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Water Quality Trends in Selected Shallow Lakes in the Waikato Region, 1995-2001

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Executive Summary

The collection and analysis of water quality data is an important tool in assessing the ecological condition of lakes and compliments ecological studies on fish, invertebrate and plant communities. Trend analysis using proven statistical methods provides a powerful tool to determine whether a waterbody has improved, degraded or has remained unchanged.

The current shallow lakes water quality monitoring programme was initiated in 1995 following a review of the previous programme.

Of the eight shallow lakes monitored by Environment Waikato, Lakes Rotomanuka North, Rotomanuka South and Waikare have deteriorated since water quality monitoring commenced. No change was detected in Lakes Mangahia, Ngaroto, Rotokauri and Waahi. Water quality monitoring of Lake Whangape by the National Institute of Water and Atmospheric Research (NIWA) between 1992 and 1996 detected a significant improvement in water quality.

Many shallow lakes within the Waikato Region are located within pastoral catchments with little or no indigenous vegetation. Inputs of contaminants from intensive land uses have contributed to an overall decline in water quality, and in many cases have contributed to a loss of indigenous biodiversity.

Improvement in the water quality of many eutrophied lakes will be difficult under current landuse activities. The input of contaminants from diffuse sources can be reduced by implementing riparian protection strategies. However, large scale changes will be required to ensure sufficient reduction in external nutrient loads.

Submerged aquatic plants are known to regulate the ecology of shallow lakes by influencing trophic state and by buffering the impact of external nutrient loads. However, many shallow lakes are now devegetated following the collapse of dominant invasive species.

The protection of remaining submerged plant communities and encouraging the re-establishment of collapsed populations is important for buffering the impact of landuse intensification and for maintaining and enhancing in-lake biodiversity.

It is recommended that monitoring of water quality continue at Lakes Waahi, Rotomanuka North and Waikare. It is further recommended that monitoring begin at Lakes Rotopiko North, Rotopiko East, Maratoto, Whangape and Taharoa. Should logistical constraints prevent monitoring at Lake Taharoa then Lake Mangakaware would be a suitable replacement.

1 Introduction

There are over 100 lakes in the Waikato Region, which vary considerably in their physical, chemical and biological characteristics. The lakes can be grouped spatially by their geographic association; the Taupo volcanic zone lakes, West Coast dune lakes, Waikato hydrolakes, Waikato peat lakes, and the lowland Waikato riverine lakes.

The majority of the Region's lakes are shallow and less than 10 hectares in size. Shallow lakes are defined as those that can be colonised by submerged macrophytes, that do not stratify for long periods and are generally less than 3 m deep (adapted from Scheffer, 1998). The intense sediment-water interaction and the potentially large impact of aquatic vegetation makes the functioning of shallow lakes different from that of deep lakes such as Lake Taupo or the Waikato hydrolakes.

Most of the Region's shallow lakes have been influenced to varying degrees by vegetation clearance and land use practices. Many lakes have degraded water quality, decreased indigenous biodiversity and have been invaded by plant and animal pests. Those lakes that retain high indigenous biodiversity values are threatened by both acute (i.e. plant and animal pests) and chronic threats (i.e. cultural eutrophication).

Water quality monitoring is a useful tool for determining the limnological condition of a waterbody and for identifying long-term changes, or "trends", in water quality condition. In the early 1980s the Waikato Valley Authority (antecedent to the Waikato Regional Council) undertook a small lakes resource survey. The aim of the survey was to obtain a comprehensive database for small lakes in the Region and for many lakes represented the only record of water quality. The data collected provided an indication of the trophic status of the waterbodies but long term water quality trends remained unidentified.

The current water quality monitoring programme was initiated in 1995 following a review of the previous programme (Hamill, 1995). The limitations of previous water quality programmes were acknowledged and a new programme designed that incorporated best practice.

This report provides the first comprehensive review of the current programme since its inception in 1995.

2 Methods

2.1 Data collection

Monitoring of water quality followed the method established by the New Zealand Lakes Water Quality Monitoring Programme, subsequently adopted as a Ministry for the Environment protocol (Burns et. al., 2000).

Samples were collected either monthly (Rotokauri, Rotomanuka South, Rotomanuka North and Ngaroto) or bimonthly (Waahi and Waikare) by Environment Waikato Environmental Monitoring staff. Samples were analysed by RJ Hill Laboratories, Hamilton.

Isothermal lakes

Lakes were analysed for thermal stratification in situ as per Burns et. al., (2000). If the lake was not stratified samples were collected at ¼ and ¾ of the maximum depth using a van Dorn sampling bottle. Two 1-litre samples were collected from the upper sampling point, collectively mixed and sub-sampled into a rinsed 1-litre sample bottle used for nutrient analysis (Burns et. al., 2000). The remainder was used for suspended sediment and chlorophyll *a* (Chla) analysis.

At the lower sampling point, a single van Dorn sample was filled for nutrient analysis. A 1-litre is adequate as no Chla samples are taken from the lower depth (Burns et. al., 2000). The position of the lower sampling point is changed if the waters are anoxic. As a rule of thumb waters with dissolved oxygen (DO) of less than 0.3 g m^{-3} are considered anoxic (Vant, 1987). When waters are anoxic the lower sampling point is taken at the mid-point of the anoxic layer. This accommodates the inaccuracies that occur in DO meters under conditions of low oxygen.

Stratified lakes

If the lake was stratified, samples were taken from both the epilimnion and hypolimnion. Sampling of the epilimnion followed the protocol established for isothermal lakes, except that the sample was collected from the mid-point of the epilimnion (mid-way between the bottom of the epilimnion and the water surface). Samples from the hypolimnion were similarly taken from the mid-point (top of the hypolimnion and the lake bottom). However, if the hypolimnion was anoxic the sample was taken from the middle of the anoxic layer.

All samples were stored on ice as soon as they were collected.

Determinants

Chlorophyll *a*, Secchi depth (SD), total phosphorus (TP), total nitrogen (TN), and phytoplankton species and biomass are generally accepted as the key indicators of trophic state in shallow, polymictic (unstable stratification) lakes. Additionally, dissolved reactive phosphorus (DRP), total ammoniacal nitrogen (NH_4-N = NH_4^+-N + NH_3-N), total oxidised nitrogen (NNN = nitrate-N + nitrite-N), phosphorus difference (Pdiff) total kjeldahl nitrogen (TKN), hydrogen or hydroxyl ion activity (pH), electrical conductivity (Cond), turbidity (Turb), total suspended solids (TSS), and volatile suspended solids (VSS), were assessed.

2.2 Data analysis

Data analysis followed parametric trend analysis techniques using deseasonalised residual data and differs from the method established by Vant & Wilson (1998). In arguing for the use of non-parametric trend analysis, Vant & Wilson (1998) state “It's generally not appropriate to analyse water quality records for trends using methods involving simple linear regression. This is because many water quality variables are not normally distributed, and so neither are their regression residuals. As a result, the necessary assumptions for using linear regression methods are generally not met. Nor do these methods satisfactorily deal with the marked seasonal variability which is often a major feature of water quality records”.

The method established by Burns et. al., (1999) is distinct from simple linear regression in that the data is deseasonalised. However, it is acknowledged that it is desirable that the analysis of water quality records should be consistent between the river's and lake's network. Re-analysis of the data following Vant & Wilson (1998) could be undertaken when published as part of Environment Waikato's State of the Environment indicator programme.

Trend analysis

Firstly, the key variables were deseasonalised. Chla, TP, TN and SD were plotted as a function of time of year collected with no regard for year of collection. A polynomial curve was then fitted to the annualised data. A residual value was calculated from the observed value less the value calculated from the polynomial for its day of observation. The observed and residual data were then plotted against time and a straight-line plot was added to both sets of data using ordinary least squares (OLS) regression.

Percent annual change (PAC) values were calculated by dividing the slope of the regression of the residual data by the average value of the variable during the period of observation. Where no seasonal trend was observed, the slope of the regression curve fitted to the observed data was used.

Only PAC values calculated from significant trend lines ($p<0.05$) were considered indicative of a trend. The PAC values determined within each lake were added together, averaged, and a p-value calculated (non-significant PAC values were replaced with zero) (Burns et. al., 2000). Changes indicating increased eutrophication were assigned positive values, whilst decreased eutrophication were given negative values (Burns et. al., 1999). The decision on whether the trophic state of each lake had changed over time was made by calculating the p-value of the PAC average and interpreting the result using the scale of probabilities developed by Burns et. al., (2000) (Table 1).

Table 1: Scale of probabilities devised by Burns et. al., (2000)

p-value of range of PAC averages	Interpretation
< 0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
> 0.3	No Change

A trophic level index (TLI) was established for each lake following Burns et. al., (2000). The TLI scheme uses the following equations to determine each individual TL values, for Chla (TLc), SD (TLs), TP (TLp), and TN (TLn):

$$TLc = 2.22 + 2.54\log(Chla) \qquad \textit{eqn. (1)}$$

$$TLs = 5.56 + 2.60\log(1/SD - 1/40) \qquad \textit{eqn. (2)}$$

$$TLp = 0.218 + 2.92\log(TP) \qquad \textit{eqn. (3)}$$

$$TLn = -3.61 + 3.01\log(TN) \qquad \textit{eqn. (4)}$$

The average trophic level index for each lake can be calculated by:

$$TLI = \sum \frac{(TLc + TLs + TLp + TLn)}{4} \qquad \textit{eqn. (5)}$$

TLI trends are stated for either individual values of TLc, TLs, TLp, or TLn (equations 1-4 respectively) or for the average TLI (equation 5). Significant changes in trophic level are expressed in TLI units per year with a p-value calculated for the slope of the regression line (Burns et. al., 1999). Table 2 illustrates the application of this procedure.

Table 2: Values of variables defining the boundaries of different Trophic Levels (from Burns et. al., 1999)

Lake Type	Trophic level	Chla (mg m^{-3})	Secchi depth (m)	TP (mg P m^{-3})	TN (mg N m^{-3})
Microtrophic	< 2.0	< 0.82	> 15	< 4.1	< 73
Oligotrophic	2.0 to 3.0	0.82 – 2.0	15 – 7.0	4.1 – 9.0	73 – 157
Mesotrophic	3.0 to 4.0	2.0 – 5.0	7.0 – 2.8	9.0 - 20	157 – 337
Eutrophic	4.0 to 5.0	5.0 – 12	2.8 – 1.1	20 – 43	337 – 725
Supertrophic	5.0 to 6.0	12-31	1.1-0.4	43-96	725-1558
Hypertrophic	6.0 to 7.0	>31	>0.4	>96	>1558

3 Results and Discussion

The results of monthly and bimonthly monitoring of eight shallow lakes in the Waikato Region (Table 3) indicate the following changes:

- Lake Whangape became less eutrophic and has shown an improvement in water quality.
- Three lakes have degraded with trophic level deteriorating over time. They are Rotomanuka South and North, and Waikare.
- Four lakes showed no detectable change in trophic level though changes in some trophic indicators were detected. They are Mangahia, Ngaroto, Rotokauri, and Waahi.

Table 3: Water quality trends in eight shallow lakes monitored by Environment Waikato between 1993 and 2001.

☺ Improving trend ☹ Deteriorating trend — No change	Mangahia	Waahi	Whangape	Waikare	Rotokauri	Rotomanuka North	Rotomanuka South	Ngaroto
Trophic Level Index	6.62	5.37	5.69	6.61	6.23	4.94	6.64	6.34
Trophic Status	H	S	S	H	H	E	H	H
Overall trend	—	—	☺	☹	—	☹	☹	—
Chlorophyll a	—	—	☺	—	☹	—	☹	—
Secchi depth	—	☹	☺	☹	—	☹	☹	☹
Total nitrogen	—	—	☺	☹	—	☹	—	—
Total phosphorus	—	—	☺	☹	—	☹	—	—
TON	—	☹	☺	☹	☹	☹	☹	☹
NH_4-N	—	—	—	—	—	—	☺	☺
NNN	—	☺	☹	☺	—	☺	—	☺
Pdiff	—	—	☹	☹	—	☹	—	☹
DRP	—	—	—	—	—	—	☺	☺
TSS	—	—	☺	☹	—	☹	☹	—
VSS	—	☹	☺	☹	☹	☹	☹	☹
Record	88-94	95-01	92-96	93-01	97-01	95-01	95-01	95-01

Notes:
Data collection and analysis at Lake Whangape was undertaken by NIWA under a Ministry for the Environment research contract. See: http://www.environment.govt.nz/freshwater/lakes/whangape.html.
H=Hypertrophic, S=Supertrophic, E=Eutrophic.
Chla = chlorophyll *a*; DRP = dissolved reactive phosphorus; Pdiff = total phosphorus minus DRP; TON = total organic nitrogen; NH_4-N = total ammoniacal-N; NNN = total oxidised nitrogen; TSS = suspended sediment; VSS = volatile suspended sediment, ISS = inorganic suspended sediment.

3.1 Lake Mangahia

Lake Mangahia is a 10 ha peat-stained lake, located in Ngahinapouri and is part of the Waipa peat lakes complex. The maximum recorded depth is 3.2 m (Irwin, 1981). The catchment is pastoral, predominantly under intensive dairying, and water drains from the surrounding developed peatland into the lake. The lake drains to the Waipa River via the Mangahia Stream (Boswell et. al., 1985). The lake is privately owned and controlled, with no public access. No submerged aquatic plants are present in the lake (Champion et. al., 1993).

Water quality samples were collected on a monthly basis between September 1988 and June 1994.

Analysis of the main trophic variables (Chla, SD, TP and TN) showed no annual pattern and no significant change over the observed period. The lake is hypertrophic with very high nutrient levels (mean TP and TN of 197 and 2403 $mg.m^{-3}$, respectively), high phytoplankton biomass (mean Chla 54.7 $mg.m^{-3}$), low water clarity (mean SD 0.27 m), and an average TLI value of 6.57.

Analysis of the other variables monitored (NNN, TON, NH_4-N, DRP and TKN) also showed no significant annual trend though NNN, NH_4-N and DRP levels were higher during winter. Suspended sediment levels were high (mean TSS 20 $g.m^{-3}$), consisted predominantly of inorganic material, and showed no annual trend. The high level of TSS may be controlling phytoplankton biomass by limiting light penetration into the water column.

Boswell et. al., (1987) sampled Lake Mangahia weekly between January and March 1982 and concluded that the lake was dystrophic (that is, it had brown coloured water and was rich in humic material) and that mean values for TP and Chla were indicative of eutrophic conditions. This cautionary conclusion was based on limited data and, with the benefit of the more extensive record provided above, a conclusion that the lake is hypertrophic is warranted. Alternatively, landuse intensification and drainage of marginal wetlands around the lake since the 1982 survey may have contributed to lake's eutrophication.

The water quality of Lake Mangahia reflects the inputs of contaminants typical of intensively farmed pastoral catchments. In this case, nutrients and sediments are expected from point source discharges such as treated dairy shed effluent and from non-point sources such as drainage networks and from subsurface drainage of adjoining pasture. The lack of fencing and absence of functioning riparian margins along many drains within the catchment exacerbates the input of contaminants.

No further monitoring of water quality at Lake Mangahia is recommended at this stage because the lake is hypertrophic, the intensive landuse in its catchment is unlikely to reduce in the near future and improvements in water quality are considered unlikely. In addition, the lake is privately owned and access is at times, difficult.

3.2 Lake Waahi

Lake Waahi is located west of Huntly, has an open water surface area of 522 ha and a maximum recorded depth of 5 m (Boswell et. al., 1985). The catchment is predominantly pastoral, however historically the lake received large inputs from coal mining activities. The lake discharges to the Waikato River via a controlled outlet on the Waahi Stream. The minimum lake level is 7.8 m (Moturiki datum) as set in the appeal's version of Environment Waikato's Proposed Regional Plan (Feb 2002).

The water quality of Lake Waahi has been studied previously by the University of Waikato (1974-76) and the Waikato Valley Authority (Boswell et. al., 1985). The first study preceded the collapse of submerged macrophytes in the late 1970s. The subsequent study described a change in stable state from clear water macrophyte dominated to one of high turbidity and high algal biomass.

Water quality samples for the current study were collected on a bimonthly basis between September 1995 and December 2001.

The lake is supertrophic, though nutrient levels straddle eutrophic thresholds (average TP and TN of 39 and 760 $mg.m^{-3}$ respectively). Phytoplankton biomass is high (mean Chla 19.9 $mg.m^{-3}$) and water clarity low (mean SD 0.61 m). TLI values averaged 5.37 for the observed period.

Seasonal variation in TP and Chla were observed with a pattern of higher values during summer. A significant decline in water clarity ($p<0.02$) was observed with SD decreasing 0.064 $m.yr^{-1}$ to yield a PAC of 10.5%.yr^{-1}. The other main trophic variables remained unchanged and no change in trophic status was concluded.

Analysis of the other variables showed an increase ($p<0.02$) in TON and a decrease ($p<0.05$) in NNN. Phosphorus was mostly particulate with little DRP detected. No trend was observed in either variable. No trend was observed in TSS though an analysis of the VSS time trend shows an increase ($p<0.02$) of 0.8 $g.m^{-3}yr^{-1}$.

Though no deterioration in trophic level over the observed period was detected, the increase in TON and VSS and decrease in water clarity is of concern. Particularly as mean SD is low and further declines may reduce the restoration potential of the aquatic plant communities. Overall, the results suggest that the lake has stabilised since the collapse of the submerged macrophytes (Boswell et. al., 1985) and that further improvement in water quality is possible should the macrophyte communities continue to recover (J.S. Clayton unpub. data).

Continuation of the bimonthly monitoring programme at Lake Waahi is recommended to track any further improvements in water quality that may occur.

3.3 Lake Whangape

Lake Whangape is the second largest lake in the lower Waikato catchment. It has a surface area of 1450 ha, an average depth of 1.5 m and a maximum depth of 3.5 m (Boswell et. al., 1985). The catchment is primarily pastoral however as with Lake Waahi, the lake received historical inflows from coal mining activities. The lake drains to the Waikato River via the Whangape Stream. A rock rubble weir has been constructed on the outlet to the lake to maintain a minimum water level of 4.91 m (Moturiki datum), as set in the appeal's version of Environment Waikato's Proposed Regional Plan (Feb 2002).

Water quality samples were collected and analysed by NIWA on a weekly basis between April 1992 and June 1996 (Burns & Rutherford, 1998a). The Lake Whangape analysis was included to provide a comparison between the national lakes monitoring programme (Burns & Rutherford, 1998b) and the current programme.

Burns & Rutherford (1998a) provide a detailed account of the analysis undertaken. In summary, Lake Whangape is supertrophic with a TLI of 5.69. The key variables measured showed significant improvement over time. Calculation of the PAC average showed a definite improvement ($p=0.01$) in water quality with time of 21.9±4.23%.yr^{-1}. The time trend showed that Chla decreased ($p<0.01$) by 5.2 $mg.m^{-3}yr^{-1}$ to yield a PAC of –21%yr^{-1} of the mean value of 24.0 $mg.m^{-3}$. SD increased with time by 0.16 $m.yr^{-1}$ ($p<0.05$), representing a PAC of –27%.yr^{-1}. TP and TN trended downward by 18 $mg.m^{-3}yr^{-1}$ and 84 $mg.m^{-3}yr^{-1}$ respectively, giving PAC values of –26%.yr^{-1} and –10%.yr^{-1}.

Burns and Rutherford (1998a) also detected a decrease in turbidity ($p<0.01$) consistent with the increase in SD. The authors found an increase in DRP, which they attributed to temporary anoxia in the lake sediments as macrophyte cover progressively increased across the lake. High NNN concentrations were thought to indicate the release of NH_4-N, which had subsequently been oxidised (Burns & Rutherford, 1998a).

Boswell et. al., (1985) sampled water quality during the summer of 1982 and concluded that Lake Whangape had a weak thermal stratification with oxygen depletion in deeper waters. The authors concluded that the presence of dense beds of *Egeria densa* probably aided anoxia of the surficial sediments. Wells et. al., (1988) quantitatively assessed the macrophyte cover within the lake at greater than 95 percent, with the standing crop dominated by *Egeria densa*, but also consisting of *Ceratophyllum demersum*, *Potamogeton ochreatus* and *Elodea canadensis*. The lake was described as reasonably clear (SD = 0.5-1.5 m), low in TSS, with Chla and TP concentrations indicative of eutrophic conditions (Boswell et. al., 1985).

Egeria densa underwent a collapse in 1987 resulting in Lake Whangape becoming largely devegetated (Champion et. al., 1993). Wells et. al., (1988) surmised that the reason for the collapse was a combination of factors including: phytoplankton blooms, epiphytes, swan browse, grass carp or koi carp grazing, cultural eutrophication, plant senescence, and/or an increase in inorganic suspensoids. However, Vant (1987) was more specific concluding that the collapse of macrophytes was due to the discharge of inorganic sediment from mining wastewater.

Ceratophyllum re-established in some areas of the lake in 1987/88. A survey of aquatic vegetation in December 1991 by NIWA found *Ceratophyllum* to be common in sheltered areas (Champion et. al., 1998). A survey in February 2001 by Environment Waikato and NIWA staff concluded that *Ceratophyllum* had increased in distribution and density throughout the lake, forming dense, surface reaching, monospecific beds (Clayton, J. unpub. data).

The increase in macrophyte biomass over the duration of the water quality sampling period probably accounts for the improvement in the key trophic variables measured. Macrophytes are known to improve water quality within shallow lakes by suppressing phytoplankton biomass, reducing wave action on bottom sediments, promoting sedimentation and acting as a nutrient sink (Scheffer, 1998; Jeppesen et. al., 1998). It is likely that water quality within the lake had declined substantially following the macrophyte collapse, and the period 1992 to 1996 represents a stabilisation of the trophic indicators as organic material from the collapse was flushed from the system and macrophytes progressively re-established.

Unless the contribution of external nutrients is reduced, the current trophic status of Lake Whangape is unlikely to improve further. However, a decline in trophic state is likely should macrophytes collapse again.

It is recommended that bimonthly water quality monitoring recommence from August/September 2002. This will allow comparisons with the NIWA study to be made and will confirm whether improvements noted in that study have continued.

3.4 Lake Waikare

Lake Waikare is the largest lake in the lower Waikato catchment (3442 ha), with an average depth of 1.5 m and a maximum of 1.8 m (Boswell, et. al., 1985). In 1965 water levels were lowered by 1 m following the implementation of the Lower Waikato Waipa Flood Control Scheme (LWWCS) and the construction of the outlet gate. The lake is managed under a strict seasonal fluctuation regime of approximately 0.3 m and discharges to the Whangamarino Wetland via the artificial Pungarehu Canal. Lake Waikare is a highly degraded hypertrophic waterbody with extremely high inorganic suspended sediment levels. The once extensive wetlands around the margins of the lake have declined by 67 percent since 1963 (Barnes, 2002).

Water quality samples were collected bimonthly between February 1993 and December 2001. The Waikato Valley Authority undertook sporadic sampling of the lake from 1982, however the frequency was not consistent enough to allow a robust trend analysis to be undertaken and consequently the analysis was restricted to data collected after February 1993.

Analysis of the four principal indicators of trophic status indicates that Lake Waikare has eutrophied since 1993. Calculation of the PAC average showed a probable degradation ($p=0.10$) in water quality with time of 5.38 ± 2.45 $\%.yr^{-1}$. Mean TN and TP are 1283 $mg.m^{-3}$ and 196 $mg.m^{-3}$, respectively. Both parameters increased significantly ($p<0.05$) during the observed period. The time trend shows TN increasing at 52.75 $mg.m^{-3}yr^{-1}$ and TP increasing 24.1 $mg.m^{-3}yr^{-1}$. PAC values were 11.8 $\%.yr^{-1}$ and 4.1 $\%.yr^{-1}$ respectively. SD declined significantly ($p<0.05$) at 8 $mm.yr^{-1}$ or 5.6 $\%.yr^{-1}$. No change in Chla was detected (mean 36 mg.m⁻3). The average TLI for the observed period was 6.61.

The increase in TN coincided with an increased conversion of NNN, -25.3 $mg.m^{-3}$ yr^{-1}, into TON, 76.5 $mg.m^{-3}$ yr^{-1}. The increase in TP is accounted for by a similar increase in particulate phosphorus, 24.2 $mg.m^{-3}$ yr^{-1}.

The levels of suspended sediment within Lake Waikare are extremely high and are thought to be the principal factor limiting the biological productivity of the lake by restricting light penetration. The time trend shows that TSS increased ($p<0.03$) by 12.8 $g.m^{-3}yr^{-1}$ to yield a PAC of 9 $\%yr^{-1}$ of the mean value of 142 $g.m^{-3}$.

The increase in particulate matter is probably due to increased phytoplankton growth efficiency (manifest in a change in phytoplankton population structure rather than biomass), since more NNN is converted into the organic form with time, and also due to increased resuspension of sedimented materials with time. No change in ISS was detected over the observed period ($p=0.171$), though observed values were highly variable suggesting wind induced re-suspension of bottom sediments

The sediment is contributed to the lake by erosion of the Matahuru catchment and resuspension from the lake bed by wave action. Anecdotal evidence suggests that suspended sediment levels have become persistently higher since the 1940s and have accelerated since the collapse of submerged aquatic plants between 1977 and 1979. Submerged plant communities remain absent from Lake Waikare and an assessment by NIWA concluded that re-colonisation is unlikely given current TSS levels (Reeves et. al., 2002).

Restoration of Lake Waikare including a reduction in trophic state and re-establishment of the submerged aquatic plant community is unlikely under the current water level regime. Restoration is further restricted by the external load of contaminants from the Matahuru catchment and from point source discharges such as the Te Kauwhata wastewater treatment plant.

A continuation of the bimonthly water quality monitoring programme is required under the terms of the resource consent held by the Asset Management Group of Environment Waikato as part of their operation of the LWWCS.

3.5 Lake Rotokauri

Lake Rotokauri is located 7 kilometres north-west of Hamilton City. It has a surface area of 77 ha and a maximum recorded depth of 4 m. Lake Rotokauri is part of the Waipa peat lake complex. The catchment is a mixture of residential, industrial and pastoral land uses. The lake drains to the Waipa River via the Ohote Stream with the lake level controlled by a weir at the outlet (Boswell et. al., 1985). The minimum lake level is 22.5 m (Moturiki datum) as set in the appeal’s version of Environment Waikato’s Proposed Regional Plan (Feb 2002).

Water quality samples were collected on a monthly basis between August 1997 and December 2001.

Analysis of SD, TP and TN showed no annual pattern and no significant change over the observed period. In contrast, Chla underwent a seasonal peak in summer and the time trend showed an increase ($p<0.001$) of 22 $mg.m^{-3}yr^{-1}$ to yield a PAC of 28 $\%yr^{-1}$ of the mean value of 79 mg.m-3. The lake is hypertrophic with very high nutrient levels (mean TP and TN of 125 and 1665 $mg.m^{-3}$, respectively), very high phytoplankton biomass (mean Chla 70 $mg.m^{-3}$), low water clarity (avg SD 0.60 m), and an average TLI value of 6.36.

Analysis of the other variables monitored (NNN, TON, NH_4-N , DRP and TKN) showed no significant trend in NNN, NH_4-N and DRP. The time trend for TON showed an increase ($p<0.02$) of 132 $mg.m^{-3}yr^{-1}$ to yield a PAC of 9.7 $\%yr^{-1}$ of the mean value of 1375 $mg.m^{-3}$. High NNN concentrations were thought to indicate the release of NH_4-N , which had subsequently been oxidised and the increase in TON and Chla represented the assimilation of nitrogen by phytoplankton. Suspended sediment levels were high (mean TSS 20 $g.m^{-3}$) and consisted of inorganic and organic material in approximately equal amounts. However, a time trend analysis of the TSS:VSS ratio showed that this relationship is changing ($p<0.001$) with the lake becoming increasingly dominated by organic matter over the sampling period. Similarly, VSS has increased ($p<0.05$) at a rate of 2.3 $g.m^{-3}yr^{-1}$ despite TSS remaining unchanged ($p>0.1$).

Boswell et. al. (1985) report water quality data from ten weekly samples collected between January and March 1980 and a comparative sample in August 1980. No values for TN, TP or Chla were reported making comparison with the present study difficult. However, SD values collected by Boswell et. al. (1985) ranged between 0.6-2.6 m compared to 0.25-1.35 m in the present study.

A survey of the lake in 1979 noted that *Egeria densa* covered 60 percent of the water surface (WVA, 1980). These beds had reached close to 100 percent coverage from 1.5-2.2 m depth in 1989 (Champion et. al., 1993). In the summer of 1996/97 a collapse of the *Egeria* beds was observed by residents adjoining the lake (Warr, 1998). The lake appears to remain devegetated (pers. obs., Feb 2002).

It is probable that the collapse of submerged macrophytes could account for the change in water clarity observed between the Boswell et. al. (1985) and the present study. Unfortunately, water quality sampling resumed in August 1997, after the vegetation collapse making statistically significant comparisons difficult. Anecdotal evidence suggests that the lake has become more turbid since the collapse and that the phytoplankton biomass has increased markedly. The VSS time trend supports this view.

Lake Rotokauri is now quite clearly a turbid lake dominated by phytoplankton. This is in contrast to the clear macrophyte dominated state observed in the 1980s. A reversion to the more desirable stable state is unlikely given current limnological conditions. However, work within the lake's catchment to reduce inputs of sediment and nutrients, marginal wetland restoration and the reconstruction of the water level control structure may facilitate this.

It is recommended that the current water quality monitoring cease at August 2002. Data collected to date is sufficient to allow statistically robust trend analysis and further monitoring is not warranted under current limnological conditions. The programme could recommence once an improvement in submerged macrophyte cover is detected. These could be communicated via the Lake Rotokauri Management Committee, responsible for the day to day administration of the lake.

3.6 Lake Rotomanuka North

Lake Rotomanuka North is located within the Waipa District, approximately 12 km north of Te Awamutu on the edge of the now largely drained Moanatuatua peat bog (Boswell et. al., 1985). The Lake Rotomanuka complex is Crown-owned and administered by the Department of Conservation. The total area of open water is 12.3 ha (DoC, 1995) and the maximum recorded depth is 8.7 m (Irwin, 1982). Lake Rotomanuka North is a peat lake and a remnant of the once larger Lake Rotomanuka. Drainage in the eastern and northern catchments, the diversion of water from the Lake Rotopiko catchment circa 1950/60, and the lowering of a formed outlet channel in 1973 resulted in a substantial lowering of water levels and the formation of two distinct waterbodies (Greenwood, 1996). Rotomanuka North is now isolated from Rotomanuka South. However, the two are hydrologically linked via 10 ha of marginal wetland that formed following the lowering of the lake (Boswell et. al., 1985). The Rotomanuka catchment is pastoral, surrounded on all sides by intensive dairy farming.

Water quality samples were collected on a monthly basis between October 1995 and December 2001. A detailed analysis of the water quality data and the implications for restoration and management of Lake Rotomanuka North is contained in Barnes (2002).

Analysis of the main trophic variables showed little seasonalility though residual values were calculated for each parameter (Burns et. al., 1999). Lake Rotomanuka North is eutrophic with an average TLI 4.94. Calculation of the PAC average showed a probable degradation ($p=0.15$) in water quality with time of 6.5 ± 3.41 $\%.yr^{-1}$. Changes were detected in SD, TP and TN, though no change in Chla. The time trend for TN showed an increase ($p<0.02$) of 20 $mg.m^{-3}yr^{-1}$ to yield a PAC of 2.5 $\%.yr^{-1}$ of the mean value of 792 $mg.m^{-3}$. TP increased ($p<0.01$) by 8$\%.yr^{-1}$ (2.3 $mg.m^{-3}yr^{-1}$) of the mean 28 $mg.m^{-3}$. Despite no change in Chla, SD declined significantly ($p<0.0001$) by 0.27 $m.yr^{-1}$ (PAC 15 $\%.yr^{-1}$) of the mean 1.78 m.

Analysis of the other variables showed an increase in TKN (represented by an increase ($p<0.001$) in TON of 34.7 $mg.m^{-3}yr^{-1}$), and particulate phosphorus ($p<0.01$), a decline ($p<0.01$) in NNN (15.0 $mg.m^{-3}yr^{-1}$), and no change in NH_4-N or DRP. The time trend shows that TSS increased ($p<0.001$) by a PAC of 11.0 $\%yr^{-1}$ of the mean value of 5.2 $g.m^{-3}$. The change in TSS can be attributed to an increase in VSS ($p<0.001$).

Barnes (2002) speculated that the decrease in water clarity and increase in total nitrogen and phosphorus is a consequence of the collapse of the macrophyte beds (dense monospecific stands of *Egeria densa*) that occurred in the summer of 1996/97, rather than an increase in the lake's external nutrient load. The resulting pulse of organic material that occurred following microbial decomposition of the plant biomass released large amounts of organic nitrogen and phosphorus that for some reason remains largely bio-unavailable.

Further monthly water quality monitoring is recommended to track changes, if any, that may occur through the implementation of proposed restoration initiatives in this ecologically significant Waipa peat lake.

3.7 Lake Rotomanuka South

Lake Rotomanuka South is located adjacent to Lake Rotomanuka North within the Lake Rotomanuka Wildlife Management Reserve. The lake is approximately 5 ha with a maximum recorded depth of 4.8 m (Boswell et. al., 1985). The lake is devoid of submerged aquatic vegetation (Champion et. al., 1993).

Water quality samples were collected on a monthly basis between October 1995 and December 2001.

Seasonal fluctuations were detected for Chla, TP and SD with phytoplankton biomass, phosphorus concentration and water clarity highest during winter. No seasonal difference was detected for TN. Calculation of the PAC average showed a probable degradation (p=0.16) in water quality with time of 10.9 ± 5.98 $\%.yr^{-1}$. The time trend showed changes in Chla, SD and TN with each trophic level indicator deteriorating over time. Chla increased ($p<0.001$) by 28 $\%.yr^{-1}$, SD declined ($p<0.01$) by 7.6 $\%.yr^{-1}$ and TN increased ($p<0.001$) by 8.1 $\%.yr^{-1}$. No change was detected for TP ($p>0.1$). The lake is hypertrophic with an average TLI of 6.51.

The increase in TN was largely accounted for by an increase ($p<0.001$) in TKN of 204 $mg.m^{-3}yr^{-1}$ to yield a PAC of 10.4 $\%.yr^{-1}$ (mean 1958.9 $mg.m^{-3}$). The TON component was responsible for this increase ($p<0.001$) rising by 228.6 $mg.m^{-3}yr^{-1}$ as NH_4-N decreased ($p<0.02$) by 11 $\%.yr^{-1}$ over the same period. No change in NNN was detected suggesting that the increase in TN followed an increased assimilation of N by phytoplankton. The large increase in Chla and a large increase ($p<0.001$) in VSS of 21.3 $\%.yr^{-1}$ supports this conclusion. Also observed was a significant decrease ($p<0.001$) in DRP of 2.06 $mg.m^{-3}yr^{-1}$ to yield a PAC of 16.2 $\%.yr^{-1}$ (mean 12.71 $mg.m^{-3}$), suggesting declining anoxic events and/or decreasing external P inputs.

As with Lake Mangahia, the water quality of Lake Rotomanuka South reflects the inputs of contaminants typical of pastoral catchments. In this case, the major drain receives treated effluent from a farm dairy, though at the time this report went to press the consent had expired and land based discharge was the preferred option. Additional inputs of nutrients and sediments are expected from non-point sources such as inputs from drainage networks and from subsurface drainage of adjoining pasture. The lack of fencing and absence of functioning riparian margins along some drains within the catchment contributes to the input of contaminants.

The deterioration of Lake Rotomanuka South is likely to be a factor of increased agricultural intensification within the catchment. Halting further eutrophication will require modification of land use practices by, in particular, implementing riparian management strategies and ensuring adequate setback from waterways.

No further water quality monitoring is recommended. The lake is hypertrophic, the intensive landuse in its catchment is unlikely to reduce in the near future and improvements in water quality are considered unlikely

3.8 Lake Ngaroto

Lake Ngaroto is situated 19 km south of Hamilton City, approximately 8 km north-west of Te Awamutu (Boswell et al., 1985). The lake, at approximately 108 ha in area, is the largest of the Waipa peat lakes, has a maximum depth of 4 m and an average depth of less than 2 metres. The catchment is predominantly pastoral, though in recent years the Waipa District Council has undertaken a riparian restoration project that acts to partially buffer the lake from the surrounding farmland. No submerged aquatic vegetation was found during the last vegetation survey in 1992 (Champion et. al., 1993).

Water quality samples were collected on a monthly basis between October 1995 and December 2001.

Lake Ngaroto is hypertrophic with an average TLI of 6.21. Seasonal fluctuations were detected in all four trophic level indicators. Water clarity and TN were highest in winter. In contrast, TP and phytoplankton biomass peaked during summer.

The time trend analysis for SD showed a decrease of 0.10 $m.yr^{-1}$ to yield a PAC of

16.2 $\%.yr^{-1}$ from a mean of 0.59 m. No change was detected in Chla, TP or TN (avg PAC 4.04 $\%.yr^{-1}$; p-value=0.39) and consequently, no overall change in lake trophic status was determined.

Though no change was observed for TP, a significant increase ($p<0.05$) was detected in particulate P and a significant decrease ($p<0.001$) in DRP. Particulate P showed a distinct peak in concentration during summer, declining through winter. DRP concentrations were generally high. However, these were highly variable with no seasonal trend apparent. Frequent anoxia could also account for the high NH_4 concentrations observed and the high NNN levels as NH_4 was subsequently oxidised, however this view is not supported by declining DRP concentrations. The exact processes underway are not fully understood however these are likely to be related to complex interactions at the sediment interface. A more detailed analysis would be required to determine such.

The decline in NNN and NH_4 was buffered by an increase ($p<0.001$) in TON of 81.3 $g.m^{-3}.yr^{-1}$ or 6 $\%.yr^{-1}$, however Chla remained unchanged. A change in the phytoplankton community structure could account for the change in the relative concentrations of nitrogen and the increase ($p<0.01$) in VSS of 0.75 $g.m^{-3}.yr^{-1}$ or 9.3 $\%.yr^{-1}$. This would be one explanation for the decline in water clarity despite no change in Chla or SS ($p>0.1$).

Lake Ngaroto's hypertrophic status is not surprising given the dominant agricultural activities within the catchment. It is positive to see that in spite of land use intensification over recent years the lake has not deteriorated further. This may be due to the restoration project though it is too early to draw such conclusions.

No further water quality monitoring is advised. The current water quality record is sufficient to allow conclusions on the trophic state of Lake Ngaroto and to identify trends in water quality. The programme could recommence after a reasonable period of time (>5 years) has elapsed, once the restoration plantings establish.

3.9 Additional lakes

It is recommended that in addition to recommencing water quality monitoring at Lake Whangape, as discussed in section 3.3, that the following lakes be added to the programme:

- Lake Maratoto
- Lake Rotopiko North
- Lake Rotopiko East
- Lake Taharoa[1]

These lakes are either nutrient limited (Taharoa), of particular limnological significance (Maratoto) or contain flora and/or fauna of conservation significance (Rotopiko East and North). Monitoring of water quality would add to our understanding of how these lakes function and help to identify threats to their values.

4 Conclusions

The collection and analysis of water quality data is an important tool in assessing the ecological condition of lakes and compliments ecological studies on fish, bird, invertebrate and plant communities. Trend analysis using proven statistical methods

[1] Lake Taharoa is located a significant distance from Hamilton City. Inclusion of this lake would add an extra day to the monthly monitoring programme. If this is not possible then the alternative recommendation is Lake Mangakaware.

has been used to determine whether shallow Waikato lake water quality has been improving, degrading or remained unchanged over the past 6 years.

Of the eight shallow lakes monitored by Environment Waikato, Lakes Rotomanuka North, Rotomanuka South and Waikare have deteriorated since water quality monitoring commenced in 1995. No change was detected in Lakes Mangahia, Ngaroto, Rotokauri and Waahi. Water quality monitoring of Lake Whangape by NIWA between 1992 and 1996 detected a significant improvement in water quality.

A waterbody's trophic state is largely determined by inputs of plant nutrients from the surrounding catchment. Changes in trophic state, in particular increasing eutrophication, increasingly reflect the discharge of diffuse contaminants associated with the intensification of mostly agricultural land use activities.

Many shallow lakes within the Waikato Region are located within pastoral catchments with little or no remaining indigenous vegetation. Inputs of contaminants from intensive land uses have contributed to an overall decline in water quality and in many cases have contributed to a loss of indigenous biodiversity. All of the shallow lakes surveyed had high nutrient levels, with most being supersaturated in nitrogen and phosphorus.

Improvement in the water quality of many eutrophied lakes within the Waikato Region will be difficult under current land use activities. The input of contaminants from diffuse sources can be reduced by preventing stock access to waterways and by maintaining grass filter strips between paddocks and watercourses. This prevents both the direct addition of nutrients and acts to intercept contaminants transported by surface and subsurface runoff. However, large scale changes to riparian management will be required to ensure sufficient reduction in external nutrient loads.

Submerged aquatic plants are known to regulate the ecology of shallow lakes by influencing trophic state and by buffering the impact of external nutrients. However, many shallow lakes within the Waikato Region are now devegetated following the collapse of dominant invasive species such as *Egeria densa*. Restoring submerged plant communities often results in improvements in trophic state, as observed in Lake Whangape.

The protection of remaining submerged plant communities and encouraging the re-establishment of collapsed populations is an important priority for buffering the impact of land use intensification and for maintaining and enhancing in-lake biodiversity.

It is recommended that the shallow lakes water quality monitoring programme be reviewed again in 2006/07.

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Appendices

A summary of the water quality data analysed for each lake monitored is presented in a series of tables in the pages that follow.

Lake Ngaroto
Analysis (10 Oct 1995 to 21 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	(7.33) (mg/m^{-3}year^{-1})	-0.10 (m year^{-1})	(-1.68) (mgP/m^{-3}year^{-1})	(-2.38) (mgN/m^{-3}year^{-1})			
p-value	p>0.1	p<0.001	p>0.1	p>0.1			
Period average	65 (mg m^{-3})	0.59 (m)	118 (mg m^{-3})	1900 (mg m^{-3})			
PAC (%/yr)	**0.0**	**16.2**	**0.0**	**0.0**	**4.04**	**4.04**	**0.39**
Average PAC	4.04%. year^{-1} with a p-value=0.39						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Oct95-Dec95	149	0.75	112	2110	7.74	5.86	6.20	6.40	6.55	0.41			
1996	52	0.72	125	2076	6.59	5.91	6.35	6.37	6.30	0.14			
1997	27	0.88	92	1495	5.86	5.67	5.96	5.95	5.86	0.07			
1998	41	0.68	109	1914	6.31	5.98	6.17	6.27	6.18	0.07			
1999	52	0.43	124	1939	6.58	6.51	6.33	6.29	6.43	0.07			
2000	164	0.38	149	2140	7.85	6.64	6.56	6.41	6.87	0.33			
2001	37	0.50	103	1736	6.19	6.33	6.09	6.14	6.19	0.05			
Averages	**65**	**0.59**	**118**	**1900**	**6.83**	**6.12**	**6.27**	**6.26**	**6.34**	**0.16**	**0.218**	**0.23**	**<0.05**

<u>Summary</u>

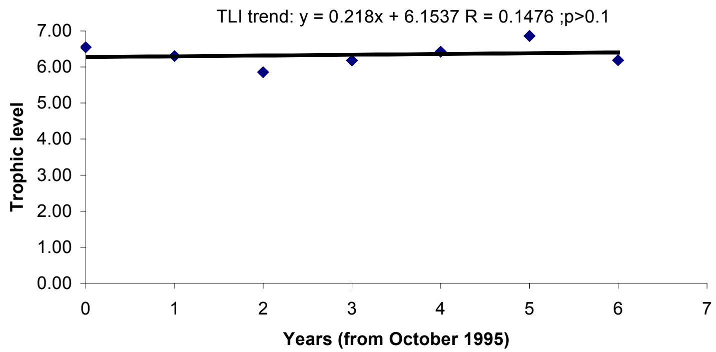
PAC = 4.04 ± 4.04 % per year
p-value = 0.39

TLI value = 6.34 ± 0.16 TLI units
TLI trend = 0.218 ± 0.23 TLI units per year
p-value >0.1

<u>Assessment</u>
Hypertrophic
No change

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Rotokauri
Analysis (27 Aug 1997 to 10 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	22 ($mg/m^{-3}year^{-1}$)	(-0.01) ($m\ year^{-1}$)	(-0.75) ($mgP/m^{-3}year^{-1}$)	(-62.97) ($mgN/m^{-3}year^{-1}$)			
p-value	$p<0.001$	$p>0.1$	$p>0.1$	$p>0.1$			
Period average	79 ($mg\ m^{-3}$)	0.60 (m)	125 ($mg\ m^{-3}$)	1665 ($mg\ m^{-3}$)			
PAC (%/yr)	**27.72**	**0.0**	**0.0**	**0.0**	**6.93**	**6.93**	**0.39**
Average PAC	6.9%. $year^{-1}$ with a p-value=0.15						

Trophic Level Index Values and Trends

Year	**Chla (mg/m^{-3})**	**Secchi (m)**	**TP (mgP/m^{-3})**	**TN (mgN/m^{-3})**	**TLc**	**TLs**	**TLp**	**TLn**	**TLI avg**	**Std. Err. TL avg**	**TLI Trend units/yr**	**Std. Err. TLI Trend**	**p-value**
Aug 1997 -98	23	0.73	105	1119	5.66	5.89	6.13	5.57	5.81	0.12			
1998	48	0.58	122	1565	6.49	6.17	6.31	6.01	6.24	0.10			
1999	47	0.59	126	1774	6.47	6.14	6.35	6.17	6.28	0.08			
2000	77	0.57	124	1765	7.02	6.17	6.33	6.16	6.42	0.20			
2001	151	0.58	137	1773	7.75	6.17	6.45	6.17	6.64	0.38			
Averages	**79**	**0.60**	**125**	**1665**	**6.90**	**6.13**	**6.34**	**6.08**	**6.36**	**0.19**	**0.183**	**0.14**	**<0.02**

Summary

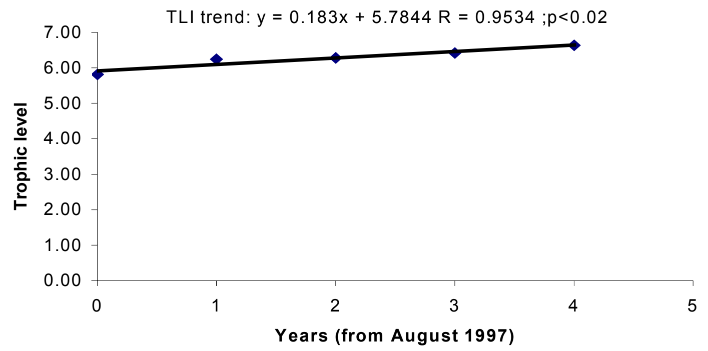
PAC = 6.93 ± 6.93 % per year
p-value = 0.39

TLI value = 6.23 ± 0.27 TLI units
TLI trend = 0.183 ± 0.15 TLI units per year
p-value <0.02

Assessment
Hypertrophic
No change

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Rotomanuka North
Analysis (10 Oct 1995 to 21 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	(-0.3) ($mg/m^{-3}year^{-1}$)	-0.27 ($m\ year^{-1}$)	2.28 ($mgP/m^{-3}year^{-1}$)	20.02 ($mgN/m^{-3}year^{-1}$)			
p-value	p<0.61	p<0.0001	p<0.01	p<0.02			
Period average	18.1 ($mg\ m^{-3}$)	1.78 (m)	28.0 ($mg\ m^{-3}$)	792 ($mg\ m^{-3}$)			
PAC (%/yr)	**0.0**	**15.4**	**8.0**	**2.5**	**6.5**	**3.41**	**0.15**
Average PAC	6.5%. $year^{-1}$ with a p-value=0.15						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Oct95-Dec95	17.5	3.24	15.3	673	5.38	4.14	3.68	4.90	4.52	0.38			
1996	18.7	2.73	25.5	766	5.45	4.35	4.33	5.07	4.80	0.28			
1997	13.4	1.89	21.2	701	5.09	4.79	4.09	4.96	4.73	0.22			
1998	24.7	1.37	33.2	842	5.76	5.16	4.66	5.20	5.20	0.22			
1999	17.0	1.51	27.5	777	5.35	5.05	4.42	5.20	5.00	0.20			
2000	17.7	1.15	32.5	834	5.39	5.37	4.63	5.20	5.15	0.18			
2001	16.2	1.53	32.8	798	5.29	5.04	4.64	5.13	5.03	0.14			
Averages	**18.1**	**1.78**	**28.0**	**792**	**5.42**	**4.85**	**4.39**	**5.12**	**4.94**	**0.22**	**0.09**	**0.12**	**<0.05**

Summary

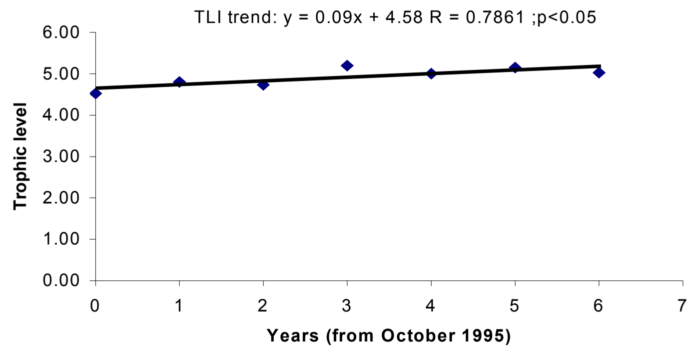
PAC = 6.5 ± 3.41 % per year
p-value = 0.15

TLI value = 4.94 ± 0.22 TLI units
TLI trend = 0.09 ± 0.12 TLI units per year
p-value <0.05

Assessment
Eutrophic
Probable degradation

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Rotomanuka South
Analysis (10 Oct 1995 to 21 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	47.81 ($mg/m^{-3}year^{-1}$)	-0.05 ($m\ year^{-1}$)	(1.14) ($mgP/m^{-3}year^{-1}$)	201.65 ($mgN/m^{-3}year^{-1}$)			
p-value	p<0.001	p<0.01	p>0.1	p<0.001			
Period average	171 ($mg\ m^{-3}$)	0.66 (m)	147 ($mg\ m^{-3}$)	2482 ($mg\ m^{-3}$)			
PAC (%/yr)	**28.0**	**7.6**	**0.0**	**8.1**	**10.9**	**5.98**	**0.16**
Average PAC	10.9%. $year^{-1}$ with a p-value=0.16						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Oct95-Dec95	42	0.62	162	1769	6.33	6.09	6.67	6.17	6.31	0.13			
1996	220	0.57	173	2502	8.17	6.18	6.75	6.62	6.93	0.43			
1997	293	0.62	202	2461	8.49	6.09	6.95	6.60	7.03	0.52			
1998	86	0.78	93	2552	7.13	5.81	5.97	6.64	6.39	0.31			
1999	84	0.85	97	2579	7.10	5.71	6.02	6.66	6.37	0.31			
2000	114	0.64	140	2526	7.45	6.04	6.49	6.63	6.65	0.29			
2001	164	0.57	162	2347	7.85	6.19	6.67	6.53	6.81	0.36			
Averages	**171**	**0.66**	**147**	**2482**	**7.87**	**6.01**	**6.54**	**6.61**	**6.64**	**0.39**	**0.01**	**0.14**	**>0.1**

Summary

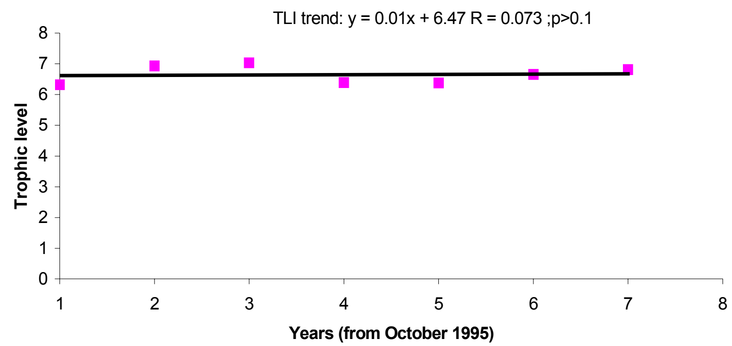
PAC = 10.9 ± 5.98 % per year
p-value = 0.16

TLI value = 6.64 ± 0.39 TLI units
TLI trend = 0.01 ± 0.14 TLI units per year
p-value >0.1

Assessment
Hypertrophic
Probable degradation

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Waahi
Analysis (22 Sept 1995 to 17 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	(-0.42) (mg/m^{-3}year^{-1})	-0.06 (m year^{-1})	(-0.95) (mgP/m^{-3}year^{-1})	(-8.84) (mgN/m^{-3}year^{-1})			
p-value	p>0.1	p<0.02	p>0.1	p>0.1			
Period average	19.9 (mg m^{-3})	0.61 (m)	39.2 (mg m^{-3})	760 (mg m^{-3})			
PAC (%/yr)	**0**	**10.5**	**0**	**0**	**2.63**	**2.63**	**0.39**
Average PAC	2.6%.year^{-1} with a p-value=0.39						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Sep95-Dec95	20.0	1.20	44.0	668.0	5.52	5.32	5.02	4.89	5.19	0.14			
1996	19.7	0.86	35.3	815.9	5.51	5.71	4.74	5.15	5.28	0.21			
1997	19.6	0.76	33.8	564.3	5.50	5.85	4.68	4.67	5.18	0.30			
1998	19.0	0.44	60.9	945.5	5.47	6.48	5.43	5.35	5.68	0.27			
1999	27.4	0.43	43.7	820.4	5.87	6.49	5.01	5.16	5.63	0.34			
2000	15.2	0.51	31.6	692.7	5.22	6.31	4.60	4.94	5.27	0.37			
2001	19.6	0.53	28.3	779.6	5.50	6.27	4.45	5.09	5.33	0.38			
Averages	**19.9**	**0.61**	**39.2**	**760**	**5.52**	**6.12**	**4.87**	**5.06**	**5.37**	**0.11**	**0.03**	**0.08**	**>0.1**

Summary

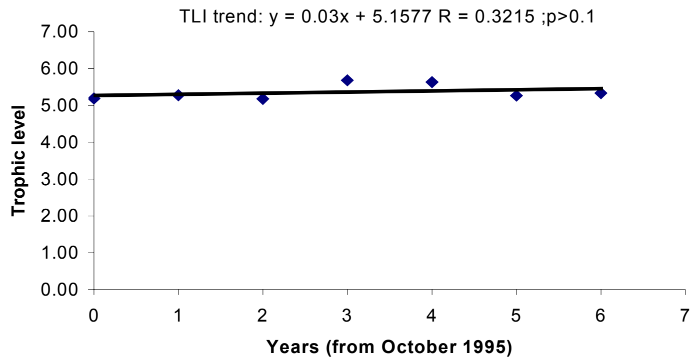
PAC = 2.6 ± 2.6 % per year
p-value = 0.39

TLI value = 5.37 ± 0.11 TLI units
TLI trend = 0.03 ± 0.08 TLI units per year
p-value >0.1

Assessment
Supertrophic
No Change

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Waikare
Analysis (25 Feb 1993 to 17 Dec 2001)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	(1.05) (mg/m^{-3}year^{-1})	-0.008 (m year^{-1})	24.1 (mgP/m^{-3}year^{-1})	52.75 (mgN/m^{-3}year^{-1})			
p-value	p>0.1	p<0.05	p<0.001	p<0.05			
Period average	36.1 (mg m^{-3})	0.13 (m)	204 (mg m^{-3})	1301 (mg m^{-3})			
PAC (%/yr)	**0.0**	**5.6**	**11.8**	**4.1**	**5.38**	**2.45**	**0.10**
Average PAC	5.38%.year^{-1} with a p-value=0.10						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Jan93-Dec93	32.4	0.16	133	995	6.06	7.61	6.42	5.41	6.38	0.46			
1994	30.8	0.14	138	1223	6.00	7.81	6.46	5.68	6.49	0.47			
1995	13.8	0.19	135	1202	5.11	7.42	6.43	5.66	6.16	0.50			
1996	59.8	0.16	139	1180	6.73	7.62	6.48	5.64	6.62	0.41			
1997	17.7	0.10	235	1203	5.39	8.11	7.14	5.66	6.58	0.64			
1998	72.3	0.13	208	1354	6.94	7.86	6.99	5.82	6.90	0.42			
1999	42.4	0.11	270	1621	6.35	8.04	7.32	6.05	6.94	0.45			
2000	28.9	0.08	410	1560	5.93	8.48	7.85	6.00	7.07	0.65			
2001	31.4	0.14	93	1210	6.02	7.76	5.96	5.67	6.35	0.48			
Averages	**36.1**	**0.13**	**204**	**1301**	**6.17**	**7.82**	**6.96**	**5.76**	**6.61**	**0.16**	**0.06**	**0.15**	**>0.1**

Summary

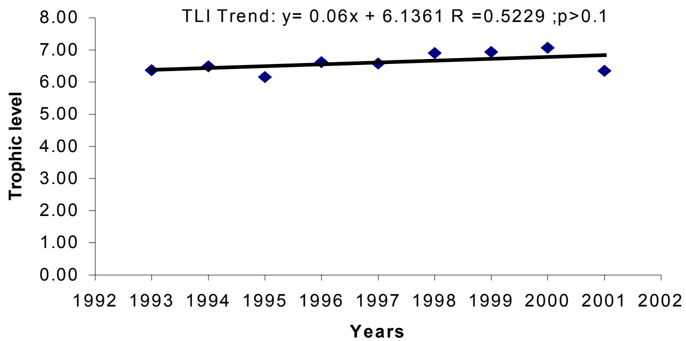
PAC = 5.38 ± 2.45 % per year
p-value = 0.10

TLI value = 6.61 ± 0.16 TLI units
TLI trend = 0.06 ± 0.15 TLI units per year
p-value >0.1

Assessment
Hypertrophic
Probable deterioration

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Whangape
Analysis (1992 to 1996)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	-5.2 ($mg/m^{-3}year^{-1}$)	0.16 ($m\ year^{-1}$)	-18.0 ($mgP/m^{-3}year^{-1}$)	-84.0 ($mgN/m^{-3}year^{-1}$)			
p-value	P<0.01	p<0.05	p<0.05	p<0.01			
Period average	24.0 ($mg\ m^{-3}$)	0.54 (m)	68.7 ($mg\ m^{-3}$)	820 ($mg\ m^{-3}$)			
PAC (%/yr)	**-21.7**	**-29.6**	**-26.2**	**-10.2**	**-21.9**	**4.23**	**0.014**
Average PAC	-21.9%.$year^{-1}$ with a p-value=0.01						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
1992/93	37.01	0.39	92	979	6.20	6.61	5.95	5.39	6.04	0.26			
1993/94	29.17	0.35	106.5	986	5.94	6.74	6.14	5.40	6.05	0.28			
1994/95	18.65	0.51	47.6	718	5.45	6.31	5.12	4.99	5.46	0.30			
1995/96	10.94	0.75	43.6	773	4.86	5.86	5.01	5.08	5.20	0.23			
Averages	**24.0**	**0.54**	**72.4**	**864**	**5.73**	**6.33**	**5.65**	**5.23**	**5.69**	**0.24**	**-0.310**	**0.15**	**<0.05**

Summary

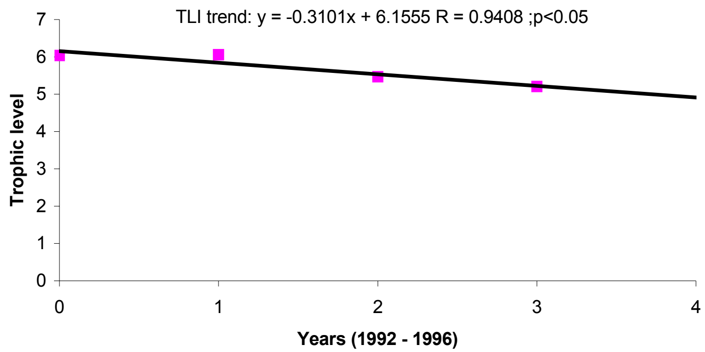
PAC = -21.9 ± 4.23 % per year
p-value = 0.01

TLI value = 5.69 ± 0.24 TLI units
TLI trend = -0.310 ± 0.15 TLI units per year
p-value <0.05

Assessment
Supertrophic
Definite improvement

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change



Lake Mangahia
Analysis (1 Sept 1988 to 13 June 1994)

Percent annual Changes

	Chla	SD	TP	TN	Avg PAC	Std Err	p-value
Annual change	(4.25) (mg/m^{-3}year^{-1})	(-0.006) (m year^{-1})	(12.66) (mgP/m^{-3}year^{-1})	(26.96) (mgN/m^{-3}year^{-1})			
p-value	p>0.1	p>0.1	p>0.1	p>0.1			
Period average	54.7 (mg m^{-3})	0.27 (m)	197 (mg m^{-3})	2403 (mg m^{-3})			
PAC (%/yr)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.39**
Average PAC	0%.year^{-1} with a p-value=0.39						

Trophic Level Index Values and Trends

Year	Chla (mg/m^{-3})	Secchi (m)	TP (mgP/m^{-3})	TN (mgN/m^{-3})	TLc	TLs	TLp	TLn	TLI avg	Std. Err. TL avg	TLI Trend units/yr	Std. Err. TLI Trend	p-value
Sep88&Dec88	16.5	0.40	131	2387	5.31	6.58	6.40	6.56	6.21	0.30			
1989	70.0	0.15	156	2100	6.91	6.97	6.62	6.39	6.72	0.13			
1990	34.5	0.40	174	2488	6.13	5.99	6.76	6.61	6.37	0.19			
1991	40.0	0.32	144	2083	6.29	6.23	6.52	6.38	6.35	0.06			
1992	64.7	0.14	324	2976	6.82	7.06	7.55	6.85	7.07	0.17			
1993	54.3	0.28	206	2414	6.63	6.34	6.98	6.57	6.63	0.13			
1994	72.3	0.28	186	2338	6.94	6.34	6.84	6.53	6.66	0.14			
Averages	**54.7**	**0.27**	**197**	**2403**	**6.63**	**6.37**	**6.92**	**6.57**	**6.57**	**0.08**	**0.067**	**0.29**	**>0.1**

Summary

PAC = 0 ± 0% per year
p-value = 0.39

TLI value = 6.62 ± 0.11 TLI units
TLI trend = 0.08 ± 0.16 TLI units per year
p-value >0.1

Assessment
Hypertrophic
No change

The guide used in the PAC average p-value evaluation is

p-value Range	Interpretation
<0.1	Definite Change
0.1 – 0.2	Probable Change
0.2 – 0.3	Possible Change
>0.3	No Change