Water quality trends at NRWQN sites for the period 1989-2007

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Executive Summary

The National Rivers Water Quality Network (NRWQN) has now been running for 20 years, having started monitoring in January 1989. Ministry for Environment wished to update analyses of water quality trends based on the NRWQN (that were last investigated by Scarsbrook (2006) for the 15-yr period 1989-2003 inclusive), and contracted NIWA for this task.

Quality-assured NRWQN data is currently available for the 19 years up to the end of 2007. Data for 20 years, up to the end of 2008, is *not* yet available because it takes considerable time to complete analyses on frozen samples, and to run crucial quality assurance checks on the data. Therefore, the trend analyses reported are for the 19 yr period: 1989-2007 inclusive. We used **Time Trends**, developed in-house by Ian Jowett, ex-NIWA, in contrast to the USGS software, S-ESTREND, that was used earlier. We examined eight variables: temperature, dissolved oxygen, visual clarity, and five forms of nutrients. However we chose not to consider ammoniacal-N because trends in this variable appear to be to some extent spurious owing to contamination issues in the laboratory that were fairly severe prior to 1995 when a new laboratory was commissioned.

In this second edition of the report we have used TimeTrend V3 with high precision trend parameters and a revised data set, thus eliminating some (spurious) zero trends and improving the precision of the trends for all water quality variables as reported in the first edition based on use of TimeTrend V2. While this has led to small changes in trend strength for some water quality variables, trend directions are still the same, and the overall picture remains one of water quality deterioration.

For the 19-yr period (1989-2007 inclusive), we found similar overall trends in water quality to those reported by Scarsbrook (2006), with trends all in the same direction. While some of the trends have weakened or decreased in magnitude (for dissolved oxygen and dissolved reactive phosphorus), upwards trends strengthened for temperature, total nitrogen, total phosphorus, oxidised nitrogen and visual clarity. We found that, consistent with Scarsbrook (2006), temperature and dissolved oxygen had few “meaningful” trends, and that trends at the national level were not significant, although a slight upwards trend in temperature is now approaching ‘significance’ at the 5% level. Similar to Scarsbrook (2006), there was a significant increase (i.e., improvement) in visual clarity at the national scale. There was, however, a *negative* correlation between visual clarity and % pasture in catchments (implying that soil erosion on pastoral land mobilises light attenuating fine sediment) which suggests that the increasing area and intensity of pastoral agriculture may compromise visibility in the future.

There were increasing overall trends in total phosphorus and in dissolved reactive phosphorus. The trend in total phosphorus was stronger than was observed by Scarsbrook (2006), while the trend in dissolved reactive phosphorus was weaker. There were also overall increasing trends in oxidised nitrogen and total nitrogen, similar in magnitude to those observed for the 1989-2003 time period. All of these increasing trends indicate deteriorating water quality mainly attributable to expansion and

intensification of pastoral agriculture. The current analysis confirms Scarsbrook's (2006) key finding that environmental gains in terms of reduced 'point' pollution of waters in New Zealand are being overshadowed by increasing 'diffuse' pollution.

We examined flow-adjusted data for 6 variables, visual clarity and forms of nutrients (for which Scarsbrook found "meaningful" trends for each of the 77 sites), for recent changes in the direction or magnitude of trends within the whole 19-year period. There were strong downwards trends in ammoniacal nitrogen particularly at low concentration 'baseline' sites, suggesting these 'trends' are probably an artefact (as mentioned earlier). Otherwise, only a few of the 462 resulting plots showed patterns of particular interest, and a selection are displayed in this report. For example, NRWQN site CH4 on the lower Waimakariri River near Christchurch shows a recent rapid upswing in both total nitrogen and oxidised nitrogen.

1. Introduction

The National River Water Quality Network (NRWQN) is New Zealand's most comprehensive freshwater quality monitoring network, although it is now increasingly augmented by regional monitoring conducted by Regional Councils. The NRWQN consists of monthly visits to 77 river sites on 35 rivers that are geographically well spread over both main islands of New Zealand and drain about one half of the nation's landscape (see Smith & McBride (1990) for a description and maps). All NRWQN sites are located at, or close to, hydrometric stations from which flow is estimated for each sampling visit. Measurements are made of: *dissolved oxygen*, pH, conductivity, *temperature*, *visual clarity*, turbidity, coloured dissolved organic matter, and different forms of the major nutrients nitrogen (N) and phosphorus (P) (nitrate-N, total-N, ammoniacal-N, dissolved reactive-P and total-P)—*italicised text* indicates *field* measurements, other measurements are made in the laboratory.

The NRWQN is now 20 years old, having commenced monitoring in January 1989. At the time of writing a full 19 years of water quality data was available for analysis (up to December 2007 inclusive). Several formal trend analyses of the NRWQN data have been conducted (usually at 5-yr intervals), broadly following the approach of Smith et al. (1996). The most recent trend analysis was that of Scarsbrook (2006) for the 15 year record: 1989-2003. The Ministry for Environment (MfE) contracted NIWA to update the formal trend analysis for the 19 year period: 1989-2007 for use in national state of environment (SoE) reporting.

This report presents the findings from formal statistical trend analysis, and addresses four main areas of assessment (Table 4). The methods as outlined in the next section of this report were tuned to address each of these areas of assessment. Note also that the "Deliverables" envisaged a draft report for electronic review by MfE, followed by a final report together with electronic access to summary data needed for an eventual MfE state of environment publication. The present report has undergone several stages of review, including external review arranged by the client, with revisions at each stage.

Our report follows the broad approach of Scarsbrook (2006) for formal trend analysis and repeated repeats many of the analyses reported therein. In particular we compare findings for the 19 yr (1989-2007) dataset with those reported by Scarsbrook (2006) for the 15 yr (1989-2003) datasets.

2. Methods

The brief from MfE identifies four main areas of assessment. The methods were designed to address each of these areas of assessment in turn as outlined below.

As specified in the brief (Table 4) trend analysis was applied to the variables covered in Project 1 (except for *E. coli* because this has only been measured since 2005), namely five forms of the nutrient elements nitrogen and phosphorus, plus dissolved oxygen and water temperature. Visual clarity, which had been omitted from the original list, was also added, giving us eight variables in all. The variable list was identical to that of Scarsbrook (2006), except for the exclusion of conductivity and pH. We may note that Scarsbrook found "meaningful" trends (increases) in conductivity at only two sites and no "meaningful" trends in pH (where "meaningful" trends are defined as 'statistically significant' trends of magnitude greater than 1% change per year in either direction). We also chose to omit ammoniacal nitrogen after it became apparent that this variable has been subject to laboratory contamination which has been progressively controlled over time, causing a (spurious) downwards trend at low concentration sites (Section 3.1.6 below).

Our approach to formal trend analysis of NRWQN data broadly followed the approach and methods of Scarsbrook (2006), which, in turn, derives from Smith et al. (1996). However, trend analysis of the NRWQN data was conducted using NIWA-developed **Time Trends** software (http://www.niwa.co.nz/ncwr/tools), in contrast to the S-ESTREND software developed by the USGS (Slack et al. 2003) used by Scarsbrook (2006).

2.1 Calculation of individual trends

The trend analysis involved firstly, flow adjustment of the data for each variable at each site, followed by trend analysis accounting for any seasonal pattern. Flow adjustment is necessary because most water quality variables are subject to either dilution (decreasing concentration with increasing flow, e.g., conductivity) or land runoff (increasing concentration with increasing flow, e.g., total phosphorus). Flow adjustment was performed using LOWESS (LOcally WEighted Scatterplot Smoothing; nested within Time Trends) with a 30% span. This allowed us to detect the overall flow-trend of all the data for each variable at each site. Every data-point in the record was then adjusted depending on the value of flow as outlined by Smith et al. (1996): adjusted value = raw value – smoothed value + median value (where the "smoothed value" is that predicted from the flow using LOWESS).

Flow-adjusted variables were plotted (together with raw data) versus time in order to visually examine trends with time, particularly trends within the 19-yr time span 1989-2007 inclusive. We only plotted the six variables that Scarsbrook (2006) reported to have 'meaningful' long-term trends (see definition below): visual clarity and five major forms of the nutrients nitrogen and phosphorus. Water temperature and DO were not examined since they showed small trends, most of which were not significant, let alone meaningful. This still resulted in our having to archive 462 time series plots (6 variables x 77 sites = 462). Only a very small fraction of these plots are presented below (Figure 3 - Figure 28), mainly those for which interesting changes in trends are visually detectable over the last four years since Scarsbrook's (2006) analysis of the 1989-2003 data.

The formal trend analysis was applied to the whole 19-yr dataset (1989-2007 inclusive). As in previous work following Smith et al. (1996), the non-parametric Seasonal Kendall Slope Estimator (SKSE) was used to represent the magnitude and direction of trends in flow-adjusted data that were often subject to appreciable seasonality. Values of the SKSE were normalised by dividing through by the raw data median to give the *relative* SKSE (RSKSE), allowing for direct comparison between sites measured as % change per year. The RSKSE may be thought of as an index of relative rate of change. A positive RSKSE value indicates an overall increasing trend, while a negative RSKSE value indicates an overall decreasing trend. The SKSE calculations were accompanied by a Seasonal Kendall test (performed within **Time Trends**) of the null hypothesis that there is no monotonic trend. If the associated P-value is small (i.e., $P < 0.05$), the null hypothesis can be rejected (i.e., the observed trend, either upwards or downwards, is most unlikely to have arisen by chance).

In the first edition of this report, some trend parameters were reported as zero as a result of the analyses being done (using TimeTrend V2) with insufficient precision. In this second edition we have repeated the trend analyses (using timeTrend V3 and a revised data set) with a greater degree of precision using more decimal places. As a result there are some small changes in detail (hence the need for this new edition of the report).

2.2 Determination of national scale trends

Overall, significant national increasing or decreasing trends in water quality variables were determined using the RSKSE values for each water quality variable and a one-tailed binomial test to assess whether or not there was a statistically significant trend in a particular direction. For example, in the event that there are 45 sites from 77 with a positive RSKSE value, the one-tailed binomial test will determine whether or not there is a statistically significant trend in a positive direction. A P value of less than 0.05 ($P < 0.05$) indicates a significant trend in either a positive or negative direction. This test can be used to determine significant positive or negative trends within datasets, and for this study, was based on the total number of positive and negative RSKSE values. The overall median RSKSE value is also a measure of the direction of the national trends. A positive median RSKSE value indicates an increasing trend, while a negative median RSKSE indicates a decreasing trend. Results from this analysis are presented in Table 1.

2.3 Statistical level of significance

All statistics are reported at the 95% confidence level (i.e., $P < 0.05$).

2.4 Period of record

The trend assessment has been conducted on the entire (19-yr) dataset for the period 1989-2007 inclusive. NRWQN data for much of 2008 were still not available at the time of report preparation.

2.5 Trends or patterns within the overall period

The brief calls for an assessment of trends within the overall trend period (1989-2007) that might be masked by application of formal trend analysis to the whole period. Application of formal trend analysis to different periods of record on a site- and variable-specific basis could be done of course, but choice of time periods for analysis is necessarily subjective and it would be difficult to compare trend parameters for different periods. Instead we chose to address this requirement by simply plotting flow-adjusted data versus time for selected variables (those variables for which Scarsbrook found a high proportion of sites with “meaningful” trends: visual clarity and five forms of nutrients). Where there appeared to be a trend in the data within the overall period of record (1989-2007) (in practice only for a few variable-site combinations) we comment on the trend.

2.6 Comparison with Scarsbrook’s (2006) trend analysis (1989-2003)

Before comparing Scarsbrook’s findings for 1989-2003 with ours for 1989-2007 we considered it important to check that the **Time Trends** software returned virtually the same values of the SKSE given by S-ESTREND software (used by Scarsbrook 2006). Accordingly, we truncated our 1989-2007 datasets at the end of 2003 (so re-creating

Scarsbrook's (2006) datasets) and re-ran the flow adjustment and calculation of the SKSE for six variables shown by Scarsbrook (2006) to have a high proportion of "meaningful" trends (visual clarity and five forms of nutrients).

Our SKSE values were plotted versus those of Scarsbrook showing very good overall agreement (high r^2 values with regression fits through 0,0 and close to the 1:1 line of perfect agreement) (Appendix 1, Figure 3).

Having shown that **Time Trends** returned trend parameters very close in magnitude to S-ESTREND we felt confident in comparing Scarsbrook's (2006) findings for 1989-2003 with ours for 1989-2007 using different software. Rather than plotting categories of trends on maps showing site locations (as done by Scarsbrook, 2006), we chose to tabulate trend parameters. RSKSE and associated *P*-values for each variable are presented in the appended table, colour-coded as to trend category (Table 5), with sites listed North-to-South. Sites are identified as being either 'baseline' (32 sites) or 'impact' (45 sites) (Smith & McBride 1989) also by colour coding. 'Baseline' sites are likely to have no or little diffuse or point source pollution and should therefore be near-natural, while 'impact' sites are downstream of areas of agriculture, forestation, industry and urbanisation (Smith & McBride 1990). It should be noted that 10 of the 32 'baseline' sites are 'pseudo-baseline', which are the best available baseline sites for a catchment or area and are presumably lightly impacted (e.g., by low intensity pastoral agriculture).

Scarsbrook (2006) gave summary box plots of the RSKSE values for each variable for 1989-2003. A similar figure for 1989-2007 was prepared for this report (Figure 1) to compare the distributions of RSKSE values with those of Scarsbrook (2006), both graphically and in terms of tabulated overall median RSKSE (% year^{-1}).

To assist in interpretation of the trends, we were interested in how pastoral land, as a proportion of catchment area, affects the water quality variables. The % pasture in NRWQN catchments based on 1997 data from the Land Cover Database via MfE, SKSE and RSKSE values were correlated with the median water quality values for each site for 2007 using the non-parametric Spearman rank test for comparison with a similar analysis carried out by Scarsbrook (2006), results of which are presented in Table 3. It was considered appropriate to use the 1997 Land Cover Database for comparison in this analysis as it provided a reference point which was midway through the period being examined. The 1997 database had also been used for the earlier analysis, therefore its further use in this study permitted comparison with the analysis completed by Scarsbrook (2006).

2.7 Categorisation of trends

Scarsbrook (2006) recognised that statistical significance of a trend (particularly with a large dataset of up to 228 (19 x 12) data points for each combination of site and variable in the NRWQN over the 1989-2007 period) does not necessarily imply a 'meaningful' trend, i.e., one that is likely to be relevant in a management sense. We have followed Scarsbrook (2006) in denoting a 'meaningful' trend as one for which the RSKSE is statistically significant and has an absolute magnitude > 1% year^{-1}. The 1% change is not merely a convenient round number that is otherwise arbitrary. A 1% change per annum corresponds to 10% change per decade – a degree of change that is likely to become noticeable or detectable to water users and casual observers within a human lifespan. Trends were accordingly categorised as follows:

i. **no significant change** – the null hypothesis for the Seasonal Kendall test **was not** rejected (i.e., $P > 0.05$);

ii. **significant increase/decrease** – the null hypothesis for the Seasonal Kendall test **was** rejected (i.e., $P < 0.05$). Note that the trend at some sites may be 'significant but not meaningful';

iii. **'meaningful' increase/decrease** – the null hypothesis for the Seasonal Kendall test was rejected (i.e., $P < 0.05$) **and** the magnitude of the trend (SKSE) was greater than one percent per annum of the raw data median (i.e., the RSKSE value was greater than 1% year^{-1}).

Scarsbrook (2006) recognised that the choice of 1% year^{-1} as the "meaningful" threshold is arbitrary, but at this stage we do not see any basis for an alternative approach. The trend parameters are colour-coded to indicate the above categories in the summary table (Table 5).

3. Results

3.1 Overall trends

The appended table (Table 5) collates all the Relative Seasonal Kendall Slope Estimators (RSKSE) and associated *P* values for seven water quality variables by 77 NRWQN sites. (RSKSE's were calculated for ammoniacal-N, but are not given in Table 5 or elsewhere in this report, since downwards trends in this variable appear to be an artefact reflecting progressive control of laboratory contamination (Refer Section 3.1.6 below). Full names and location details of the sites are provided in Table 8. Both the magnitude of the trend (RSKSE) and its significance, as indicated by *P* value, are important, and were used to categorise trends as being 'significant but not meaningful' or 'meaningful' following Scarsbrook (2006). The different variables are considered in turn below.

Information on the numbers of NRWQN sites in the different trend categories is presented in Table 1. Within these trend categories, the total number of sites (T) has been divided into baseline (B) and impact (I) sites. Also presented are national trends at the 95% significance level, determined by use of the binomial test, based on the total number of sites with positive and negative trends (RSKSE values).

Table 1: Summary of water quality trends at NRWQN sites. **(**I = Impact B = Baseline T = Total).

Water quality variable	Upward trend							Downward trend							National trend (Determined by the binomial test)
Impact/Baseline/Total	Significant upward trend	Significant but not meaningful			Meaningful			Significant downward trend	Significant but not meaningful			Meaningful			
		I	B	T	I	B	T		I	B	T	I	B	T	
Temperature	**14**	8	5	**13**	0	1	**1**	**7**	3	4	**7**	0	0	0	No significant increase *(P = 0.085)*
% Dissolved Oxygen	**15**	5	10	**15**	0	0	**0**	**23**	14	9	**23**	0	0	0	No significant change *(P = 0.82)*
Visual Clarity	**27**	1	1	**2**	16	9	**25**	**11**	0	1	**1**	9	1	**10**	Significant increase *(P =0.00004)*
Dissolved Reactive Phosphorus	**26**		1	**1**	18	7	**25**	**9**	0	2	**2**	5	2	**7**	Significant increase *(P = 0.006)*
Total Phosphorus	**23**	2	1	**3**	11	9	**20**	**9**	0	1	**1**	6	2	**8**	Significant increase *(P = 0.00001)*
Oxidised Nitrogen	**34**	2	1	**3**	22	9	**31**	**16**	0	1	**1**	7	8	**15**	Significant increase *(P = 0.020)*
Total Nitrogen	**50**	8	5	**13**	23	14	**37**	**3**	3	0	**3**	0	0	**0**	Significant increase *(P < 0.00001)*

3.1.1 Temperature

Over the 1989-2007 period there was one ‘meaningful’ increase in temperature, and also a number of ‘significant but not meaningful’ increases and decreases in water temperature.

The one ‘meaningful’ increase in temperature was observed in the South Island, in the Opuha River (Canterbury). ‘Significant but not meaningful’ increases were observed at 13 sites (5 sites in the North Island and 8 sites in the South Island), while ‘significant but not meaningful’ decreases were observed at 7 sites, 5 of which were in the South Island. The majority of these ‘significant but not meaningful’ changes were observed at sites in the South Island.

The median SKSE is 0.011 yr^{-1} (RSKSE = 0.085 % yr^{-1}), suggesting that rivers in New Zealand have warmed slightly by about 0.11 degree per decade. At the national scale, the overall trend in temperature just failed to meet the 5% ‘significance’ threshold (binomial test; $P = 0.085$), but we can now be fairly confident that a warming trend is occurring, nationally.

3.1.2 Dissolved oxygen

There were no ‘meaningful’ changes in dissolved oxygen percent saturation. There were, however, ‘significant but not meaningful’ increases at 15 sites, 7 of which were in the North Island and 8 in the South Island. There were ‘significant but not meaningful’ decreases at 23 sites, of which 19 were in the North Island and 4 were in the South Island. The median RSKSE value was -0.011 % yr^{-1}, suggesting that, overall, the % dissolved oxygen is decreasing very slightly. There was no overall significant trend in % dissolved oxygen at the national scale (binomial test: $P = 0.82$).

We acknowledge that daytime dissolved oxygen (at times of sampling visits in the NRWQN) is less appropriate for assessing state and trends of rivers than at dawn when dissolved oxygen is minimal. There is a case for continuous monitoring of dissolved oxygen in summer months at selected sites in the NRWQN so that dawn dissolved oxygen (and river metabolism) can be calculated.

3.1.3 Visual Clarity

Visual clarity exhibited a number of significant trends at sites throughout New Zealand.

A ‘significant but not meaningful’ increase was observed at 2 sites (South Island) while ‘meaningful’ increases were noted at 25 sites, 13 in the North Island and 12 in the South Island. Improvements in visual clarity were dispersed throughout the North Island, with several ‘meaningful’ increases in the greater Wellington area. In the South Island several ‘meaningful’ increases in visual clarity were observed at sites serviced by the Nelson (3) and Dunedin (5) NIWA field teams.

One ‘significant but not meaningful’ downward trend was observed in visual clarity (North Island), and ‘meaningful’ decreases were observed at 10 sites, 6 sites in the North Island, and 4 in the South Island. In the North Island ‘meaningful’ decreases were observed at 3 sites in Northland, 1 Auckland site, 1 Waikato and 1 Bay of Plenty site, while the corresponding South Island sites were in the Canterbury region.

The median RSKSE value was 0.612% yr^{-1}, suggesting that, overall, visual clarity is increasing in New Zealand rivers (it is however decreasing in some rivers). At the national level, **there was a significant increasing trend in visual clarity** (binomial test; $P < 0.00004$) consistent with Scarsbrook (2006) who also found an overall upward trend in visual clarity.

3.1.4 Dissolved Reactive Phosphorus

There were a number of significant changes in dissolved reactive phosphorus (DRP) across both islands.

One ‘significant but not meaningful’ increase was observed (South Island), and ‘meaningful’ increases were found at 25 sites. There were more ‘meaningful increases in the North Island (18) than the South Island (7). Changes were not confined to any specific area but in the North Island were widely dispersed. In the South Island, increases were observed at sites in the Canterbury (2) and Otago (5) regions.

A ‘significant but not meaningful’ downward trend was observed at 2 sites, while ‘meaningful’ downward trends were observed at 4 sites in the North Island and 3 sites in the South Island (7 in total). These ‘meaningful’ decreasing trends in DRP were dispersed throughout both islands, and showed no clear geographical pattern.

The median RSKSE value was 0.55 % yr^{-1}, indicating an increase in DRP concentrations, which was **significant at the national scale** (Binomial test; $P = 0.006$), which is consistent with the findings of Scarsbrook (2006) who also found a significant upward trend in DRP.

3.1.5 Total Phosphorus

Significant increases and decreases in total phosphorus (TP) were observed at sites throughout both islands.

‘Significant but not meaningful’ increases in TP were noted at 3 North Island sites, and ‘meaningful’ increases at 20 sites. Ten of these ‘meaningful’ increases were in the North Island, distributed throughout upper North Island, while the remaining 10 were distributed through the South Island.

‘Significant but not meaningful decreases’ in TP were found at 1 North Island site, while there were ‘meaningful’ decreases at 8 sites, 7 of which were widely distributed over the North Island while 1 of was in the South Island (Canterbury region).

The median RSKSE value was 0.47 % yr^{-1}, showing that TP concentrations were increasing in New Zealand rivers. At the national level there was a **significant increasing trend in TP** (P = 0.00001).

3.1.6 Ammoniacal Nitrogen

While trend analysis was carried out for ammoniacal nitrogen (NH_4-N) as for the other variables, the trend parameters are considered to some extent spurious (because of increasing control over time of laboratory contamination sources) and so are not included in this report. Earlier trend analysis (Scarsbrook, 2006) reported a strong downwards trend in NH_4-N which was attributed to point source clean-up. This explanation seemed plausible as there was a corresponding decreasing trend in BOD_5. Results from the current study also showed a strong decreasing trend in NH_4-N. However, the baseline sites showed a stronger downward trend overall than the impact sites, which was the *opposite* of what would be expected. Examination of flow-adjusted plots (Section 3.2 below) and consultation with senior analyst, Graham Bryers (pers. comm. March 2009) suggested that the trends were largely spurious due to progressive reduction of laboratory contamination. Therefore it was decided to omit the NH_4-N results from the present report. The following account of laboratory contamination issues is given in explanation.

Data pre-1995 suffered significant (NH_4-N) contamination from impure laboratory air sourced, at least in part, from tobacco smoke, that is, the unsuitable laboratory conditions at that time were not conducive to providing reliable low ammoniacal-N results that we have since been able to achieve since 1995 in the current laboratory premises. This contamination particularly affects clean sites at which the concentrations are less than 5 ppb, where a small degree of contamination has caused bias in the measured concentrations. In 1995 a new laboratory (with more room and better air control) was commissioned and tighter controls on smoking were implemented. Also, further control of laboratory sources of contamination, particularly from (ammonia in) laboratory air, has been achieved by improving laboratory protocols, including: covering flow injection analysis (FIA) sample tubes with aluminium foil, minimising time sub-samples are left standing on laboratory benches in free contact with laboratory air, and taking particular care with sequential filtering of samples of varying ammoniacal-N concentration (with the potential for cross-contamination).

3.1.7 Oxidised Nitrogen

"Oxidised nitrogen" refers to nitrogen in the nitrate and nitrite forms. These are typically analysed together, including in the NRWQN.

For the 1989-2007 period, there were significant increases and decreases in oxidised nitrogen (NO_x-N) throughout both islands.

'Significant but not meaningful' increases in NO_x-N were found at 3 North Island sites, while 'meaningful' increases were observed at 31 sites. Of these 'meaningful' increases, 14 were (widely distributed) in the North Island and 17 were distributed throughout the South Island.

'Significant but not meaningful' decreases were noted at 1 site, while 'meaningful' decreases were noted at 15 sites, 8 of which were in the North Island and 7 in the South Island.

The median RSKSE value was 0.49 % yr^{-1}, indicating a tendency towards an increase in NO_x-N concentrations. At the national level, there was a **significant increasing trend in NO_x-N** ($P = 0.020$).

3.1.8 Total Nitrogen

Increases in total nitrogen (TN) were observed throughout New Zealand. 'Significant but not meaningful' increases were noted at 13 sites while 'meaningful' increases were observed at 37 sites. Of these 'meaningful' increases, 13 were in the North Island and 24 were in the South Island, meaning that a higher proportion of South Island rivers is subjected to an increasing trend in TN. Otherwise this tendency towards increasing TN concentrations shows little geographic pattern and is distributed across all areas of both islands

There were 3 'significant but not meaningful' decreases in TN (North Island). There were no meaningful decreases in TN.

The median RSKSE value was 0.98% yr^{-1}, showing that, overall, TN concentrations were increasing – and more rapidly than any other variable. The highest median RSKSE value is for TN. Consistent with the trend for NO_x-N, at the national scale, there was a **significant increasing trend in TN** ($P < 0.00001$).

3.2 Trends or patterns within the overall period

3.2.1 Trends in catchments and at individual sampling sites

Figure 3 to Figure 28 (Appendix 1) show selected time series plots for combinations of variable and site where an 'interesting' pattern seemed to be emerging within the 1989-2007 period and particularly over the four years since Scarsbrook's (2006) analysis of 1989-2003 data.

For example, TN (also NO_x-N) in the Waimakariri River at site CH4 (Figure 3 and Figure 4) shows a rapid upswing over the past few years. This trend would not have been noticeable to Scarsbrook (2006), but is now very apparent. This rapid increase in nitrogen (about 50% as NO_x-N) seems likely to be the signature of intensifying land use and will undoubtedly be of interest to Environment Canterbury.

There are other interesting examples, summarised as follows:

At site RO2, on the Tarawera at Awakaponga, visual clarity (Figure 5) and % dissolved oxygen (Figure 6) have been increasing in recent years, while NH_4-N (Figure 7) and TN (Figure 8) concentrations have been decreasing. These changes may be related to improving treatment of pulp and paper wastewaters from mills near Kawerau. These improvements have been accompanied however by increased DRP (Figure 9) and NO_x-N (Figure 10) concentrations, suggesting increased diffuse source pollution from the pastoral areas of the Tarawera Catchment.

At site WA8, Teachers College in the Manawatu Catchment, similar improvements in water quality can be seen. Visual clarity (Figure 11) has increased while DRP (Figure 12), NH_4-N (Figure 13) and NO_x-N (Figure 14) concentrations have decreased. Here the RSKSE value for NO_x-N is positive, which masks the recent downward trends in concentrations. Similar improvements are again seen further downstream at site WA9, Opiki Bridge, in the Manawatu catchment. Here, visual clarity (Figure 15) has increased and DRP (Figure 16), NO_x-N (Figure 17) and TN (Figure 18) concentrations are all decreasing. NO_x-N and TN concentrations have only started to decline since the date of the last formal trend analysis by Scarsbrook (2006) and are not as yet reflected in the RSKSE value. This particular site highlights the need to visually assess the data as the RSKSE values for DRP, NH_4-N, NO_x-N and TN are positive, and 'meaningful', suggesting that concentrations are increasing while in reality, even though they had been increasing in the past, concentrations are now decreasing.

At site TK2, the Waitaki at Kurow, there have been increases in visual clarity (Figure 19), accompanied by increases in NO_x-N (Figure 20) and TN (Figure 21) concentrations.

At Site DN5, the Mataura at Seaward Down, DRP concentrations (Figure 22) have been decreasing. Also at this site, NO_x-N (Figure 23) and TN (Figure 24) concentrations, which had been steadily increasing, have now levelled off. This has also occurred at site DN7, the Oreti at Lumsden, where the rates of increase in NO_x-N (Figure 25) and TN (Figure 26) concentrations have reduced and concentrations are no longer increasing. The RSKSE values for NO_x-N and TN at both of these sites suggest increasing concentrations, again reinforcing the need to visually examine flow-adjusted data for recent changes in the direction of trends. A similar pattern is visible at site DN8, the Oreti at Riverton Highway Bridge, where concentrations of NO_x-N (Figure 27) and TN (Figure 28) were increasing steadily but now have levelled off. As with DN5 and DN7, the RSKSE values for NO_x-N and TN at this site suggests increasing concentrations, again reinforcing the need to examine raw data for recent changes in the direction of trends.

3.3 Summary of trend analysis

Box plots of the RSKSE calculated for the 15-yr period (1989-2003) analysed by Scarsbrook (2006) and the 19-year dataset (1989-2007) analysed for the present study are presented in Figure 1 and Table 2. General observations are as follows.

All the variables are showing trends in the same direction for both time periods. That is, our trend assessment (1989-2007) is consistent overall with that of Scarsbrook (2006) for the period 1989-2003. While no overall changes in trend direction have occurred, there are however differences in the magnitude of trends for individual variables. Temperature and visual clarity are increasing at a greater rate while % dissolved oxygen shows a decreased rate of change compared to those detected by Scarsbrook (2006). NO_x-N and TN concentrations are increasing at a similar rate as in the period up to 2003. DRP concentrations are showing a weaker upwards trend than in the 1989-2003 period, while TP concentrations are showing a slightly stronger upwards trend. In comparison with the findings of Scarsbrook (2006), trends in NO_x-N, TP, visual clarity and temperature have strengthened, the trend for TN remains the same, while those for DRP and %DO have weakened.

Table 2: Comparison of median RSKSE values for 1989-2003 and 1989-2007.

	Temperature	**Dissolved Oxygen %**	**Visual Clarity**	**NO_x-N**	**TN**	**DRP**	**TP**
Median RSKSE 1989-2007	0.085	-0.011	0.612	0.499	0.98	0.55	0.47
Median RSKSE 1989-2003	0.02	-0.02	0.56	0.47	0.98	0.72	0.44

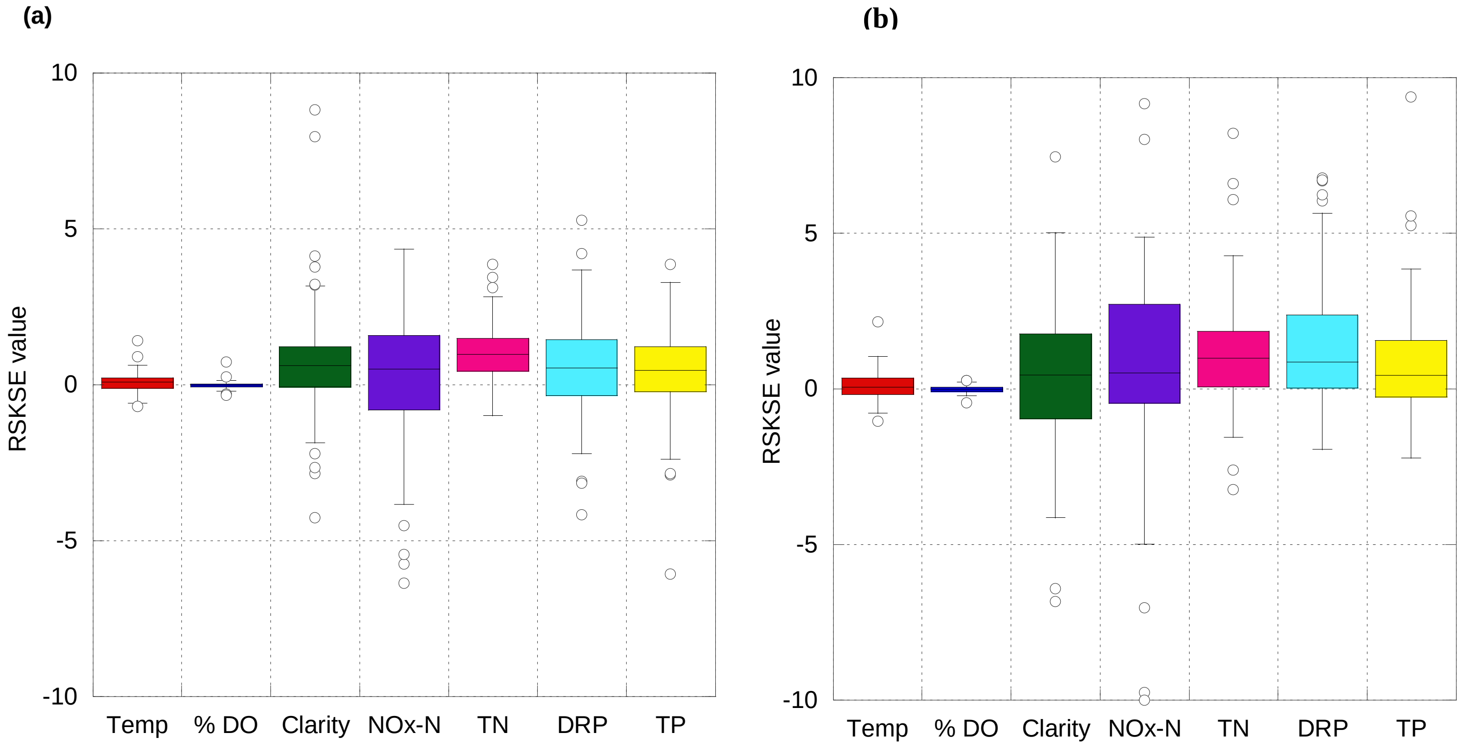

Figure 1: Box plots of RSKSE values for (a) 1989-2007 and (b) 1989-2003 as generated by KaleidaGraph. The box covers the interquartile range, i.e., 50% of the data with the median value displayed as a line. Whiskers mark the values within the data set that fall within a distance of 1.5 x IQR (interquartile range) from the box. Any values outside of this range ('outliers') are displayed as circles.

Sites have been split into baseline and impact sites and the number of changes in each category tabulated (Table 7). RSKSE values for baseline and impact sites for eash water quality variable have been plotted (Figure 2). The differences between % dissolved oxygen and temperature for baseline and impact sites are very small. For clarity, there is a positive trend at both baseline and impact sites.

NO_x-N concentrations are declining at baseline sites and increasing at impact sites. Changes in the concentrations of TP, TN and DRP do not vary significantly between baseline and impact sites: both categories of site are increasing in these nutrients at similar rates overall. The increases at impact sites seem consistent with known trends of pastoral expansion and intensification. The increase at baseline sites for TP, TN and DRP concentrations is at first surprising, but may reflect the generally lower concentrations at such sites, such that they are more susceptible to increases, possibly due to increased stocking or fertilizer use.

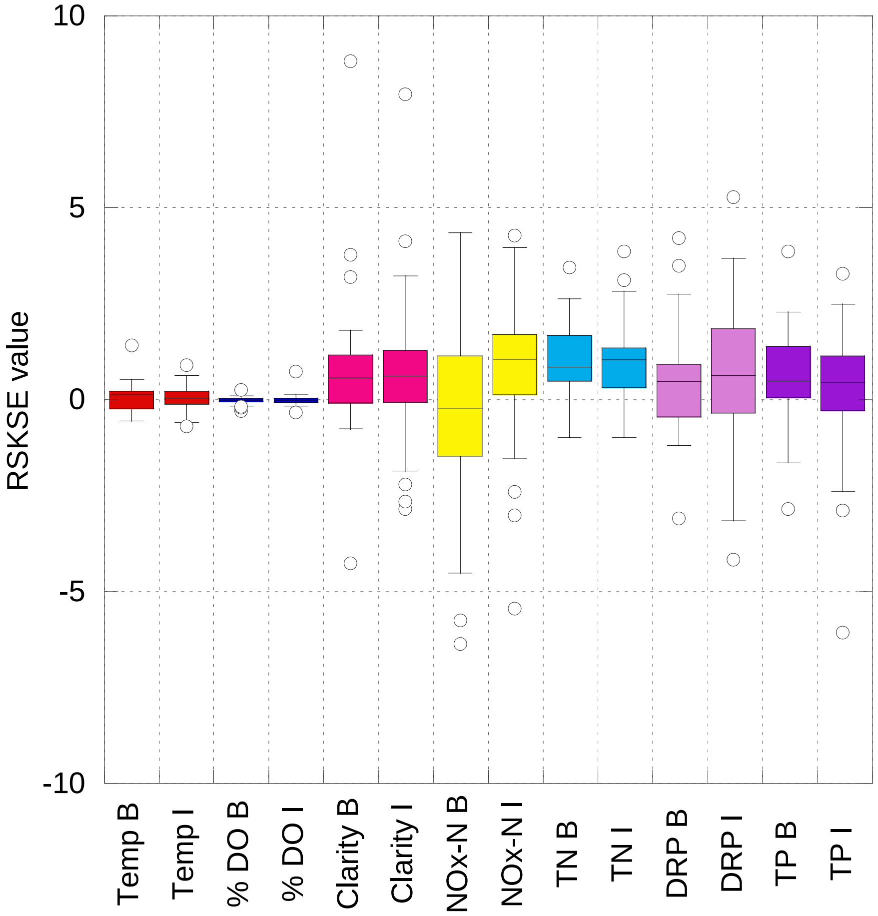

Figure 2: RSKSE values for water quality variables divided into baseline (B left) and impact (I right) sites. These box plots were generated by KaleidaGraph. The box covers the interquartile range, i.e., 50% of the data with the median value displayed as a line. Whiskers mark the values within the data set that fall within a distance of 1.5 x IQR (interquartile range) from the box. Any values outside of this range (outliers) are displayed as circles.

3.4 Links between water quality and pastoral land use

Table 3 summarizes correlations between current (2007) water quality state and % pastoral land cover (using flow-weighted percentage contributing area). This indicates how pastoral land use can affect water quality. With the exception of dissolved oxygen, all the water quality variables had highly significant relationships with the pastoral land cover in their catchments. Relationships were mainly positive indicating that as % pastoral land cover increased, concentrations of water quality constituents also increased. Temperature also increased with pastoral land use, probably reflecting solar heating of water in channels in pasture, which are mostly without shade, versus characteristically cooler water draining from shaded forested land. However, visual clarity was *inversely* related to pastoral land cover, plausibly because as pastoral land cover increases, light-attenuating fine sediment tends to be increasingly mobilised.

Table 3: Spearman rank correlations for water quality variables (annual median for 2007) and % pastoral land cover.

Variable	Median water quality 2007 and flow adjusted % pastoral land cover	RSKSE and flow adjusted % pastoral land cover	SKSE and flow adjusted % pastoral land cover
Temperature	0.444**	0.074	0.1
Dissolved Oxygen %	-0.133	-0.276*	-0.272*
Visual Clarity	-0.55**	-0.238*	-0.376**
Oxidised Nitrogen (NO_x-N)	0.65**	0.181	0.313**
Total Nitrogen (TN)	0.769**	-0.172	0.39**
Dissolved Reactive Phosphorus (DRP)	0.495**	0.285*	0.431**
Total Phosphorus (TP)	0.642**	0.134	0.317**

** = highly significant ($P < 0.01$), * = significant ($P < 0.05$)

It was considered important to include this section, because establishing the drivers for water quality state can assist in the interpretation of trends especially when the drivers are subject to change. In this case the driver for change was the extent of pastoral agriculture, consideration of which was helpful in interpreting trends which otherwise might have been unexpected.

4. Discussion

Our trend analysis of NRWQN data has shown similar trends to those identified by Scarsbrook (2006), although the overall (nation-wide) trends for most variables have weakened somewhat (1989-2007 compared with 1989-2003). There have been few noteworthy trends in dissolved oxygen (or conductivity or pH – considered by Scarsbrook (2006), but not in this present study). However, a small upwards trend in temperature (amounting to about +0.15°C per decade) is plausibly consistent with global warming, and is just bordering on ‘significant’ at the 5% level.

Over the nineteen year period 1989-2007, there has been a strong shift in importance of point source pollution relative to diffuse pollution, with pastoral agriculture dominating diffuse sources affecting our rivers. Declining BOD_5 (as discussed by Scarsbrook (2006)) is the signature of point source clean-up.

Meanwhile enrichment by the nutrients nitrogen and phosphorus has continued which may be attributed mainly to expansion and intensification of pastoral land use. The overall upwards trends in DRP has weakened somewhat, but remains strongly upwards, while the trend in TP has strengthened . The upwards trend in NO_x-N have strengthened, while the trend in TN remains as it was for 1989-2003. TN, TP and DRP are increasing at both ‘baseline’ and ‘impact’ sites, while NOx-N is decreasing at ‘baseline’ sites.

The trend of increasing visual clarity (improving water quality) overall, as reported by Scarsbrook (2006) for 1989-2003, has strengthened over the 1989-2007 period. Scarsbrook (2006) attributed this trend to improvements in waste treatment, meaning reduced inputs from point sources, rather than improving soil erosion control – because visual clarity is negatively correlated with % pastoral land in catchments, as confirmed in this study. Visibility is improving at both ‘baseline’ and ‘impact’ sites, which is something of a puzzle, but may reflect widespread soil conservation measures including stream fencing.

A few interesting temporal patterns have emerged in last four years since Scarsbrook’s (2006) report on 1989-2003 data. For example, at Site CH4 on the Waimakariri River, there has been a recent sharp upswing in TN and NO_x-N. Some improvements in water quality in the lower Tarawera River (Site RO2) may be related to improving treatment of wastewaters from the pulp and paper mills near Kawerau.

5. References

Scarsbrook, M. (2006). State and trends in the National River Water Quality Network (1989-2005). NIWA Client Report HAM2006-131 to MfE.

Slack, J.R.; Lorenz, D.L. et al. (2003). *USGS library for S-PLUS for Windows – Release 2.1*, US Geological Survey Open-File Report 03-357.

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Smith, D.G.; McBride, G.B. (1990). New Zealand's national water quality monitoring network - Design and first year's operation. *Water Resources Bulletin 26*: 767-775.

Smith, D.G.; McBride, G.B.; Bryers, G.G.; Wisse, J.; Mink, D.F.J. (1996). Trends in New Zealand's river water quality network. *New Zealand Journal of Marine and Freshwater Research 30*: 485-500.

6. Appendix 1

Table 4: Tasks and deliverables as tabulated in the project brief from the MfE (Mike Thompson) Contract 11747 C, Project 4.

Project 4. Formal trend assessment on NRWQN sites for the period 1989 – 2007.	
Tasks	Calculate trends for each parameter listed above in Project 1 (excluding *E.coli*) for each site of the NRWQN. Trends to be calculated using suitable **Time Trends** software. Analysis to include: Assessment over entire period of record (1989 to 2007/08) Consideration, on an individual site basis, of patterns within the overall trend period (1989-2007) that may be important to identify or comment on. For example, a particular site may have an overall (1989-2007) trend of increasing nitrate that masks a more recent trend of decreasing nitrate. Comparison with **Time Trends** with earlier (1989 – 2003) trend analysis (Scarsbrook 2006) and commentary on any significant differences. Categorisation of trends (i.e., no trend, significant trend, ecologically meaningful trend) following convention of Scarsbrook (unless there is good reason to depart from this methodology) Summarise assessments in an appropriate form (table and graphics) and describe key findings, methodologies/caveats in a brief technical report. Interpretation of results, beyond that described above, is not required.
Deliverables	Draft version of technical report (electronic version) to be provided at an early stage to allow MfE an opportunity to review and comment. This draft may simply be a summary of early results and skeleton of report structure. Final report, that incorporates MfE comments on the early draft (where reasonable and practicable). Access to summary data used to populate tables (and any maps) of the final report so that they can be recreated, if necessary, in the final MfE publication.

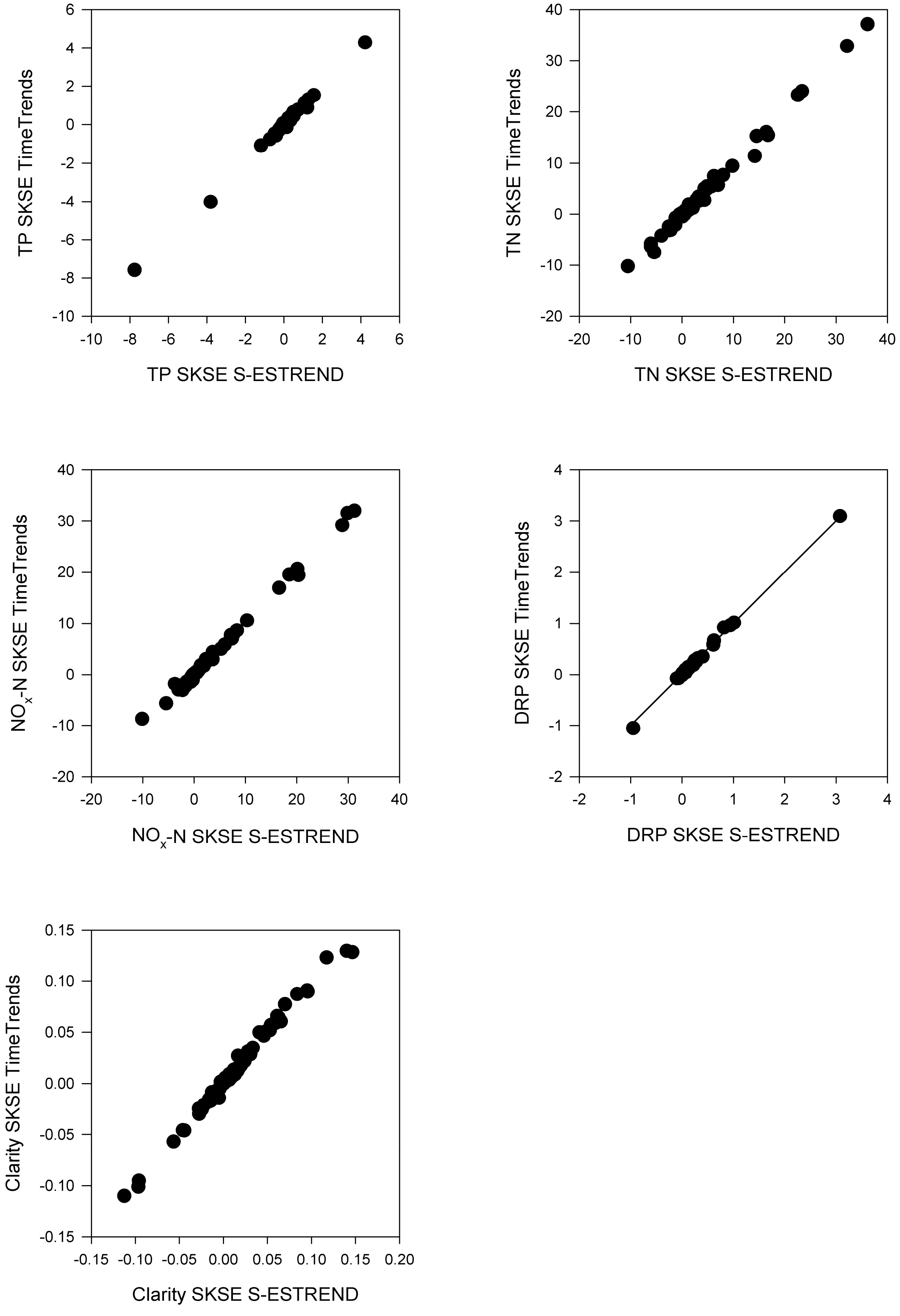

Figure 3 **Comparison of SKSE values for S-Estrend and Time Trends**.

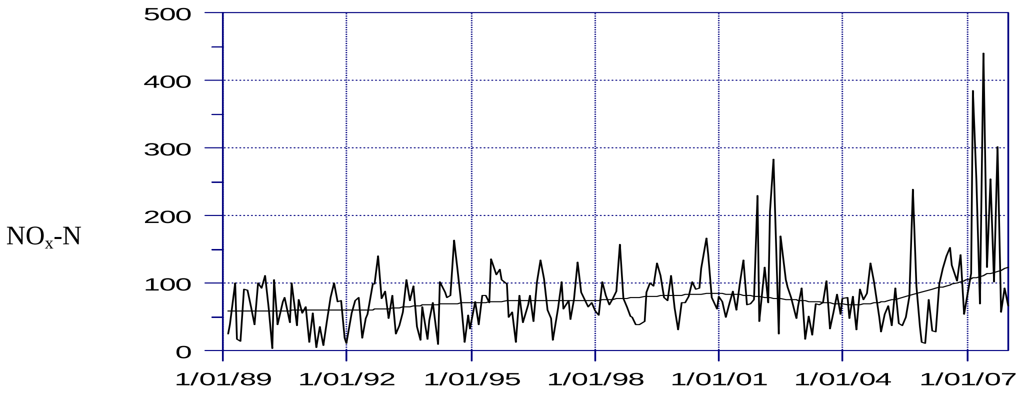

Figure 3: Oxidised Nitrogen, CH4 Waimakariri River at Christchurch.

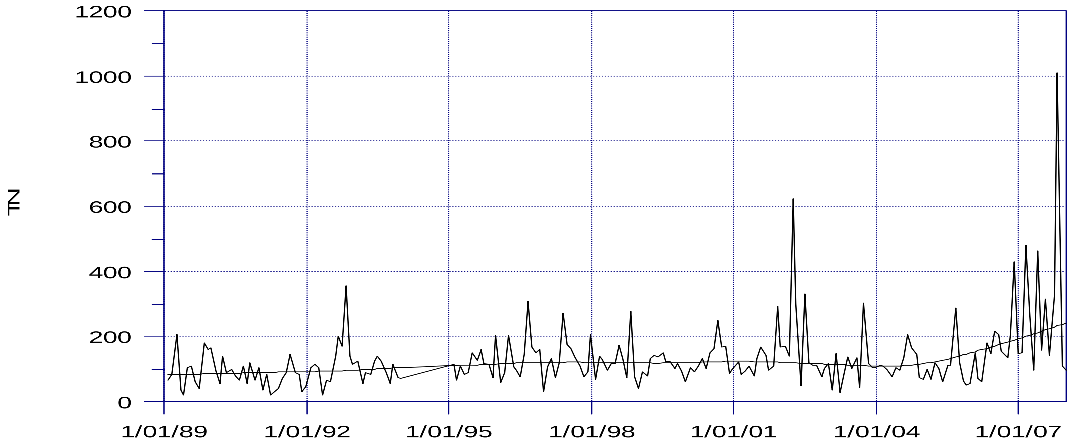

Figure 4: T TN rogen, CH4 Waimakariri River at Christchurch.

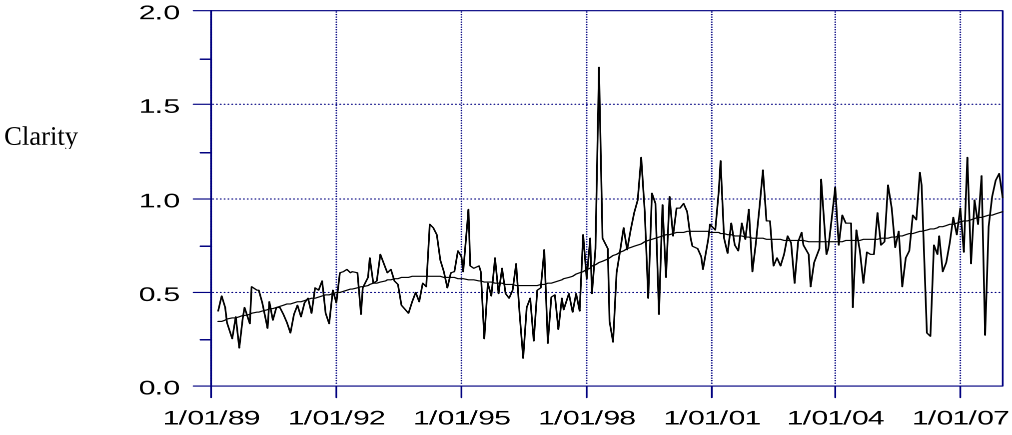

Figure 5: Visual clarity, RO2 Tarawera at Awakaponga.

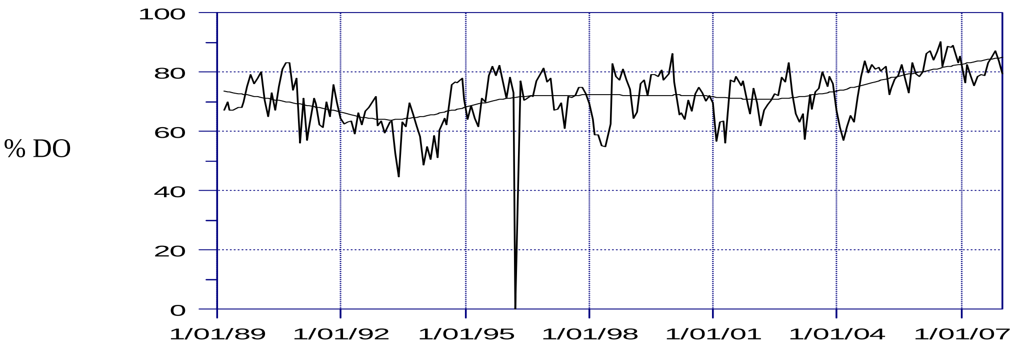

Figure 6: % Dissolved Oxygen, RO2 Tarawera at Awakponga.

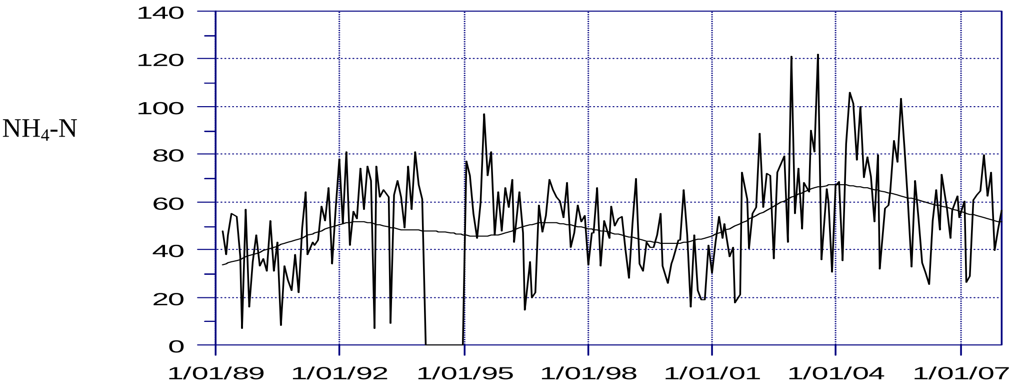

Figure 7: Ammoniacal Nitrogen, RO2 Tarawera at Awakaponga.

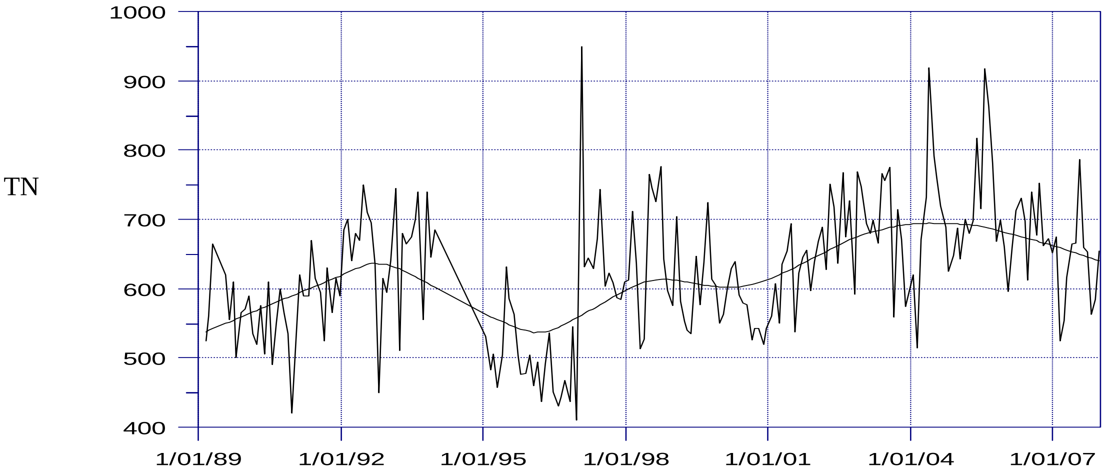

Figure 8: Total Nitrogen, RO2 Tarawera at Awakaponga.

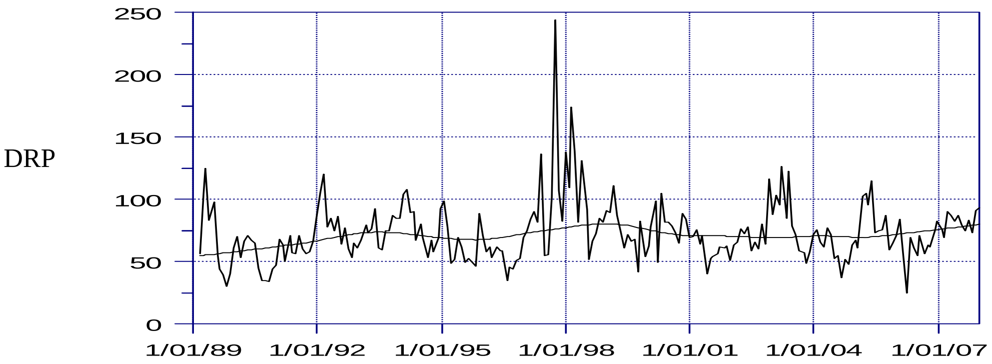

Figure 9: Dissolved Reactive Phosphorus, RO2 Tarawera at Awakaponga.

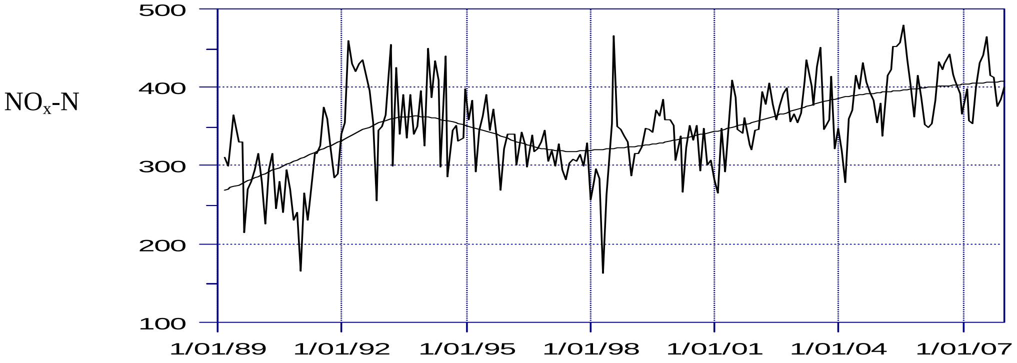

Figure 10: Oxidised Nitrogen, RO2 Tarawera at Awakaponga.

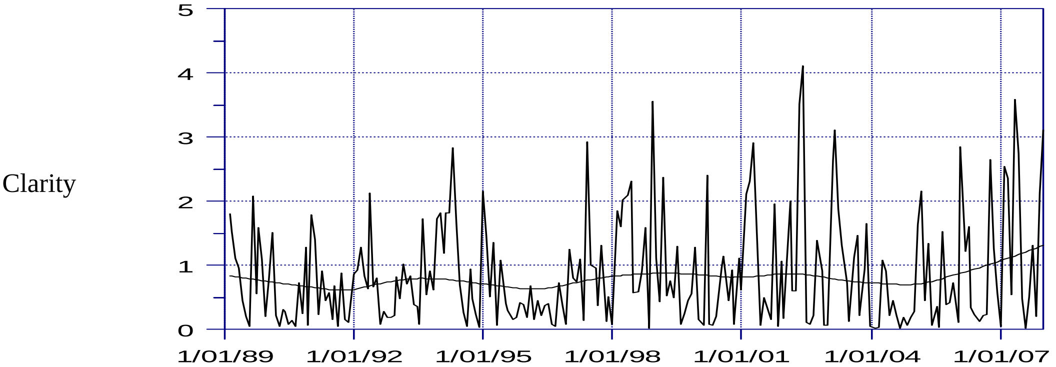

Figure 11: Visual clarity, WA8 Manawatu at Teacher’s College.

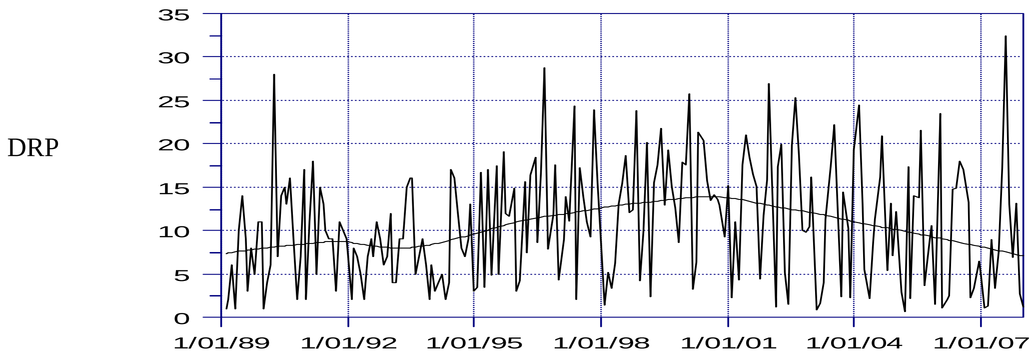

Figure 12: Dissolved Reactive Phosphorus, WA8 Manawatu at Teacher's College.

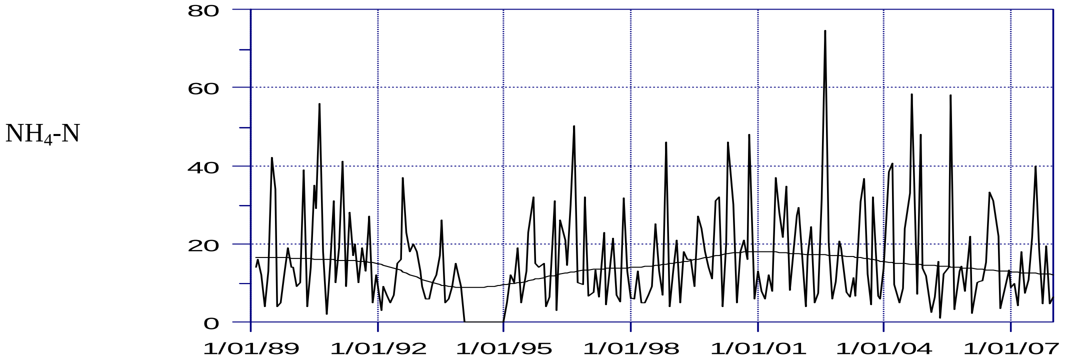

Figure 13: Ammoniacal Nitrogen, WA8 Manawatu at Teacher's College.

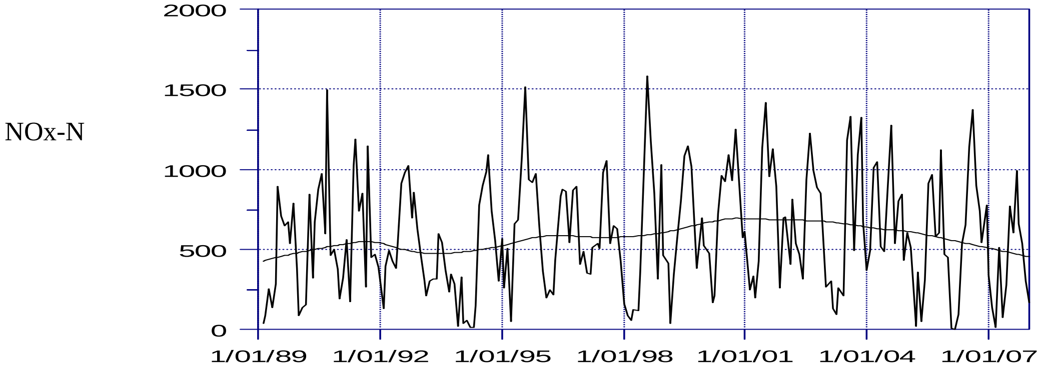

Figure 14: Oxidised Nitrogen, WA8 Manawatu at Teacher's College.

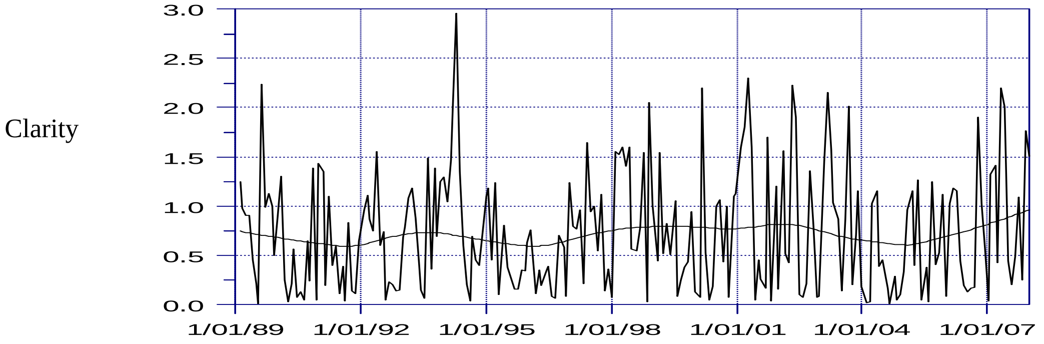

Figure 15: Visual clarity, WA9 Manawatu at Opiki Bridge.

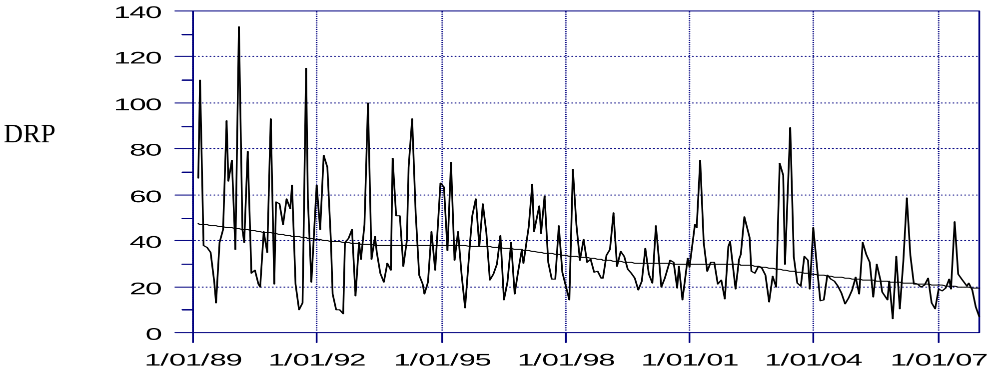

Figure 16: Dissolved Reactive Phosphorus, WA9 Manawatu at Opiki Bridge.

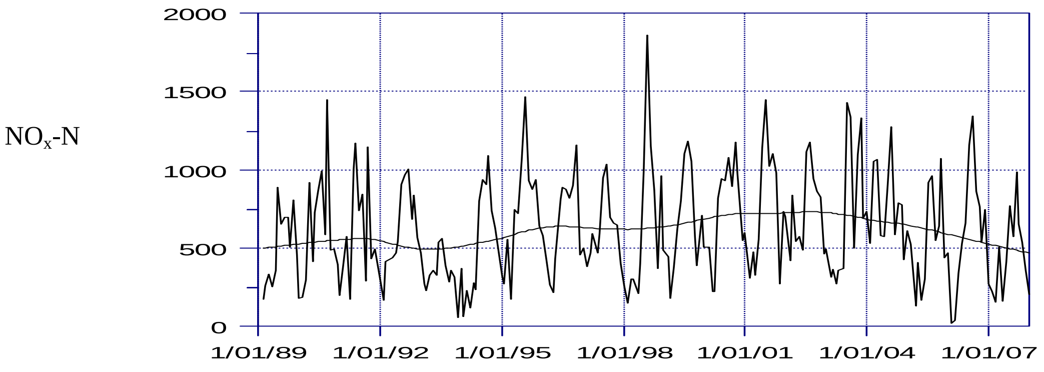

Figure 17: Oxidised Nitrogen, WA9 Manawatu at Opiki Bridge.

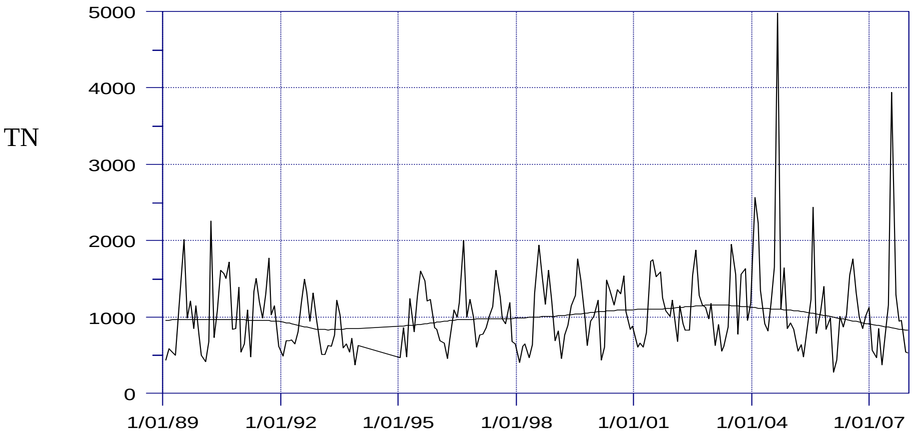

Figure 18: Total Nitrogen, WA9 Manawatu at Opiki Bridge.

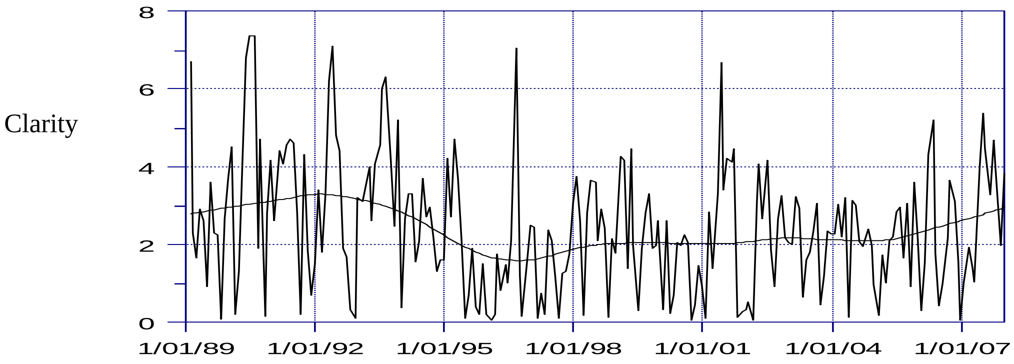

Figure 19: Visual clarity, TK2 Opihi at Rockwood.

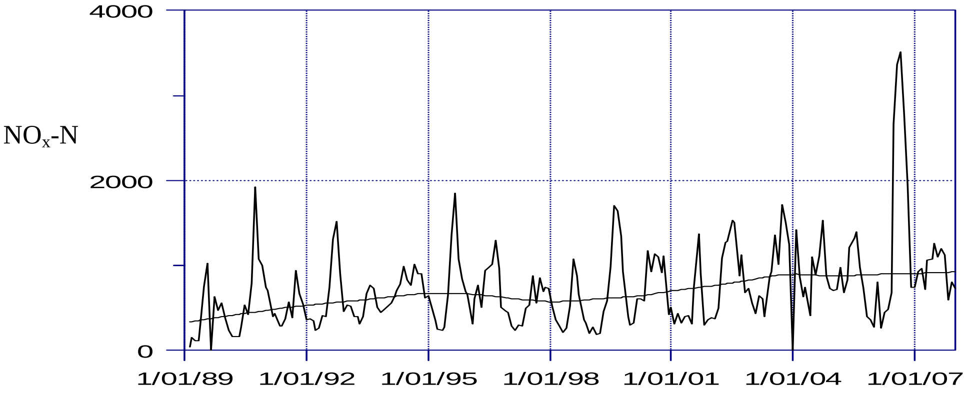

Figure 20: Oxidised Nitrogen, TK2 Opihi at Rockwood.

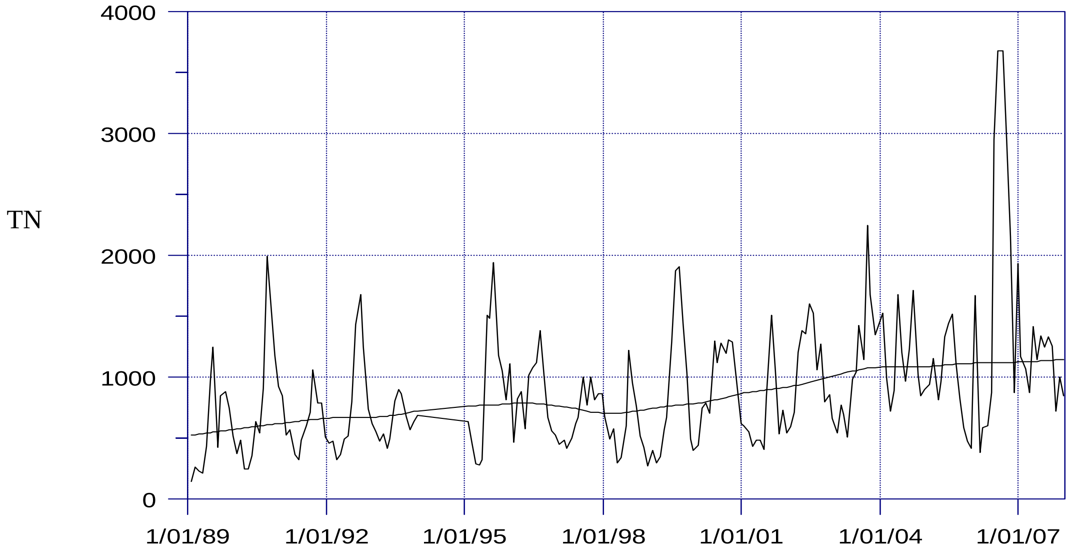

Figure 21: Total Nitrogen, TK2 Opihi at Rockwood.

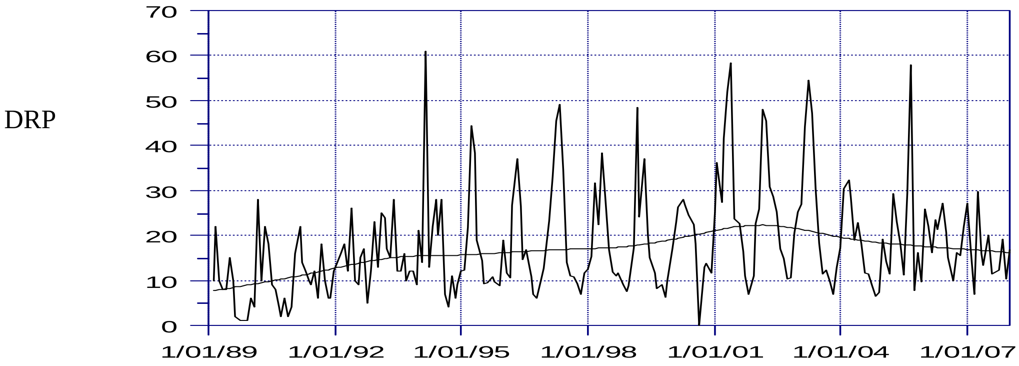

Figure 22: Dissolved Reactive Phosphorus, DN5 Mataura at Seawood Downs.

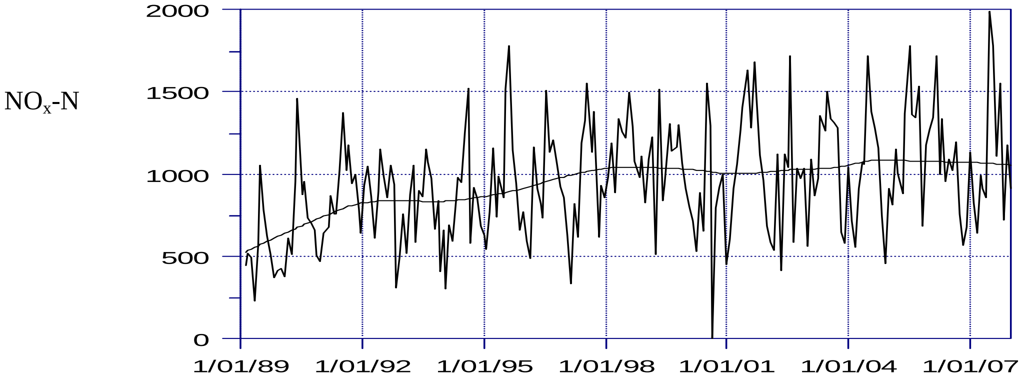

Figure 23: Oxidised Nitrogen, DN5 Mataura at Seawood Downs.

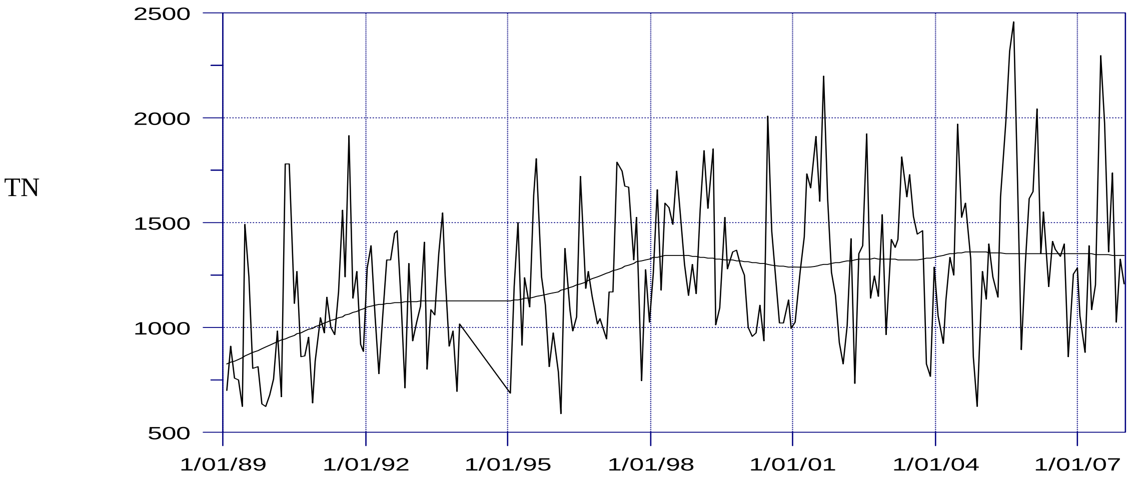

Figure 24: Total Nitrogen, DN5 Mataura at Seawood Downs.

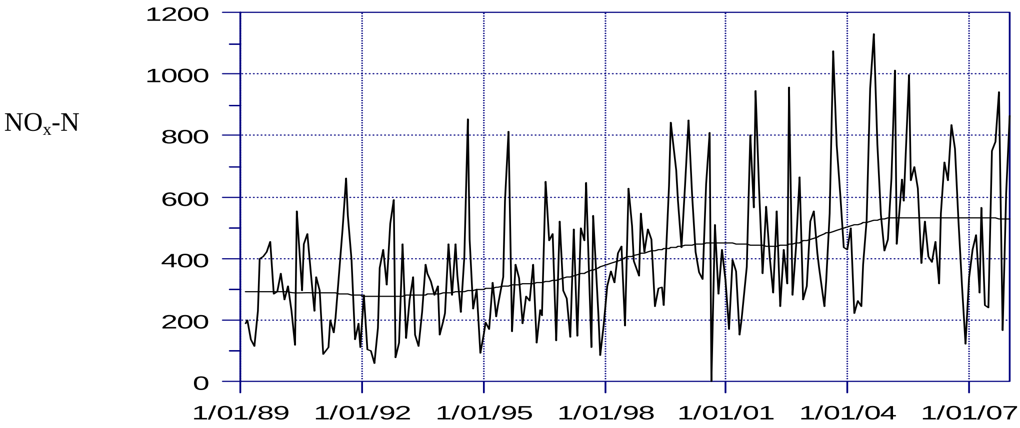

Figure 25: Oxidised Nitrogen, DN7 Oreti at Lumsden.

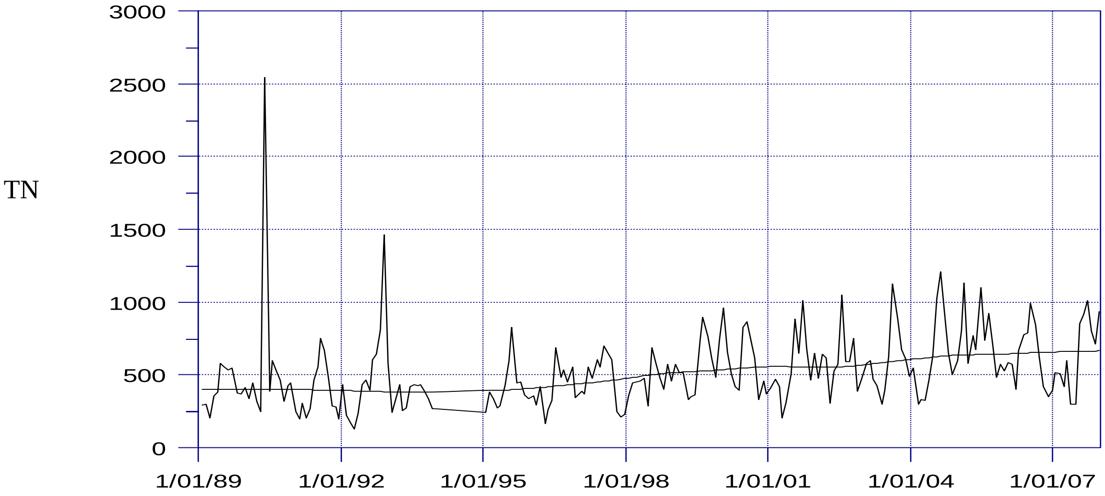

Figure 26: Total Nitrogen, DN7 Oreti at Lumsden.

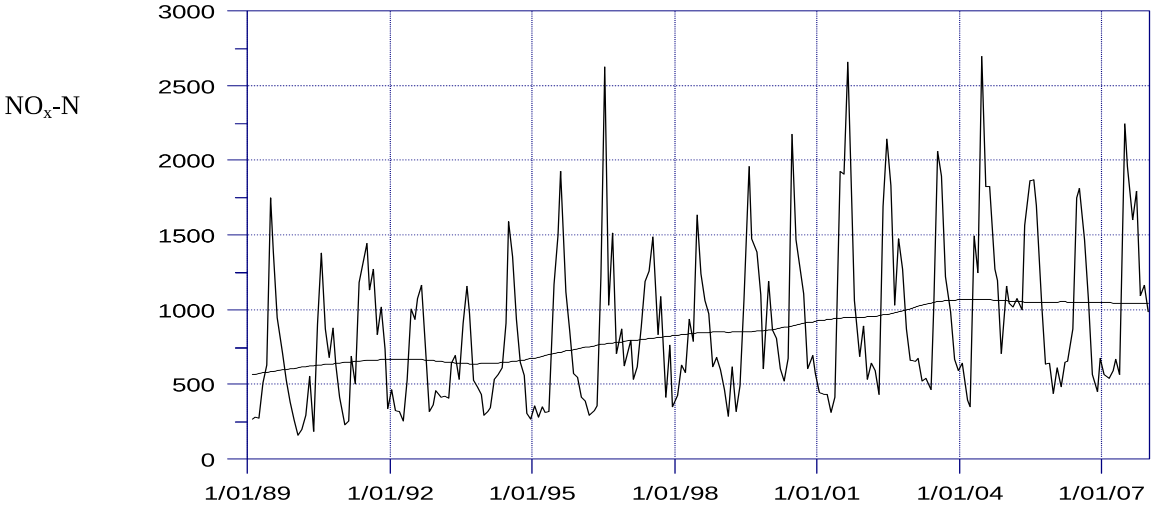

Figure 27: Oxidised Nitrogen, DN8 Oreti at Riverton Highway Bridge.

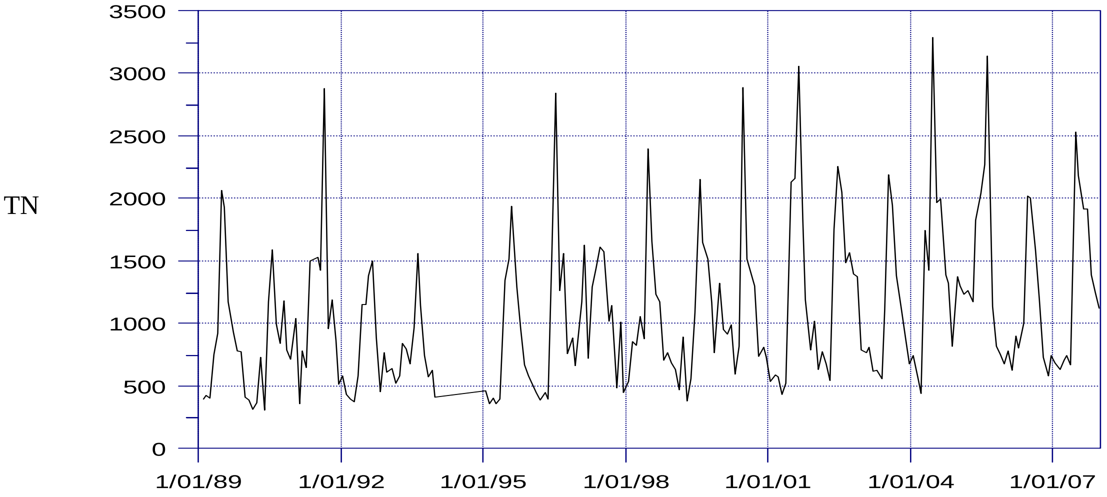

Figure 28: Total Nitrogen, DN8 Oreti at Riverton Highway Bridge.

Table 5: RSKSE and *P* values for water quality parameters at all NRWQN sampling sites – listed in order north to south. (See Table 8 for site names.)

Site	Temp			% DO		Clarity		DRP		TP		NO_x-N		TN	
	P	SKSE	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE
WH1	**0.002**	**0.077**	**0.531**	**0.008**	**-0.050**	0.880	-0.126	0.992	-0.019	0.327	0.372	**0.000**	**-2.506**	0.538	0.315
WH2	0.380	0.023	0.135	0.059	-0.041	**0.000**	**-1.857**	**0.004**	**1.529**	**0.000**	**1.878**	0.664	0.140	**0.001**	**0.814**
WH3	0.327	0.030	0.175	**0.000**	**-0.120**	**0.000**	**-2.851**	**0.000**	**2.666**	**0.000**	**2.094**	0.635	0.248	0.425	0.326
WH4	**0.001**	**0.091**	**0.540**	0.308	0.104	**0.023**	**-1.007**	**0.000**	**3.199**	**0.000**	**2.397**	0.081	-0.965	0.725	0.124
AK1	0.310	0.022	0.147	**0.024**	**-0.107**	**0.000**	**-2.205**	**0.031**	**1.051**	**0.002**	**1.125**	**0.000**	**-1.524**	**0.005**	**-0.850**
AK2	0.837	-0.004	-0.030	0.139	-0.157	**0.022**	**0.882**	0.258	0.518	0.766	0.052	**0.000**	**-3.009**	**0.032**	**-0.751**
HM1	0.565	-0.010	-0.079	**0.005**	**-0.047**	0.337	0.477	**0.000**	**1.980**	0.483	0.398	**0.038**	**0.784**	**0.005**	**0.789**
HM2	0.425	-0.016	-0.109	0.992	0.001	**0.003**	**-1.541**	0.649	-0.183	**0.008**	**0.945**	**0.008**	**0.745**	**0.008**	**0.661**
HM3	0.059	0.034	0.210	0.449	0.047	0.579	0.256	0.662	0.191	**0.002**	**0.895**	**0.006**	**1.597**	**0.000**	**1.273**
HM4	0.437	-0.016	-0.098	0.170	0.054	**0.001**	**1.219**	0.380	0.258	0.146	0.338	0.461	0.324	0.301	0.286
HM5	0.104	-0.032	-0.214	**0.000**	**-0.141**	0.104	0.741	0.512	0.128	0.237	-0.303	**0.005**	**0.314**	**0.031**	**0.295**
HM6	0.649	-0.014	-0.094	0.784	-0.011	0.770	0.147	**0.000**	**-3.099**	**0.001**	**-1.631**	**0.014**	**-0.802**	0.086	-0.627
RO1	0.070	0.044	0.278	0.719	-0.018	0.283	0.299	**0.000**	**2.731**	**0.000**	**1.388**	**0.001**	**-3.828**	**0.026**	**0.659**
RO2	0.277	-0.013	-0.080	**0.000**	**0.734**	**0.000**	**4.135**	**0.000**	**1.054**	0.509	0.098	**0.000**	**1.554**	**0.000**	**1.068**
RO3	0.677	-0.004	-0.031	**0.040**	**-0.046**	**0.000**	**-1.356**	0.799	0.047	0.307	0.186	**0.000**	**1.697**	**0.000**	**1.702**
RO4	0.170	-0.031	-0.253	**0.002**	**-0.064**	0.483	-0.296	0.130	0.177	**0.002**	**0.635**	0.069	0.494	**0.010**	**0.860**
RO5	0.662	0.006	0.040	0.645	0.038	0.289	0.513	0.414	-0.245	0.210	-0.275	**0.000**	**1.272**	**0.000**	**1.167**
RO6	**0.009**	**0.033**	**0.225**	0.768	0.005	**0.011**	**-0.760**	0.197	0.708	**0.001**	**1.207**	**0.000**	**-6.356**	**0.000**	**1.441**
TU1	0.512	-0.017	-0.135	**0.014**	**0.089**	0.354	0.514	**0.002**	**1.355**	0.164	-0.807	0.077	-0.796	**0.003**	**-0.986**
TU2	**0.011**	**-0.040**	**-0.412**	**0.024**	**0.046**	1.000	-0.010	0.976	0.002	0.614	0.105	0.214	1.061	0.195	0.736
WA1	0.831	-0.005	-0.036	0.660	0.012	0.677	-0.471	**0.019**	**1.374**	0.286	0.740	0.111	0.661	**0.025**	**0.566**
WA2	0.130	-0.030	-0.288	**0.000**	**-0.102**	**0.000**	**1.071**	**0.000**	**-1.193**	**0.022**	**-0.711**	**0.040**	**1.123**	0.204	0.598
WA3	0.927	-0.003	-0.019	**0.001**	**-0.117**	0.626	0.144	**0.000**	**5.277**	**0.000**	**3.275**	**0.000**	**1.349**	**0.000**	**1.230**
WA4	0.302	0.030	0.213	**0.024**	**-0.072**	0.120	0.856	0.115	0.740	0.784	0.162	0.434	-0.464	0.715	-0.116
WA5	0.522	0.013	0.120	0.113	-0.029	0.057	0.877	**0.048**	**1.182**	0.902	0.064	0.060	-1.421	0.403	-0.518

Site	Temp			% DO		Clarity		DRP		TP		NO_x-N		TN	
	P	SKSE	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE
WA6	0.677	-0.016	-0.123	0.036	-0.069	0.576	-0.224	0.014	1.908	0.072	1.138	0.784	0.226	0.166	0.682
WA7	0.286	0.029	0.222	0.000	-0.289	0.815	0.142	0.001	2.227	0.138	0.743	0.012	1.144	0.001	1.059
WA8	0.458	-0.020	-0.141	0.001	-0.156	0.014	1.203	0.041	1.361	0.133	0.712	0.004	1.693	0.002	1.188
WA9	0.609	-0.013	-0.087	0.048	0.146	0.171	0.612	0.000	-4.164	0.000	-2.891	0.008	1.366	0.013	0.750
GS1	0.011	0.092	0.554	0.756	0.010	0.005	2.313	0.001	3.155	0.000	-6.073	0.025	1.926	0.018	1.185
GS2	0.396	0.022	0.171	0.683	-0.009	0.688	0.276	0.000	3.492	0.000	2.224	0.000	2.159	0.000	1.742
GS3	0.180	0.042	0.332	0.396	0.035	0.797	0.065	0.000	1.899	0.000	1.780	0.629	0.205	0.008	0.843
GS4	0.102	0.034	0.255	0.001	-0.067	0.000	2.175	0.074	0.617	0.011	-1.320	0.010	-1.295	0.796	0.091
HV1	0.390	0.016	0.144	0.000	-0.147	0.000	3.783	0.033	-0.968	0.082	-1.231	0.000	-2.500	0.168	-0.976
HV2	0.702	0.011	0.066	0.020	-0.325	0.647	0.198	0.000	3.426	0.000	2.491	0.062	1.305	0.124	0.885
HV3	0.002	0.099	0.627	0.448	-0.039	0.025	1.010	0.712	-0.345	0.001	-2.885	0.792	0.132	0.440	0.428
HV4	0.046	-0.050	-0.493	0.000	-0.205	0.761	-0.076	0.302	0.537	0.384	0.518	0.000	-4.515	0.005	1.667
HV5	0.583	-0.015	-0.114	0.000	-0.147	0.000	2.780	0.120	-0.718	0.000	-2.391	0.017	1.053	0.002	1.301
HV6	0.558	-0.011	-0.105	0.000	-0.159	0.877	0.062	0.182	-0.582	0.407	0.402	0.000	1.691	0.000	1.487
WN1	0.912	0.003	0.031	0.127	0.054	0.002	1.300	0.000	-3.154	0.000	-1.839	0.358	-0.414	0.064	-0.622
WN2	0.647	0.014	0.158	0.020	0.057	0.005	1.414	0.016	-0.790	0.132	0.649	0.132	0.564	0.086	0.652
WN3	0.976	0.001	0.010	0.366	-0.039	0.391	0.308	0.164	0.596	0.074	0.751	0.619	0.424	0.741	0.165
WN4	0.173	0.032	0.248	0.001	0.133	0.000	3.174	0.483	-0.461	0.164	-0.962	0.028	1.279	0.485	0.297
WN5	0.391	0.018	0.177	0.021	0.062	0.001	1.499	0.592	0.277	0.413	0.547	0.896	-0.087	0.211	0.427
NN1	0.010	-0.066	-0.596	0.422	0.024	0.000	1.287	0.141	-0.962	0.079	0.823	0.000	3.829	0.000	2.822
NN2	0.348	-0.022	-0.271	0.006	0.034	0.002	1.008	0.305	0.405	0.000	1.768	0.366	-0.350	0.123	1.013
NN3	0.760	0.005	0.068	0.004	0.035	0.120	0.708	0.023	0.846	0.000	2.061	0.059	-1.290	0.485	0.488
NN4	0.152	-0.029	-0.203	0.004	0.124	0.066	0.877	0.084	-1.058	0.894	0.090	0.017	2.150	0.001	1.652
NN5	0.522	-0.012	-0.107	0.767	-0.004	0.000	3.198	0.468	0.675	0.480	0.341	0.023	-1.373	0.005	1.093
GY1	0.455	0.021	0.183	0.058	-0.037	0.753	0.185	0.008	-1.432	0.706	0.162	0.000	2.966	0.000	2.119
GY2	0.846	0.005	0.039	0.530	0.023	0.009	1.391	0.357	0.625	0.274	0.724	0.000	4.273	0.000	2.797
GY3	0.004	0.056	0.528	0.558	-0.026	0.086	0.842	0.925	-0.054	0.762	-0.264	0.000	2.796	0.000	1.880

Site	Temp			% DO		Clarity		DRP		TP		NO_x-N		TN	
	P	SKSE	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE	*P*	RSKSE
GY4	**0.018**	**-0.046**	**-0.552**	**0.022**	**0.035**	0.054	1.709	0.757	-0.283	0.260	-1.204	0.856	-0.080	0.133	-0.723
CH1	0.229	-0.023	-0.240	**0.002**	**0.059**	0.664	-0.258	0.590	0.570	0.193	1.219	0.525	-0.371	**0.000**	**2.081**
CH2	**0.000**	**-0.082**	**-0.691**	0.768	0.010	0.127	0.680	0.050	1.452	0.079	1.251	**0.008**	**1.079**	**0.003**	**1.049**
CH3	**0.010**	**-0.048**	**-0.514**	**0.000**	**0.103**	**0.000**	**-4.255**	0.079	0.920	**0.021**	**2.283**	0.565	-0.347	**0.022**	**0.833**
CH4	**0.039**	**-0.050**	**-0.367**	0.063	0.047	**0.001**	**-2.655**	0.607	-0.239	0.579	0.586	**0.000**	**2.435**	**0.000**	**2.783**
TK1	**0.001**	**0.055**	**0.479**	0.051	0.095	0.896	-0.073	**0.005**	**-1.874**	0.806	-0.226	**0.011**	**1.589**	**0.009**	**1.349**
TK2	**0.044**	**0.037**	**0.399**	**0.046**	**-0.063**	**0.013**	**-1.361**	**0.001**	**2.168**	**0.004**	**1.678**	**0.000**	**3.867**	**0.000**	**3.865**
TK3	**0.000**	**0.125**	**1.419**	0.130	-0.039	0.621	-0.261	0.535	0.540	**0.000**	**3.867**	**0.014**	**1.400**	**0.000**	**2.175**
TK4	**0.000**	**0.060**	**0.516**	**0.000**	**-0.186**	**0.000**	**8.818**	0.653	-0.440	**0.000**	**-2.845**	**0.000**	**-5.745**	0.245	0.506
TK5	0.402	-0.019	-0.153	**0.047**	**-0.116**	**0.000**	**-1.773**	**0.000**	**-2.198**	0.799	0.122	**0.000**	**-5.438**	**0.008**	**1.133**
TK6	**0.000**	**0.062**	**0.541**	0.773	0.012	**0.000**	**7.969**	**0.032**	**3.047**	0.179	-1.062	**0.000**	**3.540**	**0.000**	**3.107**
AX1	**0.022**	**0.027**	**0.222**	**0.000**	**0.253**	0.280	-0.387	**0.002**	**4.202**	**0.025**	**1.908**	0.147	-0.421	**0.001**	**1.246**
AX2	0.396	0.012	0.104	0.486	0.016	0.121	1.050	**0.003**	**2.749**	0.574	-0.495	**0.000**	**1.465**	**0.000**	**2.635**
AX3	0.571	0.013	0.161	**0.046**	**0.034**	0.308	0.863	0.360	0.795	0.643	0.465	0.308	0.500	**0.002**	**1.915**
AX4	**0.022**	**0.025**	**0.222**	0.868	0.005	**0.000**	**3.228**	0.437	-0.593	1.000	0.005	**0.001**	**-1.173**	**0.008**	**1.128**
DN1	0.959	-0.004	-0.043	0.756	-0.009	0.271	0.513	**0.000**	**2.283**	**0.000**	**1.812**	**0.001**	**-2.400**	**0.000**	**1.271**
DN2	0.767	0.007	0.084	0.535	0.026	0.314	0.362	0.253	-0.566	0.703	0.170	0.120	-1.473	0.956	0.026
DN3	0.705	-0.016	-0.151	**0.038**	**-0.069**	0.108	0.822	0.082	0.926	**0.000**	**1.430**	**0.032**	**-1.410**	**0.001**	**0.973**
DN4	0.065	0.041	0.351	0.405	-0.019	0.496	0.436	0.125	1.382	0.549	0.483	0.334	0.550	**0.001**	**1.719**
DN5	0.280	0.020	0.197	0.425	-0.028	**0.004**	**1.232**	**0.000**	**3.685**	**0.003**	**1.381**	**0.000**	**2.766**	**0.000**	**2.009**
DN6	0.649	0.013	0.137	0.576	-0.019	**0.000**	**1.805**	0.158	0.546	0.366	0.418	**0.000**	**1.898**	**0.000**	**1.372**
DN7	0.391	0.022	0.225	0.602	-0.015	**0.001**	**1.167**	0.784	-0.165	0.259	0.855	**0.000**	**4.347**	**0.000**	**3.442**
DN8	0.434	0.018	0.152	0.440	-0.029	**0.000**	**1.859**	**0.000**	**1.853**	0.385	0.451	**0.000**	**3.964**	**0.000**	**2.777**
DN9	**0.000**	**0.100**	**0.903**	0.074	0.075	**0.000**	**2.463**	0.084	-1.299	0.171	-0.970	**0.000**	**2.766**	**0.011**	**0.978**
DN10	0.337	0.018	0.151	0.345	-0.029	**0.006**	**0.665**	0.307	-0.874	**0.001**	**1.567**	**0.000**	**-3.330**	**0.036**	**0.689**

Table 6: Key to colour coding used in Table 6.

Key to colour code	
🟥	Meaningful increase
🟧	Significant increase
⬜	No trend
🟦	Significant decrease
🟦	Meaningful decrease
🟩	Baseline site
🟨	Impact site

Table 7: Summary of water quality changes at baseline and impact sites.

Impact	Up	Up	No	Down	Down	Baseline	Up	Up	No	Down	Down
WH2	2	1	3		1	WH1		1	4	1	1
WH3	2		3	1	1	HM1	1	2	3	1	
WH4	2	1	3		1	HM6			4	1	2
AK1	2		1	2	2	GS2	4		3		
AK2		1	4	1	1	RO1	2	1	3		1
HM2		3	3		1	RO4		2	4	1	
HM3	2	1	4			RO6	2	1	2	1	1
HM4	1		6			HV1	1		3	2	1
HM5		2	4	1		HV4	1		3	2	1
GS1	4	1	1		1	HV6	2		4	1	
GS3	2	1	4			TU2		1	5	1	
GS4	1		3	1	2	WA2	2		2	2	1
RO2	4	1	2			WA5	1		6		
RO3	2		3	1	1	WA7	3		3	1	
RO5	2		5			WN2	1	1	4	1	
HV2	2		4	1		WN5	1	1	5		
HV3	1	1	4		1	NN2	2	1	4		
HV5	3		2	1	1	NN3	1	2	4		
TU1	1	1	4	1		NN5	2		4		1
WA1	1	1	5			GY3	2	1	4		
WA3	4		2	1		GY4		1	5	1	
WA4			6	1		CH1	1	1	5		
WA6	1		5	1		CH3	1	2	2	1	1
WA8	4		2	1		TK3	4		3		
WA9	1	2	2		2	TK4	1	1	2	1	2
WN1	1		4		2	AX1	3	2	2		
WN3			7			AX2	3		4		
WN4	2	1	4			AX3	1	1	5		
NN1	3		3	1		DN2			7		
NN4	2	1	4			DN6	3		4		
GY1	2		4		1	DN7	3		4		
GY2	3		4			DN10	1	2	3		1
CH2	2		4	1							
CH4	2		3	1	1						
TK1	2	1	3		1						
TK2	4	1		1	1						
TK5	1		2	1	3						
TK6	4	1	2								
AX4	2	1	3		1						
DN1	3		3		1						
DN3	1	1	3	1	1						
DN4	1		6								
DN5	5		2								
DN8	4		3								
DN9	2	2	3								

Table 8: List of site names and field codes.

Field team	Code	River site
WHANGAREI	WH1	WAIPAPA AT FOREST RANGER
WHANGAREI	WH2	WAITANGI AT WAKELINS
WHANGAREI	WH3	MANGAKAHIA AT TITOKI BR
WHANGAREI	WH4	WAIRUA AT PURUA
AUCKLAND	AK1	HOTEO AT GUBBS
AUCKLAND	AK2	RANGITOPUNI AT WALKERS
HAMILTON	HM1	WAIPA AT OTEWA
HAMILTON	HM2	WAIPA AT WHATAWHATA
HAMILTON	HM3	WAIKATO AT HAM TRAFF BR
HAMILTON	HM4	WAIKATO AT RANGIRIRI
HAMILTON	HM5	WAIHOU AT TE AROHA
HAMILTON	HM6	OHINEMURI AT KARANGAHAKE
ROTORUA	RO1	TARAWERA AT LAKE OUTLET
ROTORUA	RO2	TARAWERA AT AWAKAPONGA
ROTORUA	RO3	RANGITAIKI AT MURUPARA
ROTORUA	RO4	WHIRINAKI AT GALATEA
ROTORUA	RO5	RANGITAIKI AT TE TEKO
ROTORUA	RO6	WAIKATO AT REIDS FARM
TURANGI	TU1	WANGANUI AT TE MAIRE
TURANGI	TU2	TONGARIRO AT TURANGI
WANGANUI	WA1	WAITARA AT BERTRAND RD
WANGANUI	WA2	MANGANUI AT SH3
WANGANUI	WA3	WAINGONGORO AT SH45
WANGANUI	WA4	WANGANUI AT PAETAWA
WANGANUI	WA5	RANGITIKEI AT MANGAWEKA
WANGANUI	WA6	RANGITIKEI AT KAKARIKI
WANGANUI	WA7	MANAWATU AT WEBER RD
WANGANUI	WA8	MANAWATU @ TEACHERS COLL
WANGANUI	WA9	MANAWATU AT OPIKI BRIDGE
GISBORNE*	GS1	WAIPAOA AT KANAKANAIA
GISBORNE*	GS2	WAIKOHU AT NO 1 BRIDGE
GISBORNE*	GS3	MOTU AT WAITANGIRUA
GISBORNE*	GS4	MOTU AT HOUPOTO
HAVELOCK NTH	HV1	MAKARORO AT BURNT BR
HAVELOCK NTH	HV2	TUKITUKI AT RED BRIDGE
HAVELOCK NTH	HV3	NGARURORO AT CHESTERHOPE
HAVELOCK NTH	HV4	NGARURORO AT KURIPAPANGO
HAVELOCK NTH	HV5	MOHAKA AT RAUPUNGA
HAVELOCK NTH	HV6	MOHAKA AT GLENFALLS
WELLINGTON	WN1	HUTT AT BOULCOTT
WELLINGTON	WN2	HUTT AT KAITOKE
WELLINGTON	WN3	RAUMAHANGA AT WAIHENGA
WELLINGTON	WN4	RAUMAHANGA AT WARDELLS
WELLINGTON	WN5	RAUMAHANGA AT SH2
NELSON	NN1	MOTUEKA AT WOODSTOCK
NELSON	NN2	MOTUEKA AT GORGE

Field team	**Code**	**River site**
NELSON	NN3	WAIRAU AT DIP FLAT
NELSON	NN4	WAIRAU AT TUAMARINA
NELSON	NN5	BULLER AT LONGFORD
GREYMOUTH	GY1	BULLER AT TE KUHA
GREYMOUTH	GY2	GREY AT DOBSON
GREYMOUTH	GY3	GREY AT WAIPUNA
GREYMOUTH	GY4	HAAST AT ROARING BILLY
CHRISTCHURCH	CH1	HURUNUI AT MANDAMUS
CHRISTCHURCH	CH2	HURUNUI AT SH1 BRIDGE
CHRISTCHURCH	CH3	WAIMAKARIRI AT GORGE
CHRISTCHURCH	CH4	WAIMAKARIRI ABOVE OLD HW BR
TEKAPO	TK1	OPIHI AT WAIPOPO
TEKAPO	TK2	OPIHI AT ROCKWOOD
TEKAPO	TK3	OPUHA AT SKIPTON BR
TEKAPO	TK4	WAITAKI AT KUROW
TEKAPO	TK5	HAKATARAMEA ABOVE MH BR
TEKAPO	TK6	WAITAKI AT SH1 BRIDGE
ALEXANDRA	AX1	CLUTHA AT LUGGATE BR
ALEXANDRA	AX2	KAWARAU AT CHARDS
ALEXANDRA	AX3	SHOTOVER AT BOWENS PEAK
ALEXANDRA	AX4	CLUTHA AT MILLERS FLAT
DUNEDIN	DN1	TAIERI AT TIROITI
DUNEDIN	DN2	SUTTON AT SH87
DUNEDIN	DN3	TAIERI AT OUTRAM
DUNEDIN	DN4	CLUTHA AT BALCLUTHA
DUNEDIN	DN5	MATAURA AT SEAWARD DOWNS
DUNEDIN	DN6	MATAURA AT PARAWA
DUNEDIN	DN7	ORETI AT LUMSDEN
DUNEDIN	DN8	ORETI AT RIVERTON HW BR
DUNEDIN	DN9	WAIAU AT TUATAPERE
DUNEDIN	DN10	MONOWAI BELOW GATES

* NIWA no longer maintains a field station at Gisborne, but the “GS” code has been retained for the ‘Gisborne’ sites – that are now serviced by the Rotorua ED team.