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Trends in River Water Quality in the Waikato Region, 1987-2007

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Disclaimer

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Abstract

Long-term records of river water quality at 113 sites in the Waikato region were analysed using non-parametric statistical methods (seasonal Kendall slope estimator and trend test). At ten Waikato River sites, records of 19 water quality variables that began in 1987 or later, and ended in 2007 were analysed. At the 103 other river sites, records of 14 variables beginning in 1990 or later and ending in 2007 were analysed. The data were generally obtained at monthly intervals, but some records were based on quarterly sampling. Most of the records were adjusted to remove the effects of flow, and both raw and flow-adjusted records were analysed for trends.

A total of 188 Waikato River water quality records were considered. Significant trends (p < 5%) were found in 83 (44%) of these. Variables for which significant trends were found at five or more of the ten Waikato River sites were conductivity, dissolved colour, biochemical oxygen demand, arsenic, boron, nitrate, ammonia, total phosphorus and dissolved reactive phosphorus. The trends of decreased concentrations in dissolved colour, biochemical oxygen demand, arsenic, boron and ammonia all represented improvements in water quality, and mostly result from improved wastewater management over the past 20 years at known point source discharges (e.g. Hamilton and Taupo wastewater treatment plants, Kinleith mill, Wairakei power station). On the other hand, the increases observed in nitrate and total phosphorus concentrations represent deteriorations, and have probably resulted from the intensification of land use within the Waikato River catchment.

A total of 1373 water quality records from the other rivers and streams were considered. Significant trends were found in 590 (43%) of these. Across the region as a whole, the following overall patterns were apparent: (1) significant increases have occurred in pH, conductivity, total nitrogen, nitrate, total phosphorus, *Escherichia coli* and enterococci; and (2) significant decreases have occurred in dissolved oxygen, dissolved colour and ammonia. While the decreases in concentrations of ammonia represented improvements, many of the other trends were deteriorations.

In many parts of the region, relatively-rapid rates of deterioration in total nitrogen, nitrate and total phosphorus were found in these other rivers and streams. While ammonia concentrations improved in many areas, this was generally out-weighed by the much larger increases in the concentrations of other forms of nitrogen, so that the net result across the region was for a deterioration in total nitrogen. Trends in other water quality variables including water temperature and concentrations of *E. coli* and enterococci were less common and more localised.

In these other rivers and streams the observed increases in concentrations of total nitrogen, nitrate, total phosphorus, *E. coli* and enterococci, and the decrease in dissolved oxygen represent a disturbing pattern of insidious water quality degradation which in many cases is likely to be related to the widespread and intense use of land for pastoral farming in the Waikato region.

1 Introduction

River water quality has been routinely monitored in the Waikato region since 1980. Monitoring at several Waikato River sites began at that time, with other sites being added later. Water quality is currently monitored at monthly intervals at ten sites between Taupo Gates at the head of the river, and Tuakau Bridge, some 300 km downstream (Figure 1). In 1990, monthly monitoring of the water quality of other rivers and streams in the region began (Figure 1). Water quality is now measured at ten sites on the Waikato River and 103 sites on other rivers and streams, with results being reported annually (e.g. Beard 2008a, b).

Vant and Wilson (1998) undertook the first comprehensive analysis of trends in water quality in Environment Waikato's river monitoring programmes, examining records for the period ending in 1997. This was subsequently extended to cover the period ending in 2002 (Vant and Smith 2004). This latest report describes a further extension of the analysis, covering the period 1987 to 2007.[1]

2 Methods

Up-to-date information on the location of the sites, the water quality variables measured, the methods used and the general nature of the results obtained are provided in the annual reports on the monitoring programmes (Beard 2008a, b). Information for five of the 100 non-Waikato River sites was obtained by NIWA as part of its National River Water Quality Network (Smith and McBride 1990).[2]

2.1 Datasets analysed

The various water quality records are of differing lengths. Some of the Waikato River records began in 1980, but others did not start until considerably later. For example, records of visual clarity did not begin until 1995, while records of *Escherichia coli* did not begin until 1998. For the Waikato River, records that began at or after the start of 1987 were analysed (i.e. records up to 21 years in length to the end of 2007).

The monitoring of the 103 sites on the other rivers and streams began at different times as follows: (1) sampling began at NIWA's five sites in 1989–90; (2) sampling began at the first three of the Environment Waikato sites in 1990; (3) a further six sites started in 1992; (4) 68 sites started in 1993; (5) 18 sites started in 1994; and (6) the final three sites started in late 2000. Furthermore, the records of the various water quality variables did not always begin at the same time—for example *E. coli* analyses did not begin until 1998.[3] For the 103 sites on other rivers and streams, records that began at or after the start of 1990 were analysed.

The field and laboratory methods used by Environment Waikato are described in the annual reports for the Waikato River and regional rivers programmes (Beard 2008a, b). Since the surveys began, however, there have been a number of changes that need to be accounted for. These are outlined below.[4]

[1] Note that this analysis only deals with <u>changes</u> in river water quality. It does not deal with the <u>state</u> (or condition) of water quality in rivers in the Waikato Region, a matter that is dealt with elsewhere (e.g. Beard 2008a, b).

[2] The five NIWA sites are Ohinemuri River at Karangahake, Waihou River at Te Aroha, Tongariro River at Turangi, Waipa River at Otewa, and Waipa River at Whatawhata. Three further sites on the Waikato River are also sampled as part of NIWA's programme, but the results for these were not considered here.

[3] Note that for the non-Waikato River sites, faecal bacteria—enterococci and *E. coli*—are monitored at 3-monthly intervals rather than monthly. Furthermore, these bacteria are monitored at just 72 of the 100 sites.

[4] Note that these comments only apply to results from sites monitored by Environment Waikato, and not to the five sites monitored by NIWA.

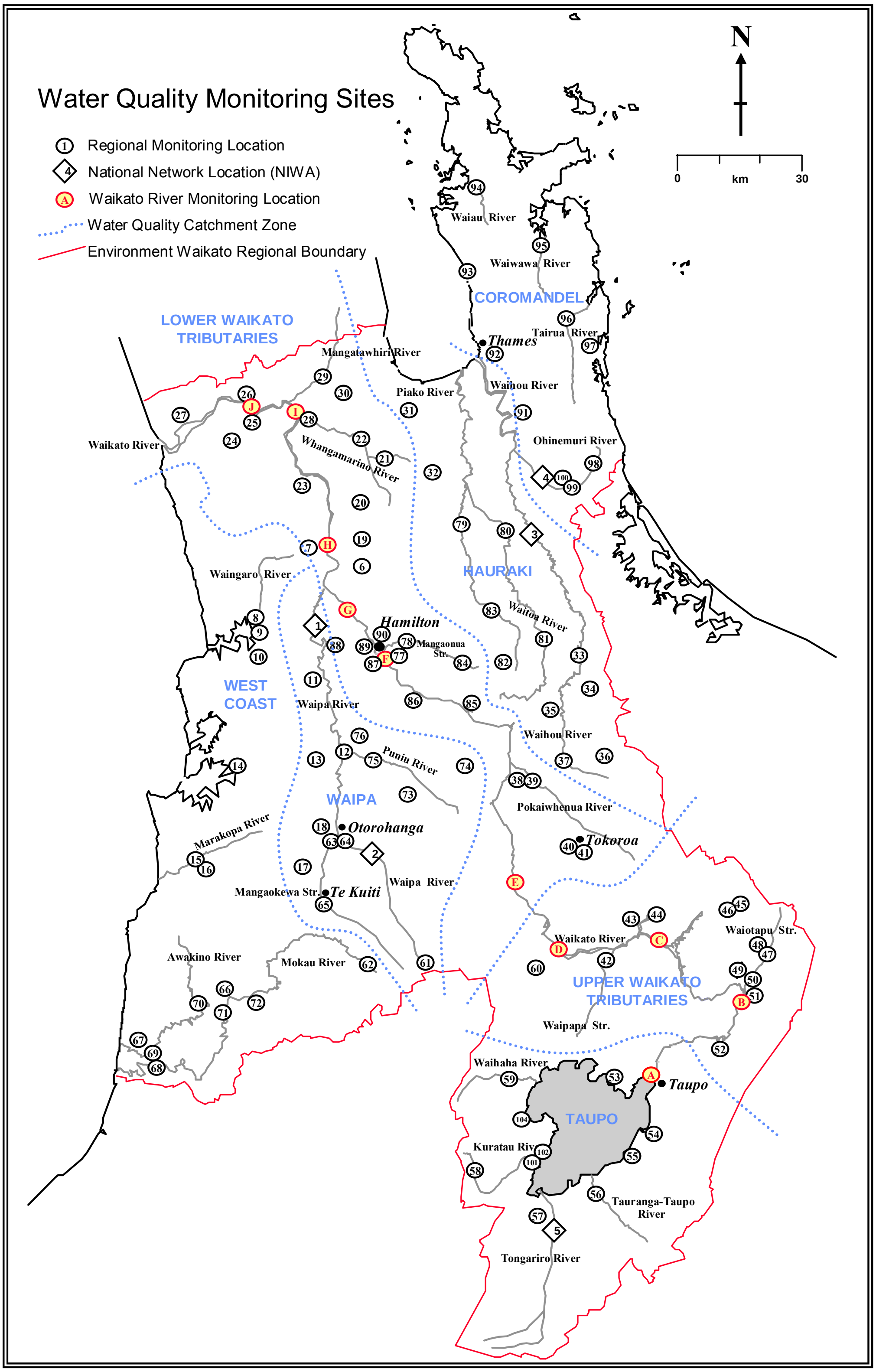

Figure 1: The Waikato region, showing the Waikato River and the 10 routine water quality sampling sites (A-to-J), and the 103 sites on the other rivers and streams (see Tables 2 and 3 for site details). The dotted lines divide the region into seven water quality zones (see text).

Ammonia. The detection limit used for the laboratory analysis up until the middle of 1989 appears to have been higher than that used subsequently (namely 0.01 g/m^3). The ammonia data from 1987–89 were therefore ignored.

Biochemical oxygen demand, BOD_5 (Waikato River only). The detection limit used for the laboratory analysis up until the middle of 1989 appears to have been higher than that used subsequently (namely 0.4 g/m^3). The BOD_5 data from 1987–89 were therefore ignored.

Chlorophyll *a* (Waikato River only). The detection limit used for the laboratory analysis has changed. Prior to 1993 it was 0.001–0.002 g/m^3; since then it has been 0.003 g/m^3. Data from earlier occasions that were lower than half the current detection limit were therefore replaced by <0.003 g/m^3 (which is evaluated as 0.0015 g/m^3).

Faecal coliforms/enterococci. There are a number of instances in records up to 1997 where the value "0" has been entered into the EW database. Since then no values lower than the detection limit (usually 1 cfu/100 mL) have been entered. Any "0" values were therefore replaced by <1 cfu/100 mL (which is evaluated as 0.5 cfu/100 mL).

pH and Conductivity. Two different laboratories have been used to analyse samples from the Environment Waikato monitoring programmes, with the change-over occurring during 1997. Inspection of the records of pH and conductivity suggested that the laboratories did not obtain the same results, and that many of the full records contained a slight degree of bias. The pH and conductivity results from 1987–97 were therefore ignored.

This change-over did not affect the NIWA programme, however, so the full records (from 1990) for the five sites from that programme are considered here.

Turbidity. A new turbidity meter (Hach 2100N) was purchased in the middle of 1995 to replace an earlier model that had been superseded (Hach 2100A). Although an attempt was made to cross-calibrate the meters, the resulting relationships were imprecise. The turbidity data from 1987–95 were therefore ignored.

Table 1 summarises information on the number of samples in the various water quality records that were analysed for trends.

2.2 Statistical analyses—general approach

It's generally not appropriate to analyse water quality records for trends using methods involving simple linear regression. This is because many water quality variables are not normally distributed, and so neither are their regression residuals. As a result, the necessary assumptions for using linear regression methods are generally not met. Nor do these methods satisfactorily deal with the marked seasonal variability which is often a major feature of water quality records. Seasonally-adjusted non-parametric methods are therefore increasingly being used to determine trends in water quality records (Gilbert 1987, Harcum et al. 1992, Helsel and Hirsch 1992). For example, these techniques have been used to analyse (1) the records of New Zealand's National River Water Quality Network (Smith et al. 1996, Scarsbrook et al. 2003), and (2) records for 229 lowland New Zealand rivers (Larned et al. 2004).

Table 1: Median numbers of samples in flow-adjusted records of water quality at the various sites that were analysed for trends (with the minima and maxima in brackets). Except where noted otherwise, all available results obtained since 1987/1990 were used.

	Waikato River (10 sites) 1987–2007		Other rivers (103 sites) 1990–2007	
Temperature	246	(184, 251)	177	(61, 216)
Dissolved oxygen	243	(181, 249)	176	(61, 216)
pH*	119	(119, 119)	119	(61, 216)
Conductivity*	120	(120, 120)	119	(61, 216)
Turbidity†	150	(150, 151)	150	(61, 216)
Visual clarity	155	(151, 156)	174	(157, 216)
Dissolved colour	234	(155, 251)	143	(61, 204)
Biochemical oxygen demand‡	214	(176, 216)	–	
Arsenic	183	(159, 210)	–	
Boron	194	(170, 229)	–	
Total nitrogen	214	(177, 241)	176	(61, 216)
Nitrate-N	230	(184, 250)	177	(61, 216)
Ammonia‡	214	(176, 216)	177	(61, 216)
Total phosphorus	245	(184, 251)	176	(61, 216)
Dissolved reactive P	245	(184, 251)	177	(61, 216)
Chlorophyll *a*	242	(183, 249)	–	
Faecal coliforms	242	(183, 247)	–	
Escherichia coli§	119	(119, 119)	40	(21, 40)
Enterococci	233	(183, 239)	58	(21, 91)

* from 1998, except for five NIWA sites
† from 1995, except for five NIWA sites
‡ from 1990
§ from 1998

Non-parametric trend analysis is based on two key measures:

- the "seasonal Kendall slope estimator" (SKSE) which measures the magnitude of the trend, and

- the associated "seasonal Kendall trend test" which determines whether the trend is significant.

As the names suggest, these techniques take account of seasonal variability.

In flowing waters, a further source of variability is the dependence of certain water quality variables on the flow at the time of sampling. This variability can obscure any real underlying trend. It is therefore desirable that water quality records from flowing waterbodies like rivers and streams be "flow-adjusted" before they are analysed for trends.

The seasonal Kendall and flow-adjustment methods are outlined below. They were described in detail by Smith et al. (1996).

2.3 Seasonal Kendall trend slope

The water quality samples were generally collected at monthly intervals (although some variables were only measured at quarterly intervals). For monthly samples the seasonal Kendall slope estimator is the median of all possible combinations of slopes for each of the months of the year. For example, in a 10-year record there will be ten observations for "January". There will thus be 45 (= 9 + 8 + … + 2 + 1) possible combinations of all pairs of "January" observations, resulting in 45 "January slopes". And this will also be the case for each of the other 11 months. The seasonal Kendall slope is computed as the median of all 540 (= 45 $\times$ 12) individual slopes (i.e. when the slopes are arranged in order, it will be the average of the 270th and 271st values). This means that seasonality is accounted for, because the results for all Januarys are compared one with another, but they are not compared with those from the other months.

Positive slopes result from an overall increase in the values of a water quality variable, while negative slopes result from an overall decrease.

Slopes are conventionally expressed in "water quality units/time". For example, analysis of a record of concentrations in g/m^3 gives a slope in units of (g/m^3)/year. However, in some instances it may be more meaningful to standardize the slopes, expressing them as a percentage change per year (e.g. % of the median value/year). Although this permits easier comparison of the rates of change of different variables (e.g. concentrations in g/m^3 with temperatures in °C), there are some difficulties with standardizing. The magnitude of the standardised slope depends on the typical level of the variable in question. For example, a given rate of change in (g/m^3)/yr will be a large percentage where typical concentrations are low, and a much smaller percentage where concentrations are high.

Furthermore, the size of the standardised slope can depend on the particular units in which the variable is reported. An increase in water temperature of 1°C/yr is equivalent to a change of about 7%/yr where the median temperature is 15°C; but re-expressing the <u>same</u> result in degrees Kelvin produces a change of just 0.3%/yr (=100 $\times$ 1 K/[273 + 15 K]). In general, trends in the same variable from different sites should not be compared without reference to the median levels at the various sites; but care must be taken when comparing (standardised) trends in different variables.

In this report the conventional procedure is generally used, and slopes are reported in water quality units/yr. Occasionally, however, the percentage change per year is also reported. Note that for many water quality variables, the numeric values of slopes expressed in common units are very small (e.g. 0.0001 $[g/m^3]$/yr). To avoid using large numbers of zeroes, the slopes have therefore often been reformatted (e.g. giving 0.1×10^{-3} $[g/m^3]$/yr for the previous example).

2.4 Seasonal Kendall trend test

The trend test calculates the probability of getting a trend slope at least as big as we have measured, if in fact there were no trend at all. This is the *p*-value. If the *p*-value is small enough we say that a "statistically significant" trend has been detected. The *p*-value is calculated by comparing the total number of increasing monthly slopes with the total number of decreasing slopes. If the net result is close to zero, the *p*-value will be large, so the slope can be regarded as being due to chance. Conversely, a large difference between the numbers of increasing and decreasing slopes produces a low *p*-value, meaning the slope is unlikely to be due to chance.

p-values can be expressed either as proportions (e.g. 0.05) or as percentages (e.g. 5%)—in this analysis they were expressed as percentages. *p*-values of 5% or less are conventionally regarded as indicating that a trend is statistically significant (i.e. unlikely to be due to chance), and this practice was followed here. Where *p*-values were less than 0.05%, the trends were described as being "highly significant". The *p*-value depends on the number of samples in a water quality record—ranging here from 21 to about 250 (Table 1). This means that weak trends are less likely to be identified in records with fewer observations (and vice versa).

It is important to note that a statistically <u>significant</u> trend is not necessarily an <u>important</u> one (Vant and Wilson 1998). That is, the *p*-value says nothing about the rate of change in water quality (or the slope of the trend), except inasmuch as a rate of change that is relatively large compared to the overall variability in the data usually results in a low or very low *p*-value. A low rate of change means there is a greater chance that circumstances may change in the future, so that an historic trend—while being statistically significant—becomes unimportant in any practical sense (e.g. because the direction of the trend reverses). As a general guide, a rate of change of 1% of the median value per year can be regarded as a threshold below which trends can be regarded as being of relatively low importance (Vant and Wilson 1998).

2.5 Flow adjustment

The flow rate of most of the region's rivers and streams varies with time. The routine monthly samples for each site are therefore generally collected at different flows. Because some water quality variables vary with flow, this increases the overall variability of the water quality record. This variability can obscure any underlying trend in water quality. However, in many situations water quality varies with flow in an identifiable fashion. As a result, identifying and allowing-for the effect of flow can usefully reduce the overall variability in a water quality record, and thus permit any underlying trend to be more readily observed.

Most of the water quality records were therefore examined for trends both before and after being flow-adjusted (but see below for exceptions to this). Flow-adjustment was done by identifying a flow corresponding to each sampling occasion (see below), and determining a relationship between flow and water quality for each variable (based on a Lowess curve fit with 30% span). In each case, the relationship identified the expected value of the water quality variable corresponding to the flow at the time of sampling. The difference between this expected value and that actually measured was the flow-dependent residual. The time series records of these residuals were then examined for trends.

Previously, locally-developed procedures were used to (1) flow-adjust the water quality records (using Data Desk), and then (2) calculate the SKSE and *p*-value (Microsoft Excel). Recently, however, NIWA has developed software that effectively and efficiently makes all the necessary calculations (TimeTrends, version 1.10, 2008), and this was used in the analysis reported here.

2.6 Flow records

For each of the routinely-monitored Waikato River sites, flow records were available for locations at or reasonably-near the sites. "Primary" sites are defined here as those where the flow recorder was located at or close to the water quality sampling site, while "secondary" sites are those where the flow recorder was some distance from the sampling site (within about 20 km). Table 2 lists the flow records used for the six primary and the four secondary Waikato River sites.

For both primary and secondary sites the flow at the time of sampling was retrieved from the relevant flow record (usually by interpolation). These flows were used to flow-adjust the water quality records.

Table 2: **Flow records used to flow-adjust water quality records for ten Waikato River sites (see the map in Figure 1 for site locations). Secondary sites—where flows were measured some distance from the relevant water quality site—are shown in italics. Identifying codes for the flow recorder sites in the TIDEDA and HYDROL timeseries software systems used by Environment Waikato are given.**

Map	Water quality site	Flow record	TIDEDA	HYDROL
A	*Taupo Gates*	Reids Farm	1143444	1131-119
B	Ohaaki Bridge	Ohaaki Bridge†	1543447	1131-159
C	Ohakuri tailrace	Ohakuri total	2774	1131-163
D	Whakamaru tailrace	Whakamaru total	2754	1131-162
E	Waipapa tailrace	Waipapa total	2734	1131-161
F	*Narrows Bridge*	Karapiro total	2714	1131-160
G	*Horotiu Bridge*	Hamilton Traffic	43466	1131-64
H	Huntly Bridge	Huntly power station	1543495	1131-74
I	Mercer Bridge	Mercer	1043446	1131-91
J	*Tuakau Bridge*	Mercer	1043446	1131-91

† rating imprecise (M. Bellingham, NIWA, pers. comm.)

For the 103 water quality sites on the region's other rivers and streams, the situation was less straight-forward. At seven of the sites, flows were considered to be reasonably steady, so no flow-adjustment was undertaken. Flows were recorded at or near 24 of the sites, so they were regarded as primary sites, and flows at the time of sampling were retrieved from the flow records. For the remaining 72 sites a "flow index" was calculated, based on the flow at the time of sampling at a location elsewhere on the relevant stream, or on a similar stream nearby. This approach must involve some uncertainty, but the magnitude of this is unclear.

Because flow-adjustment relies on identification of the pattern of flow-dependence, the actual magnitude of the flow (or flow index) is not important. As a result, there was no need to account for the differing catchment areas when deriving the flow indexes. Table 3 lists the relevant flow records for each of the sites. These were used to flow-adjust the water quality records.

The 103 sites in Table 3 are reasonably-evenly distributed across the whole Waikato Region. It is convenient to divide the region into seven separate zones, based largely on river catchments and some broad ecological features, including geology, altitude, winter temperatures, and vegetation cover and land use (Table 3, Figure 1).

2.7 Effect of land use

A preliminary examination of the results suggested that the magnitude of the trends in certain variables may vary with the intensity of land use within the catchments.[5] However, in other cases the observed trends were the result of other factors including geothermal inputs and changes to point source discharges. A subset of 86 of the 103 non-Waikato River sites where land use effects could be examined was therefore identified. The following sites were omitted from this subset:

1) Thirteen sites where the conductivity of the water is elevated (median > 20 mS/m). Examination of the results for all 103 sites showed that conductivity increases as the proportion of the catchment that is in pasture increases (cf. Biggs and Price 1987). However, at several sites in the region, very high values of conductivity are found (> 40 mS/m), indicating some effect over and above that of land use. These include streams that are affected by geothermal sources (four sites) and point source wastewaters (four sites). A value of 20 mS/m was identified as a conservative upper bound to the effect of land use,[6] and sites where the median conductivity during 2002–2007 was greater than this were excluded from this analysis.[7]

2) Three other sites where changes to point source discharges have affected stream water quality in the past decade. These are: Waitekauri (mining wastewaters), Mangamingi (sewage wastewaters) and Mangaokewa (stockyard runoff).

3) One site where as-yet unexplained source(s) appear to have markedly affected water quality in recent years: Kauwanui @ SH5.

[5] The proportion of the catchment that is in pasture, as obtained from the EW Landcover Database (Terralink 1996), was used as an index of land use (see EW document #693851).

[6] For this subset of the data (n = 89) there was a strong correlation between land use (as % pasture) and median conductivity (r = 0.65, p < 0.01%).

[7] From the data in Beard (2008b) the excluded sites are ("PS" = site affected by point source; "G" = site affected by geothermal inputs): Piako @ Paeroa-Tahuna Rd, Waitoa @ Mellon Rd (PS), Otamakokore @ Hossack Rd (G), Waiotapu @ Campbell Rd (G), Waiotapu @ Homestead Rd (G), Waipapa @ Tirohanga Rd (G), Awaroa @ Otaua Rd, Awaroa @ Rotowaro-Huntly Rd (PS), Kirikiriroa @ Tauhara Dr (PS), Komakorau @ Henry Rd, Mangaone @ Annebrooke Rd, Mangawara @ Rutherford Rd, and Waitawhiriwhiri @ Edgecumbe St (PS).

Table 3: **Flow records used to flow-adjust water quality records for 100 Waikato Region sites (see the map in Figure 1 for site locations). Sites for which a flow index was generated are shown in italics. TIDEDA and HYDROL identification codes for the flow recorder sites are given.**

Map	Water quality site	Flow record	TIDEDA	HYDROL
Coromandel (11 sites)				
91	*Hikutaia @ off Maratoto Rd*	Kauaeranga @ Smiths	9301	234-11
92	Kauaeranga @ Smiths	Kauaeranga @ Smiths	9301	234-11
4	Ohinemuri @ Karangahake (NIWA)	Ohinemuri @ Karangahake	9213	619-16
99	Ohinemuri @ Queens Head	Ohinemuri @ Queens Head	1009235	619-19
98	*Ohinemuri @SH25*	Ohinemuri @ Queens Head	1009235	619-19
96	*Tairua @ Morrisons*	Tairua @ Broken Hills	12301	940-2
93	Tapu @ Tapu-Coroglen Rd	Tapu @ Tapu-Coroglen Rd	9701	954-5
94	*Waiau @ E309 Rd*	Tapu @ Tapu-Coroglen Rd	9701	954-5
100	*Waitekauri u/s Ohinemuri*	Ohinemuri @ Queens Head	1009235	619-19
95	*Waiwawa @ SH25*	Waiwawa @ Rangihau Rd	11807	1257-2
97	*Wharekawa @ SH25*	Wharekawa @ Adams Farm	12509	1312-1
Hauraki (13 sites)				
32	*Mangawhero @ Mangawara Rd*	Mangawara @ Jefferis	1443499	481-2
35	*Oraka @ Lake Rd*	Oraka @ Pinedale	1009213	669-13
83	Piako @ Kiwitahi	Piako @ Kiwitahi	9175	749-10
79	Piako @ Paeroa-Tahuna Rd	Piako @ Paeroa-Tahuna Rd	9140	749-15
82	*Piakonui @ Piakonui Rd*	Piako @ Kiwitahi	9175	749-10
33	Waihou @ Okauia	Waihou @ Okauia	9224	1122-18
3	Waihou @ Te Aroha (NIWA)	Waihou @ Te Aroha	9205	1122-34
37	*Waihou @ Whites Rd*	Oraka @ Pinedale	1009213	669-13
36	*Waiohotu @ Waiohotu Rd*	Oraka @ Pinedale	1009213	669-13
34	*Waiomou @ Matamata-Tauranga Rd*	Waihou @ Okauia	9224	1122-18
31	*Waitakaruru @ Coxhead Rd*	Mangawara @ Jefferis	1443499	481-2
81	Waitoa @ Landsdowne Rd	Waitoa @ Waharoa Control	9112	1249-38
80	Waitoa @ Mellon Rd	Waitoa @ Mellon Rd	9179	1249-18
Inflows to Lake Taupo (11 sites)				
55	*Hinemaiaia @SH1*	Hinemaiaia @ Maungatera	2743464	171-4
58	*Kuratau @ SH41 Moerangi*	Kuratau @ SH41 Junction	1043468	282-3
101	Kuratau @ Te Rae Street	flow reasonably steady—not adjusted		
53	*Mapara @ off Mapara Rd*	Tauranga-Taupo @ Te Kono	1543413	971-4
56	Tauranga-Taupo @ Te Kono	Tauranga-Taupo @ Te Kono	1543413	971-4
57	Tokaanu @ off SH41 Turangi	flow reasonably steady—not adjusted		
5	Tongariro @ Turangi (NIWA)	Tongariro @ Turangi	1043459	1050-2
59	*Waihaha @ SH32*	Kuratau @ SH41 Junction	1043468	282-3
54	*Waitahanui @ Blake Rd*	Hinemaiaia @ Maungatera	2743464	171-4
104	*Whanganui @ Lakeside Lake Taupo*	Whareroa @ Fish Trap	1243461	1318-5
102	Whareroa @ Lakeside Lake Taupo	Whareroa @ Fish Trap	1243461	1318-5
Upland tributaries of the Waikato River (12 sites)				
48	*Kawaunui @ SH5*	Waiotapu @ Reporoa	43472	1186-9
43	*Mangaharakeke @ SH30*	Tahunaatara @ Ohakuri Rd	1043428	934-1
49	Mangakara @ SH5	flow reasonably steady—not adjusted		
60	*Mangakino @ Sandel Rd*	Mangakino @ Dillon Rd	1043427	388-2
46	Otamakokore @ Hossack Rd	Otamakokore @ Hossack Rd	2143401	683-4
52	*Pueto @ Broadlands Rd*	Waiotapu @ Reporoa	43472	1186-9
44	Tahunaatara @ Ohakuri Rd	Tahunaatara @ Ohakuri Rd	1043428	934-1
51	Torepatutahi @ Vaile Rd	flow reasonably steady—not adjusted		
47	*Waiotapu @ Campbell Rd*	Waiotapu @ Reporoa	43472	1186-9
50	*Waiotapu @ Homestead Rd*	Waiotapu @ Reporoa	43472	1186-9
42	*Waipapa @Tirohanga Rd*	Tahunaatara @ Ohakuri Rd	1043428	934-1
45	*Whirinaki @ Corbett Rd*	Otamakokore @ Hossack Rd	2143401	683-4
Lowland tributaries of the Waikato River (26 sites)				
27	*Awaroa @ Otaua Rd*	Whakapipi @ SH22	1643457	1282-8
7	*Awaroa @ Rotowaro-Huntly Rd*	Mangawara @ Jefferis	1443499	481-2
85	*Karapiro @ Hickey Rd*	Pokaiwhenua @ Puketurua	1043419	786-2
90	*Kirikiriroa @ Tauhara Dr*	Mangaonua @ Dreadnought	1543497	421-4
6	Komakorau @ Henry Rd	flow reasonably steady—not adjusted		
38	*Little Waipa @ Arapuni-Putararu Rd*	Pokaiwhenua @ Puketurua	1043419	786-2
87	*Mangakotukutuku @ Peacock Rd*	Mangaonua @ Dreadnought	1543497	421-4
40	*Mangamingi @ Paraonui Rd*	Pokaiwhenua @ Puketurua	1043419	786-2
77	*Mangaone @ Annebrooke Rd*	Mangaonua @ Dreadnought	1543497	421-4
78	*Mangaonua @ Hoeka Rd*	Mangaonua @ Dreadnought	1543497	421-4

Table 3 (continued)

Map	Water quality site	Flow record	TIDEDA	HYDROL
84	*Mangaonua @ Te Miro Rd*	Mangaonua @ Dreadnought	1543497	421-4
30	Mangatangi @ SH2	Mangatangi @ SH2	1243414	453-6
29	*Mangatawhiri @ Lyons Rd*	Mangatangi @ SH2	1243414	453-6
19	*Mangawara @ Rutherford Rd*	Mangawara @ Jefferis	1443499	481-2
86	*Mangawhero @ Cambridge-Ohaupo*	Mangaonua @ Dreadnought	1543497	421-4
20	Matahuru @ Waiterimu Rd	Matahuru @ Waiterimu Rd	43489	516-5
25	*Ohaeroa @ SH22*	Whakapipi @ SH22	1643457	1282-8
24	*Opuatia @ Ponganui Rd*	Whakapipi @ SH22	1643457	1282-8
39	Pokaiwhenua @ Arapuni-Putararu Rd	Pokaiwhenua @ Puketurua	1043419	786-2
21	*Waerenga @ Taniwha Rd*	Matahuru @ Waiterimu Rd	43489	516-5
89	*Waitawhiriwhiri @ Edgecumbe St*	Mangaonua @ Dreadnought	1543497	421-4
26	Whakapipi @ SH22	Whakapipi @ SH22	1643457	1282-8
41	*Whakauru @ SH1*	Pokaiwhenua @ Puketurua	1043419	786-2
28	*Whangamarino @ Island Block Rd*	Matahuru @ Waiterimu Rd	43489	516-5
22	*Whangamarino @ Jefferies Rd*	Matahuru @ Waiterimu Rd	43489	516-5
23	Whangape @ Rangiriri-Glen Murray	flow reasonably steady—not adjusted		
Waipa River and tributaries (16 sites)				
11	*Kaniwhaniwha @ Wright Rd*	Te Tahi @ Puketotara	1143427	1020-2
74	*Mangaohoi @ Maru Rd*	Puniu @ Pokuru	43431	818-2
65	Mangaokewa @ Te Kuiti	Mangaokewa @ Te Kuiti	1643462	414-13
76	*Mangapiko @ Bowman Rd*	Puniu @ Pokuru	43431	818-2
63	*Mangapu @ Otorohonga*	Waipa @ Honikiwi	43468	1191-13
73	*Mangatutu @ Walker Rd*	Puniu @ Pokuru	43431	818-2
13	*Mangauika @ Te Awamutu*	Te Tahi @ Pukeotara	1143427	1020-2
88	Ohote @ Whatawhata-Horotiu Rd	flow reasonably steady—not adjusted		
75	Puniu @ Bartons Corner Rd	Puniu @ Pokuru	43431	818-2
61	*Waipa @ Mangaokewa Rd*	Waipa @ Otewa	43481	1191-7
12	*Waipa @ Pirongia-Ngutunui Rd*	Waipa @ Whatawhata	43433	1191-11
2	Waipa @ Otewa (NIWA)	Waipa @ Otewa	43481	1191-7
64	*Waipa @ SH3 Otorohonga*	Waipa @ Honikiwi	43468	1191-13
1	Waipa @ Whatawhata (NIWA)	Waipa @ Whatawhata	43433	1191-11
18	*Waitomo @ SH31 Otorohonga*	Waitomo @ Aranui/Ruakuri	1943481	1253-3
17	*Waitomo @ Tumutumu Rd*	Waitomo @ Aranui/Ruakuri	1943481	1253-3
West Coast (14 sites)				
70	*Awakino @ Gribbon Rd*	Awakino @ Gorge	40810	33-14
69	*Awakino @ SH3-Awakau Rd*	Awakino @ Gorge	40810	33-14
67	*Manganui @ off Manganui Rd*	Awakino @ Gorge	40810	33-14
66	*Mangaotaki @ SH3*	Mokau @ Totoro	40708	556-9
15	*Marokopa @ Speedies Rd*	Marokopa @ Falls	41301	513-7
68	*Mokau @ Awakau Rd*	Mokau @ Totoro	40708	556-9
62	*Mokau @ Mangaokewa Rd*	Mangaokewa @ Te Kuiti	1643462	414-13
71	Mokau @ Totoro Rd	Mokau @ Totoro	40708	556-9
72	*Mokauiti @ Three Way Point*	Mokau @ Totoro	40708	556-9
9	*Ohautira @ Waingaro-Te Uku Rd*	Marokopa @ Falls	41301	513-7
14	*Oparau @ Langdon Rd*	Marokopa @ Falls	41301	513-7
16	*Tawarau @ off Speedies Rd*	Tawarau @ Te Anga	41302	976-2
8	*Waingaro @ Ruakiwi Rd*	Marokopa @ Falls	41301	513-7
10	*Waitetuna @ Te Uku-Waingaro Rd*	Marokopa @ Falls	41301	513-7

3 Results and discussion

3.1 Waikato River

Table 4 lists the *p*-values and trend slopes for the water quality records at the ten Waikato River sites. Some 188 water quality records were analysed, 83 (or 44%) of which showed trends which were significant (p < 5%); 30 of these trends were highly significant (p < 0.05%). Highly significant trends were common (5 or more sites) in the records of BOD_5, ammonia and nitrate.

The trends observed in the individual variables are described below. A small selection of water quality records is shown in Figure 2.[8]

Temperature. At most sites there was no significant trend in water temperature (Table 4). At Taupo Gates (Figure 1, site A), however, a significant trend was observed, with the median rate of increase (i.e. the SKSE) being about 0.04°C/yr, or about 0.3% of the median value per year. As increases in temperature make the water less suitable for temperature-sensitive organisms, particularly trout and native fish, the observed increase can be regarded as a (slight) deterioration.

Dissolved oxygen. At many sites there was no significant trend in dissolved oxygen levels. At the first two sites (Taupo Gates, site A, and Ohaaki, site B), however, significant increases were observed, while a significant decrease was observed at the second-to-last site (Mercer, site I). The median rate of increase was 0.1% of saturation/yr at Taupo Gates, and 0.2% of saturation/yr at Ohaaki. These increases can be regarded as (slight) improvements. The median rate of decrease at Mercer was –0.1% of saturation/yr; this slight decrease can be regarded as a (slight) deterioration.

pH. A trend in pH during 1998–2007 that was just statistically significant (*p*-value = 4.4%) was observed at one of the sites (Narrows, site F). No trends were observed at the other sites. This is in marked contrast to the results of the previous analysis of trends in pH during 1993 to 2002, when significant decreases (*p*-value ≤1%) were observed at seven sites (Vant and Smith 2004). However, as noted above, it now appears that a slight bias was introduced into the long-term records by the change in laboratories that occurred during 1997—a bias that was not previously apparent. This bias was probably responsible for most of the changes that were reported previously.[9]

Conductivity. There was a significant trend in conductivity at seven of the sites. In each case conductivity increased.[10] The SKSE ranged from 0.036 to 0.106 mS/m/yr, or between 0.2% and 0.7% of the median value per year.

Turbidity. The turbidity records began in the middle of 1995. For the period since then significant trends in turbidity were observed at four sites, one in the impounded section of the river (Waipapa, site E), and three in the reach downstream of the confluence with the Waipa River (at Ngaruawahia), namely Huntly (H), Mercer (I) and Tuakau (J). At each of these sites turbidity increased, with the SKSE ranging from 0.02 to 0.27 NTU/yr, or between 1.6% and 3.9% of the median value per year. An increase in turbidity can be regarded as a deterioration.

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[8] Most of the trends illustrated in this report were highly significant (p < 0.05%). In such cases the trends are usually visually striking. Trends that are less significant (0.05% < p < 5%), however, can be less visually striking.

[9] Indeed, analysis of the (biased) records for 1993 to 2007 showed significant decreases at six of the ten sites—three of these trends were highly significant (*p*-value < 0.05%).

[10] Significant increases were also apparent at seven sites in the (biased) records for 1987 to 2007.

Table 4: ***p*-values (%) and trend slopes (in brackets) for records of flow-adjusted water quality variables at ten Waikato River sites during 1987–2007. Secondary sites (see section 2.6) are shown in italics. Trends shown in bold are significant (p < 5%); and highly significant trends (p < 0.05%) are underlined. For each variable the total number of records that have shown significant increases or significant decreases is shown. Note that the *E. coli* records contained considerably fewer results (n = 119: Table 1) than those for the other variables.**

	Temperature (10^{-3} °C/yr)	**Dissolved oxygen (10^{-3} percent of saturation/yr)**	**pH (10^{-3}/yr)**	**Conductivity (10^{-3} [mS/m]/yr)**	**Turbidity (10^{-3} NTU/yr)**	**Visual clarity (10^{-3} m/yr)**	**Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)**	**Biochemical oxygen demand (10^{-3} [g/m^3]/yr)**	**Arsenic (10^{-3} [g/m^3]/yr)**	**Boron (10^{-3} [g/m^3]/yr)**
Taupo	**<1 (42)**	**<1 (102)**	53 (3)	52 (–9)	93 (0)	–	17 (0.0)	**<1 (–21)**	**<1 (0.1)**	**2 (–0.5)**
Ohaaki	43 (–18)	**<1 (231)**	35 (5)	8 (–50)	16 (–5)	61 (18)	37 (0.0)	**<1 (–27)**	**<1 (–0.5)**	**<1 (–5.5)**
Ohakuri	74 (5)	27 (71)	72 (2)	**<1 (101)**	31 (6)	96 (3)	**4 (0.03)**	**<1 (–30)**	47 (–0.1)	**1 (–2.1)**
Whakamaru	37 (–18)	99 (–1)	50 (4)	**<1 (79)**	64 (3)	97 (1)	17 (0.1)	**1 (–17)**	74 (0.0)	76 (–0.3)
Waipapa	7 (18)	26 (–77)	60 (2)	**<1 (106)**	**3 (20)**	16 (–25)	**<1 (–0.3)**	**<1 (–33)**	72 (0.0)	6 (–1.2)
Narrows	69 (–7)	17 (–73)	**4 (12)**	**3 (60)**	90 (–1)	63 (5)	**<1 (–0.3)**	**<1 (–36)**	**5 (–0.1)**	**4 (–1.4)**
Horotiu	13 (–24)	99 (–1)	37 (6)	**2 (55)**	25 (–17)	41 (6)	**<1 (–0.3)**	**<1 (–59)**	25 (–0.1)	6 (–1.0)
Huntly	43 (–17)	65 (–31)	43 (5)	14 (34)	**<1 (215)**	33 (–5)	**<1 (–0.3)**	**<1 (–57)**	**<1 (–0.2)**	**<1 (–1.5)**
Mercer	84 (–5)	**4 (–136)**	79 (2)	**4 (36)**	**<1 (268)**	–	**<1 (–0.5)**	**<1 (–44)**	**<1 (–0.2)**	**<1 (–1.7)**
Tuakau	31 (27)	21 (101)	71 (–1)	**<1 (60)**	**4 (189)**	7 (–8)	58 (0.1)	8 (–16)	**2 (–0.1)**	**1 (–0.9)**
Increases	1	2	1	7	4	0	1	0	1	0
Decreases	0	1	0	0	0	0	5	9	5	7

Table 4 (continued)

	Total nitrogen (10^{-3} [g/m^3]/yr)	**Nitrate-N (10^{-3} [g/m^3]/yr)**	**Ammonia (10^{-3} [g N/m^3]/yr)**	**Total phosphorus (10^{-3} [g/m^3]/yr)**	**Dissolved reactive P (10^{-3} [g/m^3]/yr)**	**Chlorophyll *a* (10^{-3} [g/m^3]/yr)**	**Faecal coliforms ([cfu/100 mL]/yr)**	***Escherichia coli* ([cfu/100 mL]/yr)**	**Enterococci ([cfu/100 mL]/yr)**
Taupo	21 (–0.6)	**<1 (–0.3)**	**<1 (–0.4)**	12 (0.0)	**1 (0.02)**	89 (0.0)	44 (0.0)	14 (–0.1)	71 (0.0)
Ohaaki	55 (0.4)	**<1 (–0.4)**	**<1 (–0.9)**	**4 (–0.1)**	**<1 (–0.2)**	87 (0.0)	**<1 (–2.0)**	7 (–0.7)	**<1 (–0.5)**
Ohakuri	78 (–0.3)	5 (0.7)	**<1 (–0.4)**	**1 (0.2)**	17 (–0.1)	**<1 (0.1)**	**<1 (–0.1)**	23 (–0.1)	45 (0.0)
Whakamaru	**<1 (3.7)**	23 (0.7)	**2 (–0.1)**	**<1 (0.4)**	39 (0.1)	10 (0.1)	30 (–0.1)	25 (0.2)	**<1 (0.1)**
Waipapa	17 (1.5)	**<1 (2.5)**	6 (–0.1)	**<1 (0.3)**	21 (0.1)	64 (0.0)	**<1 (–1.5)**	60 (–0.1)	**<1 (–0.1)**
Narrows	**<1 (3.6)**	**<1 (4.4)**	**<1 (–1.2)**	**<1 (0.3)**	72 (0.0)	**2 (–0.1)**	13 (–4.4)	46 (–2.4)	32 (0.3)
Horotiu	12 (2.2)	**<1 (4.9)**	**<1 (–1.5)**	**<1 (0.3)**	10 (0.1)	10 (–0.1)	32 (3.6)	35 (2.3)	5 (–1.7)
Huntly	22 (2.3)	**<1 (4.4)**	**<1 (–1.1)**	15 (0.3)	**4 (–0.2)**	21 (–0.1)	20 (4.0)	79 (1.7)	29 (–0.7)
Mercer	**3 (4.9)**	**2 (3.4)**	**<1 (–0.2)**	**<1 (0.8)**	**<1 (–0.2)**	71 (0.0)	6 (5.8)	23 (3.3)	**4 (0.5)**
Tuakau	70 (–1.2)	85 (0.4)	**<1 (–0.2)**	**<1 (0.7)**	**2 (–0.1)**	67 (–0.1)	99 (–0.1)	11 (3.8)	11 (0.5)
Increases	3	5	0	7	1	1	0	0	2
Decreases	0	2	9	1	4	1	3	0	2

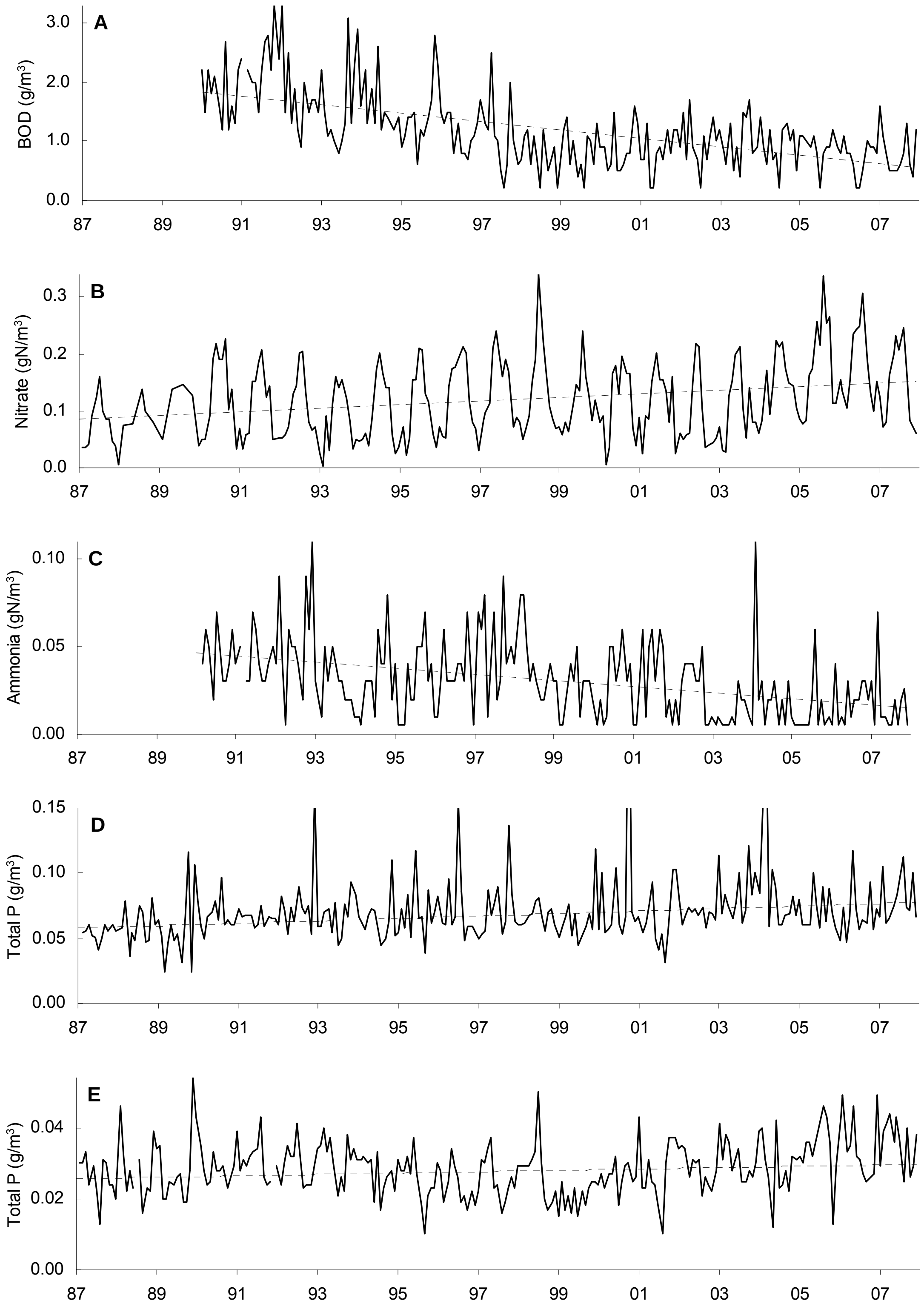

Figure 2: **Water quality at Waikato River sites during 1987–2007:** A, **BOD$_5$ at Horotiu (site G);** B, **nitrate at Waipapa (site E);** C, **ammonia at Horotiu (site G);** D, **total phosphorus at Mercer (site I); and** E, **total phosphorus at Waipapa (site E). The dashed lines show the overall trends in the records.**

Visual clarity. The black disc records began in early 1995. For the period since then no significant trends in visual clarity were observed. Weak, but not statistically significant, deteriorating trends (i.e. decreases in clarity) were observed at Huntly (site H) and Tuakau (site J), corresponding to the increases in turbidity described above.

Dissolved colour. Significant trends in dissolved colour were observed at six of the sites. At Ohakuri (site C), concentrations of dissolved colour increased, but at the other sites concentrations decreased, at rates between –1.5% and –2.7% of the median value per year. These latter five sites are all downstream of the point where treated wastewater from the pulp and paper mill at Kinleith is discharged to the river.[11] Since 1991 the concentration of coloured material in the wastewater has been roughly half that measured previously (Nagels and Davies-Colley 1997). So the decreases in dissolved colour in the river probably result from the improvements to wastewater treatment at the Kinleith mill.

Biochemical oxygen demand. Significant trends in BOD_5 during 1990–2007 were observed at nine of the ten sites (e.g. Figure 2A). In all cases BOD_5 decreased, with the SKSE being in the range –0.02 to –0.06 $g/m^3/yr$, or between about –3.6% (Mercer, site I) and –5.3% (Ohaaki, site B, and Horotiu, site G) of the median value per year. These decreases represent marked improvements during the period. They presumably reflect the combined effect of improvements in wastewater treatment at various locations, thereby reducing the overall load of oxygen-depleting carbonaceous wastes to the river. For example, the reduction in BOD_5 at Horotiu probably results largely from the recent improvements in the treatment of the sewage wastewaters discharged to the river at Hamilton (Figure 2A).

Arsenic. Significant trends in arsenic concentration were observed at six of the sites. At one site (Taupo Gates, site A) concentrations increased, while at the five other sites concentrations decreased, with the SKSE being in the range –0.1 to -0.5×10^{-3} $g/m^3/yr$, or between about –0.4% (Narrows, site F) and –1.9% (Ohaaki, site B) of the median value per year. The sites are all downstream of the point where geothermal fluid from the Wairakei power station is discharged to the river. Reinjection of some geothermal fluid into the geothermal field since 1988 has reduced the load of arsenic discharged to the river, and the observed reductions are likely to be a direct result of this. The reductions represent improvements in water quality.

However, it should be noted that although the overall trend since 1987 was a general decrease, further analysis found significant <u>increases</u> ($1\% < p < 3\%$) in arsenic concentrations over the latter half of this period (i.e. 1998–2007) at five of the sites downstream of the Wairakei station. That is, the overall decreases described above reflect improvements that were made during 1988-to-1997. Thus far, these have out-weighed the increases that have occurred since then.

Boron. Significant trends in boron concentration were observed at seven of the sites. In each case concentrations decreased, with the SKSE being in the range –0.5 to –5.5 $\times 10^{-3}$ $g/m^3/yr$, or between about –0.3% (Taupo Gates, site A) and –1.9% (Ohaaki, site B) of the median value per year. The largest decrease (-5.5×10^{-3} $g/m^3/yr$) occurred at the Ohaaki site, the first site downstream of the Wairakei power station discharge. This discharge also carries a large load of boron, so reinjection since 1988 has reduced the load to the river and contributed to the observed reductions at Ohaaki and the sites downstream of there. The reductions represent improvements in water quality.

As also noted for arsenic, however, there were significant <u>increases</u> ($1\% < p < 2\%$) in boron concentrations at several (7) of the sites during 1998–2007. So although boron concentrations in the river have generally decreased since 1987, there have been significant increases in the latter half of the period.

[11] The discharge occurs at Lake Maraetai, about 13 km upstream of the monitoring site at Waipapa—the first site at which the decreasing trend in dissolved colour is observed.

Total nitrogen. Significant trends in total N concentration were observed at three of the sites, namely Whakamaru (site D), Narrows (site F) and Mercer (site I). At each of these, concentrations increased, with the SKSE being in the range 3.6 to 4.9 × 10^{-3} g/m^3/yr. The largest relative rate of increase was 1.8% of the median value per year (at Whakamaru). The increases represent deteriorations in water quality.

Nitrate-N. Significant trends in nitrate concentration since 1987 were observed at seven of the sites (e.g. Figure 2B). At two sites near the head of the river, Taupo Gates (site A) and Ohaaki (site B), concentrations decreased, while at five sites in the middle-to-lower section concentrations increased (sites E-to-I). The average rate of increase at these latter sites was about 2% of the median value per year. The increases represent deteriorations in water quality.

During the past ten years (1998–2007), nitrate concentrations have increased significantly at all eight sites from Ohakuri (site C) downstream (p-value ≤ 0.3% in each case).[12] The average rate of increase during this period was 4.9% of the median value per year. These increases presumably result from the increase in agricultural intensity that has occurred across the catchment over recent decades.

Ammonia. Significant trends in ammonia concentration during 1990–2007 were observed at nine of the sites (e.g. Figure 2C). At each of these sites concentrations decreased, with the SKSE being in the range –0.2 to –1.5 × 10^{-3} g N/m^3/yr. At eight of the sites the trends were highly significant. The reductions represent improvements in water quality. These reductions presumably result from improvements in wastewater treatment from a variety of sources, including municipal sewage (Figure 2C, see comments above regarding BOD_5), industrial wastewaters and dairy shed discharges.

Total phosphorus. Significant trends in total phosphorus concentration since 1987 were observed at eight of the sites. At one site near the head of the river concentrations decreased (Ohaaki, site B), while at seven sites in the middle-to-lower section concentrations increased (e.g. Figures 2D, E). The average rate of increase at these latter sites was about 1% of the median value per year. The increases represent deteriorations in water quality.

The decrease at Ohaaki probably reflects the fact that discharge of sewage wastewater to the river from Taupo town ceased in the mid-1990s. Since then, however, there has been a weak, but not statistically significant trend of increasing concentrations at the Ohaaki site. A similar pattern of a decrease in total phosphorus concentrations in the mid-1990s followed by an increase since then was apparent at each of the next three sites downstream of the former discharge point (i.e. sites C-to-E), namely Ohakuri, Whakamaru and Waipapa (Figure 2E). In these cases, however, the increases over the past decade were statistically significant (see below).

During the past ten years (1998–2007), total phosphorus concentrations have increased significantly at seven of the eight sites from Ohakuri downstream (namely all except Tuakau, site J; p-value ≤ 0.4% in each case). The average rate of increase at these sites during this period was 3.5% of the median value per year. These increases presumably result from the increase in agricultural intensity that has occurred across the catchment over recent decades. That is, the removal of Taupo's sewage wastewater from the river during the mid-1990s temporarily reduced total phosphorus concentrations in the river, but this effect has generally been out-weighed by subsequent increases in the loads delivered from other sources (Figure 2E).

Dissolved reactive phosphorus. Significant trends in DRP concentration were observed at five of the sites. In one case this was an increase (Taupo Gates, site A), while the other four trends were decreases (sites B and H-to-J; SKSE = –0.1 to –0.2 ×

[12] At four of these—Waipapa, Narrows, Horotiu and Mercer—the trends were highly significant (p-value < 0.05%).

10^{-3} $g/m^3/yr$). The increase represents a deterioration in water quality, while the decreases represent improvements. It is unclear why these changes have occurred.

Chlorophyll *a*. At most sites there was no significant trend in algal biomass as indicated by chlorophyll *a* concentration. However, at Ohakuri (site C) a significant increase occurred (SKSE = 0.1×10^{-3} $g/m^3/yr$, or about 3% of the median value per year), while at Narrows (site F) a significant decrease occurred (SKSE = -0.1×10^{-3} $g/m^3/yr$, or about –1% of the median value per year). These represent a deterioration and an improvement in water quality, respectively.

Faecal coliforms. Significant trends in faecal coliform concentrations were observed at three sites in the upper part of the river, namely Ohaaki (site B), Ohakuri (site C) and Waipapa (site E). All are sites where median faecal coliform concentrations are relatively low. In each case the concentrations decreased by up to about –2 cfu/100 mL/yr. The decreases represent modest improvements in water quality.

The decrease at Ohaaki probably reflects the fact that discharge of sewage wastewater to the river from Taupo town ceased in the mid-1990s. This probably also contributed to the decreases observed at the sites further downstream.

Escherichia coli.[13] No significant trends were observed in the records of *E. coli* concentrations.

Enterococci. Significant trends in enterococci concentrations were observed at four of the sites. Increases were observed at two sites (Whakamaru, site D, and Mercer, site I), while decreases were observed at two other sites (Ohaaki, site B, and Waipapa, site E). The increases represent a deterioration in water quality, while the decreases represent improvements.

The decrease at Ohaaki probably reflects the fact that discharge of sewage wastewater to the river from Taupo town ceased in the mid-1990s. The causes of the changes at the other three sites are unclear, however.

Taken together, the results for these three microbiological indicators (faecal coliforms, *E. coli* and enterococci) suggest there has been little overall change in levels of faecal contamination in the Waikato River as a whole in the two decades since 1987 (although conditions have improved at Ohaaki, site B, since the discharge of sewage wastewater to that part of the river ceased).

3.2 Other rivers and streams

Table 5 lists the *p*-values and trend slopes for the water quality records at the 103 sites on the other rivers and streams. A total of 1373 records were analysed, namely (1) records of 11 different water quality variables at all 103 sites, (2) records of visual clarity at 96 sites, and (3) records of enterococci and *E. coli* at 72 sites. Of these, 590 records (43%) showed significant trends ($p < 5\%$). Some 268—or just under half—of the trends were highly significant ($p < 0.05\%$). The trends observed in the individual variables are described below. Selected trends are shown in Figures 3 and 4. Figure 5 shows the distribution across the region of the improvements and deteriorations in selected variables.

Records that are not flow-adjusted can occasionally show anomalous results, namely a significant trend with a zero slope. This arises because of "tied" values amongst the various slopes—where the comparison of some pairs of monthly values showed no change. Where a large number of ties occurs together with markedly different numbers of positive and negative slopes, it is possible to get a significant trend (positive slopes

[13] Note that these records are shorter than those for many other variables, so that the sample size is considerably smaller (Table 1). As a result care should be taken in comparing the trend analyses for *E. coli* with those reported for other variables.

outweigh negative slopes, or vice versa), but the median value of all slopes is zero (i.e. corresponding to a tie). This occurred on a small number of occasions in the analyses reported in Table 5, where the relevant results are shown in italics. The results for these records were omitted from subsequent analyses and summaries.

Table 6 summarises the slopes of the trends in the individual water quality variables. It shows the median values of SKSE (1) for all records (cf. Scarsbrook et al. 2003), (2) for the significant trends only (cf. Smith et al. 1996), and (3) for the highly significant trends only. In each case the binomial test was used to determine whether the overall proportion of increasing (or decreasing) slopes was significantly different ($p < 5\%$) from 0.5. This helps identify variables for which there is an overall pattern of increasing (or decreasing) trends across the region as a whole. For these variables the value of the median SKSE is shown in bold. Figure 6 shows plots of SKSE and land use for selected variables.

<u>Temperature</u>. At many sites there was no significant trend in water temperature (Table 5). However, trends were apparent at 17 sites, with 11 increases and 6 decreases. Values of the SKSE for the significant trends ranged from –0.11°C/yr (Mangapiko Stream, site #76) to 0.13°C/yr (Otamakokore Stream, #46).[14] No overall pattern of temperature change across the region as a whole was apparent (Table 6). Nor were there marked differences between the seven water zones (Table 5).

<u>Dissolved oxygen</u>. Significant trends in dissolved oxygen were observed at more than half (61) of the sites. Many (50) of these were decreases, so the overall pattern for the region as a whole was for a significant decrease in dissolved oxygen concentration (Table 6, Figure 5A). This represents a deterioration in water quality.

Considering all the records of dissolved oxygen (n = 103), the median rate of change was about –0.1% of saturation/yr (Table 6). A greater rate of change (–0.2% of saturation/yr) was found for the subset of records where significant trends occurred (n = 61), and a still greater rate (–0.3% of saturation/yr) was found for the subset of records where highly significant trends occurred (n = 26).

The greatest rate of decrease (–1% of saturation/yr) occurred at the Piako (Kiwitahi) site (#83). In three of the water zones—Taupo, Waipa and West Coast—significant decreases occurred at half or more of the sites, while in the latter two zones there were no increases. That is, most of the trends in the southern and western part of the region were deteriorations (Figure 5A). It is unclear whether there's a common cause of the observed decreases; nor is it clear what the cause(s) might be.[15]

<u>pH</u>. Significant trends in pH were observed at one-third (34) of the sites. Most (32) of these were increases, so the overall pattern for the region as a whole was for an increase in pH (Table 6). This is in marked contrast to the results of the previous analysis of trends in pH during 1993 to 2002, when significant decreases were observed at 64 sites, and increases at just 7 sites (Vant and Smith 2004). However, as noted above, it now appears that a slight bias was introduced into the long-term records by the change in laboratories that occurred during 1997—a bias that was not previously apparent. This bias was probably responsible for most of the changes that were reported previously.[16]

[14] Note that the Otamakokore Stream appears to be influenced by geothermal sources: both conductivities and (winter) temperatures are somewhat higher than expected (Beard 2008b).

[15] These could range from increased inputs of BOD_5 to decreased reaeration within the streams due to changes in the nature of the channel.

[16] Indeed, analysis of the (mostly biased) records for 1993 to 2007 showed significant decreases at 44 sites and increases at 18 sites.

Table 5: ***p*-values (%) and trend slopes (in brackets) for records of water quality variables at 100 Waikato Region sites during 1990–2007. Apart from the exceptions listed in Table 3, all of the records were flow-adjusted. Trends shown in bold are significant (p < 5%); and highly significant trends (p < 0.05%) are underlined. Anomalous results resulting from large numbers of ties are shown in italics (see text). For each variable the total number of records that have shown significant increases or significant decreases is shown (last page of table), with the numbers of highly significant increases or decreases being shown in brackets. The names of sites for which a flow index was generated (see section 2.6) are shown in italics. Note that site names have been abbreviated—see Table 3 for full description of each site (numbers in brackets are site numbers in Figure 1). Note that the *E. coli* and enterococci records contained considerably fewer results (n = 22–40 and 21–91, respectively: Table 1) than those for the other variables.**

	Temperature (10^{-3} °C/yr)	Dissolved oxygen (10^{-3} percent of saturation/yr)	pH (10^{-3}/yr)	Conductivity (10^{-3} [mS/m]/yr)	Turbidity (10^{-3} NTU/yr)	Visual clarity (10^{-3} m/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Nitrate-N (10^{-3} [g/m^3]/yr)	Ammonia (10^{-3} [g N/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Dissolved reactive P (10^{-3} [g/m^3]/yr)	*Escherichia coli* ([cfu/100 mL]/yr)	Enterococci ([cfu/100 mL]/yr)
Coromandel														
Hikutaia (91)	89 (5)	33 (47)	**<1 (29)**	29 (–13)	9 (–30)	10 (30)	35 (–0.2)	86 (–0.5)	**<1 (–2.0)**	**<1 (–0.7)**	28 (0.1)	66 (0.0)	56 (6)	16 (3)
Kauaeranga (92)	37 (36)	**<1 (135)**	16 (12)	**<1 (78)**	**<1 (45)**	**5 (–56)**	51 (0.1)	**<1 (4.2)**	36 (0.2)	20 (0.0)	6 (0.1)	69 (0.0)	30 (–7)	74 (–1)
Ohinemuri (4)	77 (8)	82 (–9)	80 (–1)	**<1 (163)**	**<1 (–22)**	45 (6)	7 (–0.2)	6 (–3.4)	**<1 (–4.9)**	25 (–0.2)	**<1 (–0.4)**	**<1 (–0.3)**	–	–
Ohinemuri (99)	92 (–4)	**<1 (–268)**	49 (–4)	**3 (32)**	**<1 (–59)**	11 (33)	81 (0.0)	22 (6.7)	99 (–0.3)	6 (–1.3)	**<1 (–1.9)**	**<1 (–1.4)**	10 (33)	44 (1)
Ohinemuri (98)	87 (–5)	31 (–73)	67 (4)	18 (–14)	5 (–19)	54 (–15)	97 (0.0)	**<1 (–10.2)**	**<1 (–8.8)**	**1 (–0.4)**	22 (–0.2)	**<1 (–0.2)**	20 (10)	84 (0)
Tairua (96)	8 (53)	12 (–89)	19 (9)	23 (–15)	15 (–14)	22 (23)	75 (0.1)	**<1 (2.9)**	**<1 (–0.6)**	86 (0.0)	16 (0.1)	29 (0.0)	85 (2)	77 (0)
Tapu (93)	8 (58)	22 (66)	45 (4)	94 (–1)	70 (–5)	19 (27)	23 (–0.2)	**<1 (2.6)**	7 (–0.1)	13 (0.0)	**1 (0.1)**	63 (0.0)	14 (–16)	37 (2)
Waiau (94)	11 (43)	**3 (101)**	12 (8)	27 (28)	**4 (50)**	12 (29)	57 (–0.1)	**<1 (3.4)**	**<1 (1.1)**	20 (0.0)	36 (0.0)	**3 (–0.1)**	96 (–1)	61 (–3)
Waitekauri (100)	23 (36)	**<1 (230)**	**3 (–11)**	**2 (–163)**	64 (5)	64 (–13)	6 (0.2)	**<1 (–25.9)**	**<1 (–21.8)**	**<1 (–2.6)**	**<1 (0.2)**	39 (0.0)	58 (–1)	47 (0)
Waiwawa (95)	26 (36)	**<1 (–155)**	44 (3)	**2 (–43)**	81 (–3)	**2 (36)**	64 (–0.2)	**<1 (2.5)**	28 (–0.2)	9 (0.0)	7 (0.1)	12 (0.0)	93 (–1)	18 (2)
Wharekawa (97)	18 (53)	**<1 (–276)**	49 (6)	56 (5)	53 (17)	63 (–10)	37 (–0.2)	**<1 (5.5)**	**<1 (1.0)**	35 (0.0)	20 (0.1)	42 (0.0)	31 (9)	10 (3)
Hauraki														
Mangawhero (32)	**<1 (–99)**	**<1 (–197)**	37 (–3)	**<1 (72)**	15 (–77)	91 (–1)	8 (–0.3)	5 (3.5)	**4 (1.8)**	**<1 (–0.04)**	**<1 (0.6)**	**<1 (1.0)**	23 (–5)	37 (–3)
Oraka (35)	11 (38)	10 (–72)	**2 (11)**	**2 (98)**	**<1 (163)**	19 (8)	**3 (0.2)**	**<1 (21.8)**	**<1 (13.7)**	72 (0.2)	29 (–0.9)	29 (–0.7)	45 (–24)	20 (20)
Piako (83)	9 (52)	**<1 (–961)**	70 (2)	7 (68)	**<1 (–221)**	**<1 (38)**	**<1 (–0.8)**	**<1 (–16.6)**	**<1 (–14.0)**	**<1 (–2.1)**	21 (–0.6)	24 (–0.3)	**4 (86)**	**2 (13)**
Piako (79)	84 (–6)	32 (–147)	**<1 (20)**	**<1 (151)**	97 (26)	97 (0)	**<1 (–1.4)**	**<1 (–50.8)**	**<1 (–39.2)**	**<1 (–3.3)**	82 (0.4)	**3 (–2.6)**	92 (6)	**2 (19)**
Piakonui (82)	26 (44)	**<1 (–235)**	70 (–1)	17 (–16)	**<1 (–179)**	**<1 (33)**	98 (0.0)	81 (0.4)	20 (–2.3)	24 (0.0)	62 (–0.1)	7 (–0.1)	96 (–1)	91 (0)
Waihou (33)	61 (–12)	56 (–27)	10 (5)	5 (48)	11 (67)	74 (–3)	**<1 (0.3)**	**<1 (16.4)**	**<1 (10.3)**	99 (0.0)	23 (–0.4)	**<1 (–0.5)**	7 (20)	20 (4)
Waihou (3)	29 (–25)	**<1 (–182)**	**<1 (–4)**	**<1 (50)**	14 (–37)	44 (3)	56 (0.0)	**<1 (5.1)**	**2 (3.4)**	**<1 (1.0)**	67 (–0.1)	92 (0.0)	–	–
Waihou (37)	**<1 (16)**	**<1 (–150)**	37 (4)	31 (5)	**<1 (–21)**	**<1 (104)**	92 (0.0)	**<1 (9.0)**	**<1 (7.8)**	**2 (–0.04)**	18 (–0.1)	50 (0.1)	69 (1)	82 (0)
Waiohotu (36)	**<1 (80)**	11 (70)	**<1 (17)**	42 (–5)	**<1 (173)**	–	**<1 (0.8)**	**<1 (8.1)**	**<1 (3.4)**	21 (0.0)	**<1 (0.4)**	7 (–0.2)	45 (5)	**3 (2)**
Waiomou (34)	99 (1)	14 (–59)	12 (8)	34 (10)	49 (17)	49 (6)	**<1 (0.3)**	**<1 (14.1)**	**<1 (7.5)**	**5 (0.3)**	**<1 (0.9)**	78 (0.0)	**2 (22)**	26 (3)
Waitakaruru (31)	85 (11)	**<1 (–482)**	16 (10)	**<1 (237)**	**<1 (–240)**	5 (13)	**<1 (–1.4)**	10 (–5.2)	**<1 (–5.8)**	**4 (–0.8)**	20 (0.5)	19 (0.3)	82 (2)	31 (3)
Waitoa (81)	28 (44)	74 (33)	**<1 (16)**	**<1 (116)**	42 (–43)	12 (–16)	**<1 (–0.9)**	71 (2.5)	23 (–11.9)	51 (0.3)	16 (0.6)	6 (0.5)	30 (37)	74 (–3)
Waitoa (80)	13 (–42)	5 (272)	**<1 (30)**	**<1 (571)**	87 (–11)	90 (1)	**1 (–0.6)**	**<1 (–37.5)**	<1 (–23.6)	**<1 (–4.5)**	**<1 (–45.5)**	**<1 (–36.1)**	62 (23)	28 (7)

Table 5 (continued)

	Temperature (10^{-3} °C/yr)	Dissolved oxygen (10^{-3} percent of saturation/yr)	pH (10^{-3}/yr)	Conductivity (10^{-3} [mS/m]/yr)	Turbidity (10^{-3} NTU/yr)	Visual clarity (10^{-3} m/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Nitrate-N (10^{-3} [g/m^3]/yr)	Ammonia (10^{-3} [g N/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Dissolved reactive P (10^{-3} [g/m^3]/yr)	*Escherichia coli* ([cfu/100 mL]/yr)	Enterococci ([cfu/100 mL]/yr)
Inflows to Lake Taupo														
Hinemaiaia (55)	96 (1)	**2 (–126)**	42 (3)	**<1 (–46)**	45 (6)	42 (12)	**1 (0.2)**	20 (0.9)	**<1 (–1.6)**	43 (0.0)	33 (–0.1)	68 (0.1)	45 (0)	87 (0)
Kuratau (58)	8 (47)	**<1 (–113)**	**<1 (17)**	79 (–3)	71 (–3)	9 (27)	19 (–0.2)	50 (–0.5)	**<1 (–3.2)**	87 (0.0)	87 (0.0)	37 (0.0)	–	–
Kuratau (101)	57 (50)	66 (–100)	12 (0)	20 (–33)	97 (1)	–	12 (–0.4)	**1 (19.1)**	9 (15.6)	45 (0.0)	93 (0.0)	**<1 (–2.0)**	65 (1)	54 (1)
Mapara (53)	**3 (29)**	**1 (129)**	**<1 (12)**	21 (13)	**<1 (–90)**	7 (9)	**<1 (–0.8)**	**<1 (11.7)**	**<1 (8.9)**	**<1 (–0.3)**	79 (0.0)	**5 (0.6)**	50 (–2)	96 (0)
Tauranga–Tau (56)	**3 (57)**	**5 (–93)**	**<1 (14)**	**5 (–17)**	20 (–6)	62 (–8)	**<1 (0.2)**	49 (0.4)	7 (–0.5)	14 (0.0)	**4 (0.1)**	98 (0.0)	–	–
Tokaanu (57)	*1 (0.0)*	**<1 (–333)**	13 (0)	30 (0)	17 (–3)	–	*5 (0.0)*	**<1 (4.9)**	**<1 (3.0)**	*<1 (0.0)*	**<1 (0.2)**	**<1 (0.4)**	–	–
Tongariro (5)	**<1 (–49)**	28 (22)	8 (1)	**<1 (–44)**	18 (–10)	41 (–9)	32 (0.0)	**2 (1.0)**	5 (0.4)	**<1 (–0.2)**	39 (0.0)	12 (0.0)	–	–
Waihaha (59)	**<1 (105)**	58 (–18)	**<1 (19)**	30 (9)	6 (–11)	25 (32)	87 (0.0)	**1 (1.6)**	33 (–0.3)	93 (0.0)	**2 (0.2)**	11 (0.1)	50 (0)	40 (0)
Waitahanui (54)	72 (7)	**3 (–82)**	**3 (12)**	22 (11)	9 (–16)	70 (–7)	**<1 (0.1)**	**<1 (11.8)**	**<1 (8.8)**	70 (0.0)	26 (–0.1)	48 (0.1)	19 (–3)	65 (0)
Whanganui (104)	16 (196)	5 (–566)	**2 (27)**	64 (–22)	46 (33)	–	20 (–0.6)	12 (–10.3)	20 (–9.8)	31 (0.2)	31 (0.3)	**<1 (–1.1)**	58 (2)	91 (0)
Whareroa (102)	20 (167)	**1 (–714)**	16 (12)	25 (25)	84 (17)	–	7 (–0.6)	**1 (29.7)**	**<1 (19.5)**	12 (0.2)	16 (–0.6)	12 (–0.6)	58 (5)	44 (4)
Upland tributaries of the Waikato River														
Kawaunui (48)	43 (19)	**<1 (–427)**	27 (6)	**<1 (283)**	72 (20)	57 (–6)	17 (0.3)	**<1 (154)**	**<1 (125)**	**<1 (3.3)**	**<1 (7.7)**	**<1 (4.3)**	46 (81)	37 (8)
Mangaharakek (43)	**<1 (63)**	78 (10)	**<1 (17)**	**<1 (71)**	38 (–38)	5 (11)	86 (0.0)	**<1 (23.3)**	**<1 (18.6)**	**2 (–0.3)**	**<1 (0.8)**	**<1 (0.7)**	12 (13)	81 (1)
Mangakara (49)	53 (–9)	45 (–25)	5 (0)	**<1 (100)**	58 (39)	14 (10)	97 (0.0)	**<1 (40.3)**	**<1 (33.3)**	51 (0.0)	54 (0.2)	92 (0.0)	**<1 (36)**	**2 (3)**
Mangakino (60)	**<1 (49)**	**<1 (–179)**	7 (8)	40 (12)	79 (5)	6 (20)	32 (0.2)	**<1 (19.1)**	**<1 (15.6)**	72 (0.0)	**4 (0.3)**	**<1 (0.3)**	–	–
Otamakokore (46)	**<1 (130)**	**<1 (271)**	**<1 (11)**	**3 (115)**	98 (1)	44 (–8)	42 (0.3)	**<1 (22.4)**	**<1 (19.7)**	**<1 (–0.2)**	**<1 (1.1)**	**<1 (1.0)**	64 (7)	99 (0)
Pueto (52)	6 (28)	74 (–22)	**4 (9)**	16 (15)	**1 (–47)**	**<1 (36)**	71 (0.0)	**<1 (7.3)**	**<1 (3.3)**	**<1 (–0.7)**	**2 (0.4)**	**<1 (1.0)**	62 (0)	72 (0)
Tahunaatara (44)	13 (42)	**5 (–74)**	17 (6)	**<1 (28)**	51 (18)	65 (–3)	**1 (0.4)**	**<1 (18.9)**	**<1 (15.1)**	97 (0.0)	7 (0.5)	6 (0.2)	**4 (12)**	29 (3)
Torepatutahi (51)	27 (14)	**<1 (572)**	**<1 (17)**	**<1 (82)**	**<1 (–41)**	–	9 (–0.1)	**<1 (14.0)**	**<1 (11.5)**	*<1 (0.0)*	36 (–0.2)	20 (0.2)	–	–
Waiotapu (47)	40 (21)	**<1 (195)**	**5 (17)**	**2 (238)**	26 (–52)	**<1 (20)**	**<1 (0.2)**	**<1 (42.2)**	**<1 (23.5)**	**<1 (9.1)**	**<1 (3.0)**	9 (0.3)	**3 (0.2)**	**<1 (0.3)**
Waiotapu (50)	81 (4)	14 (101)	**<1 (23)**	37 (76)	11 (154)	**2 (8)**	23 (–0.2)	**<1 (30.5)**	**<1 (20.4)**	15 (–1.7)	**<1 (2.8)**	10 (0.4)	–	–
Waipapa (42)	**<1 (52)**	6 (119)	**<1 (12)**	**<1 (461)**	**<1 (–129)**	**2 (11)**	17 (0.1)	**<1 (38.9)**	**<1 (32.6)**	**<1 (–0.1)**	**<1 (1.0)**	**<1 (1.2)**	10 (10)	9 (2)
Whirinaki (45)	38 (–5)	**<1 (–164)**	46 (4)	53 (3)	**3 (–20)**	–	97 (0.0)	**<1 (15.9)**	**<1 (14.9)**	**<1 (–0.1)**	7 (0.3)	**<1 (0.4)**	–	–

Table 5 (continued)

	Temperature (10^{-3} °C/yr)	Dissolved oxygen (10^{-3} percent of saturation/yr)	pH (10^{-3}/yr)	Conductivity (10^{-3} [mS/m]/yr)	Turbidity (10^{-3} NTU/yr)	Visual clarity (10^{-3} m/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Nitrate-N (10^{-3} [g/m^3]/yr)	Ammonia (10^{-3} [g N/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Dissolved reactive P (10^{-3} [g/m^3]/yr)	*Escherichia coli* ([cfu/100 mL]/yr)	Enterococci ([cfu/100 mL]/yr)
Lowland tributaries of the Waikato River														
Awaroa-Otau (27)	42 (26)	24 (–232)	6 (21)	39 (33)	<u>**<1 (524)**</u>	<u>**<1 (–30)**</u>	**5 (–0.7)**	11 (16.2)	79 (1.6)	62 (0.2)	<u>**<1 (1.9)**</u>	43 (–0.1)	–	–
Awaroa-Rotowa (7)	14 (44)	39 (71)	**2 (14)**	15 (507)	10 (–117)	**4 (18)**	<u>**<1 (–1.0)**</u>	**3 (7.9)**	29 (2.7)	42 (–0.4)	**<1 (–0.3)**	**3 (–0.1)**	71 (9)	54 (4)
Karapiro (85)	25 (–40)	<u>**<1 (–455)**</u>	90 (0)	86 (–15)	<u>**<1 (303)**</u>	17 (–11)	**4 (–0.7)**	<u>**<1 (19.0)**</u>	**<1 (9.1)**	32 (0.2)	61 (0.2)	<u>**<1 (–1.1)**</u>	**<1 (40)**	6 (13)
Kirikiriroa (90)	85 (–13)	**5 (–182)**	53 (2)	38 (–113)	**<1 (–890)**	18 (4)	<u>**<1 (–3.8)**</u>	<u>**<1 (–113)**</u>	95 (–0.2)	<u>**<1 (–101)**</u>	**<1 (–1.4)**	18 (0.2)	89 (15)	20 (32)
Komakorau (6)	18 (43)	<u>**<1 (–301)**</u>	83 (0)	**1 (167)**	**2 (957)**	**3 (2)**	<u>**<1 (–4.2)**</u>	14 (15.9)	6 (10.0)	**<1 (–17.9)**	77 (–0.1)	**<1 (–0.6)**	16 (100)	**<1 (35)**
Little Waipa (38)	**2 (32)**	**1 (240)**	**<1 (13)**	<u>**<1 (83)**</u>	**<1 (71)**	**<1 (–36)**	**<1 (0.4)**	<u>**<1 (34.0)**</u>	<u>**<1 (24.8)**</u>	9 (0.2)	**<1 (1.0)**	**1 (0.4)**	69 (2)	60 (–1)
Mangakotukut (87)	66 (17)	<u>**<1 (–303)**</u>	14 (7)	**<1 (131)**	6 (–305)	87 (1)	9 (–3.9)	<u>**<1 (43.7)**</u>	<u>**<1 (16.1)**</u>	26 (2.3)	<u>**<1 (12.6)**</u>	**<1 (5.4)**	75 (27)	16 (28)
Mangamingi (40)	91 (–6)	12 (166)	90 (–1)	42 (31)	99 (1)	99 (0)	46 (0.2)	17 (18.0)	<u>**<1 (62.0)**</u>	<u>**<1 (–33.7)**</u>	<u>**<1 (–12.2)**</u>	<u>**<1 (–11.2)**</u>	30 (42)	99 (–1)
Mangaone (77)	12 (56)	<u>**<1 (654)**</u>	**2 (16)**	6 (68)	<u>**<1 (389)**</u>	<u>**<1 (–27)**</u>	97 (0.0)	<u>**<1 (–70.6)**</u>	<u>**<1 (–92.7)**</u>	**2 (–0.7)**	<u>**<1 (3.3)**</u>	90 (0.0)	26 (44)	**<1 (55)**
Mangaonua (78)	10 (58)	7 (191)	**<1 (17)**	<u>**<1 (142)**</u>	99 (–1)	37 (–9)	<u>**<1 (–1.4)**</u>	44 (–2.6)	**1 (–10.4)**	10 (–1.4)	80 (0.1)	43 (–0.2)	35 (60)	**<1 (54)**
Mangaonua (84)	31 (34)	**3 (–110)**	83 (–1)	5 (39)	24 (34)	26 (9)	13 (–0.3)	12 (–8.3)	**<1 (–6.5)**	<u>**<1 (–2.6)**</u>	<u>**<1 (–1.9)**</u>	<u>**<1 (–2.0)**</u>	82 (6)	34 (–4)
Mangatangi (30)	70 (9)	30 (–154)	25 (5)	27 (36)	**<1 (202)**	5 (–15)	**3 (–0.6)**	**<1 (–10.1)**	<u>**<1 (–11.2)**</u>	11 (–0.1)	<u>**<1 (1.2)**</u>	28 (0.2)	–	–
Mangatawhiri (29)	97 (3)	<u>**<1(–589)**</u>	6 (–21)	<u>**<1 (126)**</u>	20 (–47)	10 (26)	71 (–0.1)	**2 (–4.5)**	<u>**<1 (–3.8)**</u>	**<1 (–0.2)**	37 (0.2)	13 (–0.1)	–	–
Mangawara (19)	92 (–6)	46 (85)	**2 (13)**	21 (72)	8 (515)	26 (–2)	<u>**<1 (–4.7)**</u>	**4 (21.6)**	16 (7.9)	42 (2.0)	<u>**<1 (4.2)**</u>	8 (–0.7)	–	–
Mangawhero (86)	16 (46)	83 (–11)	8 (9)	<u>**<1 (128)**</u>	**<1 (749)**	**1 (–4)**	<u>**<1 (–3.4)**</u>	<u>**<1 (–26.8)**</u>	<u>**<1 (–26.0)**</u>	<u>**<1 (–5.1)**</u>	86 (–0.3)	86 (0.1)	62 (34)	**1 (35)**
Matahuru (20)	**3 (85)**	**4 (–149)**	**1 (14)**	17 (39)	**<1 (737)**	20 (–4)	<u>**<1 (–2.0)**</u>	**1 (–15.3)**	<u>**<1 (–21.7)**</u>	55 (–0.4)	<u>**<1 (2.8)**</u>	51 (0.1)	–	–
Ohaeroa (25)	78 (–11)	42 (–54)	**5 (8)**	9 (43)	69 (–40)	<u>**<1 (18)**</u>	**2 (–0.5)**	<u>**<1 (21.2)**</u>	<u>**<1 (18.2)**</u>	**<1 (–0.3)**	90 (0.0)	90 (0.0)	–	–
Opuatia (24)	99 (0)	29 (–97)	46 (4)	**<1 (109)**	**<1 (300)**	**<1 (–15)**	13 (–0.4)	**2 (11.9)**	8 (5.6)	**<1 (–0.3)**	**<1 (0.7)**	24 (–0.1)	16 (21)	**<1 (7)**
Pokaiwhenua (39)	45 (18)	78 (–22)	10 (10)	<u>**<1 (80)**</u>	<u>**<1 (118)**</u>	**1 (–19)**	**3 (0.3)**	<u>**<1 (26.3)**</u>	<u>**<1 (18.7)**</u>	32 (0.1)	17 (–0.7)	<u>**<1 (–1.5)**</u>	75 (3)	55 (1)
Waerenga (21)	5 (77)	**<1 (–341)**	13 (9)	**2 (52)**	16 (–88)	91 (1)	97 (0.0)	**<1 (10.1)**	23 (3.0)	77 (0.0)	**<1 (1.0)**	**<1 (0.5)**	45 (14)	5 (8)
Waitawhiriwhiri (89)	32 (28)	**1 (–202)**	6 (14)	43 (–51)	11 (290)	**3 (–5)**	<u>**<1 (–3.9)**</u>	23 (7.0)	**<1 (14.5)**	<u>**<1 (–17.9)**</u>	17 (1.0)	13 (0.6)	26 (52)	24 (48)
Whakapipi (26)	31 (35)	**<1 (247)**	**<1 (16)**	<u>**<1 (283)**</u>	<u>**<1 (–180)**</u>	**<1 (26)**	<u>**<1 (–0.9)**</u>	<u>**<1 (72.5)**</u>	<u>**<1 (63.8)**</u>	**4 (–0.3)**	<u>**<1 (1.8)**</u>	<u>**<1 (0.7)**</u>	–	–
Whakauru (41)	15 (–31)	11 (–88)	12 (6)	98 (–1)	17 (59)	76 (1)	**5 (0.4)**	<u>**<1 (7.1)**</u>	<u>**<1 (2.6)**</u>	37 (0.0)	12 (0.4)	94 (0.0)	40 (22)	22 (8)
Whangamarino (28)	5 (105)	8 (–768)	**3 (18)**	**4 (92)**	**<1 (–2181)**	34 (–1)	**4 (–2.0)**	<u>**<1 (33.8)**</u>	<u>**<1 (–12.6)**</u>	75 (0.1)	**<1 (3.4)**	<u>**<1 (–0.4)**</u>	–	–
Whangamarino (22)	11 (74)	<u>**<1 (–525)**</u>	**2 (10)**	15 (48)	**1 (–511)**	12 (6)	46 (–0.2)	<u>**<1 (–31.0)**</u>	<u>**<1 (–32.4)**</u>	45 (0.2)	7 (0.8)	**<1 (0.7)**	–	–
Whangape (23)	95 (0)	**<1 (483)**	94 (0)	98 (0)	<u>**<1 (2816)**</u>	**<1 (–10)**	94 (0.0)	<u>**<1 (50.3)**</u>	**<1 (–0.3)**	12 (0.0)	<u>**<1 (3.9)**</u>	*<1 (0.0)*	–	–

Table 5 (continued)

	Temperature (10^{-3} °C/yr)	Dissolved oxygen (10^{-3} percent of saturation/yr)	pH (10^{-3}/yr)	Conductivity (10^{-3} [mS/m]/yr)	Turbidity (10^{-3} NTU/yr)	Visual clarity (10^{-3} m/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Nitrate-N (10^{-3} [g/m^3]/yr)	Ammonia (10^{-3} [g N/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Dissolved reactive P (10^{-3} [g/m^3]/yr)	*Escherichia coli* ([cfu/100 mL]/yr)	Enterococci ([cfu/100 mL]/yr)
Waipa River and tributaries														
Kaniwhaniwha (11)	32 (27)	**<1 (–246)**	9 (–7)	**5 (–37)**	23 (–75)	18 (9)	**2 (–0.3)**	**<1 (8.1)**	**1 (4.0)**	23 (1.0)	11 (0.4)	99 (0.0)	–	–
Mangaohoi (74)	32 (–21)	12 (54)	99 (0)	**<1 (–60)**	37 (–22)	14 (9)	26 (0.1)	66 (1.0)	12 (–1.7)	**1 (–0.1)**	46 (0.1)	21 (–0.1)	8 (–10)	33 (–1)
Mangaokewa (65)	61 (–16)	**<1 (–122)**	62 (3)	45 (–29)	93 (3)	**<1 (17)**	54 (–0.2)	**<1 (9.4)**	**<1 (8.3)**	**<1 (–3.9)**	24 (0.5)	46 (0.1)	–	–
Mangapiko (76)	**<1 (–110)**	**<1 (–356)**	84 (1)	**3 (–115)**	**<1 (393)**	41 (–4)	23 (–0.5)	14 (–22.7)	6 (–26.5)	**<1 (–4.7)**	15 (–2.6)	**<1 (–5.6)**	–	–
Mangapu (63)	71 (–10)	**<1 (–386)**	92 (–2)	35 (30)	68 (43)	23 (4)	17 (–0.2)	**<1 (11.4)**	**<1 (8.6)**	11 (–0.6)	**<1 (2.1)**	**<1 (1.4)**	26 (31)	14 (–5)
Mangatutu (73)	52 (–22)	**2 (–108)**	25 (5)	**<1 (62)**	8 (51)	36 (–7)	94 (0.0)	**<1 (10.9)**	**5 (4.8)**	75 (0.1)	**<1 (0.6)**	56 (0.0)	60 (–20)	46 (2)
Mangauika (13)	85 (5)	8 (–57)	58 (–2)	14 (–16)	63 (9)	**<1 (52)**	37 (–0.1)	**<1 (7.3)**	**<1 (5.8)**	**<1 (–0.03)**	87 (0.0)	11 (–0.1)	20 (–1)	44 (0)
Ohote (88)	99 (0)	73 (–99)	**<1 (25)**	**<1 (–300)**	82 (–13)	11 (–12)	**<1 (–2.3)**	20 (–10.3)	**1 (–12.3)**	21 (0.0)	7 (1.4)	**<1 (0.4)**	50 (8)	19 (2)
Puniu (75)	**2 (–89)**	**<1 (–493)**	25 (–7)	**2 (52)**	**<1 (163)**	**<1 (–23)**	23 (–0.2)	**<1 (16.1)**	**<1 (8.7)**	**<1 (0.6)**	**<1 (1.1)**	**5 (0.2)**	–	–
Waipa (61)	7 (68)	94 (–2)	**4 (11)**	**<1 (33)**	14 (–33)	32 (10)	**1 (–0.9)**	**<1 (17.3)**	**<1 (13.2)**	13 (0.0)	**1 (0.4)**	**2 (0.1)**	–	–
Waipa (12)	35 (–24)	**2 (–129)**	71 (–2)	79 (3)	81 (46)	73 (–2)	5 (–0.4)	**<1 (13.1)**	**<1 (7.2)**	48 (0.2)	**<1 (1.2)**	**<1 (0.3)**	93 (–5)	**4 (6)**
Waipa (2)	90 (–3)	**2 (–36)**	89 (0)	**2 (7)**	**2 (–36)**	28 (6)	71 (0.0)	**<1 (4.1)**	**<1 (2.8)**	22 (–0.1)	35 (0.1)	**<1 (0.2)**	–	–
Waipa (64)	87 (–3)	**<1 (–327)**	**1 (13)**	96 (–4)	6 (–93)	**4 (10)**	11 (–0.3)	**<1 (12.2)**	**<1 (6.8)**	42 (–0.1)	53 (0.1)	80 (0.0)	14 (36)	91 (–1)
Waipa (1)	85 (–6)	85 (–13)	73 (–1)	**<1 (51)**	32 (46)	**<1 (–7)**	25 (0.1)	**1 (7.2)**	**1 (5.0)**	8 (–0.3)	**1 (0.6)**	43 (–0.1)	–	–
Waitomo (18)	14 (–41)	**<1 (–392)**	64 (–3)	75 (9)	49 (77)	26 (4)	**4 (–0.4)**	**<1 (10.8)**	**<1 (5.4)**	**1 (–0.5)**	23 (0.3)	89 (0.0)	58 (–23)	93 (0)
Waitomo (17)	29 (–17)	**<1 (–202)**	23 (6)	6 (57)	40 (32)	75 (–2)	6 (–0.3)	**<1 (8.0)**	**<1 (7.0)**	**<1 (–0.6)**	6 (0.3)	**1 (0.1)**	85 (–4)	67 (1)

Table 5 (continued)

	Temperature (10^{-3} °C/yr)	Dissolved oxygen (10^{-3} percent of saturation/yr)	pH (10^{-3}/yr)	Conductivity (10^{-3} [mS/m]/yr)	Turbidity (10^{-3} NTU/yr)	Visual clarity (10^{-3} m/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Nitrate-N (10^{-3} [g/m^3]/yr)	Ammonia (10^{-3} [g N/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Dissolved reactive P (10^{-3} [g/m^3]/yr)	*Escherichia coli* ([cfu/100 mL]/yr)	Enterococci ([cfu/100 mL]/yr)
West Coast														
Awakino (70)	18 (–36)	**<1 (–207)**	90 (2)	7 (–27)	72 (–13)	83 (3)	95 (0.0)	90 (–0.2)	14 (–1.3)	**<1 (–0.05)**	56 (0.1)	63 (0.0)	99 (0)	20 (–3)
Awakino (69)	**5 (–83)**	**<1 (–398)**	29 (–15)	**2 (–129)**	8 (193)	51 (–8)	18 (–0.2)	**<1 (8.4)**	10 (2.8)	**1 (–0.1)**	**<1 (0.7)**	**<1 (0.2)**	85 (10)	**2 (6)**
Manganui (67)	28 (–43)	**2 (–152)**	49 (4)	**<1 (–82)**	**<1 (291)**	18 (–12)	21 (–0.1)	**<1 (5.3)**	90 (0.1)	38 (0.0)	**<1 (0.9)**	**4 (0.2)**	12 (33)	81 (–1)
Mangaotaki (66)	63 (16)	67 (–13)	53 (5)	83 (–7)	79 (16)	12 (9)	13 (–0.2)	**<1 (15.3)**	**<1 (8.4)**	**<1 (–0.4)**	**<1 (0.9)**	**<1 (0.3)**	–	–
Marokopa (15)	50 (–19)	**<1 (–208)**	44 (–8)	**5 (–47)**	27 (36)	87 (–2)	29 (0.2)	**<1 (7.6)**	**<1 (3.0)**	**5 (–0.1)**	**<1 (0.7)**	**2 (0.2)**	99 (2)	18 (3)
Mokau (68)	87 (–7)	68 (–26)	13 (10)	19 (48)	34 (212)	17 (3)	**4 (–0.6)**	**<1 (13.3)**	**<1 (5.9)**	92 (0.0)	**<1 (1.1)**	92 (0.0)	71 (–7)	47 (1)
Mokau (62)	59 (–19)	**<1 (–338)**	10 (9)	**<1 (28)**	75 (8)	66 (4)	86 (0.0)	**<1 (12.4)**	**<1 (7.7)**	49 (0.0)	**<1 (0.8)**	**<1 (0.4)**	23 (18)	40 (–2)
Mokau (71)	78 (–9)	**<1 (–161)**	27 (4)	**5 (46)**	62 (–58)	**2 (8)**	**<1 (–0.8)**	**<1 (15.5)**	**<1 (9.9)**	48 (–0.1)	**<1 (0.9)**	**<1 (0.2)**	93 (–1)	40 (7)
Mokauiti (72)	54 (–35)	**<1 (–315)**	94 (–1)	94 (3)	**4 (–308)**	**<1 (11)**	5 (–0.7)	6 (5.0)	16 (2.3)	57 (0.1)	15 (0.4)	85 (0.0)	78 (4)	24 (7)
Ohautira (9)	7 (–48)	**3 (–81)**	20 (–8)	8 (–53)	10 (271)	13 (6)	**<1 (–0.8)**	**<1 (13.5)**	**<1 (9.2)**	**3 (–0.1)**	**<1 (0.7)**	92 (0.0)	99 (–2)	11 (12)
Oparau (14)	50 (–16)	**<1 (–222)**	13 (5)	12 (–33)	5 (62)	21 (–15)	46 (–0.2)	**<1 (7.0)**	**<1 (2.1)**	22 (0.0)	13 (0.3)	87 (0.0)	–	–
Tawarau (16)	50 (20)	**<1 (–171)**	83 (1)	27 (–26)	94 (1)	38 (5)	39 (0.1)	**<1 (7.1)**	6 (1.7)	**<1 (–0.2)**	**<1 (0.7)**	**<1 (0.2)**	–	–
Waingaro (8)	**2 (–70)**	26 (94)	15 (12)	15 (–55)	**<1 (457)**	87 (–2)	**<1 (–0.9)**	**<1 (12.1)**	**<1 (8.0)**	30 (0.1)	**<1 (1.0)**	**3 (–0.1)**	–	–
Waitetuna (10)	13 (–47)	7 (–88)	15 (–8)	**4 (–29)**	**<1 (386)**	21 (–7)	**<1 (–0.7)**	**<1 (10.0)**	**<1 (6.1)**	8 (0.2)	**3 (0.6)**	**1 (–0.2)**	35 (30)	**3 (11)**
Total numbers of significant trends (numbers of highly significant trends in brackets)														
Total increases	11 (2)	11 (3)	32 (4)	36 (17)	20 (7)	17 (7)	12 (5)	69 (52)	56 (40)	5 (4)	45 (19)	29 (10)	6 (0)	13 (0)
Total decreases	6 (0)	50 (23)	2 (0)	13 (2)	17 (8)	11 (2)	29 (11)	12 (8)	22 (11)	39 (18)	7 (5)	19 (10)	0 (0)	0 (0)

Table 6: **Median values of the trend slopes (SKSE) for flow-adjusted water quality records at 103 sites on rivers and streams in the Waikato Region. Median values of the standardised slopes are shown in brackets (units, % of median value per year). Values in bold are cases where the binomial test's null hypothesis is rejected (*p* < 5%), indicating the existence of an overall pattern of change across the region as a whole.**

	All records		Significant records only		Highly significant records only	
Temperature (°C/yr)	+0.01	(+0.1%)	+0.03	(+0.2%)	+0.12	(+0.8%)
Dissolved oxygen (%sat/yr)	**–0.10**	**(–0.1%)**	**–0.18**	**(–0.2%)**	**–0.32**	**(–0.3%)**
pH (/yr)	**+0.006**	**(+0.1%)**	**+0.015**	**(+0.2%)**	+0.021	(+0.3%)
Conductivity (mS/m/yr)	**+0.03**	**(+0.2%)**	**+0.07**	**(+0.6%)**	**+0.10**	**(+0.9%)**
Turbidity (NTU/yr)	<0.01	(+0.1%)	+0.05	(+1.8%)	–0.02	(–2.8%)
Visual clarity (m/yr)	+0.003	(+0.3%)	+0.009	(+1.2%)	+0.020	(+2.1%)
Dissolved colour (A340/cm/yr)	**–0.0002**	**(–0.8%)**	**–0.0007**	**(–1.7%)**	–0.0010	(–2.6%)
Total nitrogen (g/m^3/yr)	**+0.008**	**(+1.5%)**	**+0.011**	**(+1.9%)**	**+0.012**	**(+2.1%)**
Nitrate-N (g/m^3/yr)	**+0.003**	**(+1.1%)**	**+0.006**	**(+1.4%)**	**+0.008**	**(+1.7%)**
Ammonia (g N/m^3/yr)	**<0.0001**	**(<0.1%)**	**–0.0003**	**(–3.0%)**	**–0.0014**	**(–4.8%)**
Total phosphorus (g/m^3/yr)	**+0.0003**	**(+0.9%)**	**+0.0008**	**(+2.0%)**	**+0.0012**	**(+2.3%)**
Dissolved reactive P (g/m^3/yr)	<0.0001	(<0.1%)	+0.0002	(+0.7%)	–0.0001	(<0.1%)
E. coli (cfu/100 mL/yr)	**+6.2**	**(+2.5%)**	**+29.6**	**(+12.6%)**	no data	
Enterococci (cfu/100 mL/yr)	**+1.9**	**(+3.2%)**	**+10.9**	**(+12.4%)**	no data	

The median values of the SKSE for significant and highly significant trends in pH were relatively low, being 0.015 and 0.021/yr, respectively (Table 6). Interestingly, none of the sites in the West Coast zone showed significant trends in pH, while just over half the sites in the Taupo and Upland Waikato zones showed trends. It is unclear whether there's a common cause of the observed changes, nor is it clear what the cause(s) might be. However, it is noteworthy that sedimentary rocks are common in the West Coast zone, but rather less so elsewhere, so the differences may relate to differing geology.[17]

<u>Conductivity</u>. Significant trends in conductivity were observed at about half (49) of the sites. Many (36) of these were increases, so the overall pattern for the region as a whole was for an increase in conductivity (Table 6, Figure 5B); decreases in conductivity were more likely to occur in southern and western parts of the region than elsewhere (Figure 5B).

The observed increases in conductivity probably represent a deterioration in water quality. As noted above (section 2.7), conductivity is higher in streams with more-developed catchments, indicating that disturbance of the natural environment results in increases in the concentrations of major ions (and thus in conductivity). Increases in conductivity in a given stream are thus likely to reflect increases in disturbance of the natural systems within its catchment.

Scarsbrook et al. (2003) observed an overall increase in conductivity during 1989–98 in New Zealand rivers in general. The median SKSE for all of their sites was 0.192 μS/cm/yr, or about 0.02 mS/m/yr. The equivalent value for Waikato rivers was somewhat larger than this (0.03 mS/m/yr, Table 6). The overall trend in conductivity at river sites in the Waikato Region is thus similar to that seen previously in New Zealand rivers in general.

<u>Turbidity</u>. Significant trends in turbidity were observed at 37 sites. The numbers of increases (20) and decreases (17) were similar. Increases in turbidity were uncommon in the southern part of the region (Figure 5C).

The largest decrease in turbidity was –2.2 NTU/yr (Whangamarino @ Island Block Rd, #28), while the largest increase was 2.8 NTU/yr (Whangape, #23; note that this site is

[17] However, overall differences in the buffering capacity of the stream waters in the different zones are not large. For example, the median alkalinity of stream waters in the West Coast zone in 2005 was about 28 g $CaCO_3/m^3$, compared to median values for the other zones that were in the range 14 (Coromandel) to 32 g $CaCO_3/m^3$ (Lowland Waikato): see Smith (2006).

on the outflow from Lake Whangape, a shallow lake that has experienced very high levels of algae and consequent poor water clarity in recent years; this is probably the main cause of the increased turbidity at site #23).

Visual clarity. Significant trends in clarity were observed at 28 sites (e.g. Figs 3A, B). The numbers of increases (17) and decreases (11) were broadly similar, with no indication of an overall pattern for the region as a whole (Table 6). The largest increase in clarity was 0.10 m/yr (Waihou @ Whites, #37, Figure 3A), while the largest decrease was –0.06 m/yr (Kauaeranga, #92).

There were no changes in clarity at sites in Taupo zone, and just one site in this zone showed a trend in turbidity (Mapara, #23). The incidence of trends in these variables was also below average in the West Coast zone. Water clarity was thus more stable in these areas than elsewhere in the region.

Dissolved colour. Significant trends in dissolved colour were observed at more than one-third (41) of the sites. Many (29) of these were decreases, so the overall pattern for the region as a whole was for a decrease in dissolved colour (Table 6, Figure 5D).

A distinct spatial pattern in trends in dissolved colour was apparent, with decreases generally confined to northern and western parts of the region, and increases in eastern and southern parts (Figure 5D). The zones with the greatest proportion of sites that have shown decreasing trends were Hauraki (69%) and Lowland Waikato tributaries (65%). Conversely, no sites in the Coromandel zone showed a trend (Figure 5D). Across the region as a whole, values of SKSE were inversely-correlated with land use ($r = -0.65$, $p < 0.01\%$): the largest decreases tended to occur in more-developed catchments (Figure 6A).

The decreases in dissolved colour at several Waikato River sites probably reflected improvements in wastewater treatment. For the other rivers and streams, however, it is possible that the observed decreases result from the historic drainage of wetland areas (Vant and Smith 2004). Drainage associated with historic catchment development may have caused a reduction in the export of dissolved organic carbon from areas of drained wetlands, such that we are currently seeing part of the tailing-off in the loads of these highly-coloured compounds. Some evidence for this is provided by the fact than many of the largest decreases occurred at Hauraki and Lowland Waikato sites, areas where land drainage is common. While the overall decrease in dissolved colour may therefore represent an improvement in visual water quality, it may result from a deterioration in wetland condition.

Total nitrogen. Significant trends in total N concentration were observed at many (81) of the sites. Most (69) of these were increases, with many (52) being highly significant, so the overall pattern for the region as a whole was for an increase in total N (Table 6, Figure 5E). This represents a deterioration in water quality.

The median value of the SKSE for significant trends was 0.011 $g/m^3/yr$ or about 2% of the median value per year. This represents a moderately-rapid rate of increase in total N.

Increases in total nitrogen concentration were observed in most parts of the region, while decreases were confined to northern parts, in particular the Hauraki and Lowland Waikato zones (Figure 5E). All 12 sites in the Upland Waikato zone showed a highly significant increase in total N, while all the trends in the Waipa and West Coast zones were significant increases (Figure 5E).

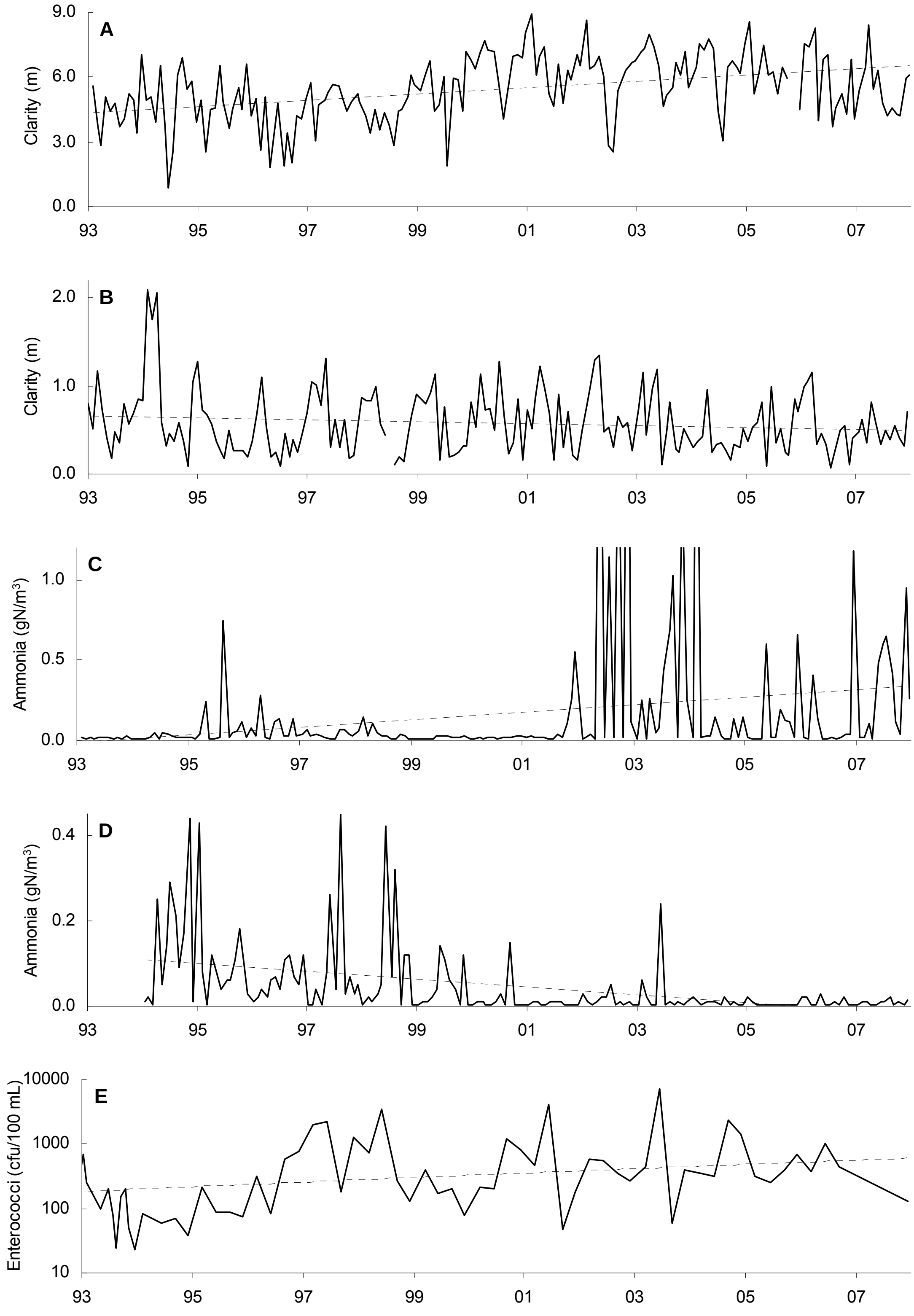

Figure 3: **Water quality at various sites during 1993–2007: A, Visual clarity at Waihou (Whites, #37); B, visual clarity at Waipa (Whatawhata, #1); C, ammonia at Kawaunui (#48); D, ammonia at Mangaonua (Te Miro, #84); and E, enterococci (logarithmic) at Piako (Paeroa-Tahuna, #79). The dashed lines show the overall trends in the records.**

Several of the observed decreases occurred downstream of areas where specific sources of N have been better-managed in recent years: Kirikiriroa (#90; landfill leachate), Mangaone (#77; spray-irrigated dairy factory wastewaters), Piako (Paeroa-Tahuna, #79; sewage and dairy factory wastewaters), Waitekauri (#100; mining wastewaters) and Ohinemuri (Karangahake, #4; mining and sewage wastewaters). Many of the larger increases, however, have occurred in more-developed catchments (Figure 6B). This is likely to reflect increased leaching losses from areas of pastoral farming following intensification in recent decades.

Nitrate-N. Significant trends in nitrate concentration were observed at many (78) of the sites (e.g. Figure 4). Many (56) of these were increases, with many (40) being highly significant, so the overall pattern for the region as a whole was for an increase in nitrate (Table 6). This represents a deterioration in water quality.

All 12 sites in the Upland Waikato zone showed a highly significant increase in nitrate (see examples in Figs 4A-to-E). The median value of the SKSE for these 12 sites was 0.019 $g/m^3/yr$ or about 3.5% of the median value per year. In addition, most of the changes in the Waipa zone and all of those in the West Coast zone were significant increases. By contrast, most of the trends in the Coromandel zone were decreases, as were about half of the trends in the Lowland Waikato zone and about one-third of the trends in the Hauraki zone. Increases were thus more common in western and southern parts of the region, while decreases were more common in the northern part.

As with total nitrogen, many of the increases in nitrate concentrations in rivers in the region are likely to reflect increased leaching losses from areas of pastoral farming following intensification in recent decades.

Ammonia. Significant trends in ammonia concentration were observed at many (44) sites (e.g. Figs 3C, D). Most (39) of these were decreases. This represents an improvement in water quality. Decreases in ammonia concentration were observed in most parts of the region (Figure 5F).

At several sites substantial decreases in ammonia have occurred in recent years as a result of the reduction or removal of loads from point source discharges further upstream: Waitekauri (#100; mining wastewaters), Kirikiriroa (#90; landfill leachate), Mangamingi (#40; sewage wastewaters) and Mangaokewa (#65; stockyard runoff).

Ignoring these point source-related changes, the largest decreases in ammonia tended to occur in more-developed catchments (Figure 6C). This may reflect improved farm practice (e.g. smaller loads of ammonia reaching streams from oxidation ponds following a major shift to land disposal of farm dairy wastes in recent years).

However, the median value of SKSE for significant trends in ammonia (–0.0003 g $N/m^3/yr$) was considerably smaller than the median value of SKSE for significant trends in total N (+0.011 g $N/m^3/yr$) (see Figure 6B). This means that the overall decreases in ammonia concentrations were more than out-weighted by increases in other forms of nitrogen (e.g. nitrate), such that the overall outcome for rivers in general across the region was an increase in concentrations of total N (Figure 7).

Total phosphorus. Significant trends in total P concentration were observed at half (52) of the sites. Most (45) of these were increases, so the overall pattern for the region as a whole was for an increase in total P (Table 6, Figure 5G). This represents a deterioration in water quality. The median value of the SKSE for significant trends was 0.0008 $g/m^3/yr$ or 2.0% of the median value per year. This represents a moderately-rapid rate of increase in total P.

As with trends in total N, increases in total phosphorus concentration were observed in many parts of the region (Figure 5G). However, the incidence of trends in total P was below average in the Hauraki and Taupo zones.

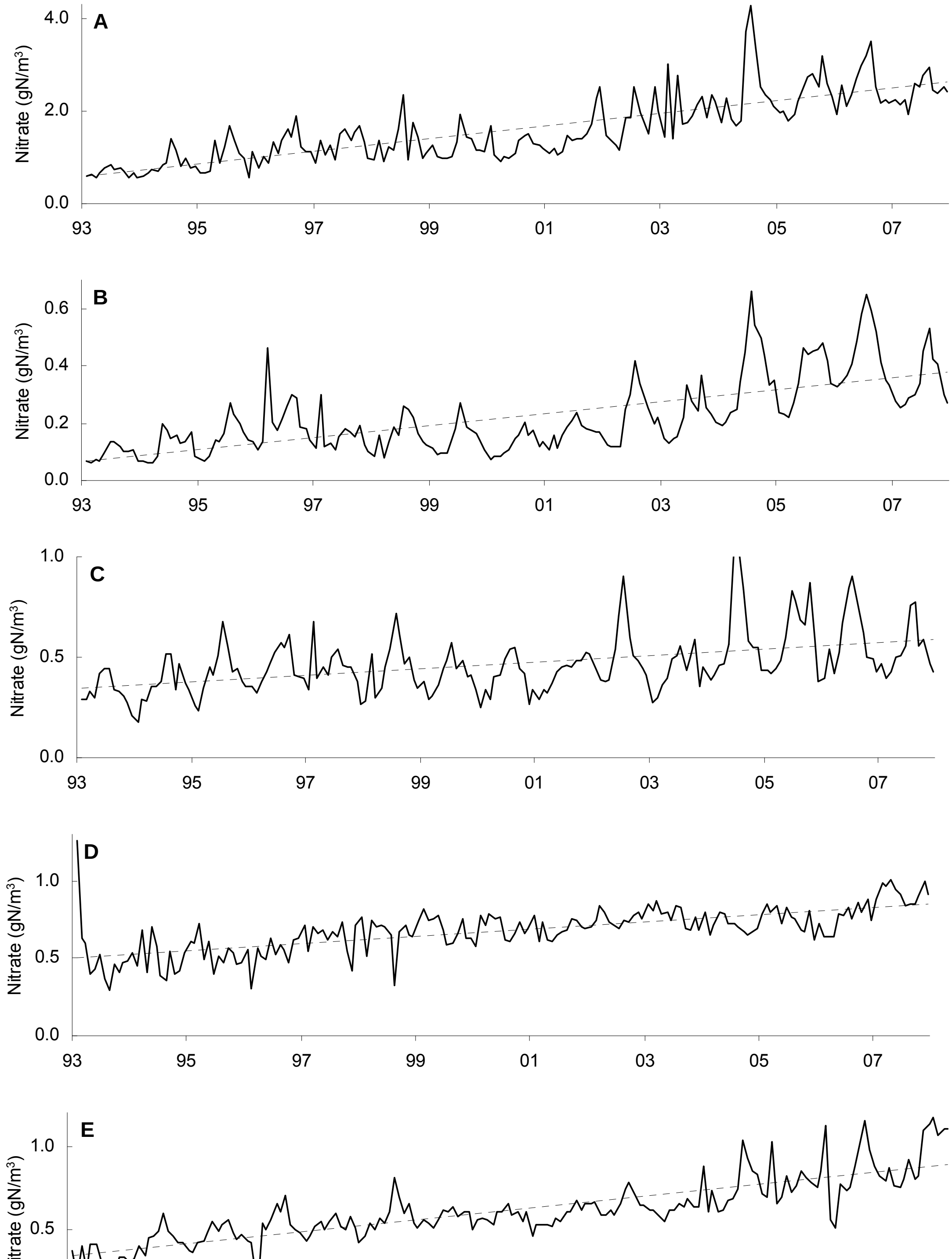

Figure 4: **Nitrate concentrations at various sites in the Upland Waikato zone during 1993–2007.** A**, Kawaunui (#48);** B**, Mangaharakeke (#43);** C**, Tahunaatara (#44);** D**, Waiotapu (Campbell, #47); and** E**, Waipapa (#42). The dashed lines show the overall trends in the records.**

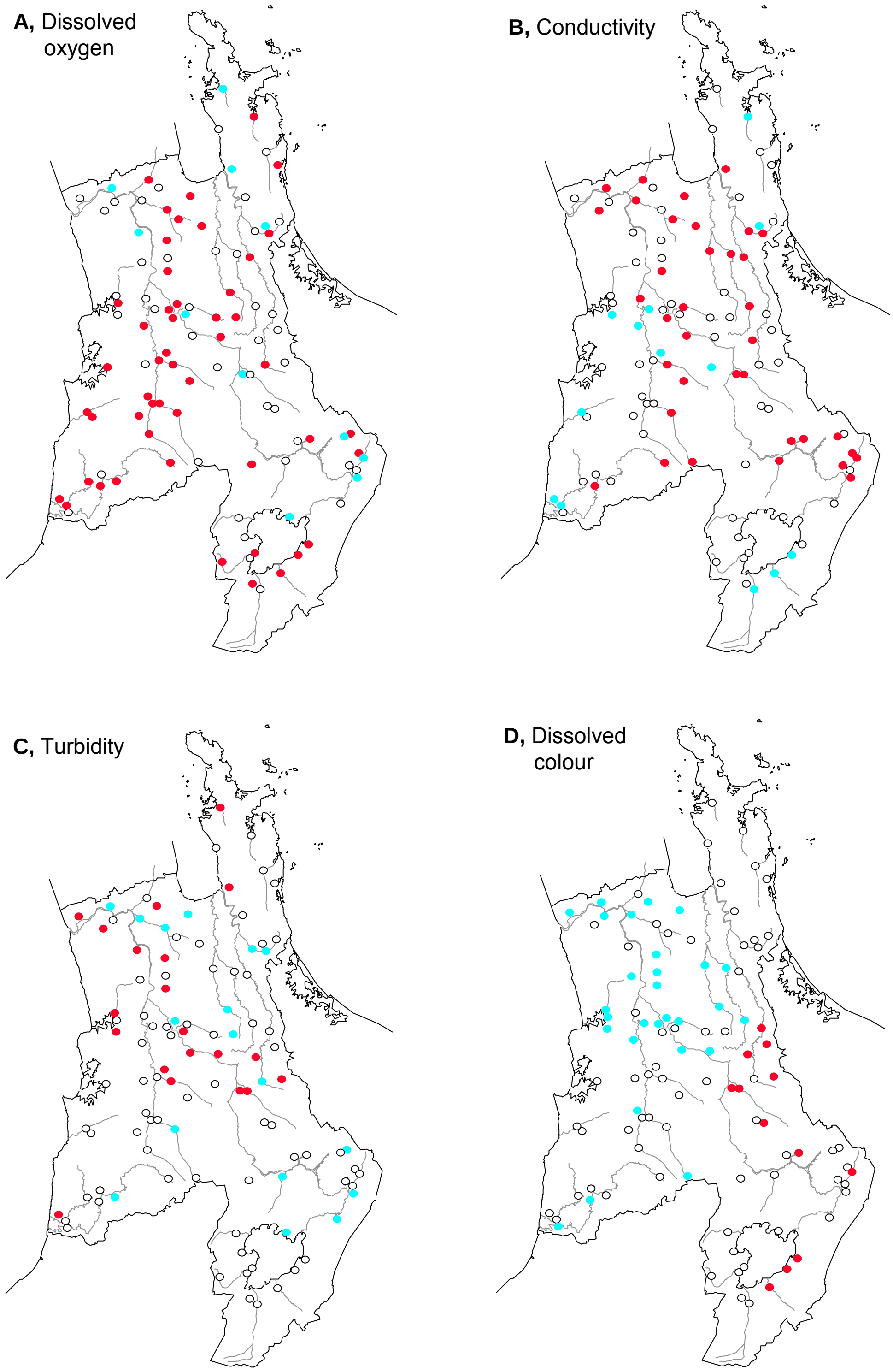

Figure 5: **Nature of trends for selected water quality variables at regional river sites during 1990–2007: sites showing improving trends are shown in blue, those showing deteriorating trends in red, and those showing no significant trends as open circles.** A, **Dissolved oxygen;** B, **conductivity;** C, **turbidity;** D, **dissolved colour;** E, **total nitrogen;** F, **ammonia;** G, **total phosphorus; and** H, **dissolved reactive phosphorus. See Figure 1 and Table 5 for details; and see text for a discussion of the direction of the trends in dissolved colour.**

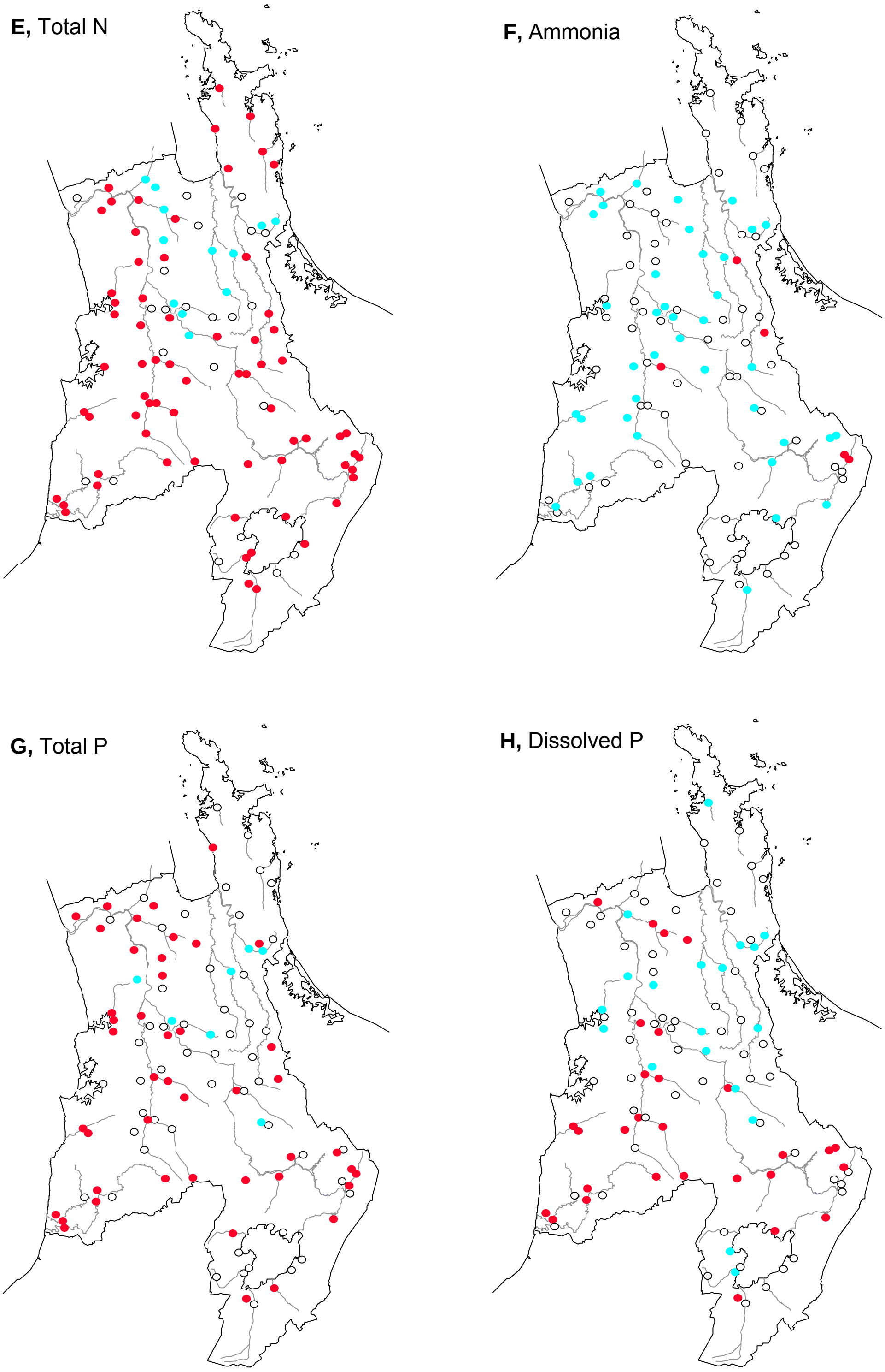

Figure 5 (continued): Nature of trends for selected water quality variables at regional river sites during 1990–2007: sites showing improving trends are shown in blue, those showing deteriorating trends in red, and those showing no significant trends as open circles. **A**, Dissolved oxygen; **B**, conductivity; **C**, turbidity; **D**, dissolved colour; **E**, total nitrogen; **F**, ammonia; **G**, total phosphorus; and **H**, dissolved reactive phosphorus. See Figure 1 and Table 5 for details; and see text for a discussion of the direction of the trends in dissolved colour.

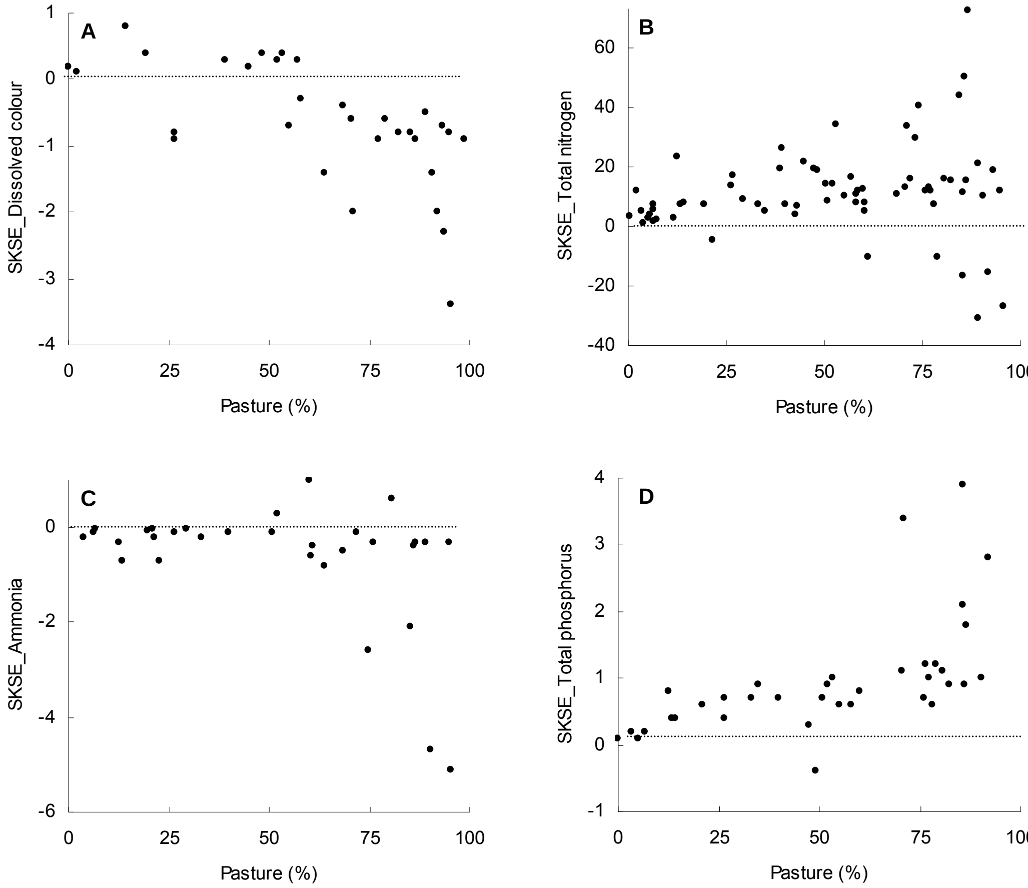

Figure 6: **Slopes for significant trends (SKSE, units as in Table 5) and land use (as percent of catchment in pasture) for selected water quality variables:** A, **Dissolved colour;** B, **total nitrogen;** C, **ammonia; and** D, **total phosphorus (excluding three outliers: see text).**

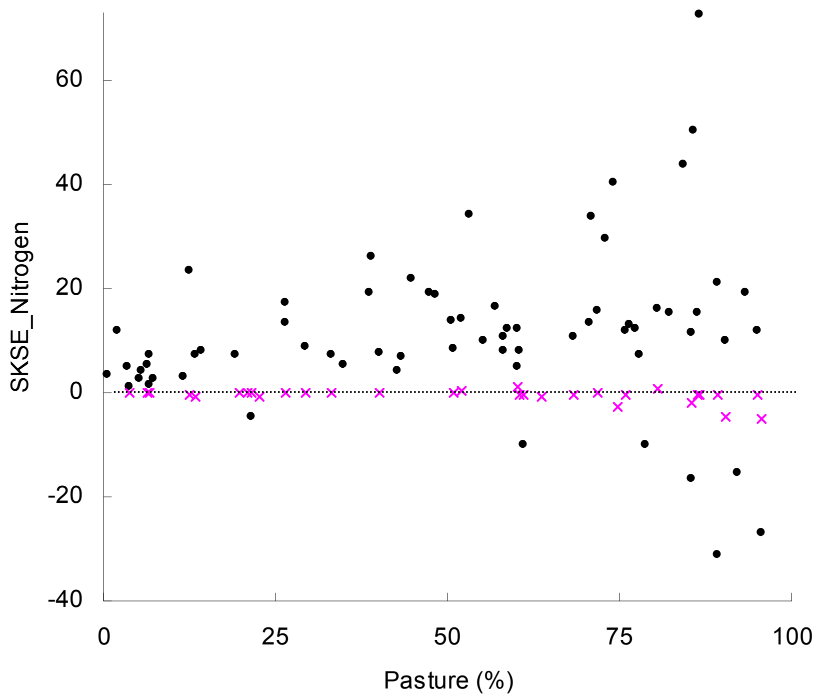

Figure 7: **Trend slopes (SKSE, units as in Table 5) and land use (as percent of catchment in pasture) for total nitrogen (circles) and ammonia (crosses): redrawn from Figures 6B and 6C, respectively.**

Ignoring three outliers,[18] values of SKSE were highly-correlated with land use (r = 0.60, p = 0.01%): see Figure 6D. That is, total P has tended to increase at a greater rate in streams in more-developed catchments. This may well reflect increased losses via surface runoff from areas of pastoral farming following intensification in recent decades.

Dissolved reactive phosphorus. Significant trends in DRP concentration were also observed at just under half (48) of the sites. As only slightly more than half of these (29) were increases (i.e. deteriorations), there was no indication of an overall pattern for the region as a whole (Table 6, Figure 5H).

At six sites significant trends in both DRP and ammonia occurred. The values of SKSE for the trends in DRP and ammonia were highly correlated (r = 0.98, p < 0.1%), so both may reflect improved farm practice in the catchments of the relevant streams (e.g. better management of farm dairy wastewaters).

Escherichia coli.[19] Significant trends in *E. coli* concentrations were observed at just six sites. All were increases (i.e. deteriorations). Three of the sites that showed increases were in the Upland Waikato zone (#44, 47 and 49), two were in the Hauraki zone (#34 and 83) and one was in the Lowland Waikato zone (Karapiro, #85).

Enterococci.[20] Significant trends in enterococci concentrations were observed at 13 sites (e.g. Figure 3E). All were increases (i.e. deteriorations). Five of the sites that showed increases were in the Lowland Waikato zone (#6, 24, 77, 78 and 86), three were in the Hauraki zone (#36, 79 and 83) and two each were in the Upland Waikato (#47 and 49) and West Coast zones (#10, 69). By contrast, no changes occurred at sites in the Coromandel or Taupo zones, and only one change occurred in the Waipa zone (#12).

[18] Mangakotukutuku, Ohinemuri (Queenshead) and Mangaonua (Te Miro).

[19] Note that these records contain fewer results than those for many other variables, so that the sample size is considerably smaller (n = 21–40: Table 1). As a result care should be taken in comparing the trend analyses for *E. coli* with those reported for other variables.

[20] Note that these records contain fewer results than those for many other variables, so that the sample size is considerably smaller (n = 21–91: Table 1). As a result care should be taken in comparing the trend analyses for enterococci with those reported for other variables.

4 Conclusions

1. Significant trends ($p < 5\%$) were found in nearly half (44%) of the water quality records from the Waikato River. One-third of these were highly significant ($p < 0.05\%$). Variables for which significant trends were found at five or more of the ten sites were conductivity, dissolved colour, BOD_5, arsenic, boron, nitrate, ammonia, total P and DRP. In several cases these were improvements that have resulted from better treatment of known point source discharges (e.g. Kinleith paper mill, Wairakei power station). Management of dairy shed wastewaters has also changed, and is likely to have contributed to the improvements in ammonia. On the other hand, the observed deterioration in nitrate and total phosphorus concentrations has probably resulted from an intensification of land use within the Waikato River catchment. An overall, semi-quantitative assessment of water quality changes in the river since 1987 is shown in Table 7.

2. Significant trends ($p < 5\%$) were also found in many (43%) of the water quality records for the other rivers and streams. About half of these were highly significant ($p < 0.05\%$). Across the region as a whole, the following overall patterns were apparent: (1) significant increases have occurred in pH, conductivity, total N, nitrate and total P; and (2) significant decreases have occurred in dissolved oxygen, dissolved colour and ammonia. While the decreases in ammonia can be regarded as improvements, the majority of these changes represent deteriorations (Table 7).

3. For some of these trends in the other rivers and streams probable causes can be identified. For example, decreases in ammonia have occurred at several sites that are downstream of locations where contaminant loads from point source discharges are known to have reduced. And the reduction in ammonia at about 30 other sites—the magnitude of which is significantly related to the proportion of pasture in the relevant catchments—may well reflect altered farm practice such as a move towards land disposal of farm dairy wastewaters. But the substantially-larger increases in total N and nitrate probably reflects the overall increase in stock numbers and farming intensity that has occurred across the region in the past decade or more (Figure 7).

Table 7: Semi-quantitative assessment of the overall nature of statistically significant trends in river water quality in the Waikato Region. Both the direction of change (“Imp”, improvement; “Det”, deterioration; “n”, no overall pattern) and the magnitude of the rate of change (as “High” or “Low”) are shown.

	Waikato River (10 sites) 1987–2007	Other rivers (103 sites) 1990–2007
Temperature	n Low	n Low
Dissolved oxygen	n Low	Det Low
pH	n Low	Det Low
Conductivity	Det Low	Det Low
Turbidity	n High	n High
Visual clarity	n Low	n High
Dissolved colour	Imp High	Det High
Biochemical oxygen demand	Imp High	no data
Arsenic	Imp Low	no data
Boron	Imp Low	no data
Total nitrogen	n High	Det High
Nitrate-N	Det Low	Det High
Ammonia	Imp High	Imp High*
Total phosphorus	Det Low	Det High
Dissolved reactive P	n Low	n Low
Chlorophyll *a*	n High	no data
Escherichia coli	n Low	Det High
Enterococci	n Low	Det High

*But as noted in section 3.2, the (relatively-high) decreases in concentrations of ammonia were out-weighed by the much larger increases in concentrations of other forms of nitrogen (Figure 7).

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