NIWA
Taihoro Nukurangi

Analysis of national river water quality data for the period 1998–2007

NIWA Client Report: CHC2010-038
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Executive Summary

This report has been prepared for the Ministry for the Environment (MfE) to provide an updated assessment of national river water quality in New Zealand. Data for this purpose have been based on routine water quality sampling undertaken by 16 regional councils and unitary authorities and by NIWA as part of the National River Water Quality Network (NRWQN). The assessment includes an analysis of water quality state (based on median data from 2003–2007) and trends in water quality calculated for 10 and 5-year time periods (1998–2007 and 2003–2007).

Analysis of water quality data shows that water quality is highly variable across the country. Median values for water quality analytes (2003–2007) frequently exceed the Australian and New Zealand Environment Conservation Council (ANZECC) trigger values in some regions, while *E. coli* numbers (95th percentile) frequently exceed the MfE/MoH (2003) Microbiological Water Quality Guidelines for recreation in all regions of the country. Median values for water quality analytes differed significantly between the regions. Classifying data using the REC (River Environment Classification) categories showed that the highest oxidised nitrogen and total nitrogen (TN) concentrations, and lowest clarity, were associated with REC Lowland *Source-of-flow* rivers (that is, rivers which have their sources in the lowlands). Poor clarity and high TN concentrations were also associated with Urban and Pasture *Land-cover* categories.

The trend analyses indicate that trend strength and direction is highly variable across the country. There were also considerable differences in trend strength and direction between the time periods. We used the binomial test to indicate whether there were “overall trends” in both regional council and NRWQN sites grouped in several ways. We deemed that there was an overall trend in a certain direction for a grouping if the number of sites that exhibited that trend were greater than could be expected if increasing and decreasing trends were equally likely. In this manner we found overall decreasing trends in clarity and increasing trends in conductivity, TN and total phosphorus (TP) at the national scale for the 1998 to 2007 period, all of which indicate degrading water quality.

When sites were grouped by region for the 1998–2007 period, we found the following overall trends, which all indicate deteriorating water quality:

- decreasing overall trends in clarity in the Waikato, Wellington, Hawke’s Bay and Manawatu-Wanganui regions

- increasing overall trends in conductivity in the Canterbury, Southland, Northland and Waikato regions

- overall increasing trends in oxidised nitrogen in the Canterbury and Waikato regions

- overall increasing trend in TN in the Waikato region
- overall increasing trends in both dissolved reactive phosphorus and TP in the Hawke's Bay and Otago regions.

However, we also found overall trends which are improvements in water quality. These trends in improving water quality make it difficult to conclude that there are strong regional patterns in water quality degradation. The improving overall trends include:

- decreasing trends in conductivity in Gisborne and Wellington regions
- decreasing trends in oxidised nitrogen in the Auckland, Wellington and Northland regions
- decreasing trends in both TN and dissolved reactive phosphorus in the Southland and Northland regions
- decreasing trends in ammoniacal nitrogen (NH_4-N) in Auckland, Canterbury and Northland regions
- decreasing overall trends in bacterial indicators (faecal coliforms and/or *Escherichia coli*) in Southland, Otago and Hawke's Bay

The strongest groupings in terms of identifying overall trends for the 1998–2007 period were the REC *Source-of-flow* and *Land-cover* categories. We found overall:

- decreasing trends in clarity in Hill and Low-elevation *Source-of-flow* categories and Pasture and Urban *Land-cover* categories
- increasing trends in TP in the Low-elevation *Source-of-flow* category and Pasture *Land-cover* category
- increasing trends in conductivity, oxidised nitrogen and TN in the Pasture *Land-cover* category.

These results suggest that water quality decreased over the 1998 to 2007 period in low-elevation areas and in catchments dominated by pastoral land cover. Over the same period however, NH_4-N showed decreasing trends in the same categories.

Trends in water quality analytes for NRWQN sites in the present study varied from those reported by a previous study that analysed trends over a 19-year period. For the 19-year trend analysis, increasing trends were reported for all nutrients. For the 10-year time period however, overall increasing trends were only reported for total nitrogen and conductivity.

The robustness of our analyses was limited by the data obtained from the regional councils some of whose monitoring networks and protocols have been configured for purposes other than trend detection over short time periods (eg, five years) and national state of environment reporting. This particularly had implications for the trend analyses. For example, some of our overall trend evaluations included many sites with stable trends, (i.e. trend slopes of exactly zero), which can arise due to lack of precision in water quality analyses and data storage. This probably reduces the certainty with which we can conclude there were overall trends for some analytes, particularly DRP, NH_4-N and TP. In addition, there may be trends which have not been detected due to the sampling frequency (i.e. less than monthly sampling). Lack of detected trends in those areas should not be used to infer that they have fewer trends. Also, trends which have been detected at sites where sampling is quarterly may actually be stronger than they appear.

1. Introduction

As part of its National Environment Reporting Programme, the Ministry for the Environment (MfE) reports on a core set of environmental indicators. There are currently five freshwater indicators, one of which is focused on river water quality. The aim and purpose of this report is to update national indicator data for river water quality in New Zealand. The report is based on regional council river water quality and National River Water Quality Network (NRWQN) data gathered up to, and including, 2007.

The data was analysed to provide summary statistics for water quality state and trends in water quality. The assessment includes an analysis of water quality state (based on median data from 2003–2007) and trends in water quality calculated for 10 and 5-year time periods (1998–2007 and 2003–2007). We also present relationships of both state and trends with natural and human factors. This assessment will provide information for state of environment reporting.

This project covered four major tasks:

- obtaining and formatting the water quality data time-series from regional councils and the NRWQN
- associating water quality monitoring sites with contextual information such as flow estimates for each sampling occasion and the River Environment Classification (REC)
- producing summary statistics for each site for the period over which water quality measurements were taken
- trend analysis for each water quality analyte and site.

The data and all results of analyses have been provided to MfE digitally. This short report describes how the data were assembled and analysed and presents some of the results and conclusions that can be drawn from the data.

2. Methods

2.1 Obtaining and formatting the data

All New Zealand regional councils (Table 1) maintain extensive water quality databases, which are frequently used by MfE and other agencies (including NIWA) for specific research projects (e.g., Sorrell *et al,* 2006, McDowell *et al*, 2006). When discussing data requirements for the current project with MfE, it was decided to use a water quality data set assembled in late 2007 (described by McDowell *et al*, 2009) rather than compile a new and more up-to-date set of data specifically tailored to MfE's needs. In retrospect, as became clear during peer review of an earlier draft of this report, the resulting data set contained some gaps in temporal and spatial coverage corresponding to:

(a) mixed (quarterly and monthly) reporting of results by individual councils

(b) incomplete geographical coverage where the 2007 data did not represent all sites in some regions

(c) absence of more recent (post-2007) data which are likely to reflect changes to monitoring programmes in some regions since the 2007 request.

Table 1: Names and abbreviations for regional councils and unitary authority whose water quality data was included in this study

Regional council name	Regional council abbreviation	Regional council name	Regional council abbreviation
Northland Regional Council	NRC	Greater Wellington Regional Council	GWRC
Auckland Regional Council	ARC	Tasman District Council	TDC
Environment Waikato	EW	Nelson City Council	NCC
Environment Bay of Plenty	EBOP	Marlborough District Council	MDC
Gisborne District Council	GDC	West Coast Regional Council	WCRC
Hawke's Bay Regional Council	HBRC	Environment Canterbury	ECAN
Taranaki Regional Council	TRC	Otago Regional Council	ORC
Horizons Regional Council	HRC	Environment Southland	ES

The consequences are that more sites than are reported here are potentially available for analysis, and that more up-to-date analyses (e.g., for 1998–2009) are now possible. It was also highlighted that some regions do have flow data corresponding to each water quality measurement but, for the original request, did not provide the flow data with their water quality data.

The data sets used for this study provided records of commonly measured water quality analytes (Table 2) at a range of sites over time, but varied widely in reporting formats, reporting conventions, analyte names, units of measurement, and sampling frequency. For example, reporting formats ranged from a single Excel sheet with all analytes for all sites stored in a single column, to multiple workbooks for individual sites with data for each site distributed over multiple worksheets with each analyte stored in a separate column. Electrical conductivity was provided as a field measurement (labelled “Conductivity” or some near equivalent), as a laboratory measurement (typically labelled EC25, i.e., conductivity at 25°C), and sometimes as both variants within a single region. Units of measurement (most notably for conductivity) varied between regions, and (less commonly) for a single analyte within a region. To consolidate these data into a uniform structure and minimise the potential for error associated with manually copying data between worksheets, we used a modified version of a MS-Access database developed for a previous MfE water quality review (Sorrell *et al.* 2006). When retrieving data for subsequent analyses, we adopted the following conventions:

1. field conductivity (COND) was used where available, otherwise EC25 (which was highly correlated ($r^2 = 0.85$) with COND for sites where both analytes were reported) was used as a surrogate

2. analytes marked as below a specified detection limit were recoded as half the detection limit. For analytes marked as above a specified level (e.g., *E. coli* > 20 000), we used the numerical value as given

3. total nitrogen (TN) for regions which did not specifically report this analyte was calculated (where possible) as the sum of Nitrate+Nitrite Nitrogen (NNN) plus Total Kjeldahl Nitrogen (TKN).

Data from the 77 sites in the National Rivers Water Quality Network (NRWQN) were also added to the database. For consistency, we used the NRWQN data when a site coincided with a regional council site (24 sites in 11 regions) and the regional council data were not used. Data associated with each site included:

- site name

- location and regional council identifier (if available)

- NZMS260 grid reference (converted from NZTM as appropriate)

- reach number (NZ Reach) as defined in the River Environment Classification (REC) scheme (Snelder and Biggs, 2002).

All sites were then assigned a unique identifier based on the corresponding regional council name and site identifier. All analyses were derived from queries of this database, which produced water quality data for the 11 analytes described in Table 2 in consistent units.

Table 2: **Water quality analytes included in this study**

Analyte type	Analyte name	Description	Units
Physical	CLAR	Black disc visibility	m
	COND	Electrical conductivity	μS/cm
	SS	Total suspended solids	ppm
Nutrients	NH_4-N	Ammoniacal nitrogen	ppm
	NO_x-N	Oxidised nitrogen	ppm
	TN	Total nitrogen	ppm
	DRP	Dissolved reactive phosphorus	ppm
	TP	Total phosphorus	ppm
Bacteria count	*E. coli*	*Escherichia coli*	n/100 mL
	FC	Faecal coliforms	n/100 mL

Within the regions, over the duration of the sampling, water quality analytical methods have changed. One example of this is field conductivity and lab conductivity at 25°C. Some regional councils previously used one method but, during the sampling period, changed to another method. In such cases, we combined the data that was analysed using different methods to provide a continuous record. In the case of field conductivity and lab conductivity, this was justifiable because the two methods produce data that are strongly correlated ($r^2 = 0.85$).

2.2 River Environment Classification

Site median values of water quality analytes and trend slopes were grouped by River Environment Classification (REC) classes in this study to provide insights into the spatial patterns of water quality state and trends and the environmental and human factors that determine these. The REC groups rivers and parts of rivers that share similar environmental characteristics and which therefore tend to have similar physical, ecological and biological characteristics (Snelder and Biggs, 2002). The REC is based on a digital representation of the New Zealand river network comprising segments with a mean segment length of ~700 m. Each segment is associated with its unique upstream catchment. The catchment of each segment is described by various environmental variables (i.e. catchment characteristics) and these are categorised to define REC classes.

REC *Source-of-flow* and *Land-cover* categories classify segments of the river network according to their dominant topography and land cover as set out in Table 3. REC

Source-of-flow and *Land-cover* categories have previously been shown to distinguish significant differences in many river characteristics including water quality and hydrology (e.g., Snelder *et al.*, 2005). We used the REC *Source-of-flow* and *Land-cover* categories to group water quality sites into categories.

Table 3: REC categories for the *Source-of-flow* and *Land-cover* groups of categories and the category criteria (see Snelder and Biggs, 2002 for details)

Category Grouping	Category	Symbol	Criteria
Source-of-flow	Low elevation	L	majority of catchment draining land lower than 400 m
	Hill	H	majority of catchment draining land between 400 and 1000 m
	Mountain	M	majority of catchment draining land greater than 1000 m
	Glacial Mountain	GM	More than 2 per cent of catchment covered by glacier
	Lake	Lk	flow strongly influenced by upstream lakes
Land-cover	Urban	U	The spatially dominant land-cover category unless P exceeds 25 per cent of catchment area, in which case class = P, or unless U exceed 15 per cent of catchment area, in which case class = U.
	Pasture	P	
	Exotic Forest	EF	
	Scrub	S	
	Indigenous Forest	IF	
	Tussock	T	

We used the geographic coordinates and site names to locate all sites in the database on the REC river network. Once linked with the river network, all sites were able to be associated with their REC categories and other data (e.g., site elevation) that were subsequently used in our analyses. Sites were discarded that could not be uniquely co-located with a single NZ Reach[1], or which were in areas (such as the Aorere River in northwest Nelson) where the REC contains unresolved errors. Sites in estuarine waters were flagged so as to avoid skewing data for analytes (such as conductivity) which are likely to be highly elevated in such environments.

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[1] The NZ reach is a unique valley segment, defined by the upstream and downstream tributaries, which is represented by the digital river network on which the REC is based.

2.3 Summary statistics

For each water quality analyte for each site for each year we calculated various (5th, 20th, 50th, 80th, 95th) percentiles. Since many sites had relatively few observations within each year, we also pooled data across years to calculate these percentiles for each analyte for each site. These percentiles were calculated using the Hazen method (Hazen, 1914) (http://www.mfe.govt.nz/publications/water/microbiological-quality-jun03/hazen-calculator.html).

Water quality state for each site was summarised by the median value of each analyte for each sampling site. The time period used for the water quality state analysis was 2003 to 2007. Sites that were included in the state analysis had data in four of the five years, and at least 16 out of 20 possible quarters were represented.

To provide an insight into the spatial patterns of water quality and the environmental and human factors that determine these, we compared the median values of selected analytes for sites grouped by regions and by REC *Source-of-flow* and *Land-cover* categories. For the regional comparisons, the NRWQN sites were grouped separately (i.e. not added to the regional council sites) to allow comparison with other studies carried out on the NRWQN data (e.g., Ballantine and Davies-Colley, 2009b). We used box plots to present these comparisons and tested for differences between groups using the non-parametric Kruskal Wallis test. Where there were significant differences we used the post-hoc, non-parametric Mann Whitney test to test for significant differences between groupings. Box plots and test of difference between groups were restricted to groups comprising at least 10 sites.

2.4 Trend analysis

2.4.1 Method

The trend assessment was carried out on data for both a ten (1998–2007) and a five (2003–2007) year period using the Time Trends software (http://www.niwa.co.nz/our-science/freshwater/tools/analysis). Trend analysis is only meaningful if calculated using a data set with few missing values. Not all data sets provided by the regional councils were sufficiently complete (see section 2.1) to provide robust trend analyses. For the 10-year trend analysis, sites that had data for 32 quarters of 40 possible quarters were included. For the five-year analysis, sites that had data for 16 out of 20 possible quarters were included. These criteria permitted the inclusion of regions where data were collected bi-monthly and quarterly. Trends for some ECAN sites and all HBRC and TDC sites are based on quarterly data while those for ORC are based on bi-monthly data and all other regions are monthly.

Trend analysis was carried out on raw data and on flow adjusted data but only the flow adjusted trends are discussed in this report. The flow adjustment procedure is built into the Time Trends software and was performed using LOWESS[2] (LOcally WEighted Scatterplot Smoothing) with a 30 per cent span. Every data point in the record was 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). For sites at which we had flow data, we used this to flow adjust the data for each analyte. We also used our flow estimation method to estimate flows at all sites and to perform flow adjustment. This allowed us to compare the results of the trend analysis based on the observed and estimated flows.

The non-parametric Seasonal Kendall Sen Slope Estimator (SKSE, Sen 1968) 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 by the raw data median to give the *relative* SKSE (RSKSE), allowing for direct comparison between sites measured as per cent change per year. The RSKSE may be thought of as an index of the 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 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 or any larger trend, either upwards or downwards, is most unlikely to have arisen by chance).

2.4.2 Determination of overall trends

We used the binomial test[3] to indicate whether there were "overall trends" in sites grouped in several ways. We deemed that there was an overall trend in a certain direction for a grouping if the number of sites that exhibited that trend were greater than could be expected if increasing and decreasing trends were equally likely. The binomial test determined whether there are more trends in a group of sites than could be expected by chance. To perform a Binomial test we first counted the number of positive RSKSE values (increasing trends). Note that all RSKSE values were included regardless of their p values. We then performed a "two-tailed" binomial test based on expectation that sites have a 50 per cent probability of having an increasing trend. If the resulting p-value was less then 0.05 we rejected the null hypothesis, i.e. we concluded that there were more trends in a group than could be expected by chance and that the group exhibited an "overall" trend. We then determined the overall trend

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[2] LOWESS (locally weighted least squares) is a data analysis technique for producing a "smooth" function that describes a "noisy" relationship between two variables (Cleveland, 1979).

[3] The binomial test is used for discrete dichotomous data, where each sampling event can result in one of only two outcomes.

direction as positive if the proportion of positive trends was greater than 50 per cent and negative if the reverse were true. A complication arises because RSKSE values can take the value zero for several reasons, some of which are related to data quality. In particular, RSKSE can be zero if there are many non-detect values in the time-series or if there are many identical values (ties), which occurs if the precision of the test or recorded concentrations are low. We added half of the number of sites with RSKSE values equal to zero to the number of increasing trends and performed the test based on this number. We provide the number of sites with RSKSE values equal to zero when reporting binomial test results to provide an indication of the data quality associated with the test. Note that the reported values are the number of sites with RSKSE values equal to zero regardless of their *p*-values and should not be confused with stable trends (i.e. RSKSE values equal to zero and $p < 0.05$).

We assessed overall trends by grouping sites in several ways. First we grouped trends for just the NRWQN sites. This allows comparison of the overall trends detected in this study with those calculated for the 19-year period by Ballantine & Davies-Colley (2009b). We grouped all sites and used the overall trends as an indication of the national trend. We also grouped trends for all sites by region and by REC *Source-of-flow* and *Land-cover* categories.

To provide an indication of trend variability within the various groupings and differences in overall trends between groups we produced box and whisker plots of the RSKSE values for these groupings and tested for significant differences in trends between groups using the non-parametric Kruskal Wallis test. Where there were significant differences in the median RSKE values we used the post-hoc, non-parametric Mann Whitney test to test for significant differences between all pairs of groupings. Box plots and test of difference between group were restricted to groups comprising at least 10 sites.

2.4.3 Categorisation of trends

Scarsbrook (2006) recognised that statistical significance of a trend does not necessarily imply a ‘meaningful’ trend, i.e., one that is likely to be relevant in a management context. We followed Scarsbrook (2006) in denoting a ‘meaningful’ trend as one for which the RSKSE is statistically significant and has an absolute magnitude > 1 per cent year^{-1}. Scarsbrook (2006) recognised that the choice of 1 per cent year^{-1} as the ‘meaningful’ threshold is arbitrary, but at the moment we have no basis for an alternative approach. Therefore, trends were categorised as follows:

i. **stable trend** – a trend (RSKSE value) with a value of exactly zero

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

iii. **significant trend** – the null hypothesis for the Seasonal Kendall test was rejected (i.e., $P < 0.05$) but the magnitude of the trend (SKSE) was less than one per cent per annum of the raw data median (i.e., the RSKSE value was less than 1 per cent year^{-1}). Note that the trend at some sites may be 'significant but not meaningful'

iv. **'meaningful' trend** – 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 per cent per annum of the raw data median (i.e., the RSKSE value was greater than 1 per cent year^{-1}).

2.4.4 Flow estimation methods

It is important to have flow measurements accompanying each water quality measurement because many water quality analytes are subject to either dilution (decreasing concentration with increasing flow, e.g., conductivity) or concentration (increasing concentration with increasing flow, e.g., total phosphorus). Data can be flow adjusted before trend analysis, to remove the effects of variation in stream flow on water quality analyte concentrations. Because changes in stream flow are tied to natural changes in precipitation and evapotranspiration, flow adjustment of water quality analyte concentrations allows trends caused by other, largely anthropogenic, changes to be more directly assessed.

Many regional council water quality sampling sites either did not have flow measurements or did not provide flow measurements corresponding to the sampling occasions (see section 2.1). Of a total of 735 sites for which we had some water quality data, 454 had no flow information provided. Therefore, we developed and tested three methods for estimating flow at the sampling location on the date corresponding to each water quality sample. Details of these methods and tests of their overall performance are provided in Appendix 1. We used the best performing method for estimating flows based on our tests. This method used data from gauging stations in the New Zealand Hydrometric Network with five or more years of data and that are free from flow modification due to abstractions and dams (n = 264). For each water quality site and each date when water quality had been measured we identified the most appropriate gauging station. This gauging station was defined as the geographically closest (straight line distance) gauging station that shared the same REC Climate and *Source-of-flow* class and that also had a record of flow on the date of interest. The flow (mean flow on the day) recorded on the date of interest at the closest gauging station was standardised by dividing by mean flow for the entire flow monitoring period. Standardised flows (i.e. recorded flow divided by mean flow) were sufficient for the purpose of flow adjustment because we were interested in the relative changes in flow on different water quality measurement occasions, rather than absolute flow magnitudes.

To characterise the accuracy of the flow estimation method we compared RSKSE values derived with observed flows and estimated flows for the period 1998–2007 for all analytes and sites with recorded flows. We characterised the accuracy of the RSKSE values derived from the estimated flows in two ways. First we characterised the accuracy of the individual RSKSE values derived from the estimated flows by linear regression of the RSKSE values derived from the observed flow (y) versus RSKSE values derived from predicted flow (x). In general terms we can have confidence in the flow estimation method if the fitted regression line is not appreciably different to the 1:1 line (i.e. a perfect correspondence between the two RSKSE values). Second, we characterised the rate of correct classification of trend direction (positive or negative) when RSKSE values were derived from the estimated flows. High correct classification rates provide confidence that the analysis of overall trends (which are based on the rate of positive or negative trends using the binomial test) was accurate.

Table 4 indicates that the individual RSKSE values derived from the estimated flows corresponded well with the RSKSE derived from the observed flows for the 10 analytes. The bacterial indicators (*E.coli* and FC) had the greatest variation from a 1:1 correspondence indicating that RSKSE for individual sites had the largest error for these analytes. Formal tests of the correspondence and quantification of the errors associated with the RSKSE values can be made, but are not reported here. The rate of correct classification of trend direction was also high (between 85% and 96%; Table 4). All trends reported in this report have been calculated using the estimated flows for consistency. However, trends calculated from observed flows were also supplied separately as part of this project.

Table 4. **Details of tests of the RSKSE values derived from the predicted flows including the number of sites included in each test, the r^2 of each of the linear regressions and the rate of correct classification of trend direction.**

Analtyte	Number of sites in test	Regression r^2	Correct classification rate
CLAR	117	0.88	85
COND	124	0.9	94
DRP	120	0.97	96
ECOLI	36	0.87	89
FC	32	0.82	88
NH4N	121	0.96	92
NO3N	122	0.95	88
SS	9	0.94	89
TN	114	0.94	87
TP	119	0.94	92

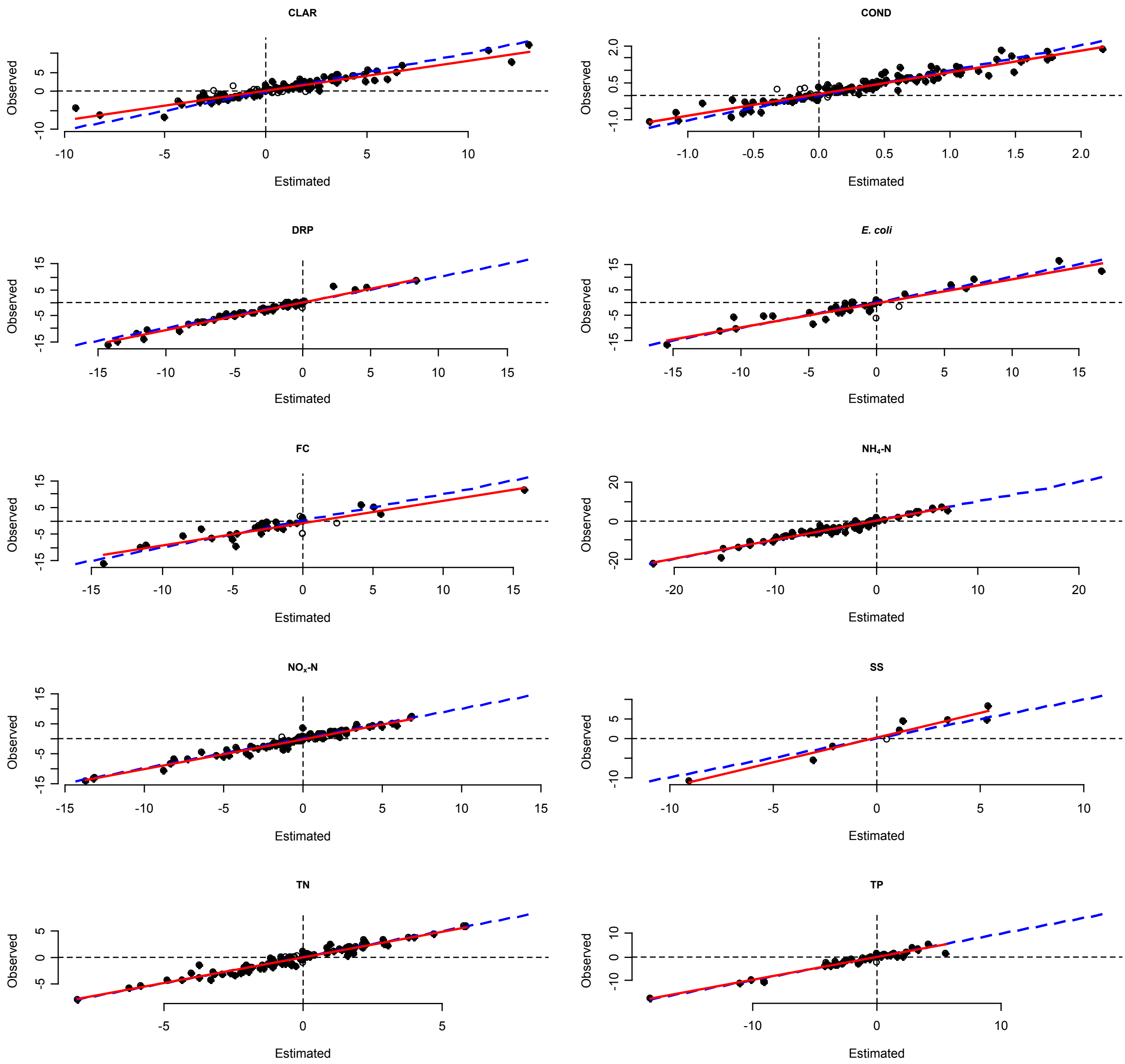

Figure 1: Comparison of RSKSE values derived with observed flows and estimated flows for the period 1998–2007 for all analytes and sites with recorded flows. The red line represents the best fit (linear regression) of the RSKSE values derived from observed versus estimated flow. The dashed blue line shows a perfect agreement between the RSKSE values. The solid points represent sites for which the classification of the trend directions (positive or negative) derived using both observed and estimated flows agree and hollow points indicate sites where these disagree.

3. Results

3.1 Water quality state by region (median values 2003–2007)

To facilitate comparison, the median values of nutrients and clarity for sites grouped by regional council and the NRWQN are presented in box plots (Figure 2 to Figure 6). Higher nutrient concentrations are indicative of reduced water quality, while higher values for clarity are indicative of better water quality. To place these values in context they have been compared with guidelines (Table 5). The median nutrient concentrations have been compared with the New Zealand trigger values for the protection of aquatic ecosystems from the Australian and New Zealand Environment Conservation Council (ANZECC) guidelines (ANZECC, 2000). The trigger values are not national standards but rather, have been devised to assess the levels of physical and chemical stressors which might have ecological or biological effects. Rather than implying that there will be ecological and biological effects caused by increased levels of physical and chemical stressors, breaches of trigger levels indicate cause for further consideration of water quality issues. Conversely, where trigger levels are *not* breached we can have reasonable confidence that water quality is sufficient to support the ecological values. We compared the median clarity measurements to the MFE (1994) water quality guidelines for clarity. The 95th percentile values for *E. coli* are presented in Figure 7 and compared with the microbiological water quality guidelines for recreational use (MfE and MoH, 2003), which are based on the 95th percentile value for *E. coli.*

Table 5: ANZECC trigger values for nutrients (based on median values), MfE guideline for clarity (based on median values) and MfE/MoH guideline value (95th percentile) for *Escherichia coli*

	CLAR (m)	DRP (ppm)	*E. coli* (/100ml)	NH_4-N (ppm)	NO_x-N (ppm)	TN (ppm)	TP (ppm)
ANZECC (lowland)		0.010		0.021	0.444	0.614	0.033
ANZECC (upland)[4]		0.009		0.010	0.167	0.295	0.026
MFE Guideline	1.6						
MfE/MoH			550[5]				

Applying the criteria outlined in section 2.3 meant that Nelson City and Marlborough District had insufficient data and were therefore not included in the state analysis. Table 6 shows the percentage of sampling sites by analyte and region at which median

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[4] Above 150 metres a.s.l.

[5] The action threshold for *E. coli* is 550 mpn/100 ml. This guideline is for recreational water quality and applies to the "summer season" (1 November to 31 March).

concentrations exceeded the guidelines shown in Table 5. Gaps in Table 6 represent analytes for which either no or insufficient data were provided.

3.1.1 Total phosphorus (TP)

Median TP for sites grouped by regional council and the NRWQN are presented in Figure 2. Median TP concentrations exceeded the ANZECC trigger values at more than 50 per cent of included sites in Northland, Auckland, Waikato and Southland regions (Table 6). Concentrations differed significantly between regions (Kruskal Wallis, $P < 0.05$). Details of significant differences between TP concentrations for individual regions are provided in Table 7. Median TP concentrations for Auckland, Northland and the Waikato were significantly higher than those for the other regions and NRWQN sites. Median TP concentrations for the NRWQN sites were significantly lower than those in the Northland, Auckland, Waikato, Wellington, Otago and Southland regions and higher than those in Tasman District. Significant differences were also observed between other regions.

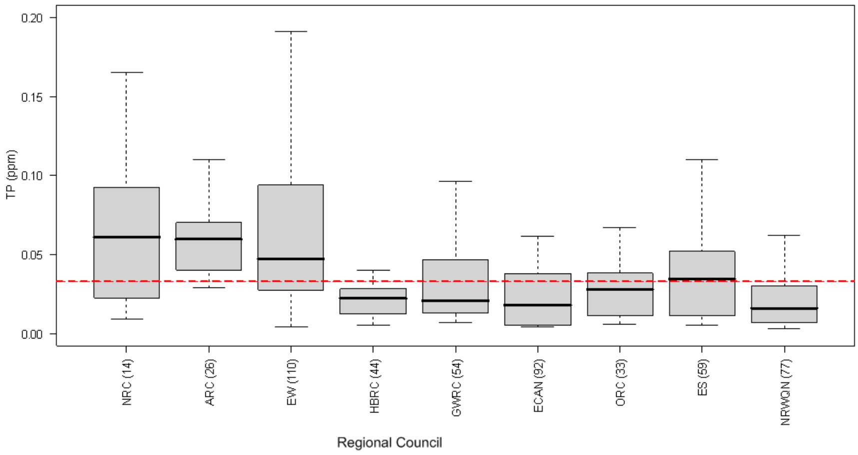

Figure 2: Median TP concentrations of sites grouped by region and the NRWQN for 2003–2007.[6] The ANZECC trigger values for TP for lowland and upland sites are 0.033 (shown on box plot) and 0.026 ppm respectively.

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[6] The lower boundary of the box plots indicates the 25th percentile, a line within the box marks the median, and the upper boundary of the box indicates the 75th percentile. Whiskers above and below the box indicate the 95th and 5th percentiles. Because percentiles were calculated by interpolation, groups were not included on the plots unless they included at least 10 data points. The number of sites in each grouping (x-axis) is shown in the brackets after the group names.

Table 6: **Percentage of sampling sites by analyte and region or the NRWQN for 2003–2007 at which median nutrient concentrations exceeded the ANZECC (2000) guidelines for nutrient, median clarity was lower than the 1.6 m guideline value (MfE, 1994) and the 95th percentile for *E. coli* exceeded the MfE/MoH action threshold. Number of sampling sites for each regional council, unitary authority and the NRWQN is included. nd = no data provided.**

Region	TP		DRP		TN		NO_x-N		CLARITY		*E. coli*	
	%	n	%	n	%	n	%	n	%	n	%	n
NRC	71	14	79	14	36	14	14	14	71	14	100	14
ARC	85	26	92	26	58	26	42	26	100	2	100	6
EW	65	110	71	110	56	110	48	110	72	98	80	83
EBOP	0	3	80	10	nd	0	40	10	nd	0	90	10
HBRC	14	44	41	44	27	44	23	44	38	40	0	3
TRC	44	9	89	9	33	9	33	9	22	9	89	9
GDC	nd	0	26	23	nd	0	10	10	nd	0	nd	0
HRC	nd	0	50	6	nd	0	50	6	67	6	100	6
GWRC	35	54	43	54	41	54	37	54	46	54	61	54
TDC	0	7	12	8	25	8	25	8	9	23	42	31
ECAN	29	92	42	92	58	92	55	92	nd	0	69	75
WCRC	nd	0	nd	0	nd	0	nd	0	nd	0	67	6
ORC	33	33	24	33	33	33	18	33	nd	0	73	33
ES	53	59	54	59	66	59	56	59	71	59	82	60
NRWQN	21	77	23	77	21	77	16	77	53	77	nd	0

3.1.2 Dissolved reactive phosphorus (DRP)

Median DRP concentrations exceeded the ANZECC trigger value at more than 50 per cent of included sites in the Northland, Auckland, Waikato, Bay of Plenty, Taranaki, and Southland regions (Table 6, Figure 3)

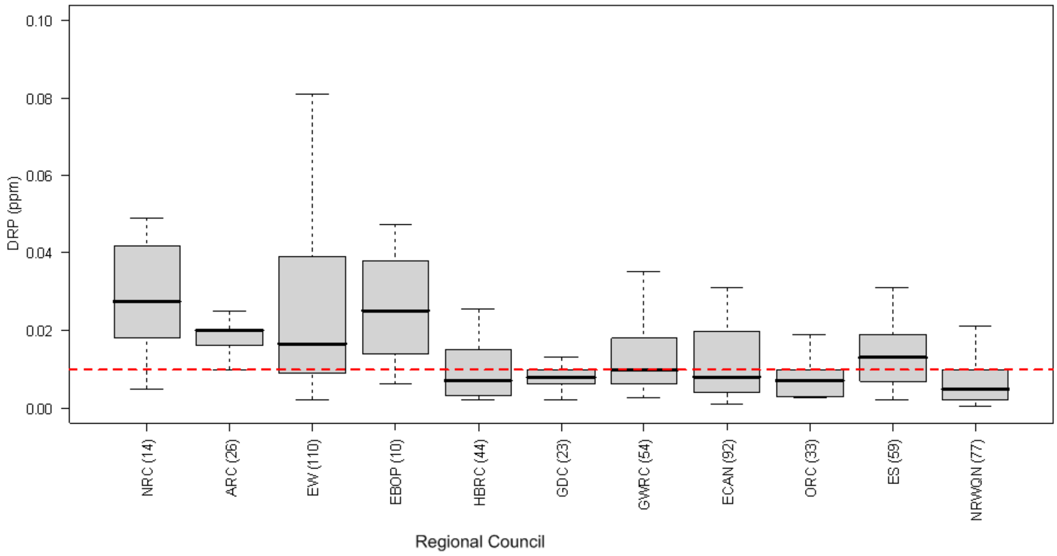

Figure 3: **Median DRP concentrations of sites grouped by region and the NRWQN for 2003–2007. See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for DRP for lowland and upland sites are 0.010 (shown on box plot) and 0.009 ppm respectively.**

3.1.3 Total Nitrogen (TN)

Median TN concentrations exceeded the ANZECC trigger value at more than 50 per cent of sites in the Auckland, Waikato, Canterbury and Southland regions (Table 6). TN concentration was highest in Southland (Figure 4).

Median TN concentrations differed significantly between some regions (Kruskal Wallis, $P<0.05$). Details of significant differences between median TN concentrations for individual regions are provided in Table 9. TN concentrations for NRWQN sites were significantly lower than those for six of the regions (Auckland, Waikato, Hawke’s Bay, Wellington, Canterbury and Southland).

3.1.4 Oxidised Nitrogen (NO_x-N)

Median NO_x-N concentrations exceeded the ANZECC trigger value at greater than 50 per cent of sampling sites for rivers in the Canterbury and Southland regions. Median NO_x-N concentration was highest in Canterbury (Figure 5).

Table 7 **Mann Whitney statistical test results undertaken to highlight differences between the median TP concentrations between regions. Statistically significant differences are highlighted. (Significance level *P* <0.05; ns = no statistical significant difference between the median concentrations; sig = significant difference between the median concentrations.)**

TP	**ARC**	**NRC**	**EW**	**BOP**	**HBRC**	**TRC**	**GWRC**	**TDC**	**ECAN**	**ORC**	**ES**
NRC	ns										
EW	ns	ns									
BOP	**sig**	ns	ns								
HBRC	**sig**	**sig**	**sig**	ns							
TRC	**sig**	ns	ns	ns	ns						
GWRC	**sig**	**sig**	**sig**	ns	ns	ns					
TDC	**sig**	sig	ns	ns	**sig**	**sig**	**sig**				
ECAN	**sig**	**sig**	**sig**	ns	ns	**sig**	**sig**	**sig**			
ORC	**sig**	**sig**	**sig**	ns	ns	ns	ns	**sig**	ns		
ES	**sig**	**sig**	**sig**	ns	ns	ns	ns	**sig**	**sig**	ns	
NRWQN	**sig**	**sig**	**sig**	ns	ns	**sig**	**sig**	ns	ns	**sig**	**sig**

Table 8: Mann Whitney statistical test results undertaken to highlight differences between the median DRP concentrations between regional councils. Statistically significant differences are highlighted. (Significance level P <0.05; ns = no statistical significant difference between the median concentrations; sig = significant difference between the median concentrations.)

DRP	**NRC**	**ARC**	**EW**	**EBOP**	**GDC**	**HBRC**	**TRC**	**HRC**	**GWRC**	**TDC**	**ECAN**	**ORC**	**ES**
ARC	ns												
EW	ns	ns											
EBOP	ns	ns	ns										
GDC	**sig**	**sig**	**sig**	**sig**									
HBRC	**sig**	**sig**	ns	**sig**	**sig**								
TRC	ns	ns	ns	ns	**sig**	**sig**							
HRC	ns	ns	ns	ns	**sig**	ns	ns						
GWRC	**sig**	**sig**	**sig**	**sig**	**sig**	ns	**sig**	ns					
TDC	**sig**	**sig**	**sig**	**sig**	**sig**	**sig**	**sig**	ns	**sig**				
ECAN	**sig**	**sig**	**sig**	**sig**	ns	**sig**	**sig**	ns	**sig**	ns			
ORC	**sig**	**sig**	ns	**sig**	ns	ns	**sig**	**sig**	**sig**	**sig**	ns		
ES	**sig**	**sig**	ns	**sig**	**sig**	ns	**sig**	**sig**	ns	**sig**	ns	ns	
NRWQN	**sig**	**sig**	**sig**	**sig**	ns	**sig**	**sig**	**sig**	**sig**	ns	**sig**	**sig**	**sig**

Table 9: Mann Whitney statistical test results undertaken to highlight differences between the median TN concentrations between regional councils. Statistically significant differences are highlighted. (Significance level *P* <0.05; ns = no statistical significant difference between the median concentrations; sig = significant difference between the median concentrations.)

TN	**NRC**	**ARC**	**EW**	**HBRC**	**TRC**	**GWRC**	**TDC**	**ECAN**	**ORC**	**ES**
ARC	**sig**									
EW	**sig**	ns								
HBRC	ns	**sig**	**sig**							
TRC	ns	ns	ns	ns						
GWRC	ns	ns	**sig**	ns	ns					
TDC	ns	ns	ns	ns	ns	ns				
ECAN	**sig**	ns	ns	**sig**	ns	**sig**	ns			
ORC	ns	**sig**	**sig**	ns	ns	ns	ns	**sig**		
ES	**sig**	ns	ns	**sig**	ns	**sig**	ns	ns	**sig**	
NRWQN	ns	**sig**	**sig**	**sig**	ns	**sig**	ns	**sig**	ns	**sig**

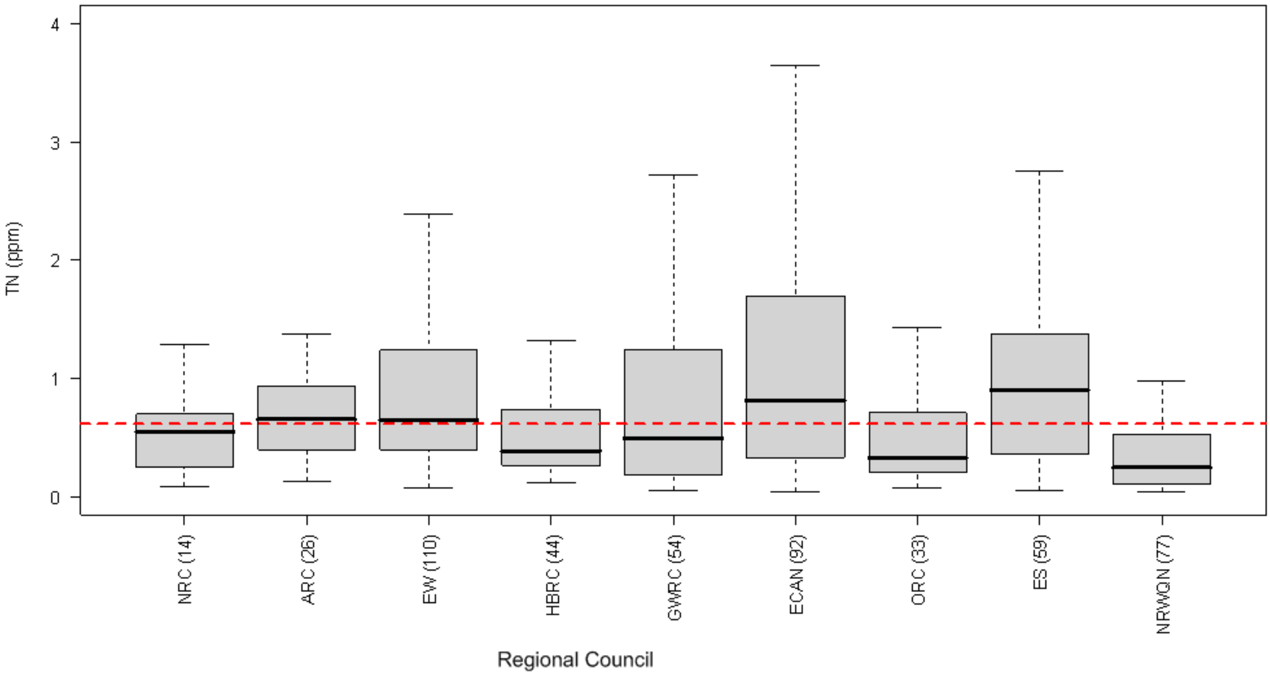

Figure 4: Median values for TN of sites grouped by region and the NRWQN (2003–2007). See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for TN for lowland and upland sites are 0.614 (shown on box plot) and 0.295 ppm respectively.

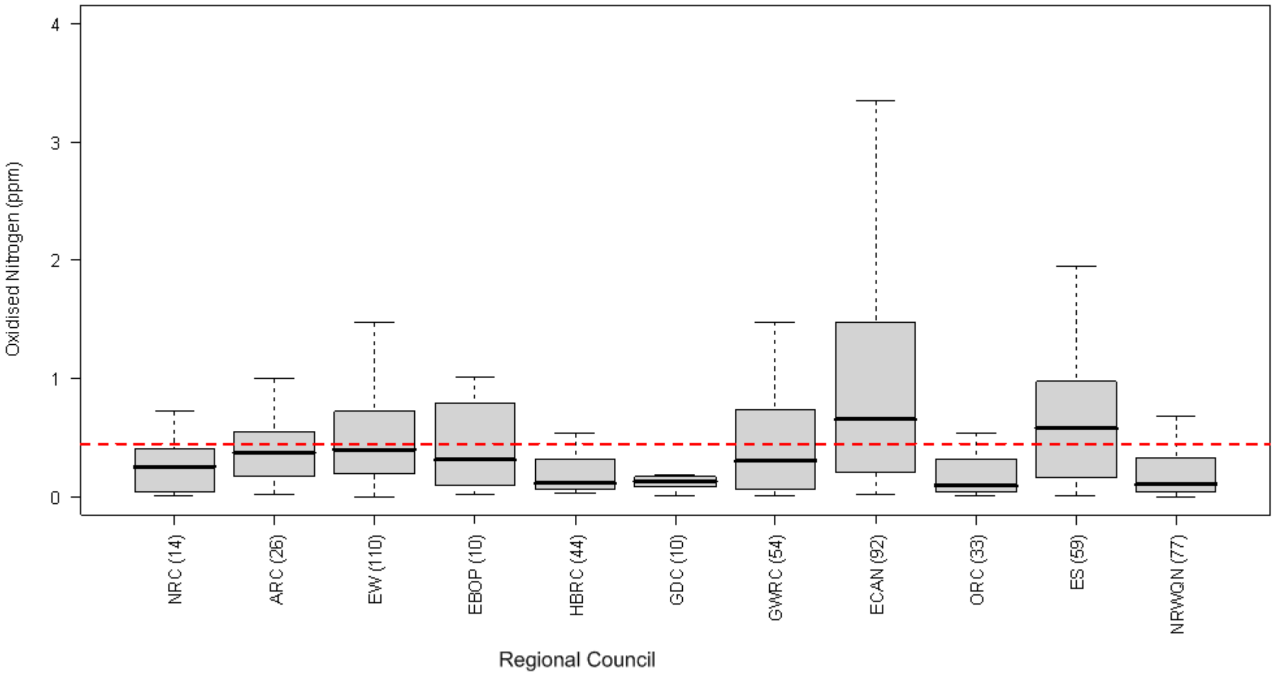

Figure 5: Median NO_x-N concentrations of sites grouped by region and the NRWQN (2003-2007). See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for TN for lowland and upland sites are 0.444 (shown on box plot) and 0.167 ppm respectively.

Median NOx-N concentrations differed significantly between some regions (Kruskal Wallis, P<0.05). Details of significant differences between median NOx-N concentrations for individual regions are provided in Table 10. NO_x-N concentrations for Canterbury were significantly different from those for seven other regions.

3.1.5 Clarity

Not all regional councils provided water clarity data. Median clarity was below (i.e. did not meet) the MfE (1994) guideline value at more than 50 per cent of sites in the Northland, Auckland, Waikato, Manawatu-Wanganui and Southland regions (Table 6). The median value for clarity was lowest in Southland and highest in Tasman district (Figure 6).

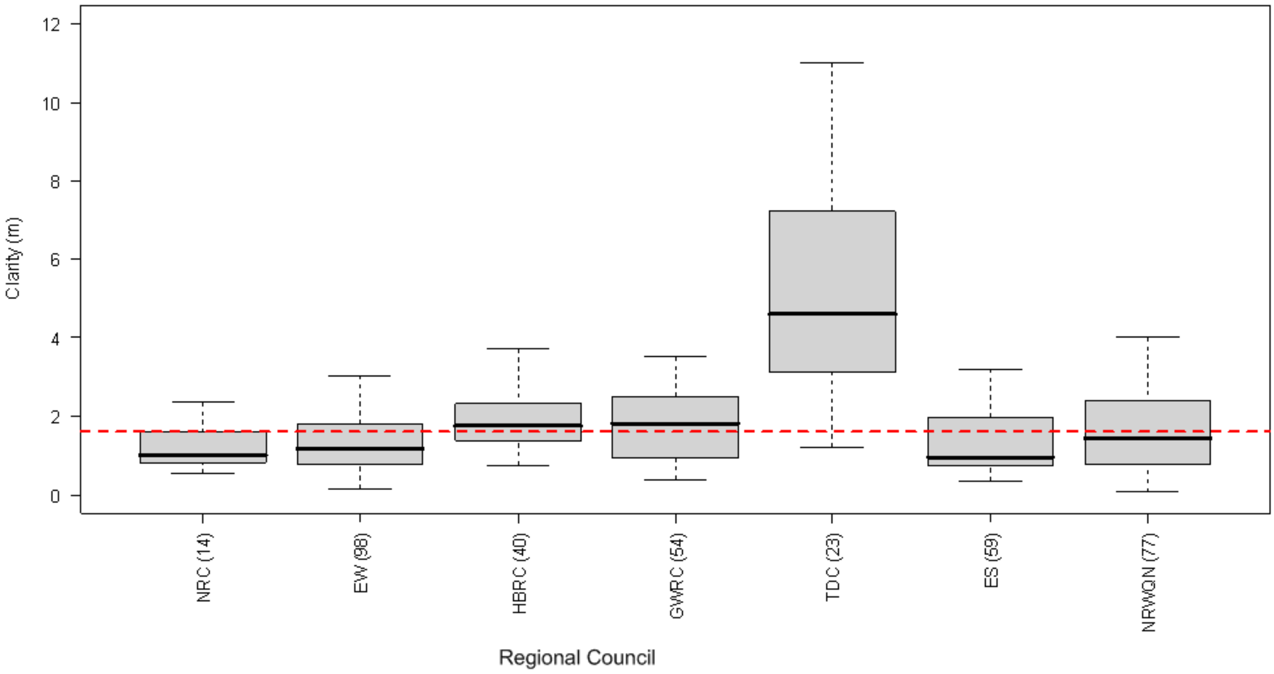

Figure 6: **Median values for clarity of sites grouped by region and the NRWQN (2003–2007). See footnote to Figure 2 for explanation of the box plots. The MfE (1994) guideline value for clarity (1.6 m) is shown on the box plot.**

Median clarity measurements differed significantly between some regions (Kruskal Wallis, $P < 0.05$). Details of significant differences between median clarity measurements for individual regions are provided in Table 11. Median clarity in Tasman District was significantly different and higher than that in all other regions.

Table 10: Mann Whitney statistical test results undertaken to highlight differences between the median NO_x-N concentrations between regional councils. Statistically significant differences are highlighted. (Significance level *P* <0.05; ns = no statistical significant difference between the median concentrations; sig = significant difference between the median concentrations.)

NO_x-N	**NRC**	**ARC**	**EW**	**EBOP**	**GDC**	**HBRC**	**TRC**	**HRC**	**GWRC**	**TDC**	**ECAN**	**ORC**	**ES**
ARC	ns												
EW	**sig**	ns											
EBOP	ns	ns	ns										
GDC	ns	**sig**	**sig**	ns									
HBRC	ns	ns	**sig**	ns	ns								
TRC	ns	ns	ns	ns	ns	ns							
HRC	ns	ns	ns	ns	ns	ns	ns						
GWRC	ns	ns	ns	ns	ns	ns	ns	ns					
TDC	ns	ns	ns	ns	ns	ns	ns	ns	ns				
ECAN	**sig**	**sig**	**sig**	ns	**sig**	**sig**	**sig**	ns	**sig**	ns			
ORC	ns	**sig**	**sig**	**sig**	ns	ns	ns	ns	**sig**	ns	**sig**		
ES	ns	ns	ns	**sig**	**sig**	ns	ns	ns	ns	ns	ns	**sig**	
NRWQN	ns	**sig**	**sig**	ns	ns	ns	ns	ns	ns	sig	**sig**	ns	**sig**

Table 11: Mann Whitney statistical test results undertaken to highlight differences between the median clarity concentrations between regional councils. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median concentrations.)

Clarity	**NRC**	**ARC**	**EW**	**HBRC**	**TRC**	**HRC**	**GWRC**	**TDC**	**ES**
ARC	ns								
EW	ns	ns							
HBRC	**sig**	**sig**	**sig**						
TRC	**sig**	ns	**sig**	**sig**					
HRC	ns	ns	ns	ns	**sig**				
GWRC	ns	ns	sig	ns	ns	ns			
TDC	**sig**	**sig**	**sig**	**sig**	**sig**	**sig**	**sig**		
ES	ns	ns	ns	**sig**	**sig**	ns	**sig**	**sig**	
NRWQN	ns	ns	**sig**	ns	ns	ns	ns	**sig**	**sig**

3.1.6 *E. coli*

The 95th percentiles for *E. coli* frequently exceeded the 'action' threshold (550 *E. coli*/100 ml) (MfE and MoH, 2003) throughout New Zealand over the period 2003–2007 (Table 6, Figure 7). 95th percentile values for *E. coli* differed significantly between regions (Kruskal Wallis, $P < 0.05$). Details of significant differences between the 95th percentiles for individual regions are provided in Table 12.

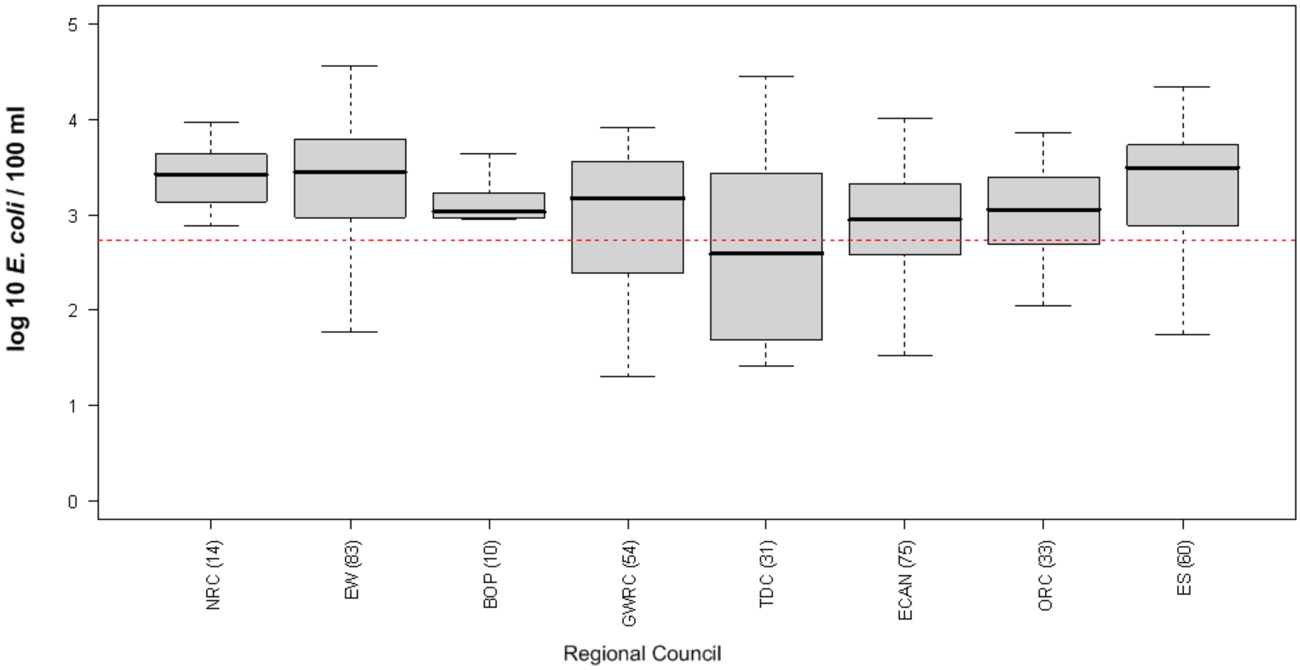

Figure 7: 95th percentiles (Hazen) for *E. coli* (n/100 ml) of sites grouped by region (using a log scale) for 2003–2007. See footnote to Figure 2 for explanation of the box plots. The MfE/MoH action threshold for *E. coli* is 550 mpn/100 ml (95th percentile) and is shown on the box plot.

3.2 Water quality state by River Environment Classification categories

Sites (belonging to both regional council networks and the NRWQN) in the different REC *Source-of-flow* and *Land-cover* categories had different water quality characteristics both in terms of their central tendencies (i.e. the median of the median site values) and their variation (i.e. the spread of the median site values). In this section, selected analytes have been presented by REC *Source-of-flow* and *Land-cover* categories for illustrative purposes.

3.2.1 Source-of-flow categories

Visual clarity was lowest, with least spread, in Low-Elevation (L) *Source-of-flow* rivers and highest, but with greatest spread, in Mountain (M) *Source-of-flow* rivers (Figure 8).

Table 12: **Mann Whitney statistical test results undertaken to highlight differences between the 95th percentile values for *E. coli* between regional councils. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the 95th percentile values; sig = significant difference between the 95th percentile values.)**

	NRC	ARC	EW	BOP	HBRC	TRC	HRC	GWRC	MDC	TDC	ECAN	WCRC	ORC
ARC	ns												
EW	ns	**sig**											
BOP	**sig**	**sig**	**sig**										
HBRC	**sig**	**sig**	**sig**	**sig**									
TRC	ns	ns	ns	**sig**	**sig**								
HRC	ns	ns	ns	**sig**	**sig**	ns							
GWRC	**sig**	**sig**	**sig**	ns	sig	**sig**	**sig**						
MDC	**sig**	**sig**	**sig**	ns	ns	**sig**	**sig**	ns					
TDC	ns	**sig**	**sig**	ns	ns	**sig**	**sig**	ns	ns				
ECAN	ns	**sig**	**sig**	ns	**sig**	**sig**	**sig**	ns	**sig**	**sig**			
WCRC	ns	**sig**	ns	**sig**	**sig**	ns	ns	**sig**	**sig**	**sig**	**sig**		
ORC	**sig**	**sig**	**sig**	ns	**sig**	**sig**	**sig**	ns	**sig**	**sig**	ns	ns	
ES	ns	ns	ns	ns	**sig**	ns	ns	**sig**	**sig**	**sig**	**sig**	ns	ns

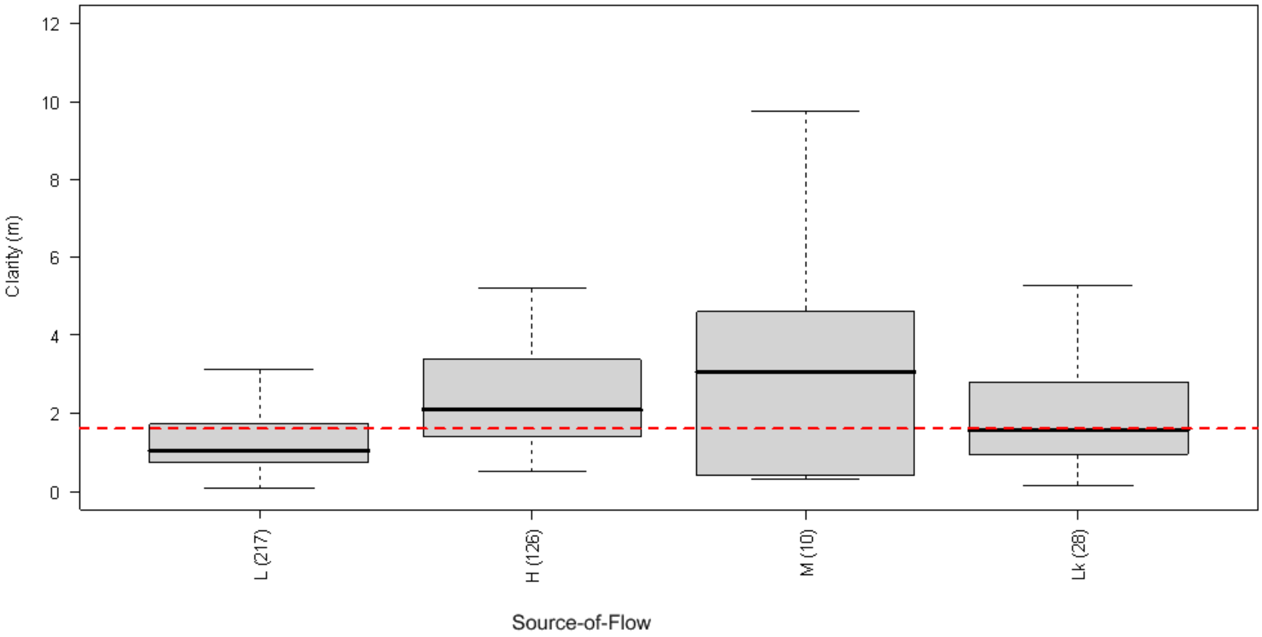

Figure 8: **Median clarity (metres) for 2003–2007 grouped by REC *Source-of-flow* classes. See footnote to Figure 2 for explanation of the box plots. The MfE (1994) guideline value (1.6 m) is shown on the box plot.**

Median clarity measurements differed significantly between REC *Source-of-flow* categories (Krusal Wallis, $P < 0.05$). Significant differences between the median clarity measurements for the individual *Source-of-flow* categories are given in Table 13. The median clarity for the Low-Elevation *Source-of-flow* category was significantly lower than that for the Hill (H), Mountain and Lake (Lk) *Source-of-flow* categories.

Table 13 **Mann Whitney statistical test results undertaken to highlight differences between the median clarity values between REC *Source-of-flow* categories. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the median clarity measurements; sig = significant difference between the median clarity measurements.)**

	Low-Elevation	Hill	Mountain	Lake
Hill	**sig**			
Mountain	**sig**	ns		
Lake	**sig**	ns	ns	
Glacial	ns	ns	ns	Ns

Median total nitrogen concentrations were generally highest in the Low-Elevation *Source-of-flow* category rivers; this class also had the largest variation in median total nitrogen and oxidised nitrogen concentrations (Figure 9 and Figure 10).

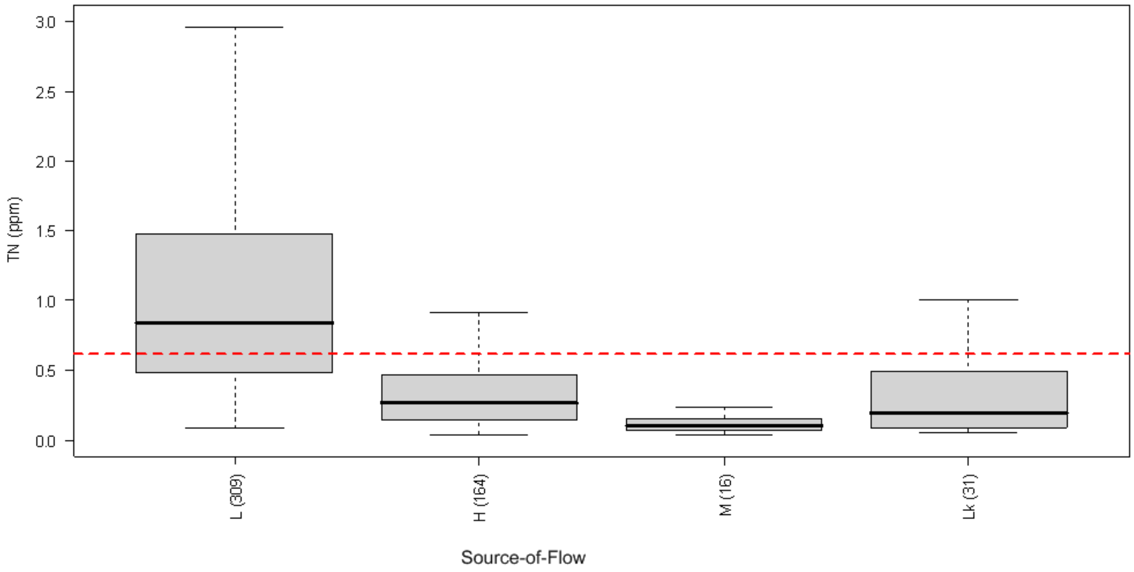

Figure 9: **Median TN concentrations (2003–2007) grouped by REC *Source-of-flow* categories. See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for TN for lowland and upland sites are 0.614 (indicated on the box plot) and 0.295 ppm respectively.**

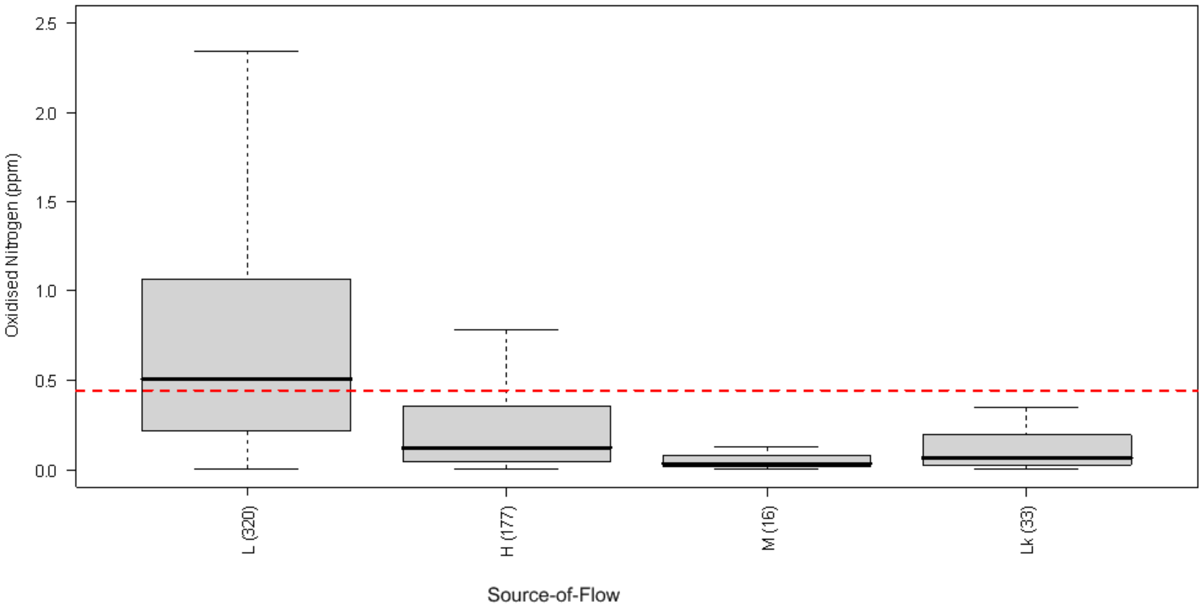

Figure 10: **Median NO_x-N concentrations (2003–2007) grouped by REC *Source-of-flow* categories. See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for TN for lowland and upland sites are 0.444 (indicated on the box plot) and 0.167ppm respectively.**

Median TN concentrations differed significantly between REC *Source-of-flow* categories (Krusal Wallis, $P < 0.05$). Significant differences between TN concentrations for individual *Source-of-flow* categories are given in Table 14. The median TN concentration was significantly higher for the Low-Elevation *Source-of-flow* category than for the other categories. Median NO_x-N concentrations were highest for the Low-Elevation *Source-of-flow* rivers (Figure 10).

Table 14: **Mann Whitney statistical test results undertaken to highlight differences between the median TN concentrations between REC *Source-of-flow* categories. Statistically significant differences are highlighted. (Significance level P <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median TN concentrations.)**

	Low elevation	Hill	Mountain	Lake
Hill	**sig**			
Mountain	**sig**	**sig**		
Lake	**sig**	ns	**sig**	
Glacial	**sig**	ns	ns	**sig**

Median NO_x-N concentrations differed significantly between REC *Source-of-flow* categories (Krusal Wallis, $P < 0.05$). Differences between NO_x-N concentrations for individual *Source-of-flow* categories are given in Table 15. The median NO_x-N concentration was significantly higher for the Low-Elevation *Source-of-flow* category than for the other categories.

Table 15: **Mann Whitney statistical test results undertaken to highlight differences between the median NO_x-N concentrations between REC *Source-of-flow* categories. Statistically significant differences are highlighted. (Significance level P <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median NO_x-N concentrations.)**

	Low elevation	Hill	Mountain	Lake
Hill	**Sig**			
Mountain	**Sig**	ns		
Lake	**Sig**	ns	ns	
Glacial	**Sig**	ns	ns	ns

3.2.2 Land cover

Sites in the Pastoral (P) and Urban (U) *Land-cover* categories tended to have the highest nitrogen concentrations (Figure 11). For forested areas (indigenous and exotic), median TN concentrations were low; however median TN concentrations were higher in areas of Exotic Forest (EF) than Indigenous Forest (IF).

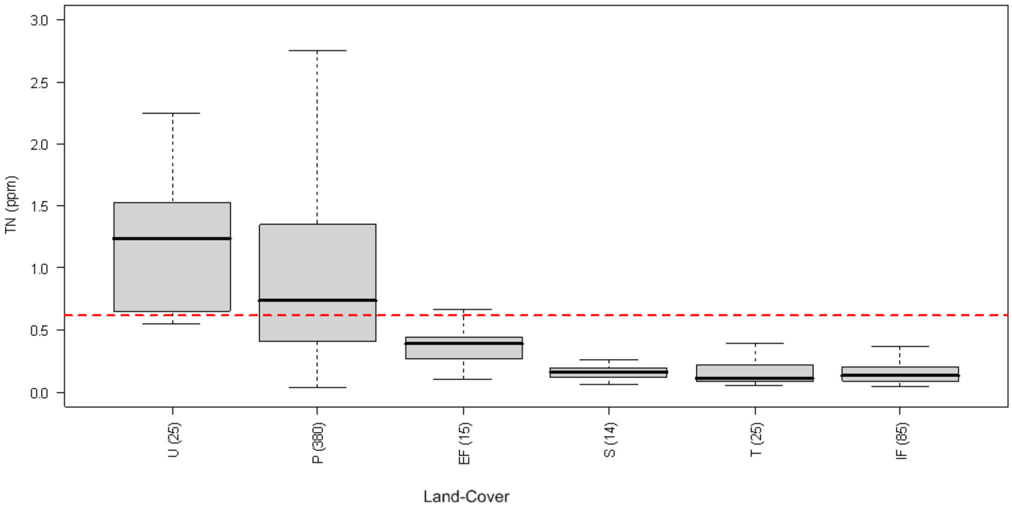

Figure 11: Median TN concentrations (2003–2007) grouped by REC *Land-cover* categories. See footnote to Figure 2 for explanation of the box plots. The ANZECC trigger values for TN for lowland and upland sites are 0.614 (indicated on the box plot) and 0.295 ppm respectively.

TN concentrations varied significantly between REC *Land-cover* categories (Kruskal Wallis, $P < 0.05$). Significant differences between TN concentrations for individual land cover categories are shown in Table 16. TN concentrations were significantly higher for the Pasture and Urban categories than for the other *Land-cover* categories.

Table 16 **Mann Whitney statistical test results undertaken to highlight differences between the median TN concentrations between REC *Land-cover* categories. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median NO_x-N concentrations.)**

	Pasture	Indigenous	Exotic	Urban	Tussock
Indigenous	**sig**				
Exotic	**sig**				
Urban	**sig**	**sig**	**sig**		
Tussock	**sig**	ns	**sig**	**sig**	
Scrub	**sig**	ns	**sig**	**sig**	ns

Clarity tended to differ between *Land-cover* categories. For example, median clarity was lowest in the Pasture and Urban categories, and highest for Tussock (T), Scrub (S), EF and IF. Median clarity was higher for Indigenous Forest than the Exotic Forest category (Figure 12).

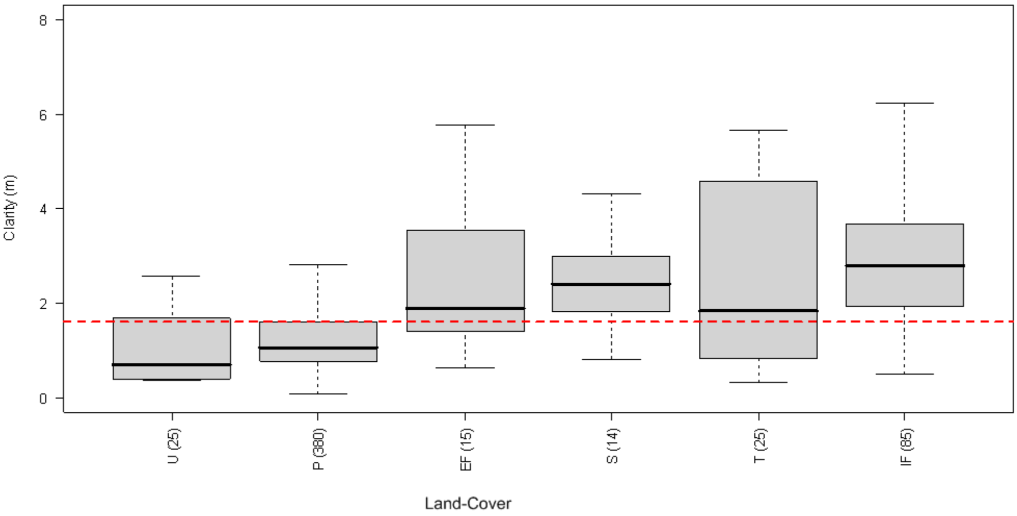

Figure 12: **Median clarity (metres) (2003–2007) grouped by REC *Land-cover* categories. See footnote to Figure 2 for explanation of the box plots. The MfE (1994) guideline for clarity (1.6 m) is indicated on the box plot.**

Median clarity differed significantly between several of the REC *Land-cover* categories (Kruskal Wallis, $P < 0.05$) (Table 17). Clarity was significantly lower for the Pasture and Urban categories than for the other *Landcover* categories.

Table 17: Mann Whitney statistical test results undertaken to highlight differences between the median clarity measurements between REC *Land-cover* categories. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the median clarity measurements; sig = significant difference between the median clarity measurements.)

	Pasture	Indigenous	Exotic	Urban	Tussock
Indigenous	**sig**				
Exotic	**sig**	ns			
Urban	ns	**sig**	**sig**		
Tussock	**sig**	ns	ns	**sig**	
Scrub	**sig**	ns	ns	**sig**	ns

3.3 Trends in water quality at NRWQN sites

Trends for the NRWQN sites and overall trends based on the NRWQN for the two time periods are presented in Table 18. For the 1998–2007 time period there were generally a mixture of both increasing and decreasing trends for all analytes. There were significant overall trends (determined by the binomial test) for four of the seven analytes measured at the 77 NRWQN sites for the 1998–2007 time period. There were increasing overall trends for conductivity and TN and decreasing overall trends for DRP and NH_4-N. Overall trends were not significant for clarity, NO_x-N and TP.

There was generally a mixture of both increasing and decreasing trends at NRWQN sites for all analytes for the 2003–2007 time period. Overall increasing trends (determined by the binomial test) were observed for conductivity and TN, while overall trends were not significant for the other analytes.

3.4 Trends for combined NRWQN and regional council sites

Summaries of trends for combined NRWQN and regional council sites by region and analyte for both the five and ten year time periods are presented in Appendix 2 and 3. Only the trends for the ten year period are discussed below.

3.4.1 National and regional trends for period 1998–2007

For the ten year period, trends in water quality analytes were generally a mixture of both increasing and decreasing trends for all analytes (Table 19). Trends were mostly significant with fewer meaningful trends detected. There were significant national trends (determined by grouping trends for all sites and using the binomial test) for seven of the ten analytes measured (Table 20). There were increasing overall trends for conductivity, TN and TP and a decreasing overall trend for clarity, all of which indicate deterioration in water quality. There were, however, also decreasing trends for *E. coli*, FC and NH_4-N, which indicate an improvement in water quality. Overall trends were not significant for SS, NO_x-N and DRP.

Table 18: Number of NRWQN sites (n = 77) with trends for 2003–2007 and 1998–2007. Key: s↑ = significant increase, m↑ = meaningful increase, s↓ = significant decrease, m↓ = meaningful decrease, ns = no significant trend. Significance level $P < 0.05$. Overall trends were determined by grouping the RSKSE values and using a one-tailed binomial test to assess whether there was a statistically significant proportion of the sites whose trends were in a particular direction.

	Clarity	Conductivity	DRP	NH4-N	NOx-N	TN	TP
1998–2007	8m↓, 1s↓, 15 m↑	1m↓, 5s↓, 15 s↑, 9m↑	20m↓, 5s↓, 1 s↑, 1m↑	37m↓, 5m↑	12m↓, 1s↓, 1 s↑, 14m↑	5m↓, 20m↑	4m↓, 1 s↑, 5m↑
Overall trend	ns	Increasing trend (P=0.022)	Decreasing trend (P =0.001)	Decreasing trend (P =<0.001)	ns	Increasing trend (P =0.04)	ns
2003–2007	6m↓, 11m↑	1s↓, 3 s↑, 16m↑	3m↓, 5m↑	2m↓, 1 s↑, 3m↑	2m↓, 1s↓, 10m↑	1m↓, 8m↑	3m↓
Overall trend	ns	Increasing trend (P =0.00)	ns	ns	ns	Increasing trend (P =0.04)	ns

Table 19: **Number of sites with significant and meaningful trends for all sites for the period 1998–2007 by analyte.**

Analyte	Total number of sites	Meaningful decreases	Significant decreases	Significant increases	Meaningful increases
Clarity	294	74	1	0	25
Conductivity	363	19	24	47	26
DRP	404	64	9	10	68
E. coli	154	14	0	0	8
FC	252	40	0	0	13
NH_4-N	402	92	1	0	25
NO_x-N	405	71	1	1	72
SS	149	16	0	0	5
TN	342	36	1	0	79
TP	361	25	2	6	42

Table 20: **National trends for the period 1998–2007 by analyte determined by grouping trends for all sites and using a binomial test (Significance level = 0.05, ns = no significant overall trend).**

Analyte	Number of sites	*p*-value (binomial test of overall trend)	Overall trend direction	Number of zero RSKSE values [7]
Clarity	294	0	Decreasing	6
Conductivity	363	0.027	Increasing	16
DRP	404	0.584	ns	184
E. coli	154	0.029	Decreasing	7
FC	252	0	Decreasing	12
NH_4-N	402	0	Decreasing	184
NO_x-N	405	0.32	ns	49
SS	149	0.19	ns	22
TN	342	0.003	Increasing	33
TP	361	0.001	Increasing	179

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[7] This value includes both significant RSKSE values equal to zero (i.e. stable trends) and insignificant RSKSE values.

Table 21: **Regions for which there were significant overall trends in the 1998–2007 period by analyte. Overall trends for each region and analyte were determined by a significant binomial test for trends grouped by region.**

Analyte	Region	Total number of sites	*p*-value (binomial test of overall trend)	Trend direction	Number of zero RSKSE values
CLAR	Waikato	106	0	Decreasing	1
	Wellington	38	0.014	Decreasing	0
	Hawke's Bay	29	0.008	Decreasing	1
	Manawatu-Wanganui	15	0.035	Decreasing	0
COND	Canterbury	41	0	Increasing	4
	Southland	36	0.011	Increasing	1
	Waikato	112	0.006	Increasing	5
	Gisborne	15	0	Decreasing	0
	Wellington	25	0.015	Decreasing	2
	Northland	12	0.006	Increasing	0
DRP	Southland	32	0.02	Decreasing	15
	Hawke's Bay	37	0.001	Increasing	12
	Northland	12	0	Decreasing	1
	Otago	42	0	Increasing	6
ECOLI	Southland	23	0	Decreasing	2
	Otago	25	0.004	Decreasing	0
FC	Southland	23	0	Decreasing	2
	Hawke's Bay	31	0	Decreasing	0
NH4N	Auckland	25	0.043	Decreasing	7
	Canterbury	51	0	Decreasing	13
	Northland	12	0	Decreasing	1
NO3N	Auckland	25	0	Decreasing	1
	Canterbury	51	0.049	Increasing	7
	Waikato	112	0	Increasing	10
	Wellington	37	0.02	Decreasing	2
	Northland	12	0	Decreasing	0
SS	Canterbury	33	0.005	Decreasing	1
TN	Southland	34	0.009	Decreasing	5
	Waikato	112	0	Increasing	8
	Northland	12	0.006	Decreasing	1
TP	Hawke's Bay	37	0	Increasing	10
	Otago	42	0	Increasing	14

Significant regional trends (determined by grouping trends for all sites by region and binomial test) for the ten year period tended to be a mixture of increasing and decreasing trends for all water quality analytes (Table 21). Of the 131 region by analyte groups, 32 have significant overall trends. It should be noted that the number of stable trends was high relative to the total number of sites for several analytes, particularly DRP, NH_4N and TP. There were only significant decreasing trends for clarity indicating a reduction in water quality. The Waikato region had the highest proportion of decreasing trends for clarity (44 per cent of the sampling sites) compared to the national average of 26 per cent (see Appendix 2). There were more significant increasing trends in conductivity than decreasing trends. Again the Waikato region had the highest proportion of increasing trends for conductivity (29 per cent of the sampling sites) compared to the national average of 20 per cent.

There were significant increases and decreases in DRP throughout the country. Most significant increases were observed in the Otago and Waikato regions (at 60 per cent and 21 per cent of sites respectively), while most significant decreases were observed in the Southland and Wellington regions (at 50 per cent and 29 per cent of sites respectively). There were more significant increasing trends in TP than decreasing trends. The Waikato region had the highest proportion of increasing trends for TP with 22 per cent of sites. However, eight Waikato region sites had decreasing trends in TP. Nationally there were approximately the same number of sites with increasing and decreasing significant trends for DRP. The Otago region had the highest proportion of significant increases with 60 per cent. There were increasing (21 per cent) and decreasing (11 per cent) trends in DRP at sites in the Waikato.

There was a similar number of significant increasing and decreasing trends in oxidised nitrogen throughout the country. The largest number of increasing trends were in the Waikato region (with 38 per cent of sites), while most decreasing trends were in the Northland, Auckland and Wellington regions, at 75, 56 and 46 per cent of sites respectively. There were more increasing than decreasing trends for TN. Most increasing trends were found in the Waikato region (45 per cent of sites).

3.4.2 Trends by River Environment Classification for period 1998–2007 Source-of-flow categories

There were 9 overall trends of the 47 analyte by *Source-of-flow* category groupings (Table 22). It should be noted that the number of stable trends was high relative to the total number of sites for several analytes, particularly NH_4N and TP. There was a significant overall decreasing trend in clarity (Binomial test; Table 22) for the Low-Elevation (median RSKSE value = -1.3 per cent) and Hill *Source-of-flow* category (median RSKSE value = -0.78 per cent) Figure 13. RSKSE values for NO_x-N were highly variable with both large positive and negative RSKSE values in the Low-Elevation, Hill and Lake categories (Figure 14). Overall however, there was no trend in NO_x-N concentrations in any of these *Source-of-flow* categories. For TN, RSKSE values were also variable and were only significantly increasing in the Lake *Source-of-flow* category (Figure 15 and Table 21). There was a significant trend in TP in the Low-Elevation *Source-of-flow* category (Binomial test; Table 22). There were no significant differences between the median RSKSE values for clarity, TN and NO_x-N between REC *Source-of-flow* categories (Kruskal Wallis, $P > 0.05$).

Table 22: **REC *Source-of-flow* categories for which there were significant trends in the 1998–2007 period by analyte. Category trends were determined by a significant binomial test for trends grouped by category**

Analyte	REC *Source-of-flow* category	Total number of Sites	*p*-value (binomial test of overall trend)	Overall trend	Number of zero RSKSE values
CLAR	H	97	0.008	Decreasing	3
	L	160	0	Decreasing	2
ECOLI	H	47	0.04	Decreasing	1
FC	H	79	0.001	Decreasing	5
NH4N	H	131	0	Decreasing	61
	L	224	0.013	Decreasing	103
	Lk	33	0.035	Decreasing	16
TN	Lk	30	0.016	Increasing	5
TP	L	199	0.023	Increasing	83

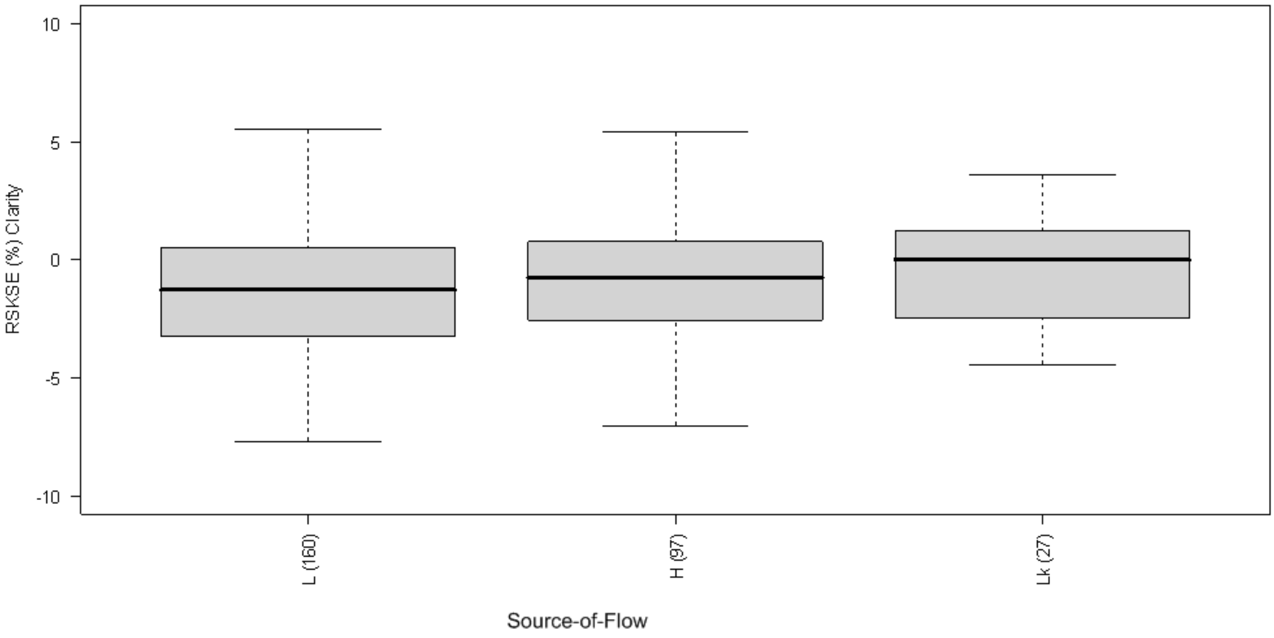

Figure 13: **RSKSE values for clarity for sites grouped by REC *Source-of-flow* categories for 1998–2007. See footnote to Figure 2 for explanation of the box plots.**

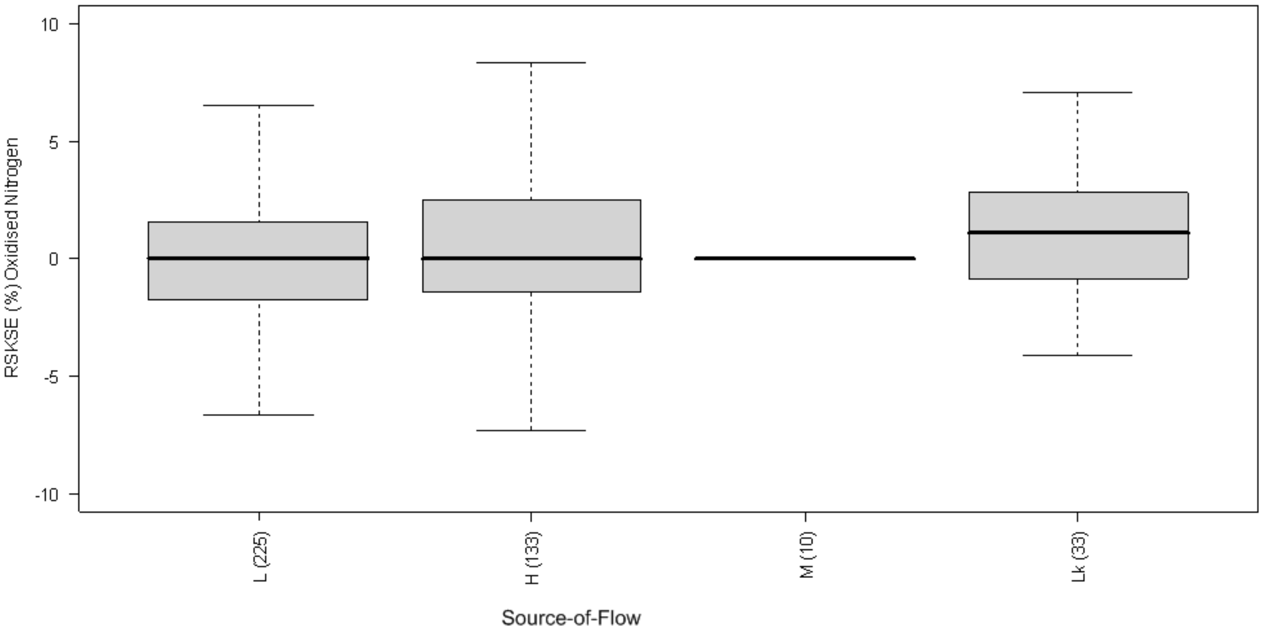

Figure 14: RSKSE values for NO_x-N grouped by REC *Source-of-flow* categories for 1998–2007. See footnote to Figure 2 for explanation of the box plots.

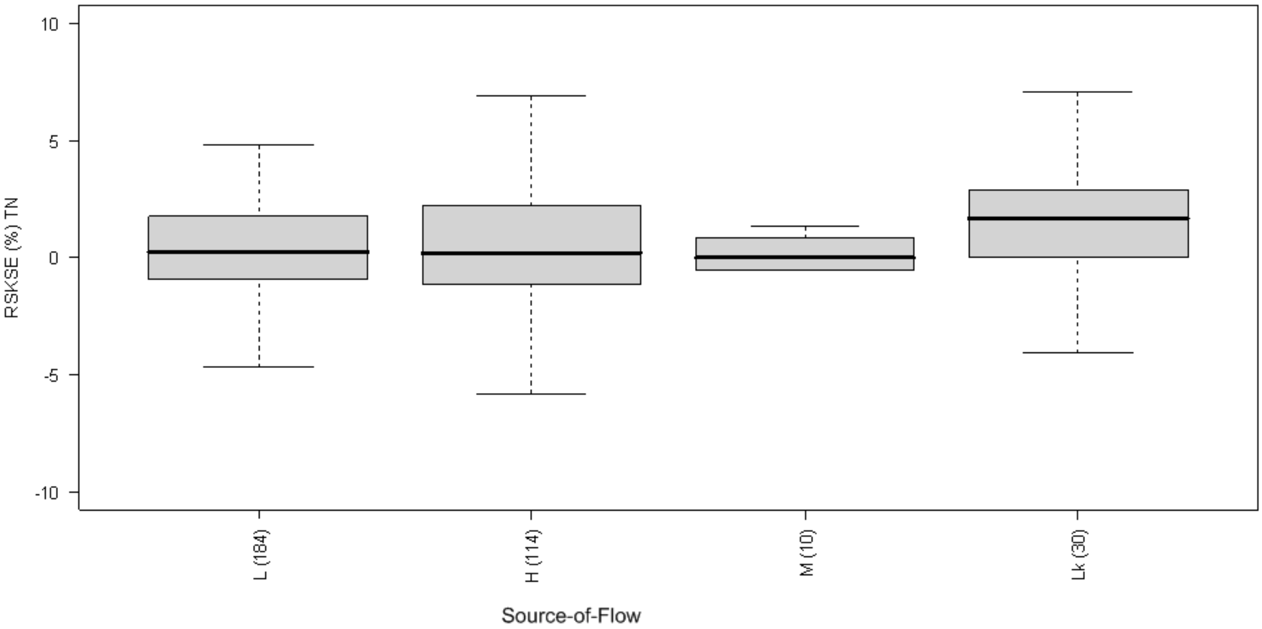

Figure 15: RSKSE values for TN grouped by REC Source-of-flow categories for 1998–2007. See footnote to Figure 2 for explanation of the box plots.

3.4.3 Trends by River Environment Classification *Land-cover* categories for 1998–2007

There were 12 overall trends of the 68 analyte by REC *Land-cover* category groupings (Table 23). It should be noted that the number of zero RSKSE values was high relative to the total number of sites for several analytes, particularly DRP, NH_4N and TP (Table 23). Although there was considerable variation in clarity RSKSE values within categories (Figure 16), overall clarity decreased for the Pasture and Urban Land-cover categories (Table 23). Median RSKSE values for clarity also differed significantly between REC *Land-cover* categories (Kruskal Wallis, $P > 0.05$). Further examination using the Mann Whitney test showed that the RSKSE median value for Tussock differed significantly from the median RSKSE value for Pasture and Indigenous *Land-cover* categories (Table 24). The Urban category had fewer than 10 sites and was not therefore included in the between category tests.

Table 23: REC *Land-cover* categories for which there were significant overall trends in the 1998–2007 period by analyte. Category trends were determined by a significant binomial test for trends grouped by category.

Analyte	REC *Land-cover* category	Total Number of Sites	*p*-value (binomial test of overall trend)	Overall trend	Number of zero RSKSE values
CLAR	P	191	0	Decreasing	3
	U	9	0.039	Decreasing	1
COND	P	240	0.002	Increasing	11
DRP	IF	70	0.041	Decreasing	41
ECOLI	IF	24	0.023	Decreasing	0
FC	IF	43	0.001	Decreasing	3
	T	6	0.031	Decreasing	1
NH4N	IF	69	0.001	Decreasing	29
	P	74	0	Decreasing	34
NO3N	P	277	0.041	Increasing	21
TN	P	244	0.012	Increasing	18
TP	P	252	0	Increasing	114

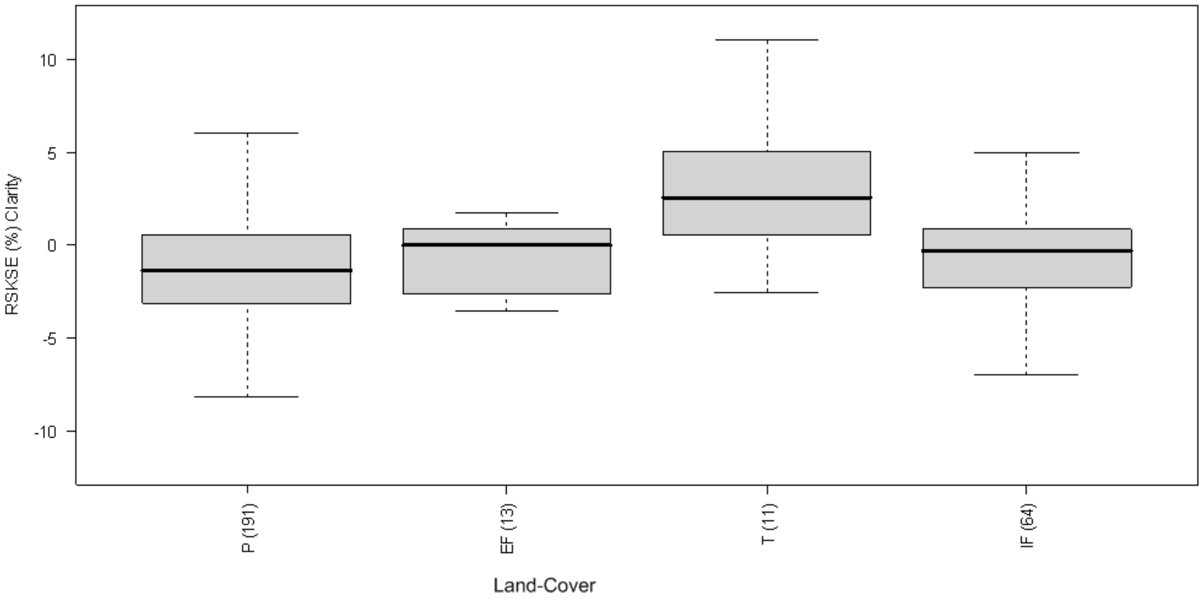

Figure 16: RSKSE values for clarity for sites grouped by REC *Land-cover* categories for 1998–2007. See footnote to Figure 2 for explanation of the box plots.

Table 24: Mann Whitney statistical test results undertaken to highlight differences in median clarity RSKSE values between *Land-cover* categories. Statistically significant differences are indicated. (Significance level *P* <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median RSKSE values.)

Clarity	**Pasture**	**Exotic**	**Tussock**
Exotic	ns		
Tussock	**sig**	ns	ns
Indigenous	ns	ns	**sig**

Table 25: Mann Whitney statistical test results undertaken to highlight differences in median TN RSKSE values between *Land-cover* categories. Statistically significant differences are indicated. (Significance level *P* <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median RSKSE values.)

TN	Urban	Pasture	Exotic	Tussock
Pasture	ns			
Exotic	ns	**sig**		
Tussock	**sig**	ns	**sig**	
Indigenous	ns	ns	**sig**	ns

There were also significant increasing overall trends in the Pasture Land-cover category for conductivity, TN (Figure 17), oxidised nitrogen (Figure 18), and TP (Table 23). Median TN RSKSE values differed significantly between REC *Land-cover* categories (Kruskal Wallis, $P < 0.05$). Further examination using the Mann Whitney test showed that there were significant differences in median RSKSE values for TN between several *Land-cover* categories (Table 25). There were significant differences in median RSKSE values for oxidised nitrogen grouped by *Land-cover* categories (Kruskal Wallis, $P < 0.05$; Figure 18). The median RSKSE for the Pasture category differed significantly from Exotic, Indigenous and Urban, and Exotic differed significantly to Indigenous (Mann Whitney, $P < 0.05$) (Table 26).

There were also significant decreasing overall trends in some analytes for some REC *Land-cover* categories (Table 23). There were decreasing overall trends in the Indigenous Forest category for DRP, *E.coli*, FC and NH_4N. FC also had a significant deceasing overall trend in the Tussock category. Finally, NH_4N had significant deceasing overall trends in the Indigenous Forest and Pasture *Land-cover* categories (Table 23).

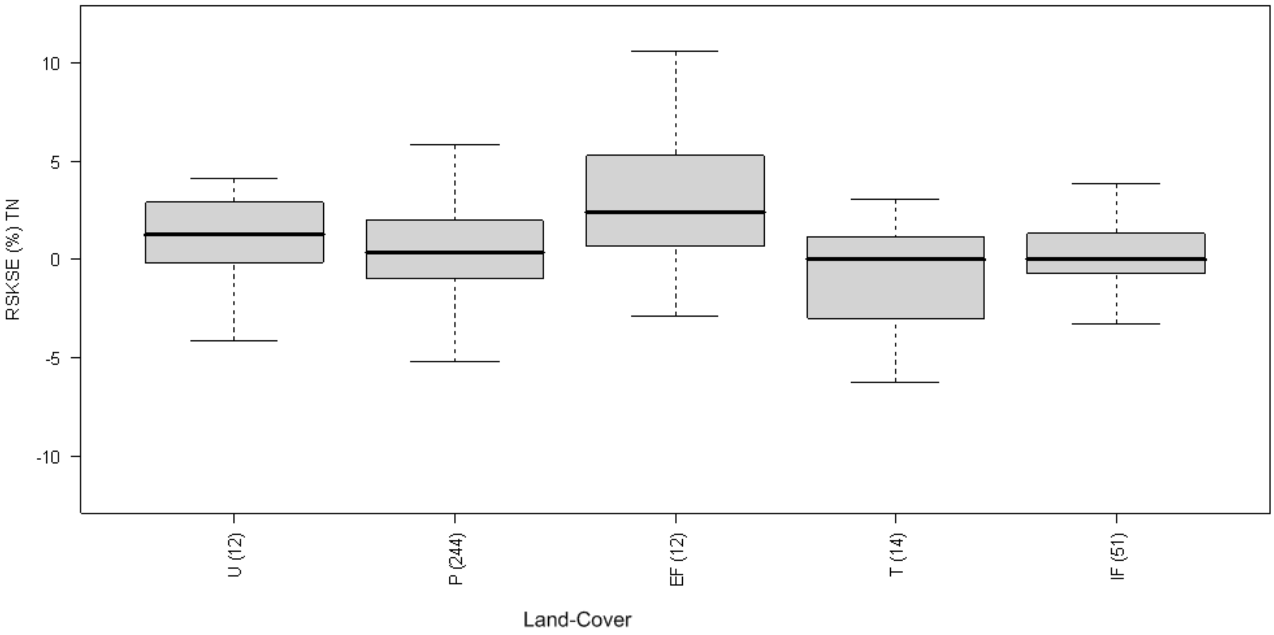

Figure 17: **RSKSE values for TN for sites grouped by REC *Land-cover* category for 1998–2007. See footnote to Figure 2 for explanation of the box plots.**

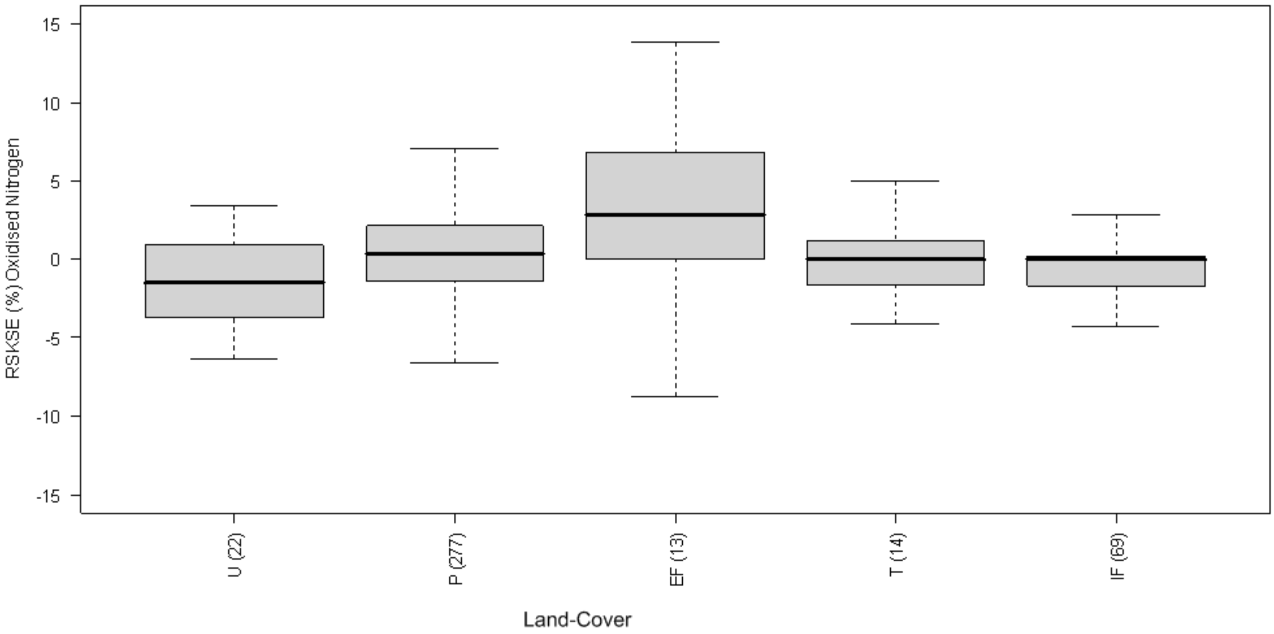

Figure 18: RSKSE values for NO_x-N for sites grouped by REC *Land-cover* categories for 1998–2007. See footnote to Figure 2 for explanation of the box plots.

Table 26: Mann Whitney statistical test results undertaken to highlight differences in median NO_x-N RSKSE values between *Land-cover* categories. Statistically significant differences are highlighted. (Significance level *P* <0.05, ns = no statistical significant difference between the median concentrations; sig = significant difference between the median RSKSE values.)

	Urban	Pasture	Exotic	Tussock
Pasture	**sig**			
Exotic	**sig**	**sig**		
Tussock	ns	ns	ns	
Indigneous	ns	**sig**	**sig**	ns

4. Discussion

4.1 Water quality state

The assessment of water quality state (period 2003–2007) shows that water quality was highly variable throughout New Zealand. Median nutrient concentrations frequently exceeded the ANZECC (2000) trigger values and were lower than the clarity guidelines (Table 3 and Table 4). Faecal bacterial levels were also high, with *E. coli* numbers exceeding the MfE/MoH (2003) action value at many sites throughout the country (based on the 95th percentiles).

Land-use impacts on water quality state were clear with the highest nutrient concentrations being associated with pastoral land cover. Nutrient concentrations were also high in urban rivers. Clarity was low in rivers whose catchments drain pastoral and urban land compared to other land-cover types. This is consistent with data reported by other authors in previous studies, (e.g., Ballantine and Davies-Colley, 2009b; Hamill and McBride, 2003; Larned *et al.*, 2003; Larned *et al.*, 2004; Snelder and Scarsbrook, 2002).

There are clear differences in water quality depending on where rivers have their source as shown by grouping sites by REC *Source-of-flow* category. NO_x-N and TN concentrations were significantly higher, and clarity significantly lower, in rivers in the Low Elevation *Source-of-flow* category, compared to rivers in the Hill, Lake or Mountain *Source-of-flow* categories.

4.2 Water quality trends

The trend analyses indicate that trend strength and direction is highly variable across the country. There were also considerable differences in trend strength and direction between the time periods. We used the binomial test to indicate whether there were “overall trends” in sites grouped in several ways. We deemed that there was an overall trend in a certain direction for a grouping if the number of sites that exhibited that trend were greater than could be expected if increasing and decreasing trends were equally likely. In this manner we found overall decreasing trends in clarity and increasing trends in conductivity, TN and TP at the national scale for the 1998 to 2007 period, all of which indicate degrading water quality. We note that the number of stable trends was high relative to the total number of sites for several analytes, particularly DRP, NH_4-N and TP. This probably reduces the certainty with which we can conclude there were overall trends for these analytes.

When sites were grouped by region for the 1998–2007 period we found the following overall trends, which all indicate deteriorating water quality:

- decreasing overall trends in clarity in the Waikato, Wellington, Hawke's Bay and Manawatu-Wanganui regions
- increasing overall trends in conductivity in the Canterbury, Southland, Northland and Waikato regions
- overall increasing trends in oxidised nitrogen in the Canterbury and Waikato regions
- overall increasing trend in TN in the Waikato region
- overall increasing trends in both dissolved reactive phosphorus and TP in the Hawke's Bay and Otago regions.

However, we also found overall trends which are improvements in water quality. These trends in improving water quality make it difficult to conclude that there are strong regional patterns in water quality degradation. The improving overall trends include:

- decreasing trends in conductivity in Gisborne and Wellington regions
- decreasing trends in oxidised nitrogen in the Auckland, Wellington and Northland regions
- decreasing trends in both TN and dissolved reactive phosphorus in the Southland and Northland regions
- decreasing trends in ammoniacal nitrogen in Auckland, Canterbury and Northland regions
- decreasing overall trends in bacterial indicators (faecal coliforms and/or *Escherichia coli*) in Southland, Otago and Hawke's Bay

The strongest groupings in terms of identifying overall trends for the 1998–2007 period were the REC *Source-of-flow* and *Land-cover* categories. We found overall:

- decreasing trends in clarity in Hill and Low-Elevation *Source-of-flow* categories and Pasture and Urban *Land-cover* categories
- increasing trends in TP in the Low-Elevation *Source-of-flow* category and Pasture *Land-cover* category
- increasing trends in conductivity, oxidised nitrogen and TN in the Pasture *Land-cover* category.

These results suggest that water quality decreased over the 1998 to 2007 period in low elevation areas and in catchments dominated by pastoral land cover. Over the same period however, NH_4N showed decreasing trends in the same categories and in the Lake *Source-of-flow* and Indigenous Forest *Land-cover* categories.

Comparison of the time periods for the NRWQN sites shows that trends tended to be stronger for the five year time period than the ten year period, with more meaningful trends (that is, greater rates of change) observed for the shorter time period at individual sampling sites than for the longer time period. For example, in the Waikato region, trends in TN and NO_x-N were stronger for the 2003–2007 period than for the 1998–2007 period. TN and NO_x-N trends were significant and increasing for the longer time period, but for the shorter time period, they were mostly meaningful and increasing. Also, for the longer period, the declining trends in visual clarity were mainly significant; but for 2003–2007 the declining trends in visual clarity were mainly meaningful (i.e. were stronger trends). Results from this study are mostly in agreement with an earlier study on Waikato River sites for the 1988–2007 time period by Vant (2008). Over the time period reported by Vant (2008), significant increases were observed in conductivity, TN, NO_x-N, TP and *E. coli*. Results from the present study also show increasing trends in TN and NO_x-N for both time periods. The present study found significant decreases in visual clarity for the Waikato region, which were not observed over the 1988–2007 period by Vant (2008).

Overall national trends observed in nutrients for the NRWQN over both time periods contrast with those reported for the 19-year time period by Ballantine and Davies-Colley (2009). In the 19-year analysis, the median RSKSE values indicated increasing trends in nutrients and visual clarity (Ballantine and Davies-Colley, 2009b). However, in this study we found no overall trend in clarity in either time period. The present study did find an overall increasing trend in TN for both time periods in agreement with that reported for the 19-year period. However, the present study found an overall decreasing trend in DRP for the ten year time period which contrasts with the earlier study.

5. Limitations of the study and recommendations

5.1 Regularity of sampling and duration of sampling records

Screening of the data showed that water quality sampling strategies and the temporal scale of data collection vary between the different regional councils. Some regional council data sets spanned long times periods and provided a robust basis for trend analysis. However, water quality data as provided by the regional councils was of variable suitability from the point of view of analysing for trends. In many cases in the present study, the records were too short and the sampling interval too long to generate meaningful trends over short time periods (e.g., five years). This could partly be an artefact of using a dataset that was collated for a different purpose. It was decided that only sites with data in more than 32 quarters for the ten year trend analysis and 16 quarters for the 5 year trend analysis would be included and therefore many sites were discarded from the analysis.

Sampling intervals (that is, time between sampling visits) vary between the regional councils. Some regional councils undertake water quality sampling on a monthly basis, while others will collect samples bimonthly or quarterly. For trend analysis, it is necessary to have long and continuous data records. Longer-term trends on time periods greater than ten years are more robust than short-term trends. Short-term trends need to be interpreted with care and be set in the context of the longer term data. This issue has been highlighted by Ballantine and Davies-Colley (2009), who on comparing long- and short-term trends in the Manawatu catchment, noted increasing trends for NO_x-N over a 19-year time period, and decreasing trends for NO_x-N over an 8-year time period.

5.1.1 Implications of sampling frequency for water quality state and trend analysis

Trend analysis is best carried out using monthly data. Monthly data was available for a wide range of sampling sites for this present study; however there are regions where data is collected on a bi-monthly and quarterly basis. Trend analysis was carried out for these regions, as long as they met the criteria outlined in section 2.4.1; however the issue of sampling frequency must be considered in interpreting the results of the trend analysis.

It has been previously observed that, using quarterly data, trends are either not observed or are weaker than they would be with monthly data (Stansfield, 2001). To illustrate this, data have been used from four NRWQN sites at which meaningful increasing and decreasing trends were observed for NO_x-N. Calculating trends on bi-monthly data gave one meaningful increasing trend with a much higher RSKSE value than for the trend based on the monthly data (Table 27). Reducing the data frequency to quarterly meant that no significant or meaningful trends were observed in the data (Table 27). The median concentration also changed with the sampling interval.

The above examination implies that accurate reporting of short term trends in water quality have been compromised in this study due to different data collection frequencies. Water quality state (reported as median concentrations) may also be inaccurately represented for regions where sampling is less frequent than monthly.

Table 27: Comparison of trends calculated for NO_x-N at 4 NRWQN sites for monthly, bi-monthly and quarterly data (2003–2007).

Site	Sampling period	Median value	*P*	RSKSE
NAT-CH04 (Waimakariri above old highway bridge)	Monthly	0.07	<0.005	14.29
	Bi-monthly	0.08	<0.005	25
	Quarterly	0.07	0.11	14.29
NAT-HV03 (Ngaruroro at Chesterhope)	Monthly	0.1	0.03	10
	Bi-monthly	0.09	0.19	11.11
	Quarterly	0.07	1	0
NAT-WA02 (Manganui at SH2)	Monthly	0.08	0.04	–12.5
	Bimonthly	0.08	0.47	–12.5
	Quarterly	0.09	0.07	–11.11
NAT-WA08 (Manawatu at Teachers College)	Monthly	0.53	0.04	–7.55
	Bi-monthly	0.51	0.09	–7.84
	Quarterly	0.54	0.27	–14.81

5.2 Flow measurements

Flow measurements are ideally required for robust trend analysis. Many of the regional council water quality observations were not associated with flow records and may be located far from the nearest available flow gauging station. We estimated flows by transferring available data recorded at gauging stations belonging to the NZ Hydrometric Network. The tests of the flow estimation methods (**Error! Reference source not found.**Table 4) indicate we can have a reasonable level of confidence in the overall findings of this study but that the trends for some sites have large errors due to uncertainties associated with the flow estimation. Uncertainties associated with these flow estimates reduce the robustness of our trend analysis in comparison to having flow measurements associated with all water quality observations.

5.3 Analysis of overall trends

This study used a binomial test of site trends (coded as either positive or negative to answer the question of whether there are overall trends in particular groupings of sites. A problem with this test is that RSKSE values can take the value zero for several reasons, some of which are related to data quality. We allocated equal shares of sites with RSKSE values equal to zero to the positive and negative groups of trends and performed the test based on this number and recorded the number of sites with zero RSKSE values to provide an indication of the data quality associated with the test. A potentially more robust test of overall trends is provided by the Regional Seasonal Kendal test (Sprague and Lorenz, 2009). The Regional Seasonal Kendal test determines whether a consistent trend is evident throughout an entire region (i.e. any grouping of sites such as we used in this study) while also accounting for seasonal variation at individual locations. We recommend that consideration be given to use of this test in future for national studies of water quality trends.

6. Water quality monitoring – an improved future

This project has been undertaken using a data set for the period 1998–2007. This could be considered an ageing data set. In the intervening period, many regional councils have revised their water quality monitoring networks and several regions have added more sites to their networks or installed flow gauging stations at river water quality monitoring sites. For example, Marlborough District Council has had a major review of their network, while Environment Southland carried out quality assurance on their database in 2009, making corrections and deleting questionable results where appropriate and adding flow records to all water quality records. Also Horizons and Northland Regional Council have doubled their spatial representation since 2003 and implemented continuous monitoring of turbidity and DO at some sites. The practice of rolling sites has been abandoned in many areas, which will lead to improved continuity in data in the future. Some regional councils have changed their laboratory analyses so that detection levels have been improved compared to those reported for this current study. The benefits of these improved water quality networks will become apparent in the future and will lead to an improved understanding of state and trends in water quality at the regional level.

Following peer review of an earlier draft of this report, several reviewers drew our attention to gaps in our data set. Table 6 appears to under-represent the number of sites for which data should be available. Other reviewers commented that many councils now have larger and more complete data sets than they did when the original data request was circulated, and that a more up-to-date analysis (e.g., for 2005–2009) should now be possible. It is beyond the scope of this study to update the data sets available to us, but we acknowledge that the data used for our analyses are incomplete. In particular, many gaps in spatial and temporal coverage reflect a lack of dialogue between NIWA and individual regional councils following the original request for data, rather than gaps in council monitoring programmes.

There are projects underway to improve the consistency of freshwater monitoring and reporting at both the regional and national scale in New Zealand. There is a regional council initiative to present river water quality data on a web portal, and data is now widely available and is being constantly updated on regional council websites. Also, under the *New Start for Fresh Water* (the Dependable Monitoring and Reporting Project) there are several workstreams underway looking at the consistency of monitoring and reporting in New Zealand for rivers, lakes and groundwater (http://www.mfe.govt.nz/issues/water/freshwater/new-start-fresh-water.html).

7. Acknowledgements

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Appendix 1. Method used to estimate flow for sites with water quality data

Flow estimation methods

When detecting trends it is ideal to have estimates of flow to accompany each water quality measurement. This is because many water quality analytes are subject to either dilution or increases due to overland runoff during high flows. Of the water quality measurements we obtained for this study, many were not accompanied by measurements of flow. This meant that we needed to estimate flows at ungauged sites on particular dates. Estimation of flow at ungauged sites can be achieved using deterministic models (e.g. TOPNET). However, deterministic models rely on accurate rainfall time-series as model input, and require flow data sets for calibration. There are no such deterministic flow models available with national coverage for New Zealand. We therefore devised and tested three empirical methods for estimating flow at an ungauged site on a particular date.

Estimated median flow

For this method we attempted to describe the frequency distribution of flows on each day of the year (Julian day) for many sites with relatively long flow records. The L-moments and the parameters describing a Generalised Extreme Value distribution were calculated from flows observed at each gauge in the NZ Hydrometric Network with five or more years of data (n = 264), for each Julian day. Frequency distributions were then generated for each gauge and each Julian day (n = 100). The median flow was then calculated from each of these frequency distributions. We located the nearest gauging station in Euclidean space that shared the same REC Climate and *Source-of-flow* class as each water quality site of interest. We estimated the flow for each water quality measurement as the median flow estimated for the appropriate Julian day from this nearest gauging station.

Mean monthly flow

For this method we utilised information on mean flows and seasonal patterns of flow that have been previously estimated for all rivers in New Zealand. The mean flow for each water quality sampling site was taken from the REC (Woods *et al.*, 2006). For each water quality measurement, the estimated mean flow was then multiplied by the proportion of flow in the appropriate REC *Source-of-flow* class for the month of the year when the water quality sample was measured (Woods, NIWA unpublished data). For this method the estimated flow for each month of the year is the same.

Standard estimated flow on date method

For each water quality site and each date when water quality had been measured we identified a substitute gauging station. The substitute gauging station was defined as the nearest gauging station in Euclidean space that shared the same REC Climate and *Source-of-flow* class and that also had a record of flow on the date of interest. The flow recorded on the date of interest at the substitute gauging station was standardised by dividing by mean flow for the entire gauged period. Standardised flows (i.e. recorded flow divided by mean flow) were sufficient for the purpose of flow adjustment because we were interested in the relative changes in flow on different water quality measurement occasions, rather than absolute flow magnitudes.

Comparison of flow estimation methods

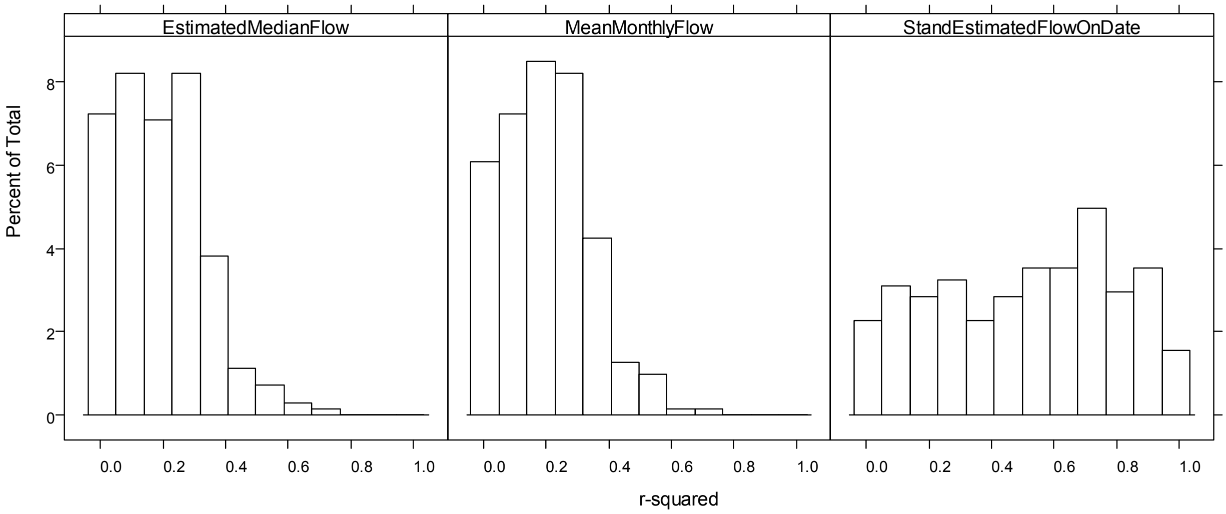

Figure A.1: Frequency distribution of R-squared values from 260 regressions for observed flow against estimated flow for each of three flow estimation methods.

Approximately 760 sites with water quality data were located on rivers rather than estuaries or lakes. Of these, 260 also contained at least two observations of flow. Figure A.1 shows r-squared values for linear regression of observed flow against estimated flow in log-log space, for each of three methods used to estimate flow, for each of these 260 sites. Higher values of r-squared indicate better estimation of the observed flows. The '*StandEstimatedFlowOnDate*' method performed better than the other two methods. Many locations had high r-squared values, indicating that the patterns of flows were well estimated. However, there was a wide range of r-squared values across sites for this method. R-squared is a function of both the number of observations and closeness of fit; therefore lower r-squared values were calculated for locations with fewer flow observations and also locations where the hydrological regime (flow pattern) was poorly estimated.

Discussion of flow estimation methods

The '*StandEstimatedFlowOnDate*' method of flow estimation was purely empirical. No physical processes controlling hydrology other than those associated with REC Climate and *Source-of-flow* class were used in the analysis. This meant that the method took no explicit account of catchment size, altitude slope or network configuration. To test the three flow estimation methods, we used daily flows measured on the same day as the water quality data. There may have been some bias in testing, as water quality sites with measured flows may have been located nearer to flow gauges than water quality sites without measured flows.

Appendix 2. Number of regional council and NRWQN sites with significant trends in water quality analytes for 1998–2007 using estimated flows. Significance level $P < 0.05$.

Table A2.1: Number of sites with significant trends for clarity for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	4	1	0	0	0	1
Bay of Plenty	12	3	0	0	0	0
Canterbury	10	0	0	0	0	3
Southland	36	3	0	0	0	3
Waikato	106	47	0	0	0	0
Gisborne	3	1	0	0	0	0
Wellington	38	7	0	0	0	4
Hawke's Bay	29	5	0	0	0	3
Manawatu-Wanganui	15	2	0	0	0	0
Marlborough	2	0	0	0	0	1
Northland	12	1	1	0	0	3
Otago	8	0	0	0	0	3
Tasman	4	0	0	0	0	3
Taranaki	11	4	0	0	0	0
West Coast	4	0	0	0	0	1
Total	**294**	**74**	**1**	**0**	**0**	**25**

Table A2.2: Number of sites with significant trends for conductivity for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	25	6	2	0	1	0
Bay of Plenty	16	0	3	0	3	0
Canterbury	41	0	0	0	4	4
Southland	36	0	0	0	2	7
Waikato	112	1	6	0	24	8
Gisborne	15	5	1	0	0	0
Wellington	25	6	5	0	0	0
Hawke's Bay	36	1	2	0	2	0
Manawatu-Wanganui	15	0	2	0	3	2
Marlborough	2	0	0	0	1	1
Northland	12	0	0	0	2	2
Otago	8	0	0	0	0	0
Tasman	5	0	0	0	2	1
Taranaki	11	0	2	0	2	1
West Coast	4	0	1	0	1	0
Total	**363**	**19**	**24**	**0**	**47**	**26**

Table A2.3: Number of sites with significant trends for DRP for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	25	3	0	3	2	1
Bay of Plenty	16	1	1	2	0	1
Canterbury	51	6	1	1	0	1
Southland	32	15	1	3	0	1
Waikato	112	11	1	8	8	15
Gisborne	3	0	0	0	0	0
Wellington	38	10	1	0	0	11
Hawke's Bay	37	1	1	0	0	7
Manawatu-Wanganui	15	5	0	0	0	4
Marlborough	2	1	0	0	0	0
Northland	12	7	0	0	0	0
Otago	42	2	1	1	0	25
Tasman	4	1	1	0	0	0
Taranaki	11	0	0	1	0	2
West Coast	4	1	1	0	0	0
Total	**404**	**64**	**9**	**19**	**10**	**68**

Table A2.4: Number of sites with significant trends for *E. coli* for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Bay of Plenty	10	0	0	0	0	3
Southland	23	5	0	0	0	0
Waikato	79	5	0	0	0	4
Northland	7	0	0	0	0	1
Otago	25	3	0	0	0	0
Tasman	2	0	0	0	0	0
Taranaki	8	1	0	0	0	0
Total	**154**	**14**	**0**	**0**	**0**	**8**

Table A2.5: Number of sites with significant trends for FC for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	16	0	0	0	0	1
Bay of Plenty	10	0	0	0	0	2
Canterbury	2	0	0	0	0	0
Southland	23	6	0	0	0	0
Waikato	79	7	0	0	0	2
Gisborne	12	0	0	0	0	0
Wellington	32	8	0	0	0	7
Hawke's Bay	31	10	0	0	0	1
Northland	1	0	0	0	0	0
Otago	34	8	0	0	0	0
Tasman	4	0	0	0	0	0
Taranaki	8	1	0	0	0	0
Total	**252**	**40**	**0**	**0**	**0**	**13**

Table A2.6: Number of sites with significant trends for NH_4-N for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	25	6	0	0	0	1
Bay of Plenty	16	2	0	0	0	1
Canterbury	51	18	0	0	0	0
Southland	34	4	0	1	0	2
Waikato	112	9	0	4	0	11
Gisborne	3	0	0	0	0	0
Wellington	38	17	0	3	0	7
Hawke's Bay	37	4	0	0	0	1
Manawatu-Wanganui	11	5	0	0	0	0
Marlborough	2	2	0	0	0	0
Northland	12	10	0	0	0	0
Otago	41	9	0	0	0	0
Tasman	4	3	0	0	0	0
Taranaki	11	0	1	0	0	2
West Coast	5	3	0	0	0	0
Total	**402**	**92**	**1**	**8**	**0**	**25**

Table A2.7: Number of sites with significant trends for NO_3-N for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	25	14	0	0	0	0
Bay of Plenty	16	0	0	0	0	7
Canterbury	51	5	0	0	0	8
Southland	34	2	0	0	0	4
Waikato	112	8	0	0	1	41
Gisborne	3	0	0	0	0	1
Wellington	37	17	0	0	0	0
Hawke’s Bay	37	2	0	0	0	5
Manawatu-Wanganui	15	3	0	1	0	0
Marlborough	2	0	0	0	0	0
Northland	12	9	0	0	0	0
Otago	42	9	1	0	0	2
Tasman	4	0	0	0	0	1
Taranaki	11	2	0	0	0	1
West Coast	4	0	0	0	0	2
Total	**405**	**71**	**1**	**1**	**1**	**72**

Table A2.8: Number of sites with significant trends for SS for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	23	5	0	0	0	1
Bay of Plenty	10	1	0	0	0	1
Canterbury	33	5	0	0	0	0
Gisborne	12	1	0	0	0	0
Hawke’s Bay	31	0	0	0	0	3
Manawatu-Wanganui	7	1	0	0	0	0
Otago	33	3	0	0	0	0
Total	**149**	**16**	**0**	**0**	**0**	**5**

Table A2.9: Number of sites with significant trends for TN for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	10	0	0	0	0	0
Bay of Plenty	10	0	0	0	0	5
Canterbury	51	7	0	0	0	5
Southland	34	6	0	0	0	3
Waikato	112	6	1	0	0	50
Gisborne	3	0	0	0	0	3
Wellington	5	0	0	0	0	0
Hawke’s Bay	37	1	0	0	0	6
Manawatu-Wanganui	7	0	0	0	0	1
Marlborough	2	0	0	0	0	0
Northland	12	5	0	0	0	0
Otago	41	5	0	0	0	4
Tasman	3	1	0	0	0	1
Taranaki	11	5	0	0	0	0
West Coast	4	0	0	0	0	1
Total	**342**	**36**	**1**	**0**	**0**	**79**

Table A2.10: Number of sites with significant trends for TP for 1998–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	25	6	0	0	2	4
Bay of Plenty	15	0	0	1	0	2
Canterbury	51	4	0	1	0	1
Southland	32	2	1	0	0	0
Waikato	112	7	1	3	2	22
Gisborne	3	0	0	1	0	0
Wellington	5	1	0	0	0	0
Hawke’s Bay	37	0	0	0	0	4
Manawatu-Wanganui	7	0	0	0	0	0
Marlborough	2	0	0	0	0	0
Northland	12	4	0	0	1	0
Otago	42	0	0	0	0	6
Tasman	3	0	0	1	0	0
Taranaki	11	0	0	0	1	3
West Coast	4	1	0	0	0	0
Total	**361**	**25**	**2**	**7**	**6**	**42**

Appendix 3: Number of regional council and NRWQN sites with significant trends in water quality analytes for 2003–2007 using estimated flows. Significance level $P < 0.05$.

Table A3.1: Number of sites with significant trends for clarity for 2003–2007

Region	**Total number of sites**	**Number of sites with meaningful decrease**	**Number of sites with significant decrease**	**Number of sites with stable trend**	**Number of sites with significant increase**	**Number of sites with meaningful increase**
Auckland	4	1	0	0	0	0
Bay of Plenty	6	0	0	0	0	1
Canterbury	10	2	0	0	0	4
Southland	65	4	0	0	0	6
Waikato	106	28	0	0	0	3
Gisborne	3	0	0	0	0	0
Wellington	59	8	0	0	0	2
Hawke’s Bay	46	2	0	0	0	3
Manawatu-Wanganui	13	0	0	0	0	2
Marlborough	2	0	0	0	0	0
Northland	18	1	0	0	0	3
Otago	8	0	0	0	0	0
Tasman	26	0	0	0	0	1
Taranaki	12	2	0	0	0	0
West Coast	4	2	0	0	0	0
	382	**50**	**0**	**0**	**0**	**25**

Table A3.2: Number of sites with significant trends for conductivity for 2003–2007

Region	**Total number of sites**	**Number of sites with meaningful decrease**	**Number of sites with significant decrease**	**Number of sites with stable trend**	**Number of sites with significant increase**	**Number of sites with meaningful increase**
Auckland	28	1	0	0	0	4
Bay of Plenty	16	2	1	0	1	0
Canterbury	86	2	0	0	1	6
Southland	65	23	0	0	0	0
Waikato	117	21	8	0	2	7
Gisborne	26	3	1	0	0	1
Wellington	59	16	0	0	0	0
Hawke’s Bay	50	2	0	0	0	4
Manawatu-Wanganui	13	0	0	0	0	0
Marlborough	2	0	0	0	0	2
Northland	18	1	0	0	0	3
Otago	8	0	0	0	0	1
Tasman	23	0	0	0	0	5
Taranaki	12	2	0	0	0	0
West Coast	6	0	0	0	0	1
	529	**73**	**10**	**0**	**4**	**34**

Table A3.3: Number of sites with significant trends for DRP for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	28	2	0	0	0	0
Bay of Plenty	16	2	1	1	0	1
Canterbury	96	3	0	0	0	2
Southland	65	1	0	0	0	3
Waikato	118	40	1	1	0	10
Gisborne	26	6	0	0	0	0
Wellington	59	8	0	0	0	5
Hawke’s Bay	49	3	0	0	0	0
Manawatu-Wanganui	13	0	0	0	0	0
Marlborough	2	0	0	0	0	1
Northland	18	1	0	0	0	3
Otago	41	0	0	0	0	17
Tasman	11	1	0	0	0	0
Taranaki	12	0	0	0	0	3
West Coast	4	0	0	0	0	0
	558	**67**	**2**	**2**	**0**	**45**

Table A3.4: Number of sites with significant trends for *E. coli* for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	1	0	0	0	2	1
Bay of Plenty	1	0	0	0	1	1
Canterbury	2	0	0	0	0	2
Southland	1	0	0	0	4	1
Waikato	2	0	0	0	2	2
Wellington	3	0	0	0	4	3
Hawke’s Bay	0	0	0	0	0	0
Manawatu-Wanganui	1	0	0	0	0	1
Northland	1	0	0	0	0	1
Otago	0	0	0	0	1	0
Tasman	1	0	0	0	1	1
Taranaki	0	0	0	0	0	0
West Coast	0	0	0	0	0	0
	13	**0**	**0**	**0**	**15**	**13**

Table A3.5: Number of sites with significant trends for FC for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Bay of Plenty	10	0	0	0	0	0
Canterbury	2	0	0	0	0	0
Southland	60	0	0	0	0	1
Waikato	83	2	0	0	0	1
Gisborne	23	0	0	0	0	0
Wellington	54	2	0	0	0	3
Hawke’s Bay	43	3	0	0	0	0
Manawatu-Wanganui	1	0	0	0	0	0
Otago	33	0	0	0	0	0
Tasman	33	0	0	0	0	0
Taranaki	9	0	0	0	0	0
West Coast	6	0	0	0	0	0
	357	**7**	**0**	**0**	**0**	**5**

Table A3.6: Number of sites with significant trends for NH_4-N for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	28	6	0	0	0	0
Bay of Plenty	16	2	0	0	0	0
Canterbury	97	2	0	0	0	0
Southland	65	0	0	1	0	6
Waikato	118	2	0	0	1	5
Gisborne	3	0	0	0	0	0
Wellington	59	3	0	0	1	5
Hawke”s Bay	49	0	0	2	0	2
Manawatu-Wanganui	12	4	0	0	0	0
Marlborough	2	0	0	0	0	0
Northland	18	3	0	0	0	0
Otago	41	2	0	0	0	0
Tasman	21	1	0	0	0	0
Taranaki	12	0	0	0	0	1
West Coast	5	0	0	0	0	0
	546	**25**	**0**	**3**	**2**	**19**

Table A3.7: Number of sites with significant trends for NO_3-N for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	28	1	0	0	0	1
Bay of Plenty	16	1	0	0	0	3
Canterbury	96	0	1	0	0	7
Southland	65	8	0	0	0	2
Waikato	118	6	0	0	0	26
Gisborne	13	1	0	0	0	0
Wellington	59	11	0	0	0	3
Hawke's Bay	49	0	0	0	0	6
Manawatu-Wanganui	13	2	0	0	0	0
Marlborough	2	0	0	0	0	0
Northland	18	2	0	0	0	0
Otago	41	4	0	0	0	1
Tasman	11	0	1	0	0	0
Taranaki	12	3	0	0	0	0
West Coast	4	0	0	0	0	0
	545	**39**	**2**	**0**	**0**	**49**

Table A3.8: Number of sites with significant trends for SS for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	26	0	0	0	0	0
Bay of Plenty	10	1	0	0	0	0
Canterbury	73	10	0	0	0	2
Southland	1	0	0	0	0	0
Gisborne	23	3	0	0	0	0
Hawke's Bay	42	0	0	1	0	0
Manawatu-Wanganui	2	0	0	0	0	0
Otago	33	0	0	0	0	5
Tasman	10	0	0	0	0	0
	220	**14**	**0**	**1**	**0**	**7**

Table A3.9: Number of sites with significant trends for TN for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	28	1	0	0	0	5
Bay of Plenty	6	0	0	0	0	0
Canterbury	96	1	0	0	0	6
Southland	65	15	0	0	0	2
Waikato	118	2	0	0	0	23
Gisborne	3	0	0	0	0	0
Wellington	59	7	0	0	0	5
Hawke’s Bay	49	0	0	0	0	4
Manawatu-Wanganui	7	0	0	0	0	0
Marlborough	2	0	0	0	0	0
Northland	18	1	0	0	0	0
Otago	41	1	0	0	0	4
Tasman	11	1	0	0	0	0
Taranaki	12	3	0	0	0	0
West Coast	4	0	0	0	0	0
	519	**32**	**0**	**0**	**0**	**49**

Table A3.10: Number of sites with significant trends for TP for 2003–2007

Region	Total number of sites	Number of sites with meaningful decrease	Number of sites with significant decrease	Number of sites with stable trend	Number of sites with significant increase	Number of sites with meaningful increase
Auckland	28	1	0	0	0	0
Bay of Plenty	9	1	0	0	0	0
Canterbury	96	7	0	0	0	1
Southland	65	2	0	0	0	3
Waikato	118	11	1	0	0	3
Gisborne	3	0	0	0	0	0
Wellington	59	2	0	0	0	7
Hawke’s Bay	49	2	0	0	0	0
Manawatu-Wanganui	7	0	0	0	0	0
Marlborough	2	0	0	0	0	0
Northland	18	2	0	0	1	2
Otago	41	0	0	0	0	8
Tasman	10	2	0	0	0	0
Taranaki	12	0	0	0	0	2
West Coast	4	0	0	0	0	0
	521	**30**	**1**	**0**	**1**	**26**