Setting the Water Quality and Nutrient Targets for Lake Rotorua:

Rationale and Historical Background

Stephen Lamb and Rebecca Burton – Bay of Plenty Regional Council

Introduction

Lake Rotorua has experienced water quality problems from the 1970s onwards, and in response to public concern and consultations, a water quality target has been set, along with the nutrient loadings to the lake to achieve that target. This introductory module describes the process that led to the current water quality target for Lake Rotorua and its associated nutrient loadings for nitrogen and phosphorus, as defined in the Bay of Plenty Regional Council Regional Water and Land Plan (now called the Regional Natural Resources Plan).

An important starting point for the discussions about nutrient loadings was the paper from 1989, "Management of Phosphorus and Nitrogen Inputs to Lake Rotorua, NZ" [1]. This work estimated target lake loads associated with water quality in the 1960s, prior to reticulated sewage discharge, to be 435 tonnes nitrogen per year (tN/yr) and 37 tonnes phosphorus per year (tP/yr).

A specific target for the water quality of Lake Rotorua based on a trophic level index (TLI, see Box) was proposed as a regulatory limit under the Resource Management Act in 2002. The TLI was first developed for Lake Rotorua in 2001[2]. Since 1989 several studies have reinforced the relationship between the TLI and sustainable nutrient load, and modelling work that has been undertaken over time has continued to support a target value of 435 tN/yr target. Specific modelling undertaken by Hamilton et al 2015 predicts a TLI equivalent to nearly reaching the target of 4.2 could be achieved by achieving the 435 tonnes of nitrogen and an associated reduction in phosphorus. ROTAN October 2016 back-modelling also indicates that the load reaching Lake Rotorua in the 1960s was close to the target of 435 tN/yr.

Trophic Level Index (TLI)
Since the early 2000s the use of TLIs has been considered 'best practice' as an indicator of lake water quality. The TLI and Lake Submerged Plant Indicators (LakeSPI) remain as practical and recognised indicators.

The Regional Natural Resources Plan describes the TLI system as a means of measuring lake water quality based on the amount of total nitrogen, total phosphorus and chlorophyll A (algae) present in the lake, and the clarity of the lake. Chlorophyll A and clarity (measured as secchi depth) are a consequence of the amount of total nitrogen and total phosphorus in a lake. The resulting numeric value is the TLI for an individual lake. The TLI methodology can be used to establish an average TLI value for a lake for the period over which water quality data has been collected, or determine the TLI trend during a specified period of time (i.e. the rate of change in the trophic level of a lake).

[1] Rutherford, J.C.; Pridmore, R.D.; White, E., 1989. Management of phosphorus and nitrogen inputs to Lake Rotorua, New Zealand, Journal of Water Resources Planning & Management 115 (4): 431-439.
[2] Lakes Consultancy May 2001 – Development of trophic level index values for all twelve Rotorua District lakes.

The TLI index is an approach that was developed internationally, but with fine-tuning to make it more appropriate to New Zealand conditions (Burns, Rutherford & Clayton, 1999[3]). For a detailed explanation of the TLI methodology refer to 'Protocol for Monitoring New Zealand Lakes and Reservoirs' (Burns, 2000)[4].

The Trophic Level Indices (TLIs) for the Rotorua Lakes were developed through public consultation exercises and were based on scientific evidence. TLIs represent community objectives for the water quality of the relevant lakes.

Plan Change 10 was based on there being no evidence from the science or modelling work to indicate that the 435 tN/yr target was inappropriate and modelling indicating that the TLI will be close to 4.2 if the nitrogen reductions (to the sustainable lake load) along with associated phosphorus reductions are achieved.

For Lake Rotorua, phosphorus has been approached differently to the regulatory pathway for nitrogen. This is due to the less robust understanding historically of the contaminant loads and the different pathways by which phosphorus moves to the lake. Specifically at the time that the Regional Policy Statement was proposed in 2010 there was a much more limited understanding of phosphorus loads reaching the lake and this could not support a regulatory target being introduced at that time.

Lake Rotorua's TLI

The water quality in Lake Rotorua had historically experienced a steady deterioration since the 1960s. This has been associated with land use change (particularly pastoral and intensification of pastoral) and an increased decline from 1976 associated with increased city sewage treatment discharge. The decline caused widespread public concern. Studies and communities suggested restoring lake conditions to the level prior to sewage treatment discharge, which is similar to the level in the 1960s[5]. The target trophic level that corresponded to the sustainable nitrogen load was confirmed in a paper *Lake Rotorua Nutrient Load Targets*[6] and further confirmed in a subsequent paper *Nutrient load targets for Lake Rotorua - a revisit*[7].

Target nitrogen and phosphorus levels depend on the lake water quality selected. For Lake Rotorua, public support was for water quality to approximate what prevailed in the 1960s. In particular this related to the water quality prior to reticulated sewage discharge into the lake. FORLD report No.14 references the findings of the Lake Rotorua Scientific Coordinating Committee's 1978 report: *"If the*

[3] Burns, Rutherford & Clayton, 1999 "A monitoring and classification system for New Zealand lakes and reservoirs", Journal of Lakes and Reservoir Management 15.
[4] Burns, 2000 "Protocol for Monitoring New Zealand Lakes and Reservoirs", Ministry for the Environment.
[5] When the Rotorua city sewage discharge was moved to land disposal, water quality expectations for the lake were stated in documents associated with the consent. That target was for Lake Rotorua's water quality to be similar to its 1960s' water quality.
[6] Rutherford, K., 2003, "Lake Rotorua Nutrient Load Targets", NIWA Client Report: HAM2003-155, October 2003.
[7] Rutherford, K., 2008, "Nutrient load targets for Lake Rotorua - a revisit", NIWA Client Report HAM2008-080, May 2008.

sewage effluent from the Rotorua Treatment Plant is diverted from Lake Rotorua, what improvements will be made to the quality of the water in Lake Rotorua, and how may these improvements be best measured by the Commission or recognised by the public? The committee concluded "that the effect of diverting sewage effluent from Lake Rotorua, provided it is accompanied by the appropriate catchment control measures, would tend to maintain the condition of the lake water quality as it was in the late 1960s and early 1970s. This effect would maintain biological activity where diatoms and green algae are likely to be the dominant algal (sic) and blue green algae are less likely to proliferate. Any changes could be slow and hard to recognise by the public in the short term." Numerical indicators of water quality were sparse or absent prior to the 1970s so a number of approaches have been used to derive numerical values for this time.

For a number of the Rotorua lakes 1994 was used as the basis for the TLI[8]. This concept was partly based on a 1993 report[9] identifying key sources of nutrients input to 14 lakes in Rotorua. In three cases (Lake Rotoiti, Rerewhakaaitu and Tarawera) these were then adjusted to recognise specific circumstances (such as the influence of Lake Rotorua on Lake Rotoiti). There are three lakes which were not set at a 1994 TLI level: Lake Ōkaro, Rotorua and Rotoehu.

The TLI of 4.2 for Lake Rotorua was consulted on through the period 2000 to 2003. This included a consultation period in late 2001 on a draft Regional Water and Land Plan (containing the TLI for Lake Rotorua) and the formal consultation process on the Proposed Regional Water and Land Plan – notified in February 2002. Following this RMA Schedule 1 submissions process, the notified Plan was subject to the Resource Management Act Hearings and Environment Court appeal processes. No changes were made to Objective 11 and Policy 21(a) that reference the TLI of 4.2 through the appeal process[10].

Lake Rotorua's 435 TN/yr Sustainable Lake Load

As noted above, the 1989 "Management of Phosphorus and Nitrogen Inputs to Lake Rotorua, NZ" paper is an important starting point to understand the origin of the 435 Tonnes Nitrogen per year (TN/yr) sustainable lake load. Since this point the sustainable lake load and its relationship to the TLI of 4.2 have been tested a number of times and they remain in place. A range of scientific studies have also been conducted that contribute to the understanding of the sustainable load/TLI relationship:

- In 2003 a study evaluated the sources of nutrients from land use in comparison to 1989 (Rutherford, K., 2003[11]). This was confirmed in a subsequent paper - Rutherford, K., 2008[12].

[8] Burns, N., 2001, "Trophic Level Index Baselines and Trends for 12 Rotorua District Lakes, 1990 to 2000", Lakes Consulting, prepared for Bay of Plenty Regional Council.
[9] Sigma Consultants, NIWA, Bioresearches Ltd and NZFRI, June 1993, "Report on Rural land Use Practices in the Rotorua District". Report prepared for Rotorua District Council.
[10] Amendments were made to other parts of the RWLP policy suite – such as to the "nutrient capping" Rules 11 to 11F which were made operative in November 2005.
[11] Rutherford, K., 2003, "Lake Rotorua Nutrient Load Targets", NIWA Client Report: HAM2003-155, October 2003. - pp. 58.
[12] Rutherford, K., 2008, "Nutrient load targets for Lake Rotorua - a revisit", NIWA Client Report HAM2008-080, May 2008.

- Independent modelling undertaken by the University of Waikato was used to ascertain what TLI would result from a range of nutrient interventions, including achieving the 435 t N target. A TLI close to 4.2 was modelled to be reached at that load (Hamilton et al, 2012[13]).
- Back calculation of the 1960s nutrient loads modelled in ROTAN 2011 and 2016 for the 1960s also supports that the annual nitrogen load over that period was in the region of 435 tN.

During 2009 to 2011 NIWA calibrated and tested the ROTAN model in the Lake Rotorua catchment (using OVERSEER® version 5.4.2) and calculated the reductions in nitrogen loss to meet the target nitrogen lake load through scenario testing – via back casting[14]. Recalibration of ROTAN using OVERSEER® version 6.2.0, together with revised groundwater boundaries and stream monitoring data was undertaken in 2016[15]. This was to test the steady state[16] and the implementation effects of PPC10. The study confirmed that the results were not statistically different from those observed in the 2011 study for the steady state and the impacts of PC10 in reaching the sustainable lake load (Statement of Evidence of Dr Rutherford PPC10 Hearing 2016).

Although some research is suggesting that the 435 tN/yr value may itself need to be refined (potentially downward[17]) this is not a current consideration for Council.

The TLI and 435 TN in RMA planning processes

The TLIs in Objective 11 in the Operative Regional Water and Land Plan represent the targets agreed through the Resource Management Act plan preparation process between 2001 and 2008 – including the formal public submission process on the Draft Regional Water and Land Plan during 2000/01 and on the Proposed Regional Water and Land Plan during 2002/2003.

In 2001, the Council released an integrated Regional Water and Land Plan as a draft which included a Natural State (lake) water quality class, including water temperature and the Trophic Level Index that applied to the Rotorua lakes. The target Trophic Level Indices (TLIs) were recommended as an Objective in the draft Proposed Regional Water and Land Plan with Lake Rotorua's set at 4.2.

After a consultation period in late 2001, the Council then notified a Proposed Regional Water and Land Plan in February 2002. The TLI levels for the 12 lakes were set out in the Proposed Plan as Objective 11:

[13] Hamilton D. et al, 2012, "Predicting the effects of nutrient loads, management regimes and climate change on water quality of Lake Rotorua". ERI report: 005. Prepared for Bay of Plenty Regional Council.
[14] Rutherford, J.C.; Palliser, C.C.; Wadhwa, S., 2011, "Prediction of nitrogen loads to Lake Rotorua using the ROTAN model", NIWA Client Report HAM2010-134. Hamilton.
[15] Rutherford, J.C., MacCormick, A., 2016, "Predicting nitrogen inputs to Lake Rotorua using ROTAN-Annual", NIWA Consultancy Report 2016102HN. Project BOP16201. October 2016.
[16] The Lake Rotorua steady state nitrogen load is interpreted as the eventual equilibrium nitrogen load to the lake with current land uses and nitrogen loss rates maintained in perpetuity.
[17] Rutherford, J.C., MacCormick, A., 2016, (pages 7 and 40) and Hamilton et al. (2013). "Effects of Climate Change on New Zealand Lakes", (page 359).

The water quality in the Rotorua lakes is maintained or improved to meet the following Trophic Level Indices:

(j) Lake Rotorua – 4.2

The Council consulted with the public on the notified Proposed Plan following the process set out in the Resource Management Act.

The Proposed Regional Water and Land Plan based the Objective 11 TLIs for most lakes on the 1994 water quality monitoring levels. This was because for a number of these lakes monitoring had shown a step change in water quality during the early 1990s due to the effect of catchment land use. However the decline in water quality for Lake Rotorua had taken place earlier than the 1990s, as already explained earlier in this report.

For Lake Rotorua the explanation provided in Objective 11 of the Regional Water and Land Plan is as follows:

Lake TLI in Objective 11	**Explanation in the Regional Water and Land Plan**
Lake Rotorua 4.2	Level set in relation to the removal of sewage from the lake. When the Rotorua city sewage discharge was moved to land disposal, water quality expectations for the lake were stated in documents associated with the consent[18]

Over time, the science and modelling has refined some of the component parts, however the core elements remain unchanged. For example, at the time of the Proposed Regional Policy Statement (RPS) the steady state for the lake was modelled at 746 tN[19] (RPS Policy WL 6B). This aligns closely with the ROTAN 2011 and 2016 results where the modelled bands straddle 755 tN. The 435 tN/yr sustainable lake load was included in the Proposed RPS notified on 9 November 2010. The 435 tN/yr nitrogen limit for Lake Rotorua was subject to submissions and appeal however it remained unchanged through these processes.

The RPS became operative on 01 October 2014 and must be given effect to in regional plans. In the Operative RPS Policy WL 3B and Policy WL 6B specifically reference the 435 tN/yr as the amount of nitrogen entering Lake Rotorua that is not to be exceeded. Policy WL 6B establishes the timeframes to achieve the required reduction[20].

Phosphorus

[18] When the Rotorua city sewage discharge was moved to land disposal, water quality expectations for the lake were stated in documents associated with the consent. That target was for Lake Rotorua's water quality to be similar to its 1960s' water quality.

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

[20] The timeframes were generated through resolving appeals to the Proposed RPS. The agreement is known as the Oturoa Agreement.

The generally accepted sustainable lake load target for phosphorus is 37 tonnes per year. This figure is again based on the 1989 "Management of Phosphorus and Nitrogen Inputs to Lake Rotorua, NZ" paper and on technical advisory group recommendations from 1989.

Estimating sustainable in-lake total phosphorus concentrations at that time was problematic. Two models[21] were used and these arrived at values of 17 ppb and 19.7 ppb (parts per billion). A value of 20 ppb was selected as a target[22]. This in-lake target was applied in a lake model which could approximate the corresponding catchment load. It indicated a catchment load target of 37 t tP/yr to achieve the in-lake concentration of 20 ppb. Based on the modelling at the time, the reduction of sewage inputs to 3 tP/yr would deliver the target load. This also recognised a 30.8 tP reduction in phosphorus from sewage inputs in 1984-85.

The 37 tP/yr target was included within the draft Lakes Rotorua and Rotoiti Action Plan 2007 (and subsequent versions of the draft) but it is not a regulatory target. Policy WL 3B in the RPS requires Council to set a limit for both nitrogen and phosphorus. No limit has yet been set for phosphorus. Confirming the appropriate target is part of the Science Review.

At the time of the RPS process, there was insufficient evidence base to include a sustainable lake load target for phosphorus as for the 435 tN/yr nitrogen limit. As the Section 32 Report for PPC10 notes: "The Operative RPS does not include a target for phosphorus, as at the time it was developed the contaminant loads for phosphorus and its behaviour in reaching the lake were not as completely understood on the basis of scientific evidence". Following the removal of sewage discharges to the Lake the "steady state" load was estimated at 39.1 tP/yr[23]. For the RPS process the difference between the "steady state" and sustainable loads of phosphorus into Lake Rotorua of 2.1 tonnes/yr was not seen as being significant enough to require an RPS limit to be set.

Recent work has provided a more robust view of phosphorus dynamics. The steady state load is now estimated to be 48.7 tP/yr[24] – including storm flow estimates (which were not included in earlier estimates as it was not considered that particulate attached phosphorus was bioreactive). The required reduction is now estimated at 10 to 15 tP/yr (43-64% of the anthropogenic phosphorus load). This indicates the sustainable phosphorus load to reach the TLI of 4.2 (in association with the 435 tN target) is 33.7 to 38.7 tP/yr. This aligns with the earlier estimate of 37 tP by Rutherford et al 1989.

The groundwater reaching Lake Rotorua is naturally enriched with dissolved reactive phosphorus which has leached from bedrock as a result of long aquifer residence times. To achieve the sustainable phosphorus load is therefore a significant challenge due to the large proportion of the phosphorus entering Lake Rotorua from natural sources (about 52%). This means that only about 48% of the phosphorus reaching the lake is manageable through land use controls.

---

[21] Rutherford, J.C.; Pridmore, R.D.; White, E., 1989. Management of phosphorus and nitrogen inputs to Lake Rotorua, New Zealand, Journal of Water Resources Planning & Management 115 (4).

[22] Ibid.

[23] Table 6 in "Proposed Lakes Rotorua and Rotoiti Action Plan", Version 5.1, 14 Nov 2007. Environmental publication 2007/11.

[24] Tempero G, Abell J, Hamilton D, McBride C, 2015, "Anthropogenic Phosphorus Loads to Lake Rotorua" ERI Report 66.