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River Water Quality

State and Trends in the Auckland Region

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River Water Quality State and Trends in Auckland Region

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Executive Summary

Auckland Regional Council (ARC) operates a long-term water quality monitoring network in rivers and streams throughout the Region. Objectives of this network include State of the Environment reporting, identification of major environmental issues, and assessment of the efficacy and efficiency of Council policy initiatives and strategies. This report provides detailed analyses of water quality state and trends at sites across this network , with the aim of reporting on each of these objectives.

Monthly water quality data from 25 sites were supplied to NIWA by ARC. Summaries of state (annual medians) and analyses of long-term trends (Seasonal Kendall tests) in water quality were carried out on this dataset, both for the entire period of record (1986-2005) and for the most recent ten years (1995-2005). Relationships between land use and water quality state and trends were also assessed.

Auckland streams tend to have high temperatures, high concentrations of nutrients, and high levels of faecal coliform bacteria and suspended sediments. Strong correlations between most water quality parameters and landcover characteristics, suggest that these water quality issues are associated with intensive landuses. In particular, the percentage of urban landcover above a site showed strong correlations with water quality parameters. This suggests that management of land-water interactions in urban streams should be a focus for ARC.

Regional scale trends of warming water temperatures, decreasing faecal bacteria and nutrient (NO_x-N, P and TP) concentrations and decreasing levels of suspended sediments (SS & TURB) were observed for the full water quality dataset. Significant improvements in faecal coliform, suspended sediment and nutrient concentrations are a very positive signal for the region, given that these parameters are major contributors to poor water quality in Auckland streams. Furthermore, a number of these trends were correlated with land use characteristics. For example, the magnitude of decreasing trends in suspended sediment concentrations were greatest at highly modified urban sites. There is some evidence that these improvements may be associated with the removal of point source discharges, but this hypothesis requires investigation at individual sites.

An analysis of the influence of flow on water quality trends was carried out, and indicated that a commonly-applied flow-adjustment procedure (LOWESS) may be inappropriate for some parameters. This raises concern over the interpretation of flow-adjusted trends. Further research is required to clarify this issue and provide a better understanding of flow-adjustement procedures used in State of the Environment reporting.

Auckland Regional Council's Rivers & Streams Water Quality Programme provides a very valuable, long-term dataset for investigating changes in state and changes over time in a selection of the Regions streams. The value of the dataset could be improved by addition of detailed information on pressures (e.g., number and type of point source discharges) and changes in these pressures over time (e.g., information on changing riparian habitat conditions). This information would improve the ability to link observed

trends in water quality directly to management activities. Development of region-specific water quality guidelines would also greatly enhance future reporting on state and trends in the Region’s rivers.

Introduction

Auckland Regional Council (ARC) operates a long-term water quality monitoring network in rivers and streams throughout the Region. The objectives of this network include providing the information that underpins state of the environment reporting as per obligations under s35 of the Resource Management Act (1991), helping to inform the efficacy and efficiency of Council policy initiatives and strategies, and assisting with the identification of large scale and/or cumulative impacts of contaminants associated with varying land uses and disturbance regimes. To meet these objectives, ARC produces annual summaries of the dataset, with five-yearly analysis of trends. The most recent report (ARC 2007), provides a summary of data for the 2005 calendar year, along with detailed information on the structure of ARC's Rivers & Streams Water Quality Programme. The last detailed analysis of spatial patterns and trends was carried out by Wilcock & Stroud (2000) and covered the period 1992-2000.

The primary aim of the present report is to present results of a detailed trend analysis of water quality indicators at 25 long-term monitoring sites in the Auckland Region within the period 1986-2005. Spatial patterns (i.e., state) are also summarised on an annual basis for the 10 year period from 1995-2005.

The project brief also required that the state and trend results be related to land use patterns to highlight changing issues in the region, and provide information that might be used to support, or modify Council policy in relation to stream management. The principal landcover categories in the Auckland region are pastoral agriculture of varying intensity, urban and native vegetation (forest and scrub). Changing land use patterns (e.g., urbanisation) in the Region have the potential to significantly affect water quality and associated values and uses, highlighting the need to link link monitoring data to these key pressures.

The final requirement of the study brief was to provide an assessment of the effects of river flow on trends in water quality, and to make reccomendations on the coverage of existing SoE sites in the region and the need for flow recorders at each monitoring site.

Methods

Monthly water quality data from 25 sites in Auckland Region were supplied to NIWA by ARC. Full details of ARC's Rivers & Streams Water Quality Programme, including the full suite of variables, the field and laboratory methods can be found in a recent data summary report (ARC 2007).

1.1 Study sites

The Rivers & Streams Water Quality Programme contains 27 sites (Figure 1) spread throughout the Auckland Region. The sites span a range of land uses and disturbance regimes (Table 1), reflecting the key management issues within the region (i.e., urbanisation and intensification of agricultural land use). Further information on each of the 25 sites included in the present report are provided in Appendix 1.

Table 1.

Site information as provided by ARC. Percentages of different land use categories are based on Landcover Database II values.

Site No.	Name	% Native Forest	% Forestry	% Horticulture	% Pasture	% Urban
ARC6604	Matakana @ Wenzlicks Farm	39.7	14.8	0.0	45.5	0.0
ARC45703	Hoteo @ Gubbs	20.2	23.9	0.1	55.6	0.2
ARC6804	Mahurangi @ Warkworth water treatment plant	19.8	23.7	0.5	54.3	1.7
ARC6811	Mahurangi @ Forestry HQ	1.9	97.9	0.0	0.2	0.0
ARC7104	Waiwera @ McCathies Falls	46.3	0.1	0.0	53.6	0.0
ARC7206	West Hoe@ Halls	99.6	0.0	0.0	0.4	0.0
ARC7506	Vaughan's @ Lower Weir	23.1	10.6	0.0	59.6	6.7
ARC7830	Lucas @ Gills Rd Bridge	10.4	7.8	0.0	40.4	41.4
ARC7811	Oteha @ Days Bridge	8.6	2.4	0.1	14.5	74.3
ARC7805	Rangitopuni @ Walkers	11.0	14.2	3.2	71.2	0.4
ARC45313	Kumeu @ No. 1 Bridge	11.4	4.5	4.8	78.4	0.9
ARC8110	Oakley @ Carrington Ck.	2.3	0.0	0.0	0.0	97.7
ARC8218	Omaru @ Taniwha St.	0.1	0.0	0.0	0.0	99.9
ARC44603	Cascade @ Confluence	100.0	0.0	0.0	0.0	0.0
ARC7904	Opanuku @ Candia Rd Bridge	83.0	0.0	0.0	17.0	0.0
ARC8217	Pakuranga @ Botany Rd	0.4	0.3	0.0	0.2	99.1
ARC8216	Pakuranga @ Guy's Rd	0.1	1.7	0.0	17.0	81.2
ARC8215	Pakuranga @ Greenmount Drive	2.2	2.7	0.0	5.6	89.5

ARC8205	Otara @ Kennel Hill	3.5	0.0	0.0	91.7	4.8
ARC8214	Otara @ East Tamaki Rd.	0.0	0.2	0.0	14.9	84.9
ARC8219	Otaki @ Middlemore Cres.	0.0	1.5	0.0	0.0	98.5
ARC43807	Puhinui @ Drop Structure	7.1	0.0	0.0	52.4	40.5
ARC8516	Wairoa @ Tourist Rd	26.7	16.1	0.0	57.2	0.0
ARC43856	Papakura @ Porchester Rd Bridge	8.1	2.5	0.9	85.6	2.9
ARC43829	Ngakoroa @ Mills Rd	4.2	0.8	20.8	74.2	0.0

1.2 Water quality parameters

The ARC directly measures, or collects water samples for the analysis of up to 25 water quality parameters. However, a number of these are measured infrequently or sporadically, and only 15 had sufficient data for analyses of trend and/or state (Table 2). Note that measurements of water temperature, dissolved oxygen and water clarity are taken in the field, with all other variables being measured using standard laboratory protocols. I have excluded clarity data from analyses in this report, as changes in field protocols have influenced the consistency of the dataset (Grant Barnes, personal communication).

Table 2.

Analytical methods for water quality parameters summarised in this report. Modified from Appendix 1, Table 4 of ARC (2007).

Identifier (+ unit)	Parameter	Method
DO (mg L^{-1})	Dissolved oxygen	Handheld meter (YSI-85)
TEMP (°C)	Temperature	Handheld meter (YSI-85)
COND @ 25 °C(mS m^{-1})	Conductivity	Handheld meter (YSI-85)
pH	pH	APHA (1998) 4500-H B
SS (mg L^{-1})	Suspended solids	APHA (1998) 2540 D
TURB (NTU)	Turbidity	APHA (1998) 2130 B
NH_4-N (mg (N) L^{-1})	Ammoniacal nitrogen	APHA (1998) 4500-NH3 G
NO_x-N (mg (N) L^{-1})	Nitrate/Nitrite nitrogen	APHA (1998) 4500-NO3 F
TKN (mg L^{-1})	Total Kjeldahl nitrogen	APHA (1998) 4500 C
TN (mg L^{-1})	Total nitrogen	Calculation NO_x-N (gN m^{-3}) + TKN (gN m^{-3})
DRP (mg L^{-1})	Dissolved reactive phosphorus	APHA (1998) 4500-P F
TP (mg L^{-1})	Total phosphorus	APHA (1998) 4500-P B, F
CL (mg L^{-1})	Chloride	APHA(2005) 4500-Cl D
FAEC (MPN/100 ml)	Faecal colifoms	APHA (1998) 9221 E

Figure 1.
27 streamwater quality monitoring locations. Note that Mahurangi Town Bridge and Awanohi Stream sites are excluded from analyses in this report.

1.3 Water quality state

An assessment of water quality state provides a snapshot in time, which is useful for comparing sites differing in land use, or other potential drivers of management interest. In the present water quality state was represented by annual median values, calculated using monthly data for 13 water quality parameters at each site from 1995 to 2005. These annual site medians were then used to calculate the annual 5th, 50th and 95th percentile values across the 25 ARC monitoring sites. The 50th percentile gives us a picture of what is happening in the regional "average" stream in terms of annual median water quality data. The 5th and 95th percentiles tells us about changes in state over time in the region's "best" and "worst" rivers. Trends in these summary values (1995-2005) were assessed using Spearman rank correlation.

For each water quality parameter I also calculated a global median value for each site for the 1995-2005 period. These median values were then correlated against land use data. Sites were also ranked by median values for each parameter, with ranking from low to high water quality for each parameter. An overall site average rank was also calculated, providing a high level summary of water quality at each site, which was then related to land use.

1.4 Water quality trends

All trend analyses in this report were done using a new trend analysis software package (Time Trends) being developed by NIWA (Ian Jowett) using Envirolink funding.

Monthly water quality data from 25 sites were analysed for trends in individual parameters using Seasonal Kendall tests on raw data. Flow adjustment using LOWESS smoothing (30% span) was also carried out, but only for the 16 sites with flow data (see Appendix 1). The Sen Slope Estimator (SSE) was used to represent the magnitude and direction of trends in data. Values of the SSE were relativised by dividing through by the raw data median (RSSE), allowing for direct comparison between sites. Trends are reported for two time periods; the full record of data at each site, and the 10 year period July 1995 until June 2005. I provide the 10-year trend analysis to highlight recent changes that will be of greater significance to river management, as well as providing a common time period across sites.

Following the convention of Scarsbrook et al. (2003) and Scarsbrook (2006), the statistical significance of trends at the regional scale (i.e., aggregating trend data for individual sites) was determined using a binomial test. The null hypothesis of this test postulates that the true proportion of upward (or downward) slopes is ½. If this hypothesis was rejected ($P < 0.05$), a regional trend for the period was inferred. This analysis used RSSE values from all sites, rather than just sites that returned a statistically significant Seasonal Kendall test.

Note that I have assumed that the laboratory methods have not changed significantly during the period of record, so assume that observed trends are 'real' rather than possible artifacts of changes in method and/or detection limit (Stansfield 2001).

1.5 Influence of flow on water quality trends

The values of many water quality variables are influenced by river flow through a range of processes including dilution and wash-off. Therefore, observed trends in water quality data may reflect variability in flow conditions that will be present in any regular monitoring programme (i.e., sampling is independent of flow conditions). To account for this dependency, flow-adjustment of raw data is routinely carried out by modelling the relationship between flow and water quality at a site. Residuals from this model are then used for subsequent "flow-adjusted" trend analysis. One of the main assumptions behind this procedure is that the fitted model (i.e., LOWESS in this case) provides an adequate fit to the data, but this is seldom tested.

To assess the relationship between flow and different water quality parameters, and the adequacy of the model used for flow adjustment, I used the Time Trends software to calculate the goodness of fit (R^2) for all LOWESS curves (flow vs. all water quality parameters) at each site. I then calculated an average R^2 value to identify which parameters have the strongest association with flow. The dataset used for this analysis consisted of the full period of record for the 16 sites with flow recorders.

Results

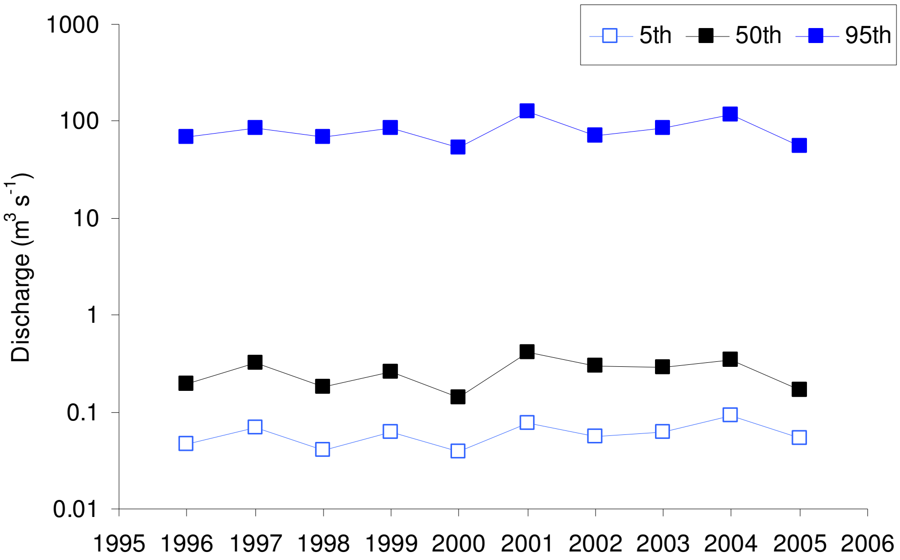
1.6 Water quality state over time (1995-2005)

The sections below provide a brief summary of annual median water quality state over the 10-year period from 1995-2005. Note that each annual period starts in July and ends in June (i.e., financial year). I have only included sites for which monitoring data covers the entire period.

Changes over time in these annual mean statistics were analysed using Spearman rank correlation.

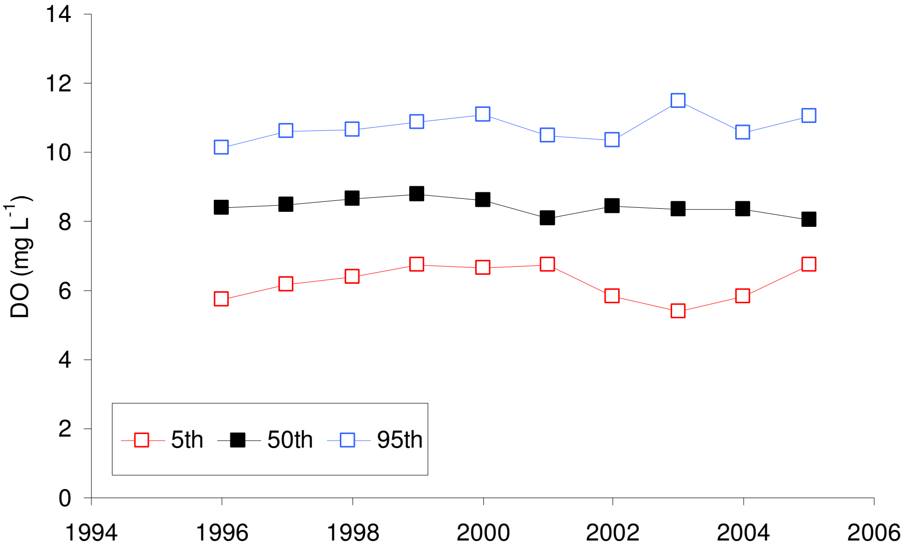
To allow for comparison of Auckland streams with other streams in the country I have provided information on water quality guidelines (ANZECC 2000) and median values from the National River Water Quality Network (NRWQN; Scarsbrook 2006).

1.6.1 Discharge ($m^3 s^{-1}$)



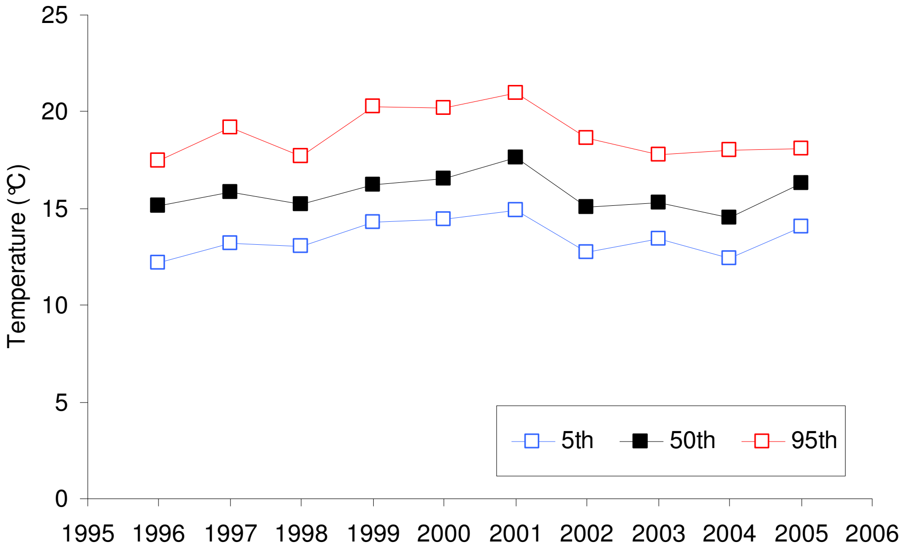
Annual median flow (measured at time of monthly water quality sampling) was relatively stable over the period 1995-2005. There were 16 sites with data covering this entire period. This result suggests that there were no strong climatic trends over the 1995-2005 period.

1.6.2 Dissolved oxygen (mg L^{-1})



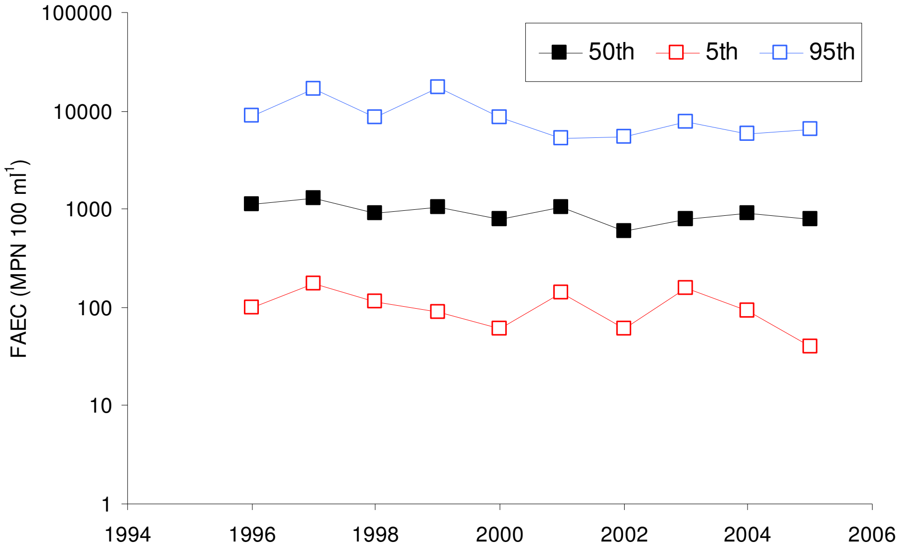
Annual median DO trended down significantly for 50th percentile rivers (Spearman rank correlation; $r_S = -0.66$; $P < 0.01$), indicating a slight deterioration in 'average' rivers over the period 1995-2005. There were 22 sites with data covering this entire period.

1.6.3 Temperature (°C)



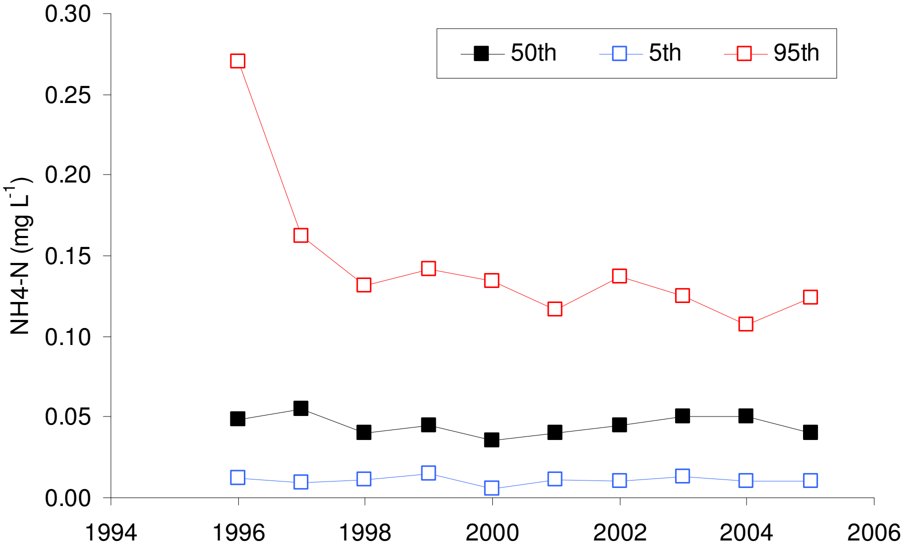
Annual median water temperatures were relatively stable over the period 1995-2005. Temperatures peaked in the 2000-2001 year. There were 22 sites with data covering this entire period. This result suggests that there were no strong climatic trends over the 1995-2005 period. Scarsbrook (2006) noted that the national annual median temperature (based on 77 NRWQN sites) for 2005 was 12.9 °C.

1.6.4 Faecal coliforms (MPN/100 ml)



Annual median faecal coliforms decreased significantly in 95th percentile (r_S = -0.70; P < 0.001), 50th percentile (r_S = -0.70; P < 0.001) and 5th percentile (r_S = -0.42; P < 0.05) sites, indicating improving conditions across the region's monitoring sites over the 1995-2005 period. Despite these decreases concentrations remain high. There were 23 sites with data covering this entire period. Note the $\log_{10}$-scale on the Y-axis.

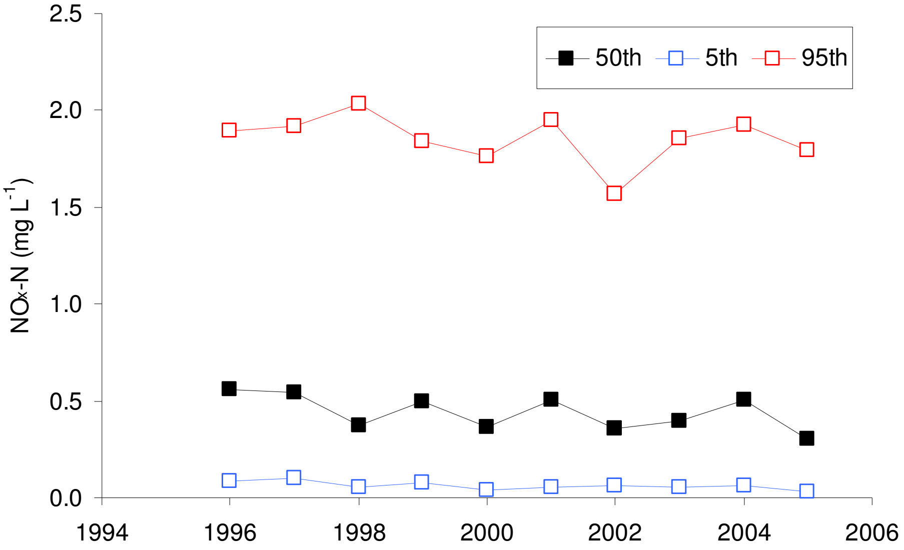
1.6.5 Ammoniacal nitrogen (mg L^{-1})



Annual median NH_4-N decreased significantly in 95th percentile rivers (r_S = -0.79; P < 0.001), indicating improving conditions in the region's 'worst' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000; see Table

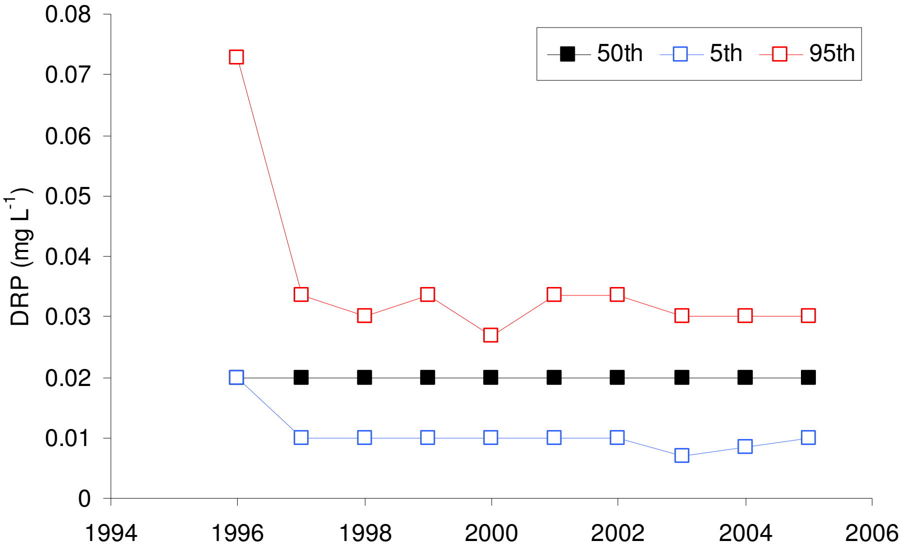
3.1.10) in lowland streams is 0.021 mg L^{-1}. Scarsbrook (2006) noted that the national annual median concentration for NH_4-N (based on 77 NRWQN sites) for 2005 was 0.004 mg L^{-1} .

1.6.6 Nitrate/nitrite nitrogen (mg L^{-1})



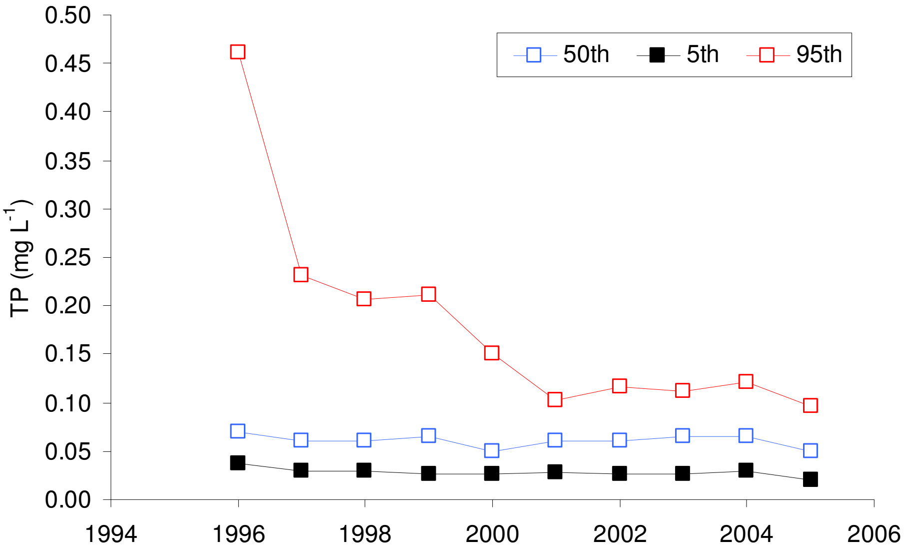
Annual median NO_x-N decreased significantly in 50th percentile ($r_S = -0.59$; $P < 0.01$) and 5th percentile ($r_S = -0.55$; $P < 0.01$) rivers, indicating improving conditions in the region's 'average' and 'best' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000) in lowland streams is 0.444 mg L^{-1}. Scarsbrook (2006) noted that the national annual median concentration for NO_x-N (based on 77 NRWQN sites) for 2005 was 0.115 mg L^{-1}.

1.6.7 Dissolved reactive phosphorus (mg L^{-1})



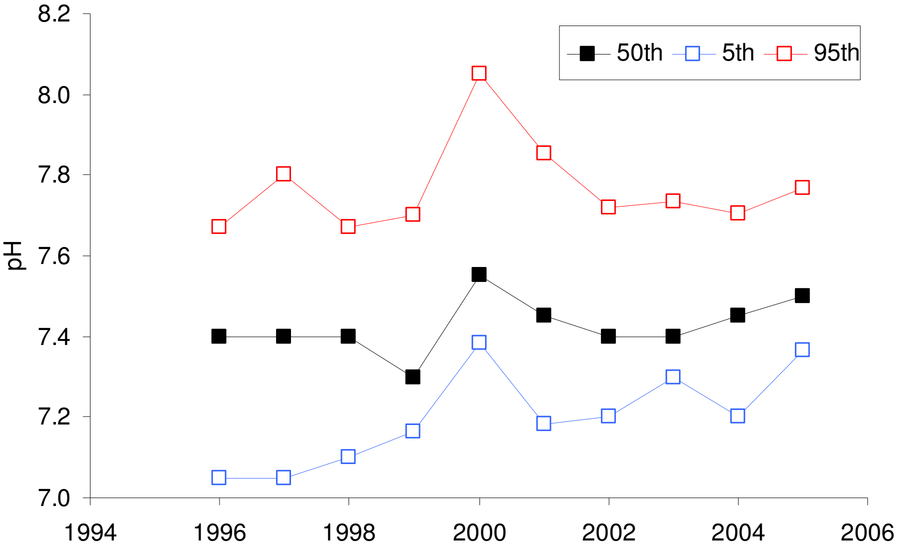
Annual median DRP decreased significantly in 5th percentile (r_S = -0.66; $P < 0.01$) and 95th percentile (r_S = -0.52; $P < 0.05$) rivers, indicating improving conditions in the region's 'best' and 'worst' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000) in lowland streams is 0.01 mg L^{-1}. Scarsbrook (2006) noted that the national annual median concentration for DRP (based on 77 NRWQN sites) for 2005 was 0.005 mg L^{-1}

1.6.8 Total phosphorus (mg L^{-1})



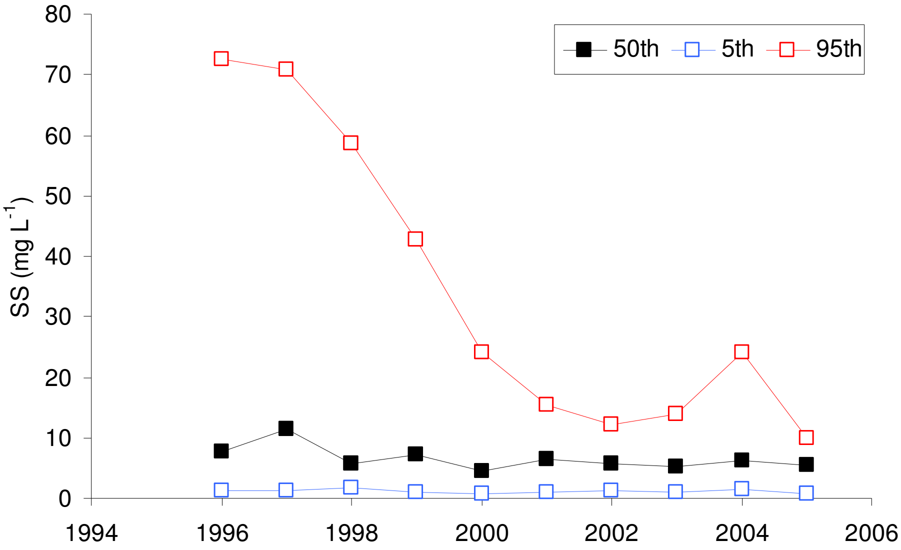
Annual median TP decreased significantly in 5th percentile (r_S = -0.64; $P < 0.01$) and 95th percentile (r_S = -0.88; $P < 0.001$) rivers, indicating improving conditions in the region's 'best' and 'worst' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000) in lowland streams is 0.033 mg L^{-1}. Scarsbrook (2006) noted that the national annual median concentration for TP (based on 77 NRWQN sites) for 2005 was 0.016 mg L^{-1}

1.6.9 pH



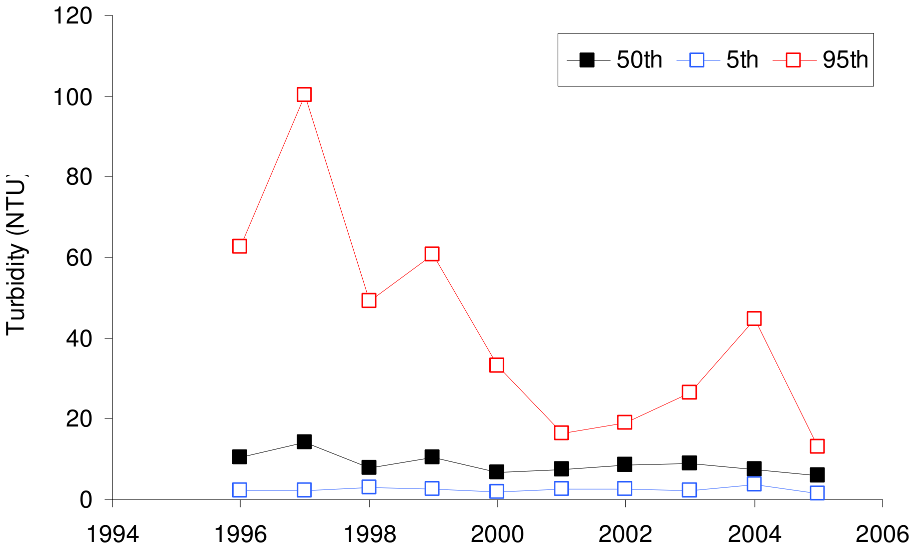
Annual median pH increased significantly in 5th percentile (r_S = -0.79; $P < 0.001$) and 50th percentile (r_S = -0.49; $P < 0.05$) rivers, indicating improving conditions in the region's 'best' and 'average' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. pH appears to have spiked in the 1999-2000 year. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000) in lowland streams is a pH range of 7.2-7.8. Scarsbrook (2006) noted that the national annual median pH (based on 77 NRWQN sites) for 2005 was 7.7.

1.6.10 Suspended sediments (mg L^{-1})



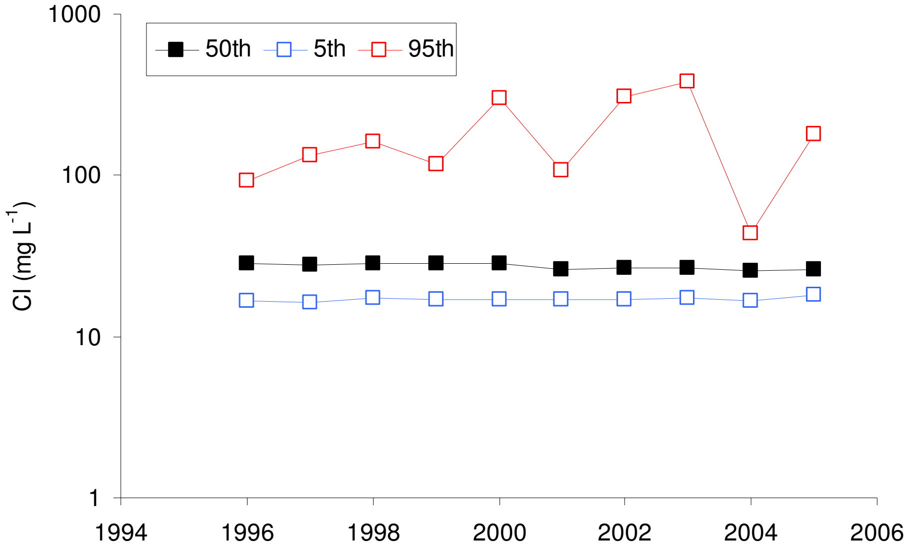
Annual median SS decreased significantly in 5oth percentile ($r_S = -0.60$; $P < 0.01$) and 95th percentile ($r_S = -0.87$; $P < 0.001$) rivers, indicating improving conditions in the region's 'average' and 'worst' sites over the 1995-2005 period. There were 23 sites with data covering this entire period.

1.6.11 Turbidity (NTU)



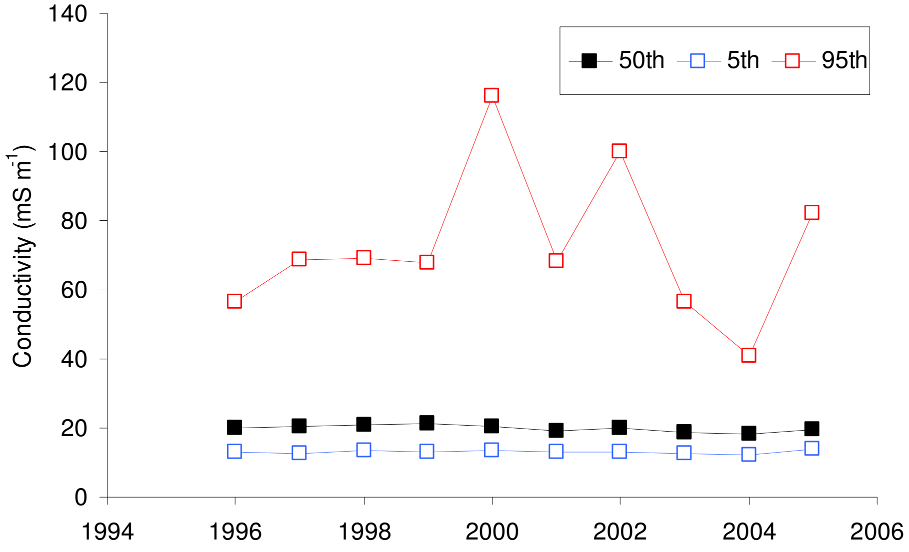
Annual median TURB decreased significantly in 5oth percentile ($r_S = -0.66$; $P < 0.001$) and 95th percentile ($r_S = -0.81$; $P < 0.001$) rivers, indicating improving conditions in the region's 'average' and 'worst' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Note that the guideline/trigger value for protection of aquatic ecosystems (ANZECC 2000) in lowland streams is 5.6 NTU.

1.6.12 Chloride (mg L^{-1})



Annual median chloride concentrations increased significantly at 5th percentile (r_S = 0.47; $P < 0.05$) and decreased significantly at 50th percentile (r_S = -0.83; $P < 0.001$) sites, indicating deteriorating conditions at the 'best' sites and improvements at the 'average' sites over the 1995-2005 period. There were 22 sites with data covering this entire period. Note the $\log_{10}$-scale on the Y-axis.

1.6.13 Conductivity (mS m^{-1})



Annual median conductivity decreased significantly at 50th percentile sites (r_S = 0.70; $P < 0.001$), indicating improving conditions at the region's 'average' sites over the 1995-2005 period. There were 23 sites with data covering this entire period. Scarsbrook

(2006) noted that the national annual median conductivity (based on 77 NRWQN sites) for 2005 was 9.5 mS m^{-1}.

1.7 Land use and water quality state (1995-2005)

Site median values were calculated for each parameter using the 1995-2005 dataset (monthly values). These median values and the overall average rank by site are presented in Table 4. In relation to mean rank, the three sites on Pakuranga Creek, and sites on Otaki Creek and Omaru Creek had the poorest overall water quality. At the other end of the scale, sites on Cascade, Ngakaroa, Matakana and West Hoe streams had the best overall water quality.

Using landcover data in Table 1, site median values were correlated (Spearman rank correlation) with percent native, pasture and urban landcovers (Table 3). The percentage of Urban landcover in the catchment showed the strongest correlations with water quality parameters, with high %Urban being associated with higher temperatures, high SS and turbidity, higher Cl concentrations and conductivity and higher concentrations of faecal coliforms and nutrients . Note that %Native and %Urban are strongly negatively correlated across the ARC monitoring sites (r_S = -0.76), so there is limited value in presenting results for both landcover categories. There were only weak correlations between median water quality parameters and %Pasture, with the exception of pH (Table 3).

Sites were classified as Forest, Rural and Urban to allow for an assessment of mean water quality rank by landcover (Figure 2). Sites dominated by urban landuse has significantly lower mean rank water quality than either forest or pasture sites.

Table 3.

Correlations (Spearman rank) between site median values from monthly data (1995-2005) and lancover. '*' $P < 0.05$; '**' $P < 0.01$; '***' $P < 0.001$. Note that number of sites (n) = 25, except for CL, where n = 24. Refer to Table 2 for units.

	%Native	%Pasture	%Urban
DO	0.32	-0.14	-0.46*
TEMP	-0.64***	0.01	0.63**
FAEC	-0.60**	-0.09	0.76***
NH_4-N	-0.71***	-0.13	0.83***
NO_X-N	-0.78***	-0.10	0.62**
DRP	-0.19	0.06	0.44*
TP	-0.58**	-0.00	0.78***
PH	-0.04	-0.572**	0.08
SS	-0.31	-0.01	0.53**
TURB	-0.17	-0.01	0.37
CL	-0.28	-0.30	0.43*
COND	-0.67	-0.40*	0.87***

Figure 2.
Mean water quality rank by dominant landcover class. Note that 'Forest' includes 3 Native Forest and 1 Exotic Forest sites. Error bars are 1SD. Letters above the bars relate to results of a Bonferroni post-hoc test, whereby different letters (a, b) indicate statistically significant pair wise differences (P < 0.05). Number of sites (n) is also given.

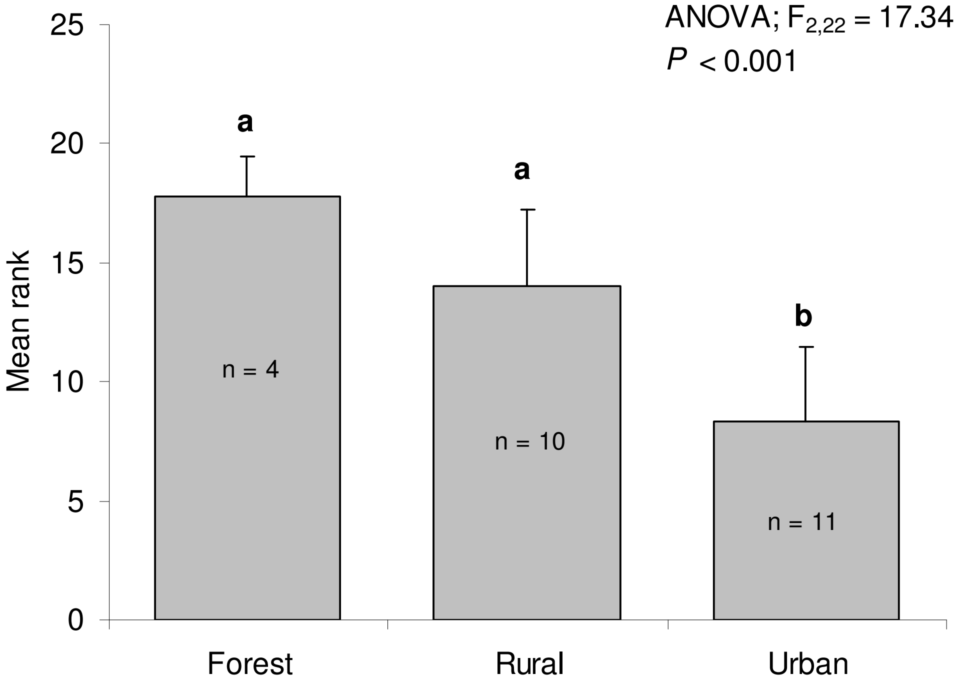


Table 4.

Median values (monthly data for period 1995-2005) for a range of water quality variables. Sites are ordered by mean rank, which relates to the average rank across all variables, with high values indicating good water quality and low values poor water quality. 'ID' = insufficient data. Refer to Table 2 for units.

Site	Name	DO	TEMP	FAEC	NH_4-N	NO_X-N	DRP	TP	PH	SS	Turb	CL	COND	Mean rank
ARC44603	Cascade @ Confluence	10.1	13.5	50	0.010	0.017	0.020	0.030	7.7	1.1	2.5	ID	16.80	20
ARC43829	Ngakoroa @ Mills Rd	9.3	15.5	300	0.010	2.226	0.010	0.020	7.3	1.1	1.9	17.40	14.80	20
ARC6604	Matakana @ Wenzlicks Farm	8.3	15.2	330	0.030	0.092	0.012	0.040	7.4	4.2	5.6	23.90	18.35	18
ARC7206	West Hoe @ Halls	9.3	13.3	80	0.010	0.024	0.012	0.030	7.5	6.0	9.6	32.70	16.75	18
ARC7904	Opanuku @ Candia Rd Bridge	9.5	13.7	1300	0.030	0.164	0.020	0.040	7.5	3.6	5.6	22.80	13.90	17
ARC8516	Wairoa @ Tourist Rd	9.6	16.2	500	0.030	0.484	0.020	0.050	7.4	5.1	6.6	16.30	11.30	16
ARC6811	Mahurangi @ Forestry HQ	9.4	13.9	140	0.030	0.237	0.010	0.030	7.5	5.2	9.8	31.35	18.30	16
ARC7104	Waiwera @ McCathies Flat	9.4	15.6	800	0.030	0.174	0.010	0.040	7.5	6.9	10.0	26.00	18.50	15
ARC6804	Mahurangi @ Warkworth WTP	9.5	15.9	800	0.040	0.236	0.020	0.050	7.7	5.0	7.1	26.70	18.10	14
ARC45703	Hoteo @ Gubbs	8.7	15.8	170	0.040	0.406	0.020	0.060	7.5	7.5	8.9	25.90	18.10	13
ARC8110	Oakley @ Carrington Creek	8.3	15.5	1300	0.048	1.650	0.020	0.060	7.5	3.6	3.7	23.05	23.70	12
ARC45313	Kumeu @ No. 1 Bridge	8.4	15.6	800	0.047	0.426	0.020	0.060	7.3	9.1	11.7	28.80	15.90	12
ARC8214	Otara @ East Tamaki Rd	9.6	16.9	3000	0.050	1.235	0.020	0.050	7.6	4.4	4.1	23.90	20.15	12
ARC43856	Papakura @ Porchester Rd	7.8	15.8	2300	0.050	0.569	0.030	0.080	7.2	4.5	6.4	26.90	18.50	11
ARC7805	Rangitopuni @ Walkers	8.1	15.5	500	0.050	0.258	0.020	0.070	7.4	9.8	11.0	27.55	21.15	11
ARC7811	Oteha @ Days Bridge	7.7	14.6	500	0.040	0.478	0.020	0.060	7.3	10.6	19.0	26.85	24.55	11
ARC7830	Lucas @ Gills Rd Bridge	8.1	14.3	800	0.060	0.304	0.010	0.070	7.3	15.0	26.0	31.05	23.75	11
ARC7506	Vaughan's @ Lower Weir	6.7	14.9	1300	0.030	0.036	0.020	0.050	7.4	10.4	13.2	39.55	23.35	10
ARC8205	Otara @ Kennel Hill	6.7	15.9	1400	0.050	0.316	0.030	0.100	7.3	8.6	8.6	29.50	22.30	9
ARC43807	Puhinui @ drop Structure	9.0	17.6	1700	0.060	0.758	0.020	0.060	7.4	9.4	8.7	27.55	21.10	9
ARC8216	Pakuranga Ck @ Guy's Road	7.6	17.2	800	0.050	0.553	0.010	0.100	7.6	37.4	34.0	24.25	25.70	8
ARC8219	Otaki Ck @ Middlemore Cres	7.5	17.2	2800	0.065	1.100	0.020	0.070	7.4	5.2	7.4	45.35	35.20	7
ARC8217	Pakuranga Ck @ Botany Road	11.6	19.0	5000	0.050	0.732	0.020	0.090	7.6	11.0	11.8	30.55	28.50	6
ARC8215	Pakuranga Ck @ Greenmount	7.3	17.4	1300	0.160	0.624	0.030	0.140	7.5	10.0	14.0	40.60	51.40	4
ARC8218	Omaru Creek @ Taniwha St	7.0	17.5	7900	0.090	0.563	0.030	0.120	7.5	13.9	10.0	201.00	90.80	3

1.8 Water quality trends (full data record)

1.8.1 Trends in raw data

Regional scale trends of warming water temperatures, decreasing faecal bacteria and nutrient (NO_x-N, P and TP) concentrations and decreasing levels of suspended sediments (SS & TURB) were observed for the full water quality dataset.

Site ARC8216 (Pakuranga @ Guy's Rd) showed statistically significant trends for 12 of the 14 variables reported in Table 5 and provides a useful illustration of patterns over time (many of these were the largest recorded changes). The warming trend at this site (Fig. 3a) should be considered ecologically significant as temperatures exceeding 20 ºC have become more common and temperatures exceeding 25 ºC have also been observed. ARC8216, like many other sites in Auckland region shows a strong decreasing trend in concentrations of NO_x-N. This is a positive sign, although it should be noted that concentrations of oxidised nitrogen still regularly exceed ANZECC (2000) guidelines for lowland streams (i.e., 0.444 mg L^{-1}). Concentrations of faecal coliforms at ARC8216 have also trended down significantly during the period 1992-2005. This decreasing trend is apparent at a number of other sites, as should be considered as very positive. The time series for faecal coliforms in Figure 3c suggest a step trend at ARC8216, with changes in mid 2000. To investigate this further I used a CUSUM figure (Fig. 4), showing cumulative differences from the long-term mean. This figure clearly shows major changes in concentrations of TP, SS, NH4-N and Faecal coliforms in mid 2000 (identifiable as the start of a linear decreasing trend in the CUSUM figure). These changes are consistent with removal of a significant point source discharge (e.g., sewage oxidation pond).

Figure 3.

Time series plots for water temperature, NO_x-N and faecal coliforms (log$_{10}$-transformed) at site ARC8216 (Pakuranga Creek at Guy's Rd).

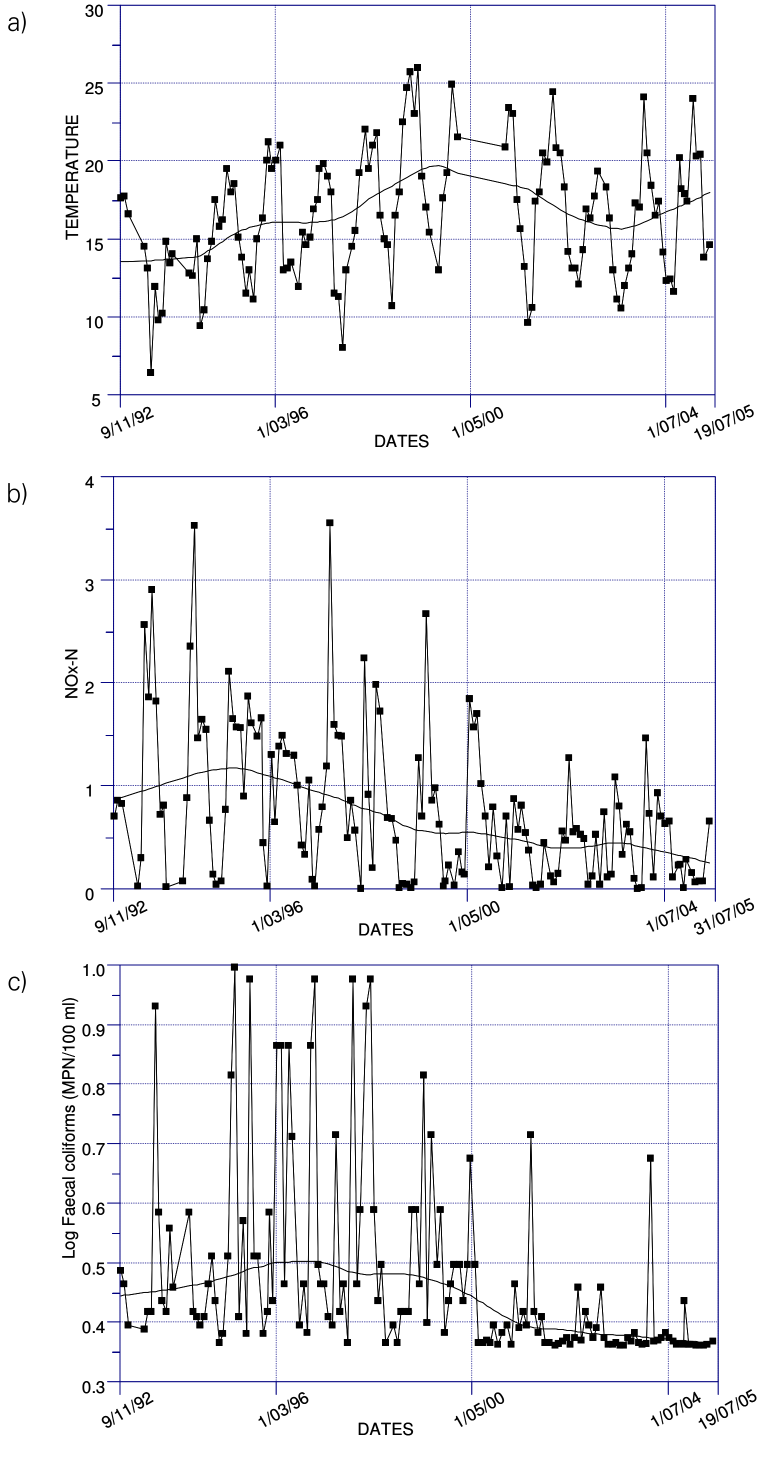
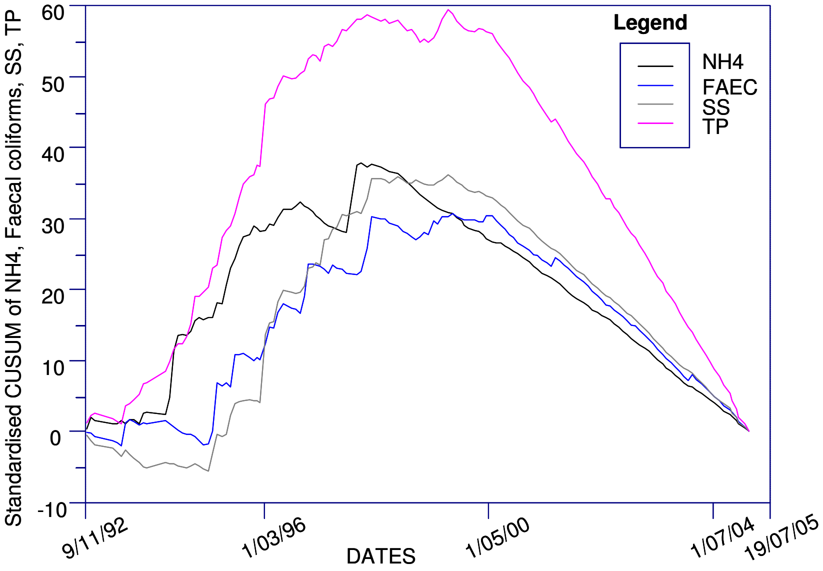


Figure 4.
CUSUM plots for NH4-N, faecal coliforms, SS and TP at site ARC8216 (Pakuranga Creek at Guy's Rd). Note: the sharp linear decreases starting in mid 2000 are indicative of a step change (reduction) in values for the four parameters.



Despite the regional scale trends of improving water quality, there were examples of sites showing deterioration over the full period of record. Examples include increasing concentrations of faecal coliforms at ARC43856 (Papakura @ Porchester Rd Bridge; Fig. 5a) and increasing concentrations of NO_x-N at ARC43829 (Ngakaroa @ Mills Rd; Fig. 5b). Given the improving trend in these variables observed at other sites, these results suggest a more detailed investigation of these sites may be warranted.

Figure 5.

Examples of deteriorating trends in water quality parameters. a) Log-transformed faecal coliform concentrations (MPN 100 ml^{-1}) at site ARC43856; b) NO_x-N concentrations (mg L^{-1}) at site ARC43829.

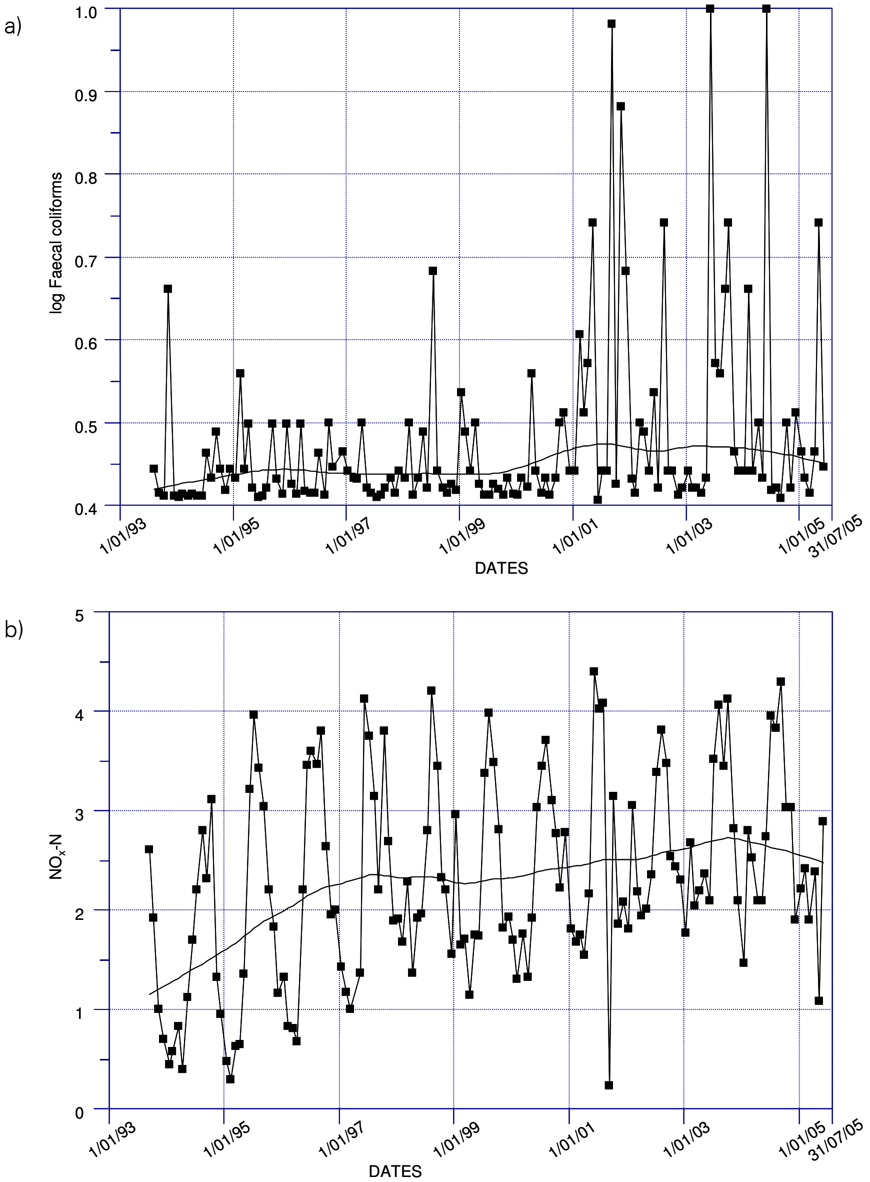


Table 5.

Results for trend analysis on raw data for the full period of record, showing Relative Sen Slope Estimates (expressed as % of data median yr^{-1}). Sites where a Seasonal Kendall test for trend was statistically significant are marked with asterisks ('*' $P < 0.05$; '**' $P < 0.01$; '***' $P < 0.001$). The total number of positive and negative trends are also given, with *P*-values for a binomial test for a regional trend. 'ID' = Insufficient data. Refer to Table 2 for units.

Site	**DO**	**TEMP**	**FAEC**	**NH_4-N**	**NO_x-N**	**DRP**	**TP**	**PH**	**SS**	**TURB**	**CL**	**COND**
ARC43807	1.13*	0.19	0.00	-3.33	-1.24	0.00	-3.59***	0.15*	-9.22***	-8.21***	-1.82**	-0.76*
ARC43829	0.54*	0.00	0.00	-2.50*	5.72***	0.00	0.00	0.33***	-6.07**	-5.02**	0.29	0.39*
ARC43856	1.27**	0.25	6.54***	0.00	-1.97**	0.00**	-4.18***	0.50***	-3.72*	-2.61	-0.94***	-0.44*
ARC44603	-0.49***	0.55***	-4.19***	0.00	0.12	0.00*	-3.50***	0.66***	-6.63***	-1.95**		0.46**
ARC45313	-0.13	0.09	0.31	0.00	-2.41**	0.00	-2.37**	0.46***	-3.43*	-0.50	-0.48**	-0.62**
ARC45703	-0.36	0.00	-0.29	0.52	-0.33	0.00	-1.59**	0.45***	0.18	0.96	-0.67***	0.91***
ARC6604	0.17	0.00	0.00	0.00	-0.15	-1.56***	-2.55***	0.42***	-0.97	-0.26	-0.68***	0.77***
ARC6804	0.84***	ID	-6.32**	1.28	-6.62***	-2.15***	-4.94***	0.39***	-4.76**	-2.34	1.40***	0.94**
ARC6811	0.00	1.14**	-1.88	0.00	-7.14***	-5.50***	-6.67***	0.45***	-7.39***	-4.52***	1.88***	1.11***
ARC7104	-0.15	0.00	1.19*	-0.37	-1.81**	0.00	-1.34***	0.37***	0.21	1.26*	-0.75***	1.05***
ARC7805	0.00	0.00	-2.35*	0.18	-3.30**	0.00	-1.28*	0.34***	-1.22	-0.34	-1.04***	0.79***
ARC7811	-0.33	0.35*	-1.32	-4.64***	-4.11***	0.00	-1.95***	0.46***	-5.87***	-4.37***	-2.16***	0.75**
ARC7830	0.59	0.98***	0.00	1.82*	1.58	-0.65*	0.00	0.20**	-0.38	4.63**	-1.78***	0.56
ARC7904	-0.35*	0.00	0.00	0.70	0.67	1.36***	-1.00**	0.68***	-3.80***	-1.94*	-1.41***	0.00
ARC8110	0.61	0.00	4.39	4.57*	-2.63***	0.00	0.00	0.00	-4.77*	-1.69	-0.24	-0.38
ARC8205	2.44***	0.43*	-5.18*	-9.12***	0.18	-5.57***	-9.03***	0.35***	-7.77***	-1.97	-2.38***	-0.98**
ARC8214	0.00	0.00	0.96	-3.89***	-2.74**	-7.40***	-10.3***	0.78***	-5.51***	-3.77***	-4.01***	-0.91***
ARC8215	2.16***	0.03	-24.1***	-8.56***	-3.89**	-6.60***	-15.7***	0.00	-12.8***	-9.77***	-0.63	-0.70
ARC8216	0.00	0.83*	-16.3***	-23.3***	-11.5***	-2.25**	-21.4***	0.71***	-21.4***	-19.7***	-10.6***	-4.76***
ARC8217	1.65**	0.00	0.00	3.28*	-3.60**	0.00	-2.50**	0.00	-12.1***	-12.5***	-0.25	-0.49
ARC8218	-1.66***	-0.62*	-4.26*	0.41	-6.87***	-2.67*	-6.32***	-0.26**	-7.00***	-5.24***	-0.85	-0.35
ARC8219	0.45	-0.17	-3.75	-1.12	-0.58	0.00	-5.83***	0.15***	-5.53***	-0.94	-7.95***	-4.80***
ARC8516	-0.10	0.35**	-4.46**	0.00	0.04	0.00	-1.52**	0.60***	-0.94	0.12	-2.29***	-0.44**
Positive	11	11	5	8	6	1	0	19	2	4	3	10
Negative	8	2	12	9	17	9	20	1	21	19	19	12
P-value	0.144	**0.010**	**0.047**	0.185	**0.012**	**0.010**	**<0.001**	**<0.001**	**<0.001**	**0.001**	**<0.001**	0.154

1.8.2 Correlations with land use

There were significant correlations (Spearman rank correlation) with the percentage of native forest (incl. scrub) and trends (RSSE) in NO_x-N, DRP, TP, SS, Turbidity and conductivity (Table 6). Similar, but opposite trends were observed for % Urban. No statistically significant correlations were observed for % Pasture. As shown in Figure 6, the largest decreasing trends in SS were observed in sites with low percentages of native forest and scrub in their catchments (note that, despite the high correlation coefficient, the relationship is poorly represented by a monotonic trend, such as the Spearman correlation). The negative correlation with % Urban implies that the greatest decreases in SS were in urban sites. I interpret the correlations in Table 6 as indicating that the improving trends in nitrate, phosphorus and suspended sediments were strongest in highly modified catchments, implying improvements in management of land-water interactions in these catchments.

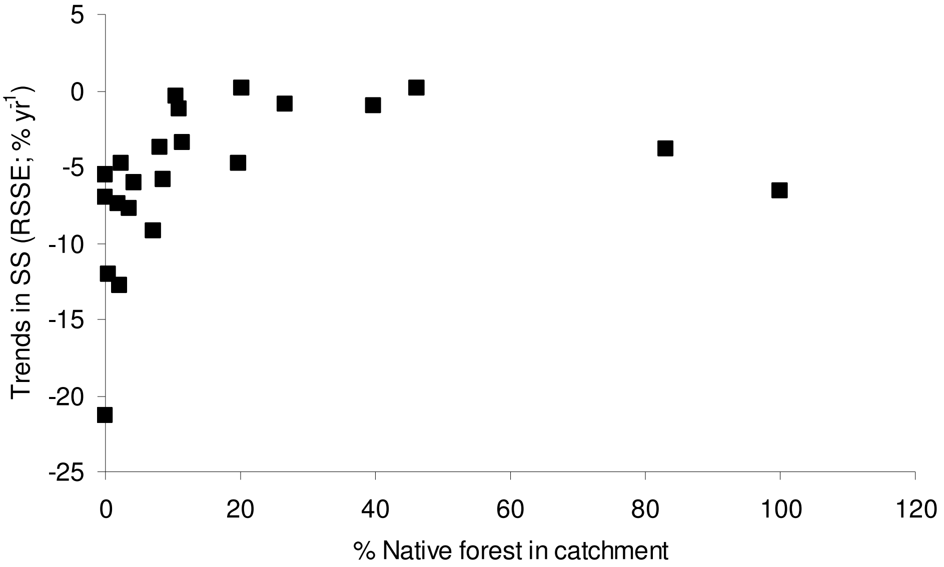
Table 6.

Spearman rank correlation coefficients for relationships between land cover and relativised sen slope estimates from seasonal kendall trend analysis (full data record). '*' $P<0.05$; '**' $P<0.01$. Refer to Table 2 for units. Note that trends (Table 5) can be negative (e.g., TP, SS). So a positive correlation for these parameters means that magnitude of decreasing trends is greatest at low levels of % Native and trends become more positive as % Native increases.

Variable	% Native forest	% Urban
DO	-0.38	0.34
Temperature	0.15	-0.26
Faecal coliforms	0.13	-0.10
NH_4-N	0.30	-0.03
NO_x-N	0.49*	-0.47*
DRP	0.51*	-0.31
TP	0.55**	-0.38
pH	0.35	-0.50*
SS	0.64**	-0.47*
Turbidity	0.63**	-0.45*
Chloride	0.18	-0.24
Conductivity	0.58**	-0.58**

Figure 6.

Scatterplot of trends in SS (expressed as Relative Sen Slope Estimates; RSSE) on % native forest & scrub for 23 monitoring sites.



1.8.3 Trends in flow-adjusted data

Analysis of flow-adjusted water quality data for the full period of record gave similar regional-scale trends to those observed in the raw data, including trends of warming water temperatures, decreasing NO_x-N and TP concentrations and decreasing levels of suspended sediments (SS).

There was a strong correlation ($r_S = 0.72$; $P < 0.01$), and approximately linear relationship between % native forest and scrub and relativised trends in SS (Fig. 7). A significant correlation was also observed for Turbidity and % native forest ($r_S = 0.51$; $P < 0.05$) , but there were no other statistically significant correlations with other landcover categories.

Figure 7.

Scatterplot of flow-adjusted trends in SS (expressed as Relative Sen Slope Estimates) on % native forest for 16 monitoring sites.

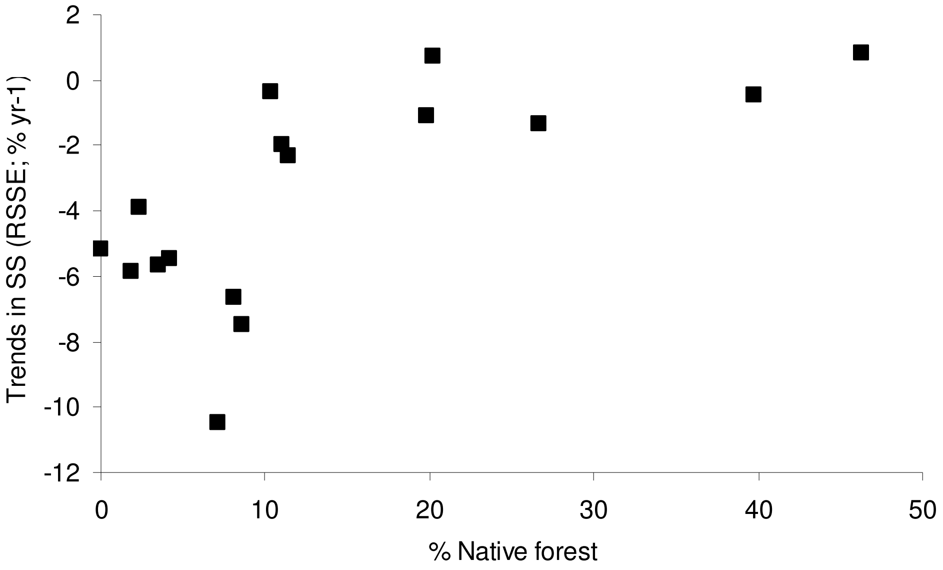


Table 7.

Results for trend analysis on flow-adjusted data for the full period of record showing Relative Sen Slope Estimates (expressed as % of data median yr^{-1}). Sites where a Seasonal Kendall test for trend was statistically significant are marked with asterisks ('*' $P < 0.05$; '**' $P < 0.01$; '***' $P < 0.001$). The total number of positive and negative trends are also given, with *P*-values for a binomial test for a regional trend. 'ID' = Insufficient data. Refer to Table 2 for units.

Site	DO	TEMP	FAEC	NH_4-N	NO_x-N	DRP	TP	PH	SS	TURB	CL	COND
ARC43807	0.76	0.42	-0.24	-3.15*	-3.73***	-0.50	-3.27*	0.18	-10.5***	-10.2***	-1.78***	-0.81
ARC43829	0.03	0.28	1.09	-2.20	4.20***	0.10	-1.15	0.29***	-5.45	-3.84**	0.42***	0.77
ARC43856	0.37	0.50	7.40*	-1.50	-4.36***	-2.33	-3.28	0.48***	-6.63***	-4.78***	-0.60	-0.04
ARC45313	0.72	-0.41*	3.45	1.02	-0.38	-3.95	-2.13	0.42***	-2.34	-0.14	-0.79	-0.99*
ARC45703	-0.43	0.18	-0.92	0.88	-2.10***	0.86	-1.27	0.38	0.71	0.96	-0.50*	0.90
ARC6604	0.25	0.00	-0.81	0.73	-2.91***	-2.00	-2.29	0.41*	-0.44	0.40	-0.81	0.62
ARC6804	1.05*	-2.20***	-6.43**	1.78	-4.92***	-2.80	-3.44	0.29*	-1.11	0.59	1.03*	0.43
ARC6811	-0.22	1.34	-3.93	0.77	-6.65***	-6.10*	-4.90	0.37**	-5.87***	-4.70***	1.66	0.96
ARC7104	-0.37	0.18	4.51	-0.10	-3.06***	0.00	-1.12	0.35**	0.82	1.85	-0.82**	0.93*
ARC7805	-0.49	0.02	-3.36	0.55	-4.79***	0.80**	-1.46	0.33	-1.97***	-0.75	-0.92	0.74
ARC7811	-0.54	0.63	-2.37	-4.91*	-3.76***	0.17	-1.50	0.44	-7.49**	-4.40**	-1.96	0.71*
ARC7830	0.58	1.54*	1.13	1.53	1.43	-3.94	0.46	0.20**	-0.37	4.49	-1.34***	1.11*
ARC8110	0.71	-0.18	7.05	4.05	-2.23***	0.47*	-0.66	0.13	-3.87*	-0.16	0.05	-0.08
ARC8205	4.29	0.03	-2.07	-11.1***	2.29*	-5.40**	-8.30***	0.33***	-5.67*	1.17	-2.34***	-2.17*
ARC8214	-0.14	0.16*	0.65	-1.40	-4.24***	-7.10	-10.24	0.68	-5.15*	-4.09*	-3.47*	-0.89**
ARC8516	-0.32*	0.48	-5.28	-0.52**	-2.37**	0.25	-1.53	0.59	-1.35	-0.45*	-2.23	-0.29
Positive	9	12	7	8	3	5	1	15	2	6	4	9
Negative	6	3	8	7	12	9	14	0	13	9	11	6
P-value	0.17456	0.00854	0.17456	0.19638	0.00854	0.15274	0.00024	<0.0001	0.00183	0.12219	0.02777	0.17456

1.9 Water quality trends (1995-2005)

1.9.1 Trends in raw data

For the 10-year period from July 1995 until June 2005 there were significant regional scale trends of cooling water temperatures, decreasing faecal bacteria and nutrient (NOx-N, TP) concentrations and decreasing levels of suspended sediments (SS and Turbidity). Significant improving trends in nitrate concentrations were observed at 20 of the 23 monitoring sites, while improving trends in SS were observed at 22 of the 23 sites (Table 9).

Overall, the regional-scale trends for the 1995-2005 period were very similar to those for the full period of record (Table 5), the only exception being the change in temperature trend from positive to negative, which may be related to climatic variability or changes in shade conditions in the cathment. The strongest decreasing temperature trends were in three urban streams (Otara @ East tamaki Rd. Otaki @ Middlemore Cres and Omaru @ Taniwha St). Further investigation is required to determine if changing riparian conditions might be driving the observed decreasing temperature trends at these sites.

1.9.2 Correlations with land use

Correlations between trends for the 1995-2005 period and landcover characteristics (Table 8) were similar to thise for the full period of record (Table 6), although generally stronger. The strongest correlations were with sediment (SS and Turbidity) and related (TP) parameters. As was observed for trends in the full record, improving trends in SS, Turbidity and TP had the greatest magnitude at sites in highly modified catchments (Fig. 8).

Table 8.

Spearman rank correlation coefficients for realtionships between land cover and relativised sen slope estimates from seasonal kendall trend analysis (1995-2005 data). '*' *P*<0.05; '**' *P*< 0.01; '***' P < 0.001. Refer to Table 2 for units.

Variable	% Native forest	% Pasture	% Urban
DO	-0.16	0.13	0.22
Temperature	0.22	-0.01	-0.25
Faecal coliforms	0.35	0.24	-0.41
NH_4-N	0.45*	0.03	-0.32
NO_x-N	0.37	0.22	-0.33
DRP	0.31	0.33	-0.42*
TP	0.72***	0.31	-0.73***
pH	0.04	0.50*	-0.22
SS	0.84***	0.38	-0.73***
Turbidity	0.75***	0.31	-0.60**
Chloride	0.28	-0.01	-0.31
Conductivity	0.38	0.11	-0.37

Figure 7.
Scatterplot of raw value trends in SS (expressed as Relative Sen Slope Estimates) on % native forest for 23 monitoring sites.

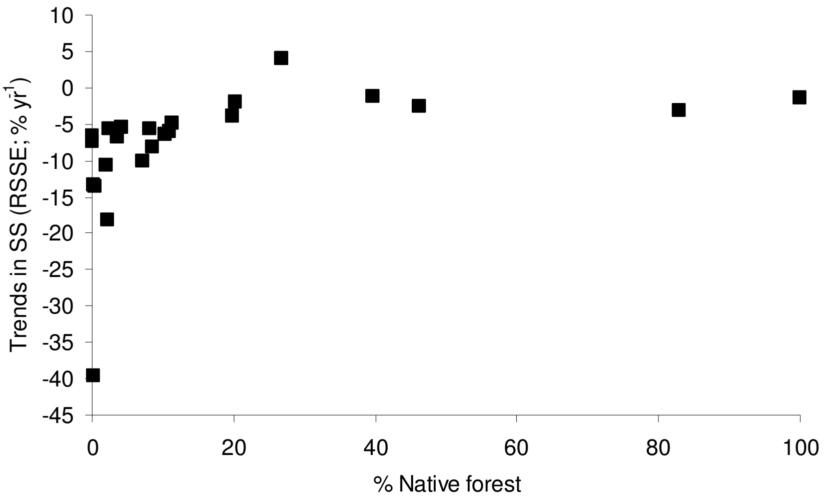


Table 9.

Results for trend analysis on raw data for the period 1995-2005 showing Relative Sen Slope Estimates (expressed as % of data median yr^{-1}). Sites where a Seasonal Kendall test for trend was statistically significant are marked with asterisks ('*' *P* < 0.05; '**' *P* < 0.01; '***' *P* < 0.001). The total number of positive and negative trends are also given, with *P*-values for a binomial test for a regional trend. 'ID' = Insufficient data. Refer to Table 2 for units.

Site	DO	TEMP	FAEC	NH_4-N	NO_x-N	DRP	TP	PH	SS	TURB	CL	COND
ARC43807	0.28	-0.19	0.00	-3.07	-5.10***	0.00	-2.78*	0.17	-10.1***	-10.3***	-2.25**	-1.12*
ARC43829	0.00	-0.28	0.00	0.00	3.65***	0.00	0.00	0.37***	-5.45	-6.31**	0.70**	0.23
ARC43856	0.43	-0.27	7.01*	0.00	-1.77*	0.00	0.00	0.59***	-5.57**	-3.57*	-0.57	-0.27
ARC44603	-0.50	0.18	-4.01	0.00***	0.00	0.00	0.00	0.00	-1.36	-0.67	ID	-0.25
ARC45313	-0.63	-0.32	0.00	0.00	-4.46***	0.00	0.00	0.49***	-4.86	-1.14	0.00	-0.24
ARC45703	-0.38	-0.35	0.00	0.00	-5.67***	0.00*	0.00	0.00	-2.04	1.39	0.12	0.36
ARC6604	-0.14	0.00	0.00	0.00	-4.08**	0.00	0.00	0.00*	-1.19	0.96	0.00	-0.39
ARC6804	ID	ID	-7.00**	2.50	-6.78***	0.00**	0.00	0.28*	-3.97	-2.70	1.06*	0.78
ARC6811	-0.35	0.36	0.00	0.00	-11.7***	0.00**	0.00*	0.33***	-10.6***	-6.93***	0.68	0.55
ARC7104	0.00	-0.55	-4.61	0.00	-4.49***	0.00	0.00	0.00	-2.49	-0.45	-0.49**	0.54
ARC7805	0.00	-0.64	-1.75	0.00	-7.30***	0.00**	0.00	0.00*	-6.06***	-2.19	-0.62	-0.27
ARC7811	-0.74	0.43	-1.17	-7.50**	-5.78***	0.00	-2.38	0.00	-8.18***	-7.23***	-2.18*	-1.65*
ARC7830	0.00	0.58	-1.66	0.00	0.06	0.00	0.00	0.23**	-6.33*	0.17	-1.65**	1.16*
ARC7904	0.15	-0.37	0.00	1.27*	-3.05	0.00	0.00	0.44***	-3.08	0.51	0.44*	0.00
ARC8110	0.69	0.00	5.61	2.98	-3.29***	0.00*	0.00	0.22*	-5.64*	-0.90	0.22	-0.20
ARC8205	2.02**	-0.16	-8.57*	-9.66***	-3.64	0.00**	-8.35***	0.51***	-6.86**	-1.17	-2.01***	-0.45
ARC8214	0.23	-1.35***	-7.20	-2.50	-5.04***	0.00	-3.96**	0.00	-7.36**	-4.09*	-2.30**	-1.24**
ARC8215	1.65***	-0.41	-7.71	-6.44***	-6.04**	-1.03**	-14.3***	0.00	-18.1***	-14.4***	-1.83*	-1.81*
ARC8216	-2.26*	-0.19	-41.2***	-20.3***	-13.71***	0.00	-31.8***	0.43**	-39.7***	-37.2***	-9.10***	-4.16***
ARC8217	1.15	-0.99	-3.76	2.12	-7.16***	0.00	-4.12*	0.00	-13.6***	-10.5***	0.46	-0.99*
ARC8218	-2.31**	-1.18***	-9.30**	0.00	-10.21***	-0.37**	-8.33***	-0.30**	-13.4***	-10.7***	0.81	1.05
ARC8219	0.00	-1.11***	-3.21	-7.66***	-2.66	0.00	-3.53**	0.00*	-6.60**	-3.43	-6.90**	-3.99*
ARC8516	-0.62*	-0.62	0.00	4.67*	-1.50	0.00	0.00	0.00	3.93	4.53*	-0.11	-0.77*
Positive	9	4	2	5	2	0	0	11	1	5	8	7
Negative	9	17	13	7	20	2	9	1	22	18	12	15
P-value	0.185	**0.018**	**0.003**	0.193	**<0.001**	ID	**0.002**	**0.003**	**<0.001**	**0.004**	0.120	**0.041**

1.9.3 Trends in flow-adjusted data

Following flow-adjustment of the 1995-2005 data, only NO_x-N, suspended sediments (SS) and pH showed significant, regional scale trends. However, decreasing trends in NOx-N and SS and increasing trends in pH remained very strong and similar in magnitude to the raw data trends.

Correlations of trends with landuse characteristics also produced similar results to those for raw data.

1.10 Water quality and river flow

There was considerable variation in goodness-of-fit values for the LOWESS flow-adjustment model across parameters and sites (Table 11). The parameters which were most strongly associated with flow were turbidity and suspended sediment, NO_x-N and temperature. In contrast, faecal coliforms, NH_4-N, DRP and pH were weakly associated with flow, as modelled by LOWESS.

Of particular concern were a number of parameters that gave negative values of R^2 at some sites (highlighted in yellow in Table 11). This indicates that the LOWESS model may be a poorer fit to the model than a horizontal line through the mean value of a given parameter, and suggests that LOWESS is inappropriate for that parameter/site combination. This issue appears to be most serious for faecal coliforms and ammoniacal nitrogen.

When carrying out flow-adjustment for a large number of sites and parameters it is usual to choose a single flow-adjustment model and apply this to all cases (e.g., Smith et al. 1996; Scarsbrook et al. 2003; Vant & Smith 2004). The results in Table 11 suggest this may be a risky procedure, as it is likely to result in unreliable trend results for flow adjusted values in some parameters. A more rigorous approach might be to run a series of flow adjustment models (e.g., log-log, LOWESS, General Additive Models) and use the best-fit model. (We will look at implementing this in further development of the Time Trends software).

The consequences of the results below are that flow-adjusted results for some parameters should be viewed with caution. For variables where flow dependency is recognised and understood (e.g., suspended sediment and related parameters) we can be more confident in the flow adjusted results, but flow-adjustment of variables such as faecal coliforms may be inappropriate, at least using LOWESS.

Table 10.

Results for trend analysis on flow-adjusted data for the period 1995-2005 showing Relative Sen Slope Estimates (expressed as % of data median yr^{-1}). Sites where a Seasonal Kendall test for trend was statistically significant are marked with asterisks ('*' $P < 0.05$; '**' $P < 0.01$; '***' $P < 0.001$). The total number of positive and negative trends are also given, with *P*-values for a binomial test for a regional trend. 'ID' = Insufficient data. Refer to Table 2 for units.

Site	DO	TEMP	FAEC	NH_4-N	NO_x-N	DRP	TP	PH	SS	TURB	CL	COND
ARC43807	-0.04	0.25	-1.20	-3.90*	-7.2***	-0.45	-2.68*	0.19	-12.43***	-13.03***	-2.23***	-1.27**
ARC43829	0.09	-0.33	0.62	-0.30	3.0***	0.20	-0.90	0.32***	-3.98	-6.14**	0.70***	0.25
ARC43856	-0.41	0.06	8.83	-0.06	-4.4***	0.10	-0.24	0.58***	-7.68***	-6.38***	-0.33	-0.03
ARC45313	-0.20	-0.84*	6.28	0.36	-2.03	-0.15	-0.02	0.44***	-2.91	-0.35	-0.27	-0.69*
ARC45703	-0.49	-0.05	6.43	-1.08	-6.1***	2.20	0.60	0.04	-1.30	0.27	0.46*	0.33
ARC6604	-0.11	-0.26	-0.61	1.03	-6.7***	2.92	0.20	0.17*	-1.59	0.08	-0.08	-0.19
ARC6804	ID	ID	-11.67	3.00	-4.8***	-0.95	-1.08	0.19*	-0.11	0.44	0.91*	0.29
ARC6811	-0.49	0.97	-4.42	0.93	-10.6***	-6.00*	-1.63	0.28**	-7.51***	-7.31***	0.50	0.44
ARC7104	-0.34	-0.74	-4.31	0.00	-6.00***	0.60	1.58	0.12**	-0.83	0.28	-0.62***	0.58*
ARC7805	-0.22	-0.11	-4.92	1.18	-6.55***	4.60**	-0.03	0.09	-7.27***	-2.96	-0.33	-0.29
ARC7811	-0.37	0.80	-1.13	-8.00*	-5.04***	-1.35	-1.92	0.04	-8.04**	-5.98**	-1.64	-1.22*
ARC7830	0.15	1.22*	0.34	-0.17	0.39	-2.40	1.53	0.25**	-3.23	0.90	-1.56***	0.58*
ARC8110	0.36	-0.21	8.61	3.04	-3.08***	3.80*	0.27	0.19	-4.06*	1.02	0.42	0.05
ARC8205	1.55	-0.07	-5.37	-8.9***	-4.46*	-4.40**	-6.50***	0.41***	-6.38*	-0.60	-1.96***	-1.09*
ARC8214	0.07	-0.85*	-12.43	-3.68	-5.30***	-1.30	-2.22	0.10	-5.46*	-3.36*	-1.60*	-1.36**
ARC8516	-0.72*	0.41	3.44	5.13**	-4.48**	-0.15	1.84	0.12	3.42	2.72*	0.07	-0.31
Positive	5	6	7	7	2	7	6	16	1	7	6	7
Negative	10	9	9	8	14	9	10	0	15	9	10	9
P-value	0.092	0.153	0.175	0.196	**0.002**	0.175	0.122	**<0.001**	**<0.001**	0.175	0.122	0.175

Table 11.

Estimates of 'goodness of fit' (R^2) for LOWESS model fitted to flow – water quality parameter relationships. The values highlighted in yellow are negative values. Refer to Table 2 for units.

Site	DO	TEMP	FAEC	NH_4-N	NO_x-N	DRP	TP	PH	SS	TURB	CL	COND
ARC43807	-15.49	19.6	15.1	-2.42	31.61	5.78	17.05	1.3	79.03	64.91	18.9	32.5
ARC43829	37.26	37.66	-1.12	10.21	46.45	4.8	3.86	5.81	1.07	10.65	16.73	40.94
ARC43856	23.96	28.19	11.07	60.32	72.42	0.04	72.02	16.43	88.48	90.7	32.63	17.1
ARC45313	-0.32	5.31	1.17	5.07	29.89	1.07	50.74	37.56	35.22	52.05	18.2	22.47
ARC45703	7.4	29.84	13.52	-0.92	56.19	-13.92	21.34	17.9	9.94	59.88	14	25.53
ARC6604	38.01	21.86	24.68	-1.6	16.56	23.76	12.61	7.62	31.31	60.29	3.37	33.61
ARC6804	11.47	31.58	-5.01	21.22	42.54	20.26	1.56	14.25	28.73	39.36	14.05	51.59
ARC6811	33.03	24.7	6.25	12.6	38.88	3.36	11.53	6.79	42.7	13	8.24	22.07
ARC7104	21.42	23.44	30.76	-0.5	55.69	2.44	19.2	15.74	23.39	42.79	1.07	43.45
ARC7805	56.5	35.62	-85.34	-0.46	56.73	7.11	33.86	1.61	36.45	51.96	12.75	31.19
ARC7811	57.64	17.49	2.44	5.29	17.76	-3.89	14.43	5.18	38.34	23.58	4.52	7.24
ARC7830	22.53	13.47	26.34	-0.12	-9.54	3.49	27.6	1.55	28.29	18.5	7.366	34.35
ARC8110	33.26	33.27	-3.66	-3.69	9.03	0.07	5.62	11.77	8.29	34.42	5.54	10.12
ARC8205	8.08	15.63	7.28	0.86	24.51	3.22	13.21	2.91	67.68	31.39	3.11	2.72
ARC8214	4.83	24.21	-4.17	-27.19	49.89	5.64	-45.22	-73.91	9.81	24.59	0.91	1.39
ARC8516	10.33	33.57	11.98	0.22	61.92	2.83	11.97	13.39	49.75	22.19	2.96	23.13
Average	21.87	24.72	3.21	4.93	37.53	4.13	16.96	5.37	36.16	40.02	10.27	24.96

Discussion and recommendations

1.11 State of Auckland streams

The last detailed review of water quality state by Wilcock & Stroud (2000) concluded that many streams in the Auckland region have poor water quality. The assessment provided in this report supports the conclusion of Wilcock & Stroud (2000). As shown by graphs of moving state over time, many Auckland streams tend to have high temperatures, high concentrations of nutrients and suspended sediments, and high levels of faecal coliform bacteria.

Strong correlations between most water quality parameters and landcover characteristics, suggest that these water quality issues are associated with intensive landuses. For example, there is a strong association between the percentage of catchment in urban landcover and concentrations of faecal coliforms, nutrient and suspended sediments found at monitoring sites. Overall, sites in urban catchments have poorer water quality than sites in forest or rural catchments. Other recent studies have also highlighted the poor water quality in urban catchments. For example, Scarsbrook et al. (2007) summarised water quality information from 545 regional council monitoring sites from around New Zealan (including ARC data), and found that urban stream water quality was poorer than that in pastoral or native catchments for almost all water quality indicators.

Summaries of changes in state over time (1995-2005) provided a number of initial indications that conditions in some Auckland streams might have improved over that time period. There were significant decreases over time in annual median concentrations of faecal coliforms, nitrate/nitrite nitrogen, and suspended sediments. These trends in annual median values are a useful tool for showing changes in state over time, and may be more easily explained to non-technical audiences than formal trend analyses.

1.12 Water quality trends

Formal trend analysis (Seasonal Kendall test) was applied to datasets covering the full period of record (i.e., 1986-2005 depending on site), as well as a dataset for a more recent period (1995-2005) that provided greater consistency across sites. At the regional scale, analyses identified a number of trends indicating improving water quality. Improving trends in concentrations of oxidised nitrogen (NOx-N) and suspended sediments (SS and Turbidity) were present regardless of time period analysed, or use of raw or flow-adjusted values. Other parameters (e.g., DRP, TP, Faecal coliforms, Chloride) showed significant regional-scale improving trends, but these trends either disappeared with flow adjustment (e.g., faecal coliforms), or were apparent for the full period, but not the shorter 10-year period (e.g., Chloride concentrations).

Observed trends in suspended sediment, phosphorus and, to a lesser extent nitrate, were correlated with landcover in the catchments upstream of the monitoring site. The largest trends were associated with highly modified catchments, particularly those having a high percentage of urban land use. These improvements are consistent with improving management of land-water interactions in these catchments, but without detailed knowledge of changing conditions at each site this should be viewed as an hypothesis only. This highlights an important point to be made about trend analysis. Without detailed information on changing pressures within a catchment it is very diffult to identify the causes of any observed trends at any one site. Trying to identify the causes of observed trends at a regional scale is even more difficult.

It is clear that turbidity and suspended sediment (SS) variables are telling a very similar story. Given the apparent redundancy, there may be justification for discontinuing one of these. Again this would require a more detailed review of the data than was possible here.

Trends over time in the Pakuranga Stream @ Guy's Rd illustrate an important aspect of trend analysis, which generally assumes that there is some gradual change over time that can be picked up with regular sampling over long periods. However, there is also the potential for rapid, step changes to occur in a stream's water quality. These step changes may occur as a result of an addition or removal of a point source of contaminants, or a removal or addition of flow (i.e., causing changes in dilution of existing contaminants). The brief summaries made of the data from Pakuranga Stream @ Guy's Rd suggest that a step change occurred in mid-2000. It would be useful to explore this further, as such case studies of water quality improvement following point source removal can be very valuable in highlighting both the importance of long-term monitoring, and the return on investment associated with removal of point source discharges.

Flow-adjustment is an important component of most water quality trend analyses, but analysts seldom assess whether the low-adjustment model being used is appropriate. The ARC data has shown that flow-adjustment using LOWESS may be inappropriate for some parameters, or some sites. This finding suggests that trends in raw data should be given priority in any management decision making, whereas flow-adjusted trends should be interpreted with caution, especially if they are telling a different story to trends in raw data.

1.13 Recommendations

- ☐ Auckland Regional Council's Rivers & Streams Water Quality Programme provides a very valuable, long-term dataset for investigating changes in state and changes over time in a selection of the Regions streams. The suite of water quality parameters is appropriate, and no major parameters are missing (I note that *E. coli* has been added recently as a faecal indicator bacterium). I suggest that the usefulness of collecting both turbidity and suspended sediment data should be looked at. These two parameters are providing very similar information.
- ☐ Only 16 of the 25 monitoring sites investigated in this report currently have flow recorders. This does not limit the ability to detect trends in raw data, but precludes the ability to carry out flow-adjustment. However, given the uncertainty that may be introduced by inappropriate flow-adjustment procedures, and the recommendation for greater emphasis on trends in raw data, I do not consider the lack of flow recorders at all monitoring sites as a major disadvantage.
- ☐ ARC should develop detailed information on pressures (e.g., number and type of point source discharges) and changes in these pressures over time (e.g., information on changing riparian habitat conditions). This information would improve the ability to link observed trends in water quality directly to management activities.
- ☐ Development of region-specific water quality guidelines would greatly enhance future reporting on state and trends in the Region's rivers. Current national guidelines (e.g., ANZECC 2000) may lead to a biased view of water quality conditions in Auckland streams (e.g., clarity guideline values for recreation (1.6 m) will seldom be met in Auckland streams).

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Appendices

1.14 Appendix 1. Site information (provided by ARC).

SITE	Easting	Northing	Flow data	Landuse	Disturbance	Altitude	From Sea (m)	Area (ha)
ARC6604	2663637	6538880	No	Rural low	low	40	2950	1406
ARC6804	2659289	6532066	Yes	Rural	high	20	3495	5008
ARC6811	2658246	6526746	No	Forestry	low	60	2702	474
ARC7104	2659256	6515392	No	Rural low	low	20	2843	2970
ARC7206	1748298	5950591	No	Native Bush	low	20	3200	386
ARC7506	2665939	6500463	Yes	Rural	high	10	1194	224
ARC7805	2654892	6494008	Yes	Rural	high	20	4223	8363
ARC7811	2661825	6495265	Yes	Urban	high	20	6331	1184
ARC7830	2661865	6496261	No	Urban low	low	20	2198	628
ARC7904	2652563	6477294	No	Native Bush	low	40	792	1647
ARC8110	2662410	6479407	No	Urban	high	10	170	1201
ARC8205	2678752	6470040	Yes	Urban low	low	10	2464	1746
ARC8214	2677814	6469148	No	Urban low	high	20	1451	826
ARC8215	2679890	6472486	No	Urban	high	20	712	334
ARC8216	2680421	6472641	No	Urban	high	20	459	170
ARC8217	2680517	6474729	No	Urban	high	20	325	773
ARC8218	2676698	6478449	No	Urban	high	10	406	333
ARC8219	2674713	6468776	No	Urban	high	10	132	160
ARC8516	2693071	6463336	Yes	Rural	high	20	12788	14820
ARC43807	2676869	6465983	Yes	Urban	high	20	5776	1195
ARC43829	2685512	6443288	Yes	Rural	high	150	3653	453
ARC43856	2681720	6462011	No	Rural	high	20	3786	4685
ARC44603	2646046	6478079	No	Native Bush	low	60	12257	270
ARC45313	2649698	6490510	Yes	Rural	high	30	40930	4582
ARC45703	2645797	6534299	Yes	Rural	high	20	21837	26787

1.15 Appendix 2. Data coverage

Table 1.

Data coverage (all data).

SITE	START	END	TOTAL	FLOW	DO	TEMP	FAEC	NH_4-N	NO_x-N	TKN	TN	NO3W	P	TP	pH	SS	TURB	Cl	COND	ECOL
ARC6604	16/12/86	01/06/05	222	210	159	221	221	218	161	48	48	0	219	219	221	221	221	215	215	0
ARC6804	07/07/93	06/09/05	141	141	118	78	138	136	141	0	0	137	139	139	139	139	140	136	141	0
ARC6811	03/08/93	01/06/05	143	142	140	143	143	140	142	48	48	0	141	140	143	142	142	143	143	0
ARC7104	24/06/86	31/05/05	229	229	159	227	228	224	160	48	48	0	225	225	228	227	228	222	222	0
ARC7206	14/02/02	01/06/05	29	22	28	29	29	27	29	28	28	1	29	29	29	28	29	27	28	0
ARC7506	04/07/01	01/06/05	42	24	42	41	42	40	42	41	41	0	41	41	42	41	42	42	42	0
ARC7805	24/06/86	31/05/05	229	226	159	228	228	225	159	48	48	0	226	226	228	228	228	222	222	0
ARC7811	24/06/86	01/06/05	228	228	157	224	226	225	160	48	48	0	224	224	226	227	227	220	221	0
ARC7830	03/08/93	01/06/05	143	140	140	143	142	141	142	48	48	0	140	140	143	141	142	143	143	0
ARC7904	26/06/86	01/06/05	229	0	158	226	226	226	161	48	48	0	224	225	229	228	229	228	229	0
ARC8110	08/08/94	01/06/05	130	123	128	128	129	128	129	48	48	0	128	126	130	129	130	129	130	0
ARC8205	08/01/92	01/06/05	162	158	160	160	161	160	161	48	48	0	160	158	162	161	162	161	162	0
ARC8214	25/06/86	07/06/05	217	216	144	201	216	213	150	65	0	214	215	215	216	216	217	216	217	58
ARC8215	09/11/92	07/06/05	152	0	144	138	151	148	151	0	0	148	150	149	151	150	151	150	151	59
ARC8216	09/11/92	07/06/05	148	0	140	133	146	143	146	0	0	142	145	144	146	145	146	145	146	59
ARC8217	09/11/92	07/06/05	152	0	144	135	151	148	151	0	0	147	150	149	151	149	151	150	150	59
ARC8218	09/11/92	07/06/05	152	0	146	139	151	148	151	0	0	148	150	149	151	150	151	150	151	59
ARC8219	09/11/92	22/06/05	152	0	146	136	151	148	151	0	0	148	150	149	151	150	151	150	151	59
ARC8516	25/06/86	01/06/05	229	226	161	227	226	226	161	109	109	0	225	225	227	228	229	228	228	0
ARC43807	02/02/94	01/06/05	134	134	132	133	133	132	133	47	47	0	132	131	134	133	134	133	133	0
ARC43829	08/09/93	01/06/05	142	142	140	138	141	140	141	48	48	0	140	139	142	137	142	141	142	0
ARC43856	04/08/93	01/06/05	143	142	142	142	142	141	142	48	48	0	141	140	143	142	143	142	143	0
ARC44603	26/06/86	31/05/05	228	0	156	226	226	221	158	48	0	74	224	225	227	223	227	0	228	226
ARC45313	03/08/93	31/05/05	140	140	137	140	140	137	139	48	48	0	137	137	140	139	139	140	140	0
ARC45703	24/06/86	31/05/05	229	229	159	224	228	225	161	48	48	0	226	227	228	228	228	222	223	0

Table 2.
Data coverage (last 10 years).

SITE	START	END	Total	FLOW	DO	TEMP	FAEC	NH_4-N	NO_x-N	TKN	TN	NO3W	P	TP	pH	SS	TURB	Cl	COND	ECOL
ARC6604	3/07/95	1/06/05	120	114	117	120	120	117	119	48	48	0	118	118	120	119	119	120	120	0
ARC6804	28/07/95	6/09/05	117	117	94	78	114	112	117	0	0	113	115	115	115	115	116	112	117	0
ARC6811	3/07/95	1/06/05	120	120	117	120	120	117	119	48	48	0	118	117	120	119	119	120	120	0
ARC7104	3/07/95	31/05/05	120	120	117	120	120	117	118	48	48	0	117	117	120	119	119	120	120	0
ARC7206	14/02/02	1/06/05	29	22	28	29	29	27	29	28	28	1	29	29	29	28	29	27	28	0
ARC7506	4/07/01	1/06/05	42	24	42	41	42	40	42	41	41	0	41	41	42	41	42	42	42	0
ARC7805	3/07/95	31/05/05	120	118	117	120	120	117	119	48	48	0	117	117	120	119	119	120	120	0
ARC7811	3/07/95	1/06/05	120	120	116	120	119	118	119	48	48	0	117	117	120	119	119	120	120	0
ARC7830	3/07/95	1/06/05	120	117	117	120	119	118	119	48	48	0	117	117	120	118	119	120	120	0
ARC7904	5/07/95	1/06/05	120	0	119	119	119	118	119	48	48	0	118	116	120	119	120	119	120	0
ARC8110	5/07/95	1/06/05	119	113	118	118	118	117	118	48	48	0	117	115	119	118	119	118	119	0
ARC8205	5/07/95	1/06/05	120	120	119	118	119	118	119	48	48	0	118	116	120	119	120	119	120	0
ARC8214	13/07/95	7/06/05	118	118	113	104	118	115	118	0	0	117	117	116	118	117	118	117	118	58
ARC8215	13/07/95	7/06/05	120	0	113	106	119	116	119	0	0	118	118	117	119	118	119	118	119	59
ARC8216	13/07/95	7/06/05	120	0	113	106	119	116	119	0	0	117	118	117	119	118	119	118	119	59
ARC8217	13/07/95	7/06/05	120	0	113	104	119	116	119	0	0	117	118	117	119	117	119	118	118	59
ARC8218	13/07/95	7/06/05	120	0	115	107	119	116	119	0	0	118	118	117	119	118	119	118	119	59
ARC8219	13/07/95	22/06/05	120	0	115	106	119	116	119	0	0	118	118	117	119	118	119	118	119	59
ARC8516	5/07/95	1/06/05	120	120	119	119	119	118	119	67	67	0	118	117	120	119	120	119	119	0
ARC43807	5/07/95	1/06/05	117	117	116	116	116	115	116	47	47	0	115	114	117	116	117	116	116	0
ARC43829	5/07/95	1/06/05	120	120	118	116	119	118	119	48	48	0	118	117	120	115	120	119	120	0
ARC43856	5/07/95	1/06/05	120	120	119	119	119	118	119	48	48	0	118	117	120	119	120	119	120	0
ARC44603	3/07/95	31/05/05	119	0	116	119	119	116	118	48	0	7	116	116	118	114	118	0	119	119
ARC45313	4/07/95	31/05/05	117	117	114	117	117	114	116	48	48	0	114	114	117	116	116	117	117	0
ARC45703	3/07/95	31/05/05	120	120	117	120	120	117	119	48	48	0	117	118	120	119	119	120	120	0