BAY OF PLENTY REGIONAL COUNCIL
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Rotorua Lakes Water Quality Report 2014/2015

Bay of Plenty Regional Council
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NEW ZEALAND

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Cover photo: Lake Rotorua near Sulphur Bay

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Executive summary

Monitoring programmes have been developed to provide water quality information to determine a lake's changing chemical balance and ecological status. This in turn provides information on how to manage lake water quality effectively. The National Policy Statement for Freshwater Management (NPS-FW) has policies that direct regional councils to make changes to regional plans, to establish freshwater objectives and water quality limits, specify targets and implement methods (regulatory and/or non-regulatory) to reach the targets. Policies in the Regional Water and Land Plan (RWLP) seek to manage water and land resources within an integrated management framework. Each of the Rotorua Te Arawa lakes has an objective Trophic Level Index (TLI) based on past lake water quality (Objective 11 of the RWLP). The TLI is a numerical limit that represents ecological and water quality aspiration of the regional community.

The objective of this report is to describe the state and trends in water quality of the 12 Rotorua Te Arawa lakes. It not only updates the TLI, but also provides insight to a range of water quality and ecology measures that have been monitored. Comparison against attributes from the NPS-FW for Freshwater National Objectives Framework (NOF), which sets compulsory national values for freshwater to protect 'human health for recreation' and 'ecosystem health', are also made.

Of the 12 Rotorua lakes in the programme, tracking of the long-term water quality trend shows:

- Improving water quality in Lakes Rotorua and Rotoehu over recent years but vulnerability to climatic conditions and a possible decline in water quality in response to longer duration of stratification,
- Lake Rotoiti had a long-term improving trend since the installation of the Ōhau Channel diversion wall, however, in 2014/15 trophic status declined,
- Improving water quality in Lakes Ōkaro, Rerewhakaaitu, and Tikitapu,
- Stable water quality in Lakes Ōkataina, Ōkareka, Rotomā and Rotomahana,
- Deteriorating water quality in Lakes Tarawera and Rotokakahi, this appears to be a consistent long-term trend.

At the time of writing, ten of the twelve Rotorua Te Arawa lakes are above the RWLP TLI objective. Recent improvements in the TLI of Lakes Ōkaro and Rerewhakaaitu have resulted in these lakes meeting community objectives for lake water quality, as stated in Objective 11 of the RWLP. National Objectives Framework lakes attributes as prescribed by the NPS are also shown. Only Lake Ōkaro did not meet the national bottom line NOF attributes for chlorophyll-*a* and total nitrogen concentrations.

The report also compares lakes based on their relationship with pastoral landuse and trophic state, as well as oxygen depletion rates in the bottom waters (hypolimnion) during stratification, cyanobacteria (blue-green algae) abundance, and Lake Submerged Plant Index (LakesSPI) results.

Lake Trophic Level Index (TLI) results

Lake Ōkāreka TLI = 3.3 (target 3.0). Improvements in TLI since 2010 (driven by improvements in chlorophyll-*a* and total nitrogen (TN)), but there has also been a strong deterioration in total phosphorus (TP) in the lake's bottom water over the same period.

Lake Ōkaro TLI= 4.6 (target 5.0). There has been considerable improvement in the water quality of Lake Ōkaro since 2002, evident in all variables in both top and bottom waters.

Lake Ōkataina TLI = 2.8 (target 2.6). The TLI has been stable over the long term with no significant trend since 2002.

Lake Rerewhakaaitu TLI = 3.3 (target 3.6). The lake has achieved the water quality target set in the RWLP (of TLI 3.6). The TLI increased during the period 2007 to 2010 and has since decreased.

Lake Rotoehu TLI = 4.5 (target 3.9). Although the lake neared its water quality target set in the RWLP in the previous two years, internal nutrient drivers and algal blooms bumped up the last TLI. The TLI has significantly improved since 2002.

Lake Rotoiti TLI = 3.7 (target 3.5) (4.1 in Okawa Bay). Lake Rotoiti water quality has considerably improved since 2002 and since 2010. In Okawa Bay, water quality improved between 2002 and 2009, but the TLI shows no improvement in the last five years (since 2010).

Lake Rotomā TLI = 2.5 (target 2.3). Water quality has remained relative stable over the long term, but since 2010 there has been a significant deterioration in the TLI and reduced water clarity. There was also evidence of increasing phosphorus and reducing dissolved oxygen concentrations in the lake bottom waters.

Lake Rotomahana TLI = 4.0 (target 3.9). The TLI has slightly deteriorated since 2002, driven by an increase in the concentration of TN and TP. Since 2010 there has been no significant change in TLI, but phosphorus has increased and dissolved oxygen has decreased in the lake's bottom waters.

Lake Rotorua TLI = 4.4 (target 4.2). The TLI has significantly improved since 2002. Reductions in phosphorus concentrations have been particularly strong, since the initiation of alum dosing of Utuhina Stream and Puarenga Stream in 2006 and 2010, respectively.

Lake Tarawera TLI = 3.1 (target 2.6). The water quality has deteriorated significantly since 2002 driven by an increase in nitrogen, phosphorus and a recent decline in water clarity. Cyanobacteria blooms occasionally occur during summer.

Lake Tikitapu TLI = 2.9 (target 2.6).The TLI has remained relatively stable since 2002.

Contents

Part 1: Introduction

The National Policy Statement for Freshwater Management (2014) (NPS-FW) sets out objectives and policies that direct Local Government to manage water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits. Key objectives include protecting outstanding freshwater bodies and maintaining or improving freshwater quality. The NPS policies direct regional councils to make changes to regional plans, to establish freshwater objectives and quality limits, specify targets and implement methods (regulatory and/or non-regulatory) to reach the targets.

The NPS-FW includes a National Objectives Framework (NOF) which sets compulsory national values for freshwater to protect 'human health for recreation' and 'ecosystem health'. The NOF defines thresholds for numeric attributes, ranked into four bands (A-D), which define water quality and effectively set 'National Bottom Lines'. This report includes a summary of results on how current lake water quality compares to the NOF attributes.

The Regional Policy Statement (RPS) sets out the policy direction for the management of the twelve Rotorua Te Arawa lakes within the Rotorua Te Arawa Lakes Programme. Water quality policies identify Lakes Rotorua, Rotoiti, Rotoehu, Ōkaro, Ōkāreka, Rotomā, Ōkataina, Tarawera, Tikitapu, Rotokakahi, Rerewhakaaitu and Rotomahana as "Catchments at Risk".

The water quality policies direct Council to:

- Establish contaminant limits within each catchment to achieve each lakes Trophic Level Index.
- Require consent for increased discharge.
- Allocate capacity to assimilate contaminants within limits.
- Manage nutrient reductions in excess of limits.

Policies in the RWLP look at managing water and land resources within an integrated management framework. Each lake has an objective TLI based on past lake water quality (Objective 11 of the Regional Water and Land Plan (RWLP)). If a lake TLI exceeds the TLI stated in the Plan by 0.2 TLI units (based on a three year moving average) for two years then Method 41, Stage 3 of the Plan applies.

Method 41 involves the development and implementation of action plans formulated in conjunction with appropriate stakeholders with the aim of improving water quality. Action plans have been (or will be) developed and contain initiatives to reduce nutrient loads (nitrogen and phosphorus) to the lakes, enhance water quality, and/or halt deterioration of water quality. This includes reducing cyanobacterial algal blooms by catchment management actions to reduce nutrients inputs.

Monitoring programmes have been developed to provide water quality information, to determine a lake's changing chemical balance and ecological status. This in turn provides information on how to manage lake quality effectively. Programmes include: physico-chemical water quality monitoring used to generate the TLI, algal monitoring, and macrophyte monitoring, which is managed using the Lake Submerged Plant Indicators (LakeSPI index).

Each programme provides information that links to separate lake 'action plans', which provide the template for any remedial action that is required for that lake or lake catchment.

The objective of this report is to describe the state and trends in water quality of the 12 Rotorua Te Arawa lakes. It not only to updates the TLI, but also provides insight to a range of water quality and ecology measures that have been monitored.

The standardised monitoring procedure known as 'LakeSPI' has also been conducted on all of the lakes to assess the presence and extent of native and invasive species. The 2013/2014 LakeSPI results are given in this report. Lake water quality has been monitored in the Rotorua Te Arawa lakes by the Bay of Plenty Regional Council since 1990. This is carried out under the Natural Environment Regional Monitoring Network (NERMN), a programme designed for general 'state of the environment' monitoring.

Part 2: Methods

2.1 Site information

Water quality is monitored in 12 Rotorua Te Arawa lakes (Figure 2.1). Most lakes are sampled at a single location near the deepest point. Lake Rotokakahi is one exception and is sampled at the lake outlet. Lake Rotorua is sampled in two locations, Site 130002 (south of Mokoia Island, Site 2) and Site 130027 (north of Mokoia Island, Site 5). Rotoiti is sampled in three locations, Okawa Bay, Site 130005 at the narrows (also known as Site 3) and Site 130059 mid-lake (also known as Site 4). Site 130059 was established in March 2003 to replace nearby Site 1, for the purpose of long term trend analysis, the data from Rotoiti Site 1 and Site 4 are combined.

Lake depth and catchment information is provided in Table 2.1.

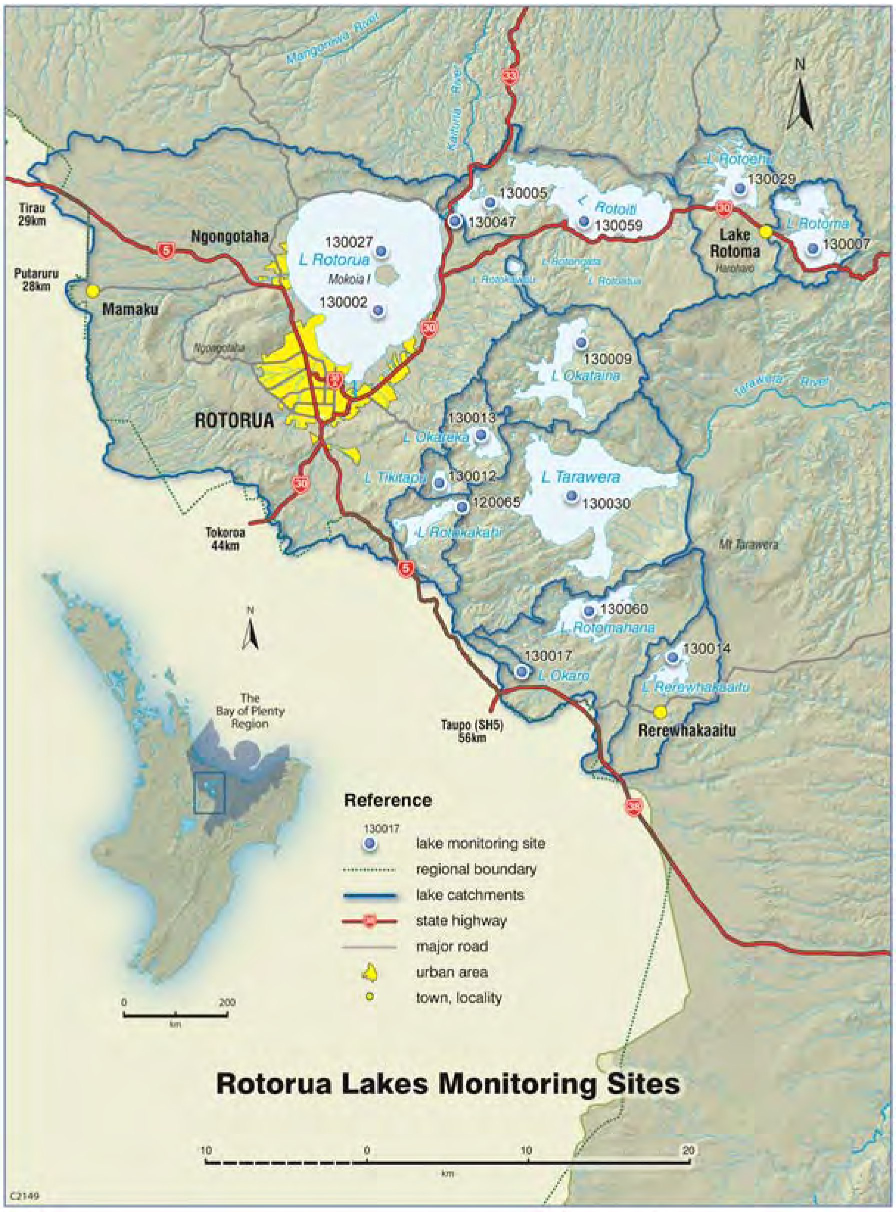


Figure 2.1 Location of the Rotorua lakes and water quality monitoring sites.

Table 2.1 Water depth and catchment cover of the Rotorua Te Arawa lakes.

Lake	Max depth (m)	Lake Area (ha)	Catchment Area (ha)	% land cover Native	Exotic	Pastoral	Urban
Lake Ōkāreka	33.5	334	1,750	44	8	37	3.0
Lake Ōkaro	18	30	183	0	6	90	0
Lake Ōkataina	78.5	1,073	6,358	79	8	8.0	0
Lake Rerewhakaaitu	15.8	517	4,056	4	17	69	1.0
Lake Rotoehu	13.5	790	4,225	31	30	34	0.6
Lake Rotoiti	126	3,369	12,056	30	49	13	2.0
Lake Rotokakahi	32	440	1,860	50	21	27	1.1
Lake Rotomā	83	1,112	3,392	41	29	22	3.0
Lake Rotomahana	125	902	8,858	23	17	40	1
Lake Rotorua	45	8,048	48,204	19	18	47	8.0
Lake Tarawera	87.5	4,115	15,001	60	15	17	1.0
Lake Tikitapu	27.5	144	597	80	14	2.0	3

Calculated from the NIWA Rivers Environment Catchment layer

Native = Native Forest, Exotic = Exotic forest

% Land cover excludes lake area

2.2 Water quality sampling

Water quality sampling of the Rotorua Te Arawa lakes is carried out monthly. Each lake is sampled at single or multiple deep water sites. Profiles of temperature, dissolved oxygen, conductivity and fluorescence are recorded by a data logger with appropriate sensor arrays. Samples are collected from the top water layer (called the epilimnion if the lake is stratified) and from the bottom layer (called the hypolimnion if the lake is stratified). In most lakes a second bottom water sample is collected in the hypoxic layer (called bottom x) in general accordance with Burns et al; (2000). The top sample is collected as an integrated sample over the depth of the typical epilimnion and the bottom samples as discrete samples using a Van-dorn sampler. In Lake Ōkaro additional discrete samples are collected through the depth profile.

Prior to July 2001 the depths sampled on any particular occasion were determined by the depth of the thermocline (as per Burns et al; 2000). Since July 2001, the samples were collected from consistent depths based on a typical thermocline (see Table 2.2). This procedure has simplified sample collection.

Water samples are stored in a chilli-bin and transported to the laboratory for analysis. Sampling and analyses were performed in accordance with Bay of Plenty Regional Council's internal protocols. Most analyses are performed by Environment Bay of Plenty's IANZ accredited laboratory, Hills Laboratory, Hamilton or NIWA laboratory Hamilton. Current laboratory and field measurement methods are described in Table 2.3.

Table 2.2 Depth at which samples were collected at top and bottom site since July 2001.

Lake site	Sample depth (m) Integrated top	Discrete bottom	Discrete Bottom x *
Lake Ōkāreka	0 - 10	26	29 - 31
Lake Ōkaro	0 - 4	14	16.5
Lake Ōkataina	0 - 17	50	63 - 65
Lake Rerewhakaaitu	0 - 12	12	n.a.
Lake Rotoehu	0 - 9	9	n.a.
Lake Rotoiti 3	0 - 12	26	27 - 30
Lake Rotoiti 4	0 - 17	50	110 - 120
Lake Rotoiti Okawa B	0 - 3	3	n.a.
Lake Rotomā	0 - 17	55	68 - 71
Rotomahana	0 - 12	50	110 - 119
Lake Rotorua 2	0 - 6	15	18 - 24
Lake Rotorua 5	0 - 6	18	21 - 24
Lake Tarawera	0 - 17	60	79 - 82
Lake Tikitapu	0 - 12	19	23 - 26

* Indicates a typical range of depths from which discrete bottom x samples were collected.

Table 2.3 Methods used for chemical/biological analysis of water samples (as of 2014).

Parameter (abbreviation)	Method	Detection Limit/ Units
Ammonium Nitrogen (NH_4-N)	Phenyl/hypochlorite colorimetry. FIA APHA 4500-NH3 G.	1 mg/m^3
Total Oxidised Nitrogen (TOx-N)	Flow injection analyser. APHA 4500 NO3-I	1 mg/m^3
Total Nitrogen (TN)	Persulphate digestion, auto cadmium reduction. FIA	
Total Phosphorus (TP)	Acid persulphate digestion, molybdate colorimetry. FIA. Apha 4500-P H	1 mg/m^3
Dissolved Reactive Phosphorus (DRP)	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	1 mg/m^3
Water clarity - Secchi disc	Secchi disc visibility measured in metres (to 0.1m increments) with a viewing tube.	0.1 m
Turbidity	APHA Method 2130B-HACH 2100N ratio and signal averaging on.	0.01 NTU
pH	APHA method 4500-H+ measurement at 25^{o}C	
Temperature	Seabird 19Plus or 19PlusV2 CTD	0.1 deg C
Conductivity	Seabird 19Plus or 19PlusV2 CTD	0.00005 S/m
Dissolved oxygen	Seabird 19Plus or 19PlusV2 CTD (accuracy 2% of saturation)	
PAR Light Sensor	Biospherical QSP-2300	µmol photon/m^2.sec
Escherichia coli (E.coli)	Membrane filtration, Standard Methods for the Examination of Water & Wastewaters (2005)	1 cfu/100ml

2.3 Datasets

Prior to analysis, the water quality dataset was consolidated and 'cleaned' in the following way:

- All censored values (less than detection limit) reduced by 50% prior to the data analysis.
- Anomalous outlying data points were removed where there was good reason to believe them to be measurement errors, i.e.:
  - In June 2004 electrical conductivity results in all lakes were 10 times lower than on other sample occasions.
  - Dissolved oxygen results with negative values were removed.
  - In Lake Rotorua Site 2, an anomalous Dissolved Reactive Phosphorous (DRP) result on April 2008 was removed. An anomalously low TN value (2.0 ppb) on February 2010, less than nitrate, was removed.
  - In Lake Ōkāreka there was anomalously high TN (984 ppb) and nitrate (935 ppb) in October 2013 inconsistent with other variables. These were removed.
  - In Lake Tikitapu there was anomalously high turbidity of 14 NTU in November 2006, inconsistent with Secchi, vertical light extinction coefficient (VLEC) or chlorophyll-*a*.
  - In Lake Tikitapu electrical conductivity was anomalously high in May 2013 (10 times above normal levels). The data point was deleted.
  - In Lake Ōkāreka, electrical conductivity was anomalously high on 5 April and 9 August.
  - In Lake Rotomahana on February 2006, total ammonia was anomalously high (247 ppb) and higher than TN.
  - In Lake Rerewhakaaitu on August 2002, September 2002 and June 2002, total ammonia was anomalously high (672 - 897 ppb) and higher than TN.
- Summary information for each sample occasion was extracted from depth profile measurements, including:
  - Minimum DO value from the depth profile,
  - Vertical light extinction coefficient (VLEC),
  - Whether the lake was stratified at the time of sampling (based on a >3^{o}C temperature difference),
  - A value for temperature, DO, %DO, and electrical conductivity representative of 'top' and 'bottom' water samples. Values for 'top' samples were averaged over the depth of the epilimnion (see Table 2.2).
- Information from depth profiles was integrated with sample data.

- Where multiple samples were collected from the epilimnion, then the average was calculated and used for analysis.

2.4 Changes in laboratory methods and detection limits

Changes in analytical procedures during the course of the monitoring programme resulted in changes in detection limits at different times. Historical laboratory methods and detection limits for the variables of TP and TN are provided in Appendix 1.

Measurements that are less than the laboratory detection limit are currently recorded as uncensored values, but in the past these have been censored. For the variables TN and TP, the majority of censored values were recorded over the period September 2008 to October 2009 (inclusive). Since November 2009, the detection limit for TN and TP was 1 ppb, and prior to August 2008, the laboratory method was not as sensitive but actual results were usually recorded which reduced bias from censoring data.

Changes in the detection limit can result in anomalous trends in oligotrophic lakes where measurements are close to detection e.g. Lake Rotomā, Ōkataina and Tarawera. The influence of changes in detection limit was tested by repeating trend analysis for TN and TP on a modified dataset, where the minimum value was set at the highest detection limit over the period. The results of the trend analysis tended to be similar to that of the unmodified dataset.

The changes in laboratory methods that occurred between August 2008 and November 2009 resulted in much lower detection limits and much less variability of results. This improves the ability to detect trends and the accuracy of assessing trophic state of the oligotrophic lakes. However, the laboratory changes also resulted in a step change decrease in TN results and a step change increase in TP. This complicates the assessment of trends in water quality.

When there is a change in laboratory or laboratory method, it is best practice to undertake a period of cross calibration, where duplicate samples are analysed by the different methods to ensure consistency. This did not occur. Furthermore, it is difficult to undertake this calibration process retrospectively because the old laboratory methods are no longer routinely run. In the absence of this calibration information, statistical methods were used to quantify the difference in TN and TP results that can be attributed to the change in laboratory methods. Strong relationships were found and adjustment factors were developed (see Appendix 2).

The analysis used in this report is based on data after adjusting TN and TP results to be equivalent to those prior to the laboratory change. The following formulas were used:

- [TN old method] = [TN new method] + 50.7 mg/m^3.
- [TP old method] = 0.829 [TP new method].

In practice, the recent laboratory changes in TN and TP mostly cancel each other out and there is very little impact on the TLI score.

2.5 Water quality state assessment

2.5.1 Trophic Level Index

Lake water quality is often expressed in terms of trophic state, which refers to the production of algae (phytoplankton), epiphytes and macrophytes in a lake. The trophic state of each lake was assessed using the TLI (Burns et al; 2000) which is only relevant to phytoplankton.

The TLI integrates four key measures of lake trophic state - total nitrogen, total phosphorus, chlorophyll-*a* and Secchi depth. The overall TLI score for a lake is the average of individual TLI scores for each variable. The overall score is categorised into seven trophic states, indicative of accelerated eutrophication as evidenced by more nutrients, more algal productivity and reduced water clarity. Trophic state categories and values of key variables defining the boundaries are shown in Table 2.4.

Table 2.4 Definition of Trophic Levels based on water quality measures (source Burns et al; 2000).

Trophic State	TLI Score	Chl-*a* (mg/m^3)	Secchi depth (m)	TP (mg/m^3)	TN (mg/m^3)
Ultra-microtrophic	<1	< 0.33	> 25	< 1.8	< 34
Microtrophic	1 - 2	0.33 – 0.82	15 - 25	1.8 – 4.1	34 - 73
Oligotrophic	2 - 3	0.82 - 2.0	15 - 7.0	4.1 – 9.0	73 - 157
Mesotrophic	3 - 4	2.0 - 5.0	7.0 - 2.8	9.0 - 20	157 - 337
Eutrophic	4 - 5	5.0 - 12	2.8 - 1.1	20 – 43	337 - 725
Supertrophic	5 - 6	12-31	1.1 - 0.4	43-96	725 - 1558
Hypertrophic	>6	>31	<0.4	>96	>1558

The TLI was calculated using three years of results (July 2011 to June 2014) (i.e. 36 samples) from the integrated top water samples (i.e. the epilimnion). Annual average values of TN, TP, Secchi depth and chlorophyll-*a* were used for the analysis to be consistent with past approaches and the method described in Burns et al; (2000)[1]. The TLI was calculated using the following regression equations from Burns et al; (2005):

TL_N = -3.61+3.01 log(TN).

TL_P = 0.218+2.92 log(TP).

TL_S = 5.10+2.6 log(1/SD-1/40).

TL_C = 2.22+2.54 log(Chl *a*).

TLI = ((TL_N + TL_P + TL_S + TL_C))/4.

[1] An alternative way to calculate the TLI is to calculate it for each individual sample occasion and then average the values over multiple years. This approach has been used for national reporting (e.g. Verberg et al; 2010). A comparison of the two approaches found that the method based on individual sample occasions resulted in consistently higher TLI scores than the method adopted for this report. The average difference in TLI scores between the calculation methods was 1.8%. The maximum differences were for Lake Ōkaro (6%) and Lake Rotomā (3.1%). Hudson et al; (2011) found a similar result using national lake data.

Where:

TN = total nitrogen (mg/m^3).

TP = total phosphorus (mg/m^3).

SD = Secchi depth (m).

Chl *a* = chlorophyll-*a* (mg/m^3).

Trophic Level Index was calculated using TN and TP data that had first been adjusted for laboratory method changes (Appendix 2). For the purpose of calculating the TLI, the effect of laboratory method changes on TN and TP mostly cancelled each other out. The TLI scores calculated using adjusted data (as done in this report) were on average 0.8% higher than those calculated using unadjusted data, but the direction of change was not consistent for different lakes. Using adjusted data had most effect on the TLI calculation for Lakes Ōkataina (3.3% higher), Rotomā (3.2% higher) and Tarawera (3% higher).

2.5.2 Potential nutrient limitation

In order to accurately assess the extent to which nutrients may limit algal growth in a lake, requires detailed investigations and bioassays. However, some indication of potential nutrient limitation can be gained by looking at the absolute concentration of nutrients in the lake and the stoichiometric ratio of nitrogen to phosphorus. In this report the potential nutrient limitation was assessed using two ratios. The ratio of TN:TP, and the ratio of DIN:TP, that is the ratio of dissolved inorganic nitrogen (DIN) to TP. The Redfield ratio of TN:TP is 7.2 (by mass). We have used TN:TP value less than 7 to indicate potential nitrogen limitation and a TN:TP value greater than 14 to indicate potential phosphorus limitation. In addition, we used a DIN:TP of < 1 (by mass) to indicate potential N limitation and a DIN:TP > 1 to indicate potential P limitation (after Schallenberg et al; 2010). This approach assumes the absence of other factors limiting phytoplankton growth.

2.5.3 Vertical Light Extinction Co-efficient (VLEC) and Euphotic zone depth (EZD)

The Vertical Light Extinction Co-efficient (VLEC) was calculated for each sample occasion, using the linear regression between Photosynthetic Available Radiation (PAR) and depth through the epilimnion.

The Euphotic Zone Depth (EZD) was defined as depth at which PAR was 1% of surface PAR. A relationship was developed between PAR and VLEC using data for 10 lakes where PAR equalled 1% surface PAR (Figure 2.1). The relationship was:

- Log EZD = 5.182 VLEC-0.936. R^2 = 0.93, n = 791.

This relationship was subsequently used for converting VLEC to EZD.

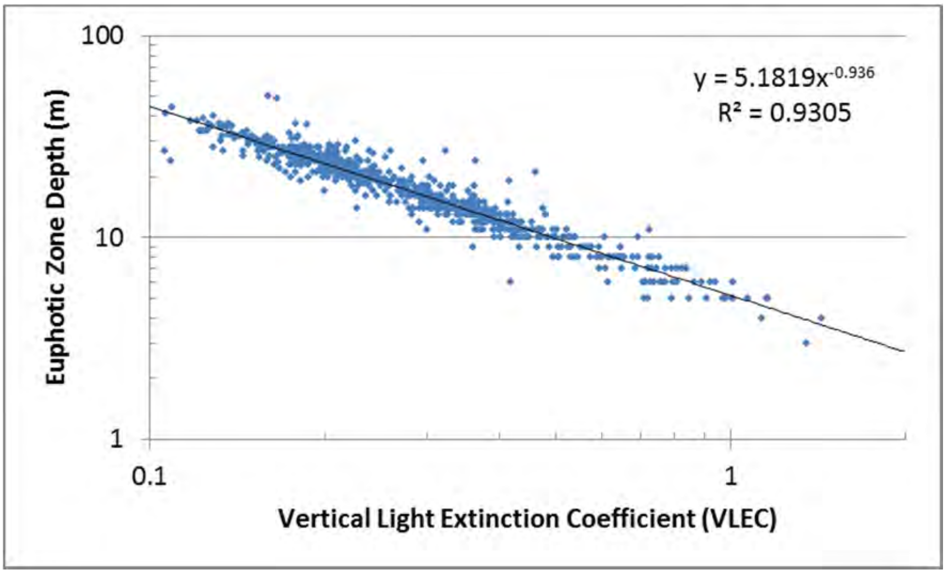


Figure 2.1 Relationship between euphotic zone depth and VLEC for Rotorua lakes.

2.6 Water quality trend analysis

Trends were assessed using the seasonal-Kendall test in the freeware "TimeTrends 5.0". This is a non-parametric test that accounts for seasonality by calculating the Mann-Kendall test on each season separately, and then combining the results (Helsel and Hirsch 1992). So for monthly "seasons", January data are compared only with January, February with February, etc. It is the approach taken for analysing national water quality trends (e.g. Ballantine and Davies-Colley 2009, Verburg et al; 2010). The results are robust to the occasional missing data and to censored data (Hirsch and Slack 1984).

The seasonal-Kendall test calculates both whether a trend is statistically significant (i.e. its *p*-value) and the magnitude of change (i.e. the Sen slope). The Sen slope is the median annual slope of all possible pairs of values in each season. The Sen slope for each test was normalised by dividing the raw data median to give the *relative* Sen (RSEN) and this was expressed as a Percent Annual Change (PAC).

The lower the *p*-value, the more likely it is that the trend is real (not due to change), and the larger the PAC, the larger the magnitude of the trend. A trend test was considered to be *statistically significant* if the *p*-value was less than 0.05; and the test was considered *meaningful* (or *practically important*) if it had a PAC of more than 1% per year (consistent with Scarsbrook 2006, Ballantine and Davies-Colley 2009). We have also reported potential emerging trends, which was defined as a *p*-value between 0.05 and 0.1, or a PAC between 0.5% and 1%.

Trend analysis is sensitive to the time period chosen for analysis, particularly as changes in water quality between years is non-linear. For the purpose of this report, the trend analysis was done on a 13 year record (January 2002 to December 2014) and a five year record (January 2010 to December 2014). The ability to detect trends improves with the amount of data available, but the shorter five year record avoids some of the problems with changes in laboratory methods and detection limits that occurred in 2009.

The trend analysis was based on 12 seasons per year (i.e. monthly data) and the median value per season. No adjustments were made for serial correlation (see McBride 2005). For the purpose of trend analysis, a TLI was calculated for individual sample occasions and occasional negative values were changed to a value of 0.1.

2.7 Lake Submerged Plant Index (LakeSPI)

Lake Submerged Plant Index was developed specifically to monitor the ecological health of lakes and a programme has been tailored and undertaken by NIWA specifically for the Rotorua Te Arawa lakes. The LakeSPI programme monitors macrophytes which are used as LakeSPI 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[2] 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.

Divers survey vegetation features along the same transect at a number of sites within each lake to develop the three condition indices.

Key features of aquatic vegetation structure and composition are used to generate three LakeSPI indices (see NIWA, 2015):

- 'Native Condition Index' - This captures the native character of vegetation in a lake based on diversity and extent of indigenous plant communities. A higher score means healthier, deeper, diverse beds.
- 'Invasive Impact Index' - This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher score means more impact from exotic species, which is often undesirable.
- 'LakeSPI Index' - This is a synthesis of components from both the native condition and invasive impact condition of a lake and provides an overall indication of lake condition. The higher the score, the better the condition.

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

Part 3: Comparison between lakes

3.1 Current state

The trophic state of Rotorua Te Arawa lakes ranges from oligotrophic (Lakes Rotomā, Tikitapu, Ōkataina, Tarawera) to supertrophic (Lake Ōkaro). For the three year period (July 2011-2014), seven lakes either achieved or were better than their RWLP target and four lakes did not achieve their targets. The four lakes that did not meet the targets were Ōkāreka, Ōkataina, Rotomā and Tarawera (Table 3.1).

Table 3.1 Summary of lake surface water quality for all variables and lake sites (average for period July 2011 to June 2014). Shaded cells indicate lakes with potential phosphorus limitation.

Variable	Ōkāreka	Ōkaro	Ōkataina	Rerewhakaaitu	Rotoehu	Rotoiti 4	Rotoiti 3	Rotoiti Okawa Bay	Rotokakahi outlet	Rotomā	Rotomahana	Rotorua 2	Rotorua 5	Tarawera	Tikitapu
TLI	3.2	5.0	2.8	3.4	3.9	3.4	3.5	4.1	3.8	2.4	3.8	4.1	4.0	2.9	2.7
TLs	2.5	3.9	2.2	3.0	3.6	2.7	3.0	3.8		1.8	3.1	3.7	3.7	2.5	2.6
TLc	3.6	5.9	3.0	3.7	4.2	3.9	4.0	4.4	4.0	2.5	3.8	4.9	4.7	2.7	3.0
TLn	3.5	5.3	2.8	4.2	3.8	3.4	3.5	4.0	3.7	2.9	3.6	4.1	4.1	2.9	3.4
TLp	2.9	5.1	3.1	2.9	4.2	3.6	3.5	4.3	3.7	2.4	4.8	3.6	3.5	3.7	1.8
TN adj (mg/m³)	234	905	139	404	290	206	222	335	271	150	244	355	373	142	214
TN (mg/m³)	183	854	89	354	239	156	171	285	220	99	193	305	323	92	163
TP adj (mg/m³)	8.3	46.6	9.6	8.1	23.1	13.9	13.7	24.5	17.8	5.4	37.6	14.5	13.3	15.9	3.6
TP (mg/m³)	10.1	56.3	11.6	9.8	27.8	16.8	16.5	29.5	14.7	6.6	45.3	17.4	16.1	19.1	4.3
Chl-a (mg/m³)	3.7	27.3	2.1	3.7	5.8	4.7	5.2	7.2	4.8	1.3	4.3	11.0	9.9	1.5	2.0
Secchi (m)	7.8	2.7	10.0	5.7	3.5	6.9	5.7	3.0		12.9	5.3	3.1	3.1	8.2	7.5
EZD (m)	15.1	7.0	21.4	11.4	8.7	16.8	14.4	7.7		27.3	12.7	8.5	8.5	22.1	23.2
Temperature	15.2	15.1	15.4	14.7	15.7	15.7	15.9	15.8	15.4	15.5	17.0	15.5	15.4	15.3	15.1
pH	7.6	8.2	7.5	7.4	7.8	7.2	7.2	7.4	7.5	7.2	7.2	6.9	7.0	7.8	7.0
EC (uS/cm)	60	82	81	53	379	126	128	124		122	1133	158	157	402	12
NOx-N (mg/m³)	2.4	16.1	3.1	6.6	6.2	2.5	3.1	5.0	3.4	4.7	34.7	36.4	56.1	1.7	8.4
NH4-N (mg/m³)	3.2	162	2.1	7.4	6.6	6.2	7.9	5.9	8.7	5.7	3.1	24.6	26.0	1.7	3.3
DRP (mg/m³)	2.9	16.0	4.8	2.6	7.5	6.3	4.3	5.8	3.8	3.3	21.2	2.0	2.0	10.4	1.4
DO min (g/m³)	3.6	2.4	3.7	7.6	7.8	4.8	5.8	8.2		5.6	5.9	7.7	7.5	6.3	4.6
TN:TP	19.8	20.9	8.4	37.3	9.3	10.5	11.3	10.2	12.8	18.1	4.3	19.7	21.6	5.2	43.4
DIN:TP	0.6	2.9	0.4	1.4	0.6	0.4	0.7	0.5	0.6	1.8	0.8	4.5	5.9	0.2	2.6

TLI calculated using Burns method

TN adj and TP adj indicate TN and TP after adjusting for laboratory changes. TLI uses adjusted values.

min DO' is the minimum dissolved oxygen concentration from depth profiles

Rotokakahi data from outlet Te Wairoa Stm.

The condition of other variables for the 2011 to 2014 period is shown in Appendix 3.

Lake trophic state approximately reflects the percent of the catchment in pasture or urban landuse (Figure 3.1). Rerewhakaaitu has water quality better than might be predicted from the delineated surface catchment landuse; this probably because the lake is perched so much of the groundwater from the catchment does not drain into the lake. Lake Rotoehu has worse water quality than might be expected for the catchment landuse; this may be influenced by it being shallow and having a relatively small volume compared to its catchment area. Most of the lakes have some geothermal influence (except Rotomā and Ōkaro). The geothermal influence in Rotomahana is particularly apparent in high electrical conductivity and relatively high concentrations of TP.

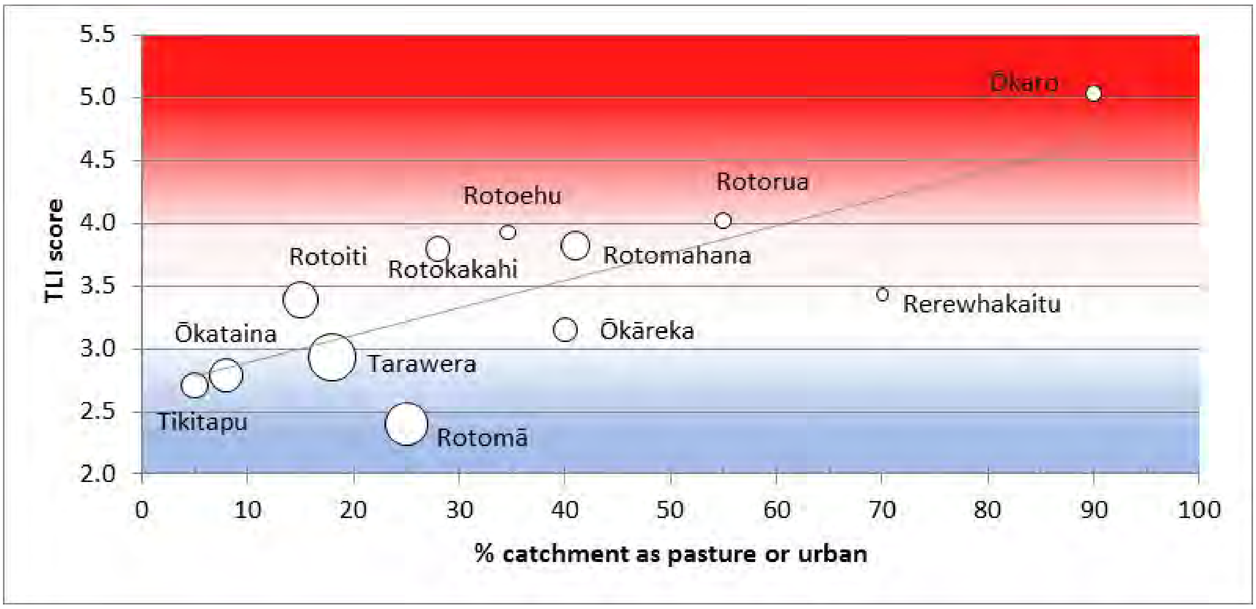


Figure 3.1 *Comparison of TLI and the percent of the catchment in pasture or urban landuse. A higher TLI score indicates worse water quality. The area of the circles indicates the ratio of lake volume to catchment area. Linear regression R2 = 0.59.*

The different variables making up the TLI are not always in balance. Chlorophyll-*a* tended to elevate the TLI compared to other variables in Lake Rotoiti and Lake Rotorua. TN elevated the TLI compared to the other variables for Lake Rerewhakaaitu, Lake Rotomā and Lake Tikitapu. TP elevated the TLI compared to the other variables for Lake Rotomahana and Tarawera (both influenced by geothermal activity). In contrast, TP lowered the TLI compared to other variables for Lakes Rerewhakaaitu, Rotorua and Tikitapu. Secchi depth reduced the TLI score, relative to the average of other variables for all the lakes, but particularly for Lakes Ōkāreka, Ōkaro, Ōkataina, Rotoiti, Rotomā, Rotomahana and Tarawera (Table 3.1).

Phytoplankton growth in lakes is rarely limited by a single nutrient all of the time, but often one nutrient will exert a stronger control more commonly than another. Lakes where phosphorus was more commonly potentially limiting to phytoplankton growth than nitrogen were Ōkaro, Rerewhakaaitu, Rotomā, Rotorua and Tikitapu (i.e. a TN:TP > 14 and DIN:TP >1). Lakes where nitrogen was more commonly potentially limiting to phytoplankton growth than phosphorus were Rotomahana and Tarawera (i.e. TN:TP < 7 and DIN:TP <1) (Table 3.1). Nutrient ratios only indicate a **relative potential** for nutrient limitation, any actual limitation of phytoplankton growth will depend on multiple factors including nutrient concentrations, phytoplankton species, light regime etc.

The rate at which oxygen is lost, the Hypolimnetic Volumetric Oxygen Depletion) rate (HVOD) is a measure of lake quality. If the hypolimnion becomes devoid of oxygen, nutrients (nitrogen and phosphorus) can be released from sediment into the water, and diffuse throughout the whole lake when mixing occurs at the onset of winter. Figure 3.2 compares HVOD rates for lakes which stratify over summer for the last five years. Lakes Ōkaro, Rotoiti, Ōkāreka, Tikitapu and Ōkataina all go anoxic over the stratification period and have the higher HVOD rates compared to the other monomictic[3] lakes.

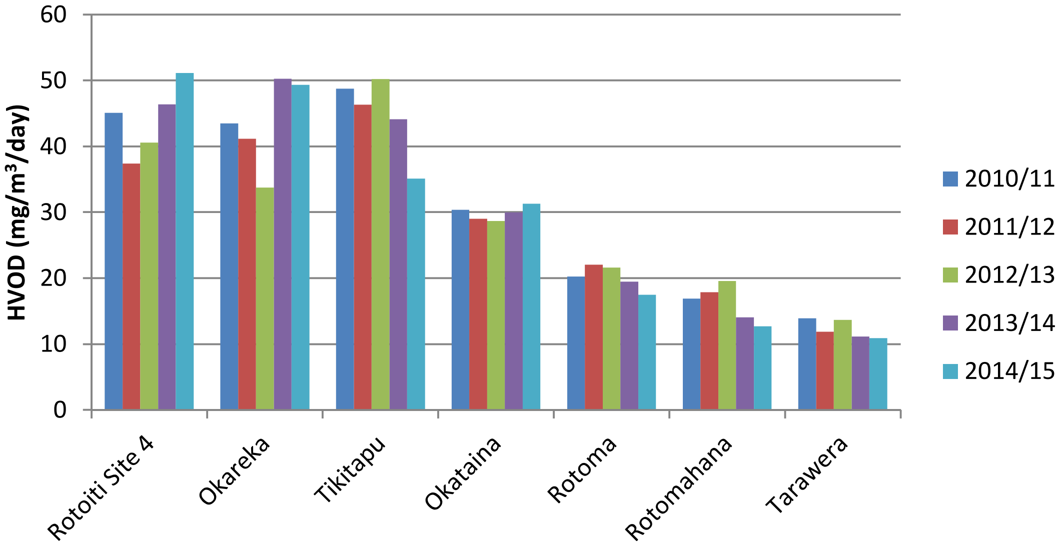


Figure 3.2 *Hypolimnetic Volumetric Oxygen Depletion rate (HVOD) rates for stratified lakes 2010 to 2015 (standardised to temperature of 11.2°C).*

The dissolved oxygen in the hypolimnion of Lake Ōkaro is depleted more rapidly than in other Rotorua Te Arawa lakes (within two months) and an accurate HVOD cannot be calculated for Lake Okaro using data from monthly monitoring. In contrast, hypolimnetic oxygen takes about five months to be depleted to anoxia in Lake Rotoiti. Interestingly, Lakes Rotomahana and Tarawera have lower HVOD rates than the more oligotrophic lakes, Ōkataina and Rotomā. Lakes Ōkataina and Rotomā have a shallower average depth than Rotomahana and Tarawera, and although they have a smaller hypolimnetic volume. The main drivers for this difference are likely to be an abundance of oxygen consumers and groundwater inflow.

Polymictic[4] lakes, such as Lakes Rotorua and Rotoehu, occasionally have periods of thermal stratification during calm warm conditions that result in oxygen depletion of the bottom waters.

[3] Monomictic lakes have only one season of free circulation. The density difference between the warm surface waters (the epilimnion) and the colder bottom waters (the hypolimnion) prevents these lakes from mixing in summer.
[4] Polymictic lakes are lakes that are too shallow to develop thermal stratification on a seasonal basis.

In late 2014, a stable anticyclonic weather system arrived over the Rotorua area and persisted for several weeks. This system simultaneously impacted Lakes Rotorua and Rotoehu setting up thermal stratification in the lakes. As the bottom waters were cut off from oxygen replenishment from the atmosphere, oxygen at depth was rapidly used up, causing bottom water anoxia for almost a month, before mixing occurred. Figure 3.3 shows this graphically occurring at the end of 2014, beginning of 2015. Both lakes experienced a very similar depletion rate and period of anoxia. This is due to the influence of the anticyclonic weather at the time on both these lakes.

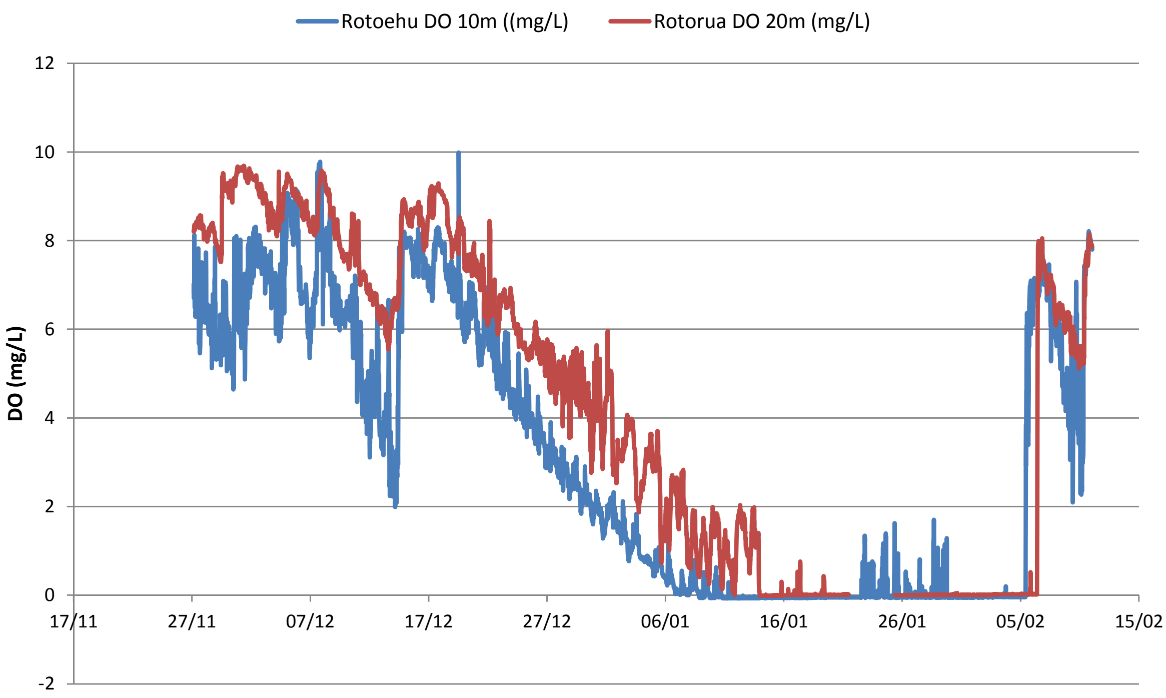


Figure 3.3 Dissolved oxygen concentration in Lake Rotorua (20 m depth) and in Lake Rotoehu (10 m depth), from the end of 2014. Figure shows the rapid depletion of oxygen in the bottom waters of both lakes.

3.1.1 Comparison with the National Objectives Framework

The amendments to the National Policy Statement for freshwater (NPS-FM, 2014) set bottom-line limits for lakes. Councils must set targets at least as stringent as the bottom-lines and implement policies to achieve them. The national bottom-lines for lakes are:

- Chlorophyll-*a* (annual median) <12 mg/m^3.
- Chlorophyll-*a* (annual maximum) <60 mg/m^3.
- Total nitrogen (annual median) <750 mg/m^3 for stratified lakes or <800 mg/m^3 for polymictic lakes.
- Total phosphorus (annual median) <50 mg/m^3.

The band values set for lakes in the NPS-FM (2014) broadly correspond to the values for different lake trophic levels in Burns et al; (2000), although the bands in the NPS-FM provide less differentiation for pristine and degraded lakes. The annual median value of NPS-FM bands for lake chlorophyll-*a*, total nitrogen (stratified lakes) and total phosphorus correspond to the following trophic states from Burns et al; (2000): Band A corresponds to 'oligotrophic' or better, Band B corresponds to 'mesotrophic', Band C corresponds to 'eutrophic', and Band D (below the bottom line) corresponds to 'supertrophic' or worse. The TN values for polymictic lakes are less stringent because many shallow lakes have naturally higher values of TN than deep lakes.

Compliance with these bottom lines was assessed using three years of data, July 2011 to June 2014 (Table 3.2). Only Lake Ōkaro failed to comply with these bottom-lines due to high levels of nitrogen and chlorophyll-*a*. Particularly poor water quality occurred in 2012 with an improvement apparent since this time.

We note that although Lake Ōkaro failed to achieve the bottom-lines set by the NPS-FM for the 2012-14 period, the same data showed that it did achieve its TLI target set in the Regional Water and Land Plan (i.e. TLI = 5). This is because the TLI includes Secchi depth (which is relatively good in Lake Ōkaro compared to other variables) and is calculated from the average of Secchi depth, chlorophyll-*a*, TN and TP, rather than having individual targets to be achieved for each variable. The RWLP TLI target for Lake Ōkaro may need to be lowered to ensure that the lake achieves the bottom lines in the NPS-FM.

Table 3.2 Current state of Rotorua Te Arawa lakes compared to the bottom lines in the NPS-FM.

		NPS-FM bottom line				Current State (2011-2014)			
		max	median (mg/m^3)			max	median (mg/m^3)		
Lake	**mixing**	**Chl-*a***	**Chl-*a***	**TN**	**TP**	**Chl-*a***	**Chl-*a***	**TN**	**TP**
Ōkāreka	stratified	60	12	750	50	9	3.5	233	8
Ōkaro	stratified	60	12	750	50	**145**	11.1	**914**	35
Ōkataina	stratified	60	12	750	50	5	1.9	139	9
Rerewhakaaitu	polymictic	60	12	800	50	7	3.3	410	8
Rotoehu	polymictic	60	12	800	50	13	5.4	285	21
Rotoiti 4	stratified	60	12	750	50	11	4.6	206	12
Rotoiti Okawa Bay	polymictic	60	12	800	50	20	5.9	309	24
Rotokakahi *	stratified	60	12	750	50	15	4.0	216	17
Rotomā	stratified	60	12	750	50	7	1.1	150	5
Rotomahana	stratified	60	12	750	50	10	3.8	242	38
Rotorua 5	polymictic	60	12	800	50	31	9.6	359	13
Tarawera	stratified	60	12	750	50	3	1.6	139	16
Tikitapu	stratified	60	12	750	50	9	1.9	206	3

Rerewhakaaitu, Rotoehu, Okawa Bay and Rotorua stratify for only short periods of time.
Rotokakahi based on sampling of outlet (Te Wairoa Stream)

3.2 Trophic Level Index and Submerged Plant Index results

Table 3.3 summarises the TLI data for the Rotorua lakes for the period ending July 2014 to June 2015.

Table 3.3 Three-yearly average TLI values, 2014/2015 annual TLI, trophic status and LakeSPI condition for the Rotorua Te Arawa Lakes.

Lake Regional Water and Land Plan Objective *TLI units*	3-yearly average TLI to 2012 *TLI units*	3-yearly average TLI to 2013 *TLI units*	3-yearly average TLI to 2014 *TLI units*	3-yearly average TLI to 2015 *TLI units*	2013/14 Annual TLI TLI units	2014/15 Annual TLI TLI units	Lake Type based on Trophic Status	LakeSPI Condition 2014/2015[5]
Ōkaro 5.0	5.1	5.4	5.1	4.8	4.5	4.5	Eutrophic	Moderate
Rotorua 4.2	4.4	4.2	4.2	4.3	4.2	4.4	Eutrophic	Moderate
Rotoehu 3.9	4.3	4.1	4.0	4.1	4.0	4.5	Eutrophic	Poor
Rotomahana 3.9	4.0	4.0	3.9	3.9	3.8	4.0	Mesotrophic	High
Rotoiti 3.5	3.8	3.7	3.5	3.5	3.4	3.7	Mesotrophic	Poor
Rerewhakaaitu 3.6	3.8	3.6	3.5	3.4	3.4	3.3	Mesotrophic	Moderate
Ōkāreka 3.0	3.3	3.2	3.3	3.2	3.3	3.3	Mesotrophic	High
Tikitapu 2.7	2.9	2.8	2.8	2.8	2.8	2.9	Oligotrophic	Moderate
Ōkataina 2.6	2.9	2.9	2.8	2.8	2.7	2.8	Oligotrophic	Moderate
Tarawera 2.6	2.9	3.0	3.0	3.0	3.0	3.1	Mesotrophic	Moderate
Rotomā 2.3	2.3	2.4	2.4	2.4	2.3	2.5	Oligotrophic	High
Rotokakahi* 3.1	4.2	3.8	3.7	3.8	4.0	4.0	Mesotrophic	Moderate

*Italicised figures are based on Te Wairoa Stream monitoring and a three-parameter TLI (no Secchi disk).

Lake water quality can fluctuate for a variety of reasons, including climatic conditions and rainfall. Trophic levels in the Rotorua Te Arawa lakes were impacted in 2014/15 by a warm settled summer resulting in prolonged stratification, especially in some polymictic lakes compared with previous years. The warm temperatures are also ideal for cyanobacterial growth and blooms. Cyanobacterial blooms occurred in Lakes Rotorua, Rotoiti, Tarawera, Rotokakahi and Rotoehu and health warnings were issued at some times in some of these lakes. Many lakes also showed marked increases in phosphorus concentrations.

[5] NIWA (2015). Assessment of the Rotorua Te Arawa lakes using LakeSPI – 2015.

Of the 12 Rotorua Te Arawa lakes in the programme, tracking of the long-term water quality trend shows:

- Improving water quality in Lakes Rotorua and Rotoehu over recent years but vulnerability to climatic conditions and a possible decline in water quality in response to a longer duration of stratification;
- Lake Rotoiti had a long-term improving trend since the installation of the Ōhau Channel diversion wall, however in 2014/15 trophic status declined;
- Improved water quality in Lakes Ōkaro, Rerewhakaaitu, and Tikitapu;
- Stable water quality in Lakes Ōkataina, Ōkāreka and Rotomā and Rotomahana;
- Deteriorating water quality in Lakes Tarawera, and Rotokakahi, which appears to be a consistent long-term trend.

Currently ten of the twelve Rotorua Te Arawa lakes are above the RWLP TLI objective. Recent improvements in the TLI of lakes Ōkaro and Rerewhakaaitu have resulted in these lakes meeting community objectives for lake water quality as stated in Objective 11 of the RWLP.

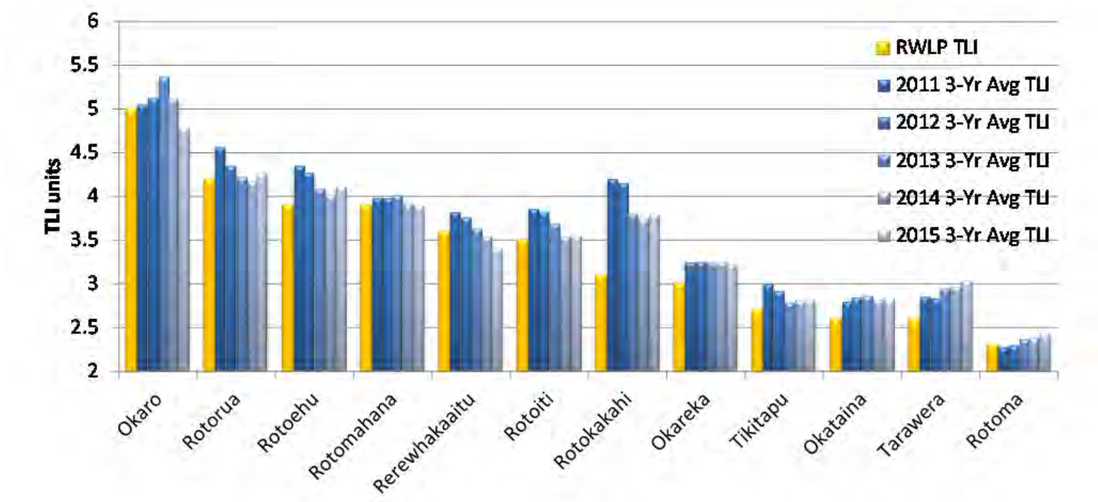


Figure 3.4 TLI 3-yearly average results and TLI RWLP objective TLI. Note: Lake Rotokakahi TLI is based on Te Wairoa Stream monitoring and a three-parameter TLI (no Secchi disk).

The largest change in lake submerged plants (LakeSPI) has occurred in lakes Tarawera and Rotomahana over the past quarter of a century (NIWA, 2015). Invasive aquatic weeds are present on all Rotorua Te Arawa lakes with the worst of these invasive weeds, hornwort (*Ceratophyllum demersum*), being present in seven of the twelve lakes.

Hornwort can out-compete and smother native aquatic vegetation growing at depths deeper than 15 m and can be surface reaching. It is the dominant invasive species in lakes Tarawera and Rotoehu and has reached a stable state in Lake Tarawera. It is possible a decline in the LakeSPI will occur in other lakes (e.g. Ōkāreka and Ōkataina) if hornwort spread continues unchecked.

Management control is occurring in these lakes and may be the reason why there has been a recent improvement in the condition of native macrophytes (aquatic plants) in Lake Ōkāreka in recent years. Figure 3.5 ranks lakes by increasing LakeSPI condition, The higher the score the better the aquatic plant community. Lake Rotomā also ranks highly (Table 3.3) and is a lake that is under threat by potential invasion from hornwort, especially as it is in close proximity to Lake Rotoehu which has a massive hornwort infestation.

Lake	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotoehu	18	25	92
Rotoiti	20	25	92
Tarawera	25	29	87
Rotokakahi	26	19	77
Rotorua	28	33	80
Ōkaro	28	22	69
Ōkataina	40	42	63
Rerewhakaaitu	40	53	72
Tikitapu	45	37	40
Rotomhana	54	53	37
Rotomā	54	55	41
Ōkāreka	55	53	36

Figure 3.5 LakeSPI results for 2014/2015 for Rotorua Te Arawa lakes. LakeSPI Indices are expressed as a percentage of lake maximum potential.

3.3 Trends in Trophic Level Indices

Trends have been calculated for the TLI parameters and the TLI using the statistical techniques described in section 2.6. Two periods were examined, 2002 to 2014 and 2010 to 2014. Results for TLI trends are displayed in Table 3.4.

Over the 13 year period (January 2002 to December 2014), three lakes had no significant change in TLI, three lakes had an increasing TLI score, showing deteriorating lwater quality, and five had a declining TLI score, showing improving water quality. Over the five year period (January 2010 to December 2014), two lakes had no significant change in TLI, two lakes had an increasing (deteriorating) TLI score, and seven had a decreasing (improving) TLI score (Table 3.4).

Lakes with deteriorating water quality and a rate of change (PAC) greater than 1% per year were Tarawera and Rotomā (Rotomā for the last five years only) – neither meet their RWLP target. Four lakes showed improving water quality periods over both periods of analysis of greater than 1% per year: Ōkaro; Rotoehu; Rotoiti (Site 4), and Rotorua.

Trends for other variables are shown in Appendix 4.

All lakes showed a step change decline in dissolved oxygen (DO) in early 2007 which corresponded to a change in meters being used. Thus, declining trends in DO spanning this period may reflect changes in meters rather than actual water quality trends.

Table 3.4 Summary state and trends in TLI for the Rotorua lakes. An increasing trend in TLI reflects a deterioration in water quality.

Lake	TLI target	TLI (2011-14)	trophic state	trend 2002-2014 direction	PAC	trend 2010-2014 direction	PAC
Ōkāreka	3.0	3.2	mesotrophic	→		↓	-1.2%
Ōkaro	5.0	5.0	supertrophic	↓	-1.2%	↓	-2.4%
Ōkataina	2.6	2.8	oligotrophic	→		→	
Rerewhakaaitu	3.6	3.4	mesotrophic	↑	0.5%	↓	-3.5%
Rotoehu	3.9	3.9	mesotrophic	↓	-1.1%	↓	-2.9%
Rotoiti 4	3.5	3.4	mesotrophic	↓	-1.4%	↓	-2.0%
Rotoiti Okawa Bay		4.1	eutrophic	↓	-1.9%	→	
Rotokakahi *	3.7	3.8	mesotrophic	↑	0.7%	↓	-3.1%
Rotomā	2.3	2.4	oligotrophic	→		↑	2.2%
Rotomahana	3.9	3.8	mesotrophic	↑	0.5%	→	
Rotorua 5	4.2	4.0	eutrophic	↓	-1.6%	↓ *	-1.3%
Tarawera	2.6	2.9	oligotrophic	↑	1.1%	↑	1.6%
Tikitapu	2.7	2.7	oligotrophic	↓	-0.8%	↓	-1.3%

TLI target from the Regional Water & Land Plan

The 5 year trend was not significant at Rotorua site 5 but was significant at site 2.

Direction key: ↑ = increase, ↓ decrease, → no significant change

Rotokakahi was samped at outlet (Te Wairoa Stream) to calculate TLI3

3.4 Cyanobacteria

The presence of toxin producing blue-green algae species (cyanobacteria) 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 cyanobacteria blooms brought on by artificially elevated nutrient enrichment.

The cyanobacteria 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 cyano-toxins. 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 cyano-toxin 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 Medical Officer of Health (MO) relies on cell counts provided by Bay of Plenty Regional Council and on the results of toxicity tests, to determine whether cyanobacteria blooms pose a public health risk and therefore whether health warnings are required. The cyanobacteria 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).

3.4.1 Dominant cyanobacteria

Dominant cyanobacteria taxa have varied over the years and may vary among sites within the same lake, and between lakes. Figure 3.6 shows average biovolumes of cyanobacteria for the dominant taxa of nine lake sites from 2004 to 2015, in relation to the total average biovolume. Although the lakes have different sampling histories; *Anabaena spiroides* was the most dominant species over this period with the highest average biovolume 544.1(mm^3/L), *Microcystis aeruginosa* had the second highest average biovolume 442.654 (mm^3/L), *Anabaena circinalis* had the average biovolume 253.4 (mm^3/L) and *Anabaena planktonica* had the lowest average biovolume 23.4 (mm^3/L) of the dominant taxa across the nine sites analysed.

These top four dominant taxa can be detected in Lake Ōkaro, Lake Rotorua and Lake Rotoiti, however, *Anabaena* planktonica is rarely found at the three sites monitored at Lake Rotoehu. In Lake Rotoehu there was a dominance of *Microcystis aeruginosa* in Ōtautū Bay, however, *Anabaena spiroides* dominated in Kennedy Bay and Te Pohue Bay.

Lake Ōkaro had a dominance of *Anabaena circinalis* and *Anabaena spiroides* for the single sampling site.

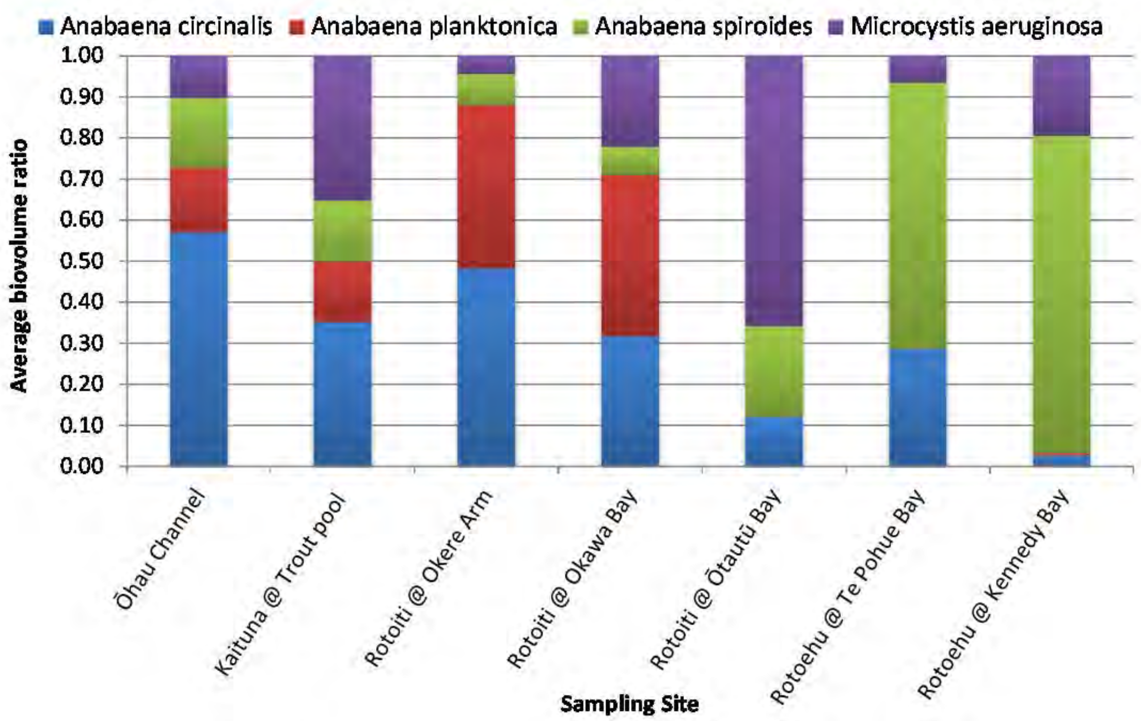


Figure 3.6 Average biovolume ratios for the four dominant taxa for the nine sites, 2004 to 2015.

In Lake Rotorua, the site at Holden's Bay has been dominated by the species *Microcystis aeruginosa*. In Lake Rotoiti there was a dominance of *Anabaena planktonica* in Okawa Bay at levels similar to Okere Arm. Okere Arm was firstly dominated by *Anabaena circinalis* and secondly by *Anabaena planktonica*, this site being influenced by Lakes Rotorua and Rotoiti.

The sites Trout Pool and Okere Arm are part of the same hydrological system that exports water from Lake Rotoiti and Ōhau Channel exports from Lake Rotorua. However, the Trout Pool site had a dominance of *Microcystis aeruginosa*, this is in contrast to the Ōhau Channel and Okere Arm, which both had dominance of *Anabaena circinalis*.

3.4.2 Comparison with the National Objectives Framework

One of the NPS for Freshwater Management (2014) (NOF) attributes for the protection of human health is the measure of planktonic cyanobacteria. The attribute bands (A-D, with no 'B' band) are based either on biovolume or cell count, compared with the eightieth percentile of samples collected over three years (Table 3.6).

Results show that over the past three years, no lakes are below the national bottom line for this human health value (Table 3.6). Hot spots for persistent bloom of blue-green algae (cyanobacteria) are Lake Ōkaro, Lake Rotoehu and Okawa Bay in Lake Rotoiti.

Table 3.5 National Objectives Framework human health value based on Cyanobacteria (planktonic) in lakes fed rivers and lakes.

Value	Attribute state (E.coli/100 ml)			
	A	B	C (bottom-line)	D
Numeric state Eightieth Percentile*.	≤0.5 mm^3/L bio-volume, or ≤500 cells/mL.	N/A	>0.5 and ≤1.8 mm^3/L toxic cyanobacteria biovolume, or >0.5 and ≤10 mm^3/L total cyanobacteria.	>1.8 mm^3/L toxic cyanobacteria biovolume, OR 10 mm^3/L total cyanobacteria.
Human health for secondary* contact (annual median).	Risk exposure from cyanobacteria is no different to that in natural conditions (from any contact with fresh water).		Low risk of health effects from exposure to cyanobacteria (from any contact with fresh water).	Potential health risks (e.g., respiratory, irritation and allergy symptoms) exist from exposure to cyanobacteria (from any contact with fresh water).

*Eightieth Percentile must be calculated using a minimum of 12 samples collected over three years.

Table 3.6 NOF banding results for Total Cyanobacteria (planktonic) biovolumes in Rotorua Te Arawa lakes, 2012 to 2015.

Lake/Site	**Attribute state**	**80 percentile biovolume** (mm^3/L)
Lake Rotorua @ Hamurana	A	0.03
Lake Rotorua @ Holdens Bay	A	0.02
Lake Rotorua @ Ngongotaha	A	0.04
Ohau Channel	A	0.26
Lake Rotoiti @ Okere Arm	A	0.12
Lake Rotoiti @ Otaramarae	A	0.03
Lake Rotoiti @ Hinehopu	A	0.04
Lake Rotoiti @ Te Weta	A	0.09
Lake Rotoiti @ Trout Pool	A	0.02
Lake Rotoiti @ Okawa Bay	C	5.58
Lake Ōkaro	C	6.82
Lake Rotoiti @ Kennedy Bay	C	3.20
Lake Rotoiti @ Ōtautū Bay	C	1.76

Part 4: Lake Okāreka

4.1 Introduction

Lake Ōkāreka is one of four small lakes between Lake Rotorua and Lake Tarawera and is of high recreational and aesthetic value. It is located in an ignimbrite plateau, with steep caldera walls on the north-eastern side. The lake receives inputs mostly from groundwater seepage, runoff and rainfall. Lake Ōkāreka discharges to Lake Tarawera via the Waitangi Spring and groundwater flows.

Lake Ōkāreka is a moderately deep lake with a maximum depth of 34 m. It has a surface catchment of 19.6 km^2, including the lake area of 3.43 km^2. Half of the catchment is forested, of which three quarters is indigenous, and the remaining land is predominantly pastoral or invasive vegetation, although the pastoral area is decreasing (Figure 4.1). Inputs from pasture in addition to septic tank inputs have contributed to nutrient enrichment. To address this, Okāreka's lakeside community septic systems were reticulated in 2011.

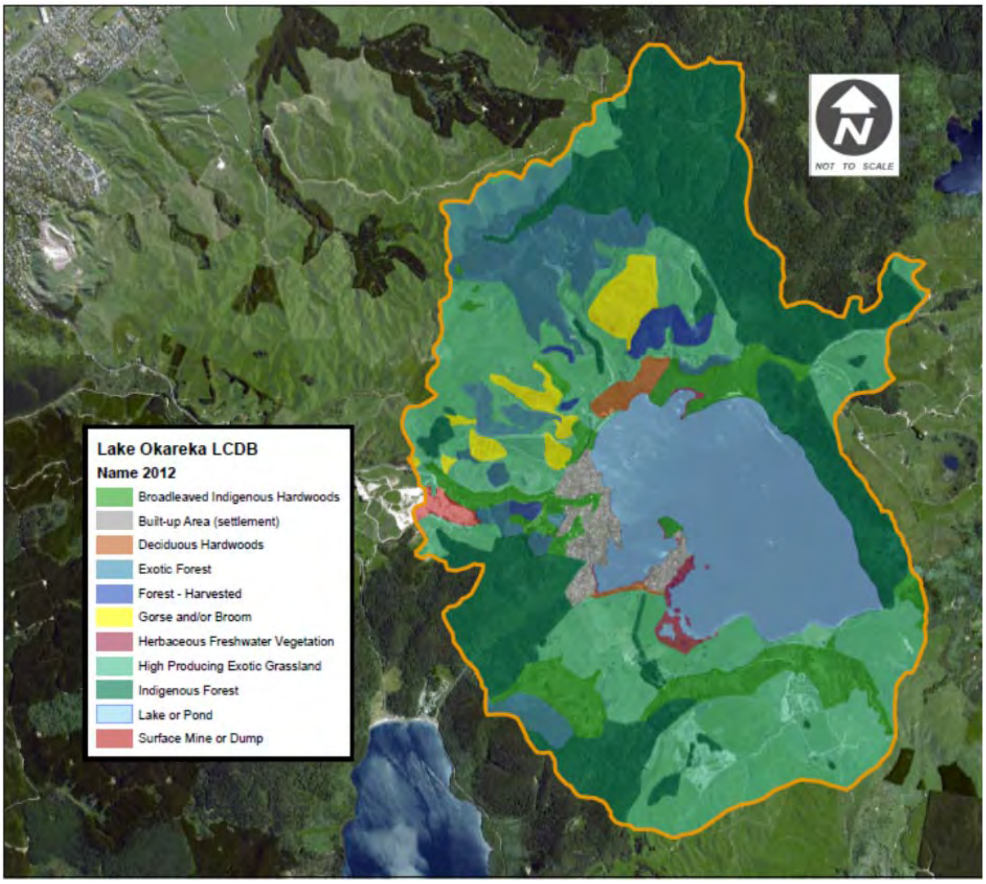


Figure 4.1 Lake Ōkāreka Catchment landuse (based on LCDB 2012).

Lake Ōkāreka is a monomictic lake, that is, it seasonally stratifies with the bottom waters (hypolimnion) being cut off from the surface waters (epiliminion) from September to May. This pattern results in changing temperature and dissolved oxygen is observed in Figure 4.4.

4.2 Results

Lake Ōkāreka is classed as mesotrophic. It has a 2014/15 TLI value of 3.3 compared to a target TLI of 3.0 set in the RWLP. The TLI has been relatively stable over the long term but there are indications of improvements in TLI, chlorophyll-*a* and TN since 2010. Conversely, there appears to have been a strong deterioration in TP, DRP and percent dissolved oxygen (DO) in the bottom waters since 2010 (Table 4.1, Figure 4.4). Hypolimnetic volumetric oxygen demand (HVOD) rates showed some improvement after the application of Phoslock in 2005 (Figure 4.3). Hypolimnetic Volumetric Oxygen Depletion rates have increased in the past two years possibly due to climatic drivers, that is, increased periods of stable warm weather.

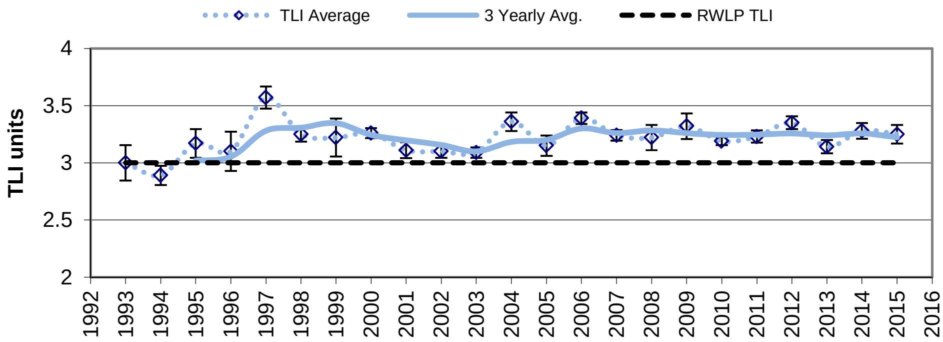


Figure 4.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Ōkāreka.

During summer stratification, the anoxic bottom water of Lake Ōkāreka has very high concentrations of phosphorus (about 300 mg/m^3 mostly as DRP) and nitrogen (about 3000 mg/m^3 mostly as ammoniacal nitrogen). This is mixed with the top waters when turnover occurs in late autumn (e.g. May and June), and helps to drive phytoplankton production during spring. Figure 4.5 shows this increase in chlorophyll-*a* concentrations in winter is diatom numbers increase, demonstrated by the increasing fluorescence of the phytoplankton (algae) at this time.

Nutrient ratios give no consistent indication of potential nutrient limitation. The TN:TP ratio indicates that phosphorus is more likely to limit phytoplankton growth, but the DIN:TP ratio indicates that dissolved nitrogen is more likely to limit. This suggests that ongoing management for both nutrients is important.

Although water clarity has been stable, it was strongly reduced over the 2014/15 summer months and reached the lowest ever recorded level of 2.9 m.

Table 4.1 Average water quality and trends in top and bottom waters for Lake Ōkāreka. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
		direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	3.2					↓	-1.2%		
Chl-*a* (mg/m³)	3.7					↓	-14.3%		
Secchi (m)	7.8								
TN * (mg/m³)	234	↑	1.0%	↗	0.9%	↓	-2.3%		
TP * (mg/m³)	8.3							↑	12.6%
%DO	86.3	↓	-1.5%	↓	-0.8%			↓	-6.3%
DO min (g/m³)	3.6			↓	-1.6%				
DIN (mg/m³)	5.3					↓	-21.5%		
NH_4-N (mg/m³)	3.2					↓	-49.2%		
DRP (mg/m³)	2.9					↑	11.2%	↑	16.7%
EC (uS/cm)	60					↑	1.3%	↑	2.0%
pH	7.6							↓	-0.5%
Temperature	15.2								
VLEC	0.3								
Turbidity (NTU)	0.79	↓	-1.5%						

* = TN and TP after adjusting for laboratory changes.
Average based on three year period July 2011 to June 2014
↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)
Shaded out cells = variable not measured
Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

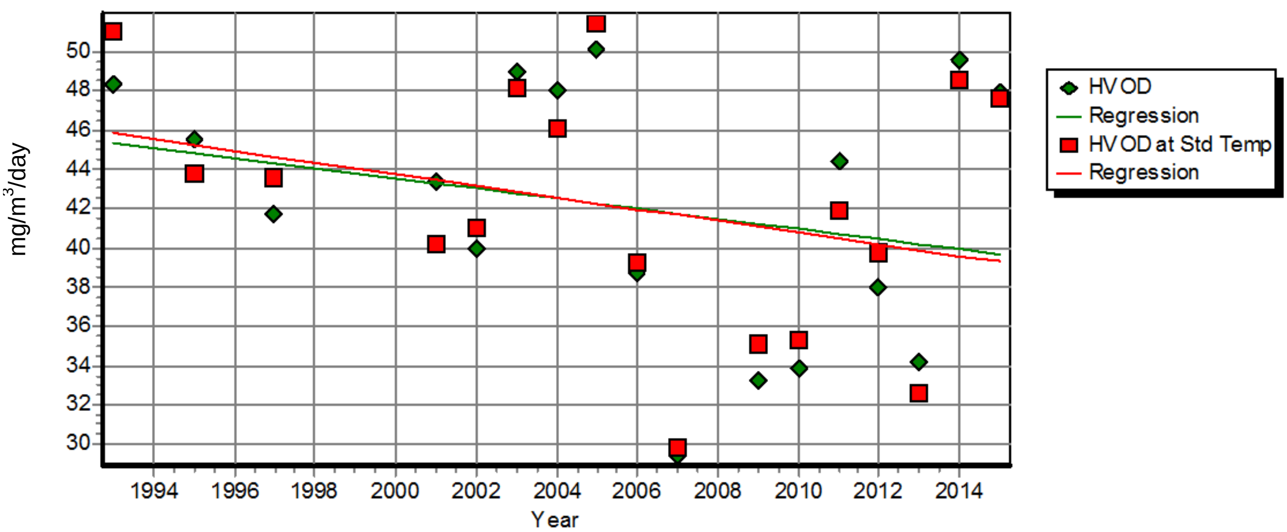


Figure 4.3 Hypolimnetic Volumetric Oxygen Depletion rates and HVOD rates adjusted to standard temperature,1993 to 2015.

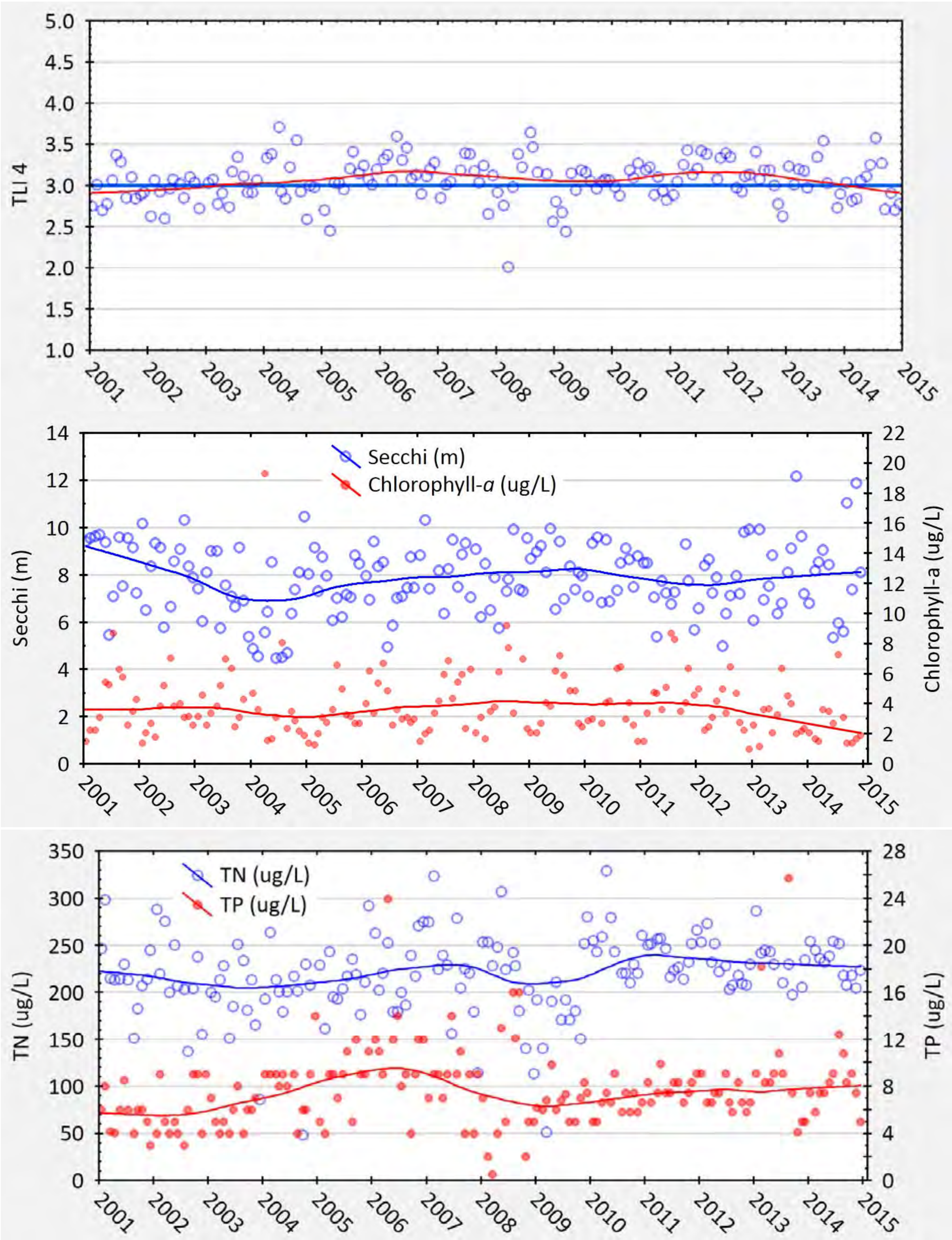


Figure 4.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Ōkāreka since 2001. The TLI target of 3 is indicated by the blue line in the top graph.

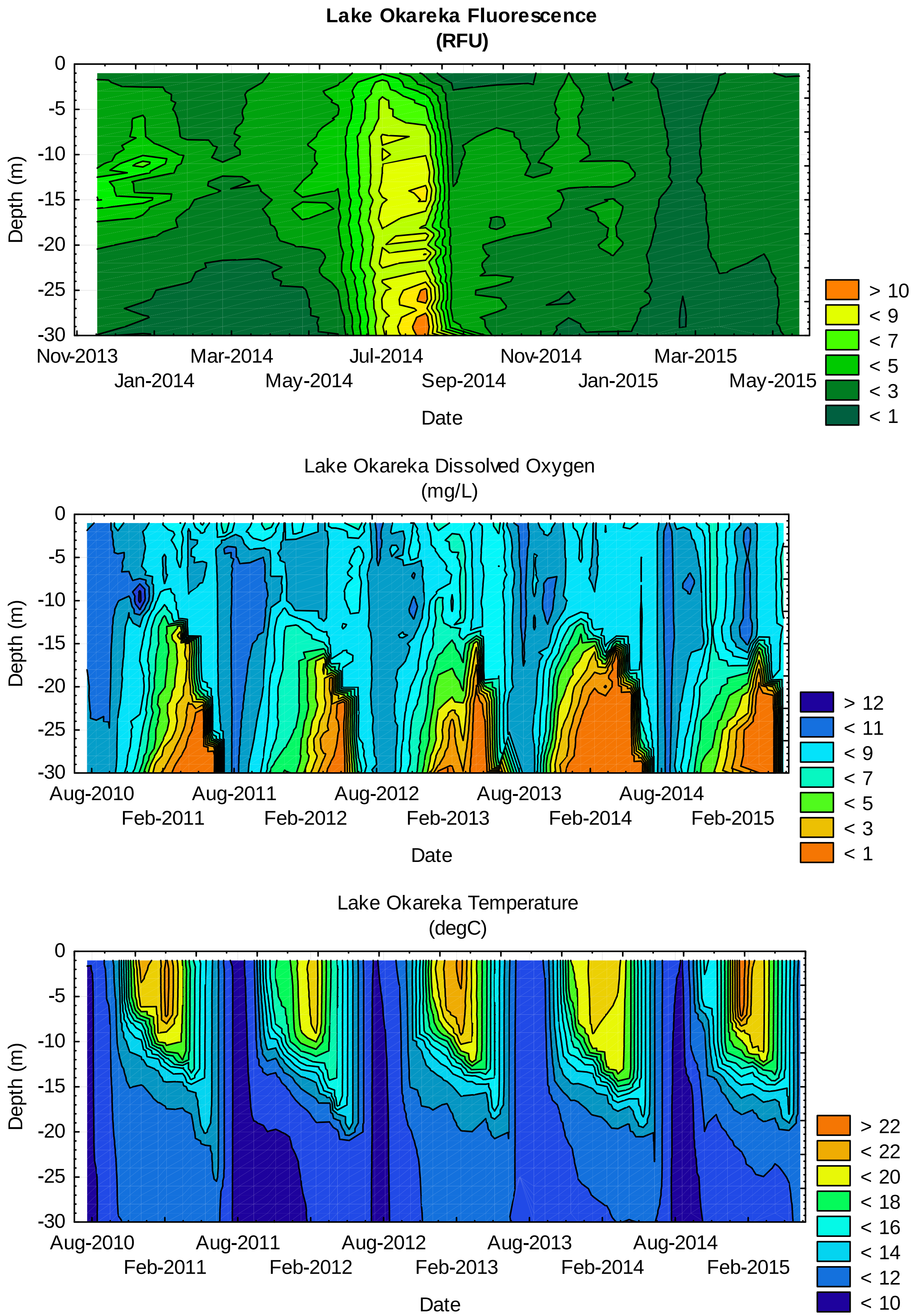


Figure 4.5 *Time and depth plots of chlorophyll-a (as measured by fluorescence in relative fluorescence units (RFU)), dissolved oxygen concentrations, and temperature.*

4.3 Lake Submerged Plant Index results

Lake Condition: High **Stability**: Improving

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Ōkāreka	55	53	36

Hornwort control within Lake Ōkāreka has helped reduce the impact of invasive aquatic weeds in favour of extensive native plant communities. The invasive weed *Egeria* had disappeared from all LakeSPI sites and *Lagarosiphon* cover had reduced, replaced by native communities.

Hornwort still remains a threat. A delimitation survey carried out in March 2013 confirming hornwort inhabits approximately 17.5 ha of the lake. While this has reduced, hornwort poses a greater threat to this lake than *Egeria*, with the potential to reduce the LakeSPI Index, by occupying a deeper range than *Egeria* and by displacing deep water charophyte meadows.

Part 5: Lake Ōkaro

5.1 Introduction

Lake Ōkaro is the smallest of the Rotorua Te Arawa lakes and is of high recreational value, especially for water skiers. It is located south of Lake Tarawera and is surrounded by pasture. Besides rainfall and overland flow, the lake receives its inputs via several small streams. The lake is drained by the Haumi Stream in the south east, which joins the Waimangu Thermal Valley Stream before entering Lake Rotomahana.

Lake Ōkaro has an average depth of approximately 12 m and a maximum depth of 18 m, with a topographical catchment area of 3.9 km^2, including the lake area of 0.31 km^2. The catchment contains few residential homes and is almost entirely pastoral. Nutrients enter the lake from remobilisation from the bottom sediments, inputs from farmland and possibly septic tank discharges. The lake is of very high productivity, and experiences severe and frequent algal blooms of cyanobacteria during spring/summer.

The lake has had an extensive program of water quality management. Land based interventions include construction of wetlands to aid the filtering of particulate phosphorus and enhance uptake of dissolved inorganic nutrients and denitrification, and detention bunds upstream of the wetland to balance peak flows and settle out particulate matter. In-lake interventions include the use of alum to flocculate and cap phosphorus within the lake sediments.

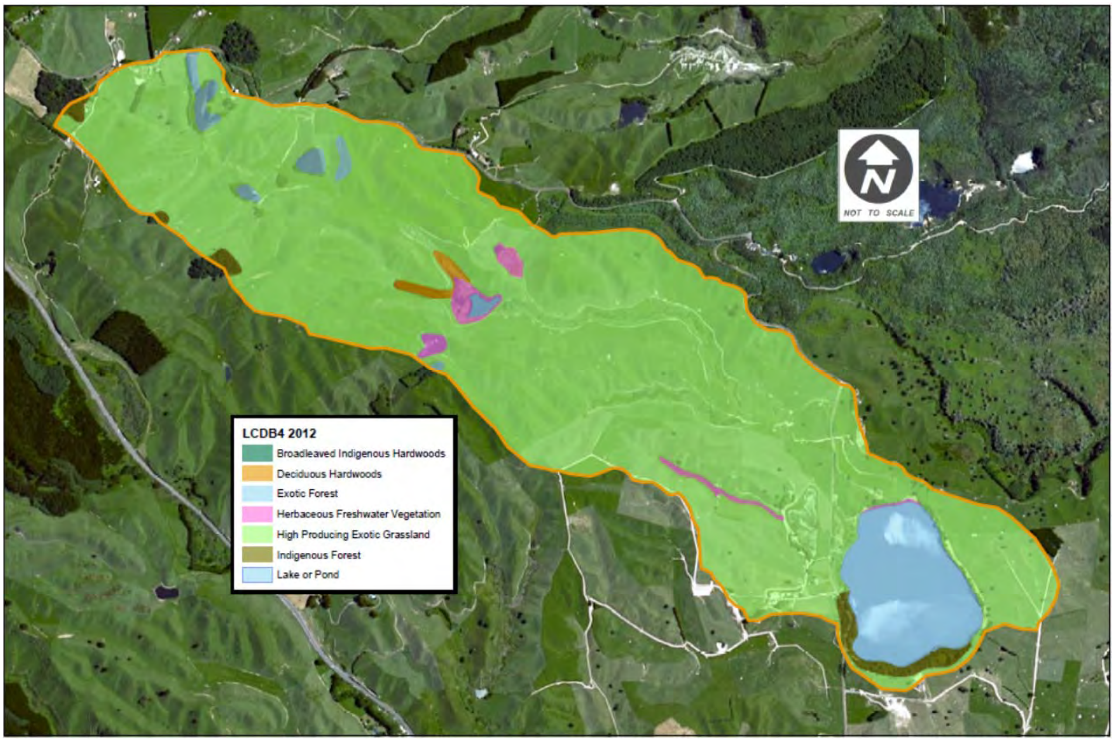


Figure 5.1 Lake Ōkāro Catchment landuse (based on LCDB 2012).

Lake Okaro is a monomictic lake, that is, it seasonally stratifies with the bottom waters (hypolimnion) being cut off from the surface waters (epiliminion) from September to May. This pattern of changing temperature and dissolved oxygen can be observed in Figure 5.4.

5.2 Results

Lake Ōkaro has previously been classified as supertrophic, but is now classified as eutrophic. The TLI in Lake Ōkaro in 2014/15 has remained below the objective of 5.0 units, for the second year in succession (Figure 5.2 and 5.3). However, the lake still failed to achieve the bottom-line values set by the NPS because of particularly high concentrations of chlorophyll-*a* and nitrogen. The RWLP TLI target for Lake Ōkaro may need to be lowered to ensure that the lake achieves the bottom lines in the NPS.

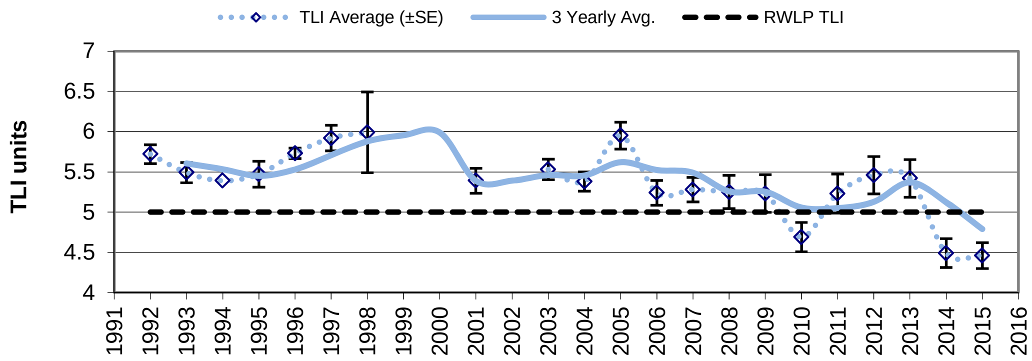


Figure 5.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Ōkāro.

During summer stratification, the anoxic bottom water of Lake Ōkaro has very high concentrations of phosphorus (about 300 mg/m^3 mostly as DRP) and nitrogen (about 3000 mg/m^3 mostly as ammoniacal nitrogen). This is released into the top waters when lake water mixes in late autumn (e.g. May and June), and helps to fuel phytoplankton blooms during spring. An example of the difference in intensity of bloom in the summer of 2013/14 compared to 2014/15 can be seen in the contour plot of fluorescence in Figure 5.4. Also of note In Figure 5.4 is the deep chlorophyll maximum (DCM) that develops over the summer at around the 10 metre depth.

Chlorophyll-*a* concentrations have remained relatively low, possibly due to the low phosphorus concentrations. This may in part be due to alum dosing in June 2014, although cyanobacteria were present at alert levels for just over two months over the 2014/15 summer (Figure 5.5). Nitrogen concentrations have also decreased in the past two years, which may also have led to the decrease in chlorophyll-*a*. Water clarity has shown an improving (i.e. increasing) trend.

There has been considerable improvement in the water quality of Lake Ōkaro since 2002 which is evident in all variables in both top and bottom waters. The reduction in percent dissolved oxygen in the top waters, in part reflects less super-saturation of oxygen that occurs due to excessive algae growth. Water quality improvements are also evident since 2010 for TLI, TN, TP, NH_4-N, DRP and electrical conductivity (Table 5.1).

A comparison of nutrient ratios suggests that phytoplankton in Lake Ōkaro is potentially more strongly phosphorus limited (see Table 3.1), although the ratio of DIN:TP indicates possible nitrogen limitation during summer.

Table 5.1 Average water quality and trends in top and bottom waters for Lake Ōkaro. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

	Top	Trend 2002 to 2014				Trend 2010 to 2014			
	Average	Top		Bottom		Top		Bottom	
Variable	**2011-14**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**
TLI *	5.0	↓	-1.2%			↓	-2.4%		
Chl-*a* (mg/m^3)	27.3	↓	-4.9%						
Secchi (m)	2.7	↑	3.4%						
TN * (mg/m^3)	905	↓	-1.5%	↓	-1.5%	↓	-6.1%		
TP * (mg/m^3)	46.6	↓	-8.0%	↓	-8.5%	↓	-14.2%	↓	-10.7%
%DO	85.0	↓	-2.4%	↘	-2.7%			↘	-10.0%
DO min (g/m^3)	2.4			↓	-3.8%				
DIN (mg/m^3)	177.8	↓	-4.5%	↓	-3.1%	↘	-8.2%		
NH_4-N (mg/m^3)	162	↓	-7.8%	↓	-2.9%	↓	-13.9%		
DRP (mg/m^3)	16.0	↓	-17.7%	↓	-12.2%	↓	-31.2%	↓	-16.6%
EC (uS/cm)	82	↓	-0.5%	↓	-0.9%	↓	-1.2%		
pH	8.2	↓	-0.5%						
Temperature	15.1								
VLEC	1.0								
Turbidity (NTU)	5.62	↓	-2.8%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

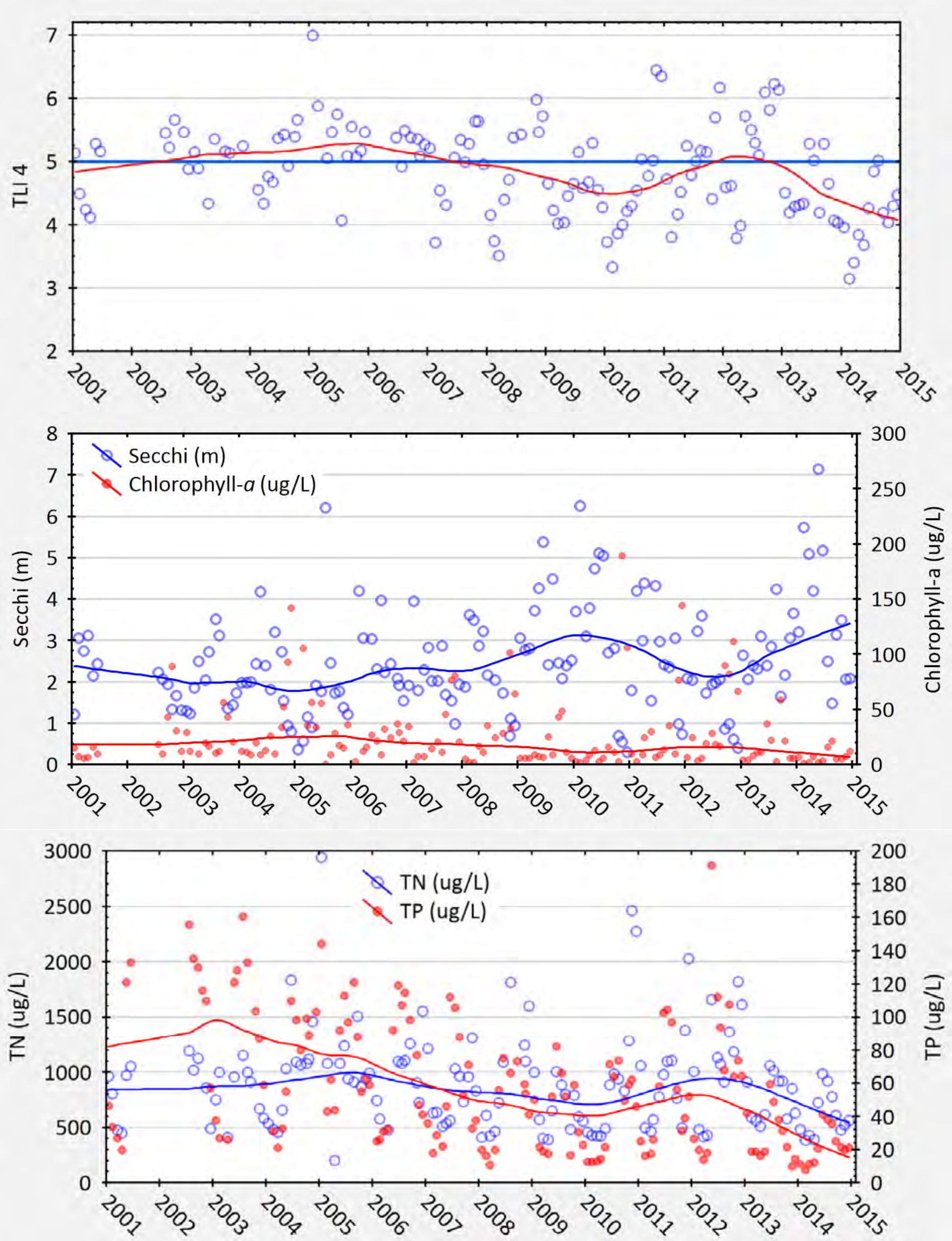


Figure 5.3 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Ōkaro since 2001. The TLI target of 5 is indicated by the blue line in the top graph.

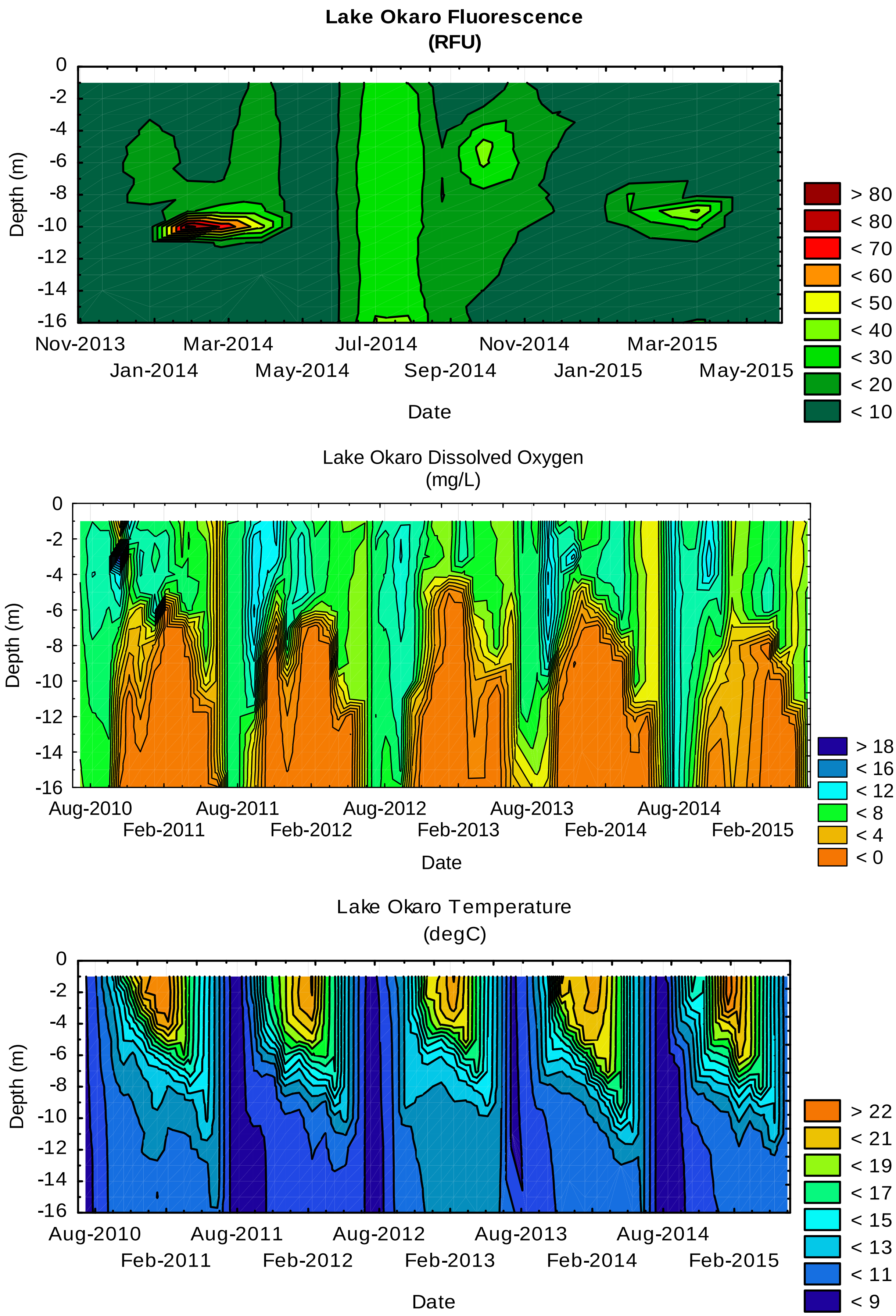


Figure 5.4 Time and depth plots of chlorophyll-a (as measured by fluorescence in relative fluorescence units (RFU)), dissolved oxygen concentrations, and temperature.

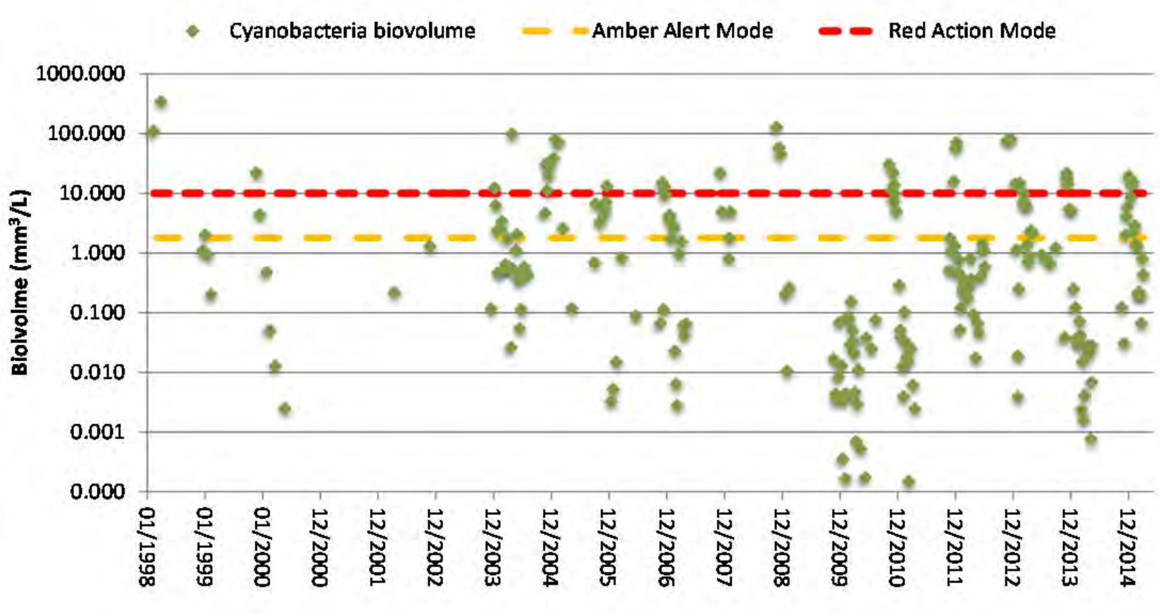


Figure 5.5 Total cyanobacteria biovolume as sampled at Lake Ōkaro boat ramp.

5.3 Lake SPI results

Lake Condition: Moderate Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Ōkaro	28	22	69

Degradation of Lake Ōkaro's water quality and dominance of phytoplankton (algae) have resulted in fluctuating LakeSPI scores over the years. The Invasive Impact scores have been particularly affected with a 20% improvement between 2011 and 2013 surveys. *Elodea* remains the only invasive species, with the highly eutrophied lake being poor habitat for submerged vegetation.

Part 6: Lake Ōkataina

6.1 Introduction

Lake Ōkataina is a large, deep lake with a maximum depth of 78.5 m, and a topographical catchment of 60 km^2, including the lake area of 10.8 km^2. The catchment is predominantly indigenous forest, with small proportions of exotic forestry and dry stock land. Geothermal springs occur on the eastern shore.

Lake Ōkataina has no surface water outlet and water levels can fluctuate widely between years, depending on long term rainfall patterns. There is thought to be a subterranean discharge towards Lake Tarawera.

The lake is in pristine condition due to the high proportion of the catchment in native vegetation. However, there has been recent concern with the effects of pest species, particularly wallabies, which strip the understory in the forested catchment.

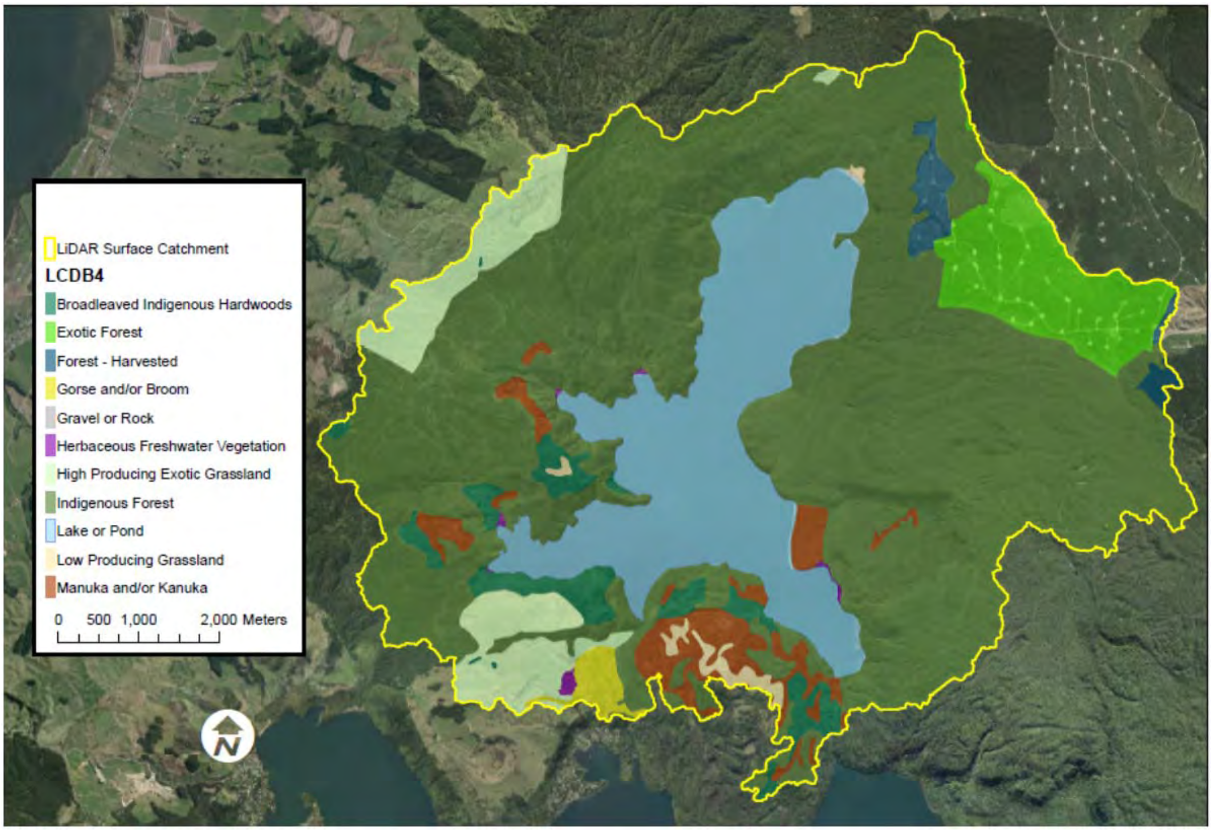


Figure 6.1 Lake Ōkataina Catchment landuse (based on LCDB 2012).

Lake Ōkataina is a monomictic lake, that is, it seasonally stratifies with the bottom waters (hypolimnion) being cut off from the surface waters (epiliminion) from September to May. Bottom waters near the sediment interface do go anoxic during stratification. This pattern of changing temperature and dissolved oxygen can be observed in Figure 6.4

6.2 Results

The lake is in pristine condition and is classified as oligotrophic. It has a 2014/15 TLI of 2.9 compared to a target TLI of 2.6 set in the RWLP. The TLI has been stable over the long term with no significant trend in TLI since 2002. However, there is evidence of a reduction in the concentration of chlorophyll-*a*, and dissolved nitrogen (DIN and NH_4-N), and an increase in phosphorus (TP and DRP) (Table 6.1, Figure 6.2 and 6.4).

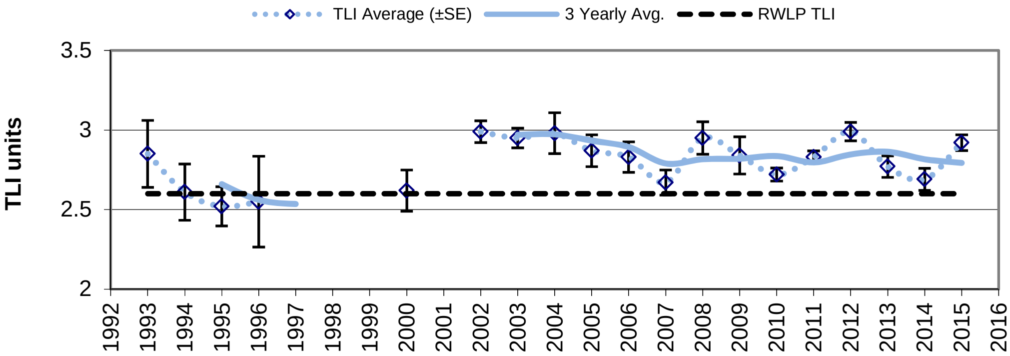


Figure 6.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Ōkataina.

The HVOD rates appear to have reduced compared to 2003 and 2004 (Table 6.1, Figure 6.3), although the last HVOD (2014/15) has shown a slight increase due to a slightly longer and more stable period of anoxia. This may also explain a recent increasing trend in DRP.

The ratio of nitrogen to phosphorus is reasonably balanced and the lake phytoplankton is mostly co-limited (Table 3.1). Increase in the annual average phosphorus is the predominant reason for the TLI increase. Phosphorus concentrations peaked after winter turnover in 2014 although they had not increased appreciably in the hypolimnion in 2013.

The oxygen depletion rate was slightly higher in the hypolimnion in 2013-14 and 2014-15 compared to previous years, although this did not appear to have impacted dissolved reactive phosphorus levels, and ammonium levels also remained low (Figure 6.3, Figure 6.5).

Table 6.1 Average water quality and trends in top and bottom waters for Lake Ōkataina. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014 Top direction	Trend 2002 to 2014 Top PAC	Trend 2002 to 2014 Bottom direction	Trend 2002 to 2014 Bottom PAC	Trend 2010 to 2014 Top direction	Trend 2010 to 2014 Top PAC	Trend 2010 to 2014 Bottom direction	Trend 2010 to 2014 Bottom PAC
TLI *	2.8								
Chl-*a* (mg/m^3)	2.1	↓	-2.5%			↓	-5.0%		
Secchi (m)	10.0								
TN * (mg/m^3)	139					↓	-4.2%	↘	-2.6%
TP * (mg/m^3)	9.6	↑	2.8%						
%DO	87.5	↓	-1.4%	↘	-0.6%	↓	-1.8%		
DO min (g/m^3)	3.7			↓	-2.4%				
DIN (mg/m^3)	5.0	↓	-7.0%	↓	-4.7%	↓	-14.3%		
NH_4-N (mg/m^3)	2.1	↓	-9.5%			↘	-33.3%		
DRP (mg/m^3)	4.8	↑	5.0%	ns		↑	8.4%	↑	7.2%
EC (uS/cm)	81								
pH	7.5								
Temperature	15.4								
VLEC	0.2								
Turbidity (NTU)	0.58	↓	-1.9%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

Figure 6.3 HVOD rates and HVOD rates adjusted to standard temperature, 1994 to 2015.

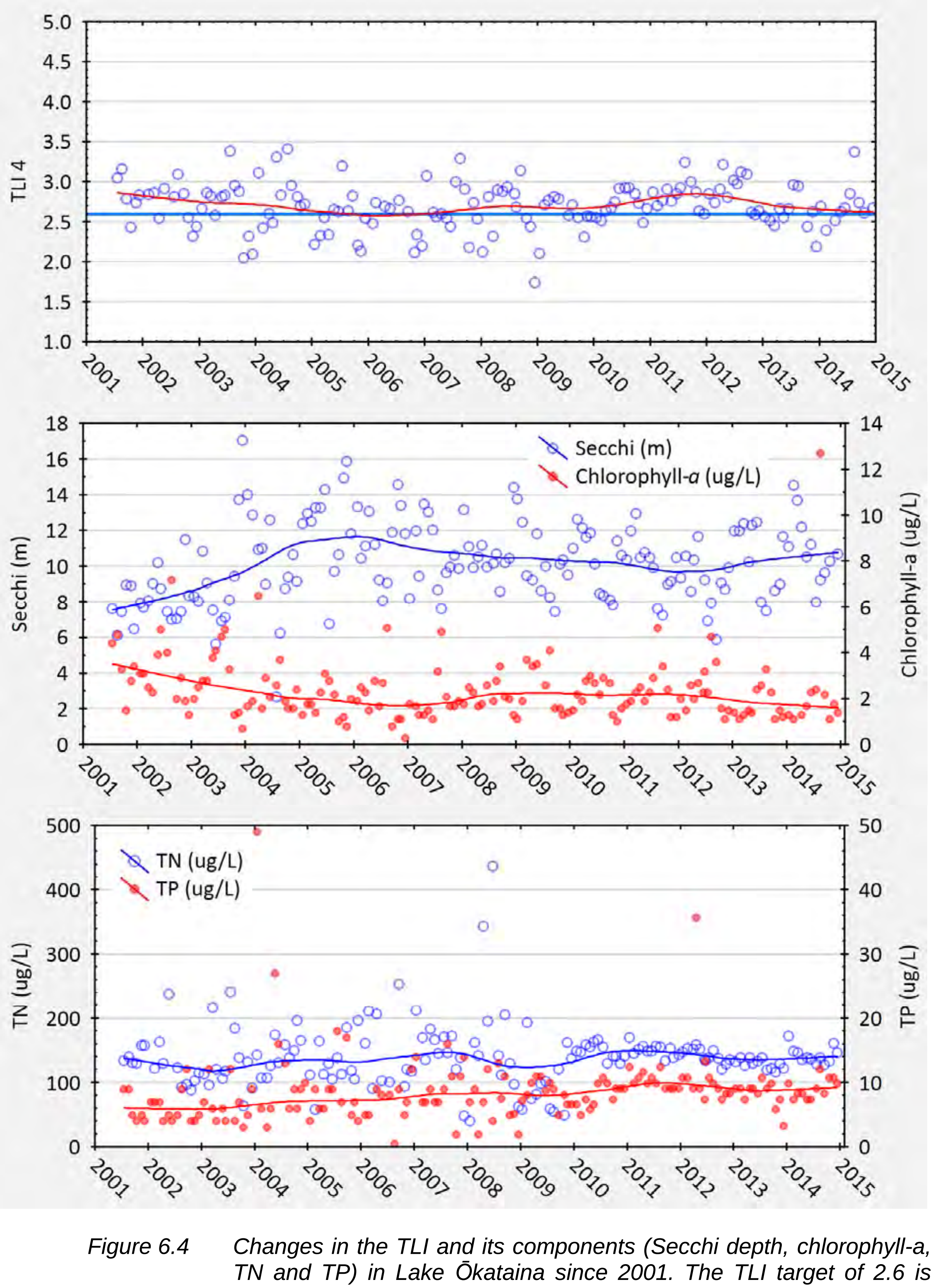


Figure 6.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Ōkataina since 2001. The TLI target of 2.6 is indicated by the blue line in the top graph.

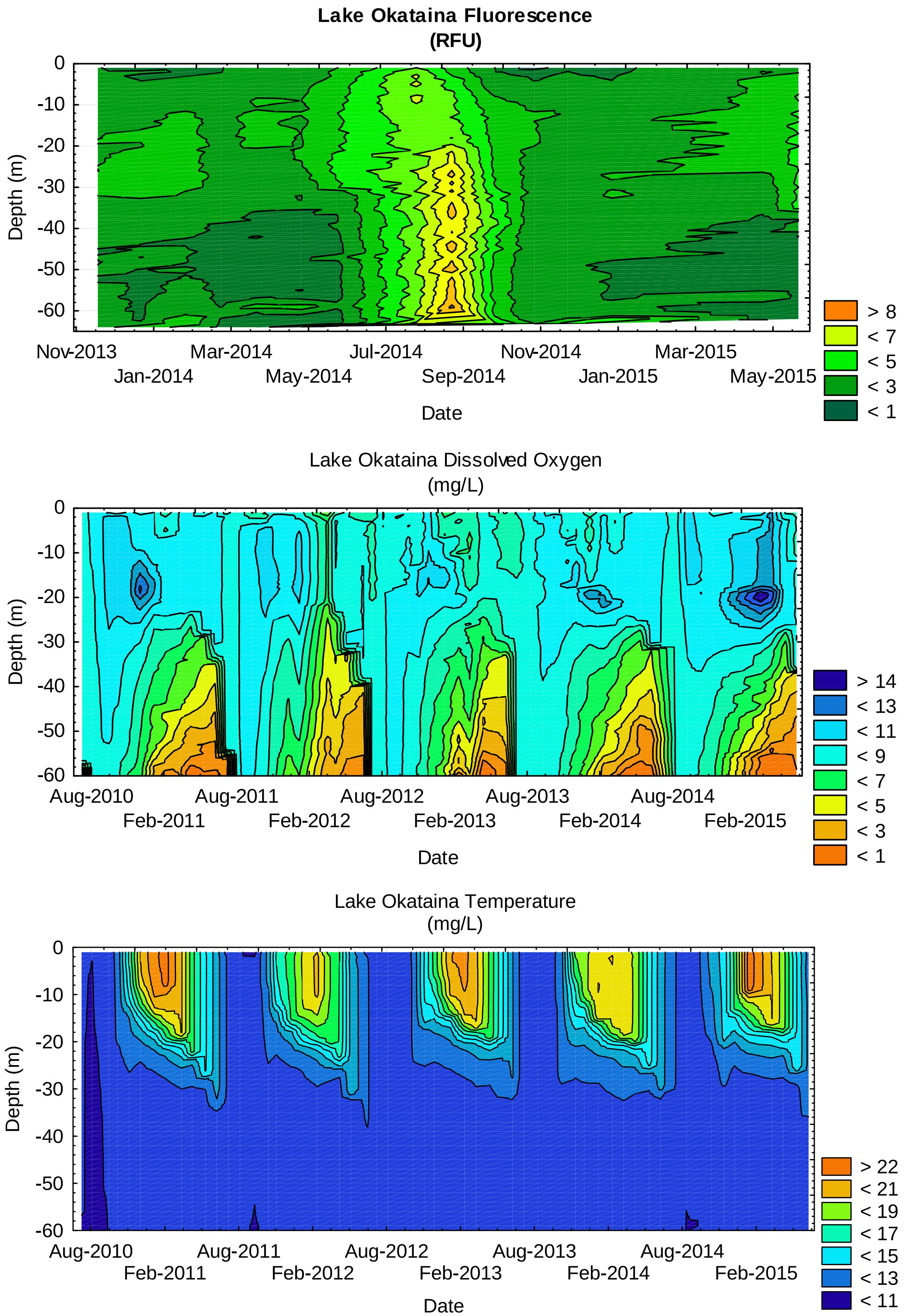


Figure 6.5 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom).

6.3 Lake SPI results

Lake Condition: Moderate   Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Ōkataina	40	42	63

Lake Ōkataina is categorised as being in moderate ecological condition predominantly due to the invasive species *Lagarosiphon* forming high cover weed beds at most sites which generates an Invasive Impact Index of 63%. Hornwort was also discovered in the lake in 2007 but has not been found at any LakeSPI transects. Although, originally thought of as eradicated, additional infestations were found at the north end of the lake, well away from the high risk area near boat launching sites. Hornwort continues to pose the most serious threat to the future condition of Lake Ōkataina. The infestations are actively managed with herbicide applications, and re-introductions are potentially being prevented with the installation of a weed cordon at the southern boat ramp.

Photo: Lake Ōkataina boat ramp with weed cordon.

Part 7: Lake Rerewhakaaitu

7.1 Introduction

Lake Rerewhakaaitu is a relatively small shallow lake located immediately south of Mount Tarawera. It is the southern most of the Rotorua lakes, with the highest altitude (438 m a s l). The lake is of high recreational value to boaters and swimmers, and is a popular destination for holiday makers. The area around the lake is of special wildlife interest, with the largest breeding population of banded dotterel in the Rotorua district.

Surface outflows occur only during high lake levels, when it drains to Mangaharakeke Stream (a tributary of the Rangitaiki River). It is likely to be the source of local springs and groundwater flowing southeast through the Rangitaiki Ignimbrite to the Rangitaiki River Catchment. The lake is also linked to Lake Rotomahana via groundwater.

Lake Rerewhakaaitu occupies a shallow basin in the centre of its 37 km^2 catchment, including the lake area of 5.5 km^2 and has a maximum depth of 15.8 m. Pasture is the dominant land cover in the catchment (65 %); however, there has been an increase in exotic and indigenous forest over the past few decades. The lake itself lies within a perched sub-catchment, and probably receives only part of the catchment flow. Two small streams enter from the south.

The pastoral farming community surrounding Rerewhakaaitu has taken action to reduce nutrients in the Rerewhakaaitu Lake Catchment. Initiated by a sustainable farming fund, farming advisors and other experts have aided this voluntary cooperative strategy to work towards a variety of mitigations in the interests of sustainable and economically profitable pastoral farming.

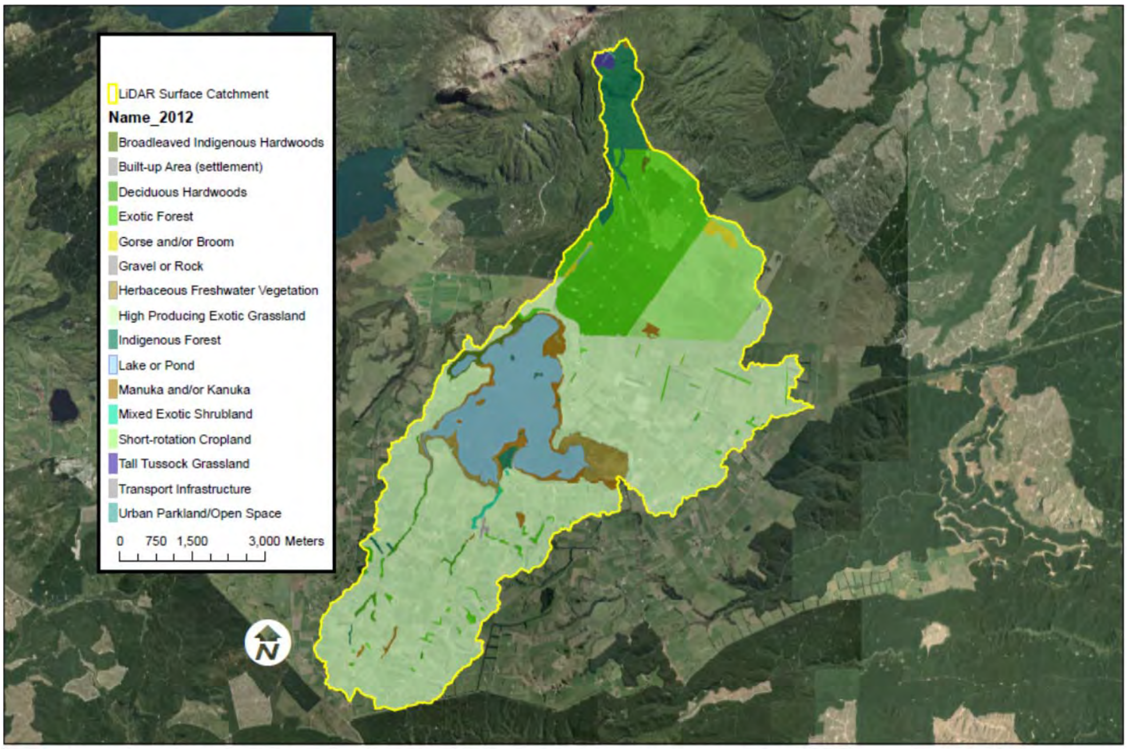


Figure 7.1 Lake Rerewhakaaitu Catchment landuse (based on LCDB 2012).

Lake Rerewhakaaitu is a polymictic lake that intermittently stratifies in summer. This pattern of changing temperature and dissolved oxygen can be observed in Figure 7.4.

7.2 Results

Its water quality is classed as mesotrophic. The 2014/15 TLI is 3.3, so the lake has achieved the water quality target set in the RWLP (of TLI 3.6). The TLI increased during the period 2007 to 2010 and has since decreased. A similar pattern was observed for dissolved nitrogen (Table 7.1, Figure 7.2, Figure 7.3).

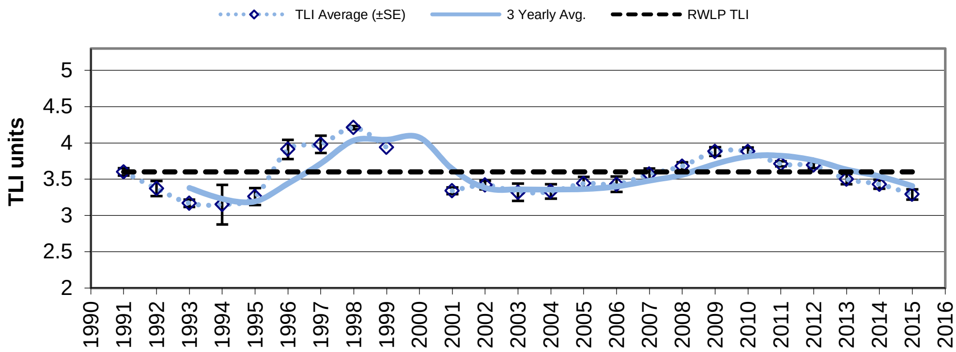


Figure 7.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rerewhakaaitu.

Phytoplankton growth in Lake Rerewhakaaitu is likely to be more strongly phosphorus limited. It has consistently high ratios of TN:TP and DIN:TP. This is likely to be caused by iron-rich volcanic sediments binding the phosphorous in the water column. The bottom waters of Rerewhakaaitu are thought to be reasonably well oxygenated and seldom hypoxic. However, continuous monitoring of bottom water dissolved oxygen will test this assumption, as anoxic conditions could cause the release of iron-bound phosphorus.

Water clarity and nitrogen levels continue to be the main driver for an improving trophic state. Phosphorus levels remain relatively stable and although stratification was observed in October 2014 and January 2015, oxygen levels remained high in bottom waters (Figure 7.4).

Table 7.1 Average water quality and trends in top and bottom waters of Lake Rerewhakaaitu. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

	Top Average	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
Variable	**2011-14**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**
TLI *	3.4	↑	0.5%			↓	-3.5%		
Chl-*a* (mg/m³)	3.7	↑	2.1%			↓	-15.5%		
Secchi (m)	5.7	↘	-1.4%			↑	15.5%		
TN * (mg/m³)	404	↑	1.0%			↓	-4.3%	↓	-4.9%
TP * (mg/m³)	8.1					↓	-10.0%	↓	-7.4%
%DO	85.5	↓	-1.5%	↓	-1.7%				
DO min (g/m³)	7.6			↓	-2.3%				
DIN (mg/m³)	14.0					↓	-15.0%	↓	-12.5%
NH_4-N (mg/m³)	7.4					↓	-23.5%	↓	-23.6%
DRP (mg/m³)	2.6								
EC (uS/cm)	53	↑	1.0%			↑	1.0%	↑	1.3%
pH	7.4								
Temperature	14.7								
VLEC	0.4	↑	2.6%			↓	-6.4%		
Turbidity (NTU)	1.05	↑	1.7%			↓	-8.0%		

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

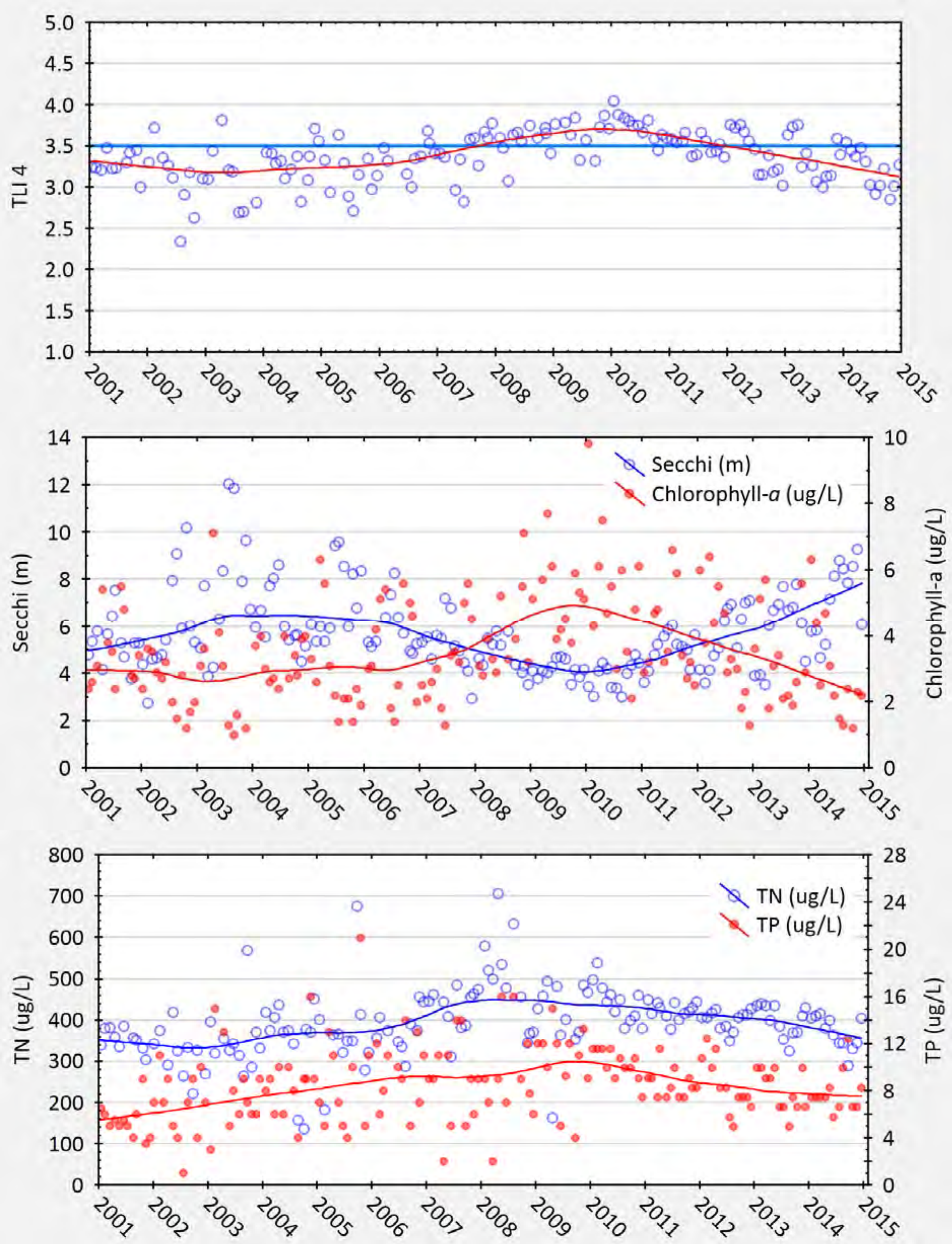


Figure 7.3 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Rerewhakaaitu since 2001. The TLI target of 3.6 is indicated by the blue line in the top graph.

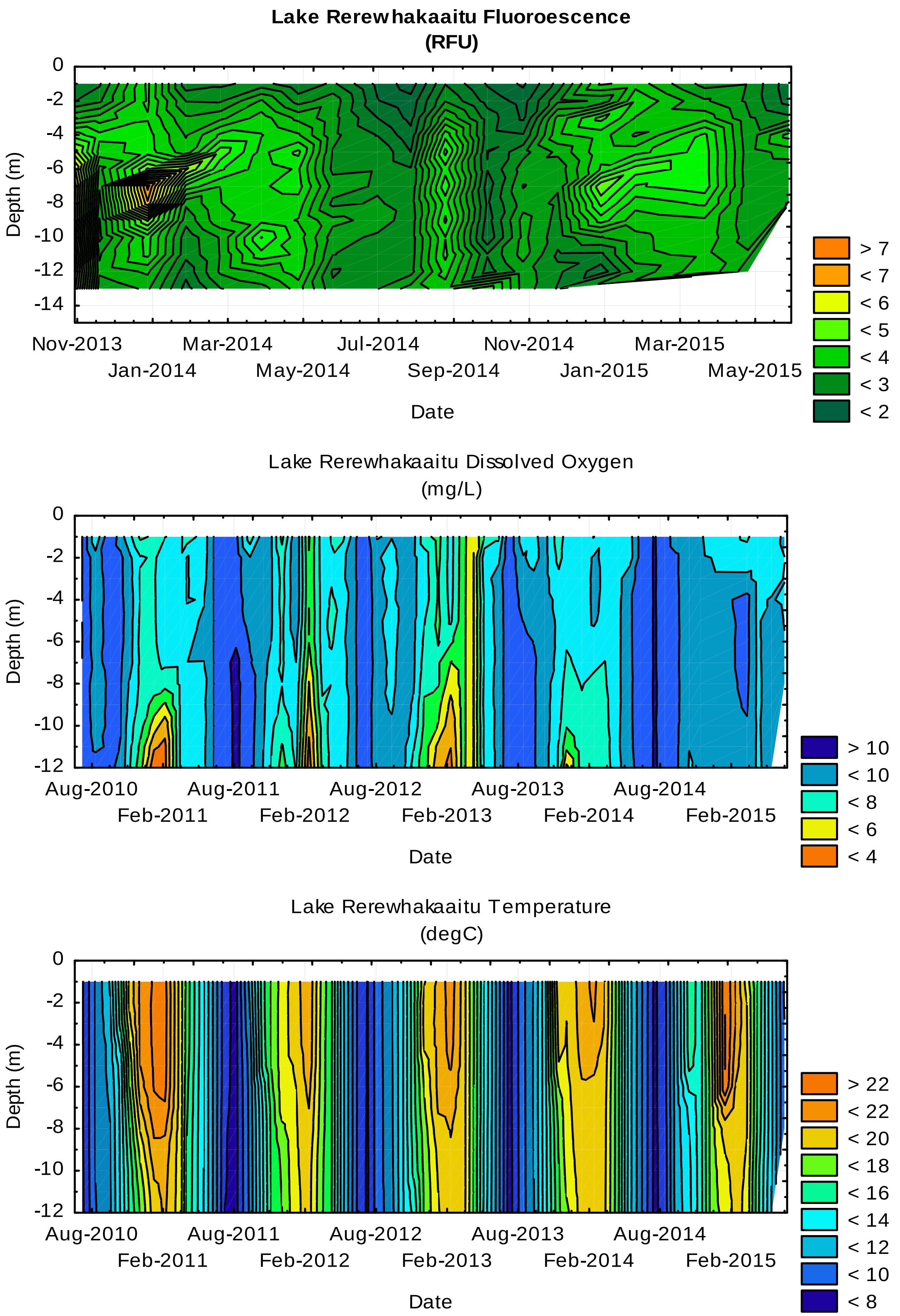


Figure 7.4 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom).

7.3 LakeSPI results

Lake Condition: Moderate   Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rerewhakaaitu	40	53	72

After a period of instability following invasion by *Lagarosiphon* and *Egeria*, Lake Rerewhakaaitu appears to have stabilised, remaining in the moderate LakeSPI category. *Egeria densa* is now the most dominant invasive species after it was first observed in 2000. However, native charophyte meadows are present at all LakeSPI transects and were present to a maximum depth of 7 m.

Part 8: Lake Rotoehu

8.1 Introduction

Lake Rotoehu is a 795 ha lake formed along with Lake Rotomā by the Rotomā eruption approximately 8,500 years ago. The lake has no surface outlet. Water exits the lake through a sinkhole in one of the northern lake arms and there may be other sub-surface outlets. The lake receives input via the Waitangi Soda Spring, which is a natural geothermal pool used for bathing. The pumice soils around Lake Rotoehu produce small, clear streams that emerge as springs. The springs, including the Waitangi Spring, tend to be high in phosphorus dissolved from underlying volcanic geology and geothermal activity.

The lake is relatively shallow (maximum depth of 13.5 m). The topographical catchment area is 36.7 km^2, including the lake area of 7.9 km^2. The landuse is about equal proportions of native bush, plantation forest and pasture. There is a small amount of wetland on the southern banks, and residential properties surrounding the lake have not yet had septic systems reticulated. The pastoral landuse is mostly sheep and beef livestock farming with a dairy farm on flat land to the southeast of the lake.

Management interventions undertaken within the catchment to help improve lake water quality include harvesting of aquatic weeds from the southern end of the lake since 2008, conversion of pastoral land to forestry, alum dosing to remove phosphorus from the Soda Springs geothermal inflow since 2011, in-lake aeration during summer for a period since 2011, and deployment of a floating wetland in the south of the lake.

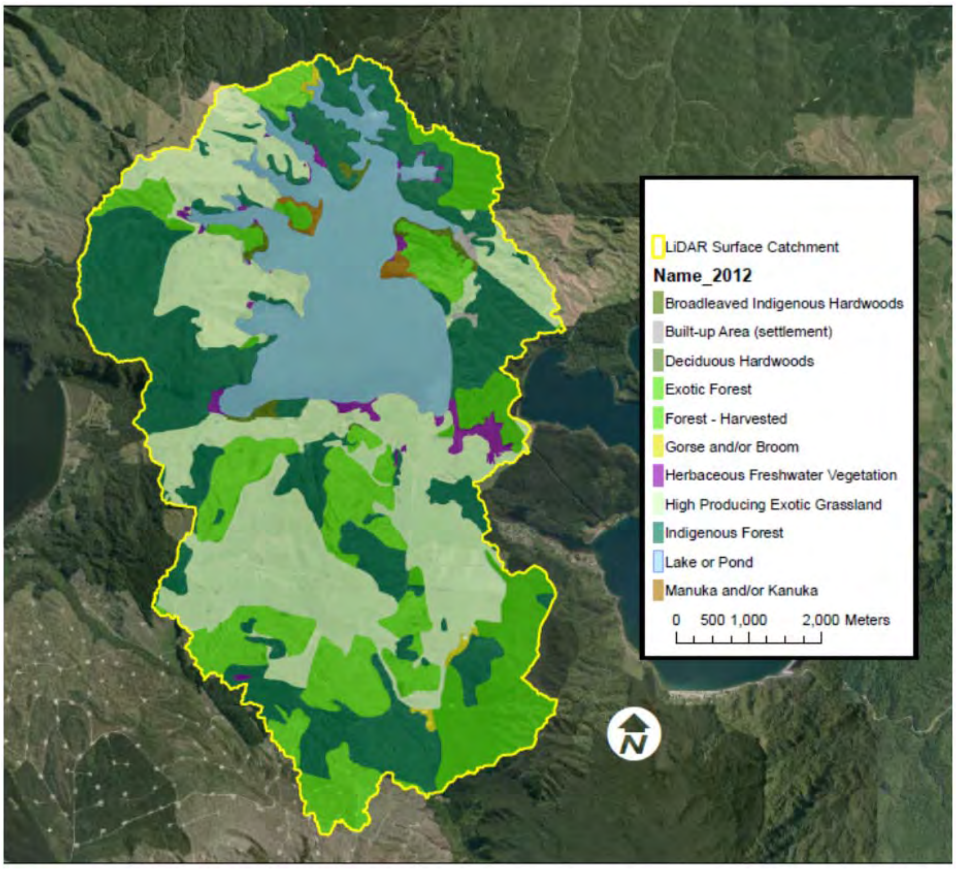


Figure 8.1 Lake Rotoehu Catchment landuse (based on LCDB 2012).

8.2 Results

Lake Rotoehu is now classified as mesotrophic. The TLI is currently 4.5, a sudden jump above the annual TLI results of the previous two years (Figure 8.2). Rotoehu's water quality declined, possibly due to the sustained settled weather which produced a period of prolonged stratification. Dissolved oxygen levels were depleted at the bottom of the lake due to this one-month stratification event, giving rise to increased concentrations of phosphorus and dissolved inorganic nitrogen.

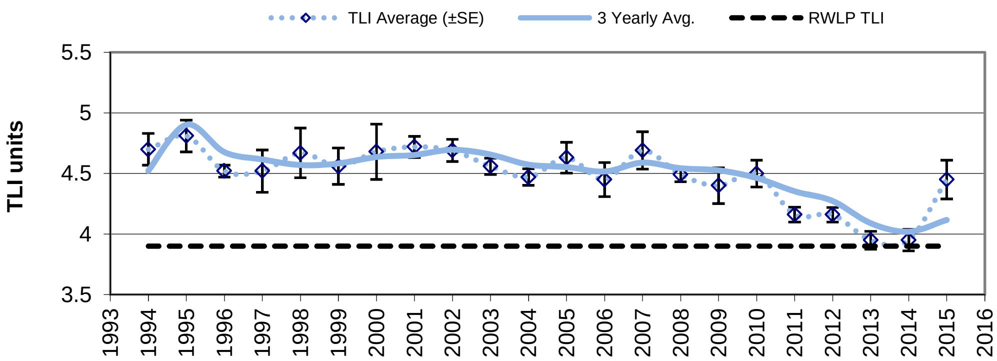


Figure 8.2 Annual average TLI results with standard error bars, three yearly average TLI results and RWLP TLI objective for Lake Rotoehu.

Cyanobacterial concentrations also rose during and after the stratification event, reaching red alert levels in early February. Further anoxia occurred in March, and was associated with increases in phosphate and ammonium, with cyanobacteria remaining at orange alert levels until early April 2015 (Figure 8.3). Increase of chlorophyll-*a* through the water column in the last summer can be observed through the increase in fluorescence as displayed in Figure 8.4.

Phytoplankton community structure in the lake is similar to that observed in other eutrophic lakes. Community composition is dominated by chlorophytes (green algae) and cyanobacteria (blue-green algae) during warmer periods and diatoms dominated when water temperatures were cooler (<15°C). Cyanobacteria drive changes in community abundance, which is dependent on lake stability (McBride et al; 2015).

The increase in the TLI from 3.95 in 2013/14 to 4.45 in 2014/15 may be due to increased internal nutrient release and subsequent increases in algal productivity. The three-year average TLI was 4.12, a little above the RWLP target of 3.9.

Lake Rotoehu's water quality had considerably improved since 2010. There have been significant reductions in TLI, chlorophyll-*a*, TN and TP and an improvement in water clarity (e.g. Secchi depth). Dissolved nitrogen (nitrate and ammoniacal nitrogen) have also significantly reduced since 2002 (see Table 8.1 and Figure 8.4).

Nitrogen and phosphorus are both potentially limiting to phytoplankton growth, with the relative importance changing seasonally. The ratio of DIN:TP indicates possible nitrogen limitation during summer (Table 3.1).

The lake stratified in January 2011 and the bottom waters became anoxic (Figure 8.5). A brief period of stratification and bottom water anoxia also occurred in January 2015 but this is not reflected in Figure 8.5 due to its short duration.

Table 8.1 Average water quality and trends in top and bottom waters of Lake Rotoehu. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014 Top direction	Trend 2002 to 2014 Top PAC	Trend 2002 to 2014 Bottom direction	Trend 2002 to 2014 Bottom PAC	Trend 2010 to 2014 Top direction	Trend 2010 to 2014 Top PAC	Trend 2010 to 2014 Bottom direction	Trend 2010 to 2014 Bottom PAC
TLI *	3.9	↓	-1.1%			↓	-2.9%		
Chl-*a* (mg/m^3)	5.8	↓	-6.2%			↓	-12.7%		
Secchi (m)	3.5	↑	3.3%			↑	6.7%		
TN * (mg/m^3)	290	↓	-3.7%	↓	-3.6%	↓	-6.3%	↓	-8.2%
TP * (mg/m^3)	23.1	↓	-2.4%	↓	-4.0%	↓	-8.2%	↓	-11.2%
%DO	87.8	↓	-1.6%			↓	-2.2%		
DO min (g/m^3)	7.8			↓	-1.4%				
DIN (mg/m^3)	12.8	↓	-15.7%	↓	-13.3%	↘	-9.8%		
NH_4-N (mg/m^3)	6.6	↓	-18.8%	↓	-10.5%			↘	-23.3%
DRP (mg/m^3)	7.5					↓	-19.0%	↓	-18.6%
EC (uS/cm)	379	↓	-0.6%	↓	-0.7%				
pH	7.8								
Temperature	15.7								
VLEC	0.6	↓	-4.2%						
Turbidity (NTU)	2.07	↓	-3.8%			↓	-11.0%		

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

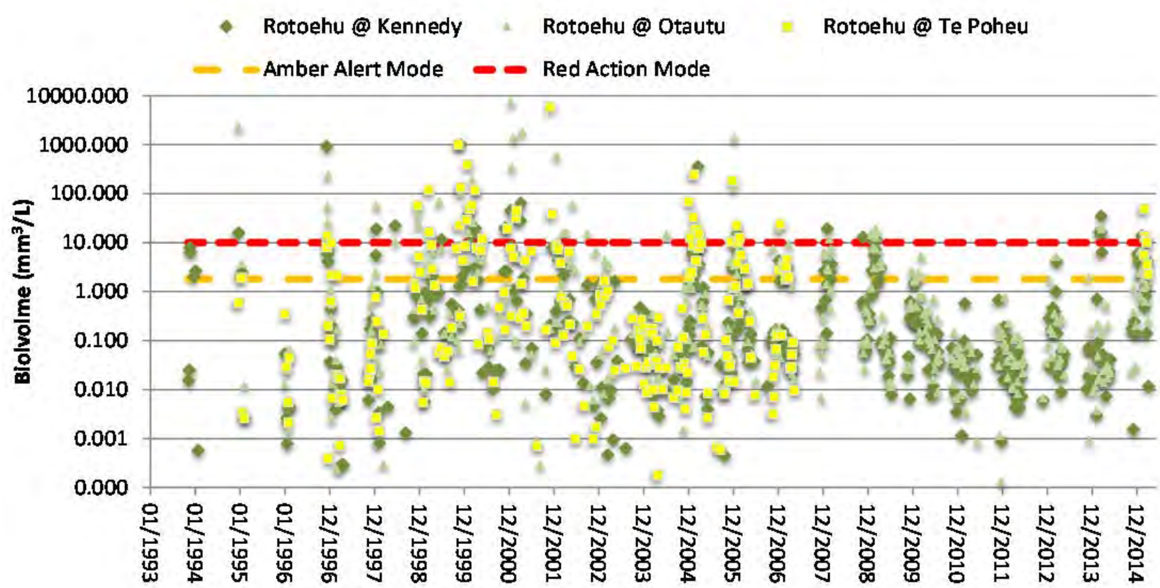


Figure 8.3 Total cyanobacteria biovolume, Lake Rotoehu.

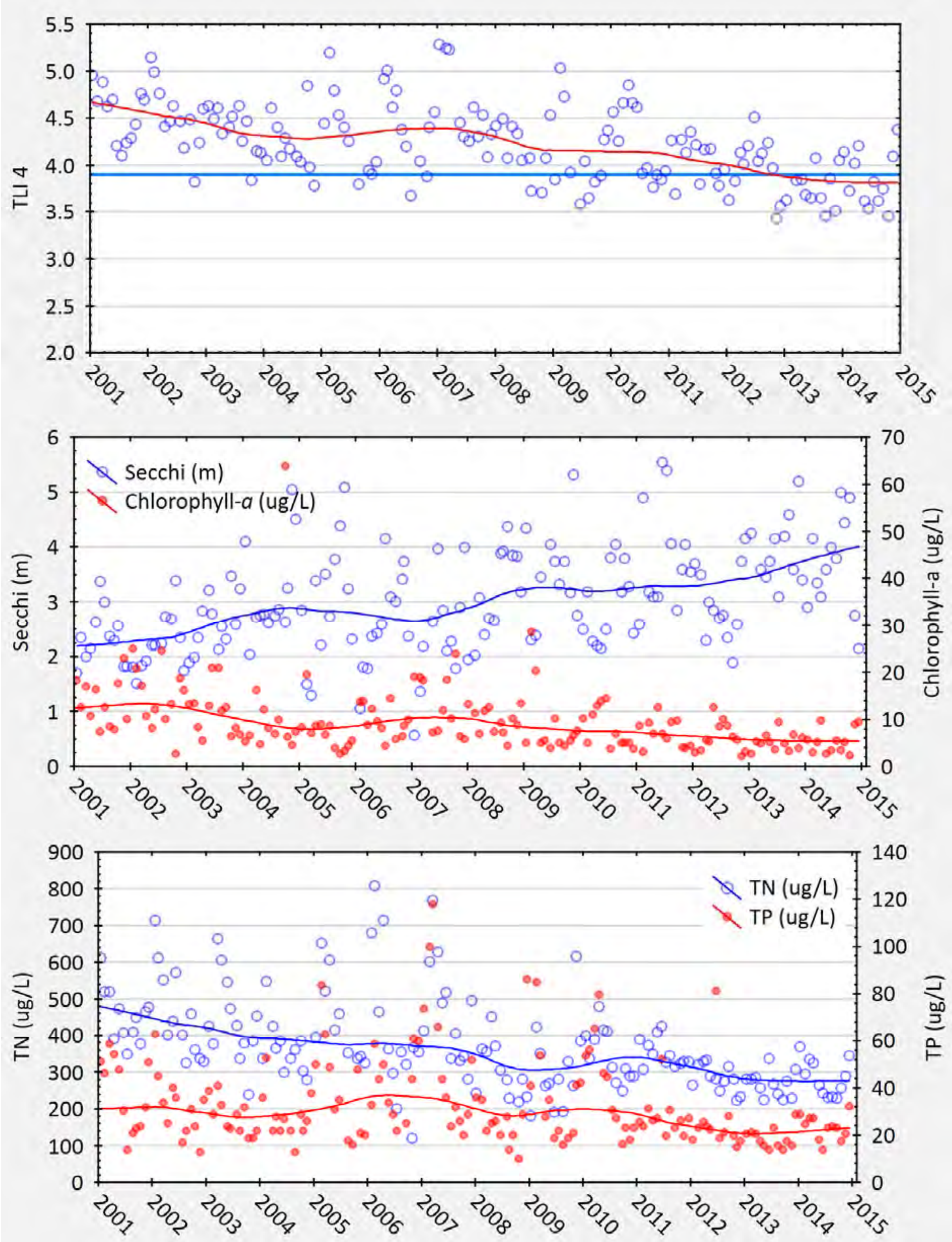


Figure 8.4 *Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Rotoehu since 2001. The TLI target of 3.9 is indicated by the blue line in the top graph.*

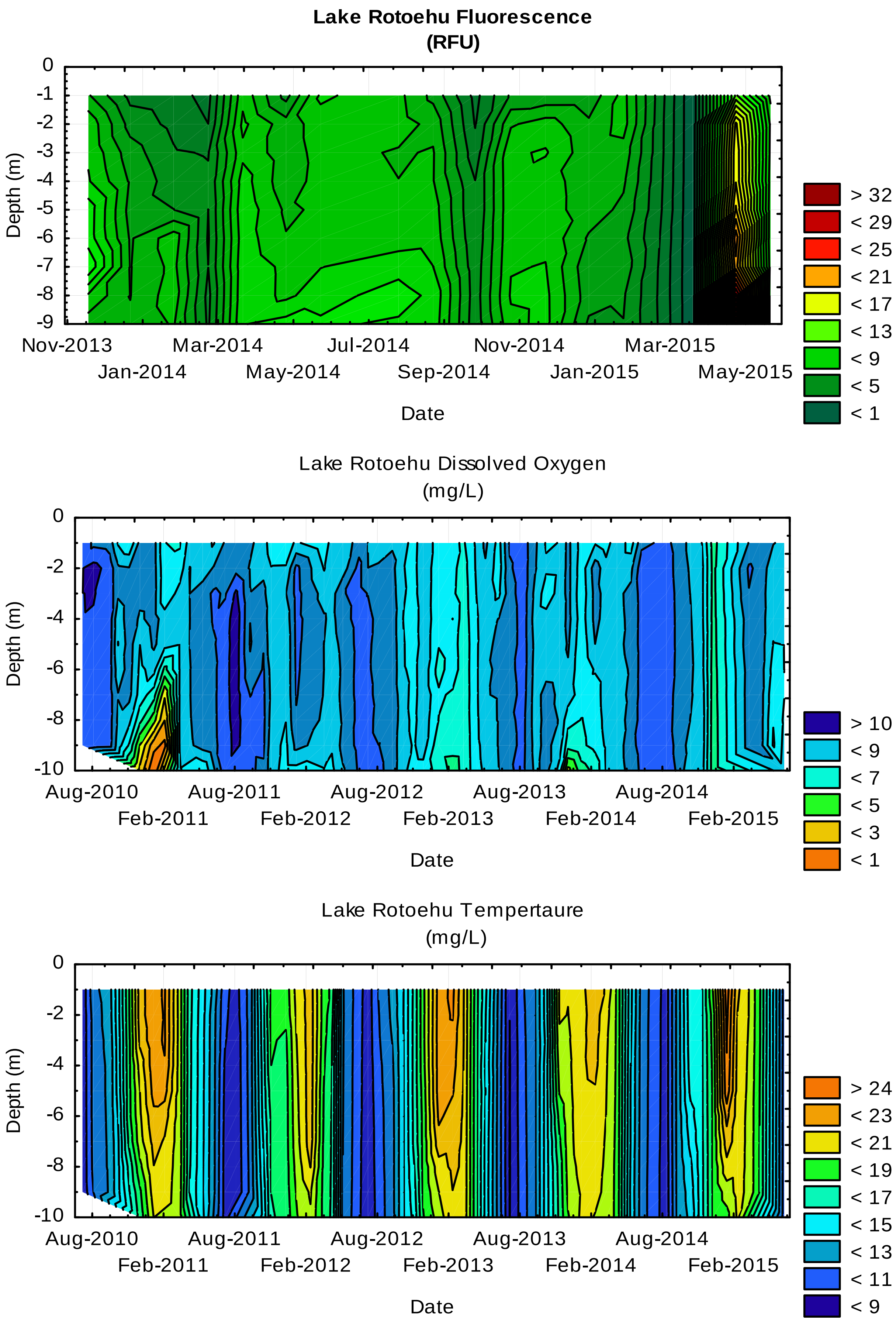


Figure 8.5 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom).

8.3 LakeSPI results

Lake Condition: Poor Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotoehu	18	25	92

The poor ecological condition of Lake Rotoehu which gives the lowest LakeSPI score of the Rotorua Te Arawa lakes is largely due to the infestation of hornwort which thrives in the shallow lake. Hornwort was discovered in 2004 and by 2008 it had reached 'habitat saturation'. The lake has commonly suffered from frequent cyanobacterial blooms (blue-green algae) due to its eutrophic state. Uptake of nutrients by hornwort and subsequent harvesting of hornwort does provide a nutrient removal mechanism for the lake which contributes a large portion towards the annual nutrient removal target for the lake.

Photo: Hornwort being harvested in the southern part of Lake Rotoehu (Richard Mallinson).

Part 9: Lake Rotoiti

9.1 Introduction

Lake Rotoiti is the third largest of the Rotorua Lakes occupying part of the Haroharo Caldera, and is of high recreational and aesthetic value. The lake receives most of its input via the Ōhau Channel that drains Lake Rotorua into the western basin. The Ōhau Channel diversion wall was completed in July 2008 to divert water from Lake Rotorua directly to the Kaituna River outlet instead of mixing with Lake Rotoiti. Several small streams discharge into the lake, and numerous geothermal inputs (the largest being the Tikitere geothermal field).

Lake Rotoiti is a deep lake, which deepens from west to east, changing from an average of 10 m to a maximum depth of 125 m northeast of Gisborne Point. The lake has a surface topological catchment of 124.8 km^2, including the lake area of 34.0 km^2. The catchment is predominantly covered in indigenous vegetation and exotic forestry, with considerable conversion of pasture to forestry over the past 30 years.

There are three monitoring locations, one in the deep eastern basin (Site 4), one in the narrows between the two western basins (Site 3), and one in Okawa Bay.

In the early 2000s, Rotoiti had severe blooms of cyanobacteria, which prompted the construction of a diversion wall and reticulation of lakeside communities (Okawa Bay), with many households scheduled from reticulation in the coming years. The diversion wall has reduced the nutrient load by 150 t N y^{-1} and 20 t P y^{-1}, and significantly increased the residence time from an estimated 1.5 y to 6.5 y.

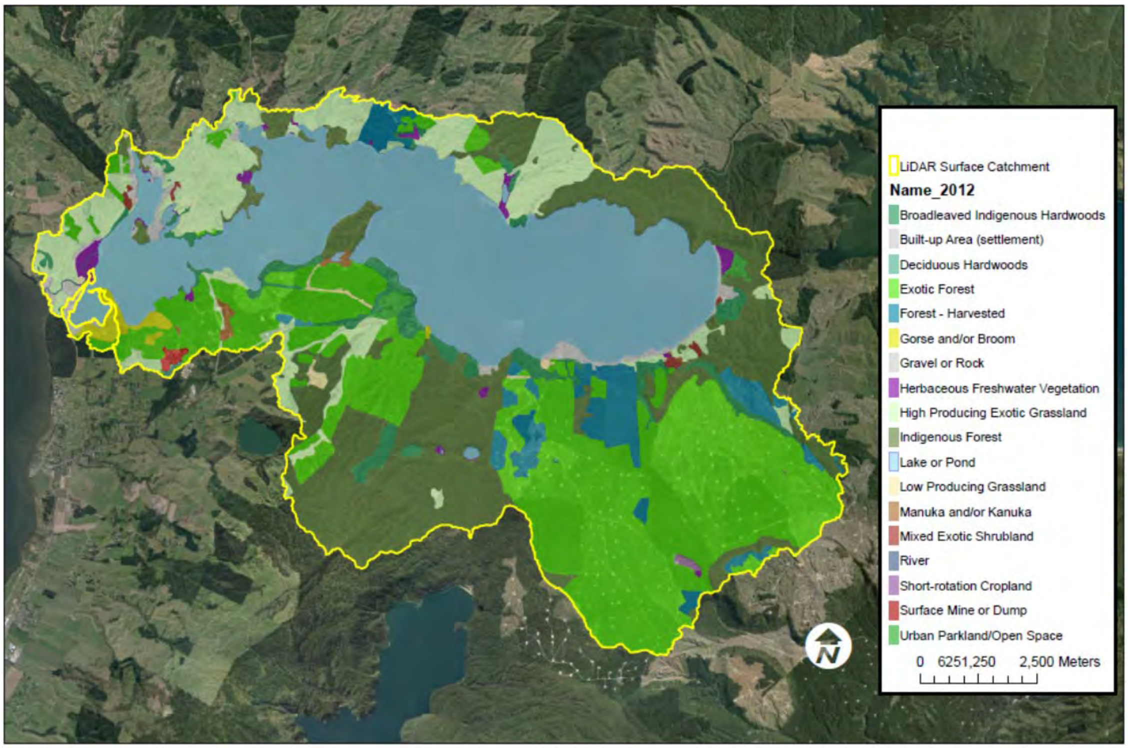


Figure 9.1 Lake Rotoiti Catchment landuse (based on LCDB 2012).

9.2 Results

The main body of Lake Rotoiti is classified as mesotrophic but Okawa Bay is eutrophic. Lake Rotoiti's annual average TLI increased to 3.81 TLI units, which was higher than the previous three years. The three year average TLI of 3.55 is currently above the RWLP objective TLI of 3.5.

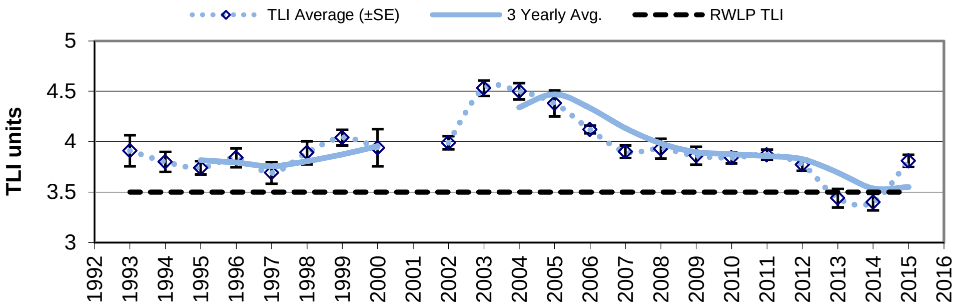


Figure 9.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotoiti.

The bottom waters of the lake become anoxic following a period of stratification in late summer (Figure 9.6, 9.7). This results in the release of phosphorus and nitrogen from the sediments. When the lake mixes in early winter, the nutrient rich bottom waters mix with surface waters and support elevated phytoplankton biomass during winter.

Annual average nitrogen and phosphorus concentrations were higher than the previous three years. Of note in 2014/15 is the increased DRP concentrations in both the epilimnion and hypolimnion following winter turnover and during stratification. Chlorophyll-*a* concentrations were also elevated; however water clarity was only marginally affected. Cyanobacterial concentrations were also higher in some areas of the lake in 2014/15 summer than they have been for a few years, reaching orange alert levels at times over the late summer early autumn (Figure 9.8).

Lake Rotoiti water quality has considerably improved since 2002, although this follows a period of serious decline. In the main basins there has been a significant improvement in the TLI, reduced nutrient concentrations and improved water clarity over the long term (since 2002) and this improvement has continued in recent years (since 2010) (Table 9.1, Table 9.2 and Figure 9.4). In Okawa Bay, there were considerable water quality improvements between 2002 and 2009, but water quality has not significantly improved since this time (Table 9.2 and Figure 9.5). This may in part be due to the management regime of the invasive aquatic weeds. Herbicide application undertaken in late spring causes the slow realise of nutrients from the aquatic weeds during die-off which adds to the nutrient loading. Management of aquatic weeds in this location has been reviewed.

Dissolved oxygen depletion over stratification has reduced since the installation of the Ōhau Channel wall. Figure 9.3 displays hypolimnetic volumetric oxygen demand rates since 2004 and shows a significant improvement in the last decade. This is in line with improving trend in water clarity throughout the lake (Tables 9.1- 9.3, Figure 9.4).

Nitrogen and phosphorus are both potentially limiting to phytoplankton growth, with the relative importance changing seasonally. The ratio of DIN:TP indicates possible nitrogen limitation during summer (Table 3.1).

Table 9.1 Average water quality and trends in top and bottom waters of Lake Rotoiti. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Lake Rotoiti Site 4 (eastern basin)

Variable	Average Top	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
		direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI4 *	3.4	↓	-1.4%			↓	-2.0%		
Chl-a (mg/m^3)	4.7	↓	-4.3%						
Secchi (m)	6.9	↑	3.5%			↑	6.0%		
TN * (mg/m^3)	206	↓	-2.7%	↓	-4.0%	↓	-3.8%	↓	-6.5%
TP * (mg/m^3)	13.9	↓	-5.2%	↓	-7.9%	↓	-9.4%	↓	-10.6%
%DO	86.8	↓	-1.2%			↓	-2.6%		
DO min (g/m^3)	4.8								
DIN (mg/m^3)	8.6	↓	-13.8%	↓	-6.8%			↘	-5.7%
NH4-N (mg/m^3)	6.2	↓	-15.0%	↓	-5.8%	↘	-19.8%		
DRP (mg/m^3)	6.3			↓	-7.3%	↓	-11.2%	↓	-11.4%
EC (uS/cm)	126	↓	-1.6%	↓	-1.7%	↓	-2.2%	↓	-2.2%
pH	7.2					↑	0.7%	↑	0.8%
Temperature	15.7								
VLEC	0.3	↓	-1.8%			↓	-2.6%		
Turbidity (NTU)	0.81	↓	-3.9%						

Lake Rotoiti Site 3 (the narrows)

Variable	Top Average 2011-14	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
		direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	3.5	↓	-1.5%			↓	-2.0%		
Chl-*a* (mg/m^3)	5.2	↓	-6.2%						
Secchi (m)	5.7	↑	3.5%			↑	7.1%		
TN * (mg/m^3)	222	↓	-4.1%	↓	-5.3%	↓	-5.4%	↓	-8.1%
TP * (mg/m^3)	13.7	↓	-5.7%	↓	-9.2%	↓	-11.0%	↓	-21.8%
%DO	87.1	↓	-1.0%			↘	-2.2%		
DO min (g/m^3)	5.8								
DIN (mg/m^3)	11.2	↓	-20.0%	↓	-13.2%			↓	-19.4%
NH_4-N (mg/m^3)	7.9	↓	-20.1%	↓	-12.9%				
DRP (mg/m^3)	4.3	↓	-4.2%	↓	-9.5%			↓	-34.1%
EC (uS/cm)	128	↓	-1.7%	↓	-1.9%	↓	-2.8%	↓	-2.2%
pH	7.2					↑	0.7%		
Temperature	15.9								
VLEC	0.4	↓	-3.2%			↓	-5.0%		
Turbidity (NTU)	0.95	↓	-5.6%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

Table 9.2 Average water quality and trends in top and bottom waters of Lake Rotoiti (Okawa Bay). Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
		direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	4.1	↓	-1.9%						
Chl-*a* (mg/m^3)	7.2	↓	-10.2%						
Secchi (m)	3.0	↑	4.8%						
TN * (mg/m^3)	335	↓	-2.7%	↓	-4.4%				
TP * (mg/m^3)	24.5	↓	-4.3%	↓	-4.6%				
%DO	85.9	↓	-2.3%	↓	-1.6%				
DO min (g/m^3)	8.2			↓	-2.0%			↑	3.7%
DIN (mg/m^3)	10.8			↓	-7.7%				
NH_4-N (mg/m^3)	5.9			↓	-6.4%				
DRP (mg/m^3)	5.8	↑	3.3%	↗	2.0%	↘	-12.5%		
EC (uS/cm)	124	↓	-2.1%	↓	-1.9%	↓	-1.2%	0.051	-1.3%
pH	7.4					↑	0.8%	↑	1.4%
Temperature	15.8								
VLEC	0.8	↓	-3.8%						
Turbidity (NTU)	1.86	↓	-8.0%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

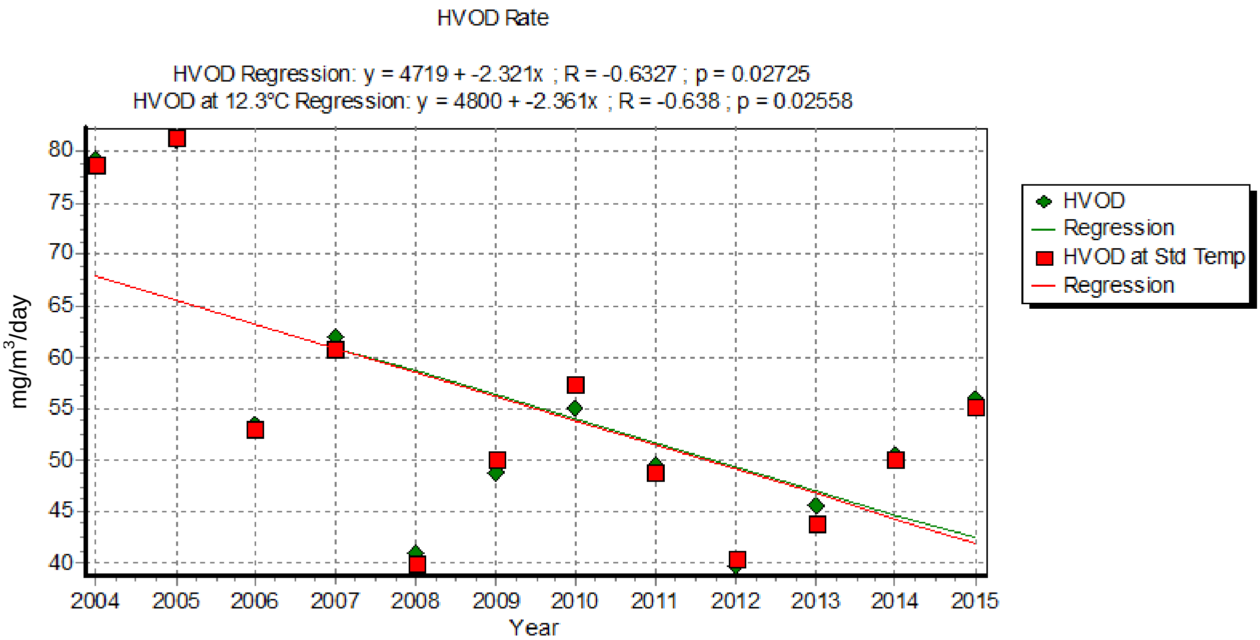


Figure 9.3 Hypolimnetic Volumetric Oxygen Depletion rates and HVOD rates adjusted to standard temperature, 2004 to 2015.

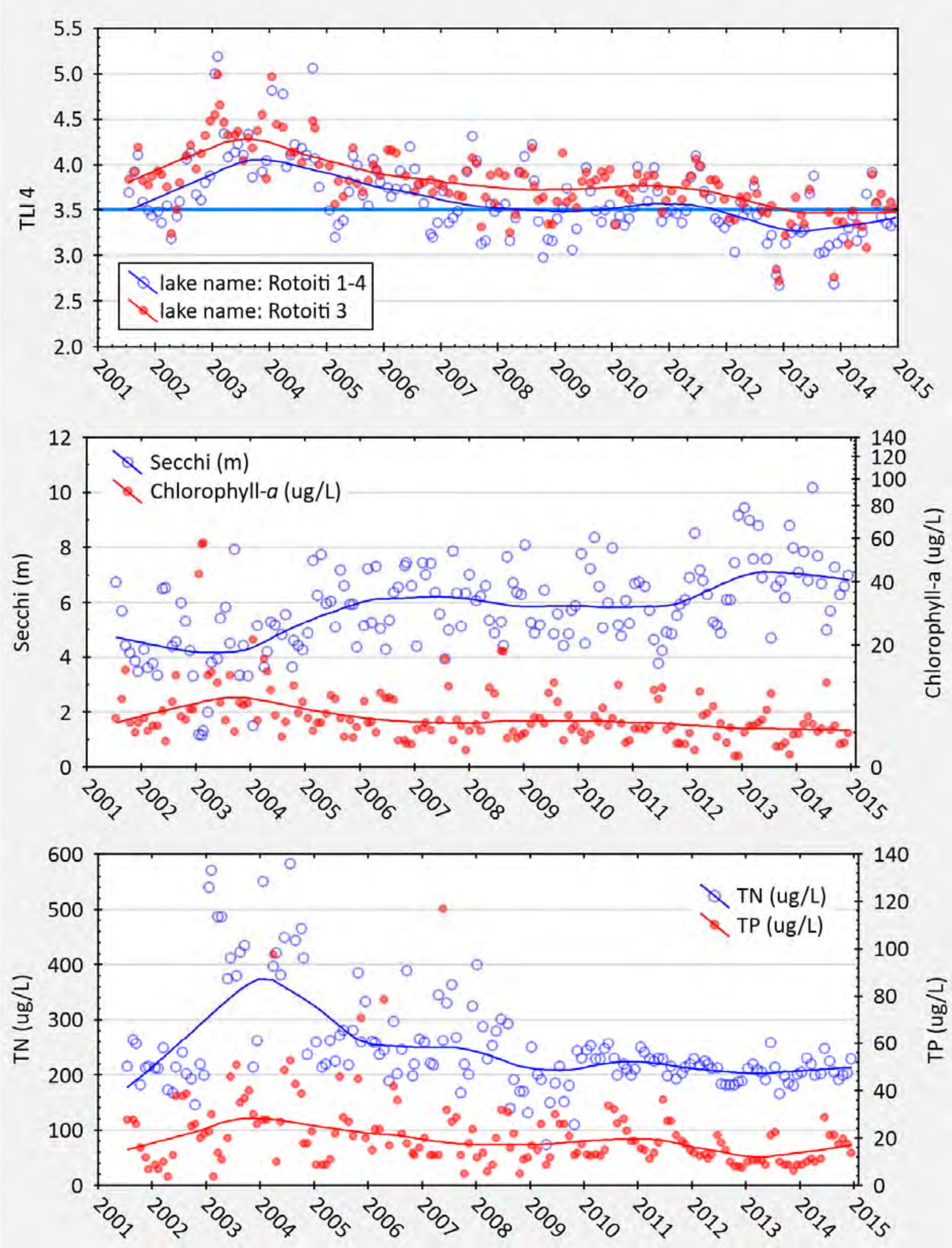


Figure 9.4 *Changes in the TLI (Rotoiti Site 4 and Site 3) and its components (Secchi depth, chlorophyll-a, TN and TP) since 2001 at Rotoiti 4 (eastern basin). The TLI target of 3.5 is indicated by the blue line in the top graph.*

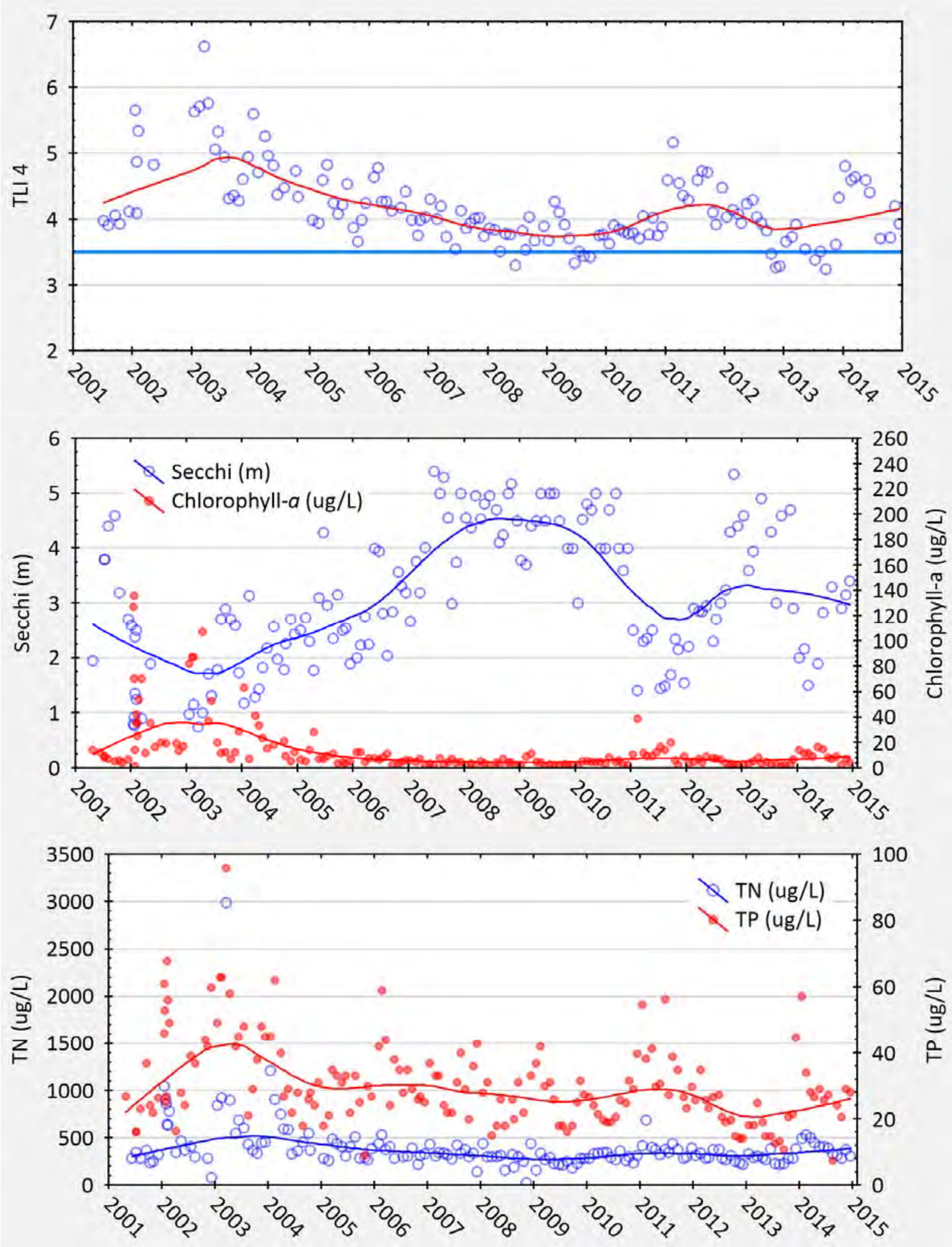


Figure 9.5 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) since 2001 in Lake Rotoiti (Okawa Bay). The TLI target of 3.5 is indicated by the blue line in the top graph.

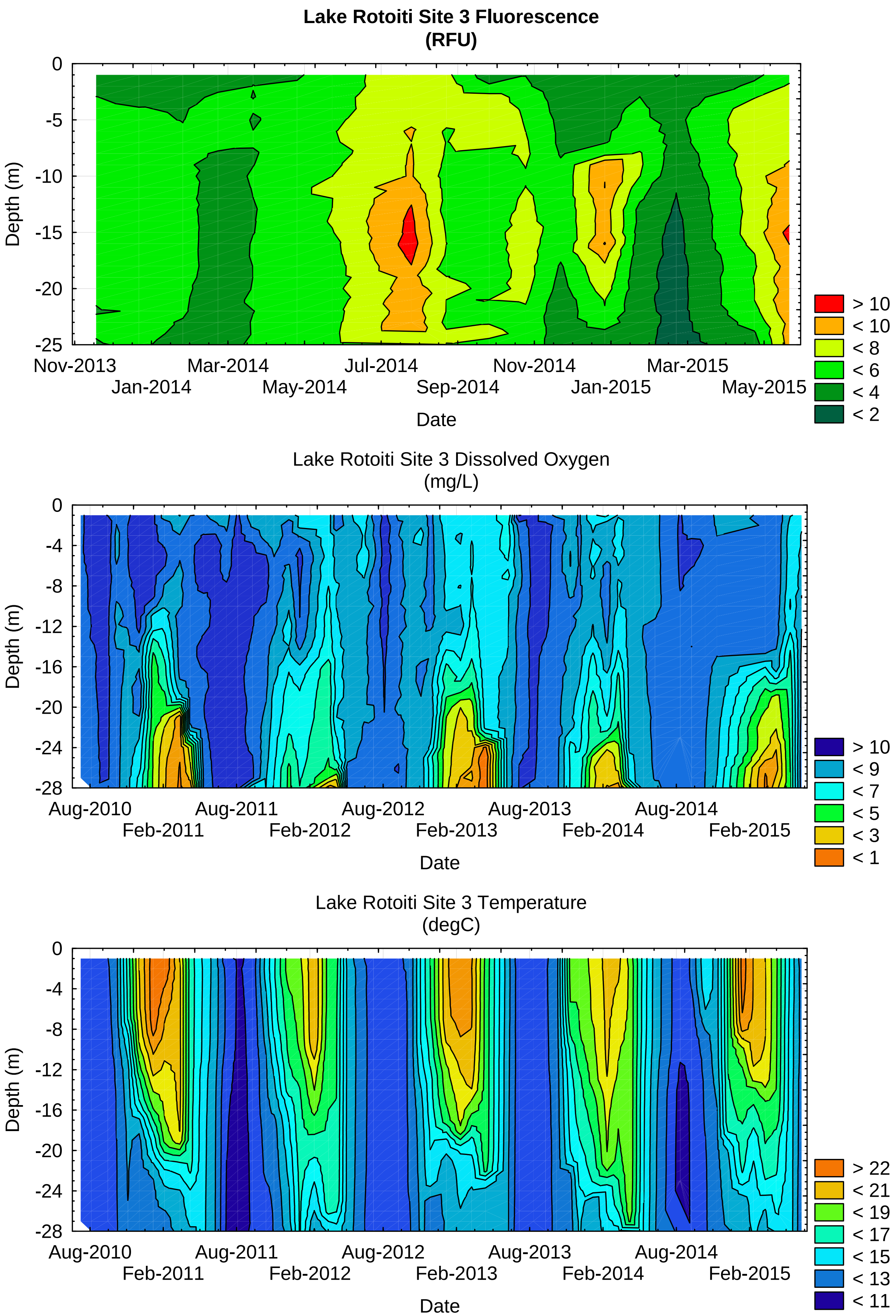


Figure 9.6 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom), Lake Rotoiti Site 3 (the narrows).

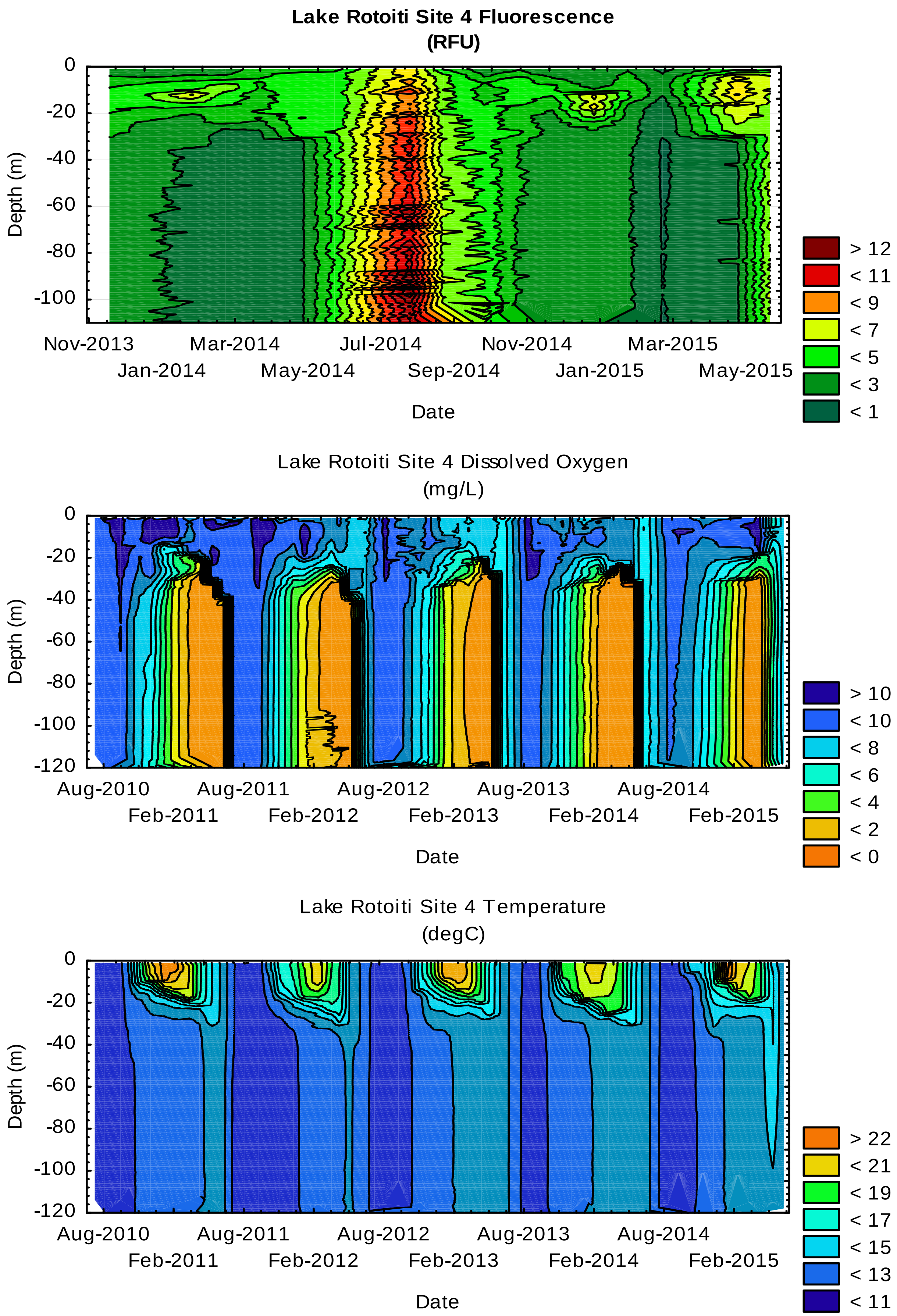


Figure 9.7 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom), Lake Rotoiti Site 4 (eastern basin).

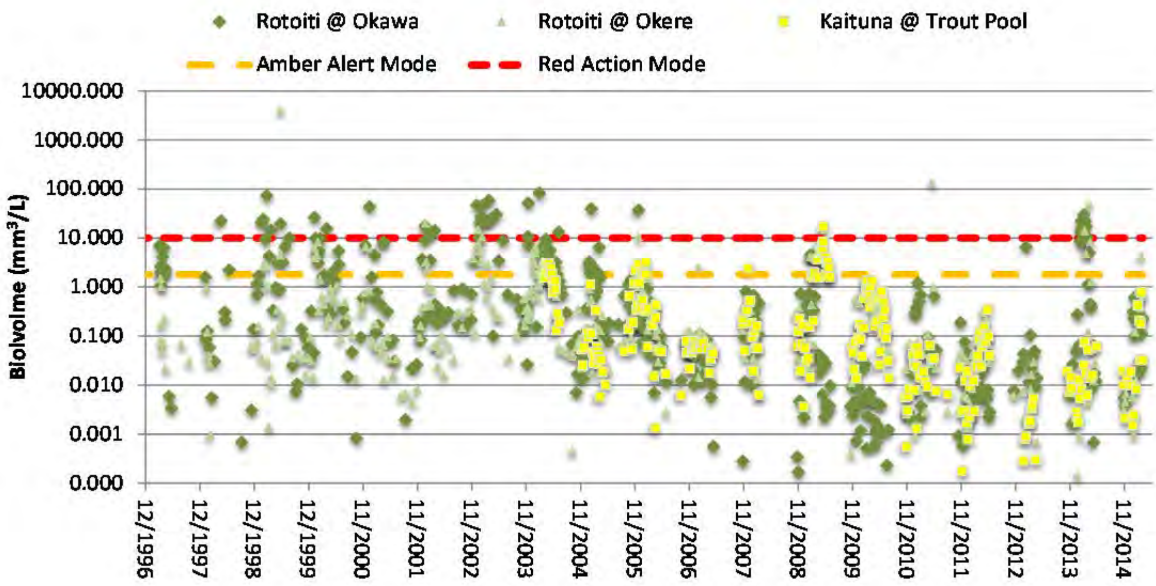


Figure 9.8 Total cyanobacteria biovolume, Lake Rotoiti, including Trout Pool, Kaituna River.

9.3 LakeSPI results

Lake Condition: Moderate Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotoiti	20	25	92

Lake Rotoiti maintains a moderate ecological rating for LakeSPI even though it consistently has one of the worst Invasive Impact Index scores. There has been a progressive decline in submerged vegetation in several arms of Lake Rotoiti, predominantly in the western end of the lake, such as Okawa Bay, Wairau Bay and Te Weta Bay.

The Native Condition Index has shown some improvement with development of some deeper charophyte meadows. This may in part be due to water clarity gains being made through diversion of Lake Rotorua water down the Kaituna River, by the Ōhau Channel diversion wall.

Photo: Beached hornwort, Okawa Bay, 2001.

Part 10: Lake Rotokakahi

10.1 Introduction

Lake Rotokakahi or Green Lake is one of the four small lakes located between Lake Rotorua and Lake Tarawera. The lake is fed by small steams and groundwater, with the outlet at the north eastern end forming the Te Wairoa Stream, which flows into Lake Tarawera. Rotokakahi was previously monitored up to 1996, but since 1999, most monitoring has been undertaken at the lake outlet. The lake is privately owned under the authority of Te Arawa iwi, Tuhourangi, and remains relatively undisturbed as a result.

Lake Rotokakahi is of moderate size and depth, with a lake surface area of 4.4 km^2 and a maximum depth of 32 m. It has a surface topological catchment of area of 19.7 km^2, including the lake area. Landuse within the catchment is a mix of indigenous forest, exotic forestry and dry stock pastoral land. The lake is of moderate productivity and its water quality is classed as mesotrophic. Rotokakahi had average surface water concentrations of 235 mg TN m^{-3} and 55 mg TP m^{-3} for the period 2009-2014, although the water quality is known to be highly variable. The TN:TP ratio is 4.3:1, which is the lowest of all Bay of Plenty lakes and indicates that algal growth in Rotokakahi is N-limited. In order to improve lake water quality, the focus will be towards management of catchment sources of phosphorus.

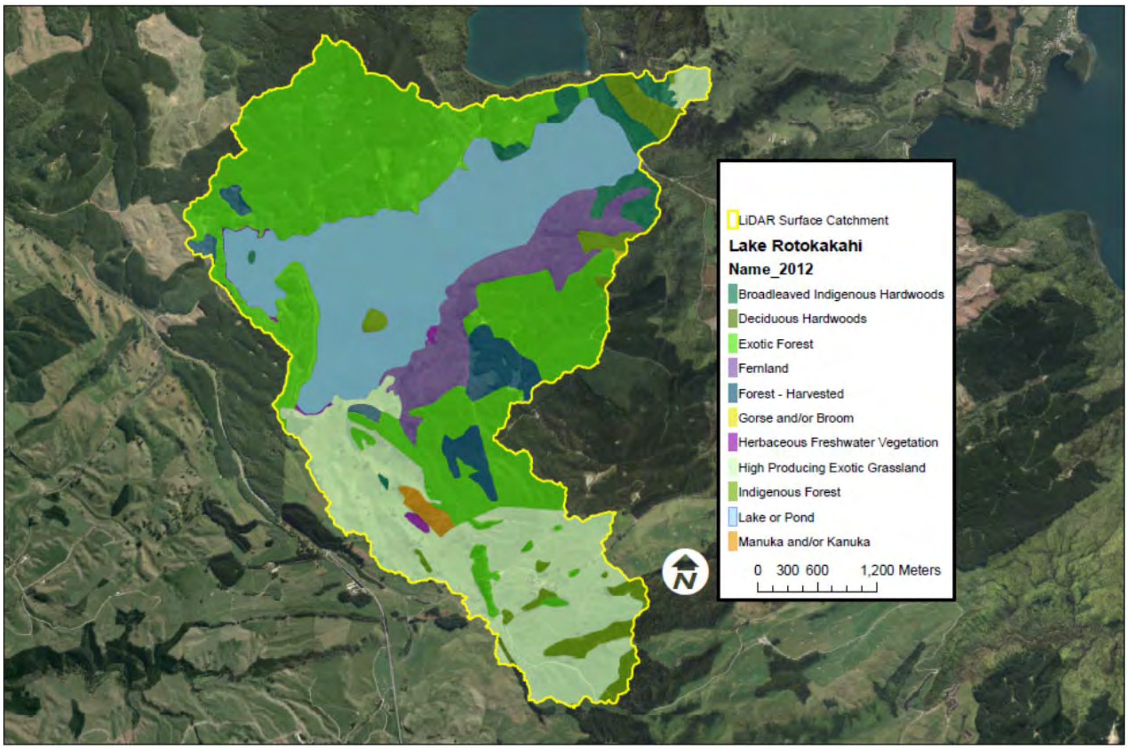


Figure 10.1 Lake Rotokakhi Catchment landuse (based on LCDB 2012).

10.2 Results

Lake Rotokakahi is mesotrophic and has a 2014/15 TLI of 4.0 (Figure 10.2). The TLI is above the water quality target of 3.7 set in the RWLP. Lake Rotokakahi (as measured at the outflow, Te Wairoa Stream) showed a decline in trophic status compared to the previous four years. The TLI increased over the 2002 to about 2009/10 period followed by a decrease (improvement) from 2009/10 to 2011/12. Overall there has been a deterioration in water quality since 2002 (i.e. higher concentrations of TN and TP), with algal blooms occurring in 2010 resulting in an elevated TLI (Figure 10.2, Figure 10.3, Table 10.1). Since 2010, algal bloom have not been as intense with the TLI being more stable.

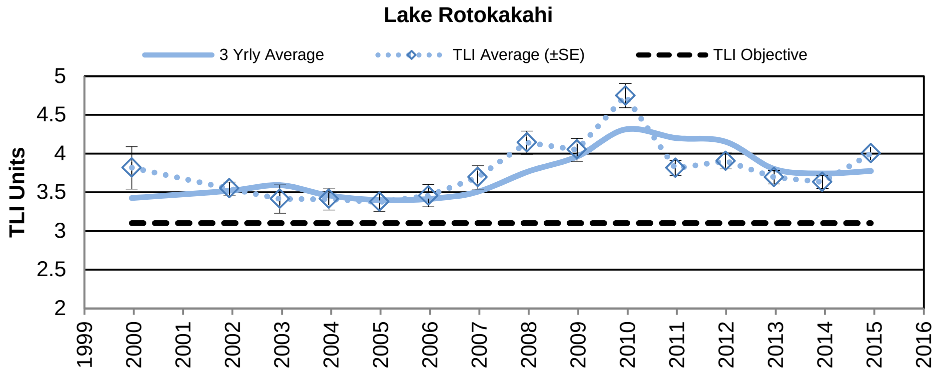


Figure 10.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotokakahi.

Late summer cyanobacteria blooms in 2015, contributed to low water clarity and elevated chlorophyll-*a* concentrations at Te Wairoa Stream and in the main body of the lake (Figure 10.2). Increased total and dissolved phosphorus in the hypolimnion, may also have occurred in response to a prolonged period of anoxia, during stratification.

Phytoplankton biomass (indicated by chlorophyll-*a*) usually peaks in June and July. This corresponds to an increase in ammoniacal nitrogen during June – possibly as a result of bottom waters mixing with the breakdown of thermal stratification.

Nitrogen and phosphorus are both potentially limiting to phytoplankton growth, with the relative importance changing seasonally. The median ratio of TN:TP was 13 which indicates these nutrients are reasonably balanced for phytoplankton growth. The ratio of DIN:TP indicates possible nitrogen limitation for most of the year but P limitation often occurring in June due to an increase in DIN in the water column.

Table 10.1 Average water quality and trends in outlet water of Lake Rotokakahi. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Average 2011-14	Trend 2002 to 2014 Te Wairoa outlet direction	PAC	Trend 2010 to 2014 Te Wairoa outlet direction	PAC
TLI *	3.8	↑	0.7%	↓	-3.1%
Chl-*a* (mg/m³)	4.8			↓	-11.1%
TN * (mg/m³)	271	↑	1.8%	↓	-4.2%
TP * (mg/m³)	14.7	↑	3.2%	↓	-8.4%
%DO	99.3				
DIN (mg/m³)	12.1			↓	-29.8%
NH_4-N (mg/m³)	8.7			↓	-28.4%
DRP (mg/m³)	3.8				
pH	7.5	↓	-0.2%	↘	-0.7%
Temperature	15.4				
Turbidity (NTU)	1.50	↑	2.2%		

* = TN and TP after adjusting for laboratory changes.
Average based on three year period July 2011 to June 2014
↑ = increase, ↓ = decrease, ↗ = increase *p*-value >0.05 and <0.1), ↘ = decrease (*p*-value >0.05 and <0.1)

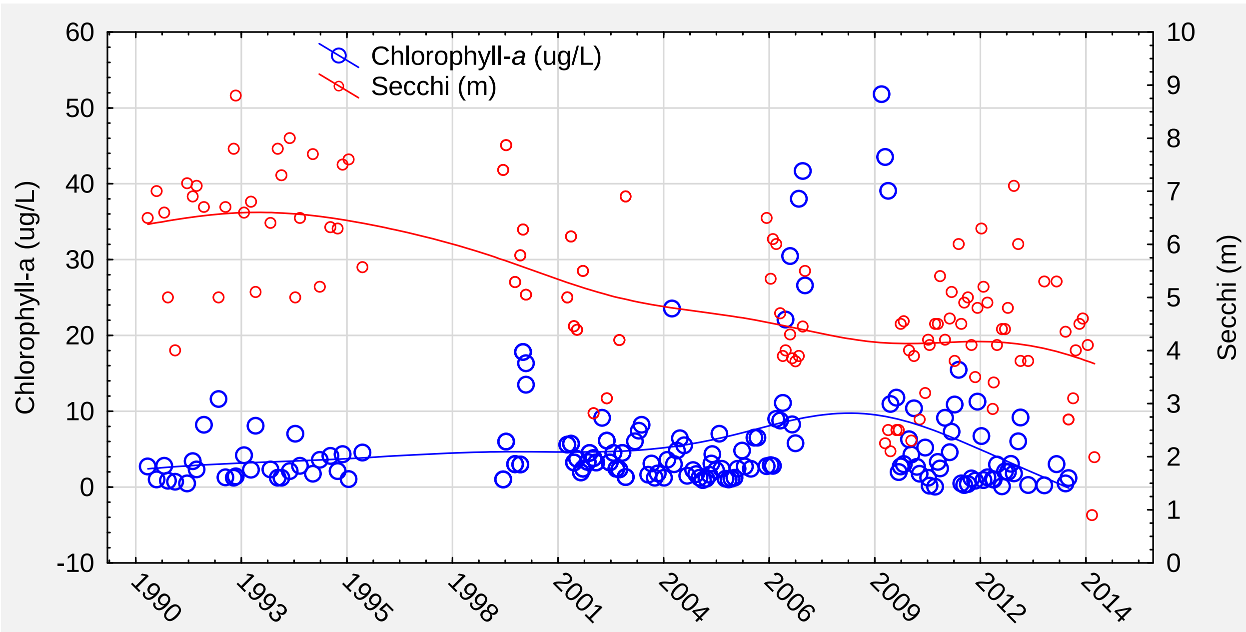


Figure 10.3 Changes in Secchi depth, chlorophyll-a in Lake Rotokakahi since 1990.

10.3 LakeSPI results

Lake Condition: Moderate   Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotokakahi	26	19	77

According to its LakeSPI index, Lake Rotokakahi has a moderate ecological condition. The LakeSPI index declined some time between 1988 and 2005 with the invasive *Elodea canadensis* dominating native charophyte meadows. *Elodea* continued to displace native charophyte meadows, but more recently, filamentous algae have been observed on submerged vegetation. Together with cyanobacteria mats covering sediments beyond the maximum depth of plant growth eutrophication of this lake is also likely to be impacting the LakeSPI index.

Lake Rotokakahi, together with Lake Ōkaro, are the only Rotorua Te Arawa lakes to remain relatively free of other invasive weed species.

Part 11: Lake Rotomā

11.1 Introduction

Lake Rotomā is one of the most pristine of all the Bay of Plenty lakes and is of high recreational and aesthetic value. It was formed by the Rotomā eruptions and consists of northern and southern basins, with monitoring occurring in the southern basin, which has a depth of 73.5 m. Most of the inflow comes from rainfall, with three small streams and springs around the lake margin. There is no surface outflow, resulting in large water level fluctuations depending on rainfall in preceding years. However, water does discharge via groundwater through the porous pumice substrate at a rate of 1.5 cumecs (about 7% of lake volume each year).

Lake Rotomā is a deep monomictic lake with a maximum depth of 83 m, and a surface topographical catchment of 27.9 km^2, including the lake area of 11.2 km^2. The lake seasonally stratifies with the bottom waters (hypolimnion) being cut off from the surface waters (epiliminion) from September to June. This pattern of changing temperature and dissolved oxygen can be observed in Figure 11.5.

The catchment is predominantly indigenous forest, with an area of low intensity dry stock land in the eastern catchment; however, nutrient loads from this area are thought to be partially intercepted by lagoons near the lake shore (Figure 11.1).

The low land to lake surface area ratio, and low nutrient inputs' gives Lake Rotomā the best lake water quality in the Bay of Plenty, with average surface water concentrations of 102 mg TN m^{-3}, 5.3 mg TP m^{-3}, and 1.1 mg chlorophyll-*a* m^{-3} for the period 2009-2014. It has a high TN:TP ratio of 19:1, indicating that the lake is likely to be P-limited.

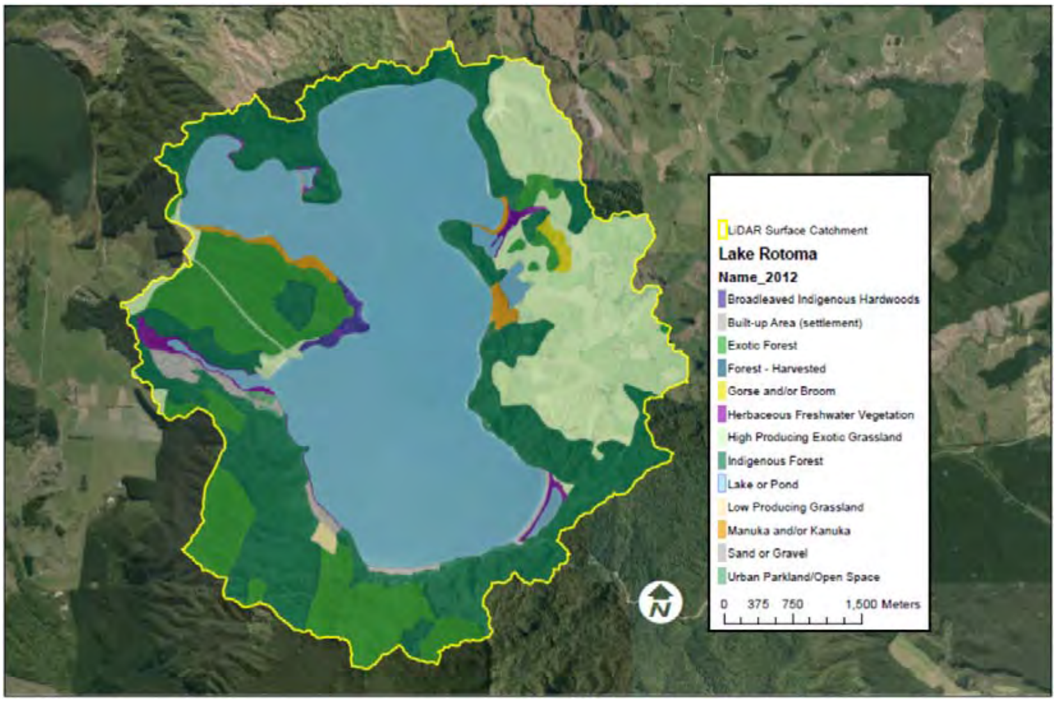


Figure 11.1 Lake Rotoma Catchment landuse (based on LCDB 2012).

11.2 Results

Lake Rotomā is oligotrophic and has the best water quality of any lake in the Bay of Plenty. It has a TLI value of 2.5, slightly above the target of 2.3 set in the RWLP (Figure 11.2).

Annual average phosphorus concentrations were the highest recorded, with peak concentrations occurring over summer. Chlorophyll-*a* concentrations were also some of the highest observed at winter turnover but returned to typically low levels in spring. Nitrogen levels were also elevated, with ammonium concentrations increasing in bottom waters just before mixing. Ammonium may have been released from the bottom sediments, as dissolved oxygen levels were less than 2 g/m^3 at the sediment water interface.

Over the period 2002 to 2014, the TLI has not significantly changed but there was a small decline in chlorophyll-*a* concentrations. In the last five years (2002-2014) there was a significant deterioration in the TLI and reduced water clarity. There is also evidence of increasing phosphorus and reducing dissolved oxygen concentrations in the lake bottom waters (Table 11.1, Figure 11.3, Figure 11.4). These trends should be closely watched to see whether or not these initial signs of deterioration continue.

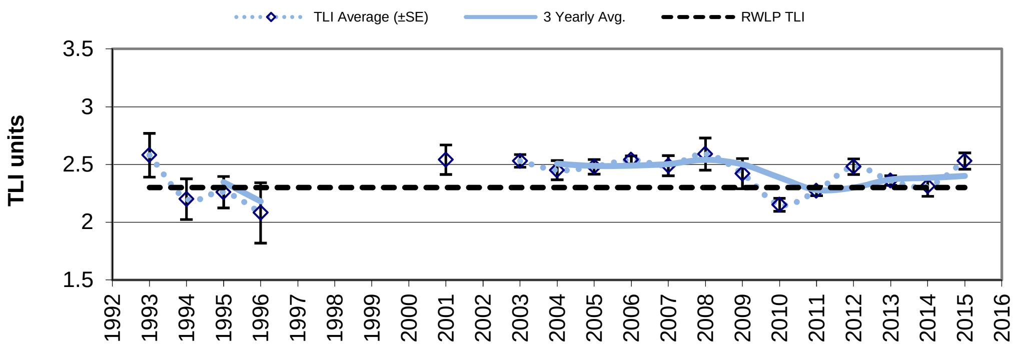


Figure 11.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotomā.

Low concentrations of dissolved nitrogen and phosphorus limit phytoplankton growth in Lake Rotomā, but nutrient ratios suggest that phosphorus is potentially more limiting than nitrogen (Table 3.1).

Table 11.1 Average water quality and trends in top and bottom waters of Lake Rotomā. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

	Top	Trend 2002 to 2014				Trend 2010 to 2014			
	Average	Top		Bottom		Top		Bottom	
Variable	**2011-14**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**	**direction**	**PAC**
TLI *	2.4					↑	2.2%		
Chl-*a* (mg/m³)	1.3	↓	-1.0%			↗	6.1%		
Secchi (m)	12.9					↓	-3.8%		
TN * (mg/m³)	150	↗	0.7%						
TP * (mg/m³)	5.4			↑	0.7%	↗	5.6%	↑	5.0%
%DO	88.4	↓	-1.4%	↓	-1.1%	↓	-1.8%	↓	-2.0%
DO min (g/m³)	5.6			↓	-2.1%			↓	-4.1%
DIN (mg/m³)	10.4					↓	-10.8%	↑	8.0%
NH_4-N (mg/m³)	5.7	↘	-3.5%			↓	-25.1%	↓	-33.5%
DRP (mg/m³)	3.3	↑	6.3%					↑	12.5%
EC (uS/cm)	122					↑	1.0%	↑	1.0%
pH	7.2								
Temperature	15.5								
VLEC	0.2								
Turbidity (NTU)	0.42	↓	-1.3%			↘	-3.0%		

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

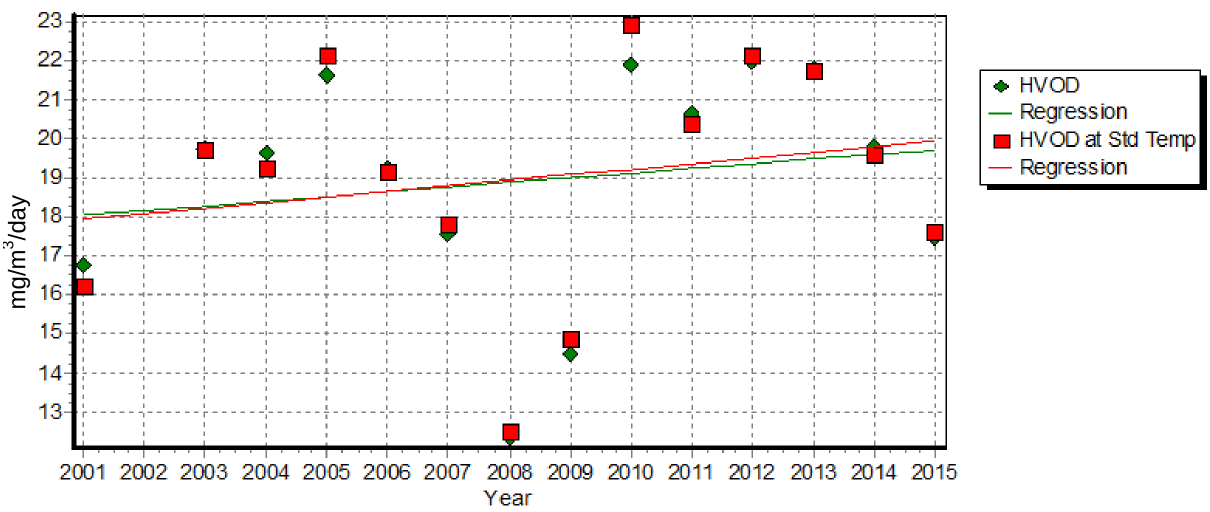


Figure 11.3 HVOD rates and HVOD rates adjusted to standard temperature, 2001 to 2015.

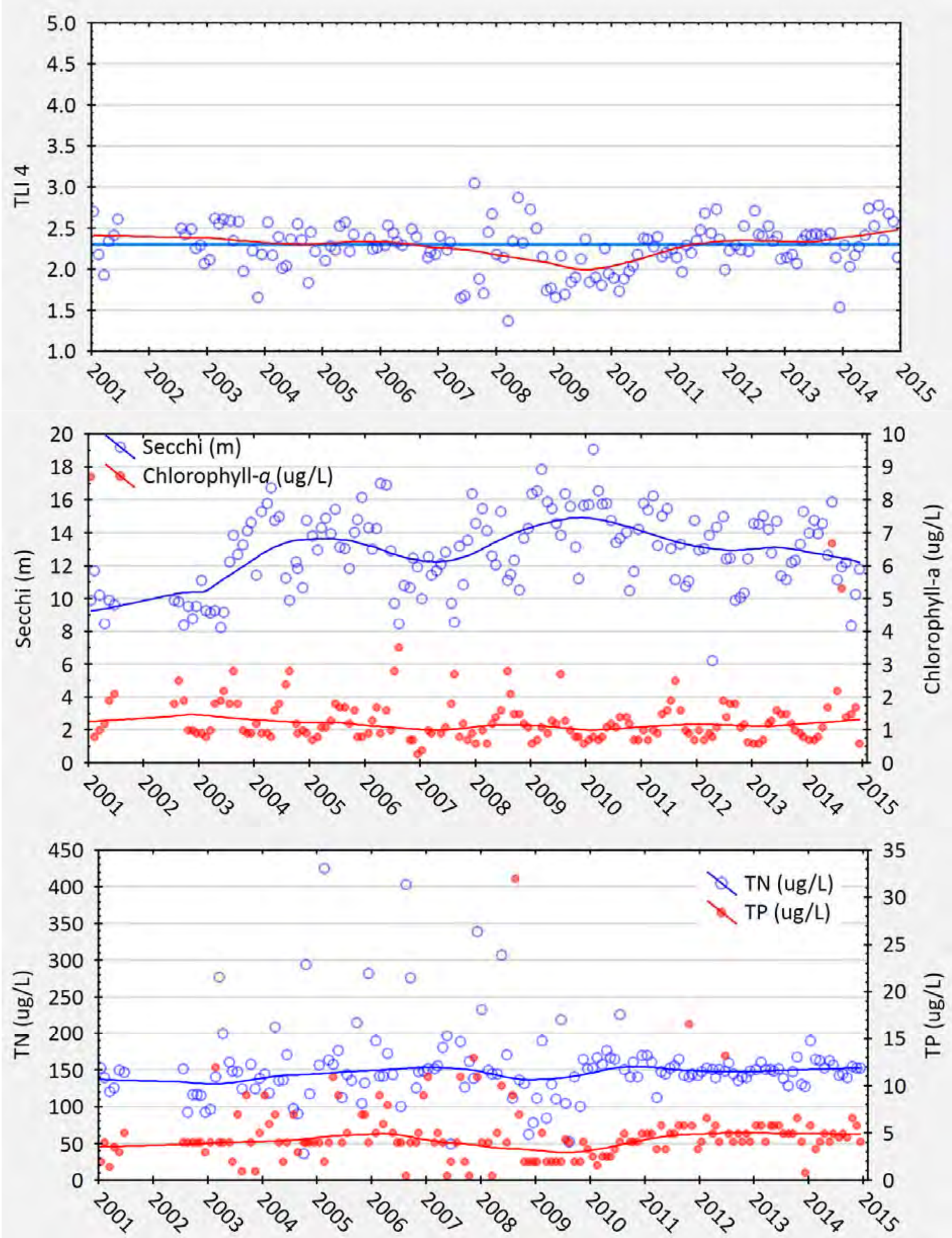


Figure 11.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Rotomā since 2001. The TLI target of 2.3 is indicated by the blue line in the top graph.

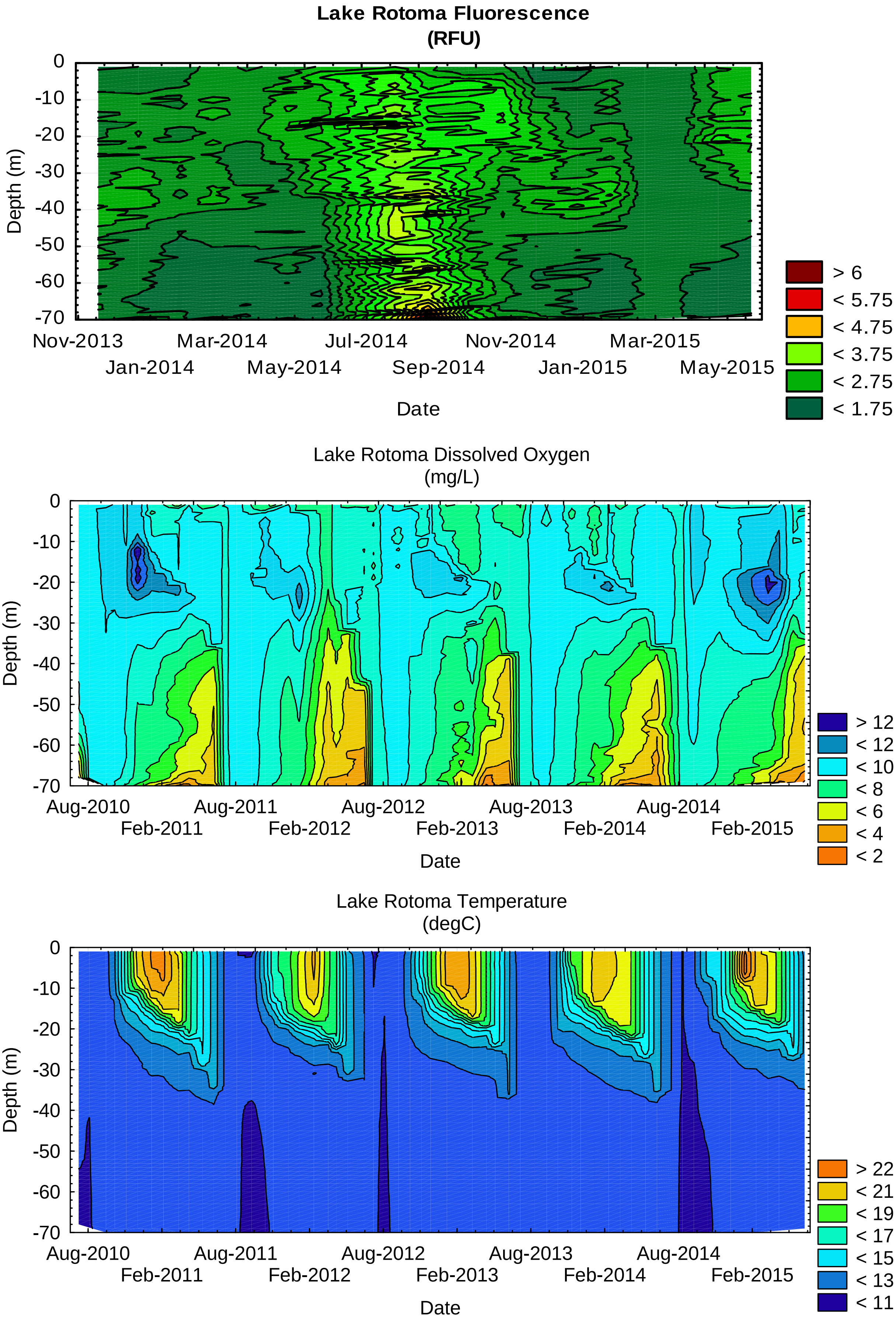


Figure 11.5 Time and depth plots of chlorophyll-a (top) dissolved oxygen concentrations, and temperature (bottom).

11.3 LakeSPI results

Lake Condition: High Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotomā	54	55	41

Lake Rotomā is categorised as having high ecological condition and is ranked the highest of monitored lakes in the Rotorua region. *Lagarosiphon* is the major dominant invasive aquatic plant reaching a depth of 6.1 m in places. The lake is threatened by the potential for hornwort (*Ceratophyllum demersum*) to establish as hornwort is prevalent in the adjacent Lake Rotoehu. Weed cordons and regular invasive weed surveys, along with public education are tools used to reduce the risk of other invasive species taking a hold in this lake.

Part 12: Lake Rotomahana

12.1 Introduction

Lake Rotomahana is the deepest of the Rotorua lakes and was formed by the joining of two previously separated lakes as a consequence of the Tarawera eruption in 1886. The lake is one of the most geothermally active, and the western basin features several hot springs located on the lake bed. Water enters the lake via the Waimangu Thermal Valley Stream which drains Lake Okaro. There is no surface outlet but sub-surface seepage drains towards Tarawera.

Lake Rotomahana has a maximum depth of 125 m. It has a surface topographical catchment area of 83.0 km^2, including the lake area of 9.1 km^2. Most of the catchment is forested with large areas of mānuka/kanuka and exotic forestry, and there are also large areas of dry stock pastoral land.

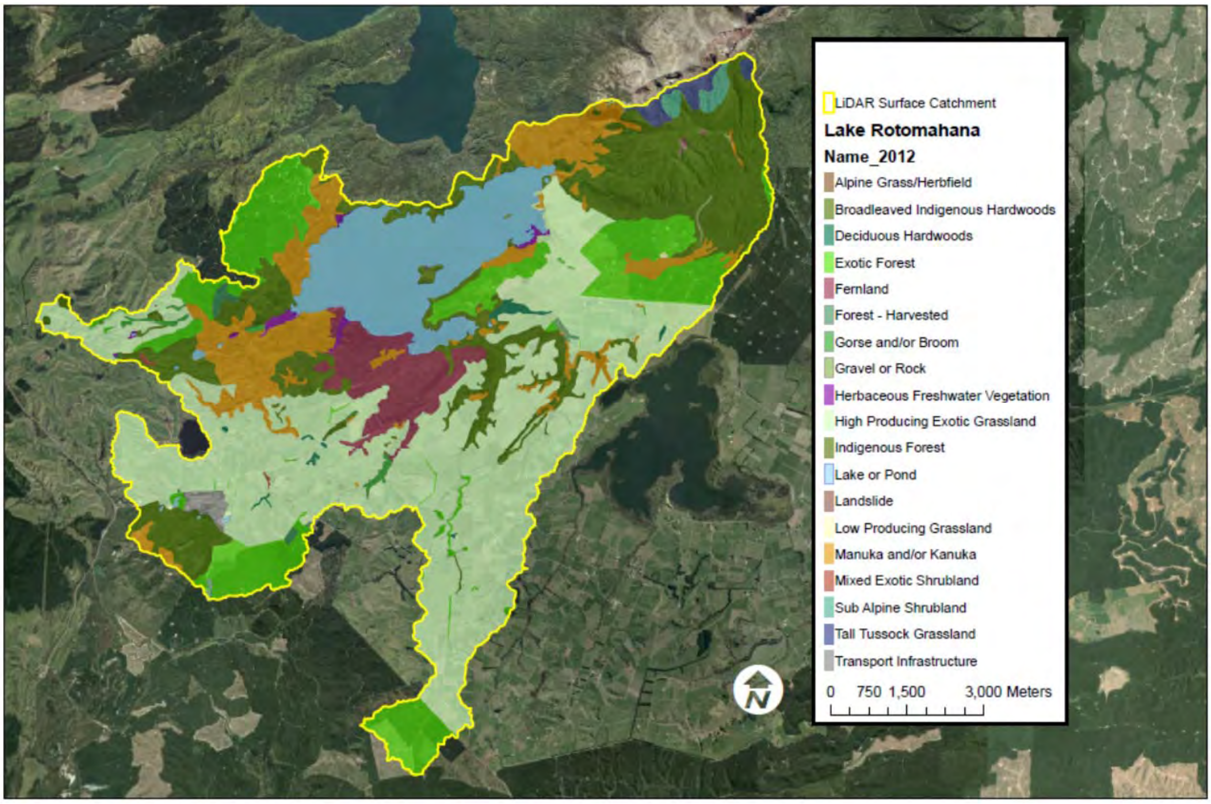


Figure 12.1 Lake Rotomahana Catchment landuse (based on LCDB 2012).

Lake Rotomahana is a monomictic lake, that is it seasonally stratifies with the bottom waters (hypolimnion) being cut off from the surface waters (epiliminion) from September to May. This pattern of changing temperature and dissolved oxygen can be observed in Figure 12.5.

12.2 Results

Lake Rotomahana is mesotrophic. It has a TLI value of 4.0, slightly above the target of 3.9 set in the RWLP. The TLI is weighted towards the phosphorus component of the TLI due to the relatively high concentrations of phosphorus in the lake – possible as a result geothermal activity. Geothermal activity also elevates the water temperature and electrical conductivity in the lake.

The 2014/15 TLI for Rotomahana increased to the same value as for 2012/13. It was 4.02 compared to 3.81 TLI units the previous year (Figure 12.2). This was largely due to the annual total phosphorus concentration increasing from an annual average of 45.0 mg/m3 to 58.9 mg/m^3, the increase occurring after winter turnover. The TLI has slightly deteriorated since 2002, driven by an increase in the concentration of TN and TP. Since 2010 there has been no significant change in TLI, but both total phosphorus (TP) and dissolved phosphorus (DRP) has increased and dissolved oxygen has decreased in the lake's bottom waters (Table 12.1, Figure 12.4).

There appears to be a correlation between total phosphorus concentrations and the hypolimnetic volumetric oxygen demand (HVOD), with higher TP concentrations occurring in years with higher HVOD (Figure 12.3 and 12.4).

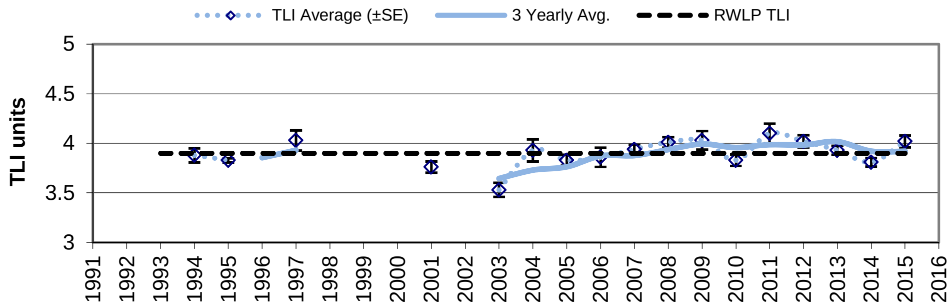


Figure 12.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotomahana.

The ratios of nitrogen to phosphorus suggest that phytoplankton growth in Lake Rotomahana is more strongly limited by nitrogen rather than phosphorus (Table 3.1). The lake's surface water has relatively high concentrations of dissolved reactive phosphorus throughout the year – which also suggests that the phytoplankton are replete in phosphorus.

The highest concentrations of phytoplankton (chlorophyll-*a*) and the lowest concentrations of oxygen (anoxia) tends to occur in the water column at the thermocline (Figure 12.5).

Table 12.1 Average water quality and trends in top and bottom waters of Lake Rotomahana. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014 Top direction	Trend 2002 to 2014 Top PAC	Trend 2002 to 2014 Bottom direction	Trend 2002 to 2014 Bottom PAC	Trend 2010 to 2014 Top direction	Trend 2010 to 2014 Top PAC	Trend 2010 to 2014 Bottom direction	Trend 2010 to 2014 Bottom PAC
TLI *	3.8	↑	0.5%						
Chl-*a* (mg/m^3)	4.3								
Secchi (m)	5.3								
TN * (mg/m^3)	244	↑	1.5%	↑	1.8%				
TP * (mg/m^3)	37.6	↑	3.4%	↑	2.9%			↑	4.6%
%DO	89.3	↓	-1.1%	↓	-1.6%	↓	-1.5%	↓	-1.7%
DO min (g/m^3)	5.9			↓	-2.4%				
DIN (mg/m^3)	37.8								
NH_4-N (mg/m^3)	3.1	↓	-8.9%			↓	-50.4%		
DRP (mg/m^3)	21.2	↑	8.4%	↑	4.8%	↑	11.6%	↑	8.2%
EC (uS/cm)	1133	↓	-0.7%	↓	-0.8%	↓	-0.9%	↓	-0.8%
pH	7.2								
Temperature	17.0								
VLEC	0.4	↑	1.1%						
Turbidity (NTU)	0.90								

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

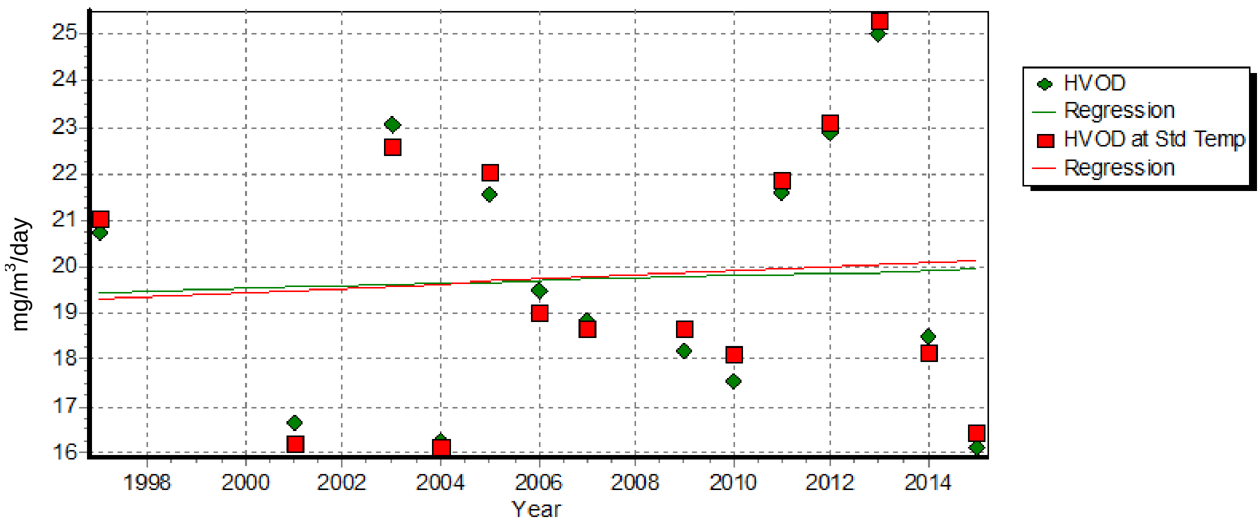


Figure 12.3 HVOD rates and HVOD rates adjusted to standard temperature, 1997 to 2015.

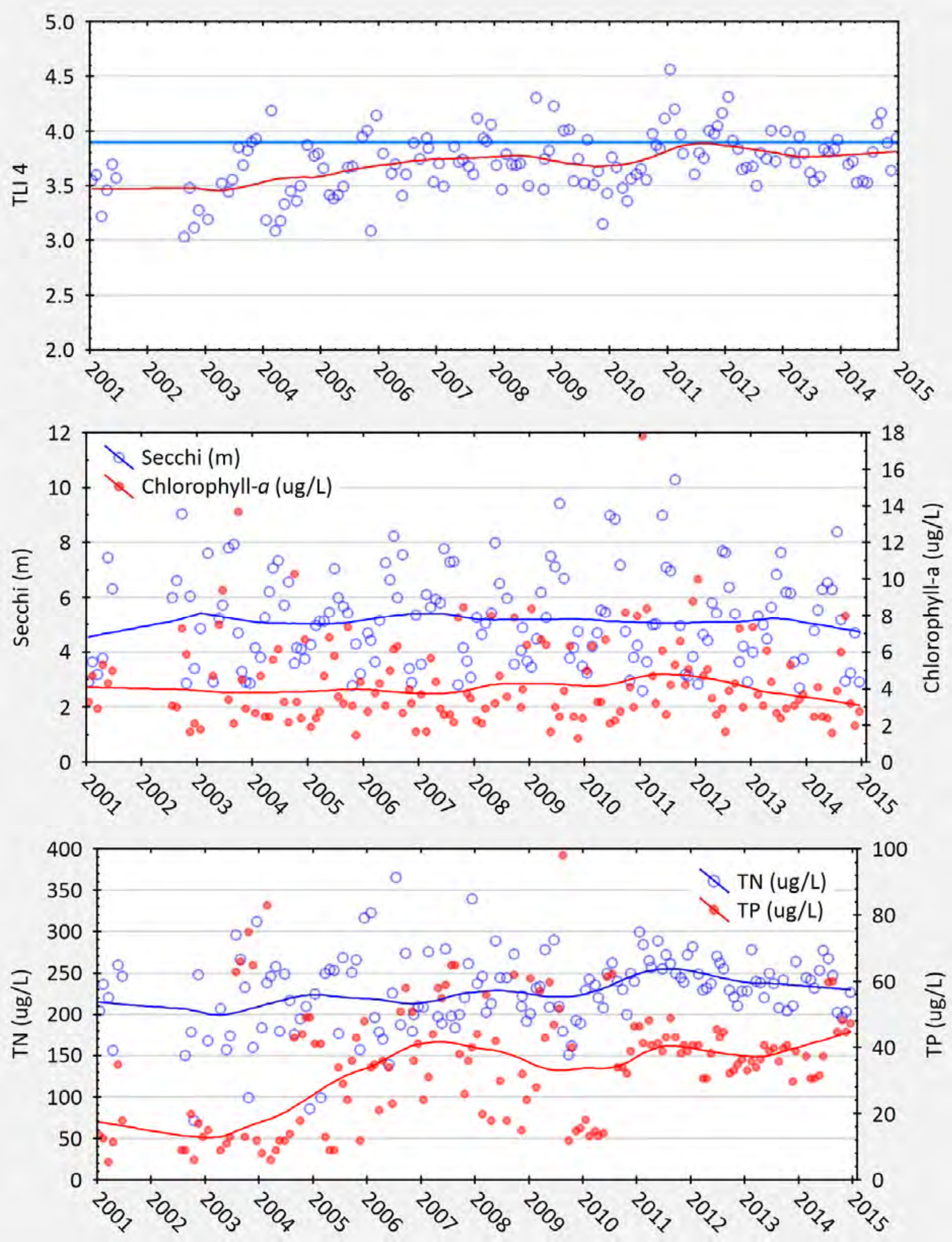


Figure 12.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Rotomahana since 2001. The TLI target of 3.9 is indicated by the blue line in the top graph.

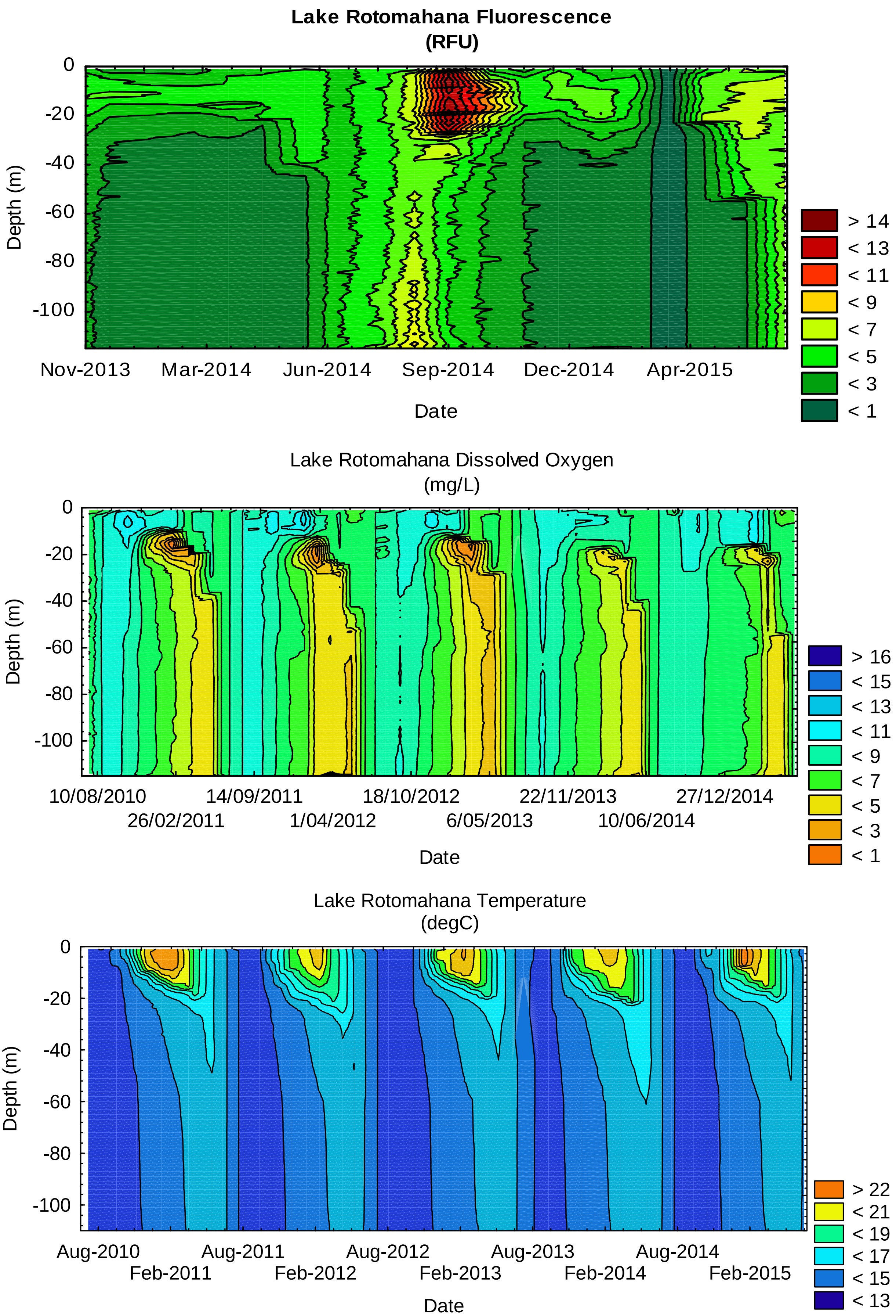


Figure 12.5 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom).

12.3 LakeSPI results

Lake Condition: High Stability: Stable?

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotomhana	54	53	37

Although categorised as moderate, Lake Rotomahana has declined rapidly in the past decade due to the introduction of invasive species hornwort and *Egeria*. First found in 2007, these invasive weeds are impacting the quality and diversity of the indigenous plant communities. However, since 2013 *Egeria* cover in the lake has reduced, although the reasons for the reduction are not clear.

There still remains the risk the Native Condition Index could further decline, as hornwort has only been found at two of the five transects performed in the Lake SPI assessment.

Part 13: Lake Rotorua

13.1 Introduction

Lake Rotorua is the second largest lake in New Zealand in terms of surface area. It occupies a caldera created by the Manuku Ignimbrite eruption. The lake is fed by numerous small streams (the largest being Hamurana Stream). Geothermal water enters from hot springs on the southern shore and via some streams (e.g. Puarenga and Waiohewa Streams). The lake discharges to Lake Rotoiti and the Kaituna River via the Ōhau Channel.

Although Lake Rotorua has the largest surface area of all the Rotorua lakes (80.97 km^2), it is a relatively shallow polymictic lake with an average depth of 10 m. Lake Rotorua has a topographical surface catchment of 597.4 km^2, including the lake surface. A large proportion of the catchment is forested with an even mix of exotic and indigenous vegetation, and there is a similar amount of pastoral land used for dairy (Figure 13.1). Rotorua city lies within the catchment. The lake has pressures from urban and rural landuses.

Recent management interventions to improve water quality in the lake include: land disposal of the city's wastewater since 1991 (into the Puarenga Stream Catchment), sewage reticulation of smaller communities, trial of nitrogen removal of water from Tikitere geothermal field (2011), alum (aluminium sulphate) dosing to lock phosphorus from Utuhina Stream (2006) and Puarenga Stream (2010), and rules to cap land based inputs.

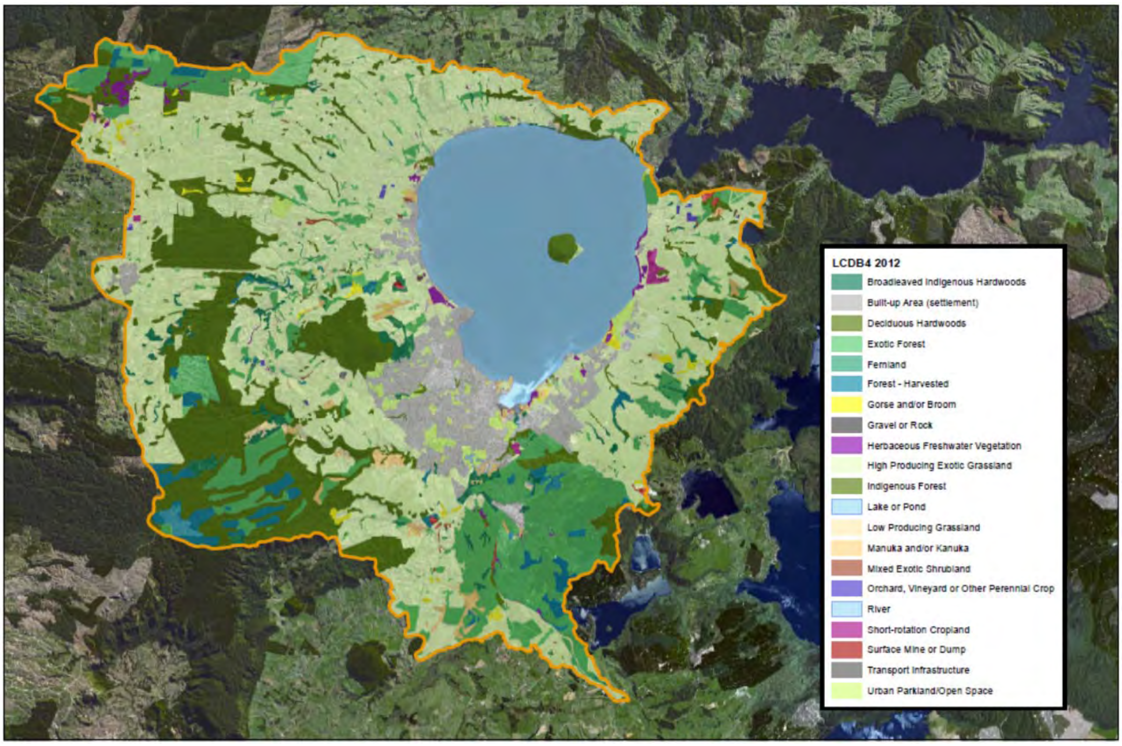


Figure 13.1 Lake Rotorua catchment landuse (based on LCDB 2012).

13.2 Results

Lake Rotorua is eutrophic. It has a 2014/15 TLI value of 4.4 TLI units, slightly greater than the target of 4.2 set in the RWLP (Figure 13.2). The stable anticyclonic weather system that persisted for a good part of the 2014/15 summer, resulted in one of the longest period of stratification of Lake Rotorua waters observed since installation of the monitoring buoy in 2007 (Figure 13.3). Stratification lasted almost one month, with the resultant anoxia of the bottom waters contributing to an apparent release of phosphorus from bottom sediments and into the water column, most notable during the month of January 2015.

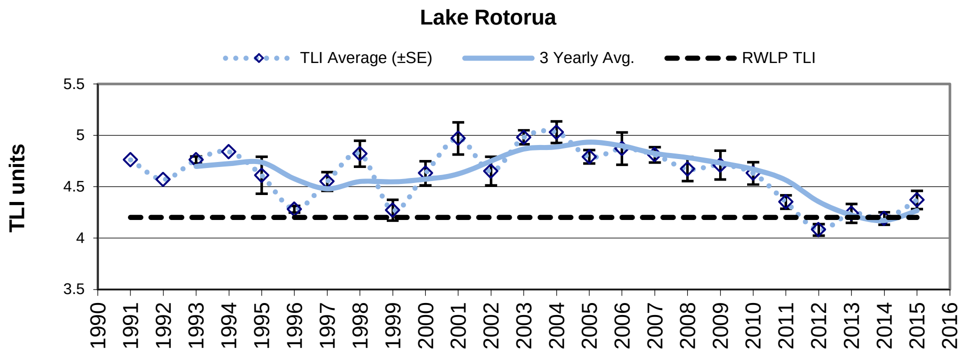


Figure 13.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Rotorua.

A stronger algal presence also occurred at this time than the previous summer (Figure 13.3). Chlorophyll-*a* concentrations increased, demonstrated by the fluorescence profile of the lake and an increase in cyanobacteria to alert levels (Figure 13.7).

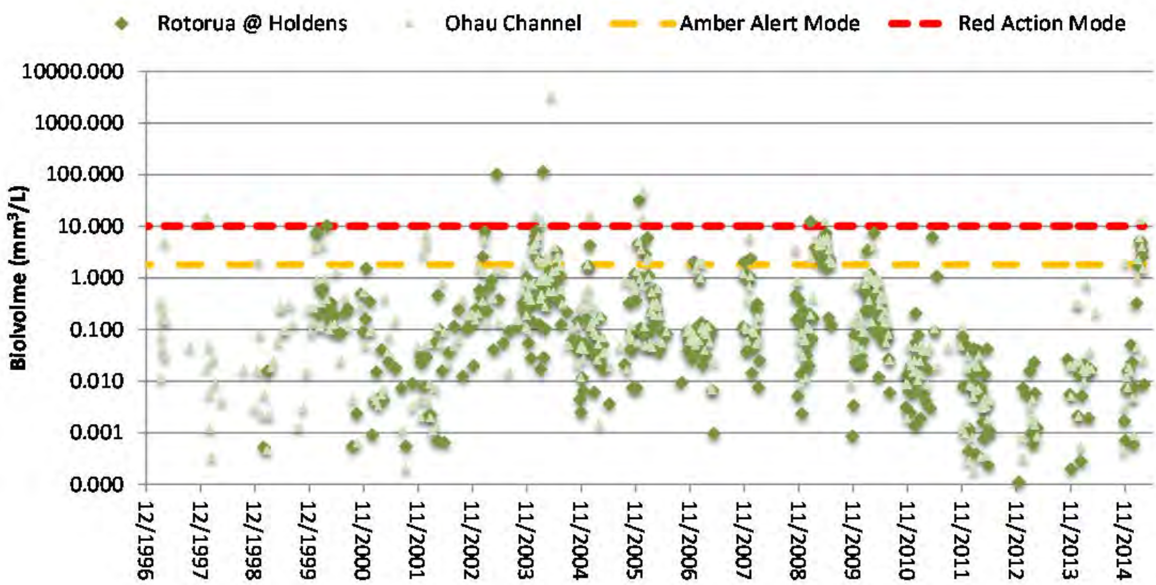


Figure 13.3 Total cyanobacteria biovolume from Holdens Bay, Lake Rotorua and Ōhau Channel.

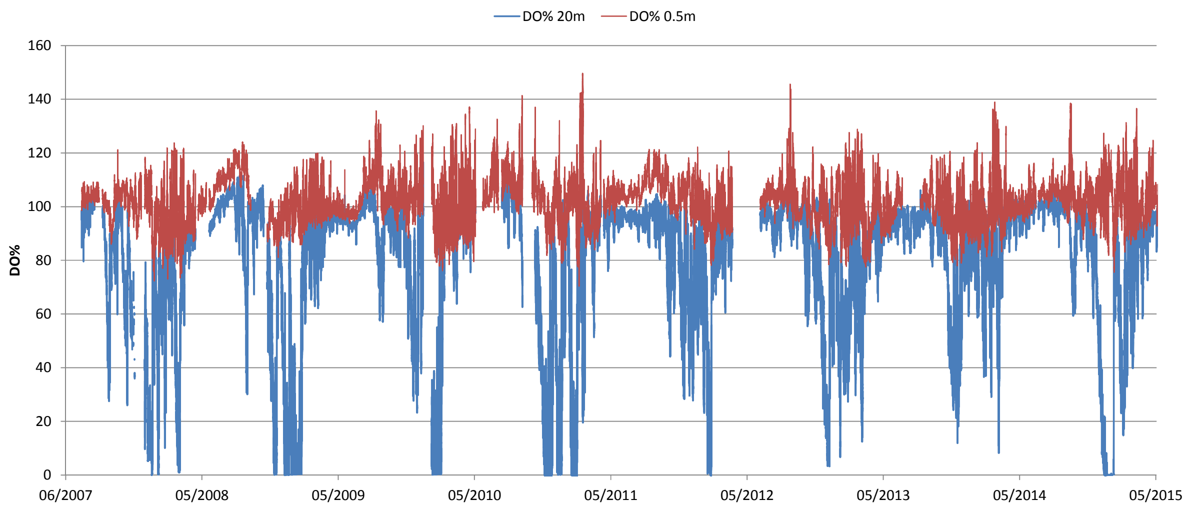


Figure 13.4 Percentage saturated dissolved oxygen measured near lake surface and at 20 m depth, Rotorua monitoring buoy.

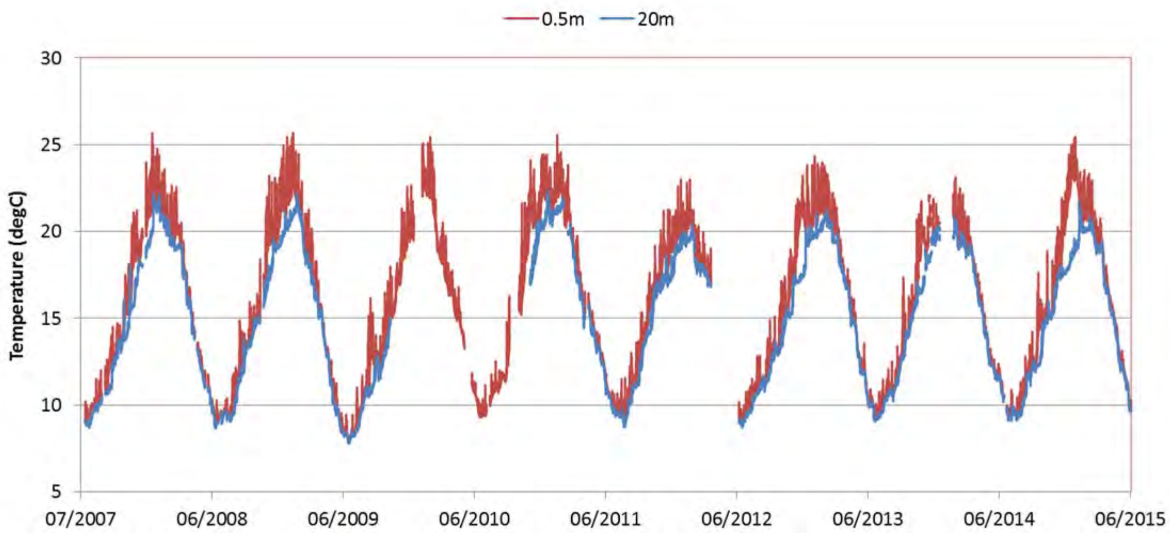


Figure 13.5 Temperature measured near lake surface and at 20 m depth, Rotorua monitoring buoy.

The northern site has slightly better water quality. The TLI has significantly improved since 2002 with reduced nutrient concentrations, reduced chlorophyll-*a* and increased water clarity, particularly during summer. Improvements in phosphorus concentrations are apparent since 2006 and 2010 – corresponding with alum dosing of Utuhina Stream and Puarenga Stream respectively (Table 13.1, Table 13.2, Figure 13.4).

The reduction of phosphorus concentrations as a result of alum dosing has shifted the balance of nitrogen to phosphorus, so phytoplankton growth is now much more strongly limited by phosphorus than by nitrogen. This is also indicated by very low concentrations of dissolved phosphorus in the lake since 2008, with a corresponding increase in dissolved nitrogen. However, the lake is still vulnerable to phytoplankton blooms during occasional periods when the lake stratifies to cause bottom water anoxia and release of phosphorus from the sediments (e.g. in early 2015).

Table 13.1 Average water quality and trends in top and bottom waters of Lake Rotorua. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Lake Rotorua Site 2 (south of Mokoia Island)

	Top	Trend 2002 to 2014				Trend 2010 to 2014			
	Average	Top		Bottom		Top		Bottom	
Variable	2011-14	direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	4.1	↓	-1.7%			↓	-1.7%		
Chl-*a* (mg/m³)	11.0	↓	-7.5%			↘	-11.2%		
Secchi (m)	3.1	↑	3.2%						
TN * (mg/m³)	355	↓	-2.9%	↓	-2.9%	↓	-4.7%	↓	-6.2%
TP * (mg/m³)	14.5	↓	-10.8%	↓	-11.1%	↘	-5.9%		
%DO	87.9	↓	-1.2%	↓	-0.8%			↓	-2.2%
DO min (g/m³)	7.7			↓	-1.2%				
DIN (mg/m³)	61.0	↑	5.3%						
NH_4-N (mg/m³)	24.6								
DRP (mg/m³)	2.0	↓	-19.7%	↓	-16.7%				
EC (uS/cm)	158	↓	-0.6%	↓	-0.7%				
pH	6.9								
Temperature	15.5								
VLEC	0.6	↓	-3.8%						
Turbidity (NTU)	1.82	↓	-5.0%			↓	-7.9%		

Lake Rotorua Site 5 (north of Mokoia Island)

	Top	Trend 2002 to 2014				Trend 2010 to 2014			
	Average	Top		Bottom		Top		Bottom	
Variable	2011-14	direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	4.0	↓	-1.6%			↘	-1.3%		
Chl-*a* (mg/m³)	9.9	↓	-7.8%			↘	-12.0%		
Secchi (m)	3.1	↑	2.7%						
TN * (mg/m³)	373	↓	-2.6%	↓	-3.5%	↓	-3.1%	↓	-7.7%
TP * (mg/m³)	13.3	↓	-10.5%	↓	-10.1%				
%DO	86.1	↓	-1.6%	↓	-0.9%	↓	-1.7%		
DO min (g/m³)	7.5			↓	-1.6%				
DIN (mg/m³)	82.1	↑	8.6%						
NH_4-N (mg/m³)	26.0								
DRP (mg/m³)	2.0	↓	-18.0%	↓	-13.4%				
EC (uS/cm)	157	↓	-0.7%	↓	-0.6%				
pH	7.0					↗	0.5%	↑	0.8%
Temperature	15.4								
VLEC	0.6	↓	-3.6%						
Turbidity (NTU)	2.06	↓	-4.8%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (p -value >0.05 & <0.1), ↘ =decrease (p -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. p -value >0.05 to <0.01 or PAC >0.5% to <1%.

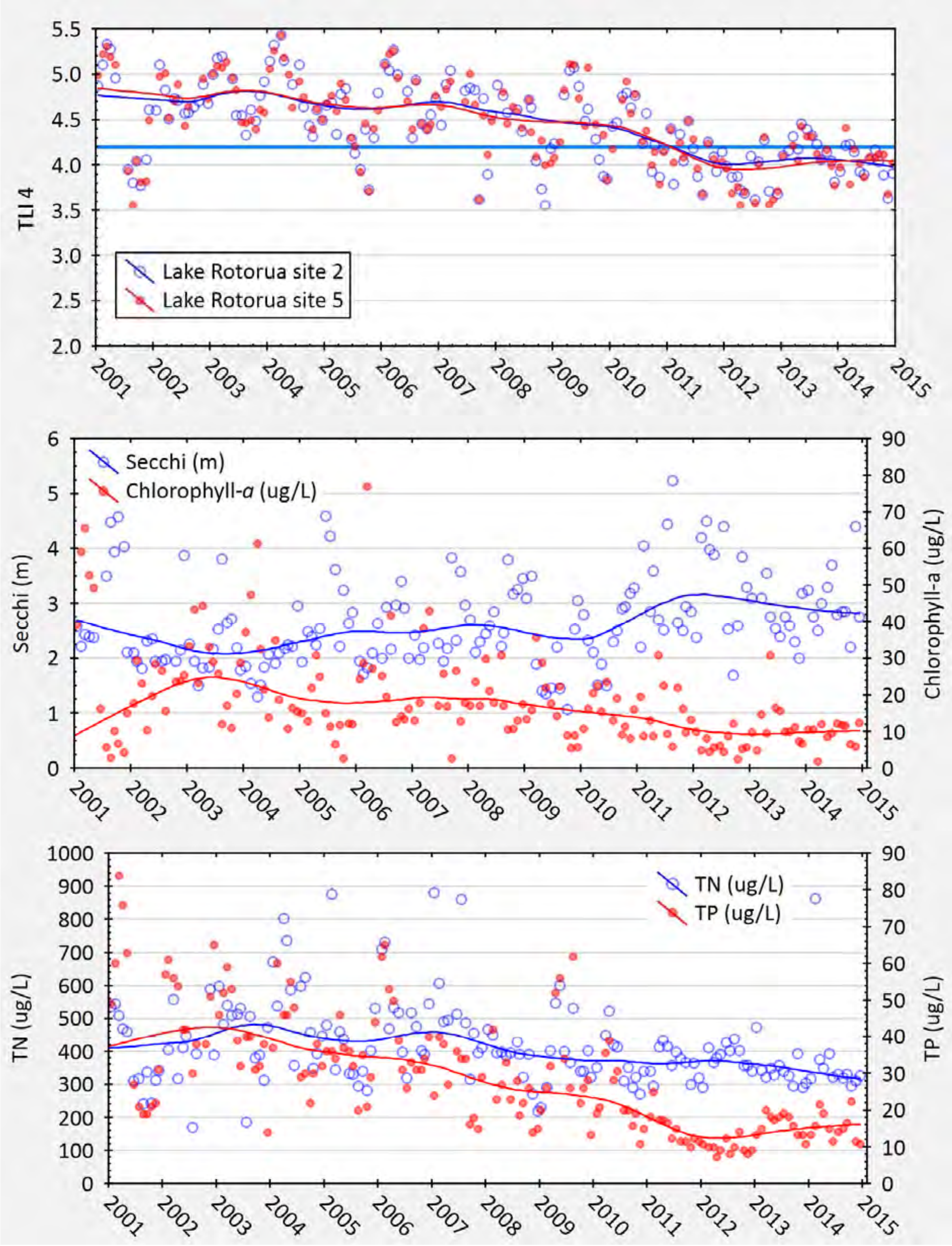


Figure 13.6 Changes in the TLI (Rotorua sites 2 and 5) and its components (Secchi depth, chlorophyll-a, TN and TP) (Rotorua Site 5) since 2001. The TLI target of 4.2 is indicated by the blue line in the top graph.

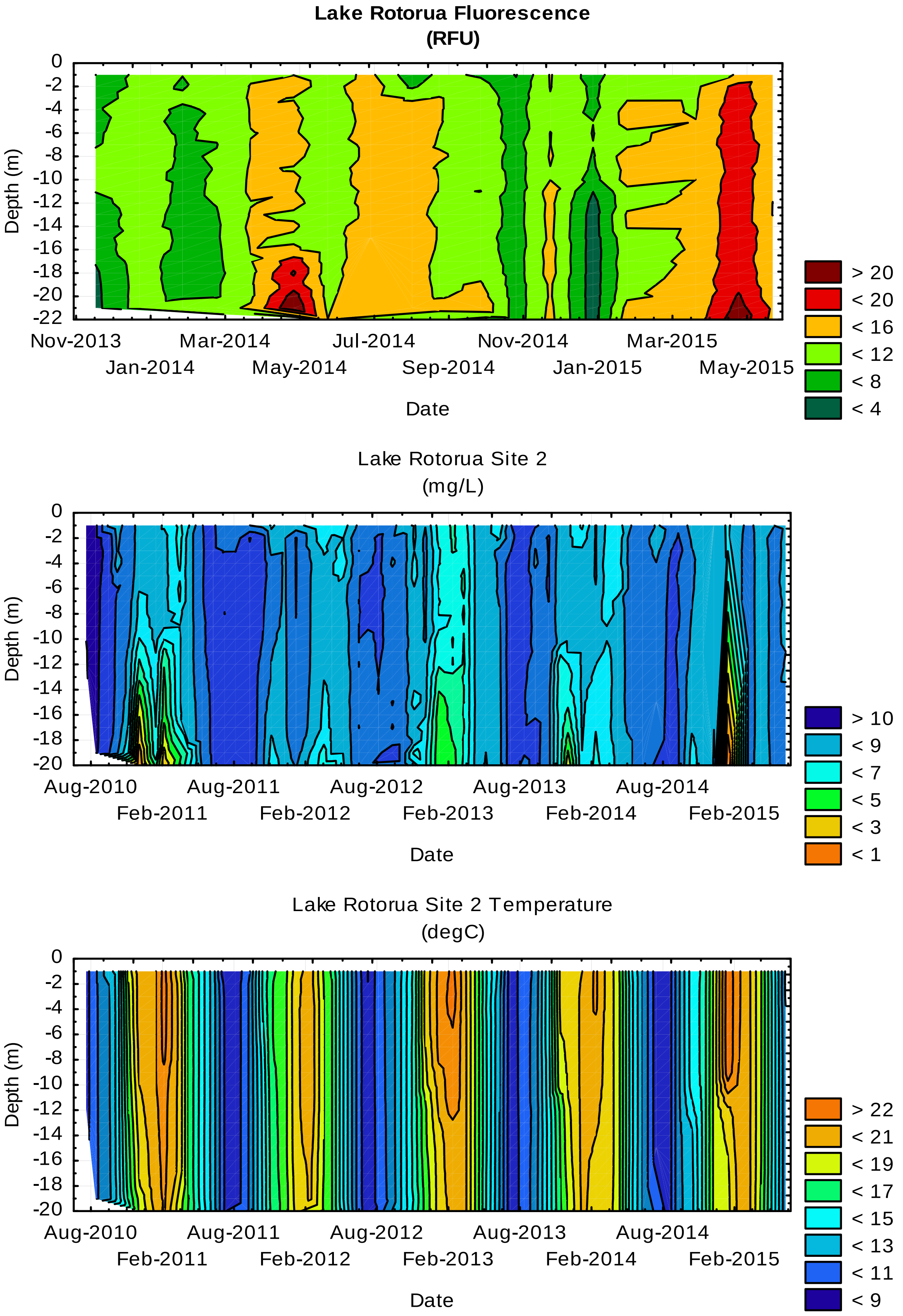


Figure 13.7 Time and depth plots of chlorophyll-a (top), dissolved oxygen concentrations, and temperature (bottom).

13.3 Lake SPI results

Lake Condition: Moderate   Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Rotorua	28	33	80

Lake Rotorua macrophytes have remained in stable but moderate ecological condition for over three decades. A slight improvement has been detected between 2011 to 2015, due to improvement in the Native Condition Index. The large area of shallow littoral waters that are impacted by wave action reduces the build-up of large areas of surface reaching submerged vegetation around the lake margins. These margins have had some development of native turf-forming species along with shallow-water charophyte beds, but these communities have been variable.

Part 14: Lake Tarawera

14.1 Introduction

Lake Tarawera is a relatively large lake and is a very popular holiday destination, with high recreational and aesthetic value. It is located in the southwest section of the Haroharo Caldera and it is fed by seven other lakes. Inflows come directly from Lake Ōkāreka via Waitangi Springs and Lake Rotokakahi via Te Wairoa Stream. Inflows also enter through the sub-surface from Lakes Tikitapu and Ōkataina, and Rotomahana at times of high lake levels, via a buried stream conduit. Tarawera also receives indirect inflows from Lake Ōkaro and Lake Rerewhakaaitu, as they discharge to Lake Rotomahana. The lake discharges via the Tarawera River. Springs in the lake bed toward the south-west shore provide geothermal input. There is a monitoring buoy in the centre of the lake to monitor water quality and effectiveness of interventions to reduce nutrient loading.

Lake Tarawera is a deep lake of fairly low productivity, with a maximum depth of 87 m. It has a surface topological catchment of 143.4 km^2, including the lake area of 41.5 km^2.The catchment is mostly covered in indigenous forest and scrub with approximately 20% pasture cover. There is a lakeside community which has not yet been reticulated. Land management initiatives such as riparian protection works are continuing in the catchment.

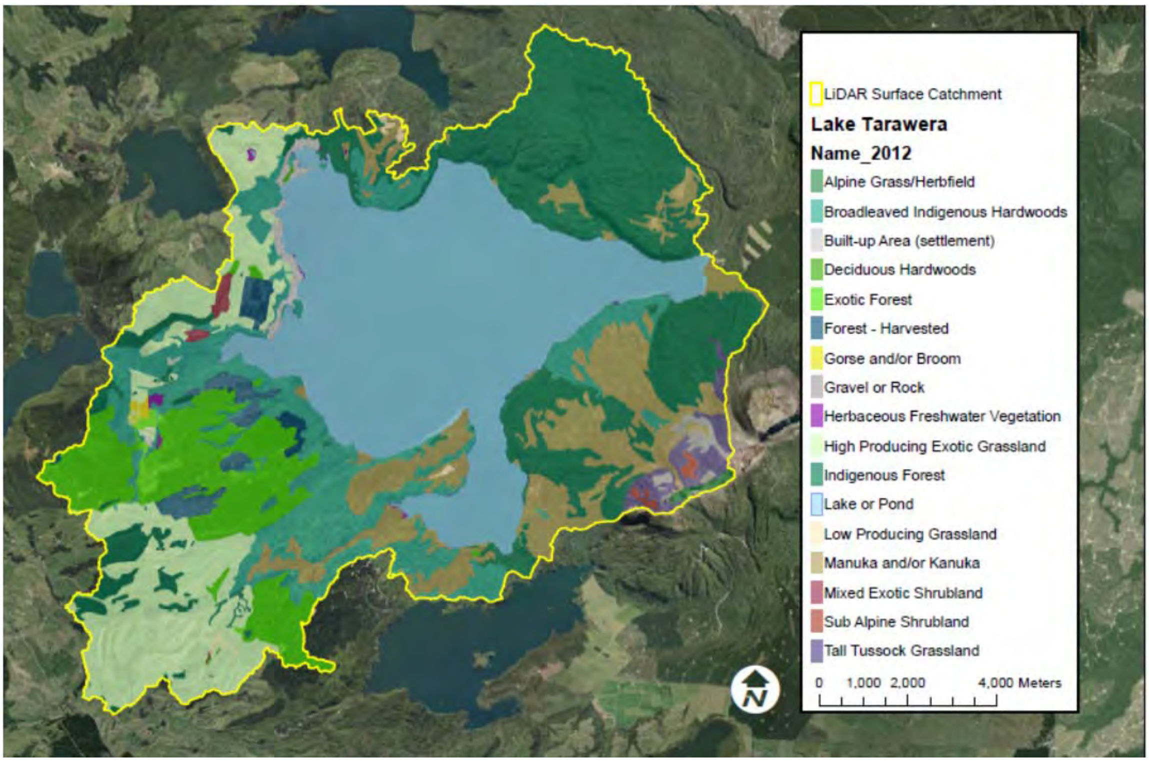


Figure 14.1 Lake Tarawera catchment landuse (based on LCDB 2012).

This monomictic lakes stratifies in September, mixing again to a isothermal condition in late autumn. Stratification can be observed in the temperature and dissolved oxygen contour plots in Figure 14.5.

14.2 Results

Lake Tarawera is oligotrophic but water quality is deteriorating and cyanobacteria blooms occasionally occur during summer. It has a TLI value of 3.1, which is worse than the RWLP target of 2.6. The TLI score is influenced by phosphorus, which is possibly elevated by geothermal inputs and/or increases in sediment inputs. The water quality has significantly deteriorated since 2002 driven by an increase in nitrogen and phosphorus. Water clarity has reduced in the last five years (since 2010) (Table 14.1; Figure 14.2, Figure 14.4).

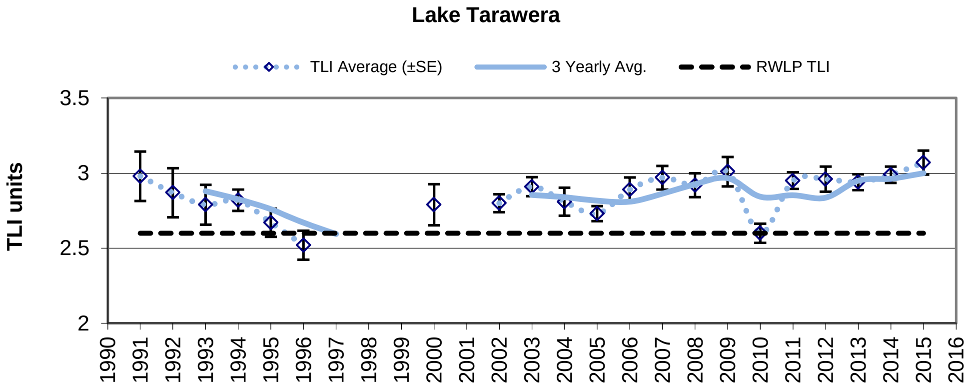


Figure 14.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Tarawera.

Any increase in eutrophication does not seem to be explained by any internal nutrient loadings, as conditions for sediment nutrient release are not observed. Oxygen concentrations in the hypolimnion of Lake Tarawera have remained relatively stable over the last decade (Figure 14.3), and hypolimnetic depletion rates are the lowest observed in any of the Rotorua Te Arawa lakes. Given the downwards trends in water quality, oxygen concentrations in the hypolimnion remain resilient to any increases in organic enrichment. Reasons for this may be the residence time of organic material in the lake or perhaps the addition of oxygen from fractured groundwater aquifers, or a combination of both.

The ratios of nitrogen to phosphorus suggest that phytoplankton growth in Lake Tarawera is more strongly limited by nitrogen rather than phosphorus (Table 3.1). The lake's surface water has relatively high concentrations of dissolved reactive phosphorus throughout the year – which also suggests that phytoplankton is replete in phosphorus. This suggests that managing nitrogen loads from the catchment is particularly important for maintaining the lake water quality.

Table 14.1 *Average water quality and trends in top and bottom waters of Lake Tarawera. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).*

Variable	Top Average 2011-14	Trend 2002 to 2014 Top direction	PAC	Trend 2002 to 2014 Bottom direction	PAC	Trend 2010 to 2014 Top direction	PAC	Trend 2010 to 2014 Bottom direction	PAC
TLI *	2.9	↑	1.1%			↑	1.6%		
Chl-*a* (mg/m^3)	1.5								
Secchi (m)	8.2					↓	-5.6%		
TN * (mg/m^3)	142	↑	1.7%	↑	2.7%			↑	4.2%
TP * (mg/m^3)	15.9	↑	7.2%	↑	6.5%			↑	4.3%
%DO	87.9	↓	-1.3%	↓	-1.0%	↓	-2.2%		
DO min (g/m^3)	6.3			↓	-2.7%				
DIN (mg/m^3)	3.4	↓	-4.2%					↑	14.1%
NH_4-N (mg/m^3)	1.7	↓	-8.3%						
DRP (mg/m^3)	10.4	↑	11.7%	↑	8.3%	↑	3.2%	↑	9.4%
EC (uS/cm)	402								
pH	7.8								
Temperature	15.3								
VLEC	0.2	↑	1.5%						
Turbidity (NTU)	0.74					↗	4.3%		

* = TN and TP after adjusting for laboratory changes.
Average based on three year period July 2011 to June 2014
↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)
Shaded out cells = variable not measured
Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

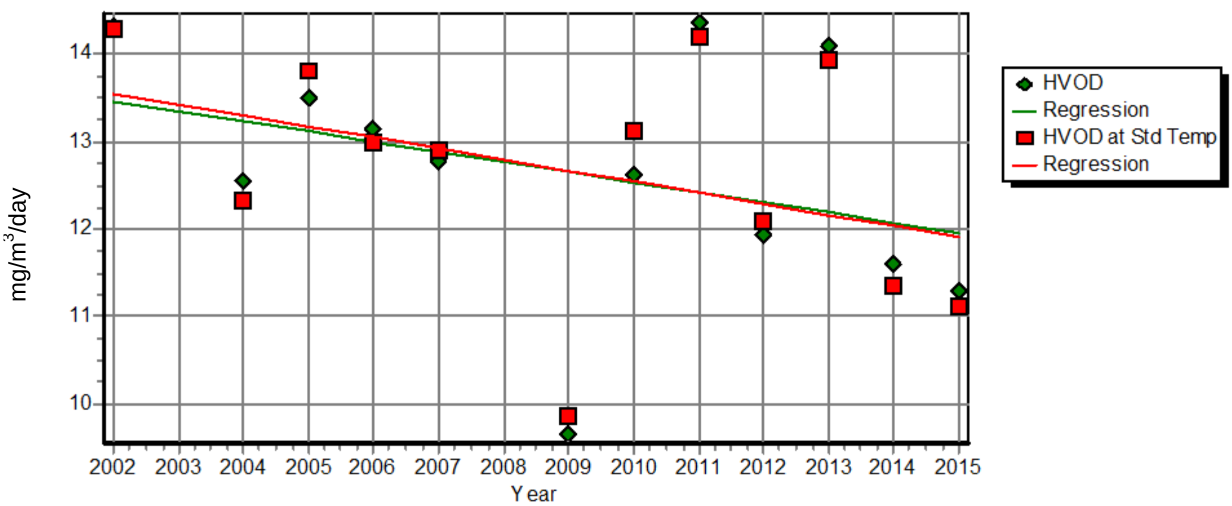


Figure 14.3 *HVOD rates and HVOD rates adjusted to standard temperature, 2002 to 2015.*

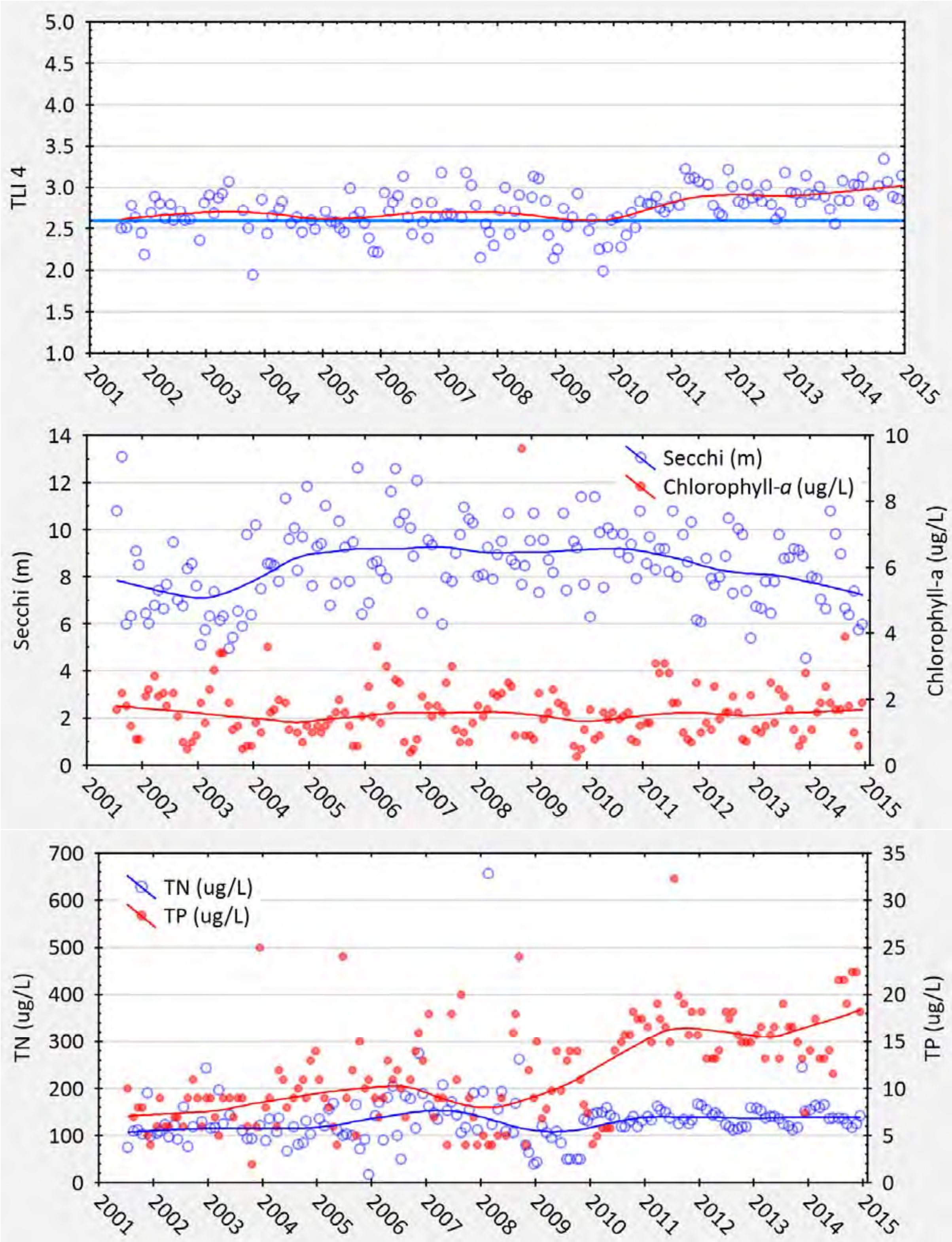
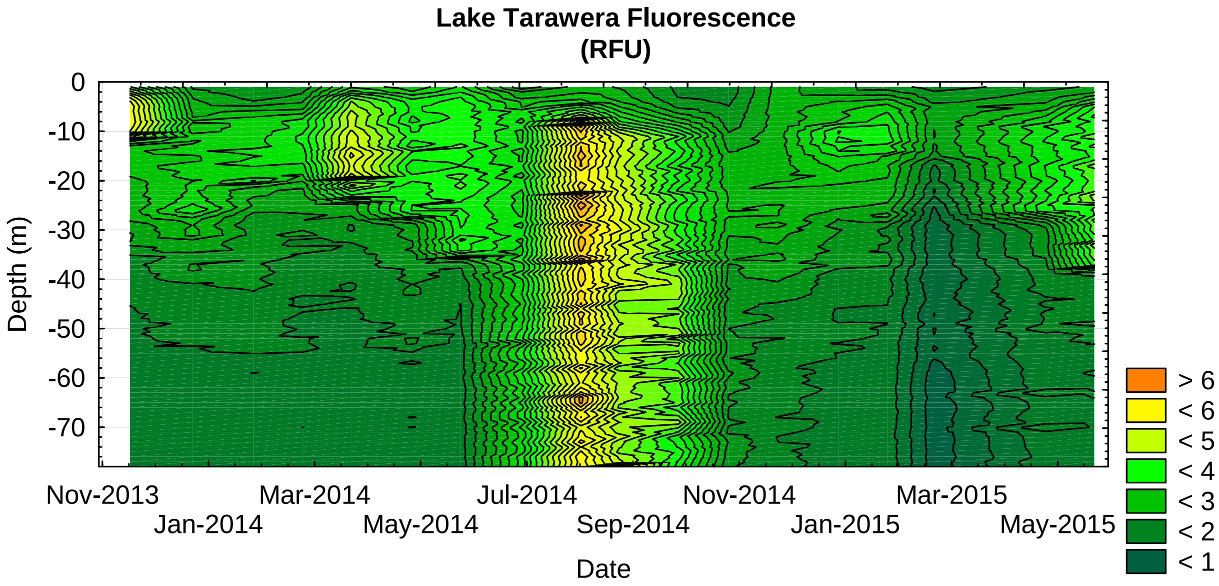
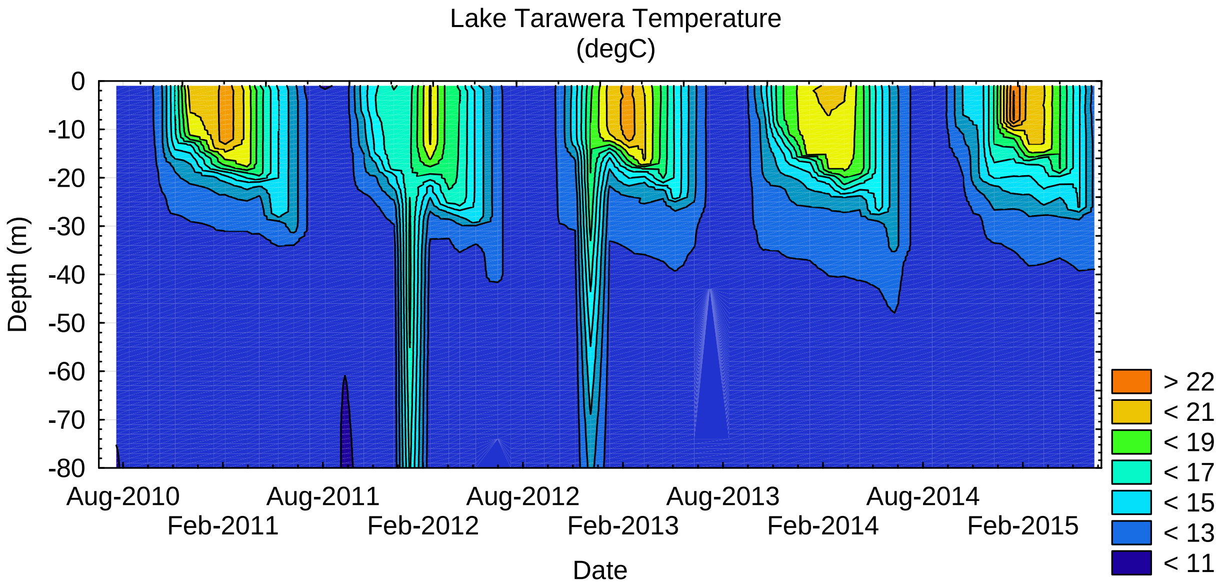


Figure 14.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Tarawera since 2001. The TLI target of 2.6 is indicated by the blue line in the top graph.





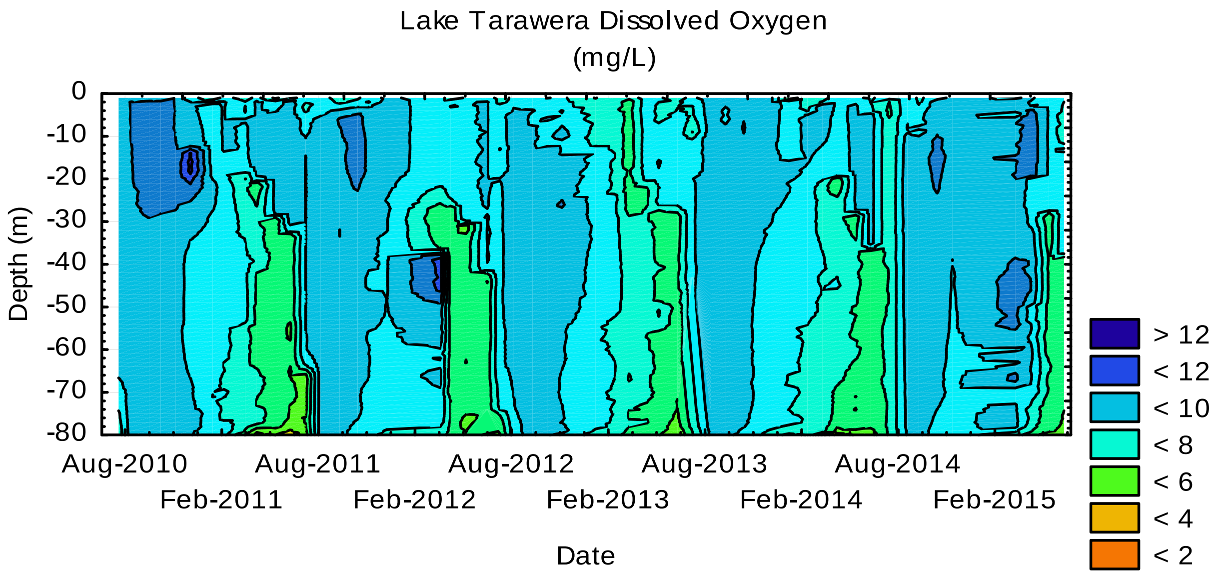


Figure 14.5 Time and depth plots of chlorophyll-a (top), temperature and dissolved oxygen concentrations (bottom).

14.3 LakeSPI results

Lake Condition: Moderate Stability: Stable

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Tarawera	25	29	87

In 1988 *Lagarosiphon* and *Elodea* were the two dominant invasive weed species in Lake Tarawera, with hornwort being observed only in Kotukutuku Bay. Hornwort is now the dominant invasive species reaching a maximum extent of 11.8 m and thought to have reached a stable range. Its dominance has resulted in the displacement of much of the deep-water charophyte meadows reducing the Native Condition Index to less than 30%.

Part 15: Lake Tikitapu

15.1 Introduction

Lake Tikitapu, also known as the Blue Lake is located north of Lake Rotokakahi at a higher elevation (418 m a s l). It formed as a result of a lava dam around 13,300 years ago. The lake has only small surface inflows, and has no surface outlet. Outflow is thought to occur through the sub-surface to Lake Tarawera via Lake Rotokakahi. The lake is of high aesthetic and recreational value, as it is frequently used for a range of water based recreational activities.

Lake Tikitapu is a small monomictic lake of low productivity. It has a flat lake bed with a maximum depth of 27.5 m. It has a topological catchment area of 6.2 km^2, including the lake area of 1.5 km^2, with the predominant land cover being indigenous vegetation. There is a lakeside campground and public amenities in the catchment, which were reticulated in 2010.

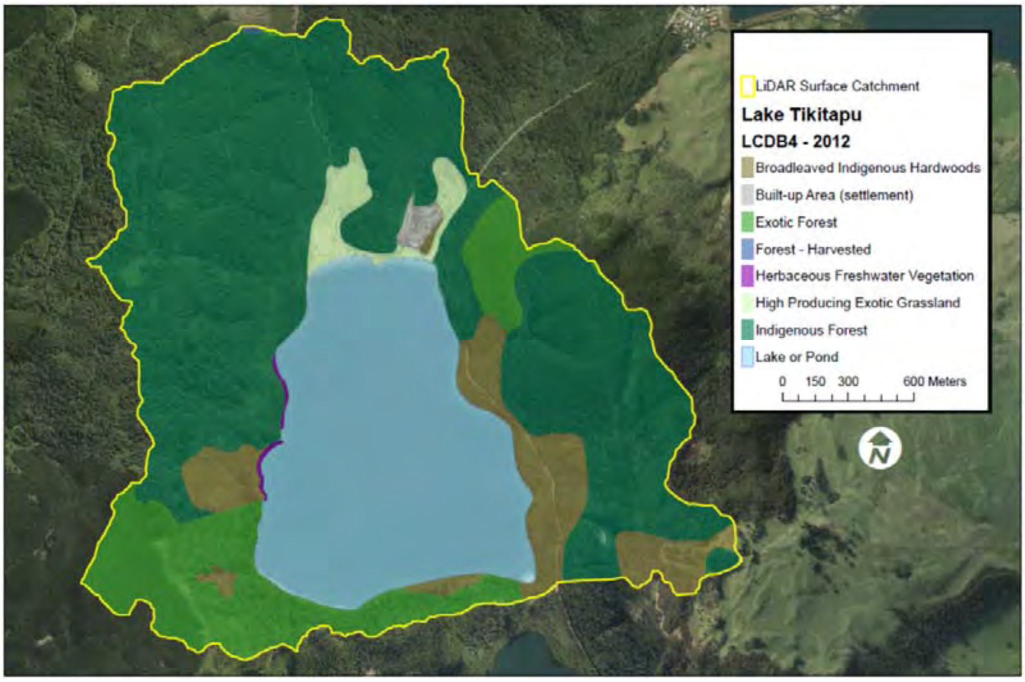


Figure 15.1 Lake Tikitapu catchment landuse (based on LCDB 2012).

15.2 Results

Lake Tikitapu is oligotrophic. It has a 2014/15 TLI value of 2.9, above the target of 2.6 in the RWLP. The TLI has remained relatively stable since 2002, but water clarity has improved and phosphorus concentrations have decreased (Table 15.1; Figure 15.2; Figure 15.4). There is also a weak indication of reduced oxygen demand in the bottom waters in recent years (Figure 15.3).

Ammonium concentrations in the hypolimnion appeared to be lower than in previous years, possibly reflecting a lower oxygen depletion rate in the hypolimnion compared to the past five years (Figure 15.4).

Low concentrations of dissolved nitrogen and phosphorus limit phytoplankton growth in Lake Tikitapu, but nutrient ratios suggest that phosphorus is potentially more limiting than nitrogen (Table 3.3). This is also indicated by consistently low concentrations of dissolved reactive phosphorus.

Chlorophyll-*a* concentrations tend to highest in winter (June to August) – probably due to the mixing of dissolved nutrients from the bottom waters as thermal stratification breaks down in early winter (Figure 15.5).

Fluorescence profiles show the deep chlorophyll maximum near the thermocline that dominates lake productivity over the summer months (Figure 15.5). Chlorophytes dominate primary productivity due to the low concentrations of silica in the lake limiting diatom growth (Ryan 2006).

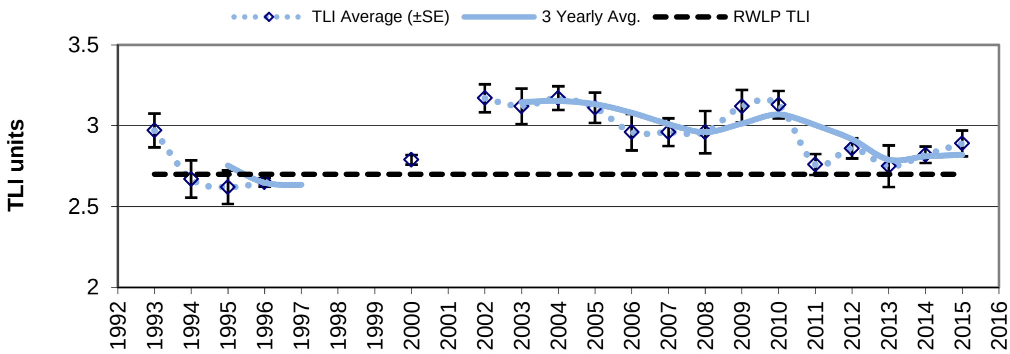


Figure 15.2 Annual average TLI with standard error bars, three yearly average TLI and RWLP TLI objective for Lake Tikitapu.

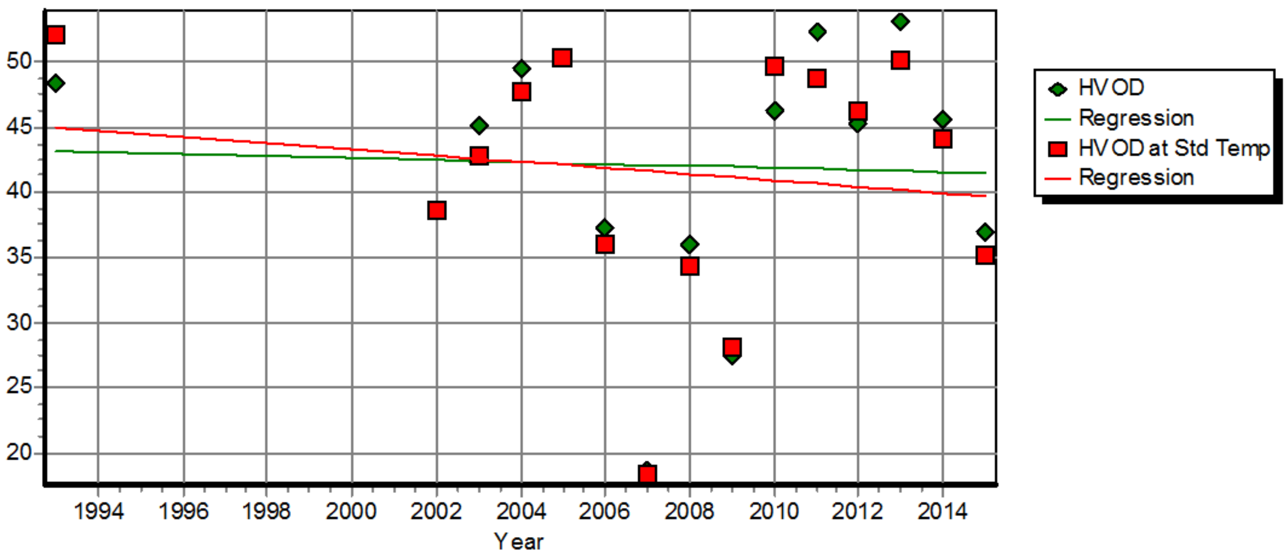


Figure 15.3 HVOD rates and HVOD rates adjusted to standard temperature, 1993 to 2015.

Table 15.1 Average water quality and trends in top and bottom waters of Lake Tikitapu. Arrows indicate the direction of a statistically significant trend or a potential emerging trend (in grey).

Variable	Top Average 2011-14	Trend 2002 to 2014				Trend 2010 to 2014			
		Top		Bottom		Top		Bottom	
		direction	PAC	direction	PAC	direction	PAC	direction	PAC
TLI *	2.7	↓	-0.8%			↘	-1.3%		
Chl-*a* (mg/m³)	2.0								
Secchi (m)	7.5	↑	1.7%						
TN * (mg/m³)	214			↓	-0.9%				
TP * (mg/m³)	3.6	↓	-4.1%	↓	-5.4%				
%DO	87.4	↓	-1.2%						
DO min (g/m³)	4.6			↓	-1.0%				
DIN (mg/m³)	11.8	↓	-4.8%	↓	-6.0%	↓	-24.8%	↓	-37.6%
NH_4-N (mg/m³)	3.3	↓	-5.3%	↓	-5.0%	↓	-22.4%	↓	-65.6%
DRP (mg/m³)	1.4								
EC (uS/cm)	12	↓	-0.5%	↓	-0.7%	↑	1.6%	↑	1.9%
pH	7.0	↑	0.7%	↑	1.1%			↑	1.5%
Temperature	15.1								
VLEC	0.2	↓	-0.9%						
Turbidity (NTU)	0.72	↓	-1.9%						

* = TN and TP after adjusting for laboratory changes.

Average based on three year period July 2011 to June 2014

↑ =increase, ↓ =decrease, ↗ =increase (*p* -value >0.05 & <0.1), ↘ =decrease (*p* -value >0.05 & <0.1)

Shaded out cells = variable not measured

Text in grey indicate a possible emerging trend, i.e. *p* -value >0.05 to <0.01 or PAC >0.5% to <1%.

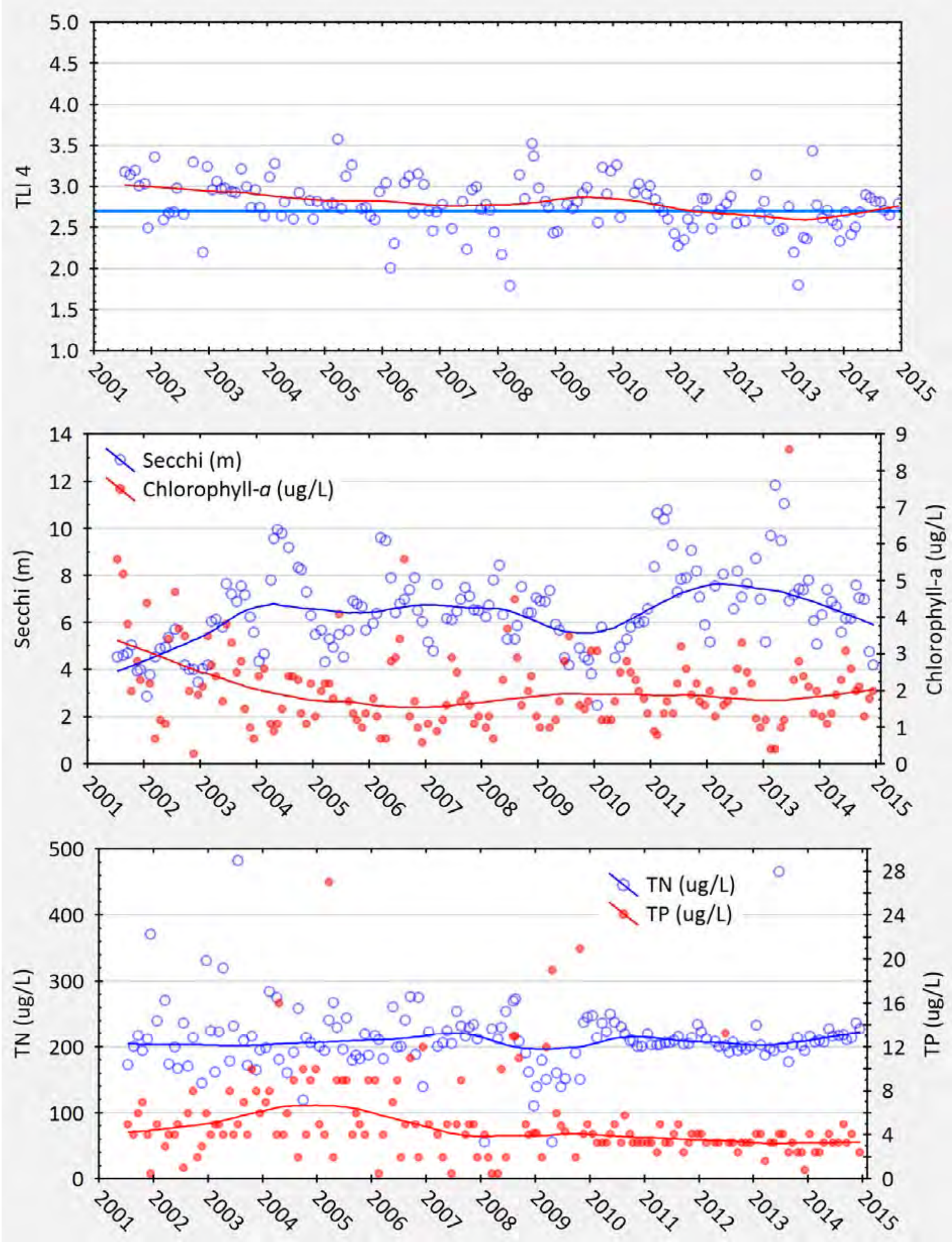


Figure 15.4 Changes in the TLI and its components (Secchi depth, chlorophyll-a, TN and TP) in Lake Tikitapu since 2001. The TLI target of 2.6 is indicated by the blue line in the top graph.

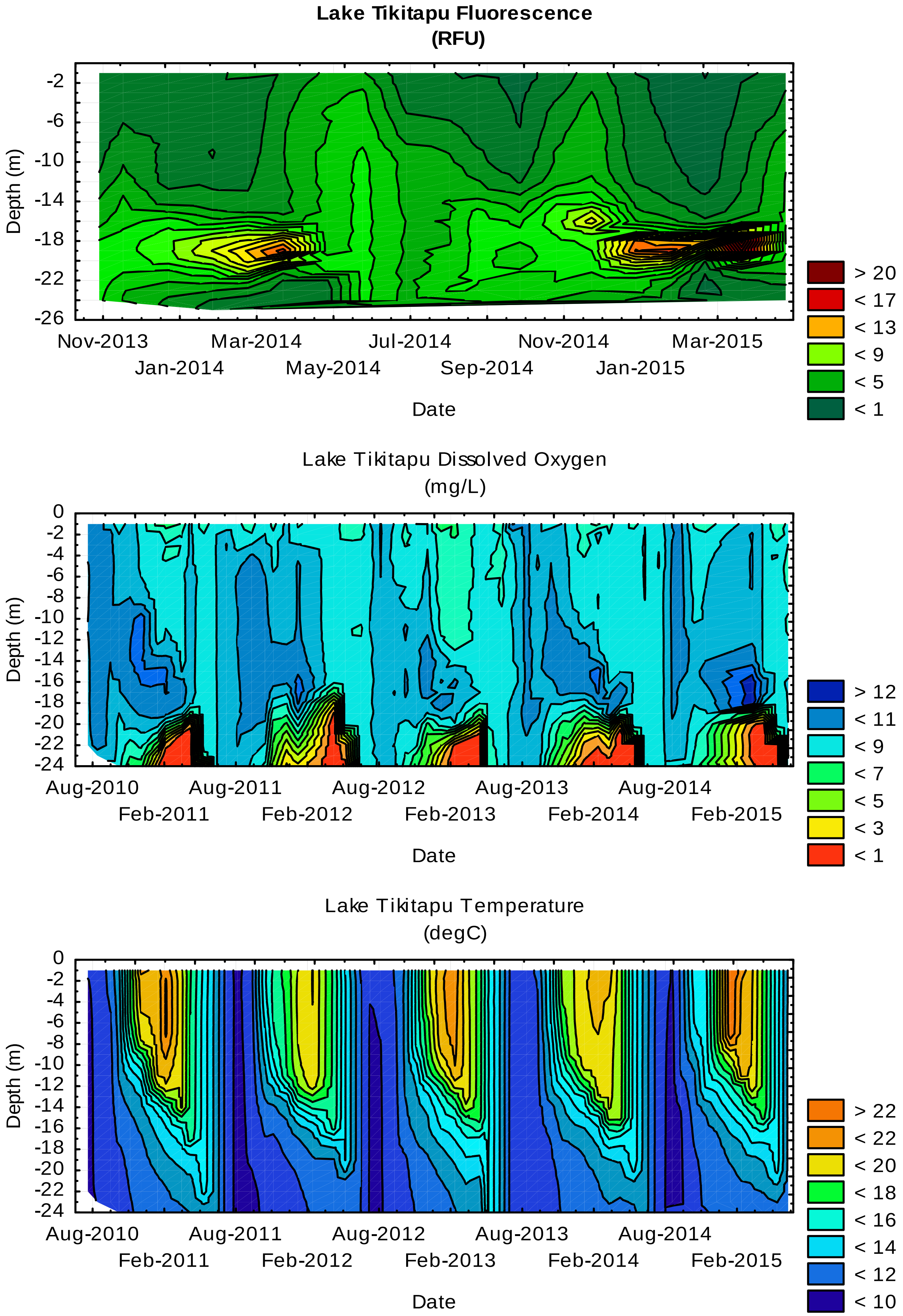


Figure 15.5 Time and depth plots of chlorophyll-a and dissolved oxygen concentrations, and temperature.

15.3 LakeSPI results

Lake Condition: Moderate   Stability: Improving?

	LakeSPI Condition %	Native Condition %	Invasive Impact %
Tikitapu	45	37	40

Tikitapu is categorised has having a moderate condition index and has potentially seen some improvement. Deep water native charophytes between depths of 16 to 20 m have developed, but the nature and extent is variable and it may be too early to say if these have recovered enough to be a consistent feature.

The invasive species *Lagarosiphon* was also found to be in lower abundance, with Tikitapu currently having the lowest Invasive Impact Index of the Rotorua Te Arawa lakes.

Part 16: Summary and conclusions

16.1 Summary

Significant improvements in water quality have occurred in Lakes Ōkāreka, Ōkaro, Rotoehu, Rotoiti, and Rotorua. In order to meet the RWLP targets, further improvements will be required in Lake Ōkāreka, and in Okawa Bay (Lake Rotoiti). Further improvements will also be needed in Lake Ōkaro to achieve the national bottom-lines set in the NPS.

There is evidence of deteriorating in water quality in Lake Rotomā, Lake Rotomahana, and Lake Tarawera. The reason for deterioration is not clear but these lakes should be closely monitored.

Calculating water quality trends in total nitrogen and total phosphorus over the period 2008 to 2010 was complicated by changes in laboratory methods. Adjustment factors were developed to account for these changes laboratory methods, and it is recommended that these adjustment factors are used when calculating trends over this period.

There also appeared to be step change decline in dissolved oxygen readings occurring in 2007 due to changes in meters. Caution is needed when assessing trends in DO occurring over this period and it may be more reliable to estimate trends in DO by using the Hypolimnetic Volumetric Oxygen Demand (HVOD).

Lake Ōkāreka is classed as mesotrophic and the TLI has not achieved its target (the TLI is 3.3 compared to its target of 3.0). There has been improvements in TLI since 2010 (driven by improvements in chlorophyll-*a* and TN), but there has also been a strong deterioration in TP in the lakes bottom water over the same period.

Lake Ōkaro has improved its classification from supertrophic (i.e. TLI of > 5.0) to eutrophic. There has been considerable improvement in the water quality of Lake Ōkaro since 2002 evident in all variables in both top and bottom waters. As a result, the lake now meets its TLI target set in the RWLP (TLI of 4.5). However, it has not achieved moving past the bottom-line values set by the NPS-FM because of particularly high concentrations of chlorophyll-*a* and nitrogen. The RWLP TLI target for Lake Ōkaro may need to be lowered, to ensure that the lake achieves the bottom lines in the NPS-FM.

Lake Ōkataina is in pristine condition and is classified as oligotrophic. It has a TLI of 2.9 compared to a target TLI of 2.6 set in the RWLP. The TLI has been stable over the long term with no significant trend since 2002.

Lake Rerewhakaaitu is mesotrophic. Its TLI is 3.3, so the lake has achieved the water quality target set in the RWLP (of TLI 3.6). The TLI increased during the period 2007 to 2010 and has since decreased.

Lake Rotoehu is classified as eutrophic. The TLI is 4.4, and although the lake neared its water quality target set in the RWLP (TLI of 3.9) in the previous two years, internal nutrient drivers and algal blooms bumped up the last TLI. However, the TLI has significantly improved since 2002 and since 2010.

The main body of Lake Rotoiti is classified as mesotrophic but Okawa Bay is eutrophic. The TLI is 3.8 and 4.1 in Okawa Bay. Lake Rotoiti water quality has considerably improved since 2002 and since 2010. In Okawa Bay, there were considerable improvements in water quality between 2002 and 2009, but the TLI shows no improvement in the last five years (since 2010).

Lake Rotomā is oligotrophic and has the best water quality of any lake in the Bay of Plenty. It has a TLI value of 2.5, slightly above the target of 2.3 set in the RWLP. Water quality has remained relative stable over the long term but since 2010 there was a significant deterioration in the TLI and reduced water clarity. There was also evidence of increasing phosphorus and reducing dissolved oxygen concentrations in the lake bottom waters.

Lake Rotomahana is mesotrophic with a TLI value of 4.0, slightly better than its target of 3.9 set in the RWLP. The lake is strongly influenced by geothermal activity. The TLI has slightly deteriorated since 2002, driven by an increase in the concentration of TN and TP. Since 2010 there has been no significant change in TLI, but phosphorus has increased and dissolved oxygen has decreased in the lake's bottom waters.

Lake Rotorua is eutrophic with a TLI value of 4.4, slightly worse than the target of 4.2 set in the RWLP. The TLI has significantly improved since 2002. Reductions in phosphorus concentrations has been particularly strong since the initiation of alum dosing of Utuhina Stream and Puarenga Stream in 2006 and 2010 respectively.

Lake Tarawera is on the cusp of oligotrophic and mesotrophic, but water quality is deteriorating and cyanobacteria blooms occasionally occur during summer. It has a TLI value of 3.1, which is worse than the RWLP target of 2.6. The water quality has significantly deteriorated since 2002 driven by an increase in nitrogen, phosphorus and a recent decline in water clarity.

Lake Tikitapu is oligotrophic. It has a TLI value of 2.9, which is above the target set in the RWLP. The lake has few pressures and the TLI has remained relatively stable since 2002.

Part 17: References

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Appendices

Appendix 1 – Laboratory Analysis Method Changes for Total Nitrogen, Total Phosphorous and Dissolved Reactive Phosphorous

Table A2.1 Historical laboratory method changes of TN, TP and DRP.

Internal Method Ref:	Date in use	Description	Lab	Detection Limit (g/m^3)
TKN-1	Up to Oct 08	APHA Method 4500B NIWA mod., Oct 1990	BOPRC (Env. BOP)	0.09 (mostly recorded as actual values)
TKN-7	Oct 08 – Oct 09 (some intermittent use 05/06	Kjeldahl Digestion. Phenol/hypchlorite colorimetry (discrete Analyser) APHA 4500-Norg C (modified)	RJH	0.1
TN-2	Project use 92	Persulphate digestion, AA hydrazine reduction	NIWA	0.001
TN-5	Nov 09 – present NIWA (intermittent 05/06)	Persulphate digestion, auto cadmium reduction. FIA	BOPRC (20.08.10) NIWA	0.001
TP-1	Up to July 08	NWASCO Misc Pub. No38, 1982 Antimony – Phosphate Molybdate, derived Murphy-Riley Method (1962)	BOPRC (Env. BOP)	*listed as* 0.008 recorded as 0.001
TP-6	Aug 08 – Oct 09	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. Apha 4500-P E(modified)		0.004
TP-2	Nov 09 – Aug 10	Acid persulphate digestion/ molybdenum blue colorimetry	NIWA	0.001
TP-5	Aug 10 - present	Acid persulphate digestion, molybdate colorimetry. FIA. Apha 4500-P H	BOPRC (20.08.10)	0.001
DRP-1	Up to Sept 08	NWASCO Misc Pub. No38, 1982 Antimony – Phosphate Molybdate, derived Murphy-Riley Method (1962)	BOPRC (Env. BOP)	*historically listed as* 0.004 recorded as 0.001
DRP-6	Oct 08 – Oct 09	Molybdenum blue colorimetry, discrete analyser, APHA 4500 P –E (Modified)	Hills	0.004
DRP-5	Nov 09 – Aug 10	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	NIWA (08.12.09)	0.001
DRP-5	Aug 10 - present	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	BOPRC (20.08.10)	0.001

Appendix 2 – Adjusting for changes in laboratory analysis of total nitrogen and total phosphorus

Introduction

Changes in laboratory methods for analysing total nitrogen (TN), total phosphorus (TP) and dissolved reactive phosphorus (DRP) occurred in late 2008 and 2009 (see Appendix 1). The recent laboratory changes have resulted in less variability of results but also caused a step change decrease in TN results and a step change increase in TP (Table A3.1). This complicates the assessment of trends in water quality and may affect the calculation of the TLI and comparisons with target values.

When there is a change in laboratory or laboratory method, it is best practice to undertake a period of cross calibration - where duplicate samples were analysed by the different methods to ensure consistency. This did not occur. Furthermore, it is difficult to undertake this calibration process retrospectively because the old laboratory methods are no longer routinely run. In the absence of this calibration information, statistical methods were used to quantify the difference in TN and TP results that can be attributed to the change in laboratory methods.

Method

Lakes and rivers with few pressures and relatively stable water quality were selected and median values of TN and TP were calculated for the four year period of July 2004 to June 2008 (before the method changes) and July 2010 to June 2014 (after the method changes). A regression was made between the two periods. The analysis was repeated using seasonal data rather than four year medians and the results were very similar.

Sites used in the analysis were: Lakes Ōkāreka, Ōkataina, Rotomā, Rotomahana, Tarawera and Tikitapu. Rivers used in the analysis were Utuhina Stream, Waiohewa Stream, Waiowhiro Stream and Omanawa River. Data from other rivers in the region were not used to quantify the effect of the laboratory method change, because of either changing pressures in the catchments or too few data points or because they had trends in nitrate concentration (a substantial component of TN in rivers). For lake samples the results from surface waters, bottom waters and hypoxic bottom waters were used independently in the analysis.

The sites used in the analysis were further refined based trends in TN, TP or nitrate that was apparent before or after the time of laboratory changes. The TN analysis did not include Waiowhiro Stream or Omanawa River because concentrations of nitrate were significantly different between the periods. The TP analysis did not include: Lake Tarawera, Ōkāreka (bottom and bottom x), Rotomahana (bottom), or Utuhina Stream. This was because these lake sites had significant trends in TP during the period after January 2010 and alum dosing occurs in the Utuhina Stream (see Table A3.2).

No lake had completely stable water quality for all variables but the lakes with few pressures and reasonably stable TN and TP concentrations, for the five year period before July 2008 and the five years after January 2010 were:

- Ōkāreka: TN showed no significant trend in five year period before but a decline in five year period after (PAC -2.3%). TP showed no significant trend before or after.
- Ōkataina: TN showed no significant trend before but a decline in the five year period after (PAC -4.2%). TP had no significant trend before or after.
- Rotomā: TN showed an increasing trend before July 2008 (PAC 4.7%) but no trend after. TP showed no significant trend before or after.

- Rotomahana: TN showed no significant trend before or after the period. TP showed no significant trend before or after.
- Tarawera: TN showed an increasing trend before July 2008 (PAC 13%) but no trend after. TP showed no significant trend before or after.
- Tikitapu: TN and TP showed no significant trend before or after the period.

Total Phosphorous was reasonably stable in all these lakes for the five year periods before and after the method change. However the only lakes that showed no trend in TN were Rotomahana and Tikitapu. Tarawera and Rotomā had an increasing trend before July 2008, so including these lakes in the analysis might make a more conservative assessment of declines due to method changes.

Results

The new laboratory method appears to have resulted in a step change increase in total nitrogen of about 50.7 mg/m^3 ([TN old method] = 1.0008 [TN new method] + 50.7 mg/m^3, R^2 0.9992, n = 20).

The analysis confirmed that the new laboratory method reports lower TP values compared to the old method. The relationship between the two methods can be expressed by the equation:

[TP old method] = 0.829 [TP new method] $R^2 = 0.99$, n = 15.

Dissolved inorganic nitrogen (DIN) is a large component of total nitrogen in rivers but usually a small component of TN in lakes. The changes in the ratio of TN:DIN was used to confirm the effect of a lab method change. The TN:DIN ratio for the periods before and after the lab method change was compared from nine tributaries to Lake Rotorua and eleven other rivers throughout the region. All sites had an apparent decline in the TN:DIN ratio occurring in late 2009 when laboratory methods changed (CUSMUM test). A statistically significant decline occurred in 15 out of the 20 sites.

Table A3.1 Arithmetic mean (ppb) and standard error of mean of lake surface water samples for the four year periods before July 2008 and after July 2010.

Arithmetic mean

Lake	TN before	TN after	TP before	TP after	DRP before	DRP after
Ōkāreka	220.6	183.9	8.68	9.71	2.73	2.73
Ōkataina	154.3	90.6	8.21	11.76	3.49	4.67
Rotomā	174.2	101.0	5.26	6.27	2.14	3.16
Rotomahana	223.3	196.3	36.74	46.70	10.58	20.74
Tarawera	149.2	90.2	9.88	19.33	5.05	10.60
Tikitapu	212.4	162.3	5.85	4.36	2.56	1.50

Standard Deviation

Lake	TN before	TN after	TP before	TP after	DRP before	DRP after
Ōkāreka	47.17	20.07	3.931	4.010	2.616	1.267
Ōkataina	68.66	12.43	3.775	4.998	3.245	1.329
Rotomā	80.68	16.98	3.091	2.789	1.906	2.079
Rotomahana	56.63	23.13	14.835	7.313	5.388	4.618
Tarawera	88.96	22.48	4.470	4.007	3.968	2.368
Tikitapu	40.03	39.52	4.524	2.015	2.406	1.716

Table A3.2 Median TN (ppb) and TP for the four year periods before July 2008 and after July 2010 for stable sites used in the analysis.

site	layer	TN before	TN after	TP before	TP after	comment
Lake Ōkāreka	top	221	182	9	9	
Lake Ōkāreka	bottom	215.75	159			Upward TP trend since 2010
Lake Ōkāreka	bottom x	229	179			Upward TP trend since 2010
Lake Ōkataina	top	145	89	7.5	11	
Lake Ōkataina	bottom	121.5	78	9	12	
Lake Ōkataina	bottom x	129.25	90	14	16	
Lake Rotomā	top	152	100	4	6	
Lake Rotomā	bottom	131	80	4	5	
Lake Rotomā	bottom x	145.5	91	5	6	
Lake Rotomahana	top	213	194	36	47	
Lake Rotomahana	bottom	228	195			Upward TP trend since 2010
Lake Rotomahana	bottom x	248.5	210	44	51	
Lake Tarawera	top	136.5	88			
Lake Tarawera	bottom	108.75	61.5			Upward TP trend since 2010
Lake Tarawera	bottom x	116	70			
Lake Tikitapu	top	213.75	156	5	4	
Lake Tikitapu	bottom	232.5	159	6	5	
Lake Tikitapu	bottom x	251.75	169.5	7	5	
Omanawa River	river			29	38.25	Upward nitrate trend
Utuhina River	river	815.5	729			Alum dosing for P
Waiohewa Stream	river	2640	2595	62	72.5	
Waiowhiro Stream	river			45	54.5	Upward nitrate trend

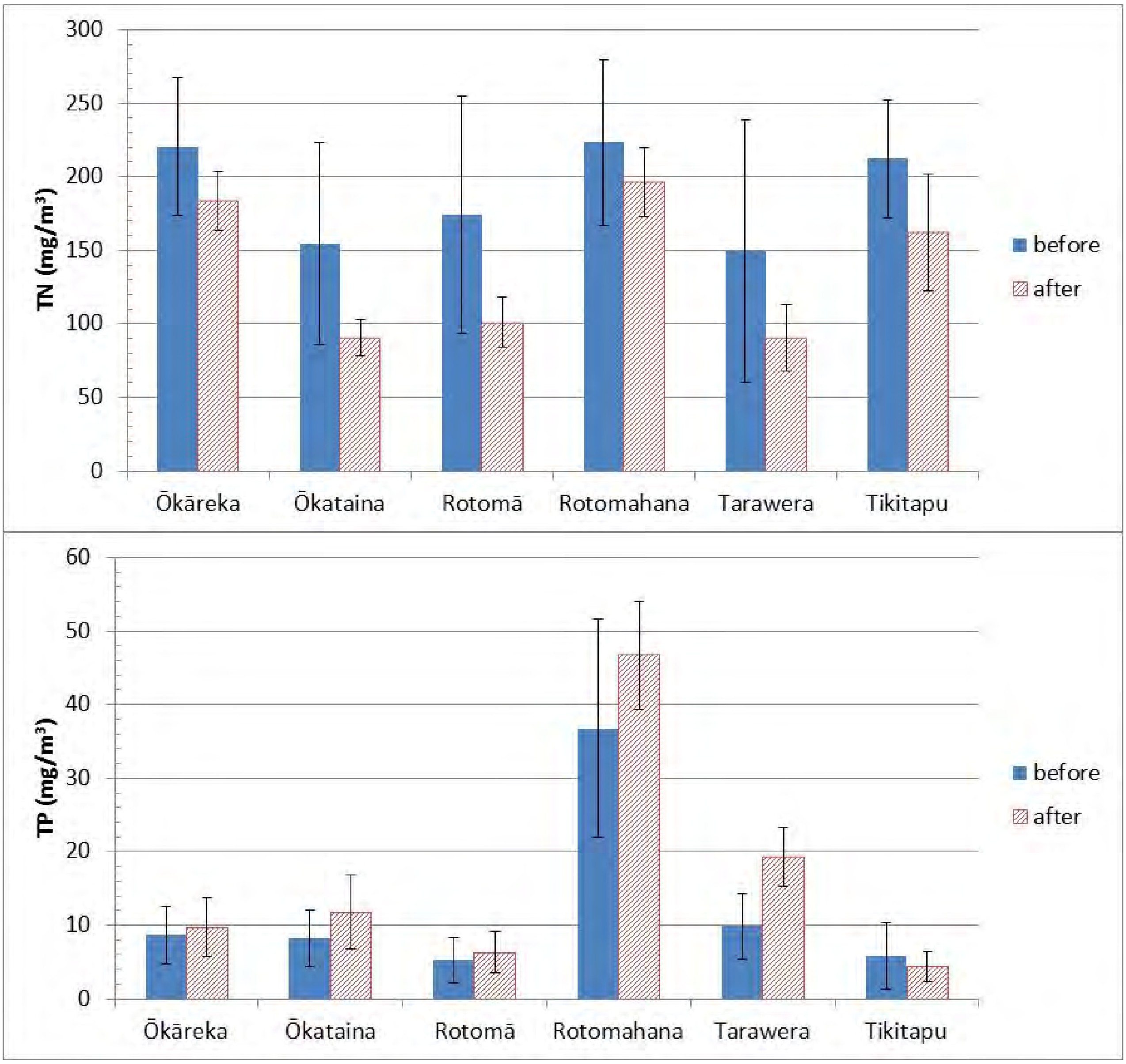

Figure A3.1 Comparison of average TN (top) and TP (bottom) results for the three year period before July 2009 and after July 2010. For Rotorua lakes with relatively stable water quality, the changes in laboratory methods resulted in lower TN, higher TP and less variation. Error bars are one standard deviation.

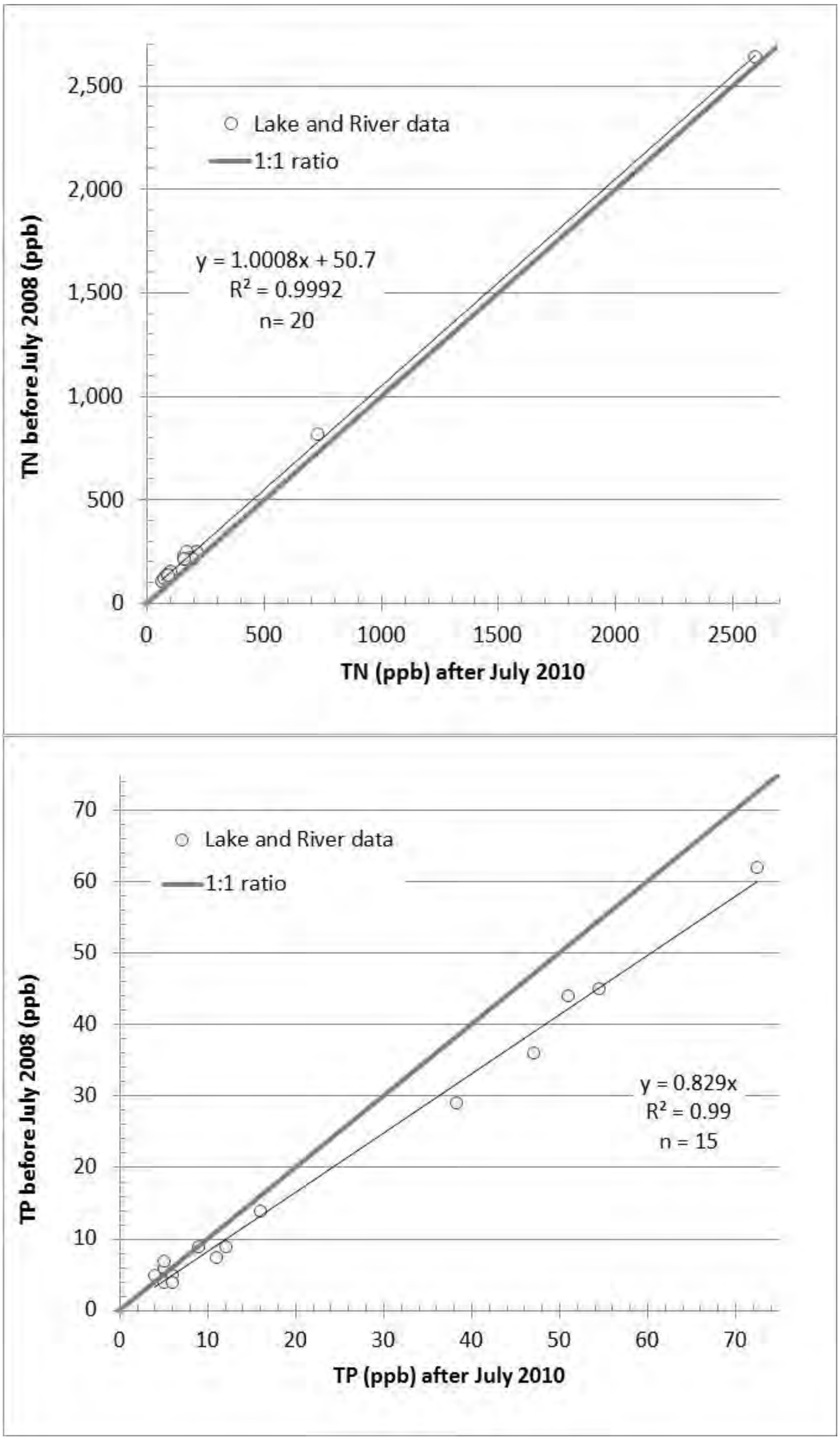

Figure A3.2 Four year median TN (top) and TP (bottom) in stable lakes and rivers compared before and after laboratory method changes. The 1:1 ratio indicates the relationship if there was no difference between the time periods.

Conclusions

It is recommended that the following adjustment factors are applied to data since November 2009 prior to undertaking trend analysis that spans the period August 2008 to November 2009:

- [TN old method] = [TN new method] + 50.7 mg/m^3
- [TP old method] = 0.829 [TP new method]

It is possible that the adjustment is also applicable for data since August 2008 for TP and since October 2008 for TN but this could not be confirmed by the analysis.

The recent laboratory changes have resulted in a decrease in TN results and an increase in TP results. For the purpose of calculating TLI scores, these changes mostly cancel each other out and there is very little impact on the TLI score.

The formulas calculated in this analysis provide an approximate adjustment factor. A more accurate way to assess the effect of changes in laboratory method would be to analyse a range of water samples, using both the new and the old method. Unfortunately, the old laboratory methods are no longer routinely run, so this approach would require a separate investigation.

Appendix 3 – Lake water quality state (July 2011-June 2014)

Lake	Variable	Minimum	Maximum	Mean	Median	75 percentile	25 percentile	Standard deviation
Ōkāreka	TLI4 adj	2.6	3.5	3.1	3.1	3.3	3.0	0.2
Ōkāreka	TN (mg/m^3)	147.0	236.0	183.0	182.0	194.0	168.0	20.8
Ōkāreka	TP (mg/m^3)	5.0	31.0	10.1	9.0	11.0	8.0	4.5
Ōkāreka	Chl-*a* (mg/m^3)	1.0	8.7	3.7	3.5	4.6	2.3	1.8
Ōkāreka	Secchi (m)	5.0	12.2	7.8	7.8	8.8	6.8	1.5
Ōkāreka	DIN (mg/m^3)	1.5	23.0	5.3	3.8	7.0	2.0	4.8
Ōkāreka	DRP (mg/m^3)	1.0	9.0	2.9	3.0	3.0	2.0	1.4
Ōkāreka	pH	6.7	8.0	7.6	7.7	7.8	7.5	0.3
Ōkāreka	temperature	9.5	21.7	15.2	15.2	18.6	10.9	3.9
Ōkāreka	%DO	67.3	101.2	86.3	85.7	92.9	81.0	8.5
Ōkaro	TLI4 adj	3.2	6.2	4.8	4.6	5.3	4.1	0.8
Ōkaro	TN (mg/m^3)	336.5	1975.0	854.1	863.3	1052.5	486.5	425.1
Ōkaro	TP (mg/m^3)	9.5	231.0	56.3	42.0	77.3	22.3	47.7
Ōkaro	Chl-*a* (mg/m^3)	1.5	144.6	27.3	11.1	32.0	6.0	34.8
Ōkaro	Secchi (m)	0.4	7.2	2.7	2.4	3.2	2.0	1.5
Ōkaro	DIN (mg/m^3)	1.5	1264.0	177.8	33.8	320.8	7.6	272.7
Ōkaro	DRP (mg/m^3)	0.5	143.0	16.0	5.0	11.5	2.5	28.7
Ōkaro	pH	6.9	10.2	8.2	7.9	8.9	7.4	1.0
Ōkaro	temperature	8.4	22.0	15.1	15.6	19.7	11.2	4.6
Ōkaro	%DO	49.8	125.3	85.0	84.5	101.5	70.0	19.5
Ōkataina	TLI4 adj	2.2	3.2	2.7	2.7	2.9	2.6	0.2
Ōkataina	TN (mg/m^3)	66.0	122.0	88.8	88.0	98.3	80.8	12.4
Ōkataina	TP (mg/m^3)	4.0	43.0	11.6	11.0	12.0	9.8	5.7
Ōkataina	Chl-*a* (mg/m^3)	1.1	5.1	2.1	1.9	2.6	1.3	1.0
Ōkataina	Secchi (m)	5.9	14.6	10.0	10.0	11.7	8.7	2.0
Ōkataina	DIN (mg/m^3)	1.5	42.0	5.0	2.8	5.0	1.8	7.2
Ōkataina	DRP (mg/m^3)	3.0	10.0	4.8	4.0	5.0	4.0	1.4
Ōkataina	pH	7.1	8.5	7.5	7.5	7.6	7.4	0.3
Ōkataina	temperature	11.0	20.8	15.4	15.4	18.8	12.1	3.4
Ōkataina	%DO	69.1	107.4	87.5	89.2	94.1	80.4	9.9
Rerewhakaaitu	TLI4 adj	3.0	3.8	3.4	3.4	3.6	3.2	0.2
Rerewhakaaitu	TN (mg/m^3)	275.0	395.0	353.7	359.0	376.5	333.5	28.9
Rerewhakaaitu	TP (mg/m^3)	6.0	15.0	9.8	9.0	11.5	8.5	2.1
Rerewhakaaitu	Chl-*a* (mg/m^3)	1.3	6.6	3.7	3.3	4.9	2.5	1.5
Rerewhakaaitu	Secchi (m)	3.6	8.2	5.7	5.8	6.8	4.7	1.3
Rerewhakaaitu	DIN (mg/m^3)	2.0	43.0	14.0	11.0	20.5	6.0	10.9
Rerewhakaaitu	DRP (mg/m^3)	1.0	5.0	2.6	2.0	3.5	2.0	1.2
Rerewhakaaitu	pH	7.0	8.0	7.4	7.4	7.6	7.3	0.2
Rerewhakaaitu	temperature	7.6	21.0	14.7	15.4	18.8	10.5	4.5
Rerewhakaaitu	%DO	51.5	103.5	85.5	88.1	90.9	81.2	9.3
Rotoehu	TLI4 adj	3.4	4.5	3.9	3.9	4.1	3.7	0.3
Rotoehu	TN (mg/m^3)	173.0	319.0	239.3	234.0	276.0	210.5	40.0
Rotoehu	TP (mg/m^3)	17.0	98.0	27.8	25.5	31.5	21.0	13.4
Rotoehu	Chl-*a* (mg/m^3)	2.3	12.8	5.8	5.4	6.8	3.6	2.6
Rotoehu	Secchi (m)	1.9	5.4	3.5	3.6	4.1	2.9	0.8
Rotoehu	DIN (mg/m^3)	1.5	101.0	12.8	5.0	11.5	2.0	22.3
Rotoehu	DRP (mg/m^3)	4.0	16.0	7.5	7.0	8.5	6.0	2.8
Rotoehu	pH	6.9	8.1	7.8	7.9	8.0	7.7	0.2
Rotoehu	temperature	9.0	22.5	15.7	16.0	19.7	11.6	4.3
Rotoehu	%DO	72.8	108.8	87.8	86.8	94.1	82.9	7.6

Lake	Variable	Minimum	Maximum	Mean	Median	75 percentile	25 percentile	Standard deviation
Rotoiti 1-4	TLI4 adj	2.7	4.0	3.3	3.3	3.5	3.1	0.3
Rotoiti 1-4	TN (mg/m^3)	115.0	208.0	155.7	155.0	168.0	140.0	19.6
Rotoiti 1-4	TP (mg/m^3)	8.0	35.0	16.8	14.0	21.5	11.5	7.3
Rotoiti 1-4	Chl-*a* (mg/m^3)	1.2	11.0	4.7	4.6	5.6	2.8	2.4
Rotoiti 1-4	Secchi (m)	4.3	10.2	6.9	6.8	7.8	6.0	1.5
Rotoiti 1-4	DIN (mg/m^3)	1.5	81.0	8.6	3.5	7.0	2.0	16.7
Rotoiti 1-4	DRP (mg/m^3)	1.0	29.0	6.3	3.0	9.0	2.0	6.8
Rotoiti 1-4	pH	6.7	8.2	7.2	7.2	7.3	7.1	0.3
Rotoiti 1-4	temperature	11.1	21.0	15.6	15.8	18.7	12.4	3.3
Rotoiti 1-4	%DO	58.0	107.6	86.8	88.8	93.3	82.6	10.5
Rotoiti 3	TLI4 adj	2.7	4.0	3.5	3.5	3.7	3.4	0.3
Rotoiti 3	TN (mg/m^3)	138.0	218.0	171.2	170.0	187.5	156.8	19.9
Rotoiti 3	TP (mg/m^3)	9.0	31.0	16.5	15.0	19.0	12.8	5.8
Rotoiti 3	Chl-*a* (mg/m^3)	1.3	9.0	5.2	5.0	6.1	4.0	2.2
Rotoiti 3	Secchi (m)	2.7	9.2	5.7	5.6	6.9	4.3	1.7
Rotoiti 3	DIN (mg/m^3)	1.5	129.0	11.2	3.5	10.0	1.5	24.3
Rotoiti 3	DRP (mg/m^3)	0.5	17.0	4.3	3.0	5.5	1.5	4.1
Rotoiti 3	pH	6.5	7.8	7.2	7.2	7.3	7.1	0.3
Rotoiti 3	temperature	10.9	21.3	15.9	16.1	18.6	12.4	3.4
Rotoiti 3	%DO	67.6	101.5	87.1	87.9	91.9	83.6	7.3
Rotoiti Okawa Bay	TLI4 adj	3.2	4.8	4.0	4.0	4.4	3.6	0.5
Rotoiti Okawa Bay	TN (mg/m^3)	172.0	485.0	284.8	258.0	337.0	232.0	81.8
Rotoiti Okawa Bay	TP (mg/m^3)	13.0	69.0	29.5	29.0	33.5	22.0	11.6
Rotoiti Okawa Bay	Chl-*a* (mg/m^3)	1.7	20.2	7.2	5.9	9.0	3.3	4.9
Rotoiti Okawa Bay	Secchi (m)	1.5	5.4	3.0	2.9	4.1	2.2	1.1
Rotoiti Okawa Bay	DIN (mg/m^3)	1.5	141.0	10.8	4.0	6.5	3.0	23.5
Rotoiti Okawa Bay	DRP (mg/m^3)	1.0	29.0	5.8	4.0	6.0	3.0	5.4
Rotoiti Okawa Bay	pH	6.8	8.5	7.4	7.4	7.6	7.2	0.4
Rotoiti Okawa Bay	temperature	8.7	22.4	15.8	16.4	19.9	11.8	4.2
Rotoiti Okawa Bay	%DO	72.4	102.0	85.9	84.3	91.8	79.7	8.0
Rotomā	TLI4 adj	1.5	2.7	2.3	2.4	2.4	2.2	0.2
Rotomā	TN (mg/m^3)	77.0	140.0	99.3	99.5	105.5	91.5	12.2
Rotomā	TP (mg/m^3)	1.0	20.0	6.6	6.0	7.0	5.0	3.1
Rotomā	Chl-*a* (mg/m^3)	0.6	6.7	1.3	1.1	1.6	0.8	1.0
Rotomā	Secchi (m)	6.2	15.9	12.9	13.1	14.6	11.8	2.0
Rotomā	DIN (mg/m^3)	1.5	49.0	10.4	6.0	13.8	3.8	10.7
Rotomā	DRP (mg/m^3)	0.5	13.0	3.3	3.0	4.0	2.0	2.4
Rotomā	pH	6.5	8.0	7.2	7.1	7.4	7.0	0.3
Rotomā	temperature	11.0	21.2	15.5	15.7	18.6	11.9	3.5
Rotomā	%DO	72.0	102.5	88.4	89.4	93.5	82.3	7.8
Rotomahana	TLI4 adj	3.5	4.3	3.8	3.8	3.9	3.7	0.2
Rotomahana	TN (mg/m^3)	154.0	231.0	192.9	191.0	209.5	179.0	20.9
Rotomahana	TP (mg/m^3)	36.0	59.0	45.3	46.0	49.0	40.3	5.8
Rotomahana	Chl-*a* (mg/m^3)	1.6	10.0	4.3	3.8	5.1	2.9	2.0
Rotomahana	Secchi (m)	2.7	10.3	5.3	5.3	6.3	3.9	1.7
Rotomahana	DIN (mg/m^3)	1.5	112.0	37.8	12.0	79.8	5.3	38.6
Rotomahana	DRP (mg/m^3)	11.0	30.0	21.2	21.0	24.8	18.3	4.4
Rotomahana	pH	6.4	7.9	7.2	7.3	7.5	6.9	0.4
Rotomahana	temperature	13.6	21.9	17.0	16.4	19.3	14.2	2.8
Rotomahana	%DO	62.7	121.3	89.3	87.8	99.4	77.8	13.5

Lake	Variable	Minimum	Maximum	Mean	Median	75 percentile	25 percentile	Standard deviation
Rotorua 2	TLI4 adj	3.6	4.5	4.0	4.1	4.2	3.9	0.2
Rotorua 2	TN (mg/m^3)	228.0	377.0	304.8	297.0	343.0	279.0	41.2
Rotorua 2	TP (mg/m^3)	9.0	43.0	17.4	15.5	21.5	13.0	6.8
Rotorua 2	Chl-*a* (mg/m^3)	4.6	29.8	11.0	9.5	14.2	7.0	5.7
Rotorua 2	Secchi (m)	1.8	4.9	3.1	3.0	3.6	2.6	0.7
Rotorua 2	DIN (mg/m^3)	3.0	196.0	61.0	45.5	94.0	11.0	56.7
Rotorua 2	DRP (mg/m^3)	0.5	8.0	2.0	2.0	2.0	1.0	1.4
Rotorua 2	pH	5.4	7.6	6.9	6.8	7.2	6.7	0.4
Rotorua 2	temperature	9.1	22.3	15.5	15.3	19.3	11.4	4.1
Rotorua 2	%DO	68.3	106.7	87.9	88.6	92.4	82.9	8.5
Rotorua 5	TLI4 adj	3.6	4.4	4.0	4.0	4.2	3.8	0.3
Rotorua 5	TN (mg/m^3)	240.0	812.0	322.6	308.5	342.5	274.5	94.4
Rotorua 5	TP (mg/m^3)	9.0	26.0	16.1	15.5	19.0	12.0	4.5
Rotorua 5	Chl-*a* (mg/m^3)	1.9	31.0	9.9	9.6	11.6	5.9	5.6
Rotorua 5	Secchi (m)	1.7	5.3	3.1	3.0	3.7	2.6	0.8
Rotorua 5	DIN (mg/m^3)	2.0	509.0	82.1	64.0	113.0	11.5	93.9
Rotorua 5	DRP (mg/m^3)	0.5	6.0	2.0	2.0	2.5	1.0	1.2
Rotorua 5	pH	6.3	7.4	7.0	7.0	7.1	6.8	0.2
Rotorua 5	temperature	9.0	21.4	15.4	15.4	19.0	11.6	4.0
Rotorua 5	%DO	71.3	99.7	86.2	85.2	90.1	82.5	7.0
Tarawera	TLI4 adj	2.6	3.2	2.9	2.9	3.0	2.8	0.2
Tarawera	TN (mg/m^3)	62.0	195.0	91.5	88.0	104.0	73.3	24.8
Tarawera	TP (mg/m^3)	9.0	39.0	19.1	19.0	21.0	16.0	4.5
Tarawera	Chl-*a* (mg/m^3)	0.6	2.8	1.5	1.6	2.0	1.1	0.6
Tarawera	Secchi (m)	4.6	10.8	8.2	8.0	9.5	7.2	1.6
Tarawera	DIN (mg/m^3)	1.0	17.0	3.4	2.0	3.5	1.5	3.6
Tarawera	DRP (mg/m^3)	3.0	17.0	10.4	10.0	12.0	9.0	2.6
Tarawera	pH	7.1	8.1	7.8	7.8	8.0	7.6	0.2
Tarawera	temperature	11.1	20.8	15.3	15.4	17.8	11.9	3.2
Tarawera	%DO	71.8	98.6	87.9	87.1	94.7	83.9	7.2
Tikitapu	TLI4 adj	1.8	3.4	2.6	2.7	2.8	2.5	0.3
Tikitapu	TN (mg/m^3)	127.0	416.0	163.3	155.0	163.0	149.3	45.6
Tikitapu	TP (mg/m^3)	1.0	16.0	4.3	4.0	5.0	3.3	2.3
Tikitapu	Chl-*a* (mg/m^3)	0.4	8.6	2.0	1.9	2.4	1.3	1.3
Tikitapu	Secchi (m)	5.1	11.9	7.5	7.4	8.1	6.5	1.5
Tikitapu	DIN (mg/m^3)	1.5	263.0	11.8	4.0	6.9	2.0	43.8
Tikitapu	DRP (mg/m^3)	0.5	5.0	1.4	1.0	1.8	0.6	1.1
Tikitapu	pH	6.2	7.8	7.0	7.1	7.3	6.7	0.3
Tikitapu	temperature	9.7	21.3	15.1	15.1	18.4	11.0	3.8
Tikitapu	%DO	74.0	103.1	87.4	86.6	95.4	81.9	7.5
Rotokakahi outlet	TLI3 adj	3.2	4.4	3.7	3.7	3.9	3.4	0.3
Rotokakahi outlet	TN (mg/m^3)	169.0	328.0	220.2	215.5	231.0	199.0	34.5
Rotokakahi outlet	TN adj (mg/m^3)	219.6	378.6	270.8	266.1	281.6	249.6	34.5
Rotokakahi outlet	TP (mg/m^3)	11.0	29.0	17.8	17.0	20.5	14.5	4.3
Rotokakahi outlet	TP adj (mg/m^3)	9.1	24.0	14.7	14.1	17.0	12.0	3.6
Rotokakahi outlet	Chl-*a* (mg/m^3)	1.1	15.3	4.8	4.0	6.0	2.5	3.2
Rotokakahi outlet	Secchi equiv (m)	1.8	5.9	3.7	3.8	4.6	2.9	1.1
Rotokakahi outlet	Temperature	9.9	21.3	15.4	15.9	19.2	11.0	3.9
Rotokakahi outlet	pH	6.7	8.1	7.5	7.5	7.7	7.3	0.3
Rotokakahi outlet	DRP (mg/m^3)	1.0	8.0	3.8	4.0	4.5	3.0	1.5
Rotokakahi outlet	NH_4-N (mg/m^3)	1.0	58.0	8.7	3.5	9.5	1.0	13.6
Rotokakahi outlet	DIN (mg/m^3)	1.5	77.0	12.1	5.3	12.5	2.8	16.9
Rotokakahi outlet	%DO	87.8	111.1	99.3	99.7	102.2	95.4	6.0

Rotokakahi data was from outlet (Te Wairoa Stream) and TLI calculated as TLI3.

Appendix 4 – Lake water quality trends

Table A4.1 Trend in surface water samples from January 2002 to December 2014.

	Okareka		Okaro		Okataina		Rerewhakaitu		Rotoehu		Rotoiti 1-4		Rotoiti 3		Rotoiti Okawa Bay		Rotoma		Rotomahana		Rotorua 2		Rotorua 5		Tarawera		Tikitapu	
Variable	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**
TL4 adj	0.081	0.3%	0	-1.2%	ns		0.018	0.5%	0	-1.1%	0	-1.4%	0	-1.5%	0	-1.9%	ns		0	0.5%	0	-1.7%	0	-1.6%	0	1.1%	0	-0.8%
Chl-a	ns		0.007	-4.9%	0.001	-2.5%	0.031	2.1%	0	-6.2%	0	-4.3%	0	-6.2%	0	-10.2%	0.055	-1.0%	ns		0	-7.5%	0	-7.8%	ns		ns	
Secchi	ns		0.007	3.4%	ns		0.092	-1.4%	0	3.3%	0	3.5%	0	3.5%	0	4.8%	ns		ns		0	3.2%	0	2.7%	ns		0.002	1.7%
TN *	0.016	1.0%	0.003	-1.5%	ns		0.008	1.0%	0	-3.7%	0	-2.7%	0	-4.1%	0.001	-2.7%	0.098	0.7%	0.001	1.5%	0	-2.9%	0	-2.6%	0.003	1.7%	ns	
TP *	ns		0	-8.0%	0	2.8%	ns		0.006	-2.4%	0	-5.2%	0	-5.7%	0	-4.3%	0.096	0.4%	0.009	3.4%	0	-10.8%	0	-10.5%	0	7.2%	0	-4.1%
%DO	0	-1.5%	0	-2.4%	0	-1.4%	0	-1.5%	0	-1.6%	0	-1.2%	0.001	-1.0%	0	-2.3%	0	-1.4%	0	-1.1%	0	-1.2%	0	-1.6%	0	-1.3%	0	-1.2%
DIN	ns		0.001	-4.5%	0	-7.0%	ns		0	-15.7%	0	-13.8%	0	-20.0%	ns		ns		ns		0.029	5.3%	0.014	8.6%	0.006	-4.2%	0.022	-4.8%
DRP	0	0.0%	0	-17.7%	0	5.0%	0.035	0.0%	ns		0.037	0.0%	0.003	-4.2%	0.006	3.3%	0	6.3%	0	8.4%	0	-19.7%	0	-18.0%	0	11.7%	ns	
EC	ns		0	-0.5%	0	-0.2%	0	1.0%	0	-0.6%	0	-1.6%	0	-1.7%	0	-2.1%	ns		0	-0.7%	0	-0.6%	0	-0.7%	0	-0.2%	0	-0.5%
min DO	0	-1.6%	0.009	-3.8%	0	-2.4%	0	-2.3%	0	-1.4%	ns		ns		0	-2.0%	0	-2.1%	0	-2.4%	0.003	-1.2%	0.001	-1.6%	0	-2.7%	0.001	-1.0%
NH4	ns		0	-7.8%	0	-9.5%	ns		0	-18.8%	0	-15.0%	0	-20.1%	ns		0.064	-3.5%	0	-8.9%	ns		ns		0.002	-8.3%	0.017	-5.3%
NH4 DL	0.045	0.0%	0	-7.4%	0	-6.7%	ns		0	-18.1%	0	-12.7%	0	-20.0%	ns		0.036	-2.1%	0	-6.7%	ns		ns		0.001	0.0%	0.007	-2.1%
pH	ns		0	-0.5%	0	-0.2%	0	-0.3%	0	-0.2%	ns		0.004	0.2%	0.002	-0.3%	0	-0.5%	0.072	0.0%	0.009	-0.2%	0.011	-0.2%	0	-0.1%	0	0.7%
Temp	0.081	0.2%	ns		ns		ns		ns		0.099	0.1%	0.06	0.2%	ns		ns		ns		ns		ns		ns		0.015	0.3%
Turb	0.025	-1.5%	0.037	-2.8%	0.024	-1.9%	0.048	1.7%	0	-3.8%	0	-3.9%	0	-5.6%	0	-8.0%	0.038	-1.3%	ns		0	-5.0%	0	-4.8%	ns		0.001	-1.9%
VLEC	ns		ns		ns		0	2.6%	0	-4.2%	0	-1.8%	0	-3.2%	0.001	-3.8%	ns		0.004	1.1%	0	-3.8%	0	-3.6%	0	1.5%	0.022	-0.9%
water height	ns		0	0.0%	0	0.0%	0	0.0%	0.004	0.0%	ns		ns		ns		0	0.0%	0	0.1%	0.01	0.0%	ns		0.018	0.0%	0.031	0.0%

* Analysis on TN and TP after adjusting for laboratory changes.

Table A4.2 Trend in bottom-water samples from January 2002 to December 2014.

	Okareka		Okaro		Okataina		Rerewhakaitu		Rotoehu		Rotoiti 1-4		Rotoiti 3		Rotoiti Okawa Bay		Rotoma		Rotomahana		Rotorua 2		Rotorua 5		Tarawera		Tikitapu	
Variable	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**
%DO	0.001	-0.8%	0.054	-2.7%	0.081	-0.6%	0	-1.7%	ns		ns		ns		0.001	-1.6%	0	-1.1%	0	-1.6%	0	-0.8%	0.004	-0.9%	0	-1.0%	ns	
DIN	ns		0.001	-3.1%	0.002	-4.7%	ns		0	-13.3%	0	-6.8%	0	-13.2%	0	-7.7%	ns		ns		ns		ns		ns		0.001	-6.0%
DRP DL	0	0.0%	0	-12.2%	ns		0.042	0.0%	ns		0	-7.3%	0	-9.5%	0.098	2.0%	0.001	0.0%	0	4.8%	0	-16.7%	0	-13.4%	0	8.3%	0.084	0.0%
EC	ns		0	-0.9%	0	-0.2%	ns		0	-0.7%	0	-1.7%	0	-1.9%	0	-1.9%	0	-0.2%	0	-0.8%	0	-0.7%	0	-0.6%	0	-0.3%	0	-0.7%
NH4 DL	ns		0	-2.9%	0	0.0%	ns		0	-10.5%	0	-5.8%	0	-12.9%	0	-6.4%	0.062	0.0%	0	0.0%	ns		ns		0	0.0%	0.001	-5.0%
pH	0.002	0.1%	ns		ns		ns		ns		0	0.3%	0	0.4%	ns		0.083	0.0%	ns		ns		ns		ns		0	1.1%
TN *	0.078	0.9%	0.003	-1.5%	ns		ns		0	-3.6%	0	-4.0%	0	-5.3%	0	-4.4%	ns		0	1.8%	0	-2.9%	0	-3.5%	0	2.7%	0.039	-0.9%
TP *	ns		0	-8.5%	ns		ns		0	-4.0%	0	-7.9%	0	-9.2%	0	-4.6%	0.017	0.7%	0.001	2.9%	0	-11.1%	0	-10.1%	0	6.5%	0	-5.4%

* Analysis on TN and TP after adjusting for laboratory changes.

Table A4.3 Trend in surface water samples from January 2010 to December 2014.

	Okareka		Okaro		Okataina		Rerewhakaitu		Rotoehu		Rotoiti 1-4		Rotoiti 3		Rotoiti Okawa Bay		Rotoma		Rotomahana		Rotorua 2		Rotorua 5		Tarawera		Tikitapu	
Variable	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**
TLI4	0.048	-1.2%	0.04	-2.4%	ns		0	-3.5%	0.003	-2.9%	0.001	-2.0%	0	-2.0%	ns		0.004	2.2%	ns		0.022	-1.7%	0.092	-1.3%	0.041	1.6%	0.07	-1.3%
Chl a	0.002	-14.3%	ns		0.034	-5.0%	0	-15.5%	0.023	-12.7%	ns		ns		ns		0.06	6.1%	ns		0.071	-11.2%	0.06	-12.0%	ns		ns	
Secchi	ns		ns		ns		0	15.5%	0.025	6.7%	0.001	6.0%	0.004	7.1%	ns		0.001	-3.8%	ns		ns		ns		0.001	-5.6%	ns	
TN	0.019	-2.3%	0.028	-6.1%	0.005	-4.2%	0	-4.3%	0	-6.3%	0.001	-3.8%	0	-5.4%	ns		ns		ns		0	-4.7%	0.017	-3.1%	ns		ns	
TP	ns		0.009	-14.2%	ns		0.001	-10.0%	0.047	-8.2%	0	-9.4%	0	-11.0%	ns		0.086	5.6%	ns		0.095	-5.9%	ns		ns		ns	
%DO	ns		ns		0.006	-1.8%	ns		0.006	-2.2%	0.025	-2.6%	0.07	-2.2%	ns		0.003	-1.8%	0.029	-1.5%	ns		0.037	-1.7%	0	-2.2%	ns	
DIN	0.002	-21.5%	0.056	-8.2%	0.012	-14.3%	0.01	-15.0%	0.068	-9.8%	ns		ns		ns		0.023	-10.8%	ns		ns		ns		ns		0.001	-24.8%
DRP	0.002	11.2%	0.001	-31.2%	0	8.4%	ns		0.008	-19.0%	0.015	-11.2%	ns		0.069	-12.5%	0.028	0.0%	0	11.6%	ns		ns		0.034	3.2%	ns	
EC	0.001	1.3%	0.006	-1.2%	ns		0.028	1.0%	ns		0	-2.2%	0	-2.8%	0.008	-1.2%	0	1.0%	0.001	-0.9%	ns		ns		ns		0	1.6%
min DO	ns		ns		ns		ns		ns		ns		ns		0.042	3.7%	0.011	-4.1%	ns		ns		ns		ns		ns	
NH4-N	0.021	-49.2%	0.023	-13.9%	0.07	-33.3%	0	-23.5%	ns		0.051	-19.8%	ns		ns		0	-25.1%	0.005	-50.4%	ns		ns		ns		0.001	-22.4%
pH	ns		ns		0.094	0.4%	ns		ns		0.008	0.7%	0.035	0.7%	0.042	0.8%	ns		ns		ns		0.087	0.5%	ns		ns	
Temp	ns		ns		ns		ns		ns		ns		ns		ns		ns		ns		ns		ns		ns		ns	
Turb	ns		ns		ns		0.002	-8.0%	0.001	-11.0%	ns		ns		ns		0.087	-3.0%	ns		0.029	-7.9%	ns		0.051	4.3%	ns	
VLEC	ns		ns		ns		0	-6.4%	ns		0.033	-2.6%	0.021	-5.0%	ns		ns		ns		0.1	-5.6%	ns		ns		ns	

Table A4.4 Trend in bottom-surface water samples from January 2010 to December 2014.

	Okareka		Okaro		Okataina		Rerewhakaitu		Rotoehu		Rotoiti 1-4		Rotoiti 3		Rotoiti Okawa Bay		Rotoma		Rotomahana		Rotorua 2		Rotorua 5		Tarawera		Tikitapu	
Variable	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**	**p-value**	**PAC**
%DO	0.003	-6.3%	0.06	-10.0%	ns		ns		ns		ns		ns		ns		0.017	-2.0%	0.004	-1.7%	0.043	-2.2%	ns		ns		ns	
DIN	ns		ns		ns		0.023	-12.5%	ns		0.055	-5.7%	0.013	-19.4%	ns		0.016	8.0%	ns		ns		ns		0.024	14.1%	0	-37.6%
DRP	0	16.7%	0.033	-16.6%	0.002	7.2%	0.002	0.0%	0.002	-18.6%	0.001	-11.4%	0.001	-34.1%	ns		0.001	12.5%	0	8.2%	ns		ns		0	9.4%	ns	
EC	0	2.0%	ns		0.014	0.2%	0.008	1.3%	ns		0	-2.2%	0	-2.2%	0.051	-1.3%	0	1.0%	0	-0.8%	ns		ns		ns		0	1.9%
NH4	ns		ns		ns		0.007	-23.6%	0.056	-23.3%	ns		ns		ns		0.003	-33.5%	ns		ns		ns		ns		0	-65.6%
pH	0.034	-0.5%	ns		ns		ns		ns		0.003	0.8%	0.001	1.0%	0	1.4%	0.015	0.5%	ns		ns		0.023	0.8%	ns		0.047	1.5%
TN	ns		ns		0.087	-2.6%	0	-4.9%	0	-8.2%	0.002	-6.5%	0.001	-8.1%	ns		ns		ns		0	-6.2%	0	-7.7%	0.011	4.2%	ns	
TP	0	12.6%	0.007	-10.7%	ns		0.001	-7.4%	0.002	-11.2%	0	-10.6%	0	-21.8%	ns		0.024	5.0%	0.035	4.6%	ns		ns		0.012	4.3%	ns	