Environment Waikato Technical Report 2004/02

Trends in river water quality in the Waikato Region, 1987–2002

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Prepared by:
Bill Vant & Paul Smith

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

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Reviewed by:
Nick Kim
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Approved for release by:
Peter Singleton
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Summary

We analysed trends in river water quality at 110 sites in the Waikato Region using non-parametric statistical methods (seasonal Kendall slope estimator and trend test). At ten Waikato River sites we analysed records of 19 water quality variables that began in 1987 or later and ended in 2002. At the 100 other river sites records of 14 variables beginning in 1990 or later and ending in 2002 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 92 (49%) of these. Variables for which significant trends were found at five or more of the ten Waikato River sites were pH, dissolved colour, biochemical oxygen demand, arsenic, boron, ammonia and faecal coliforms. Apart from faecal coliforms, all these showed decreasing trends. The decreases in dissolved colour, biochemical oxygen demand, arsenic, boron and ammonia all represent improvements in water quality, and mostly result from improved wastewater management at known point source discharges (e.g. Kinleith mill, Wairakei power station). The decrease in pH, however, represents a deterioration. The cause of this decrease is not clear. Some of the trends in faecal coliform levels resulted from a probably harmless, non-sewage discharge to the lower river that went un-noticed until 2002, but has subsequently ceased. A more reliable measure of faecal contamination of the lower river is probably provided by the 1988–2002 records of enterococci bacteria. None of the enterococci records at the five lower river sites have shown increasing trends.

A total of 1334 water quality records from the other rivers and streams were considered. Significant trends were found in 589 (44%) of these. Across the Region as a whole, the following overall patterns were apparent: (1) significant increases have occurred in conductivity, visual clarity, total nitrogen and total phosphorus; and (2) significant decreases have occurred in dissolved oxygen, pH, turbidity, dissolved colour and ammonia. While some of these overall trends were improvements (increases in clarity and decreases in turbidity, decreases in ammonia), we consider that many of the other trends were deteriorations. The magnitudes of the trends in conductivity, visual clarity, dissolved colour, total nitrogen, ammonia, total phosphorus and dissolved reactive phosphorus were significantly correlated with the proportion of the catchment area that was in pasture (i.e. the trend slopes were correlated with land use).

For a small number of the trends at the non-Waikato River sites we can identify probable causes. However, the processes that are likely to have resulted in many of the other trends are less obvious. Some of these changes have also been observed in rivers throughout New Zealand (e.g. decreases in pH, increases in conductivity), although often at slower rates than those observed in the Waikato Region. It is therefore possible that the processes responsible are operating at a national rather than a regional scale. We consider that a concerted effort needs to be made to investigate this.

Contents

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 100 sites on other rivers and streams, with results being reported annually (e.g. Smith 2003a,b).

Vant & 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. We have extended their analysis to cover the period that ended in 2002 (i.e. a further five years). This report describes this updated analysis of water quality trends in rivers in the Waikato Region.

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 (Smith 2003a,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 & McBride 1990).[1] We did not, however, consider the results from three additional Waikato River sites that are also sampled as part of the National Network.

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, we chose to consider records that began at or after the start of 1987 (i.e. records up to 16 years in length to the end of 2002). The monitoring of the 100 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; and (5) the final 18 sites started in 1994. And records for some water quality variables began even later—for example *E. coli* analyses began in 1998.[2] For the 100 sites on other rivers and streams we chose to consider records that began at or after the start of 1990.

The field and laboratory methods used by Environment Waikato are described in the annual reports for the Waikato River and RERIMP programmes (Smith 2003a,b). Since the surveys began, however, there have been a number of changes that need to be accounted for. These are outlined below.[3]

<u>Ammonia</u>. 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). As a result we chose to ignore the earlier data (1987–89), and just considered the ammonia records from 1990 onwards.

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[1] 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.

[2] 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 69 of the 100 sites.

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

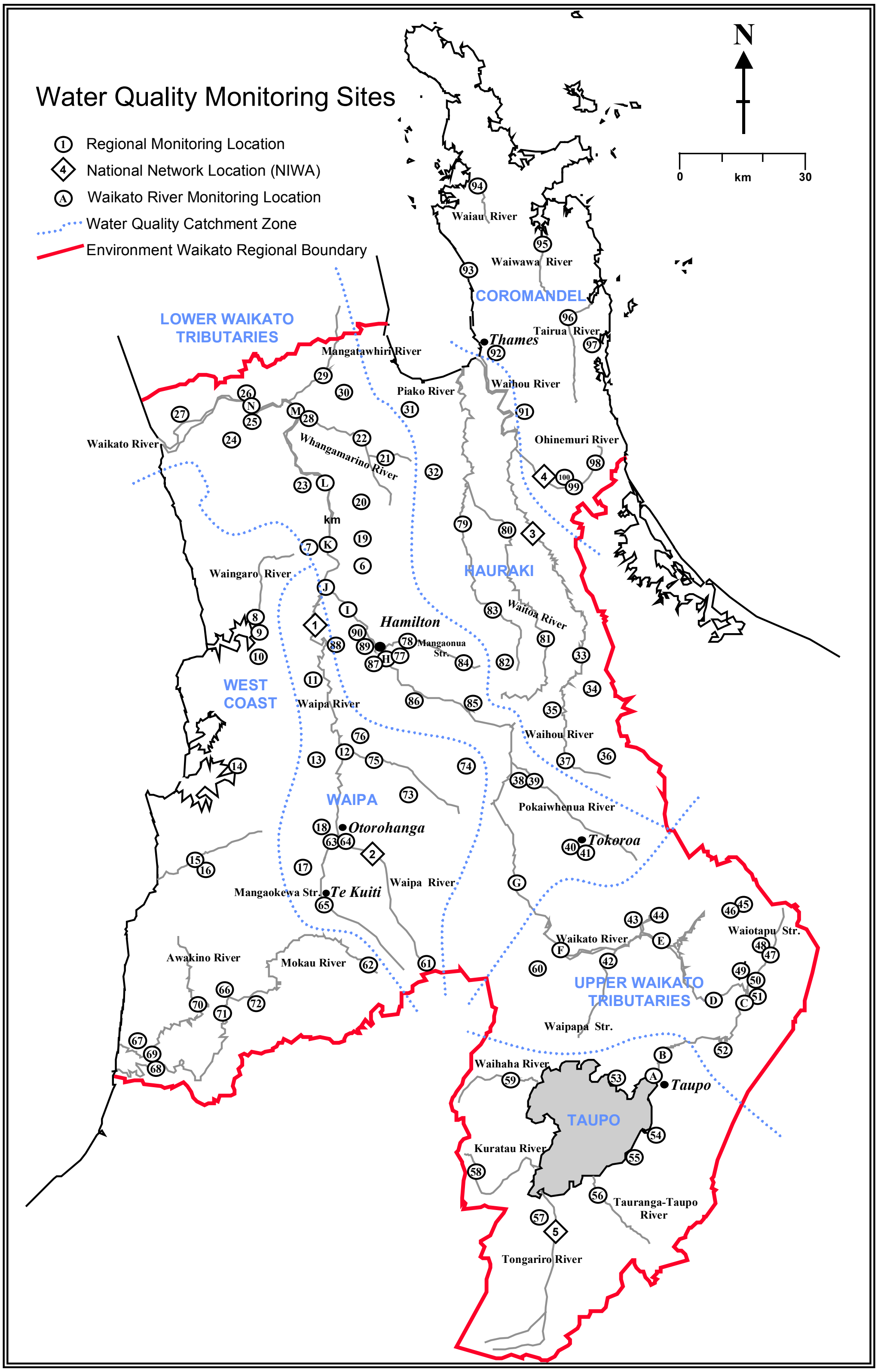

Figure 1: The Waikato Region, showing the Waikato River and the 10 routine water quality sampling sites, and the 100 sites on the other rivers and streams (see Tables 2 and 3 for site details). The dotted lines divide the region into seven water quality zones (see text).

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). As a result we chose to ignore the earlier data (1987–89), and just considered the BOD_5 records from 1990 onwards.

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. As a result we chose to replace values from earlier occasions that were lower than half the current detection limit 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 database. Since then no values lower than the detection limit (usually 1 cfu/100 mL) have been entered. As a result we chose to replace any "0" values by <1 cfu/100 mL (which is evaluated as 0.5 cfu/100 mL).

pH. Prior to 1993 pH was either measured in the field (until late 1991) or in the laboratory, using what is now regarded as a lower quality meter (until the end of 1992). Examination of these records suggests this earlier data is suspect. As a result we chose to ignore the earlier data (1987–92), and just considered the pH records from 1993 onwards.

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. As a result we chose to ignore the earlier data (1987–95), and just considered the results obtained using the new meter.

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

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

	Waikato River (10 sites) 1987–2002		**Other rivers (100 sites) 1990–2002**	
Temperature	186	(124, 191)	119	(105, 156)
Dissolved oxygen	183	(121, 189)	119	(105, 156)
pH*	120	(103, 120)	119	(105, 156)
Conductivity	185	(134, 191)	119	(105, 156)
Turbidity†	83	(83, 84)	90	(87, 156)
Visual clarity	96	(92, 96)	118	(102, 156)
Dissolved colour	185	(95, 191)	84	(81, 144)
Biochemical oxygen demand‡	154	(116, 156)	–	
Arsenic	123	(99, 150)	–	
Boron	134	(110, 169)	–	
Total nitrogen	154	(117, 181)	119	(105, 156)
Nitrate-N	171	(124, 190)	119	(105, 156)
Ammonia‡	154	(116, 156)	119	(105, 156)
Total phosphorus	185	(124, 191)	119	(105, 156)
Dissolved reactive P	185	(124, 191)	119	(105, 156)
Chlorophyll *a*	182	(123, 189)	–	
Faecal coliforms	182	(123, 187)	–	
Escherichia coli	59	(59, 59)	20	(18, 20)
Enterococci	175	(124, 179)	38	(34, 71)

* from 1993 (except for five NIWA sites)
† from 1995 (except for five NIWA sites)
‡ from 1990

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 & 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).

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 often 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 Environment Waikato 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 × 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 standardized 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 standardized 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 same 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 (standardized) trends in different variables.

Here we generally adopt the conventional procedure, and report slopes in water quality units/yr. Occasionally, however, we also refer to the percentage change per year (compared to the median level). 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, we therefore often reformat the number (e.g. giving 0.1 $\times$ 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%): we have chosen to express them here 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). We followed this practice in this analysis. The *p*-value depends on the number of samples in a water quality record—ranging here from about 20 (or less) to nearly 200 (Table 1). This means that weak trends are less likely to be identified in records with fewer observations (and vice versa).

Following Vant & Wilson (1998), we used a Microsoft Excel spreadsheet to calculate the values of the SKSE and the *p*-value.

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 (at each site). Following Smith et al. (1996), we used the LOWESS smoothing technique with a 30% span to compute these relationships (software: Data Desk, version 6.0.1; Data Description Inc.). In each case, the LOWESS 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 sum of this residual and the median value of the raw data gave the "flow-adjusted" value of the variable.

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. Here we distinguish between sites with "primary" flow records, where the flow recorder was located at or close to the water quality sampling site, and "secondary" sites, 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.

For the 100 water quality sites on the region's other rivers and streams, the situation was less straight-forward. At six of the sites, flows were considered to be reasonably steady, so no flow-adjustment was undertaken. Flows were recorded at or near 23 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 71 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 100 sites in Table 3 are reasonably-evenly distributed across the whole Waikato region. We chose to divide the region into seven different zones (Table 3, Figure 1). These were based largely on river catchments and some broad ecological features, including geology, altitude, winter temperatures, and vegetation cover and land use.

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.[4] However, in

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
C	Ohaaki Bridge	Ohaaki Bridge[†]	1543447	1131-159
E	Ohakuri tailrace	Ohakuri total	2774	1131-163
F	Whakamaru tailrace	Whakamaru total	2754	1131-162
G	Waipapa tailrace	Waipapa total	2734	1131-161
H	*Narrows Bridge*	Karapiro total	2714	1131-160
I	*Horotiu Bridge*	Hamilton Traffic	43466	1131-64
K	Huntly Bridge	Huntly power station	1543495	1131-74
M	Mercer Bridge	Mercer	1043446	1131-91
N	*Tuakau Bridge*	Mercer	1043446	1131-91

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

[4] We use the proportion of the catchment that is in pasture as obtained from the EW Landcover Database (Terralink 1996) as an index of land use (see EW DOCS #693851).

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 (8 sites)				
55	*Hinemaiaia @SH1*	Hinemaiaia @ Maungatera	2743464	171-4
58	*Kuratau @ SH41 Moerangi*	Kuratau @ SH41 Junction	1043468	282-3
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
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
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

Table 3 (continued)

Map	Water quality site	Flow record	TIDEDA	HYDROL
19	*Mangawara @ Rutherford Rd*	Mangawara @ Jefferis	1443499	481-2
86	*Mangawhero @ Cambridge-Ohaupo Rd*	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 Rd	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

other cases the observed trends were the result of other factors including geothermal inputs and changes to point source discharges. We therefore identified a subset of 82 of the 100 non-Waikato River sites where land use effects could be examined. The following sites were omitted from this subset:

1. Fourteen sites where the conductivity of the water is elevated (median > 20 mS/m). Examination of the results for all 100 sites showed that conductivity increases as the proportion of the catchment that is in pasture increases (cf. Biggs & 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,[5] and sites where the median conductivity during 1998–2002 was greater than this were excluded from this analysis.[6]

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.

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. We analysed 188 water quality records, just under half (92) of which showed trends which were significant ($p < 5\%$). The *p*-values for more than half (55) of the trends were lower than 0.05%, so these trends could be described as being "highly significant". All of the trends in arsenic, boron and dissolved colour were highly significant, as were most of the trends in BOD_5 and pH.

Of the 92 significant trends in the flow-adjusted records, a total of 10 were not seen in the raw records. That is, flow-adjusting reduced the overall variability of the latter datasets to the extent that the underlying trends became apparent.[7]

The trends observed in the individual variables are described below. A small selection of these is shown in Figure 2.

Temperature. At most sites there was no significant trend in water temperature. At Waipapa, however, a significant trend was observed, with the median rate of increase (i.e. the SKSE) being about 0.05°C/yr, or about 0.3% of the median value per year. This corresponded to an increase of about 0.7°C over the 16-year period at this site.[8] 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 deterioration.

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[5] For this subset of the data ($n = 86$) there is a strong correlation between land use (as % pasture) and median conductivity ($r = 0.66$, $p < 0.01\%$).

[6] From the data in Smith (2003b) 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, Waitawhiriwhiri @ Edgecumbe St (PS) and Whangape @ Rangiriri-Glen Murray Rd.

[7] As it happened, seven of the raw records showed significant trends that were not seen in the corresponding flow-adjusted records. These results are not described here, however.

[8] The trend was apparent only in the flow-adjusted data. At Waipapa—and indeed at all the Waikato River sites—no significant trend was apparent in unadjusted water temperatures.

Table 4: *p*-values (%) and trend slopes (in brackets) for records of flow-adjusted water quality variables at ten Waikato River sites during 1987–2002. Secondary sites (see section 2.6) are shown in italics. Trends shown in bold are significant ($p < 5\%$). 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 ($n = 59$: 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	11 (29)	**4 (104)**	**<1 (–31)**	**<1 (91)**	96 (3)	–	5 (0.0)	**<1 (–48)**	16 (0.0)	**<1 (–1.5)**
Ohaaki	7 (61)	74 (32)	16 (–7)	**<1 (–150)**	9 (–18)	**1 (231)**	16 (0.0)	**<1 (–44)**	**<1 (–1.3)**	**<1 (–11)**
Ohakuri	44 (13)	91 (12)	52 (1)	64 (15)	89 (–3)	12 (72)	23 (0.0)	**<1 (–55)**	**<1 (–0.7)**	**<1 (–6.2)**
Whakamaru	53 (–19)	84 (20)	83 (1)	68 (21)	31 (21)	**2 (56)**	90 (0.0)	**1 (–30)**	**<1 (–0.5)**	**<1 (–5.7)**
Waipapa	**1 (46)**	73 (40)	**1 (–11)**	7 (47)	10 (47)	11 (85)	**<1 (–0.5)**	**<1 (–42)**	**<1 (–0.5)**	**<1 (–4.9)**
Narrows	81 (5)	42 (–75)	**<1 (–23)**	60 (–12)	96 (–4)	7 (40)	**<1 (–0.5)**	**<1 (–75)**	**<1 (–0.5)**	**<1 (–4.7)**
Horotiu	99 (0)	67 (27)	**<1 (–28)**	38 (–19)	41 (–36)	**1 (50)**	**<1 (–0.5)**	**<1 (–96)**	**<1 (–0.6)**	**<1 (–4.4)**
Huntly	52 (–33)	81 (25)	**<1 (–17)**	32 (22)	**1 (220)**	66 (5)	**<1 (–0.7)**	**<1 (–84)**	**<1 (–0.7)**	**<1 (–4.2)**
Mercer	81 (7)	82 (15)	**<1 (–29)**	**<1 (74)**	**1 (450)**	–	**<1 (–1.0)**	**<1 (–78)**	**<1 (–0.6)**	**<1 (–3.9)**
Tuakau	34 (41)	**<1 (410)**	**<1 (–35)**	**4 (47)**	**1 (451)**	99 (0)	94 (0.1)	**2 (–49)**	**<1 (–0.2)**	**<1 (–2.3)**
Increases	1	2	0	3	3	3	0	0	0	0
Decreases	0	0	7	1	0	0	5	10	9	10

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	**2 (–1.9)**	**<1 (–0.5)**	**<1 (–0.7)**	7 (–0.1)	**<1 (0.1)**	79 (0.0)	45 (0.0)	94 (0.0)	**2 (0.1)**
Ohaaki	32 (–1.3)	**<1 (–1.0)**	**<1 (–1.4)**	**<1 (–0.5)**	13 (–0.1)	14 (0.0)	**<1 (–2.8)**	35 (–1.6)	**<1 (–0.7)**
Ohakuri	**3 (–3.5)**	85 (–0.1)	**<1 (–0.6)**	61 (–0.1)	47 (0.0)	**2 (0.1)**	**<1 (–0.2)**	**1 (–0.6)**	69 (0.0)
Whakamaru	9 (–2.9)	**<1 (–2.1)**	**<1 (–0.6)**	37 (–0.1)	36 (0.1)	11 (0.2)	**1 (–0.3)**	**1 (–0.9)**	72 (0.0)
Waipapa	**3 (–3.4)**	8 (0.9)	28 (–0.1)	83 (0.0)	38 (–0.1)	11 (0.1)	**<1 (–1.8)**	43 (–0.7)	**<1 (–0.4)**
Narrows	37 (–1.4)	5 (2.3)	**<1 (–1.8)**	75 (0.0)	14 (–0.1)	10 (–0.2)	**1 (28.1)**	10 (33.2)	43 (0.5)
Horotiu	45 (–1.3)	36 (1.4)	**<1 (–1.3)**	99 (0.0)	19 (–0.2)	42 (–0.1)	**<1 (49.2)**	43 (17.7)	21 (–1.9)
Huntly	16 (–4.7)	90 (–0.7)	**<1 (–0.9)**	63 (–0.2)	**<1 (–0.6)**	78 (0.0)	**<1 (51.1)**	35 (25.7)	61 (–0.9)
Mercer	33 (–4.3)	24 (–2.5)	**<1 (–0.5)**	**<1 (0.6)**	**<1 (–0.5)**	30 (0.2)	**<1 (19.3)**	72 (1.7)	42 (0.3)
Tuakau	**1 (–12.3)**	**2 (–5.8)**	**2 (–0.3)**	**1 (0.8)**	**<1 (–0.3)**	33 (0.3)	18 (6.0)	28 (8.4)	45 (–0.3)
Increases	0	0	0	2	1	1	4	0	1
Decreases	4	4	9	1	3	0	4	2	2

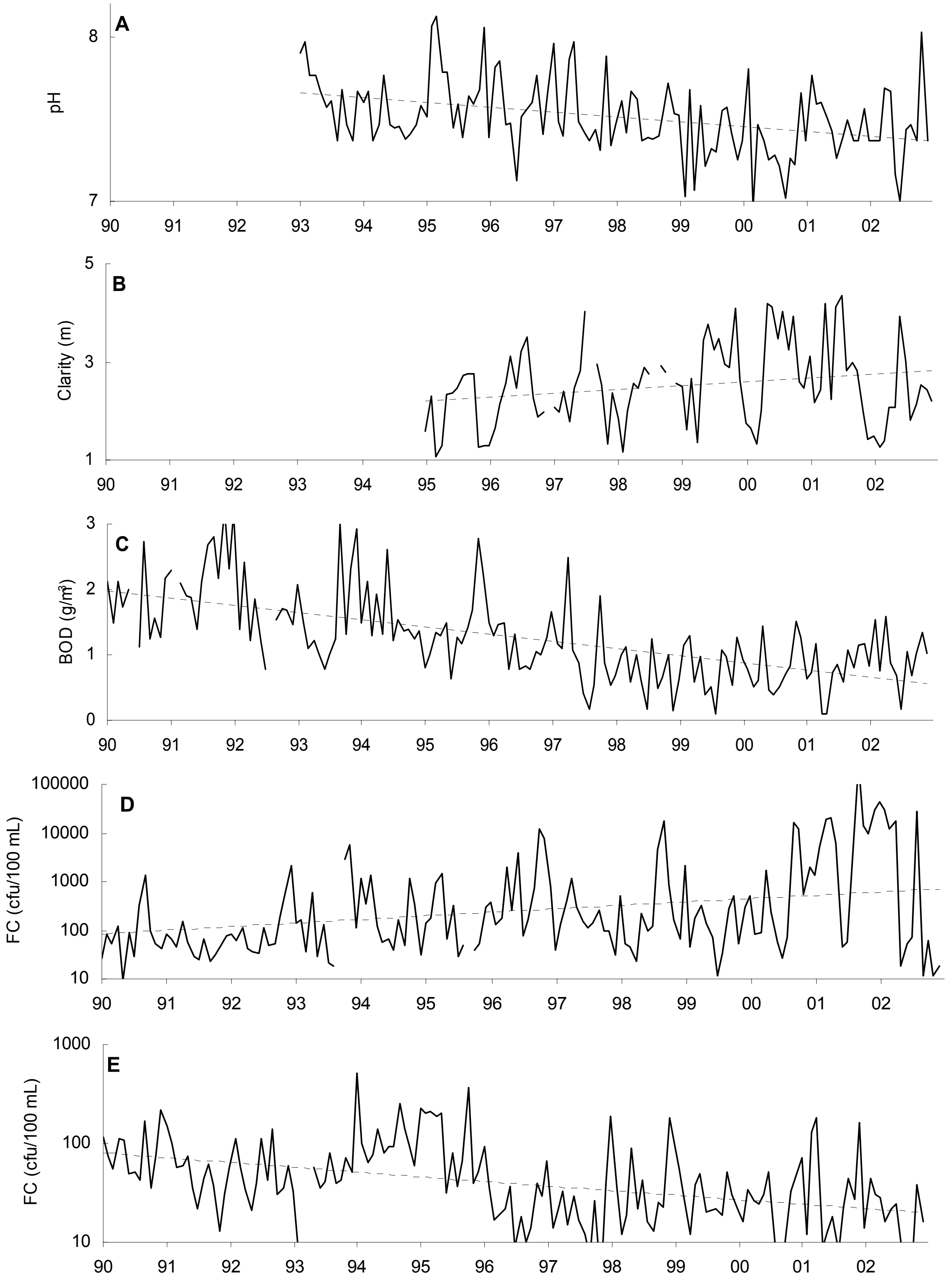

Figure 2: Water quality at Waikato River sites during 1990–2002: **A**, pH at Horotiu; **B**, Visual clarity at Whakamaru; **C**, BOD_5 at Horotiu; **D**, Faecal coliforms at Narrows; and **E**, Faecal coliforms at Ohaaki. The dashed lines show the overall trends in the records. Plots A to C are of flow-adjusted data; D and E are of raw data.

Dissolved oxygen. At most sites there was no significant trend in dissolved oxygen levels. At the first (Taupo Gates) and last (Tuakau) sites, however, significant increases were observed. The median rate of increase was 0.1% of saturation/yr at Taupo Gates, and 0.4% of saturation/yr at Tuakau. These slight increases can be regarded as improvements.

pH. Significant trends in pH were observed at seven of the sites (e.g. Fig. 2A). In all cases pH decreased, with the SKSE being in the range –0.01 to –0.04/yr. Over the 10-year period examined, values of pH therefore declined by 0.1–0.4. While these changes may seem slight, it is important to note that as pH varies with the base-10 logarithm of the hydrogen ion concentration, a reduction in pH of 0.3 for example is equivalent to a doubling of the hydrogen ion concentration. As the pH of Waikato River water is approximately neutral,[9] a decrease in pH represents a slight acidification of the water, so the trends can be regarded as deteriorations.[10]

Conductivity. At six of the sites there was no significant trend in conductivity. At one site—Ohaaki—conductivity declined significantly. This is the first monitoring site that is downstream of the discharge to the river of high-conductivity geothermal fluid from the Wairakei power station.[11] Since 1988 the volume of geothermal fluid discharged to the river has decreased as some of the extracted fluid is reinjected into the geothermal field. The observed decline in conductivity at the Ohaaki site is probably a result of this. The reduction in the volume of geothermal fluid discharged to the river is regarded as an improvement.

At three other sites, however, conductivity increased significantly. One of these—Taupo Gates—is upstream of the Wairakei discharge, while the other two—Mercer and Tuakau—are well downstream. The changes observed at these three sites are thus unrelated (or probably unrelated) to the changes at Wairakei. The changes observed at Mercer and Tuakau may be related to land use (see later).

Turbidity. Significant trends in turbidity were observed at three sites, all in the lower part of the river. At each of these sites turbidity increased, with the SKSE ranging from 0.22 NTU/yr to 0.45 NTU/yr, or between 4.4% and 6.3% of the median value/yr. An increase in turbidity can be regarded as a deterioration. There is no obvious reason why turbidity could have been expected to increase in recent years. Furthermore, because of instrument changes, the records of turbidity used here are rather shorter (7-years) than those of the other water quality variables. It will be important to watch these records closely in the future to determine whether these early indications of deterioration persist.

Visual clarity. The black disc records began in 1995 (i.e. an 8-year record to the end of 2002). For the period 1995–2002, significant trends in visual clarity were observed at three of the eight sites where this variable is monitored (e.g. Fig. 2B). Water clarity increased at each site, with the SKSE ranging from 0.05 m/yr to 0.23 m/yr, or between 2.3% and 4.7% of the median value/yr. An increase in water clarity can be regarded as an improvement.

However, when the results from the first year (1995) were omitted from the analysis, the trends disappeared. That is, no significant trends were apparent in the records for the period 1996–2002 at any of the sites. As noted by Vant & Wilson (1998), it is possible that the 1995 results were in fact under-estimates of the true clarity in that year due to initial difficulties in establishing satisfactory field measurement protocols. The water clarity records during 1996–2002 can be compared with the results for the turbidity records for the same 7-year period (see above). Interestingly, although deteriorating trends in turbidity were seen at

[9] The median pH at all ten sites during 1998–2002 was in the range 7.3–7.6.
[10] An increase in pH would also be a deterioration.
[11] The discharge has a conductivity of about 400 mS/m (Contact Energy 2001), compared to a conductivity in the river upstream of the discharge point of 12 mS/m (result for Waikato River @ Taupo Gates, median for 1998–2002).

Huntly and Tuakau, there was no corresponding deterioration in water clarity at these sites.[12] In the meantime we therefore regard the trends in visual clarity from 1995 as being inconclusive.

Dissolved colour. Significant trends in dissolved colour were observed at five of the sites. At each of these sites concentrations of dissolved colour decreased, at rates between –3.3 and –4.5% of the median value/yr. The five sites are all downstream of the point where treated wastewater from the pulp and paper mill at Kinleith is discharged to the river.[13] Since 1991 the concentration of coloured material in the wastewater has been roughly half that measured previously (Nagels & Davies-Colley 1997). So the decreases in dissolved colour in the river probably result from the improvements to wastewater treatment at the Kinleith mill. At Waipapa for example, the average concentration of dissolved colour in the last three years of the record (2000–2002) was about 45% lower than the average value in the first three years (1987–1989); at Mercer it was 35% lower. Reductions of this magnitude represent a marked improvement in the appearance of the river (i.e. in its visual water quality).

Biochemical oxygen demand. Significant trends in BOD_5 were observed at all ten of the sites (e.g. Fig. 2C). In all cases BOD_5 decreased, with the SKSE being in the range –0.03 to –0.1 g/m^3/yr, or between about –4% (Whakamaru) and –10% (Taupo Gates and Ohakuri) of the median value per year. These decreases represent marked improvements over the period 1990–2002. While we're unable to link these reductions to particular activities in the catchment, they presumably reflect the combined result of improvements in wastewater treatment at various locations, thereby reducing the overall load of oxygen-depleting carbonaceous wastes to the river.

Arsenic. Significant trends in arsenic concentration were observed at nine of the sites. At each of these sites concentrations decreased, with the SKSE being in the range –0.2 to –1.3 × 10^{-3} g/m^3/yr, or between about –1.5% (Tuakau) and –4.9% (Ohaaki) of the median value per year. The sites are all downstream of the Wairakei power station's discharges to the river (see above). Reinjection of 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.

Boron. Significant trends in boron concentration were observed at all ten of the sites. In all cases concentrations decreased, with the SKSE being in the range –1.5 to –11 × 10^{-3} g/m^3/yr, or between about –0.9% (Taupo Gates) and –3.9% (Ohaaki) of the median value per year. The largest decrease (–11 × 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. However, it is not clear why boron concentrations also decreased at the site at Taupo Gates, although the rate of decrease at this site was not as large as those at the other sites, particularly that at Ohaaki. The reductions represent improvements in water quality.

Total nitrogen. Significant trends in total N concentration were observed at four of the sites. At each of these sites concentrations decreased, with the SKSE being in the range –1.9 to –12 × 10^{-3} g/m^3/yr, or between about –1.3% (Waipapa) and –2.9% (Taupo Gates) of the median value per year. The fact that three of the four reductions occurred at sites in the upper part of the river where there are few municipal and industrial discharges suggests they

[12] A deteriorating trend in turbidity during 1996–2002 was also seen at a third site (Mercer), but black disc water clarity was not measured at this site.

[13] 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.

may be somehow associated with land use changes rather than with wastewater discharges. The reductions represent improvements in water quality.

Nitrate-N. Significant trends in nitrate concentration were also observed at four of the sites, including three sites in the upper part of the river. At each of these sites concentrations decreased, with the SKSE being in the range –0.5 to –5.8 × 10^{-3} g N/m^3/yr, or between about –2.2% (Tuakau) and –22% (Taupo Gates) of the median value per year. The reductions represent improvements in water quality.

Ammonia. Significant trends in ammonia concentration were observed at nine of the sites. At each of these sites concentrations decreased, with the SKSE being in the range –0.3 to –1.8 × 10^{-3} g N/m^3/yr, or between –3.6% (Huntly) and –14% (Whakamaru) of the median value per year. The reductions represent improvements in water quality.

Total phosphorus. Significant trends in total P concentration were observed at three of the sites. In two cases these were increases (SKSE = 0.6 to 0.8 × 10^{-3} g/m^3/yr, or 0.9% to 1.2% of the median value/yr), while the other trend was a decrease (SKSE = –0.5 × 10^{-3} g/m^3/yr, or –4% of the median value/yr). The increases represent deteriorations in water quality, while the decrease represents an improvement.

Dissolved reactive phosphorus. Significant trends in DRP concentration were observed at four of the sites. In one case this was an increase (SKSE = 0.1 × 10^{-3} g/m^3/yr, or 12% of the median value/yr), while the other trends were decreases (SKSE = –0.3 to –0.6 × 10^{-3} g/m^3/yr, or –2.1% to –2.4% of the median value/yr). The increase represents a deterioration in water quality, while the decreases represents improvements.

Chlorophyll *a*. At most sites there was no significant trend in algal biomass as indicated by chlorophyll *a* concentration. At Ohakuri, however, a significant increase was observed, with the SKSE being 0.1 × 10^{-3} g/m^3/yr, or 2.7% of the median value/yr. This increase represents a deterioration in water quality.

Faecal coliforms. Significant trends in faecal coliform concentration were observed at eight sites. Concentrations increased at four sites on the lower part of the river (e.g. Fig. 2D), and decreased at four sites in the upper part of the river (e.g. Fig. 2E). In 2002 an unexpected discharge of faecal coliform bacteria was discovered in the vicinity of Cambridge, and there is some evidence that this had been a major source of the concentrations found at sites between Narrows and Tuakau for several years (Smith 2003a). The discharge of faecal coliforms has now ceased, and concentrations since May 2002 have mostly been much lower (Fig. 2D), so the increases at the four lower river sites can be expected to reverse in due course.

The decrease observed at Ohaaki is likely to be due to the fact that the discharge to the river of treated sewage wastewater from Taupo ceased during 1995 (Fig. 2E). However, the reasons for the decreases observed at three other upper river sites are less clear. They may be associated with improved management of certain activities on farms (e.g. disposal of farm dairy effluent). The decreases represent improvements in water quality.

Escherichia coli.[14] Significant trends in *E. coli* concentrations were observed at just two sites. Both were decreases, and occurred at two of the upper river sites where faecal coliform concentrations had also decreased.[15] The records of *E. coli* are relatively short (5-

[14] Note that these records are shorter than those for many other variables, so that the sample size is considerably smaller (n = 59: Table 1). As a result care should be taken in comparing the trend analyses for *E. coli* with those reported for other variables.

[15] Note that *E. coli* are a type of faecal coliform, and that in many natural waters they are the dominant type, so concentrations of faecal coliforms and *E. coli* can be expected to covary.

years), having started in 1998. For much or all of the time these records have existed, it's therefore likely the source near Cambridge had been contributing to the concentrations measured in samples from sites downstream of there. As a result, there is no earlier period of lower concentrations in these records, so that increases similar to those for faecal coliform concentrations are not apparent. However, there has been a substantial decrease in concentrations at these sites since May 2002, so we can expect to see decreasing trends emerging in the future.

Enterococci. Significant trends in enterococci concentrations were observed at three of the sites. In one case this was an increase (Taupo Gates), while decreases were observed at two sites (Ohaaki and Waipapa). All three sites were in the upper part of the river. The increase represents a deterioration in water quality, while the decreases represents improvements.

Enterococci concentrations at sites in the lower river did not appear to be affected by the discharge of faecal coliforms/*E. coli* discovered near Cambridge. As a result, for the lower river sites the 1988-onwards records of enterococci bacteria probably provide the most reliable long-term record of faecal indicator bacteria at this stage. And during 1988–2002 there were no significant trends in enterococci concentrations at the five sites between Narrows and Tuakau.

3.2 Other rivers and streams

Table 5 lists the *p*-values and trend slopes for the water quality records at the 100 sites on the other rivers and streams. We analysed (1) records of 11 different water quality variables at all 100 sites, (2) records of visual clarity at 96 sites, and (3) records of enterococci and *E. coli* at 69 sites, giving a total of 1334 records. Of these, 589 records (44%) showed significant trends ($p < 5\%$). Some 259—or just under half—of the trends were highly significant ($p < 0.05\%$).

Of the 589 significant trends in the flow-adjusted records, a total of 130 (22%) were not seen in the raw records. That is, flow-adjusting reduced the overall variability of the latter datasets to the extent that the underlying trends became apparent.[16] Selected trends are shown in Figures 3–5.

Table 6 provides a summary of the slopes of the trends in the individual water quality variables. It shows the median values of SKSE for both (1) the significant trends only (cf. Smith et al. 1996), and (2) for all records (cf. Scarsbrook et al. 2003). In each case we used the binomial test 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.

Correlations between SKSE and land use were examined in the subset of the results for 82 sites. Table 7 shows the correlation coefficients. Figure 6 shows plots of SKSE and land use for selected variables. The trends observed in the individual variables are described below.

Temperature. At most sites there was no significant trend in water temperature. Trends were apparent at just 12 sites, with seven increases and five decreases. Values of the SKSE for the significant trends ranged from –0.2°C/yr (Mangapiko Stream) to 0.2°C/yr

[16] As it happened, 120 of the raw records showed significant trends that were not seen in the corresponding flow-adjusted records. These results are not described here, however.

Table 5: *p*-values (%) and trend slopes (in brackets) for records of water quality variables at 100 Waikato Region sites during 1990–2002. Apart from the exceptions listed in Table 3, all of the records were flow-adjusted. Sites for which a flow index was generated (see section 2.6) are shown in italics. Trends shown in bold are significant ($p < 5\%$). For each variable the total number of records that have shown significant increases or significant decreases is shown (last page of table). 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 = 18–20 and 34–71, 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)	98 (11)	98 (6)	88 (–2)	**2 (50)**	54 (34)	69 (–26)	83 (–0.1)	88 (0.7)	**1 (–4.0)**	7 (–0.7)	**3 (0.6)**	**1 (0.3)**	39 (–25)	48 (6)
Kauaeranga (92)	31 (57)	**1 (196)**	**<1 (–31)**	**<1 (65)**	82 (–6)	80 (9)	96 (0.0)	**4 (3.9)**	46 (0.4)	77 (0.0)	**<1 (0.3)**	18 (0.0)	**4 (–17)**	55 (–3)
Ohinemuri (4)	63 (35)	76 (17)	99 (0)	**<1 (301)**	**<1 (–45)**	58 (8)	**<1 (–0.4)**	**4 (–5.7)**	**4 (–6.2)**	57 (–0.3)	**1 (–0.4)**	**1 (–0.2)**	–	–
Ohinemuri (99)	83 (26)	47 (188)	**1 (–29)**	14 (208)	**2 (–99)**	**1 (75)**	26 (–0.4)	97 (–0.5)	22 (–8.8)	**1 (–3.5)**	10 (–1.5)	**<1 (–1.4)**	70 (–35)	34 (–2)
Ohinemuri (98)	64 (35)	78 (46)	**<1 (–52)**	**2 (37)**	**<1 (–99)**	**3 (148)**	14 (–0.4)	**3 (–15.0)**	**5 (–12.5)**	7 (–0.8)	27 (–0.3)	51 (–0.1)	36 (–19)	40 (–6)
Tairua (96)	35 (51)	**3 (–188)**	**<1 (–36)**	**<1 (48)**	6 (–66)	**4 (58)**	76 (–0.2)	**<1 (4.9)**	84 (–0.1)	73 (0.0)	39 (0.2)	35 (0.0)	39 (–13)	79 (2)
Tapu (93)	16 (137)	22 (92)	**<1 (–30)**	**<1 (52)**	40 (26)	9 (61)	46 (–0.1)	**1 (4.4)**	22 (–0.2)	12 (0.0)	**2 (0.2)**	**<1 (0.1)**	**4 (–27)**	30 (6)
Waiau (94)	11 (88)	**2 (168)**	**<1 (–30)**	**<1 (73)**	82 (–16)	**<1 (102)**	**<1 (–0.7)**	**<1 (5.9)**	**<1 (3.2)**	30 (0.0)	91 (0.0)	14 (0.1)	7 (–26)	96 (–1)
Waitekauri (100)	6 (128)	**<1 (432)**	**<1 (–22)**	**<1 (–698)**	**2 (–54)**	**1 (96)**	17 (0.3)	**<1 (–47)**	**<1 (–39)**	**<1 (–4.8)**	56 (0.1)	**4 (0.1)**	24 (–16)	96 (0)
Waiwawa (95)	**3 (116)**	48 (–53)	**<1 (–43)**	**<1 (52)**	**2 (–47)**	**1 (83)**	75 (–0.6)	**5 (4.1)**	66 (–0.1)	40 (0.0)	66 (0.1)	91 (0.0)	70 (–6)	61 (4)
Wharekawa (97)	35 (58)	**<1 (–318)**	**<1 (–37)**	**<1 (51)**	**5 (–90)**	**1 (63)**	35 (–0.4)	**<1 (9.0)**	**<1 (1.7)**	14 (–0.1)	**1 (0.5)**	14 (0.1)	**1 (–75)**	78 (2)
Hauraki														
Mangawhero (32)	25 (–90)	44 (–82)	6 (–14)	**5 (59)**	81 (–97)	**<1 (53)**	**1 (–1.0)**	31 (2.7)	**2 (3.8)**	**<1 (–0.2)**	34 (0.4)	**3 (0.5)**	39 (–10)	87 (3)
Oraka (35)	40 (34)	19 (–149)	**3 (–14)**	**<1 (254)**	**<1 (373)**	**<1 (56)**	**2 (0.6)**	**2 (26.8)**	**<1 (21.8)**	60 (–0.4)	96 (0.1)	14 (–1.6)	39 (–175)	96 (0)
Piako (83)	74 (27)	94 (–90)	70 (2)	**<1 (94)**	**<1 (–368)**	**<1 (93)**	**1 (–1.5)**	**<1 (–38)**	**<1 (–26)**	**<1 (–3.7)**	28 (–1.0)	**<1 (–1.9)**	90 (15)	75 (3)
Piako (79)	22 (–67)	27 (–336)	94 (1)	**<1 (130)**	8 (–365)	12 (15)	**<1 (–3.3)**	**<1 (–102)**	**<1 (–87)**	**<1 (–5.3)**	9 (–3.7)	**<1 (–6.3)**	90 (37)	13 (17)
Piakonui (82)	42 (59)	9 (–207)	**<1 (–26)**	**1 (33)**	**3 (–344)**	**<1 (59)**	32 (0.4)	42 (–3.2)	**4 (–5.7)**	27 (0.1)	5 (1.1)	**<1 (0.5)**	90 (–1)	42 (–3)
Waihou (33)	82 (–13)	5 (–103)	**2 (–18)**	**<1 (168)**	78 (98)	**<1 (43)**	**4 (0.7)**	6 (9.3)	6 (9.6)	52 (–0.1)	86 (–0.2)	25 (–0.5)	**1 (53)**	9 (–6)
Waihou (3)	87 (–6)	**2 (–145)**	**<1 (–10)**	**<1 (49)**	**1 (–142)**	5 (11)	68 (0.0)	35 (3.0)	12 (3.0)	**<1 (1.3)**	**3 (–0.9)**	87 (0.0)	–	–
Waihou (37)	8 (–18)	71 (–31)	**<1 (–14)**	**<1 (90)**	56 (12)	**<1 (126)**	90 (0.0)	7 (3.0)	**<1 (3.6)**	27 (0.0)	79 (0.1)	60 (0.1)	11 (7)	70 (0)
Waiohotu (36)	23 (5)	5 (155)	**<1 (–32)**	**<1 (30)**	23 (131)	–	36 (0.4)	**<1 (9.0)**	**<1 (3.7)**	16 (0.0)	**1 (0.6)**	12 (0.3)	90 (9)	55 (–1)
Waiomou (34)	98 (–1)	25 (–58)	**<1 (–33)**	**<1 (98)**	78 (–19)	**<1 (68)**	5 (0.5)	**<1 (15.1)**	**<1 (8.4)**	19 (0.1)	11 (0.4)	94 (0.0)	90 (1)	**<1 (–12)**
Waitakaruru (31)	65 (–19)	**<1 (–1031)**	**<1 (–20)**	**<1 (185)**	**<1 (–712)**	**<1 (49)**	**3 (–2.9)**	48 (–4.5)	5 (–5.9)	**4 (–1.4)**	21 (1.3)	**<1 (–1.1)**	71 (–12)	43 (2)
Waitoa (81)	69 (–39)	**<1 (–704)**	10 (–6)	15 (60)	99 (4)	78 (–10)	**<1 (–1.7)**	31 (–13)	**<1 (–30)**	64 (–0.4)	25 (1.0)	73 (0.2)	54 (64)	21 (27)
Waitoa (80)	**3 (–94)**	**3 (502)**	**<1 (22)**	**<1 (417)**	11 (196)	79 (5)	**<1 (–1.1)**	11 (–19)	99 (–0.8)	**4 (–3.7)**	15 (–24)	14 (–19)	90 (56)	6 (16)

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)	94 (6)	**1 (–187)**	**<1 (–22)**	**<1 (109)**	11 (–29)	**<1 (97)**	**4 (0.3)**	98 (0.0)	**<1 (–2.8)**	22 (0.0)	55 (0.1)	**2 (0.4)**	71 (3)	57 (0)
Kuratau (58)	35 (48)	12 (–118)	**<1 (–31)**	**3 (21)**	91 (–1)	**4 (64)**	90 (0.1)	5 (–2.8)	**<1 (–5.2)**	99 (0.0)	46 (0.1)	**<1 (0.4)**	–	–
Mapara (53)	**<1 (94)**	**<1 (314)**	**1 (11)**	**<1 (172)**	**2 (–123)**	**2 (16)**	**<1 (–2.7)**	**<1 (29.0)**	**<1 (22.7)**	7 (–0.6)	88 (–0.1)	88 (–0.2)	90 (1)	**4 (4)**
Tauranga–Tau (56)	**4 (97)**	**<1 (–343)**	**<1 (–41)**	**<1 (79)**	10 (–26)	**3 (62)**	**<1 (0.5)**	9 (–1.5)	**<1 (–2.1)**	79 (0.0)	19 (0.3)	**2 (0.2)**	–	–
Tokaanu (57)	11 (0)	**<1 (–412)**	64 (0)	**<1 (100)**	**1 (–13)**	–	60 (0.0)	44 (1.0)	44 (0.8)	**2 (<0.1)**	6 (0.3)	**<1 (0.5)**	–	–
Tongariro (5)	35 (–22)	43 (–32)	41 (–1)	29 (–32)	37 (–11)	93 (2)	59 (0.0)	20 (0.9)	10 (0.5)	**<1 (–0.3)**	39 (0.0)	**1 (0.1)**	–	–
Waihaha (59)	16 (55)	49 (–45)	**<1 (–28)**	**<1 (44)**	29 (–17)	**<1 (211)**	63 (0.1)	7 (2.3)	59 (0.2)	49 (0.0)	52 (0.1)	22 (0.2)	90 (0)	38 (0)
Waitahanui (54)	70 (10)	**2 (–126)**	**1 (–14)**	**<1 (110)**	**<1 (–78)**	**<1 (110)**	**<1 (0.3)**	**<1 (4.0)**	**<1 (3.7)**	21 (0.0)	14 (0.2)	**<1 (0.6)**	11 (–13)	88 (0)
Upland tributaries of the Waikato River														
Kawaunui (48)	62 (33)	**<1 (–638)**	**2 (16)**	**<1 (392)**	13 (168)	79 (6)	**<1 (1.0)**	**<1 (99.5)**	**<1 (86.1)**	**4 (1.6)**	**<1 (8.2)**	**<1 (3.1)**	**1 (357)**	27 (13)
Mangaharakek (43)	39 (43)	**3 (–122)**	**<1 (–12)**	**<1 (50)**	7 (–217)	**<1 (64)**	63 (0.1)	**<1 (12.2)**	**<1 (7.0)**	**<1 (–0.7)**	**1 (1.1)**	**<1 (1.1)**	**<1 (40)**	96 (0)
Mangakara (49)	38 (–33)	27 (–82)	78 (0)	**<1 (100)**	6 (–289)	**<1 (47)**	90 (0.0)	**1 (14.8)**	**<1 (13.3)**	96 (0.0)	44 (–0.6)	25 (–0.5)	18 (18)	60 (2)
Mangakino (60)	31 (59)	**<1 (–238)**	**<1 (–24)**	**<1 (121)**	56 (–30)	**<1 (84)**	18 (0.5)	**<1 (18.1)**	**<1 (11.1)**	94 (0.0)	**<1 (0.6)**	**<1 (0.6)**	–	–
Otamakokore (46)	**<1 (208)**	34 (202)	87 (0)	**<1 (658)**	23 (–58)	**4 (38)**	**<1 (2.4)**	22 (5.0)	34 (5.2)	18 (–0.2)	18 (1.2)	**<1 (1.8)**	90 (–15)	32 (5)
Pueto (52)	**4 (66)**	12 (117)	**<1 (23)**	**<1 (168)**	15 (–55)	**<1 (64)**	21 (–0.1)	62 (1.3)	**1 (–3.0)**	**<1 (–1.6)**	**<1 (1.7)**	**<1 (1.1)**	**3 (–5)**	**<1 (–2)**
Tahunaatara (44)	98 (2)	11 (–89)	**<1 (–36)**	**<1 (91)**	78 (21)	**<1 (48)**	13 (0.7)	**<1 (14.2)**	**<1 (12.2)**	19 (–0.1)	42 (0.6)	6 (0.5)	54 (12)	16 (–5)
Torepatutahi (51)	60 (0)	**<1 (663)**	**<1 (25)**	70 (0)	**<1 (–130)**	–	**<1 (–0.7)**	99 (0.0)	18 (–1.9)	**<1 (–1.0)**	47 (–0.2)	**5 (–0.9)**	–	–
Waiotapu (47)	70 (28)	**<1 (400)**	**4 (–10)**	**<1 (699)**	97 (2)	**<1 (44)**	83 (0.0)	**<1 (54.9)**	**<1 (26.1)**	**<1 (12.1)**	94 (0.1)	**<1 (2.1)**	71 (0)	43 (1)
Waiotapu (50)	62 (37)	82 (–41)	59 (3)	**<1 (631)**	**<1 (890)**	**<1 (17)**	**1 (–0.9)**	**<1 (29.5)**	**<1 (14.3)**	49 (2.1)	55 (0.8)	39 (–0.3)	–	–
Waipapa (42)	25 (44)	**<1 (308)**	**1 (–12)**	**<1 (223)**	**<1 (425)**	**<1 (37)**	14 (–0.2)	**<1 (30.7)**	**<1 (29.2)**	**3 (–0.1)**	**<1 (–1.1)**	**<1 (1.0)**	54 (1)	72 (0)
Whirinaki (45)	**5 (–35)**	**1 (–250)**	**<1 (–27)**	**<1 (58)**	30 (–16)	–	69 (0.0)	**<1 (12.5)**	**<1 (11.3)**	**1 (–0.2)**	**1 (0.6)**	**<1 (1.0)**	–	–

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)
Lowland tributaries of the Waikato River														
Awaroa-Otau (27)	25 (81)	21 (–429)	42 (–6)	52 (63)	**5 (285)**	**<1 (–32)**	**1 (–2.0)**	10 (21.1)	78 (2.6)	66 (–0.4)	**4 (1.6)**	78 (–0.1)	–	–
Awaroa-Rotowa (7)	12 (79)	15 (162)	**1 (21)**	**<1 (1347)**	7 (–268)	**<1 (89)**	**2 (–1.3)**	81 (2.1)	38 (–4.4)	**<1 (–2.3)**	7 (–0.4)	**4 (–0.1)**	27 (–22)	43 (9)
Karapiro (85)	40 (–50)	**1 (–501)**	**<1 (–25)**	16 (57)	**2 (373)**	**2 (21)**	15 (–1.2)	**<1 (21.6)**	25 (6.5)	88 (0.1)	50 (–0.4)	**<1 (–3.2)**	71 (21)	19 (18)
Kirikiriroa (90)	98 (–11)	97 (–6)	52 (–3)	**<1 (–412)**	33 (–628)	13 (9)	**<1 (–10)**	**<1 (–156)**	65 (6.1)	**<1 (–180)**	48 (0.8)	52 (–0.3)	90 (–41)	21 (61)
Komakorau (6)	**<1 (139)**	34 (–100)	60 (0)	**<1 (300)**	76 (–250)	**1 (5)**	**<1 (–14)**	88 (3.7)	41 (8.2)	**2 (–28.3)**	22 (–1.5)	**3 (–1.0)**	81 (–83)	53 (4)
Little Waipa (38)	94 (–1)	14 (–299)	**2 (–9)**	**<1 (121)**	**<1 (154)**	74 (–8)	**3 (1.1)**	**<1 (26.1)**	**<1 (20.1)**	8 (0.2)	**<1 (2.4)**	**<1 (1.1)**	27 (6)	16 (–7)
Mangakotukut (87)	56 (–40)	6 (–205)	**2 (–9)**	52 (60)	97 (15)	93 (–1)	57 (–1.1)	**<1 (60.0)**	9 (15.2)	93 (0.4)	**<1 (20.7)**	15 (2.9)	18 (272)	26 (48)
Mangamingi (40)	**2 (–114)**	**2 (561)**	61 (4)	32 (48)	37 (36)	**3 (29)**	32 (0.4)	74 (–7.7)	**<1 (78.8)**	**<1 (–69)**	24 (–6.7)	38 (–6.1)	90 (–69)	36 (–26)
Mangaone (77)	52 (45)	**<1 (1166)**	**2 (18)**	31 (80)	56 (77)	31 (8)	83 (0.2)	**<1 (–131)**	**<1 (–139)**	19 (–0.6)	**2 (2.1)**	29 (–0.8)	71 (17)	30 (40)
Mangaonua (78)	48 (55)	**<1 (822)**	60 (–1)	**4 (80)**	73 (76)	60 (–6)	**<1 (–3.9)**	98 (–1.3)	7 (–12.1)	21 (–1.7)	**4 (2.7)**	88 (0.1)	54 (123)	55 (14)
Mangaonua (84)	88 (12)	83 (33)	**<1 (–42)**	9 (–41)	29 (112)	**1 (40)**	89 (–0.1)	12 (–12)	**1 (–16.6)**	**<1 (–4.9)**	26 (–1.7)	**<1 (–2.9)**	54 (42)	70 (6)
Mangatangi (30)	59 (42)	62 (–129)	**1 (–16)**	82 (8)	28 (–124)	44 (6)	**<1 (–3.6)**	55 (–3.1)	34 (–4.2)	5 (–0.4)	**<1 (2.0)**	**1 (–1.1)**	–	–
Mangatawhiri (29)	70 (38)	7 (–502)	**<1 (–54)**	37 (26)	70 (–21)	**<1 (92)**	**1 (–0.9)**	52 (–2.1)	17 (–1.7)	27 (–0.1)	86 (0.0)	9 (–0.2)	–	–
Mangawara (19)	83 (–17)	18 (262)	57 (4)	**<1 (352)**	37 (426)	26 (–2)	**<1 (–11)**	**2 (42.3)**	59 (8.7)	**2 (8.7)**	**<1 (10.6)**	**<1 (–3.8)**	–	–
Mangawhero (86)	32 (100)	78 (30)	52 (–2)	**<1 (144)**	**1 (1289)**	48 (–3)	**<1 (–9.4)**	9 (–32.6)	**<1 (–56)**	12 (–3.1)	**<1 (11.0)**	10 (–1.7)	27 (197)	26 (44)
Matahuru (20)	28 (87)	29 (–95)	12 (10)	18 (52)	11 (1124)	78 (–1)	**<1 (–4.3)**	26 (–15)	**1 (–29.3)**	83 (0.5)	**<1 (2.8)**	**<1 (–1.5)**	–	–
Ohaeroa (25)	75 (7)	11 (–125)	**1 (–15)**	**<1 (121)**	99 (–13)	**<1 (38)**	**<1 (–1.4)**	**1 (18.8)**	17 (9.7)	20 (–0.3)	46 (0.4)	88 (0.0)	–	–
Opuatia (24)	87 (–7)	64 (70)	96 (–1)	**<1 (98)**	32 (218)	96 (–1)	8 (–1.1)	50 (3.7)	32 (–6.8)	**<1 (–0.8)**	**<1 (1.6)**	7 (0.2)	24 (–70)	**1 (13)**
Pokaiwhenua (39)	45 (–31)	**<1 (–342)**	27 (–8)	**<1 (80)**	**3 (167)**	55 (–12)	**4 (0.7)**	14 (14.0)	82 (2.5)	59 (0.1)	82 (–0.2)	**4 (–1.7)**	18 (27)	34 (–4)
Waerenga (21)	24 (99)	**<1 (–713)**	**1 (–21)**	**<1 (78)**	81 (59)	**3 (27)**	13 (–0.5)	**<1 (16.6)**	18 (9.6)	11 (0.2)	7 (1.1)	71 (0.1)	90 (–1)	**5 (14)**
Waitawhiriwhiri (89)	98 (2)	93 (–10)	88 (2)	60 (–44)	85 (–25)	65 (–3)	17 (–3.3)	19 (18.1)	**<1 (25.1)**	**<1 (–30)**	**1 (3.9)**	88 (0.1)	71 (80)	79 (24)
Whakapipi (26)	28 (74)	**1 (596)**	16 (–7)	**<1 (200)**	**5 (–230)**	**<1 (56)**	**<1 (–2.9)**	5 (79.7)	8 (68.5)	16 (–0.3)	**<1 (1.5)**	92 (0.0)	–	–
Whakauru (41)	**3 (–105)**	88 (–16)	**1 (–20)**	**<1 (62)**	78 (55)	**<1 (51)**	**4 (0.8)**	45 (2.0)	**2 (–1.3)**	12 (–0.1)	74 (0.1)	**4 (0.5)**	27 (60)	30 (–8)
Whangamarino (28)	**5 (158)**	47 (–870)	40 (9)	**1 (150)**	6 (–3102)	63 (–2)	**2 (–6.2)**	**2 (37.7)**	**<1 (–21)**	55 (–1.0)	**<1 (11.5)**	**<1 (–0.8)**	–	–
Whangamarino (22)	12 (87)	**1 (–527)**	81 (–1)	**<1 (152)**	**<1 (–1306)**	**<1 (31)**	19 (–1.4)	6 (–19.0)	**1 (–21.7)**	40 (0.7)	40 (0.6)	5 (–0.8)	–	–
Whangape (23)	92 (0)	9 (–632)	9 (20)	**<1 (310)**	67 (150)	**<1 (61)**	**2 (–3.5)**	70 (–4.8)	35 (0.3)	64 (0.0)	**<1 (–2.3)**	11 (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)	27 (66)	**5 (–228)**	**<1 (–31)**	**<1 (124)**	87 (–63)	**2 (36)**	**<1 (–1.5)**	**<1 (14.7)**	**<1 (8.1)**	**2 (1.0)**	**1 (1.4)**	98 (0.0)	–	–
Mangaohoi (74)	52 (–28)	12 (103)	**<1 (–34)**	**1 (49)**	45 (–39)	8 (22)	96 (0.0)	15 (5.9)	34 (–2.3)	**1 (–0.3)**	6 (0.7)	34 (0.2)	48 (–18)	74 (–2)
Mangaokewa (65)	32 (51)	25 (–67)	5 (–15)	**<1 (119)**	29 (94)	**<1 (29)**	32 (–0.7)	13 (7.9)	14 (5.2)	**<1 (–5.5)**	7 (1.5)	46 (0.2)	–	–
Mangapiko (76)	**1 (–206)**	**<1 (–1158)**	**<1 (–36)**	46 (69)	**1 (–516)**	**<1 (46)**	23 (–0.8)	**2 (51.3)**	8 (44.3)	**1 (–7.0)**	27 (–4.3)	**<1 (–8.0)**	–	–
Mangapu (63)	75 (20)	**<1 (–619)**	96 (0)	**<1 (281)**	41 (–212)	**1 (20)**	7 (–0.7)	**<1 (31.2)**	**<1 (20.4)**	46 (0.7)	**<1 (6.0)**	**<1 (2.1)**	71 (61)	23 (–10)
Mangatutu (73)	13 (–108)	**1 (–185)**	**<1 (–41)**	**1 (50)**	91 (–7)	**1 (33)**	69 (0.1)	68 (3.5)	53 (–2.9)	50 (0.2)	37 (0.5)	99 (0.0)	7 (–95)	42 (4)
Mangauika (13)	40 (46)	**<1 (–124)**	**<1 (–41)**	**<1 (62)**	48 (–49)	10 (76)	26 (0.3)	27 (3.2)	73 (0.7)	17 (0.0)	33 (0.1)	7 (0.1)	27 (–15)	96 (0)
Ohote (88)	98 (0)	**2 (–1275)**	88 (0)	60 (55)	61 (–183)	12 (–28)	**<1 (–8.0)**	13 (–20)	**<1 (36.9)**	95 (0.0)	**<1 (4.6)**	36 (0.1)	90 (2)	66 (1)
Puniu (75)	8 (–133)	**1 (–405)**	**<1 (–39)**	**<1 (83)**	91 (–9)	**2 (39)**	89 (–0.1)	14 (9.6)	68 (2.2)	8 (0.6)	**4 (1.3)**	16 (–0.3)	–	–
Waipa (61)	10 (99)	62 (27)	**<1 (–53)**	**<1 (84)**	78 (–13)	81 (–8)	28 (–0.8)	**<1 (20.4)**	**<1 (12.4)**	**1 (0.2)**	**<1 (1.2)**	**<1 (0.7)**	–	–
Waipa (12)	98 (3)	7 (–132)	**<1 (–17)**	**<1 (136)**	65 (–143)	**<1 (31)**	**1 (–1.3)**	**4 (12.3)**	22 (7.1)	82 (0.1)	**<1 (2.5)**	45 (0.1)	39 (–136)	30 (6)
Waipa (2)	35 (–45)	22 (–33)	**<1 (–6)**	15 (–6)	82 (8)	**4 (–18)**	54 (0.1)	10 (2.3)	6 (2.9)	**<1 (–0.3)**	36 (0.2)	**<1 (0.3)**	–	–
Waipa (64)	64 (30)	**<1 (–257)**	**<1 (–29)**	**1 (55)**	**2 (–261)**	**<1 (41)**	36 (–0.5)	25 (6.2)	88 (0.5)	**1 (–0.7)**	8 (0.8)	79 (0.0)	18 (31)	**4 (–17)**
Waipa (1)	18 (–68)	14 (–73)	**<1 (–12)**	**<1 (56)**	12 (109)	36 (–3)	92 (0.0)	**<1 (14.5)**	**<1 (11.2)**	29 (–0.4)	12 (0.6)	39 (0.1)	–	–
Waitomo (18)	7 (–77)	6 (–343)	**<1 (–20)**	**3 (93)**	65 (121)	**2 (16)**	**<1 (–1.2)**	**<1 (22.4)**	**<1 (10.0)**	**<1 (–1.2)**	**<1 (1.4)**	35 (0.1)	90 (–46)	36 (–4)
Waitomo (17)	59 (–26)	**<1 (–298)**	**<1 (–17)**	**2 (82)**	94 (24)	**<1 (36)**	13 (–0.6)	**<1 (11.0)**	14 (4.0)	**<1 (–1.6)**	**1 (0.9)**	**<1 (0.3)**	90 (0)	48 (6)

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)	74 (–25)	10 (–141)	**<1 (–57)**	98 (0)	61 (–48)	**<1 (84)**	41 (–0.2)	98 (0.1)	74 (–0.4)	27 (0.0)	70 (–0.1)	**5 (–0.2)**	36 (–20)	43 (–2)
Awakino (69)	86 (–5)	8 (–332)	**<1 (–46)**	13 (37)	78 (–63)	**2 (29)**	**4 (–0.6)**	**1 (9.7)**	16 (3.6)	14 (–0.2)	17 (0.6)	9 (0.2)	70 (–28)	43 (–3)
Manganui (67)	99 (8)	60 (105)	**<1 (–48)**	13 (31)	15 (240)	**1 (40)**	9 (–0.3)	8 (5.6)	43 (–0.9)	17 (–0.1)	50 (0.3)	8 (0.2)	90 (–4)	18 (–5)
Mangaotaki (66)	53 (13)	83 (13)	**<1 (–21)**	**<1 (89)**	55 (–62)	**<1 (33)**	**5 (–0.5)**	**<1 (18.5)**	**<1 (10.1)**	**3 (–0.3)**	**5 (0.8)**	**<1 (0.5)**	–	–
Marokopa (15)	73 (–28)	**<1 (–379)**	**<1 (–47)**	7 (45)	35 (76)	**1 (28)**	57 (0.3)	**<1 (10.2)**	7 (2.3)	**<1 (–0.5)**	**<1 (1.2)**	29 (0.1)	11 (–29)	55 (3)
Mokau (68)	86 (9)	45 (76)	**<1 (–25)**	**1 (88)**	56 (392)	70 (–2)	**1 (–1.9)**	**<1 (17.6)**	12 (7.4)	10 (0.6)	**<1 (2.5)**	86 (0.0)	24 (–75)	64 (–2)
Mokau (62)	85 (15)	**<1 (–404)**	**<1 (–37)**	**<1 (89)**	97 (–3)	**1 (39)**	76 (–0.2)	**<1 (11.0)**	**<1 (5.2)**	5 (–0.1)	**1 (1.0)**	**<1 (0.7)**	11 (35)	13 (–9)
Mokau (71)	74 (–24)	**<1 (–200)**	**<1 (–39)**	**<1 (85)**	37 (–204)	**<1 (22)**	**<1 (–1.8)**	**<1 (17.5)**	**3 (8.3)**	82 (0.0)	**<1 (1.5)**	52 (0.1)	90 (–10)	50 (–4)
Mokauiti (72)	66 (–31)	5 (–247)	**<1 (–30)**	**<1 (87)**	23 (–529)	**<1 (26)**	**<1 (–4.7)**	42 (4.0)	45 (2.0)	66 (0.3)	8 (1.1)	**3 (–0.3)**	9 (–87)	38 (–5)
Ohautira (9)	22 (–51)	**<1 (–163)**	**<1 (–33)**	8 (58)	71 (119)	**<1 (24)**	**<1 (–2.2)**	**<1 (15.6)**	**<1 (13.0)**	**3 (–0.2)**	**1 (1.3)**	98 (0.0)	90 (–53)	63 (–3)
Oparau (14)	61 (–11)	**<1 (–653)**	**<1 (–69)**	**2 (41)**	**3 (161)**	74 (10)	9 (–0.7)	**2 (7.2)**	**<1 (4.1)**	37 (0.0)	57 (0.2)	**3 (0.2)**	–	–
Tawarau (16)	75 (23)	**<1 (–345)**	**<1 (–44)**	16 (43)	48 (167)	**5 (16)**	57 (–0.2)	**<1 (9.1)**	43 (0.8)	**<1 (–0.5)**	**<1 (1.4)**	25 (0.2)	–	–
Waingaro (8)	7 (–120)	8 (229)	**<1 (–22)**	89 (–7)	9 (394)	**1 (29)**	**<1 (–2.6)**	**2 (14.9)**	**1 (11.7)**	98 (0.0)	**3 (1.3)**	**1 (–0.3)**	–	–
Waitetuna (10)	22 (–68)	**2 (–203)**	**<1 (–39)**	15 (35)	18 (345)	7 (17)	**<1 (–2.1)**	**2 (10.9)**	**4 (7.1)**	17 (0.2)	10 (1.0)	10 (–0.2)	39 (190)	42 (6)
Total increases	7	12	7	73	8	63	10	46	33	7	39	28	3	3
Total decreases	5	33	64	2	19	2	37	7	20	31	4	19	4	3

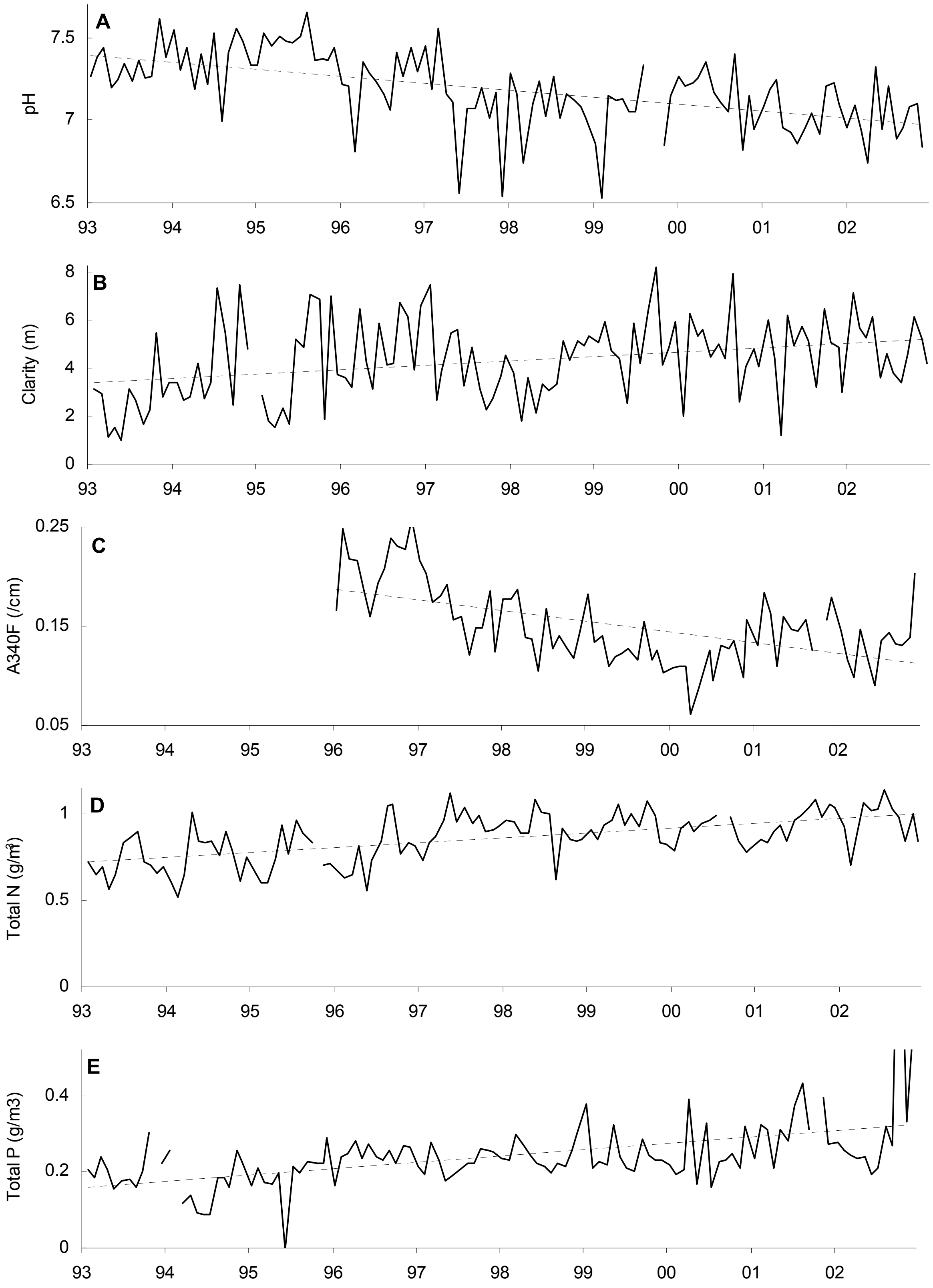

Figure 3: Flow-adjusted water quality at various sites during 1993–2002: **A**, pH at Waiwawa @ SH25; **B**, Visual clarity at Waihaha @ SH32; **C**, Dissolved colour at Mangawara @ Rutherford Rd; **D**, Total nitrogen at Mapara @ off Mapara Rd; and **E**, Total phosphorus at Mangawara @ Rutherford Rd. The dashed lines show the overall trends in the records.

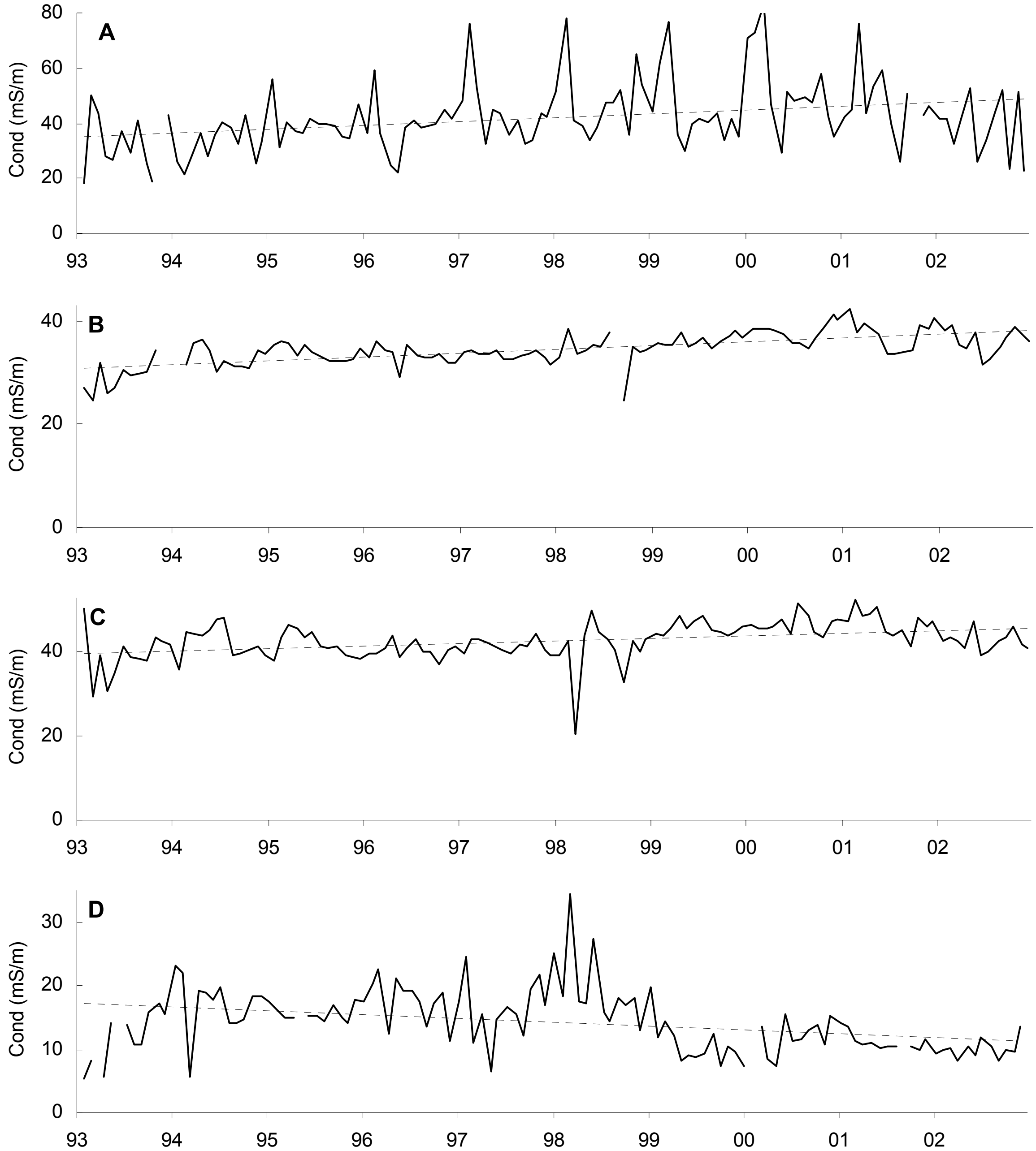

Figure 4: Flow-adjusted conductivity at various sites during 1993–2002: **A**, Awaroa @ Rotowaro-Huntly Rd; **B**, Otamakokore @ Hossack; **C**, Waiotapu @ Homestead Rd; and **D**, Waitekauri u/s Ohinemuri. The dashed lines show the overall trends in the records.

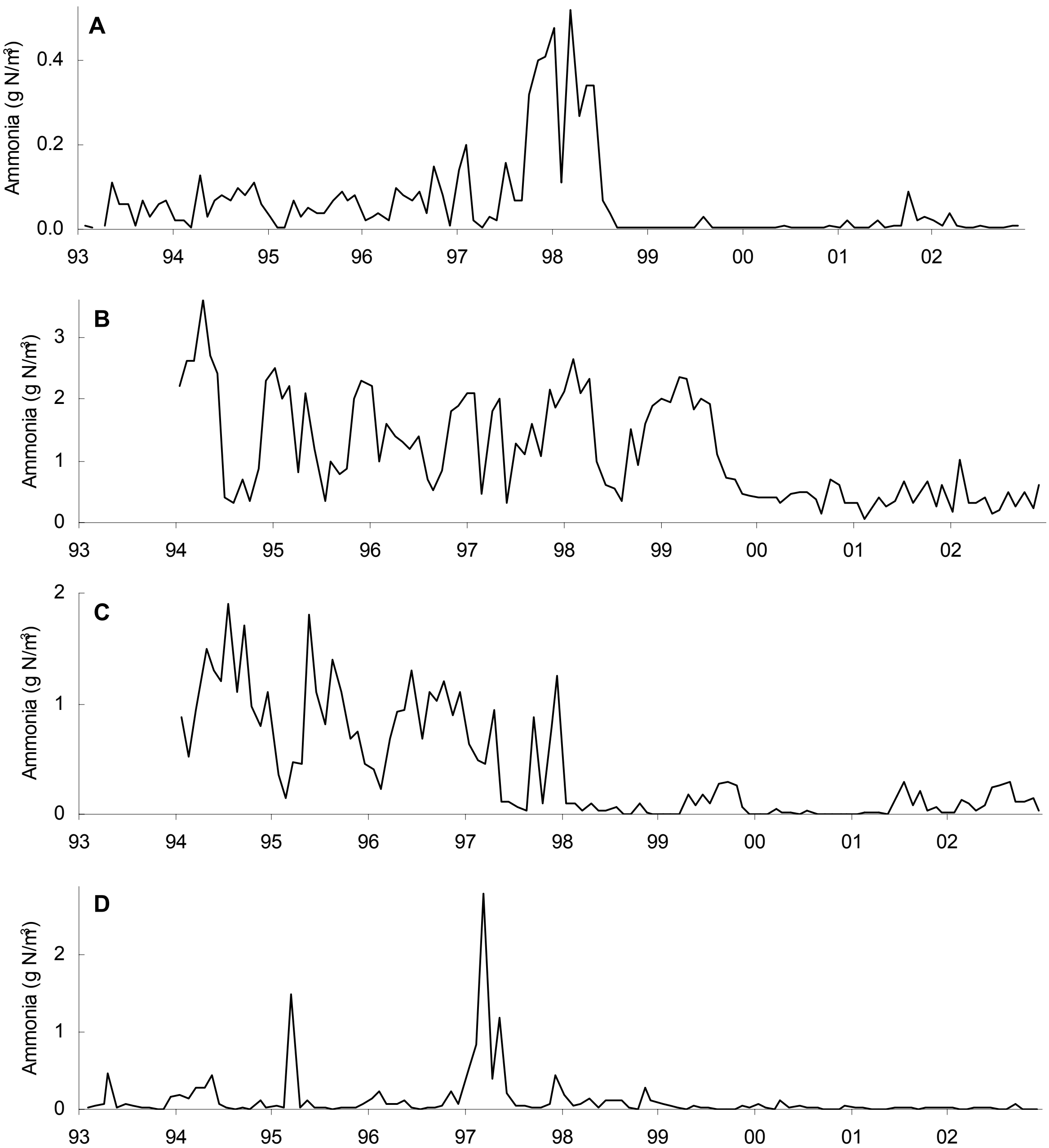

Figure 5: Ammonia at various sites during 1993–2002: **A**, Waitekauri u/s Ohinemuri; **B**, Kirikiriroa @ Tauhara Dr; **C**, Mangamingi @ Paraonui Rd; and **D**, Mangaokewa @ Te Kuiti. Values are not flow-adjusted.

(Otamakokore Stream).[17] 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.

Dissolved oxygen. Significant trends in dissolved oxygen were observed at about half (45) of the sites. Many (33) 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). This represents a deterioration in water quality. The greatest rate of decrease occurred at the Ohote Stream (–1.3% of saturation/yr). 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. It's unclear whether there's a common cause of the observed decreases; nor is it clear what the cause(s) might be.

pH. Significant trends in pH were observed at many (71) of the sites (e.g. Fig. 3A). Most (64) of these were decreases, so the overall pattern for the Region as a whole was for a significant decrease in pH (Table 6). Values of the SKSE for many of the decreases were similar: between –0.02 and –0.04/yr. As with the decreases observed for the Waikato River, over a 10-year period these rates correspond to declines in pH of 0.2–0.4, or an approximate doubling of hydrogen ion concentration in many cases. The general pattern of decline was particularly marked in three water zones—Coromandel, Waipa and West Coast, with 80–100% of sites in each of these having shown decreasing trends. By contrast, only 35% of sites in the Lowland Waikato tributaries zone showed decreases.

It's unclear whether there's a common cause of the observed decreases; nor is it clear what the cause(s) might be. The magnitude of pH change did not depend on the intensity of land use: both undeveloped and highly-developed catchments showed similar decreases (Fig. 6A). However, as with the Waikato River, this slight acidification of stream waters throughout the Region can be regarded as a somewhat-disturbing deterioration.

Scarsbrook et al. (2003) also observed an overall decline in pH during 1989–98 in New Zealand rivers in general (77 sites). However, the median SKSE for all of their sites was just –0.004/yr, or about five times lower than the equivalent value for Waikato rivers (–0.02/yr, Table 6). The overall trend in pH in the Waikato Region is thus consistent with, but considerably stronger than that reported for NZ rivers in general.

Conductivity. Significant trends in conductivity were observed at many (75) of the sites. Most (73) of these were increases, so the overall pattern for the Region as a whole was for a significant increase in conductivity (Table 6). This probably represents a deterioration in water quality.

The largest increases in conductivity (0.6–1.3 mS/m/yr) occurred at the following four sites: Awaroa @ Rotowaro-Huntly Rd (Fig. 4A), Waiotapu @ Campbell Rd, Otamakokore @ Hossack Rd (Fig. 4B) and Waiotapu @ Homestead Rd (Fig. 4C). These are all sites where the median level of conductivity is unusually high: in the range 34–67 mS/m during 1998–2002 (Smith 2003b). The high level in the Awaroa Stream is thought to arise from the (consented) discharge to the stream of decant water from settling ponds associated with nearby mining activities. Flocculants used as part of the settling process are presumably responsible for the elevated stream conductivities. The other three streams are all influenced by geothermal sources, and this is probably responsible for the high conductivity in them. It is likely that the specific circumstances responsible for the elevated conductivity at each of these four sites are also responsible for the unusually high rates of increase observed there. Interestingly, the largest decrease in conductivity (–0.7 mS/m/yr in the

[17] Note that the Otamakokore Stream appears to be influenced by geothermal sources: both conductivities and (winter) temperatures are somewhat higher than expected (Smith 2003b).

Waitekauri Stream: Fig. 4D) also appears to be due to a specific cause, namely the cessation of mining activities in the catchment in 1997–98. However, in this case the median conductivity was never particularly high (about 18 mS/m for the period to the end of 1998, and about 11 mS/m for the period since then).

At many other sites, the absolute magnitude of the SKSE was considerably smaller, so that the median value for sites with significant trends was 0.09 mS/m/yr, or just under 1% of the median value/yr. In the Hauraki and Upland Waikato tributaries zones increases in conductivity occurred at most (c. 90%) of the sites (and no decreases occurred). By contrast, in the West Coast, increases occurred at less than half of the sites. At certain sites specific causes of the increases can be identified (see above). At the majority of sites, however, while the trends do seem to be associated with the intensity of land use (Fig. 6B; $p < 1\%$), the precise nature of the processes responsible for this are unclear.

Scarsbrook et al. (2003) also 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 about four times larger than this (0.08 mS/m/yr, Table 6). Similarly, Larned et al. (2004) reported an overall increase in conductivity in lowland New Zealand rivers during 1996–2002, but at a rate equivalent to about one-tenth of that for the Waikato Rivers (0.07% of the median value per year, cf. 0.7%/yr, Table 6). The overall trend in conductivity in the Waikato Region is thus consistent with, but considerably stronger than those reported for NZ rivers in general.

<u>Turbidity</u>. Significant trends in turbidity were observed at 27 sites. Most (19) of these were decreases, so the overall pattern for the Region as a whole was for a significant decrease in turbidity (Table 6). This represents an improvement in water quality. The largest decrease in turbidity was –1.3 NTU/yr (Whangamarino @ Jefferis Rd), while the largest increase was 1.3 NTU/yr (Mangawhero @ Cambridge-Ohaupo Rd). The median rate of change for significant trends was equivalent to a moderately-high –4.8% of the median value/yr.

The zones containing the highest proportion of sites that have shown decreasing trends were Coromandel (55%) and Taupo (38%). Decreases were least common in the Lowland Waikato tributaries (8%) and West Coast (0%) zones; indeed, in both these zones there were more sites with increases. There was little dependence of SKSE on land use (Table 7): although SKSE at four undeveloped sites was low (–0.01 to –0.09 NTU/yr), at developed sites both marked increases (Mangawhero) and marked decreases (Whangamarino) occurred. It is therefore unclear whether there's a common cause of the observed decreases; nor is it clear what the cause(s) might be.

<u>Visual clarity</u>.[18] Significant trends in clarity were observed at many (65) of the sites. Most (63) of these were increases, so the overall pattern for the Region as a whole was for a significant increase in clarity (Table 6). This represents an improvement in water quality. The largest increase was 0.2 m/yr at the Waihaha River site (Fig. 3B). The median SKSE for significant trends was 0.04 m/yr.

The Upland Waikato tributaries zone had the highest proportion of sites that have shown increasing trends (90%), while the Lowland Waikato tributaries zone had the lowest (46%). Values of SKSE were inversely-correlated with land use ($p < 0.1\%$): increases tended to be larger in least-developed catchments, and smaller in more-developed catchments. It's unclear whether there's a common cause of the observed increases; nor is it clear what the

[18] Note that these records of visual clarity are generally longer than those for sites on the Waikato River (Table 1). In most cases visual clarity has been measured at these other rivers and streams since monitoring began (i.e. in 1990, 1992, 1993 or 1994). The doubts raised over the reliability of the 1995 results at the Waikato River sites therefore do not apply to these sites.

Table 6: Median values of the seasonal Kendall slope estimator for flow-adjusted water quality records at non-Waikato River sites (median of the standardized slopes in brackets; units, % of median value/yr). Values in bold are cases where the binomial test's hypothesis is rejected (p < 5%), indicating the existence of an overall pattern of change across the Region as a whole.

	Significant (p<5%) trends (% of records*)	**Significant records only**		**All records**	
Temperature (°C/yr)	12	0.08	(0.6)	0.01	(0.1)
Dissolved oxygen (%sat/yr)	45	**–0.23**	**(–0.2)**	**–0.11**	**(–0.1)**
pH (/yr)	71	**–0.03**	**(–0.4)**	**–0.02**	**(–0.2)**
Conductivity (mS/m/yr)	75	**0.09**	**(0.9)**	**0.08**	**(0.7)**
Turbidity (NTU/yr)	27	**–0.08**	**(–4.8)**	–0.01	(–0.6)
Visual clarity (m/yr)	65	**0.043**	**(3.7)**	**0.031**	**(2.7)**
Dissolved colour (A340/cm/yr)	47	**–0.0015**	**(–4.9)**	**–0.0005**	**(–2.1)**
Total nitrogen (g/m^3/yr)	53	**0.014**	**(2.5)**	**0.006**	**(1.3)**
Nitrate-N (g/m^3/yr)	53	0.005	(1.6)	**0.003**	**(0.8)**
Ammonia (g N/m^3/yr)	38	**–0.0008**	**(–6.8)**	**–0.0001**	**(–1.7)**
Total phosphorus (g/m^3/yr)	43	**0.0014**	**(4.0)**	**0.0006**	**(1.3)**
Dissolved reactive P (g/m^3/yr)	47	0.0002	(1.4)	**0.0001**	**(0.6)**
E. coli (cfu/100 mL/yr)	7	–5.0	(–17)	–0.7	(–4.1)
Enterococci (cfu/100 mL/yr)	6	1.0	(–1.9)	0.6	(1.3)

* In most cases, records from 100 rivers and streams were analysed; the exceptions were visual clarity (96 records) and *E. coli* and enterococci (69 records in both cases).

Table 7: Correlation coefficient (r) for correlations between the SKSE for significant trends and the proportion of the catchment in pasture (see text). Values in bold are significant (p < 5%).

	r
Temperature	–0.28
Dissolved oxygen	–0.21
pH	0.20
Conductivity	**0.37**
Turbidity	–0.06
Visual clarity	**–0.48**
Dissolved colour	**–0.60**
Total nitrogen	**0.35**
Nitrate-N	–0.15
Ammonia	**–0.50**
Total phosphorus	**0.40**
Dissolved reactive P	**–0.47**
E. coli	0.69
Enterococci	0.50

cause(s) might be.

The overall trend for the Region as a whole was for turbidity to decrease and visual clarity to increase (Table 6). Furthermore, significant decreases in turbidity were often associated with increases in visual clarity (14 sites), and vice-versa (1 site). But somewhat surprisingly, at four sites significant increases were observed in both turbidity and visual clarity.

Larned et al. (2004) also reported an overall increase in visual clarity in lowland New Zealand rivers during 1996–2002, but at a rate equivalent to less than one-tenth of that for the Waikato Rivers (0.16% of the median value per year, cf. 2.7%/yr, Table 6). The overall trend in visual clarity in the Waikato Region is thus consistent with, but considerably stronger than that reported for NZ rivers in general.

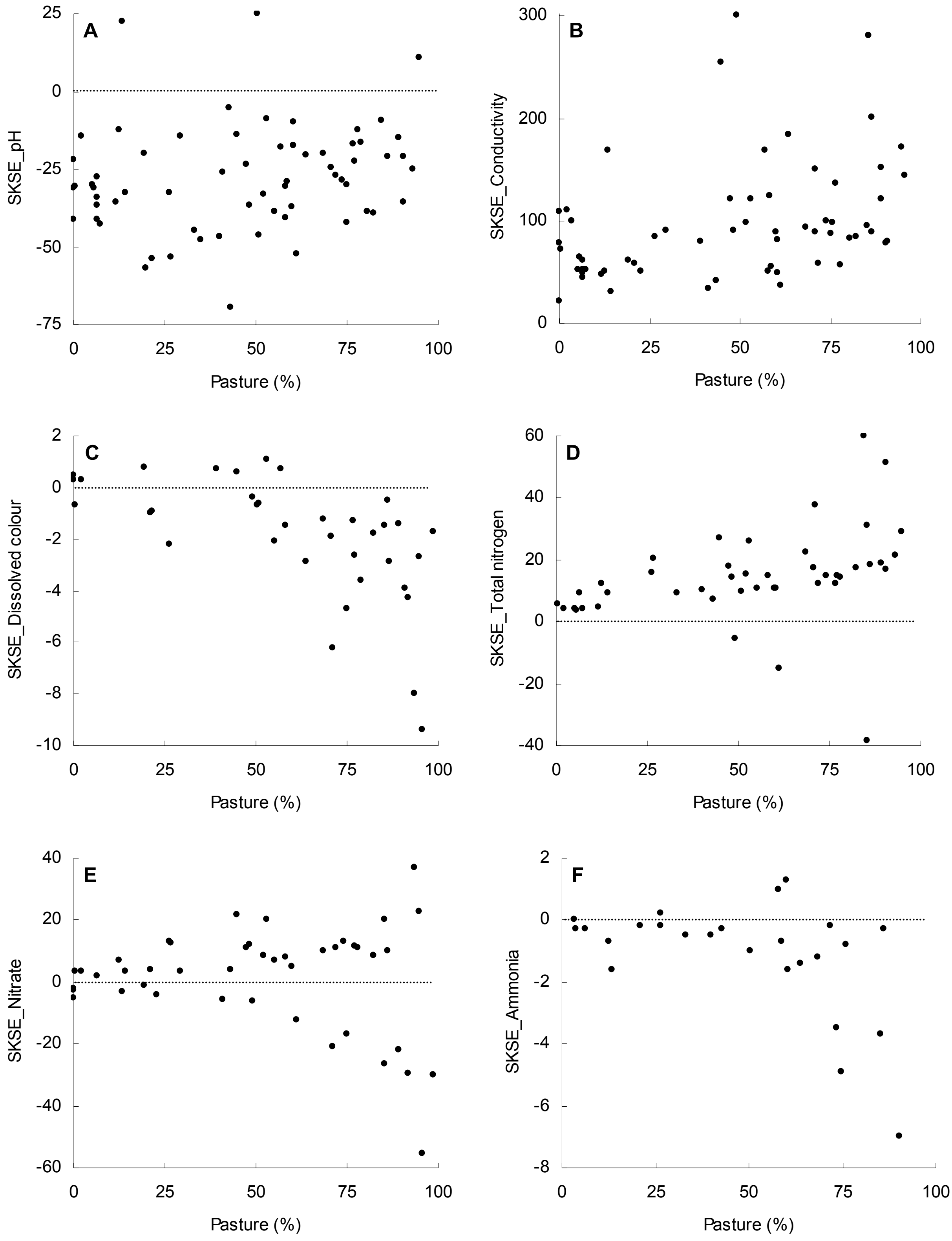

Figure 6: Trend slopes (SKSE, units as in Table 5) and land use (as percent of catchment in pasture) for different water quality variables: **A**, pH; **B**, Conductivity; **C**, Dissolved colour; **D**, Total nitrogen; **E**, Nitrate; and **F**, Ammonia. See Table 7 also.

Dissolved colour. Significant trends in dissolved colour were observed at about half (47) of the sites. Most (37) of these were decreases, so the overall pattern for the Region as a whole was for a significant decrease in dissolved colour (Table 6). We regarded similar decreases in dissolved colour at the Waikato River sites as representing improvements in the visual water quality of that waterbody (see above), and this might appear to be the case for the non-Waikato River sites as well. However, as we show below, there is an alternative interpretation.

The zones with the greatest proportion of sites that have shown decreasing trends were Hauraki (46%), Lowland Waikato tributaries (54%) and West Coast (57%). Conversely, in the Taupo zone just one site (13%) showed a decrease while dissolved colour increased at three sites. Values of SKSE were inversely-correlated with land use ($p \approx 0.01\%$): the largest decreases tended to occur in more-developed catchments (Fig. 6C). It's possible that drainage associated with historic catchment development caused a reduction in the export of dissolved organic carbon from areas of drained wetlands, and 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[19] occur at sites in the catchments of the lower parts of the Waikato and Waipa Rivers and in the Hauraki Plains, all areas where land drainage is common (e.g. Fig. 3C). 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 about half (53) of the sites. Most (46) of these were increases (e.g. Fig. 3D), so the overall pattern for the Region as a whole was for a significant increase in total N (Table 6). This represents a deterioration in water quality.

The median value of the SKSE for significant trends was 0.014 $g/m^3/yr$ or 2.5% of the median value/yr. This represents a moderately-rapid rate of increase in total N. Several of the decreases occurred downstream of areas where specific sources of N have been better-managed in recent years: Kirikiriroa (landfill leachate), Mangaone (spray-irrigated dairy factory wastewaters), Piako (sewage and dairy factory wastewaters) and Waitekauri/Ohinemuri (mining wastewaters). Ignoring these (and trends at the other sites identified earlier as exhibiting "non-land use effects"), values of the SKSE were moderately-correlated with land use ($p = 2\%$). That is, total N has tended to increase at a greater rate in streams in more-developed catchments (Fig. 6D). 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 also observed at about half (53) of the sites. Not quite as many of these were increases as was the case for total N (33 cf. 46); just over one-third of the trends in nitrate were decreases (i.e. improvements). In most cases where there were significant trends in both total N and nitrate, the directions of the trends were the same: all but one of 29 increases in total N were associated with increases in nitrate, while at six sites both total N and nitrate showed decreases. However, at ten sites there were decreases in nitrate, but no significant trends in total N. As a result, there was no simple pattern with land use: values of the SKSE for nitrate tended to be small in less-developed catchments, but tended to both increase and decrease (i.e. large negative) in more-developed catchments (Fig. 6E). While the increases in SKSE with catchment development may well reflect the same intensification pressures that resulted in corresponding increases for total N, it is unclear why decreases in nitrate occurred in other developed areas.

[19] That is, trends where the value of the SKSE was more negative than –0.003 A340 nm/cm/yr (i.e. rate of decrease was more rapid than this).

Ammonia. Significant trends in ammonia concentration were observed at just over one-third (38) of the sites. Most (31) of these were decreases. This represents an improvement in water quality. 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 (Fig. 5): Waitekauri (mining wastewaters), Kirikiriroa (landfill leachate), Mangamingi (sewage wastewaters) and Mangaokewa (stockyard runoff). Ignoring these (and trends at the other sites identified earlier as exhibiting "non-land use effects"), values of the SKSE were inversely-correlated with land use (p = 1%). That is, the largest decreases in ammonia tended to occur in more-developed catchments (Fig. 6F). 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).

Scarsbrook et al. (2003) also observed an overall decline in ammonia during 1989–98 in New Zealand rivers in general (77 sites).[20] The median SKSE for all of their sites was –0.355 μg N/L/yr, or about –0.0004 g N/m^3/yr. The equivalent value for Waikato rivers was four times lower than this (–0.0001 g N/m^3/yr, Table 6). The general trend in ammonia in the Waikato Region is thus consistent with, but rather weaker than that reported for NZ rivers in general.

Total phosphorus. Significant trends in total P concentration were observed at slightly less than half (43) of the sites. Most (39) of these were increases (e.g. Fig. 3E), so the overall pattern for the Region as a whole was for a significant increase in total P (Table 6). This represents a deterioration in water quality.

The median value of the SKSE for significant trends was 0.0014 g/m^3/yr or 4.0% of the median value/yr. This represents a moderately-rapid rate of increase in total P. Few sites in the Hauraki and Taupo zones showed changes in total P, but a similarly-large proportion of sites showed an increase in each of the other zones.

Values of SKSE were moderately-correlated with land use (p < 2%). That is, total P has tended to increase at a greater rate in streams in more-developed catchments. This may 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 (47) of the sites. Slightly more than half of these (28) were increases (i.e. deteriorations). In contrast to the situation with total P, values of the SKSE were inversely-correlated with land use (p < 1%). That is, the largest decreases in DRP tended to occur in more-developed catchments. Significant values of SKSE for trends in DRP and ammonia were highly correlated (r = 0.91, p < 0.01%), so both may reflect improved farm practice.

Scarsbrook et al. (2003) observed an overall increase in DRP during 1989–98 in New Zealand rivers in general (77 sites).[21] The median SKSE for all of their sites was 0.049 μg/L/yr, or about 0.00005 g/m^3/yr. The equivalent value for Waikato rivers was twice as large as this (0.0001 g/m^3/yr, Table 6). The general trend in DRP in the Waikato Region is thus consistent with, but stronger than that reported for NZ rivers in general.

[20] Larned et al (2004) also found a general tendency for ammonia concentrations to decline in lowland New Zealand rivers during 1996–2002, but the overall result was not statistically significant. As with the other results reported by this group, the median rate of change for the 229 lowland rivers was much lower than that found in the Waikato Region.

[21] Larned et al (2004) also found a general tendency for DRP concentrations to decline in lowland New Zealand rivers during 1996–2002, but the overall result was not statistically significant. As with the other results reported by this group, the median rate of change for the 229 lowland rivers was much lower than that found in the Waikato Region.

Escherichia coli.[22] Significant trends in E. coli concentrations were observed at just seven sites. Three were increases and four were decreases.

Enterococci.[23] Significant trends in enterococci concentrations were observed at six seven sites. Three were increases and three were decreases.

4 Conclusions

1. Significant trends ($p < 5\%$) were found in nearly half of the water quality records from the Waikato River. Some 60% of these were highly significant ($p < 0.05\%$). Variables for which significant trends were found at five or more of the ten sites were pH, dissolved colour, BOD_5, arsenic, boron, ammonia and faecal coliforms. In several cases these were improving trends that have resulted from improvements to the treatment of known point source discharges (e.g. Kinleith paper mill, Wairakei power station). However, we regard the decline in pH as a deterioration. It is not clear why this trend has occurred, but it may be linked to intensification of land use within the Waikato River catchment. Conversely, land use changes may also be the cause of the improvements (i.e. decreases) in both total nitrogen and nitrate at four sites. An overall, semi-quantitative assessment of water quality changes in the river since 1987 is shown in Table 8.

2. Significant trends ($p < 5\%$) were also found in many (44%) 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 conductivity, visual clarity, total N and total P; and (2) significant decreases have occurred in dissolved oxygen, pH, turbidity, dissolved colour and ammonia. The magnitudes of the trends in conductivity, visual clarity, dissolved colour, total N, ammonia, total P and dissolved reactive P were significantly correlated with the proportion of the catchment area that was in pasture (i.e. were correlated with land use). While some of these overall trends can be regarded as improvements (increases in visual clarity, decreases in ammonia), the majority of them represent deteriorations (Table 8).

3. For a small number of these trends in the other rivers and streams we can identify probable causes. 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 (e.g. the sites in Fig. 5). For some of the other trends we can make reasonable inferences about likely causes. For example, the reduction in ammonia at about 20 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. Similarly, the increases in total N, which are also significantly related to land use in the relevant catchments, may reflect the overall increase in stock numbers and farming intensity that has occurred across the Region in the past decade or more.

4. However, the processes that are likely to have resulted in many of the other trends are less obvious: (1) it is not clear why pH has decreased at many sites, regardless of catchment land use; (2) it is not clear why conductivity has increased at many sites, with the magnitude of the increase reflecting the proportion of pasture in the catchment; (3) it is not clear why visual clarity has increased at many sites, with sites in less-developed

[22] Note that these records contain fewer results than those for many other variables, so that the sample size is considerably smaller (n = 18–20: Table 1). As a result care should be taken in comparing the trend analyses for *E. coli* with those reported for other variables.

[23] Note that these records contain fewer results than those for many other variables, so that the sample size is considerably smaller (n = 34–71: Table 1). As a result care should be taken in comparing the trend analyses for enterococci with those reported for other variables.

catchments showing the largest increases; and (4) it is not clear why dissolved colour has decreased at many sites, with the magnitude of the decrease reflecting the proportion of pasture in the catchment. Nor is it clear how severe many of these changes are (i.e. how concerned we should be about them).

5. Some of these changes have also been observed in rivers throughout New Zealand (e.g. decreases in pH, increases in conductivity), although often at slower rates than those observed in the Waikato Region. It is therefore possible that the general processes responsible are operating at a very broad scale. If this is the case, then the task of identifying and testing hypotheses to account for the observed changes is probably best undertaken by the national science agencies (i.e. FoRST and the agriculture, land, and water crown research institutes). We recommend that Environment Waikato strongly promotes the need for these multi-disciplinary investigations. In the meantime, we consider that not enough is known about the causes of many of the changes in river water quality in the Waikato Region that have been identified by this analysis for remedial action to be planned yet.

6. Even so, the observed changes are disturbing, and we recommend that Environment Waikato and other relevant agencies should continue to be mindful of this. Routine water quality monitoring should continue at all sites, with comprehensive statistical analysis for trends being undertaken at 5-yearly intervals.

Table 8: Semi-quantitative assessment of the overall nature of trends in river water quality in the Waikato Region. Both the direction of change (“+”, improvement; “–”, deterioration; “n”, no overall pattern) and the magnitude of the rate of change (“H”, high; “M”, moderate; “L”, low) are shown.

	Waikato River (10 sites) 1987–2002	**Other rivers (100 sites) 1990–2002**
Temperature	n L	n L
Dissolved oxygen	n L	– L
pH	– M	– M
Conductivity	n M	– M
Turbidity	n H	+ H
Visual clarity	n H*	+ H
Dissolved colour	+ H	– H
Biochemical oxygen demand	+ H	no data
Arsenic	+ M	no data
Boron	+ M	no data
Total nitrogen	+ M	– M
Nitrate-N	+ M	n M
Ammonia	+ H	+ H
Total phosphorus	n M	– H
Dissolved reactive P	n M	n M
Chlorophyll *a*	n L	no data
Faecal coliforms	n H†	not analysed
Escherichia coli	n L	n M
Enterococci	n L	n L

* no trend apparent if the first year of record is ignored
† major load to lower river ceased during 2002

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