, so any management measures need to be tailored to both situations. In Lakes Rotorua and Rotoiti it is known that the N:P ratio varies between 5 to 15:1 although it has gone as high as

19:1. The current target for the N:P ratio is 15:1(John McIntosh pers comm.), which, according to Professor Hamilton, may be too low to prevent blue-green blooms.

There is not enough information to say whether the lakes flip from being nitrogen limited to phosphorus limited during the year, but the situation in both lakes puts them in a category where either nitrogen or phosphorus could be limiting. This subtle balance makes it difficult to say whether one or the other nutrient is truly limiting without bioassay studies.

Thus, it is most important to reduce excess levels of both phosphorus and nitrogen, and manage the N:P ratio to prevent blooms of phytoplankton that cause problems. In the case of Lakes Rotorua and Rotoiti, the priority should be on reducing or eliminating blue-green blooms, so the N:P ratio should be about 20-22:1 or greater, especially over the late spring, summer and autumn period.

While such 'numerical' targets are important, the overall water quality and state of the lakes must not be forgotten through 'lake health' indicators like the TLI, which cover water clarity as well as nitrogen and phosphorus levels.

Recommendation 20: That EBOP focuses as a priority in the short-term on studies and investigations leading to management measures that reduce lake total nitrogen and lake total phosphorus concentrations and produce a high N:P ratio of 20-22:1 or greater in Lakes Rotorua and Rotoiti, especially during the late spring, summer and autumn period.

6.5 Understanding the lakes

Internal loads from sediment resuspension events

Many of those who have studied the lakes have emphasised the importance of the internal nutrient loads that are released when the lakes stratify and destratify. Recent work by Professor Hamilton and a PhD student is showing that these loads could be quite high, at least half of the catchment loads. Dr Rutherford in his most recent work concludes that the internal loads have always been, and will remain, a feature of the lake. However, if external loads can be reduced then internal loads can be expected to become less frequent and smaller, although it could take at least 20 years for such reductions to become apparent in Lake Rotorua based on known release coefficients and modelling.

The situation is complicated with Lake Rotoiti because it gets a lot of its nutrients from Lake Rotorua through the Ohau Channel as well as nutrients from internal loadings during stratification, which are recycled during destratification. Lake Rotoiti also has geothermal inputs, which are discussed below.

Another important factor in Lake Rotorua is resuspension of the sediments by stronger winds, which can then be transported through the Ohau Channel especially with the dominant summer westerly winds. There needs to be a better understanding of both the frequency of stratification-destratification and resuspension events in Lake Rotorua to focus short-term management measures. This can best be achieved by further monitoring and hydrodynamic modelling of both the deoxygenation-nutrient release and sediment resuspension events for a range of meteorological conditions.

Recommendation 21: That EBOP focuses in the short-term on monitoring of the stratification and destratification, and sediment resuspension events over the most common meteorological conditions in Lake Rotorua, including concurrent monitoring of the Ohau Channel to provide critical data for management.

Recommendation 22: That EBOP uses the data collected from implementation of Recommendation 21 to interactively carry out hydrodynamic modelling to quantify the quantities and timing of nutrients and phytoplankton transport through the Ohau Channel into Lake Rotoiti.

Geothermal inputs

It is well known that there are a number of geothermal inputs into Lake Rotoiti but their contributions of nutrients and energy, and how they modify transport processes and residence times are not well known. These 'hot' inputs need to be better understood as part of developing a better understanding of the hydrodynamic processes that move nutrients and cause algal and blue-green blooms in Lake Rotoiti.

Recommendation 23: That EBOP initiates studies to characterise the geothermal inputs to Lake Rotoiti, especially to determine if they contribute nutrients and how they interact with other hydrodynamic processes to cause algal blooms.

Baseline monitoring and phytoplankton succession

Very useful monitoring has been carried out over many years in Lakes Rotorua and Rotoiti. Since 1990, this has been done systematically by EBOP and much valuable data has been collected as shown in the *Rotorua Lakes Water Quality Report 2002* (Ref 3). But a more complete understanding of a complex interconnected system like Lakes Rotorua and Rotoiti will need more frequent monitoring for a number of parameters. This will provide a firm foundation on which to build more intensive studies to quantify particular processes.

The current EBOP monitoring regime for both lakes consists of monthly profiles and samples taken at three to four stations on each lake. Profiles are taken with a Seabird CTD probe, which gives cm-resolution of conductivity, temperature, dissolved oxygen and chlorophyll fluorescence. These data are then post-processed to give 1-metre depth resolution of these parameters.

The other monthly data include an integrated surface mixed layer sample and a near-bottom sample of nutrients (phosphate, nitrate, ammonium, total nitrogen and total phosphorus). Samples for phytoplankton identification and enumeration are taken only intermittently as part of the routine monitoring. These data are pooled over the course of a year, to produce an annual 'snapshot' of phytoplankton species composition.

There is a separate blue-green algal monitoring programme, which involves collection of samples, mostly around the foreshores and bays, for identification and enumeration of blue-green cell counts at intervals corresponding to public health standards.

Discussions have been held with scientists at NIWA and Professor Hamilton, and the consensus is that monitoring needs to be stepped up to at least two weekly and possibly even weekly, given the importance of the lakes and the potential costs of management. One to two additional deep water samples could be required for Lake Rotoiti. More frequent monitoring should include all algal species that are present to gain a better understanding of the succession of algal blooms as an aid to determining the best management measures. More intensive studies would need even more intensive monitoring tailored to meet the needs of the study.

It would be wrong to be prescriptive on the detail of more frequent monitoring as this should be determined by EBOP working with NIWA and Professor Hamilton to determine the best regime to suit the agreed aims and objectives, and data needs for modelling and management. More frequent monitoring of blue-green blooms will also provide better information for the public and how the blooms progress along the lakes and intensify in bays. The latter understanding will aid cosmetic management measures which are suggested below.

Recommendation 24: EBOP should work with NIWA and Professor David Hamilton to establish a more frequent monitoring regime for Lakes Rotorua and Rotoiti to gain a better understanding of the processes that cause algal blooms, especially blue-green blooms as a basis for management measures that will best eliminate or reduce them.

The Ohau Channel and hydrodynamic processes

The Ohau Channel flow has been, and will be, a major focus for management of algal blooms in Lake Rotoiti given the large amount of nutrients and other material it transports into the lake. As discussed earlier in this report, there is good evidence that the channel flow falls into the deeper parts of Lake Rotoiti as an 'underflow' in winter and into the western arm of the lake and down the Kaituna River as an 'overflow' some of the time in summer.

Recent analysis of a range of data has led to thoughts that other intermediate flows or 'interflows' could occur under various conditions (Burns, Scholes and Gibbs *pers comm.).* These 'interflows' may not always flow into the Kaituna River and could be entering the surface waters in the western end of Lake Rotoiti and be a contributing cause of algal blooms (see the foldout diagram in Appendix 3)

Longer-term climate information shows that the Rotorua district has been warmer than average for about 20 years and that, as a consequence, there has been an average 1 degree Celsius rise in the average water temperature of the Rotorua lakes. This may also be having an effect on the flow from Lake Rotorua to Lake Rotoiti.

For all of these reasons, it is vital that there is a better understanding of the hydrodynamics of the flow of the Ohau Channel water into Lake Rotoiti and its fate once it enters the lake. This will be important for the whole lake, but will be especially important in managing areas like Okawa Bay and other parts of the lake's western end that have experienced bad blue-green blooms and are quite degraded. This understanding will be critical for any management measures that might be tried, including diversion of the Ohau Channel for all or part of the year, using part of the flow to flush Okawa Bay, or building groynes to channel the water from the deeper parts of Lake Rotorua into the channel.

From discussions, it is clear that appropriate hydrodynamic modelling could be done relatively quickly with simpler models being available in less than six months and a more sophisticated model available in 12 months. Some additional monitoring would be needed, such as a temperature sensor in the Ohau Channel and a thermistor chain in Lake Rotoiti. This modelling would provide a number of benefits, including:

- simulations of the flow path or mixing of Ohau Channel water in Lake Rotoiti and circulation patterns induced by the inflow
- residence times in various bays and lake areas that are subject to algal blooms
- assessment of the sensitivity of Ohau Channel underflow/interflow/overflow to air-temperature changes or channel diversions
- assessment of the impact of full or partial diversion of the Ohau Channel on circulation in the western bays of Lake Rotoiti
- simulation of the effects of engineering structures on flows and therefore clarification of the best engineering structures to trial management options
- simulation of the path of algal blooms blown or carried from specific areas
- assessment of typical wind-driven circulation patterns and connectivity between the western and eastern ends of Lake Rotoiti.

EBOP is aware that this work is urgently needed and is moving to have it commenced. Thus the recommendation below is strong reinforcement of an action that is already underway. Both NIWA and Professor Hamilton have strong modelling capabilities and it may be advantageous to have cross collaboration for this important work (see also Recommendation 26).

Recommendation 25: That EBOP continues to pursue as a high priority further monitoring and hydrodynamic modelling of the flow of the Ohau Channel into Lake Rotoiti as the basis for short-term management decisions on manipulation of this flow to improve the health of the lake and reduce or eliminate blue-green blooms.

6.6 Short-term lake management options

Groynes in Lake Rotorua

It is clear that one of the main sources of nutrients, sediment and possibly algae in Lake Rotoiti is the resuspension and transport through the Ohau Channel of sediments from the shallows of Lake Rotorua. Given that much of the movement of this suspended material is from the shallows on each side of the entrance of the Ohau Channel, a quick way to reduce the amounts is to build groynes on each side of the entrance.

This should trap the majority of the suspended material, which may have to be removed from time to time. Initially the groynes should not be built all the way to the deeper water as not enough is known about the importance of the flows of deeper Lake Rotorua water into Lake Rotoiti. The groynes could be extended later when the modelling work recommended earlier provides sufficient understanding of the best way to manage the deeper water flows.

It would be prudent to build temporary groynes first until the best configuration to minimise transport of suspended material is determined. Engineering investigations and design will be needed to determine the best length and position for the groynes but work should be able to be commenced relatively quickly.

Recommendation 26: That EBOP and RDC initiate engineering design and construction of temporary groynes on either side of the entrance of the Ohau Channel to minimise transportation of suspended material into Lake Rotoiti. Permanent structures can be constructed when the best configuration to minimise transport of suspended material is determined.

Ohau Channel

As stated earlier, diversion of the Ohau Channel for all or part of the year has been considered a number of times and is still being assessed, but as discussed in section 7.5 this should not be trialled until the flow regime into Lake Rotoiti is better understood as recommended above. The monitoring and modelling needed to provide this understanding should not take long, 12 months at most.

Engineering designs for temporary structures to trial favoured diversions of the Ohau Channel, whether into the Kaituna River or to flush Okawa Bay, should be commenced as soon as possible in an interactive process as modelling results become available. Trials can then begin quickly and the models can be tested and tuned against real world data. In time, more permanent structures can be built, but because of the dynamic nature of the Ohau Channel flow and the hydrodynamic processes in Lake Rotoiti, ongoing monitoring and adjustments may be needed.

In addition, there are water level control gates at the head of the Okere Falls on the Kaituna River and any management measures that are trialled for the Ohau Channel should take these gates into account as some manipulation of water levels and flows at the gates may be beneficial.

Recommendation 27: That EBOP and RDC begin engineering investigations and designs for trial structures to divert the Ohau Channel to the Kaituna and/or Okawa Bay as soon as possible, and interactively with the monitoring and modelling work that has been recommended in Recommendations 24 and 25, so that work on trial structures can begin as soon as resource consent approvals have been obtained.

Recommendation 28: That EBOP builds temporary structures to test the favoured options for diversion of the Ohau Channel to the Kaituna River and/or Okawa Bay when resource consent approvals have been obtained, and monitor the trials to further refine the hydrodynamic models for the channel flows and the western end of Lake Rotoiti before building any more permanent diversion structures.

Oxygenation and nutrient stripping in the lakes

Oxygenation has been used successfully in several large waterways (for example, the Thames River) and smaller-scale trials have been successful in improving oxygen levels and reducing nutrients in several smaller waterways in the south west of Western Australia. When used in combination with Phoslock in smaller freshwater systems in Western Australia (Ref 9), dominated by blue-green algal blooms, similar nutrient reductions were obtained and, in at least one case, the blue-green blooms were eliminated and replaced by less dense, green phytoplankton blooms.

EBOP is trialling a number of chemical and mineral additives to strip nutrients (for example, alum in Lake Okaro) and is investigating the use of oxygen to improve oxygen levels in several stressed lakes. EBOP is also aware of the benefits of Phoslock and is in the process of obtaining ERMA approval for its use in New

Zealand. An earlier recommendation was for EBOP to form a partnership with the Department for the Environment in Western Australia to jointly trial Phoslock and this would also apply to the joint use of oxygenation and Phoslock.

It is likely that direct oxygenation of Lake Rotorua over the short periods when it is stratified and longer-term oxygenation of Lake Rotoiti in combination with diversion of the Ohau Channel will prove beneficial for both lakes. Clearly, smaller oxygenation trials (for example in Lake Okaro or parts of Lake Rotoiti) and investigations of the best way to carry out oxygenation of the larger lakes would be needed before any large-scale work could begin.

Phoslock could be used in conjunction with oxygenation where it would be useful in stripping phosphorus from the water column and locking it up in the sediments. Trials in Western Australia indicate an amount the equivalent of 1 mm depth coverage of the sediment will achieve this (Ref 9). If no new sediment is being introduced this could be a cost-effective method of modifying at least some of the conditions that cause algal blooms.

Another bonus is that direct oxygenation and nutrient stripping with Phoslock or other materials, could be used in combination to manipulate the N:P ratio and thus eliminate or significantly reduce blue-green blooms.

Recommendation 29: That EBOP continues trials with nutrient stripping materials such as Alum and Phoslock and begins trials with direct oxygenation separately and in combination, to determine the best methods of using these methods to reduce nitrogen and phosphorus in the lakes and manipulate the N:P Ratio.

Recommendation 30: That the use of oxygenation and nutrient stripping materials be built into the modelling proposed in Recommendation 25 so as to inform any trials and help predict the best options for using these management methods individually and together in Lakes Rotorua and Rotoiti.

Trapping and removing algal blooms

Blue-green blooms are buoyant and in light-wind conditions float to the surface and can be blown into bays or inlets. This certainly occurred in Lake Rotoiti last summer and high densities were measured in a number of locations. Oil pollution booms have been used in other places to contain similar blooms and even concentrate them further.

Suction trucks using hoses with skimmer heads can then be used to remove the worst accumulations. While this is mainly a cosmetic management measure it can help to allay public concern and remove the worst concentrations.

Given the observation that most of the blooms started in the western end of Lake Rotoiti and sometimes in bays and inlets, oil pollution booms may be able to be used to contain the spread of some blooms. The Department of the Environment in Western Australia have had experience with these techniques and could be contacted for advice.

Recommendation 31: That EBOP and RDC investigate the use of oil pollution booms to contain and concentrate the worst algal blooms, and the use of 'suction trucks' to remove the worst of the accumulations

Use of herbicides – a wild card

Herbicides are rarely used in natural water bodies to kill algae because of the danger of adverse effects on aquatic life. However, in some situations, targeted spraying, even in narrow waterways has proved effective.

There is currently treatment of large aquatic weeds with herbicide when they become a nuisance in some of the Rotorua lakes, including Lake Rotoiti. Thus there is experience with the use of herbicides and this could be extended to careful trials on blue-green blooms, but extreme care would need to be taken to minimise any adverse effects on aquatic life, especially the prized fish.

Recommendation 32: That EBOP and the RDC, in liaison with the appropriate authorities, investigate the potential use of herbicides to control blue-green algal blooms.

Algal bloom risk prediction

While not a direct short-term management measure, the ability to predict blooms would be beneficial to keep the public informed and allow EBOP to be prepared with short-term management measures, such as herbicide spraying and containment of blooms with booms, if these methods prove feasible and environmentally acceptable.

Blooms caused by buoyant algae can appear suddenly, usually associated with periods of calm weather in summer when a phytoplankton community circulating through the mixed layer accumulates on the surface and is blown into bays. Adverse publicity invariably follows, particularly when the blooms are those of toxic species.

Discussions with NIWA indicate that risk prediction could operate at two relevant time scales; up to three months ahead and up to 10 days ahead.

1) The risk of a summer bloom up to three months ahead may be derived from current lake phytoplankton information, a knowledge of the previous lake history and the probabilities, derived from NIWA's climate models, of (say) an impending above average summer temperature and above average number of summer calm days.

2) For shorter periods of 10 days or less, information gained from more frequent phytoplankton monitoring of the mixed layer (as recommended earlier) should show if the species composition is dominated by potentially buoyant algae. Monitoring frequencies can then be increased so that the phytoplankton monitoring can be linked to 10 day (or less) forecasts of calm weather.

NIWA could supply the longer-term weather forecasting and work with EBOP to combine this with the phytoplankton monitoring, to provide a high quality algal bloom risk prediction capacity.

Recommendation 33: That EBOP considers working with NIWA to develop an algal bloom risk prediction capacity for both longer periods (three months) and shorter periods (10 days or less).

6.7 Other management issues and options

Cross regional cooperation and learning

From discussions with NIWA, Professor David Hamilton and staff from the Ministry for the Environment it became clear that similar problems to those in the Rotorua lakes are occurring in other waterways. For example, considerable work has been done for Lake Taupo to identify the levels of nutrient reduction that are necessary to prevent the type of algal blooms that have occurred in Lake Rotoiti. Much of this work is being carried out by the same organisations that are working with EBOP on the Rotorua lakes.

In the case of Lake Taupo, the responsible authority is Environment Waikato and they were participants at the Rotorua Lakes 2003 Symposium. It is understood that EBOP and Environment Waikato are collaborating and it is important that this continue, because lake and other waterway systems are complex and there needs to be pooling of knowledge and experience to get the best and most cost-effective management outcomes.

In addition, various authorities can jointly contribute to studies and investigations that need to be done, that have applicability across a number of systems. This is true for both catchment management and in-water management.

Recommendation 34: That EBOP continues to work with Environment Waikato, and other organisations carrying out lake investigations, to share information and contribute to joint studies and management trials where appropriate.

Science coordination

While a number of good studies have been done on Lakes Rotorua and Rotoiti over the last 35 years, it is apparent that the science has not been coordinated as well as it might to produce a whole systems understanding that leads to the best management options. EBOP is now doing a good job in coordinating the various science and management investigations, but it is the author's view that this could be strengthened by bringing the scientists together to debate the science that is needed to best support the highest priority management options.

Clearly this is a matter for EBOP to determine, but similar approaches in other parts of the world have helped to optimise the final management measures. This is especially true of the critical investigations that have been referred to earlier, to support the short-term management measures that have been recommended.

Recommendation 35: That EBOP considers ways of better coordinating and focusing the scientific investigations that will underpin the preferred short- and longer-term management measures.

Trout fishing

Trout fishing is an important part of the tourist economy for the Rotorua district and Lake Rotoiti is prized for its large 'trophy trout'. Lake Rotorua is also an important lake for trout fishing. Fish and Game New Zealand have a sophisticated monitoring and release strategy to optimise larger trout, especially in Lake Rotoiti.

There is evidence that the average fish size in Lake Rotoiti is declining (Fish and Game New Zealand and Ted Boucher *pers comm.)* and this is concerning for the tourist industry and the economy of the district. Recent studies by the University of Waikato are showing that marked habitat changes have occurred in Lake Rotoiti over the last decade (Chris G McBride, Brendan J Hicks and Michael van den Heuvel) and that the area of the lake habitable for fish over the summer months has decreased.

While the exact cause for the decline in size is not clear, it is important that this work continues as it is valuable for the tourist industry and it provides another link in the relationship between the decline in the lakes and the responses of the biota.

Recommendation 36: That EBOP continues to work with Fish and Game New Zealand and the University of Waikato to support investigations into the impact of the decline of Lakes Rotorua and Rotoiti on the trout fishery.

Ecosystem targets and management

While it is not directly part of this report, the overall health of Lakes Rotorua and Rotoiti must be considered and this is more than just the frequency and severity of algal blooms. Important also is the overall ecological health of the lakes, including the aquatic plants, the native fish and the fringing vegetation. Discussions with both EBOP and the Department of Conservation indicate considerable concern at the deterioration of the ecosystems in both lakes.

This is exemplified by the decline in native aquatic plants which have been smothered by invasive exotic aquatic weeds. NIWA (John Clayton and Tracey Edwards) supported by EBOP has developed ‘lake health indicators’ based on both the condition of native aquatic plants and the degree of impact by invasive weed species. A combined index, the Lake SPI or lake ‘Submerged Plant Indicators’ is a new management tool that uses submerged plants from within lakes to indicate lake ecological condition.

The results of this work for Lakes Rotorua and Rotoiti as set out in a poster presented by NIWA in 2003 are:

Lake Rotorua

- lake condition very poor
- lake SPI Index increased slightly due to declining invasive species
- blue-green algae covering plants
- worst invasive weed (hornwort) present but having little effect
- lake condition moderated by high exposure that helps to minimise invasive weed impact and water quality features.

Lake Rotoiti

- overall condition – very poor
- lake SPI Index has decreased
- blue-green algae smothering plants
- invasive weed species close to maximum impact
- worst rating weed (hornwort) dominant
- native condition at only 18% of its potential.

Overall, this work supports the TLI measurements and Professor Hamilton's work that shows the worst lakes are Lake Rotoiti, Lake Okaro and Lake Rotorua. While the toxic blue-green algal blooms have taken the limelight because of their immediate public impact, it is the overall ecological health of the lakes that is most important.

EBOP is to be commended for supporting the work to develop the Lake SPI Index and should continue to support this type of work to develop and refine broader ecological and ecosystem targets to aid management of the lakes. The following recommendation is perhaps a fitting place to end this report as it is about overall ecosystem health, for this is what we all, iwi and pakeha alike strive for.

Recommendation 37: That EBOP works with other organizations, such as the Department of Conservation and the Ministry for the Environment, to develop readily measurable lake ecosystem health indicators as an aid to measure the success of short- and longer-term management measures.

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APPENDICES

1. Table 1 taken from Rotorua Lakes Water Quality 2002, Environment Bay of Plenty, January 2003.

2. Table 2 taken from Rotorua Lakes Water Quality 2002, Environment Bay of Plenty, January 2002.

3. Lakes Rotorua and Rotoiti – System Dynamics and Adaptive Management.

4. Table 5: Rotorua Nutrient Inputs and Water Quality – Loads and Targets 1965 – 2002 (adapted from Kit Rutherford's Draft Report, 3 November 2003, Ref 4 in this report).

Appendix 1

Table 1 ***Comparisons of TLI values for the Rotorua district lakes***

Lake	Observed TLI 2001	Observed TLI 2002	PAC value 2002	Long-term Trend
	TLI units	*TLI units*	*% per year*	*In terms of TLI units*
Okaro*	5.72 ± 0.10	NS		
Rotorua	4.63 ± 0.07	4.66 ± 0.07	0.69	No change
Rotoehu	4.67 ± 0.05	4.67 ± 0.05	1.03	No change
Rotoiti	NS	3.87 ± 0.05	0.27	No change
Okareka	3.24 ± 0.09	3.23 ± 0.09	0.00	No change
Rotomahana*	3.77 ± 0.09	NS		
Rerewhakaaitu	3.63 ± 0.11	3.60 ± 0.11	0.23	No change
Rotoma*	2.36 ± 0.12	NS		
Okataina	NS	2.70 ± 0.06	1.51	No change
Tarawera	NS	2.69 ± 0.06	0.75	No change
Tikitapu	NS	2.84 ± 0.13	0.94	Probable degradation
Rotokakahi**	3.25 ± 0.05			

* Not sampled in either the period 1 July 2000 to 30 June 2001 or the period 1 July 2001 to 30 June 2002.

** Historical data

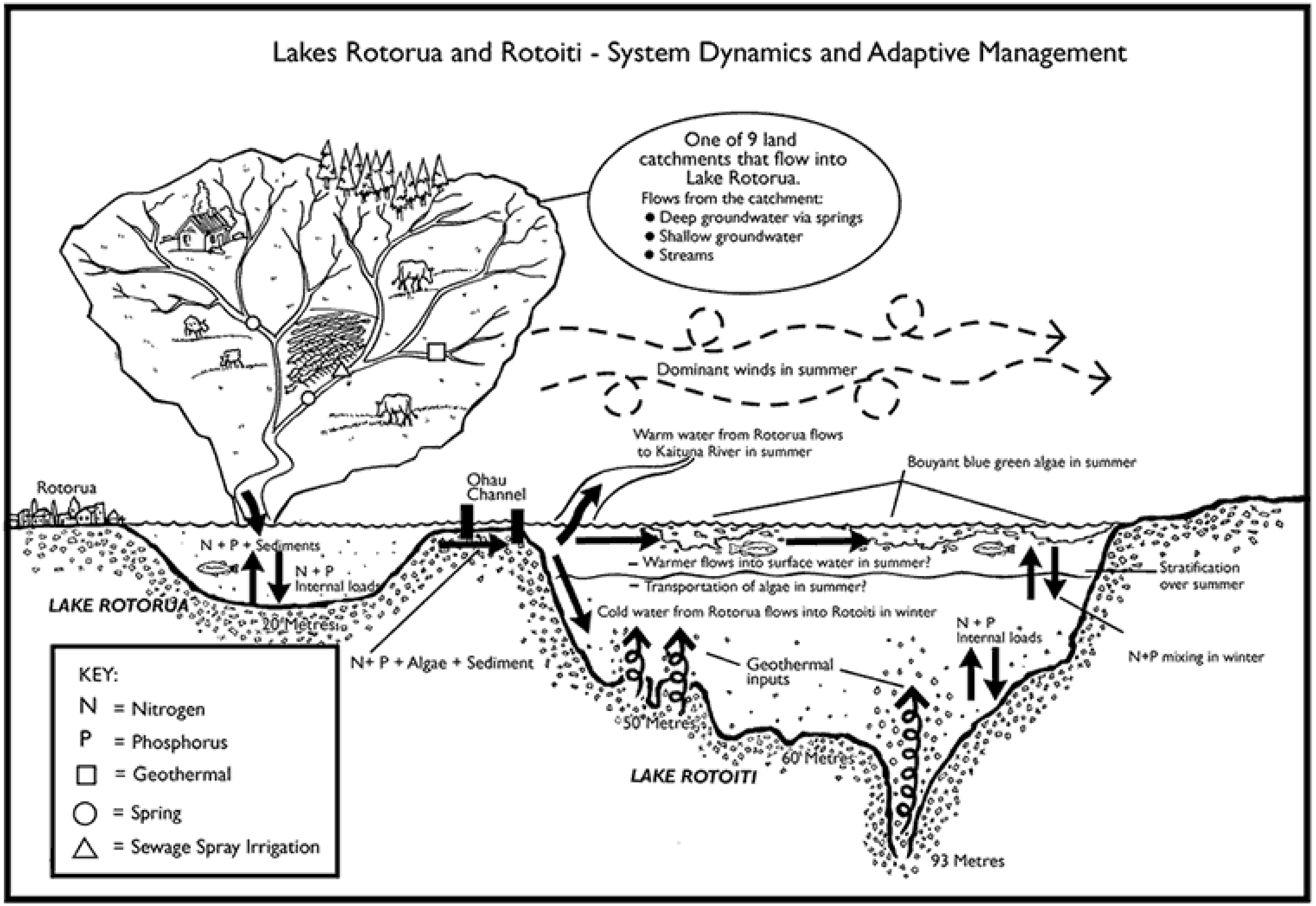
Appendix 2

Table 2 ***Yearly average TLI values for the Rotorua district lakes in comparison to the TLI values set in the Regional Water and Land Plan.***

Lake	3 yearly average TLI to 2000	3 yearly average TLI to 2001	3 yearly average TLI to 2002	Regional Water & Land Plan	3 yearly Trend
	TLI units	*TLI units*	*TLI units*	*TLI units*	*In terms of TLI units*
Okaro	5.76	5.75		5.0	No change
Rotorua	4.62	4.61	4.63	4.2	No change
Rotoehu	4.67	4.66	4.67	3.9	No change
Rotoiti	3.86		3.87	3.5	No change
Okareka	3.24	3.24	3.24	3.0	No change
Rotomahana	3.79	3.78		3.9	No change
Rerewhakaaitu	3.65	3.65	3.63	3.6	No change
Rotoma	2.34	2.35		2.3	No change
Okataina	2.66		2.67	2.6	No change
Tarawera	2.65		2.67	2.6	No change
Tikitapu	2.78		2.80	2.7	No change
Rotokakahi*	3.25				

* Historical data collected from 1990 to 1996

Appendix 3



Lakes Rotorua and Rotoiti - System Dynamics and Adaptive Management
One of 9 land catchments that flow into Lake Rotorua.
Flows from the catchment:
• Deep groundwater via springs
• Shallow groundwater
• Streams
Dominant winds in summer
Warm water from Rotorua flows to Kaituna River in summer
Bouyant blue green algae in summer
Rotorua
Ohau Channel
N + P + Sediments
N + P Internal loads
LAKE ROTORUA
20 Metres
N+ P + Algae + Sediment
- Warmer flows into surface water in summer?
- Transportation of algae in summer?
Stratification over summer
Cold water from Rotorua flows into Rotoiti in winter
N + P Internal loads
N+P mixing in winter
Geothermal inputs
50 Metres
60 Metres
LAKE ROTOITI
93 Metres
KEY:
N = Nitrogen
P = Phosphorus
= Geothermal
= Spring
= Sewage Spray Irrigation

Appendix 4

Table 5. Lake Rotorua Nutrient Inputs and Water Quality – Loads and Targets 1965-2002

	1965	1976-77	1981-82	1984-85	2002	Target	Reduction from 2002 to meet target
Population	25,000	50,000	52,600	54,000		-	
Phosphorus input							
Raw sewage t/y	5	18	30	47		-	
Treated sewage t/y	5	7.8	20.6	33.8	1	3	
Stream t/y[a]	34	34	34	34	34	34	
Internal t/y	ND	0	20	35		0[b]	
Total t/y	39	42	75	103	35	37	nil
Nitrogen input							
Raw sewage t/y	34	100	170	260		-	
Treated sewage t/y	20	73	134	150	32	30	-2
Stream t/y[a]	455	485	420	415	660	405	-255
Septic tanks t/y	50	80	15	10		0	
Internal t/y	ND	0	140	>260		0[a]	
Total t/y	475	558	694	>825	692	435	-257
Average lake quality							
Total phosphorus mg/m^3		23.8	47.9	72.6		20	
Total nitrogen mg/m^3		310	519	530		300	
Chlorophyll mg/m^3		5.5	37.8	22.6		10	
Peak chlorophyll mg/m^3		28	62	58		17-24	
Secchi disc m	2.5-3	2.3	1.9	1.7		2.5-3	
Deoxygenation $g/m^3/d$		0.4	0.7	0.9		0.25	

[a] flood flow particulate P and N are excluded because they probably settle on the lakebed and are not 'available' to phytoplankton

[b] internal loads may be non-zero even when external loads are reduced