Briefing notes on the Lake Rotorua 435 t N target

The information referenced is from attached papers by White et al and Rutherford et al.

The second report referenced is the attached draft modelling report completed by Hamilton et al.

Statements from the Water Quality Technical Advisory group are also attached as they hold information that explains this target.

The paper from 1989 “Management of Phosphorus and Nitrogen Inputs to Lake Rotorua, NZ, is an important starting point to understand the origin of the target N level of 435 t N/yr. This has remained the council position since that time and the recent modelling work supports this target.

The report abstract is a useful summary of situation faced in 1989:

ABSTRACT: The water quality of Lake Rotorua has deteriorated since the 1960s because of excessive phytoplankton growths caused by increased inputs of phosphorus and nitrogen from the Rotorua city sewage treatment plant. Removal of phosphorus alone may produce no measurable improvement in lake condition unless it can be made the limiting nutrient. Even then, this may take a number of years, because of recycling of phosphorus already in the lake system. Removal of nitrogen alone may reduce phytoplankton growth in the short term (say 5–10 yr) but is not recommended because the algal community may become dominated by heterocystous blue-green algae, which can meet their nitrogen requirements by fixing dissolved molecular nitrogen and form dense unsightly assemblages. Thus, removal of both nitrogen and phosphorus is recommended. A suggested aim is to restore the lake condition to that which prevailed prior to the 1960s, before widespread public concern about phytoplankton growths developed. The scientific view is that this lake condition is achievable and will reduce the frequency and magnitude of nuisance algal blooms, maintain reasonable water appearance and clarity for recreational purposes, minimize periods of deoxygenation, and reduce internal nutrient inputs. Removal of all sewage effluent from the catchment is expected to achieve the nutrient load reduction that is required. Any sewage discharge increases the risk that the lake condition will be unsatisfactory, but this risk is probably low if the sewage inputs are less then 3 tonnes (t) of phosphorus and 30 t of nitrogen per year.

Some key points from this paper are summarized below:

1. At the time treated wastewater was being discharged directly to the lake,
2. Water quality deterioration since 1976 could be attributed to the wastewater input,
3. The resulting increase in deoxygenation of bottom waters was causing increased releases of nutrients from the bottom sediments,
4. Table 1 below contains key information on the nutrient inputs and targets proposed at that time:

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.

5. Columns 2 to 5 show the nutrient inputs through time. A sequential increase in N and P can be seen in the totals. Column 6 shows the recommended target nutrient inputs.
6. The in-lake water quality over time and the targets are detailed in the lower third of the table.
7. The in-lake TN and TP in the table remain as lake targets. Modelling techniques have been used to independently ascertain what nutrient load equates to the target TLI. A TN load of 435 t TN/yr was found to yield a TLI close to 4.2 in the University of Waikato modelling.
8. At the time that Table 1 was put together the sewage inputs made significant contributions of N and P (50 and 27% respectively).
9. From 1976-77 to 1984-5 the number of days of calm weather to produce anoxic bottom waters had reduced from 14 to 7 days. It is under anoxic conditions that N and P releases from bottom sediments in the lake are greatly enhanced.
10. It was evident that the internal input loads contributed substantially to lake nutrient concentrations.
11. N and P enrichment are not considered to cause excessive growths of introduced weeds, but improvements in lake clarity may make their growth more vigorous. Over the duration of the data presented in Figure 1, excessive growth of exotic weeds appeared to be less of a concern.
12. N and P levels will depend on the lake WQ selected. Public support was for water quality to approximate what prevailed prior to the 1960s. Numerical indicators of water quality were

sparse or absent prior to the 1960s so a number of approaches have been used to derive some numerical values for this time.

13. Estimating TP concentrations was problematic. Two models used arrived at values of 17 ppb and 19.7 ppb. A value of 20 ppb was selected as a worthy target.
14. 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 an in-lake concentration of 20 ppb. From Table 1 it can be seen that cutting sewage to 3 t TP/yr, then the combined total of stream flow and sewage loads would equal 37 t (i.e., the target).
15. Wastewater N targets were based on (a) existing sewage N inputs, (2) internal N loads, (3) relationships between bottom-water DO concentrations leading to N releases from bottom sediments. Although in Rutherford et al there was commentary about achieving an idealised input of zero N from these sources, it was considered politically appropriate to set a target of 30 t TN, even though the paper suggests either 21 t +/-23 (30 is in this range)or 25 t N.
16. Commentary was provided on the likely recovery rate of the lake if the wastewater targets were achieved. The rate was expected to be affected by prevailing climatic conditions and their impact on lake deoxygenation.

In 1988 White et al. put together a paper on “Phosphorus reduction required to control eutrophication at Lake Rotorua NZ”. Some key points from that paper are:

1. The lake has not been observed to be P limited over the last 10 years (i.e. prior to 1987).
2. To achieve an average chlorophyll-a concentration of 10 mg m^{-3}, *(i.e. a TLI of c. 4.2*) it would be necessary to reduce P by 76%, which equates to 59% of the average of the total phosphorus figures listed in Table 1. *(We have effectively achieved this for Lake Rotorua by alum dosing, 45 ppb (c. 2004) → 20 ppb (c. 2014) = 55% reduction)*
3. *The paper indicated that achieving P-limitation of phytoplankton in the lake was difficult. Consideration was not given to an inflow dosing protocol to control P. This alum treatment has exceeded expectations and reduced P in the lake to levels sufficiently low to exert strong limitation of phytoplankton.*

I have attached the Water Quality TAG statements for Lake Rotorua and general lake advice as these provide useful context on the position of WQTAG with respect to lake nutrients.

Prof Hamilton et al. have completed a Draft report “Assessing the effects of alum dosing of two inflows to Lake Rotorua against external nutrient load reductions: Model simulations for 2001-2012”

Some key points from the Executive Summary are:

1. The Puarenga Stream shows a clear decrease in TN concentrations since 2009

2. In-lake concentrations of TP and DRP began to decrease about 2007/8, despite no major changes in P loading in tributary inflows.

3. Modelling indicates effects of alum have impacted beyond Utuhina and Puarenga, and substantially reduced in-lake TP.

4. Rates of oxygen consumption by bottom sediments have decreased considerably since 2007.

5. Lake TP concentrations are currently about one-half the levels observed in the mid-2000s

6. High nitrate concentrations in 2011/12 suggest release of N limitation – possibly due to P limitation of phytoplankton.

7. There is a need to consider the intensity and sustainability of alum dosing, particularly in relation to addressing N and P loads against changes in catchment land use and practice.

Key points from the discussion of this report are:

1. There has been a substantial reduction in surface and bottom-water phosphorus concentrations from 2008 to 2013

2. DRP and TP concentrations in lake inflows have remained static (with the possible exception of some decrease in SRP in the Puarenga Stream), or in several cases appear to have increased (e.g. Waiteti Stream)

3. There is, however, a possibility that deposited alum floc is re-suspended and transported more widely within the lake (e.g. during strong winds generating wave action that re-suspends sediment in the shallow near-shore area)

4. The original intent of the alum dosing was to 'lock up' the phosphorus contained in the Utuhina and Puarenga streams but the evidence from this report suggests a more extensive mode of action including increased in-lake sedimentation and partial capping of P releases from bottom sediments

5. High-frequency monitoring at the lake buoy site shows a substantial decrease in the frequency of anoxia over the past 2-3 years

6. 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

7. The lake model was not adapted specifically to dynamically simulate alum effects of dosing; this explains differences between TLI observations and model outputs over 2011/12 and 2009/10

8. It will be important for model development to be undertaken to specifically simulate alum dynamics

9. The legacy effects of alum dosing may persist over a 2-3 year duration following termination

10. In-lake TP concentrations average around one-half of the very high levels observed in the lake in the mid-2000s (see commentary above on sustainable P loads).

11. There are no obvious chemical or biological effects from alum dosing except for an area of enrichment of Al in bottom sediments at the Utuhina Stream mouth in the lake

12. It is recommended that pH continue to be monitored at high frequency and that indicator biota be analysed for aluminium concentrations in tissue samples

13. It is recommended that Bay of Plenty Regional Council considers a regular programme for monitoring nutrient limitation, at least in lakes where alum dosing is being undertaken.

The recommendations are taken directly from the report (quoted text):

Here we summarise some of the recommendations that were mentioned in the discussion section. These recommendations apply specifically to programmes of monitoring that should be considered by the Water Quality Technical Advisory Group and the Lakes Strategy Group for the Rotorua lakes.

1. We recommend that consideration be given to wider use of biota as an assessment tool for monitoring potential chronic effects from alum in the lake. Tissue sampling could be conducted on key species (e.g. kākahi, koura and trout) to encompass a broad representation of different feeding strategies and species of cultural and recreational significance.

2. We recommend that a regular, repeatable monitoring protocol be adopted for determining phytoplankton nutrient limitation in Lake Rotorua. Analysis of the data should include considerations of alum dosing rates, concentrations of inorganic and total nutrients, and time of year in relation to phytoplankton composition.

3. We recommend close examination of pH from the high-frequency lake monitoring buoy to better understand its variability and the possibility of any untoward consequences from relationships between alum dosing, phytoplankton biomass and pH variations.

4. We recommend that increased frequency of in-lake measurements of Al be complemented with development of a dynamic module for simulating Al concentration in DYRESM-CAEDYM, should this model continue to be used to provide key information on the effectiveness of alum and to generate hypothetical scenarios (e.g., if alum dosing was not undertaken).

5. Sediment oxygen demand over stratification events should be calculated from high-frequency lake buoy data. The most recent six-year period of high-frequency monitoring as well as data collected in 2004-5 can be used to examine any conspicuous trends and potential correspondence to alum dosing.

Final conclusions from Andy Bruere on the reports referenced:

1. There is no evidence from the science work that the 435 t N target is inappropriate and recent modelling work indicates that the TLI will be close to the 4.2 target if the N reductions are achieved,
2. It is possible to conclude from the most recent modelling work that we may need to *"over achieve"* the phosphorus target to reliably achieve the 4.2 TLI, and that may be achieved by on-going low-level alum dosing until the lake gets to equilibrium,
3. The modelling work and alum dosing have shown that the lake can be P limited. However, earlier information shows that this requires a very strong approach to reducing P. In 1988 it was predicted that a 59% reduction in in-lake P would be required. We have achieved this by alum dosing. A question remains whether this reduction could be achieved by controlling catchment P. I have asked the University to investigate the sources of P and evaluate if control to that level would be possible (i.e. what is P derived from anthropogenic sources and what is natural), or alternatively, what level of P control is possible in view of this potential 59% target,
4. There are risks around alum dosing, and we should maintain a very proactive and strong programme of testing as recommended, to understand these risks and address them if necessary.