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Lake Wairarapa water quality monitoring technical report

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Executive summary

The state and trends of water quality in Lake Wairarapa were analysed using LakeWatch software and the protocols outlined in Burns et al, 2000.

The current water quality of the lake is similar to that reported in the past (Morton, 1995; Stansfield, 1996; 1999). High levels of total nitrogen, total phosphorus, algal biomass and low water clarity are all suggestive of a highly modified, eutrophied system. The lake is classed as being in a supertrophic state.

There is some indication of a slight improvement in water quality since monitoring began, with decreases in total nitrogen and increases in secchi depth occurring. However, the rate of change is minor and considered to be of little biological relevance with the overall lake water quality remaining in a relatively stable, albeit poor state.

Increases in conductivity were observed and are a result of increased salinity caused by back flow from Lake Onoke. Increases in salinity may adversely affect the lake ecosystem and also have implications for agricultural uses in the region.

Addition of phytoplankton, zooplankton and fish community analysis to the sampling regime would produce additional information about the health of the lake's ecosystem.

A comprehensive review of the lake monitoring programme is needed to keep up to date with best scientific and management practices utilised in lake water quality monitoring. A review will also provide an opportunity to investigate the possibility of adding other lakes to the Greater Wellington Regional Council's lake water quality monitoring programme.

Contents

1. Introduction

Lake Wairarapa is situated in the southern end of the extensive Ruamahanga Catchment in the Wairarapa. It is part of the largest wetland complex in the southern North Island and is considered to have ecological, cultural and recreational values worth protecting (DOC, 1999).

It is a large (80 km^2), isothermal, shallow lake (2.5 m at its deepest point), and is situated in a large, highly developed, agricultural catchment. The wetland complex has been substantially modified by flood control management. In 1974 the lower Ruamahanga River was diverted to by-pass the lake and flow directly into Lake Onoke. As a result of the Ruamahanga diversion, the lake catchment has been reduced by around 80%.

Inputs of water to the lake include the Tauherenikau River at the North Eastern corner and from numerous small streams of which most occur along the western shore. Treated wastewater from the Featherston Wastewater Treatment Plant enters the lake via Abbots Creek and under flood conditions, water from the Ruamahanga River enters the lake via the Oporua Floodway in the middle of the eastern shore.

Current lake management involves regulating lake levels by opening and shutting the barrage gates at the exit to Lake Onoke.

Monitoring of lake water quality began in 1994 to enable the management and protection of aquatic ecosystems in accordance with the Regional Freshwater Plan (Stansfield, 1999) and is currently a part of Greater Wellington Regional Council's Freshwater State of the Environment monitoring programme. This programme is undertaken to:

- Assist in the detection of spatial and temporal changes in fresh waters.
- Contribute to our understanding of freshwater biodiversity in the region.
- Determine the suitability of fresh waters for designated uses.
- Provide information to assist in targeted investigations where remediation or mitigation of poor water quality is desired.
- Provide a mechanism to determine the effectiveness of policies and plans.

Water quality monitoring allows us to determine the current state of the lake (i.e. trophic status) and to reveal any trends over time.

The water quality of Lake Wairarapa was last reported on in 1999. That report concluded that for the 1994 to 1998 period there had been no change in water quality and that overall water quality of the lake was poor and remained in a eutrophic/ supertrophic state (Stansfield, 1999).

This document reports on trends in water quality and trophic status for the 1994 to 2005 period.

2. Methods

Water quality is sampled at four sites (Figure 2.1). These sites were chosen to give an overall representation of general lake status (Berry, 1993). In order to increase the sensitivity of the statistical analyses in this report, the data from the four sites was pooled.

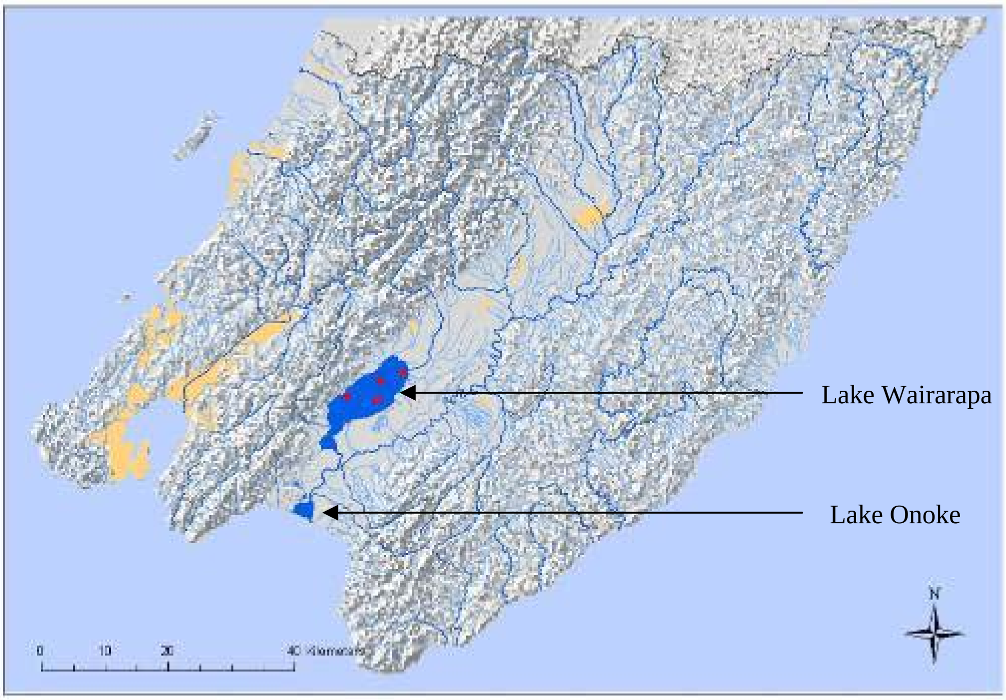

Figure 2.1: Lake Wairarapa and the location of sampling points.

While attempts have been made to collect samples on a quarterly basis, in practice this rarely occurs. This is because strong winds common in the Southern Wairarapa often make sampling impossible. As a result sampling has occurred intermittently since the monitoring programme begun with two to three samples taken each year being the norm.

With sampling being restricted to calm days the data set will be biased towards less turbulent conditions. Sediment disturbance by wind-induced turbulence has been shown to have a strong effect on lake dynamics (Burns el al, 2000) and this should be remembered when viewing the reported results.

Samples were collected in accordance with the sub surface grab method for sampling isothermal lakes described in Smith et al, 1989.

LakeWatch software, in conjunction with protocols set by Burns et al (2000), were used to analyse lake water quality data. Burns et al identify four key variables associated with determining status and trends in isothermal lake water quality; secchi depth, chlorophyll *a*, total phosphorus, and total nitrogen. These variables allow the calculation of Percent Annual Change (PAC) and the Trophic Level Index (TLI) which can be interpreted to indicate changes in lake water quality.

PAC is the average annual rate of change of secchi depth, chlorophyll *a*, total phosphorus, and total nitrogen. It involves deseasonalising (removing seasonal effects) the data for the four key variables. This is done by plotting the data as a function of month with no regard to the year of collection. A polynomial curve is then fitted to this data and allows for the deseasonalised residuals to be calculated. The observed and deseasonalised residuals are then plotted against time and straight line plots are then fitted using ordinary least squares regression. Statistical analysis enables interpretation of the probability of the average annual rate of change in lake water quality (see Burns et al, 2000 for full details).

TLI gives a clear idea of the actual state of the lake and changes over time can be calculated from the slope of the regression line. It is calculated using the appropriate trophic level values for chlorophyll *a* (TLc), secchi depth (TLs), total nitrogen (TLn) and total phosphorus (TLp). Table 2.1 indicates the application of this procedure (see Burns et al, 2000 for full details).

Table 2.1: Values of variables that define boundaries of different trophic levels (Burns et al, 2000).

Lake Type	**Trophic Level**	**Chlorophyll a (mg m^{3-})**	**Secchi Depth (mg m^{3-})**	**Total Phosphorus (mg m^{3-})**	**Total Nitrogen (mg m^{3-})**
Ultra-microtrophic	0.0-1.0	0.13-0.33	33-25	0.84-1.8	16-34
Microtrophic	1.0-2.0	0.33-0.82	25-15	1.8-4.1	34-73
Oligotrophic	2.0-3.0	0.82-2.0	15-7.0	4.1-9.0	73-157
Mesotrophic	3.0-4.0	2.0-5.0	7.0-2.8	9.0-20	157-337
Eutrophic	4.0-5.0	5.0-12	2.8-1.1	20-43	337-725
Supertrophic	5.0-6.0	12-31	1.1-0.4	43-96	725-1558
Hypertrophic	6.0-7.0	>31	<0.4	>96	>1558

Trend analysis of "non-key" variables was carried out using similar methodology to that involved in calculating PAC values (i.e. data was deseasonalised and then plotted against time). Variables analysed included temperature, dissolved oxygen, pH, conductivity, turbidity, suspended solids, volatile suspended solids, faecal coliforms, ammonia, nitrate, and dissolved reactive phosphorus.

Data values at detection limits were halved for the analysis (e.g. <2 became 1), except in the case of chlorophyll *a*. The difficulties of accurately analysing chlorophyll *a* concentrations in samples with high total suspended solids resulted in a wide range of detection limits (<1.3 to <13 mg m^{-3}). Because there was no way of estimating what the true value may have been these values were left out of the analysis.

Data points considered to be outliers or errors were also removed prior to analysis. This was achieved by comparing results between the four monitored sites. Preliminary investigation showed high correlation between sites and thus inconsistent values could easily be located and removed.

3. Results

Table 3.1 shows the median, minimum and maximum values for the variables analysed in this report. Altogether, 28 water records were collected since 1994. All data was collected from 1994 to 2005; except for total suspended solids, inorganic suspended solids (1995 - 2005), faecal coliforms (1997 – 2005) ammonia, nitrate and dissolved reactive phosphorus (1998 – 2005). Large ranges were typical for many of the measured variables, with maximum values commonly being an order of magnitude greater than the median values.

Table 3.1: Minimum, median and maximum values for various water quality variables monitored over the 1994 to 2005 period.

Variable	Median	Min	Max
Temperature (°C)	13.5	7	22.27
Dissolved Oxygen (%sat)	99.00	91.60	116.40
Secchi Depth (m)	0.19	0.02	1.5
Chlorophyll a (mg m^{-3})	12	1.1	49
Total Phosphorus (mg m^{-3})	106	10	1167
Total Nitrogen (mg m^{-3})	483.5	100	1730
Dissolved Reactive Phosphorus (mg m^{-3})	10	1.5	25
Ammonia (mg m^{-3})	8	2.5	45
Nitrate (mg m^{-3})	45	1	631
pH	7.75	7.22	8.58
Electrical Conductivity (µs cm^{-1})	348.5	58	2780
Faecal Coliforms (cfu $100ml^{-1}$)	5	1	108
Turbitity (NTU)	45	1.3	190
Total Suspended Solids (g m^{-3})	59.5	7	788
Inorganic Suspended Solids (g m^{-3})	47.7	2	774.4

Figures 3.1 to 3.4 show the annualised plots for the key variables. These plots show that while there is some scatter in all variables with time of year, seasonal trends are apparent. Highest values for secchi depth are observed during the winter months and for the rest of the year seem to be fairly constant. Total phosphorus concentrations remain stable for most of the year, but may have a peak mid summer. Total nitrogen and chlorophyll *a* concentrations exhibit similar patterns with their lowest values occurring in late summer and early winter, before beginning to climb in late winter and peaking in spring.

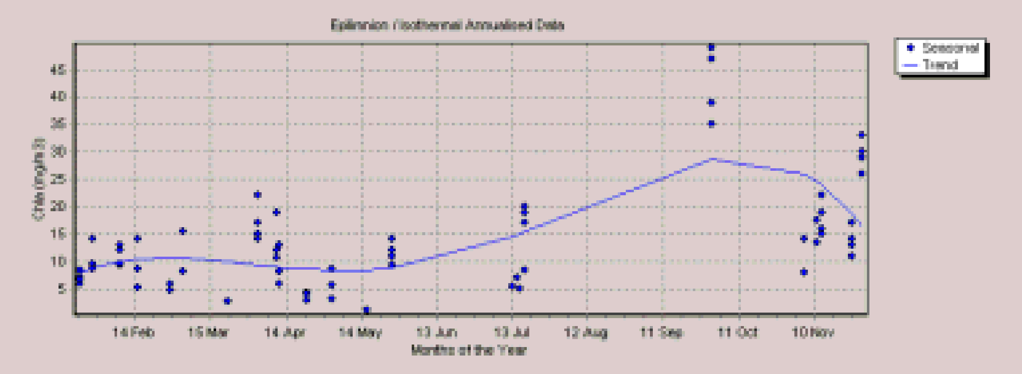

Figure 3.1: Chlorophyll ***a*** plotted against month with no regard for year of collection.

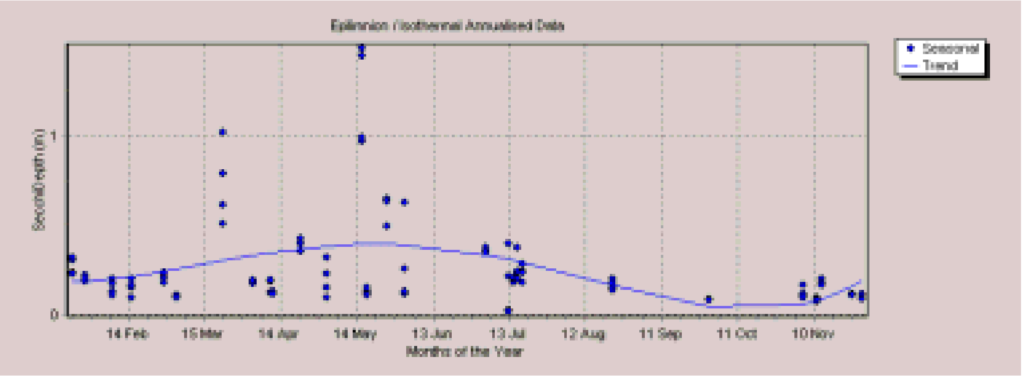

Figure 3.2: Secchi depth plotted against month with no regard for year of collection.

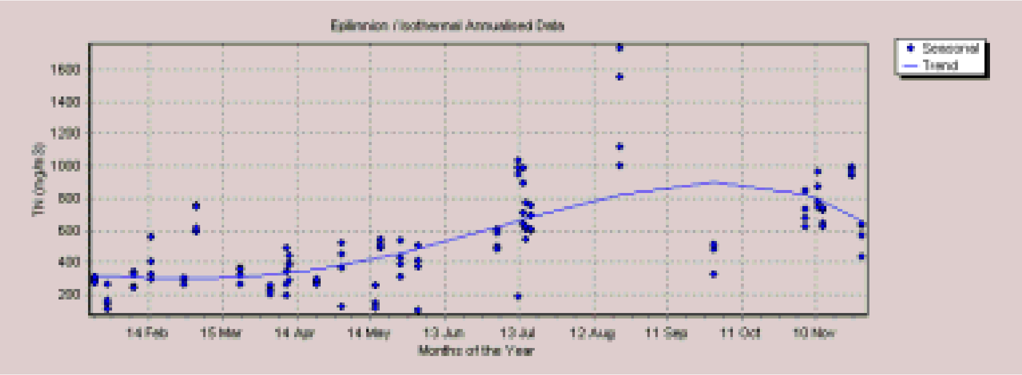

Figure 3.3: Total nitrogen plotted against month with no regard for year of collection.

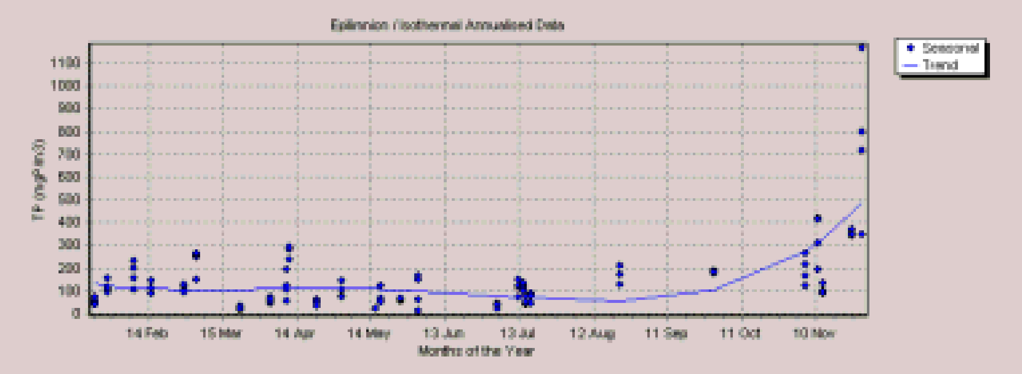

Figure 3.4: Total phosphorus plotted against month with no regard for year of collection.

Plots of deseasonalised data over time are shown in figures 3.5 to 3.8. Secchi depth increased significantly by 0.03 m year^{-1} (p = 0.0002) and total nitrogen decreased significantly by

16.84 mg m^{-3} year^{-1} (p = 0.009). Chlorophyll *a* showed an increasing trend while total phosphorus decreased; however, neither trend was statistically significant.

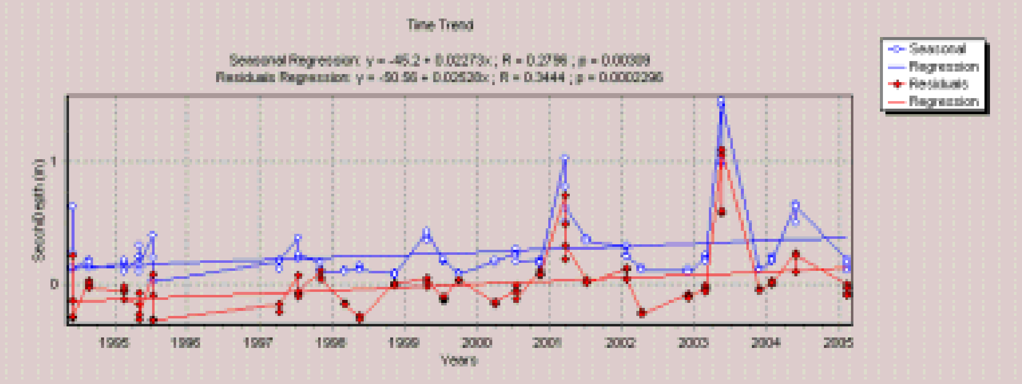

Figure 3.5: Plot of observed and deseasonalised time trends for secchi depth.

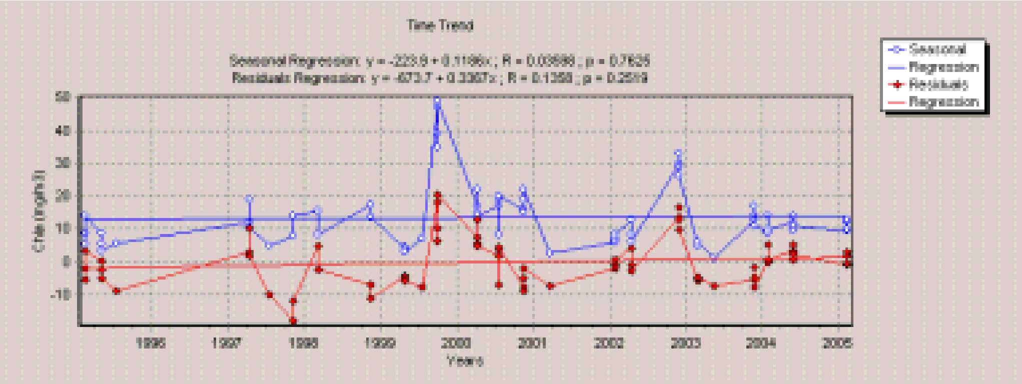

Figure 3.6: Plot of observed and deseasonalised time trends for chlorophyll ***a***.

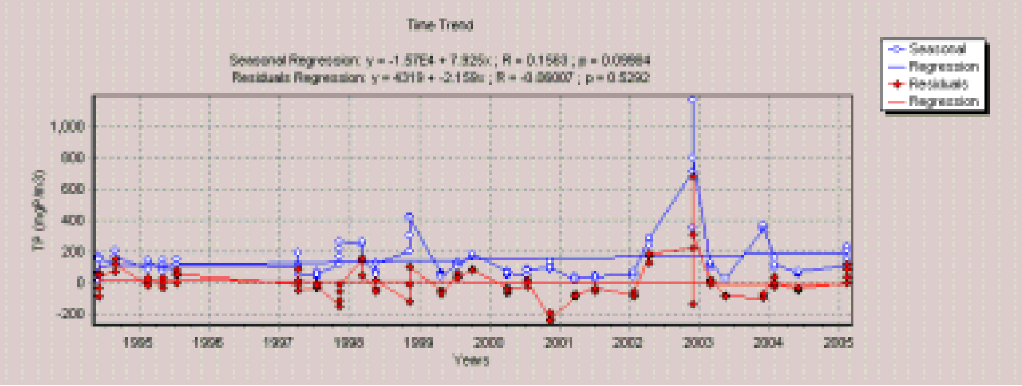

Figure 3.7: Plot of observed and deseasonalised time trends for total phosphorus.

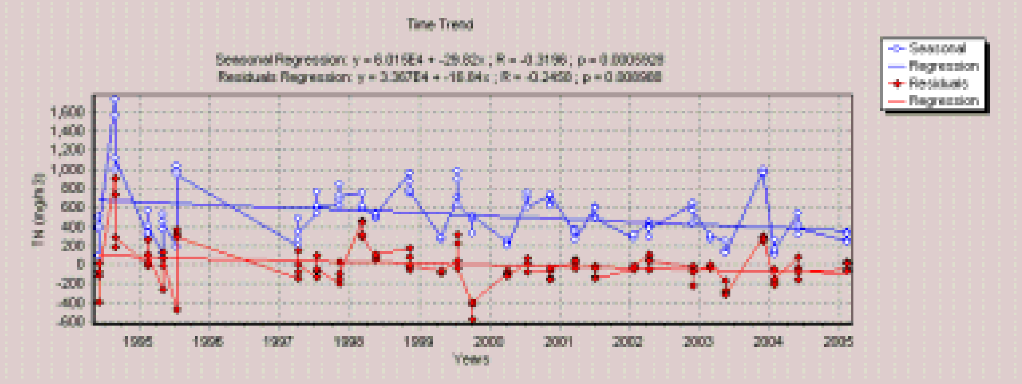

Figure 3.8: Plot of observed and deseasonalised time trends for total nitrogen.

Table 3.2 shows the annual change values for the period of 1994 to 2005. A P value of 0.26 indicates that there was a possible change in the average PAC value of -3.59 % year^{-1}, which corresponds to possible improvement in lake water quality.

Table 3.2: Percent annual change values for key variables (non-significant changes are in brackets).

	Chlorophyll a (mg m^{3-})	**Secchi Depth (mg m^{3-})**	**Total Phosphorus (mg m^{3-})**	**Total Nitrogen (mg m^{3-})**	**Avg PAC**	**Std Err**	**P-Value**
Change - Units Per Year	(0.34)	0.03	(-2.16)	-16.84			
Average Over Period	(13.48)	0.27	(146.96)	515.55			
Percent Annual Change (%/Year)	0.00	-11.11	0.00	-3.27	-3.59	2.62	0.26

Figure 3.9 is a plot of trophic level index (TLI) over time and while not significant ($p = 0.3685$) indicates an apparent improvement in trophic state over time.

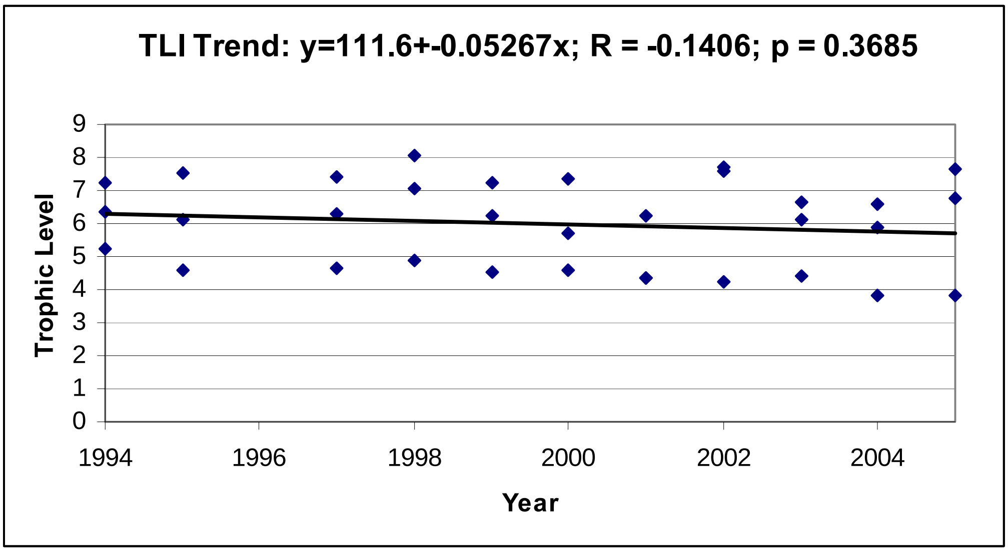

Figure 3.9: Trophic Level Index (TLI) time trend.

A closer look at how the key variables influence the TLI is shown in Table 3.3. The average TLn and TLc values fall into trophic categories at least two lower than the average TLs and TLp values. The overall average value (TLI) falls into the supertrophic category.

The TLn value of 4.46 is lower than the average TLp value of 6.28 (Table 3.3). This indicates that nitrogen limitation, in regards to phytoplankton growth, is occurring some of the time. The average TLc and TLn values fall into the same trophic category further reinforcing the link between total nitrogen and algal growth.

Table 3.3: Annual average values for chlorophyll a, secchi depth, total phosphorus and total nitrogen.

Period	Chlorophyll a (mg m^{-3})	Secchi Depth (mg m^{-3})	Total Phosphorus (mg m^{-3})	Total Nitrogen (mg m^{-3})	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units yr-1
Jan 1994 - Dec 1994		0.23	125.75	848.75		7.23	6.35	5.21	6.26	0.59	
Jan 1995 - Dec 1995	8.09	0.17	106.08	517.00	4.53	7.53	6.13	4.56	5.69	0.72	
Jan 1997 - Dec 1997	11.43	0.19	118.92	556.92	4.91	7.44	6.28	4.65	5.82	0.65	
Jan 1998 - Dec 1998	13.66	0.11	217.00	673.83	5.10	8.08	7.04	4.90	6.28	0.77	
Jan 1999 - Dec 1999	21.38	0.23	114.08	513.75	5.60	7.23	6.23	4.55	5.90	0.56	
Jan 2000 - Dec 2000	17.03	0.20	76.58	523.42	5.35	7.37	5.72	4.57	5.75	0.59	
Jan 2001 - Dec 2001	2.60	0.55	26.50	434.38	3.27	6.21	4.37	4.33	4.55	0.61	
Jan 2002 - Dec 2002	15.51	0.17	360.42	410.33	5.24	7.58	7.68	4.26	6.19	0.86	
Jan 2003 - Dec 2003	8.74	0.59	161.42	471.08	4.61	6.14	6.67	4.44	5.46	0.55	
Jan 2004 - Dec 2004	10.94	0.41	87.75	290.63	4.86	6.56	5.89	3.80	5.28	0.60	
Jan 2005 - Dec 2005	11.00	0.15	171.50	289.00	4.87	7.66	6.74	3.80	5.77	0.88	
Averages	**12.04**	**0.27**	**142.36**	**502.64**	**4.83**	**7.19**	**6.28**	**4.46**	**5.71**	**0.19**	**-0.06**

Of the other variables analysed for trends only faecal coliforms and conductivity showed statistically significant trends. Faecal coliforms decreased by 1.719 cfu 100ml^{-1} year^{-1} ($p = 0.03$), (Figure 3.10). While conductivity increased by 46.53 µs cm^{-1}year^{-1} ($p = 0.002$), (Figure 3.11).

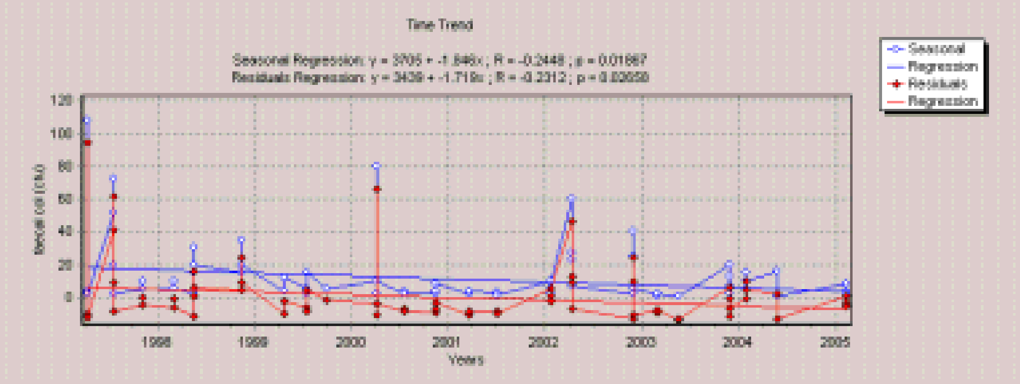

Figure 3.10: Plot of observed and deseasonalised time trends for faecal coliforms.

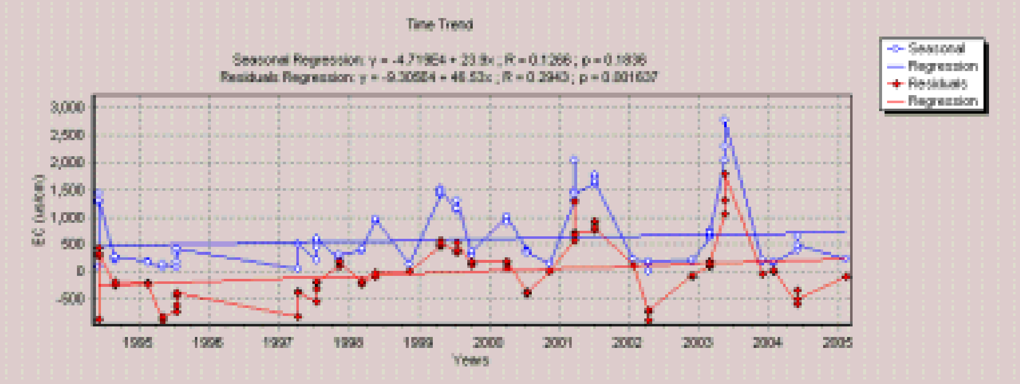

Figure 3.11: Plot of observed and deseasonalised time trends for electrical conductivity.

4. Discussion

Eutrophication of water bodies is a common problem in modified catchments and Lake Wairarapa is no exception. Increases in nutrients, organic matter and silt inputs have occurred since development of the catchment first began and these have likely accelerated in later years as agricultural practices have intensified.

The current water quality of the lake is similar to that reported in the past (Morton, 1995; Stansfield, 1996; 1999). High levels of total nitrogen, total phosphorus, algal biomass and low water clarity are all suggestive of a highly modified, eutrophied system.

Average levels of total phosphorus and secchi depth are consistently indicative of a hypertrophic state whereas levels of chlorophyll *a* and total nitrogen are more in line with those associated with a lower trophic level and fall into the eutrophic category. Overall lake water quality is classified as supertrophic.

Since monitoring began in 1994, many of the measured variables have fluctuated widely, with maximum values often an order of magnitude greater than the median value. However, variables such as temperature, dissolved oxygen, pH and ammonia, which can have acutely negative effects on aquatic biota, have remained at levels unlikely to be detrimental.

In shallow lakes, sediment disturbance by wind-induced turbulence can be a stronger process acting on lake dynamics than those caused by the seasons (Burns et al, 2000). With this data set collected over such a long period, the overall effects of wind could be considered to be negligible (Burns, pers. comm.). However, with sampling restricted to windless or near windless days the data set could be considered biased, especially as strong winds are considered to be the norm in the region. On days deemed too rough to sample, the resuspension of sediments by wind-induced turbulence would likely lead to significantly higher nutrient (and faecal bacteria) concentrations and a decrease in secchi depth. Thus the classification of the lake as “supertrophic” could be favourable, with actual lake water quality in an even poorer state.

Average PAC values indicate that there has been some possible improvement in the overall lake water quality since monitoring began. Statistically significant decreases in total nitrogen and increases in secchi depth are the main drivers behind the observed improvement. Regression of TLI values also shows an apparent (not statistically significant) improvement in water quality. Thus there is some indication that the lake may be shifting slowly to an improved trophic state.

The similarities in the TLn value to the TLc and the fact that the average TLp falls into a trophic category two higher than the TLn suggests that lake is nitrogen limited, and thus total nitrogen concentrations are exhibiting some control over the algal biomass. High levels of suspended solids are also thought to impact on some biological processes, such as reducing algal production (Barnes, 2002). This could also be occurring in Lake Wairarapa.

With nitrogen limitation occurring, decreasing total nitrogen levels are likely to further decrease chlorophyll *a* concentrations, resulting in an improved trophic state. However, the slow rate of decline, 16.84 mg m^{-3} $year^{-1}$, is likely to have little effect on biological processes in the lake for some time to come. The current reduction in total nitrogen concentration is not easily explained, given increases in farming intensity and a nine fold increase in nitrogen fertiliser application in the region over the last ten years (Statistics New Zealand, 2004). These land use effects may become apparent over time and reverse the current trend.

A trend of increasing secchi depth of 0.03 m $year^{-1}$ indicates an increase in water clarity. However, with increasing water clarity the corresponding trends we would expect to see, decreasing chlorophyll *a* and total suspended solids, were not observed. In this case, occasional extreme events in water clarity rather than a general increase may be the main driving force behind the observed trend. Since 2000 some sampling occasions have returned secchi depths of up to 5 times greater than the median value of 0.19 m. The cause of these extreme events of increased water clarity is unknown. The relevance of this small increase in water clarity to the lake ecosystem is probably limited, however, if it continues benefits may be observed.

Increasing conductivity is of some interest and is an indication of the overall complexity of the Lake Wairarapa Wetland complex. Back flow of saline water from the coastal Lake Onoke into Lake Wairarapa occurs under certain conditions. Saltwater intrusion into Lake Wairarapa may be a natural phenomenon or an artefact of changes made to the catchment by agricultural and flood management activities.

The highest salinity reached since measurements began is roughly equivalent to 4% seawater (using a conversion factor of 0.64 to convert from electrical conductivity (μs cm^{-1}) to total dissolved solids (NZLTC, 2000)). The effects of saltwater intrusion on the lake ecosystem are unknown, but trends in increasing conductivity need to be watched as many agricultural uses of water are seriously affected by salinity levels (Thornton et al, 1996).

A reduction of faecal coliforms is of interest, but probably of little biological significance. Levels are generally low and are never near levels where the safety of recreational uses becomes an issue.

Analysis of the following variables failed to find any significant trends: temperature, dissolved oxygen, pH, turbidity, suspended solids, volatile suspended solids, nitrate, and dissolved reactive phosphorus. A lack of trends in these variables and any strong trends in the key variables may indicate that lake is in a relatively stable state.

5. Conclusion

Lake Wairarapa is a large, shallow nutrient-rich lake that has likely undergone progressive eutrophication since catchment development and intensification began. The lake appears to be in a relatively stable state with little changes in water quality occurring since monitoring began in 1994. It can currently be classified as being in a supertrophic state.

Analysis of key variables gave some indication that water quality may be slowly improving with decreases in total nitrogen and increases in secchi depth occurring. However, rates of changes are extremely slow and it is likely to have little biological significance at this stage.

Increases in conductivity and a reduction in faecal coliforms were also observed. Any increase in conductivity is of interest and deserves closer investigation. Increases in conductivity are caused by saltwater intrusion from the Lake Onoke system and its effects on the Lake Wairarapa ecosystem are unknown. A reduction of faecal coliforms is considered of little importance to the overall wetland complex.

A water body’s trophic state is largely determined by nutrient inputs from the surrounding catchment (Barnes, 2002). Therefore, significant improvement in lake water quality is probably unlikely with current landuse activities and practices in the catchment.

6. Recommendations

A comprehensive review of the existing lake water quality monitoring programme is recommended to ensure that monitoring reflects current best scientific and management practices utilised in lake water quality monitoring. It will also provide an opportunity to investigate the possibility of incorporating other lakes in the Wellington Region into the existing lake water quality monitoring programme.

More effort should be made to complete sampling on a quarterly or more frequent basis; to date sampling has been completed no more than three times every year. A more stringent sampling regime would provide more information on the effects of seasonality and improve the ability to detect trends in water quality.

Monitoring the algal and zooplankton communities can also be valuable in indicating the trophic state of a lake (Burns et al, 2000; Duggan et al, 2002). The addition of taxonomic analysis of algal and zooplankton species to the sampling programme would provide valuable information enabling some linking between the physical, chemical and biological processes taking place in the lake.

Fish communities are an important component of lake ecosystems, and their abundance and composition have been found to be strongly related to habitat quality. Monitoring of fish populations in Lake Wairarapa would provide additional information in regards to water quality and ecosystem health.

Acknowledgements

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