Auckland
Regional Council
TE RAUHITANGA TAIAO

Water Quality of Selected Lakes In the Auckland Region (1992 – 2005)

June 2005 TP268

Auckland Regional Council
Technical Publication No. 268, June 2005
ISSN 1175 502X ISBN 1-877-353-83-8
www.arc.govt.nz

Water Quality of Selected Lakes in the Auckland Region (1992 – 2005)

Prepared by:
Grant Barnes
Auckland Regional Council

Noel Burns
Lakes Consulting Ltd [1]

1. 42 Seabreeze Rd
Devonport, Auckland

ARC Technical Publication 268 (TP268)
Auckland Regional Council
Auckland

June 2005

Acknowledgments

The authors wish to thank Auckland Regional Council field staff for the data collection, special thanks to Ross Winterburn for his efforts over the past 17 years.

Contents

Recommended citation:

Auckland Regional Council 2005: Water quality of selected lakes in the Auckland Region (1992 – 2005). Environmental Management, Technical Publication 268, Auckland. 61 pages.

Executive Summary

Lake water quality has been monitored quarterly in the Auckland Regional since 1988. Water quality is currently monitored at Lake's Kereta, Kuwakatai, Ototoa, Pupuke, Tomarata and Wainamu.

A trend analysis was undertaken on the dataset using the trophic level assessment method assisted by specialised software (Lakewatch).

Lake Ototoa had the highest water quality of the seven lakes monitored, followed in order of declining water quality by Pupuke, Kereta, Tomarata, Wainamu, Kuwakatai and Spectacle. Ototoa was moderately enriched (mesotrophic), Pupuke, Kereta, Tomarata and Wainamu were eutrophic, Kuwakatai was supertrophic and Spectacle, the most degraded lake, was hypertrophic.

Trend analysis showed water quality has probably improved in Lake Kereta and Tomarata. No change was detected in Lake Kuwakatai, Pupuke and Wainamu, however some interesting patterns did emerge which warrant further investigation. Of concern was the fact that water quality significantly declined in Lake Ototoa and Lake Spectacle.

The observed decline in Lake Ototoa is particularly concerning given its relatively good water quality (low trophic level). Further degradation may result in adverse changes to the Lake's high ecological values.

The changes in trophic level observed in all four lakes is a combination of many interacting factors including inputs of contaminants from catchment landuses, internal nutrient cycling, weather patterns, and biotic influences such as phytoplankton abundance and animal and plant pest perturbations.

1 Introduction and Rationale

Lake water quality has been routinely monitored quarterly in the Auckland Region since 1988, though infrequent records exist for Lake Pupuke from 1966. Water quality is currently monitored at Lakes Kereta, Kuwakatai, Ototoa, Pupuke, Tomarata and Wainamu (Figure 1).

The Auckland Regional Water Board (ARWB) undertook the first comprehensive data analysis in 1990, examining records from lakes excluding Pupuke for the period 1988 to 1989. The same year a comparative review of historic water quality records (1966 to 1990) from Lake Pupuke was completed (Vant et. al., 1990). Subsequent data summaries of all seven lakes have been reported annually (various Auckland Regional Council (ARC) Technical Publications and unpublished reports). A review of the lakes monitoring programme undertaken in 1999 provides a useful description of the monitored lakes (Gibbs et. al., 1999).

This report extends those analyses to cover the period ended March 2005. Trend analysis is restricted to the period 1992 to 2005 where data across all major parameters are consistent and reported.

1.1 Background

There are over 30 lakes in the Auckland Region, which vary considerably in their physical, chemical and biological characteristics. Most are shallow and less than 10 hectares in size. The seven lakes monitored by the ARC are the largest natural fresh waterbodies in the Auckland Region (excluding the ten water supply reservoirs in the Hunua and Waitakere Ranges) (photographs in Appendix 4).

The Region's lakes are inextricably linked to their catchments. Land use activities contribute quantities of nutrients, sediment and other contaminants to varying degrees. These inputs can alter water quality and affect the diversity of plants and animals contained within.

Contaminants enter lakes through either point sources (e.g. stormwater, treated effluent, or factory wastewater), or via diffuse sources (e.g. runoff from agriculture or groundwater inputs). Most of the Region's lakes exhibit accelerated eutrophication (nutrient enrichment) as a result of these inputs.

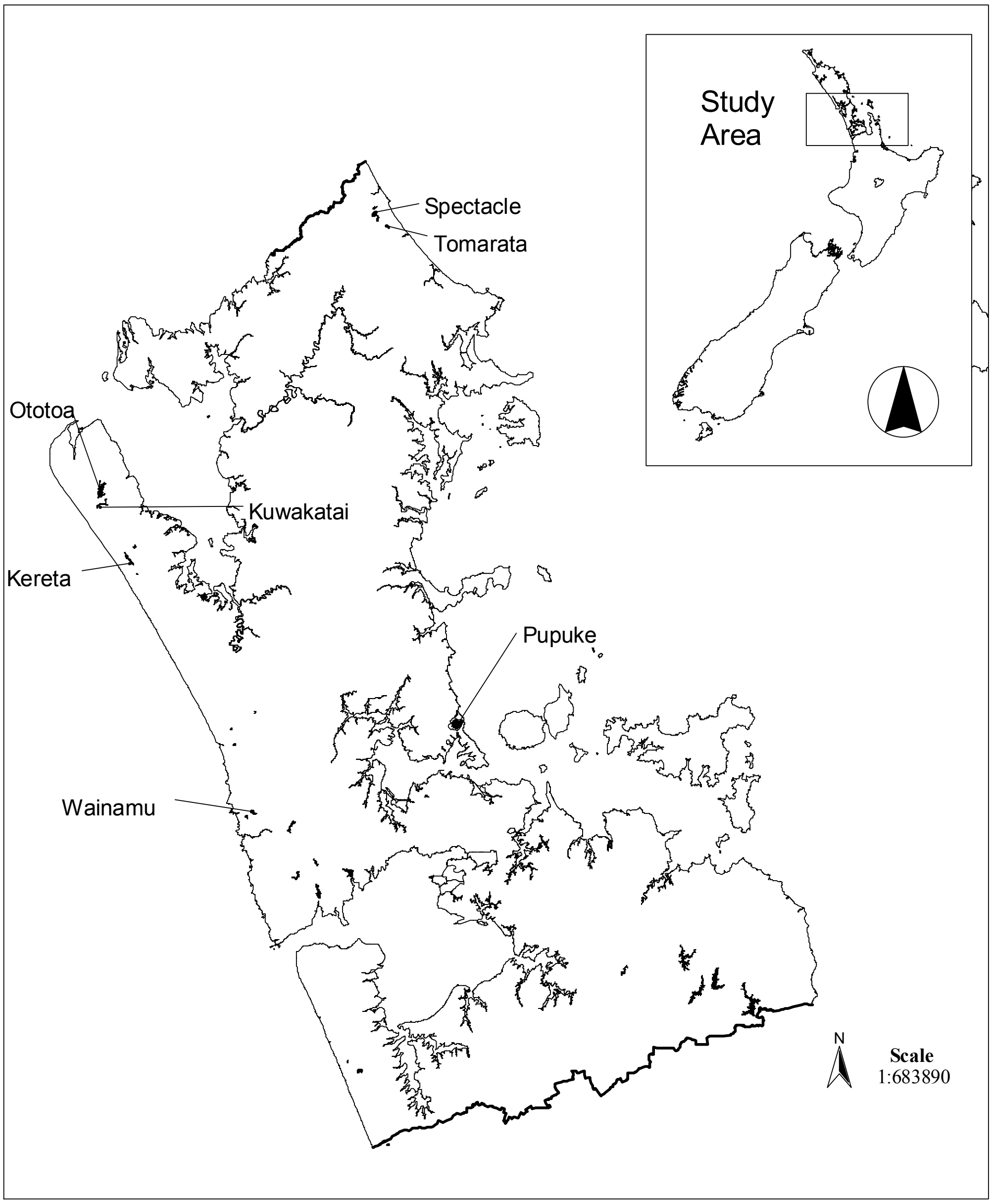


Figure 1: Location of the seven monitored lakes within the Auckland Region.

1.2 Project Rationale

The water quality monitoring programme was designed to provide a measure of trophic state (i.e. how enriched a lake is) and to determine whether changes to trophic state have occurred over time. Timely remedial work may then be undertaken if necessary.

The objectives of the programme are to:

- Determine the temporal and spatial variability of selected water quality parameters at representative lakes throughout the region.
- Provide a baseline of water quality information from which the presence, direction and magnitude of trends can be determined.

Subsidiary to these aims are the:

- Identification of the present and potential impacts of catchment development activities
- Collection of baseline data for calibration of short-term surveys of similar areas
- Evaluation of improvement in water quality in response to pollution abatement activities
- Assessment of the effectiveness of land use planning policies intended to protect water quality
- Determination that existing environmental controls are adequate to avoid unacceptable adverse environmental impacts

Lakes have been selected that best represent or integrate the influences of specific land uses on water quality and are representative of the Region as a whole. This is achieved by including:

- Seven of the largest natural lakes within the region.
- Lakes located within catchments of different development types; rural, native and urban.
- Lakes with water quality ranging from good to poor.
- Lakes that are representative of the different types within the Region (i.e. dune and volcanic).

2 Methods

2.1 Datasets

Water quality records for the present programme commenced March 1988. These are incomplete for several important parameters up to November 1992, which restricted trend analysis prior to this period. Comparison of trophic state with earlier studies is undertaken. The extensive Pupuke dataset allows examination of records collected in 1966-67 (Barker, 1976), 1984-86 (Vant et. al., 1990), 1992-96 (Burns & Coffey, 2003)[1].

Several changes to the analytical procedures have occurred during the course of the monitoring programme. This is to be expected with a continuous dataset of over 15 years. Where appropriate suspect data was removed from the record during inspection to identify outlier values. For example, the detection limit for Chlorophyll *a* (Chla) varied widely during 1995/96 (0.6 - 70 $mg.m^{-3}$). Inclusion of Chla during this period, even at half the detection limit, would have exceeded the highest observed value at several lakes monitored (Table 1). All Chla values recorded at detection limit were removed from the analysis.

The high detection limit of Biological Oxygen Demand (BOD) (2 parts per million (ppm)) relative to *in situ* levels limited the proportion of observed values versus those reported at detection limit. For example, over 90% of BOD values from Lake Ototoa were recorded at detection limit. Following conventional analytical practice and halving the detection limit would have adversely skewed the result. Consequently BOD values recorded at detection limit were removed from the analysis.

All other values recorded at detection limit (phosphorus (P), nitrogen (N), suspended solids) were halved and included in the data analysis.

Analytical precision for phosphorus was problematic as total and soluble values were consistently reported in ppm to 2 decimal places. This reduced the precision of P at Lake Ototoa and Pupuke on most occasions to stepwise changes between 0.01 to 0.02 ppm, making trend analysis difficult.

Water levels were routinely observed during the first third of the monitoring programme, continued sporadically subsequently, before ceasing completely in the latter half. The lack of a complete water level record makes interpretation of some trends observed in section 1 difficult.

[1] Temperature, dissolved oxygen and Secchi data collected between 1992-1996 by NIWA under the New Zealand Lake Monitoring Programme was included in the trend analysis.

2.2 Data collection

Monitoring of water quality was consistent with the New Zealand Lakes Water Quality Monitoring Programme (Burns et. al., 2000).

Samples were collected quarterly with most sites accessed by helicopter (excluding Pupuke). Each lake was sampled from a single deep-water station where temperature and dissolved oxygen profiles were determined. Sampling was stratified by depth with two vertically distinct samples (epilimnion and hypolimnion) collected at all lakes except Pupuke (n=3) and Kereta (n=1). Watercare Services Ltd provided analytical services.

Table 1 summarises parameters analysed for trophic state and trend. A description of each parameter measured is provided in Table 1.

Table 1: Median number of samples analysed at the seven monitored lake sites. Values in brackets are minima and maxima.

		Regional lakes (7 sites) 1992 to 2005	
Parameter	Units	Median	Min, Max
Temperature	°C	63	(17.7, 20.0)
Dissolved oxygen	$mgO.m^{-3}$	51	(8.7, 10.4)
Total phosphorus	$mgP.m^{-3}$	65	(14.6, 100)
Dissolved reactive phosphorus	$mgP.m^{-3}$	64	(6.5, 10.0)
Total nitrogen	$mgN.m^{-3}$	49	(396, 1366)
Total ammoniacal nitrogen	$mgN.m^{-3}$	65	(10.4, 52.5)
Total oxidised nitrogen	$mgN.m^{-3}$	65	(8.7, 17.0)
Chlorophyll *a*	$mg.m^{-3}$	53	(5.5, 65.0)
Visual clarity	m	61	(0.4, 4.5)
Total suspended solids	$g.m^{-3}$	49	(1.1, 21.5)
pH	pH units	64	(7.3, 8.5)
Conductivity	$mS.m^{-3}$	62	(17.2, 28.2)

2.3 Data analysis

Analysis of data was primarily undertaken using the Lakewatch software (Lakes Consulting, 2000). The software incorporates the Burns trophic level assessment method (Burns et. al., 2000), and provides an efficient means of elucidating key water quality indicators to determine trophic level and trend.

Trophic level classification was determined quantitatively based on four key variables; Chla, visual clarity (Secchi depth (SD)), total phosphorus (TP) and total nitrogen (TN). Lakes were assigned the normal descriptive terms of oligo-, meso-, eutro-, super, or hypertrophic depending on their trophic level index (TLI). The TLI was determined from the sum of the following equations used to determine each individual trophic level (TL) value for Chla (TLc), SD (TLs), TP (TLp), and TN (TLn):

$$TLc = 2.22 + 2.54\log(Chla)$$

$$TLs = 5.56 + 2.60\log(\frac{1}{SD} - \frac{1}{40})$$

$$TLp = 0.218 + 2.92\log(TP)$$

$$TLn = -3.61 + 3.01\log(TN)$$

The equations normalise the annual average values of Chla, SD, TP and TN allowing comparison between variables (i.e. TLn significantly lower than TLp indicates the lakes is N-limited) and with other lakes following the lake classification system in Table 2 (Burns et. al, 2005).

Table 2: Values of key variables defining the boundaries of different lake types and trophic levels (Burns et. al., 2000).

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

Trends were determined by applying parametric analysis techniques using deseasonalised residual data (Burns et. al., 2000). Firstly, the key variables were deseasonalised whereby Chla, TP, TN and SD were plotted as a function of the time of year collected with no regard for year of collection. A polynomial curve was then fitted to the annualised data with the residual value 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.

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). Changes indicating increased eutrophication were assigned positive values, whilst decreased eutrophication were given negative values. The conclusion that 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 from Table 3, and was based on the premise that most or all of the key variables in a eutrophied lake should indicate a similar magnitude of change (Burns et. al., 2000, 2005).

Table 3: Scale of probabilities indicating change in trophic state over time.

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

3 Results and discussion

A summary of each lake monitored is provided in Table 4 and includes morphological, chemical and catchment landuse data. Lakes Ototoa and Pupuke were the largest and deepest lakes monitored, Wainamu and Tomarata were comparatively small and Lake Kereta the shallowest at just 1.5 m deep. Catchment landuse ranged from almost exclusively intensive agriculture (Spectacle) or urban (Pupuke), to a mix of plantation forestry, native scrub and agriculture (Ototoa).

Table 4: Summary data for the seven monitored lakes in the Auckland Region from September 1992 to March 2005.

	Kereta	Kuwakatai	Ototoa	Pupuke	Spectacle	Tomarata	Wainamu
Lake area (ha)[a]	32	29	110	110	50	16	14
Max. depth (m)[a]	1.5	19	29	57	7	5	15
Av. Annual Chla (mg.m^{-3})	12.1	54.1	4.7	8.3	89.1	10.3	9.7
Av. Annual SD (m)	ns	1.4	4.8	4.7	0.4	1.6	1.0
Av. Annual TP (mgP.m^{-3})	37.5	46.3	16.7	22.6	402.2	22.5	34.9
Av. Annual TN (mgN.m^{-3})	745	827	496	621	1300	663	421
Av. TLc (TLI units)	4.6	6.5	3.9	4.5	7.1	4.7	4.6
Av. TLs (TLI units)	ns	5.2	3.7	3.7	6.7	5.0	5.6
Av. TLp (TLI units)	4.7	5.1	3.8	4.1	6.1	4.2	4.7
Av. TLn (TLI units)	4.8	5.1	4.3	4.5	5.7	4.8	4.2
Av. Annual TLI (TLI units)	4.7	5.5	3.9	4.2	6.4	4.7	4.8
TLp - TLn	-0.1	0	-0.5	-0.4	0.4	-0.6	0.5
Catchment area (ha)[b]	430	410	510	105	500	83	480
Native forest/scrub[c]	18%	11%	34%	7%	5%	29%	96%
Exotic forest[c]	28%	4%	27%	0%	15%	17%	0%
Pasture[c]	54%	85%	39%	0%	80%	54%	4%
Urban[c]	0%	0%	0%	93%	0%	0%	0%

a. Gibbs et. al. (1999).

b. Calculated from the NIWA Rivers Environment Catchment layer (Snelder et. al., 2004).

c. Calculated from Landcover Database (LCDBII) (Leathwick et. al. 2003).

Lake Ototoa had the highest water quality of the seven lakes monitored, followed in order of declining water quality by Pupuke, Kereta, Tomarata, Wainamu, Kuwakatai and Spectacle (Table 5). Ototoa was moderately enriched (mesotrophic), though any marginal increase in its trophic level index would result in a eutrophic classification. Lakes Pupuke, Kereta, Tomarata and Wainamu were eutrophic, Kuwakatai was supertrophic and Spectacle, the most degraded lake, was hypertrophic.

Table 5: Three year rolling average trophic level values for the seven monitored lakes in the Auckland Region from September 1992 to March 2005.

Lake	Trophic state	TLI 3 yr rolling avg to 2005 TLI units	TLI 3 yr rolling avg to 2004 TLI units	TLI 3 yr rolling avg to 1995 TLI units
Ototoa	Mesotrophic	4.0	4.0	3.6
Pupuke	Eutrophic	4.3	4.5	4.1
Kereta	Eutrophic	4.3	4.3	5.4
Tomarata	Eutrophic	4.4	4.6	4.7
Wainamu	Eutrophic	4.6	4.8	4.8
Kuwakatai	Supertrophic	5.4	5.6	5.6
Spectacle	Hypertrophic	6.5	6.4	6.2

The 3-year rolling average incorporates mean TLI scores for the year noted and the two preceding. A comparison with the 1995 3-year rolling average indicated potential change in trophic state over time for several lakes, particularly Ototoa and Spectacle (deteriorating), and Tomarata and Kereta (improving). Detailed trend analyses for each lake follows in the sections below.

3.1 Key variables trend analysis

Results of the trend analysis indicate the following changes (Table 6):

- Lakes Kereta and Tomarata became less eutrophic indicating a possible improvement in water quality.
- Lake Ototoa has eutrophied since 1992 with water quality declining significantly.
- Water quality at Lake Spectacle has probably deteriorated since 1992.
- No change in water quality was detected at Lakes Kuwakatai, Pupuke, and Wainamu.

Table 6: Summary of significant water quality trends expressed as average percent annual change (PAC) and for individual key variables for seven lake sites. Trends expressed as (↑) for improving trend, (↓) for deteriorating trend and (—) for no change. Significant trend at p-value <5% unless otherwise stated in brackets. ns = not sampled.

	Ototoa	Pupuke	Kereta	Tomarata	Wainamu	Kuwakatai	Spectacle
PAC trend	↓ (0.03)	—	↑ (0.20)	↑ (0.26)	—	—	—
TLI Trend (TLI units)	0.04±0.02	—	-0.13±0.03	-0.02±0.02	—	—	—
Chlorophyll a	↓	↓	↑	↑	—	—	↑
Secchi depth	↓	↓	ns	↑	—	—	↓
Total nitrogen	↓	—	—	—	—	↑	↓
Total phosphorus	↓	—	↑	—	↑	—	↓

Lake Kereta indicated the greatest overall improvement in water quality of approximately 0.13 TLI units/yr, whilst Lake Tomarata's probable improvement occurred at a rate of 0.02 TLI units/yr[2]. In contrast, water quality at Lake Ototoa deteriorated by 0.04 TLI units/yr.

Table 7 lists the p-values and trend slopes for all variables monitored at the seven lakes. Ninety one results were analysed of which 33% (30) were significant, 16 highly significant ($p<0.001$). Conductivity showed the highest number of significant trends with only Lake Pupuke insignificant. Five lakes exhibited significant trends in Chla. Other variables with significant trends included SD and TP (four out of seven lakes), and TN, total suspended solids (TSS) and pH (three out of seven lakes). Temperature, dissolved oxygen (% saturated), dissolved reactive phosphorus and faecal coliforms showed no significant trend.

3.2 Ototoa

The average PAC determined from the four key variables indicated a significant decline in water quality ($p<0.01$) between 1992 and 2005, with all four deteriorating (Table 6). The decline in water clarity appeared to be driven by an increase in phytoplankton abundance due to increasing levels of inorganic nitrogen (Table 7). The lack of analytical precision in dissolved reactive phosphorus measurements prevented detection of any trend in inorganic phosphorus, although total phosphorus had increased by 0.60 $mg.m^{-3}$/yr ($p<0.01$) over the observed period (Table 7).

[2] Standard errors for Lake Kereta and Tomarata 0.03 and 0.02 TLI units/yr respectively.

Table 7: P-values and trend slopes (brackets) for records of all measured variables at seven monitored lakes between 1992 and 2005. Trends shown in bold are significant (P<5%). For each variable the total number of records that have shown significant increases or significant decreases is shown. Table modified from Vant & Smith (2004).

	Temperature (10^{-2} °C/yr)	Dissolved oxygen(10^{-2} percent of saturation/yr)	Chlorophyll *a* (10^{-2} [mg/m^3]/yr)	Visual clarity (m/yr)	Total phosphorus (10^{-2} [mg P/m^3]/yr)	Total nitrogen (mg N/m^3/yr)	Total ammoniacal nitrogen (10^{-2} [mg N/m^3]/yr)	Total oxidisable nitrogen (10^{-2} [mg N/m^3]/yr)	Dissolved reactive phosphorus (10^{-2} [mg P/m^3]/yr)	Total suspended solids (10^{-2} [g/m^3]/yr)	Conductivity (10^{-2} [mS/m^{-3}]/yr)	PH (10^{-2}/yr)	Faecal coliforms (MPN/yr)
Ototoa	86 (1)	7 (-44)	**4 (15)**	**1 (-13)**	**<1 (60)**	**4 (20)**	**1 (257)**	**2 (36)**	22 (-12)	63 (-3)	**<1 (9)**	99 (0)	11 (-0.4)
Pupuke	31 (2)	88 (3)	**4 (-52)**	**<1 (-11)**	55 (-21)	8 (39)	44 (99)	59 (-25)	88 (3)	28 (-5)	55 (3)	85 (0)	61 (0.2)
Kereta	15 (11)	76 (48)	**<1 (-170)**	ns	**<1 (-347)**	10 (-47)	13 (-45)	33 (24)	12 (-46)	**3 (-75)**	**<1 (-40)**	**3 (7)**	34 (-13)
Tomarata	19 (5)	97 (-1)	**<1 (-87)**	**3 (4)**	31 (24)	63 (6)	26 (78)	11 (42)	11 (22)	**<1 (-15)**	**2 (-9)**	**1 (3)**	58 (0.5)
Wainamu	66 (-2)	26 (-55)	19 (-36)	10 (-2)	**<1 (-166)**	15 (17)	99 (0)	34 (86)	7 (38)	55 (-3)	**<1 (-16)**	16 (1)	54 (0.7)
Kuwakatai	49 (-3)	39 (57)	71 (-63)	66 (1)	87 (11)	**2 (-33)**	81 (67)	6 (-62)	9 (-34)	74 (5)	**<1 (-27)**	15 (3)	21 (-0.7)
Spectacle	32 (4)	89 (7))	**3 (-430)**	**<1 (-2)**	**<1 (480)**	**<1 (64)**	9 (657)	31 (305)	37 (26)	**<1 (156)**	**<1 (-41)**	**3 (3)**	53 (4.0)
Decreased	0	0	4	3	2	1	0	0	0	2	5	0	0
Increased	0	0	1	1	2	2	1	1	0	1	1	3	0

The overall decline in water quality is supported when compared with data between September 1987 and August 1992 as reported by ARWB (1990) and converted to the TLI system. The TLI for this period was 3.54±0.2 TLI units, lower than recorded for the 1992 – 2005 period (Table 4)[3]. Cunningham et. al., (1957) found during a 1950 survey of the lake an SD of 9 m, 0.5 m higher than the maximum recorded during the present study (Appendix 3).

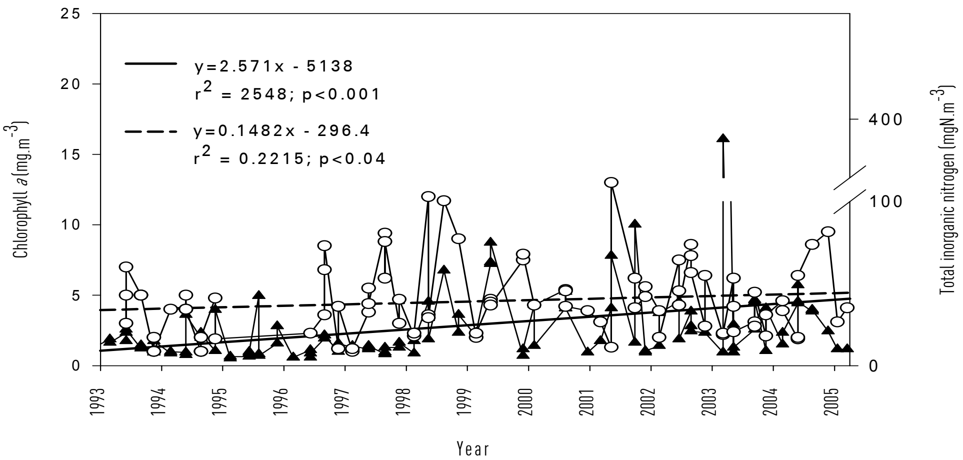


Figure 2: Time series plot of epilimnetic/isothermic Chlorophyll a (open circles) and total inorganic nitrogen (triangles) concentrations in Lake Ototoa between 1993 and March 2005. Simple linear regression fitted.

Lake Ototoa stratified regularly during summer, although the thermocline tended to be unstable, frequently disrupted, and the hypolimnetic volume relatively small (Hawes & Haskew, 2003). No change was detected in temperature (p=86%) or dissolved oxygen (p=7%) in the epilimnion or during isothermal conditions between 1992 and 2005 (Table 7). Closer inspection of the hypolimnion indicated a deteriorating trend in dissolved oxygen (-3.6%sat/yr; p<0.01) (Figure 3), which appeared to manifest as a stepwise decline in oxygen concentration from 1999.

[3] Comparison with 1987 – 1992 must be treated with some caution due to TN missing from the record. Calculation of the TLI consisted of Chla, water clarity and TP only.

Figure 3: Time series plot of hypolimnetic dissolved oxygen from Lake Ototoa between 1993 and March 2005. Simple linear regression fitted.

Closer analysis of the time series data indicated that for most variables the data appeared to show a cycle rather than a gradual increase. This was particularly true for Secchi data, which showed a high – low – high oscillation between 1992 and 2005 and when plotted with the El Niño Southern Oscillation phenomenon (ENSO)[4] exhibited evident correspondence between 1999 and 2002 (Figure 4). The low water clarity period observed between 1998 to 2002 appeared to coincide initially with a strong El Niño event and continued though subsequent La Niña years until recovering from 2002 onwards. This suggests observed changes to Lake Ototoa water quality may haven been cyclic, climate driven behaviour rather than a typical linear trend.

---

[4] The El Niño - Southern Oscillation (ENSO) is a global climatic phenomenon marked by seesaw shifts in air pressure between the Indo-Australian and eastern regions of the Tropical Pacific. Sustained positive values often indicate El Niño episodes. In El Niño conditions, New Zealand experiences more south-westerly wind than usual, and analysis of rainfall records shows that the west and south of the South Island generally receive enhanced precipitation. Conversely, in La Niña conditions, the wind anomalies are from the northeast, and the west and south receive reduced precipitation. The most recent strong El Niño was in 1997/98. Source of ENSO data http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html.

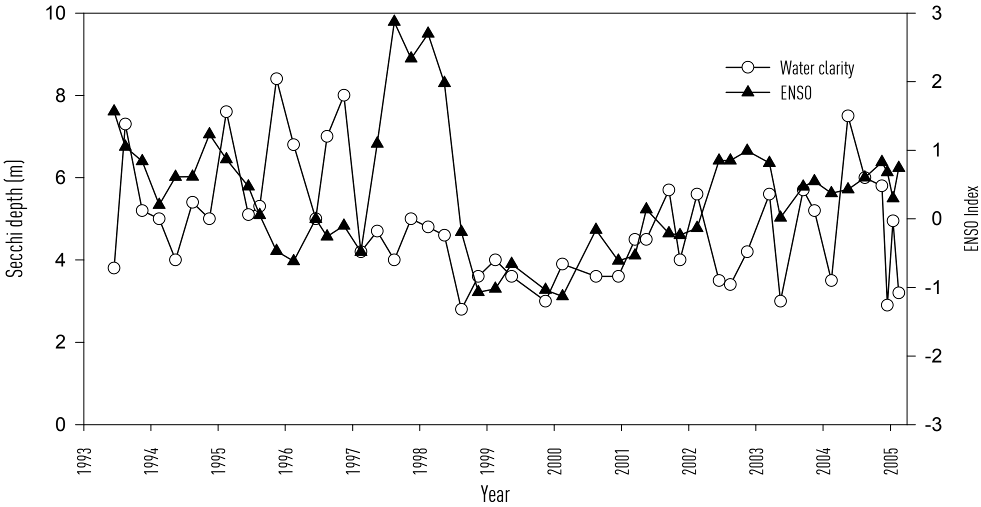


Figure 4: Time series comparison of water clarity (Secchi depth) and the El Niño Southern Oscillation Index (ENSO) from Lake Ototoa between 1993 and March 2005. Values greater than 0.5 indicative of El Niño conditions, less than –0.5 La Niña conditions.

To further investigate this we plotted the difference in temperature between 1 and 15 m (delta T) (as an index of stratification), with the difference in oxygen between the same depths (delta O_2) (as the variation in oxygen concentration) (Figure 5). The resulting string correlation supports the view that more intensive stratification leads to more oxygen depletion, which over time has increased the concentration of inorganic nitrogen in the water column, thus promoting increased algal productivity and decreased water clarity.

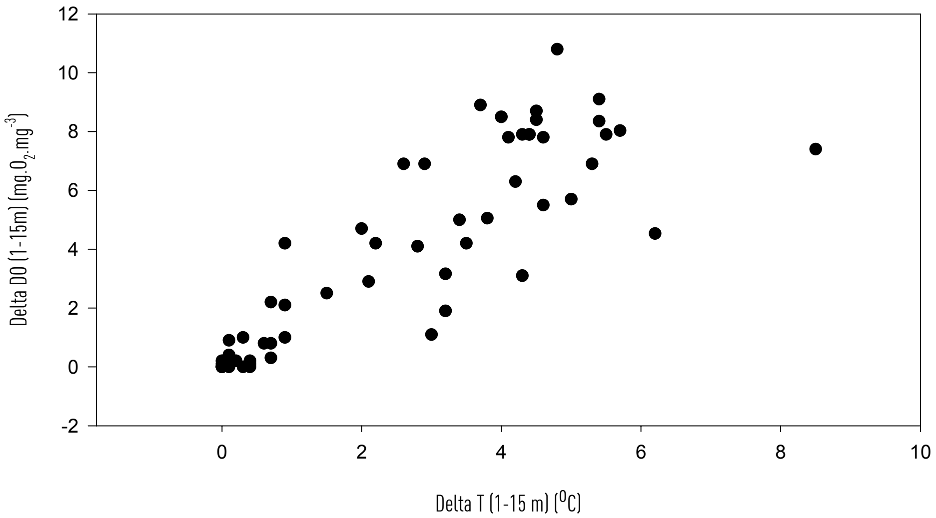


Figure 5: Comparison of the difference between dissolved oxygen at 1 metre and 15 metres (ΔDO) with the corresponding difference in temperature (ΔT) in Lake Ototoa between 1993 and March 2005.

Figure 6 demonstrates that the accumulation of ammonium in the hypolimnion may be linked with climate driven oxygen depletion.

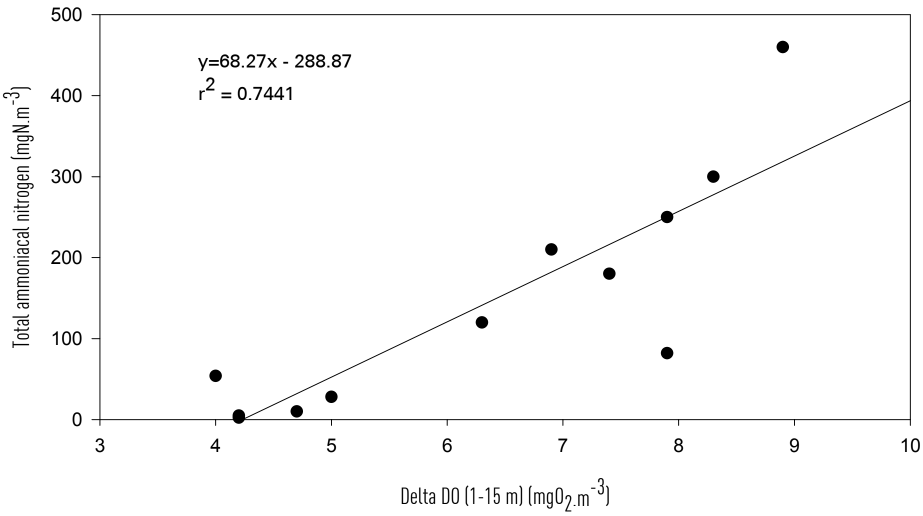
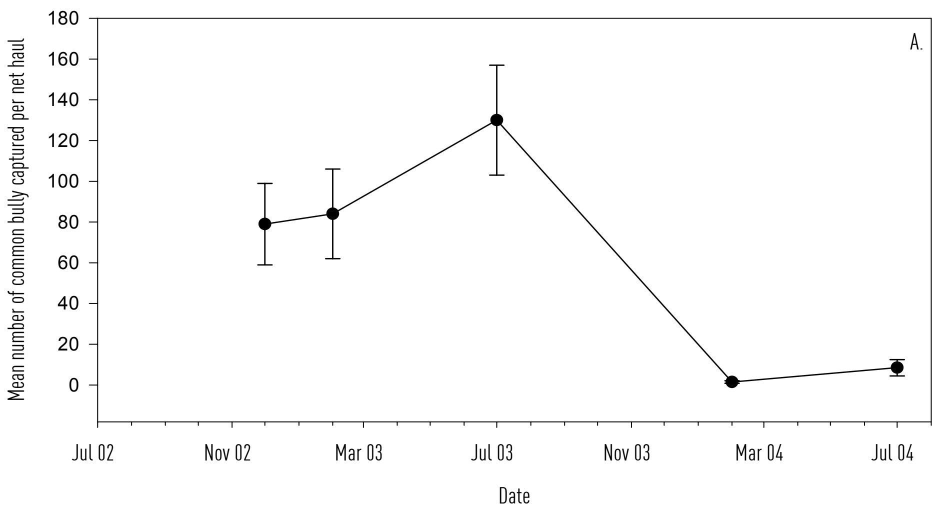


Figure 6: Comparison of annual summer hypolimnetic ammoniacal nitrogen from Lake Ototoa (25 m) between 1993 and March 2005 with ΔDO (1-15 m) of the corresponding period and depth.

There have been no substantial changes in landuse within the Ototoa catchment over the past 20 years. Landuse remains a mix of indigenous and exotic forestry and pastoral agriculture. Agricultural intensification may have occurred in recent years but this requires further investigation to quantify the nature and extent of external inputs to the Lake.

The influence of exotic fish on water quality is an unknown entity, particularly with regard to the recent introduction of perch (Perca fluviatilis). The population of this piscivorous fish within Lake Ototoa has reached sufficient density to have caused the substantial decline in populations of dwarf inanga (Galaxias divergens), common bully (Gobiomorphus cotidianus) and koura (Paranephrops planifrons) (Figure 7).



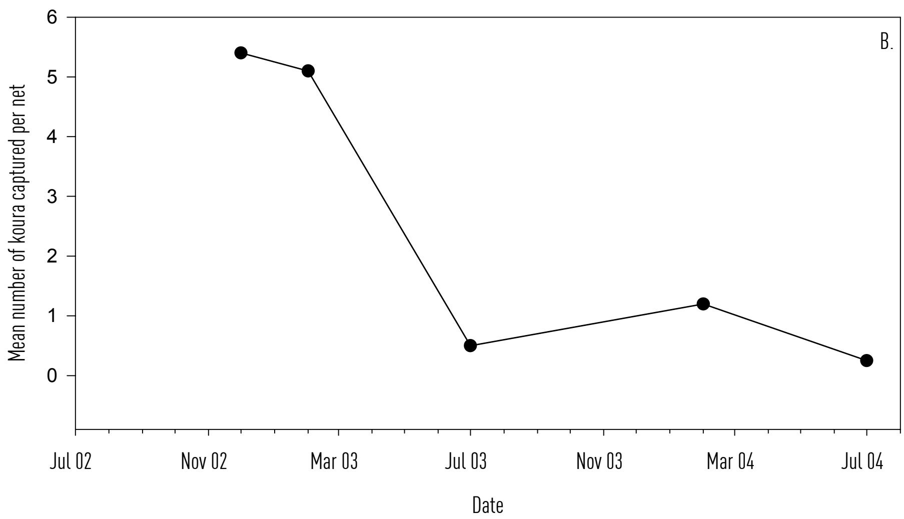


Figure 7: Mean catch per unit effort of common bully (A.) and koura (B.) from successive surveys at Lake Ototoa since 2002. Data courtesy of the Auckland/Waikato Fish and Game Council.

3.3 Pupuke

Water quality in Lake Pupuke is stable and has not changed from 1992 to March 2005 (Table 6). Average TLI was 4.2 TLI units, within a eutrophic classification (Table 4).

Water clarity and Chla were the only key variables to change significantly during the observed period with SD declining by 2.35 %/yr (-0.11±0.03 m/yr; p<0.001) (Table 6). The decline manifested in a significant increase in turbidity, although TSS remained unchanged (Table 7). Chla confounded the results by significantly declining at –6.52 %/yr (-0.52±0.25 $mg.m^{-3}$/yr; p= 4%) (Table 6).

Lake Pupuke was strongly monomictic[5], consistently destratifying during August of each year, restratifying again in late September/early October. Hypolimnetic dissolved oxygen rapidly diminished thereafter. Release of P and N from anoxic sediments occurred periodically in summer during the observed period, particularly during a period of incomplete mixing during the 1998/99 stratified season when P was released to the hypolimnion (Figure 8). However, no subsequent increase of P in the surface waters was detected (or obvious increase in Chla) suggesting rapid sedimentation of released P.

[5] Monomictic – a term used to describe lakes that undergo one period of complete mixing during the year separated by one period of thermal stratification.

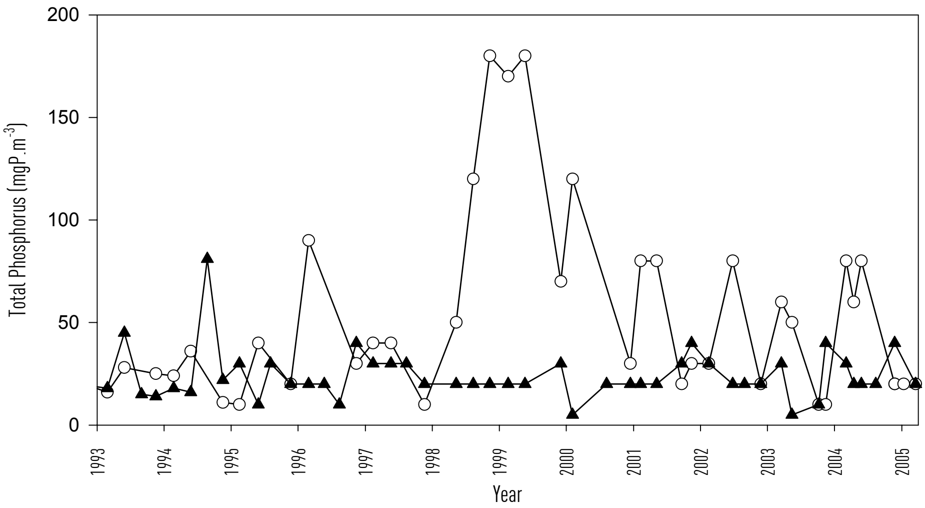


Figure 8: Comparison of hypolimnetic (open circles) and epilimnetic/isothermal waters (triangles) total phosphorus concentrations for Lake Pupuke between 1993 and March 2005.

No change was detected in epilimnetic temperature (p=31%) or dissolved oxygen (p=88%) (Table 7), although the hypolimnion warmed significantly by 0.4°C ($p<0.001$)(Figure 9).

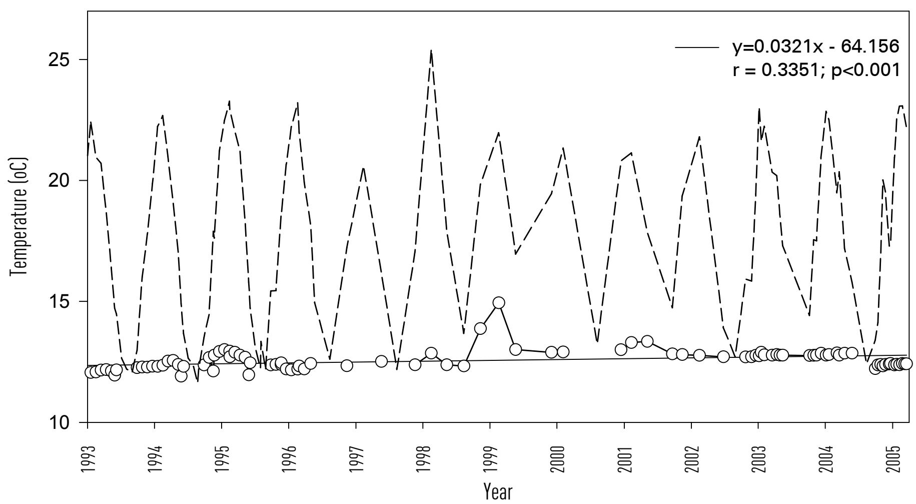


Figure 9: Comparison of hypolimnetic (open circles) and epilimnetic/isothermic waters (dashed line) temperature data for Lake Pupuke between 1993 and March 2005.

Changes in water clarity require careful consideration. Several authors have tracked improvements in water clarity since the University of Auckland completed the first comprehensive assessment in 1966/67 (Barker, 1967). Both Vant et al. (1990) and Burns & Coffey (2003) describe greater water clarity and lower concentrations of plant nutrients and Chla (Table 8). Figure 10 illustrates improved water clarity between 1966 and 2005 at an overall rate of 7 mm/yr (p<0.001), although also depicted is an apparent decline from 1998 onwards. An inter-decadal comparison of SD between the 1960s and 2005 suggests that water clarity consistently improved up to the 1990s before subsequently declining from 2000 onwards (Figure 11).

Table 8: Comparison of water quality in Lake Pupuke between the current study (1992 –2005) and three preceding studies in 1966/67, 1984/85 and 1992-96. Values are means (with range in brackets).

	1966/67[a]	1984/85[b]	1992-96[c]	Present study
Water clarity (m)	2.4 (1.0-5.2)	3.3 (1.2-7.2)	5.5 (1-9)	4.2 (1.4-8.5)
Chlorophyll *a* ($mg.m^{-3}$)	22 (0.8-61)	5.7 (0.5-26)	6.3 (1.5-14)	8.3 (1-44)
Near-surface nitrate ($mg.m^{-3}$)	45 (20-60)[d]	16 (1.0-70)	7.8 (1-47)	11.8 (1-63)
Near-surface ammonia ($mg.m^{-3}$)	125 (30-410)[d]	10 (1.0-46)	9.3 (1-49)	17.2 (2.5-130)

a. Barker (1967); b. Vant et. al., (1990); c. Burns & Coffey (2003)

d. Author's note results may be unreliable as mean values are close to detection limits of the methods employed at the time.

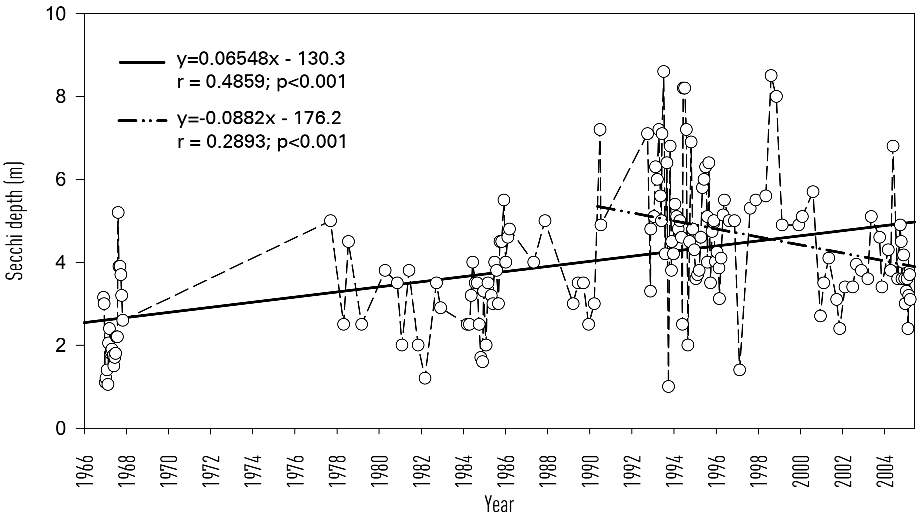


Figure 10: Complete water clarity (Secchi depth) record for Lake Pupuke combining Barker (1967), Auckland Regional Water Board archive (1979-1990) and the current ARC monitoring programme (1992-05). Simple linear regression fitted; closed line 1966 – 2005, dashed line 1990 - 2005.

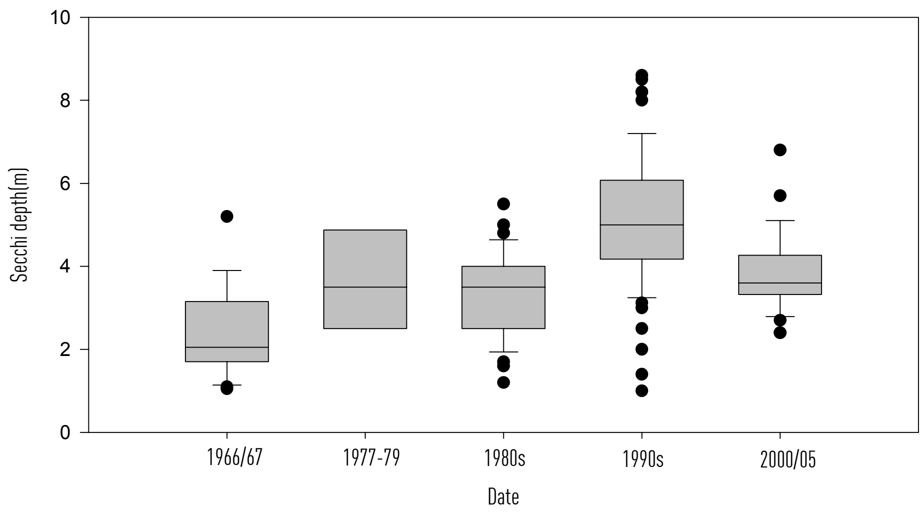


Figure 11: Interdecadal comparison of observed Secchi depth at Lake Pupuke between 1967 and 2005. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles, outliers by closed circles. 90th and 10th percentiles are absent from 1977-79 due to insufficient data points (n=4).

Statistical analysis of five distinct monitoring periods (1966/67, 1977/78, 1980s, 1990s and 2000-05) by one-way analysis of variables (ANOVA) confirmed a significant variation in mean SD over time ($F=24.297$; $p<0.0001$), although the coefficient of determination was poor ($r^2=38\%$) indicating other factors may also explain the variation. A Tukey's test was then applied to all pairwise differences between means, which confirmed significant differences between the 1990s and all other comparisons (confidence range 95%; $p<0.0001$)[6]. Interestingly, SD during 2000-05 was not significantly different to water clarity conditions observed in the 1980s.

The SD record indicated that while improvements in water clarity and hence water quality from 1966/67 has been significant through to the late 1990s, analysis of recent data showed these improvements have not continued. This suggests that improvement to lake condition following nutrient load reduction (diversion of domestic sewage and agricultural waste) has peaked. Further improvement may be limited by remnant point source discharges (stormwater), diffuse inputs (fertiliser, faecal matter) or by internal nutrient recycling, particularly P.

[6] The 1977/78 period was removed from the analysis due to the low number of observations (n=4).

3.4 Kereta

The key variables indicated water quality at Lake Kereta has possibly improved between 1992 and 2005. The improvement appeared to be driven by an improvement in water clarity indicated by a downward trend in Chla (Table 6)[7]. This is further reinforced by highly significant decreases in TSS, TP and conductivity (Table 7).

Lake Kereta remained fully mixed throughout the study period. No change was detected in temperature (p=15%) or dissolved oxygen (p=76%) (Table 7).

Climate induced fluctuations in water quality variables observed at Lake Ototoa may also explain a period of high TSS at Lake Kereta during 1997/98, when strongly El Niño climatic conditions were experienced (Figure 12).

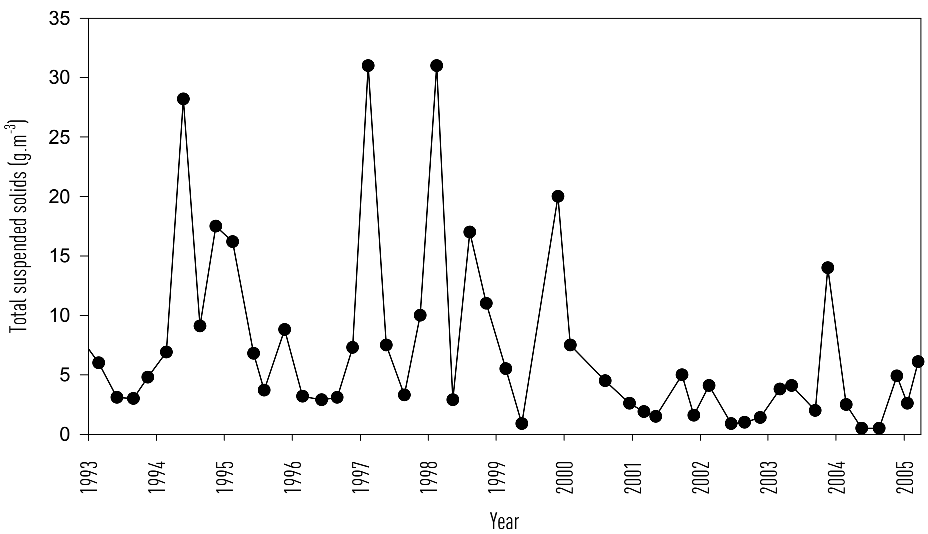


Figure 12: Time series plot of total suspended solids from Lake Kereta between 1993 and March 2005.

Nutrient concentrations in the present study were consistently lower than encountered by ARWB (1990), with N and P typically bound in their organic form. Despite this the Lake remained eutrophic (Table 4)[8]. The source of elevated nutrients is difficult to determine, though we assume they are from a combination of catchment contributions and internal cycling.

The lower TLc value relative to TLp and TLn indicated phytoplankton production might be limited, which could in part be due to the extreme abundance of the exotic

[7] The shallow nature of Lake Kereta prevents the capture of meaningful Secchi data due to clarity exceeding maximum depth.
[8] The average TLI value for the period September 1987 to August 1992 was 5.24±0.2 TLI units.

macrophyte *Ceratophyllum demersum* (hornwort) throughout the entire water column[9]. Hornwort was not present during the 1988/89 study with ARWB (1990) recording the native macrophyte *Myriophyllum propinquum*. An earlier study in 1953 by Cunningham et. al., (1957) found beds of *Potemogeton ochreatus*, another native species.

It has been suggested that allelopathy (inter-species chemical inhibition) may occur, where macrophytes chemically inhibit phytoplankton production and biomass accumulation (Scheffer, 1998). A decline in macrophyte abundance via senescence or perturbation may in the future reverse recent water quality improvement if the mineralisation of macrophyte-derived organic matter adds to nutrient availability and competition for nutrients decreases, and if sediment resuspension increases. The large presence of the noxious pest koi carp (*Cyprinus carpio*) is likely to complicate nutrient cycling by adding to the inorganic nutrient pool and dislodging buried hornwort stems.

The extent of pastoral landuse has not changed during the observed period, with a deer farm along the eastern shore being the predominant agriculture. Cattle are present at low density. Stock have access to the Lake along portions of its eastern shore.

3.5 Tomarata

Water quality may have improved between 1992 and March 2005, with the key variables indicating an improvement in water clarity of 0.04 m/yr (p=3%) and a decrease in Chla concentration (0.87 $mg.m^{-3}/yr$; $p<0.01$) (Table 6). TSS declined significantly (0.15 $g.m^{-3}/yr$; $p<0.01$) over the same period. No significant change was detected in TN or TP (Table 7), which limited our confidence in confirming an overall improvement in water quality (P-value of average PAC = 0.26) (Table 3). A comparison of the TLI value obtained in 1989/90 (4.6 TLI units) with the three year rolling average to 2005 TLI (4.4 TLI units) further supported this view (Table 5).

Lake Tomarata remained fully mixed throughout the study period, though oxygen was periodically depleted to the point of anoxia from the bottom 1-2 m during summer. No change was detected in temperature (p=19%) or dissolved oxygen (p=97%) (Table 7).

Average mean annual nutrient, Chla and SD values confirmed the Lake's eutrophic status. The TLp:TLn ratio indicated the Lake was probably phosphorus limited.

The lake is approximately 4 m deep over 90% of its area with an extensive area of wetland (20 ha) on its southern and western margins and exotic forestry to the east. Landuse in the wider catchment is predominantly intensive dairy (Table 4). The lake retains a marked humic colouration, with particulate organic matter derived from the adjoining wetland possibly accounting for its colour. This was reflected in the high TLc values relative to the other trophic level indicators (Table 4).

---

[9] This may account for the low concentration of inorganic N and P observed.

Whilst eutrophic, the relative health of Lake Tomarata compared with the neighbouring Spectacle, despite similar morphology, origin, and agricultural influences, may be due to its extensive wetland margin, which filters nutrient inputs from neighbouring farms. There are no direct inflows to the lake outside heavy rainfall events, rather inputs are most likely a combination of rainfall and sub-surface infiltration through the wetland and forestry. This may account for the very low concentrations of inorganic N and P recorded (Appendix 3).

A survey of submerged flora in November 1999 noted the previously recorded extensive charophyte community (dominated by *Chara corallina* and *Nitella* between 0.75 and 4 m) by ARWB (1990), was locally extinct, despite sufficient light penetration. The introduced herbivorous fish rudd (*Scardinius erythrophthalmus*) may have been a contributing factor.

3.6 Wainamu

Key variables indicate no overall change in water quality between September 1992 and March 2005 (Table 6), though TP declined significantly by 1.7 $mgP.m^{-3}/yr$ ($p<0.01$) (Table 7).

Lake Wainamu is eutrophic with elevated concentrations of plant nutrients N and P, high Chla and low water clarity. High TLs values relative to TLc, Tlp and TLn suggest a non-phytoplankton influence on low water clarity, indicated by consistently high suspended sediment concentration (Appendix 3).

Lake water quality appeared similar to that encountered by ARWB (1990) with an average TLI of 4.8 TLI units between 1987 and 1988, identical to the present study (Table 5).

Of particular interest is the period 1997/99 when a sudden increase in turbidity and nitrate, a decline in water clarity and, after an initial spike, a decline in Chla concentration was apparent.[10] Anecdotal evidence suggests the previously extensive beds of the exotic macrophyte *Egeria densa*, which formed surface reaching swards beyond emergent beds of *Eleocharis sphacelata* and *Baumea articulata*, collapsed during the 1996/97 summer. The resultant pulse of organic material that could have occurred following microbial decomposition of the plant biomass may have released inorganic N and P, which initially promoted phytoplankton growth. Subsequent light limitation due to an increase in turbidity following sediment resuspension may have negatively influenced phytoplankton production.

[10] Selected variables (Sept 1992-Aug 1999): SD = -0.14 m/yr, $p<0.01$; turbidity = 2.10 NTU/yr, $p<0.01$; NO_2NO_3 = 8.28 $mg.m^{-3}/yr$, $p<0.01$.

It is not clear what lead to the collapse of *Egeria*, though observations of similar occurrences in Waikato shallow lakes suggest a combination of factors including nutrient fluxes, sediment anoxia at the root zone, herbivory or general senescence (Barnes, 2002). The collapse of *Egeria* coincided with a period of strong El Niño weather patterns, during which predominant south-westerly winds may have driven an increase in sediment re-suspension and water clarity decline (Figure 13). This was immediately followed by a period of relative calm when bottom waters tended anoxic between 1998 – 2001 (Figure 14).

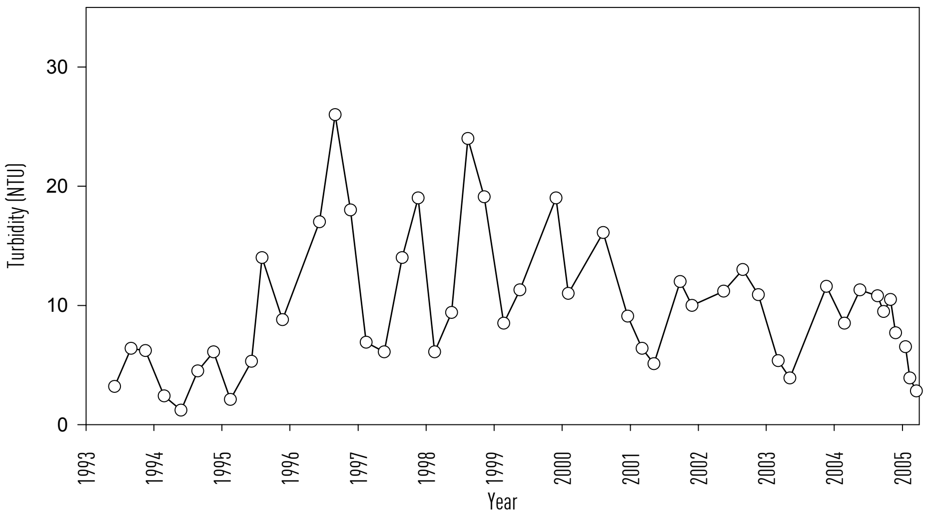


Figure 13:Time series plot of turbidity (open circles) in Lake Wainamu between 1993 and March 2005.

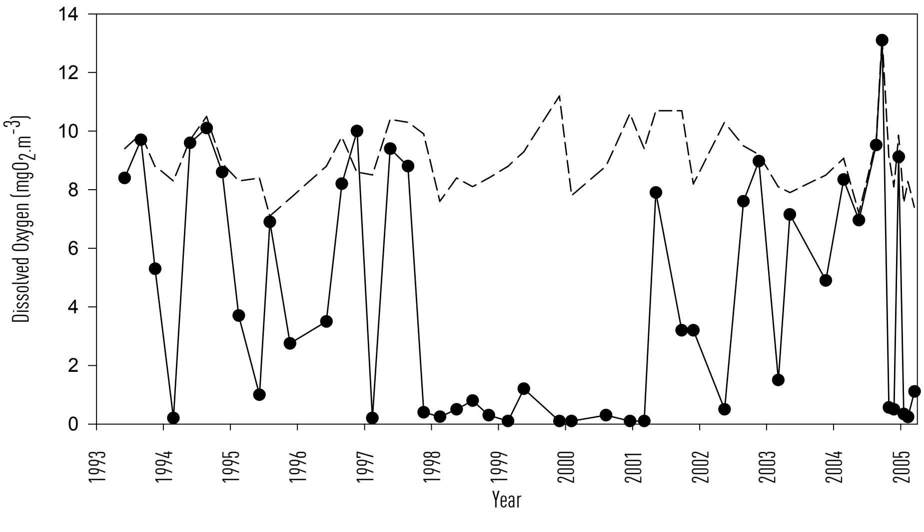


Figure 14: Comparison of near bottom (open circles) and surface waters (dashed line) dissolved oxygen for Lake Wainamu from 1993 to March 2005.

Water quality appears to have stabilised since 2000 with turbidity declining significantly (-0.57 NTU/yr; p=4%), and recent SD amongst the highest recorded since 1992 (2.6 m).

3.7 Kuwakatai

Water quality did not change between September 1992 and March 2005 (Table 6).

Lake Kuwakatai is the second most enriched lake monitored after Lake Spectacle). Average TLI for 1992 to 2005 was 5.46±0.1 TLI units, firmly within a supertrophic classification. Total phosphorus and TN were consistently high with an average annual mean of 46 and 827 $mg.m^{-3}$, respectively (Table 4). As expected, Chla was elevated and water clarity low[11].

Lake Kuwakatai tended not to stratify consistently throughout the observed period. However, the frequency and magnitude of thermal stratification became stronger during the mid 1990's, peaking in 2000 and 2001, with cooler bottom temperatures indicating less efficient wind mixing in summer (Figure 15).

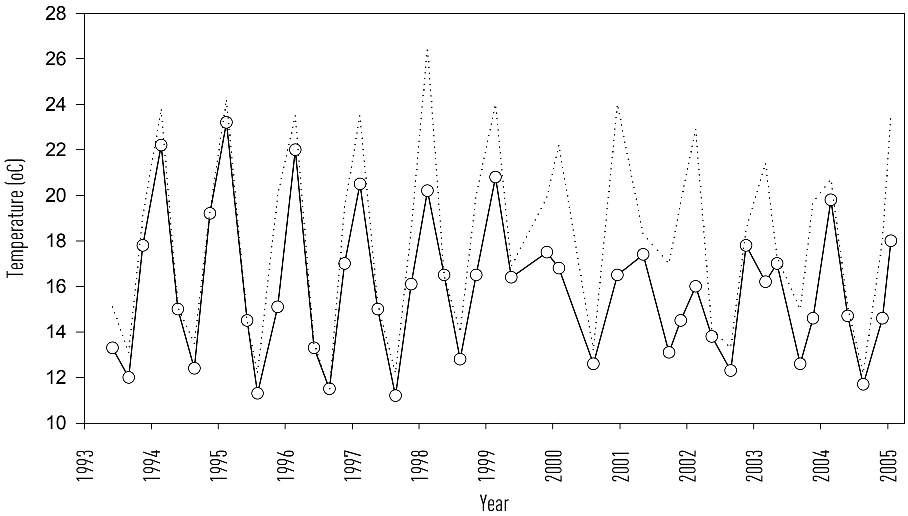


Figure 15: Near bottom (open circles) and surface (dashed line) temperature data for Lake Kuwakatai between 1993 and March 2005.

Comparison with ENSO indicates similar climatic influences on Lake Kuwakatai as observed for Ototoa. This was illustrated most clearly with delta O_2 (1–11m), which showed a consistent pattern of bottom water depletion to anoxia occurred more frequently between 1999 to 2002 and coincided with a lengthy period of La Niña

[11] Mean annual average Chla = 54 $mg.m^{-3}$, SD = 1.4 m.

conditions (Figure 16). Elevated ammoniacal nitrogen levels were common during this period (Figure 17).

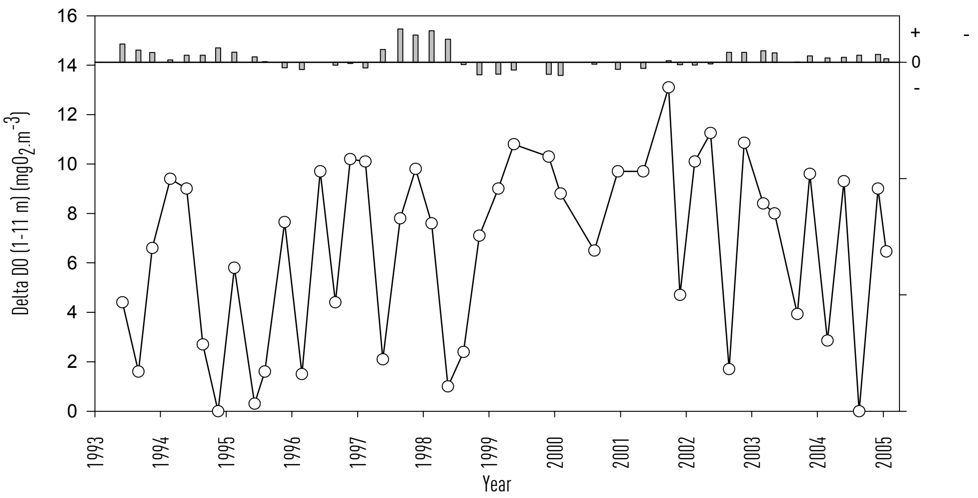


Figure 16: Time series plot of ΔDO (1 – 11m) (open circles) in Lake Kuwakatai between 2003 and March 2005. Quarterly ENSO data is provided (grey bars), with El Niño conditions tending +ve and La Niña –ve.

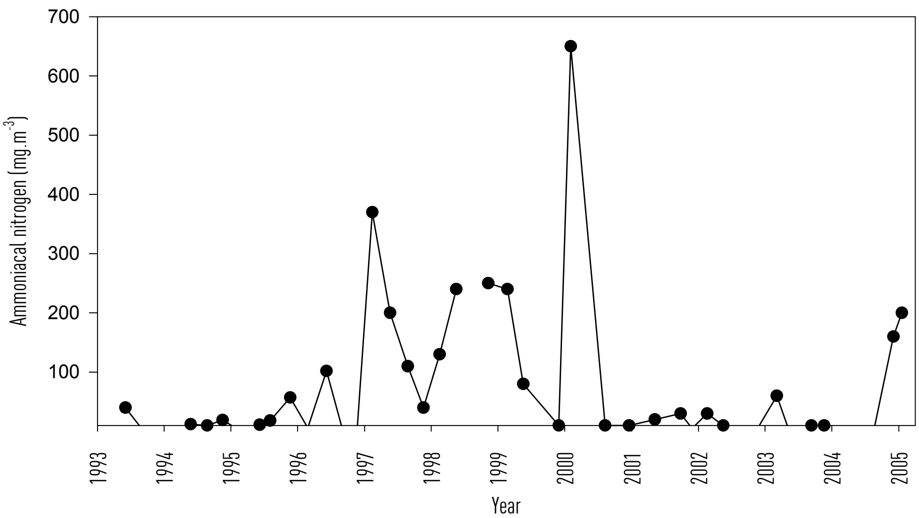


Figure 17: Time series plot of bottom water ammoniacal nitrogen from Lake Kuwakatai between 1993 and March 2005.

Cyanobacterial blooms were observed during the latter part of the study period, frequently dominated by *Anabaena* and *Microcystis* species. Nitrogen fixation by *Anabaena* may have influenced the high ammonium concentrations periodically recorded.

Despite no overall change detected in water quality, comparison with a 1950 survey suggested water clarity at Lake Kuwakatai was once considerably higher (SD = 7.0 m) (Cunningham et. al. 1957). Changes in landuse during the past 50 years are likely to account for this apparent eutrophication, particularly agricultural intensification. Stock access during most of the study period and introduced fish could both have contributed to destabilisation of near shore sediments, and hence high turbidity.

3.8 Spectacle

The average PAC at Lake Spectacle indicated no change in water quality over the observed period, despite significant declines of similar magnitude in SD, TN and TP. These deteriorating trends were likely confounded by a decrease in Chla over the same time period. Whilst this tends to be indicative of improving water clarity in most lakes, closer examination of TSS at Lake Spectacle suggests an increase in non-phytoplankton derived suspended material has contributed to a decline in water clarity and a decrease in algal productivity (Table 7). When TSS is considered as a surrogate for Chla in the PAC analysis an overall deteriorating trend is apparent[12].

Lake Spectacle did not stratify during the study period, although anoxic events were recorded within bottom depths occasionally during summer. No change was detected in temperature (p=32%) or dissolved oxygen (p=89%) (Table 7).

The lake is shallow, exposed, devegetated, with a limited riparian margin and located within a catchment where intensive agriculture dominates landuse (Table 4). Nutrient levels are very high with an average annual mean of 102 and 1300 $mg.m^{-3}$ for TP and TN respectively (Appendix 3). Water clarity was very low with SD typically less than 0.5 m.

It is probable that Lake Spectacle has undergone progressive eutrophication as the catchment was converted from native terrestrial and wetland vegetation to pastoral landuse. Intensive agriculture is likely to contribute significant inputs of nutrients to the lake either directly via a network of drains or through diffuse surface and groundwater channels. Regeneration of internal sediment derived N and P is also possible during summer anoxia.

It is not clear what facilitated the increase in total suspended sediment observed since 1993. We consider it possibly due to a combination of interacting factors not limited to the lack of a submerged aquatic macrophyte community, the presence of koi carp, shallow depth and exposure to prevailing winds, and the sandy nature of the underlying substrate.

It is unlikely that any changes to catchment landuse will result in an immediate improvement in water quality, not least until the assumed high internal load is deactivated, the high suspended sediment levels dissipate, exotic fish are controlled and a submerged aquatic plant community returns. However, it is probable that water quality will continue to decline until substantial reductions are made in the quantity of catchment derived nutrients that enter the lake.

---

[12] Average PAC 4.6±1%/yr (p<0.001).

4 Conclusion

The ARC Regional Lakes Water Quality Monitoring Programme provides an important tool in assessing and managing these valuable natural resources. The extensive data record allowed for a robust determination of changes in trophic state in the seven lakes monitored.

Lake Ototoa had the highest water quality of the seven lakes monitored, followed in order of declining water quality by Pupuke, Kereta, Tomarata, Wainamu, Kuwakatai and Spectacle. Ototoa was moderately enriched (mesotrophic), Pupuke, Kereta, Tomarata and Wainamu were eutrophic, Kuwakatai was supertrophic and Spectacle, the most degraded lake, was hypertrophic.

Trend analysis showed water quality has probably improved in Lake Kereta and Tomarata. No change was detected in Lake Kuwakatai, Pupuke and Wainamu, though some interesting patterns did emerge which warrant further investigation. Disappointingly, water quality significantly declined in Lake Ototoa and Lake Spectacle.

The observed decline in Lake Ototoa is of concern given its relatively low trophic state. Further deterioration may result in adverse changes to the Lake's high ecological values, including the extensive beds of regionally sparse charophytes.

The changes in trophic state observed in all four lakes is a combination of many interacting factors including inputs of contaminants from catchment landuses, internal nutrient cycling, climatic weather patterns, and biotic influences such as phytoplankton abundance and animal and plant pest perturbations.

The presence, extent and composition of submerged plant communities appear closely related to water quality state and trend. We conclude that changes to these communities has either improved water quality (Kereta), promoted greater variation (Wainamu), or in the case of Spectacle, their absence has exacerbated water quality deterioration.

Exotic fish may also be an important factor influencing water quality, however this can be very difficult to attribute due to limited opportunities to separate effects of fish on water quality from other influences. It is apparent though that the presence of perch in Ototoa, rudd in Tomarata and koi in Spectacle and Kuwakatai has had negative consequences.

5 Recommendations

The monitoring programme is effective and the accumulated data of sufficient quality and resolution to quantify lake trophic state and determine possible trends.

Frequent data analysis (5-yearly) is essential to ensure water quality deterioration is detected early enough to allow targeted investigation and effective management intervention.

In order to further strengthen the monitoring programme the authors recommend:

- Monitoring frequency increases to 6 times per year.
- Improvements to the analytical precision of N and P analytes.
- Sampling stations are clearly marked with permanent buoys.
- Continuous data loggers are installed in each lake to record;
    - surface and bottom temperatures,
    - water level,
    - dissolved oxygen (Pupuke and Ototoa only).
- A baseline assessment of submerged aquatic macrophyte community composition and abundance be completed in each lake, repeated 5-yearly.

References

Auckland Regional Water Board (1990). Freshwater lakes water quality survey first annual report. Auckland Regional Water Board Technical Publication No. 89, May 1990.

Barker, M.A. (1967). The limnology of Lake Pupuke. Unpublished Master of Science Thesis, University of Auckland. 146 p.

Barnes, G.E. (2002). Water quality trends in selected lakes in the Waikato region, 1995 – 2001. Environment Waikato Technical Publication 2002/11, July 2002.

Burns, N.M. & B.T. Coffey (2003). Management perspectives on Lake Pupuke. Report to North Shore City Council, June 2003.

Burns, N.M., G. Bryers, & E. Bowman (2002). Protocol for monitoring trophic levels of New Zealand lakes and reservoirs. Ministry for the Environment, Wellington.

Burns, N.M., J. McIntosh & P. Scholes (2005). Strategies for managing the lakes of the Rotorua District, New Zealand. *Lakes and reservoir management,* Vol. 21(1) 61-72.

Cunningham, B.T., N.T. Moar, A.W., Torrie, & P.J. Parr (1957). A survey of western coastal dune lakes of the North Island, New Zealand. *Australian journal of marine and freshwater research* 4:343-386.

Gibbs, M., I. Boothroyd, P. Champion, J. Green, & I. Duggan (1999) ARC Lakes Monitoring Programme Review. NIWA Client Report: ARC00256, November 1999.

Hawes, I. & Haskew R. (2003). Summer oxygen depletion in lakes Pupuke and Ototoa. NIWA Client Report: ARC03296, June 2003.

Lakes Consulting (2000). LakeWatch – a programme for the evaluation of lake and reservoir monitoring data. Lakes Consulting, 42 Seabreeze Rd., Devonport, New Zealand. (www.lakewatch.net).

Leathwick, J.R., G. Wilson, D. Rutledge, P. Wardle, F. Morgan, K. Johnston, M. McLeod, R. Kirkpatrick (2003). Land environments of New Zealand. David Bateman, Auckland.

Scheffer, M. (1998). Ecology of shallow lakes. Chapman and Hall, London.

Snelder, T., B. Biggs, & M. Weatherhead (2004). New Zealand river environment classification guide. Ministry for the Environment, Wellington.

Vant, W.N. & P. Smith (2004). Trends in river water quality in the Waikato Region, 1987 – 2002. Environment Waikato Technical Publication 2004/02, March 2004.

Vant, W.N., R.D. Pridmore, & D.A. Challis (1990). Changes in water quality of Lake Pupuke 1966 – 1990. Auckland Regional Water Board Technical Publication No. 93, November 1990.

Appendix 1

List of variables routinely monitored in the ARC Lakes Water Quality Monitoring Programme. A full description is reproduced in Wilcock & Martin (2003).

Conductivity	A measure of the total soluble salt content of water. Salt content is an important influence on the biota that can inhabit an ecosystem. The lakes monitored are all close to the sea and may be influenced to varying degrees by wind blown salt spray.
Dissolved oxygen	A measure of the life supporting capacity of a waterbody, influenced by atmospheric transfer, respiration, photosynthesis and temperature. DO concentrations can also regulate the release of bioavailable nutrients from sediments.
BOD	A measure of the amount of oxygen required to oxidise organic material by aerobic microbial decomposition to a stable inorganic form.
Temperature	Organisms can only tolerate a particular range of temperatures. Outside of this range metabolic rates can be affected. Temperature profiles are a useful measure of the annual pattern of stratification many lakes exhibit. Separate layers of water can develop in warm calm conditions that exhibit different physical and chemical characteristics. All these factors can impact the life supporting capacity of water.
pH	Indicates the acid/alkaline state of water. Natural freshwaters normally have a pH approaching neutrality (7), although the accepted range for most biota is 6 – 9. High pH mobilises toxic compounds, which may potentially affect aquatic organisms.
Bacterial Indicator Organisms	Indicates the level of faecal contamination. Major sources of microbial pollution in the environment are derived from agricultural and urban land uses.
Turbidity & Suspended solids	Provides a measure of the level of material suspended in the water column potentially available to scatter light and reduce water clarity. High turbidity and suspended solids can reduce the productivity of a waterbody and interfere with the respiration organs of some aquatic biota.
Nitrite, Nitrate, Ammonia, Phosphorus	Nitrogen and phosphorus are essential elements for plant growth. When found in high quantities of their bio-available form excessive growths of algae may result, degrading water quality.
Chlorophyll *a*	An indirect measure of photosynthetic algae abundance.

Appendix 2

Kereta

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	-1.70		-3.47	(-46.55)				
Average Over Period	11.91		37.74	(810.76)				
Percent Annual Change (%/Year)	**-14.27**	**0.00**	**-9.19**	**0.00**	**0.00**	**-7.82**	**4.18**	**0.20**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	18.50		46.00	668.75	5.44		5.07	4.89	5.14	0.16			
Sep 1993 - Aug 1994	14.00		59.00	1,302.50	5.13		5.39	5.77	5.43	0.18			
Sep 1994 - Aug 1995	29.50		58.25	1,390.75	5.95		5.37	5.85	5.73	0.18			
Sep 1995 - Aug 1996	13.35		37.50	644.75	5.08		4.81	4.85	4.91	0.08			
Sep 1996 - Aug 1997	10.40		45.00	778.38	4.80		5.05	5.09	4.98	0.09			
Sep 1997 - Aug 1998	23.65		36.67	992.75	5.71		4.79	5.41	5.30	0.27			
Sep 1998 - Aug 1999	16.50		40.00	677.33	5.31		4.90	4.91	5.04	0.14			
Sep 1999 - Aug 2000	10.50		33.33	388.00	4.81		4.66	4.18	4.55	0.19			
Sep 2000 - Aug 2001	1.53		20.00	126.00	2.69		4.02	2.71	3.14	0.44			
Sep 2001 - Aug 2002	7.66		24.00	206.00	4.47		4.25	3.35	4.02	0.34			
Sep 2002 - Aug 2003	2.40		20.00	1,508.50	3.19		4.02	5.96	4.39	0.82			
Sep 2003 - Aug 2004	3.08		44.00	527.60	3.46		5.02	4.58	4.35	0.46			
Sep 2004 - Mar 2005	5.53		24.00	478.33	4.11		4.25	4.46	4.27	0.10			
Averages	**12.05**		**37.52**	**745.36**	**4.63**		**4.74**	**4.77**	**4.71**	**0.13**	**-0.13**	**0.03**	**0.0001**

SUMMARY:

PAC = -7.82 ± 4.18 % per year
P-Value = 0.20

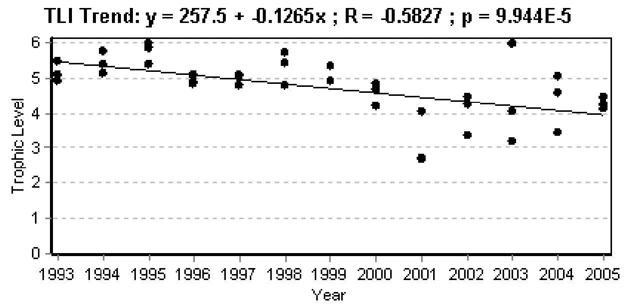
TLI Value = 4.71 ± 0.13 TLI units
TLI Trend = -0.13 ± 0.03 TLI units per year
P-Value = 0.0001

ASSESSMENT:

Eutrophic
Possible Improvement

The guide used in the PAC average P-Value evaluation is

P-Value Range	**Interpretation**
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Kuwakatai

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.63)	(0.01)	(0.11)	-32.93				
Average Over Period	(55.69)	(1.38)	(46.90)	842.50				
Percent Annual Change (%/Year)	**0.00**	**0.00**	**0.00**	**-3.91**	**0.00**	**-0.98**	**0.98**	**0.39**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	98.00	1.42	62.00	801.75	7.28	5.12	5.45	5.13	5.74	0.52			
Sep 1993 - Aug 1994	75.38	1.43	46.00	1,034.50	6.99	5.12	5.07	5.46	5.66	0.45			
Sep 1994 - Aug 1995	27.20	1.20	40.25	1,182.38	5.86	5.32	4.90	5.64	5.43	0.21			
Sep 1995 - Aug 1996	53.60	1.25	36.25	594.31	6.61	5.27	4.77	4.74	5.35	0.44			
Sep 1996 - Aug 1997	69.21	1.09	48.57	1,172.88	6.89	5.43	5.14	5.63	5.77	0.39			
Sep 1997 - Aug 1998	44.30	1.25	47.14	768.43	6.40	5.27	5.10	5.08	5.46	0.32			
Sep 1998 - Aug 1999	25.75	1.40	33.33	835.17	5.80	5.14	4.66	5.18	5.20	0.23			
Sep 1999 - Aug 2000	34.52	1.50	60.00	741.50	6.13	5.06	5.41	5.03	5.41	0.26			
Sep 2000 - Aug 2001	34.02	1.70	30.00	1,088.00	6.11	4.91	4.53	5.53	5.27	0.35			
Sep 2001 - Aug 2002	80.11	1.63	51.25	623.83	7.06	4.96	5.21	4.80	5.51	0.52			
Sep 2002 - Aug 2003	53.57	1.60	41.67	840.33	6.61	4.98	4.95	5.19	5.43	0.40			
Sep 2003 - Aug 2004	68.87	1.37	62.86	720.00	6.89	5.16	5.47	4.99	5.63	0.43			
Sep 2004 - Mar 2005	38.60	1.07	42.75	349.50	6.25	5.46	4.98	4.05	5.18	0.46			
Averages	**54.09**	**1.38**	**46.31**	**827.12**	**6.53**	**5.17**	**5.05**	**5.11**	**5.46**	**0.10**	**-0.02**	**0.03**	**0.3984**

SUMMARY:

PAC = -0.98 ± 0.98 % per year
P-Value = 0.39

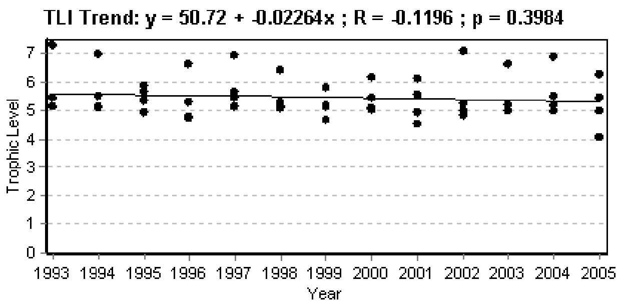
TLI Value = 5.46 ± 0.10 TLI units
TLI Trend = -0.02 ± 0.03 TLI units per year
P-Value = 0.3984

ASSESSMENT:

Supertrophic
No Change

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Pupuke

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	-0.52	-0.11	(-0.21)	(39.42)				
Average Over Period	7.98	4.69	(22.53)	(543.53)				
Percent Annual Change (%/Year)	**-6.52**	**2.35**	**0.00**	**0.00**	**0.00**	**-1.04**	**1.91**	**0.62**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993		5.90	22.83			3.38	4.19		3.78	0.40			
Sep 1993 - Aug 1994	8.75	4.89	28.83	535.80	4.61	3.62	4.48	4.60	4.33	0.24			
Sep 1994 - Aug 1995	10.00	4.99	22.00	472.83	4.76	3.60	4.14	4.44	4.23	0.25			
Sep 1995 - Aug 1996	6.43	4.43	17.50	246.81	4.27	3.75	3.85	3.59	3.86	0.15			
Sep 1996 - Aug 1997	6.88	3.90	28.33	507.50	4.35	3.91	4.46	4.53	4.31	0.14			
Sep 1997 - Aug 1998	12.06	6.53	20.00	416.30	4.97	3.24	4.02	4.27	4.12	0.36			
Sep 1998 - Aug 1999	17.40	6.45	20.00	206.33	5.37	3.26	4.02	3.36	4.00	0.49			
Sep 1999 - Aug 2000	4.62	5.23	21.00	220.80	3.91	3.53	4.08	3.45	3.74	0.15			
Sep 2000 - Aug 2001	9.23	3.43	20.00	1,164.50	4.67	4.07	4.02	5.62	4.59	0.37			
Sep 2001 - Aug 2002	8.69	3.25	23.75	961.75	4.60	4.13	4.23	5.37	4.59	0.28			
Sep 2002 - Aug 2003	6.00	4.17	18.33	1,845.00	4.20	3.82	3.91	6.22	4.54	0.57			
Sep 2003 - Aug 2004	5.60	4.42	21.25	480.36	4.12	3.75	4.09	4.46	4.11	0.15			
Sep 2004 - Mar 2005	4.10	3.62	30.00	404.10	3.78	4.00	4.53	4.24	4.14	0.16			
Averages	**8.31**	**4.71**	**22.60**	**621.84**	**4.47**	**3.70**	**4.15**	**4.51**	**4.20**	**0.08**	**0.02**	**0.02**	**0.3905**

SUMMARY:

PAC = -1.04 ± 1.91 % per year
P-Value = 0.62

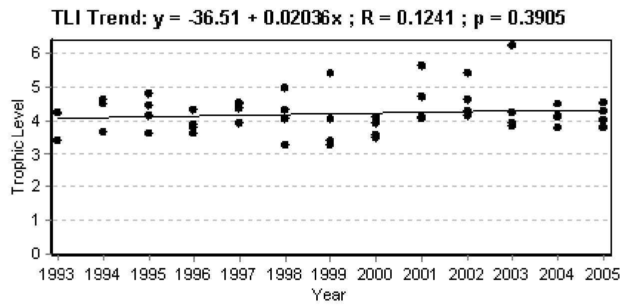
TLI Value = 4.20 ± 0.08 TLI units
TLI Trend = 0.02 ± 0.02 TLI units per year
P-Value = 0.3905

ASSESSMENT:

Eutrophic
No Change

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Ototoa

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.15	-0.13	0.60	19.60				
Average Over Period	4.59	4.66	16.27	448.29				
Percent Annual Change (%/Year)	**3.27**	**2.79**	**3.69**	**4.37**	**0.00**	**3.53**	**0.34**	**0.00**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	5.00	5.55	9.00	221.30	4.00	3.46	3.00	3.45	3.48	0.20			
Sep 1993 - Aug 1994	2.50	4.90	11.00	386.82	3.23	3.62	3.26	4.18	3.57	0.22			
Sep 1994 - Aug 1995	3.35	5.75	14.90	484.30	3.55	3.41	3.64	4.47	3.77	0.24			
Sep 1995 - Aug 1996	5.30	6.80	17.00	293.80	4.06	3.19	3.81	3.82	3.72	0.19			
Sep 1996 - Aug 1997	4.57	5.22	23.00	415.75	3.90	3.53	4.19	4.27	3.97	0.17			
Sep 1997 - Aug 1998	5.35	4.30	16.25	656.19	4.07	3.78	3.75	4.87	4.12	0.26			
Sep 1998 - Aug 1999	4.47	3.73	18.57	241.29	3.87	3.96	3.92	3.56	3.83	0.09			
Sep 1999 - Aug 2000	5.77	3.50	12.86	619.29	4.15	4.04	3.46	4.79	4.11	0.27			
Sep 2000 - Aug 2001	5.32	4.20	17.50	1,306.50	4.06	3.81	3.85	5.77	4.37	0.47			
Sep 2001 - Aug 2002	5.57	4.44	18.33	327.14	4.11	3.74	3.91	3.96	3.93	0.08			
Sep 2002 - Aug 2003	3.79	4.27	21.43	792.29	3.69	3.79	4.10	5.12	4.18	0.33			
Sep 2003 - Aug 2004	4.02	5.58	16.25	474.23	3.75	3.45	3.75	4.44	3.85	0.21			
Sep 2004 - Mar 2005	5.57	3.45	20.33	237.00	4.11	4.06	4.04	3.54	3.94	0.13			
Averages	**4.66**	**4.75**	**16.65**	**496.61**	**3.89**	**3.68**	**3.75**	**4.33**	**3.91**	**0.07**	**0.04**	**0.02**	**0.0261**

SUMMARY:

PAC = 3.53 ± 0.34 % per year
P-Value = 0.00

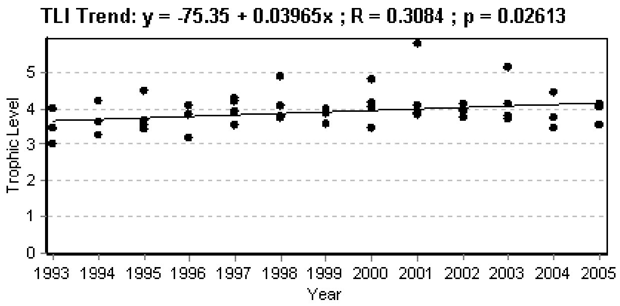
TLI Value = 3.91 ± 0.07 TLI units
TLI Trend = 0.04 ± 0.02 TLI units per year
P-Value = 0.0261

ASSESSMENT:

Mesotrophic
Definite Degredation

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Spectacle

WQ trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	-4.30	-0.02	4.80	64.48				
Average Over Period	87.19	0.38	102.91	1,304.49				
Percent Annual Change (%/Year)	**-4.93**	**5.26**	**4.66**	**4.94**	**0.00**	**2.48**	**2.48**	**0.39**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	63.50	0.55	56.57	597.33	6.80	6.22	5.34	4.75	5.78	0.46			
Sep 1993 - Aug 1994	90.63	0.45	85.00	1,110.88	7.19	6.45	5.85	5.56	6.26	0.36			
Sep 1994 - Aug 1995	144.17	0.40	89.63	1,422.75	7.70	6.58	5.92	5.88	6.52	0.43			
Sep 1995 - Aug 1996	140.88	0.43	92.50	1,037.06	7.68	6.49	5.96	5.47	6.40	0.47			
Sep 1996 - Aug 1997	100.50	0.48	88.57	1,042.64	7.31	6.39	5.90	5.47	6.27	0.39			
Sep 1997 - Aug 1998	77.90	0.34	127.14	1,529.21	7.02	6.78	6.36	5.98	6.53	0.23			
Sep 1998 - Aug 1999	124.73	0.47	111.67	1,318.00	7.54	6.41	6.20	5.78	6.48	0.38			
Sep 1999 - Aug 2000	72.75	0.53	128.33	1,645.50	6.95	6.25	6.37	6.07	6.41	0.19			
Sep 2000 - Aug 2001	37.00	0.28	125.00	1,808.50	6.20	6.98	6.34	6.19	6.43	0.19			
Sep 2001 - Aug 2002	94.62	0.38	98.00	1,079.50	7.24	6.64	6.03	5.52	6.36	0.37			
Sep 2002 - Aug 2003	72.70	0.30	76.67	1,375.67	6.95	6.91	5.72	5.84	6.35	0.33			
Sep 2003 - Aug 2004	38.46	0.21	149.00	1,856.60	6.25	7.32	6.56	6.23	6.59	0.25			
Sep 2004 - Mar 2005	100.83	0.21	101.00	1,088.50	7.31	7.31	6.07	5.53	6.55	0.45			
Averages	**89.13**	**0.39**	**102.24**	**1300.93**	**7.09**	**6.67**	**6.05**	**5.71**	**6.38**	**0.09**	**0.03**	**0.02**	**0.2031**

SUMMARY:

PAC = 2.48 ± 2.48 % per year
P-Value = 0.39

TLI Value = 6.38 ± 0.09 TLI units
TLI Trend = 0.03 ± 0.02 TLI units per year
P-Value = 0.2031

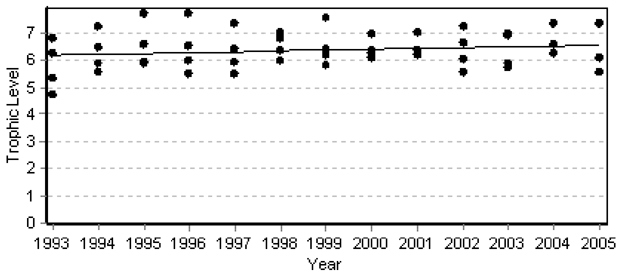
ASSESSMENT:

Hypertrophic
No Change

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

TLI Trend: y = -56.37 + 0.03139x ; R = 0.1794 ; p = 0.2031



Tomarata

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	-0.87	0.04	(0.24)	(5.48)				
Average Over Period	10.15	1.54	(22.49)	(621.76)				
Percent Annual Change (%/Year)	**-8.57**	**-2.60**	**0.00**	**0.00**	**0.00**	**-2.79**	**2.02**	**0.26**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	23.00	1.40	20.88	517.13	5.68	5.14	4.07	4.56	4.86	0.35			
Sep 1993 - Aug 1994	11.86	1.80	19.57	382.14	4.95	4.84	3.99	4.16	4.49	0.24			
Sep 1994 - Aug 1995	15.40	1.72	16.88	752.25	5.24	4.89	3.80	5.05	4.75	0.32			
Sep 1995 - Aug 1996	6.20	1.03	26.25	520.00	4.23	5.50	4.36	4.57	4.67	0.29			
Sep 1996 - Aug 1997	10.24	1.15	28.57	605.38	4.79	5.37	4.47	4.76	4.85	0.19			
Sep 1997 - Aug 1998	11.20	1.30	25.00	693.00	4.89	5.23	4.30	4.94	4.84	0.19			
Sep 1998 - Aug 1999	11.17	1.52	21.67	636.00	4.88	5.05	4.12	4.83	4.72	0.21			
Sep 1999 - Aug 2000	6.60	1.47	15.83	465.83	4.30	5.09	3.72	4.42	4.38	0.28			
Sep 2000 - Aug 2001	10.53	2.03	25.00	2,018.75	4.82	4.70	4.30	6.34	5.04	0.45			
Sep 2001 - Aug 2002	8.55	1.42	23.00	560.50	4.59	5.12	4.19	4.66	4.64	0.19			
Sep 2002 - Aug 2003	7.00	1.80	25.00	528.67	4.37	4.84	4.30	4.59	4.52	0.12			
Sep 2003 - Aug 2004	5.93	1.49	24.00	536.00	4.18	5.07	4.25	4.60	4.53	0.20			
Sep 2004 - Mar 2005	5.90	2.27	21.00	406.50	4.18	4.57	4.08	4.24	4.27	0.11			
Averages	**10.28**	**1.57**	**22.51**	**663.24**	**4.70**	**5.03**	**4.15**	**4.75**	**4.66**	**0.07**	**-0.02**	**0.02**	**0.1930**

SUMMARY:

PAC = -2.79 ± 2.02 % per year
P-Value = 0.26

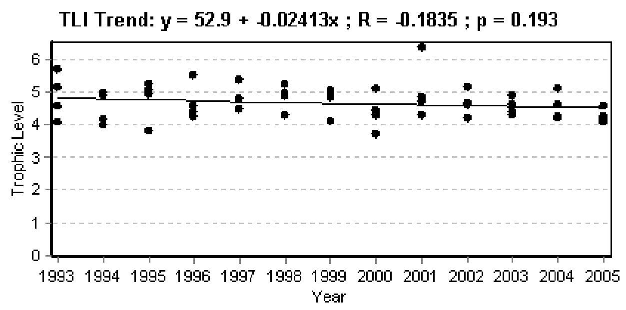
TLI Value = 4.66 ± 0.07 TLI units
TLI Trend = -0.02 ± 0.02 TLI units per year
P-Value = 0.1930

ASSESSMENT:

Eutrophic
Possible Improvement

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Wainamu

WQ Trend Analysis (1 Sep 1992 - 30 Mar 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	(-0.36)	(-0.02)	-1.66	(16.71)				
Average Over Period	(9.08)	(1.04)	35.87	(451.36)				
Percent Annual Change (%/Year)	**0.00**	**0.00**	**-4.63**	**0.00**	**0.00**	**-1.16**	**1.16**	**0.39**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Sep 1992 - Aug 1993	19.75	1.38	66.14	288.67	5.51	5.16	5.53	3.80	5.00	0.41			
Sep 1993 - Aug 1994	6.29	1.40	34.86	506.00	4.25	5.14	4.72	4.53	4.66	0.19			
Sep 1994 - Aug 1995	6.50	1.50	38.43	374.14	4.28	5.06	4.85	4.13	4.58	0.22			
Sep 1995 - Aug 1996	13.53	1.02	31.67	251.17	5.09	5.50	4.60	3.61	4.70	0.41			
Sep 1996 - Aug 1997	9.83	0.92	32.86	401.25	4.74	5.62	4.65	4.23	4.81	0.29			
Sep 1997 - Aug 1998	12.33	0.66	38.33	508.50	4.99	6.01	4.84	4.54	5.09	0.32			
Sep 1998 - Aug 1999	16.48	0.80	40.00	546.80	5.31	5.79	4.90	4.63	5.16	0.25			
Sep 1999 - Aug 2000	6.23	0.90	32.00	531.00	4.24	5.65	4.61	4.59	4.77	0.31			
Sep 2000 - Aug 2001	6.60	0.97	22.50	216.50	4.30	5.57	4.17	3.42	4.36	0.45			
Sep 2001 - Aug 2002	9.54	0.76	33.00	599.67	4.71	5.85	4.65	4.75	4.99	0.29			
Sep 2002 - Aug 2003	4.65	0.97	23.33	539.33	3.92	5.57	4.21	4.61	4.58	0.36			
Sep 2003 - Aug 2004	8.00	0.60	30.00	512.38	4.51	6.12	4.53	4.55	4.93	0.40			
Sep 2004 - Mar 2005	5.88	1.43	30.60	207.60	4.17	5.12	4.56	3.36	4.30	0.37			
Averages	**9.66**	**1.02**	**34.90**	**421.77**	**4.62**	**5.55**	**4.68**	**4.21**	**4.76**	**0.09**	**-0.02**	**0.02**	**0.4650**

SUMMARY:

PAC = -1.16 ± 1.16 % per year
P-Value = 0.39

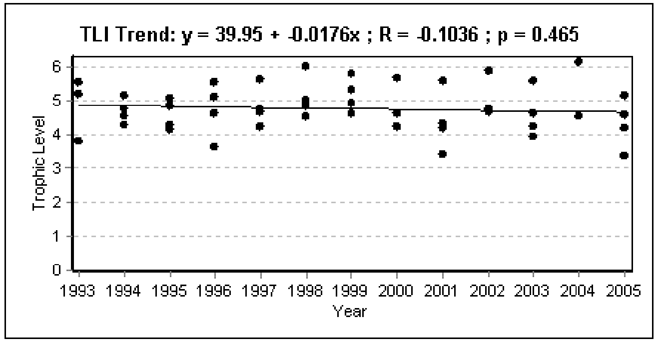
TLI Value = 4.76 ± 0.09 TLI units
TLI Trend = -0.02 ± 0.02 TLI units per year
P-Value = 0.4650

ASSESSMENT:

Eutrophic
No Change

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



Appendix 3:

Summary data based on inter-annual means of 12 water quality variables between 1993 and 2005.

Lake Wainamu								Lake Tomarata							
	Count	Mean	Median	Minimum	Maximum	IQR	Skewness		Count	Mean	Median	Minimum	Maximum	IQR	Skewness
Total phosphorus (mgP.m^{-3})	13	34.9	32.9	22.5	66.1	8.4	2.1		13	22.5	23.0	15.8	28.6	4.8	-0.4
Total nitrogen (mgN.m^{-3})	13	425.6	506.0	216.5	599.7	261.9	-0.4		13	663.2	536.0	382.1	2018.8	173.0	3.2
Chlorophyll *a* (mg.m^{-3})	13	9.7	8.0	4.7	19.8	6.7	1.1		13	10.3	10.2	5.9	23.0	5.1	1.7
Total oxidised nitrogen (mgN.m^{-3})	13	26.7	24.9	6.0	54.8	24.5	0.5		13	10.6	11.0	5.4	20.8	5.2	1.1
Total ammoniacal nitrogen (mgN.m^{-3})	13	11.9	10.0	4.9	20.0	7.4	0.1		13	17.5	13.2	7.0	46.7	15.8	1.6
Dissolved reactive phosphorus (mgP.m^{-3})	13	12.7	12.5	6.0	18.3	7.2	-0.2		13	8.5	7.5	5.6	15.0	3.8	1.3
pH	13	7.6	7.6	7.3	7.8	0.3	-0.4		13	7.4	7.3	7.2	7.7	0.2	0.9
Conductivity (mS/m^{-3})	13	20.9	20.8	19.0	22.4	1.6	-0.3		13	17.5	17.7	16.1	19.1	1.1	0.2
Total suspended solids (g.m^{-3})	13	3.9	3.7	2.9	5.1	1.1	0.3		13	2.8	2.6	1.9	4.0	1.3	0.5
Temperature (°C)	13	16.1	16.2	13.1	18.7	2.3	-0.2		13	17.9	17.3	13.1	22.2	2.4	0.0
Dissolved oxygen (% saturation)	13	82.6	80.3	73.6	99.2	12.6	0.8		13	82.0	80.5	74.6	89.7	7.6	0.4
Water clarity (m)	13	1.0	1.0	0.6	1.5	0.6	0.4		13	1.6	1.5	1.0	2.3	0.5	0.5

Lake Kereta								Lake Kuwakatai						
	Count	Mean	Median	Minimum	Maximum	IQR	Skewness	Count	Mean	Median	Minimum	Maximum	IQR	Skewness
Total phosphorus ($mgP.m^{-3}$)	13	37.5	37.5	20.0	59.0	21.5	0.2	13	46.3	46.0	30.0	62.9	17.4	0.3
Total nitrogen ($mgN.m^{-3}$)	13	745.4	668.8	126.0	1508.5	714.5	0.5	13	827.1	801.8	349.5	1182.4	389.3	-0.1
Chlorophyll *a* ($mg.m^{-3}$)	13	12.0	10.5	1.5	29.5	13.2	0.7	13	54.1	53.6	25.8	98.0	38.0	0.5
Total oxidised nitrogen ($mgN.m^{-3}$)	13	7.6	7.0	3.4	14.3	3.6	1.2	13	29.1	17.3	4.5	64.9	43.7	0.4
Total ammoniacal nitrogen ($mgN.m^{-3}$)	13	12.0	12.8	5.0	20.0	8.7	0.3	13	49.7	24.2	4.6	117.5	101.8	0.6
Dissolved reactive phosphorus ($mgP.m^{-3}$)	13	11.2	8.8	6.7	26.7	6.6	2.0	13	9.1	8.1	3.8	21.1	5.4	1.6
pH	13	8.8	8.6	8.1	10.0	0.9	0.9	13	8.0	8.1	7.7	8.3	0.3	-0.1
Conductivity (mS/m^{-3})	13	25.3	25.1	23.8	30.1	1.5	2.1	13	23.2	23.0	21.1	25.1	2.1	-0.2
Total suspended solids ($g.m^{-3}$)	13	7.2	5.1	2.0	15.2	7.9	0.6	13	6.3	6.5	2.8	8.7	3.6	-0.3
Temperature (°C)	11	19.0	19.3	12.0	24.5	2.4	-0.3	13	17.0	17.4	13.3	19.1	2.8	-0.6
Dissolved oxygen (% saturation)	7	120.4	119.3	102.5	153.2	22.2	1.1	13	82.6	84.1	60.6	92.9	11.9	-1.2
Water clarity (m)	ns	ns	ns	ns	ns	ns	ns	13	1.4	1.4	1.1	1.7	0.3	0.0

Lake Ototoa								Lake Pupuke						
	Count	Mean	Median	Minimum	Maximum	IQR	Skewness	Count	Mean	Median	Minimum	Maximum	IQR	Skewness
Total phosphorus (mgP.m^{-3})	13	16.6	17.0	9.0	23.0	5.6	-0.4	13	22.6	21.3	17.5	30.0	6.0	0.8
Total nitrogen (mgN.m^{-3})	13	496.6	415.8	221.3	1306.5	370.2	1.8	12	621.8	476.6	206.3	1845.0	423.3	1.8
Chlorophyll *a* (mg.m^{-3})	13	4.7	5.0	2.5	5.8	1.6	-0.9	12	8.3	7.8	4.1	17.4	3.8	1.4
Total oxidised nitrogen (mgN.m^{-3})	13	8.3	7.4	3.7	12.7	6.5	0.0	13	14.8	14.5	4.3	26.8	10.5	0.1
Total ammoniacal nitrogen (mgN.m^{-3})	13	18.3	12.9	4.3	70.8	16.7	2.4	13	24.3	14.3	5.0	80.0	18.7	1.9
Dissolved reactive phosphorus (mgP.m^{-3})	13	6.8	6.2	4.0	11.1	2.4	1.2	13	9.7	8.3	4.5	16.7	8.5	0.3
pH	13	7.8	7.8	7.3	8.5	0.3	1.3	13	8.4	8.4	8.0	8.9	0.4	0.6
Conductivity (mS/m^{-3})	13	21.2	21.2	20.1	21.9	1.2	-0.4	12	27.7	27.6	26.3	28.9	0.7	-0.3
Total suspended solids (g.m^{-3})	13	1.7	1.6	0.8	3.2	1.1	0.9	13	2.0	1.7	1.3	3.1	1.0	0.8
Temperature (°C)	13	17.3	16.9	13.6	20.2	3.3	-0.1	13	16.7	16.4	14.7	19.4	3.9	0.4
Dissolved oxygen (% saturation)	13	91.9	91.2	85.9	99.2	6.8	0.3	13	88.7	87.0	79.7	106.6	10.3	1.3
Water clarity (m)	13	4.7	4.4	3.5	6.8	1.6	0.5	13	4.7	4.4	3.3	6.5	1.9	0.5

Lake Spectacle	Count	Mean	Median	Minimum	Maximum	IQR	Skewness
Total phosphorus ($mgP.m^{-3}$)	13	102.2	98.0	56.6	149.0	39.3	0.2
Total nitrogen ($mgN.m^{-3}$)	13	1300.9	1318.0	597.3	1856.6	526.3	-0.1
Chlorophyll *a* ($mg.m^{-3}$)	13	89.1	90.6	37.0	144.2	44.7	0.1
Total oxidised nitrogen ($mgN.m^{-3}$)	13	50.2	38.4	5.2	195.5	49.9	2.0
Total ammoniacal nitrogen ($mgN.m^{-3}$)	13	56.1	26.3	5.0	231.1	42.7	2.0
Dissolved reactive phosphorus ($mgP.m^{-3}$)	13	13.1	13.3	5.2	22.0	8.4	0.3
pH	13	7.7	7.7	7.2	9.1	0.6	1.7
Conductivity (mS/m^{-3})	13	27.8	28.8	24.1	30.0	3.1	-0.7
Total suspended solids ($g.m^{-3}$)	13	22.9	22.0	11.0	35.5	10.4	0.3
Temperature (°C)	13	17.6	17.0	12.8	21.7	2.8	-0.1
Dissolved oxygen (% saturation)	13	79.9	78.1	73.0	93.0	8.0	1.0
Water clarity (m)	13	0.4	0.4	0.2	0.5	0.2	-0.4

Appendix 4

Photograph 1: Southerly aerial view of Lake Kereta.

Photograph 2: Aerial view of Lake Spectacle to the southeast.

Photograph 3: Aerial view of Lake Tomarata to the northwest.

Photograph 4: Easterly aerial view of Lake Wainamu.

Photograph 5: South-westerly aerial view of Lake Ototoa.

Photograph 6: Aerial view of Lake Pupuke looking south towards Takapuna City.