BEFORE THE HEARINGS PANEL

IN THE MATTER of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council

---

SECTION 42A REPORT OF MR MAX MARTIN GIBBS

ON BEHALF OF HORIZONS REGIONAL COUNCIL

---

1. INTRODUCTION

My qualifications/experience

1. My name is Max Martin Gibbs. I have an NZCS from Wellington Polytechnic, majoring in Chemistry, which I completed in 1967. I am a scientist and consultant with the National Institute of Water and Atmospheric Research Ltd. (NIWA) and I have been employed by NIWA and its predecessors for 44 years.

2. I joined the Department of Scientific and Industrial Research (DSIR) in 1965 and was employed for eight years at Chemistry Division, DSIR, as an analytical technician in the fields of pesticide and organic chemistry. In 1973 I transferred to Ecology Division, DSIR, studying the causes and consequences of eutrophication in lakes. I was granted a Fellowship to Edinburgh University, Scotland, between 1980 and 1981 based out of the Freshwater Biological Association laboratory at Windermere, Cumbria, studying iron cycling in lakes (Hilton and Gibbs. 1985). With the formation of the Crown Research Institutes in 1992, I was transferred to NIWA, Hamilton, as a scientist and consultant in the field of aquatic chemistry. Examples of my work include: I reviewed the water quality data on the lakes in the Auckland Regional Council area (Gibbs *et al*., 1999); I was specifically requested by Environment Bay of Plenty to review the current knowledge on the Lake Rotorua-Rotoiti hydraulic coupling and to assess the potential effects of implementing engineering options for improving the water quality of Lake Rotoiti, including diversion of the Lake Rotorua water directly to the Kaituna River outlet (Gibbs *et al*., 2003); and I currently lead a NIWA team providing weekly advice to WaterCare Services Ltd. on the management of the 10 water supply reservoirs for Auckland City (eg. Gibbs and Cook, 2006).

3. I have conducted research in numerous projects and commercial contracts and have also produced more than 60 scientific papers published in refereed journals, and more than 90 internal and contract reports. I have also presented more than 20 conference papers, both in New Zealand and overseas. I was a co-organiser of the 4th International Conference on Applications of Stable Isotope Techniques to Ecological Studies, held in Wellington, New Zealand, in 2004.

4. I have extensive experience in analytical techniques and the interpretation of water quality and hydrological data from lakes, estuaries and groundwater. I have studied the limnology and water quality of many lakes throughout New Zealand, from Lake Wakatipu, in the South Island, to Lake Kapoai, a dune lake in Northland. I have studied Lake Taupo since 1973 and I provide annual reports on Lake Taupo's water quality to

Environment Waikato (eg. Gibbs, 2009). I am a member of the Technical Advice Group (TAG) to Environment Bay of Plenty for the restoration of the Te Arawa lakes in the Rotorua area, and was part of the team advising on the need for and positioning of the Ohau Channel diversion wall (eg. Gibbs *et al*., 2003). I am currently working on nutrient (nitrogen (N) and phosphorus (P)) cycling from the sediments of these lakes, especially Lake Okaro (Paul *et al*., 2008) and Lake Rotorua (Burger *et al*., 2007). I have recently tested the use of several P inactivation agents to cap lake sediments to block the release of P (Gibbs *et al*., 2008), which is a major factor in the production of cyanobacteria blooms. I am providing science support for Environment Bay of Plenty during the consultation process with iwi, rural land owners, lake action groups, and ratepayers for the consent process to enable small-scale trials of three sediment capping agents on the bed of Lake Rotorua, as the next step in the restoration process for this lake.

5. Suspended sediment is another major contaminant in rivers, estuaries and lakes, and often carries N and P in particulate form. I have developed a forensic technique using stable isotopes to identify the sources of terrigenous soil by land use contributing to sediment deposition (Gibbs, 2008). I have used this technique to study sediment transport in the Waitetuna River catchment for the Foundation for Research, Science and Technology (FRST), and in Mahurangi Harbour for Auckland Regional Council (Gibbs, 2005), the Whangapoua Estuary (Gibbs et al., 2005) and the Wharekawa Estuary (Gibbs and Bremner, 2007) for Environment Waikato. I have also used it to identify the sources and relative contributions of sediment adversely affecting the Whangamarino Wetland for the Department of Conservation (Gibbs, 2009).

6. My sediment tracking and tracing technique has been accepted internationally. It currently forms part of a joint Food and Agriculture Organization (FAO) of the United Nations and International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) titled Integrated Isotopic Approaches for an Area-Wide Precision Conservation to Control the Impacts of Agricultural Practices on Land Degradation and Soil Erosion. I was invited to Vienna, Austria, as a consultant to draft the CRP proposal and am now a member of the Research Co-ordination Meeting team reviewing research plans and protocols to achieve the objectives of the CRP.

7. I have read the Environment Court's practice note, Expert Witnesses – Code of Conduct, and agree to comply with it.

My role in the Proposed One Plan

8. I have no previous involvement with the One Plan. My current role is to assemble and present evidence according to the Scope of evidence, below.

Scope of evidence

9. My evidence will:

- Describe my experience in relation to lake water quality research, with particular reference to work done in the Manawatu-Wanganui Region;
- Describe the nutrient cycle in lakes and common issues with shallow lake water quality;
- Describe the effects of nutrient enrichment of lakes (ie. cyanobacteria blooms, etc);
- Review the lake water quality standards and the water quality standards that apply to streams and rivers in natural lake catchments which flow directly or indirectly into lakes, within Schedule D of the Proposed One Plan, and comment on any recommended changes to these standards including:
    - i. whether each parameter is appropriate for a lake situation;
    - ii. whether the numerical value (range) is appropriate; and
    - iii. whether there is any sensible intervention Manawatu-Wanganui Regional Council could make if the natural water quality falls outside the range.

10. Within this section of evidence I will consider the general characterisation of lakes in the Manawatu-Wanganui Region, their separation by geomorphic differences, and the importance of these differences to the lake water quality.

- Consider the effects of the proposed approach to control intensive land use and impose nutrient loss limits on all intensive operations in lake catchments (Water Management Zones) on lake water quality; and
- Suggest recommendations for lakes water quality monitoring (ie. parameters, frequency, spatial and depth considerations).

2. EXECUTIVE SUMMARY OF EVIDENCE

11. ***Relevant experience:*** I have worked on lakes in New Zealand and in England since 1973. Much of my work has focussed on large lakes, including Lakes Wakatipu, Rotorua, Rotoiti, and Taupo, but I have also studied several of the coastal dune lakes north of Auckland as well as Lake Horowhenua and Virginia Lake in the Manawatu-Wanganui Region. In England, I studied iron cycling in Esthwaite Water, a small lake in Cumbria, and that research is directly relevant to many of the coastal dune lakes in the

Manawatu-Wanganui Region, as they occur in the iron-rich sands along the west coast of the North Island of New Zealand.

12. ***Nutrient cycles and nutrient enrichment of lakes:*** In my evidence I have described the nutrient cycle in lakes and common issues with shallow lake water quality, including the effects of nutrient enrichment and enhanced turbidity due to wind-wave action on the lake bed and shore line. In summary:

- The water quality of a lake is classified in terms of trophic condition based on the amount of oxygen, the nutrients nitrogen (N) and phosphorus (P), and chlorophyll *a*, and the clarity of the water. There are three main trophic conditions – oligotrophic (high quality), mesotrophic (medium quality), and eutrophic (low quality), with additional steps at both ends to allow classification of exceptionally high and low quality. At the low end, increased nutrient enrichment causes the water quality to decrease from eutrophic > hypertrophic > supertrophic. Many of the dune lakes in the Manawatu-Wanganui Region are highly nutrient enriched and fall into the lower two classifications.
- Nutrients N and P enter a lake from the catchment via surface inflows and groundwater. Land use practices affect the amount of nutrients in these inflows, with native forests yielding the least, and market gardening the most, nutrients per hectare per annum. In deep lakes, these nutrients can be buried in the sediment, but in shallow lakes they remain in the well-lit surface waters (euphotic zone) where they can be used by algae for growth. Because of the way dune lakes were formed, very few have surface outflows and thus they accumulate all the nutrients that enter them and become more eutrophic over time.
- The key difference between shallow (c. <5 m) and deeper lakes is that deeper lakes can thermally stratify in summer, with the warmer upper layer (epilimnion) being isolated from the cooler lower layer (hypolimnion) by the density gradient (thermocline) between the layers. The thermocline prevents the rapid exchange of water, and thus nutrients and dissolved oxygen, between the epilimnion and hypolimnion. In winter, thermal stratification disappears and the upper and lower water layers can mix again. This stratification and mixing cycle repeats each year. However, strong winds can cause partial mixing during the summer stratified period.
- Nutrient cycling within a lake is largely regulated by the concentration of oxygen dissolved in the water. The dissolved oxygen is consumed by decomposition of organic matter (carbon). In deeper stratified lakes, there can be complete removal of dissolved oxygen from the hypolimnion, causing the water to become anoxic. Decomposition processes in the sediments release the nutrients nitrogen (N) and

phosphorus (P) in soluble forms which can be used by plants and free-floating algae for growth. In shallow, well oxygenated lakes, the P is sequestered (bound) by iron and manganese at the sediment-water interface. This binding process is reversible in the absence of dissolved oxygen. Consequently, there can be relatively high concentrations of P in the anoxic hypolimnion of a deeper lake. Under calm conditions, the thermocline prevents the N and P in the hypolimnion from reaching the epilimnion and algal growth is restricted in the epilimnion. However, wind-induced mixing events can bring some P into the epilimnion in summer, stimulating algal growth at that time. All of the P will become available when the lake mixes, but most will be sequestered by iron and returned to the sediments.

- Algal growth uses N and P at an optimum ratio of 7.2 g N for every 1 g P. Because the N is used faster than the P, there is often an excess of P in the waters of eutrophic lakes in summer. Under these conditions, blue-green algae (cyanobacteria) which can use (fix) atmospheric N for growth and thus use some of the excess P, dominate. This leads to nuisance growths of cyanobacteria which can reach bloom proportions, releasing toxins into the lake water.

13. I have used these general descriptions to describe the nutrient cycling in dune lakes, with specific reference to Lake Horowhenua as it was when I studied it.

14. ***Lake water quality standards*****:** I have reviewed the water quality standards for lakes, within Schedule D of the Proposed One Plan. I have commented on each standard and I have recommended changes to these standards where I believe the parameter is not appropriate for a lake situation and/or the numerical value (range) is not appropriate. I have also commented where I believe there is no sensible intervention Horizons Regional Council could make if the natural water quality falls outside the range of the standard. In summary by standard:

A key point: I believe that one standard is not appropriate for all lakes and that the standards should be different for shallow (c. <5 m) and deeper lakes, which can stratify in summer.

I recommend that for the Proposed One Plan, a shallow lake is defined as a lake which does not develop stable thermal stratification during summer.

i. “The pH of the water shall be within the range 7 to 8.5 and shall not be changed by more than 0.5 pH”:

I recommend that the pH range should be revised to “6.5 to 8.5” and that the narrative “and shall not be changed by more than 0.5 pH” is replaced with a narrative that links pH above 8.5 with ammoniacal nitrogen concentrations and the potential for chronic ammonia toxicity in the surface waters, or epilimnion if the lake can become thermally stratified.

ii. The temperature of the water shall not be changed by more than 1°C:

I recommend that temperature change in the lake is not used as a standard. However, temperature change should be used as a condition in a resource consent to discharge water into a lake.

iii. The Dissolved Oxygen concentration shall not be less than 80% in the surface waters (defined as less than 2 metres deep):

I recommend that dissolved oxygen concentration in the lake is not used as a standard. However, dissolved oxygen change should be used as a condition in a resource consent to discharge water into a lake, and the words “of saturation” should be inserted after “80%”.

iv. The five-days Biological Oxygen Demand shall not exceed 1 g/m^3:

I recommend that five-days Biological Oxygen Demand in the lake is not used as a standard. I believe that it would be more useful to have a standard based on water column or hypolimnetic oxygen depletion (HOD) rate and sediment oxygen demand.

v. The annual average algal biomass shall not exceed 5 mg Chlorophyll a/m^3 and no sample shall exceed 15 mg Chlorophyll a/m^3:

I recommend that the values used in this standard (mesotrophic) are applied to the deeper lakes only and that shallow dune lakes use values appropriate for eutrophic conditions, ie. an annual average algal biomass of less than 12 mg chlorophyll *a* $/m^3$ with a maximum algal biomass of 30 mg chlorophyll *a* $/m^3$. The proviso is that the existing water quality is protected by the standard and improved.

vi. The annual average total phosphorus concentration shall not exceed 20 mg/m^3; and

vii. The annual average total nitrogen concentration shall not exceed 337 mg/m^3:

I recommend that the values used in these standards (mesotrophic) are applied to the deeper lakes only and that shallow dune lakes use values appropriate for eutrophic conditions, ie. an annual average of less than 43 mg total P $/m^3$ and 725 mg total N $/m^3$. The proviso is that the existing water quality is protected by the standard and improved.

viii. The concentration of ammoniacal Nitrogen shall not exceed 337 mg/m^3:

I recommend that this standard is revised to include a pH limit and a depth range, eg. "… shall not exceed 337 mg/m^3 when the pH is greater than 8.5 measured within the epilimnion or within 2 m of the water surface". There is no need for an ammoniacal standard below pH 8.5 as toxicity would not be an issue and ammoniacal N, as part of the total N, is covered by the Total N standard, Standard 7.

ix. For toxicants not otherwise defined in these standards, the concentration of toxicants in the water shall not exceed the trigger values defined in the 2000 ANZECC guidelines Table 3.4.1 with the level of protection of 95 % of species:

This standard is acceptable.

x. The clarity of the water measured as Secchi depth shall not be less than 2.8 m and shall not be changed by more than 20%:

I recommend that the word "… changed …" is replaced with the word "… reduced …". I also recommend that the proposed standard is applied to deeper lakes only and that a separate standard that reflects safe swimming is applied to shallow lakes. A suggested minimum clarity standard for shallow lakes would be 0.8 m with the same limit on reduction of clarity.

xi. The turbidity shall not be changed by more than 20%. This standard shall apply only when physical conditions existing at the site prevent adequate water clarity (Secchi Disc) measurement:

I recommend that this standard is removed.

xii. The concentration of Escherichia coli shall not exceed 260 per 100 millilitres. This standard applies during the period 1st November to 30th April inclusive; and

xiii. The concentration of Escherichia coli shall not exceed 550 per 100 millilitres. This standard applies during the period 1st May to 31st October inclusive year round:

These standards are acceptable.

xiv. The concentration of toxins due to cyanobacteria (blue-green algae) shall not exceed 20 milligrams per cubic metre. This standard applies year round:

I am not competent to assess this standard. However, I am aware that there are several different cyanotoxins which need to be specified and thus a single value standard may not be appropriate. The use of cyanobacteria cell counts may also need to be considered as a guide for when to measure cyanotoxins. There will also need to be continued cyanotoxin measurements after the cyanobacteria proliferation has dispersed as the cyanotoxins can remain in the water for extended periods after a bloom.

xv. I have also reviewed the Streams and rivers in natural lake catchments water quality standards (Schedule D, Tables 19 and 20) and found there was little reason to have a separate set of standards for the streams and rivers flowing into a lake.

I recommend that "Streams and rivers in natural lake catchments" water quality standards are removed and that the "Streams and rivers water quality standards are used for all streams and rivers in the Manawatu-Wanganui Region.

xvi. I have also considered the effects of the proposed approach to control intensive land use and impose nutrient loss limits on all intensive operations in lake catchments (Water Management Zones) on lake water quality.

Key points:

- Dune lakes receive much of their water from groundwater.
- Nutrient loads in groundwater come from the land use on soil surface by leaching with infiltrating rain and irrigation water.
- Groundwater flow is slow such that there will be a lag of many years before the nutrient legacy from today reaches the dune lake.
- Most dune lakes have no surface outflow, causing those nutrients and other organic matter to accumulate in the lake, driving eutrophication.

- Consequently, even if the proposed approach to control intensive land use and impose nutrient loss limits on all intensive operations in many lake catchments were implemented today, the water quality of a dune lake is likely to get worse before it improves.
- Mitigation of the groundwater nutrient legacy requires implementation of additional targeted management strategies for each lake, such as stock exclusion by fencing and the refurbishing of lake-edge buffer zones.

xvii. I have suggested some recommendations for lakes water quality monitoring (ie. parameters, frequency, spatial and depth considerations) based on published water quality monitoring protocols.

I recommend that the detailed water quality monitoring protocols given in Burns *et al*. (2000) be used as a basis for developing water quality monitoring protocols for the Proposed One Plan. These should be adapted to meet the specific requirements of Horizons.

3. EVIDENCE

15. My experience with lake water quality research began on Lake Taupo in 1973 and continues on that lake to the present day. As a consequence of this long-term study and the association and collaboration with visiting scientists, as well as discussions with scientists at conferences in New Zealand and overseas, I have gained a broad understanding of lake physical and chemical processes and the factors that affect lake water quality.

16. As an analytical chemist I have collected water samples and measured the chemical parameters that are used to define water quality and to assign a trophic state to a lake. Consequently, I am fully aware of the major chemical and biogeochemical interactions that can occur between nutrients (ie. P, N, and trace metals) in a lake water column and across the sediment-water interface at the bed of the lake.

17. I have collected water samples for the determination of algal biomass, as indicated by the measurement of chlorophyll *a*, from material removed from the water on glass fibre filters, and as enumerated by specialist algal taxonomists as cell counts converted to cell volume (biovolume). I have also evaluated the stimulation of phytoplankton growth by the addition of nutrients to natural populations of phytoplankton in containers of lake

water. (Phytoplankton are the natural assemblage of algal species.) From this aspect of my research I have a basic understanding of the different classes and species of algae that can be found in New Zealand lakes and estuaries, and their nutrient and physiological requirements (eg. Gibbs and Vant, 1997; Safi and Gibbs, 2003).

18. My understanding of lakes recognises that a lake is an integral part of the catchment. Lake water quality is dependent on land use practices that affect the nutrient concentrations in the surface and groundwater flows into the lake, and direct rainfall on the lake surface. I have sampled and measured the chemical parameters in lake inflows (eg. John *et al.,* 1978; Gibbs, 1979; White *et al.,* 1980; Burger *et al.,* 2007; Vant and Gibbs, 2006) in order to produce nutrient budgets for lakes.

19. A nutrient budget is the sum of all nutrient inflows and outflows from a lake over a specified time period. It is a fundamental part of understanding the drivers influencing the water quality of a lake and the exacerbation of lake eutrophication. By "drivers" I mean the key processes controlling the supply, form, and availability of essential nutrients for the growth of phytoplankton and the development of nuisance algal blooms in lakes.

20. Eutrophication is the enrichment of natural waters with plant nutrients. It is a natural process that can be accelerated by catchment development. The resultant degradation of lake water quality can be reversed, but rarely to the original lake water quality.

21. My research on large lakes such as Lake Wakatipu and Lake Taupo provides an insight to the beginning of the eutrophication process in lakes. The high water quality of such lakes is vulnerable to even small changes in nutrient inputs from the catchment. The data from my studies on Lake Taupo contributed to Variation 5 (RPV5) to the Waikato Regional Plan, legislation implemented by Environment Waikato to protect Lake Taupo. RPV5 has the aim to ensure that by 2080 the water quality of Lake Taupo is as it was in 2001-2005. In the 10-year life of the plan there will be a 20% reduction in the manageable load of N from the catchment.

22. In Northland, I was the science provider to a group of farmers co-ordinated by AgResearch to improve the water quality of Lake Kapoai, a dune lake that was experiencing severe nuisance blooms of the cyanobacteria *Microcystis sp*. During this study, the farmers around the lake "bought into" a scheme that aimed to restore the water quality of their lake. Initial resistance to "outsider" influence was overcome by guiding them rather than regulating them, using methods including: showing them the

benefits of basic restoration practices such as using fences to keep stock out of the lake; managing existing wetlands rather than draining them; taking advantage of naturally occurring plant communities to strip nutrients from groundwater; and reducing suspended sediment concentrations by establishing lake edge buffer zones of aquatic plants to reduce wave action that was causing bank erosion and lake bed disturbance.

23. In 1989 I was part of a research team from the Taupo Research Laboratory, DSIR, studying Lake Horowhenua, one of the largest and shallowest lakes in the Manawatu-Wanganui Region. During that study we evaluated the hydrology, chemistry and biology of the lake over a 12-month period. At the end of the field work, I produced a computer simulation (model) to examine the processes occurring in the lake. I also used the model to assess the likely effects of implementing a range of different strategies for lake restoration. I presented the results of this modelling at the Shallow Lakes '92 Symposium on Nutrient dynamics and biological structure in shallow freshwater and brackish lakes, at Silkeborg, Denmark, and the work was subsequently published (Gibbs and White, 1994). During this study, I learned the importance of micro zones and short-term bottom water deoxygenation. As Lake Horowhenua is a dune lake in iron sand, my earlier studies of iron cycling in lakes were highly relevant. By "iron sand" I mean the iron rich sands along the west coast of the North Island of New Zealand. The majority of the coastal lakes in the Manawatu-Wanganui Region occur in iron sand and iron can sequester or release phosphorus, a key water quality nutrient, depending on the dissolved oxygen concentration in the lake water.

24. In April 2004 I was asked by Wanganui Water Services (WWS) of Wanganui District Council (WDC), to assess the likely effects of discharging stormwater from the Rotokawau stormwater pond into Virginia Lake (Gibbs, 2004). Subsequently, following a series of cyanobacteria blooms which closed the lake to contact recreation and may have been responsible for fish and bird kills, I was asked for advice on how to control the cyanobacteria and about the possibilities for restoration of the Lake. As part of this advice, on 24 October 2007 a one-day public workshop on the ways forward for Virginia Lake was held in Wanganui for iwi, Horizons Regional Council, WDC, and Virginia Lake users groups (via an Envirolink Small Advice Grant). I presented an overview of the problems occurring in Virginia Lake, including a range of options available to solve these problems, and for the restoration of the lake (Gibbs and Hickey, 2007). A low level dialogue with WWS has continued on from this meeting.

Nutrient cycle in lakes and common issues with shallow lake water quality

25. The most common issues affecting shallow lakes are either excessive aquatic plant (macrophyte) growth, especially exotic (non-native) macrophytes or excessive algal (phytoplankton) growth, especially blue-green algal (cyanobacteria) blooms. Both issues are symptoms of high nutrient loadings.

26. Lakes are nutrient sinks for their catchments, ie. nutrients tend to accumulate in the lake. This means that, over time, the nutrient content of the lake will increase as the lake progresses along the eutrophication path. By eutrophication path, I mean the natural transition from high quality oligotrophic water to low quality eutrophic water due to nutrient enrichment. Nutrients enter the lake in surface water inflows (rivers, streams), rainfall, and via the groundwater.

27. The accumulation of nutrients in a lake is generally a function of the hydraulic residence time and the nutrient load from the catchment. By “hydraulic residence time”, I mean the average time it takes for a drop of water entering the lake to leave the lake. Hydraulic residence times much less than a year tend to wash the external nutrient loads from the catchment out of the lake, either in solution or incorporated in algal cells. Hydraulic residence times very much greater than a year inhibit the wash-out effect enhancing the net accumulation of nutrients in the lake sediment.

28. Although a short residence time tends to result in cleaner lakes, this is not always true. For example, Lake Horowhenua has a mean theoretical residence time of 50 days (Gibbs and White, 1994).

29. Dune lakes often have no surface outflow and water loss is via groundwater seepage and evaporation. This means that they have very long residence times (years). Consequently, dune lakes are especially vulnerable to any nutrient inputs from the catchment as these will accumulate in the lake.

30. Whereas nutrient loads from surface inflows are relatively easy to quantify, the nutrient loads in groundwater inflows are more difficult. In large lakes, eg. Lake Taupo, the groundwater component of the water balance may be small at around 5% (Forsyth and Howard-Williams, 1983: Table 5, page 51). Consequently, the groundwater component tends to be overlooked or ignored. However, as groundwater nutrient concentrations may be an order of magnitude higher than the surface inflows (Table 1), the nutrient load in the groundwater may be a substantial part of the lake nutrient budget.

31. Table 1 presents the nutrient data from a synoptic survey of Virginia Lake (from Gibbs, 2004). Groundwater NO_3-N concentrations at around 11,000 mg m^{-3} are substantially greater than the surface inflow NO_3-N concentrations at around 1,500 to 2,000 mg m^{-3}.

Virginia Lake nutrient data collected on 20 July 2004

Concentrations in mg m^{-3} except for Alkalinity in g equivalents $CaCO_3$ m^{-3} and Secchi depth in m

Sample description	Depth	Secchi	DRP	DOP	NH_4-N	NO_3-N	DON	Alk
Virginia Lake	0 m	3.3	115	13	265	152	335	95
	5 m		112		271	148		
	10 m		113		283	135		
	15 m		113		292	126		
	20 m		113	15	308	114	347	
Groundwater seep			19	3	14	11100	<10	
Stormwater pond	0 m		24	7	81	1490	159	95
Inflow stream			5		15	2060		

P recycled from lake sediments N from external inflows

32. In many small dune lakes, the groundwater contribution may be very much greater than 5%, and thus is the main source of nutrients. For example, the groundwater inflow to Lake Horowhenua is around 50% of the total inflow to the lake (Gibbs and White, 1994).

33. Catchment development and different land use practices can increase the nutrient loads in the surface and groundwater inflows to the lake, and thus accelerate the eutrophication processes. Different land uses have different nutrient yields. For example, the estimated N yields from different land uses in New Zealand are given in Table 2.

Table 2. Compiled from Menneer *et al.* (2004) and Clothier *et al.,* (2007)

Nitrogen loss from land-use leaching (kg N / ha / yr)

Land-use	Range	Mean	Data source
Market gardens	80 - 292	177	Menneer et al., 2004
Market gardens	100 - 300		Clothier et al., 2007
Dairy farming	15 - 155	65	both
Mixed cropping (arable farming)	35 - 110	61	Menneer et al., 2004
Cropping	10 - 140		Clothier et al., 2007
Orcharding (Kiwi fruit)	50	50	Menneer et al., 2004
Sheep farming	6 - 66	21	Menneer et al., 2004
Sheep/beef	6 - 60		Clothier et al., 2007
Forestry	3 - 20	3*	Menneer et al., 2004

* Best estimate for forestry

34. For further information on nitrogen leaching in relation to land use, please refer to the evidence of Drs Roygard, Clothier and Mackay.

35. As a lake is the focus of its catchment, a change in land use within that catchment from low to high N yield will accelerate the eutrophication process, while a change from a high to low N yield land use may improve the water quality.

36. There will be a time lag after the land use change, before the effect of that change is seen in the lake. This is because groundwater flow rates are very slow (eg. I have measured groundwater flows of 0.3 m per day in the central volcanic plateau, meaning it would take a year for the groundwater front to travel 100 m). Consequently, the groundwater entering a lake may be very old, having travelled through the catchment for many years and integrating all of the nutrient inputs from different land uses in the catchment above. In the Lake Rotorua catchment, the average age of the groundwater is 60 years and some groundwater may be as old as 170 years. Groundwater age was determined using tritium dating techniques on water pumped from deep bores around the catchment by the Institute of Geological and Nuclear Sciences Ltd.

37. While the mean values in Table 1 may suggest a steady N loss throughout the year, this is not necessarily true and there can be a strong seasonal cycle to the leaching, mostly associated with fertiliser application, rainfall, and seasonal nutrient uptake for plant growth.

38. Consequently, there is often a strong seasonal cycle to the nutrient concentrations in a lake. This is true in Lake Horowhenua, where the lake water can have high dissolved reactive phosphorus (DRP) but low nitrate-N (NO_3-N) concentrations in summer, then high NO_3-N but low DRP concentrations in winter (Fig. 1).

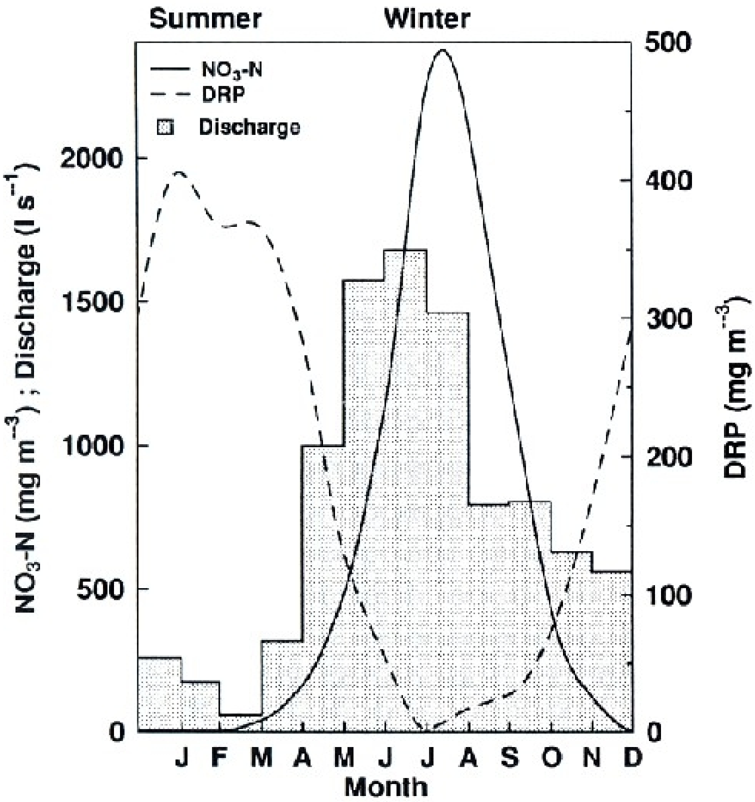

Figure 1. Shows the annual cycle of nitrate-N (NO_3-N) and dissolved reactive phosphorus (DRP) concentrations within Lake Horowhenua relative to the annual discharge via the Hokio Stream (redrawn from Gibbs and White, 1994)

39. Nutrients that accumulate in a lake are used by phytoplankton and vascular aquatic plants, and eventually settle to the sediments in particulate form. There, they may be buried by fresh sediment and lost from the lake nutrient cycle, or they may be recycled back into the water column by biogeochemical processes.

40. By biogeochemical processes, I mean the biological processes of bacterial decomposition and the geochemical transformations of minerals between reduction and oxidation states associated with the absence or presence, respectively, of oxygen.

41. Bacterial decomposition processes use carbon as fuel and consume oxygen. This causes the sediments to lose all oxygen and become anoxic. Under these anoxic conditions, decomposition of organic material releases P in the form of phosphate (ie. DRP) and N is released in the form of ammoniacal-N (NH_4-N). The DRP and NH_4-N accumulate to very high concentrations in the anoxic pore water of the sediment before diffusing up into the overlying lake water.

42. By ammoniacal-N I mean the sum of ammonium ions (NH_4^+) plus free (unionised) ammonia (NH_3). Free ammonia is only found in very low proportions in natural waters when the pH is less than 8. Above pH 8 there is a shift from low toxicity ammonium ions to the more toxic unionised ammonia (ANZECC 2000: Table 8.3.7). Ammonia toxicity is presented in Dr Bob Wilcock's evidence.

43. If the overlying lake water is well oxygenated (aerobic), a class of bacteria called nitrifiers will oxidise the NH_4-N to NO_3-N at the sediment-water interface. This process is called nitrification. At the same time, another class of bacteria (denitrifiers) may remove the oxygen from the NO_3-N and release the nitrogen as N_2 gas, which is lost to the atmosphere. This process is called denitrification and it is an important natural mechanism for removing N from a lake.

44. Denitrification is a rate-limited process which is dependent on the NO_3-N being in contact with the anoxic sediments and thus the denitrifier bacteria population. If the rate of nitrification is greater than the rate of denitrification, the excess NO_3-N will escape into the overlying lake water, where it can be used for phytoplankton growth.

45. Nitrification and, consequently, denitrification do not occur in the sediments when the overlying lake water is anoxic. Under these conditions, the NH_4-N diffuses out of the sediment and into the overlying lake water unchanged, ie. the anoxic lake water will have elevated concentrations of NH_4-N.

46. For DRP diffusing out of the sediments, if the overlying lake water is aerobic, metal oxides adsorb the phosphate ions at the sediment-water interface and prevent the DRP leaving the sediments. The metals most commonly associated with this process are iron (Fe) and manganese (Mn). As most of the lakes along the west coast of the North Island of New Zealand are well oxygenated and are influenced by iron sands, there is an expectation that any P entering these lakes will be locked up with the iron in the sediments ie. the lake waters will be depleted in DRP.

47. While this is true in Lake Horowhenua in winter, it is not true in summer when very high concentrations of DRP are found in the lake water (Fig. 1).

48. The explanation for this apparent anomaly is associated with the oxygen concentrations in the lake water column. If the overlying lake water becomes anoxic, the metals are reduced to their soluble form and there are no oxides to bind the DRP. This allows the DRP to diffuse up into the overlying lake water unimpeded.

49. Although the processes are different, the form and concentration of N and P in the water column of a lake is controlled by the oxygen concentration in the lake. When the lake water column is well oxygenated, there will be little DRP and the N will be present as nitrate. When the lake water column is anoxic there may be elevated concentrations of DRP and the N will be present as ammonium.

50. The nutrient pattern described above is similar to that observed in Lake Horowhenua in winter and summer, respectively (Fig. 1). However, there is an apparent anomaly in that Lake Horowhenua is a very shallow lake which is "well oxygenated" all year round.

51. Oxygen concentrations in a lake are derived from diffusion of oxygen from the atmosphere as the source, balanced against oxygen consumption by the decomposition of carbon in the sediments as the sink. When the carbon load in the sediment is small, the atmospheric source overcomes the consumption processes to keep the lake well oxygenated. Conversely, when the carbon load is large, as in a eutrophic lake, oxygen consumption may be greater than the diffusion of oxygen from the atmosphere.

52. While diffusion rates are very slow, wind stress across the lake causes wave action which rapidly mixes the oxygen down into the lake. Consequently, the upper waters of a eutrophic lake will be well oxygenated, despite the large demand for oxygen by decomposition processes in the sediment (ie. sediment oxygen demand (SOD)). As decomposition is a microbial process dependent on temperature, the sediment oxygen demand will be highest in the warm summer months and lowest in the cold winter months.

53. The solubility of oxygen in water is also affected by temperature. Oxygen is less soluble in warm water and the oxygen saturation concentration at 20ºC is around 20% less than it is at 10ºC.

54. Strong wind mixing, high solubility and low sediment oxygen demand in winter result in a well oxygenated water column, whereas weak wind mixing (calm weather), low solubility, and high sediment oxygen demand in summer result in oxygen depletion in the water column.

55. The efficiency of wind mixing depends on the depth of the lake. In a very shallow lake, the turbulent mixing currents from surface wind waves extend to the sediments, and the water column has uniform nutrient and oxygen concentrations. In deeper lakes, the

depth of wind-induced mixing may only reach the lake bed in winter (eg. Lake Taupo mixes to 150 m in winter).

56. In summer, solar radiation may warm the upper water column faster than the heat can be transferred to the bottom waters and the lake becomes thermally stratified (ie. warm water is less dense than cold water and floats as a layer on top of the colder bottom water).

57. The boundary zone between the upper water column (epilimnion) and lower water column (hypolimnion) is called the metalimnion (thermocline). The thickness of the thermocline and the temperature gradient across it affects its resistance to wind-induced mixing and the rate of transfer of nutrients, heat and oxygen between the epilimnion and the hypolimnion.

58. In summer the thermocline is often very strong (ie. has a high resistance to wind-induced mixing) and it becomes a barrier to oxygen reaching the hypolimnion. Consequently, if there is a high sediment oxygen demand, the hypolimnion can become anoxic and have elevated concentrations of DRP and NH_4-N. The thermocline is also a barrier to the upwards movement of these nutrients into the epilimnion. As summer is also a period of low stream flow, there are likely to be reduced inputs of nutrients from the catchment (external load) and the epilimnion becomes depleted in nutrients.

59. In autumn, the thermocline weakens due to surface water cooling and becomes vulnerable to wind-induced mixing. When mixing occurs, all of the nutrients that accumulated in the hypolimnion during the stratified period become available for phytoplankton growth, and algal blooms can occur. The nutrients that accumulate in the hypolimnion from sediment release are called the internal load.

60. In most deep New Zealand lakes, thermal stratification occurs once each year and the stratified period lasts from spring through to autumn (eg. Lake Taupo). If the lake is small and sheltered from wind, thermal stratification may remain almost all year resulting in very high nutrient concentrations in the hypolimnion (eg. Virginia Lake).

61. In shallower lakes, thermal stratification may occur on several occasions when there is calm weather in summer (eg. Lake Rotorua). The sediment oxygen demand determines whether the hypolimnion becomes anoxic during the stratified period.

62. Very shallow lakes such as Lake Horowhenua (mean depth 1.3 m) are thought to be fully mixed all year round. My studies have shown that this may not be true and the lake may stratify on every occasion when calm weather persists for more than a few hours. During summer, Lake Horowhenua forms a micro zone, or thin layer of anoxic water, above the sediments almost every morning before the wind rises and mixes the lake. The source of the high DRP in this lake in summer (Fig. 1) is the result of almost daily release of DRP into these micro zones, a process which acts as a nutrient pump. The lack of ammonium in the water column in summer is due to rapid and complete uptake of all dissolved inorganic nitrogen by phytoplankton.

63. In contrast to the internal load of nutrients released from the sediments in the deepest parts of the lake, nutrients in groundwater enter the lake at the edge. (Exceptions are springs from confined aquifers.) The important difference between the groundwater nutrient inputs and the internal nutrient load is that the internal nutrient load is a summer phenomenon while the groundwater input continues all year at a near constant rate because the hydraulic gradient around the lake remains largely unchanged. Because groundwater travels very slowly, nutrient concentrations in the groundwater entering the lake also change very slowly.

64. The entry of groundwater to the lake at the lake edge means that riparian and marginal vegetation in the lake (the buffer zone) can take up the nutrients, reducing the effect of those nutrients on the lake water quality (Fig. 2). Wetlands perform the same function of nutrient attenuation in the catchment. Consequently, lake edge buffer zones and wetlands are important to the water quality of a lake, but are vulnerable to land use change and land development.

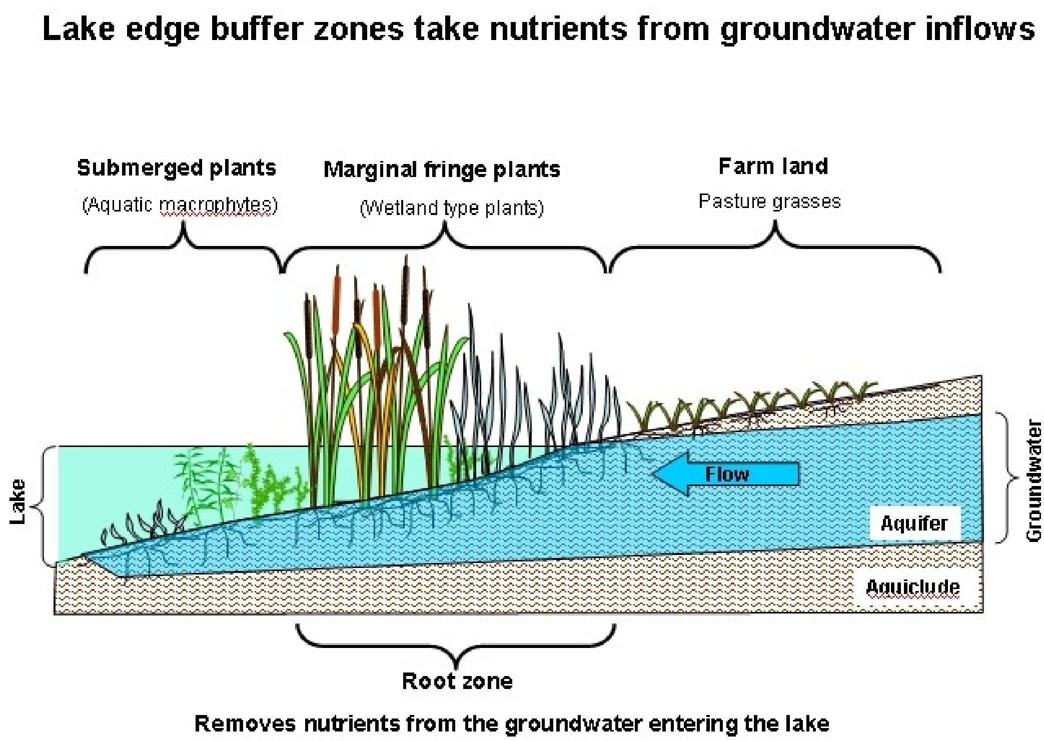

Figure 2. Schematic of a buffer zone on a lake shore

65. Removal of the buffer zone through poor land management at the margin, or from fluctuating or reducing lake levels, will adversely affect the water quality of the lake by reducing the attenuation of nutrients in the groundwater and by promoting increases in turbidity through bank erosion and the suspension of sediment. By poor land management, I mean human activities which deliberately (eg. clearance for urban development and boating access) or inadvertently (eg. allowing direct stock access to the lake; introducing swans, geese and herbivorous coarse fish to the lake; allowing water-skiing with associated boat wakes) damage the natural lake-edge plant buffer zone.

66. How the surface water and groundwater inflows enter the lake is affected by temperature. In winter, the nutrients in these inflows will be rapidly dispersed through the lake by wind mixing and wave action. In summer, if the surface inflow is warmer than the lake water, it will mix rapidly into the lake but if it is colder than the lake water, it will flow as a density current along the lake bed and may enter the hypolimnion without mixing in the epilimnion. A density current is a flow of water in a lake at a depth of equal buoyancy determined by temperature or salt induced density.

67. Because groundwater stays at a relatively constant temperature, in summer it will be colder than the lake water and thus it will slowly flow as a very thin layer down the slope

of the lake bed. As lake-edge waters are high light zones, the nutrients in the groundwater will be taken up by periphyton or filamentous algae on the lake bed near the lake shore.

68. **The effects of nutrient enrichment of lakes** are often seen as a persistent high algal biomass in the water column all year round. For short periods, there may be a proliferation of an algal species to nuisance proportions as an algal bloom (eg. cyanobacteria blooms). There have been a number of definitions of “algal bloom” that can be summarised in general terms as “a rapid increase in the population of algae above the normal range in an aquatic system”. A discussion of the definition of an algal bloom is included in the Appendix. The relevance to the Proposed One Plan will become apparent when considering the lake water quality standard for cyanobacteria later.

69. Why cyanobacteria develop nuisance blooms is not fully understood, and there are a number of factors involved. For growth, plants (including phytoplankton) need the N and P to be available in the optimum atom ratio of 16 to 1 (Redfield, 1958). This converts to 7.2 to 1 as a mass ratio and means that for every mg of P, 7.2 mg of N will be used for phytoplankton growth.

70. When there is an excess of N (eg. Lake Horowhenua in winter; Fig. 1) phytoplankton will grow until all the P is used. There is no preference for the algal species that can grow, and the dominant species may be due to timing and chance. When there is an excess of P (eg. Lake Horowhenua in summer; Fig. 1) phytoplankton will grow until all the N is used. At this point, some cyanobacteria species have an advantage over all other algal species because they can use (fix) nitrogen from the air to continue growing.

71. Cyanobacteria are naturally buoyant and can regulate their position in the water column to take advantage of light. In windy conditions, they may be mixed deep in the lake but in calm conditions they float up to the surface and can form thick layers or scums (Fig. 3). These scums block the light from the other less-buoyant algal species, which tend to sink and die in calm conditions. Thus, the cyanobacteria outcompete the other algal species.

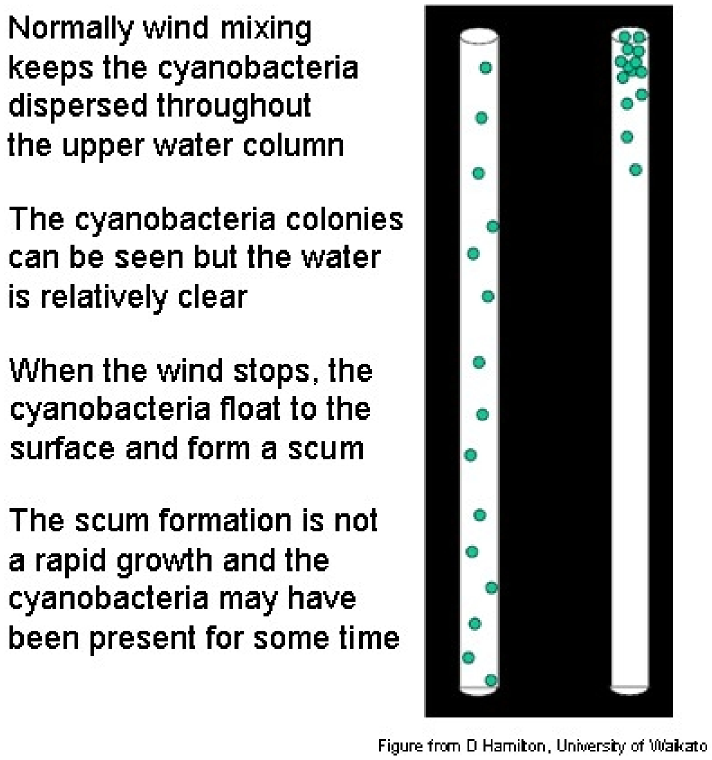

Figure 3. Schematic showing how water clarity changes with the formation of a cyanobacteria scum in calm conditions, without any change in algal abundance or growth

72. The buoyant layers drift across the lake surface with light breezes to form the characteristic nuisance shoreline scums associated with cyanobacteria blooms.

73. In Lake Horowhenua and Lake Rotorua, there is a species of midge or lake fly (*Chironomid zelandica*) with larvae that feed on the cyanobacteria around the edge of the lake before hatching in summer. The extremely large numbers of lake fly can be a major problem for people close to the lake at the time of the hatch.

Lake water quality standards (Schedule D, Table 18)

74. It is assumed that the reason for having lake water quality standards is to have a legally enforceable set of criteria that, if met, would ensure the lakes covered by the Proposed One Plan meet the values that apply to water bodies in the Manawatu-Wanganui Region, as set out in Schedule D, Table 2.

75. However, before an appropriate water quality standard can be applied to a lake, it is essential to have some understanding of the lake, its present water quality, and the connectivity between the lake and its catchment, both surface and groundwater, that drives that water quality.

76. The natural water quality of a lake can usually be defined by its trophic condition as oligotrophic, mesotrophic, or eutrophic, with two extra trophic levels above and below these to classify the lakes with more extreme water qualities. Many of the lakes in Horizons' Region appear to fall into the lower water quality classes of eutrophic, supertrophic, or hypertrophic (Table 3). I will come back to trophic condition and connectivity later.

Table 3. Values of variables that define the boundaries of different Trophic Levels

Lake Type	Trophic Level	Chlorophyll *a* (mg/m^3)	Secchi depth (m)	Total P ($mg\ P/m^3$)	Total N ($mg\ N/m^3$)
Ultra-microtrophic	0.0 to 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	16 - 34
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 - 15	1.8 - 4.1	34 - 73
Oligotrophic	2.0 to 3.0	0.82 - 2.00	15 - 7.0	4.1 - 9.0	73 - 157
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	157 - 337
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	12 - 31	1.1 - 0.4	43 - 96	725 -1558
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>1558

(From Burns et al., 1999, 2000)

77. The National Water Quality Management Strategy (ANZECC, 2000) states in section 2.1.4 Water quality guidelines, that, "*A water quality guideline is a numerical concentration limit or narrative statement recommended to support and maintain a designated water use*"; and that, "*The guidelines are used as a general tool for assessing water quality and are the key to determining water quality objectives that protect and support the designated environmental values of our water resources, and against which performance can be measured*." The Lake Water Quality Standards set out in Schedule D, Table 18, of the Proposed One Plan constitute the "numerical concentration limit or narrative statement" required to support and maintain the coastal lakes and lagoons in each of the Water Management Zones. As standards, there is an obligation for these standards to be met, while guidelines may never be met but aim to focus management strategies towards achieving the water quality in those guidelines.

78. Conceptually, the 14 lake water quality standards in the Proposed One Plan represent the required water quality of these lakes to meet the values assigned to them in

Schedule D, Table 2. Comparing the actual water quality of these lakes with those water quality standards should enable assessment of the present condition of each lake, and the management needed for that lake to meet those water quality standards, regardless of whether those standards are achievable or not. Notwithstanding this, the standards should be set with the purpose of achieving and maintaining the best possible water quality for each lake in the context of the lake history (ie. What was the natural condition of the lake pre-European?) and intended use (ie. Is the lake required for contact recreation, a water supply (human or stock), an irrigation supply, flood control, or the open water extension to a wetland or sanctuary?).

79. A single standard for each lake water quality parameter is unlikely to be appropriate for all lakes. This is because of the uncertainties in the connectivity between land use and the nutrient loads from different land uses, plus the lags in nutrient arrival at the lake after being leached in the catchment, and the high level of seasonal and diurnal variability of nutrient concentrations from in-lake processes. This is also consistent with the philosophy underpinning the determination of standards for rivers in different Water Management Zones.

80. The standards applied to each lake should recognise that lake water quality is an integration of all the historical land use actions in the catchment over the time lag of the groundwater inflow, as well as present day catchment discharges to the rivers and streams flowing into the lake. The standards applied should also be tempered with the knowledge that historically, a specific lake may have always been at a particular trophic level and thus a higher water quality is unlikely to be achieved in some cases.

81. I have reviewed the Lake Water Quality Standards with respect to their appropriateness to the coastal lakes and lagoons in each of the Water Management Zones and I have compared them with “benchmark” or “trigger values” for Australian lakes and wetlands, contained in Section 3 of the ANZECC document. I have also assessed whether each parameter is appropriate for a dune lake situation, whether the numerical value or range is appropriate, and whether there is any sensible intervention Horizons could make if the natural water quality falls outside that range. In order to assess the water quality of the coastal lakes and lagoons in the Proposed One Plan, I have summarised the available water quality data from these lakes in a table (Table 4).

Table 4. Summary of the water quality monitoring data provided by Manawatu-Wanganui Regional Council for some of the lakes covered by the Proposed One Plan. For many of the named lakes in the Proposed One Plan Management Zones, there is no available data or the parameters in the water quality standards have not been measured. The water quality standard number is across the top of the table and the standard numerical value or narrative limit is included in the table. (Ann avg = annual average; Δ = change by the specified value)

LAKE MONITORING DATA	WQ Standard				1	2	3	4	5	6	7	8	9	10	11	12	13	14
Source Name	**Management Zone**	**Depth m**	**Area km^2**	**Date range yyyy-yyyy**	**pH pH**	**Temp ºC**	**DO g/m^3**	**BOD_5 g/m^3**	**Chl_a mg/m^3**	**TP mg/m^3**	**TN mg/m^3**	**NH_4-N mg/m^3**	**Toxicants ANZECC Table 3.4.1**	**Secchi m**	**Turb NTU**	**E. coli summer MPN/100mL**	**E. coli winter MPN/100mL**	**Microcystins mg/m^3**
Standard numerical value or narrative limit					7.0-8.5 Δ <0.5	Δ <1ºC	80% sat in surface	1	5 / <15 Ann avg	<20 Ann avg	<337 Ann avg	<337 Ann avg	95% of species	2.8 Δ <20%	Δ <20%	260 Nov.-Apr.	550 May-Oct.	20
LAKE WESTMERE	West_1			2007-2008	7.2-10.1	13.6-29.7	3.2-9.5			83-1270	1260-10400	5.0-74			3.1-199	135-24500		
BASON RESERVE	West_1			2007-2008	6.7-8.9	12.2-22.2	0.5-8.9			27-298	580-1450	2.5-177			1.1-8.1	10-7300		
VIRGINIA LAKE	Whai_7b	25	0.45	2007	7.39-9.37	16.2-27.6	2.05-11.1			22-116	410-2660	2.5-89			1.0-179	10-7700		
LAKE KAITOKE	West_4																	
LAKE WIRITOA	West_4	19.5		1998-2008	7.2-9.8	15.5-23.3	2.9-15.9	0.5		14-64	680-1580	2.5-12			0.3-116	1-280		0.25-96.9
LAKE PAURI	West_4	13		2005-2008	6.2-9.68	15.8-23.7	3.5-10.2	0.5-48		52-3050	140-26600	5.0-315			0.7-8000	5.0-270		3.9-3581
LAKE WAIPU	Tura_1			2000	8.1	20.2	0.4	28		(63-4200)		80-13000			60			
LAKE ORAEKOMIKO	Tura_1																	
LAKE DUDDING	West_5	10.5		2007-2008	5.8-9.2	14-24	3.9-13.8	0.5-1.0	105	23-90	750-2440	2.5-408			0.6-88	1-375		7.8
LAKE HEATON	West_5			1991	9										6.2			
LAKE VIPAN	West_5																	
LAKE BERNARD	West_5																	
LAKE WILLIAM	West_5																	
LAKE HERBERT	West_5																	
LAKE HICKSON	West_5																	
LAKE ALICE	West_5																	
LAKE KOITIATA	West_5																	
Northern Manawatu Lakes	West_6																	
Waitarere (lakes and lagoons)	West_7																	
PUKEPUKE LAGOON	West_7	1.3	0.17															
LAKE HOROWHENUA	Hoki_1	1.8	3.9	1998-2009	5.2-11.4	5.4-21.1	4.0-10.0	0.5-46	0.95-4520	14-1750	5-16200	2.5-1420		0.1-1.7	0.4-440	20-80		<0.5-931
LAKE PAPAITONGA	West_8		0.62	2008	6.9-8.97	6.8-20.7	0.6-14.8			58-176	2291-6130	67-3140			3.3-23.5	62-4900		

82. As a general observation, the monitoring data available (Table 4) are inadequate for assessing most lakes covered by the Proposed One Plan. For a few lakes, some parameters have been measured for several years while other parameters have only a few months' data. Although water temperature is a simple measurement, there are limited temperature data which are generally insufficient to define the annual seasonal range for most lakes. For many of the lake water quality standards in the Proposed One Plan, no data have ever been collected. Although not a standard, there are no lake level data. Water level fluctuations, especially in shallow lakes, directly affect water clarity through erosion of the exposed lake bed by breaking waves and rainfall, and the resuspension of sediment and pore-water nutrients in the shallow water by wave action. While this omission does not invalidate the lake water quality standards chosen, it requires measurement of those parameters monthly for at least one year before it is possible to determine whether any lake is in breach of some of those standards.

83. The monitoring data (Table 4) provided by Horizons contain some obvious errors, such as Secchi depth values greater than the maximum depth of the lake and pH values of around 48, which is well above the maximum possible value for pH of 14. These data points have been omitted from Table 3. However, these obvious errors raise doubts about the validity of other extreme values such as a chlorophyll *a* value around 4500 mg/m^3 or a turbidity value of 8000 NTU. While such errors may be "typos", that they exist – if they are errors – means that all the data are suspect. An important part of any monitoring programme is quality control and the validation of the data before it is entered into a database. There should also be a mechanism which allows correction or culling of errors when these are found. This should be part of the sampling protocols, which I will come back to later.

84. Notwithstanding this, I have used professional judgement to exclude the more obvious incorrect values and to assess the water quality and to characterise each lake. As trophic levels of lakes are critical indicators of water quality, I have also considered the values of four key parameters that define the boundaries of different Trophic Levels (Table 3). For the review of each lake water quality standard, I have used the data from Table 4 and the parameter ranges from Table 3 to illustrate specific points.

85. A key issue with water quality data are the detection limits of the analytical methods used and how "below detection limit" values have been treated in the data base and for reporting. In general, the analytical methods used should have a range which includes at least 90% of the expected range of concentrations in the samples. The few samples above that range can be estimated after dilution, while those below the detection limit for

that parameter should be recorded as <DL, where DL is the detection limit of the analytical method used. For compliance monitoring reporting, <DL is appropriate. For lake water quality assessment of trends, with less than 10% of the data as <DL, the convention is to use half the detection limit to provide a number, acknowledging that there is large uncertainty in that number but recognising that the error will be small relative to the full range of results. Where the occurrence of <DL results becomes more common, the analytical method should be changed (if possible) to meet the lower range being measured (Scarsbrook and McBride, 2007; section 4.2).

86. When setting the numerical concentration and narrative range for the lake water quality standard, it is reasonable to expect that both the numerical concentration and narrative range can be measured by the regulatory authority. In the proposed standards for Biochemical Oxygen Demand, the standard is set as 1 $g/m^{3,}$ which is the detection limit for that parameter. This means that any value above the detection limit is a breach of the standard and that there is no way of determining whether the lake water quality is approaching the standard when the values are below detection limit.

87. The water quality standards for streams and rivers in the Proposed One Plan have been reviewed on behalf of Palmerston North City Council by Keith Hamill (Hamill, 2008). Although this review is primarily with respect to the standards in the Manawatu River, many of the points made in that review also apply to the lake water quality standards. However, this does not presuppose that each standard is appropriate for a dune lake or that it should be applied to a dune lake situation. There are aspects of the standards not covered in the Hamill report which may not be a concern for flowing waters but are important issues for lakes (eg. sampling).

88. With the exception of Lake Water Quality Standard 3 on dissolved oxygen, the lake water quality standards do not specify where the measurements should be taken, when, or how. As some parameters are strongly affected by the day-night (diurnal) cycle and some lakes are deep enough to have extended periods of thermal stratification in summer, sampling method is critical and will affect the variability of the data to a greater extent than analytical variability. As sampling method applies to all the standards, a definition of what constitutes a sample and the protocols for collecting each sample should be added to the Water Quality Standards for Natural Lakes and Lake Catchments section preamble in Schedule D of the One Plan.

89. I will come back to sampling protocols later. For the purposes of reviewing each lake water quality standard, I have assumed that sampling protocols exist and that those protocols are being followed.

90. *1. "The pH of the water shall be within the range 7 to 8.5 and shall not be changed by more than 0.5 pH"*: This range is higher than for the Australian lakes and reservoirs, which have guidelines of 6.5 to 8.0, but it is the same as the Australian trigger values for wetlands. Shifts in pH are typically caused by changes in carbon dioxide (CO_2) concentrations in the water. Changes in CO_2 concentrations accompany changes in dissolved oxygen related to photosynthesis and respiration. During photosynthesis, CO_2 is assimilated by the plant/algae and the pH rises. During respiration, CO_2 is released by decomposition processes and the pH falls. Both processes occur concurrently with photosynthesis exceeding respiration in the light, while respiration becomes dominant in the dark. Consequently, pH can vary with depth in the lake water column, it can vary over the diurnal cycle, and it may also vary seasonally due to temperature effects on the two rate processes and the succession and abundance of different algal species. For example, the Region's dune lakes (Table 4) have a broader pH range than the proposed standard, from as low as 5.2 up to 11.4 (Lake Horowhenua). This range is consistent with poor water quality due to high organic loads enhancing respiration, and algal blooms enhancing photosynthesis.

91. The pH standard of 7 to 8.5 is an acceptable range for most deep lakes, but the lower limit of 6.5 would recognise that a dune lake receives much of its water via groundwater and wetlands, which will tend to lower the pH. The upper limit of 8.5 recognises that the dune lakes are likely to have elevated levels of algal biomass, which will cause the pH to rise. I recommend that the pH range be changed to "… 6.5 to 8.5 …".

92. The narrative, "and shall not be changed by more than 0.5 pH", is not acceptable, unless applied as a condition to a resource consent for an unnatural discharge to the lake. The natural diurnal cycle and depth dependency of sampling need to be addressed. I recommend that the narrative links pH above 8.5 with ammoniacal nitrogen concentrations and potential for ammonia toxicity in the surface waters or epilimnion, if the lake can become thermally stratified. This would recognise that exceeding the standard requires remedial work to reduce algal blooms.

93. *2. The temperature of the water shall not be changed by more than 1°C*: Temperature has a strong seasonal cycle, a strong diurnal variation, and often strong variation with depth. Consequently, temperature by itself is not a useful standard for a lake. While

temperature change is a useful standard, because it defines the permitted level of response to some activity in the lake or lake catchment, natural variation during the day due to direct sun or shading by cloud may be greater than the 1ºC limit and thus the standard may not be enforceable. For enforcement, this standard implies a knowledge of the lake water temperature and a method for assessing whether a change has occurred, eg. the place and time of measurement, the depth of the measurement, and the number of measurements that need to be taken on consecutive days to establish the benchmark against which the change is to be measured. Although temperature has been measured in many of the dune lakes (Table 4), the data are inadequate to provide a benchmark for this standard. This suggests that either a better and more comprehensive monitoring programme is required, or that the requirement for a benchmark becomes part of any resource consent under the Resource Management Act. I recommend that temperature change in the lake is not used as a standard but that this parameter is measured in association with depth-dependent sampling based on lake water column structure, such as the assessment of Trophic Lake Index (Burns *et al.,* 1999; 2000).

94. A temperature change standard would be appropriate for any resource consent under the RMA to discharge water into a lake. In this case, the increase should not exceed 3ºC above ambient within a specified distance from the discharge point to preserve the thermal regime of the lake, and the increase should not cause the receiving water temperature to exceed a maximum value. The maximum temperature would most likely be 23ºC for a coarse fishery and 21ºC for a trout fishery. I note that the diurnal cycle may cause the surface water temperatures to exceed these values for 2-3 hours around midday in February, but the whole water column will be unlikely to exceed these values, thus maintaining a thermal refuge zone for aquatic fauna including fish.

95. *3. The Dissolved Oxygen concentration shall not be less than 80% in the surface waters (defined as less than 2 metres deep)*: The dissolved oxygen (DO) 80% value should be amended to read “80% of saturation”. Dune lakes are typically shallow although some in the Region have greater depths up to 25 m. DO concentrations can vary with depth, seasonally and diurnally, due to high sediment oxygen demand on the bottom waters, the reducing solubility of oxygen in water as the temperature rises in summer, and photosynthesis during the day versus respiration at night. DO concentrations are likely to be lowest near dawn. All of the values in the monitoring data (Table 4) were collected during the day. The stipulation of surface waters “defined as less than 2 metres deep” may be intended to avoid bottom water oxygen depletion in lakes where that occurs, but puts the measurement in the warmest water in the lake where oxygen solubility is lowest

naturally. I recommend that dissolved oxygen concentration in the lake is not used as a standard but is measured using a protocol that recognises the depth-dependent nature of DO in the lake water column and its relationship to nutrient release from the lake bed. The proposed dissolved oxygen standard would be appropriate as a condition for any resource consent under the RMA to discharge water into a lake.

96. *4. The five-days Biological Oxygen Demand shall not exceed 1 g/m³*: Five-days Biochemical Oxygen Demand (BOD_5) is a measure of microbial respiration in the water column, and includes chemical oxygen consumption. This parameter will vary seasonally due to elevated inputs of organic matter from the catchment via surface inflows, especially when flows are high in winter, and the decomposition of algal biomass following algal blooms in summer. BOD_5 will vary with depth during the period of thermal stratification in the deeper lakes, and also in the short term with sediment resuspension due to wind wave actions and boat wakes on the shallow near-shore sediments. The value of 1 is a desirable target for the standard, but it may not be achievable in degraded dune lakes. As the value of 1 is also the detection limit of the analytical method, compliance monitoring would be difficult, but this aspect will be dealt with in the evidence of Dr John Quinn. I believe that the BOD_5 standard is not appropriate for dune lakes and it would be more useful to have a standard based on water column or hypolimnetic oxygen depletion (HOD) rate and sediment oxygen demand as an integrated measure of in-lake respiration (Burns, 1995; Burns *et al.,* 1996). Putting this into perspective, the hypolimnetic oxygen depletion rate for oligotrophic Lake Taupo is 15 mg m^{-3} d^{-1} while in eutrophic Lake Rotorua it is around 800 mg m^{-3} d^{-1}. A standard based on hypolimnetic oxygen depletion rate for a dune lake would need to be determined from in-lake measurements from a range of lakes. As the hypolimnetic oxygen depletion rate will change relatively rapidly in response to changing water quality, it can be a good indicator for the trend of any change in water quality or for the effectiveness of any lake management strategy.

97. *5. The annual average algal biomass shall not exceed 5 mg Chlorophyll a/m³ and no sample shall exceed 15 mg Chlorophyll a/m³*: This standard is similar to the Australian lakes and reservoirs guidelines of 3 to 5 mg/m^3 chlorophyll *a*. As an annual average, 5 mg/m^3 chlorophyll *a* is a reasonable lake water quality standard, and the narrative limit of up to 15 mg/m^3 for an individual sample recognises that there will be seasonal changes in algal biomass and that the spring growth phase is likely to exceed the annual average. Notwithstanding this, an annual average of 5 mg/m^3 chlorophyll *a* is the lower boundary condition for mesotrophic lakes (Table 3), which is not appropriate as a single standard for all dune lakes, many of which are eutrophic or supertrophic.

98. There were surprisingly few chlorophyll *a* data in Horizons' monitoring data (Table 3). The data available indicate that Lake Dudding and Lake Horowhenua would not meet this standard. For example, the Lake Horowhenua chlorophyll *a* data (Fig. 4) is the most comprehensive dataset for any of the Region's dune lakes. These data show the variability in chlorophyll *a* concentrations on a seasonal basis, and between years, since 1998. The annual average concentration was greater than 30 mg/m^3 each year and the maximum value for a single sample was greater than 70 mg/m^3 in any year. Comparing these data with the ranges in Table 3 indicate that Lake Horowhenua is hypertrophic.

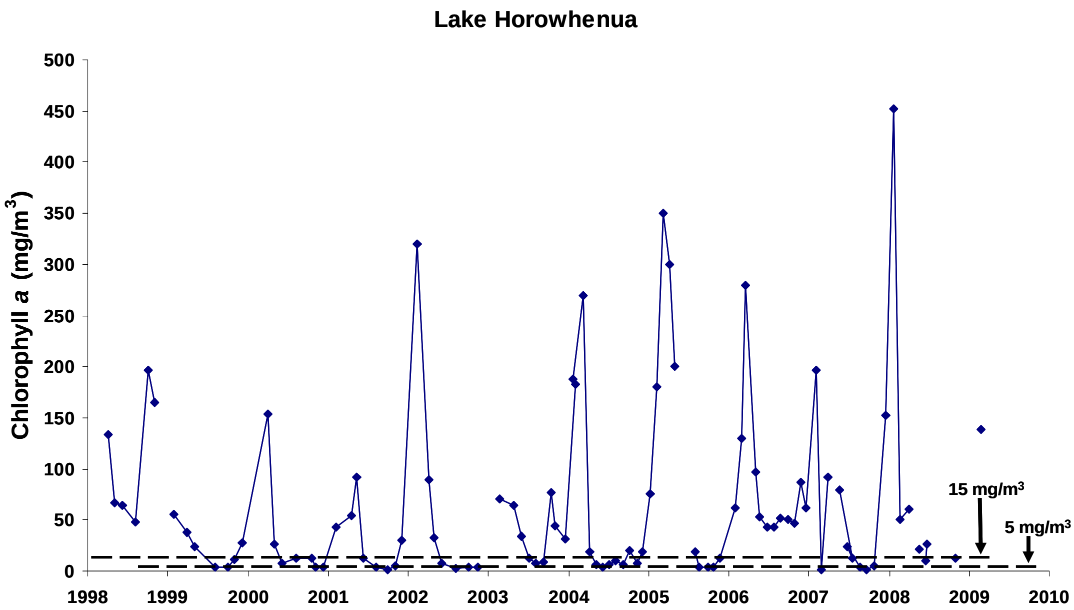

Figure 4. Time-series chlorophyll *a* concentrations measured in Lake Horowhenua, showing the seasonality of the data and the timing of the annual bloom in late summer to autumn. Broken lines indicate the 5 mg/m^3 standard and the 15 mg/m^3 maximum.

99. While the Proposed One Plan target of having all lakes in a mesotrophic condition is commendable, it would take considerable intervention by Horizons to achieve that level of water quality in all the dune lakes, although it might be possible for some. I recommend that a uniform chlorophyll *a* standard is not used across all lakes. Rather, a standard should be written for each lake or a group of lakes that reflects their historical trophic level, ie. pre-European, and will enforce an improvement in water quality from the present level. A useful separation between lake groups could be based on mixing depth, as defined by Davies-Colley (1988). As a starting point, I recommend that the standards for lakes that are too shallow to thermally stratify (ie. remain mixed throughout the year), should be based on eutrophic levels (see Table 3) (ie. an annual average of

less than 12 mg chlorophyll *a* /m^3 with a maximum algal biomass of 30 mg chlorophyll *a* /m^3). The proviso is that the existing water quality is protected by the standard, and improved. For deeper lakes that stratify in summer, the standard should be based on mesotrophic levels, as stated in the existing Schedule D standard.

100. Given the lag in nutrient loads entering the lake through the groundwater, it is likely that in some lakes chlorophyll *a* concentrations will remain in breach of these standards for some time before improving, even if catchment interventions were put in place today to reduce those catchment loadings.

101. *6. The annual average total phosphorus concentration shall not exceed 20 mg/m^3*: and

102. *7. The annual average total nitrogen concentration shall not exceed 337 mg/m^3*: These two standards are also set at the lower boundary conditions for mesotrophic lakes (Table 3), which are not appropriate as single standards for all dune lakes. Based on the data in Table 4, almost all the dune lakes for which there are total phosphorus and total nitrogen data, are supertrophic to hypertrophic, and Lake Wiritoa may have an eutrophic classification. As previously commented, for the chlorophyll *a* standard, the Proposed One Plan target of having the lakes in a mesotrophic condition is commendable, but a more appropriate standard should be written for each lake or groups of lakes that reflects their historical trophic level (pre-European) and will enforce an improvement in water quality from the present level. A useful separation between lake groups could be based on mixing depth as defined by Davies-Colley (1988). As a starting point, I recommend that the standards for lakes that are too shallow to thermally stratify (ie. remain mixed throughout the year), should be based on eutrophic levels (see Table 3) (ie. an annual average of less than 43 mg total-P /m^3 and 725 mg total-N /m^3). The proviso is that the existing water quality is protected by the standard, and improved. For deeper lakes that stratify in summer, the standard should be based on mesotrophic levels, as stated in the existing Schedule D standard.

103. Given the potential lag in nutrient loads entering the lake through the groundwater, it is likely that in some lakes total phosphorus and total nitrogen concentrations will continue to increase for some time before declining, even if catchment interventions were put in place today to reduce those catchment loadings.

104. *8. The concentration of ammoniacal Nitrogen shall not exceed 337 mg/m^3:* This standard is very much higher than the Australian lakes and reservoirs guideline of 10 mg/m^3 for a single sample. The value 337 appears to come from the TN standard as

the lower boundary for mesotrophic lakes. It may also reflect concerns about ammonia chronic toxicity, in which case the standard should include a pH value limit or a reference to an appropriate pH versus ammonium/ammonia toxicity table. The toxicity aspect is covered in Dr Bob Wilcock's evidence, and the lake standard for ammonia toxicity should be consistent with that for flowing waters.

105. The presence of ammoniacal nitrogen in the open surface waters of a lake is unusual as ammonium is rapidly assimilated by algae for growth, or nitrified to nitrate. However, during the collapse of an algal bloom, ammonium concentrations may be high in the surface waters due to decomposition processes. If an algal bloom caused the pH to rise above 8.5, at a total ammoniacal N concentration of 337 mg/m^3, ammonia concentrations would exceed the 95% freshwater trigger level for chronic toxicity in the ANZECC 2000 guidelines (ANZECC 2000; Table 8.3.7, page 8.3-161).

106. Under non-bloom conditions, concentrations of ammoniacal N will also vary with depth, being higher in the bottom water during periods of thermal stratification and low oxygen. Elevated concentrations of ammonium may appear in the surface waters of a lake during wind mixing following periods of thermal stratification and anoxia (eg. Table 1: Virginia Lake). Under these circumstances, the ammonium which had accumulated in the hypolimnion would be mixed into the surface waters by wind stirring, but would be unlikely to persist in that form; rather, it would be rapidly nitrified to nitrate N. This major potential source of ammoniacal nitrogen is the lake itself and thus is beyond the direct control of Horizons, although catchment measures taken to achieve the Total N standard (Standard 7) will also reduce the internal load of ammoniacal N.

107. As written, this standard is not appropriate and should be revised to include a pH limit and a depth range, eg. "… shall not exceed 337 mg/m^3 when the pH is greater than 8.5 measured within the epilimnion or within 2 m of the water surface". There is no need for an ammoniacal standard below pH 8.5 as toxicity would not be an issue. At pH less than 8.5, ammoniacal N is part of the total N and thus covered by the Total N standard, Standard 7.

108. *9. For toxicants not otherwise defined in these standards, the concentration of toxicants in the water shall not exceed the trigger values defined in the 2000 ANZECC guidelines Table 3.4.1 with the level of protection of 95 % of species*: Although this is not my field of expertise, this standard is the acceptance of specified ANZECC guideline trigger values as standards for the Proposed One Plan. This is reasonable and acceptable.

109. *10. The clarity of the water measured as Secchi depth shall not be less than 2.8m and shall not be changed by more than 20%*: Again, this standard is set at the lower boundary conditions for mesotrophic lakes (Table 3), which is not appropriate as a single standard for all dune lakes. This standard should be revised to reflect the historical water quality of each lake and be set at a level to improve lake water quality. The word “changed” should be replaced with “reduced”, as greater clarity is acceptable.

110. Notwithstanding this, the clarity of a lake is not just a function of algal biomass but is also strongly influenced by turbidity associated with elevated concentrations of suspended solids. The sources of suspended solids include phytoplankton, sediment resuspension in shallow lakes or shore-line erosion by wave action around exposed lake edges, and river, stream, and stormwater-drain inflows during storm events and floods. The amount of sediment resuspension and lake bed erosion will be affected by fluctuating water levels. Fine sediment may remain in suspension for a considerable time. In shallow lakes, the time between successive wind suspension events may be shorter than the settling time of the suspended particles, and the lake will remain turbid. This is beyond the direct control of Horizons and therefore it is inappropriate to have a clarity standard for a shallow lake. However, stock exclusion by fencing and establishing lake-edge buffer zones would be a good first step towards reducing suspended solids concentrations.

111. If clarity standards are essential for all dune lakes, the method of measurement should be directly comparable. The use of a Secchi disc for clarity measurement in deeper dune lakes is appropriate, but in shallow lakes the black disc technique, which measures water clarity horizontally through the water, is more appropriate than measuring turbidity. The black disc technique is used to assess water clarity in rivers and streams. Both Secchi disc and black disc techniques use light transmission (ie. visual assessment of the point of extinction of a target as viewed through the water) to assess water clarity, and thus the values are comparable after appropriate cross calibration. In contrast, turbidity measures a different optical property – scatter – with scatter being affected by particle size rather than occlusion of a visual target.

112. While the clarity standard defined as a Secchi depth of not less than 2.8 m, as stated in this standard, is appropriate for the deeper lakes less affected by sediment resuspension, for shallow lakes a more appropriate clarity standard should be related to the concept of safety for swimming. In this context, it is important for adult bathers to be able to see their feet while standing more than knee-deep in the water. To meet this requirement, the standard for shallow lakes would need to be defined as a Secchi disc

or black disc equivalent of not less than 0.8 m. For both standards, the narrative should be “and shall not be reduced by more than 20%”.

113. A useful separation between shallow and deeper lake groups could be based on mixing depth, as defined by Davies-Colley (1988).

114. *11. The turbidity shall not be changed by more than 20%. This standard shall apply only when physical conditions existing at the site prevent adequate water clarity (Secchi Disc) measurement*: As written, there is no standard value for turbidity and therefore the narrative, “The turbidity shall not be changed by more than 20%”, is meaningless. As the intention of this standard is to provide an alternative to Secchi disc measurements for clarity, it is inappropriate. The use of a black disc technique, as explained above, is more appropriate. I recommend that this turbidity standard is removed. Turbidity is covered in the evidence of Dr Davies-Colley.

115. *12. The concentration of Escherichia coli shall not exceed 260 per 100 millilitres. This standard applies during the period 1st November to 30th April inclusive;* and

116. *13. The concentration of Escherichia coli shall not exceed 550 per 100 millilitres. This standard applies during the period 1st May to 31st October inclusive year round*: Although this is not my field of expertise, as far as I am aware, these standards are appropriate. The November to April standard is consistent with the water quality guidelines in use in New Zealand (Harding *et al.,* 2004; Table 11.4) and is considered acceptable in a single sample interpretation (MfE, 2003. Horizons’ water quality data (Table 4) indicate that on some occasions, the lakes covered by the Proposed One Plan would meet these standards but on others these standards would be exceeded.

117. *14. The concentration of toxins due to cyanobacteria (blue-green algae) shall not exceed 20 milligrams per cubic metre. This standard applies year round:* I am not competent to comment on the appropriateness of the concentration of toxins in this standard and assume that the value used is appropriate for all lakes to safeguard “Public Health”. Notwithstanding this, I am aware of the main toxins and the toxicity issues associated with cyanobacteria in the water supply reservoirs for Auckland City. In monitoring for cyanobacteria toxicity (cyanotoxins) in those water supplies, it is recognised that the toxins can be grouped into four types, depending on their mode of action. These are:

- Hepatotoxins, which affect the liver, eg. microcystin, nodularin and cylindrospermopsin (produced by *Microcystis sp.*, *Anabaena sp.,* and *Cylindrospermopsis sp*.);
- Neurotoxins, which affect the nervous system, eg. Paralytic Shellfish Poisons (saxitoxin, neosaxitoxin), anatoxins (produced by dinoflagellates and some forms of *Anabaena sp.*);
- Lipopolysaccharide endotoxins or cell surface compounds, which produce gastrointestinal and allergy type reactions; and
- General cytotoxins which affect multiple organ systems (largely associated *Cylindrospermopsis* blooms) but generally uncharacterised.

118. For water supplies (MoH, 2005), the toxin limits are defined in terms of Maximum Acceptable Values (MAV), which are defined as: "The MAV of a determinand in drinking-water represents the concentration of a determinand in the water that, on the basis of present knowledge, is not considered to cause any significant risk to the health of the consumer over their lifetime of consumption of that water." There are a range of MAVs for the "cyanotoxins" (Table 5), and all are lower than the suggested lake water quality standard of 20 mg/m^3 (0.020 mg/L). Given that the lake water is unlikely to be a potable water supply, the higher cyanotoxin level of this standard may be appropriate for the dune lakes.

Table 5. Maximum acceptable values (MAVs) in mg/L for organic determinands (cyanotoxins) of health significance. (Data from MoH, 2005; Table 2.3)

Name	**MAV**
anatoxin-a	0.006 mg/L
anatoxin-a(s)	0.001 mg/L
cylindrospermopsin	0.001 mg/L
homoanatoxin-a	0.002.mg/L
LPS endotoxin	0.003 mg/L
microcystins	0.001 mg/L
nodularin	0.001 mg/L
saxitoxin	0.003 mg/L

119. The World Health Organisation (WHO) recognises that exceeding the MAV guideline value can be tolerated and that short-term deviations (less than 14 days) above the guideline do not necessarily mean that the water is unsuitable for consumption. It does require some action to be taken to reduce the MAV. Because the development of a cyanobacteria bloom and the subsequent production of cyanotoxins is beyond the direct

control of Horizons, I recommend that a comparable level of flexibility is included in the lake water quality standard.

120. I would like to comment here on the appropriateness of the use of a toxin-based standard rather than a cell count-based standard. The use of cell count-based cyanobacteria trigger points of <2000 cells/ml for drinking water and <20,000 cells/ml for contact recreation makes the assumption that above those trigger values, the water will be unsafe for those purposes due to toxins. The use of cell counts does not recognise that some cyanobacteria may not produce toxins, and that different cyanobacteria species have different cell sizes such that very small species may produce much less toxin than larger species. It also does not recognise that the toxins may persist in the water for some time after the cyanobacteria bloom has passed. These differences are accommodated in the toxin-based standard. Notwithstanding this, the cell count-based trigger point provides a guide as to when to begin toxin testing as cyanobacteria begin to grow. (See Appendix for discussion on algal blooms).

Streams and rivers in natural lake catchments water quality standards (Schedule D, Tables 19 and 20)

121. Apart from processes occurring within a lake, the lake is the receiving water for the streams and rivers, and the groundwater sources of those streams and rivers that flow into the lake from the catchment, and the direct inflow of groundwater through the lake bed. The quality of the water these streams, rivers, and groundwater carry directly or indirectly into lakes is an important consideration for the water quality of lakes.

122. Although rivers are not my field of expertise, they provide some of the input loading for lake nutrient budgets. The nutrient loads carried into lakes have a direct effect on the lake water quality at that time and may affect whether a lake water quality standard is breached. In this context, the streams and rivers water quality standards should include numerical or narrative standards that are consistent with those of the lake water quality standards. Consequently, the Streams and Rivers water quality standard for each parameter must be considered, together with the corresponding Lake water quality standard.

123. In this context, I have reviewed the Streams and Rivers Water Quality Standards in Natural Lakes Catchments in Schedule D, Tables D.19 and D.20, of the Proposed One Plan. I have also compared these standards with the proposed Water Quality Standards

for Streams and Rivers in Water Management Sub-zones in Schedule D, Tables D.16 and D.17.

124. Apart from the inclusion of total phosphorus and total nitrogen in the Streams and Rivers Water Quality Standards in Natural Lakes Catchments versus dissolved reactive phosphorus and soluble inorganic nitrogen in the proposed Water Quality Standards for Streams and Rivers in Water Management Sub-zones, there is little difference between the two sets of standards. In which case there is little justification for having a separate set of water quality standards for streams and rivers that flow into lakes. As dissolved reactive phosphorus and soluble inorganic nitrogen concentrations in the inflow waters will have a direct and immediate effect on lake water quality, it would be more appropriate to use the proposed Water Quality Standards for Streams and Rivers in Water Management Sub-zones (Tables D.16 and D.17) for all streams and rivers, and delete the proposed Streams and Rivers Water Quality Standards in Natural Lakes Catchments from the Proposed One Plan (Tables D.19 and D.20).

125. Evidence on the appropriateness of the water quality standards for rivers is provided by Dr John Quinn, Dr Bob Wilcock, Dr Barry Biggs, Dr Rob Davies-Colley, Dr Roger Young, and Kate McArthur.

Effects of the proposed approach to control intensive land use and impose nutrient loss limits on all intensive operations in many lake catchments (Water Management Zones) on lake water quality

126. While nutrient losses from land use are outside my field of expertise, I am aware of some of the issues involved. I am aware that, while models such as Overseer® can estimate the amount of N that will be lost to the ground from different land uses by leaching, there can be attenuation of those nutrients in the ground by as much as 50% before they reach the stream, giving rise to uncertainty in the nutrient loadings from catchment land uses in surface streams and groundwater. I am also aware that the surface topography may not coincide with the groundwater aquifers, and that the groundwater catchment may be larger or smaller than the surface catchment. Also, a variety of underground flow regimes may provide short cuts to deliver nutrients to lakes (Zarour, 2008). These factors are important when considering where to apply land use controls and are largely due to the way the coastal dune lakes were formed.

127. Although the majority of the coastal lakes in the Manawatu-Wanganui Region covered by the Proposed One Plan come under the heading of dune lakes, I have characterised

these into two main types, "drowned valley" and "perched". Many of these dune lakes are relatively young, being formed over the last few centuries, but some (eg. Lake Horowhenua) may have been formed 2000 to 5000 years before present (Lowe and Green, 1987).

128. Drowned valley dune lakes are the relatively deep lakes (eg. c. > 5 m) that formed behind coastal sand dunes when wind-blown sand blocked a valley along the coastal plains. In this type of dune lake, water from the catchment enters via small streams and may leave via seepage through the sand dune to groundwater, if there is no surface outflow. Over time, silt gradually seals the sand of the blocking dune, causing water retention, and the water level rises. This sealing of the sand often forms an impermeable sill below which the lake level will not fall via surface outflow or groundwater seepage.

129. These dune lakes frequently have very different soil types and characteristics on the inland side versus the coastal side. Examples of drowned valley dune lakes include Lakes Wiritoa, Waipu and Dudding, which have narrow arms extending inland through agricultural land opposite the straight-line face of the blocking sand dune. These three lakes have V-shaped beds from the original valley and maximum water depths greater than 10 m.

130. With drowned valley dune lakes, there is a high level of connectivity between land use in the catchment and the lake, via surface inflows and groundwater. However, the groundwater catchment is defined by the underlying geology and may not be the same as the land catchment defined by the surface topography.

131. Perched dune lakes form where silt and clay have been deposited on the dunes, either by wind deposition between existing dunes or during flood events. The lagoons have a similar structure to perched lakes but are bodies of water trapped when moving sand dunes blocked the connection to the sea. The deposits of silt and clay have low vertical permeability (ie. water moves down through them very slowly) and are known as 'clay lenses'. The presence of the clay lens can provide locally 'perched' water tables (Zarour, 2008; Section A-6.5 Perched aquifers, p 154). Originally, these lakes may have been very large and the clay lens may have been the original lake bed. Over time, the lake has gradually in-filled with sediment, leaving only a very small area of open water. As the clay lenses are subterranean features, the groundwater catchment for each lake can be much smaller than the land catchment defined by the surface topography.

132. Perched dune lakes are typically very shallow and may have only small surface inflows, or none at all, and receive most of their water from the groundwater. However, because they occur on clay lenses, their groundwater source may be restricted to the catchment area of the perched water table on the lens, with groundwater from the greater catchment bypassing them or flowing beneath them. As the clay lens was most likely the original lake bed, the in-filling sediment that forms the surface catchment on the lens is generally very fertile. Examples of this type of dune lake in Horizons' Region may include some in the Northern Manawatu Lakes and Waitarere Management Zones West 6 and West 7, respectively, as those lakes are in the flood plains of the Rangitikei and Manawatu Rivers.

133. There is a low level of connectivity between land use in the topographic catchments and the perched dune lakes via surface inflows and groundwater. These lakes are very sensitive to local land use around their shores.

134. Lake Horowhenua has characteristics of both the drowned valley and the perched types. The lake has formed behind a blocking dune and has very different soil types and characteristics on the inland side versus the coastal side, consistent with a drowned valley type. However, Lake Horowhenua is also very shallow, consistent with the perched type. There are a number of dune lakes along the west coast of the North Island, between Manukau and Kaipara Harbours, which have similar characteristics (ie. shallow and elongated parallel to the shoreline) and all appear to be collections of water in the depression at the leading edge of once-mobile dunes. The other characteristic in common with Lake Horowhenua is that they are also hypertrophic to supertrophic. As with Lake Horowhenua, they receive a very high proportion of their water input from groundwater draining agricultural land. In the northern dune lakes, the blocking dune face appears to intercept and direct the groundwater flow into these lakes from outside the surface topographical catchment. A similar phenomenon may be occurring around Lake Horowhenua, giving the lake a larger groundwater catchment than expected from the surface topography.

135. There is a high level of connectivity between land use in the topographic catchment inland from the lake and Lake Horowhenua via surface inflows and groundwater. The major surface inflows to the lake are the Arawhata Stream, Queen Street Drain, Patiki Stream, and the Mangaroa Stream, previously identified as the major sources of nutrients to the lake (Gibbs and White, 1994). I note that it has been suggested by Champion *et al.* (2002; section 3.4) that the nutrient loads, especially phosphorus loads,

in these inflow streams have changed since the early measurements in 1975-1977, by the Manawatu Catchment Board, and 1988-1989 by Gibbs and White (1994).

136. In my opinion, these two types of dune lake (ie. deeper drowned valley lakes and shallower perched lakes) are sufficiently different to support my contention that it is inappropriate to have one set of standards for all lakes.

137. In terms of basic hydrology, the stream and river inflows carry water into the lake as part of the hydraulic budget of the lake. Consequently, the inflow volume must also be considered as it affects the hydraulic residence time of the lake and thus, how internal lake processes will affect the parameters measured in the lake water quality standards. For example, abstraction of river water for irrigation during summer would reduce the water level in the downstream lake, causing its temperature (and turbidity) to rise. The flow-on effect would be an increase in the hydraulic residence time and thus, reduction in the flushing of nutrients and algal biomass from the lake, leading to enhanced nutrient retention in the lake – a key factor in the acceleration of eutrophication.

138. Although groundwater is not specifically included in the Proposed One Plan water quality sections, the connectivity between groundwater, rivers and lakes should be considered. Apart from direct rainfall and overland flow, the water in streams and rivers comes from groundwater. Some groundwater will flow directly into the lake. The land use above the groundwater recharge zones will affect the nutrient loads carried in the groundwater (Table 2) and thus, the water quality of the streams and rivers, and ultimately the water quality of the lake. However, as there is a lag between nutrients being leached from land use into the groundwater and the arrival of those nutrients at the stream or river, the accumulation of nutrients in the groundwater over many years may present a future legacy which may breach the present streams and rivers water quality standards. Examples of the groundwater nutrient lag effect are the Hamurana Stream catchment at Lake Rotorua, where nitrogen concentrations in the groundwater discharge at the spring are predicted to rise substantially, and potentially double over the next 100 years. Also, the RPV5 for the Waikato Regional Plan acknowledges that the nitrogen load in the groundwater entering the lake will increase for about 30 years before declining again by 2080 to levels found in 2001-2005.

139. A similar precautionary approach to the influence of intensive land use on the dune lakes would be prudent, as the poor water quality seen in the available data may get substantially worse before improving.

Key points:

- Dune lakes receive much of their water from groundwater.
- Nutrient loads in groundwater come from the land use on soil surface, by leaching with infiltrating rain and irrigation water.
- Groundwater flow is slow such that there will be a lag of many years before the nutrient legacy from today reaches the dune lake.
- Most dune lakes have no surface outflow, causing those nutrients and other organic matter to accumulate in the lake.
- Consequently, even if the proposed approach to control intensive land use and impose nutrient loss limits on all intensive operations in many lake catchments were implemented today, the water quality of a dune lake is likely to get worse before it improves.
- Mitigation of the groundwater nutrient legacy requires implementation of additional targeted management strategies, such as stock exclusion by fencing and the refurbishing of lake-edge buffer zones.

Lake water quality standard overview

140. The proposed lake water quality standards have the purpose of protecting the water quality of each lake from further deterioration and providing a goal that all lakes should meet. The difficulty with this approach is that the lakes are mostly degraded beyond the trophic level of the proposed water quality standards, and it is unlikely that the standards can be met without major intervention by Horizons. Applying the same standard to all lakes is not appropriate, and imposing these standards on all lakes within the various management zones without some knowledge of their present water quality is not recommended.

141. Evaluation of the major groupings of dune lakes indicates that there are two main types of dune lake – drowned valley and perched. Each type will have different water quality because of the way they were formed, the land use in their catchments and physical characteristics of depth and surface area. At the very least, the dune lakes should be classified by depth into shallow and deep. A useful separation between shallow and deeper lake groups could be based on mixing depth, as defined by Davies-Colley (1988). The definition of shallow should be tempered with observations of the characteristics of shallow dune lakes and the intended use of the lake in Horizons' Region.

142. Almost all shallow lakes will develop some form of thermal stratification in summer but it will be transient (ie. not lasting more than a few hours). Lake Horowhenua is such a lake. Therefore, for the purposes of the Proposed One Plan, I propose that a shallow lake is defined as "*a lake which does not develop stable thermal stratification during summer*".

143. By "stable thermal stratification", I mean stratification that persists for weeks to months. Once established, the stratification is resistant to breakdown, although wind-stirring may cause partial mixing. The degree of resistance can be described using a Brunt-Väisälä frequency N. If $N > 0$ then the stratification is stable and if $N < 0$, stratification is unstable. The Schmidt Stability index has also been used to describe resistance to mixing in New Zealand lakes (Viner, 1984).

144. A further sub-classification may be required, based on whether the lakes are dominated by aquatic plants or by phytoplankton and suspended solids. Many of the lakes in Horizons' Region have been surveyed for aquatic plants (eg. Champion, 2002; Champion *et al.,* 2002; Edwards and Clayton, 2002; Champion and Wells, 2003). This is a good basis for future lake water quality evaluation using the "LakeSPI" technique of Clayton and Edwards (2006).

145. Lake water quality is an integration of the external nutrient loads from the catchment, over which Horizons has some direct control via the rivers standards, and the internal nutrient loads from the lake sediments, over which Horizons has no direct control unless a restoration programme is implemented for each lake. By restoration programme, I mean a management strategy designed to improve the water quality of the lake to achieve a predefined goal by direct intervention. Direct intervention could include the refurbishing of lake-edge buffer zones, establishing wetland filters on the inflow streams, direct control of the internal nutrient load through the use of active sediment capping agents, or a combination of these in conjunction with the land use management strategies. By active sediment capping agent, I mean a product that, when applied as a thin (< 2-mm thick) layer across the bottom of the lake, permanently binds with the phosphorus being released from the lake sediments and prevents it from being used by algae for growth.

146. An integral part of any lake restoration programme is a monitoring programme that provides data on the effectiveness of the restoration, and thus the management strategies used. Before restoration begins, the criteria or revised criteria in the proposed standards should be used as a basis for designing the monitoring programme to assess the present water quality. The lake restoration programme needs to be able to use the

monitoring data to make adjustments to the restoration strategies (ie. adaptive management) to achieve the defined restoration goal.

147. Strategic monitoring programmes are also required to enable inter-comparison of the water quality of all lakes within Horizons' Region. This will track the changes occurring and whether intervention is needed. Apart from LakeSPI (Clayton and Edwards, 2006), Trophic Lake Index (TLI) (Burns *et al.,* 2000) is an appropriate tool for assessing the relative water quality of all lakes in the Region. It can also be used to determine whether there has been a change in water quality in response to any management strategy or land use change in the catchment.

148. The TLI is obtained from the sum of numerical representations of the annual average of four water quality parameters: clarity (Secchi depth), chlorophyll *a*, total phosphorus, and total nitrogen, all of which are proposed standards. To use the TLI method requires regular measurement of those four parameters, as described in the monitoring protocols (Burns *et al.,* 2000).

149. If the TLI method is used, the monitoring programme to obtain those key parameters should be extended to include additional parameters which provide some understanding of in-lake processes and the seasonal cycles in the lake. Additional parameters measured should include depth-related temperature, dissolved oxygen, pH, dissolved reactive phosphorus, nitrate-nitrogen, and ammoniacal-nitrogen. By "depth-related", I mean parameters measured on water samples taken from different depths, or data collected by instrument probe lowered through the depth of the water column. For shallow lakes, an integrated water sample (tube sample) from the whole water column depth should be used. For deeper lakes, a messenger-activated closing water sampler (eg. van Dorne) should be used to collect water from different depths above and below any thermocline determined from a temperature profile (Burns *et al.,* 2000).

150. Because these lakes are dune lakes and some will have no natural outflow, chloride concentrations should also be measured. Because chloride is a conservative parameter (ie. it does not change), it can be used as an indicator of dilution (due to high water inflows), or concentration (due to evaporation), to normalise changes in other parameters and aid in the interpretation of cycles in other parameters.

151. A word of caution with lake restoration strategies. The TLI is a tool that can be used to assess the change in lake water quality in response to the implementation of a management strategy. It is not a decision-support tool to determine what strategy should

be used for management. The decision support comes from the information collected during the monitoring programme and the interpretation of those data with respect to lake processes occurring in that lake.

152. In preparing this evidence, it has become apparent that there are water quality and other data (including fish surveys (eg. Chisnall and Jellyman (1999)) in different documents and reports that are not readily accessible to Horizons in a single database. I recommend that such data be collated into an appropriate bibliography or database so that they are not overlooked and can be used to assist with decisions on setting of standards for the management of the lakes in the Region.

Water quality monitoring

153. The proposed standards do not specify where the measurements should be taken or whether they constitute a surface "grab" sample (less than 2 m deep) or an integrated water sample from the whole depth of the lake. As some parameters are strongly affected by the day-night (diurnal) cycle, there is no indication of when the sample should be taken if a single sample or whether the standard should refer to the average of water samples taken by auto sampler over a 24-hour period. As these observations apply to all the standards, a definition of what constitutes a sample, and the protocols for sampling, should be added to the Water Quality Standards for Natural Lakes and Lake Catchments section preamble in Schedule D of the Proposed One Plan. Alternatively, a set of water quality monitoring protocols should be written as an appendix to Schedule D or as a separate document (eg. a field guide or handbook). Part of the sampling protocols must be a means of validating the data (ie. is it within the expected and valid range for that parameter from that lake and, if not, is the analytical value valid?).

154. A water quality monitoring programme must be designed for the purpose, whether it is the collection of State of the Environment, catchment-specific strategic information, information for a consent, or testing for compliance. While the parameters measured are determined by objectives of the monitoring programme, there is no reason why fundamental parameters such as temperature, dissolved oxygen and water clarity (Secchi depth or black disc) should not be collected as a matter of course, to build up a strategic database.

155. A fundamental question in any monitoring programme is "What constitutes a sample?". A sample should be representative of the thing being sampled, whether it is water or sediment, or the algae and periphyton that live in or on the water or sediment. It should

not be biased because of wind drift effects or proximity to some feature (eg. point source discharge). Most water sampling is biased in time towards daylight and the nominal work hours during the day.

156. There are several books and reports on the design of monitoring programmes, including one from the ANZECC (ANZECC & ARMCANZ 2000). Within the design concept, it is important to recognise that each lake is different and that a specific set of water quality monitoring protocols may be required for an individual lake or group of lakes within the Water Management Zones of the Proposed One Plan.

157. A comprehensive set of monitoring protocols for assessing the Trophic Level Index of a lake are contained in Burns *et al.* (2000). These protocols include details of the general concepts and principles associated with the design of the monitoring programme for each lake, including where to sample, the depths to be sampled, the handling and analysis of the samples, and the validation of the analytical data. I would recommend that these protocols be adopted as the basis for any monitoring programme on the dune lakes.

158. The protocols for assessing the lake Trophic Level Index use data from water samples collected at long time scales (months) through the year. These protocols do not accommodate diurnal variations and wind effects in shallow lakes, or in-lake processes that stimulate cyanobacteria blooms, such as the release of nitrogen and phosphorus from the sediment (ie. processes which may operate at time scales of less than a week). Water clarity in shallow lakes may be dominated by wind, with time scales of a few hours. To answer questions about these short-term variations, I would recommend the use of *in-situ* data loggers that can be set to record a range of parameters at a range of time intervals, from a few minutes to hours or days. The range of parameters that can be measured includes temperature, dissolved oxygen, turbidity, pH, chlorophyll fluorescence and cyanobacteria.

4. REFERENCES

Note – those references in bold type I consider to be key references that may be useful to consult to amplify points made in my evidence. Other references are listed – and cited in evidence – mainly for scholarly 'authority'.

ANZECC (2000). Australian and New Zealand guidelines for fresh and marine water quality. October 2000 ed. Canberra, Australia, National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC & ARMCANZ (2000). Australian guidelines for water quality monitoring and reporting. National Water Quality Management Strategy Paper No 7, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

Burger, D.F., D.P. Hamilton, C.A. Pilditch, and M.M. Gibbs (2007). Benthic nutrient fluxes in a eutrophic, polymictic lake. Hydrobiologia 584:13–25.

Burns, N.M. (1995). Using hypolimnetic dissolved oxygen depletion rates for monitoring lakes. New Zealand Journal of Marine and Freshwater Research 29:1-11.

Burns, N.M., G. Bryers and E. Bowman (2000). Protocol for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs. Wellington: Ministry for the Environment.
122 p.

Burns, N.M., M.M. Gibbs, and M.L. Hickman (1996): Measurement of oxygen production and demand in lake waters. New Zealand Journal of Marine and Freshwater Research, 30(1):127-133.

Burns, N.M., J.C. Rutherford and J.S. Clayton (1999). A monitoring and classification system for New Zealand lakes and reservoirs. Journal of Lake and Reservoir Management 15:255-271.

Champion, P. (2002). Aquatic vegetation survey of nine water bodies in the Manawatu. NIWA Client Report HAM2002-03 to Horizons Regional Council. 11p.

Champion, P., T. Dugdale, and F. Matheson (2002). Lake Horowhenua – assessment of the status of *Egeria densa* and implications for lake stability. NIWA Client Report HAM2002-058 to Horizons Regional Council. 25p.

Champion, P.D., and R.D.S.Wells (2003). The aquatic vegetation of the Manawatu-Wanganui Region: status and management. NIWA Client report HAM2003-109 to Horizons Regional Council. 31p.

Chisnall, B.L., and D.J. Jellyman (1999). Synoptic fisheries survey of Lake Horowhenua. NIWA client report TOW90501 prepared for Treaty of Waitangi Fisheries Commission, Te Ohu Kai Moana. 33p.

Clayton, J. and T. Edwards (2006). Aquatic Plants as Environmental Indicators of Ecological Condition in New Zealand Lakes. Hydrobiologia 570:147-151.

Clothier,B., A. Mackay, A. Carran, R. Gray, R. Parfitt, G. Francis, M. Manning, M. Duerer, and S. Green (2007). Farm Strategies for Contaminant Management. A report by SLURI, the Sustainable Land Use Research Initiative, for Horizons Regional Council. 64p.

Davies-Colley, R.J. (1988). Mixing depths in New Zealand lakes. New Zealand Journal of Marine and Freshwater Research 22:517-527.

Edwards, T., and J. Clayton (2002). Aquatic vegetation in Lakes Dudding, Wiritoa, Horowhenua and Pukepuke Lagoon. NIWA client report HMW02201 to Manawatu-Wanganui Regional Council, 24 p.

Forsyth, D.J. and C. Howard-Williams (1983). Lake Taupo: Ecology of a New Zealand lake. DSIR Information series No. 158. Government Printer, Wellington.

Gibbs, M.M. (2009). Lake Taupo long term monitoring programme 2007-2008. NIWA Consultancy Report to Environment Waikato, Report No.HAM2009-044. 91p.

Gibbs, M.M. (2008). Identifying Source Soils in Contemporary Estuarine Sediments: A New Compound-Specific Isotope Method. Estuaries and Coasts 31:344–359.

Gibbs M. (2004). Rotokawau-Virginia Lake Study: a preliminary assessment. NIWA client report HAM2004-112 to Wanganui Water Services. 16 p.

Gibbs, M.M. (1979). Groundwater input to Lake Taupo, New Zealand: nitrogen and phosphorus inputs from Taupo township. New Zealand Journal of Science, 22: . 235-243.

Gibbs, M., D. Bremner and M. van Kooten (2008). Comparison of efficacy of four P-inactivation agents on Lake Rotorua sediments. NIWA client report HAM2008-105 to Environment Bay of Plenty. 47p.

Gibbs, M. and D. Bremner (2007). Wharekawa Estuary sediment sources. NIWA report No. HAM2007-111 to Environment Waikato. Environment Waikato Technical report series.

Gibbs, M. and C. Hickey (2007). "What is happening to Virginia Lake?" Oral presentation at a one day public workshop on the ways forward, in Wanganui, for Regional Council (Horizons) and Wanganui District Council, 24 October, 2007. Funded by Envirolink grant HLZC51.

Gibbs, M., I. Hawes and S. Stephens (2003). Lake Rotoiti – Ohau Channel: assessment of effects of engineering options on water quality. NIWA Client Report: HAM2003-142 (December).

Gibbs, M.M., I.K.G. Boothroyd, P.D. Champion, J. Green, I Duggan (1999): ARC lakes monitoring programme review. NIWA Hamilton client report ARC00256 to Auckland Regional Council. 82 p.

Gibbs, M.M. and W.N. Vant (1997): Seasonal changes in factors controlling phytoplankton growth in Beatrix Bay, New Zealand. New Zealand Journal of Marine and Freshwater Research, 31: 237-248.

Gibbs, M.M. and E White (1994). Lake Horowhenua: a computer model of its limnology and restoration prospects. Hydrobiologia, 275/276: 467-477.

Hilton, J. and M.M. Gibbs (1985). The horizontal distribution of major elements and organic matter in the sediment of Esthwaite Water, England. Chemical Geology 47: 57-83.

John, P.H., M.M. Gibbs, and M.T. Downes (1978). Groundwater quality along the eastern shores of Lake Taupo, 1975-76. New Zealand Journal of Marine and Freshwater Research, 12: 59-66.

Hamill, K. (2008). Review of Water Quality Standards in the Proposed One Plan. Opus International Consultants Ltd., report to Palmerston North City Council for One Plan. 19p.

Lowe, D. and J.D. Green (1987). Origins and development of the lakes. *In* A.B. Viner (Ed) Inland Waters of New Zealand. DSIR Bulletin 241. DSIR Science Information Publishing Centre, Wellington.

Menneer, J.C., S.F. Ledgard and A.G. Gillingham (2004). Land use Impacts on Nitrogen and Phosphorus Loss and Management Options for Intervention. AgResearch Ltd. client report to Environment Bay of Plenty. 52 p.

MfE (2003). Microbiological water quality guidelines. Ministry for the Environment, Wellington, New Zealand.

MoH (2005). Drinking water standards for New Zealand (2005). Ministry of Health, Wellington, New Zealand. 130p.

Paul, W.J., D.P. Hamilton and M.M. Gibbs (2008). Low-dose alum application trialled as a management tool for internal nutrient loads in Lake Okaro, New Zealand. New Zealand Journal of Marine and Freshwater Research 42: 207–217.

Redfield, A.C. (1958). The biological control of chemical factors in the environment. American Scientist 46: 205–222.

Safi, K.A. and M.M. Gibbs (2003). Importance of phytoplankton. New Zealand Journal of Marine and Freshwater Research 37: 267-272.

Scarsbrook, M. and G. McBride (2007). Best practice guidelines for the statistical analysis of freshwater quality data. NIWA client report HAM2007-088 to the Ministry for the Environment. Project number MFE06202. p84.

Vant, W.N. and M. Gibbs (2006). Nitrogen and phosphorus in Taupo rainfall. Environment Waikato Technical Report No. 2006/46. 12 p.

Viner, A.B. 1984. Resistance to mixing in New Zealand lakes. New Zealand Journal of Marine and Freshwater Research, 18: 73-82.

White, E., M. Downes, M. Gibbs, L. Kemp, L. Mackenzie, and G. Payne (1980). Aspects of the physics, chemistry, and phytoplankton biology of Lake Taupo. New Zealand Journal of Marine and Freshwater Research, 14: 139-148.

White, P.A., M. Raiber, C. Meilhac and H. Zarour (2009). Horowhenua groundwater – surface water interaction and water budget. GNS Science Consultancy Report to Horizons Regional Council. (Draft version only cited). p91.

Zarour, H. (2008). Groundwater Resources in the Manawatu-Wanganui Region. Horizons Regional Council Technical Report No: 2008/EXT/948. p262.

Max Gibbs

August 2009

APPENDIX

On defining the term “Algal Bloom”

Early definitions of what constitutes an Algal Bloom focus on the way they develop:

- Algal blooms are sudden population explosions in marine or freshwater algae.
- Sudden, massive growths of microscopic and macroscopic plant life, algae, and cyanobacteria, which develop in lakes, reservoirs, and marine waters.
- Excessive and rapid growth of algae.
- Algal blooms occur when the growth of algae is excessive.
- When microscopic plants called algae become so thick that they make lake water look like pea soup, the condition is called an algal bloom.
- At times algae can grow so quickly and densely that they form a "bloom".

More recently, there has been an attempt to put a level of quantification into the definition:

- In Florida, when chlorophyll (an indicator of algae presence) concentrations reach a level over 40 micrograms per litre, some scientists will call it an "algae bloom" or "algal bloom."

Due to the lack of a single definition for algal blooms, it is impossible to say if variability in algal biomass is a function of natural fluctuations in algal levels.

It is generally agreed that the concentration of algae that defines an algal bloom varies widely between species. This is significantly affected by the different sizes and growth rates of particular species. Consequently, different definitions of algal blooms have been suggested for non-toxic and toxic algal species as only a small number of toxic algae/mL may result in a health risk:

- Water and Rivers Commission in Western Australia defined algal blooms: for moderate to large algal cells (greater than 15 to 20 microns in diameter) as bloom conditions if there were > 15,000 cells per mL of water. For small microscopic non-toxic cells (less than 1–5 microns) at around 100,000 cells per mL, and even densities of 500–2,000 cells per mL require action by managers. The Commission, however, also suggests that a bloom of a toxic species in a shellfish harvesting area could pose a threat at densities as low as 5 cells per mL.

Concentrations are also specific to particular water bodies. For example, species may occur naturally at significant levels in some water bodies, while in others the same levels may not be natural and may instead indicate ecosystem imbalances or nutrient enrichment. In order to derive algal bloom definitions for particular water bodies, data must be related to background levels typically found within each water body, so that interpretation can be related to the conditions in each water body that are considered 'normal'.

At the ASLO Summer Meeting 2005, Santiago de Compostela, Spain, they proposed an operational bloom definition based on the site-specific statistical properties of chlorophyll measurements, characterizing blooms as ***observations above the confidence interval of their distribution***.

Using this definition, if algal growth follows a normal seasonal cycle within a given range of chlorophyll concentrations for that water body at that time of year, it is not an "algal bloom". However, if the chlorophyll concentrations dramatically increase beyond that given range or occur at a different time of year, then it is likely to be an algal bloom.

This means that an eutrophic water body with naturally high chlorophyll concentrations is less likely to experience an algal bloom than an oligotrophic water body with naturally low chlorophyll concentrations, where even a small increase in algal biomass may be well outside the "normal range".

Because of the above difficulties in defining an algal bloom, the term should be regarded as qualitative. For health studies, a more quantitative definition based on cell counts of specific algal species, or toxicity levels, as alert levels would seem more appropriate, as the presence of that cell count of that species is likely to have the same level of toxicity irrespective of whether the water body is oligotrophic or eutrophic. Some agreed levels may be found in ANZECC 2000 and the Drinking-Water Standards for New Zealand 2005. This is likely to be clarified by the release of National Guidelines on cyanobacterial toxicity, currently in draft form.