Analysis of Lake Rotorua water quality trends: 2001–2012

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1. INTRODUCTION

1.1 Aim

The primary aim of this report is to present the results of analyses undertaken to ascertain the presence and, if applicable, characteristics (magnitude and direction) of temporal trends in the water quality of Lake Rotorua during the period 2001–2012.

1.2 Background

1.2.1 Lake characteristics

Lake Rotorua (Bay of Plenty) is large (80.8 km^2) and relatively shallow (mean depth ≈ 10 m). The lake is eutrophic and deterioration of water quality in Lake Rotorua has been a concern since at least the 1960s (Fish, 1969; Rutherford, 1984; PCE, 2006). The lake is classified as polymictic which means that it thermally stratifies and mixes numerous times throughout the year in response to ambient weather characteristics (e.g. see Figure 1.1).

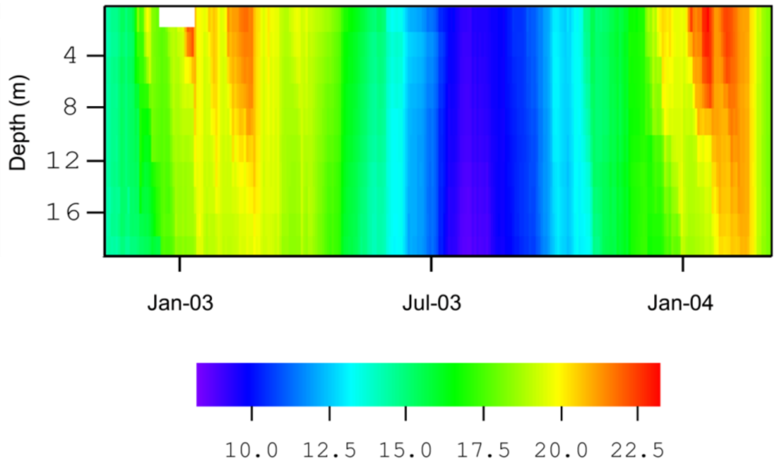

Figure 1.1 Vertical temperature profile of Lake Rotorua derived from measurements made at 2 m intervals, November 2002 – April 2004. Note the episodic pattern of vertical thermal stratification and mixing (coalescence of temperature) that is characteristic of this polymictic lake. Figure reproduced with permission from Burger (2006)

1.2.2 Monitoring

The Trophic Level Index (TLI; Burns et al., 1999) is used by lake managers to provide a measure of the trophic state of the lake (Table 1). When recorded through time it indicates the extent of eutrophication and is therefore a measure of water quality. The TLI is based on water column measurements of Secchi depth (a measure of clarity) and concentrations of total nitrogen, total phosphorus and chlorophyll *a* (a measure of algae abundance). A consistent monthly sampling programme conducted by the Bay of Plenty Regional Council at two sites (Figure 1.2) in the lake since October 2001 provides a reasonably extensive dataset to examine temporal changes in TLI over 11 years.

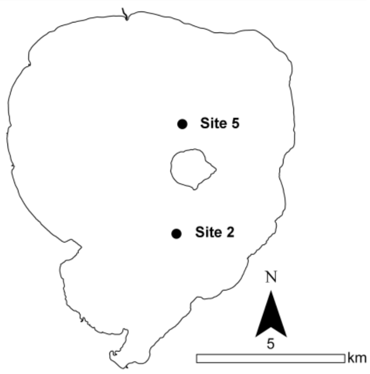

Figure 1.2 Location of Lake Rotorua monitoring Sites 2 and 5

Table 1.1 Summary of the Trophic Level Index used to quantify lake trophic status (Burns et al. 1999)

Trophic state	Trophic Level Index	Productivity	Perceived water quality
Ultra–microtrophic	0–1	Very low	Excellent
Microtrophic	1–2	↓	↓
Oligotrophic	2–3		
Mesotrophic	3–4		
Eutrophic	4–5		
Supertrophic	5–6		
Hypertrophic	6–7	Very high	Very bad

1.2.3 Land and water management

To provide some context, several notable land and water management actions that have occurred in the catchment of Lake Rotorua during 2001–2012 are presented in Figure 1.3. Further information about recent alum dosing is provided in Appendix A1.

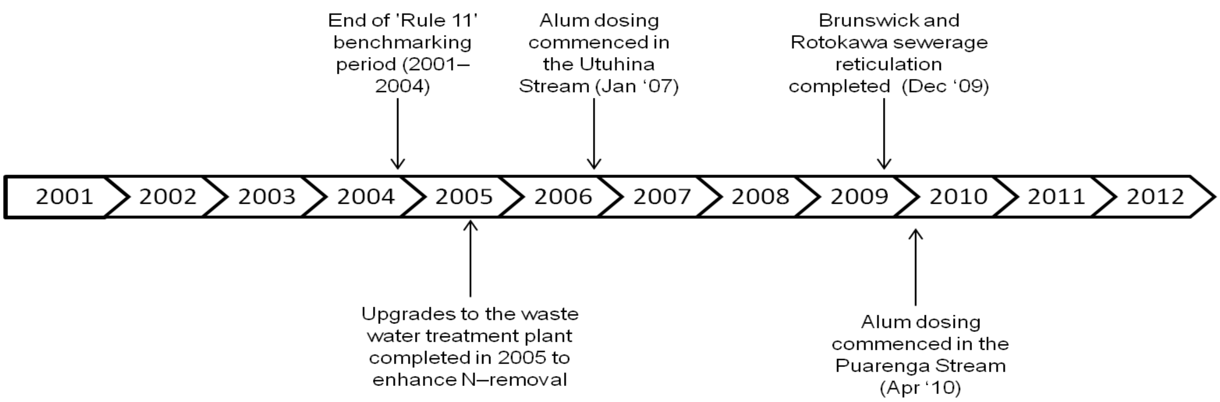

Figure 1.3 Timeline of the more significant land and water management actions that have occurred in the catchment of Lake Rotorua during 2001–2012

1.3 Context of this report

The Proposed Bay of Plenty Regional Policy Statement (Proposed RPS; notified November 2010) contains Water Quality and Land Use (WL) policies designed to affect how land and water are managed in the region (BoPRC, 2012). The Proposed RPS defines the catchment of Lake Rotorua as being "*at risk*" due to the potential for contaminant discharge to cause adverse effects on significant values attributed to the catchment (WL 2B). 'At risk' catchments are subject to a number of policies in the Proposed RPS. The following two policies, specific to Lake Rotorua, are currently under appeal:

> WL 3B (c): *"For Lake Rotorua the total amount of nitrogen that enters the lake shall not exceed 435 tonnes per annum."*
>
> WL 6B (c): *"No discharge of nitrogen onto or into land or water in the Lake Rotorua catchment that results in the exceedance of the limit for that lake is authorised by a rule in a plan or a discharge permit beyond 2022."*

An Environment Court facilitated mediation was held on 21 November 2012. It involved discussion of management issues related to Lake Rotorua, with specific reference to the Water Quality and Land Use provisions of the Proposed RPS. The meeting included discussion of the status of trends in Lake Rotorua water quality and presenters highlighted a need for updated analysis of contemporary water quality monitoring data. It was agreed that representatives of the University of Waikato[1] and DairyNZ meet and seek agreement on the scope of a common dataset to be used as the basis of trend analysis (see Appendix 2). Consequently, a common dataset was made available to both parties comprising data relating to integrated surface water samples (0–6 m) collected during the period of October 2001 – October 2012 by the Bay of Plenty Regional Council. Raw data that comprise the common dataset are presented and summarised in Chapter 2. These data represent the longest available contemporary time–series collected using consistent methodology that can be used to examine trophic state. A large number of samples have also been collected at other depths, however, analysis of data relating to these samples was considered beyond the scope of this study. This decision reflects the variation in the exact depths that were sampled and the consequent potential for uncertainty when defining whether a sample was collected when the lake was fully mixed, or, collected either from above or below the thermocline[2]. It is acknowledged, however, that such data for other depths provide further useful information about the state of lake water quality and undertaking future analysis of temporal trends in these data should not be discounted. Full details of the agreed scope of the dataset considered in this report are provided in Appendix 3.

This report documents the methodologies and outcomes of trend analysis conducted separately by the University of Waikato and DairyNZ using the common dataset. The approach of replicating analyses using a common dataset was designed to support constructive decision–making by helping to achieve consensus amongst stakeholders on recent water quality trends in Lake Rotorua.

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[1] Acting on behalf of Bay of Plenty Regional Council

[2] The distinct transition between the surface mixed layer and the denser bottom waters in a thermally stratified lake

1.4 Report production and format

The format of this report reflects the agreed approach of undertaking duplicate analyses of a common dataset, described above. The two analyses are documented separately in Chapters 3 (University of Waikato) and 4 (DairyNZ). Each of these two chapters is authored solely by scientists affiliated with each respective organisation with no editing by the other party. Chapter 5 presents conclusions that are consistent with both analyses. Chapter 5 was jointly produced by all authors.

2. COMMON DATA SET

Raw data that comprise the common dataset (see Appendix 3) are presented below (Figure 2.1).

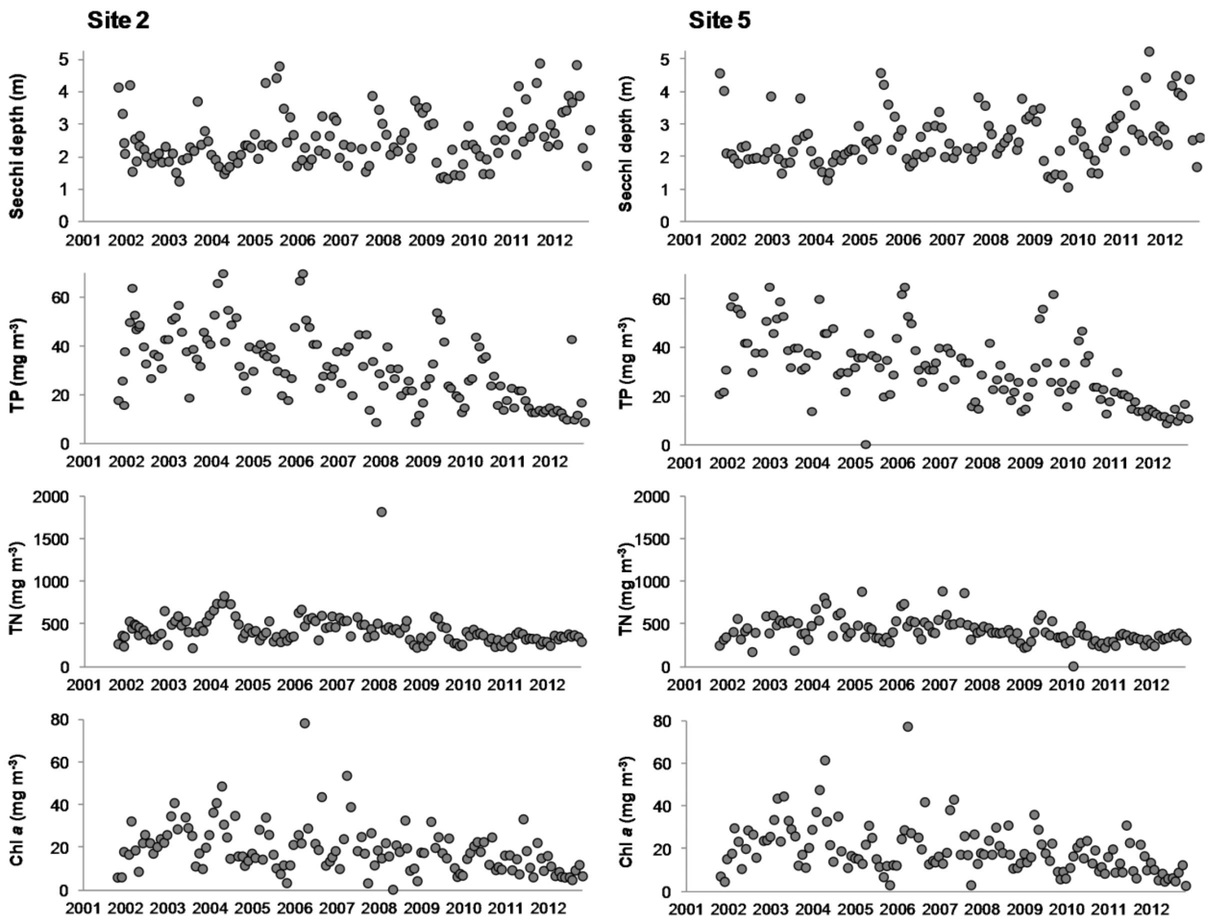

Figure 2.1 Raw data that comprise the common dataset used for trend analyses

Tables 2.1 and 2.2 present annual mean values and sample numbers for both monitoring locations. There is close agreement between data for the two sites.

Table 2.1 Summary of Site 2 data for TLI component variables

Year	Secchi depth (m)		TP (mg m^{-3})		TN (mg m^{-3})		chl *a* (mg m^{-3})	
	Mean	n	Mean	n	Mean	n	Mean	n
2002	2.26	14	43	14	418	14	21.2	12
2003	2.24	12	42	12	472	12	25.0	11
2004	2.02	12	45	12	576	11	25.3	12
2005	3.03	12	33	12	359	12	16.5	12
2006	2.44	12	42	12	524	12	26.9	11
2007	2.48	10	30	11	472	11	22.3	11
2008	2.76	12	23	12	506	12	15.3	12
2009	2.03	12	29	12	359	12	16.4	11
2010	2.35	12	28	12	335	12	16.4	12
2011	3.18	12	16	12	320	12	14.7	12
2012	3.25	10	15	10	334	10	7.6	10

Table 2.2 Summary of Site 5 data for TLI component variables

Year	Secchi depth (m)		TP (mg m^{-3})		TN (mg m^{-3})		chl *a* (mg m^{-3})	
	Mean	n	Mean	n	Mean	n	Mean	n
2002	2.21	11	49	11	409	9	22.2	11
2003	2.27	12	40	12	452	12	26.8	12
2004	1.98	12	38	11	554	10	28.2	11
2005	2.92	12	31	12	426	12	14.8	12
2006	2.38	12	41	12	501	12	27.3	11
2007	2.57	10	28	11	538	11	21.1	11
2008	2.78	12	25	11	376	12	18.9	12
2009	2.09	11	34	12	389	12	16.6	12
2010	2.44	12	28	12	291	12	15.5	12
2011	3.21	12	18	12	315	12	15.0	12
2012	3.35	9	12	10	336	10	6.8	10

3. LAKE ROTORUA WATER QUALITY TREND ANALYSIS (UNIVERSITY OF WAIKATO)

3.1 Overview of statistical approach used

Time series of ecological data can comprise three components: i) seasonality, ii) trend, and iii) irregular fluctuation from i and ii (Jassby & Powell, 1990). It is beneficial to first remove any seasonality present in time series before examining whether any trend is present.

Seasonality is present but relatively weak in the dataset for Lake Rotorua, reflecting the shallow polymictic nature of the lake and subsequent potential for isolated weather events to affect processes such as sediment resuspension and thermal stratification that can influence water quality. Nonetheless, there is tendency for poorer water quality in mid–summer to autumn and better water quality in winter and early spring (see chl *a* data for Site 2 as an example; Figure 3.1).

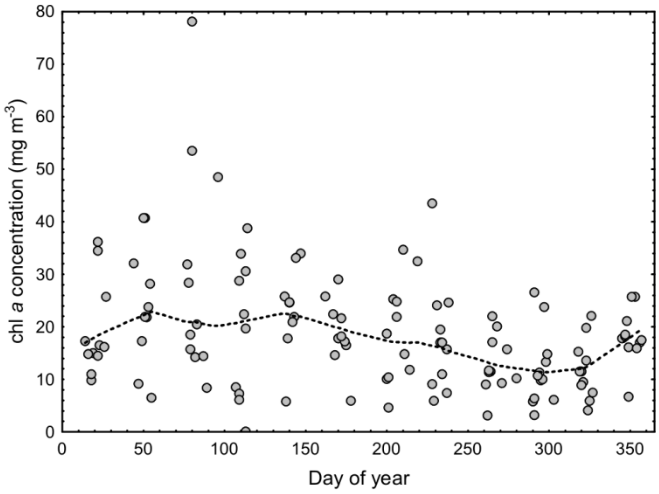

Figure 3.1 Relationship between chlorophyll *a* (chl *a*) concentration and day of the year for Site 2. Seasonal trend is delineated by fitting a Lowess curve (smoothing parameter = 0.25)

Due to the seasonality present, a seasonal Kendall test was chosen to analyse for the presence of trend in the four TLI component variables. This is a non–parametric test as the data did not conform to normal frequency distributions. The freely–available software 'Time Trends' (v. 3.31 2012) was used to apply the test. Aside from seasonal effects, no attempt was made to correct for further temporal autocorrelation that may be present in the data. This differs from some other approaches to time series analysis (e.g. Rutherford, 1984). This decision was justified based on the following:

- The objective was to determine trend within the period of record and not extrapolate beyond it (see McBride, 2005, p. 44).
- The temporal resolution of the data (c. 1 month) was deemed sufficiently coarse that any temporal autocorrelation could be disregarded.
- The effect of any temporal autocorrelation is to deflate (not inflate) the standard error of residuals (Ellis et al., 1989). Thus to not consider temporal autocorrelation is a conservative approach which was deemed appropriate given the resolution and extent of the data.

Annual TLI values were calculated for each site from 2002–2012 inclusively. Values were calculated as the average of each of the four TLI components (TLs, TLc, TLn, TLp) which in turn were calculated using annual mean values for each component variable and the equations presented by Burns et al. (2009). Values of TLI were not calculated for 2001 as the dataset only included the final three months of that year. Note also that the 2012 TLI value does not include data for November and December. It is important to note that, due to differences in methodology (e.g. non–inclusion of hypolimnetic samples), TLI values calculated in this study differ from those calculated for state of the environment reporting by Bay of Plenty Regional Council. Temporal trend in annual TLI was assessed for both sites separately using ordinary least squares regression. Trend was also calculated for annual TLI calculated as the mean of the TLI for each site. Regression was performed using Statistica v. 9 (StatSoft) and data met assumptions of the parametric test. A significance level of $p < 0.05$ was adopted for all inferential tests.

3.2 Anomalous data

A small number of anomalous values were identified in the common dataset (c. 0.4% of data; Table 3.1). These values were retained for both sets of analyses and the non–parametric Seasonal Kendall tests are insensitive to the presence of outliers. It is recommended that the identified values are checked against original laboratory reports to confirm whether errors have been introduced following reporting. If not, it is recommended that these values are removed from the permanent dataset.

Table 3.1 Anomalous data identified during analysis

Site	Date	Variable	Value (mg m^{-3})	Concern
2	23/03/2005	TP	0.5	Anomalously low value is < DRP concentration.
2	16/01/2008	TN	1810.5	Anomalously high value is inconsistent with concentrations of chl *a* and NO_3+NH_4.
2	22/04/2008	chl *a*	0.1	Anomalously low value is inconsistent with the measured chl *a* concentration at Site 5 on the same day (29.8 mg m^{-3}).
5	18/02/2010	TN	2.0	Anomalously low value is inconsistent with chl *a* concentration and < concentration of NO_3-N+NH_4-N.

3.3 Results

Results of the seasonal Kendall trend tests are presented separately for both sites in Table 3.2.

Table 3.2 Summary of the results of seasonal Kendall tests for TLI component variable data at Sites 2 and 5, October 2001–October 2012

Site	Variable	n	Median	Direction of linear trend	*Z*	*p*	Median annual Sen slope	Magnitude (% y^{-1})
2	Secchi (m)	127	2.35	Increasing	3.26	< 0.01	0.06	2.6
	TP (mg m^{-3})	128	31	Decreasing	-6.97	< 0.01	-2.73	-9.0
	TN (mg m^{-3})	127	384	Decreasing	-4.15	< 0.01	-13.91	-3.6
	chl *a* (mg m^{-3})	125	17.1	Decreasing	-4.80	< 0.01	-1.20	-7.0
5	Secchi (m)	125	2.38	Increasing	3.86	< 0.01	0.06	2.6
	TP (mg m^{-3})	125	31	Decreasing	-7.58	< 0.01	-2.54	-8.2
	TN (mg m^{-3})	123	391	Decreasing	-4.15	< 0.01	-13.78	-3.5
	chl *a* (mg m^{-3})	125	16.9	Decreasing	-4.79	< 0.01	-1.13	-6.7

Results for both sites showed good correspondence, reflecting the high degree of similarity between the sites (see Chapter 2). Statistically significant ($p < 0.01$) linear trends were present at both sites for all four TLI component variables. Secchi depth exhibited a linear increasing trend during the study period and concentrations of TN, TP and chl *a* exhibited a linear decreasing trend. The slope of the trend is approximated by the median annual Sen slope statistic and is relative to the units for each respective variable. This statistic can be expressed as a proportion of the median value of each variable to derive a measure of the magnitude of each linear trend, i.e. percentage change per year. Consequently, the magnitude of change in the four variables conformed to the order: Secchi depth (2.6%) < chl *a* (-7% to -6.7%) < TN (-3.6% to -3.5%) <TP (-9.0% to -8.2%).

Trophic Level Index at both sites exhibited a decreasing trend during the study period (Figure 3.2).

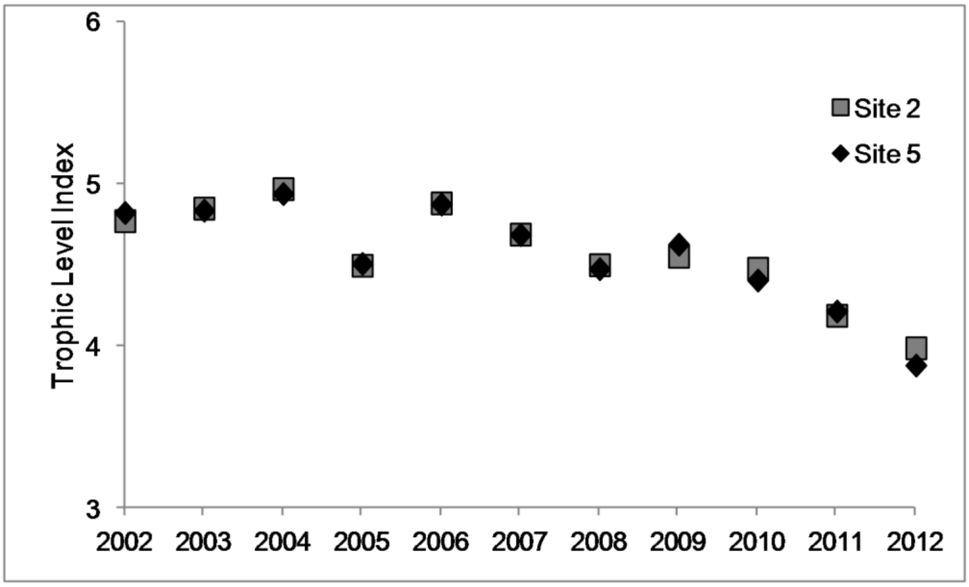

Figure 3.2 Annual Trophic Level Index values for Lake Rotorua based on integrated surface samples (0–6 m) collected at Sites 2 and 5, 2002–2012

The decreasing trend in TLI was statistically significant (p = 0.001) based on ordinary least squares regression (Table 3.3). Based on the slope of the regression lines, the rate of linear decrease for the whole study period was approximately 0.078 TLI units per year (based on TLI calculated using the mean of data for both sites).

Visual inspection indicated that the rate of this decrease was greatest for the period 2009–2012 inclusive. There was no statistically significant trend in TLI if only the years 2002–2008 inclusive were considered (Site 2: p = 0.22; Site 5: p = 0.14).

Table 3.3 Summary of TLI trend analysis, 2002–2012. Results relate to ordinary least squares linear regression. Results based on data for Site 2 and 5 are presented separately. In addition, results based on TLI calculated using the mean of annual TLI for both sites ('both') is presented

Site	10–year linear trend direction	Magnitude of linear trend (TLI units y^{-1})	r^2 (adjusted)	p
2	Decreasing	-0.075	0.67	0.001
5	Decreasing	-0.081	0.68	0.001
Both	Decreasing	-0.078	0.68	0.001

4. LAKE ROTORUA WATER QUALITY TREND ANALYSIS (DAIRYNZ)

4.1 Methods

Detailed descriptions of the methodology are provided in Appendix 4. To summarise, surface water (0-6 m depth) site-specific monitoring data on total nitrogen (TN), total phosphorus (TP), chlorophyll a (chl *a*) and Secchi depth (SD) were analysed by non-parametric approaches, involving:

1. Time-series decomposition into seasonal (average), trend (loess smoother) and random/unexplained components of the overall change in TLI parameters (Cleveland et al., 1990) in the statistical package 'R' using the 'stl' function of the 'stats' package;
2. Seasonal Kendall trend tests, to determine the direction, significance and relative magnitude of trends (Gilbert, 1987) in the statistical package 'TimeTrends' v.3.2, produced by NIWA in conjunction with Northland and Hawkes Bay Regional Councils for the analysis of hydrological time-series data (Jowett, 2011).

In steps 1 and 2, data remain in corresponding units of measurement (TN, TP, chl *a* = mg m^{-3}; SD = m). Both steps 1 and 2 are robust to the effects of outliers or anomalous samples, precluding the need to remove outliers from the dataset (Cleveland et al., 1990; Gilbert, 1987).

Step 1 decomposes a time-series (e.g., monitored information on chl *a*) into three cumulative data-series: (1) a replicated seasonal pattern determined from the data using a specified 12-month repetitive window; (2) a long-term loess-smoothed trend determined from observations that have had seasonal variation removed; and (3) a remainder or residual estimate of variance, unexplained by the loess smoother in (2) or the seasonal variation in (1). Output is graphical, to help demonstrate the periods of change in TN, TP, chl *a* and Secchi Depth (SD) within both sites (i.e., changes that do not correspond to a repetitive pattern of intra-annual or seasonal changes in nutrient cycling, algal biomass or water clarity). To meet a criterion of equi-distance in time, daily observations were averaged into monthly estimates of each TLI parameter, by site.

Step 2 offers precise estimates of the direction, magnitude and statistical significance of changes observed in TN, TP, chl *a* and SD at both Sites 2 and 5. Relative measures (%) of per annum change in each of these parameters are provided (i.e., relative seasonal Kendall estimates [RSKE] [Gilbert, 1987]). Samples were entered as daily observations that yielded monthly medians in 'TimeTrends'.

Combined, steps 1 and 2 provide graphical and statistical measures of change to TLI parameters for each site, highlighting the periods of greatest likely water quality change during the past 11 years at Lake Rotorua.

4.2 Results

4.2.1 Time-series decomposition

Average monthly, surface water (0-6 m) estimates demonstrated similar seasonal profiles shared by chl *a*, TP and TN in both sites 2 and 5 (Figures 4.1, 4.2). Seasonal minima in the latter occurred during the austral summer, bracketed by higher concentrations during the austral spring and autumn. Seasonal variation in SD is anti-phased with changes to nutrients (i.e., peaks in water clarity occurred during periods of reduced nutrient concentration and algal biomass). Removal of seasonal variation, demonstrated marked long-term variability in each parameter (Figures 4.1, 4.2). Long-term trends appear highly similar between sites for each parameter, and between changes in nutrient concentrations (TN, TP) to algal biomass (chl *a*). Long-term improvement in water quality is evident in declining concentrations of TP, TN and chl *a* since c.2003 (albeit interrupted by a peak in abundance amongst the three parameters c.2006). Prior to c.2003, concentrations of TN, TP and chl *a* were rising. Long-term trends in SD are more complex involving anti-phased minima during peak algal biomass and nutrient concentrations (c.2003 and c.2006), followed by improvement to greater clarity since c.2009.

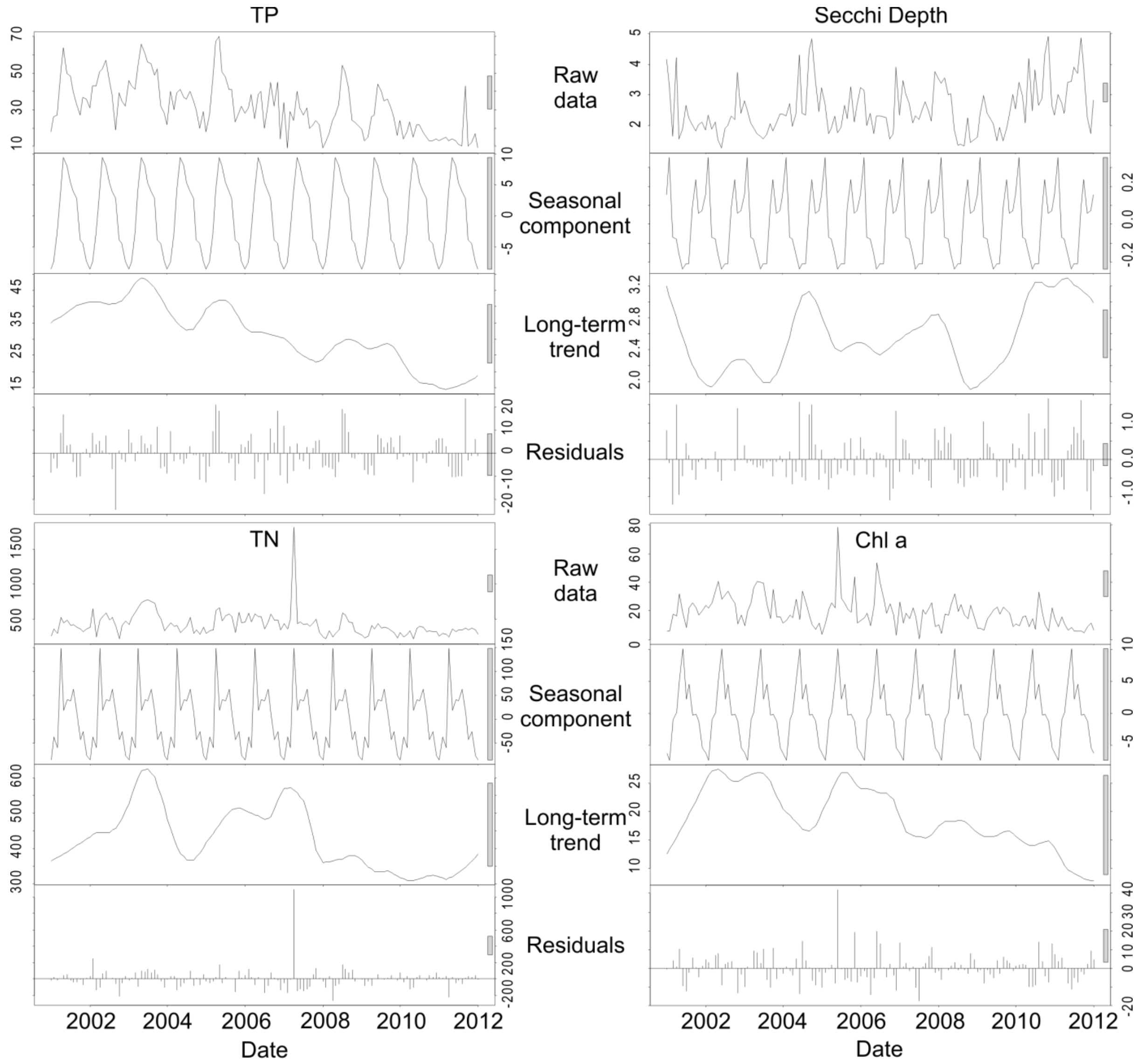

Figure 4.1 Decomposed time-series components for site 2 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by the seasonal component (12-month period), long-term trend (loess smoothed) and residuals in corresponding units

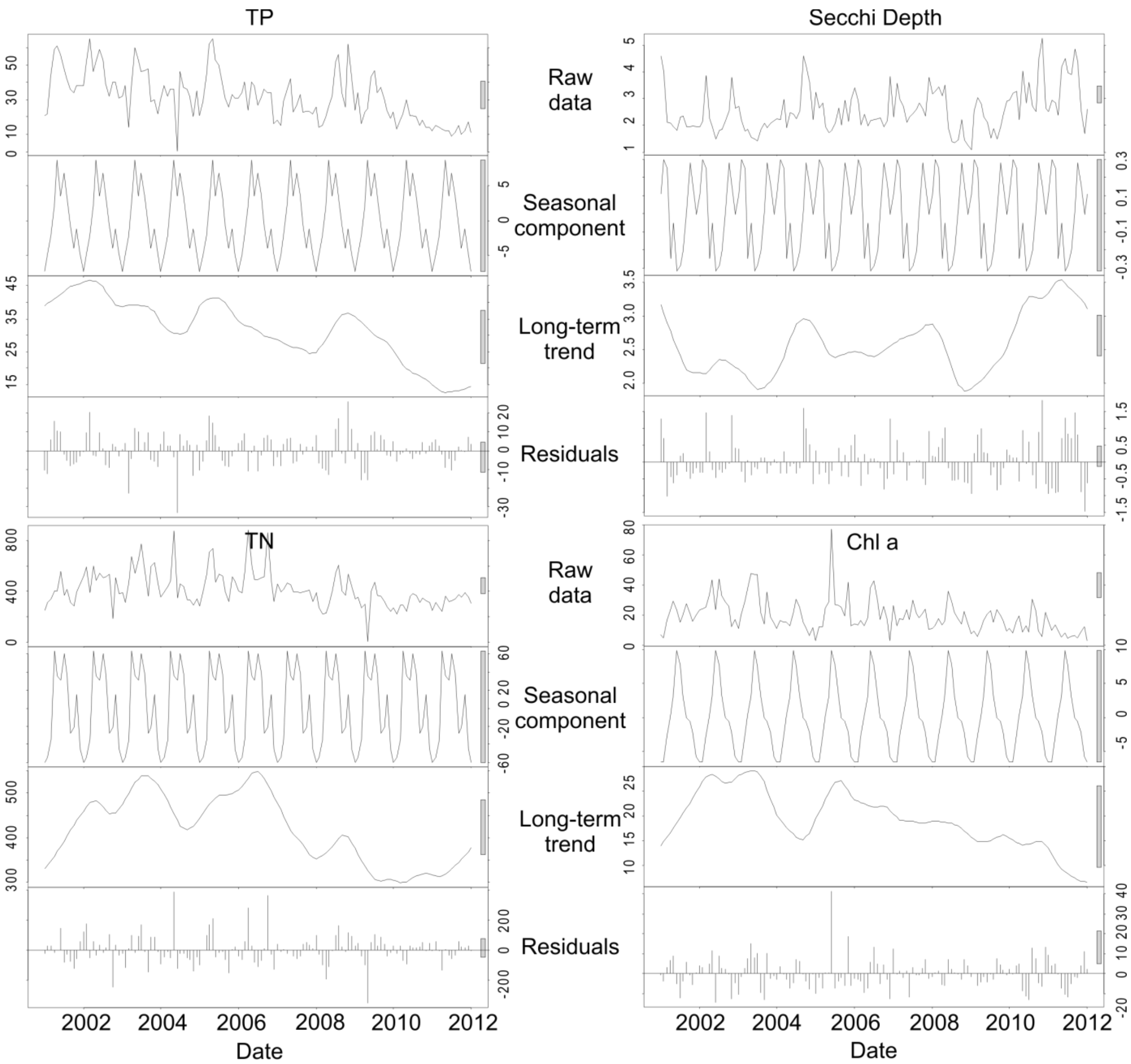

Figure 4.2 Decomposed time-series components for site 5 amongst TLI parameters for the period 17/10/2001-17/10/2012 (units: TP, chl *a* and TN = mg/m^{-3}; Secchi depth = m). Daily observations of surface water quality (0-6 m depth) are plotted as the uppermost graph of each TLI parameter, followed by the seasonal component (12-month period), long-term trend (loess smoothed) and residuals in corresponding units

4.2.2 Trend analysis

Seasonal Kendall trend test results are presented in Tables 4.1, 4.2. These confirm the similarity of changes observed in TLI parameters between sites, through the similarity of SKSE and RSKE statistics (median and relative Kendall slope estimates respectively). This reinforces the results presented in *Section 4.2.1.*, for highly similar seasonal and long-term trends in TN, TP and chl *a* between sites, anti-phased to SD.

At each site, highly significant (p<0.001), ecologically meaningful (>1% [Jowett, 2001]), changes are recorded in all TLI parameters. These confirm that long-term improvements in each parameter have occurred in surface water at Lake Rotorua since October 2001 (i.e., direction of changes are to greater SD, and lower TP, TN and chl *a*). When adjusted for temporal autocorrelation (i.e., failure to observe short-term data independence), only declining trends in TN are greatly affected at each site, albeit remaining significant at p<0.05. However, the magnitude of observed change in TN, limits the likelihood of between-season serial correlation (note: the choice of starting season can also have substantial effect on adjusted *p*-values [Hirsch and Slack, 1984]). Thus, unadjusted *p*-values are likely to be robust measures of statistical significance in each TLI parameter and indicate significant long-term improvement to water quality across all four parameters, at each site.

The relative magnitudes of change in TLI parameters, observed at each site, also support the above interpretations for long-term improvements in water quality. For instance, a ~9.0% and ~8.2% reduction in TP occurred (values refer to per annum changes on median concentrations at sites 2 and 5 respectively, for the period 17/10/2001 to 17/10/2012). A similar magnitude of reduction in chl *a* also occurred, by ~7.0% and ~6.7% per annum. The concentration of TN also decreased but by a lesser magnitude (~3.6% and ~3.5%). Likewise, SD improved during this period by ~2.6% at both sites. Importantly, greater reductions in TP relative to TN at both sites, resulted in highly significant ($p<0.001$) trends for rising TN:TP ratios (~6.3% and ~6.1% per annum), with median and average ratios in excess of 17 during the past two years.

Table 4.1 Seasonal Kendall trend test results for site 2 (RSKE = magnitude [per annum % change on annual median for 17/10/2001-17/10/2012])

Site 2	*Median value*	*Kendall stat (Sk)*	*Variance*	*Z*	*Direction of trend*	*P*	*P-adj*	*Median annual Sen slope (SKSE)*	*Magnitude (% yr^{-1}) (RSKE)*
TP	30.5	-299	1825.67	-6.9744	Decreasing	<0.001	0.0032	-2.7344	**-8.9653**
chl *a*	17.1	-200	1716.67	-4.803	Decreasing	<0.001	0.006	-1.2016	**-7.0269**
TN:TP	13.8846	265	1801.67	6.2197	Increasing	<0.001	0.004	0.8798	**6.3365**
TN	384	-177	1799.67	-4.1487	Decreasing	<0.001	0.0544	-13.9143	**-3.6235**
Secchi	2.35	143	1789.00	3.3572	Increasing	<0.001	0.0296	0.0614	**2.6128**

Table 4.2 Seasonal Kendall trend test results for site 5 (RSKE = magnitude [per annum % change on annual median for 17/10/2001-17/10/2012])

Site 5	*Median value*	*Kendall stat (Sk)*	*Variance*	*Z*	*Direction of trend*	*P*	*P-adj*	*Median annual Sen slope (SKSE)*	*Magnitude (% yr^{-1}) (RSKE)*
TP	31	-315	1715.67	-7.5808	Decreasing	<0.001	0.0016	-2.5382	**-8.1878**
chl *a*	16.9	-201	1741.00	-4.7933	Decreasing	<0.001	0.0133	-1.1333	**-6.7059**
TN:TP	13.25	210	1608.00	5.212	Increasing	<0.001	0.0143	0.8099	**6.1125**
TN	391	-169	1641.00	-4.1472	Decreasing	<0.001	0.0536	-13.7844	**-3.5254**
Secchi	2.38	161	1721.67	3.8561	Increasing	<0.001	0.0193	0.0626	**2.6303**

5. CONCLUSIONS

Analysis was undertaken of trends in Lake Rotorua water quality for the period October 2001 – October 2012. The analysis focused on the Trophic Level Index (TLI) and the four constituent variables: Secchi depth (a measure of clarity) and concentrations of total nitrogen (TN), total phosphorus (TP) and chlorophyll *a* (chl *a*). Analyses were undertaken separately by scientists affiliated with the University of Waikato and DairyNZ using a common dataset provided by Bay of Plenty Regional Council. The dataset was based on integrated surface water (0–6 m) samples collected at approximate monthly frequency from two monitoring sites. The large number of samples and high degree of correspondence between data for the two sites suggests that the dataset was appropriate for examining broad–scale temporal variability in water quality of this large lake.

Both parties adopted very similar approaches to the analysis and the methodologies used to examine trends in TLI component variables. Consequently, the following conclusions were shared by all authors:

- There has been a relative decrease in the Trophic Level Index of Lake Rotorua during the discrete study period. There has been a linear increase in Secchi depth, and linear decreases in the concentrations of TN, TP and chl *a,* all of which are statistically significant (p<0.001).
- The similarity in direction, magnitude and statistical significance of long-term trends of TLI parameters between both monitoring sites underscores the likelihood of basin–wide improvements in water quality within Lake Rotorua since c.2001.
- Total phosphorus concentrations exhibited the greatest relative change at both sites during the period (-9.0% and -8.2% per annum changes to median values since c.2001, at sites 2 and 5 respectively). Reductions in chl *a* concentration were of similar magnitude (-7.0% and -6.7%). Relative reductions in TN concentrations (-3.6%, -3.5%) and Secchi depth were more moderate (+2.6%, +2.6%).
- These changes have resulted in statistically significant ($p < 0.001$) linear reductions in annualised TLI over the study period.
- Since c.2001, greater reductions in TP concentration relative to TN concentration have resulted in highly significant ($p < 0.001$) increases in the mass ratios of TN:TP of surface waters (0-6 m depth; +6.3% and +6.1%).

This study has not considered the underlying causes of the trends that have been identified.

6. REFERENCES

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APPENDIX 1: BACKGROUND INFORMATION ABOUT ALUM DOSING FOR THE STUDY PERIOD

Alum (potassium aluminium sulphate) dosing is used to adsorb dissolved phosphorus from the Utuhina and Puarenga Streams and remove it from the water column of Lake Rotorua. Alum dosing was initiated in the Puarenga Stream in 2007 and in the Utuhina Stream in 2010. (Figure A1).

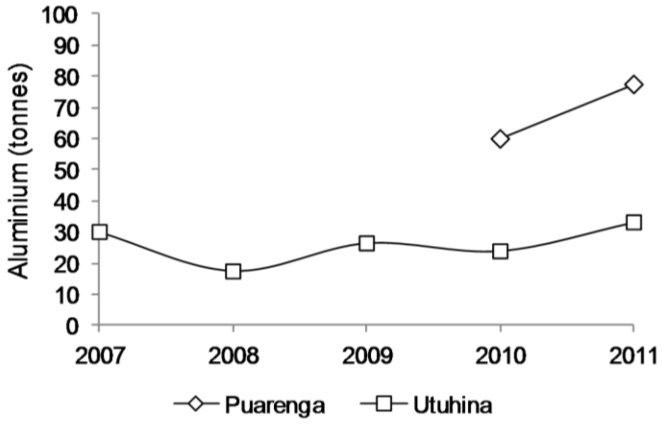

Figure A1 Mass of aluminium applied to the Utuhina and Puarenga streams, 2007–2011. Data were presented at a Rotorua lakes Statutory Group meeting, 4/4/2012

APPENDIX 2: RECORD OF MEDIATION, 21 NOVEMBER 2012

Record of Mediation between parties at mediation at Rotorua on Wednesday 21 November 2012.

(1) The parties heard from Professor David Hamilton for the Regional Council and Dr Tom Stephens for DairyNZ on water quality issues. Those experts have agreed to meet to see if agreement can be reached on the common data set and its scope for further modelling purposes.

(2) The experts shall prepare a report as to the outcome of the meeting and circulate the report to all parties by Friday 21 December 2012. The report shall also be provided to the Regional Council's Technical Advisory Group for consideration.

(3) On receipt of the report, any suggested amendments by parties to ~~Policy~~ policies WL5 + WL6B (amended version as tabled by Regional Council at this mediation) shall be referred back to RPS Appeals Sub Committee for consideration, prior to any further mediation. The parties shall be advised of the Committee's response.

(4) The parties will advise the Court whether further mediation is required in early March 2013.

[signature] Bay of Plenty Regional Council

[signature] Federated Farmers

[signature] DairyNZ Oliver Parsons

Lachlan McKenzie

[signature] Rotorua Primary Producers Collective

[signature] Fonterra Cooperative Group Ltd
I JOHNSON

APPENDIX 3: AGREED PROCEDURE FOR LAKE ROTORUA WATER QUALITY ANALYSIS: COMMON DATA SET

A meeting was held between representatives from DairyNZ (Tom Stephens) and the University of Waikato (Jonathan Abell, Deniz Özkundakci and Chris McBride) on 22 November 2012. Agreement was reached regarding the dataset to be used as the basis for analysis of trends in Lake Rotorua water quality. The results of this analysis are due to be presented in a report by 21 December 2012, as agreed during the mediation meeting held on 21 November 2012.

All agreed to the following:

- Separate analyses will be undertaken for each of two sampling sites: 'Site 2' and 'Site 5'.
- Analysis will be undertaken of trends in time for the following variables: total phosphorus concentrations, total nitrogen concentrations, chlorophyll *a* concentrations, Secchi depth and annual Trophic Level Index (TLI).
- Data pertaining to the following period will be analysed: October 2001 – October 2012. This represents the most recent period for which data are available continuously at approximately monthly intervals.
- Analysis will focus on using data relating to surface integrated samples collected from a depth of 0–6 m and only these data will be used for TLI calculations. This decision reflects the desire to ensure consistency in sampling protocol for all data and potential uncertainty related to classifying whether the polymictic lake is 'stratified' or 'mixed' during each sampling event. It is noted that this approach therefore differs from the approach outlined in Burns *et al.* (1999) and may differ from the approach used in other studies of the lake.
- Calculation of TLI will use annual means of data. Calculation of TLI on a monthly basis has the potential to be misleading.
- Calculation of TLI will be undertaken using the equation for TL_s (the Secchi depth component) given in Burns *et al*. (1999).

Reference

Burns NM, Rutherford JC, Clayton JS (1999) A monitoring and classification system for New Zealand lakes and reservoirs. *Journal of Lakes Research & Management* 15, 225-271.

APPENDIX 4: METHODOLOGIES EMPLOYED BY DAIRYNZ FOR TREND ANALYSIS OF AGREED DATASET

Decomposition of trends were performed in R, using the non-parametric stl() regression function (Cleveland et al., 1990), specifying the start and finish of the time-series as well as the frequency (12-monthly). Linear interpolation was employed to generate data for at most 9 of the total 120 months, in any parameter [see Table A1]). The function generates a monthly mean for the series (i.e., all January values) and repeats this for all months before generating variance about the monthly means, which is used to generate the magnitude of changes attached to between-month mean observations. This is the seasonal component (S_t), and is removed from the data series (X_t) before the remainder is smoothed with loess regression to find the underlying inter-annual trend (T_t). Irregular residuals are the differences from X_t-(S_t+T_t). The approach is limited by the underlying assumption that samples were taken at equispaced points in time. Averaging to monthly resolution alleviates this criterion.

Table A1. Number of interpolated samples in each series of 120 observations for chl *a*, TP, TN and SD from 17/10/2001-17/10/2012 (simple linear equation)

Interpolation *n*	TP	TN	chl *a*	SD
Site 2	5	6	8	6
Site 5	8	9	7	6

4.2 Trend Analysis

Trend analysis was carried out on daily observations using TimeTrends v.3.20 (Jowett, 2011), a software package developed by NIWA for trend analysis of hydrologic data. The Seasonal Kendall Slope Estimator (SKSE) test was chosen as it can handle non-parametric distributions, calculating season (month) specific Mann-Kendall S-statistics. The Sen slope (SKSE) is the median slope of all possible pairs of variable values in each season (expressed in units of the variable, standardised to a year [i.e., the Sen slope is the median annual slope per season, or month]). Division of SKSE values by the variable median, yields relative change in a variable per annum that can be compared between sites (Gilbert, 1987). Note: when the product of the number of seasons (12) by the number of years (11) is greater than 25 (132 – values in brackets correspond to this study), than Kendall's Sk statistic will be zero in the absence of a trend, positive in an increasing trend, and negative in a decreasing trend. Furthermore, Hirsch and Slack (1984) demonstrated that the presence of serial autocorrelation (dependence of subsequent variable values upon preceding values), violates the assumption of data-independence, and adjusted the significance routine accordingly. The P-adj. value is therefore a more conservative estimate of whether the Sk statistic is significantly different from zero (i.e., whether the Sk statistic implies a trend) but should only be used where sufficient temporal autocorrelation is expected (e.g., >10 years).