Rotorua Lakes Water Quality Report 2009

Environment Bay of Plenty
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Cover Photo: Lake Rotorua

Acknowledgements

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Executive Summary

The water quality of the Rotorua Lakes has been monitored by Environment Bay of Plenty since 1990. This monitoring forms one of the modules of the Natural Environment Regional Monitoring Network (NERMN), a programme for general 'state of the environment' monitoring.

The emphasis of this report is on the Trophic Level Index (TLI) for each of the Rotorua Lakes which is based on physico-chemical monitoring. Ecological monitoring also forms part of the overall assessment of lake quality and is primarily based on the cyano-bacteria and macrophyte monitoring programmes (adventive macropyte surveillance and LakeSPI) undertaken by both Environment Bay of Plenty and NIWA.

All of the Rotorua Lakes exceed the TLI set in the RWLP (Objective 11). Method 41 of the Plan requires Action Plans to be implemented where the three-year average TLI is exceeded by 0.2 units for two consecutive years and this is the case for most of the lakes.

Action Plans have been completed for Lakes Okareka, Okaro, Rotoehu, Rotorua-Rotoiti and Rotoma. Lakes Tarawera, Tikitapu, Rerewhakaaitu, and Okataina have action plan processes underway or will have in the coming year. An action plan for Rotomahana is less urgent as the TLI does not exceed the 0.2 unit trigger.

Three yearly average TLI values for the Rotorua District lakes in comparison to the TLI values set in the Regional Water and Land Plan, and LakeSPI condition.

Lake	3 yearly average TLI to 2009 TLI units	Regional Water & Land Plan TLI units	LakeSPI Condition 2008/2009	Lake Type based on Trophic Level
Okaro	5.3	**5.0**	Poor	Supertrophic
Rotorua	4.7	**4.2˜**	Moderate	Eutrophic
Rotoehu	4.5	**3.9˜˜**	Poor	Eutrophic
Rotoiti	3.9	**3.5˜**	Poor	Mesotrophic
Rotomahana	4.0	**3.9ˆ**	High	Mesotrophic
Rerewhakaaitu	3.7	**3.6ˆ**	Moderate	Mesotrophic
Okareka	3.3	**3.0ˆ**	Moderate	Mesotrophic
Tikitapu	3.0	**2.7ˆ**	Moderate	Oligotrophic
Okataina	2.8	**2.6ˆ**	Moderate	Oligotrophic
Tarawera	2.9	**2.6ˆ**	Moderate	Oligotrophic
Rotoma	2.6	**2.3ˆ**	High	Oligotrophic
Rotokakahi	4.0	**3.1**	Moderate	Mesotrophic

*Extrapolated three yearly TLI average. (Rotokakahi has not been monitored in the last three years)
ˆBased on 1994 data. ˜˜Based on 1993 data. ˜Based on 1960 data.

Contents

Tables and Figures

Part 1: Introduction

The water quality of the Rotorua Lakes has been monitored by Environment Bay of Plenty since 1990. This monitoring forms one of the modules of the Natural Environment Regional Monitoring Network (NERMN), a programme for general 'state of the environment' monitoring.

The main objective of this report is to update the Trophic Level Index (TLI) for the 12 Rotorua Lakes (Figure 1.1) with data collected from 1 July 2008 to 30 June 2009. The TLI is an indicator of the environmental quality of a lake and is composed of two biological and two chemical components. This information is supplemented with oxygen monitoring data and other information including the status of submerged plants ('LakeSPI') and presence of blue-green algal blooms.

Each of the Rotorua Lakes (excluding Lake Rotokakahi) is sampled monthly and has an objective TLI based on past lake water quality (Objective 11 of the Regional Water and Land Plan). If a lake TLI exceeds its TLI objective by 0.2 TLI units for two years (based on a three year moving average) then Method 41, Rule 11 applies. Method 41 involves the development and implementation of action plans to improve water quality formulated in conjunction with appropriate parties.

For each of the lakes action plans have been or will be developed. These plans will be instrumental in formulating management decisions that once implemented will help to reduce the nutrient load to the lakes, enhance water quality and/or halt deterioration. A risk assessment has also been undertaken (as outlined by Method 41) for the seven lakes without existing action plans.

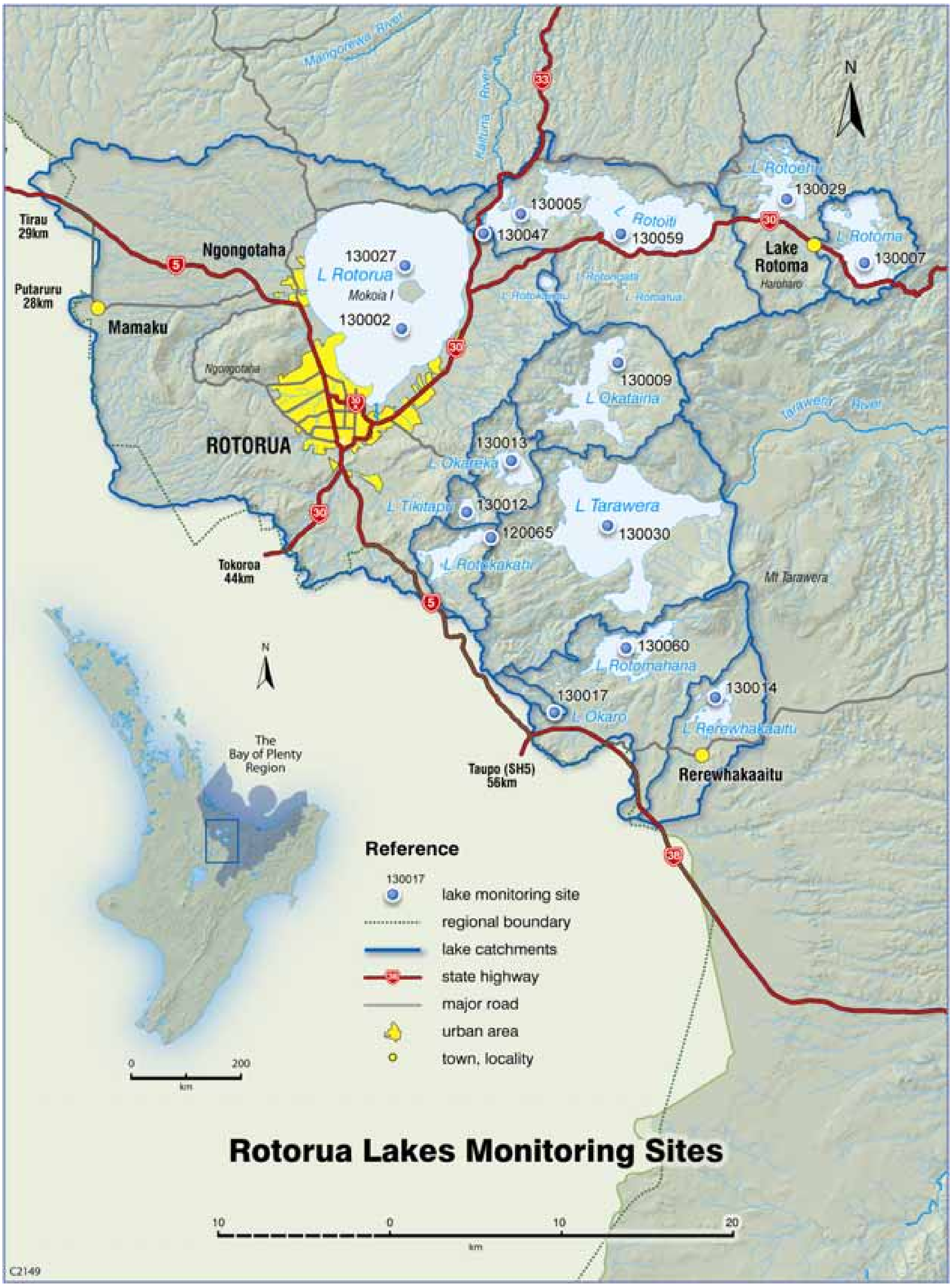


Figure 1.1 Location of the Rotorua Lakes and water quality monitoring sites.

Part 2: TLI results and discussion

Monitoring programmes have been developed to provide water quality and ecological information for each of the Rotorua Lakes. This information is needed to manage lake water quality effectively. Programmes include physico-chemical water quality monitoring, algal monitoring and macrophyte (submerged plant) monitoring using the LakeSPI index.

Each of the Rotorua Lakes is sampled monthly at single or multiple deep water sites. Profiles of temperature, dissolved oxygen, conductivity and algal fluorescence are recorded using a data logger with a sensor array. Sampling is dependant upon lake stratification with samples taken to represent the epilimnion (top layer) and the hypolimnion (bottom layer).

TLI analysis has been performed with the aid of the 'LakeWatch' database. The LakeWatch software is a useful tool for monitoring observations and trends in a lake's chemical and physical state and for the computation of the Trophic Level Index (TLI).

LakeWatch evaluates the trend in each lake based on the statistical significance of the Percent Annual Change (PAC). Comments on the change in a lake relate to the average percent change of secchi depth (water clarity), chlorophyll *a* (indicating algal biomass levels), total nitrogen, total phosphorus and the oxygen depletion rate (HVOD).

In this report the observations and trends identified cover the periods for which Environment Bay of Plenty has data. If a different period was chosen for magnitude of the trend would be different. This can result in quite different trends from year to year depending on the analysis period.

2.1 Trophic Level Index

The Trophic Level Index (TLI) is an indicator of lake water quality. It is compiled using data on total nitrogen (TN), total phosphorus (TP), chlorophyll a (Chl-a), Secchi disc (SD) and, if applicable, hypolimnetic dissolved oxygen data (Burns, 2001).

The LakeWatch software programme has been used to help analyse the water quality data in this report including calculation of TLI and PAC values. Full details of how LakeWatch functions can be found in Burns *et al.* (2000), and Burns (2001).

2.1.1 Dissolved oxygen and temperature

Dissolved oxygen (DO) and temperature are measured at intervals from the lake surface to the lake bottom. Over the summer most of the lakes stratify into layers. During this time the deeper layer (the hypolimnion) becomes isolated from atmospheric oxygen and oxygen charged surface water which is a vital source of oxygen renewal. The rate at which oxygen is lost (the Hypolimnetic Volumetric Oxygen Depletion rate, HVOD) is a measure of lake water quality. It is a relative measure of how fast oxygen is consumed by micro-organisms and chemical reactions in the hypolimnion. If the hypolimnion becomes devoid of oxygen, nutrients (nitrogen and phosphorus) can be released from the sediment into the water and then diffuse throughout the whole lake when mixing occurs at the onset of winter.

DO readings are performed by lowering a DO sensor through the water column. A problem was found with the DO data measured from January 2007 to July 2007 due to a pump limitation setting not being correctly set after calibration of the instrument. This has resulted in significantly lower oxygen readings over this period although HVOD rates are still able to be calculated.

2.1.2 Nitrogen and phosphorus

The nutrients nitrogen and phosphorus are among the essential elements for much of the primary production in a lake. Phosphorus and nitrogen can be limiting factors for primary productivity (by algae and submerged plants) within a lake and are also the main drivers of lake quality. Changes to the lake catchments within the last century have in many cases increased the load of nutrients entering the lakes. As nutrient levels increase, algal cell numbers and density increase, and water clarity decreases. This phenomenon is often referred to as eutrophication or nutrient enrichment.

Because of the important role that nitrogen and phosphorus play in lake productivity the management of lakes typically focuses on controlling the loads of these nutrients.

2.1.3 Chlorophyll *a*

Chlorophyll *a* is the major pigment in live algal and plant cells. The concentration of chlorophyll *a* in lake water gives a measure of the amount of algae in the lake. Algae settle out onto the lake bed as they die forming a build up of organic matter. If the lake is stratified, oxygen is consumed as the algae decay reducing the supply of oxygen in the bottom layer (the hypolimnion). If all the oxygen is consumed in the hypolimnion then this layer becomes anoxic (devoid of oxygen) and reducing conditions change the chemical equilibrium at the sediment-water interface. These are the conditions that promote the release of nutrients from the bottom sediments (see 2.2.1).

2.1.4 Secchi disc depth

This is a measure of clarity and is measured as the maximum depth below the lake surface that the black and white Secchi disc is visible.

Between 2000 and 2001 a change in the method of measuring secchi depth was introduced. From June 2000 a viewing tube was used which increases the accuracy of the measurement by cutting out reflective light from the water surface thereby generally increasing depth measurements.

Due to this difference between data sets (pre-viewing tube and post-viewing tube) secchi depth data was correlated against vertical light extinction data (measured using a light sensing instrument) to produce a model representative of the difference between the two secchi methods. In the past three annual Lakes Reports this difference has been applied to the secchi data from June 2000 to July 2006 to adjust the data to be representative of secchi depth measured without a viewing tube. Over this period data secchi data was collected with and without the viewing tube.

This report uses secchi data obtained using the viewing tube, i.e. data from June 2000 onwards. Data previous to the June 2000 date has been modelled and adjusted for each lake based on correlation of secchi measurements with and without the viewing tube.

2.1.5 Percent Annual Change

Percent Annual Change (PAC) allows an estimate to be made of the probability of change. PAC is determined by calculating the slope of the regression line of the residuals in the data and dividing this by the average value of the variable (i.e. secchi depth, chlorophyll *a*, total nitrogen, total phosphorus, and the oxygen depletion rate (HVOD)) during the period of observation. PAC values are calculated only from significant trends ($p<0.05$) determined by parametric analysis of deseasonalised data.

Calculation of the PAC value for a lake over the analysis period is then based upon averaging only significant PAC values for each variable, as well as a *p*-value. If a *p*-value is < 0.05 then a trend is accepted as significant (Burns, 2001). The PAC value along with its standard error shows the scale of change in the lake, with increased eutrophication assigned positive values and decreased eutrophication negative values. The higher the *p*-value the more unlikely it is that the lake has changed with time.

2.2 Lake types

The following table shows the range of each of the four key values that are used to calculate the TLI within the LakeWatch database, and the numerical range of TLIs that defines each lake type. Based upon the quantitative TLI assessment, the lakes are assigned a descriptive term (the Trophic Status).

Table 2.1 Lake classification based on the four TLI variables.

Lake Type (Trophic State)	Trophic Level Index	Chl*a* ($mg.m^{-3}$)	Secchi Depth (m)	TP ($mgP.m^{-3}$)	TN ($mgN.m^{-3}$)
Ultra-microtrophic	**0.0 – 1.0**	0.13 – 0.33	31 – 24	0.84 – 1.8	16 – 34
Microtrophic	**1.0 – 2.0**	0.33 – 0.82	24 – 15	1.8 – 4.1	34 – 73
Oligotrophic	**2.0 – 3.0**	0.82 – 2.0	15 – 7.8	4.1 – 9.0	73 – 157
Mesotrophic	**3.0 – 4.0**	2.0 – 5.0	7.8 – 3.6	9.0 – 20.0	157 – 337
Eutrophic	**4.0 – 5.0**	5.0 – 12.0	3.6 – 1.6	20.0 – 43.0	337 – 725
Supertrophic	**5.0 – 6.0**	12.0 – 31.0	1.6 – 0.7	43.0 – 96.0	725 – 1558
Hypertrophic	**6.0 – 7.0**	> 31.0	< 0.7	> 96.0	> 1558

2.3 Cyano-bacteria monitoring

The presence of toxin producing blue-green algae species (cyano-bacteria) and the occurrence of blooms of these in the lakes is a natural phenomenon. However, the intensity of the blooms is increased by inputs of nutrients from human activities. Blooms occur in some of the ‘cleaner’ (oligotrophic) lakes (including Lakes Tarawera and Okataina). A number of the lakes have a history of cyano-bacteria blooms brought on by artificially elevated nutrient enrichment.

The cyano-bacteria monitoring programme was set up in 1997 after blooms exceeded levels safe for drinking and recreation in four of the Rotorua lakes (Lakes Okaro, Rotoiti, Rotorua, and Rotoehu). Blooms have affected these lakes on an almost annual basis since 1997. At least two other lakes and the Kaituna River are also affected by blooms intermittently. The monitoring programme has now been tailored to anticipate and pre-empt periods of heightened bloom activity to enable timely health warnings. Advice given by the District Health Board is that it is no longer safe to drink from these lakes but that water sports may still be safe provided bloom activity remains at low levels.

A number of blue-green algae are known to produce cyanotoxins. These include the cyclic peptides (microcystin and nodularin) alkaloids (cylindrospermopsin, anatoxins and saxitoxins) and lipopolysaccharides (LPS) (Wood 2004). Microcystin and its various analogues are the most prevalent cyanotoxin in the Rotorua Lakes and therefore also potentially the most harmful. There are numerous documented cases of toxicity and fatalities in wild and domestic animals from microcystis blooms in stock drinking water supplies.

The only documented cases of human fatalities involving microcystins resulted from contaminated water at a dialysis treatment clinic in Caruaru, Brazil. There is epidemiological evidence showing that long-term exposure to microcystins (even at low levels) may pose a cancer risk to humans. There are also results from animal studies demonstrating the potential for promotion of tumour growth. Microcystins may also cause progressive active hepatic injury (liver damage). Hence, people repeatedly exposed to the water contaminated with microcystins are at the highest risk (*pers. comm*. Susie Wood).

The Medical Officer of Health (MO) relies on cell counts provided by Environment Bay of Plenty and on the results of toxicity tests to determine whether cyano-bacteria blooms pose a public health risk and therefore whether health warnings are required. The cyano-bacteria monitoring programme targets areas where the public is likely to have the greatest exposure to cyano-toxins (either through immersion, consumption or inhalation of water affected by cyano-toxins or irritants).

2.4 LakeSPI and adventive macrophyte surveillance programme

LakeSPI was developed specifically to monitor the ecological health of lakes and a programme has been tailored by NIWA specifically for the Rotorua Lakes. The LakeSPI programme monitors macrophytes which are used as Submerged Plant Indicators (SPI) to classify the ecological condition of the lakes.

Underpinning LakeSPI is the principle that the ecological status of a lake can be characterised by the composition of native and invasive plants and the changing ratio of both plant groups over time. A pristine lake is typically one in which there are no invasive weed species and where the lake contains intact native macrophyte beds right down to their natural maximum depth limit[1] and an abundance of koura (crayfish) and kakahi (freshwater mussels). A worst-case scenario is likely to be one in which there are no koura, kakahi or plants, native or invasive.

Many of the lakes contain the most invasive macrophyte species and in these lakes the condition of the native macrophytes continues to decline. For example, in Lake Tarawera hornwort (*Ceratophyllum derersum*), which took just five years to spread around the lake, continues to smother the deep-occurring native (charophyte) beds.

[1] The maximum depth native aquatic plants could be expected to grow in an unmodified lake.

There is still a risk of new invasive plant species being introduced into pest plant free lakes. The Adventive Macrophyte Surveillance Programme targets six lakes: Lakes Rotoma, Rerewhakaaitu, Okataina, Rotokakahi, Tikitapu, and Rotomahana. Lake Okaro is added to the surveillance list because although it is highly degraded in water quality terms, this lake is presently free of the most damaging pest plant species.

Part 3: Results

Trophic Level Index data for the 2008/2009 year is summarised in Table 3.0. For each of the TLI parameters the annual TLIx is given. TLp-TLn is also shown to give an indication of nutrient limitation of a lake: positive being more phosphorus limited; negative being more nitrogen limited. Some lakes will be co-limited.

Three yearly average TLI results to the 2009 and 2004 years are also given in Table 3.0 for comparison of the current trophic state with that which occurred five years previously.

Summary data for each lake on the annual average TLI parameters, PAC values, and TLIx components are given in Appendix 1.

Table 3.0 Summary data for the Rotorua Lakes, 1990 to 2007 (analysis periods for lakes vary).

	Okareka	**Okaro**	**Okataina**	**Rerewhakaaitu**	**Rotoehu**	**Rotoiti**	**Rotoma**	**Rotomahana**	**Rotorua**	**Tarawera**	**Tikitapu**	**Rotokakahi**
Lake area (km^2)	3.3	0.33	10.8	5.8	8.1	34.6	11.2	9.0	80.8	41.7	1.5	4.5
Catchment Area (km^2)	19.6	3.9	59.8	37.0	49.2	123.7	27.8	83.3	508.0	143.1	6.2	19.7
Max. depth (m)	33.5	18	78.5	15.8	13.5	124	83	125	45	87.5	27.5	32
Av. TLc (TLI units)	3.8	5.9	3.0	3.7	4.8	4.4	2.5	3.9	5.2	2.7	2.9	4.5
Av. TLs (TLI units)	2.9	4.7	2.6	3.5	4.0	3.6	2.3	3.7	4.4	2.9	3.2	-
Av. TLp (TLI units)	2.6	6.0	2.8	2.8	5.1	4.3	2.0	4.4	4.9	3.0	2.2	4.0
Av. TLn (TLI units)	3.4	5.6	2.8	4.2	3.7	3.8	2.9	3.5	4.3	2.6	3.4	3.7
Av. Annual TLI 09' (TLI units)	**3.3**	**5.3**	**2.8**	**3.9**	**4.4**	**3.9**	**2.6**	**4.0**	**4.7**	**2.8**	**3.1**	**4.1**
TLp-TLn	-0.80	0.43	-0.01	-1.35	0.48	0.50	-0.90	0.95	0.56	0.42	-1.15	-0.10
3-yr Av. TLI to 04'	3.2	5.5	3.0	3.4	4.6	4.3	2.5	3.7	4.9	2.9	3.2	3.5
3-yr Av. TLI to 09'	3.3	5.3	2.8	3.7	4.5	3.9	2.6	4.0	4.7	2.9	3.0	4.0

3.1 Lake Okareka

TLI 3 year average = 3.3
TLI 2008/2009 = 3.32
TLI Objective = 3.0

PAC 1992-2009 = 0.39 (*p*=0.66)

Mesotrophic

% LakeSPI 2009 = 33 *Moderate*

Lake Okareka is located in an ignimbrite plateau and has steep caldera walls on its north-eastern side, testament to the processes that formed the Haroharo Caldera. The lake receives most of its input via groundwater seepage, runoff and rainfall. The lake level is controlled via a valve at Waitangi Spring and a channelled and piped stream. The discharge flows into Lake Tarawera.

The lake is subject to nutrient enrichment from septic tank inputs and pasture, although the pastoral area is decreasing (Table 3.1). Okareka is of high recreational and aesthetic value and has been undergoing some in-lake treatment to reduce phosphorus levels.

Table 3.1 Lake Okareka attributes.

Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	18.7	Exotic forest	0.0	2.6	7.6
Lake area (km^2)	3.43	Indigenous forest/scrub	44.4	38.1	51.6
Maximum depth (m)	33.5	Pasture	55.6	55.8	37.8
Mean depth (m)	20	Urban		2.9	2.9
Altitude (m)	355				
Age (x 1000 years)	19				

3.1.1 TLI results and trends

The TLI increased from 3.22 TLI units in 2007/2008 to 3.32 in 2008/2009 (Figure 3.2). The three yearly average indicates little change over the last five years. Phosphorus and Chl-a are the two parameters of note that have shown an increase compared to previous years.

Nitrogen levels are reasonably stable with some decline in the 2008/2009 year (Figure 3.1). Nitrate and ammonium are showing recent increasing trends (since 2001), ammonium-nitrogen in the epilimnion only.

Water clarity remains stable although the long term trend is a decreasing one. Likewise, chlorophyll-a concentrations are also stable although a slightly higher winter peak occurred in 2008.

Figure 3.1 TN, TP & Chla concentrations & secchi depths with deseasonalised residuals, 1992 to 2009.

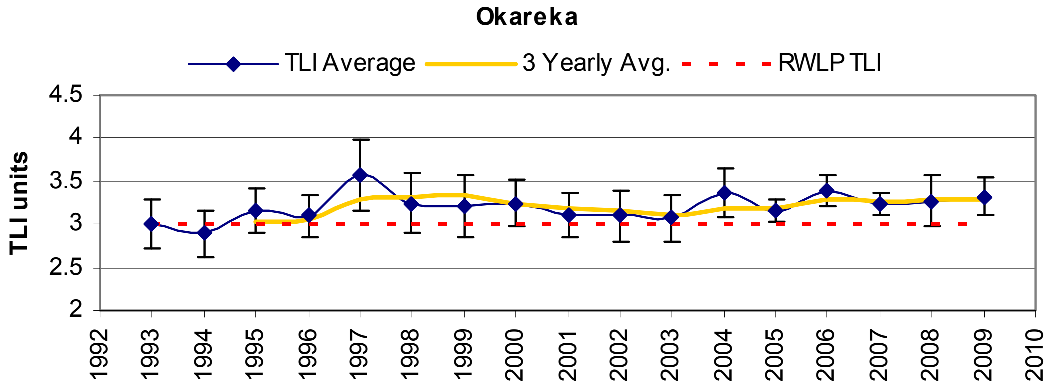


Figure 3.2 Annual TLI averages with standard error bars, 3 yearly average TLI and RWLP TLI objective for Lake Okareka.

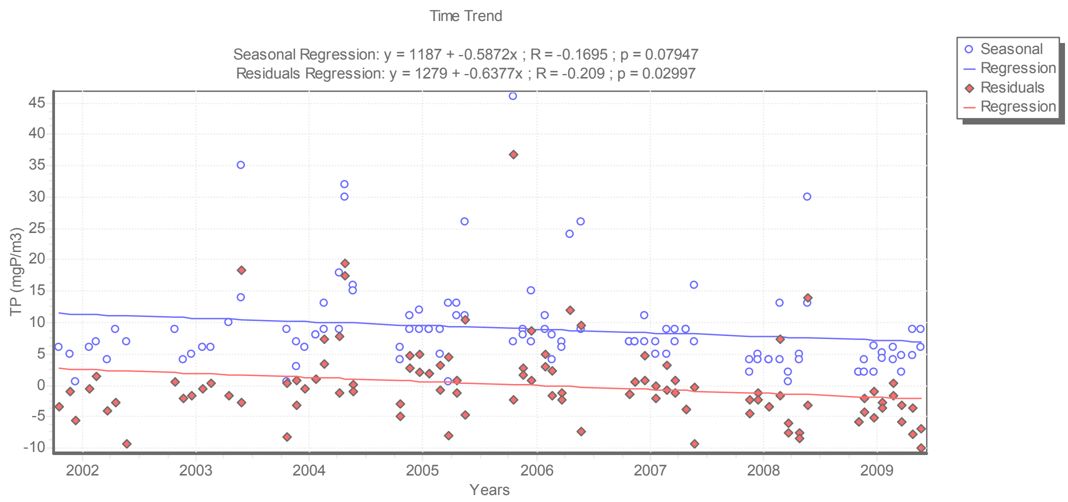


Figure 3.3 Hypolimnetic TP concentrations with deseasonalised residuals and trend.

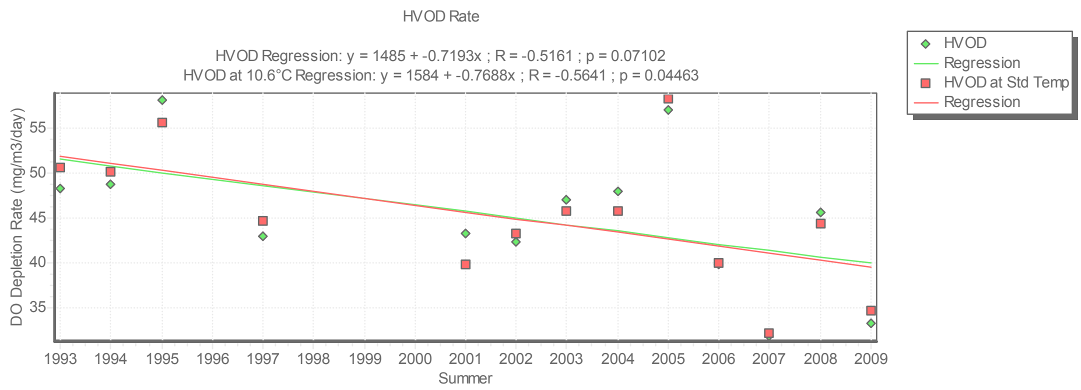


Figure 3.4 HVOD rates, Lake Okareka, 1993 to 2009.

Lake Okareka typically stratifies in early October and becomes isothermal (fully mixed) in late May to early June. Anoxia can occur within 140 days and depletion rates (HVOD) have been improving (Figure 3.4) with depletion of 34.7 mg/m^3/day at a standard temperature of 10.6 degrees recorded in 2008/2009. This is lower than the rising HVOD values that occurred in 2001 to 2005.

3.1.2 Blue-green algae

Over the last two to three years potentially toxic cyano-bacteria species have been recorded twice in Lake Okareka. Although blooms have been short-lived, Okareka has joined a number of lakes that are now monitored occasionally.

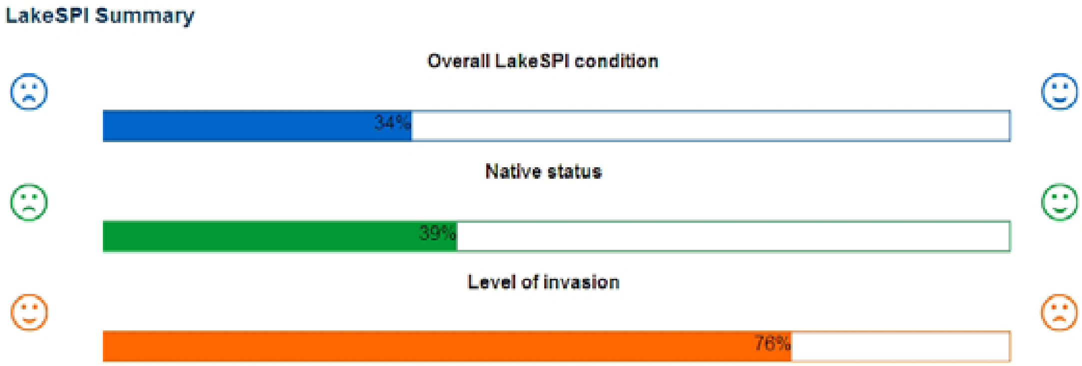
3.1.3 LakeSPI (Submerged Plant Indicators)

Egeria was first reported in Lake Okareka in 2000 and continues to spread around occupying deeper water than the longer established pest weed Lagarosiphon. As yet the lake is still free of hornwort, but if accidentally introduced this species would be expected to eliminate all remaining deep water native charophyte meadows.

LakeSPI 2009 rank: 5th highest ranked lake for LakeSPI

Current condition: average

Long-term trend: declining



3.1.4 Lake Management

The Lake Okareka Catchment Management Plan was agreed in 2004. This is a long-term plan to improve the water quality of the lake, through interventions like sewage reticulation, in-lake chemical treatment and farm nutrient management.

Sewage reticulation is progressing with the help of Government funding. Reticulation for nearby Lake Tikitapu is expected to be completed by October 2010.

Since 2006, phosphorus levels have been decreasing in the hypoliminion (bottom waters) due to Phoslock applications reducing phosphorus-release from the sediment. Nitrogen levels have stayed fairly constant. There are indications that more phosphorus is entering the lake from septic tank sources than previously thought.

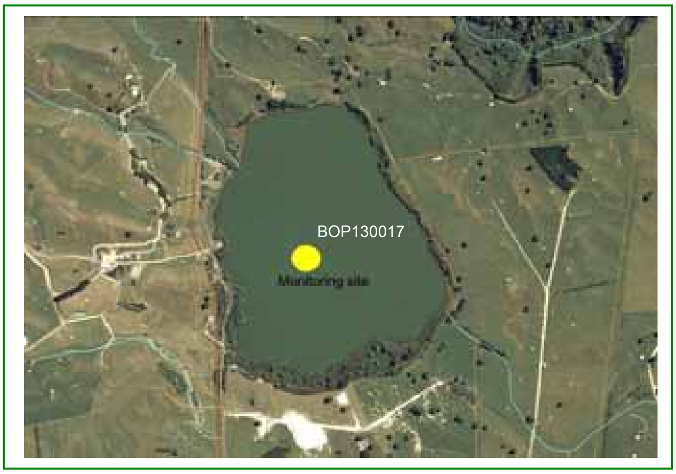
Phoslock, a lanthanum clay-based phosphorus-removing product, was applied to the lake yearly over the period 2005 – 2007. Monitoring after the first application indicated a potential decline in fish health but further monitoring (before the second application) showed fish health to be improved compared to those in Lake Tikitapu. The apparent decline was found to be a normal seasonal change in the trout physiology. Further studies have shown some bioaccumulation of lanthanum in trout and koura but with no detrimental health affects to either.

Several land management options are also addressed by the action plan including:

- Enhancing marginal wetland areas.
- Best practice farm management options with rural landowners.
- Provision for land use changes.

The catchment plan also considers other options including bio-manipulation, restriction of pest fish and weeds and filtering of stormwater.

3.2 Lake Okaro



TLI 3 year average = 5.3
TLI 2008/2009 = 5.29
TLI Objective = 5.0

PAC 1991-2009 = -1.07%/yr (p=0.2)

Supertrophic

% LakeSPI 2008 = 21 Poor

Lake Okaro is surrounded by pasture, is the smallest of the Rotorua Lakes and has the smallest catchment. Besides direct inputs from rainwater and overland flow, the lake is fed by several small streams and has an outlet stream (Haumi Stream) to the east draining to Lake Rotomahana.

Lake Okaro has an average depth of around 12 metres and sampling occurs at the maximum lake depth of 18 metres.

Table 3.2 Lake Okaro attributes.

Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	3.89	Exotic forest	0.0	0.7	6.3
Lake area (km^2)	0.31	Indigenous forest/scrub	0.0	3.6	2.1
Maximum depth (m)	18	Pasture	100.0	95.7	90.6
Mean depth (m)	12.1	Urban	0.0	0.0	0.0
Altitude (m)	423				
Age (x 1000 years)	0.8				

3.2.1 TLI results and trends

Lake Okaro's three yearly average TLI continues to remain stable at 0.3 TLI units above its RWLP TLI target of 5.0 units (Figure 3.5).

Total nitrogen has remained reasonably constant over the past seven years (Figure 3.6) which is likely to be due to a stable algal biomass. Dissolved inorganic nitrogen has shown some decline in the hypolimnion over the past few years.

The sediment capping intervention applied to Lake Okaro continues has caused a marked improvement in phosphorus concentrations in the lake (Figure 3.6). TP levels have continued to decline since alum treatment begun in 2005. DRP has also been significantly reduced although there was in increase in DRP in the epilimnion in the late summer/early autumn of 2009, possibly due to inflows.

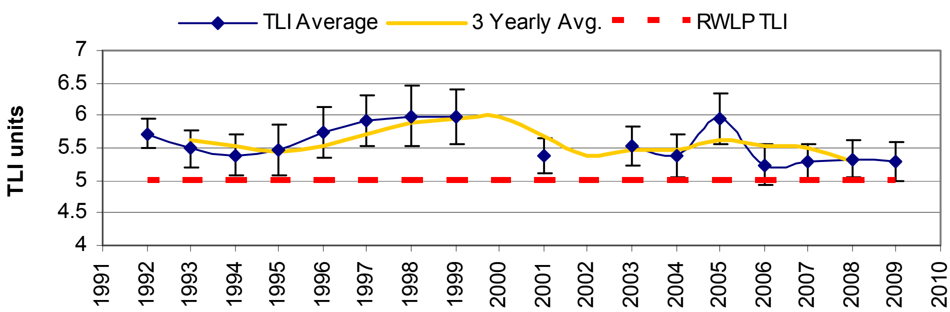


Figure 3.5 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for lake Ōkaro.

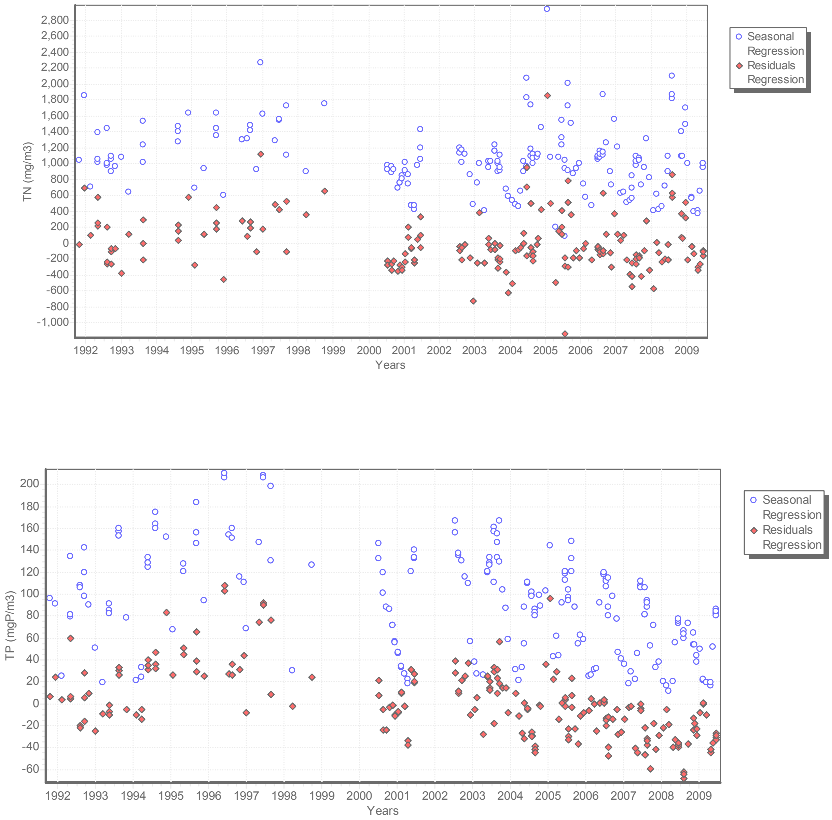


Figure 3.6 TN and TP concentrations with deseasonalised residuals, 1991 to 2009.

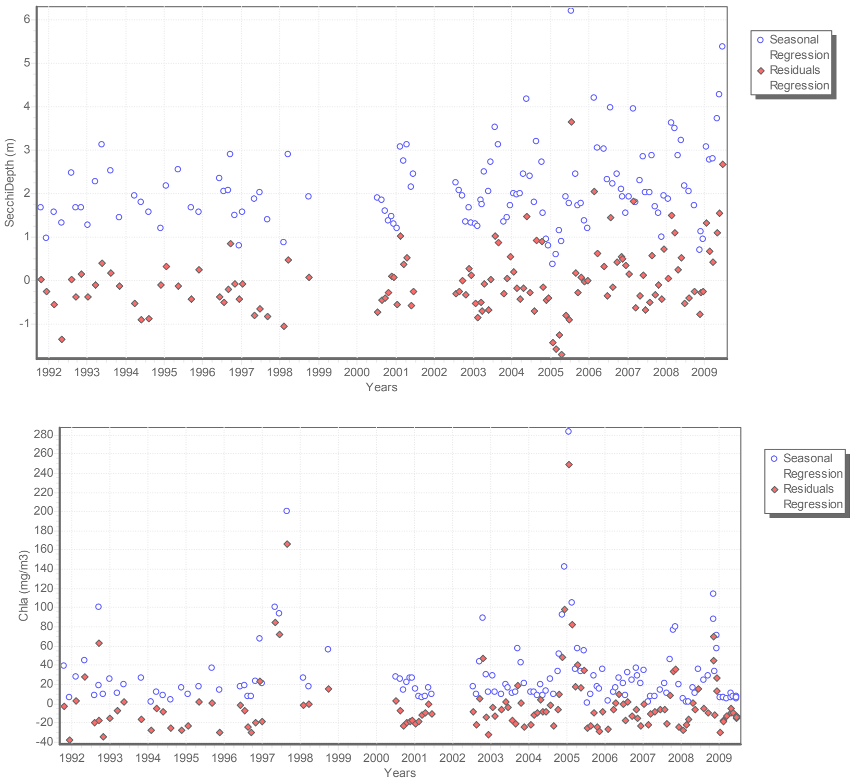


Figure 3.7 Chla concentrations and secchi depths with deseasonalised residuals, 1991 to 2009.

Secchi disc water clarity has on average improved although an intense algal bloom in the early summer of 2008/2009 reduced the visibility to less than 1 metre. Figure 3.7 shows that the Chl-a concentrations quickly returned and remained at a very stable level for the next six months as water clarity continued to improve.

Oxygen levels continue to be rapidly depleted with the onset of stratification around late September (Figure 3.8). There has been a decline in the HVOD rate in the past three years from 114 mg/m^3/day in 2007, taking around 60 days to move into anoxia, to 42 mg/m^3/day in 2009, taking almost twice as long to move into anoxia.

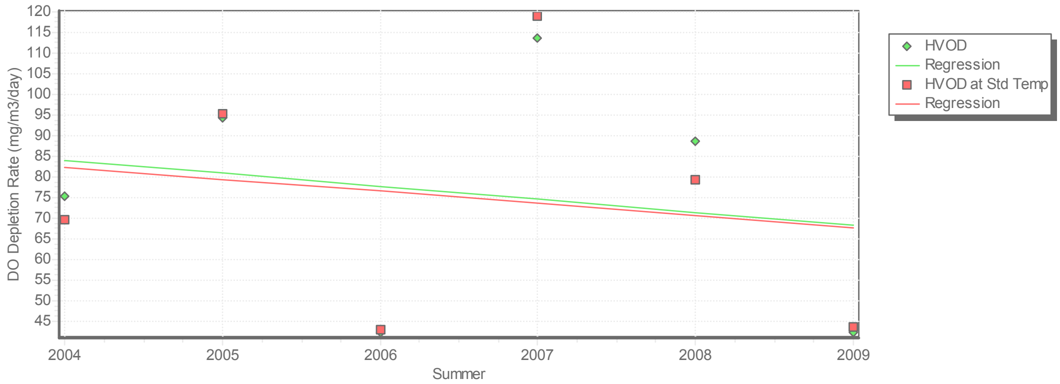


Figure 3.8 HVOD rates, Lake Okareka, 2004 to 2009.

3.2.2 Blue-green algae

Lake Okaro is historically one of the first lakes to bloom and is often also the first to resolve itself. In 2008, Lake Okaro began blooming on the 20th of November, nearly 2 months earlier than Lake Rotoehu, the next lake to bloom. The bloom in Okaro ebbed and its health warning was lifted on the same day as the first of Lake Rotoehu's health warnings were imposed for the season.

Where in 2008/2009 other lakes experienced a return to *Microcystis* dominated blooms, Lake Okaro's initial blooms were almost entirely dominated by *Anabaena* species. It was only midway through January that *Aphanocapsula holsatica*, a pico-cyanobacteria species, began dominating before it too crashed along with other cyano-bacterial species at the end of January.

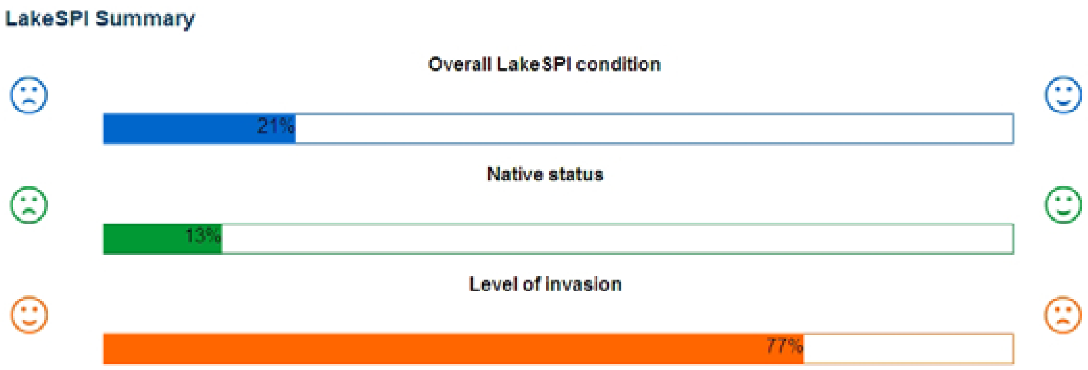
3.2.3 LakeSPI (Submerged Plant Indicators)

Poor water clarity in Lake Okaro restricts plant growth to the shallow margins and the super-eutrophic condition of the lake provides poor conditions for submerged plant growth. While the lake contains few invasive weed species, the native condition index is the lowest of the 12 lakes and subsequently the LakeSPI score is one of the lowest recorded.

LakeSPI 2009 rank: 10th lowest ranked lake for LakeSPI

Current condition: poor

Long-term trend: stable



3.2.4 Lake management

There is an operative action plan formulated for Lake Okaro and a working party established to focus on management objectives. The primary objective is to reduce external and internal nutrient loads.

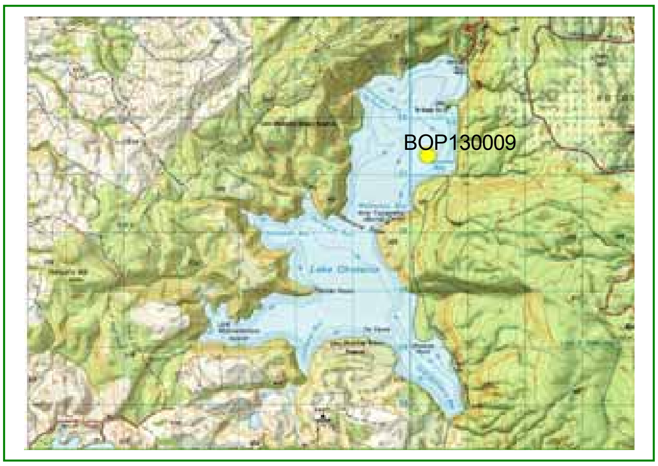
A 2.3 hectare wetland has been constructed and is designed to intercept dissolved nutrients through incorporation into organic matter within the wetland and through denitrification of nitrate to nitrogen gas.

Several treatments of sediment capping agents have been applied to the lake, the first being an application of alum in 2003. Two treatments of alum coated zeolite have been made to the lake, one in 2007 and the second in July 2009.

Other key actions to be implemented are:

- P-absorbent lake bed cap.
- Full riparian protection.
- Allophane treatment of main inflow for to remove phosphorus.
- Stormwater detention on farmland.
- Best management practices with rural landowners.
- Ongoing monitoring.

3.3 Lake Okataina



TLI 3 year average = **2.8**
TLI 2008/2009 = ***2.84***
TLI Objective = 2.6

PAC 1992-2009 = 1.18%/yr
(p=0.18)

Oligotrophic

% LakeSPI 2009 = 45 moderate

Lake Okataina has a moderately sized catchment at around 60 km^2. The catchment is mostly in native forest and scrub (84%) through which the majority of inflows to the lake appear as sub-surface and surface water runoff. There is no surface outflow but it is likely that there is subterranean outflow to Lake Tarawera. Monitoring of the water quality in Lake Okataina occurs in the shallower of its two basins.

Table 3.3 Lake Okataina attributes.

Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	59.8	Exotic forest	3.6	5.7	7.8
Lake area (km^2)	10.8	Indigenous forest/scrub	85.8	84.6	84.1
Maximum depth (m)	78.5	Pasture	10.7	9.6	7.8
Mean depth (m)	39.4	Urban	0.0	0.0	0.0
Altitude (m)	311				
Age (x 1000 years)	7				

3.3.1 TLI results and trends

The TLI for Lake Okataina remains above the RWLP objective but has decreased compared to the previous year (Figure 3.9). A downward trend of the three yearly average TLI has occurred over the last five years.

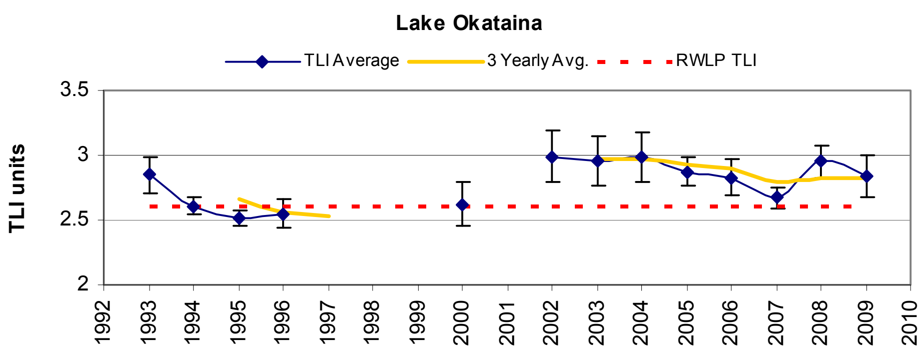


Figure 3.9 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Okataina.

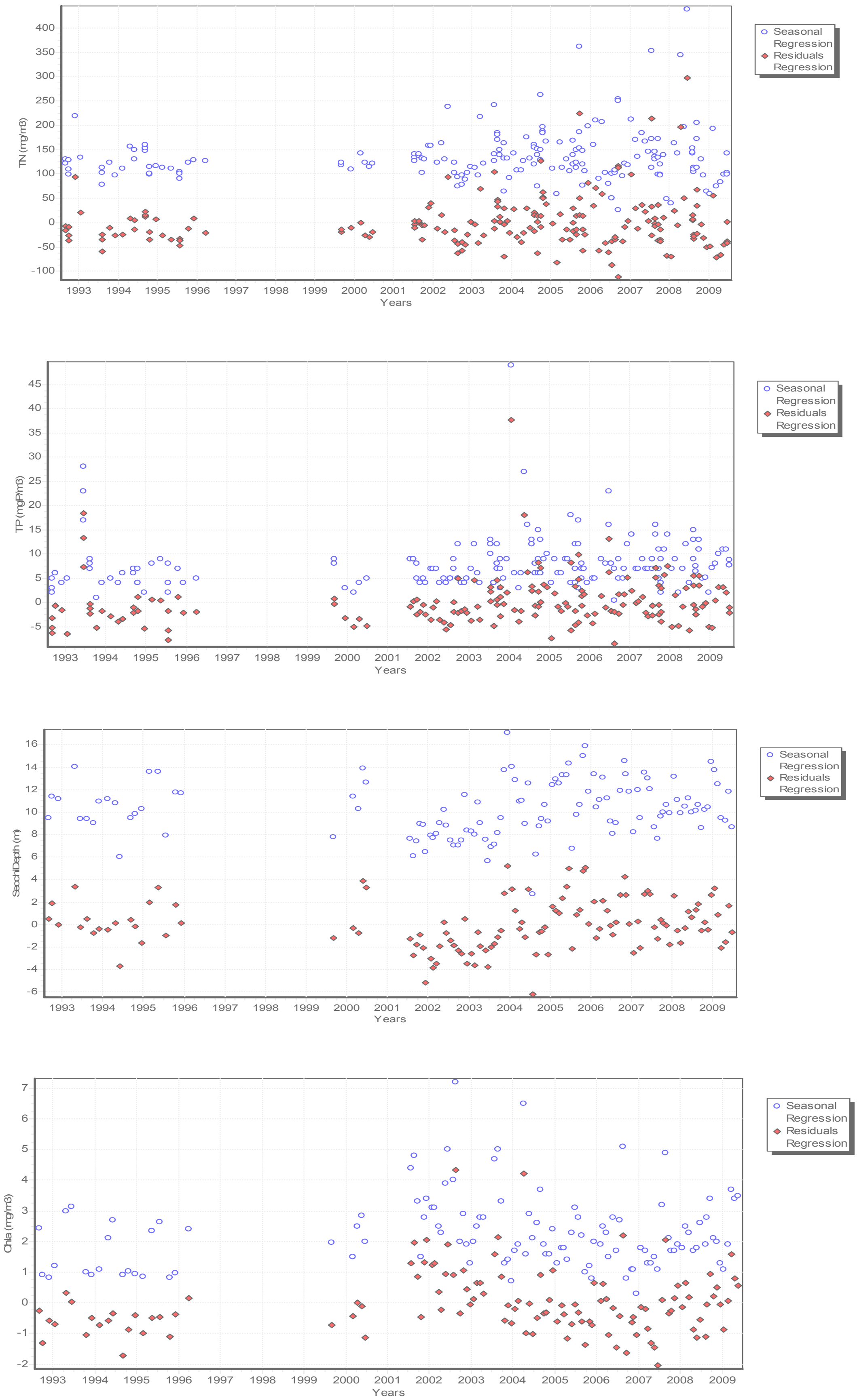


Figure 3.10 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1992 to 2009.

Average TN concentrations for 2008/2009 show a decrease although Chl-a average concentrations have increased (Figure 3.10). A similar pattern occurred in 2002/2003 and may be due to lake level fluctuations.

TP has remained stable over the past five years. TP increased in the hypolimnion in 2008/2009 although not to the extent that occurred in 2004 when the lake level was at its lowest recorded in the last 10 years.

Water clarity remains on average above 10 metres. There is a trend of improving water clarity since 2001 ($p<0.01$), however this may show a slight decline since 2005. Improvements in water clarity have occurred as Chl-a concentrations have also shown a decline since 2001 ($p<0.001$).

Lake Okataina stratifies in early October and can remain stratified until mid-June. Oxygen concentrations are known to decline to less than 3.0 g/m^3 over this period. HVOD rates over 2006/2007 and 2008/2009 were below 24 mg/m^3/day, lower than previously calculated (Figure 3.11).

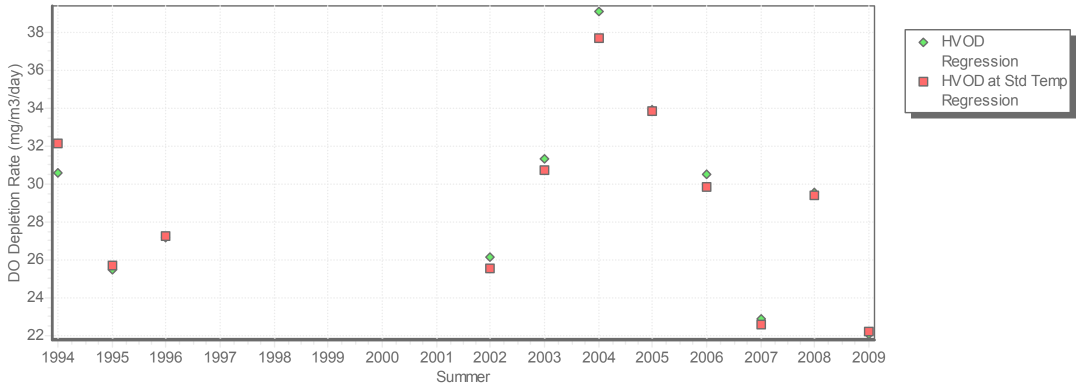


Figure 3.11 HVOD rates, Lake Okareka, 2004 to 2009.

3.3.2 LakeSPI (Submerged Plant Indicators)

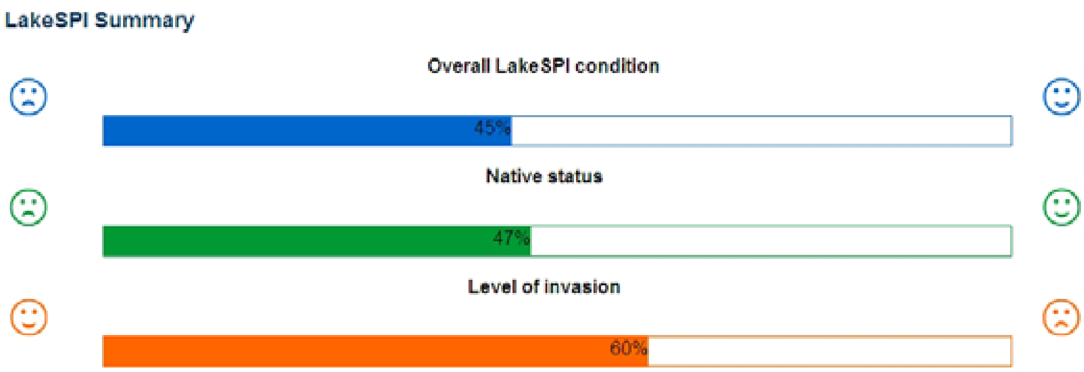
All three indices (native, invasive and LakeSPI condition) have remained relatively stable since records began. However, there is a high risk of hornwort and Egeria becoming established. Both species pose a significant threat to Lake Okataina.

There have been two recent hornwort incursions; one in 2007, which was removed and another in 2009. The source of the recent incursion has yet to be found.

LakeSPI 2009 rank: 3rd highest ranked lake out of the 12 Rotorua lakes.

Current condition: good

Long-term trend: stable



3.3.3 Lake Management

The TLI for Lake Okataina is 0.2 units above its objective and therefore the need for an Action Plan has been triggered. The lake has been prioritised as the third highest priority lake for Action Plan implementation and work on this is scheduled for early 2010.

The catchment of Lake Okataina is covered predominantly with indigenous vegetation and therefore the options available to improve water quality are limited. The focus of an action plan may therefore be on identifying and targeting other nutrient sources and nutrient paths.

3.4 Lake Rerewhakaaitu

TLI 3 year average = 3.7
TLI 2008/2009 = 3.88
TLI Objective = 3.6

PAC 1990-2006 = 0.96%/yr
(p=0.19)

Mesotrophic

% LakeSPI 2008 = 41
moderate

Lake Rerewhakaaitu is the southernmost of the Rotorua Lakes and is also at the highest altitude (438 m a.s.l). The lake occupies a shallow basin in the centre of its 37 km^2 catchment and has a maximum depth of 15.8 metres. Pasture is the dominant land cover in the catchment (Table 3.4) and there has been an increase in exotic and indigenous forest cover over the past few decades.

Two small streams to the south, the Mangakino and Awaroa, feed into the lake and there is no permanent outflow. The Mangaharakeke Stream is the only outlet and flows when the lake level is high. Springs at the head of the Te Kauae Stream are likely to be sourced from the lake and groundwater may also flow southeast of the lake through Rangitaiki Ignimbrite and into the Rangitaiki River Catchment.

Table 3.4 Lake Rerewhakaaitu attributes.

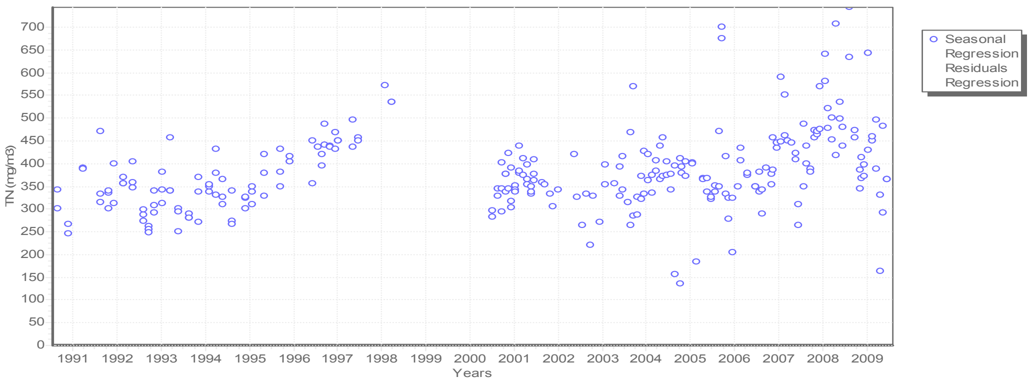
Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	37.0	Exotic forest	0.0	14.7	15.2
Lake area (km^2)	5.3	Indigenous forest/scrub	0.0	6.2	7.2
Maximum depth (m)	15.8	Pasture	100.0	76.7	75.3
Mean depth (m)	7	Other			2.3
Altitude (m)	438				
Age (x 1000 years)	0.7				

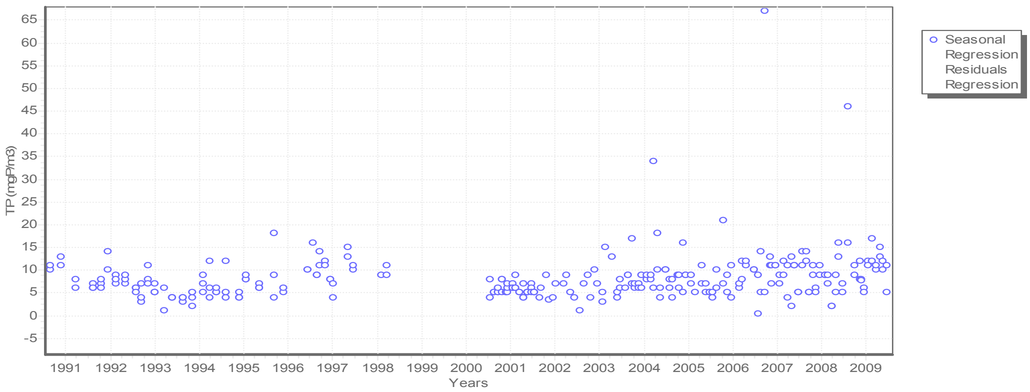
3.4.1 TLI results and trends

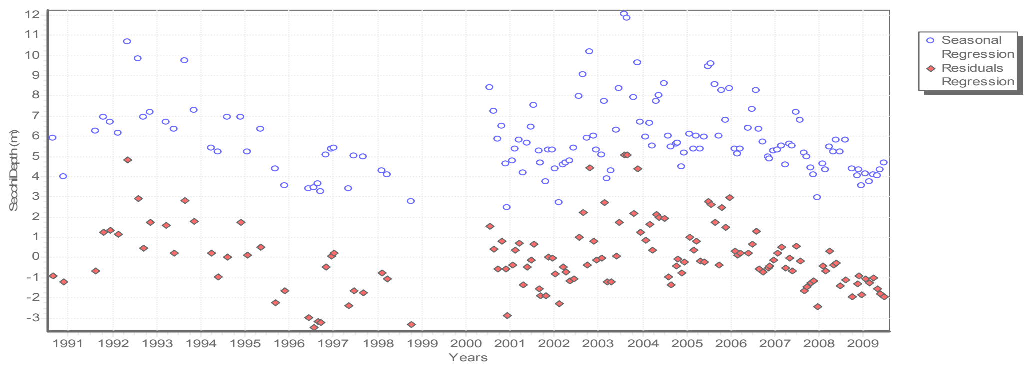
Lake Rerewhakaaitu is mesotrophic and has had an increasing TLI trend since 2002 (Figure 3.13). For the first time in the last nine years the 2008/2009 TLI is almost 0.2 above the target TLI. If an increasing trend continues, this will trigger Method 35 of the RWLP. The TLI has not reached the level it did in 1997/1998, but this was an artefact of a decrease in lake level (Figure 3.15).

Nitrogen concentrations show a strong increasing trend since 2000. The 2008/2009 average TN is lower than the previous two years, although the TN trend is an increasing one ($p<0.001$) (Figure 3.12). Only the next few years of data will tell if the TN trend will start to decrease again.

Dissolved inorganic nitrogen (DIN) levels have also shown recent increases and oxides of nitrogen (predominantly nitrate) displayed a large continuous increase from the start of 2008 to mid-2008 (Figure 3.14). Similar increases can be seen in the inflow data from the Mangakino Stream indicating some nitrogen increases are related to land inputs and flow.







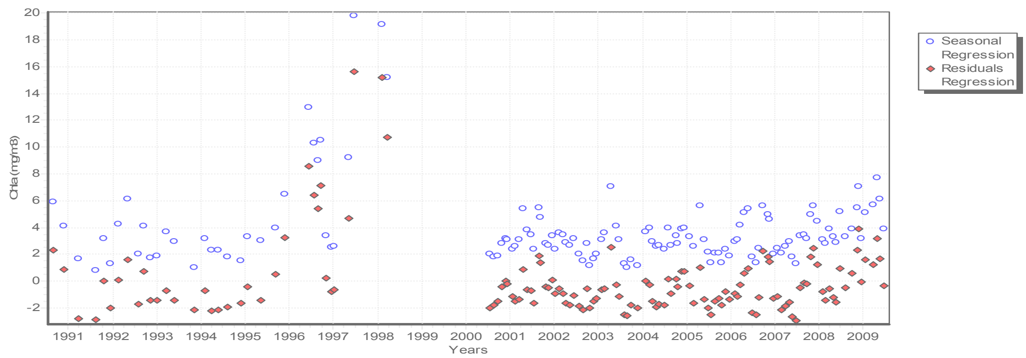


Figure 3.12 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1990 to 2009.

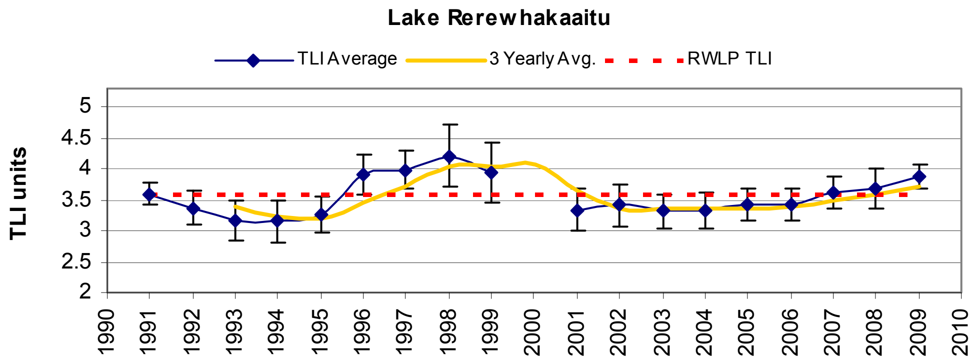


Figure 3.13 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rerewhakaaitu.

Like TN, TP also shows a steady increasing trend since 2000 ($p<0.01$) as does DRP. The annual average TP concentration for 2008/2009 is the highest since 1990.

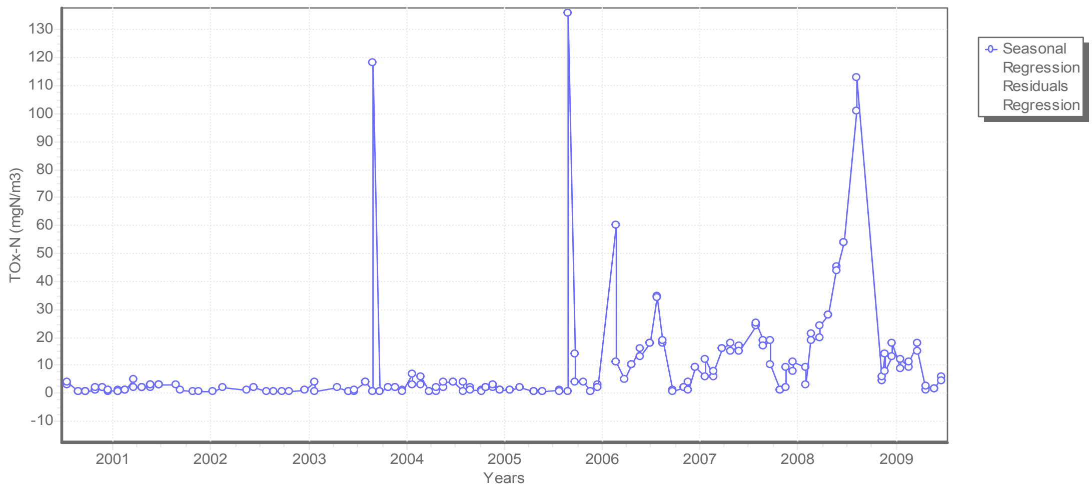


Figure 3.14 TOx-N concentrations, 2000 to 2009.

Water clarity indicated by secchi disc displays a decreasing trend since 2003. A decrease in water clarity corresponds to an increase in Chl-a concentrations (Figure 3.12). This is supported by a decreasing VLEC trend (vertical light extinction coefficient) over the 2000 to 2009 period ($p<0.01$).

Dissolved oxygen levels have been on average lower in the lake over the past few years than previously. The 2008/2009 summer levels were particularly low with bottom water becoming anoxic in January-February 2009.

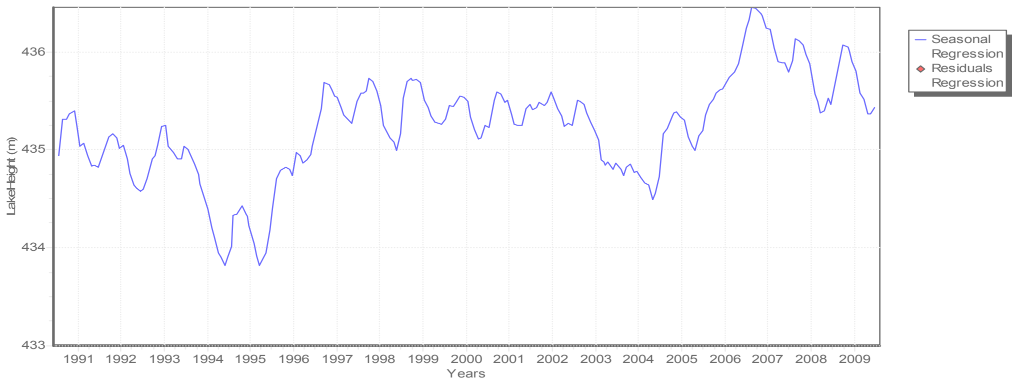


Figure 3.15 Lake Rerewhakaaitu water level above Moturiki datum.

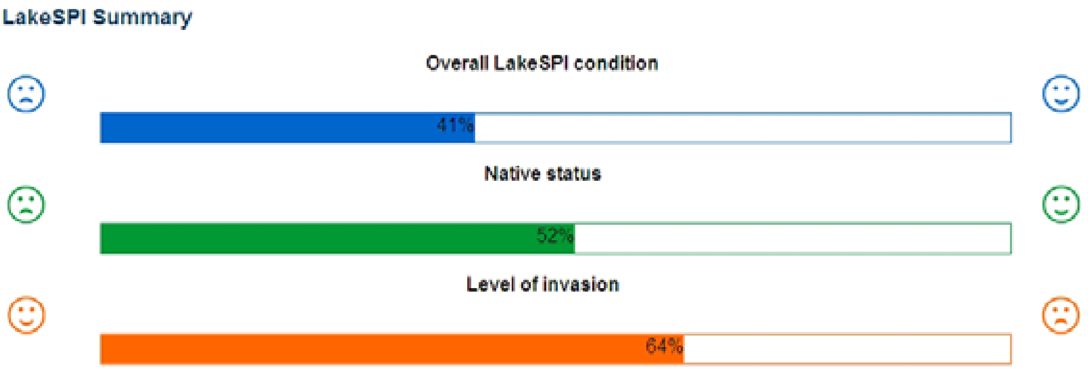
3.4.2 LakeSPI (Submerged Plant Indicators)

There has been some improvement in the ecological health of the lake since the 1970's due to improved water quality and a subsequent downward extension of the bottom plant boundary. However, negative effects have resulted from the accidental introduction of *Lagarosiphon* and more recently *Egeria*. This lake is presently free of hornwort, the worst aquatic pest plant in the region.

LakeSPI 2008 rank: 4th highest ranked lake for LakeSPI

Current condition: good

Long-term trend: stable



3.4.3 Lake Management

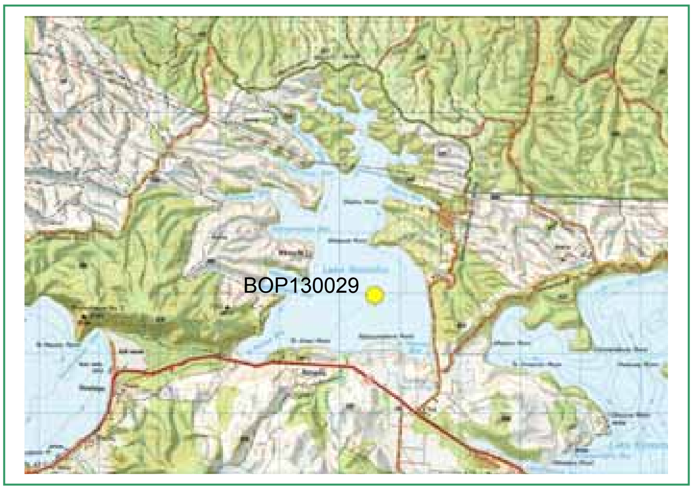
Environment Bay of Plenty plans to engage with the Rerewhakaaitu communities prior to December 2009 to start developing an Action Plan for the lake.

The Rerewhakaaitu community continues to take a pro-active interest in lake restoration issues, and together with Environment Bay of Plenty, NIWA and AgResearch are exploring a range of land management options to help reduce the flow of nutrients into the lake.

Grass filter strips are being explored as a best management practice (BMP) to remove contaminants from intensively grazed pasture. This study is looking at the potential of grass filter strips on hill slope or alternative locations to strip contaminants in runoff by a combination of deposition, physical filtering, and infiltration.

Trials of ‘P-socks’ have been undertaken in the Mangakino Stream. Socks were filled with melter slag, which has high phosphorus adsorption properties, with the aim of reducing the phosphorus content of the stream and hence phosphorus loads to the lake. The trial found that the contact time of the socks with the stream water was not sufficient to achieve a meaningful reduction in phosphorus to the lake.

3.5 Lake Rotoehu



TLI 3 year average = 4.5
TLI 2008/2009 = 4.40
TLI Objective = 3.9

PAC 1993-2009 = -0.01%/yr
(p=0.99)

Eutrophic

% LakeSPI 2008 = 18 *poor*

Lake Rotoehu was formed by the lava damming of a river valley. The catchment has seen an increase in exotic forestry since 1977 and now land cover is evenly distributed between exotic forestry, indigenous vegetation and pasture. Geothermal inputs enter the lake via a stream to the southeast at Waitangi Springs and possibly also through groundwater in the southwest. There is no lake outlet, but water flows through a hole in the bed near one of the northern arms.

The maximum depth of 13.5 metres is found in the northern arms and physico-chemical monitoring takes place in the 10 metre deep south basin (see map above).

Table 3.5 Lake Rotoehu attributes.

Attribute	Measure	Land Cover (%)	1977	1996	2003
Catchment area (km^2)	49.2	Exotic forest	9.5	29.7	32.0
Lake area (km^2)	7.96	Indigenous forest/scrub	39.3	29.1	33.4
Maximum depth (m)	13.5	Pasture	51.1	39.9	34.2
Mean depth (m)	8.2	Urban			0.4
Altitude (m)	295				
Age (x 1000 years)	8.5				

3.5.1 TLI results and trends

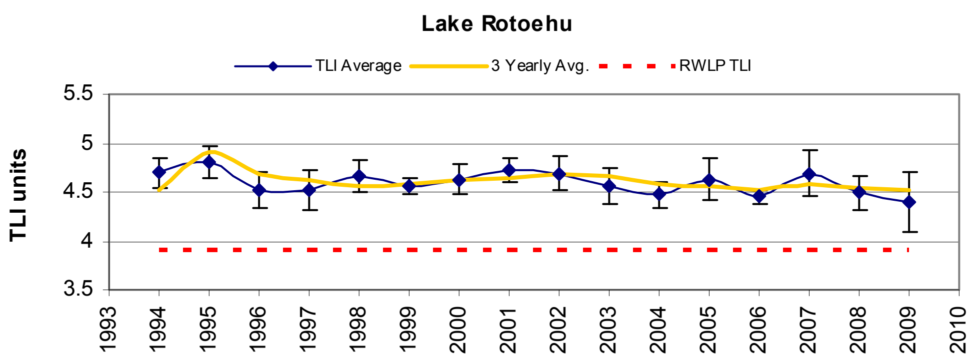


Figure 3.17 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotoehu.

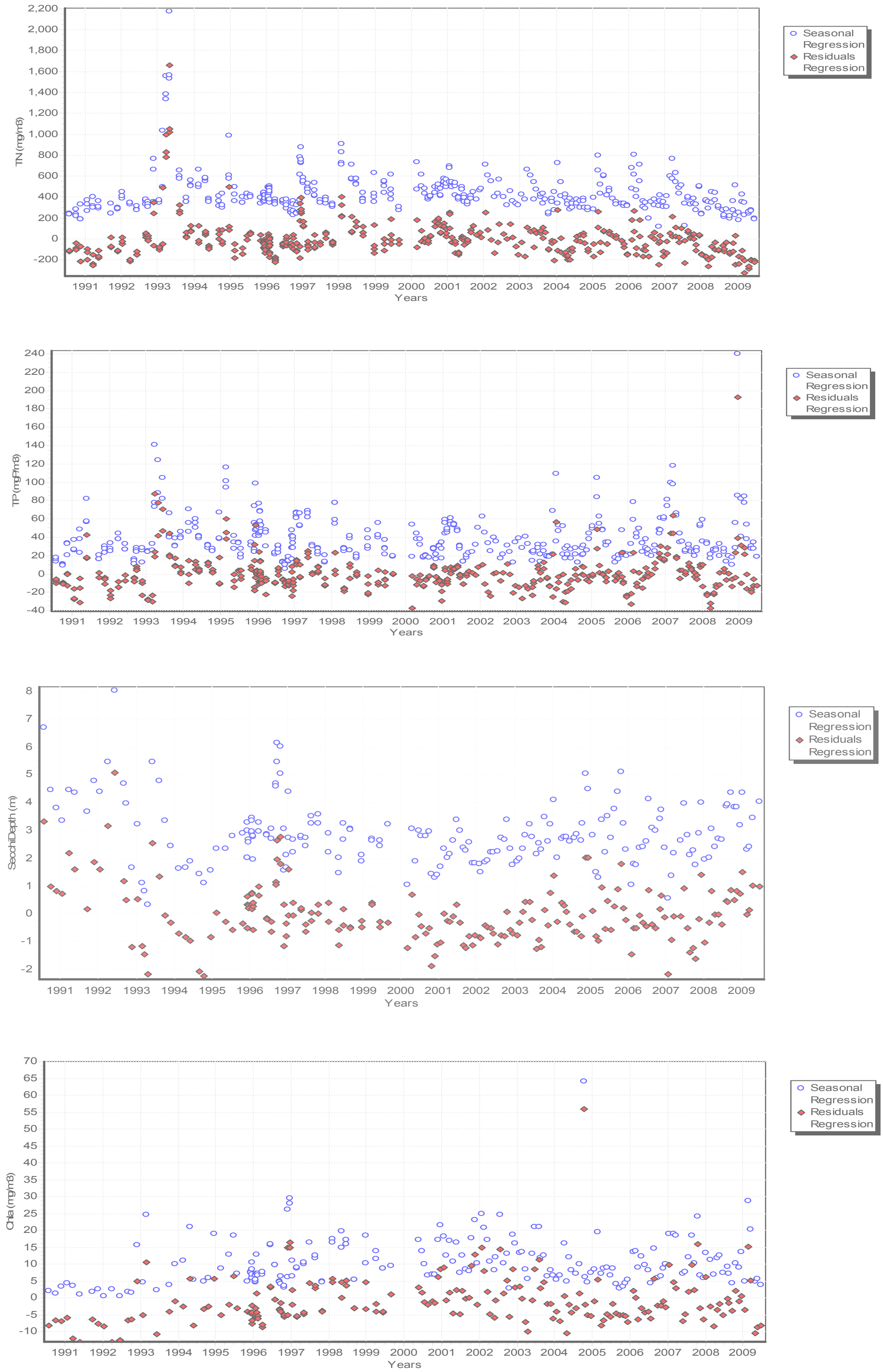


Figure 3.18 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1990 to 2009.

The 2008/2009 TLI result for Lake Rotoehu is the lowest it has been since 1992. This has only impacted the three yearly average TLI marginally moving from 4.54 to 4.53 TLI units (Figure 3.17), indicating that the TLI remains relatively stable.

Figure 3.16 displays TN concentrations from 1990 to 2009. There is a strong seasonal pattern as TN concentrations reach a maximum in summer and decline as the lake become colder. TN concentrations have shown a decline over the past two years contributing to a decreasing TLI. Harvesting of hornwort (*Ceratophyllum demersum*) may be the reason for this decrease in TN as an estimated 4.5 tonnes of nitrogen has been removed from the lake. This is over half of the annual nitrogen reduction target given in the Lake Rotoehu Action Plan.

Ammonium-nitrogen concentrations increase over summer as anoxic conditions occur. Nitrate-nitrogen peaks in winter most probably as inflows increase over this period.

TP concentrations in the lake remain relatively stable (Figure 3.16) and like TN concentrations are highest over summer. This is a result of DRP releases from the sediment over the summer as periodic anoxic conditions occur (Figure 3.18). An illustration of the lake moving to anoxic conditions is given in Figure 3.19, which shows the lake stratifying under summer conditions.

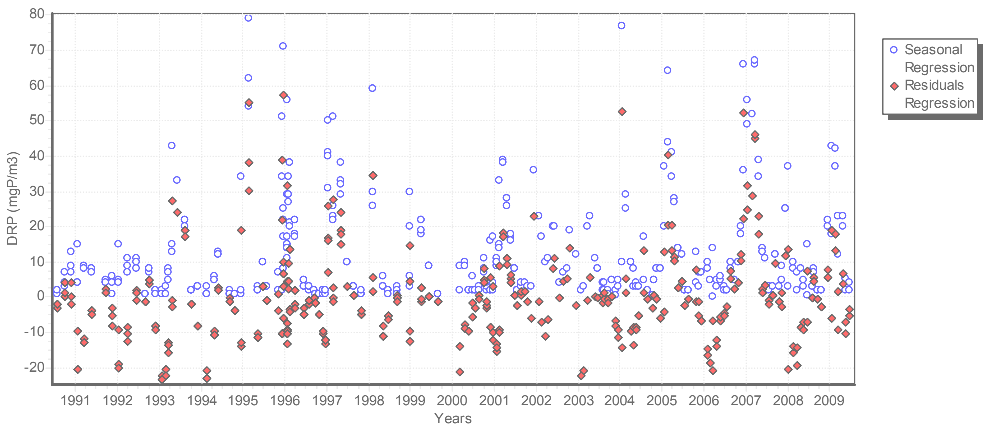


Figure 3.18 DRP concentrations with deseasonalised residuals, 1990 to 2009.

Average water clarity improved by over one metre in 2008/2009 compared to 2007/2008. Water clarity strongly relates to seasonal changes in TN (Figure 3.16), which appears to be a better indicator of algal biomass than Chl-a in this lake. Chl-a average concentrations have also decreased in 2008/2009 compared to 2007/2008, another reason why TN values are lower for 2008/2009.

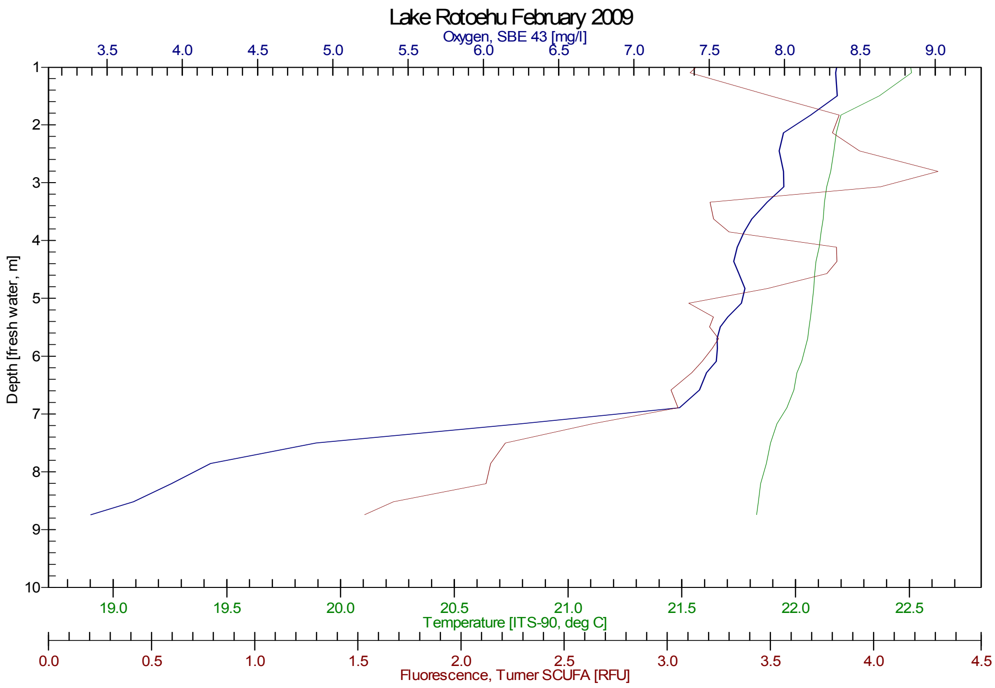


Figure 3.19 DO profile, with temperature and fluorescence, February 2009.

3.5.2 Blue-green algae

In 2008-2009 blooms in Lake Rotoehu occurred more or less consistently from the end of January to the beginning of April, continuing the pattern of persistent blooms in this lake.

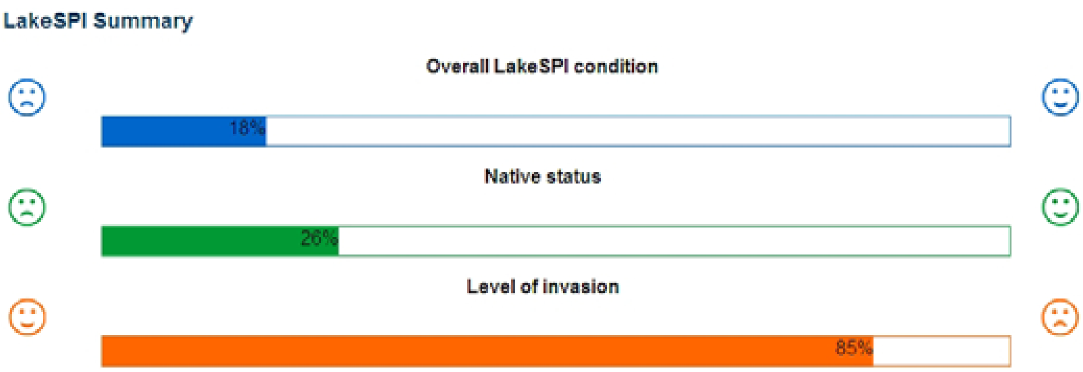
3.5.3 LakeSPI (Submerged Plant Indicators)

Recent LakeSPI results highlight the ongoing negative impact hornwort is having in the lake. This invasive species was accidentally introduced into Lake Rotoehu in 2004 and is now surface-reaching in all but the deepest parts of the lake. The mechanical removal of hornwort is helping to strip nutrients from the lake, contributing to the nutrient reduction target. This lake is now sitting in the bottom group of lakes categorised as being in poor condition.

LakeSPI 2008 rank: 11th lowest ranked lake for LakeSPI

Current condition: poor

Long-term trend: declining

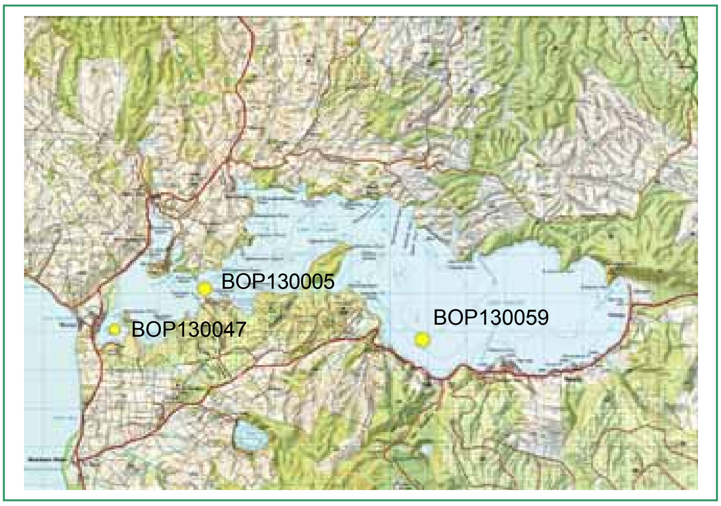


3.5.4 **Lake Management**

The Lake Rotoehu Action Plan was finalised in 2007. This is a long-term plan to improve water quality through changes such as better farming practices, weed harvesting and the creation of wetlands. The plan sets out a range of actions to be undertaken to reach nutrient removal targets of 8,880 kg/yr of nitrogen and 708 kg/yr of phosphorus. Nutrient removal actions being considered or implemented include:

- Hornwort harvesting. Approximately 4.5 T of nitrogen and 0.75 T of phosphorus was removed from the lake in the summer of 2008/2009.
- Constructed wetland to remove nutrients. A trial of floating wetland is also currently being conducted at Lake Rotoehu and trial floating wetland was placed in the lake in 2007.
- Treatment boxes to remove nitrate from streams.
- In-lake remediation including sediment capping or algal harvesting.
- Biological products to alter the lake ecology.
- Phosphorus locking of inflows e.g. Waitangi Springs.
- Riparian protection works.
- Alternative land use/management options with landowners and farm nutrient benchmarking.

3.6 Lake Rotoiti



TLI 3 year average = 3.9
TLI 2008/2009 = 3.86
TLI Objective = 3.5

PAC 1992-2009 = 1.46%/yr
(p=0.11)

Mesotrophic

% LakeSPI 2009 = 21 Poor

Lake Rotoiti is the third largest of the Rotorua Lakes occupying part of the Haroharo Caldera. The lake deepens from west to east changing from an average of 10 metres deep to a maximum of 125 metres deep to the northeast of Gisborne Point. The 123.7 km^2 catchment is predominantly covered in indigenous vegetation (36.4%) and exotic forestry (46.2%). There has been a conversion of pastoral lands to forestry over the past thirty years.

There are numerous geothermal inputs to the lake with the largest being from the Tikitere geothermal field. Several small streams discharge to the lake in the eastern basin and a few warm streams discharge into the western basin, but the main input to the lake is via the Ohau Channel into the western basin. Water from Lake Rotorua passes through the channel at an average rate of 15 m^3/s. Prior to the construction of the Ohau Channel diversion wall, this water sometimes plunged as an underflow into the eastern basin of Lake Rotoiti. The flow is now effectively diverted directly to the outlet at Okere and on to the Kaituna River.

Three water quality monitoring sites are located in the lake. One in the deep eastern basin, another in the narrows between the two western basins and one in Okawa Bay (see map above).

Table 3.6 Lake Rotoiti attributes.

Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	123.7	Exotic forest	7.1	30.4	46.2
Lake area (km^2)	34.0	Indigenous forest/scrub	45.8	42.9	36.4
Maximum depth (m)	125	Pasture	44.6	23.9	15.9
Mean depth (m)	60	Urban	0.0	1.1	1.5
Altitude (m)	279				
Age (x 1000 years)	8.5				

3.6.1 TLI results and trends

The Lake Rotoiti TLI continues to improve (Figure 3.21) with the three yearly average under 4.0 for the past two years. Because of this the lake has now moved from a eutrophic classification to mesotrophic. Continued improvement is required if the lakes is to meet its target TLI of 3.5 units.

Figure 3.20 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1992 to 2009.

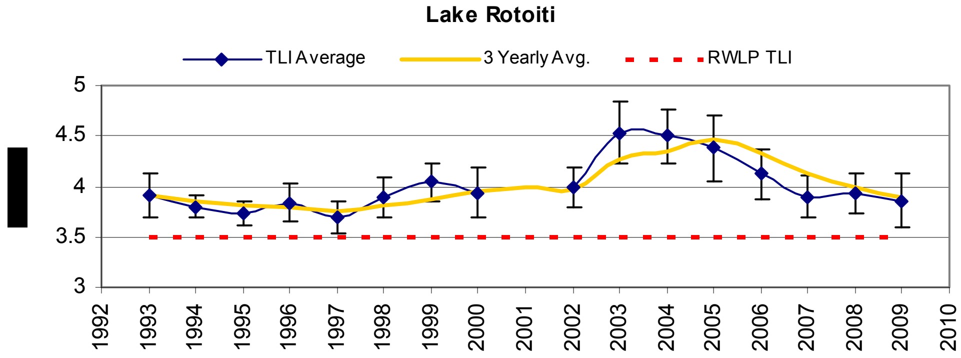


Figure 3.21 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotoiti.

The only TLI parameter to improve in 2008/2009 was TN which continues to show a steady decline from its historical maximum concentration reached in 2003/2004 (Figure 3.20). Ammonium-nitrogen continues to build up the in hypolimnion during stratification with concentrations reducing since 2003, but stable over the past two years.

DRP and TP concentrations increased in the hyplominion in 2008/2009 compared to the previous year (Figure 3.22), however the average annual TP concentration for 2008/2009 remains stable.

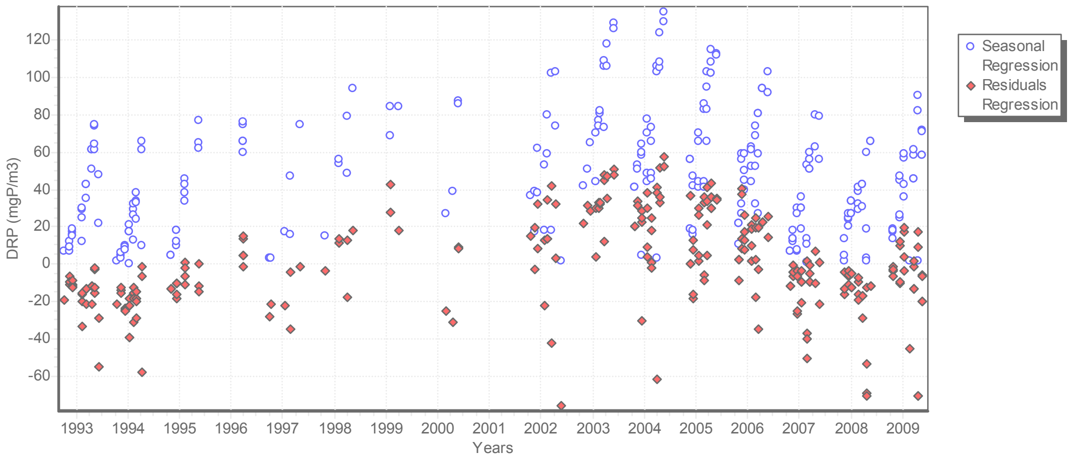


Figure 3.22 DRP concentrations with deseasonalised residuals, 1992 to 2009.

Water clarity improved slightly in 2008/2009 compared to the previous year and the bottom of Okawa Bay has been observed for the first time in many years. VLEC values for 2008/2009 indicate that light penetration has improved in the lake, better than has been seen for the past seven years.

Algal biomass as indicated by Chl-a concentrations shows no improvement over the previous few years (Figure 3.20). An improvement in this parameter will help to show any water quality gains from interventions like the Ohau Channel diversion wall.

HVOD rate for 2008/2009 shows little change from the previous year (Figure 3.23) indicating the reduction of oxygen from Ohau Channel waters has not impacted the oxygen content of the hyplominion.

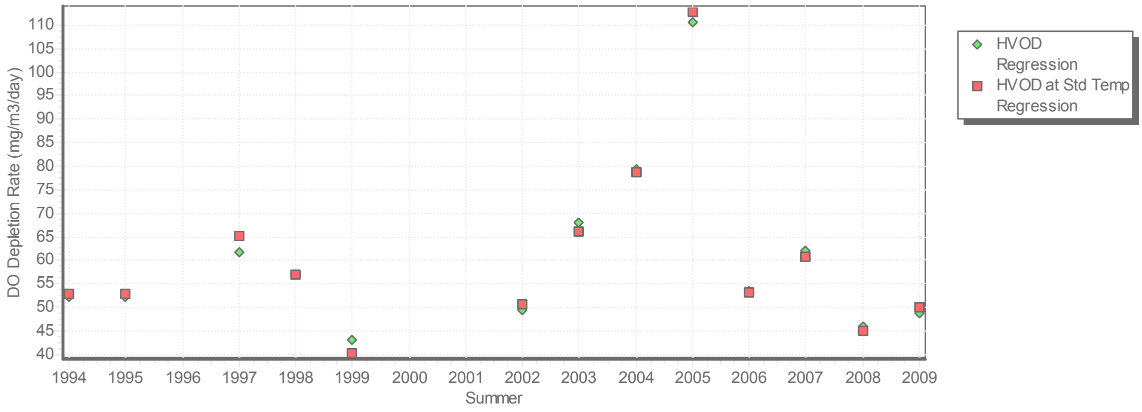


Figure 3.23 HVOD rates, Lake Rotoiti, 1994 to 2009.

3.6.2 Blue-green algae

After three consecutive bloom-free years late blooms affected Okere Arm at the western end of Lake Rotoiti from April to June 2009. Blooms in Okere Arm closely mirrored the timing and intensity of blooms in Lake Rotorua, particularly bloom activity closer to the Ohau Channel. Areas east of the Ohau Channel diversion wall remained bloom free.

Okawa Bay, one of the areas with the most intense blooms historically, did register a short spike in bloom activity in February. However, this was not long-lived and there was no health warning issued for Okawa Bay in the 2008/2009 season.

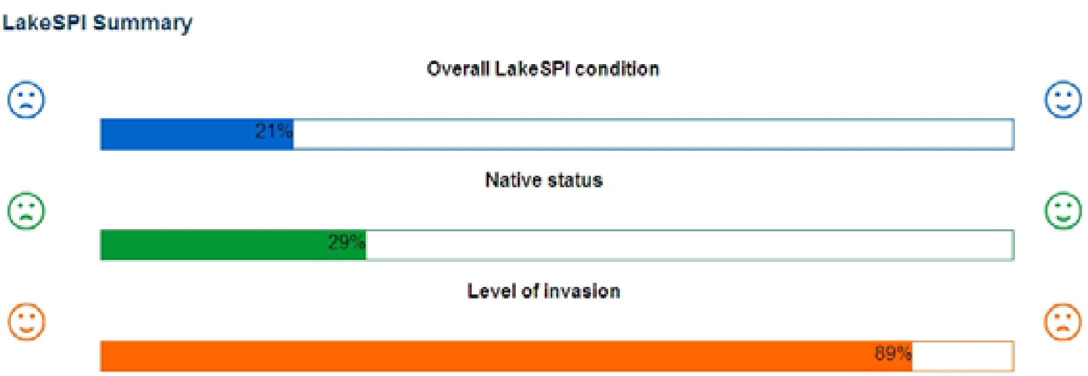
3.6.3 LakeSPI (Submerged Plant Indicators)

Lake Rotoiti has both the second highest ranked invasive condition and the lowest ranked LakeSPI index. While the LakeSPI index is stable, several embayments such as Okawa, Te Weta and Wairau Bays have shown signs of further deterioration with filamentous algae and blue-green algae mats replacing true plants in some areas. The LakeSPI scores indicate relatively poor water quality in this lake.

LakeSPI 2009 rank: 12th lowest ranked lake out of the 12 Rotorua lakes.

Current condition: poor

Long-term trend: stable



3.6.4 Lake management

The Lake Rotorua and Rotoiti Action Plan was approved by the Rotorua Te Arawa Lakes Strategy Group on 24 July 2009. Actions and nutrient targets for the two lakes are outlined in the Plan.

The Ohau Channel diversion wall was completed in July 2008 and results in nutrient reduction to Lake Rotoiti in the order of 76 % for phosphorus and up to 73% for nitrogen. Flow measurement have undertaken by the University of Waikato and show that the wall is working as it was intended with minimal backflow of Ohau Channel water into Lake Rotoiti.

Modelling of Lake Rotoiti by NIWA, the University of Waikato and Environment Bay of Plenty is continuing. The results of this work will help predict the future condition of the lake and guide any remediation work.

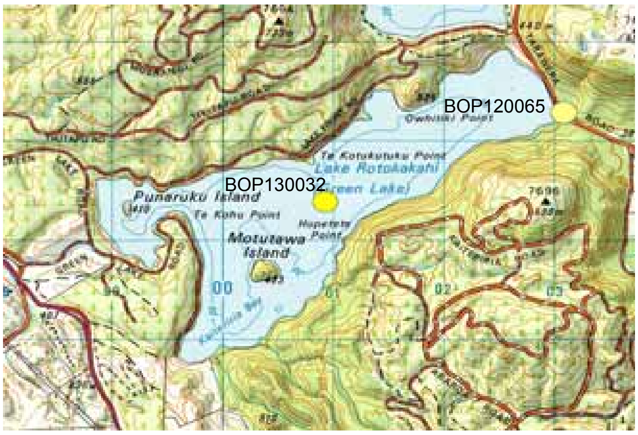
The reticulation of sewage from the Okawa Bay community was completed in 2008 and may be one of the reasons for the water clarity improvements seen at Okawa Bay.

Land management options continue to be developed around the lake with riparian plantings and fencing off of waterways from stock. Options for wetland creation and enhancement are being assessed.

Oxygenation and capping of the lake bed sediments are interventions that could result in improvements to Lake Rotoiti.

An electronic cyano-bacteria health warning sign at Gisborne Point continues to provide lake users with up-to-date health warning information.

3.7 Lake Rotokakahi



TLI 3 year average = 4.0*
TLI 2008/2009 = 4.05*
TLI Objective = 3.1

Mesotrophic

% LakeSPI 2008 = 31 Moderate

The catchment of Lake Rotokakahi is predominantly forested with around 26% in pasture. The lake is fed by small streams and groundwater with the lake outlet being at the north eastern end forming Te Wairoa stream. This stream flows to Lake Tarawera.

Lake Rotokakahi was previously monitored up to 1996 but since 1999 most monitoring has been undertaken at the outlet of the lake, Te Wairoa Stream (site BOP120065).

Table 3.7 Lake Rotokakahi attributes.

Attribute	Measure	Land Cover (%)	1977-1978	1996	2003
Catchment area (km^2)	19.7	Exotic forest	56.4	46.5	57.1
Lake area (km^2)	4.4	Indigenous forest/scrub	28.6	24.7	16.6
Maximum depth (m)	32	Pasture	15.1	27.8	26.3
Mean depth (m)	17.5	Urban	0.0	0.0	0.0
Altitude (m)	394				
Age (x 1000 years)	13.3				

3.7.1 TLI results and trends

The TLI results have been based on water quality data collected from Te Wairoa Stream. Some monitoring of the lake has occurred in the past few years and this information will in future be used to check the validity of using data from Te Wairoa Stream for TLI calculations.

The TLI calculated from 1999 to 2009 is based on only three TLI parameters rather than four. Secchi depth can not be taken at the outlet stream and so a three parameter TLI is presented in Table 3.8. This shows that the annual average TLI remains elevated for the second consecutive year at just above 4.0 units (Figure 3.24).

* Figures based on lake outflow data.

The Chl-a concentration remains well above the average recorded in previous years. This may be due to extended period of anoxia resulting in increased phosphorus releases, potentially explaining the recent increases in phosphorus. However, in 2007 hypolimnetic waters went anoxic towards the end of February which corresponds to early lake monitoring data in 1997 and 1995. Forest harvesting occurred in 2007 but it is not expected that sediment from recently harvested areas would contribute significantly to the increasing phosphorus levels in the lake.

Table 3.8 TLI time trends and Chla, TP and TN annual averages from 1990 to 2005. Figures in italics (from 1999) indicate data from Te Wairoa Stream, the Lake Rotokakahi outlet.

Period	Chla (mg/m³)	TP (mg/m³)	TN (mg/m³)	TLIc	TLIp	TLIn	TLI Average
Jul 1990 - Jun 1991	1.60	12.9	195.3	2.74	3.46	3.28	3.16
Jul 1991 - Jun 1992	3.60	13.3	182.4	3.63	3.50	3.20	3.44
Jul 1992 - Jun 1993	4.29	9.3	218.1	3.83	3.05	3.43	3.44
Jul 1993 - Jun 1994	2.76	7.1	188.2	3.34	2.70	3.24	3.09
Jul 1994 - Jun 1995	3.06	8.8	208.9	3.45	2.97	3.37	3.27
Jul 1995 - Jun 1996	3.01	8.4	188.5	3.43	2.91	3.24	3.20
Jul 1999 - Jun 2000	*7.84*	*13.0*	*228.0*	*4.49*	*3.47*	*3.49*	*3.82*
Jul 2001 - Jun 2002	*4.22*	*10.8*	*248.0*	*3.81*	*3.24*	*3.60*	*3.55*
Jul 2002 - Jun 2003	*4.59*	*8.1*	*223.3*	*3.90*	*2.88*	*3.46*	*3.41*
Jul 2003 - Jun 2004	*3.80*	*9.5*	*225.5*	*3.69*	*3.07*	*3.47*	*3.41*
Jul 2004 - Jun 2005	*2.69*	*12.3*	*215.5*	*3.31*	*3.40*	*3.41*	*3.38*
Jul 2005 - Jun 2006	*2.92*	*14.4*	*207.2*	*3.40*	*3.60*	*3.36*	*3.45*
Jul 2006 - Jun 2007	*3.7*	*17.3*	*245.6*	*3.66*	*3.83*	*3.58*	*3.69*
Jul 2007 - Jun 2008	*8.21*	*20.5*	*297.4*	*4.54*	*4.05*	*3.83*	*4.14*
Jul 2008 - Jun 2009	*8.21*	*19.1*	*257.3*	*4.54*	*3.96*	*3.65*	*4.05*
Averages	4.30	12.3	221.9	3.72	3.34	3.44	3.50

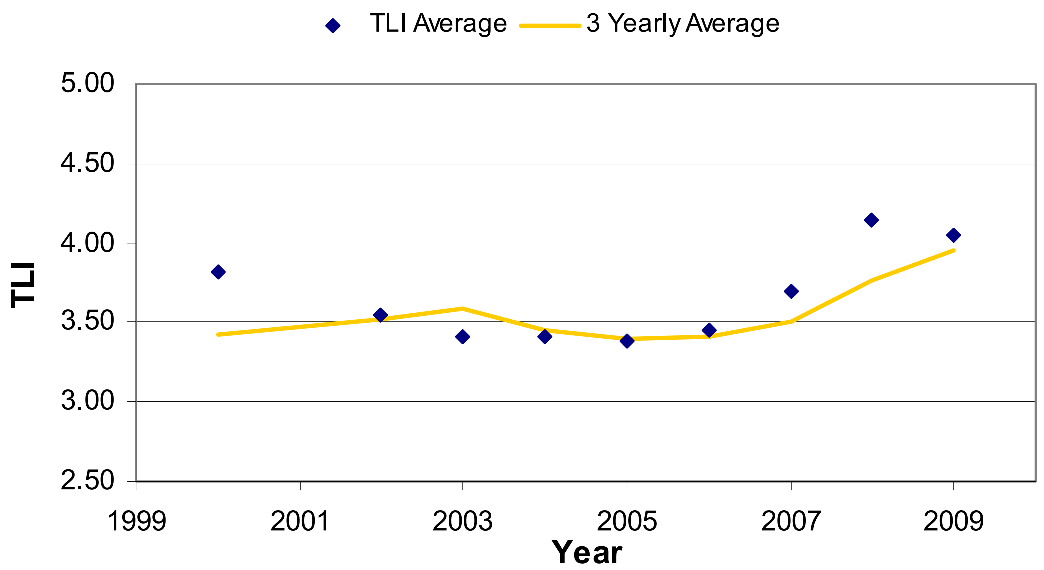


Figure 3.24 TLI averages from 1999 to 2009, Te Wairoa Stream, Rotokakahi outlet.

Increased turbidity in Te Wairoa stream is predominantly attributable to increased algal concentrations. Figure 3.25 show the seasonal patterns of both these parameters which have a good correlation. It is likely that increased algal activity will be impacting on the lakes water clarity.

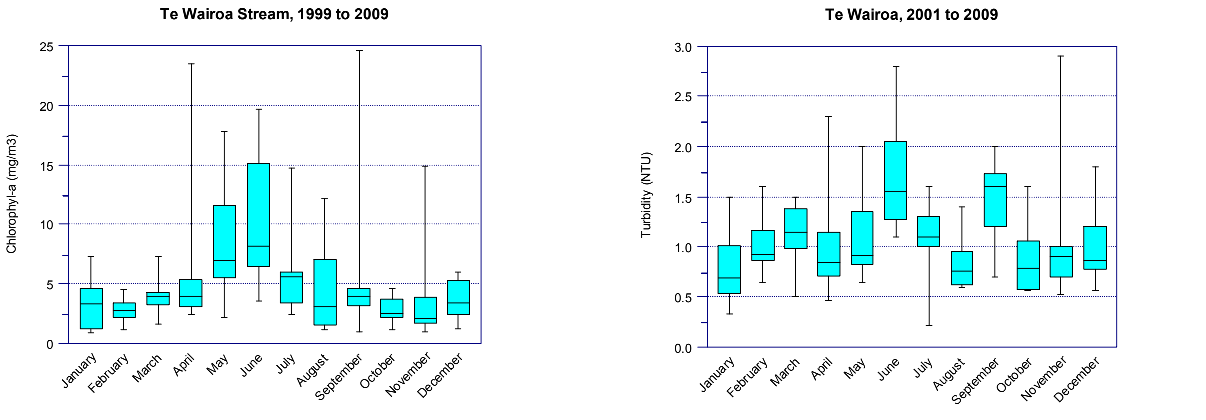


Figure 3.25 Seasonal box whisker plots of Chl-a and turbidity, Te Wairoa Stream.

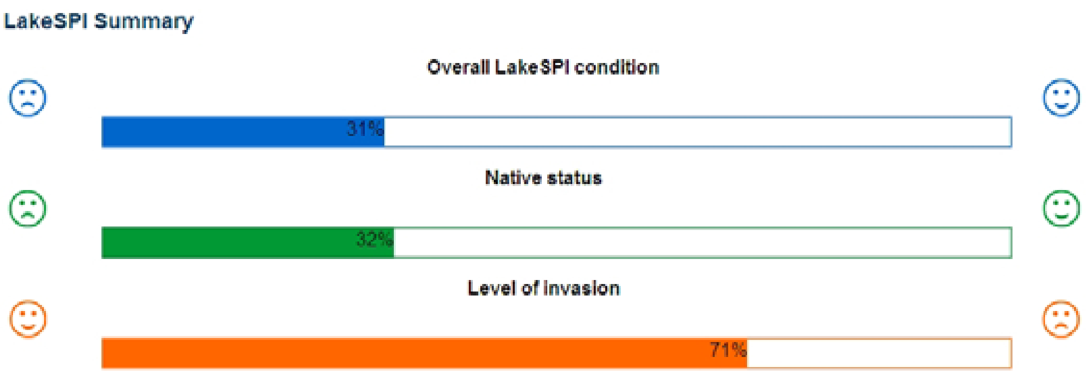
3.7.2 LakeSPI (Submerged Plant Indicators)

Plant growth is now restricted to a significantly shallower depth range confirming that there has been a decline in water quality. Deep occurring native charophyte meadows have all but disappeared from the deeper parts of the lake, having being replaced by blue-green algal mats, a probable sign of declining lake health. Lake Rotokakahi contains none of the worst aquatic pest plants but is vulnerable to plant invasion from nearby lakes.

LakeSPI 2008 rank: 7th highest ranked lake for LakeSPI

Current condition: average

Long-term trend: declining

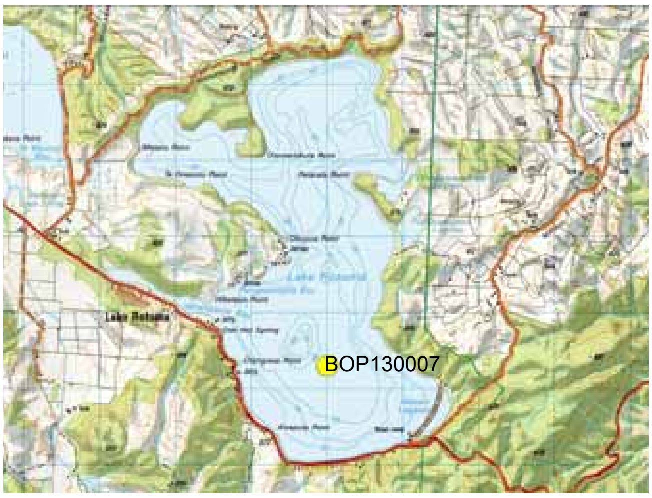


3.7.3 Lake management

A full determination of the TLI of this lake has not occurred since 1996. However, based upon a three parameter TLI assessment of the outlet the three yearly average TLI objective in the RWLP has been exceeded by 0.2 TLI units for more than two years. The LakeSPI assessment confirms the deteriorating lake water quality.

Land management options to reduce nutrient loading are likely to be necessary to halt any further water quality deterioration. A risk assessment has been completed and the lake is ranked fifth out of the seven lakes in terms of priority for action.

3.8 Lake Rotoma



TLI 3 year average = 2.5
TLI 2008/2009 = 2.42
TLI Objective = 2.3

PAC 1991-2009 = 0.67%/yr
(p=0.37)

Oligotrophic

% LakeSPI 2009 = 47 *High*

Lake Rotoma was formed by the Rotoma eruptions and consists of two basins. The northern basin is the deepest at 83 metres, with monitoring occurring in the southern basin which has a maximum depth of 73.5 metres.

Inflows are from rainfall, three small streams and springs around the lake margin. Outflow is through the porous pumice substrate flowing towards Lakes Rotoehu and Rotoiti. It is thought around 1.5 $m^3 s^{-1}$ is contributed to Lake Rotoiti from Rotoma and Rotoehu with about 7% of the lake volume being lost annually via groundwater (Donald, 1997).

Table 3.9 Lake Rotoma attributes.

Attribute	Measure	Land Cover (%)	1977	1996	2003
Catchment area (km^2)	27.8	Exotic forest	2.2	31.7	26.7
Lake area (km^2)	11.1	Indigenous forest/scrub	39.9	39.8	46.0
Maximum depth (m)	83	Pasture	56.3	22.8	23.4
Mean depth (m)	36.9	Urban	1.6	1.1	
Altitude (m)	313	Other			3.9
Age (x 1000 years)	8.5				

3.8.1 TLI results and trends

The TLI for Lake Rotoma remains stable at around 2.5 TLI units (Figure 3.27), above its target TLI of 2.3 units.

The annual average TN concentration is lower than previous years. Higher TN concentrations generally occur in winter when the lake becomes isothermal (Figure 3.26). Ammonium-nitrogen displays a trend of increasing concentrations in the hypolimnion, although this is not consistent with DRP which has decreased over the past three years.

Phosphorus levels remain stable with an overall decrease in 2008/2009 in the hypolimnion compared to the previous six years.

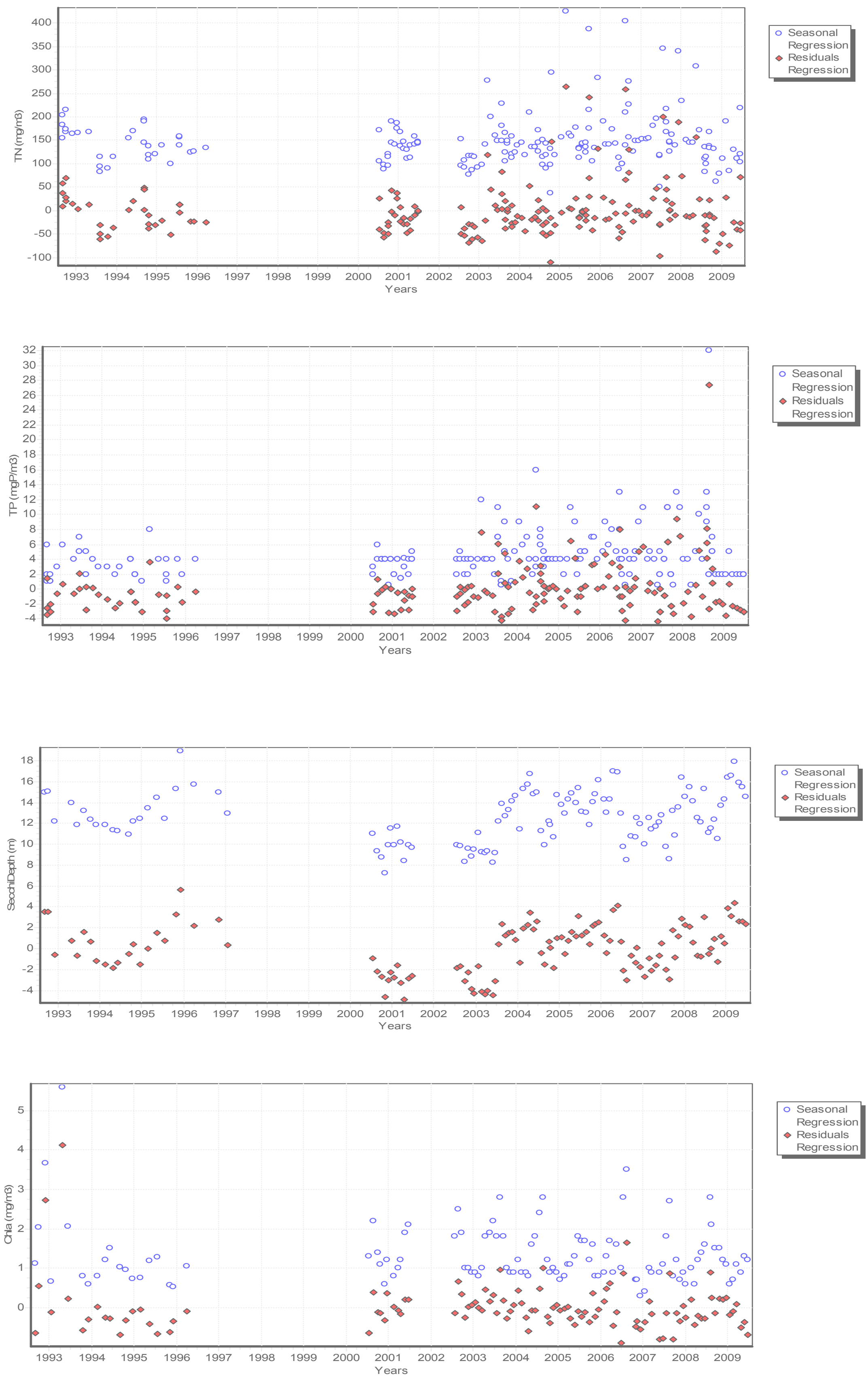


Figure 3.26 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1992 to 2009.

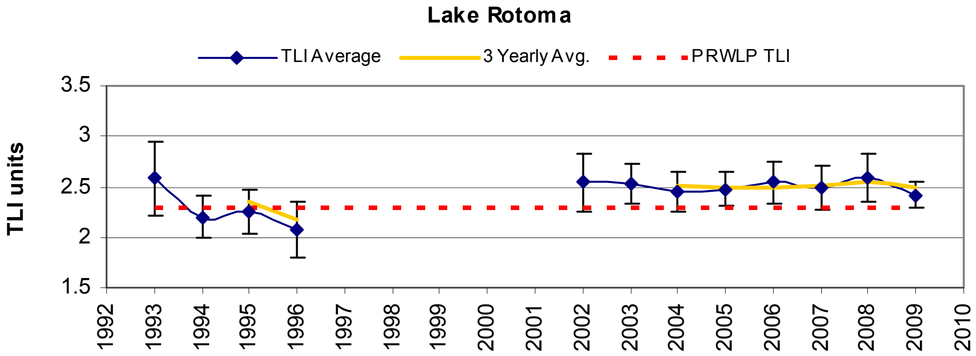


Figure 3.27 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotoma.

Water clarity for 2008/2009 was improved on average compared to the previous two years, at over 14 metres on average. The secchi depth is usually lowest in mid-winter when algal levels are at their maximum as displayed in Figure 3.26 by the Chl-a concentrations. Algae concentrations increase when the lake becomes isothermal and nutrients released from the bottom waters are mixed and become available to algae nearer the water surface. Chl-a concentrations remain very stable.

Oxygen depletion rates, as described by the HVOD rate, have improved over the past two years (Figure 3.28) and this may explain decreased nutrient levels and improved water clarity.

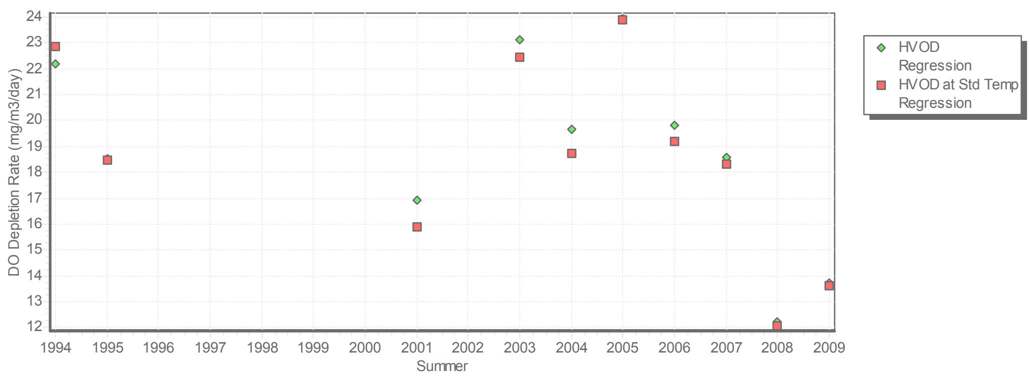


Figure 3.28 HVOD rates, Lake Rotoma, 1994 to 2009.

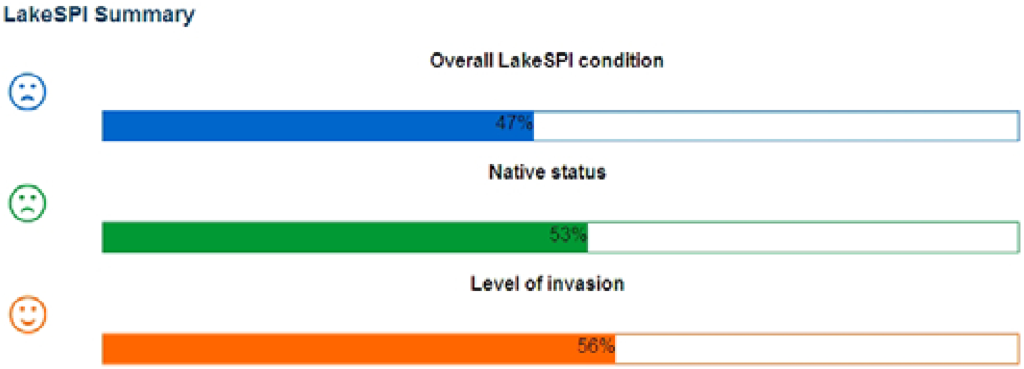
3.8.2 LakeSPI (Submerged Plant Indicators)

The deepest occurring plants in this lake have not altered their position since records began 35 years ago suggesting that this lake continues to enjoy stable water quality/clarity. Lake Rotoma presently contains the most intact native plant community of the Rotorua lakes. However this lake remains highly vulnerable to pest plant invasion particularly now that hornwort has established in neighbouring lakes.

LakeSPI 2009 rank: 2nd highest ranked lake out of the 12 Rotorua lakes.

Current condition: good

Long-term trend: stable



3.8.3 Lake management

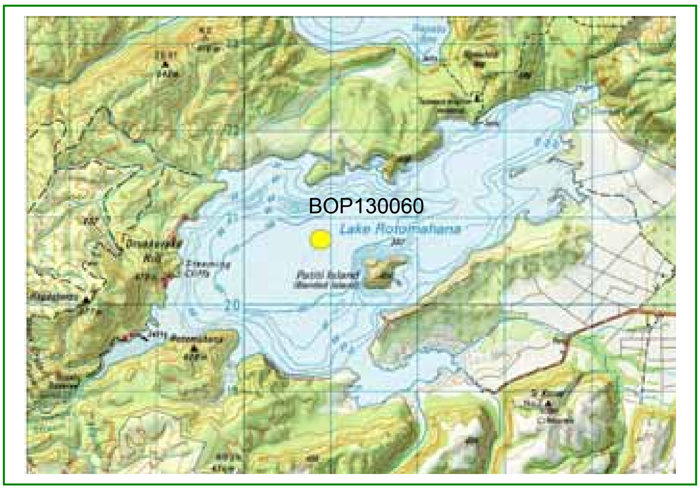
Public feedback on the Draft Lake Rotoma Action Plan closed in early July 2009. The analysis of the public feedback has been largely completed. Submissions raised questions about various topics in the Draft Action Plan including: science (nutrient sequestration and Trophic Level Indices), stewardship approaches and planning tools that require further research.

The last remaining areas of lake and stream margins are being fenced from stock and planted. Specialised plants on the lake margins are needed as the water level of Lake Rotoma can fluctuate considerably.

Rotorua District Council plan to reticulate the Rotoma community sewage by 2014. If a system cannot be reticulated then the new rules under the Onsite Effluent Treatment Plan apply. This plan will help to restrict the discharge of nitrogen from septic tanks to the lake.

Electronic pest weed signage at the Whangaroa Bay boat ramp and a weed cordon are designed to remind recreational users to check their boats for weed before launching and to prevent any weed from infesting the wider lake. This is particularly important given the recent outbreak of hornwort in the adjacent Lake Rotoehu.

3.9 Lake Rotomahana



TLI 3 year average = 4.0
TLI 2008/2009 = 4.03
TLI Objective = 3.9

PAC 1991-2009 = 0.28%/yr
(p=0.73)

Mesotrophic

% LakeSPI 2009 = 63 High

Lake Rotomahana is the deepest of the Rotorua Lakes and was formed by the joining of two previously separate lakes as a consequence of the Tarawera eruption in 1886. The lake is one of the most geothermally active with the western basin having several hot springs located on the lake bed. A number of small streams provide inflows to the lake from the catchment including water from Lake Okaro. A stream between Lakes Rotomahana and Tarawera was buried forming a ridge between the lakes, but this still acts as an outflow conduit for Rotomahana to Tarawera.

Table 3.10 Lake Rotomahana attributes.

Attribute	Measure	Land Cover (%)	1977	1996	2003
Catchment area (km^2)	83.3	Exotic forest	4.1	14.1	16.3
Lake area (km^2)	8.99	Indigenous forest/scrub	47.2	42.7	39.7
Maximum depth (m)	125	Pasture	46.2	41.4	43.2
Mean depth (m)	60				
Altitude (m)	335				
Age (x 1000 years)	111				

3.9.1 TLI results and trends

The TLI for Lake Rotomahana continues to show a steady increase over the past five years (Figure 3.29), although the 2008/2009 is unchanged from the previous year. The annual average TLI for the last two years has been at 4.0 units, just above the target TLI of 3.9.

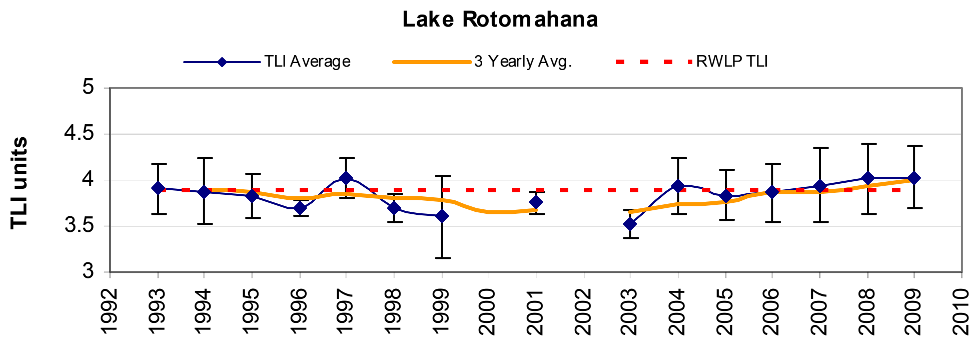


Figure 3.29 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotomahana.

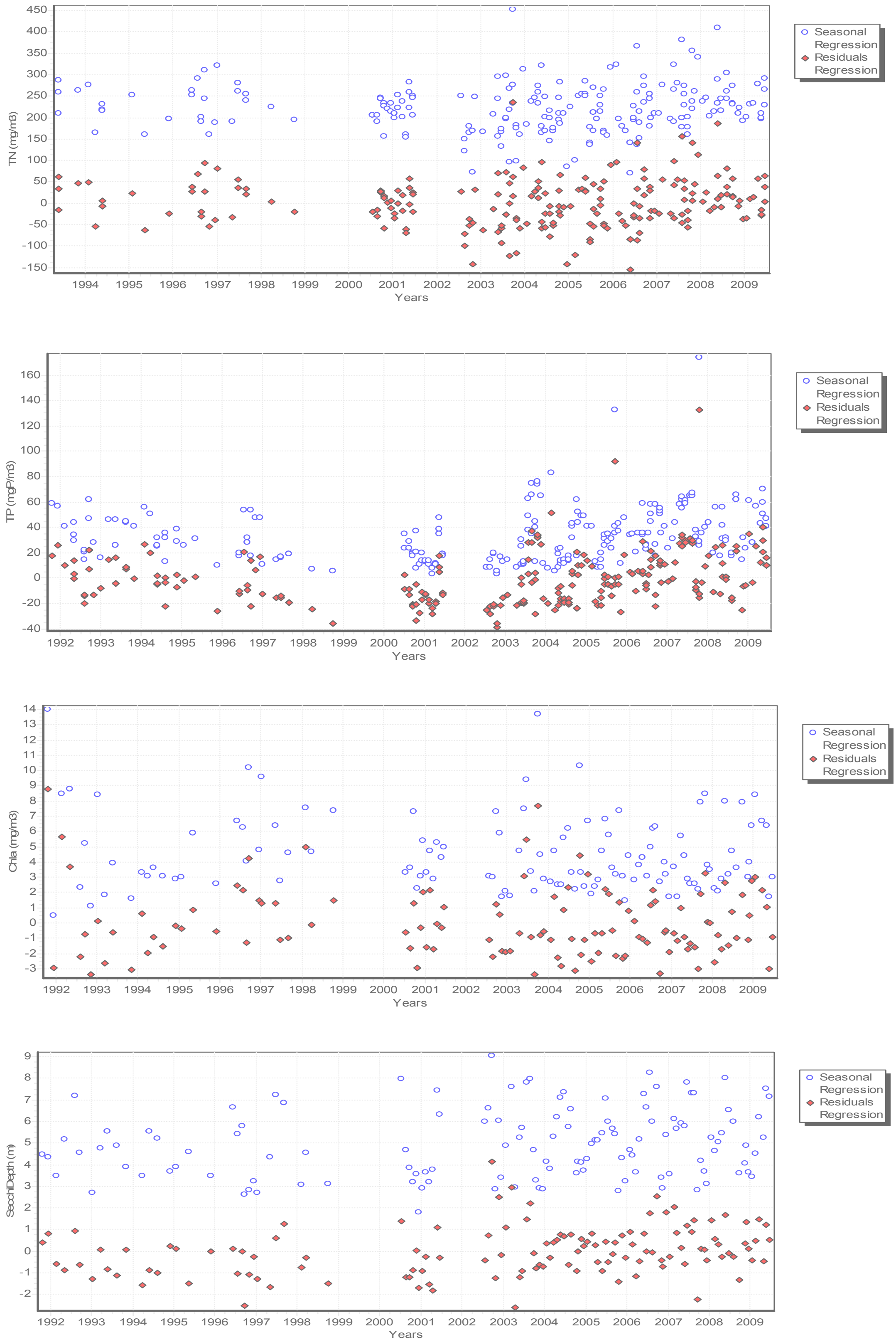


Figure 3.30 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1991 to 2009.

A recent decrease in TN is shown by the data (Figure 3.30) and this decrease is strongest in the hypolimnion. Both ammonium-nitrogen and nitrate-nitrogen are also lower in the hypolimnion than the previous two years. Nitrate-nitrogen concentrations build up in the hypolimnion over the stratification period and at turnover (early May) nitrate-nitrogen concentrations increase 10-fold in the surface waters. However, this only has a small impact on algal growth presumably because of dissolved inorganic nitrogen coming from geothermal sources all year round.

Phosphorus levels remain elevated compared to eight years ago, although slightly down on the previous year. There does appear to be an increasing trend in phosphorus since 2001 (Figure 3.31) but this trend does not occur in the hypolimnion.

Water clarity remains stable (Figure 3.30) and has a strong seasonal fluctuation. The water is much clearer in winter with over 2.5 metres increase in secchi depth compared to summer. Chl-a is often lowest in winter, but not always with differing seasonal fluctuations exhibited. As such, changes in Chl-a relating to algae do not always correspond with secchi depth changes. This may be due to the species of algae and its location in the water column during monitoring. VLEC does correspond a little better to the seasonal algae fluctuations. VLEC has been stable for the past eight years.

DO concentrations can drop below 5 g/m^3 towards the end of the stratification period, but depletion rates as calculated by the HVOD are generally low (Figure 3.31). The HVOD rate for 2008/2009 was 18.2 mg/m^3/day an increase from 2007/2008.

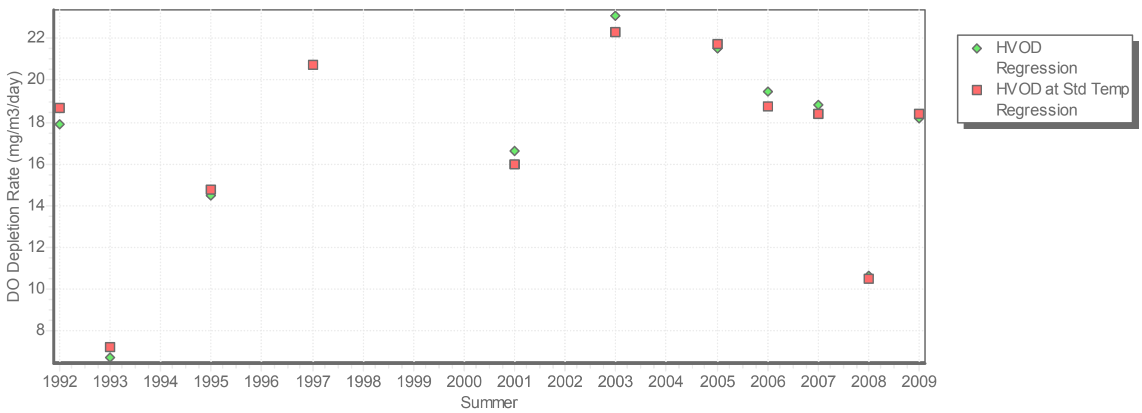


Figure 3.31 HVOD rates, Lake Rotomahana, 1992 to 2009.

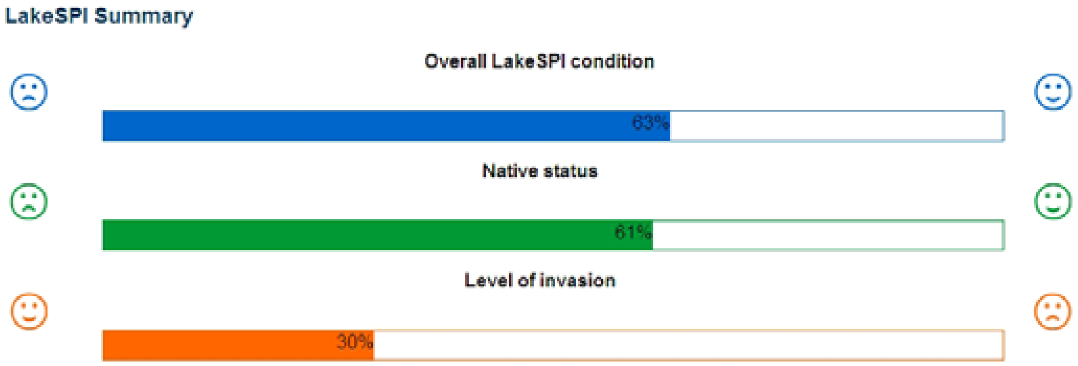
3.9.2 LakeSPI (Submerged Plant Indicators)

Lake Rotomahana has until recently had the highest native condition index score and the lowest invasive index score out of all the Rotorua lakes. With the introduction of hornwort and Egeria into Lake Rotomahana in 2006-2007, the once intact native plant communities are expected to decline in the short term. Egeria in particular has shown early signs of spread and in 2009 was found to have established at two out of the five monitored LakeSPI sites.

LakeSPI 2009 rank: highest ranked out of the 12 Rotorua lakes.

Current condition: good

Long-term trend: stable but with signs of decline



3.9.3 Lake management

Lake Rotomahana has been just over its RWLP TLI objective for the past two years but not enough to trigger Method 35 of the RWLP (instigation of an action plan). As with several of the Rotorua Lakes, a risk assessment for the lake has been undertaken and it has been ranked sixth out of seven in the priority ranking.

Limiting stock access and providing riparian protection are the main lake water protection tools being implemented.

3.10 Lake Rotorua

TLI 3 year average = 4.7
TLI 2008/2009 = 4.71
TLI Objective = 4.2

PAC 1990-2006 = 0.94%/yr (p= 0.54)

Eutrophic

% LakeSPI 2009 = 27
Moderate

Lake Rotorua occupies a caldera created by the Mamaku Ignimbrite eruption. The lake has a 45 metre deep crater located north of Sulphur Point, but is otherwise relatively flat bottomed with its deeper contour at around 26 metres, west of Mokoia Island. At 80 km^2 Lake Rotorua has the largest surface area of all the Rotorua Lakes and it also has the largest catchment area at around 508 km^2. Pasture is the main land cover in the catchment followed by indigenous vegetation.

The lake is fed by a variety of streams and of these the Hamurana Stream has the greatest flow. Geothermal inputs flow via streams such as the Puarenga and Waiohewa Streams. Hot springs are also located along the southern shore of the lake. There are two monitoring sites for this lake located north and south of Mokoia Island, each having maximum depths of around 20 metres.

Table 3.11 Lake Rotorua attributes.

Attribute	Measure	Land Cover (%)	1977-78	1996
Catchment area (km^2)	441.4	Exotic forest	8.3	14.3
Lake area (km^2)	80.6	Indigenous forest/scrub	30.6	25.1
Maximum depth (m)	44.8	Pasture	52.9	51.8
Mean depth (m)	11	Urban	8.1	8.1
Altitude (m)	280			
Age (x 1000 years)	140			

3.10.1 TLI results and trends

The three yearly average TLI results have shown a decline since 2004 (Figure 3.33) with annual TLI results fluctuating around 4.7 to 4.9 units, above the target TLI of 4.5. A slight increase in the 2008/2009 TLI is due to an increase in the TLp while the TLn decreased (see Appendix 1).

TN is showing a steady decrease from 2007 (Figure 3.32) with minimal seasonal increase occurring in the 2007/2008 summer. Both ammonium-nitrogen and nitrate-nitrogen concentrations were also low over this summer period compared to previous years. An increase in TN occurred late in the summer of 2008/2009 continuing to increase into autumn due to a sustained *Microcystis* algal bloom. However the average TN for 2008/2009 was lower than previous years possibly due to low algal biomass at the beginning of the summer.

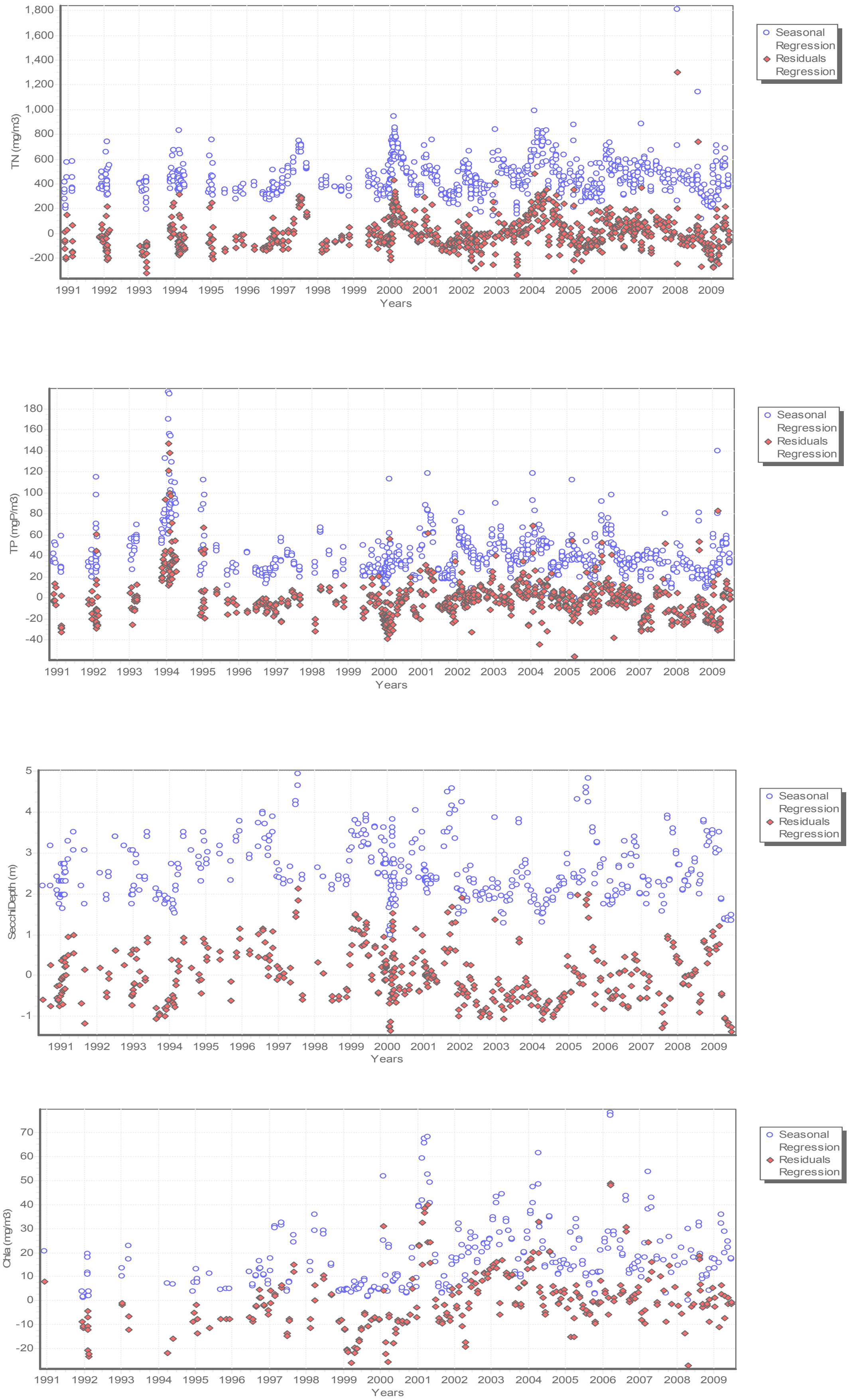


Figure 3.32 TN, TP & Chla concentrations & secchi depths with deseasonalised residuals, 1991 to 2009.

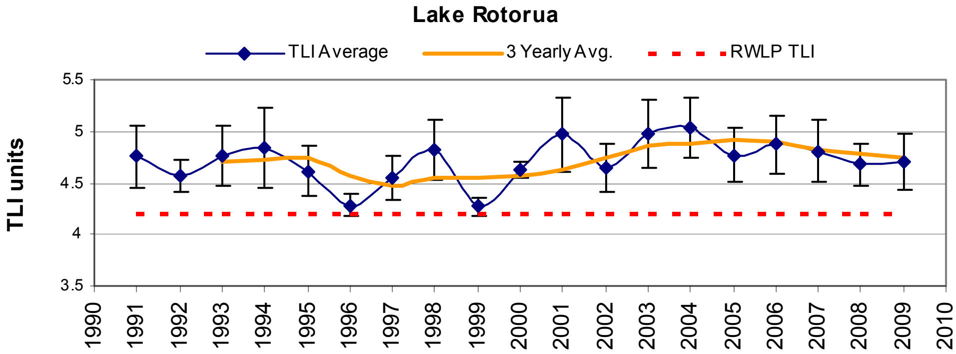


Figure 3.33 Annual TLI averages with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotorua.

The average annual TP concentrations have been under 35 mg/m^3 for the last three years compared to the six years previous to those, where for all but one year TP was over 40 mg/m^3 (Figure 3.32). DRP increases over the summer period for the last three years have also been less intensive, which is the predominant reason for lower TP levels over these years. Continuous DO data from the Rotorua monitoring buoy does show that the lake became anoxic in both the 2007/2008 and 2008/2009 summers (Figure 3.34). It is likely that previous years had greater periods of anoxia due to longer or more frequent stratification periods.

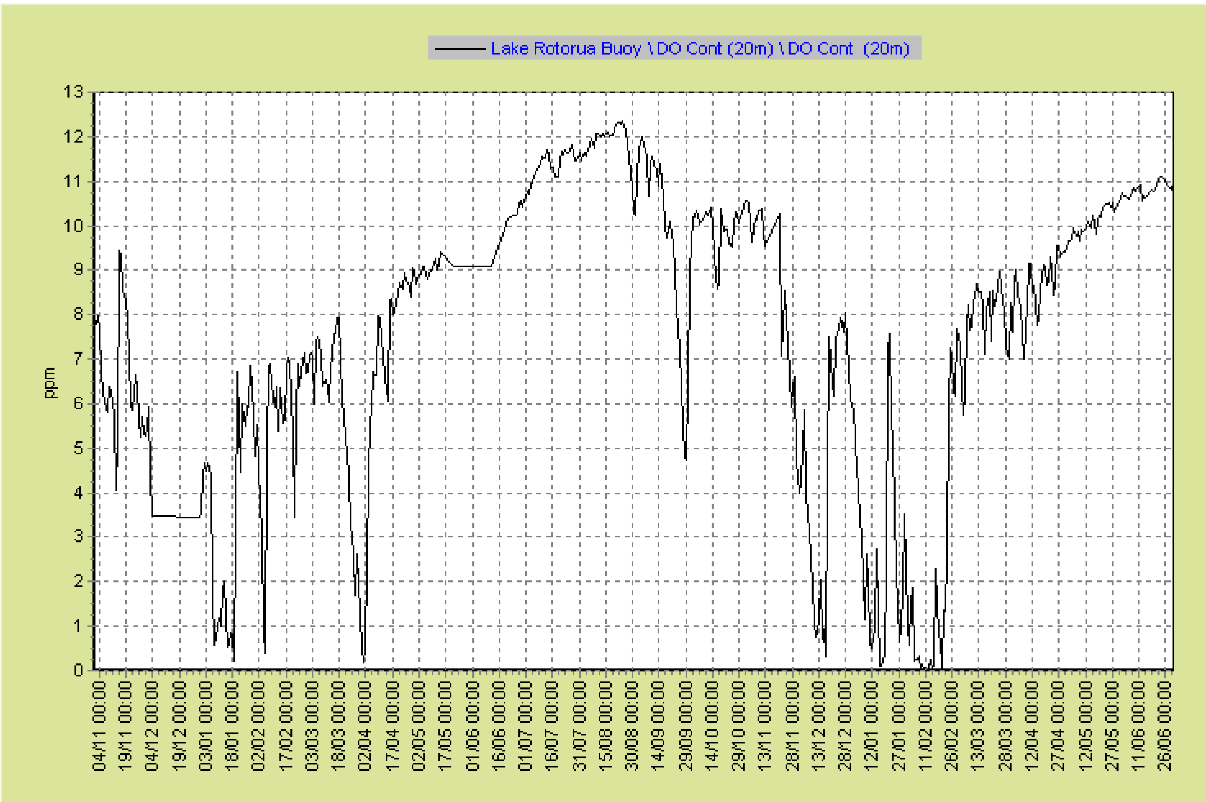


Figure 3.34 Average daily DO concentrations at 20m depth, Lake Rotorua monitoring buoy, November 2007 to June 2009 (flat line show maintenance periods).

Water clarity has remained stable over the last five years with the exception of a rapid decline with the onset of the *Microcystis* algal bloom late in the 2008/2009 summer. Figure 3.32 highlights this decrease in secchi depth and also shows the rapid increase in Chl-a when then this cyano-bacterial bloom occurred. Chl-a levels continue to remain high.

3.10.2 Blue-green algae

In the 2008/2009 season sustained bloom activity was recorded for up to 12 weeks, beginning late in the season (March) and ending in June. A species not seen forming major blooms previously was identified, *Microcystis wesenbergii*. The species formed pooled slicks in slower flowing waters of the Ohau Channel and Okere Arm. A health warning occurred for most of this period.

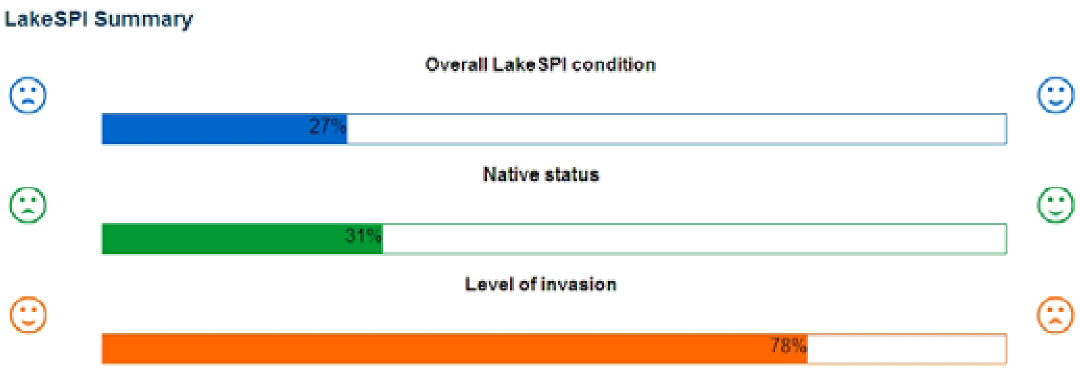
3.10.3 LakeSPI (Submerged Plant Indicators)

The lake's 'native condition' remains low but stable. The invasive condition has improved slightly only because Egeria underwent a major decline in Lake Rotorua in the late eighties and has never recovered. Future water quality improvements in this lake will cause aquatic pest plant species to proliferate however, increasing the risk for large weed strandings. Lake Rotorua contains three of the regions' worst aquatic pest plant species and so poses a risk to neighbouring lakes that are free of these species.

LakeSPI rank 2009: 9th lowest ranked lake out of the 12 Rotorua lakes.

Current condition: poor

Long-term trend: stable



3.10.4 Lake management

The three yearly average TLI for Lake Rotorua remains above the TLI objective as set by the RWLP. There is now a comprehensive list of actions and proposed tasks to help restore water quality set out in the Lake Rotorua-Rotoiti Action Plan (approved in July 2009). Actions and nutrient targets for the two lakes are outlined in the Plan.

Internal phosphorus and nitrogen recycling between the sediment and water column contributes a significant proportion of the nutrient load to Lake Rotorua. This combined with the relatively old age of inflowing nutrient laden groundwater, means that restoration of the lake is not likely to be achieved over a short time-frame.

The Action Plan summarises the water quality problems, the urgent actions, and the long-term land use changes and management changes needed to improve lake quality.

Sewage reticulatation woks have been occurring with the plan to treat sewage from the communities of Mourea, Brunswick Park, Rotokawa and Hamurana – or to upgrade to advanced onsite effluent treatment systems. Brunswick and Rotokawa sewage reticulation is programmed to be completed late in 2009.

Alum dosing of the Utuhina Sream to bind much of the phosphorus from this source has been occurring for several years. Another alum dosing plant is also being established on the Puarenga Stream.

A nitrification-denitrification plant has been approved for trial to reduce nitrogen added to the lake from the Tikitere geothermal field via the Waiohewa Stream.

The Rotorua working party will continue to work on the problems in Lake Rotorua with a range of techniques being considered or implemented including:

- Inflow diversions.
- Inflow treatments.
- In-stream and lake chemical flocculation of phosphorus.
- Land use change and land use management change.
- Improvements in stormwater management.
- Best management practices for urban and rural areas.
- Sediment capping, dredging, oxygenation.
- Engineering structures to reduce nutrients.
- Improvement in sewage treatment.

3.11 **Lake Tarawera**

TLI 3 year average = 2.9
TLI 2008/2009* = *2.90
TLI Objective = 2.6

PAC 1994-2009 = -0.09
(p=0.96)

Oligotrophic

% LakeSPI 2008 = 22
Moderate

Lake Tarawera is located in the southwest section of the Haroharo Caldera. It is a large lake at 41 km^2 and over 87 metres at its deepest extent. The catchment is largely covered in indigenous forest and scrub with about 20% pasture cover and 16% exotic forest.

The lake is fed by seven other lakes. Direct inputs are from Lake Okareka via Waitangi Springs and Lake Rotokakahi via the Te Wairoa Stream. Lake Rotomahana flows through a buried stream at times of high lake levels and via other ground water paths as do Lakes Tikitapu and Okataina. The lake drains to the Pacific Ocean through the Tarawera River with the outlet being at the eastern extent of the lake. Geothermal input to the lake is through springs in the lake bed located towards the south-western shore.

Table 3.12 Lake Tarawera attributes.

Attribute	Measure	Land Cover (%)	1967	1996	2003
Catchment area (km^2)	143.1	Exotic forest	12.1	15.4	16.0
Lake area (km^2)	41.3	Indigenous forest/scrub	70.8	60.1	62.4
Maximum depth (m)	87.5	Pasture	16.7	21.1	19.7
Mean depth (m)	50	Urban	0.0	0.7	
Altitude (m)	299	Other			1.9
Age (x 1000 years)	5				

3.11.1 **TLI results and trends**

The TLI for Lake Tarawera is 0.3 units above the target TLI and has been steady at this level for the last four years (Figure 3.36). The 2008/2009 annual average TLI is almost unchanged from the previous year as is the three year annual average. However the TLn for 2008/2009 has decreased and the TLp has increased compared to the previous year (see Appendix 1).

The lower annual average TN concentration for the 2008/2009 year is a result of strongly declining TN concentrations from the winter of 2008 into early summer (Figure 3.35). These concentrations increased in mid-summer as algal concentrations increased. Ammonium-nitrogen shows an increasing trend since 2002 particularly in the hypolimnion (p<0.01).

Figure 3.35 TN, TP & Chla concentrations & secchi depths with deseasonalised residuals, 1994 to 2009.

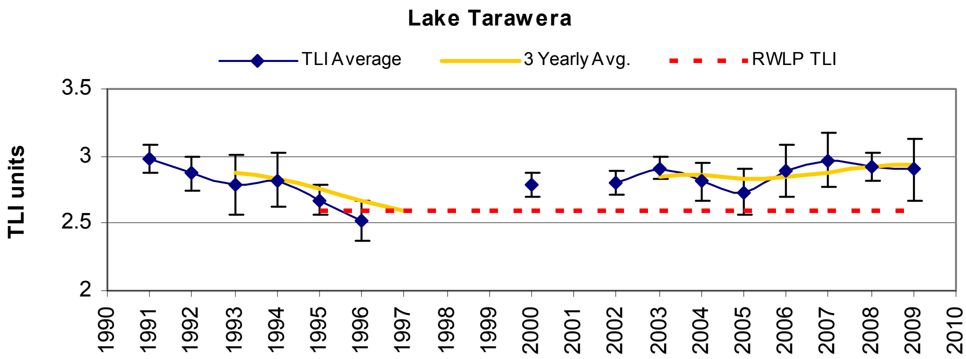


Figure 3.36 Annual TLI averages with standard error bars, 3 yearly average TLI and RWLP TLI objective for Lake Tarawera.

TP also has an increasing trend in both the epilimnion (0.87 mg/m^3/yr, p<0.01) and hypolimnion (2.54 mg/m^3/yr, p<0.01). The same trend exists also for DRP (Figure 3.37). Average annual TP for 2008/2009 is the highest calculated in the 15 year period of record. DRP does build up in the hypolimnion over the stratification period, although monitoring does not indicate the hypolimnion going anoxic which leads to reducing conditions promoting phosphorus release from sediments. Oxygen depletion rates are very low compared to other lakes. HVOD estimates indicate some improvement in past two years (Figure 3.38). If sediment releases are not a major source of increased phosphorus other inflows could be elevating lake phosphorus levels.

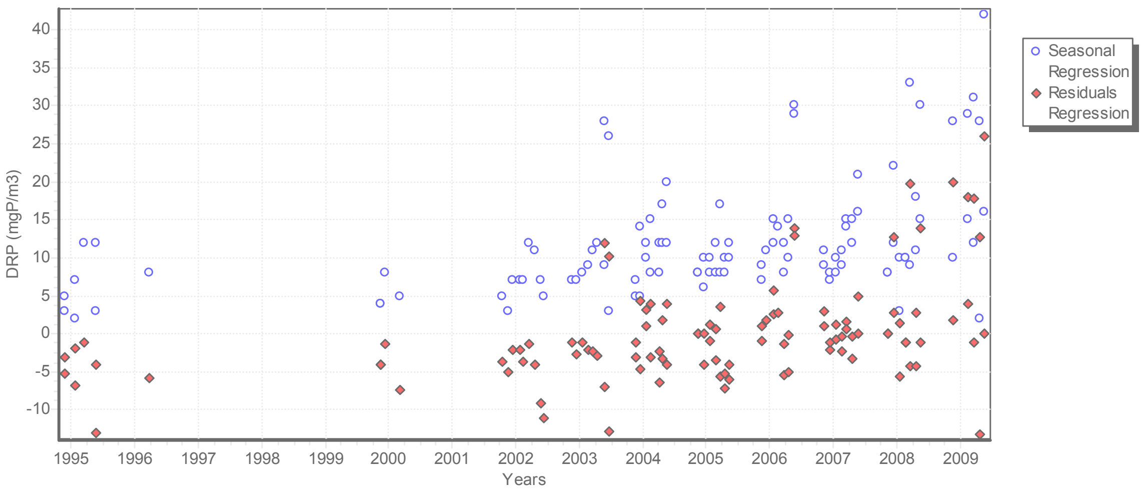


Figure 3.37 DRP concentrations in the hypolimnion with deseasonalised residuals, 1994 to 2009.

Water clarity has remained relatively stable over the past six years with some improvement compared to earlier years (Figure 3.35). VLEC data indicate a decline in the euphotic depth of the lake from late summer to winter 2009 which coincides with a period of increasing Chl-a (Figure 3.35) indicating that increasing algal biomass has reduced light penetration into the lake.

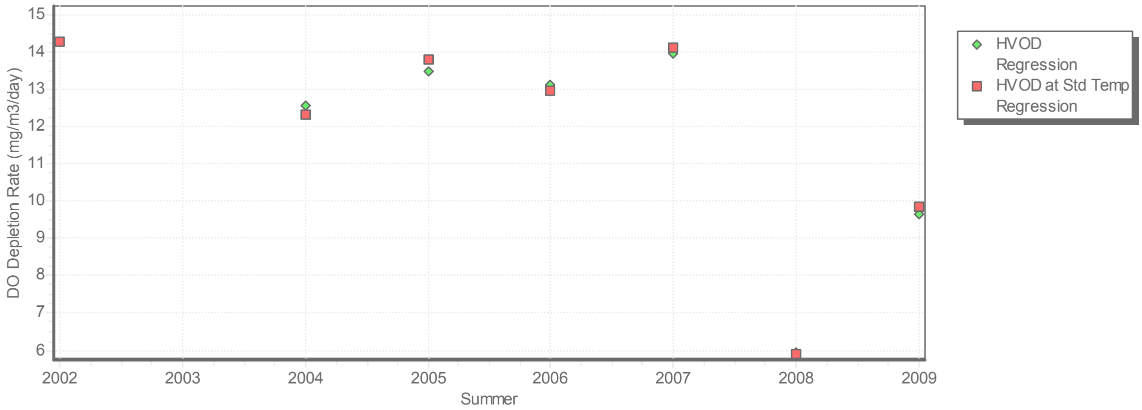


Figure 3.38 HVOD rates, Lake Tarawera, 2002 to 2009.

3.11.2 Blue-green algae

There are occasional blooms in localised areas during summer months. Lake Tarawera has experienced several years where there has been no sustained bloom activity.

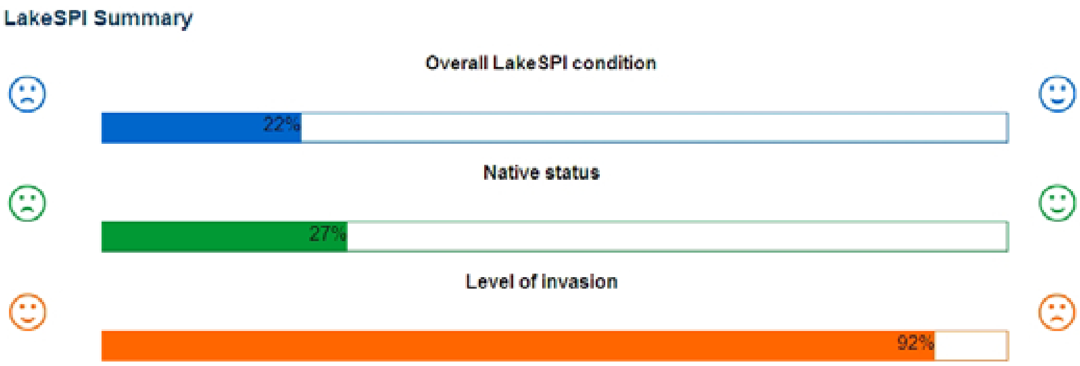
3.11.3 LakeSPI (Submerged Plant Indicators)

A 92% invasive index score, the highest of any of the Rotorua lakes, was due in part to the introduction and spread of hornwort in this lake. The introduction of hornwort doubled the depth range of invasive species. This resulted in the displacement of even the deepest occurring native charophyte meadows and the native condition index has remained low since. The presence of hornwort in Lake Tarawera increases the risk of its spread to nearby, presently unaffected lakes (Tikitapu, Rotokakahi and Okareka).

LakeSPI 2008 rank: 8th lowest ranked lake out of the 12 Rotorua lakes.

Current condition: poor

Long-term trend: stable



3.11.4 Lake management

The three yearly average TLI for Lake Tarawera has been above 0.2 of its TLI objective for several years. There are plans to engage with the Tarawera community before the end of 2009 to start formulation of a draft Action Plan.

The urban community of Lake Tarawera is concentrated around the western fringe of the lake and relies on septic tanks for disposal and treatment of effluent. Reticulation is planned to be completed by 2013. If communities using individual septic tank based systems are not reticulated then they may be subject to new rules under the On-site Effluent Treatment Regional Plan, which seeks to improve treatment and discharge standards specifically targeting greater removal of nitrogen.

Land management initiatives such as riparian protection works are continuing in the catchment.

A monitoring buoy has been established on the lake by Environment Bay of Plenty and the University of Waikato. Data received from this buoy will help ascertain changes in the water quality and monitoring of interventions that are designed to reduce nutrient loading to the lake.

3.12 Lake Tikitapu

TLI 3 year average = 3.0
TLI 2008/2009 = 3.12
TLI Objective = 2.7

PAC 1992-2009 = 1.05 (*p*=0.84)

Oligotrophic

% LakeSPI 2008 = 32
Moderate

Lake Tikitapu has a small catchment and the predominant land cover is indigenous vegetation (Table 3.13). Situated north of Lake Rotokakahi and at a higher elevation (418 m a.s.l.), the lake was formed by a lava dam around 13,300 years ago. The lake has a flat bed with a maximum depth of 27.5 metres. Fed by rainwater and small surface flows the lake has no surface outlet, but is thought to leak groundwater to Lake Tarawera via Lake Rotokakahi.

Table 3.13 Lake Tikitapu attributes.

Attribute	Measure	Land Cover (%)	1977-78	1996	2003
Catchment area (km^2)	6.2	Exotic forest	11.4	17.3	17.9
Lake area (km^2)	1.5	Indigenous forest/scrub	80.9	79.2	74.3
Maximum depth (m)	27.5	Pasture	7.7	3.5	7.0
Mean depth (m)	18	Urban	0.0	0.0	0.8
Altitude (m)	417.8				
Age (x 1000 years)	13.3				

3.12.1 TLI results and trends

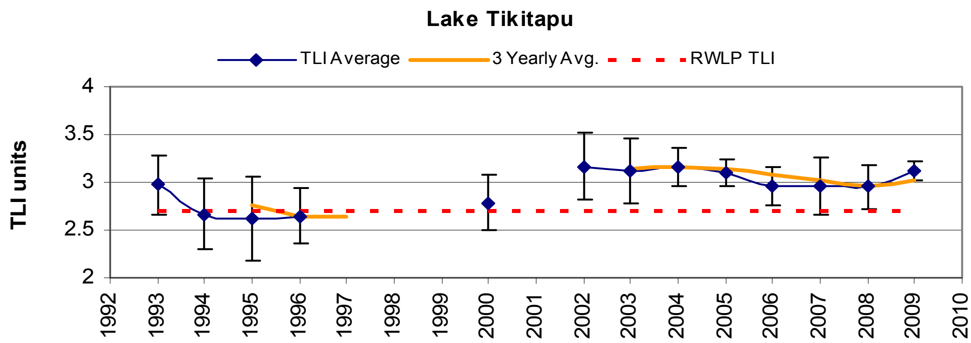


Figure 3.39 Annual TLI averages with standard error bars, 3 yearly average TLI and RWLP TLI objective for Lake Tikitapu.

Figure 3.40 TN, TP and Chla concentrations and secchi depths with deseasonalised residuals, 1992 to 2009.

The three yearly average TLI for Lake Tikitapu increased slightly with a small increase in the 2008/2009 TLI (Figure 3.39). The increase puts the lake on the cusp of the mesotrophic classification and further away from the target TLI of 2.7 units.

The 2008/2009 year saw a decrease in TN concentrations ending a trend of increasing TN in the epilimnion. An increasing trend in ammonium-nitrogen is still occurring (1.03 mg/m^3/yr, $p<0.01$) possibly due to increasing period of anoxia in the hypolimnetic sediments.

TP concentrations on average have remained stable since 2002 (Figure 3.40) although the 2008/2009 average concentration has increased, partly driving the increased TLI. Since 2002 DRP does show an increasing trend in the epilimnion but not in the hypolimnion.

The water clarity of the lake remains stable with a slight decrease in 2008/2009. There have been greater seasonal fluctuations in the VLEC average data in the past three years which corresponds to greater seasonal fluctuations in Chl-a over the same period.

After a trend of increasing oxygen depletion from 2002 to 2005 HVOD rates have declined (Figure 3.41). However, the onset of anoxia in the hyplominion under stratified conditions has increased. The sediment water interface has become anoxic as early as January over the last two summers compared to April in the previous few years.

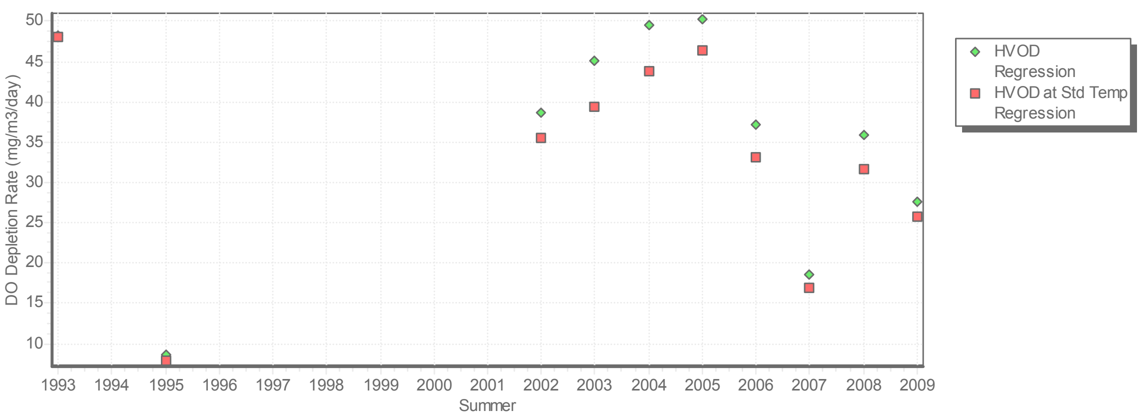


Figure 3.41 HVOD rates, Lake Tikitapu, 1993 to 2009.

3.12.2 LakeSPI (Submerged Plant Indicators)

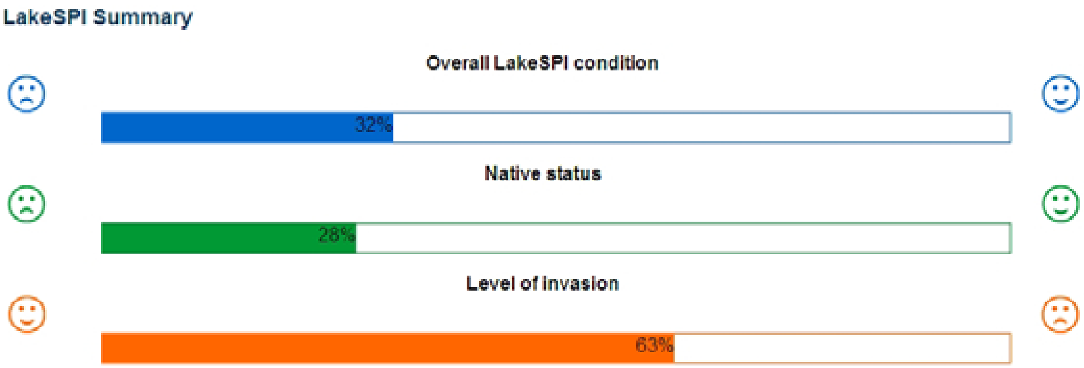
Since records began Lake Tikitapu has experienced a 31% reduction in LakeSPI condition, the largest drop of any of the Rotorua Lakes over the same 1988-2008 period. The reduction in native condition has not been caused so much by the competitive impacts of invasive pest plant species as by the contracted depth range and condition of submerged native plant species. Where previously the bottom plant boundary extended to a depth of almost 13 metres, the deepest plants recorded in 2008 were in depths of less than 9 metres.

Lake Tikitapu is presently free of two of the worst invasive aquatic weeds in the region, hornwort and Egeria. It is however surrounded by lakes containing these species so is extremely vulnerable to infestation.

LakeSPI 2008 rank: 6th highest ranked lake for LakeSPI

Current condition: average

Long-term trend: declining



3.12.3 Lake management

The three yearly average TLI for Lake Tikitapu has been 0.2 units above its RWLP objective for more than two years. Work on an Action Plan for the lake is scheduled for 2010.

Lake Tikitapu has received the highest priority ranking in the lake quality assessment and action plan prioritisation process,

The catchment of Lake Tikitapu is dominated by indigenous and exotic forest and therefore there is little in the way of land management options that can be used to improve water quality. One option that will be implemented is the reticulation of the public toilets at the motor camp in conjunction with the Lake Okareka reticulation scheme. Sewage reticulation for Lake Tikitapu will be connected with Lake Okareka reticulation by 2010.

Part 4: Conclusions

The three year average TLI for each of the 12 Rotorua Lakes have been calculated for the 2008/2009 year and are presented in Table 4.1 along with Lake Type and Lake SPI condition.

Table 4.1 Three yearly average TLI values for the Rotorua District lakes in comparison to the TLI values set in the Regional Water and Land Plan, and LakeSPI condition.

Lake *Regional Water & Land Plan TLI units*	3 yearly average TLI to 2006 *TLI units*	3 yearly average TLI to 2007 *TLI units*	3 yearly average TLI to 2008 *TLI units*	3 yearly average TLI to 2009 *TLI units*	Lake Type *based on Trophic Level*	LakeSPI Condition 2008/2009
Okaro **5.0**	5.5	5.5	5.3	5.3	Supertrophic	Poor
Rotorua **4.2**	4.9	4.8	4.8	4.7	Eutrophic	Moderate
Rotoehu **3.9**	4.5	4.6	4.5	4.5	Eutrophic	Poor
Rotoiti **3.5**	4.3	4.1	4.0	3.9	Mesotrophic	Poor
Rotomahana **3.9**	3.9	3.9	3.9	4.0	Mesotrophic	High
Rerewhakaaitu **3.6**	3.4	3.5	3.6	3.7	Mesotrophic	Moderate
Okareka **3.0**	3.3	3.3	3.3	3.3	Mesotrophic	Moderate
Tikitapu **2.7**	3.1	3.0	3.0	3.0	Mesotrophic	Moderate
Okataina **2.6**	2.9	2.8	2.8	2.8	Oligotrophic	Moderate
Tarawera **2.6**	2.9	2.9	2.9	2.9	Oligotrophic	Moderate
Rotoma **2.3**	2.5	2.5	2.6	2.6	Oligotrophic	High
Rotokakahi **3.1**	3.4	3.5	3.8	4.0	Mesotrophic	Moderate

All of the lakes exceed the TLI set in the RWLP (Objective 11). Method 41 of the Plan requires Action Plans to be implemented where the three-year average TLI is exceeded by 0.2 units for two consecutive years and this is the case for most of the lakes.

Action Plans have been completed for Lakes Okareka, Okaro, Rotoehu, Rotorua-Rotoiti and Rotoma. Lakes Tarawera, Rerewhakaaitu, and Okataina have action plan processes underway or will have in the coming year. An action plan for Rotomahana is less urgent as the TLI does not exceed the 0.2 unit trigger.

The TLI for Lake Rotorua remains stable despite a severe cyano-bacterial bloom that occurred in late summer 2009.

A continued improvement is seen in Lake Rotoiti with the lake now classified as mesotrophic (improving from eutrophic). Nitrogen levels have declined and water clarity has increased, although lake productivity remains stable. These improvements may be attributable to the diversion of nutrient-rich Lake Rotorua water by the Ohau Channel wall which was completed in July 2008. The reticulation of the Okawa Bay community sewage infrastructure was also completed in 2008 and may be one of the reasons for the water clarity improvements seen at Okawa Bay.

The annual TLI for Lake Okaro has not improved in the last year despite actions to reduce the internal phosphorus load for the last four years. The lakes productivity and water clarity remains stable and phosphorus levels continue to decline in response to the interventions within the lake to arrest the internal phosphorus loading.

The TLI in Lake Rotoehu improved in 2008/2009, with nitrogen levels lower on average than the previous year. Some nutrient reduction may be attributable to the harvesting of hornwort (*Ceratophyllum demersum*) which has the effect of removing nutrient from the lake catchment.

Two mesotrophic lakes, Rerewhakaaitu and Rotomahana, have had slightly increasing trends in their TLI's. The nitrogen levels in Lake Rerewhakaaitu have been increasing in recent years and this coincides with a large increase in nitrate-nitrogen partially attributable to surface water inflows. Water clarity shows a decreasing trend which correlates to increasing chlorophyll-a concentrations (algae biomass).

Potential hornwort infestation continues to remain a risk to native charophyte meadows in Lake Okareka. The TLI in Okareka is stable although TP and chlorophyll-a have shown increases. Additional phosphorus may be being added to the lake system as TP continues to be at low levels in the hypolimnion due to a Phoslock application.

Lake Tikitapu is on the cusp of the mesotrophic-oligotrophic classification and the TLI increased slightly in 2008/2009. Although oxygen depletion rates have not increased the earlier onset of anoxia in the lake is cause for concern and could result in greater nutrient concentrations. Sewage reticulation for Lake Tikitapu will be connected with Lake Okareka reticulation by 2010.

The TLI for Lake Tarawera remains stable although nutrients have shown a significantly increasing trend over the past 8 years. This increase has not impacted on the water clarity or productivity of the lake.

The TLI for Lake Okataina decreased slightly in 2008/2009 remaining above its RWLP target TLI. Phosphorus levels show some increase in the hypolimnion. Invasive hornwort fragments were found in Lake Okataina in 2009. After an extensive delimitation survey no established plants were found.

The TLI for Lake Rotoma decreased slightly from 2.6 in 2007/2008 to 2.4 in 2008/2009, primarily due to a decrease in total nitrogen concentrations (the three-yearly average TLI remains at 2.5). Other TLI parameters remained stable with a marginal increase in water clarity.

Lake Rotokakahi has been assessed by monthly monitoring of the outflow at the Te Wairoa Stream. The TLI assessed for the lake using three TLI parameters (chlorophyll-a, TP and TN) is elevated compared to previous years. All three TLI parameters increased. Potential causes are increasing anoxia and added nutrients from surface inflows exacerbated by recent forest harvesting.

Lakes Rotoehu, Rotorua and Okaro all had health warnings placed on them in the last year due to cyano-bacteria blooms. An extensive *Microcystis* bloom that originated in Lake Rotorua also impacted on the Okere Arm of Lake Rotoiti.

Part 5: References

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Appendices

Appendix I – TLI and PAC Results

Lake Okareka

1992 to 2009 Site 1 (1 Jul 1992 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.05)	-0.10	0.22	-1.46	-0.81			
Average Over Period	(4.35)	8.07	7.15	218.90	44.79			
Percent Annual Change (%/Year)	**0.00**	**1.24**	**3.08**	**-0.67**	**-1.81**	**0.37**	**0.84**	**0.68**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1992 - Jun 1993	3.16	10.56	5.86	231.75	3.49	2.55	2.46	3.51	3.00	0.29			
Jul 1993 - Jun 1994	2.44	9.97	4.91	226.15	3.20	2.64	2.24	3.48	2.89	0.28			
Jul 1994 - Jun 1995	3.88	7.79	6.23	220.63	3.72	3.00	2.54	3.44	3.17	0.26			
Jul 1995 - Jun 1996	3.10	8.04	5.92	229.50	3.47	2.95	2.47	3.50	3.10	0.24			
Jul 1996 - Jun 1997	9.70	7.36	7.79	260.14	4.73	3.08	2.82	3.66	3.57	0.42			
Jul 1997 - Jun 1998	5.40	9.06	6.25	245.25	4.08	2.78	2.54	3.58	3.25	0.36			
Jul 1998 - Jun 1999	5.23	8.55	5.75	236.40	4.04	2.86	2.44	3.53	3.22	0.36			
Jul 1999 - Jun 2000	5.12	7.92	7.00	209.45	4.02	2.97	2.69	3.38	3.26	0.29			
Jul 2000 - Jun 2001	3.62	8.70	6.20	216.86	3.64	2.84	2.53	3.42	3.11	0.26			
Jul 2001 - Jun 2002	4.03	8.31	5.41	210.41	3.76	2.91	2.36	3.38	3.10	0.30			
Jul 2002 - Jun 2003	3.90	8.03	5.75	183.45	3.72	2.95	2.44	3.20	3.08	0.27			
Jul 2003 - Jun 2004	5.21	6.45	6.72	229.03	4.04	3.26	2.63	3.49	3.36	0.29			
Jul 2004 - Jun 2005	2.93	7.42	7.75	197.55	3.41	3.07	2.81	3.30	3.15	0.13			
Jul 2005 - Jun 2006	4.51	7.59	10.70	215.21	3.88	3.03	3.22	3.41	3.39	0.18			
Jul 2006 - Jun 2007	3.12	7.72	9.00	225.30	3.48	3.01	3.00	3.47	3.24	0.13			
Jul 2007 - Jun 2008	4.32	7.88	6.61	219.43	3.83	2.98	2.61	3.44	3.22	0.27			
Jul 2008 - Jun 2009	4.62	8.41	10.14	199.32	3.91	2.89	3.16	3.31	3.32	0.22			
Averages	**4.37**	**8.22**	**6.94**	**220.93**	**3.79**	**2.93**	**2.64**	**3.44**	**3.20**	**0.06**	**0.01**	**0.01**	**0.3480**

Lake Okaro

1991 to 2009 Site 1 (1 Sep 1991 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(0.05)	0.04	-3.12	(-2.28)	(-2.91)			
Average Over Period	(29.71)	2.11	90.87	(1,088.91)	(74.97)			
Percent Annual Change (%/Year)	**0.00**	**-1.90**	**-3.43**	**0.00**	**0.00**	**-1.07**	**0.70**	**0.20**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1991 - Jun 1992	29.55	1.38	84.33	1,177.83	5.96	5.15	5.84	5.63	5.65	0.18			
Jul 1992 - Jun 1993	27.75	2.08	91.67	1,015.67	5.89	4.67	5.95	5.44	5.49	0.29			
Jul 1993 - Jun 1994	12.35	1.93	101.10	1,259.33	4.99	4.76	6.07	5.72	5.39	0.31			
Jul 1994 - Jun 1995	12.15	1.87	138.00	1,193.71	4.97	4.80	6.47	5.65	5.47	0.38			
Jul 1995 - Jun 1996	22.85	1.86	165.83	1,271.83	5.67	4.80	6.70	5.73	5.73	0.39			
Jul 1996 - Jun 1997	42.74	1.85	146.78	1,492.44	6.36	4.81	6.54	5.94	5.92	0.39			
Jul 1997 - Jun 1998	81.68	1.72	119.33	1,246.33	7.08	4.90	6.28	5.71	5.99	0.46			
Jul 1998 - Jun 1999	55.90	1.94	126.00	1,754.00	6.66	4.76	6.35	6.15	5.98	0.42			
Jul 1999 - Jun 2000													
Jul 2000 - Jun 2001	17.10	2.02	99.17	1,013.54	5.35	4.71	6.05	5.44	5.39	0.27			
Jul 2001 - Jun 2002													
Jul 2002 - Jun 2003	26.54	1.85	107.94	936.54	5.84	4.81	6.15	5.33	5.53	0.29			
Jul 2003 - Jun 2004	19.73	2.38	103.66	984.78	5.51	4.51	6.10	5.40	5.38	0.33			
Jul 2004 - Jun 2005	77.18	1.48	92.76	1,266.94	7.01	5.08	5.96	5.73	5.95	0.40			
Jul 2005 - Jun 2006	17.05	2.74	84.67	986.73	5.35	4.34	5.85	5.40	5.24	0.32			
Jul 2006 - Jun 2007	19.97	2.42	75.33	975.78	5.52	4.49	5.70	5.39	5.28	0.27			
Jul 2007 - Jun 2008	27.28	2.37	62.15	1,034.78	5.87	4.52	5.45	5.46	5.33	0.29			
Jul 2008 - Jun 2009	24.46	2.60	54.61	1,256.07	5.75	4.41	5.29	5.72	5.29	0.31			
Averages	**32.14**	**2.03**	**103.33**	**1179.14**	**5.86**	**4.72**	**6.05**	**5.62**	**5.56**	**0.08**	**-0.02**	**0.01**	**0.2074**

Lake Okataina

1992 to 2009 Site 1 (1 Jul 1992 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(0.02)	(0.04)	(0.14)	(1.36)	(-0.11)			
Average Over Period	(2.26)	(10.33)	(7.92)	(136.13)	(28.84)			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.00**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1992 - Jun 1993	1.92	11.10	9.92	139.44	2.94	2.47	3.13	2.84	2.85	0.14			
Jul 1993 - Jun 1994	1.56	9.57	5.56	117.91	2.71	2.70	2.39	2.63	2.61	0.07			
Jul 1994 - Jun 1995	1.23	11.37	6.00	124.00	2.44	2.44	2.49	2.69	2.52	0.06			
Jul 1995 - Jun 1996	1.71	10.44	5.00	112.17	2.81	2.57	2.26	2.56	2.55	0.11			
Jul 1996 - Jun 1997													
Jul 1997 - Jun 1998													
Jul 1998 - Jun 1999													
Jul 1999 - Jun 2000	2.16	11.21	5.14	121.50	3.07	2.46	2.29	2.66	2.62	0.17			
Jul 2000 - Jun 2001													
Jul 2001 - Jun 2002	3.34	8.11	6.40	143.62	3.55	2.94	2.57	2.88	2.99	0.20			
Jul 2002 - Jun 2003	3.11	8.20	8.12	111.28	3.47	2.93	2.87	2.55	2.95	0.19			
Jul 2003 - Jun 2004	2.76	11.08	10.70	142.13	3.34	2.48	3.22	2.87	2.98	0.19			
Jul 2004 - Jun 2005	2.12	10.47	8.70	144.95	3.05	2.57	2.96	2.90	2.87	0.11			
Jul 2005 - Jun 2006	1.89	11.53	9.16	150.48	2.92	2.42	3.03	2.94	2.83	0.14			
Jul 2006 - Jun 2007	1.65	11.42	7.00	134.53	2.77	2.43	2.69	2.80	2.67	0.08			
Jul 2007 - Jun 2008	2.35	10.20	8.75	163.90	3.16	2.60	2.97	3.06	2.95	0.12			
Jul 2008 - Jun 2009	2.46	10.84	8.81	119.77	3.21	2.51	2.98	2.65	2.84	0.16			
Averages	**2.17**	**10.43**	**7.64**	**132.74**	**3.04**	**2.58**	**2.76**	**2.77**	**2.79**	**0.04**	**0.02**	**0.01**	**0.0287**

Lake Rerewhakaaitu

1990 to 2009 Site 1 (1 Jul 1990 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.06)	(-0.03)	0.19	5.07				
Average Over Period	(3.81)	(5.85)	8.22	381.44				
Percent Annual Change (%/Year)	**0.00**	**0.00**	**2.31**	**1.33**	**0.00**	**0.91**	**0.56**	**0.20**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1990 - Jun 1991	3.90	4.95	9.83	321.86	3.72	3.60	3.12	3.94	3.60	0.17			
Jul 1991 - Jun 1992	3.14	7.34	8.00	356.96	3.48	3.08	2.86	4.07	3.37	0.27			
Jul 1992 - Jun 1993	2.74	7.41	5.47	310.22	3.33	3.07	2.37	3.89	3.17	0.32			
Jul 1993 - Jun 1994	2.20	6.92	5.40	334.14	3.09	3.16	2.36	3.99	3.15	0.33			
Jul 1994 - Jun 1995	2.42	6.37	6.50	329.85	3.19	3.27	2.59	3.97	3.26	0.28			
Jul 1995 - Jun 1996	7.80	3.78	8.86	398.14	4.49	3.95	2.98	4.22	3.91	0.33			
Jul 1996 - Jun 1997	8.43	4.34	10.53	446.27	4.57	3.77	3.20	4.37	3.98	0.31			
Jul 1997 - Jun 1998	17.18	4.45	9.67	547.67	5.36	3.74	3.10	4.63	4.21	0.50			
Jul 1998 - Jun 1999	7.38	2.78	6.00	499.50	4.42	4.32	2.49	4.51	3.94	0.48			
Jul 1999 - Jun 2000													
Jul 2000 - Jun 2001	2.97	5.62	5.74	359.46	3.42	3.44	2.43	4.08	3.34	0.34			
Jul 2001 - Jun 2002	3.33	4.88	5.65	348.07	3.55	3.62	2.41	4.04	3.41	0.35			
Jul 2002 - Jun 2003	2.93	6.68	6.93	333.33	3.40	3.21	2.67	3.98	3.32	0.27			
Jul 2003 - Jun 2004	2.35	8.25	9.61	376.59	3.16	2.92	3.09	4.14	3.33	0.28			
Jul 2004 - Jun 2005	3.42	5.88	7.50	338.63	3.58	3.38	2.77	4.00	3.43	0.26			
Jul 2005 - Jun 2006	2.82	7.01	8.78	389.92	3.37	3.14	2.97	4.19	3.42	0.27			
Jul 2006 - Jun 2007	2.87	5.77	10.98	469.68	3.38	3.41	3.26	4.43	3.62	0.27			
Jul 2007 - Jun 2008	3.87	4.93	8.54	483.54	3.71	3.61	2.94	4.47	3.68	0.31			
Jul 2008 - Jun 2009	5.15	4.29	12.17	429.70	4.03	3.79	3.39	4.32	3.88	0.20			
Averages	**4.72**	**5.65**	**8.12**	**392.97**	**3.74**	**3.47**	**2.83**	**4.18**	**3.56**	**0.07**	**0.01**	**0.01**	**0.5807**

Lake Rotoehu

1990 to 2009 Sites 1 & 3 (1 Jul 1990 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.04)	-0.04	(0.08)	-6.22				
Average Over Period	(11.58)	2.87	(38.17)	435.41				
Percent Annual Change (%/Year)	**0.00**	**1.39**	**0.00**	**-1.43**	**0.00**	**-0.01**	**0.58**	**0.99**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1990 - Jun 1991	2.60	4.52	31.28	285.44	3.27	3.72	4.58	3.78	3.84	0.27			
Jul 1991 - Jun 1992	1.59	5.28	28.53	324.40	2.73	3.52	4.47	3.95	3.67	0.37			
Jul 1992 - Jun 1993	35.45	2.67	48.19	801.75	6.16	4.37	5.13	5.13	5.20	0.37			
Jul 1993 - Jun 1994	10.28	2.63	46.44	502.50	4.79	4.39	5.09	4.52	4.70	0.15			
Jul 1994 - Jun 1995	11.67	1.76	47.06	443.76	4.93	4.87	5.10	4.36	4.81	0.16			
Jul 1995 - Jun 1996	7.90	2.81	44.82	405.45	4.50	4.31	5.04	4.24	4.52	0.18			
Jul 1996 - Jun 1997	11.90	3.45	35.63	434.97	4.95	4.06	4.75	4.33	4.52	0.20			
Jul 1997 - Jun 1998	13.54	2.81	33.85	529.85	5.09	4.31	4.68	4.59	4.67	0.16			
Jul 1998 - Jun 1999	10.33	2.57	32.50	458.50	4.80	4.42	4.63	4.40	4.56	0.09			
Jul 1999 - Jun 2000	13.55	2.45	30.10	461.10	5.10	4.48	4.54	4.41	4.63	0.16			
Jul 2000 - Jun 2001	12.65	2.25	37.09	486.43	5.02	4.58	4.80	4.48	4.72	0.12			
Jul 2001 - Jun 2002	14.53	2.12	30.27	459.90	5.17	4.65	4.54	4.40	4.69	0.17			
Jul 2002 - Jun 2003	13.38	2.52	26.50	438.12	5.08	4.44	4.37	4.34	4.56	0.18			
Jul 2003 - Jun 2004	10.07	2.78	32.63	382.76	4.77	4.32	4.64	4.16	4.47	0.14			
Jul 2004 - Jun 2005	13.27	2.99	39.83	426.34	5.07	4.24	4.89	4.31	4.63	0.21			
Jul 2005 - Jun 2006	7.97	2.80	33.00	433.43	4.51	4.31	4.65	4.33	4.45	0.08			
Jul 2006 - Jun 2007	11.05	2.78	54.68	418.16	4.87	4.33	5.29	4.28	4.69	0.24			
Jul 2007 - Jun 2008	11.75	2.56	30.25	349.35	4.94	4.42	4.54	4.05	4.49	0.18			
Jul 2008 - Jun 2009	10.21	3.60	45.67	275.87	4.78	4.01	5.06	3.74	4.40	0.31			
Averages	**11.77**	**2.91**	**37.28**	**437.79**	**4.76**	**4.30**	**4.78**	**4.30**	**4.54**	**0.06**	**0.01**	**0.01**	**0.3311**

Lake Rotoiti

1992 to 2009 Sites 1,2,3 & 4 (1 Jul 1992 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.24	(-0.02)	0.52	2.49				
Average Over Period	8.20	(5.14)	25.35	293.84				
Percent Annual Change (%/Year)	**2.93**	**0.00**	**2.05**	**0.85**	**0.00**	**1.46**	**0.65**	**0.11**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1992 - Jun 1993	7.58	5.50	20.43	267.10	4.45	3.47	4.04	3.69	3.91	0.22			
Jul 1993 - Jun 1994	4.15	5.07	21.33	273.70	3.79	3.57	4.10	3.73	3.80	0.11			
Jul 1994 - Jun 1995	4.48	5.52	19.97	253.27	3.87	3.46	4.02	3.62	3.74	0.12			
Jul 1995 - Jun 1996	5.28	5.74	23.40	265.23	4.06	3.41	4.22	3.69	3.84	0.18			
Jul 1996 - Jun 1997	5.13	6.33	17.70	244.67	4.02	3.28	3.86	3.58	3.69	0.16			
Jul 1997 - Jun 1998	6.09	5.80	22.28	288.33	4.21	3.40	4.15	3.79	3.89	0.19			
Jul 1998 - Jun 1999	6.49	4.64	27.00	285.07	4.28	3.69	4.40	3.78	4.04	0.18			
Jul 1999 - Jun 2000	8.01	5.53	22.56	252.56	4.52	3.46	4.17	3.62	3.94	0.24			
Jul 2000 - Jun 2001													
Jul 2001 - Jun 2002	7.30	4.44	23.06	249.15	4.41	3.74	4.20	3.60	3.99	0.19			
Jul 2002 - Jun 2003	17.63	3.32	31.05	354.14	5.39	4.11	4.57	4.06	4.53	0.31			
Jul 2003 - Jun 2004	12.03	4.30	39.83	447.77	4.96	3.79	4.89	4.37	4.50	0.27			
Jul 2004 - Jun 2005	13.39	5.05	34.51	374.08	5.08	3.58	4.71	4.13	4.38	0.33			
Jul 2005 - Jun 2006	7.15	5.21	33.12	307.06	4.39	3.54	4.66	3.88	4.12	0.25			
Jul 2006 - Jun 2007	5.70	5.84	24.67	289.37	4.14	3.39	4.28	3.80	3.90	0.20			
Jul 2007 - Jun 2008	7.35	5.36	20.41	277.27	4.42	3.50	4.04	3.74	3.93	0.20			
Jul 2008 - Jun 2009	7.67	5.50	21.77	209.82	4.47	3.47	4.12	3.38	3.86	0.26			
Averages	**7.84**	**5.20**	**25.19**	**289.91**	**4.40**	**3.55**	**4.28**	**3.78**	**4.00**	**0.06**	**0.02**	**0.01**	**0.0694**

Lake Rotoma

1992 to 2009 Site 1 (1 Jul 1992 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.02)	(0.04)	0.15	(0.86)	(-0.35)			
Average Over Period	(1.34)	(12.57)	4.48	(149.60)	(18.55)			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**3.35**	**0.00**	**0.00**	**0.67**	**0.67**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1992 - Jun 1993	2.52	13.63	3.45	176.89	3.24	2.14	1.79	3.16	2.58	0.36			
Jul 1993 - Jun 1994	0.98	11.99	3.00	117.50	2.20	2.35	1.61	2.62	2.20	0.21			
Jul 1994 - Jun 1995	0.93	12.71	3.44	139.67	2.14	2.26	1.79	2.85	2.26	0.22			
Jul 1995 - Jun 1996	0.85	15.61	2.83	139.83	2.04	1.90	1.54	2.85	2.08	0.28			
Jul 1996 - Jun 1997		14.00				2.09			2.09	0.00			
Jul 1997 - Jun 1998													
Jul 1998 - Jun 1999													
Jul 1999 - Jun 2000													
Jul 2000 - Jun 2001	1.96	9.81	3.27	137.91	2.96	2.66	1.72	2.83	2.54	0.28			
Jul 2002 - Jun 2003	1.47	9.36	4.00	129.84	2.65	2.73	1.98	2.75	2.53	0.19			
Jul 2003 - Jun 2004	1.37	14.16	4.91	147.07	2.56	2.07	2.24	2.91	2.45	0.19			
Jul 2004 - Jun 2005	1.33	13.01	4.85	150.24	2.54	2.22	2.22	2.94	2.48	0.17			
Jul 2005 - Jun 2006	1.27	14.30	6.33	164.55	2.48	2.06	2.56	3.06	2.54	0.21			
Jul 2006 - Jun 2007	1.23	11.23	4.10	162.93	2.45	2.46	2.01	3.05	2.49	0.21			
Jul 2007 - Jun 2008	1.21	13.05	5.72	195.75	2.43	2.21	2.43	3.29	2.59	0.24			
Jul 2008 - Jun 2009	1.33	14.20	5.55	122.67	2.54	2.07	2.39	2.68	2.42	0.13			
Averages	**1.37**	**12.85**	**4.29**	**148.74**	**2.52**	**2.25**	**2.02**	**2.92**	**2.42**	**0.06**	**0.02**	**0.01**	**0.1560**

Lake Rotomahana

1991 to 2009 Sites 1 & 2 (1 Jul 1991 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.05)	0.06	0.77	(0.47)	(-0.20)			
Average Over Period	(4.54)	4.98	34.32	(222.03)	(18.71)			
Percent Annual Change (%/Year)	**0.00**	**-1.20**	**2.24**	**0.00**	**0.00**	**0.21**	**0.56**	**0.73**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1991 - Jun 1992	7.95	4.36	44.17		4.51	3.77	5.02		4.43	0.36			
Jul 1992 - Jun 1993	3.80	4.95	34.75	251.33	3.69	3.60	4.72	3.61	3.91	0.27			
Jul 1993 - Jun 1994	2.90	4.46	40.56	228.42	3.39	3.74	4.91	3.49	3.88	0.35			
Jul 1994 - Jun 1995	3.72	4.35	29.43	206.00	3.67	3.77	4.51	3.35	3.83	0.24			
Jul 1995 - Jun 1996	4.63	5.07	16.00	237.00	3.91	3.57	3.73	3.54	3.69	0.09			
Jul 1996 - Jun 1997	5.94	4.28	31.00	240.00	4.19	3.79	4.57	3.55	4.03	0.22			
Jul 1997 - Jun 1998	5.63	4.84	13.00	239.33	4.13	3.63	3.47	3.55	3.70	0.15			
Jul 1998 - Jun 1999	7.38	3.10	6.00	195.00	4.42	4.19	2.49	3.28	3.60	0.44			
Jul 1999 - Jun 2000													
Jul 2000 - Jun 2001	4.21	4.36	20.15	219.48	3.81	3.77	4.03	3.44	3.76	0.12			
Jul 2002 - Jun 2003	4.65	5.49	13.69	181.38	3.92	3.47	3.54	3.19	3.53	0.15			
Jul 2003 - Jun 2004	4.62	5.29	37.12	226.29	3.91	3.52	4.80	3.48	3.93	0.31			
Jul 2004 - Jun 2005	4.38	5.00	30.75	198.43	3.85	3.59	4.56	3.31	3.83	0.27			
Jul 2005 - Jun 2006	3.84	4.94	37.09	202.18	3.70	3.61	4.80	3.33	3.86	0.32			
Jul 2006 - Jun 2007	3.76	5.70	47.64	235.69	3.68	3.42	5.12	3.53	3.94	0.40			
Jul 2007 - Jun 2008	4.31	5.28	48.33	249.23	3.83	3.52	5.14	3.60	4.02	0.38			
Jul 2008 - Jun 2009	5.11	5.12	43.05	237.13	4.02	3.56	4.99	3.54	4.03	0.34			
Averages	**4.80**	**4.79**	**30.79**	**223.13**	**3.91**	**3.66**	**4.40**	**3.45**	**3.86**	**0.07**	**0.00**	**0.01**	**0.9160**

Lake Rotorua

1990 to 2009 Sites 2 & 5 (1 Jul 1990 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.86	(-0.01)	-0.76	4.23				
Average Over Period	18.47	(2.57)	41.87	454.47				
Percent Annual Change (%/Year)	**4.66**	**0.00**	**-1.82**	**0.93**	**0.00**	**0.94**	**1.36**	**0.54**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1990 - Jun 1991	20.60	2.35	37.62	379.08	5.56	4.52	4.82	4.15	4.76	0.30			
Jul 1991 - Jun 1992	7.47	2.28	42.55	423.48	4.44	4.56	4.97	4.30	4.57	0.15			
Jul 1992 - Jun 1993	15.82	2.60	52.57	371.95	5.27	4.41	5.24	4.13	4.76	0.29			
Jul 1993 - Jun 1994	7.00	2.14	92.94	457.10	4.37	4.64	5.97	4.40	4.84	0.38			
Jul 1994 - Jun 1995	8.73	2.93	54.00	421.76	4.61	4.26	5.28	4.29	4.61	0.24			
Jul 1995 - Jun 1996	7.77	3.18	28.31	344.23	4.48	4.16	4.46	4.03	4.28	0.11			
Jul 1996 - Jun 1997	14.55	3.16	30.78	421.90	5.17	4.17	4.56	4.29	4.55	0.22			
Jul 1997 - Jun 1998	21.69	2.90	39.68	490.95	5.61	4.27	4.89	4.49	4.82	0.30			
Jul 1998 - Jun 1999	5.77	3.21	30.13	401.37	4.15	4.15	4.54	4.23	4.27	0.09			
Jul 1999 - Jun 2000	10.81	2.48	31.43	536.00	4.85	4.46	4.59	4.60	4.63	0.08			
Jul 2000 - Jun 2001	29.17	2.56	47.51	459.24	5.94	4.42	5.11	4.40	4.97	0.36			
Jul 2001 - Jun 2002	14.51	2.71	40.35	386.26	5.17	4.35	4.91	4.18	4.65	0.23			
Jul 2002 - Jun 2003	28.13	2.03	41.96	447.46	5.90	4.70	4.96	4.37	4.98	0.33			
Jul 2003 - Jun 2004	26.36	2.17	46.57	531.98	5.83	4.62	5.09	4.59	5.03	0.29			
Jul 2004 - Jun 2005	19.93	2.56	35.70	452.92	5.52	4.43	4.75	4.38	4.77	0.26			
Jul 2005 - Jun 2006	21.82	2.60	45.35	464.23	5.62	4.41	5.06	4.42	4.87	0.29			
Jul 2006 - Jun 2007	23.24	2.52	32.55	481.36	5.69	4.44	4.63	4.46	4.81	0.30			
Jul 2007 - Jun 2008	16.06	2.61	31.11	483.03	5.28	4.40	4.58	4.47	4.68	0.20			
Jul 2008 - Jun 2009	19.00	2.57	34.52	407.74	5.47	4.42	4.71	4.25	4.71	0.27			
Averages	**16.76**	**2.61**	**41.87**	**440.11**	**5.21**	**4.41**	**4.90**	**4.34**	**4.71**	**0.06**	**0.01**	**0.01**	**0.2798**

Lake Tarawera

1994 to 2009 Sites 1 & 5 (1 Jul 1994 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(0.01)	0.11	0.56	(1.37)	-0.58			
Average Over Period	(1.58)	8.47	10.23	(119.34)	12.60			
Percent Annual Change (%/Year)	**0.00**	**-1.30**	**5.47**	**0.00**	**-4.60**	**-0.09**	**1.62**	**0.96**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1994 - Jun 1995	1.23	8.05	7.00	116.05	2.45	2.95	2.69	2.60	2.67	0.11			
Jul 1995 - Jun 1996	1.17	7.93	5.60	92.70	2.40	2.97	2.40	2.31	2.52	0.15			
Jul 1996 - Jun 1997		8.93				2.80			2.80	0.00			
Jul 1997 - Jun 1998													
Jul 1998 - Jun 1999													
Jul 1999 - Jun 2000	1.89	7.98	7.11	113.79	2.92	2.96	2.71	2.58	2.79	0.09			
Jul 2000 - Jun 2001													
Jul 2001 - Jun 2002	1.81	7.91	7.50	112.32	2.87	2.98	2.77	2.56	2.80	0.09			
Jul 2002 - Jun 2003	1.81	7.08	8.13	130.12	2.87	3.13	2.87	2.75	2.91	0.08			
Jul 2003 - Jun 2004	1.42	7.52	9.45	108.21	2.61	3.05	3.07	2.51	2.81	0.14			
Jul 2004 - Jun 2005	1.21	9.40	10.59	112.69	2.43	2.73	3.21	2.57	2.73	0.17			
Jul 2005 - Jun 2006	1.76	9.00	12.36	109.20	2.84	2.79	3.41	2.53	2.89	0.19			
Jul 2006 - Jun 2007	1.57	9.47	14.05	142.98	2.72	2.72	3.57	2.88	2.97	0.20			
Jul 2007 - Jun 2008	1.61	9.18	10.59	154.23	2.74	2.76	3.21	2.98	2.92	0.11			
Jul 2008 - Jun 2009	1.56	8.94	14.19	102.22	2.71	2.80	3.58	2.44	2.88	0.25			
Averages	**1.55**	**8.45**	**9.69**	**117.68**	**2.69**	**2.89**	**3.04**	**2.61**	**2.81**	**0.04**	**0.02**	**0.01**	**0.0213**

Lake Tikitapu

1992 to 2009 Site 1 (1 Jul 1992 - 30 Jun 2009)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.02)	(-0.02)	0.23	1.88	(-1.45)			
Average Over Period	(2.05)	(6.40)	5.30	209.50	(38.06)			
Percent Annual Change (%/Year)	**0.00**	**0.00**	**4.34**	**0.90**	**0.00**	**1.05**	**0.84**	**0.28**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jul 1992 - Jun 1993	2.93	7.37	4.21	203.74	3.40	3.07	2.04	3.34	2.97	0.32			
Jul 1993 - Jun 1994	1.46	6.56	3.07	180.89	2.64	3.23	1.64	3.18	2.67	0.37			
Jul 1994 - Jun 1995	1.56	6.70	2.42	185.27	2.71	3.20	1.34	3.22	2.62	0.44			
Jul 1995 - Jun 1996	1.23	7.27	3.75	179.69	2.45	3.09	1.89	3.18	2.65	0.30			
Jul 1996 - Jun 1997													
Jul 1997 - Jun 1998		7.86				2.98			2.98	0.00			
Jul 1998 - Jun 1999													
Jul 1999 - Jun 2000	1.52	6.78	4.25	190.71	2.68	3.19	2.05	3.25	2.79	0.28			
Jul 2000 - Jun 2001													
Jul 2001 - Jun 2002	2.89	4.44	4.59	209.90	3.39	3.74	2.15	3.38	3.17	0.35			
Jul 2002 - Jun 2003	2.69	5.04	4.47	221.64	3.31	3.58	2.12	3.45	3.12	0.34			
Jul 2003 - Jun 2004	1.78	7.24	8.74	281.31	2.86	3.10	2.97	3.76	3.17	0.20			
Jul 2004 - Jun 2005	2.12	6.43	7.30	210.79	3.05	3.26	2.74	3.38	3.11	0.14			
Jul 2005 - Jun 2006	1.54	6.85	6.29	214.47	2.69	3.17	2.55	3.41	2.96	0.20			
Jul 2006 - Jun 2007	1.94	6.51	4.50	235.24	2.95	3.24	2.13	3.53	2.96	0.30			
Jul 2007 - Jun 2008	1.74	6.84	5.50	223.05	2.83	3.18	2.38	3.46	2.96	0.23			
Jul 2008 - Jun 2009	2.04	6.33	8.25	196.78	3.00	3.28	2.89	3.29	3.12	0.10			
Averages	**1.96**	**6.59**	**5.18**	**210.27**	**2.92**	**3.24**	**2.22**	**3.37**	**2.94**	**0.07**	**0.02**	**0.01**	**0.0903**