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

UPDATED TO INCLUDE OUTCOME OF WATER QUALITY EXPERT CAUCUSING, 3rd APRIL 2017, MILLENNIUM HOTEL ROTORUA BETWEEN DR THOMAS STEPHENS, PROF DAVID HAMILTON & MR ANDY BRUERE

03 April 2017

Cnr Ruakura Road & SH 26
Newstead
Hamilton 3286

OUTCOME OF CAUCUSING HELD ON 3rd APRIL 2017 AT MILLENNIUM HOTEL ROTORUA – WATER QUALITY

1. DETAILS OF CAUCUSING BETWEEN WATER QUALITY EXPERTS

1.1 Caucusing was called between water quality experts for the University of Waikato (Prof. David Hamilton), DairyNZ (Dr. Thomas Stephens) and Bay of Plenty Regional Council (Mr. Andy Bruere) in the matter of proposed Plan Change 10 as regards water quality science. Dr. David Burger (DairyNZ) was also present on 3rd April 2017, during caucusing held at the Millennium Hotel, Rotorua.

1.2 The pertinent points of agreement and a point of disagreement that remain of earlier water quality matters in contention.

2. CAUCUSED MATTERS IN AGREEMENT

2.1 The primary statement of evidence (Evidence) of Dr. Stephens is broadly supportive of the other water quality experts including Prof. Hamilton and Mr. Bruere. Collectively, we agree upon the need for a comprehensive science review, to ensure adaptive nutrient management achieves and sustains a TLI ≤4.2 in Lake Rotorua.

2.2 From this, we 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.

2.3 To avoid confusion, we have not proposed any change in the recommended nitrogen targets of LR Policy 1 in PC 10. Hence, despite our confidence that reductions in P have plausibly driven recent improvement to water quality, we support both N and P being managed at this time. Instead, it is our opinion the balance of N and P reductions might change through improved understanding of algal-nutrient dynamics and specific knowledge about P-management strategies in the Lake Rotorua catchment. To act on that knowledge 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.

2.4 The science review proposed by LR M2 and M3 should be tasked with testing and reaching consensus on P-deficiency having driven improved water quality recently. The potential for alternative P-limited but dual nutrient managed scenarios to achieve Objective 11 (TLI ≤4.2), and contrasting these with the current proposed dual nutrient reductions in PC 10, is recommended for implementation of an adaptive management approach.

2.5 We agree that the analysis provided by Dr. Stephens in regards trends is correct, and as produced for Abell et al. (2012). The apparent disagreement stemmed from the use of the seasonal Kendall slope estimator in conjunction with time-series deconstruction, to determine both the median rate of change and also the precise timing of change. Clarification was needed to confirm all trend information and periods of analysis were as stated for 2001-2012.

2.6 We agree the evidence proposed by Dr. Stephens demonstrates likelihood for P-deficiency having driven recent improved TLI to ≤4.2 at Lake Rotorua (e.g., equivalent magnitude of decreasing trends for TP and Chl-a that are two-fold greater than TN; increased TN/TP ratios during 2012 and 2014 of TLI ≤4.2; alum-driven reduction directly targeting TP, leading to reduced algal biomass since 2006, and a consequent reduction in TN). Cyanobacteria, in particular potentially N-fixing groups, underwent a x1000 fold reduction following alum dosing, in line with increased P-deficiency and potentially resulting in lesser atmospheric N inputs (i.e., fixation) (as evident in Figure 7 of Smith et al., 2016 reproduced here on page 11).

2.7 Pieced together in chronological order, reduced in-lake TN and ON of 3%/yr and 5%/yr respectively (2001-2012, $p<0.05$), is plausibly *a consequence rather than cause* of reduced algal, especially cyanobacterial, biomass. The timing of that reduction in cyanobacterial biomass since 2006 noted in 2.6 above, with the onset of alum dosing, instead points to a deficiency of P caused by alum having been a likely cause (i.e., driving the equivalent magnitude of reduction in TP and Chl-a, and lesser reduction in TN).

2.8 From 2.1-2.7 above, we agree that robust information should be prioritised by the science review about P-mitigation across all land use types, to generate specific estimates of catchment-scale P-loading reductions (i.e., potential for, effects and cost of actions to reduce P-loss, tailored to catchment-specific land users). This will also be critical to exploring alternative dual nutrient management approaches focussed on greater P-limitation to sustain a TLI ≤4.2, but under reduced anthropogenic P-loading instead of our present reliance on alum.

3. CAUCUSED MATTER IN DISAGREEMENT

3.1 Following caucusing between experts, a single matter remains in disagreement but that disagreement does not affect the proposed structure and implementation of PC 10. Instead, it should be prioritised for review and addressed by consensus in the science review proposed by LR M2 and M3.

3.2 In Section 5 of the Summary of Evidence of Dr. Stephens, multiple independent strands of whole-lake, long-term evidence in Lake Rotorua have been linked to a deficiency of P (or P-limitation) being likely responsible for recently improved water quality. However, a point of disagreement remains about the weighting to assign this evidence and that of nutrient enrichment bioassays in the primary statement of evidence of Prof. Hamilton. This point of disagreement is also one expressed in the international literature around the relevance of methods that can be used to identify nutrient limitation of phytoplankton. Whether P-limitation is sufficiently widespread and consistent to be definitive cannot be agreed by all experts and needs to be addressed by the science review.

3.3 Whilst we agree managing P-alone could plausibly and effectively deliver the same outcome as managing N and P together for a TLI of ≤4.2. We disagree on the loading of P required to do so. This point should also be addressed by the Science Review proposed by LR M2 and LR M3.

3.4 In clarifying this point, we reiterate strong support for Methods LR M2 and M3, including assessment of in-lake nutrient processes and phytoplankton nutrient limitation, to resolve disagreement in 3.2.

PERSONAL SUMMARY OF EVIDENCE

DR THOMAS STEPHENS (DAIRYNZ & FONTERRA)

What follows hereafter is and remains the expert opinion of Dr. Thomas Stephens only, following and revised by caucusing

CONTENTS

4. INTRODUCTION

4.1 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.

5. SUMMARY

5.1 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.

5.2 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, five findings are presented, three of which are visited in greater detail in later sections:

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

5.2.2 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 increasingly likely to be 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 at the time 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 review has suggested nutrient addition bioassays to be inappropriate and the information they generate, contradictory and spurious, for identifying which nutrient(s) to manage algal blooms to lesser biomass with;

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

5.2.4 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-mitigation strategies as part of the adaptive management proposed by PC 10.

5.2.5 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 (referring to 2.2.2, relative to mass ratio). That will counter-act or make reductions in N-loss by land users less effective, and could increase potential toxicity effects on the lake for both native biodiversity and recreational users.

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

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

6.2 The statistical information I reported in my Evidence is identical to those reported in Abell et al. (2012), where in fact, I led the time-series analysis. Likewise, in paragraph 4.4 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). This applied to all further reference in my Evidence about trend statistics (e.g., paragraphs 5.2, 5.4, 5.5, 6.4 of my Evidence).

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

6.4 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). This required clarification in caucusing.

6.5 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).

6.6 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 misunderstanding repeated at paragraphs 2.10 and 2.11 of Prof. Hamilton's rebuttal.

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

7.1 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

[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".

in technical reporting by other Council scientists (e.g., Scholes 2013; Scholes and Hamill, 2016[2]).

7.2 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 reasonably be directly linked to reduced P-loading. So, greater incidence of 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 directly but has potentially reduced water column N.

7.3 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 directly altered denitrification or internal N-cycling from Lake Rotorua (Hecky, pers. comm., 29/03/2017). Increased TN/TP ratios resulted in more 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.

7.4 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 an 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 both stations in Lake Rotorua from over a decade of monitoring algal responses to changes in nutrient availability.

7.5 Adopting recommended 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 in magnitude from changes in TN, provide a second line of evidence that P-deficiency or P-limitation is the cause of recent improved water quality.

[2] Scholes and Hamill (2016:83) state “phytoplankton growth is now much more strongly limited by phosphorus than nitrogen”.

7.6 In their peer-reviewed review of the science, Schindler et al. (2016) demonstrate that nutrient addition bioassays have consistently failed to predict lake responses, to real-world *reductions* rather than *addition* of nutrients, from over 40 years of whole-lake experimentation. Nutrient addition bioassays, being conducted for very limited periods of time (days) in minute fractions of a whole lake (litres) "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]. For this reason, we need to exert caution about interpreting the findings of nutrient addition bioassays in isolation from whole-lake information.

7.7 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 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).

7.8 The alum-driven decline in atmospheric N-fixation plausibly 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 likely to be 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]).

7.9 Pieced together in chronological order, reduced in-lake TN of 3%/yr (2001-2012, p<0.05), is plausibly *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.

7.10 Essentially, whilst the anthropogenic N-tap continued to flow, the atmospheric N-tap driven by cyanobacteria was likely reduced, 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 through greater P-limitation (caused by alum), is one recommended by Schindler et al. (2016) to reliably identify a deficient nutrient(s) to prioritise for lake management of algal blooms.

7.11 In Section 5 of my Evidence, I have purposely linked multiple independent strands of whole-lake, long-term evidence in Lake Rotorua, to a deficiency of P (or P-limitation) being highly likely to be responsible for recently improved water quality. From this, managing P-

[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.

alone could plausibly and effectively deliver the same outcome as managing N and P together for a TLI of ≤4.2.

7.12 I would reiterate the comprehensive review by Schindler et al. (2016) that identifies an inability of short-term, nutrient addition bioassays to represent whole-lake algal-nutrient dynamics, and that adding nutrients to a lake does not indicate the effect of their removal. Schindler et al. (2016:8924-8925) suggest caution about an approach reliant on nutrient addition bioassays, 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”. Earlier caucusing remains in disagreement about the weighting and value of whole-lake and bioassay based evidence.

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

8.1 Prof. Hamilton omits preceding text of 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.

8.2 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 possible 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 definitively be the case in Lake Rotorua as I stressed in Section 7 at paragraphs 7.3, 7.6 and 7.7.

8.3 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 use.

8.4 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). Notably, an update to estimated anthropogenic TP loadings is required to more reliably indicate contemporary land-use associated TP-loading (e.g., sources, proportions).

8.5 In Section 6, my Evidence points out that whether the lessons of alum-driven greater 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 caucusing has agreed should be a priority for the science reviews proposed by LR M2.

8.6 To avoid confusion, I should reiterate that in paragraph 6.6 of my evidence I state both the lack of supporting research into P-management 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 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 6.3.

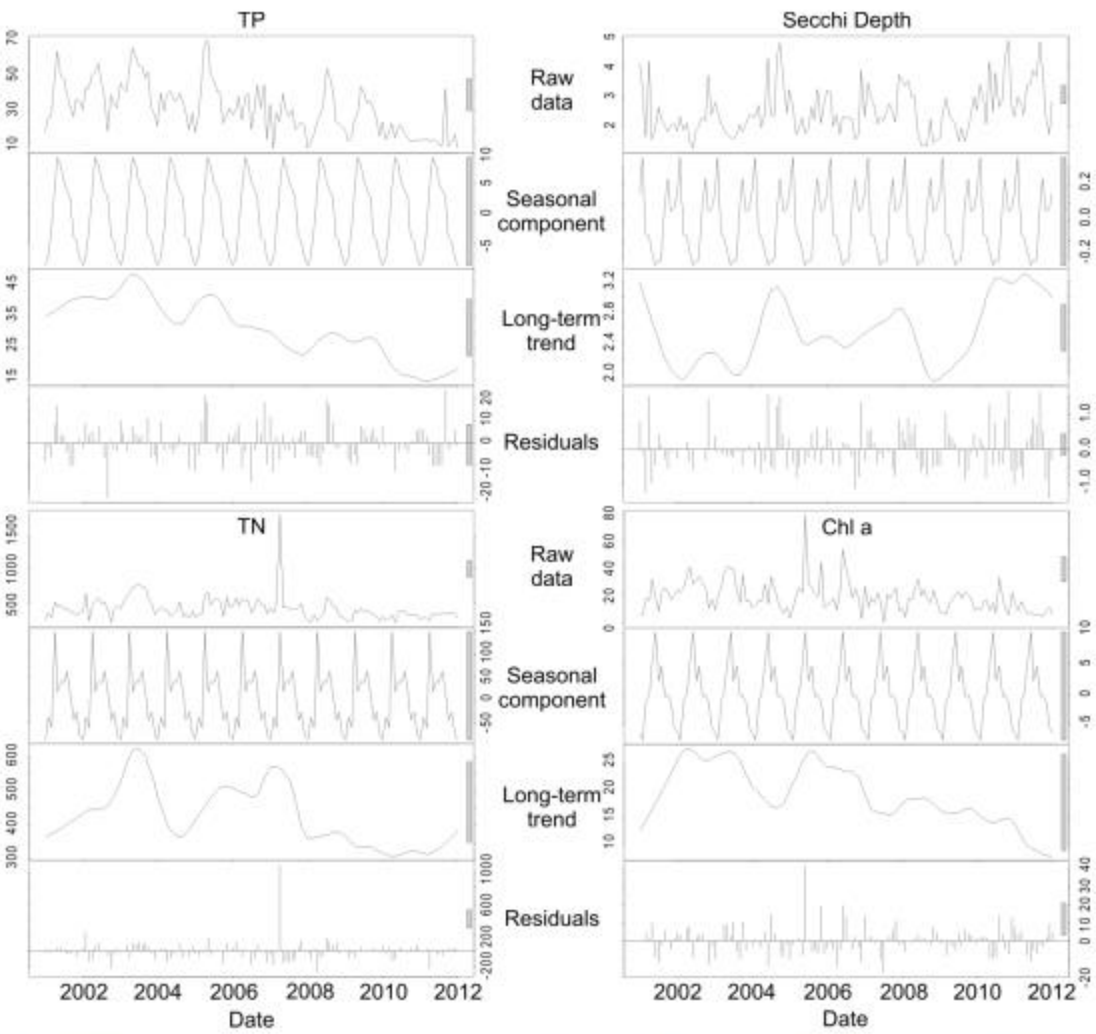

Figure 4.1 Decomposed time-series components for site 2 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by 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 6.3.

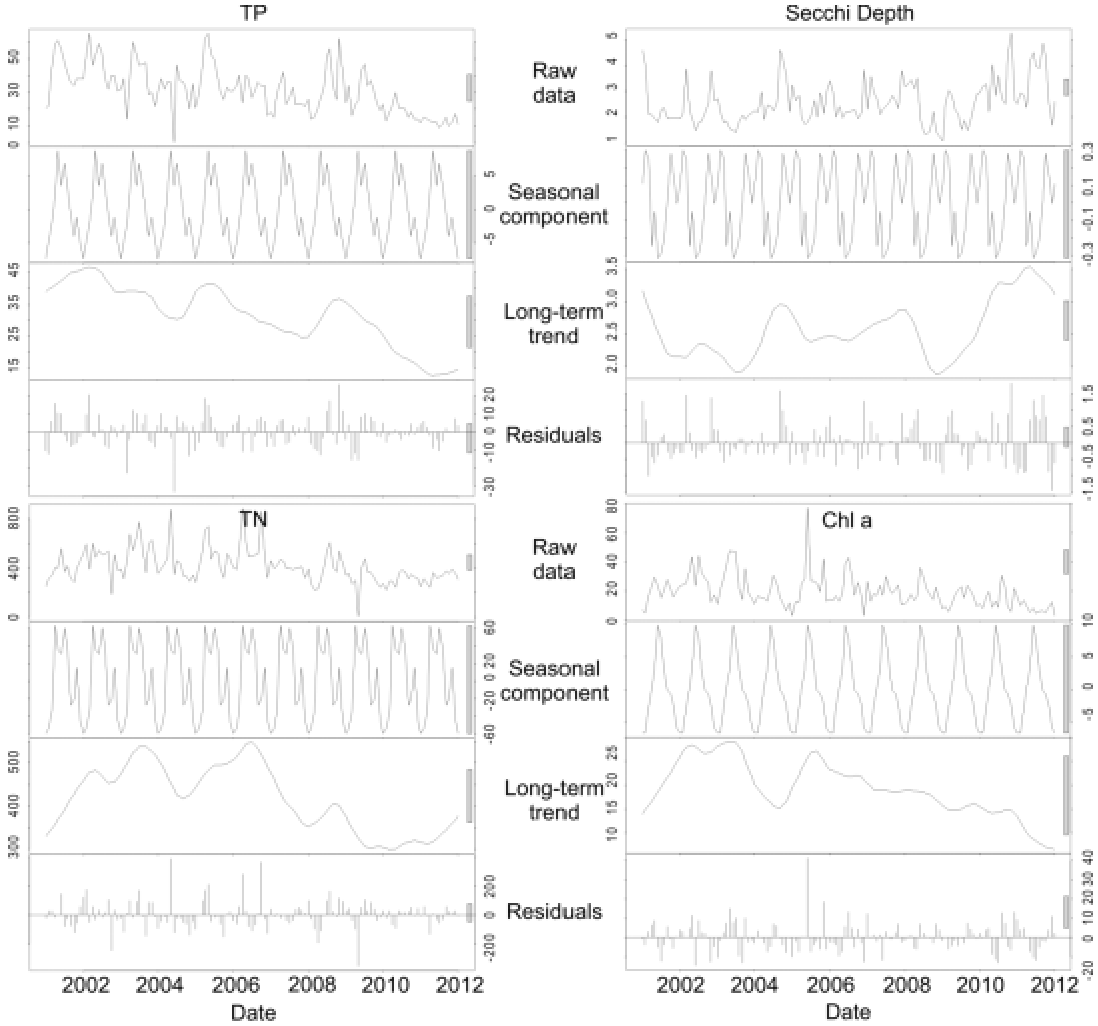

Figure 4.2 Decomposed time-series components for site 5 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by 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^3m^{-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 7.7.

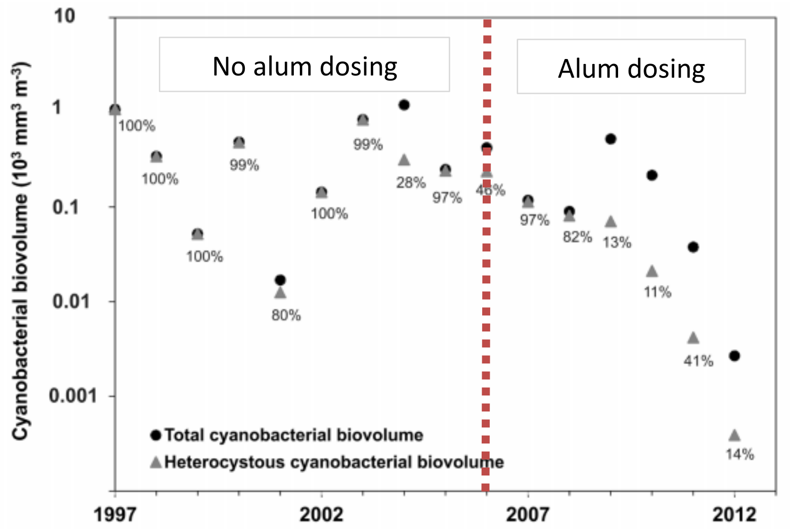

Fig. 7. Total cyanobacterial biovolumes and total heterocytous cyanobacterial biovolumes. Percentages show proportion of heterocytous cyanobacteria in each sample. Data are averages from 4 sites around the edge of Lake Rotorua (Hamurana, Holdens Bay, Ngongotaha, and Ohau Channel Bay).