IN THE MATTER OF The Resource Management Act 1991

AND

IN THE MATTER OF Lake Rotorua Nutrient Management – **PROPOSED PLAN CHANGE 10** to the Bay of Plenty Regional Water and Land Plan

---

STATEMENT OF EVIDENCE OF Andrew Charles Bruere ON BEHALF OF THE BAY OF PLENTY REGIONAL COUNCIL

Evidence topic: Overview of Science and Restoration Initiatives.

Contents:

Qualifications and experience

1. My full name is **Andrew Charles Bruere.** I am employed by the Bay of Plenty Regional Council as the Lake Operations Manager, a position I have held for nine years.

2. Prior to this I was employed by the Bay of Plenty Regional Council in the area of RMA consents and compliance. I was initially employed as a Resource Consents Officer in 1990 and progressed through the Compliance Team Leader to Manager of Consents and Compliance.

3. I have the following qualifications: MAgSc in engineering. I am also a member of the North American Lake Managers Society.

4. My role as Lake Operations Manager involves three main areas of activity: implementation of in-lake restoration actions; delivery of the lake science for the Rotorua Lakes Programme; and preparation and delivery of Lake Action Plans required as part of the Regional Water and Land Plan to achieve water quality improvements to the Rotorua Lakes. The in-lake restoration actions include some very significant projects such as the Ohau diversion wall and the alum dosing programme on four lakes, which are discussed below under “Lake Interventions” These projects include researching and investigating alternative methods, gathering science research and some further research, leading the resource consent applications and commissioning the projects.

5. The delivery of science involves maintaining linkages with science providers including internal science staff, external Crown Research Institutes (CRI) and consultants and the relationship with the University of Waikato. I convene the Water Quality Technical Advisory Group and the Land Technical Advisory Group[1]. These groups provide technical input to the programme. Their advice ranges from key research and modelling to help understand the behaviour of our lakes to advice on specific interventions and prototypes used in our programme. Much of the science is provided to support planning and policy direction by council, and forms a significant part of the basis for Proposed Plan Change 10 (PPC 10).

6. I have read the Expert Witness Code of Conduct set out in the Environment Court’s Practice Note 2014 and I agree to comply with it. I confirm that the issues addressed in this statement of evidence are within my area of expertise, except where I state I

---

[1] Discussed below under ‘Rotorua Lakes Programme and science’.

am relying on the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from my expressed opinion.

7. I am authorised to provide this evidence by the Regional Council.

Scope of my evidence

8. The scope of my evidence is to provide an overview of the science informing the restoration of the Te Arawa Rotorua Lakes, and in particular PPC 10 and contributing initiatives for Lake Rotorua.

9. I explain how the science programme works, how it feeds into the planning process and interventions planning, what the science issues have been, and how they have been resolved, in the development of the nitrogen reduction planning specific to Lake Rotorua. The relevant science in terms of PPC 10 is generally around these issues:

   (i) how do we know how much Nitrogen gets to the Lake and when?

   (ii) what's the relationship between the main nutrients (Nitrogen and Phosphorous)?

   (iii) how can we manipulate them to get a cleaner lake?

   (iv) are our models robust and in line with good practice and current thinking?

10. This is only a part of the wider story on the efforts to restore and maintain the health of the Rotorua Lakes.

11. Ultimately, as the person responsible for implementation of in-lake restoration actions, delivery of the lake science for the Rotorua Lakes Programme and preparation and delivery of Lake Action Plans required as part of the Regional Water and Land Plan to achieve water quality improvements to the Rotorua Lakes, I am of the opinion that the science work that has been undertaken provides a solid base for the planning proposals that have been made in PPC 10 for Lake Rotorua, and that land use change is the most vital part of the sustainable long term recovery for Lake Rotorua, and this is supported by the science programme.

12. The detailed technical evidence on the scientific reports is provided by Professor Hamilton and Dr Rutherford in respect of their specific investigations and conclusions. My evidence is intended only to provide an overview.

Introduction: The Rotorua Lakes Programme and science

13. The Rotorua Lakes Programme (RLP) is underpinned by the work of the science team that consists of several components. The Bay of Plenty Regional Council has a specialist science team of internal staff and external consultants that undertakes science monitoring and research within the Rotorua Lakes District. The structure of the science team, how it fits with the RLP and how new ideas are introduced to the programme is covered in Figure 1.

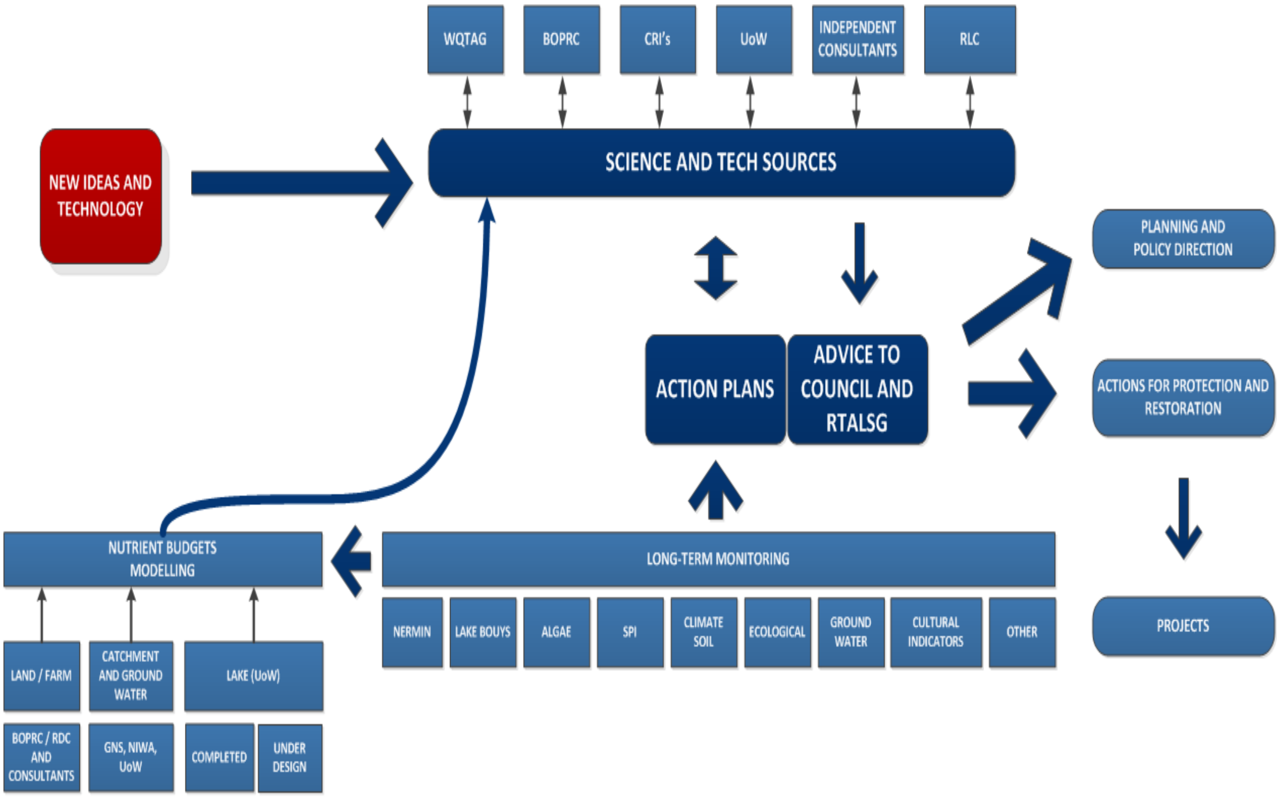


Figure 1. Science interactions for RLP.

14. The science providers feed information into regional planning to support policy formation as well as action plans aimed at protecting and restoring the lakes. Key outputs of this are the components that support the long term monitoring. This

information is critical to supporting the RLP, environmental modelling, the development of council policy for the lakes, identifying sources of lake water contamination and potentially identifying and assessing actions to solve poor lake water quality and environmental degradation.

15. One of the key outputs of this team is the Natural Environment Regional Monitoring Network (NERMN). This network has provided regular environmental monitoring of multiple locations around the region since about 1990. This includes the monthly monitoring of the twelve Rotorua lakes and many of the contributing streams. This monitoring provides a platform of data that is essential in understanding long term trends on our lakes. This is supported by a number of other ongoing science monitoring initiatives such as in-lake monitoring buoys, summer cyano-bacteria monitoring and the lake submerged plant index, which provide more detailed but regular state of the environment monitoring data and information.

16. The RLP has a specialist advisory group known as the Water Quality Technical Advisory Group with internal and external specialists in the area of lake water quality, ground water science, water chemistry, catchment and lake modelling. This group has been in existence advising on the lakes since the 1970s. The Bay of Plenty Regional council also funds a Chair (Professor) in Lake Restoration at the University of Waikato (UoW). This has a number of objectives:

    (i) To continue to explore the development of a centre of excellence and provide a vehicle, for focussing research on lake processes in New Zealand, with emphasis on the Rotorua/Te Arawa Lakes. In particular to identify how the programme can be incorporated into the recently developed University of Waikato Environmental Research Institute.

    (ii) To foster an integrated approach to research and management of the lakes and their catchments.

    (iii) To encourage research that has management and restoration objectives.

    (iv) To encourage cooperation between the University and both territorial and regional governments, the community and iwi in lake issues.

    (v) To maintain and enhance the capability to attract external research funding focussed on lake restoration.

(vi) To build an educational base into freshwater restoration through undergraduate teaching and postgraduate research and training.

17. This Chair with the UoW has been in existence since 2002, and the position has been held by Professor Hamilton since its inception.

18. The Council also has a Land Technical Advisory Group which was formed in 2014 to provide advice on economic, land science and farmer liaison. It also has a range of expertise, including soil and land scientists, economists and experts in farmer engagement and liaison.

Water Quality Targets

19. The RLP consists of a programme of restoration and protection for the 12 lakes in the Rotorua district. The largest of these lakes is Lake Rotorua (80 km^2) with a surface catchment area of 502 km^2 and a total catchment area (including an aquifer outside the surface catchment) of 537 km^2 (White et al., 2015)

20. Water quality targets have been set for each of the 12 lakes in the Regional Water and Land Plan, which became operative in 2005. The targets are measured by the lake trophic level index (TLI).

21. Each lake has its own TLI target that was set based on historic information about water quality. The water quality for Lake Rotorua has been the subject of concern since the 1970s and has been researched in a number of publications since before that time (Mueller et al, 2015). The water quality of the 1960s (before widespread public concern about phytoplankton growths developed) was identified by the WQTAG in 1986 as a suitable and achievable target for Lake Rotorua (Rutherford et al., 1989). This target was subsequently endorsed by the WQTAG in 2005 and carried through into the Regional Water and Land Plan in the form of specific water quality targets for TLI (4.2) .

Trophic Lake Index (TLI)

22. The TLI is a statistical indicator of lake water quality based on monitoring results of four water quality measurements: total nitrogen, total phosphorus, chlorophyll-a and secchi disc water clarity. The water quality of a lake can be manipulated by altering concentrations of nitrogen and/or phosphorus as these are plant nutrients that stimulate algal growth. Chlorophyll-a is a measure of the concentration of algae present. Higher algal concentrations generally result in poor water quality. Secchi

disc water quality is the distance a black and white disc can be lowered into the water before it disappears from sight. The water quality TLI target relates to specific in-lake nitrogen and phosphorus concentrations along with chlorophyll-a and secchi disc levels for the lake.

23. The water quality of the Rotorua lakes is variable and ranges from oligotrophic to eutrophic lakes. The TLI for a lake is an index of its trophic state and can be used to classify and monitor changes over time of a particular lake. For example, lakes with a TLI of 2 – 3 are considered "oligotrophic" (An oligotrophic lake is a lake with low primary productivity, as a result of low nutrient content). Lakes with a TLI of 3 – 4 are considered "mesotrophic" (Mesotrophic lakes are lakes with an intermediate level of productivity. These lakes are commonly clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients). Lakes with a TLI of 4 – 5 are considered "eutrophic" (A eutrophic lake has high biological productivity, due to excessive nutrients, especially nitrogen and phosphorus).

Achieving and maintaining the TLI

24. Based on the TLI target of 4.2 as set in the Regional Water and Land Plan for Lake Rotorua, research supports the conclusion that 435 t y^{-1} nitrogen and 37 t y^{-1} phosphorus are the sustainable nutrient load inputs from the catchment required to achieve and maintain the TLI of 4.2 (Rutherford et al., 1989). More recent research (Tempero 2015) indicates that the sustainable P load may need to be within the range of 33.7 to 38.7 t y^{-1} in order to achieve the target TLI.

25. The first research that supported the 435 t y^{-1} nitrogen load target was the paper by Rutherford et al., (1989) which estimated the annual catchment load in the 1960s to be 455 t y^{-1} including septic tank leaching of 50 t y^{-1} and rain falling directly on the lake of 30 t y^{-1} plus an additional 20 t y^{-1} from sewage after treatment (see Table 1 below).

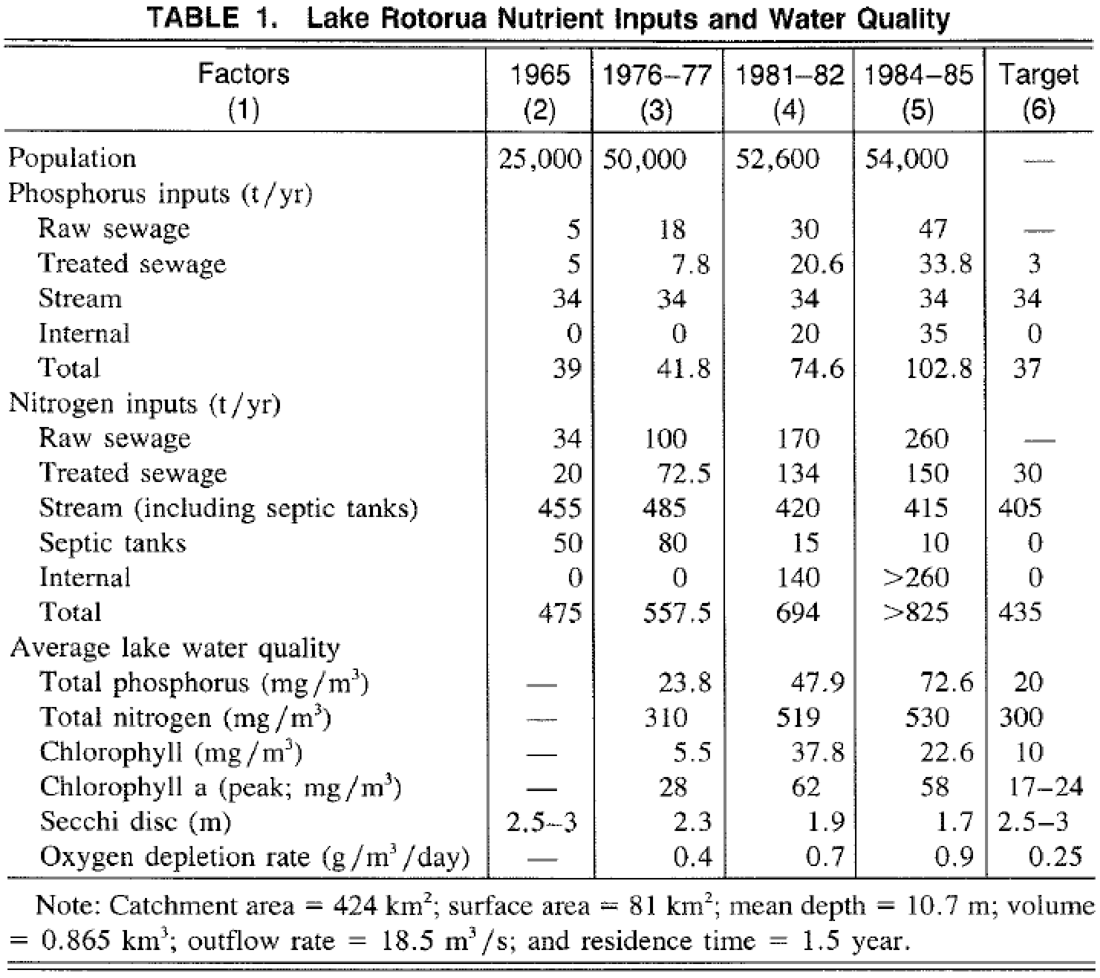


TABLE 1. Lake Rotorua Nutrient Inputs and Water Quality

Factors (1)	1965 (2)	1976–77 (3)	1981–82 (4)	1984–85 (5)	Target (6)
Population	25,000	50,000	52,600	54,000	—
Phosphorus inputs (t/yr)					
Raw sewage	5	18	30	47	—
Treated sewage	5	7.8	20.6	33.8	3
Stream	34	34	34	34	34
Internal	0	0	20	35	0
Total	39	41.8	74.6	102.8	37
Nitrogen inputs (t/yr)					
Raw sewage	34	100	170	260	—
Treated sewage	20	72.5	134	150	30
Stream (including septic tanks)	455	485	420	415	405
Septic tanks	50	80	15	10	0
Internal	0	0	140	>260	0
Total	475	557.5	694	>825	435
Average lake water quality					
Total phosphorus (mg/m^3)	—	23.8	47.9	72.6	20
Total nitrogen (mg/m^3)	—	310	519	530	300
Chlorophyll (mg/m^3)	—	5.5	37.8	22.6	10
Chlorophyll a (peak; mg/m^3)	—	28	62	58	17–24
Secchi disc (m)	2.5–3	2.3	1.9	1.7	2.5–3
Oxygen depletion rate (g/m^3/day)	—	0.4	0.7	0.9	0.25

Note: Catchment area = 424 km^2; surface area = 81 km^2; mean depth = 10.7 m; volume = 0.865 km^3; outflow rate = 18.5 m^3/s; and residence time = 1.5 year.

Note: Table 1 is from Rutherford et al., (1989). Rutherford (2008) confirms that the 405 tN y^{-1} target includes the rainfall component (viz., nitrogen in rain that falls on the lake surface) and that the 435 tN y^{-1} RPS target includes nitrogen derived from treated sewage including septic tanks plus rainfall onto the lake.

26. The nitrogen and phosphorus targets were recommended in 1986 by an expert panel (the WQTAG) which extrapolated back to the 1960s from measurements made in the 1970s and 1980s of nutrients reaching the lake from the catchment and sewage, as outlined in the paper by Rutherford et al., (1989). The phosphorus targets are supported by recent modelling by Tempero (2015).

27. The manipulation of the levels of nitrogen and phosphorus into and in lake can have a potential impact on the concentration of algae present as well as the type of algae. Generally if one nutrient can be made limiting (i.e., the nutrient in most limited supply for growth), then the lack of that nutrient will limit algae growth. The relationships between these factors are complex and can be affected by a number of variables such as natural variations in rainfall, temperature, attenuation through the soil and

underlying geology. The nutrient pathways from the point of discharge to the lake are not direct. However, Council has undertaken research that supports that the proposed levels of reduction will meet and maintain the target TLI of 4.2. The impact of manipulating the levels of each of these nutrients will be expanded in Professor Hamilton's evidence. The planning context of the target of 435 tN y^{-1} sustainable load is explained in the evidence of Stephen Lamb, and in the Section 32 report (section 1.5).

28. Since the 1960s the Lake Rotorua TLI has increased over time and peaked in in 1985, 1989, 2001 and 2003 (Hamilton et al., 2015). The most recent peak in 2003 reached a TLI of 5.03 (pers. comm., Paul Scholes, Environmental Scientist, BOPRC). Since then the lake TLI has reduced and for three years 2012 to 2014 the lake complied with its TLI target of 4.2. The most recent TLI calculation is 4.4 for the 2015/16 year (July to June). This short period of compliance with the TLI target is a result of the alum dosing programme on the lake. Details of this are explained in Professor Hamilton's brief (paragraph 15(h)) and below.

Conclusion re water quality targets

29. At a TLI target of 4.2 Lake Rotorua will remain in the eutrophic bracket according to the classification. However, it is a continuous scale and a move from a TLI over 5[2] down to 4.2 is expected to produce a valuable improvement. The experience with the lake over the past 5 years when it has either reached the 4.2 TLI target or come close to it, is that nuisance algal blooms are largely eliminated and water clarity has improved. An explanation of the TLI system and some examples of lakes in each bracket is attached as Appendix 1. A graph of the TLI history for Lake Rotorua is included below at paragraph 85.

Control of Nutrients

Background

30. Some level of nutrient is lost to the environment from all forms of land use. Nitrogen and phosphorus are the most common nutrients that are limiting to aquatic plant growth in the environment and so they are seen as typical control nutrients. Within the Rotorua catchment, pastoral farming contributes the majority of nitrogen and a major portion of the phosphorus from urine, faeces and soil erosion. Nitrogen is

---

[2] See evidence of Professor Hamilton: absent alum, the TLI3 for the simulation period would be 5.57 (Without the inclusion of Secchi depth the TLI3 is approximately 0.1 units higher than the four-parameter TLI value).

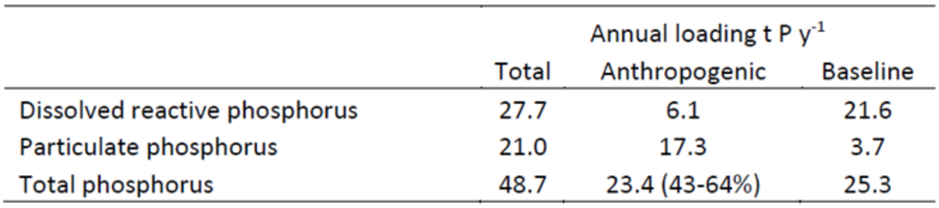
generally in a soluble form (or readily breaks down into a soluble form) and travels through the soil into ground water. In contrast phosphorus is generally absorbed onto soil particles and does not travel in the ground water from land uses. Rotorua and Taupo are unusual, however, in that phosphorus dissolves slowly from the volcanic rock in the slightly acidic rainwater resulting in moderately high soluble phosphorus concentrations being found in old groundwater (Morgenstern et al, 2004). In effect nitrogen travels in the ground water and depending upon what part of the catchment it is released in it can take anywhere from less than 1 year to more than 100 years to reach the lake via ground water and discharge to springs recharging streams. The average age of ground water reaching Lake Rotorua is 60 years (Morgenstern et al, 2004). So once in the ground water it is likely to take a long time to reach the lake. In contrast, for phosphorus the main route to water from farmland is via overland flow, and this is a more rapid pathway to the lake than the nitrogen travelling via ground water. Depending on rainfall and soil conditions, the time of travel is hours, days and weeks rather than years. However, sediment movement in streams will influence the time of phosphorus travel to the lake.

Management of both N and P

31. The science experts have consistently advised that addressing the problem of poor water quality/eutrophication in Lake Rotorua cannot be solved by the control of a single nutrient, nitrogen or phosphorus, most recently in the WQTAG advice of September 2015 (Appendix 2). As early as 1989 Rutherford et al advised control of nitrogen alone could cause the algal community to become dominated by blue-green algae and control of phosphorus alone would need to be to the extent that it made phosphorus the limiting nutrient. “Thus, removal of both nitrogen and phosphorus is recommended”.

32. The work of Tempero et al., (2016) shows that the natural (baseline) inputs of dissolved reactive phosphorus from the catchment are dominant (44% of total load). Land use control to limit anthropogenic (human induced) sources of phosphorus will need to focus on particulate phosphorus, and will be challenging. Table 1 below (from Tempero et al., 2016) shows the relative phosphorus contributions from anthropogenic (human) and natural (baseline) sources.

Table 1. Summary of annual phosphorus loading to Lake Rotorua, including estimated percentage range of anthropogenic total phosphorus reduction needed to achieve a TLI target of 4.2 (in parentheses).



	Annual loading t P y^{-1}		
	Total	Anthropogenic	Baseline
Dissolved reactive phosphorus	27.7	6.1	21.6
Particulate phosphorus	21.0	17.3	3.7
Total phosphorus	48.7	23.4 (43-64%)	25.3

Note: Baseline = natural phosphorus inputs

33. The phosphorus load to achieve the target TLI of 4.2 is estimated to be 34-38 tP y^{-1} (Tempero et al., 2015). This will require a reduction in the total estimated phosphorus load reaching the lake of 10–15 tP y^{-1} or 43-64% of the anthropogenic contribution.

34. The focus of the PPC 10 rules is on the reduction of nitrogen. Some reduction in phosphorus is also expected in association with nitrogen reduction actions[3], but the level of phosphorus reduced in this way is as yet uncertain. In the meantime interim external methods such as alum dosing[4] provides for the temporary management of phosphorus. However, alum is not seen as a long term solution as it has a number of potential risks; sectors of the community are opposed to its long term application and it has an on-going cost to the community for the supply alum for dosing[5]. The risks associated with alum dosing are presented in Tempero et al., (2015)[6], and summarised in the evidence of Professor Hamilton. In addition resource consents authorising the use of alum terminate in 2018 and 2019. Although the council is planning to continue alum dosing (10 year plan), we cannot assume ongoing consents will be granted, or if so, under what conditions.

Management of Nitrogen

35. The approach to nitrogen management in the proposed rules is covered in the evidence of Stephen Lamb, and in detail in the Section 32 report in section 9. However, in summary the approach is to manage N via rules, the $40M incentives fund, and gorse control. It has been established by research at SCION that gorse can be the source of high levels of nitrogen leaching due to its capacity to fix atmospheric nitrogen.

---

[3] See evidence of Professor Hamilton at paragraph 15(l).
[4] Alum dosing is explained below at paragraph 42 and from paragraph 77 onwards.
[5] See Sandra Barns 2016 regarding economic costs.
[6] See section 32 report at section 9.4 and the science reports website for the full report of Tempero.

Management of Phosphorus as Part of PPC 10

36. Science advice has consistently informed that controlling phosphorus via land use change will be challenging as the natural levels of phosphorus in ground water are elevated, and that land use contributes only a portion of the lake phosphorus input. As noted above, this has been clarified by research undertaken by Tempero et al., (2016) that shows only about 48% of phosphorus reaching the lake comes from anthropogenic sources within the Rotorua catchment. The largest proportion of anthropogenic phosphorus reaching Lake Rotorua is in the particulate form resulting from sediment run off to streams and the lake.

37. In addressing the approach to manage nitrogen or phosphorus it is of value to understand the key methods of travel for each nutrient (explained in paragraph 30). Following land use changes that lower nitrogen losses, it will take many years for the full benefits to be seen in terms of reduced nitrogen load reaching the lake. Rutherford (2016) report that under the proposed land use change scenario aimed at reaching the 435 $t\ y^{-1}$ nitrogen target, lake loads are expected to be within 25% of the target within 25 years (i.e., there will be a gradual change as ground water flows down from the catchment to the lake). Land use change needs to be started now to achieve improvements in lake water quality within a time frame acceptable to the public. In contrast, phosphorus does not stay in a soluble form within the environment when it is in contact with soil particles. It is readily attached to soil particles and does not tend to flow down the soil profile into ground water in a soluble form. As detailed in Tempero et al., (2015), the largest pool of anthropogenic phosphorus is attached to sediment particles. Effectively, the main route to water is via overland flow, and this is a more rapid pathway to the lake than the nitrogen travelling via ground water.

38. Further study is being undertaken to estimate phosphorus that will potentially be removed as nitrogen interventions are implemented, because changes in land use targeted for nitrogen loss reduction will also benefit phosphorus reduction to some extent. This will help inform of the potential for phosphorus to be removed in association with nitrogen. Due to the difference in travel times between nitrogen and phosphorus reaching the lake it is feasible to address further phosphorus reductions as a result of monitoring inflows and lake water and respond with additional actions as it becomes clearer what phosphorus reductions have been achieved.

Assessing How Much Nitrogen Reaches the Lake

39. NIWA has developed a catchment nitrogen model (ROTAN7)) that takes account of the ground water age (travel times) for each of the main Rotorua sub-catchments. Recalling the average age of ground water in the catchment is about 60 years with some of the sub-catchments having ground water over 100 years old. The ROTAN computer model has been developed to accept estimates of nitrogen losses from land use (inputs) over the Rotorua catchment (e.g., estimated using the OVERSEER® model). The model has been calibrated to match measured stream concentrations from the 1970s to the present. The model can then be used to make predictions about the impact of different combinations of land use looking to the past or future. The model takes account of the fact that water will travel at differing rates to the lake depending upon whether it is travelling over the surface or through ground water aquifers, with differing travel times. I briefly explain the two versions of the ROTAN modelling (ROTAN-2011 and ROTAN-Annual) below. Technical details of the modelling can be found in the evidence of Dr Rutherford.

Environmental Modelling

40. Since 1989 three specific studies have delivered modelling outcomes that support the nitrogen target of 435 tN y^{-1}. These are the ROTAN-2011 report (Rutherford et al., 2011), the University of Waikato alum modelling report (Hamilton et al., 2015) and ROTAN-Annual 2016 (Rutherford 2016). This reliance on environmental modelling is necessary to simulate the flow of nutrients through the environment as it is not possible to take measurements that would be representative of the complete environmental footprint. This modelling is also necessary to make predictions of the environmental effect of changing practices and to test if they achieve the desired outcomes. I briefly explain those three modelling studies below in the context of 'Environmental modelling' and then provide a fuller description of the models. Technical details are given in the evidence of Professor Hamilton and Dr Rutherford.

ROTAN-2011 model description

41. The ROTAN-2011 model (Rutherford et al. 2011) makes weekly predictions of stream and groundwater flows, stream nitrogen concentrations and lake loads for the period 1920 to 2010. Predicted loads for the period 1950 to 1970 show fluctuations

---

[7] See below starting at paragraph 41 for explanation.

around 405 tN y^{-1} which supports the target for acceptable lake water quality (similar to that experienced in the 1960s) being 405 tN y^{-1} from the catchment plus 30 tN y^{-1} from rainfall.

University of Waikato Alum Modelling Report

42. Hamilton et al., 2015 modelled[8] the impact of a 435 t y^{-1} nitrogen target along with an associated phosphorus reduction. Their results indicate that a reduction in nitrogen of about 300 tN y^{-1} will bring the lake close to the target TLI of 4.2. However, action was also required to get sediment releases of phosphorus under control. Currently this is being achieved through the use of alum dosing into two tributary streams.

ROTAN-Annual model description

43. The ROTAN-Annual model (Rutherford 2016) makes annual predictions of lake load. It complements and updates predictions made earlier by ROTAN-2011 using revised groundwater boundaries and 12 years of additional stream monitoring. The 405 tN y^{-1} nitrogen load target falls within the range predicted during the 1960s.

Overseer farm nutrient programme

44. OVERSEER® is a farm nutrient programme jointly owned by the Ministry for Primary Industries (MPI), AgResearch Limited and the Fertiliser Association of New Zealand (FANZ). The OVERSEER computer model is a farm nutrient model that can be used to predict the cycling of nutrients in a farm system. It predicts nitrogen and phosphorus lost or leaching below the plant root zone. The nitrogen losses modelled in this way are used as inputs to the ROTAN catchment nitrogen models.

ROTAN-2011 results

45. ROTAN-2011 (Rutherford et al., 2011) predicted that if nitrogen losses remained constant at 2010 levels, the steady state load reaching the lake would be 725 t y^{-1} nitrogen (plus 30 t y^{-1} nitrogen in rainfall on the lake), and that it would reach this level in the next 70 years. 755 tN y^{-1} (including rainfall) is one estimate taking into account groundwater age, existing land use and current measured loads reaching the lake. Two other estimates of the load on the lake have been presented in the Lakes

---

[8] The modelling approach (DYRESM-CAEDYM) is explained in the evidence of Professor Hamilton from paragraph 20 onwards. The model was used to predict how Lake Rotorua will respond to reductions in external loads, using various nitrogen and phosphorus loading with and without inflow alum dosing.

Rotorua Rotoiti Action Plan, Draft 5 (2007), of 746 tN y^{-1} and 783 tN y^{-1} (both including rainfall). The estimate of 746 tN y^{-1} was provided by GNS-Science based on their dynamic groundwater model (Morgenstern et al., 2006). The estimate of 783 tN y^{-1} is based on land use coefficients from known land use in the catchment. This estimate is related to the predicted outputs from the OVERSEER farm nutrient programme. Since the ROTAN-2011 estimate was established changes to the OVERSEER model have resulted in changes to the predicted nutrient outputs from some land uses.

46. The steady-state load predicted by ROTAN-2011 of 755 tN y^{-1} is made up of individual loads coming from land use activities within the catchment plus 30 tN y^{-1} coming from rainfall on the lake (Rutherford et al., 2011). These are detailed in Table 1 below from ROTAN-2011 (Rutherford et al., 2011).

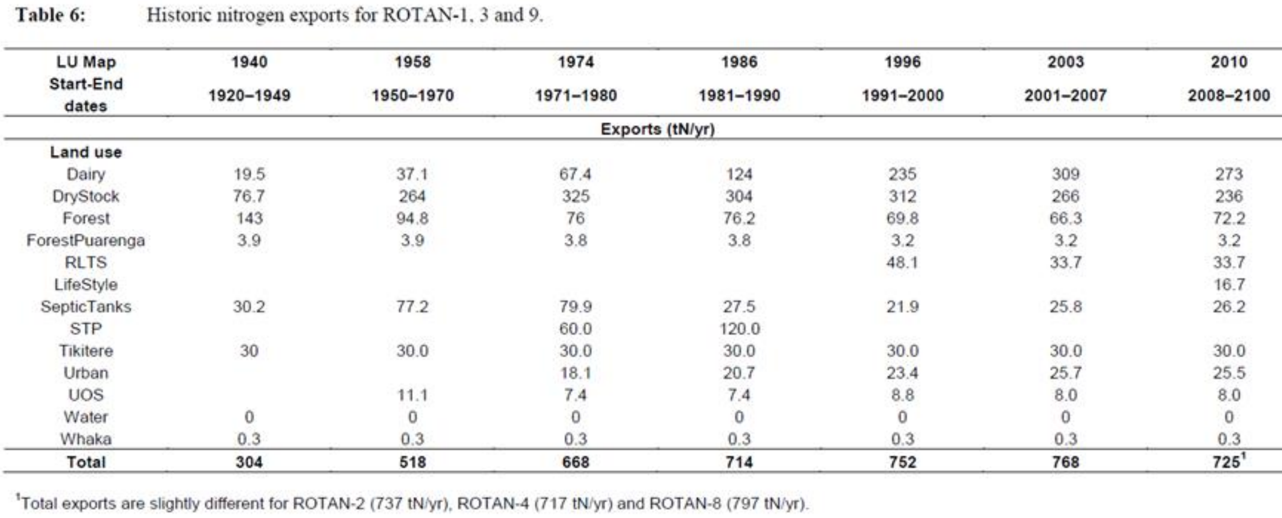


Table 6: Historic nitrogen exports for ROTAN-1, 3 and 9.

LU Map	1940	1958	1974	1986	1996	2003	2010
Start-End dates	**1920–1949**	**1950–1970**	**1971–1980**	**1981–1990**	**1991–2000**	**2001–2007**	**2008–2100**
				Exports (tN/yr)			
Land use							
Dairy	19.5	37.1	67.4	124	235	309	273
DryStock	76.7	264	325	304	312	266	236
Forest	143	94.8	76	76.2	69.8	66.3	72.2
ForestPuarenga	3.9	3.9	3.8	3.8	3.2	3.2	3.2
RLTS					48.1	33.7	33.7
LifeStyle							16.7
SepticTanks	30.2	77.2	79.9	27.5	21.9	25.8	26.2
STP			60.0	120.0			
Tikitere	30	30.0	30.0	30.0	30.0	30.0	30.0
Urban			18.1	20.7	23.4	25.7	25.5
UOS		11.1	7.4	7.4	8.8	8.0	8.0
Water	0	0	0	0	0	0	0
Whaka	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total	**304**	**518**	**668**	**714**	**752**	**768**	**725**[1]

[1] Total exports are slightly different for ROTAN-2 (737 tN/yr), ROTAN-4 (717 tN/yr) and ROTAN-8 (797 tN/yr).

ROTAN-Annual results

47. In 2015 the OVERSEER programme was updated to version 6.2.0. (For an explanation of this see the evidence of Alastair MacCormick). This resulted in estimates of nitrogen outputs for farming land use in the Lake Rotorua catchment increasing significantly compared to the OVERSEER 5.4.9 estimates used in ROTAN-2011. There was a desire to re-run the ROTAN catchment model using OVERSEER 6.2.0 losses, recalibrate the model to the observed nitrogen concentrations in streams and confirm the findings of the ROTAN-2011 study. This would then provide the opportunity to re-test scenarios of the impact of different land uses on predictions of effect on lake water quality.

48. The ROTAN-2011 model is a GIS-based catchment hydrology and water quality model. This GIS platform is no longer supported by the vendor and so the model is unable to be run in its original form. This is a common characteristic of modelling programmes as they are constantly being improved in the same way programmes like MS Word are upgraded. Consequently BOPRC contracted NIWA to re-develop the ROTAN model and run a range of scenarios to test the effect on nitrogen loads reaching the lake from existing land use and other land uses where nitrogen loss has been reduced. This model is called ROTAN-Annual. Dr Rutherford explains this model and outcomes in his evidence.

49. Development of the ROTAN models involves using an understanding of the processes within the environment, and attempting to represent those in the model. In this case ROTAN has been used to model nitrogen processes in the environment between the bottom of the land use root zone and water reaching the lake. The model is then calibrated using known inputs (nitrogen losses from farm land predicted using OVERSEER together with measured losses from the RLTS, geothermal sources, septic tanks and urban land, plus measured groundwater residence times). Calibration involves matching model predictions to measured stream concentrations from the 1970s to the present. Streams flowing to the lake carry water travelling via overland flow as well as a component of ground water that feeds back into the streams at springs. Some ground water also travels directly to the lake. The ROTAN models attempt to quantify the main flow pathways but it is important to note that estimates are subject to a level of error and uncertainty as is the case with all environmental modelling. In addition, the nitrogen input estimates rely on the OVERSEER model and are subject to any errors within the OVERSEER model or the input data supplied to OVERSEER, and may be subject to change if the model is reviewed (see MacCormick evidence).

50. The stream measurements used for model calibration are limited by their location and frequency of sampling. Monitoring points cannot be located at the exact point where nitrogen enters the lake and are typically upstream of the lake entry point for practical reasons. Water carrying nitrogen can also reach the lake via underground flows and estimating inputs from this source are reliant on knowledge of the ground water flows and nitrogen concentrations.

51. BOPRC also engaged GNS to confirm the extent of the surface and ground water catchment estimates (White et al., 2015). An estimate of the surface

catchment area and boundary is necessary to understand what areas of land will drain by overland flow to Lake Rotorua, and is referred to as the "surface catchment". The boundaries of the surface catchment do not always coincide with the boundaries of the ground water catchment. This is due to contrasts in the surface topography and the underlying geology. In parts of the Lake Rotorua catchment water may drain away from the lake if it flows over the surface, but water that infiltrates into the soil and becomes ground water may flow into the lake. Mapping the two catchment boundaries provides information for modelling and other work to inform the possible direction of flow.

52. Additional science work has identified other changes in data since 2011 that has been used to enhance the output from the new ROTAN model. These changes include refinement of the ground water boundary and age, additional stream flow and nitrogen monitoring to support calibration of the model and nitrogen losses below the plant root zone have been recalculated using OVERSEER v6.2.0.

53. ROTAN-Annual has predicted that the nitrogen load reaching the lake under current land use will most likely reach 750 t y^{-1} nitrogen with a 95% confidence limit of 670 to 840 t y^{-1} nitrogen. This aligns with the 725 t y^{-1} initially modelled by ROTAN-2011 (Rutherford 2011). (Dr Rutherford explains the statistical probability within that range in his evidence in detail, including that it more likely that the higher figure will be reached than the lower.)

54. Comparison of the level of nitrogen provided for in the 435 t y^{-1} target (required to reach the TLI of 4.2) and the level of losses recorded by ROTAN pastoral activity (725 t y^{-1} + 30 t y^{-1} from rainfall) has shown that a significant reduction in nitrogen is required.

55. The ROTAN-Annual model (Rutherford 2016) has also predicted the nitrogen load reaching the lake as a result of land use change in alignment with what would be required to meet the 435 t y^{-1} nitrogen target. The most likely load assuming nitrogen reductions from land use change is 420 t y^{-1} (plus 30 t y^{-1} in rainfall giving 450 t y^{-1} in total), with a confidence limit of 390–460 t y^{-1}. While the most likely load of 450 t y^{-1} exceeds the target of 435 t y^{-1} the difference is not statistically significant. It is of value to note that the ROTAN-Annual estimate can vary depending upon assumptions as to where the land use change will be located in the catchment (i.e., a lower or higher estimate may be attained by

changing the location of areas of specific land use). In spite of these complexities, which are typical of modelling natural and variable phenomena, input and output estimates have been made using the best available data. The ROTAN-2011 model was run using a range of input scenarios ranging from status quo (755 t y^{-1} reaching the lake) to scenarios where nitrogen leaching from land use is reduced by up to 350 t y^{-1}. The results indicate that the target lake load of 435 t y^{-1} will be achieved with a load reduction of between 300 and 350 t y^{-1}. Assuming a linear relationship for N reductions between 300 and 350 t y^{-1} lead Council to estimate that a 320 t y^{-1} reduction is required from the catchment to reach the 435 t y^{-1} target (Rutherford et al., 2011). However, his conclusion from the more recent ROTAN-Annual modelling is that it is more likely that the reductions required from PC10 and associated non-regulatory reductions may slightly undershoot the reduction target than overshoot it. Science reviews and modelling will continue to monitor progress towards the sustainable lake load target.

Conclusion re modelling

56. In spite of the uncertainty and expected opportunity for errors (due to complexity) in the ROTAN model input and output estimates, it is my opinion that Council has undertaken a thorough process of understanding the processes of water and nitrogen flow between the catchment and the lake. The conclusion is that PPC10 is based on the most recent science available to predict the loads to the Lake and the required level of reduction to maintain the state desired by the community (TLI of 4.2).

57. Therefore, the most recent science advice is that the operative RPS level of 435 t y^{-1} nitrogen remains the sustainable lake load target to maintain the TLI of 4.2. Although water quality targets have been set for the 12 Rotorua Lakes as TLI targets in the Regional Water and Land Plan, the recent National Policy Statement for Freshwater requires regional councils to manage water according to specific criteria. Through a process of prioritisation across the region the Rotorua Lakes have been identified as a Water Management Area (WMA). The WMA process is to be completed for Rotorua between 2020 and 2025 will need to consider management of other contaminants within Lake Rotorua such as phosphorus. However, the indications from the modelling is that this is not expected to change the limit of 435t nitrogen, although it may require additional

action to be taken within the catchment to reduce phosphorus if current actions and policies are not working.

Attenuation

58. In an ideal world attenuation would be measured as the sum of the nitrogen losses occurring between where it leaves the land surface and arrives at the lake. Unfortunately, this is very complicated to achieve due to the complexities of the biophysical environment of a lake catchment. OVERSEER estimates nitrogen losses from farm land occur just below the plant root zone. Water then travels down through the vadose or unsaturated zone and into ground water before emerging as seepage or spring flow into either streams or the lake. Nitrogen losses occur at different rates in the vadose zone and groundwater depending on how much organic matter and dissolved oxygen is present and the electrochemical status (redox) of the water. Nitrogen losses also occur in streams at different rates depending on their depth, velocity and the abundance of aquatic plants.

59. For any particular area in the catchment water and nitrogen travel times are complicated by specific geological conditions and local climate. So it is not possible to simply sample inputs and outputs like you may in a river situation where the water contents are homogeneously mixed and you can follow the flow path from beginning to finish and calculate a difference.

60. In contrast to the single river example, in a ground water situation there are diffuse nitrogen inputs across every part of the catchment that emerge after some time in the lake (or stream). The only practical way to establish the difference (attenuation) is to model the farms everywhere in the catchment (using say OVERSEER) to estimate outputs and compare with estimates of nitrogen reaching the lake. The best estimate of nitrogen reaching the lake is sampling of ground water and streams near the lake. The difference between these two estimates provides an estimate of attenuation. This estimate does not only account for process losses of nitrogen between the root zone and the lake but also has a component of error or uncertainty due to the methods used to estimate the inputs and outputs. As noted above, understanding attenuation (difference between input nitrogen and output nitrogen) helps to understand how much nitrogen reaches the lake from various land uses. Part of the difference between nitrogen estimated as being lost below the root zone and

what is received in the lake can be accounted for by temporary storage (also termed groundwater lags). When estimating attenuation, in addition to estimating the difference between input and output nitrogen the ROTAN model takes account of the time that nitrogen takes to reach the lake. At any time water, carrying nitrogen, reaching Lake Rotorua, comprises a mixture of water that started this journey anywhere between less than one year ago up to more than 100 years (dependant on the nature of the sub-catchment). This is a complex situation and estimating attenuation from input and output concentrations is complicated. The ROTAN model uses a simplified model of groundwater flow but is calibrated to match groundwater travel times published by GNS-Science based on measurements of tritium and other tracers.

61. Part of the difference between nitrogen estimated as being lost below the root zone and what is received in the lake is nitrogen loss through uptake by plants and microbes, including denitrification. De-nitrification requires contact with a carbon source and low oxygen conditions and can occur in the vadose zone, groundwaters, wetlands and stream sediments.

62. After accounting for groundwater lags, the ROTAN-2011 model found reasonably close alignment between what was modelled as leaving the farm root zones (using OVERSEER v5.4.2) and what was measured in streams (viz., attenuation was negligibly small). The exception was the Puarenga catchment where nitrogen levels reaching the stream were 30-40% lower than estimated to leave pasture and forest in the catchment. It was noted at the time that typically catchment-scale attenuation is c. 50% and negligible attenuation was unexpected (Rutherford et al. 2011).

63. One possible reason is that OVERSEER v5.4.2 under-estimated nitrogen losses from farmland in the Rotorua catchment. This suggestion is supported by the fact that OVERSEER v6.2.0 estimates significantly higher nitrogen losses than OVERSEER v5.4.2 for the same land use, farming practice, rainfall and soil types (Alastair MacCormick, Bay of Plenty Regional Council, pers. comm.).

64. However, Morgenstern et al., (2015) concluded that once groundwater in the Rotorua catchment has passed the root zone, it shows no further decrease in oxygen, indicating an absence of bioavailable electron donors (carbon source) to facilitate de-nitrification. Nitrate that leaches out of the root zone from land

use activities into the deeper part of the groundwater system, therefore, can be expected to travel with the ground water to the lake rather than be denitrified.

65. So for ROTAN-2011 where nitrogen attenuation was estimated to be negligibly small this aligned with the science advice on ground water conditions not being suitable to facilitate de-nitrification. There was, however, one specific catchment (the Puarenga) where a higher level of attenuation was necessary for calibration of the model. This was not unexpected as it is understood that the level of attenuation can be site specific and if conditions are not suitable then it simply will not occur.

66. Subsequently the application of OVERSEER v6.2.0 to the land use in the catchment revealed a major increase in the predicted nitrogen leaching (losses) for the catchment. Across the catchment this equated to about an 80% increase in nitrogen leaching. This does not result in more nitrogen reaching the lake, but it does bring into question what might be happening to nitrogen as it travels to the lake. It also brings into question the methods of estimating nitrogen inputs in the ROTAN-2011 model, and whether the conclusions reached by that study are robust. This question is addressed in the ROTAN-Annual report. Rutherford (2016) concludes that from the most recent work undertaken using ROTAN-Annual and OVERSEER v6.2.0 catchment-scale attenuation lies in the range of 32-50% (higher than previously estimated), and that this compares favourably with published estimates of catchment scale attenuation in other catchments both in New Zealand and overseas. Dr Rutherford provides an explanation as to how ROTAN-Annual deals with attenuation in his evidence.

Lake Restoration Interventions

67. The RLP has not only undertaken a significant science research effort and notified rules to reduce the amount of nitrogen going into the lake, but it has also focussed considerable effort on identifying and implementing lake restoration actions. The programme (and land owners for the Rerewhakaaitu catchment) has developed nine lake action plans over ten lakes in the programme. These action plans are developed with the community and are aimed at identifying actions that will protect and restore lake water quality in each lake. The action plans are required by the Regional Water and Land Plan pursuant to Method 41. In summary Method 41 requires action plans to be developed for each of the Rotorua lakes. The priority of development relates to

water quality, and the first lakes required to have action plans are the five that exceeded their TLI at the time the Regional Water and Land Plan was notified (Rotorua, Rotoiti, Ōkāreka, Rotoehu and Ōkaro). These five lakes were also the subject of Rule 11 that regulated nitrogen and phosphorus discharges from land use. For the remaining seven lakes the plan specifies the conditions when an action plan is required to be developed to address water quality. This relates to the water quality as measured by the TLI. The other lakes that have an action plan developed are: Ōkataina, Tikitapu, Rotomā, Tarawera, Rerewhakaaitu. Of the remaining two lakes that do not yet have action plans one is subject to a detailed research programme to identify the issues and the other has not triggered the plan requirement for an action plan.

68. For Lake Rotorua a proposed action plan was developed in combination with Rotoiti. The lakes are connected by the Ōhau Channel and so it was logical to integrate the two lakes into one plan due to the significant interactions between them.

69. The proposed action plan has since been superseded by the deed of the funding agreement with the Crown, the integrated framework for nutrient management and PPC 10. The deed funding agreement is a $72.2 M agreement with the Crown to support lake restoration actions on the 5 priority lakes (Rotorua, Rotoiti, Ōkāreka, Rotoehu and Ōkaro). BOPRC and RLC are required to match the $72.2 M for any interventions. While the proposed action plan contained specific actions for lake restoration and many have been implemented, a review of the science and logic around some of the actions has led to changes that are now reflected in the deed and the PPC 10.

70. Effectively the main changes that have occurred are that two major interventions, a diversion wall for the Hamurana Stream and the capping of lake sediments, have been removed or put on hold. The value of those two interventions is estimated at $16 M and $25 M respectively. The programme instead has been changed to bring a larger portion of the funding to achieving sustainable long term land use change to lower the level of nutrients into the Lake, rather than relying on external shorter term interventions. New land use funding is managed by the Incentives Board, a committee of council. The Incentives Board is tasked with purchasing 100t of N: see the evidence of Stephen Lamb and the s32 report.

71. The actions in the action plan comprise two types of approach: firstly actions that will create long term sustainable improvement in lake water quality, and then actions that can be implemented to make a more rapid improvement in water quality. The long term actions include the changes to land use required by PPC 10, incentivised land use change managed by the Incentives Board, and incentivised control of gorse weed that can leach nitrogen.

72. The actions that have been implemented are:

    (i) Investigation of sediment treatment,

    (ii) Investigate biomass harvesting,

    (iii) Upgrade the Rotorua Waste water treatment plant,

    (iv) Reticulation of septic tank communities in the catchment,

    (v) Alum dosing to treat phosphorus in streams,

    (vi) Benchmarking of rural properties as required by Rule 11,

    (vii) Research of innovative technologies, detainment bunds, algae harvesting, nano bubbles and aeration,

    (viii) Investigated Hamurana diversion,

    (ix) Investigated wetland development,

    (x) Ohau Diversion Wall

73. Two key interventions undertaken that merit further explanation here are the alum dosing programme and the Ohau diversion wall.

Ohau Diversion Wall

74. While the Ohau diversion wall has no impact on improving water quality in Lake Rotorua, it has been put in place to protect Lake Rotoiti from the poor water quality of Rotorua. Interestingly the land use around Lake Rotoiti is not considered high intensity and the water quality of Rotoiti is not thought to be negatively impacted as a result of the lake's own catchment land use. However, land use around Lake Rotorua is more intense and the legacy of nutrients from

land use and many years of sewage discharge have been flowing through the Ōhau Channel and contaminating Lake Rotoiti.

75. The wall has been implemented with the understanding that it is necessary to protect Rotoiti *until such time as the water quality of Rotorua meets its TLI target reliably*. Once Rotorua water quality is reliably improved, the wall can be removed and water can then resume it natural flow path into Rotoiti. The following satellite image shows graphically the effect of the wall on diverting the outflow of Lake Rotorua away from the main body of Rotoiti and down the Kaituna River. The wall was commissioned in 2008 and is expected to remain in place for more than 50 years. This time is required to enable the changes to land use around Lake Rotorua to take effect and the legacy nutrients in ground water and sediments to have improved. This is an important linkage where the community has been prepared to temporarily accept the impacts of constructing a wall to divert the nutrient rich water but on the understanding and condition that council is committed to the longer term sustainable improvement of land use around Lake Rotorua, so that the wall can be removed in the future.

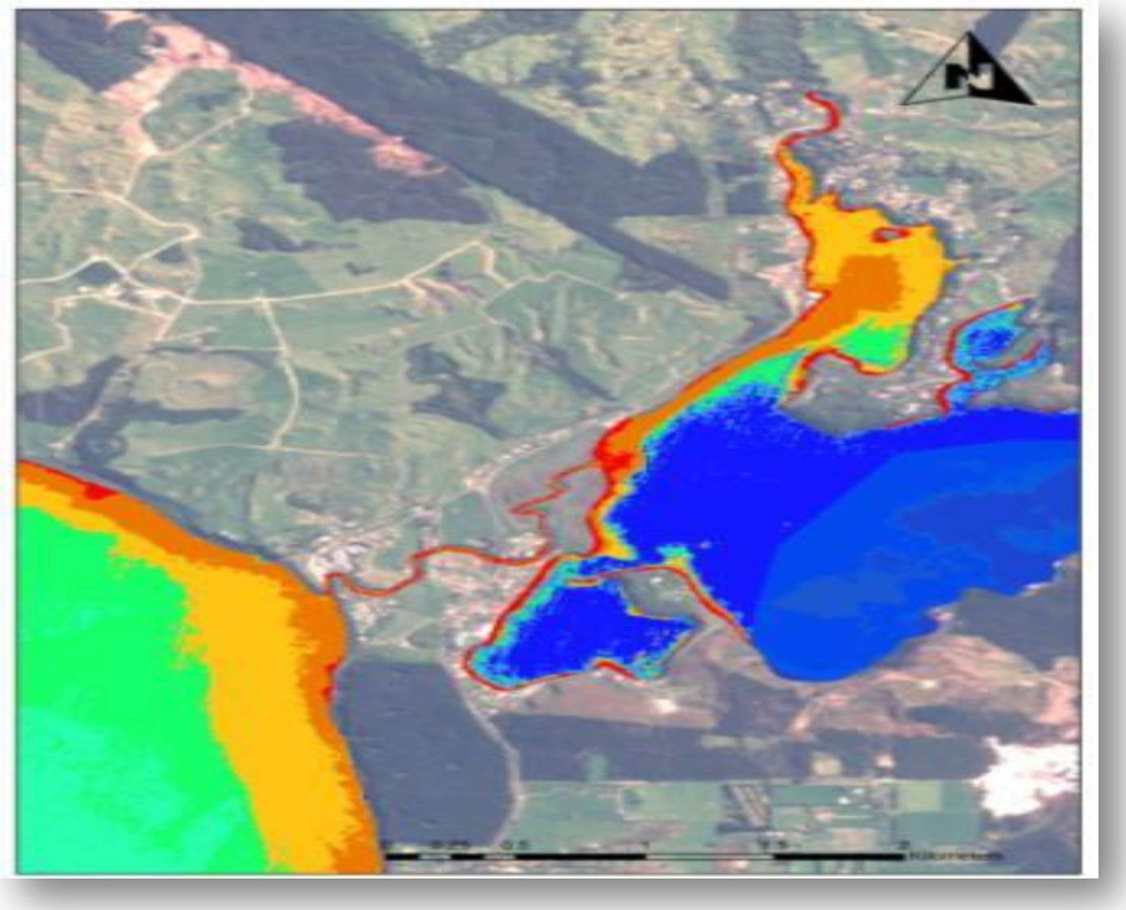


Figure 2. Satellite image enhanced for water temperature, Lakes Rotorua, Rotoehu and Ōhau Channel, showing the impact of the Ohau diversion wall (scale not accurate at this level).

Alum dosing

76. The alum dosing programme for Lake Rotorua has been an interesting and highly successful project. Alum is an abbreviation for aluminium sulphate, which is a commonly used flocculent, typically used in the treatment of drinking water. When used to treat drinking water alum is dosed and mixed with the incoming raw water from a reservoir or stream. It provides an electrical charge to particles in the water that makes them attract and flocculate. The particles can then be settled and be filtered out of the water. This water then is treated in any further stages before being reticulated to the community or other end use.

77. Alum has been used for more than 45 years in lakes for the treatment of phosphorus in lakes Cooke et al 2005. In contrast to the traditional water

treatment where the water is being clarified by removing particulate matter, in these applications the alum is being used as it has a capacity to combine aluminium with phosphate. Once combined the phosphate is effectively locked up and non-available to algae or plant growth. The only mechanism for phosphorus release is an extreme shift in water pH, and generally this can be controlled with the co-addition of other balancing chemicals if necessary. (Tempero 2015) notes the risk of acidification and hydrothermal eruption for Lake Rotorua use of alum.)

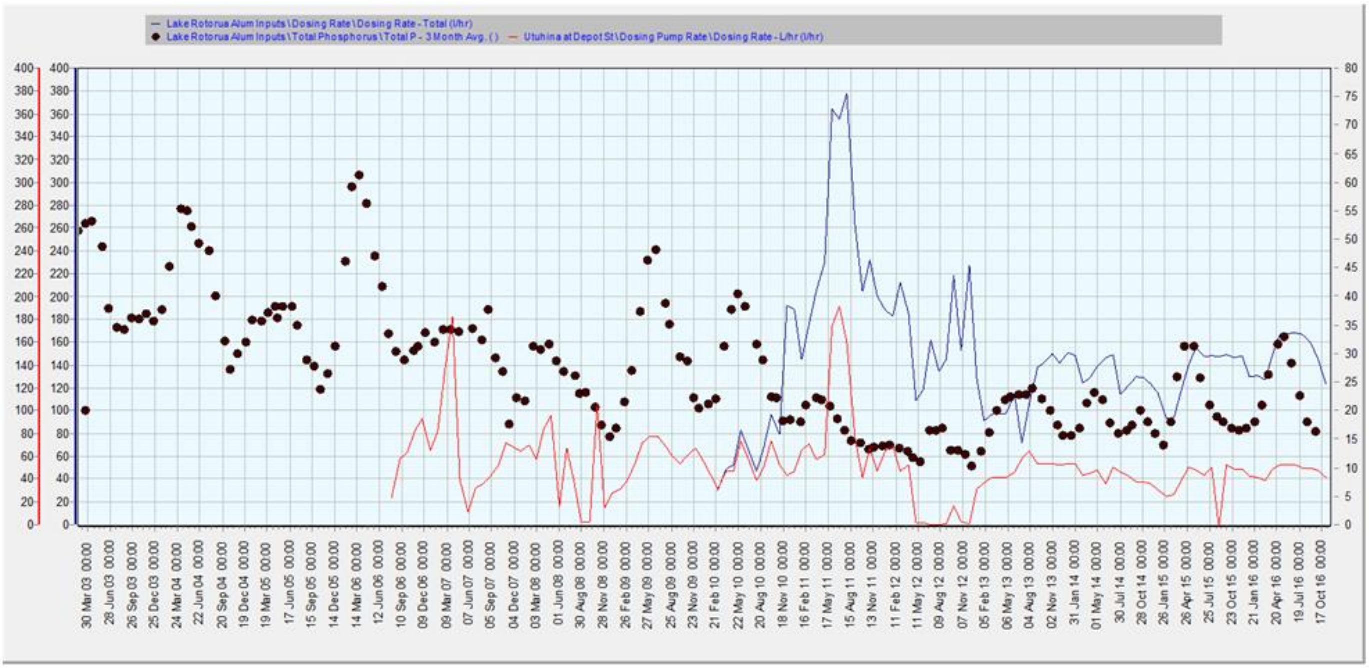
78. Aluminium dosing was first used in Sweden, but has since become a popular lake management tool where hundreds of lake treatments have taken place. In the USA where it has been used in numerous treatments the typical method of operation is to estimate the phosphorus supply in the lake sediments and the water column and apply a shock dose of alum in proportion to the phosphorus present. This involves application of a very large alum dose over the period of a day or a few days.

79. Another method of application is treating the source streams with alum to remove incoming phosphorus. This is detailed in Harper 2014, where this technique is applied to storm water flows in the State of Florida. In this application storm water is diverted to a treatment pond where alum is dosed. The treated water has time to settle and a portion of the alum phosphate product can settle while the water can be released to the environment.

80. In the case of Lake Rotorua the alum is dosed into two contributing streams; the Utuhina and the Puarenga Streams. Dosing on the Utuhina started in 2006 and 2010 in the Puarenga. It was initially thought that alum dosing should be applied to three streams in the catchment to intercept phosphorus coming from the catchment and remove about 6 t of phosphorus annually. The mechanism for managing the dosing rate was to be based on stream flow. When stream flow increased then the dosing rate would increase in response thereby getting alignment between the level of phosphorus coming down the streams and alum available to “lock” it up.

81. Through the process of public consultation to get the treatment plants in place there was some opposition to the location of a third dosing plant and only two have been commissioned. The following graph shows the in-lake concentration

of phosphorus, the rate of dosing of alum and when each treatment plant was commissioned.



- **Figure 3**. Lake Rotorua monthly phosphorus concentrations and alum dosing rates from the Utuhina and Puarenga dosing plants.
- Note: Black Dots = Lake Rotorua / Total phosphorus 3 month average mg/L,
  - Red Line = Utuhina Alum dosing rate L/hour,
  - Blue line = Lake Rotorua Alum inputs/Total Dosing rate L/hour

82. Alum has effectively provided a temporary method to reduce phosphorus to such an extent that it has become the limiting nutrient much of the time. In 2013 on the advice of the WQTAG we changed the dosing protocol from managing according to stream flows to managing depending upon the in-lake phosphorus concentration. Effectively we discovered we were dosing more alum than necessary and we were reducing in-lake phosphorus levels below the control points necessary to meet the 4.2 TLI.

83. Hamilton et al 2015 concluded that the alum dosing programme is addressing the soluble phosphorus loads coming down the two streams and that residual alum is either directly or indirectly altering the composition of the lake bottom sediments by either reducing the rates of oxygen consumption or capping

phosphorus releases from the lake sediments; effectively reducing the recycling of phosphorus from lake sediments.

84. The lake TLI since 1990 is shown in Figure 4 below. It is of value to identify the interventions that may have contributed to the changes in TLI over this period. In 1990 the diversion of the sewage from a lake discharge to the Whakarewarewa Forest made an immediate reduction in nitrogen and phosphorus reaching the lake of about 150 t and 30 t respectively (Pers comm, Alison Lowe RLC Scientist). This may have contributed to improvements in water quality over the early part of the 1990s. However, nitrogen breakthrough in the land treatment disposal system and an increasing load of nitrogen coming from the delayed signature of catchment land use resulted in nitrogen levels approaching similar levels 10 to 15 years after the land treatment system was commissioned. The land treatment system does however continue to provide a substantial reduction in sewage phosphorus reaching the lake.

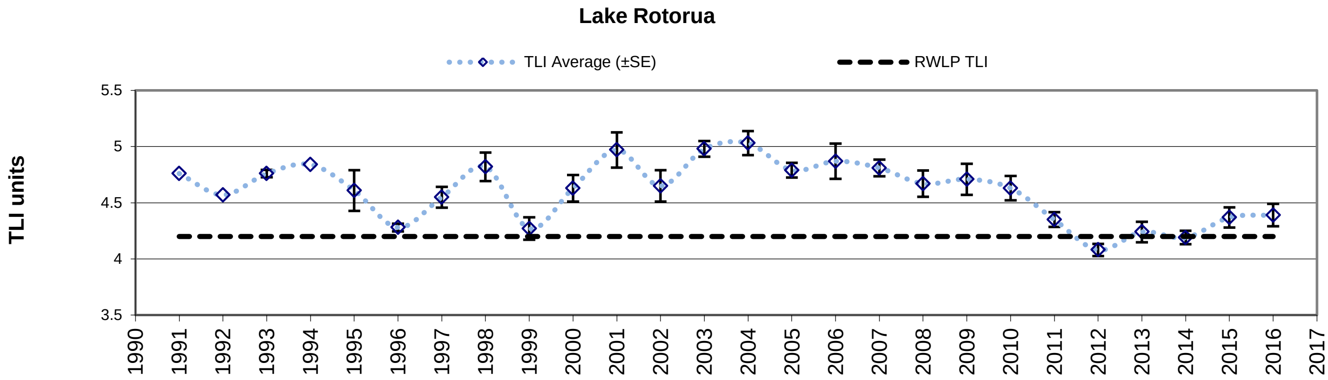


Figure 4, Historic Lake Rotorua TLI.

85. Alum dosing commenced in 2006 on the Utuhina Stream and 2010 on the Puarenga Stream. Figure 3 above shows the ongoing alum dose rate. The continuous blue line depicts the total hourly dose rate from both plants. In mid-2011 dose rates were increased substantially. This had a clear effect in that phosphorus levels dropped significantly over the period May 2010 to May 2013. During this period in-lake phosphorus levels were monitored and reached concentrations lower than the in-lake target for phosphorus to reach the lake

TLI. During this period the alum dose rate was controlled in proportion to stream flow rate (as described above in paragraph 83). In effect the dose rate was higher than required and that resulted in residual alum flowing to the lake and treating phosphorus in the lake water and sediments. At times the lake was becoming phosphorus limited and this had the impact of lowering the TLI quickly and resulted in the compliance with the TLI target over the period 2012 – 2014.

86. Hamilton et al 2015, comment on the effect of alum in the modelling study: *"We suggest that alum has either indirectly or directly altered the composition of the bottom sediments in a way that has resulted in lower rates of oxygen consumption and lower rates of phosphorus release. The direct mode of action may be due to changes in the chemical composition of bottom sediments due to alum floc deposition (with lower rates of oxygen consumption than the basal sediments) while the indirect mode of action may be linked to overall improvements in lake trophic status and reductions in the rate of organic matter deposition generally."*

87. Although a range of interventions have been trialled and implemented with differing success, these interventions can be broken into short term and long term interventions. Short term interventions generally are those that have a rapid and often short term impact such as the alum dosing, where the application of alum to a lake can be successful in removing phosphorus to an extent where its concentration in the lake limits algal growth. However, once the dosing is stopped then the level of phosphorus increases and algal blooms may resume after a few years to plague the lake.

88. Sewage reticulation of lakes side communities can have a rapid impact on reducing nitrogen and phosphorus from reaching the adjacent lake but the impact of the ongoing reticulation is seen as a more enduring solution than alum.

Conclusion

89. The key long term solution for many of our lakes is to ensure that the inputs of nitrogen and phosphorus are managed to a level that meets the sustainable nutrient load associated with meeting the lakes target TLI as specified in the Regional Water and Land Plan[9]. For Lake Rotorua these have been set at 435 t

---

[9] Refer evidence of David Hamilton.

nitrogen (through the Regional Policy Statement) and 33.7 to 38.7 t phosphorus. If these targets for nutrient input are not achieved then any short term intervention such as alum dosing or other options will need to be implemented on an ongoing basis. This is not viewed as a sustainable long term option.

90. Long term land use changes as required by PPC 10 rules, the RLP Incentives programme and Gorse control programme will take time to implement and for the effects of these changes in nutrient status to flow through to the lake. The short term interventions being used within the programme are designed to hasten lake recovery by complementing the land use change as well as providing some support for addressing legacy impacts, for example alum is having an impact on reducing the legacy impact of phosphorus releases from the lake sediments during summer stratification events. However, land use change is the most vital part of the sustainable long term recovery for Lake Rotorua, and this is supported by the science programme. Without land use change to meet the sustainable nutrient targets either the TLI will not be sustainably achieved or ongoing interventions such as alum dosing will need to continue in perpetuity to achieve the lake TLI target.

Andrew Bruere

16 January 2017

References:

Abell, J. M., D. P. Hamilton, and C. G. McBride, 2015. Comment on “Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand” by Morgenstern et al. Hydrol. Earth Syst. Sci. Discuss., 12, 10379 10388, 2015 www.hydrol-earth-syst-sci-discuss.net/12/10379/2015/doi:10.5194/hessd-12-10379-2015 © Author(s) 2015. CC Attribution 3.0

Cooke, G. D., E. B. Welch, S. A. Peterson, and S. A. Nichols 2005. Restoration and Management of Lakes and Reservoirs, third edition, CRC Press, Taylor and Francis Group.

Harper, H. 2014, Control of Watershed Loadings Using Chemical Treatment: In Lake Line, A Publication of the North American Lake Management Society, Fall 2013.

Lakes Rotorua and Rotoiti Action Plan (2007), Draft 5 BOPRC 2007.

Morgenstern, U., Gordon, D. 2006, Prediction of Future Nitrogen Loading to Lake Rotorua. GNS Science Consultancy Report 2006/10.

Morgenstern, U., C. J. Daughney, G. Leonard, D. Gordon, F. M. Donath, and R. Reeves, 2015. Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand. Hydrol. Earth Syst. Sci., 19, 803–822, 2015www.hydrol-earth-syst-sci.net/19/803/2015/doi:10.5194/hess-19-803-2015

Morgenstern U, Reeves, R. Daughney C. Cameron S. 2004. Groundwater age, Time Trends in Water Chemistry, and Future Nutrient Load in the Lakes Rotorua and Okareka Area GNS Client report 2004/17.

Mueller H, Hamilton DP, Doole GJ. 2015. Response lags and environmental dynamics of restoration efforts for Lake Rotorua, New Zealand. Environmental Research Letters 10 (7): 074003. DOI: 10.1088/1748-9326/10/7/074003

Rutherford, J.C., Pridmore, R.D. and White, E. (1989). "Management of Phosphorus and Nitrogen Inputs to Lake Rotorua, New Zealand." *J. Water Resour. Plann. Manage.*, 10.1061/(ASCE)0733-9496(1989)115:4(431), 431-439.

Rutherford, J.C., 2008. Nutrient load targets for Lake Rotorua a revisit, NIWA Client Report: HAM2008-080, May 2008

Rutherford, J.C., Palliser, C.C. and S. Wadhwa, 2011. Prediction of nitrogen loads to lake Rotorua using the ROTAN model. Prepared for BOPRC, April 2011.

Hamilton, D.P., C.G. McBride and H.F.E. Jones, 2015. Assessing the effects of alum dosing of two inflows to Lake Rotorua against external nutrient load reductions: Model simulations for 2001-2012. Environmental Research Institute Report 49, University of Waikato, Hamilton, 56 pp.

Tempero, G.W. 2015. Ecotoxicological Review of Alum Applications to the Rotorua Lakes. ERI Report No. 52. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, Faculty of Science and Engineering, University of Waikato, Hamilton, New Zealand. 37 pp

Tempero G.W., McBride C.G., Abell J., and Hamilton D.P. 2015. Anthropogenic phosphorus loads to Lake Rotorua. Client report prepared for Bay of Plenty Regional Council. *Environmental Research Institute Report No. 66*. The University of Waikato, Hamilton. 31 pp.

Water Quality TAG, June 2014. A statement of the significance of phosphorus and nitrogen in the management of the Rotorua lakes.

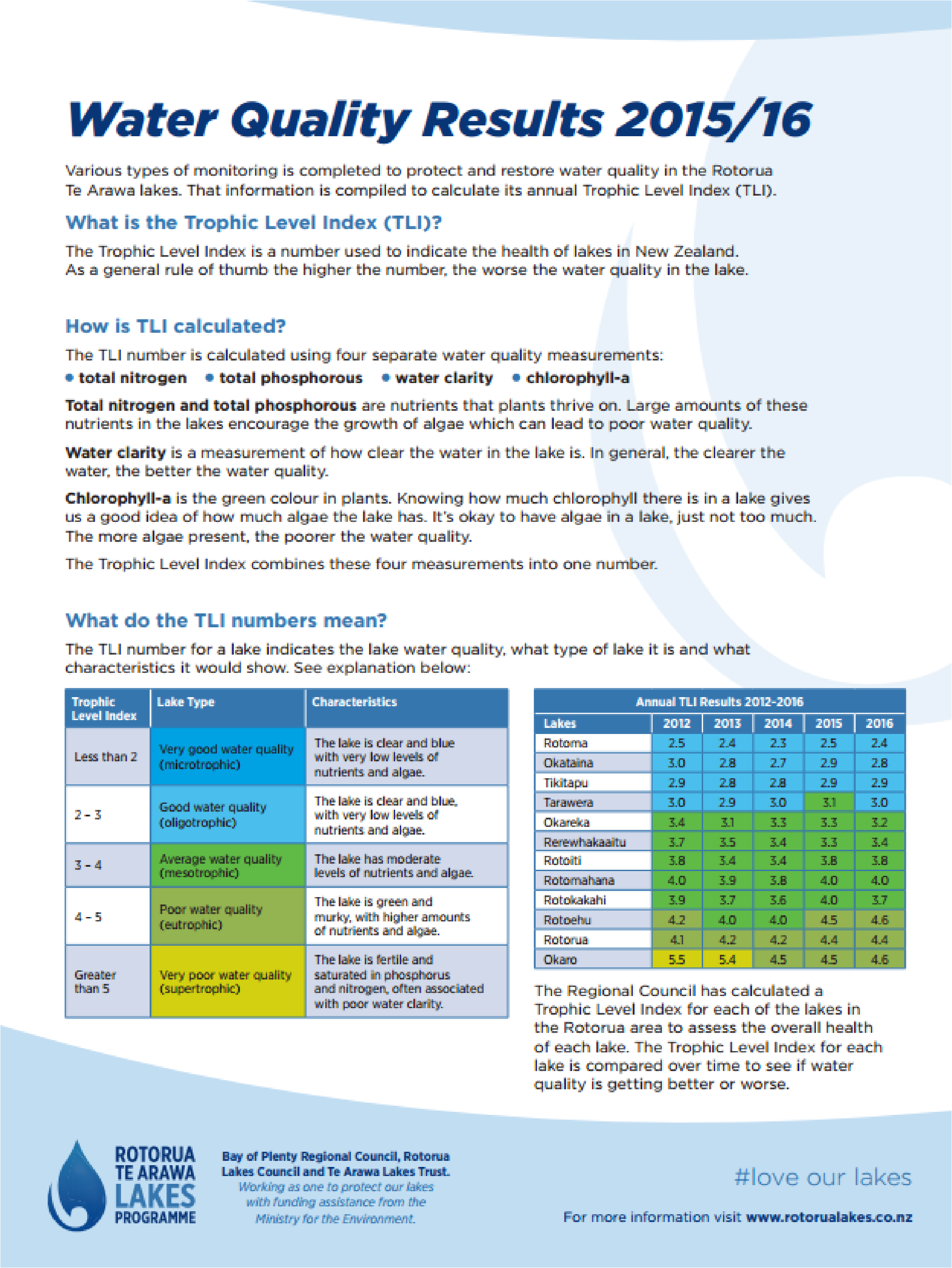
Water Quality TAG Statement September 2015.

White, P.A, Zemansky, G., Hong, T., Kilgour, G., Wall, M., 2007. Lake Rotorua groundwater and Lake Rotorua nutrients – phase 3 science programme technical report. GNS Client report 2007/220 to Environment Bay of Plenty. 402p.

White P., A Lovett, C Tschritter and M. Cusi 2014. Lake Rotorua catchment boundary relevalnt to Bay of Plenty Regional Council's water and land management policies. GNS Science Consultancy Report 2014/111, August 2014.

Appendices

Appendix 1. Rotorua Lakes Fact Sheet 3 Trophic Level Index.



Water Quality Results 2015/16

Various types of monitoring is completed to protect and restore water quality in the Rotorua Te Arawa lakes. That information is compiled to calculate its annual Trophic Level Index (TLI).

What is the Trophic Level Index (TLI)?

The Trophic Level Index is a number used to indicate the health of lakes in New Zealand. As a general rule of thumb the higher the number, the worse the water quality in the lake.

How is TLI calculated?

The TLI number is calculated using four separate water quality measurements:

- **total nitrogen**
- **total phosphorous**
- **water clarity**
- **chlorophyll-a**

Total nitrogen and total phosphorous are nutrients that plants thrive on. Large amounts of these nutrients in the lakes encourage the growth of algae which can lead to poor water quality.

Water clarity is a measurement of how clear the water in the lake is. In general, the clearer the water, the better the water quality.

Chlorophyll-a is the green colour in plants. Knowing how much chlorophyll there is in a lake gives us a good idea of how much algae the lake has. It's okay to have algae in a lake, just not too much. The more algae present, the poorer the water quality.

The Trophic Level Index combines these four measurements into one number.

What do the TLI numbers mean?

The TLI number for a lake indicates the lake water quality, what type of lake it is and what characteristics it would show. See explanation below:

Trophic Level Index	Lake Type	Characteristics
Less than 2	Very good water quality (microtrophic)	The lake is clear and blue with very low levels of nutrients and algae.
2 - 3	Good water quality (oligotrophic)	The lake is clear and blue, with very low levels of nutrients and algae.
3 - 4	Average water quality (mesotrophic)	The lake has moderate levels of nutrients and algae.
4 - 5	Poor water quality (eutrophic)	The lake is green and murky, with higher amounts of nutrients and algae.
Greater than 5	Very poor water quality (supertrophic)	The lake is fertile and saturated in phosphorus and nitrogen, often associated with poor water clarity.

Annual TLI Results 2012-2016

Lakes	2012	2013	2014	2015	2016
Rotoma	2.5	2.4	2.3	2.5	2.4
Okataina	3.0	2.8	2.7	2.9	2.8
Tikitapu	2.9	2.8	2.8	2.9	2.9
Tarawera	3.0	2.9	3.0	3.1	3.0
Okareka	3.4	3.1	3.3	3.3	3.2
Rerewhakaaitu	3.7	3.5	3.4	3.3	3.4
Rotoiti	3.8	3.4	3.4	3.8	3.8
Rotomahana	4.0	3.9	3.8	4.0	4.0
Rotokakahi	3.9	3.7	3.6	4.0	3.7
Rotoehu	4.2	4.0	4.0	4.5	4.6
Rotorua	4.1	4.2	4.2	4.4	4.4
Okaro	5.5	5.4	4.5	4.5	4.6

The Regional Council has calculated a Trophic Level Index for each of the lakes in the Rotorua area to assess the overall health of each lake. The Trophic Level Index for each lake is compared over time to see if water quality is getting better or worse.

ROTORUA
TE ARAWA
LAKES
PROGRAMME

Bay of Plenty Regional Council, Rotorua Lakes Council and Te Arawa Lakes Trust.
Working as one to protect our lakes with funding assistance from the Ministry for the Environment.

#love our lakes

For more information visit **www.rotorualakes.co.nz**

The Science

Water Quality Trends and TLI

Lake Rotoehu ●
Target = 3.9 | 15/16 Result = 4.6

Lake Rotoiti ●
Target = 3.5 | 15/16 Result = 3.8

Lake Rotomā ●
Target = 2.3 | 15/16 Result = 2.4

Lake Rotorua ●
Target = 4.2 | 15/16 Result = 4.4

Lake Ōkataina ●
Target = 2.6 | 15/16 Result = 2.8

Lake Ōkāreka ●
Target = 3.0 | 15/16 Result = 3.2

Lake Tikitapu ●
Target = 2.7 | 15/16 Result = 2.9

Lake Rotokakahi ●
Target = 3.1 | 15/16 Result = 3.7

Lake Tarawera ●
Target = 2.6 | 15/16 Result = 3.0

Lake Rotomahana ●
Target = 3.9 | 15/16 Result = 4.0

Lake Ōkaro ●
Target = 5.0 | 15/16 Result = 4.6

Lake Rerewhakaaitu ●
Target = 3.6 | 15/16 Result = 3.4

● Improving ● Stable ● Declining ● To be investigated

ROTORUA TE ARAWA LAKES PROGRAMME

Bay of Plenty Regional Council, Rotorua Lakes Council and Te Arawa Lakes Trust.
Working as one to protect our lakes with funding assistance from the Ministry for the Environment.

#love our lakes

For more information visit **www.rotorualakes.co.nz**

Appendix 2: Water Quality Technical Advisory Group Statement.

A Statement of the Significance of Phosphorus and Nitrogen in the Management of the Rotorua lakes

Rotorua Lakes: Water Quality Technical Advisory Group

June 2014

1 This statement is the collective thoughts of a Technical Advisory Group (TAG) established by Bay of Plenty Regional Council, Te Arawa Lakes Trust and Rotorua District Council to assess technical aspects of lake research. It aims to present a scientific view of the contribution of phosphorus and nitrogen to the current condition of the Rotorua lakes.

2 Eutrophication of some Rotorua lakes first became evident in the early 1960s due to increased phytoplankton caused principally by greater loads of phosphorus and nitrogen. At the same time introductions of invasive macrophytes (oxygen weeds) began causing access and aesthetic issues.

3 Phosphorus and nitrogen enrichment is not generally considered to cause excessive growth of introduced aquatic macrophytes. Indeed, lake management aimed at reducing phytoplankton growth and improving water clarity may cause macrophyte beds to become more vigorous and expand in area, which may necessitate control actions such as weed harvesting.

4 The Bay of Plenty Regional Council's Regional Water and Land Plan is aimed at restoring lake water quality to that which prevailed during an earlier period prior to widespread public issues with phytoplankton blooms. The consequence of not meeting this goal is likely to be:

(i) Increased frequency of occurrence of nuisance algal blooms.
(ii) Water clarity decline.
(iii) Periods of de-oxygenation of the bottom waters of lakes and associated increased lake-sediment releases of phosphorus and nitrogen that exacerbate declining water quality.

5 Nutrient inputs to lakes come from a variety of different external (viz. from the catchment) and internal (viz. nutrient releases from the lake bed) sources. Natural geothermal springs and seeps represent highly concentrated sources of nutrients

in some lakes but loads are mostly relatively small. Wild fowl, pollen and nutrient loads in rainwater similarly represent relatively minor loads to the lakes.

6 Increases in nutrient loads to the lakes have been associated with land use change over many decades, from forests to more intensive forms of agriculture such as dairying, as well as intensification within individual agricultural industries. Nutrient inputs from sewage have also contributed to increases in nutrient loads as human populations around the lakes have expanded, and prior to changes in treatment and disposal of wastewater (e.g. Lake Rotorua in 1991) and recent sewage reticulation of some lakes (e.g. Tikitapu, Okareka and parts of Rotoiti).

7 Internal nutrient loads can contribute substantially to total nutrient loads to some lakes, particularly in those that have been affected by eutrophication (e.g. Rotorua, Rotoehu, Okaro and Rotoiti), while wind resuspension of nutrients and sediment may also affect shallower lakes (e.g. Rotorua).

8 A combination of catchment management and in-lake actions has been used under the Water and Soil Act (1967) and RMA (1991) to address excess nutrient loads that lead to lake eutrophication. Examples include land use change, improved management practices in forestry and agricultural industries, inflow diversion in Lake Rotoiti, dosing alum to two inflows to Lake Rotorua, in-lake chemical treatments in lakes Okaro, Okareka and Okawa Bay of Lake Rotoiti, destratification, wetland construction or enhancement, as well as sewage reticulation and treatment.

9 Evidence from recent monitoring data indicates that the alum dosing of two inflows to Lake Rotorua (Utuhina commencing 2006 and Puarenga commencing 2010) is highly effective in reducing phosphorus. An improvement has also occurred in nitrogen concentrations in the lake water, resulting in improved water clarity and reduced occurrence of algal blooms. Similarly, the Ohau Channel diversion wall completed in 2008 has been effective in reducing nutrient loads into Lake Rotoiti and improving water quality.

10 Land disposal of treated wastewater from the Rotorua Treatment Plant commencing in 1991 was initially highly effective in reducing its nutrient load on Lake Rotorua but since 1991 there has been a net increase in the total nutrient load to Lake Rotorua due to increases in diffuse pollution (particularly nitrate) from

agriculture. Furthermore, despite improved treatment (viz. higher relative rates of nutrient removal) by the Rotorua Treatment Plant, it may be difficult to further reduce nutrient loads because the land disposal site has become progressively less effective in removing nitrogen and wastewater inputs to the treatment plant have progressively increased with sewage reticulation of lakeside communities.

11 Ultimately, reducing sewage nutrient inputs to the lowest loads practicable and aligning catchment land use (urban and rural) to achieve sustainable lake nutrient inputs are the only sustainable ways to achieve the lake water quality goals set in the Water and Land Plan. These actions will negate reliance on short term interventions. Reductions in nutrient loads through sewage reticulation and better treatment provide reliable long-term gains that can have almost immediate benefits where communities are located on leaky soils close to the lakes. In some lakes sewage reticulation can meet the nutrient reduction targets needed and meet the goals of the Water and Land Plan.

12 Bioassays have been carried out intermittently in a number of lakes from the 1970s to present. Phytoplankton responses to these small-scale additions of nitrogen and phosphorus have varied amongst lakes and in some cases within individual lakes.

13 While implementing alum dosing (via two streams) for Lake Rotorua has been successful in getting the lake to its target TLI, there are high natural P loads from the lake catchment which could make achieving long-term P limitation without alum dosing unlikely. Bioassay work indicates that a dual nutrient reduction approach is more likely to achieve the long term TLI in the absence of alum dosing by maximising periods of nutrient limitation of phytoplankton growth. A focus only on nitrogen reductions is not advisable as it may increase the probability that the phytoplankton population becomes dominated by undesirable cyanobacteria. The primary objective should be to reduce concentrations of nitrogen and phosphorus in the lake water to the point where they limit the productivity of phytoplankton to meet the Water & Land Plan objectives.

14 The ongoing programme is one of adaptive management based on the outcomes of research, implementation of actions and monitoring, both within the catchment and in some cases within lakes. Emphasis on adaptive management is important in light of the potential for both unforeseen (e.g. weather 'bombs') and foreseen

events (e.g. future climate change) to affect lake water quality responses to nutrient loads.