IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	Lake Rotorua Nutrient Management – **PROPOSED PLAN CHANGE 10** to the Bay of Plenty Regional Water and Land Plan
BETWEEN	DairyNZ Limited
AND	Bay of Plenty Regional Council

SUMMARY OF EXPERT EVIDENCE OF DR THOMAS STEPHENS FOR DAIRYNZ LIMITED AND FONTERRA

15 March 2017

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CONTENTS

1. INTRODUCTION

1.1 My full name is Thomas William Stephens. My qualifications and expertise are set out in my Statement of Primary Evidence (“Evidence”). I confirm I have read the Expert Witness Code of Conduct set out in the Environment Court Practice Note 2014 and agree to comply with it.

2. SUMMARY

2.1 The purpose of my Evidence is limited to the need for a comprehensive science review to ensure an adaptive management approach is adopted for P and N, by PC 10.

2.2 To emphasise the need for ongoing science reviews, my Evidence examined the evolution of science regarding algal-nutrient dynamics within Lake Rotorua, from the early 1970s to Present. In particular:

2.2.1 Lake Rotorua attained a TLI ≤4.2 in 2012 and 2014 unexpectedly, under circumstances of increased anthropogenic N-loading and decreased P-loading by alum;

2.2.2 The lake’s response to alum including x1000 fold reductions in N-fixing cyanobacteria and statistical evidence for lake-wide, long-term rising P deficiency are robust evidence that algal biomass was P-limited throughout the period of improving water quality (e.g., TP and Chl-a trending down at twice the rate of TN; TN/TP ratios rising 6%/yr over 2001-2012; TN/TP mass ratios >20 indicating strong P-limitation during 2012 and 2014 [Abell et al., 2012]). By contrast, in the 1970s scientific consensus believed algae were largely N-limited, before revising this in the 2000’s to suggest algae were alternately P, N or co-limited, and most recently, scientific consensus believes nutrient addition bioassays to be inappropriate and the information they generate, contradictory and spurious, for identifying which nutrient(s) to manage algal blooms with;

2.2.3 Lake improvement by P-limitation raises the potential for greater emphasis on P-management to manage for algal blooms in Lake Rotorua;

2.2.4 Marked reductions in P-loading will be required whether for a P- or co-limited TLI ≤4.2 in Lake Rotorua, emphasising the need for robust research into P-strategies as part of the adaptive management proposed by PC 10.

2.2.5 If equal or greater reductions in P are not made to match any reduction in N, water quality will be degraded by increased cyanobacterial dominance. That will counter-act or make reductions in N-loss by land users less effective, and increase toxicity effects on the lake for both native biodiversity and recreational users.

3. MATTERS IN AGREEMENT

3.1 My Evidence is broadly supportive of other water quality experts including Dr. Rutherford, Prof. Hamilton and Mr. Bruere. Collectively, we agree upon the need for a comprehensive science review, to assure adaptive nutrient management achieves and sustains a TLI ≤4.2 in Lake Rotorua.

3.2 From this, I strongly support proposed Methods LR M2 and M3 or the need for robust science underpinning loss, mitigation and effects of both P and N upon algal blooms in the lake.

4. MATTERS IN DISAGREEMENT

4.1 I have read the rebuttals of Prof. Hamilton and Mr. Bruere. On review, there is little reason to change my original Evidence. There are several points where I believe a discussion between the experts would resolve differences, where my Evidence has been misinterpreted and where peer-reviewed, pertinent lake management research has been omitted.

4.2 Three points require clarification as they are in disagreement with Prof. Hamilton but which underpin the purpose of my Evidence to rationalise the need for a science review through LR M2, particularly into P-limitation and P-management.

4.3 In clarifying these points, I reiterate strong support for Methods LR M2 and M3. My points emphasise the need for a science review prioritising research into P-management, including its reporting, and explore alternative nutrient management approaches in light of P-limitation under alum but supported instead by catchment reductions in anthropogenic P-loading, to nonetheless achieve a TLI ≤4.2. Doing so by 2022, will enable a comparison to be drawn with the approach currently promoted by PC 10, to determine which is the better and regardless, ensure a robust P-reporting tool/allocation framework has been developed.

5. TLI IMPROVED PRIOR TO ALUM DOSING (PRE-2006)

5.1 In paragraphs 1.4, 2.4 and 2.9 of Prof. Hamilton's rebuttal, he alleges the time-series analyses reported in my Evidence were "truncated" or "selective", to suggest I was incorrect to identify improving TLI prior to alum dosing in 2006.

5.2 The statistical information I reported in my Evidence are identical to those reported in Abell et al. (2012), where in fact, I led the time-series analysis. Likewise, in paragraph 4.5 of my Evidence I stress the time-period over which trend statistics were generated, to be 2001-2012, in keeping with my analyses for Abell et al. (2012).

5.3 In Figures 4.1 and 4.2 of Abell et al. (2012), improved TLI is evident since 2003, primarily in the deconstructed time-series for TP and Chl-a. Both figures are reproduced here on pages 9-10.

5.4 Time-series deconstruction is a common statistical tool that complements trend testing. The latter determines the typical or median rate of change scaled to the full time-window, whilst the former indicates precisely where in that window change originated (i.e., unless you deconstruct a time-series, trend analysis will not tell you when a change began).

PAUSE TO DESCRIBE FIGURES 4.1 AND 4.2

5.5 With that in mind, I identified in paragraphs 4.4 and 4.5 of my Evidence, that trends for reduced TP and Chl-a began three years prior to alum dosing, in 2003. Given little change in climate was noted by Hamilton et al. (2012:19)[1] for the period 2000-2009, and as alum dosing began later in 2006, this points to an important but poorly understood process driving TLI in Lake Rotorua (i.e., causing ~0.5 TLI variation over two years).

5.6 In paragraph 4.5 of my Evidence I link this inference to the value of frequent science reviews, and not to detract from the importance of alum dosing driving later improvement. For instance, I indicate in paragraph 4.5 that most marked improvement in TLI occurred later, between 2010 and 2012, following increased alum dosing. Hence, I disagree with Prof. Hamilton in paragraph 2.9 of his rebuttal where he suggests my evidence "should be disregarded" for using a starting period of 2003, when in fact I have not done so here nor too in Abell et. al. (2012) – a mistake he repeats in his rebuttal at paragraphs 2.10 and 2.11.

6. A DEFICIENCY OF P (P-LIMITATION) DROVE TLI IMPROVEMENT SINCE 2006

6.1 Alum is the principal cause of improvement in TLI since 2006 – I noted no disagreement in that inference. However, it was suggested the lake had not then become more P-limited by Prof. Hamilton in paragraphs 2.14 and 2.25(ii) of his rebuttal, despite this being acknowledged in technical reporting by other Council scientists (e.g., Scholes 2013; Scholes and Hamill, 2016[2]).

6.2 To explain Section 5 of my Evidence linking alum to evidence for P-deficiency or P-limitation, it is worth noting that alum has a direct impact only on P availability, essentially locking or sequestering P. Now, if alum is the principal cause of marked improvement in TLI to ≤4.2 in 2012 and 2014, then because anthropogenic N-inputs actually rose over the last decade, the root cause of any lake improvement can only be directly linked to reduced P-loading. So, greater P-limitation of algae. For instance, Scholes (2013) revealed significantly increased NNN concentrations in 6 of 8 inflowing streams ranging between 0.1-1.4%/yr ($p<0.05$), to conclude that TN-loading from the land had actually increased during the period of improved TLI at Lake Rotorua (2002-2012). Again, alum has not locked up or sequestered N.

[1] Footnote 19 from Evidence – "whilst globally there have been obvious warming trends for the 1960s and 2010, there appears to have been little change in air and water temperature of Rotorua and the lake".
[2] Scholes and Hamill (2016:83) state "phytoplankton growth is now much more strongly limited by phosphorus than nitrogen".

6.3 Alum release into the Utuhina and Puarenga streams and sequestration of P both in-stream and in-lake, explains how in-lake dissolved P and TP reduced by 19%/yr and 8%/yr respectively from 2001-2012 ($p<0.05$). Together with rising anthropogenic N-loading, alum offers an explanation for why whole-lake TN/TP ratios also rose by 6%/yr (2001-2012; $p<0.05$), particularly as alum is unlikely to have altered denitrification or sedimentary N-cycling from Lake Rotorua (Hecky, pers. comm., 29/03/2017).

6.4 Increased TN/TP ratios resulted in strongly P-limited conditions for 2012 and 2014 when TN/TP ranged 20-28, the very same years when in-lake conditions met long-term objectives for lake TLI of ≤4.2. This is my first line of evidence pointing to P-deficiency having driven improved water quality in Lake Rotorua.

6.5 A second line of evidence is the similarity of change or trends in TP and Chl-a concentrations from 2001-2012. TP and Chl-a reduced by equivalent rates of 7%/yr and 8%/yr whereas TN reduced by less than half that of algal biomass ($p<0.05$) (Abell et al., 2012). In the most exhaustive and comprehensive peer-reviewed synthesis of lake algal-nutrient research to date, Schindler et al. (2016) recommend such a trend-based approach to identifying which nutrient(s) to direct policy at for managing lakes to lesser algal productivity. A deficient nutrient to target for control will be that or those approximating change in algal biomass, across the whole-lake and over multiple blooms (Schindler et al., 2016). Here, Abell et al. (2012) reveal the trends reported above were indeed lake-wide, being reproduced by multiple stations in Lake Rotorua from over a decade of monitoring algal responses to changes in nutrient availability.

6.6 Adopting international best scientific practice for lake algal-nutrient management, the equivalent reductions in whole-lake TP and Chl-a across Lake Rotorua for more than a decade and their dissimilarity from changes in TN, provide a second line of evidence that P-deficiency or P-limitation is the cause of recent improved water quality.

6.7 At this point I should also note that in their peer-reviewed state of the science, Schindler et al. (2016) eschew the approach taken by Professor Hamilton to rely on nutrient addition bioassays to inform nutrient management for improved water quality. Schindler et al. (2016) demonstrate that the latter have consistently failed to predict lake responses, to real-world *reductions* rather than *addition* of nutrients, from over 40 years of whole-lake experimentation, globally. Nutrient addition bioassays, being conducted for very limited periods of time (days) in minute fractions of a whole lake (litres), provide "often give spurious and confusing results" that bear little relevance to solving the problem of algal blooms in lakes (Schindler et al., 2016: 8923)[3].

6.8 Now, in a third line of evidence for P-deficiency having driven recent improved TLI to ≤4.2 at Lake Rotorua, I revealed that the alum-driven reduction in algal biomass since 2006 was most

[3] Schindler et al. (2016) refer to small-scale experiments of short duration, where nutrients are added rather than removed which include nutrient addition bioassays.

stark in cyanobacterial species. Cyanobacteria, especially N-fixing forms, underwent a x1000 fold reduction (please refer to Figure 7 of Smith et al., 2016 reproduced here on page 11).

PAUSE TO DESCRIBE FIGURE 7

6.9 The alum-driven decline in atmospheric N-fixation explains why organic or algal-supplied N fell by 5%/yr from 2001-2012 ($p<0.05$), considerably more than coeval TN declines of 3%/yr, and whilst anthropogenic N-loading actually increased by 0.1-1.4%/yr (from 2002-2012; $p<0.05$) (Scholes, 2013). That difference of greater organic-N reduction on a background of rising inorganic-N is important; it suggests any reduction in TN was not linked to N-deficiency as inorganic-N is the principal source of N for algae (i.e., for inorganic N to be limiting, TN reductions would have been equal to or greater than that of organic-N [Schindler et al., 2016]).

6.10 Pieced together in chronological order, reduced in-lake TN of 3%/yr (2001-2012, $p<0.05$), is in fact *a consequence rather than cause* of reduced algal, especially cyanobacterial, biomass. The timing of that reduction in cyanobacterial biomass since 2006, with the onset of alum dosing, instead points again to a deficiency of P caused by alum having directly driven an equivalent reduction in Chl-a and then indirectly, considerably less reduction in TN but primarily organic-N.

6.11 Essentially, whilst the anthropogenic N-tap continued to flow, the atmospheric N-tap driven by cyanobacteria was closed, through the reduction in TP caused by alum. This deductive approach to explaining changes not simply in TP and Chl-a but also algal community composition and TN across the whole-lake and in the long-term by P-limitation, through a link to the introduction of alum, is recommended by Schindler et al. (2016) to reliably identify a deficient nutrient(s) to prioritise for lake management of algal blooms.

6.12 In Section 5 of my Evidence, I have purposely followed cutting-edge *international* best scientific practice for lake algal-nutrient science. By linking multiple independent strands of whole-lake, long-term evidence in Lake Rotorua, a deficiency of P or P-limitation is almost certainly responsible for recently improved water quality. From this, managing P-alone could plausibly and effectively deliver the same outcome as managing N and P together for a TLI of ≤4.2, contrary to paragraphs 2.16, 2.25 (ii) and 2.26 of Prof. Hamilton's rebuttal, and evidenced by actual conditions occurring in the lake now.

6.13 It is my opinion that Prof. Hamilton's reliance on a single strand of evidence presented by nutrient addition bioassays, fails to implement the recommendations or reflect the scientific consensus of our lake eutrophication peers. I would reiterate the comprehensive state of the science review by Schindler et al. (2016) identifies the inability of short-term, nutrient addition bioassays to represent whole-lake algal-nutrient dynamics, and the irrational belief that adding nutrients to a lake indicates the effect of their removal. Schindler et al. (2016:8924-8925) are damning about the approach taken by Prof. Hamilton when they state "we suggest that such assays no longer be used to guide eutrophication management in whole lakes" and "it is unfortunate this short-coming of nutrient enrichment bioassays has not been understood by…regulatory agencies".

7. P-MANAGEMENT IS UNCERTAIN BUT CRITICAL TO MANAGING LAKE ROTORUA

7.1 Prof. Hamilton misquotes my Evidence in paragraph 2.26 of his rebuttal, to omit my stating "the scientific evidence is *uncertain regarding, whether*" (emphasis added) prioritising P-management would carry with it lesser cost or risk. Instead, he alleges that is in fact the case.

7.2 Certainly, P-management has been successful the world over in managing algal blooms, and is widely accepted to incur costs between a quarter to a tenth those of both P- and N-management (Sterner, 2008; Schindler et al., 2008). Schindler et al (2016) cite numerous independent peer-reviewed publications documenting 39 lakes of varying state, size and land use across 9 developed countries where eutrophication decreased following P-management. Although likely to incur considerably lesser cost, given the limited research into dedicated P-strategies, that is those that target P rather than N specifically on Rotorua urban, farm or forestry land, I cannot say by how much nor too confirm therefore it will be the case in Lake Rotorua as I stressed in Section 7 at paragraphs 7.3, 7.6 and 7.7.

7.3 I acknowledge the recently circulated note by Dr. Richard McDowell into the potential efficacy of P-management strategies across wider New Zealand and Australia. This information like the earlier McDowell (2010) and McDowell et al. (2013) report, is largely generic with widely varying estimates of modelled P-reduction, although updated to include a single representative dairy farm from within the Rotorua catchment but remaining otherwise reliant on information gathered from differing farming systems on dissimilar soils, slope and climate in New Zealand – all key drivers of TP-loss from land users.

7.4 It remains highly uncertain what the potential for, efficacy and cost of P-mitigations will be in the Rotorua catchment, as reported by Park (2017) who states "there is considerable uncertainty about the level of P loss from different activities and the options available for reducing these P losses". This is especially the case for drystock, forestry and urban land users given the focus of McDowell et al. (2017) on dairying only. For instance, whether a single modelled dairying farm is representative of all dairy farms in Rotorua catchment, Table 4A in Hamilton et al. (2012:69) notes dairying contributes only 16% of the lake's anthropogenic P-load (4 of 25.3 tonnes/yr). Instead, 53% is contributed from drystock (13.4 tonnes TP/yr), 15% by urban and wastewater sources (3.9 tonnes TP/yr) and 7% from forestry users (1.8 tonnes TP/yr).

7.5 In Section 6, my Evidence points out that whether the lessons of alum-driven P-limitation alter future lake management, to achieve the 43-64% reduction in anthropogenic P-loss proposed by PC 10 for co-limitation to TLI ≤4.2, P-strategies will need to be better researched. Principally, the costs, risks and effects thereof when tailored to the specific catchment farming systems, forestry blocks and urban sources, which I believe should be a priority for the science reviews proposed by LR M2.

7.6 To avoid confusion, I should reiterate that in paragraph 6.6 I state both the dearth of research into P-strategies and a possible requirement of the operative Regional Policy Statement for a TN rather than effects-based objective, I have not proposed any change in the recommended nitrogen targets of LR Policy 1 in PC 10. Hence, despite my confidence that reductions in P alone have driven recent improvement to water quality, I have to support both N and P being managed at this time. Instead, it is my opinion the balance therein might change through improved understanding of algal-nutrient dynamics and specific knowledge about P-strategies in the Lake Rotorua catchment. To act on that knowledge though requires formal and robust best international scientific practice, with reviews of sufficient scope to redefine nutrient targets for the same fixed algal and clarity (effects) expected under Objective 11 of the Regional Policy Statement.

FIGURES REFERRED TO IN EVIDENCE

Figure 4.1 from Abell et al (2012) – deconstructed time-series showing the "long-term trend" for improvement beginning in 2003 for TP and Chl-a at Site 2 (Lake Rotorua). Note less distinct response of TN even after alum dosing began in 2006 supporting its reduction only after and through P-limitation of algae. Referred to in Paragraph 4.4.

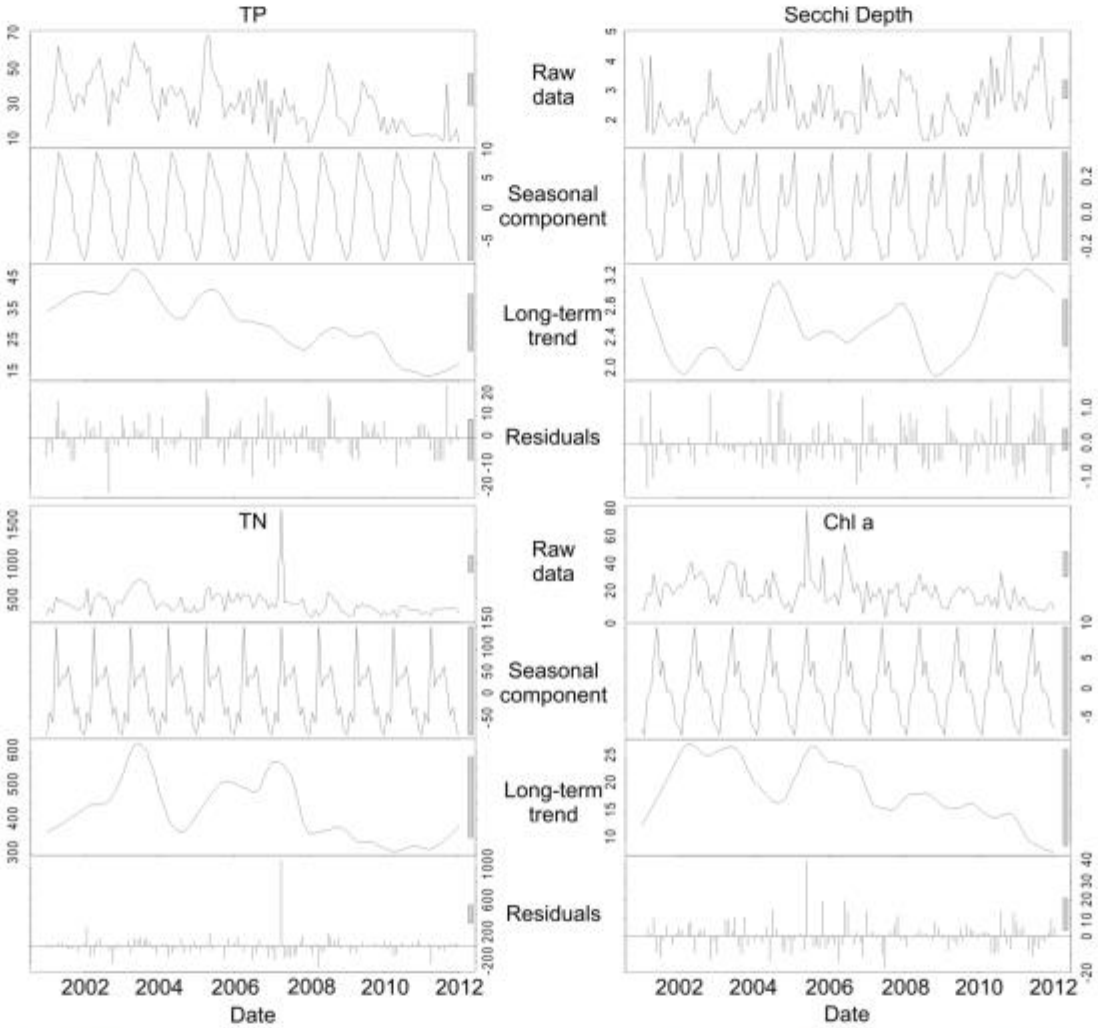

Figure 4.1 Decomposed time-series components for site 2 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by the seasonal component (12-month period), long-term trend (loess smoothed) and residuals in corresponding units

Figure 4.2 from Abell et al (2012) – deconstructed time-series showing the "long-term trend" for improvement beginning in 2003 for TP and Chl-a at Site 5 (Lake Rotorua). Note later response of TN after alum dosing began in 2006 supporting its reduction only after and through P-limitation of algae. Referred to in Paragraph 4.4.

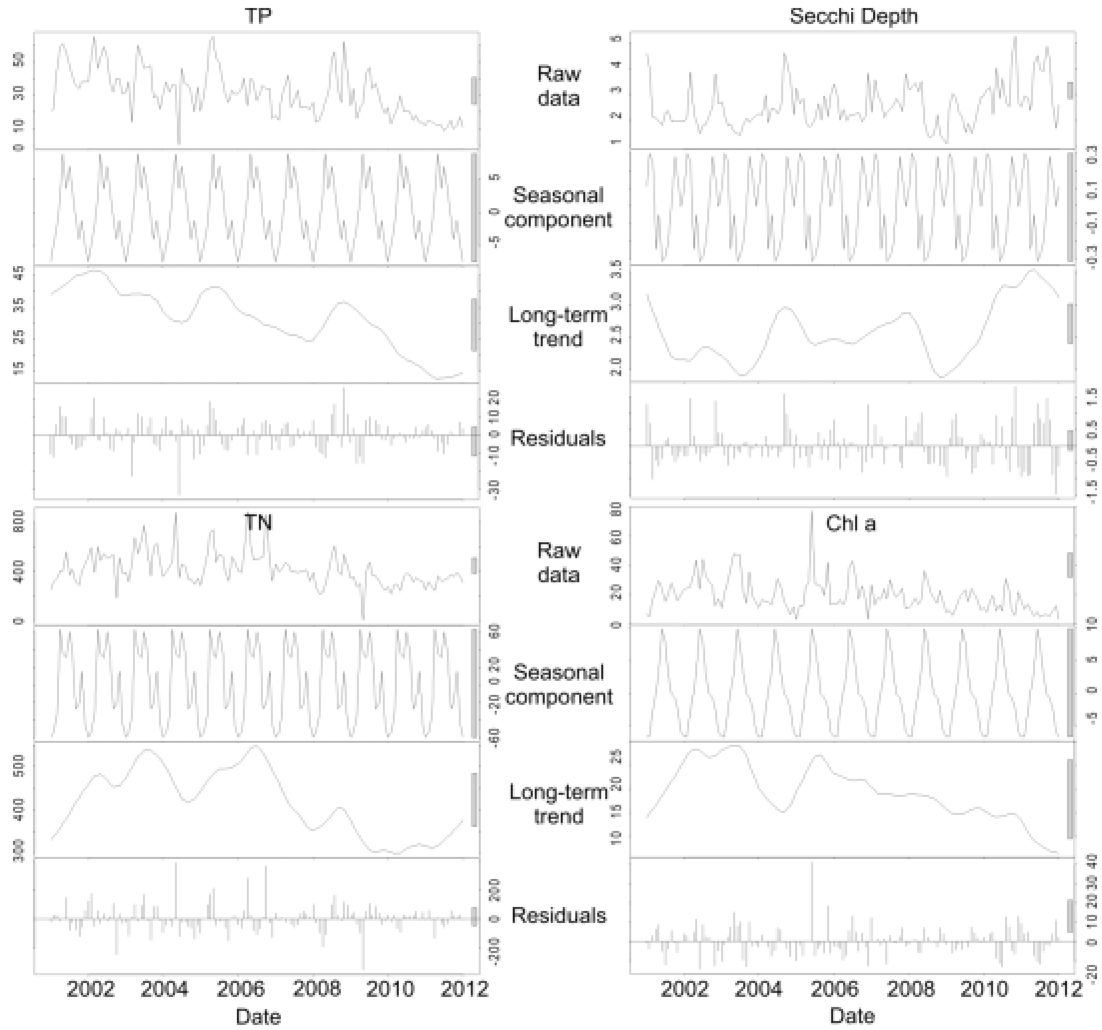

Figure 4.2 Decomposed time-series components for site 5 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by the seasonal component (12-month period), long-term trend (loess smoothed) and residuals in corresponding units

Figure 7 from Smith et al., (2016) – changes in cyanobacterial biovolume ($mm^3 m^{-3}$) since 1997 that demonstrate an approximately x1000 fold reduction in N-fixing forms as well as collectively, all cyanobacteria (beginning between 2003 and 2006). Note logarithmic scale for cyanobacterial biovolume. **Red line** marks onset of alum dosing in 2006 (Utuhina Stream), linking reductions in total and N-fixing cyanobacteria to reduced P at Lake Rotorua. Referred to in Paragraph 5.5 and Footnote 30.

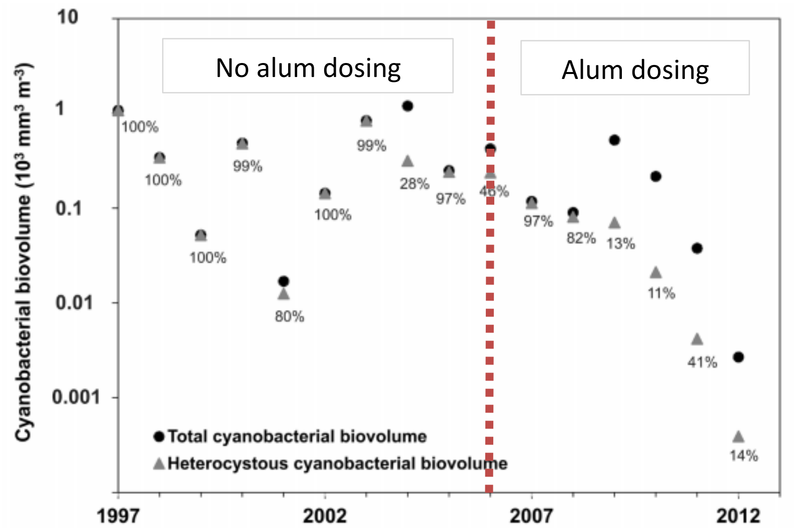

Fig. 7. Total cyanobacterial biovolumes and total heterocytous cyanobacterial biovolumes. Percentages show proportion of heterocytous cyanobacteria in each sample. Data are averages from 4 sites around the edge of Lake Rotorua (Hamurana, Holdens Bay, Ngongotaha, and Ohau Channel Bay).