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Trends in river water quality in the Waikato region, 1993-2012

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Prepared by:
Bill Vant

For:
Waikato Regional Council
Private Bag 3038
HAMILTON

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Peer reviewed by:
Dr Jonathan Caldwell Date July 2013

Approved for release by:
Dr Dominique Noiton Date August 2013

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Abstract

Trends in long-term (20-year) records of river water quality at 114 sites in the Waikato region were analysed using non-parametric statistical methods (seasonal Kendall slope estimator and trend test). At ten Waikato River sites, records of 17 water quality variables obtained during 1993–2012 were analysed, while at the 104 other river sites, records of 12 variables were analysed for this period. Sites were generally sampled monthly, 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 the Waikato River, 11 of the 17 water quality variables were regarded as being key measures of the river's water quality. Records of these variables were analysed at 8–10 sites, giving a total of 106 records. Statistically significant (p-value < 5%) trends in water quality during 1993–2012 were found in 60 records. For 46 of these (43% of the total), the absolute values of the trend slopes or rates of change in water quality were larger than ±1% of the median value per year. These latter trends were regarded as being both statistically significant and environmentally important. About half (22) of these significant and important trends were improvements in water quality, while the remainder (24) were deteriorations.

Records of temperature and dissolved oxygen at Waikato River sites were either stable or showed only slight trends. Records of arsenic and *E. coli* showed only a small number of important trends, both improvements and deteriorations. There were also only small numbers of important trends in biochemical oxygen demand (2) and total phosphorus (3), but all were improvements. Important improvements were more common in records of chlorophyll *a* (6) and ammonia (8). Conversely, important deteriorations were generally observed in records of turbidity (8) and total nitrogen (9). The improvements in BOD and ammonia have probably resulted from improved treatment of point source discharges to the river, while the development and intensification of pastoral farming in the Waikato catchment probably caused the deterioration in total N.

For the other rivers and streams, records for eight key water quality variables were analysed at 69–104 sites, giving a total of 789 records. Average water quality during 1993–2012 was found to be stable in 375 (48%) of these records. Statistically significant trends were found in the remaining 414 records, with 258 records (33% of the total) showing trends that were both significant and important. Some 117 (15%) of these latter trends represented important improvements in water quality, and the other 141 (18%) trends represented important deteriorations.

Records of temperature and dissolved oxygen at these monitoring sites were either stable or showed only slight trends. Records of *E. coli* showed only a small number of important trends, namely six improvements and one deterioration. Important improvements occurred in records of ammonia at about half of the sites (53), and slight improvements at a further 18 sites; deteriorations occurred at only two sites. At many sites, concentrations of total phosphorus were either stable (61 sites) or showed only slight trends (14 sites); important improvements occurred at 22 sites, while important deteriorations occurred at 7 sites. Important deteriorations in turbidity were about twice as common (37 sites) as important improvements (16 sites). Important deteriorations in total nitrogen occurred at more than half of the sites (59), while important improvements occurred at 11 sites.

The reductions in concentrations of ammonia were more than offset by the increases in concentrations of nitrate (plus nitrite), the other inorganic form of nitrogen found in the rivers. The net result of this was for concentrations of total nitrogen to generally increase across the region. Runoff and leaching of nitrogen from areas of pastoral farming probably accounts for much of this deterioration. In the south-eastern part of the region where large groundwater aquifers are present in the freely-draining volcanic soils, older water that fell as rain prior to the development of the area has been progressively replaced with newer water that is more-contaminated with development-based nitrogen. This means that increasing nitrogen concentrations have been common in streams in this area in recent decades.

1 Introduction

River water quality has been routinely monitored in the Waikato region since 1980. Monitoring at several Waikato River sites began then, 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—but particularly from 1993—monthly monitoring of the water quality of other rivers and streams in the region began (Figure 1). In addition to the ten sites on the Waikato River, water quality is now measured at 104 sites on other rivers and streams, with results being reported annually (e.g. Tulagi 2013a, b).

Vant and Wilson (1998) undertook the first comprehensive analysis of trends in water quality in Waikato Regional Council's river monitoring programmes, examining records for the period ending in 1997. This was subsequently extended at 5-yearly intervals, covering the periods ending in 2002 and 2007 (Vant and Smith 2004a, Vant 2008). This latest report describes a further extension of the analysis, covering the 20-year period 1993 to 2012.[1]

2 Methods

Up-to-date information on the location of the sites, the water quality variables measured, the methods used and the general nature of the results obtained are provided in the annual reports on the monitoring programmes (Tulagi 2013a, b). Information for five of the 104 non-Waikato River sites was obtained by NIWA as part of its National River Water Quality Network (Smith and McBride 1990).[2]

2.1 Datasets analysed

Many of the monitoring sites whose records are considered here were established in 1993 or 1994,[3] but a small number were established later, typically around the year 2000. In addition, records of visual clarity did not begin at any site until 1995, while records of *Escherichia coli* did not begin until 1998.

The field and laboratory methods used by Waikato Regional Council are described in the annual reports for the Waikato River and regional rivers programmes (Tulagi 2013a, b). Since 1993 most of the methods used have remained essentially unchanged; however, there are some changes to database and laboratory procedures that need to be accounted for. These are outlined below.[4]

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

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[1] Note that this analysis only deals with changes in river water quality. It does not deal with the state (or condition) of water quality in rivers in the Waikato region, a matter that is dealt with elsewhere (e.g. Tulagi 2013a, b).

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

[3] Results obtained prior to 1993, for example at the Waikato River sites, are not described here, although the data are available and have been analysed previously (e.g. Vant 2008).

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

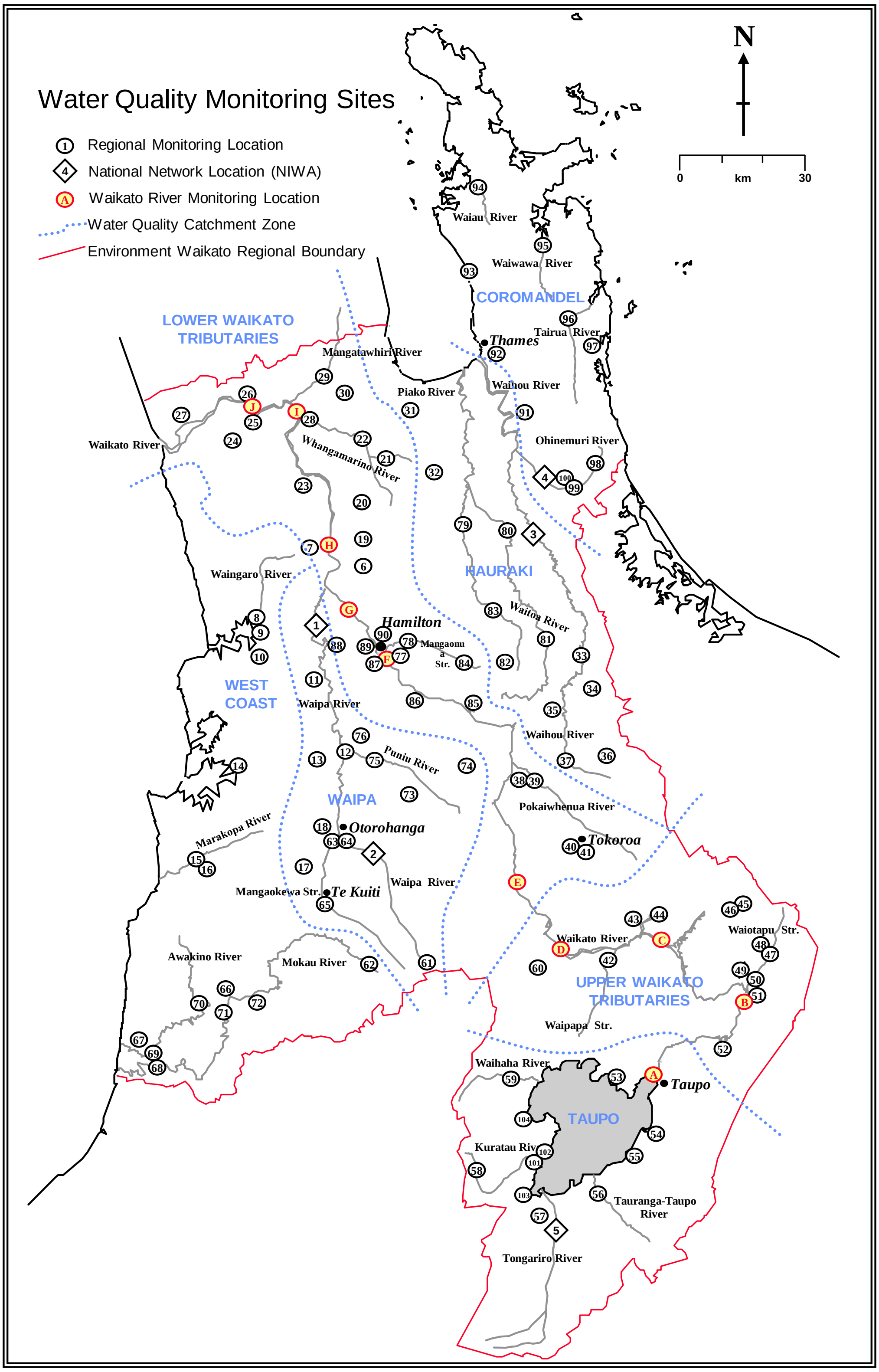

Figure 1: **The Waikato region, showing the Waikato River and the ten routine water quality sampling sites (A-to-J), and the 104 sites on the other rivers and streams (see Tables 2 and 3 for site details). The dotted lines divide the region into seven water quality zones (see text).**

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

Phosphorus. During 2004–05 changes were made to the laboratory methods used for analysing both total phosphorus (TP) and dissolved reactive phosphorus (DRP). For TP, a modified method was introduced which did not include the procedure for dealing with possible interferences caused by the presence of arsenic. For DRP, the change involved sample handling rather than chemical reactions, with sample handling changing from “flow injection” analysis to “discrete” analysis.

Inspection of the data showed that at some sites these changes to laboratory procedures had noticeably affected the long-term records of TP and DRP. Appendix 1 describes an investigation we undertook into the effect of omitting the arsenic-correction procedure on samples collected from the ten Waikato River sites. It also assesses three different methods of correcting the TP results for interference by arsenic, one of which was used to correct the records of TP for the ten Waikato River sites that are reported here.

It was not possible to adjust for the change in the DRP method, so the records for sites where visual inspection indicated that the change had an effect are described, but are identified as being “suspect”.

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

2.2 Statistical analyses—general approach

It is 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, Helsel and Hirsch 1992). For example, these techniques have been used to analyse (1) the records of New Zealand’s National River Water Quality Network (e.g. Smith et al. 1996), 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 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).

Table 1: Median numbers of samples in the 20-year (1993–2012) records of water quality at the 114 monitoring sites that were analysed for trends (with the minima and maxima in brackets).

	Waikato River (10 sites)		Other rivers (104 sites)	
Temperature	236	(220, 240)	231	(120, 240)
Dissolved oxygen	236	(221, 240)	230	(118, 240)
Conductivity	236	(221, 240)	231	(120, 240)
Turbidity[†]	210	(207, 211)	207	(120, 240)
Visual clarity	213	(204, 215)	230	(199, 240)
Biochemical oxygen demand[‡]	236	(221, 240)	–	
Arsenic	222	(216, 224)	–	
Boron	223	(221, 224)	–	
Total nitrogen	236	(221, 240)	230	(120, 240)
Nitrate-N	236	(221, 240)	231	(120, 240)
Ammonia	236	(221, 240)	230	(120, 240)
Total phosphorus	236	(221, 240)	228	(120, 240)
Dissolved reactive P	236	(221, 240)	230	(120, 240)
Chlorophyll *a*	236	(221, 240)	–	
Faecal coliforms	234	(220, 239)	–	
Escherichia coli[§]	178	(175, 178)	60	(57, 60)
Enterococci	234	(220, 239)	78	(73, 87)

[†] from mid-1995, except for the five NIWA sites

[§] from 1998 for WRC sites; and from 2005 for the five NIWA sites

2.3 Seasonal Kendall trend slope

The monitoring sites were generally visited monthly (although some variables were only measured quarterly). 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, it is often more meaningful to standardize the slopes (“relative SKSE”, or RSKSE), expressing them as a 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% per year where the median temperature is 15°C; but re-expressing the <u>same</u> result in degrees Kelvin produces a change of just 0.3% per year (=100 × 1 K/[273 +

15 K]). In this report RSKSEs are used, but care should be taken when comparing the results for different variables.

2.4 Seasonal Kendall trend test

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

p-values can be expressed either as proportions (e.g. 0.05) or as percentages (e.g. 5%)—in this report they are expressed as percentages. *p*-values of 5% or less are conventionally regarded as indicating that a trend is statistically significant (i.e. unlikely to be due to chance), and this practice was followed here. The *p*-value depends on the number of samples in a water quality record—ranging here from 57 to 240 (Table 1). This means that weak trends are less likely to be identified in records with fewer observations (and vice versa).

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

2.5 Flow adjustment

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

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

NIWA has developed software that both adjusts water quality records for changes in flow, and calculates the SKSE and the *p*-value (TimeTrends, version 3.10, 2010), and this was used in the analyses reported here.

2.6 Flow records

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

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

For the 104 water quality sites on the region’s other rivers and streams, the situation was less straight-forward. At seven of the sites, flows were considered to be reasonably steady, so no flow-adjustment was undertaken. Flows were recorded at or near 25 of the sites, so they were regarded as primary sites, and flows at the time of sampling were retrieved from the flow records. For the remaining 72 sites a “flow index” was calculated, based on the flow at the time of sampling at a location elsewhere on the relevant stream, or on a similar stream nearby. This approach must involve some uncertainty, but the magnitude of this is unclear.

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

The 104 sites in Table 3 are reasonably-evenly distributed across the whole Waikato region. It is convenient to divide the region into seven separate zones, based largely on river catchments and some broad ecological features, including geology, altitude, winter temperatures, and vegetation cover and land use (Table 3, Figure 1).

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 WISKI timeseries software system used by Waikato Regional Council are given.**

Map	Water quality site	Flow record	WISKI
A	*Taupo Gates*	Reids Farm	1131-119
B	Ohaaki Bridge	Ohaaki Bridge[†]	1131-159
C	Ohakuri tailrace	Ohakuri total	1131-163
D	Whakamaru tailrace	Whakamaru total	1131-162
E	Waipapa tailrace	Waipapa total	1131-161
F	*Narrows Bridge*	Karapiro total	1131-160
G	*Horotiu Bridge*	Hamilton Traffic	1131-64
H	Huntly Bridge	Huntly power station	1131-74
I	Mercer Bridge	Mercer	1131-91
J	*Tuakau Bridge*	Mercer	1131-91

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

Table 3: **Flow records used to flow-adjust water quality records for 104 Waikato region sites (see the map in Figure 1 for site locations). Sites for which a flow index was generated are shown in italics. WISKI identification codes for the flow recorder sites are given.**

Map	Water quality site	Flow record	WISKI
Coromandel (11 sites)			
91	*Hikutaia @ off Maratoto Rd*	Kauaeranga @ Smiths	234-11
92	Kauaeranga @ Smiths	Kauaeranga @ Smiths	234-11
4	Ohinemuri @ Karangahake (NIWA)	Ohinemuri @ Karangahake	619-16
99	Ohinemuri @ Queens Head	Ohinemuri @ Queens Head	619-19
98	*Ohinemuri @SH25*	Ohinemuri @ Queens Head	619-19
96	*Tairua @ Morrisons*	Tairua @ Broken Hills	940-2
93	Tapu @ Tapu-Coroglen Rd	Tapu @ Tapu-Coroglen Rd	954-5
94	*Waiau @ E309 Rd*	Tapu @ Tapu-Coroglen Rd	954-5
100	*Waitekauri u/s Ohinemuri*	Ohinemuri @ Queens Head	619-19
95	*Waiwawa @ SH25*	Waiwawa @ Rangihau Rd	1257-2
97	*Wharekawa @ SH25*	Wharekawa @ Adams Farm	1312-1
Hauraki (13 sites)			
32	*Mangawhero @ Mangawara Rd*	Mangawara @ Jefferis	481-2
35	*Oraka @ Lake Rd*	Oraka @ Pinedale	669-13
83	Piako @ Kiwitahi	Piako @ Kiwitahi	749-10
79	Piako @ Paeroa-Tahuna Rd	Piako @ Paeroa-Tahuna Rd	749-15
82	*Piakonui @ Piakonui Rd*	Piako @ Kiwitahi	749-10
33	Waihou @ Okauia	Waihou @ Okauia	1122-18
3	Waihou @ Te Aroha (NIWA)	Waihou @ Te Aroha	1122-34
37	*Waihou @ Whites Rd*	Oraka @ Pinedale	669-13
36	*Waiohotu @ Waiohotu Rd*	Oraka @ Pinedale	669-13
34	*Waiomou @ Matamata-Tauranga Rd*	Waihou @ Okauia	1122-18
31	*Waitakaruru @ Coxhead Rd*	Mangawara @ Jefferis	481-2
81	Waitoa @ Landsdowne Rd	Waitoa @ Waharoa Control	1249-38
80	Waitoa @ Mellon Rd	Waitoa @ Mellon Rd	1249-18
Inflows to Lake Taupo (12 sites)			
55	*Hinemaiaia @SH1*	Hinemaiaia @ Maungatera	171-4
58	*Kuratau @ SH41 Moerangi*	Kuratau @ SH41 Junction	282-3
101	Kuratau @ Te Rae Street	Flow reasonably steady—not adjusted	
53	*Mapara @ off Mapara Rd*	Tauranga-Taupo @ Te Kono	971-4
56	Tauranga-Taupo @ Te Kono	Tauranga-Taupo @ Te Kono	971-4
57	Tokaanu @ off SH41 Turangi	Flow reasonably steady—not adjusted	
103	Tokaanu Power Station tailrace	Tokaanu outflow	1491-1
5	Tongariro @ Turangi (NIWA)	Tongariro @ Turangi	1050-2
59	*Waihaha @ SH32*	Kuratau @ SH41 Junction	282-3
54	*Waitahanui @ Blake Rd*	Hinemaiaia @ Maungatera	171-4
104	*Whanganui @ Lakeside Lake Taupo*	Whareroa @ Fish Trap	1318-5
102	Whareroa @ Lakeside Lake Taupo	Whareroa @ Fish Trap	1318-5
Upland tributaries of the Waikato River (12 sites)			
48	*Kawaunui @ SH5*	Waiotapu @ Reporoa	1186-9
43	*Mangaharakeke @ SH30*	Tahunaatara @ Ohakuri Rd	934-1
49	Mangakara @ SH5	Flow reasonably steady—not adjusted	
60	*Mangakino @ Sandel Rd*	Mangakino @ Dillon Rd	388-2
46	Otamakokore @ Hossack Rd	Otamakokore @ Hossack Rd	683-4
52	*Pueto @ Broadlands Rd*	Waiotapu @ Reporoa	1186-9
44	Tahunaatara @ Ohakuri Rd	Tahunaatara @ Ohakuri Rd	934-1
51	Torepatutahi @ Vaile Rd	Flow reasonably steady—not adjusted	
47	*Waiotapu @ Campbell Rd*	Waiotapu @ Reporoa	1186-9
50	*Waiotapu @ Homestead Rd*	Waiotapu @ Reporoa	1186-9
42	*Waipapa @Tirohanga Rd*	Tahunaatara @ Ohakuri Rd	934-1
45	*Whirinaki @ Corbett Rd*	Otamakokore @ Hossack Rd	683-4

Table 3 (continued)

Map	Water quality site	Flow record	WISKI
Lowland tributaries of the Waikato River (26 sites)			
27	*Awaroa @ Otaua Rd*	Whakapipi @ SH22	1282-8
7	*Awaroa @ Rotowaro-Huntly Rd*	Mangawara @ Jefferis	481-2
85	*Karapiro @ Hickey Rd*	Pokaiwhenua @ Puketurua	786-2
90	*Kirikiriroa @ Tauhara Dr*	Mangaonua @ Dreadnought	421-4
6	Komakorau @ Henry Rd	Flow reasonably steady—not adjusted	
38	*Little Waipa @ Arapuni-Putararu Rd*	Pokaiwhenua @ Puketurua	786-2
87	*Mangakotukutuku @ Peacock Rd*	Mangaonua @ Dreadnought	421-4
40	*Mangamingi @ Paraonui Rd*	Pokaiwhenua @ Puketurua	786-2
77	*Mangaone @ Annebrooke Rd*	Mangaonua @ Dreadnought	421-4
78	*Mangaonua @ Hoeka Rd*	Mangaonua @ Dreadnought	421-4
84	*Mangaonua @ Te Miro Rd*	Mangaonua @ Dreadnought	421-4
30	Mangatangi @ SH2	Mangatangi @ SH2	453-6
29	*Mangatawhiri @ Lyons Rd*	Mangatangi @ SH2	453-6
19	*Mangawara @ Rutherford Rd*	Mangawara @ Jefferis	481-2
86	*Mangawhero @ Cambridge-Ohaupo*	Mangaonua @ Dreadnought	421-4
20	Matahuru @ Waiterimu Rd	Matahuru @ Waiterimu Rd	516-5
25	*Ohaeroa @ SH22*	Whakapipi @ SH22	1282-8
24	*Opuatia @ Ponganui Rd*	Whakapipi @ SH22	1282-8
39	Pokaiwhenua @ Arapuni-Putararu Rd	Pokaiwhenua @ Puketurua	786-2
21	*Waerenga @ Taniwha Rd*	Matahuru @ Waiterimu Rd	516-5
89	*Waitawhiriwhiri @ Edgecumbe St*	Mangaonua @ Dreadnought	421-4
26	Whakapipi @ SH22	Whakapipi @ SH22	1282-8
41	*Whakauru @ SH1*	Pokaiwhenua @ Puketurua	786-2
28	*Whangamarino @ Island Block Rd*	Matahuru @ Waiterimu Rd	516-5
22	*Whangamarino @ Jefferies Rd*	Matahuru @ Waiterimu Rd	516-5
23	Whangape @ Rangiriri-Glen Murray	Flow reasonably steady—not adjusted	
Waipa River and tributaries (16 sites)			
11	*Kaniwhaniwha @ Wright Rd*	Te Tahi @ Puketotara	1020-2
74	*Mangaohoi @ Maru Rd*	Puniu @ Pokuru	818-2
65	Mangaokewa @ Te Kuiti	Mangaokewa @ Te Kuiti	414-13
76	*Mangapiko @ Bowman Rd*	Puniu @ Pokuru	818-2
63	*Mangapu @ Otorohonga*	Waipa @ Honikiwi	1191-13
73	*Mangatutu @ Walker Rd*	Puniu @ Pokuru	818-2
13	*Mangauika @ Te Awamutu*	Te Tahi @ Pukeotara	1020-2
88	Ohote @ Whatawhata-Horotiu Rd	Flow reasonably steady—not adjusted	
75	Puniu @ Bartons Corner Rd	Puniu @ Pokuru	818-2
61	*Waipa @ Mangaokewa Rd*	Waipa @ Otewa	1191-7
12	*Waipa @ Pirongia-Ngutunui Rd*	Waipa @ Whatawhata	1191-11
2	Waipa @ Otewa (NIWA)	Waipa @ Otewa	1191-7
64	*Waipa @ SH3 Otorohonga*	Waipa @ Honikiwi	1191-13
1	Waipa @ Whatawhata (NIWA)	Waipa @ Whatawhata	1191-11
18	*Waitomo @ SH31 Otorohonga*	Waitomo @ Aranui/Ruakuri	1253-3
17	*Waitomo @ Tumutumu Rd*	Waitomo @ Aranui/Ruakuri	1253-3
West Coast (14 sites)			
70	*Awakino @ Gribbon Rd*	Awakino @ Gorge	33-14
69	*Awakino @ SH3-Awakau Rd*	Awakino @ Gorge	33-14
67	*Manganui @ off Manganui Rd*	Awakino @ Gorge	33-14
66	*Mangaotaki @ SH3*	Mokau @ Totoro	556-9
15	*Marokopa @ Speedies Rd*	Marokopa @ Falls	513-7
68	*Mokau @ Awakau Rd*	Mokau @ Totoro	556-9
62	*Mokau @ Mangaokewa Rd*	Mangaokewa @ Te Kuiti	414-13
71	Mokau @ Totoro Rd	Mokau @ Totoro	556-9
72	*Mokauiti @ Three Way Point*	Mokau @ Totoro	556-9
9	*Ohautira @ Waingaro-Te Uku Rd*	Marokopa @ Falls	513-7
14	*Oparau @ Langdon Rd*	Marokopa @ Falls	513-7
16	*Tawarau @ off Speedies Rd*	Tawarau @ Te Anga	976-2
8	*Waingaro @ Ruakiwi Rd*	Marokopa @ Falls	513-7
10	*Waitetuna @ Te Uku-Waingaro Rd*	Marokopa @ Falls	513-7

3 Results and discussion

3.1 Waikato River

Appendix 2 lists the *p*-values and trend slopes for the water quality records at the ten Waikato River sites for two time periods: 1993–2012 (20-years) and 2003–12 (10-years). In each case, a total of 168 separate water quality records were analysed. Table 4 lists the trend slopes (RSKSE) for 11 key variables over the past 20 years. In this report, trends where the *p*-value is less than 5% are regarded as being statistically significant (section 2.4). Furthermore, in both Appendix 2 and Table 4 a distinction is made between significant trends that are "important"—where the absolute value of the slope exceeds 1% per year (shown in bold)—and those that are "slight", where the slope is smaller than this.

The trends observed in the 11 key variables for the 20-year period 1993–2012 are described below. A small selection of water quality records is shown in Figure 2.[5]

Temperature. Significant trends in water temperature were observed at six sites, being four increases and two decreases (Table 4). However, all these trends were slight, being no larger than ±0.4% per year (or about ±0.06°C per year). No important improvements or deteriorations were observed. As increases in temperature make the water less suitable for temperature-sensitive organisms, particularly trout and native fish, the observed increases can be regarded as slight deteriorations, and vice versa.

Table 4: **Slopes (% per year) of statistically significant (*p* < 5%) trends in flow-adjusted water quality at ten Waikato River sites during 1993–2012 (see Appendix 2 for further details). Secondary sites (see section 2.6) are shown in italics. Important improvements are shown in bold; important deteriorations are bold underlined; "ns", not significant.**

	Temperature	**Dissolved oxygen**	**Turbidity**	**Visual clarity**	**Biochemical oxygen demand**	**Arsenic**	**Total nitrogen**	**Ammonia**	**Total phosphorus**	**Chlorophyll *a***	***Escherichia coli***
Taupo	0.4	ns	**2.4**	–	ns	**1.2**	ns	**–1.3**	**–2.3***	ns	ns
Ohaaki	ns	0.1	**1.2**	**–1.8**	ns	–0.9	**1.5**	**–5.0**	**–1.8**	ns	ns
Ohakuri	0.2	ns	**1.2**	**–1.3**	ns	ns	**1.8**	**–3.8**	ns	ns	ns
Whakamaru	ns	ns	**1.2**	**–1.3**	–	0.4	**2.5**	**–1.1**	ns	–	**3.4**
Waipapa	0.2	–0.2	**1.2**	**–2.1**	ns	ns	**2.0**	ns	ns	**–2.0**	ns
Narrows	0.2	ns	ns	ns	ns	ns	**1.5**	**–1.7**	ns	**–2.1**	ns
Horotiu	ns	ns	ns	ns	**–2.4**	ns	**1.1**	**–5.0**	ns	**–3.2**	ns
Huntly	ns	ns	**1.7**	ns	**–2.6**	–0.8	**1.0**	**–4.0**	**–1.0**	**–3.6**	**–3.2**
Mercer	–0.3	–0.3	**3.0**	–	–0.9	**–1.3**	**2.0**	ns	ns	**–3.2**	ns
Tuakau	–0.4	–0.3	**1.3**	**–1.2**	ns	**–1.0**	**1.4**	**–1.1**	ns	**–2.7**	ns
Total numbers of important trends											
Improvements	0	0	0	0	2	2	0	8	3	6	1
Deteriorations	0	0	8	5	0	1	9	0	0	0	1

*Note that the error due to arsenic interference is relatively large compared with the typically low phosphorus concentrations found at this site (see Appendix 1), so there is some uncertainty about this particular trend result.

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

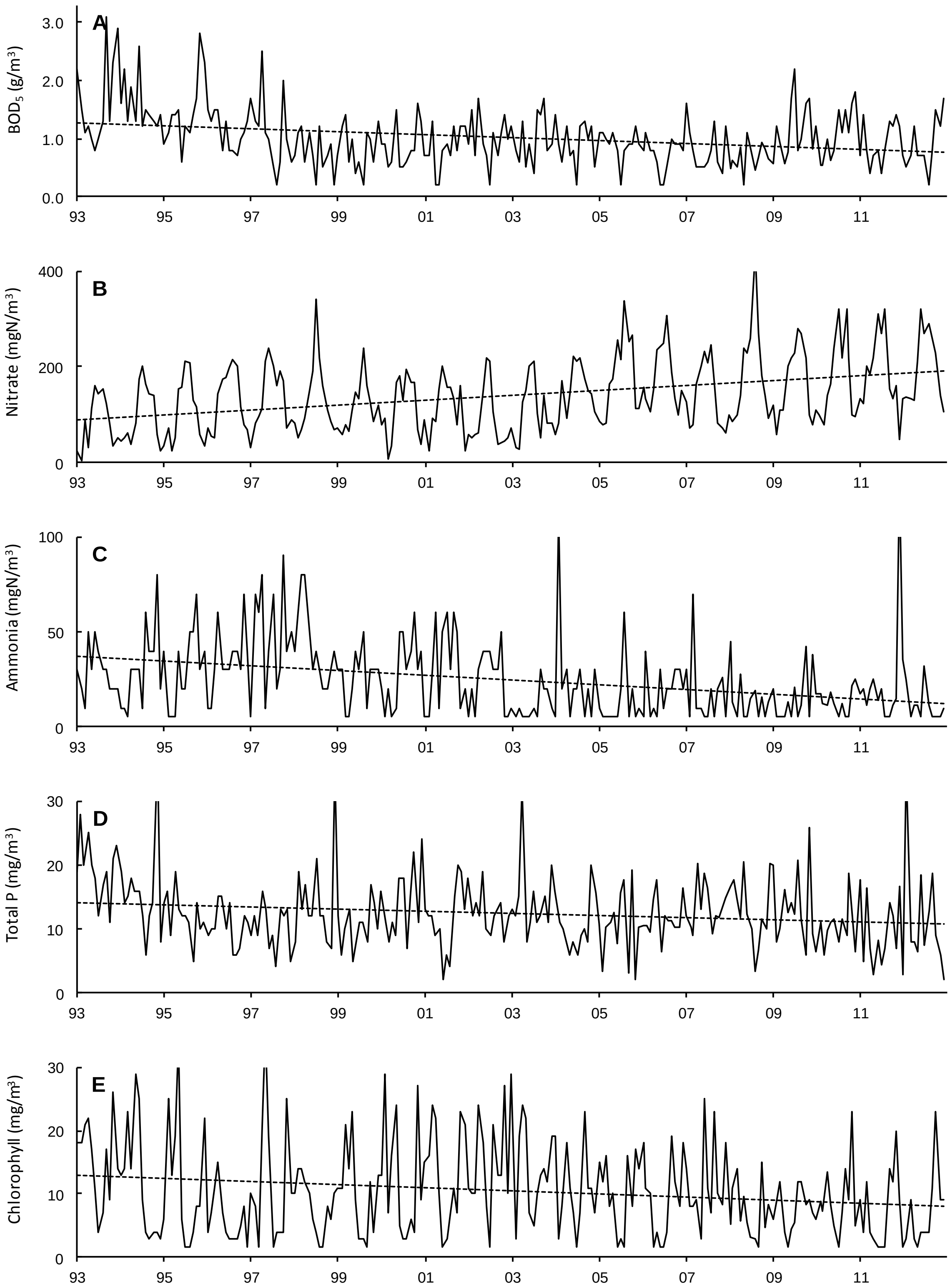

Figure 2: **Water quality at Waikato River sites during 1993–2012:** A, **BOD$_5$ at Horotiu (site G);** B, **nitrate at Waipapa (site E);** C, **ammonia at Horotiu (site G);** D, **total phosphorus at Ohaaki (site B); and** E, **chlorophyll at Narrows (site F). The dashed lines broadly indicate the overall trends in the records. Note that the units used for total phosphorus concentrations are mg/m^3, while in Appendix 1 the units used are g/m^3.**

Dissolved oxygen. At six sites there was no significant trend in dissolved oxygen levels (Table 4). Significant decreases were observed at three sites, and a significant increase at one site. However, the slopes or rates of change were all regarded as being slight (with none being larger than ±0.3% per year). The observed increase can be regarded as a slight improvement, and the decreases as slight deteriorations.

Turbidity. The turbidity records began in the middle of 1995 (18-year records). Significant trends in turbidity were observed at eight sites (Table 4), namely all except for Narrows (site F) and Horotiu (site G). In each case turbidity increased, with the slopes being in the range 1.2 to 3.0 % per year; all can thus be regarded as being important deteriorations. It is not clear why these changes have occurred.

Visual clarity. The black disc records began in early 1995 (18-year records); visual clarity was not measured at Taupo Gates (site A) or Mercer (site I). Significant trends in visual clarity were observed at five of the eight sites (Table 4), namely all except for Narrows (site F), Horotiu (site G) and Huntly (site H). In each case visual clarity decreased, with the slopes being in the range –1.2 to –2.1% per year; all can thus be regarded as being important deteriorations. These changes are consistent with the observed deteriorations in turbidity, but once again it is not clear why they occurred.

Biochemical oxygen demand. A significant increase in BOD_5 was observed at Whakamaru (site D; see Appendix 2). However, inspection of the record revealed a number of spikes and other higher values in recent years that are likely to be related to a safety-related change to sampling protocols at times when flows in the power station tailrace are high. Under these conditions fragments of filamentous algae and other biological material appear to be entrained into the water near the sampling location, thus contaminating the sample. The trend results for Whakamaru are therefore suspect—and are shown as shaded in Appendix 2, and have been omitted from Table 4.

Significant decreases in BOD_5 were observed at three sites, with those at Horotiu (site G, see Fig. 2A) and Huntly (site H) being important (slopes –2.4 and –2.6% per year, respectively). No significant trends were observed at the other sites. The decreases at Horotiu and Huntly probably reflect reductions in the loads of BOD_5 discharged to the river from upstream point sources, especially Hamilton sewage wastewater and the Horotiu meatworks. Wastewater treatment at these operations has improved markedly over the past 20–30 years.

Previous analyses found similar reductions in BOD_5 at most of the other monitoring sites on the river (e.g. Vant 2008). But in these cases much of the reduction occurred more than 20 years ago, and average values were stable during 1993–2012.

Arsenic. Significant trends in arsenic concentration were observed at six of the sites, with three of these being important (Table 4). Important improvements were observed at Mercer (site I) and Tuakau (site J). These are the most downstream of the monitoring sites, so the reductions in arsenic concentrations there seem unlikely to be connected to changes in discharges in the geothermal areas near the head of the river. Otherwise it is not clear why they occurred.

An important deterioration occurred at Taupo Gates (site A) at the head of the river. This suggests that increased loads from natural geothermal sources in and around Lake Taupo have been responsible for this particular change—noting that the site is upstream of the natural and industrial geothermal discharges to the section of the river between Taupo and Ohakuri (site C).

No important trends were observed in concentrations of boron (Appendix 2), a related geothermal contaminant, although slight decreases occurred at Ohaaki (site B, downstream of the Wairakei discharges) and Mercer (site I).

Total nitrogen. Significant trends in total N concentration were observed at nine sites (Table 4), namely all except for Taupo Gates (site A). In each case total N increased, with the slopes being in the range 1.0 to 2.5% per year; all can thus be regarded as being important deteriorations in water quality.

Since the 1990s, the moderate-to-large point source discharges of nitrogen to the river have either remained constant or have decreased (Vant 1999, 2010), such that the combined load from these point sources is now about half what it was during the 1990s.[6] This suggests that the increased total N concentrations observed throughout the river downstream of Taupo reflect increased losses from areas of developed land in the catchment. Indeed, as described below, important increases in concentrations of total N occurred in many of the river's tributaries during 1993–2012, particularly those in the catchment of the upper river where point source discharges are uncommon.

A similar pattern was observed in the trends in nitrate concentrations (Appendix 2), the main inorganic component of total N at many of the monitoring sites. Important deteriorations in nitrate occurred at the same nine sites (e.g. Figure 2B), but in this case the slopes were generally higher, with the average for the nine sites being 2.8% per year, compared with an average of 1.6% per year for total N. Larger increases were observed at some of these sites during the last ten years, 2003–12 (Appendix 2), indicating that the rate of deterioration there has recently increased.

Ammonia. Significant trends in ammonia concentration were observed at eight of the sites (e.g. Figure 2C). All of these were important improvements, with rates of change in the range –1.1 to –5.0% per year (Table 4). The lower concentrations in the river presumably result from improvements in the treatment of wastewaters from a variety of sources, including municipal sewage (Figure 2C, see comments above regarding BOD_5), industrial wastewaters and dairy shed discharges.

Total phosphorus. As noted above (section 2.1), a different method was used by the laboratory during 2004–12 to analyse total phosphorus concentrations. However, the results were affected by the presence of arsenic in the water samples, and a procedure was subsequently devised to deal with this (Appendix 1). In the trend analyses described here, total phosphorus results obtained during 2004–12 were corrected using this procedure.

Significant trends in total phosphorus concentration were observed at three of the sites: Taupo Gates (site A), Ohaaki (site B; see Figure 2D) and Huntly (site H). All were important improvements, with rates of change in the range –1.0 to –2.3% per year.[7]

The reduction in the total phosphorus concentration at Taupo Gates reflects a similar reduction that occurred during 2002–11 in Lake Taupo itself (Vant 2013). It is thought that this may reflect a reduction in the loads of particulate forms of phosphorus carried into the lake as the soil conservation measures that were implemented during 1976–89 reduced the erosion of the pumice soils in the Taupo catchment. Indeed, similar reductions in total

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[6] Unpublished results from consent monitoring and other sources, summarized in DM#1384112.

[7] A rather different outcome would have been obtained if the samples collected during 2004–12 had not been corrected for arsenic interference. In that case the 1993–2012 records showed important deteriorations at three sites, with rates of change of about 1.5% per year in each case. At these sites, namely Ohakuri, Whakamaru and Waipapa, phosphorus concentrations were relatively low and arsenic concentrations were relatively high, so the effects of arsenic interference were relatively important (Appendix 1). Previous trend analyses were probably affected by this (e.g. that for the period 1987–2007: Vant 2008).

phosphorus concentrations occurred during 2003–12 in several of the streams flowing into Lake Taupo (Appendix 3).

The reduction in the total phosphorus concentration at Ohaaki probably reflects the fact that discharge of sewage wastewater to the river from Taupo town ceased in the mid-1990s. Similarly, the reduction at Huntly may result from the improved treatment of wastewaters at facilities in the Hamilton-to-Ngaruawahia reach of the river. In particular, the discharge of treated sewage wastewater from Hamilton is an important source of phosphorus to the lower river, and in recent years the load discharged has been about 35% lower than that discharged during the 1990s.[8]

Chlorophyll *a*. A significant increase in chlorophyll *a* concentration was observed at the Whakamaru (site D; see Appendix 2). However, as with the record of BOD_5 at this site, inspection of the record revealed a number of spikes and other higher values in recent years that are likely to be related to a change to sampling protocols. Filamentous algae and other biological material may well have contaminated some recent samples. The trend results for Whakamaru are therefore suspect—and are shown as shaded in Appendix 2, and have been omitted from Table 4.

Significant trends in chlorophyll *a* concentration were observed at six sites, with all of these being important improvements (Table 4). The six sites were all downstream of Waipapa (site E), and had rates of change in the range –2.0 to –3.6% per year. In each case a similar long-term pattern in chlorophyll *a* concentrations was apparent, with average values being higher during 1993–94 and 2000–04 and lower during 2009–12 (e.g. Fig. 2E, Narrows).

It is not clear why these general reductions in chlorophyll *a* concentrations have occurred. Phytoplankton abundance is controlled by many factors, only some of which are routinely monitored (e.g. concentrations of nitrogen and phosphorus). Interestingly, during 2002–11 chlorophyll *a* concentrations declined in Lake Taupo (Vant 2013), and in Lake Rotoma, an oligotrophic lake in the Rotorua area (Bay of Plenty Regional Council, unpublished results). A possible explanation for the observed reductions is that the phytoplankton in these waterbodies are increasingly being eaten by a North American species of the zooplankton *Daphnia* which first appeared in North Island waters in the 1990s (Duggan et al. 2006, Balvert et al. 2009).

Escherichia coli. At eight sites there was no significant trend in *E. coli* concentrations (Table 4). An important improvement occurred at Huntly (site H), and an important deterioration at Whakamaru (site D).

The summary rows at the bottom of Table 4 provide an overview of the trend results for the 11 key water quality variables at the ten Waikato River sites during 1993–2012. The results can be summarised as follows:

- mixed results: records of water temperature and dissolved oxygen showed some slight improvements, slight deteriorations or little change; for *E. coli*, one important improvement and one important deterioration occurred, otherwise the records were stable; and two important improvements and one important deterioration occurred in concentrations of arsenic, otherwise changes were slight or the records were stable;
- general improvement: important improvements were observed in ammonia at eight sites, and in chlorophyll *a* at six sites;
- some improvement: important improvements were observed in biochemical oxygen demand at two sites, and in total phosphorus at three sites;
- general deterioration: important deteriorations were observed in turbidity (eight sites) and visual clarity (five sites), and in total nitrogen at nine sites.

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[8] Unpublished results from consent monitoring and other sources, summarized in DM#1384112.

3.2 Other rivers and streams

Appendix 3 lists the *p*-values and trend slopes for the water quality records at the 104 sites on the other rivers and streams for two time periods: 1993–2012 (20-years) and 2003–12 (10-years). In each case, about 1190 separate water quality records were analysed. Table 5 lists the trend slopes (RSKSE) from the 20-year records for eight key variables. As noted above, trends where the *p*-value is less than 5% are regarded as being statistically significant (section 2.4). Furthermore, both Appendix 3 and Table 5 distinguish between significant trends that are "important"—where the absolute value of the slope exceeds 1% per year (shown in bold)—and those that are "slight", where the slope is smaller than this.

The trends observed in the eight key variables for the 20-year period 1993–2012 are described below (Table 5). A small selection of water quality records is shown in Figure 3, and the spatial distribution of results for four of the variables is shown in Figure 4.

Table 6 summarizes the slopes of the trends in the individual water quality variables. It shows the median values of the standardized slope (RSKSE) (1) for all records (cf. Scarsbrook et al. 2003), (2) for the significant trends only (cf. Smith et al. 1996), and (3) for the significant and important trends only. In each case the binomial test was used to determine whether the overall proportion of increasing (or decreasing) slopes was significantly different (*p*-value < 5%) from 0.5. This helps identify variables for which there is an overall pattern of change across the region as a whole. In such cases, the median RSKSE is shown in bold.

Temperature. At many sites there was no significant trend in water temperature (Table 5). Significant, but slight trends occurred at 40 sites, all but two of which (Mangawhero Stream, site #36, and Tongaririo River, site #5) were increases (i.e. slight deteriorations). The median rate of change was 0.4% per year or about 0.06°C per year. The sites at which these trends occurred were distributed reasonably evenly across the seven water zones (Table 5).

Only one of the significant trends was important, namely that at the Whanganui Stream (site #102). In this case the temperature increased, so the trend was an important deterioration. The rate of increase was 1.2% per year or 0.13°C per year.

Dissolved oxygen. Significant trends were observed at more than half (63) of the sites; almost all (62) were slight. Many (46) trends were decreases (e.g. Figure 3A), so the overall pattern for sites in the region as a whole was a decrease in dissolved oxygen levels (Table 6). This represents a deterioration in water quality. However, the median value of the slopes (RSKSE) for the significant trends was low, being just –0.1% per year.

Only one of the significant trends was important, namely that at the Mangaone Stream (site #77). In this case dissolved oxygen levels increased, so the trend was an important improvement. The rate of increase here was 1% per year. The greatest rate of decrease (–0.5% per year) was observed in the Komakorau Stream (site #6).

Table 5: **Slopes (% per year) of statistically significant (*p* < 5%) trends in flow-adjusted water quality at 104 Waikato region river sites during 1993–2012 (see Appendix 3 for further details). Important improvements ("Imp") are shown in bold; important deteriorations ("Det") are bold underlined; "ns", not significant. The names of sites for which a flow index was generated (see section 2.6) are shown in italics. Note that site names have been abbreviated—see Table 3 for full description of each site (numbers in brackets are site numbers in Figure 1 and Table 3).**

	Temperature	Dissolved oxygen	Turbidity	Visual clarity	Total nitrogen	Ammonia	Total phosphorus	*Escherichia coli*
Coromandel								
Hikutaia (91)	ns	0.1	**–1.5**	**–1.2**	**–1.4**	**–7.9**	**–2.0**	ns
Kauaeranga (92)	ns	ns	**1.9**	**–2.2**	**3.3**	–0.1	ns	ns
Ohinemuri (4)	0.3	–0.2	ns	ns	ns	**–3.5**	**–3.4**	–
Ohinemuri (99)	ns	–0.2	**–1.7**	ns	**1.2**	ns	**–6.7**	**–10.2**
Ohinemuri (98)	ns	–0.1	ns	**–2.9**	ns	**–7.0**	**–2.0**	ns
Tairua (96)	0.5	–0.1	ns	ns	ns	–0.1	ns	ns
Tapu (93)	0.5	ns	ns	ns	ns	–0.1	ns	**–9.7**
Waiau (94)	0.3	ns	ns	ns	ns	–0.5	**–2.5**	ns
Waitekauri (100)	ns	ns	ns	**–1.8**	**–4.6**	**–24.6**	ns	**–8.1**
Waiwawa (95)	ns	–0.2	ns	ns	ns	ns	ns	ns
Wharekawa (97)	0.4	ns	**1.5**	ns	**2.2**	–0.6	ns	ns
Imp – Det	0 – 0	0 – 0	2 – 2	0 – 4	2 – 3	4 – 0	5 – 0	3 – 0
Hauraki								
Mangawhero (32)	–0.4	–0.2	ns	ns	0.6	**–1.1**	ns	ns
Oraka (35)	ns	ns	**3.4**	ns	0.9	ns	**–1.0**	**–7.4**
Piako (83)	0.4	–0.4	**–1.7**	ns	ns	**–5.3**	**–1.5**	ns
Piako (79)	ns	0.3	ns	**–1.5**	–0.8	**–4.1**	–0.9	ns
Piakonui (82)	ns	–0.2	**–2.4**	**1.7**	ns	**–1.3**	**–2.1**	ns
Waihou (33)	ns	ns	**2.1**	ns	**1.0**	**–2.3**	–0.6	ns
Waihou (3)	ns	–0.1	**1.4**	ns	0.5	ns	ns	–
Waihou (37)	0.1	–0.1	ns	ns	**1.7**	–0.3	–0.6	ns
Waiohotu (36)	0.7	–0.1	**2.0**	–	**1.4**	ns	ns	ns
Waiomou (34)	ns	ns	**2.0**	ns	**1.5**	ns	ns	ns
Waitakaruru (31)	ns	ns	**–1.3**	ns	**–1.1**	**–2.6**	ns	ns
Waitoa (81)	ns	ns	ns	**–1.7**	ns	**–4.5**	**–1.5**	ns
Waitoa (80)	ns	0.6	ns	**–1.4**	–0.8	**–4.6**	**–18.0**	ns
Imp – Det	0 – 0	0 – 0	3 – 5	1 – 3	1 – 4	8 – 0	5 – 0	1 – 0
Inflows to Lake Taupo								
Hinemaiaia (55)	ns	–0.2	**1.5**	**–1.2**	**1.1**	ns	–0.5	ns
Kuratau (58)	0.6	–0.1	ns	**–1.0**	ns	–0.5	**–1.5**	–
Kuratau (101)	0.5	ns	ns	–	**2.5**	0.0	ns	–
Mapara (53)	0.2	0.1	**–1.4**	ns	**1.1**	**–4.1**	–0.8	ns
Tauranga–Tau (56)	0.7	–0.1	**1.2**	**–1.5**	**1.6**	ns	–0.7	–
Tokaanu (57)	0.1	–0.2	**2.1**	–	**1.4**	0.0	ns	–
Tokaanu Pow (103)	ns	0.3	**5.0**	–	ns	ns	ns	–
Tongariro (5)	–0.2	ns	**–2.9**	**1.2**	**1.0**	**–5.0**	ns	–
Waihaha (59)	0.9	ns	ns	**–1.8**	0.7	ns	ns	ns
Waitahanui (54)	0.2	–0.1	ns	**–1.4**	**2.6**	ns	–0.8	**–7.2**
Whanganui (104)	**1.2**	–0.3	ns	–	**–2.5**	ns	ns	–
Whareroa (102)	ns	ns	ns	–	**1.4**	ns	**–2.8**	–
Imp – Det	0 - 1	0 - 0	2 - 4	1 - 5	1 - 8	2 - 0	2 - 0	1 - 0

Table 5 continued

	Temperature	Dissolved oxygen	Turbidity	Visual clarity	Total nitrogen	Ammonia	Total phosphorus	*Escherichia coli*
Upland tributaries of the Waikato River								
Kawaunui (48)	0.3	–0.2	ns	ns	**5.1**	ns	ns	ns
Mangaharakek (43)	0.7	ns	ns	ns	**6.0**	**–4.1**	ns	ns
Mangakara (49)	ns	ns	**1.6**	ns	**3.2**	**–3.0**	ns	ns
Mangakino (60)	0.5	–0.1	**1.3**	ns	**3.0**	ns	ns	–
Otamakokore (46)	0.3	0.3	**1.3**	**–1.3**	**1.7**	**–4.6**	ns	ns
Pueto (52)	0.4	ns	ns	ns	**1.9**	**–7.6**	ns	ns
Tahunaatara (44)	0.4	ns	**1.1**	**–1.2**	**2.1**	–0.7	ns	ns
Torepatutahi (51)	0.3	0.3	ns	–	**3.7**	0.0	–0.5	–
Waiotapu (47)	ns	0.2	ns	0.6	**1.9**	0.6	ns	ns
Waiotapu (50)	ns	0.3	ns	0.8	**1.2**	–0.5	ns	–
Waipapa (42)	0.2	0.1	ns	ns	**5.8**	–0.8	–0.7	ns
Whirinaki (45)	0.1	–0.1	ns	–	**2.2**	–0.5	ns	–
Imp – Det	0 – 0	0 – 0	0 – 4	0 – 2	0 – 12	4 – 0	0 – 0	0 – 0
Lowland tributaries of the Waikato River								
Awaroa-Otau (27)	ns	ns	**4.4**	**–4.8**	0.9	ns	**2.3**	–
Awaroa-Rotowa (7)	0.5	ns	ns	ns	**2.8**	ns	**–1.3**	ns
Karapiro (85)	ns	–0.3	**3.2**	**–2.0**	**1.3**	ns	–0.8	ns
Kirikiriroa (90)	ns	–0.2	**–2.0**	ns	**–4.1**	**–11.8**	**–2.7**	ns
Komakorau (6)	0.4	–0.5	**1.1**	ns	ns	**–2.3**	ns	ns
Little Waipa (38)	0.2	0.3	**3.6**	**–2.3**	**2.3**	ns	ns	ns
Mangakotukut (87)	ns	–0.2	**–1.3**	ns	ns	**–2.2**	**1.4**	ns
Mangamingi (40)	ns	ns	**2.7**	**–1.6**	0.5	**–9.9**	**–3.5**	ns
Mangaone (77)	0.5	**1.0**	**2.1**	**–2.4**	**–1.2**	**–4.6**	ns	ns
Mangaonua (78)	ns	0.4	ns	**–1.2**	ns	**–1.2**	**–1.8**	ns
Mangaonua (84)	0.3	–0.1	ns	ns	**–1.1**	**–17.3**	**–5.0**	ns
Mangatangi (30)	ns	ns	**5.8**	**–4.2**	**–1.2**	**–1.5**	0.7	–
Mangatawhiri (29)	ns	–0.4	ns	ns	**–2.1**	**–2.7**	ns	–
Mangawara (19)	ns	0.5	**1.0**	ns	ns	–0.8	ns	–
Mangawhero (86)	0.4	ns	**1.7**	**–1.3**	ns	**–4.1**	ns	ns
Matahuru (20)	0.4	ns	**3.0**	**–1.3**	–0.9	**–1.9**	0.8	–
Ohaeroa (25)	ns	ns	ns	**1.1**	**1.6**	**–3.6**	ns	–
Opuatia (24)	ns	–0.1	**4.1**	**–3.2**	**1.4**	**–2.7**	**1.6**	ns
Pokaiwhenua (39)	0.2	ns	**2.9**	**–1.6**	**1.7**	**–1.5**	**–1.9**	ns
Waerenga (21)	0.5	ns	**2.4**	**–1.5**	**1.1**	ns	ns	ns
Waitawhiriwhiri (89)	ns	–0.1	ns	ns	ns	**–2.0**	**–1.0**	ns
Whakapipi (26)	ns	0.2	**–1.6**	ns	**1.4**	**–4.7**	**1.7**	–
Whakauru (41)	ns	ns	**4.7**	**–2.6**	**5.7**	ns	**2.3**	**5.8**
Whangamarino (28)	0.6	ns	**–3.0**	ns	**2.1**	ns	ns	–
Whangamarino (22)	0.4	ns	ns	ns	**–1.8**	**–2.8**	ns	–
Whangape (23)	ns	0.4	**13.4**	**–5.5**	**5.4**	ns	**4.5**	–
Imp – Det	0 – 0	1 – 0	4 – 15	1 – 14	6 – 11	17 – 0	7 – 6	0 – 1

Table 5 continued

	Temperature	**Dissolved oxygen**	**Turbidity**	**Visual clarity**	**Total nitrogen**	**Ammonia**	**Total phosphorus**	***Escherichia coli***
Waipa River and tributaries								
Kaniwhaniwha (11)	0.5	–0.2	ns	ns	ns	**–1.7**	ns	–
Mangaohoi (74)	ns	ns	**–1.5**	**1.0**	–0.8	**–2.7**	–0.7	ns
Mangaokewa (65)	ns	–0.1	ns	ns	**1.3**	**–12.3**	ns	–
Mangapiko (76)	ns	ns	**2.4**	**–1.3**	–0.9	**–5.5**	ns	–
Mangapu (63)	ns	–0.2	ns	ns	**1.3**	ns	ns	ns
Mangatutu (73)	ns	ns	**1.0**	**–1.0**	**2.0**	**–1.5**	ns	ns
Mangauika (13)	0.5	–0.1	**3.6**	ns	**3.5**	–0.2	ns	ns
Ohote (88)	ns	ns	ns	**–2.6**	ns	ns	ns	ns
Puniu (75)	ns	–0.3	**3.6**	**–2.7**	**2.0**	**1.4**	ns	–
Waipa (61)	0.7	ns	ns	–0.9	**2.6**	ns	ns	–
Waipa (12)	ns	–0.1	ns	**–1.3**	**1.2**	ns	ns	ns
Waipa (2)	ns	0.0	**–3.6**	**2.1**	**1.0**	ns	**–1.3**	–
Waipa (64)	ns	–0.2	**–1.5**	ns	**1.9**	**–1.5**	**–1.0**	ns
Waipa (1)	ns	–0.1	**1.7**	**–1.2**	**1.0**	ns	**1.2**	–
Waitomo (18)	ns	–0.4	**1.0**	ns	0.9	**–2.3**	ns	ns
Waitomo (17)	ns	–0.1	ns	ns	0.9	**–7.2**	ns	ns
Imp – Det	0 – 0	0 – 0	3 – 6	2 – 6	0 – 10	8 – 1	2 – 1	0 – 0
West Coast								
Awakino (70)	ns	–0.2	ns	ns	**–1.2**	–0.3	ns	ns
Awakino (69)	ns	ns	ns	ns	**1.0**	**–2.5**	ns	ns
Manganui (67)	ns	–0.2	ns	ns	**1.0**	**–1.1**	ns	ns
Mangaotaki (66)	ns	ns	ns	ns	**1.3**	**–3.0**	ns	–
Marokopa (15)	ns	–0.1	ns	–0.7	**1.1**	**–2.0**	ns	**–7.9**
Mokau (68)	ns	ns	ns	**1.2**	**1.1**	**–1.9**	**–1.2**	ns
Mokau (62)	ns	–0.3	ns	–0.9	**1.7**	ns	0.9	ns
Mokau (71)	ns	–0.1	**–1.5**	ns	**1.3**	**–2.9**	ns	ns
Mokauiti (72)	ns	–0.2	**–1.6**	**1.6**	0.8	**–1.3**	ns	ns
Ohautira (9)	ns	ns	ns	**1.0**	**1.5**	**–5.3**	ns	ns
Oparau (14)	ns	ns	ns	–0.9	**1.0**	–0.3	ns	–
Tawarau (16)	ns	–0.1	ns	ns	0.9	**–1.7**	ns	–
Waingaro (8)	ns	0.2	ns	ns	**1.1**	**–1.8**	ns	–
Waitetuna (10)	ns	ns	**2.1**	**–1.1**	**1.5**	ns	ns	ns
Imp – Det	0 – 0	0 – 0	2 – 1	3 – 1	1 – 11	10 – 0	1 – 0	1 – 0
Total numbers of important trends								
Improvements	0	1	16	8	11	53	22	6
Deteriorations	1	0	37	35	59	1	7	1

Table 6: **Median values of the standardized trend slopes (RSKSE, % per year) for flow-adjusted water quality records at 104 sites on rivers and streams in the Waikato region, 1993–2012. Values in bold are cases where the binomial test's null hypothesis is rejected (*p* < 5%), indicating the existence of an overall pattern of change across the region as a whole.**

	All records	**Significant records**	**Significant and important records**
Temperature	**0.2**	**0.4**	1.2
Dissolved oxygen	**–0.1**	**–0.1**	–
Turbidity	**0.4**	**1.5**	**1.5**
Visual clarity	**–0.6**	**–1.3**	**–1.4**
Total nitrogen	**1.1**	**1.3**	**1.4**
Ammonia	**–1.3**	**–2.2**	**–2.9**
Total phosphorus	**–0.4**	**–1.0**	**–1.5**
E. coli	–0.2	–7.9	–7.9

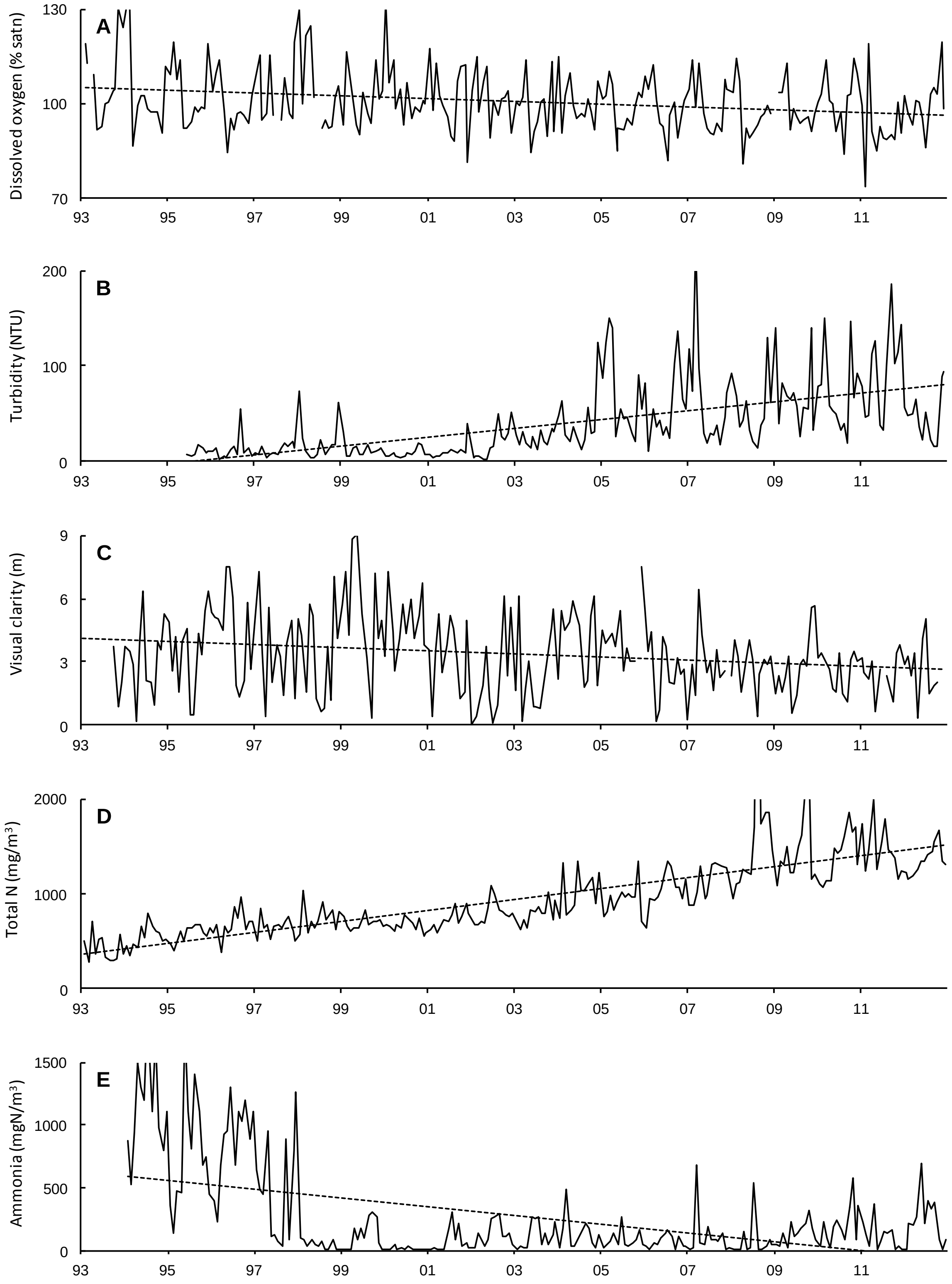

Figure 3: **Water quality at various sites during 1993–2012:** A**, Dissolved oxygen at Waitomo (Otorohanga, #18);** B**, turbidity at Whangape (#23);** C**, visual clarity at Kauaeranga (#92);** D**, total nitrogen at Waipapa (#42); and** E**, ammonia at Mangamingi (#40). The dashed lines broadly indicate the overall trends in the records.**

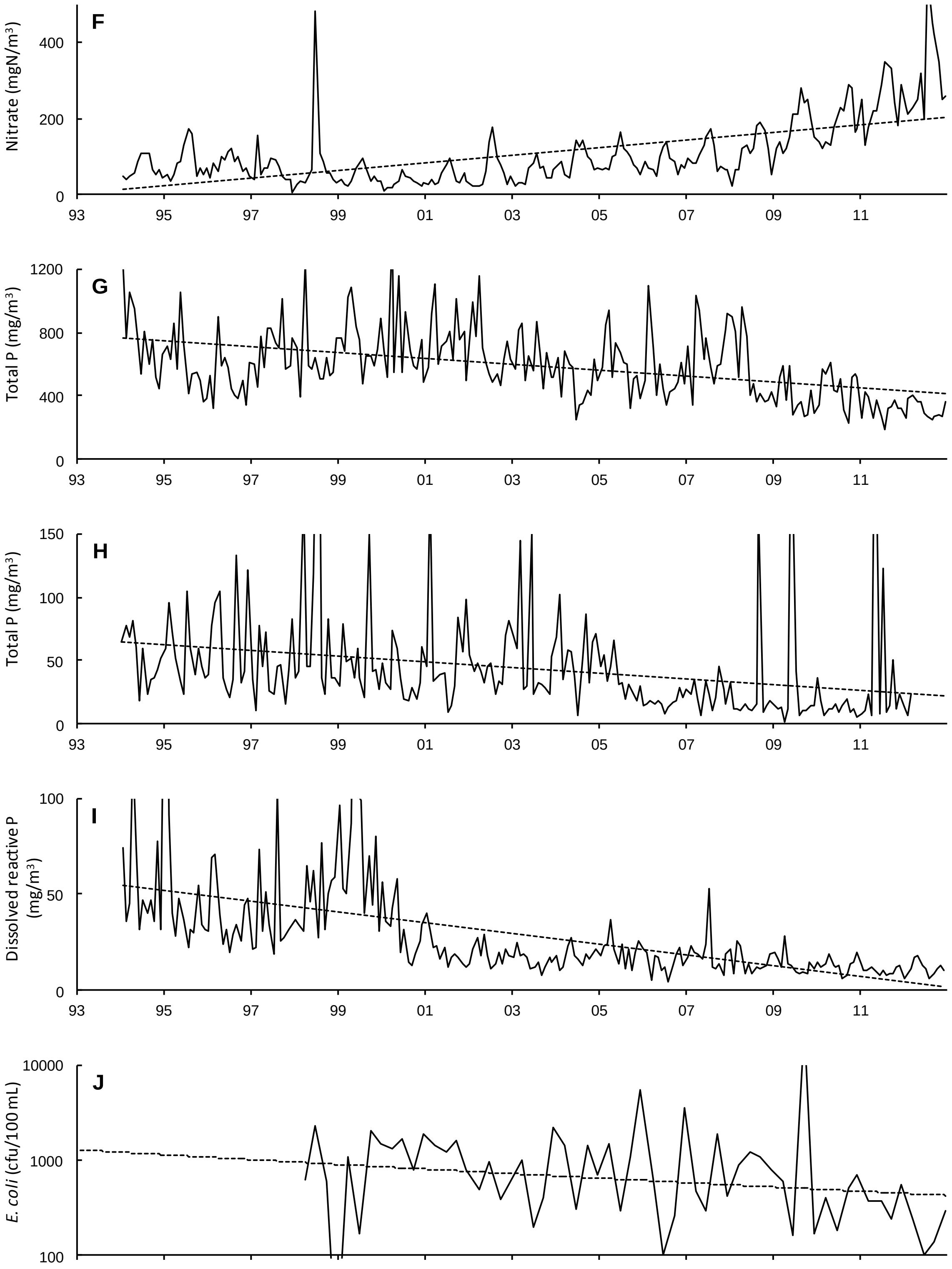

Figure 3 (continued): **Water quality at various sites during 1993–2012:** F**, Nitrate at Whakauru (#41);** G**, total phosphorus at Mangamingi (#40);** H**, total phosphorus at Ohinemuri (Queenshead, #99);** I**, dissolved reactive phosphorus at Mangaonua (Te Miro, #84); and** J**, *E. coli* (logarithmic scale) at Oraka (#35). The dashed lines broadly indicate the overall trends in the records. Note that the units used for phosphorus concentrations are mg/m^3, while in Appendix 1 the units used are g/m^3.**

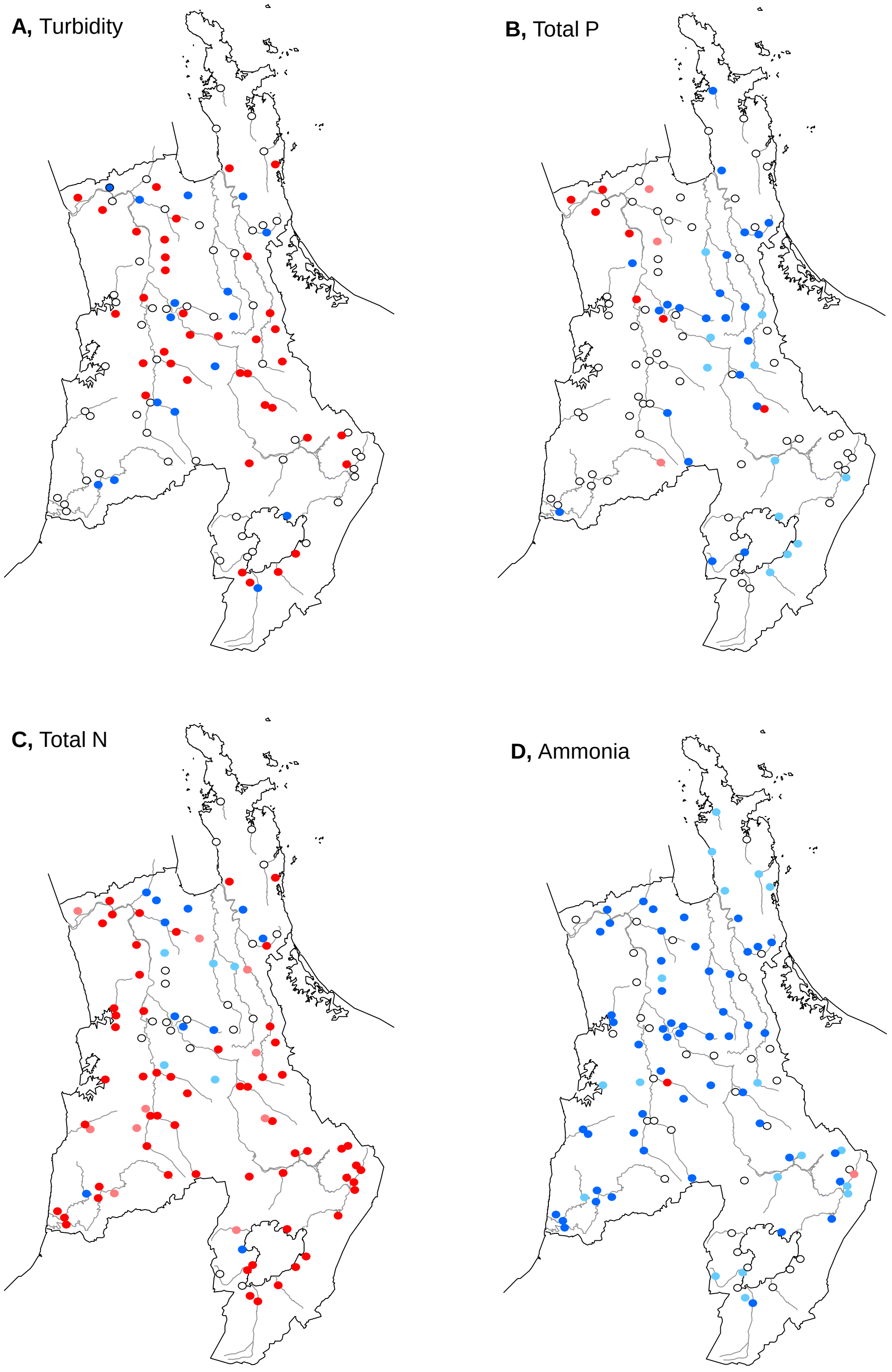

Figure 4: **Nature of trends for selected water quality variables at regional river sites during 1993–2012. The symbols distinguish between records showing no significant trend (open circles), and those showing one of the following significant trends: important improvement (dark blue), slight improvement (pale blue); slight deterioration (pink) and important deterioration (red).** A**, Turbidity;** B**, total phosphorus;** C**, total nitrogen; and** D**, ammonia;. See Figure 1 and Table 5 for details.**

In two of the water zones—Taupo and Upland Waikato, both of which are in the higher country in the south-east part of the region—similar numbers of improvements and deteriorations in dissolved oxygen occurred. In the other areas deteriorations tended to outweigh improvements, particularly in the Waipa and West Coast zones. It is unclear whether there's a common cause of the observed decreases; nor is it clear what the cause(s) might be.[9]

Turbidity. Significant trends in turbidity were observed at half (53) of the sites, and all were important trends. Deteriorations (37) were more than twice as common as improvements (16), so the overall pattern for sites in the region as a whole was a deterioration in turbidity (Table 6). The median value of the slopes (RSKSE) for the significant and important trends was 1.5% per year. Deteriorations in turbidity tended to be less common in the southern part of the region (Figure 4A).

The largest improvement in turbidity was –3.6% per year (Waipa @ Otewa, #2), while the largest deterioration was 13.4% per year (Whangape, #23; see Figure 3B). Note that the latter site is on the outflow from Lake Whangape, a shallow lake that has experienced very high levels of algae and resuspended bottom sediment for the past decade. This has probably caused the increased turbidity in the outflow.

Visual clarity. Visual clarity and turbidity are both measures of the optical properties of water, so they tend to broadly covary: higher turbidity is associated with lower clarity, and vice versa. So the trends in visual clarity that were observed in the region's streams are similar to those described above for turbidity.

Significant trends in visual clarity were observed at about half (49) of the sites at which it was measured (96), and most (88%) were also important trends. Of these, deteriorations (35; e.g. Figure 3C) were more than four times as common as improvements (8), so the overall pattern for sites in the region as a whole was a deterioration in visual clarity (Table 6). The median value of the slopes (RSKSE) for the significant and important trends was –1.4% per year.

The largest improvement (2.1% per year) and the largest deterioration (–5.5% per year) occurred at the sites that also experienced the largest changes in turbidity, namely Waipa River @ Otewa (site #2) and Whangape Stream (site #23). The smallest number of trends occurred in the Upland Waikato zone, so visual clarity was most stable over time in this area.

Total nitrogen. Significant trends in total N concentration were observed at many (85) of the sites, and many (82%) were important trends. Of these, deteriorations (59; e.g. Figure 3D) were about five times as common as improvements (11), so the overall pattern for sites in the region as a whole was a deterioration in total N (Table 6). The median value of the slopes (RSKSE) for the significant and important trends was 1.4% per year.

Deteriorations in total N occurred in most parts of the region (Figure 4C), but improvements tended to occur in the lowland areas of the Hauraki and Lowland Waikato zones. Important deteriorations in total N were observed at all sites in the Upland Waikato zone (e.g. Figure 3D), with the median rate of change there being 2.6% per year, well above the value for the region as a whole (Table 6). Many of these streams are spring-fed, with large underground aquifiers. Studies in the nearby Taupo catchment have shown that the water in such streams is often several decades old (Vant & Smith 2004b, Morgenstern 2007). So the progressive replacement of older water that fell as rain prior to the development of the catchment with newer water that is more-contaminated with development-based nitrogen

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

means that ongoing increases in stream nitrogen concentrations have been common in recent decades.

Some of the important improvements in total N occurred in highly-modified streams where specific sources of nitrogen have been better-managed over the past decade or more: Kirikiriroa (#90; landfill leachate), Mangaone (#77; spray-irrigated dairy factory wastewaters), and Waitekauri (#100; mining wastewaters). Many of the important deteriorations, however, have occurred in more-developed catchments. This is likely to reflect increased leaching losses from areas of pastoral farming following intensification in recent decades.

Ammonia. Significant trends in ammonia concentration were observed at many (73) of the sites, and many (74%) were also important trends. All but one (Puniu River, site #75) of these were improvements (e.g. Figure 3E), so the overall pattern for sites in the region as a whole was an improvement in ammonia concentrations (Table 6). Sites at which improvements occurred were reasonably-evenly distributed across the region (Figure 4D). The median value of the slopes (RSKSE) for the significant and important trends was –2.9% per year.

At several sites substantial decreases in ammonia have occurred during the past two decades as a result of the reduction or removal of loads from point source discharges further upstream: Waitekauri (#100; mining wastewaters), Kirikiriroa (#90; landfill leachate), Mangamingi (#40; sewage wastewaters; Figure 3E) and Mangaokewa (#65; stockyard runoff).

However, the median value of SKSE—that is, the slopes expressed in concentration units—for significant trends in ammonia (–0.3 mg $N/m^3/yr$) was considerably smaller than the median value of SKSE for significant trends in total N (+9.0 mg $N/m^3/yr$). This means that the overall decreases in ammonia concentrations were substantially out-weighted by increases in other forms of nitrogen (e.g. nitrate, see Appendix 3; e.g. Figure 3F), such that the overall outcome for rivers in general across the region was an increase in concentrations of total N (Figures 4C and 4D).

Total phosphorus. As described above, the laboratory analyses for total P carried out during 2004–12 did not include the previously-used procedure to correct for possible interference by arsenic in the water samples (see Appendix 1). In contrast to the situation for the Waikato River sites, however, arsenic was not routinely determined in samples from the sites on the other rivers and streams, at least four of which are affected by geothermal waters.[10] This means it was not possible to use the calculations outlined in Appendix 1 to correct the records for the non-Waikato River sites.

Noticeable biases were apparent in the total P records for the four geothermally-affected sites, so the total P results for samples from them collected during December 2004 to September 2012 were ignored in the trend analyses described here. However, the change in laboratory method did not appear to have affected the records for the other 100 sites, so their records were not edited in this way.

Significant trends in total P concentration were observed at less than half (43) of the sites, with many (67%) also being important. Of these, improvements (22; e.g. Figures 3G, 3H and 3I) were three times as common as deteriorations (7), so the overall pattern for sites in the region as a whole was an improvement in total P concentrations (Table 6). The median value of the slopes (RSKSE) for the significant and important trends was –1.5% per year.

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[10] Note that the five sites monitored by NIWA are not in geothermal areas, and although the total phosphorus method now used for these sites does not include a procedure to correct for possible interference by arsenic, NIWA considers that total phosphorus results for the sites are unlikely to be unduly affected by any such interference: G Bryers, NIWA, pers. comm.

Improvements in total P concentration tended to be more common in the eastern half of the region, and deteriorations tended to be focused in the north-west area, while total P concentrations were reasonably stable in the Taupo, Waipa and West Coast zones (Figure 4B).

Escherichia coli.[11] Significant trends in *E. coli* concentrations were observed at just seven sites, and all were important. All but one (Whakauru, site #41) were improvements (e.g. Figure 3J), and the median value of the slopes (RSKSE) was –7.9% per year. However, the small number of trends meant that there was no evidence of a pattern across the region as a whole (Table 6). Three of the sites where improvements occurred were in the Coromandel zone, with one improvement in each of the Hauraki, Taupo and West Coast zones.

The summary rows at the bottom of Table 5 provide an overview of the trend results for the eight key water quality variables at the 104 river sites during 1993–2012. The results can be summarised as follows:

- mixed results: records of water temperature and dissolved oxygen showed (1) some slight improvements, (2) larger numbers of slight deteriorations, or (3) little change; and for *E. coli*, five important improvements and one important deterioration occurred, otherwise the records were stable;
- general improvement: important improvements in ammonia concentration occurred at just over half of the sites;
- some improvement: important improvements in total phosphorus concentration occurred at more than one-fifth of the sites;
- some deterioration: important deteriorations in turbidity and visual clarity occurred at about one-third of sites (but modest numbers of important improvements occurred as well);
- general deterioration: important deteriorations in total nitrogen concentration occurred at just over half of the sites.

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[11] Note that these records contain fewer results than those for many other variables, so that the sample size is considerably smaller (n = 57–60: Table 1). As a result care should be taken in comparing the trend results for *E. coli* with those reported for other variables.

4 Conclusions

1. For the Waikato River, records for 11 key water quality variables were analysed at 8–10 monitoring sites, giving a total of 106 records that were considered (Table 4). Average water quality during 1993–2012 was found to be stable in 46 (43%) of these records. Statistically significant (*p*-value < 5%) trends were found in the remaining records, with 46 records (43%) showing trends that were both significant and important (i.e. the absolute value of the slope, RSKSE, a measure of the rate of change in water quality, was greater than 1% per year). About half (22) of these latter trends represented important improvements in water quality, and the remainder (24) represented important deteriorations. Figure 5A summarises the changes in water quality in the Waikato River during 1993–2012.

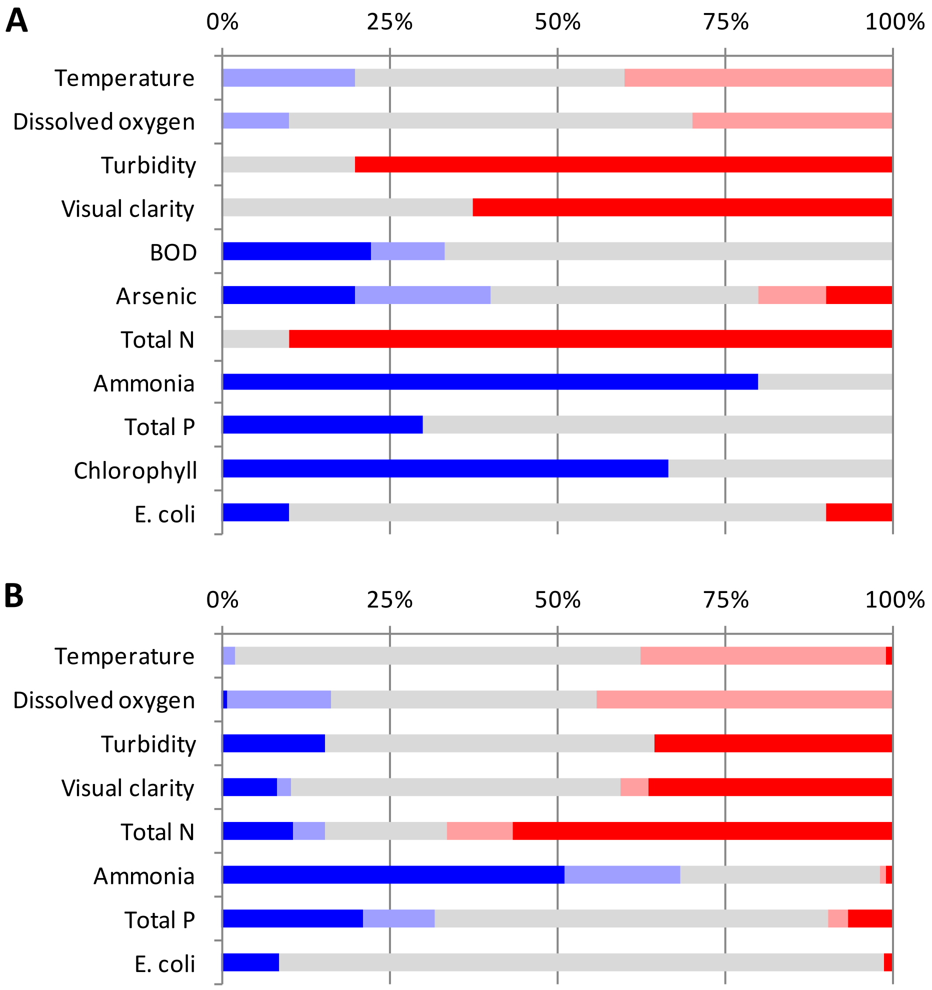

Figure 5: **Proportion of records showing trends in key water quality variables at monitoring sites on rivers in the Waikato region, 1993–2012. A, Waikato River (see Table 4 for further details); B, other rivers and streams (see Table 5 for further details). The colours distinguish between records showing no significant trend (grey), and those showing one of the following significant trends: important improvement (dark blue), slight improvement (pale blue); slight deterioration (pink) and important deterioration (red).**

2. Records of temperature and dissolved oxygen at Waikato River sites were either stable or showed only slight trends. Records of arsenic and *E. coli* showed only a small number of important trends, both improvements and deteriorations. There were only small numbers of important trends in biochemical oxygen demand (2) and total phosphorus (3) as well, but all were improvements. Important improvements were more common in records of chlorophyll *a* (6) and ammonia (8). Conversely, important deteriorations were generally observed in records of visual clarity (5), turbidity (8) and total nitrogen (9). The improvements in BOD and ammonia have probably resulted from improved treatment of point source discharges to the river, while intensification of pastoral farming in the Waikato catchment probably caused the deterioration in total N.

3. For the other rivers and streams, records for eight key water quality variables were analysed at 69–104 sites, giving a total of 789 records that were considered (Table 5). Average water quality during 1993–2012 was found to be stable in 375 (48%) of these records. Statistically significant trends were found in the remaining records, with 258 records (33% of the total number) showing trends that were both significant and important. Some 117 (15%) of these latter trends represented important improvements in water quality, and the remainder (141, or 18%) represented important deteriorations. Figure 5B summarises the changes in water quality in the other rivers and streams during 1993–2012.

4. Records of temperature and dissolved oxygen at these other river and stream sites were either stable or showed only slight trends. Records of *E. coli* showed only a small number of important trends, namely six improvements and one deterioration. Important improvements occurred in records of ammonia at about half of the sites, and slight improvements at a further 18 sites; deteriorations occurred at only two sites. At many sites, concentrations of total phosphorus were either stable (61 sites) or showed only slight trends (14 sites). Important improvements in total phosphorus occurred at 22 sites, while important deteriorations occurred at 7 sites. Important deteriorations in turbidity were about twice as common (37 sites) as important improvements (16 sites); similar results were found for visual clarity (35 sites and 8 sites, respectively). Important deteriorations in total nitrogen occurred at more than half of the sites (59), while important improvements occurred at 11 sites.

5. The reductions in concentrations of ammonia were more than offset by the increases in concentrations of nitrate (plus nitrite), the other inorganic form of nitrogen found in the rivers. The net result of this was for concentrations of total nitrogen to generally increase across the region. Runoff and leaching of nitrogen from areas of pastoral farming probably accounts for much of this deterioration. In the south-eastern part of the region where large groundwater aquifers are present in the freely-draining volcanic soils, older water that fell as rain prior to the development of the catchment has been progressively replaced with newer water that is more-contaminated with development-based nitrogen. This means that increasing nitrogen concentrations have been common in streams in this area in recent decades.

References

Balvert SF, Duggan IC, Hogg ID 2009. Zooplankton seasonal dynamics in a recently filled mine pit lake: the effect of non-indigenous Daphnia establishment. Aquatic Ecology 43:403–413.

Duggan IC, Green JD, Burger DF 2006. First New Zealand records of three non-indigenous zooplankton species: Skistodiaptomus pallidus, Sinodiaptomus valkanovi, and Daphnia dentifera. New Zealand Journal of Marine and Freshwater Research 40:561–569.

Gilbert RO 1987. Statistical methods for environmental pollution monitoring. New York, Van Nostrand Reinhold.

Helsel DR, Hirsch RM 1992. Statistical methods in water resources. Amsterdam, Elsevier.

Larned ST, Scarsbrook MR, Snelder TH, Norton NJ, Biggs BJF 2004. Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. New Zealand Journal of Marine and Freshwater Research 38: 347–366.

Morgenstern U 2007. Lake Taupo streams—water age distribution, fractions of landuse impacted water, and future nitrogen load. Environment Waikato technical report 2007/26. Hamilton, Waikato Regional Council (Environment Waikato)

Scarsbrook MR, McBride CG, McBride GB, Bryers GG 2003. Effects of climate variability on rivers : consequences for long-term water quality analysis. Journal of the American Water Resources Association 39:1435–1447.

Smith DG, McBride GB 1990. New Zealand's national water quality monitoring network: design and first year's operation. Water Resources Bulletin 26:767–775.

Smith DG, Macaskill JB, Stevenson CD, Edgerley WHL eds. 1982 Physical and chemical methods for water quality analysis. Water and Soil miscellaneous publication 38. Wellington, National Water and Soil Conservation Organisation.

Smith DG, McBride GB, Bryers GG, Wisse J, Mink DFJ 1996. Trends in New Zealand's national river water quality network. New Zealand Journal of Marine and Freshwater Research 30:485–500.

Tulagi A 2013a. Waikato River water quality monitoring programme : data report 2012. Waikato Regional Council Technical Report 2013/12. Hamilton, Waikato Regional Council.

Tulagi A 2013b. Regional Rivers water quality monitoring programme : data report 2012. Waikato Regional Council Technical Report 2013/13. Hamilton, Waikato Regional Council.

Vant B 1999. Sources of the nitrogen and phosphorus in several major rivers in the Waikato region. Environment Waikato Technical Report 1999/10. Hamilton, Waikato Regional Council (Environment Waikato).

Vant B 2008: Trends in river water quality in the Waikato region, 1987–2007. Environment Waikato Technical Report 2008/33. Hamilton, Waikato Regional Council (Environment Waikato).

Vant WN 2010. Water quality. In: Collier KJ, Hamilton DP, Vant WN, Howard-Williams C eds. Waters of the Waikato: ecology of New Zealand's longest river. Hamilton, Waikato Regional Council and University of Waikato. 93-114.

Vant B 2013. Recent changes in the water quality of Lake Taupo and its inflowing streams. New Zealand Journal of Forestry 58:14–17.

Vant B, Smith P 2004a. Trends in river water quality in the Waikato region, 1987–2002. Environment Waikato Technical Report 2004/02. Hamilton, Waikato Regional Council (Environment Waikato).

Vant B, Smith P 2004b. Nutrient concentrations and water ages in 11 streams flowing into Lake Taupo. Environment Waikato Technical Report 2002/18R. Hamilton, Waikato Regional Council (Environment Waikato).

Vant B, Wilson B 1998. Trends in river water quality in the Waikato region, 1980–97. Environment Waikato Technical Report 1998/13. Hamilton, Waikato Regional Council (Environment Waikato).

Appendix 1: Adjusting Waikato River total phosphorus results for interference by arsenic

For many years the routinely-used method for determining phosphorus in New Zealand freshwaters involved a thiosulphate reduction step to minimise interferences from arsenic (Smith et al. 1982). This was particularly suited to the analysis of samples collected from the Waikato River where geothermal waters in both naturally-occurring and industrial inflows mean that concentrations of arsenic are relatively high (e.g. averaging about 0.03 g/m^3 at the Whakamaru hydrolake, downstream of the main geothermal inputs: Vant 2010).

Up until late 2004, the total phosphorus analyses for all water quality samples collected under the Waikato River (and Regional Rivers) monitoring programmes included the thiosulphate reduction step. However, in December 2004 the council's contractor, Hill Laboratories, introduced a modified analysis for total phosphorus which did not include procedures to avoid interference with arsenic. Following an investigation by council and laboratory staff, the thiosulphate reduction step was re-instated in October 2012. This means that all samples analysed for total phosphorus during the period December 2004 to September 2012 were subject to interference by arsenic. As a result, concentrations of total phosphorus determined during this period are likely to be higher than the true value, with the extent of the over-estimate depending on the concentration of arsenic in the water sample: higher concentrations of arsenic mean a larger error, and vice versa.

During April 2012 to March 2013 we undertook an investigation of the extent to which the method in use during 2004–12 overestimated the concentration of total phosphorus in samples collected from the Waikato River. This involved analysing paired samples from all ten routinely-monitored sites for total phosphorus both with and without the thiosulphate reduction step. Monthly samples (12) were collected from each site, meaning a total of 120 paired samples were analysed, spanning a wide range of both total phosphorus and arsenic concentrations.

For each pair of samples, the error is the difference between the result obtained without thiosulphate reduction and that obtained with it. Figure A1 shows the error in the total phosphorus analysis for each of the 120 paired samples, plotted against the arsenic concentration measured in each water sample. Although there is a considerable amount of scatter in the results, the error in the phosphorus analyses clearly increased as the arsenic concentration increased (r = 0.39, p-value <0.01%). The scatter in the results probably arises from several sources of uncertainty, including analytical variability in the laboratory. In particular, inspection of the data showed that both "within month" and "between month" variability occurred, with the latter possibly reflecting slightly different handling procedures for each (monthly) batch of analyses (e.g. resulting in different contact times for the various chemical reactions).

Figure A2 shows the average error at each site over the 12-month period plotted against the average arsenic concentration for that site. In this case the values were highly-correlated, with only the result for Tuakau ("T") appearing as an outlier (r = 0.98, p-value <0.001%, omitting the Tuakau result).

The relationships shown in Figures A1 and A2 provide a way of adjusting the total phosphorus results that were obtained during 2004–12 using the method that did not correct for arsenic interference (noting that phosphorus results which were below the detection limit of 0.004 g/m^3 were not adjusted). For each water sample, the error in the total phosphorus result can be estimated from the arsenic concentration measured in that sample ([As]). Using the relationship shown in Figure A1, the quantity $[TP]_{cor1}$ (or "Total phosphorus concentration, correction method #1") can be obtained as (units are g/m^3):

$$[TP]_{cor1} = [TP]_{uncorrected} - (0.2206\times[As] - 0.0017)$$

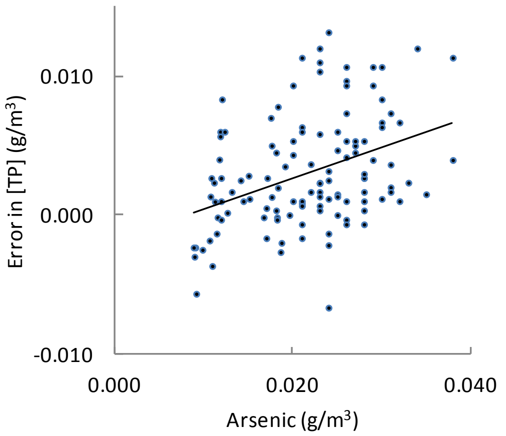

Figure A1: Errors in total phosphorus concentration plotted against arsenic concentration in samples from 10 Waikato River sites.

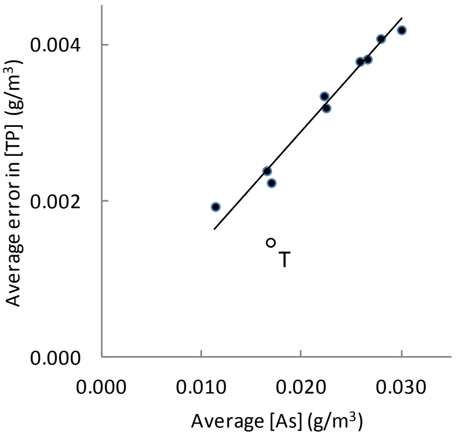

Figure A2: Average errors in total phosphorus concentration plotted against average arsenic concentration in samples from 10 Waikato River sites. "T", results for site at Tuakau.

Similar results were obtained by forcing the regression line in Figure A1 to pass through the origin (r = 0.36, p-value <0.01%), giving $[TP]_{cor1B}$. In principle this is a more rigorous approach: "no arsenic present implies no error (rather than a negative error)".

Similarly, the relationship shown in Figure A2—obtained using "force zero" regression of the site-average errors and arsenic concentrations (Table A1) for sites other than Tuakau—allows calculation of "Total phosphorus concentration, correction method #2" or $[TP]_{cor2}$ as:

$$[TP]_{cor2} = [TP]_{uncorrected} - 0.1460\times[As]$$

Finally, the individual monthly results obtained at each site can be corrected by subtracting the average error at that site (Table A1) as:

$$[TP]_{cor3} \text{ (site } i) = [TP]_{uncorrected} - \text{Average error (site } i)$$

Table A1 shows the average values of the uncorrected total phosphorus concentration at each of the ten sites, together with the corresponding values for the corrected concentrations based on each of the three methods outlined above.

Between Taupo Gates and Horotiu, the average error was an appreciable proportion (7–35%) of the total phosphorus concentration. Between Huntly and Tuakau it was a minor proportion (2–3%). This indicates that the need to correct for arsenic interference is greater at the upper river sites—where phosphorus concentrations were relatively low and arsenic concentrations were relatively high—than at lower river sites where the converse applied.

The various correction methods all gave broadly similar results for each of the sites (Table A1). The second method ($[TP]_{cor2}$) is used in the trend analyses described in this report.

Table A1: Average arsenic and uncorrected total phosphorus concentrations, errors in the total phosphorus concentration and corrected total phosphorus concentrations (see text) at ten Waikato River sites, April 2012 to March 2013. *n* = 12 in each case. Units are g/m^3 (note that units of mg/m^3 are used for phosphorus in Figures 2 and 3)

Site	**[As]**	**$[TP]_{uncorrected}$**	**Error**	**$[TP]_{cor1}$**	**$[TP]_{cor1B}$**	**$[TP]_{cor2}$**	**$[TP]_{cor3}$**
Taupo Gates	0.011	0.006	0.002	0.005	0.004	0.004	0.004
Ohaaki	0.027	0.016	0.004	0.011	0.012	0.012	0.012
Ohakuri	0.030	0.026	0.004	0.020	0.021	0.021	0.022
Whakamaru	0.028	0.029	0.004	0.024	0.024	0.024	0.025
Waipapa	0.026	0.033	0.004	0.029	0.029	0.029	0.029
Narrows	0.022	0.041	0.003	0.037	0.037	0.038	0.038
Horotiu	0.022	0.050	0.003	0.047	0.047	0.047	0.047
Huntly	0.017	0.065	0.002	0.063	0.063	0.063	0.063
Mercer	0.016	0.072	0.002	0.070	0.069	0.069	0.069
Tuakau	0.017	0.070	0.001	0.068	0.067	0.067	0.068

Appendix 2: ***p*-values (%) and, in brackets, trend slopes (% per year) for monthly records of flow-adjusted water quality variables at ten Waikato River sites. For each site the results in the upper row are for 1993–2012 (20-year record); lower row, 2003–12 (10-year record). Important improvements (see text) are shown in bold; important deteriorations are bold underlined. Values in shaded cells are suspect: see text. The names of sites for which a flow index was generated (see section 2.6) are shown in italics.**

	Temperature	**Dissolved oxygen**	**Conductivity**	**Turbidity**	**Visual clarity**	**Biochemical oxygen demand**	**Arsenic**	**Boron**	**Total nitrogen**	**Nitrate-N**	**Ammonia**	**Total phosphorus**	**Dissolved reactive P**	**Chlorophyll a**	**Faecal coliforms**	***Escherichia coli***	**Enterococci**
Taupo	<1 (0.4)	23 (0.0)	7 (0.1)	**<1 (2.4)**	–	7 (1.0)	**<1 (1.2)**	17 (0.1)	15 (0.8)	**1 (–1.4)**	**<1 (–1.3)**	**1 (–2.3)**	9 (–0.6)	98 (0.0)	92 (0.1)	94 (–0.1)	85 (0.3)
	31 (0.3)	6 (–0.2)	<1 (–0.3)	**<1 (7.1)**	–	**1 (6.6)**	29 (0.2)	39 (0.2)	49 (1.5)	11 (4.4)	4 (0.1)	**1 (–4.7)**	**<1 (–6.3)**	24 (0.0)	10 (7.2)	9 (7.3)	92 (0.5)
Ohaaki	7 (–0.2)	1 (0.1)	<1 (–0.4)	**2 (1.2)**	**<1 (–1.8)**	18 (0.6)	<1 (–0.9)	<1 (–0.7)	**<1 (1.5)**	**1 (1.0)**	**<1 (–5.0)**	**<1 (–1.8)**	**<1 (–2.4)**	21 (0.0)	**<1 (–6.5)**	6 (–2.3)	**2 (–2.3)**
	34 (0.3)	2 (–0.4)	39 (0.2)	**<1 (4.0)**	**<1 (–4.7)**	**<1 (7.6)**	55 (0.3)	74 (0.2)	27 (1.2)	**<1 (4.4)**	52 (0.8)	16 (–1.7)	**4 (–4.7)**	7 (0.0)	50 (–2.0)	99 (–0.2)	21 (3.1)
Ohakuri	1 (0.2)	16 (–0.1)	16 (0.1)	**<1 (1.2)**	**<1 (–1.3)**	7 (1.0)	30 (0.2)	18 (0.3)	**<1 (1.8)**	**<1 (2.0)**	**<1 (–3.8)**	47 (0.3)	11 (–0.7)	77 (0.1)	**1 (–3.0)**	63 (–0.7)	6 (–1.7)
	11 (0.4)	49 (–0.1)	25 (0.3)	34 (0.5)	**<1 (–3.2)**	8 (2.5)	74 (–0.2)	49 (0.3)	98 (0.1)	23 (1.3)	98 (–0.5)	86 (–0.4)	**1 (–3.5)**	9 (–2.1)	40 (–3.9)	38 (–2.5)	37 (–2.6)
Whakamaru	15 (0.2)	42 (0.0)	7 (0.1)	**<1 (1.2)**	**<1 (–1.3)**	**2 (1.5)**	4 (0.4)	14 (0.3)	**<1 (2.5)**	**<1 (2.5)**	**1 (–1.1)**	18 (0.4)	72 (–0.1)	**2 (1.6)**	38 (1.0)	**5 (3.4)**	**1 (5.3)**
	<1 (0.8)	42 (0.2)	45 (–0.2)	10 (1.2)	**<1 (–5.1)**	**<1 (7.5)**	71 (–0.1)	79 (0.1)	15 (1.0)	83 (0.2)	**4 (1.4)**	**1 (–1.1)**	**<1 (–5.7)**	28 (2.5)	26 (–3.6)	83 (0.8)	69 (–2.0)
Waipapa	2 (0.2)	<1 (–0.2)	29 (0.1)	**1 (1.2)**	**<1 (–2.1)**	61 (0.2)	36 (0.1)	8 (0.3)	**<1 (2.0)**	**<1 (3.1)**	26 (0.7)	27 (0.3)	**1 (1.0)**	**1 (–2.0)**	**<1 (–4.3)**	15 (–2.4)	98 (0.0)
	<1 (0.6)	90 (0.0)	45 (–0.2)	34 (–0.8)	**1 (–2.6)**	**<1 (5.2)**	8 (–0.6)	49 (–0.3)	**1 (1.9)**	**<1 (3.4)**	17 (2.3)	**<1 (–2.5)**	24 (–1.1)	**2 (–4.4)**	37 (–2.7)	23 (–5.3)	53 (–0.9)
Narrows	2 (0.2)	14 (–0.1)	67 (0.0)	54 (–0.3)	66 (–0.2)	50 (–0.3)	11 (–0.3)	43 (0.1)	**<1 (1.5)**	**<1 (3.9)**	**1 (–1.7)**	10 (–0.3)	28 (0.6)	**1 (–2.1)**	**<1 (–18)**	99 (0.0)	45 (1.4)
	1 (0.8)	39 (–0.1)	92 (0.0)	9 (–2.0)	90 (0.3)	6 (2.9)	16 (–0.7)	45 (–0.3)	21 (1.1)	**<1 (3.6)**	70 (–0.7)	**<1 (–2.4)**	8 (–2.6)	**1 (–5.5)**	43 (1.8)	40 (3.4)	54 (1.8)
Horotiu	17 (–0.1)	87 (0.0)	25 (–0.1)	75 (–0.1)	23 (–0.5)	**<1 (–2.4)**	12 (–0.3)	73 (0.0)	**<1 (1.1)**	**<1 (3.7)**	**<1 (–5.0)**	23 (–0.4)	**<1 (1.2)**	**<1 (–3.2)**	**<1 (–7.8)**	28 (1.8)	**1 (–3.7)**
	70 (0.2)	78 (–0.1)	39 (–0.2)	74 (–0.4)	17 (–1.5)	78 (0.6)	**3 (–1.0)**	45 (–0.4)	6 (1.4)	**<1 (4.6)**	62 (0.9)	**<1 (–3.3)**	8 (–2.6)	**<1 (–6.6)**	30 (3.3)	**5 (5.8)**	20 (5.2)
Huntly	75 (0.1)	94 (0.0)	30 (–0.1)	**1 (1.7)**	13 (–0.7)	**<1 (–2.6)**	<1 (–0.8)	13 (–0.3)	**<1 (1.0)**	**<1 (2.3)**	**<1 (–4.0)**	**<1 (–1.0)**	11 (–0.4)	**<1 (–3.6)**	**<1 (–5.2)**	**4 (–3.2)**	29 (–1.1)
	29 (0.3)	99 (0.0)	59 (–0.1)	59 (–0.6)	18 (–1.3)	82 (0.3)	25 (–0.6)	90 (–0.2)	49 (0.5)	**4 (2.5)**	10 (–2.7)	**<1 (–4.0)**	6 (–1.7)	**1 (–4.3)**	35 (–2.8)	64 (–2.1)	35 (4.2)
Mercer	1 (–0.3)	<1 (–0.3)	79 (0.0)	**<1 (3.0)**	–	4 (–0.9)	**<1 (–1.3)**	<1 (–0.7)	**<1 (2.0)**	**<1 (3.5)**	13 (–0.5)	82 (0.0)	39 (–0.3)	**<1 (–3.2)**	92 (–0.1)	6 (2.7)	**<1 (5.3)**
	13 (–0.5)	14 (–0.4)	52 (–0.1)	23 (2.0)	–	55 (1.0)	**1 (–1.4)**	13 (–0.7)	**2 (1.6)**	**<1 (4.1)**	10 (–0.2)	**<1 (–3.6)**	**3 (–2.3)**	**1 (–4.6)**	96 (1.0)	92 (0.5)	20 (9.6)
Tuakau	<1 (–0.4)	<1 (–0.3)	2 (0.1)	**3 (1.3)**	**<1 (–1.2)**	16 (0.8)	**<1 (–1.0)**	11 (–0.4)	**<1 (1.4)**	**<1 (3.5)**	**1 (–1.1)**	6 (–0.6)	30 (–0.4)	**<1 (–2.7)**	**4 (–4.2)**	8 (2.8)	**1 (4.2)**
	8 (–0.6)	16 (–0.4)	90 (0.0)	59 (0.4)	45 (–1.2)	74 (0.1)	16 (–0.9)	70 (–0.2)	**5 (1.2)**	**<1 (4.9)**	52 (–0.3)	**<1 (–3.9)**	37 (–1.2)	**<1 (–6.0)**	60 (1.4)	71 (1.3)	20 (3.9)

Appendix 3: ***p*-values (%) and, in brackets, trend slopes (% per year) for monthly records of flow-adjusted water quality at 104 Waikato region sites. For each site the results in the upper row are for 1993–2012 (20-year record); lower row, 2003–12 (10-year record). Important improvements (see text) are shown in bold; important deteriorations are bold underlined. Values in shaded cells are suspect: see text. The names of sites for which a flow index was generated (see section 2.6) are shown in italics. Note that site names have been abbreviated—see Table 3 for full description of each site (numbers in brackets are site numbers in Figure 1 and Table 3). Note that the *E. coli* and enterococci records contained considerably fewer results (*n* < 60 and *n* < 87, respectively: Table 1) than those for the other variables.**

	Temperature	**Dissolved oxygen**	**Conductivity**	**Turbidity**	**Visual clarity**	**Total nitrogen**	**Nitrate-N**	**Ammonia**	**Total phosphorus**	**Dissolved reactive P**	***Escherichia coli***	**Enterococci**
Coromandel												
Hikutaia (91)	99 (0.0)	<1 (0.1)	65 (0.0)	**3 (–1.5**)	**2 (–1.2**)	**1 (–1.4)**	**<1 (–2.9)**	**<1 (–7.9)**	**<1 (–2.0)**	**<1 (–1.7)**	39 (–1.6)	38 (2.4)
	34 (0.3)	90 (–0.1)	4 (–0.3)	74 (0.5)	**<1 (–4.5)**	**<1 (–4.3)**	29 (–3.3)	**<1 (–7.1)**	**<1 (–7.0)**	**<1 (–15.4)**	14 (5.3)	96 (–0.7)
Kauaeranga (92)	67 (0.1)	36 (0.0)	<1 (0.6)	**2 (1.9)**	**<1 (–2.2)**	**<1 (3.3)**	**3 (2.1)**	<1 (–0.1)	9 (0.0)	4 (–0.2)	64 (1.3)	6 (5.8)
	78 (0.2)	55 (0.0)	5 (–0.6)	98 (0.1)	**5 (–2.0)**	14 (2.0)	14 (4.0)	14 (–0.1)	14 (0.0)	7 (–0.1)	40 (6.2)	10 (8.7)
Ohinemuri (4)	1 (0.3)	<1 (–0.2)	<1 (0.8)	36 (0.5)	6 (0.6)	27 (–0.5)	8 (–0.7)	**<1 (–3.5)**	**<1 (–3.4)**	**<1 (–7.3)**	–	–
	35 (0.3)	<1 (–0.5)	**<1 (2.5)**	96 (–0.2)	**4 (2.5**)	57 (0.5)	8 (1.8)	99 (0.0)	**<1 (–5.8)**	**<1 (–6.7)**	61 (4.5)	–
Ohinemuri (99)	76 (–0.1)	<1 (–0.2)	**<1 (2.4)**	**2 (–1.7)**	41 (–0.3)	**<1 (1.2)**	**<1 (1.0)**	91 (–0.2)	**<1 (–6.7)**	**<1 (–10.8)**	**3 (–10.2)**	70 (1.4)
	96 (0.1)	53 (–0.2)	**<1 (3.3)**	38 (1.2)	25 (–1.1)	44 (0.9)	**3 (1.9)**	6 (5.7)	**<1 (–14.4)**	**<1 (–19.4)**	**1 (–26.8)**	30 (–11.9)
Ohinemuri (98)	96 (0.0)	1 (–0.1)	83 (0.0)	53 (–0.3)	**<1 (–2.9)**	10 (–0.4)	7 (–0.6)	**<1 (–7.0)**	**<1 (–2.0)**	**<1 (–3.7)**	70 (–1.9)	99 (0.0)
	69 (0.2)	69 (–0.1)	2 (–0.3)	35 (1.1)	**<1 (–6.8)**	**4 (1.1)**	**1 (1.6)**	**2 (–4.0)**	**<1 (–5.7)**	**<1 (–6.6)**	23 (–8.9)	82 (–3.1)
Tairua (96)	<1 (0.5)	2 (–0.1)	11 (0.1)	14 (–0.8)	23 (–0.6)	52 (0.3)	**3 (–1.4)**	3 (–0.1)	6 (–1.7)	3 (–0.3)	23 (–2.9)	64 (0.8)
	6 (0.8)	69 (–0.1)	<1 (–0.4)	36 (1.8)	7 (–2.7)	**<1 (–3.4)**	54 (1.3)	<1 (–0.6)	**<1 (–8.0)**	1 (–0.9)	35 (–7.2)	58 (–4.0)
Tapu (93)	<1 (0.5)	24 (0.0)	1 (0.1)	60 (–0.4)	80 (0.0)	52 (0.4)	9 (–2.6)	1 (–0.1)	32 (–0.4)	1 (–0.6)	**<1 (–9.7)**	76 (–0.8)
	9 (0.7)	42 (0.0)	12 (–0.2)	92 (0.3)	12 (–2.2)	18 (–2.4)	10 (–1.5)	10 (0.0)	**<1 (–13.2)**	**<1 (–2.1)**	**3 (–16.0)**	71 (–2.5)
Waiau (94)	1 (0.3)	38 (0.0)	<1 (0.1)	89 (0.1)	56 (0.4)	43 (–0.4)	37 (–0.6)	<1 (–0.5)	**<1 (–2.5)**	**<1 (–5.2)**	13 (–2.5)	8 (–3.0)
	12 (0.5)	13 (–0.2)	1 (–0.4)	67 (–0.7)	42 (–1.1)	**<1 (–4.9)**	**1 (–6.3)**	5 (0.1)	**<1 (–7.4)**	**<1 (–7.7)**	78 (–1.3)	46 (–6.4)
Waitekauri (100)	35 (0.2)	29 (0.0)	**<1 (–2.4)**	55 (0.6)	**<1 (–1.8)**	**<1 (–4.6)**	**<1 (–5.7)**	**<1 (–24.6)**	78 (0.0)	8 (–0.4)	**<1 (–8.1)**	34 (–2.2)
	99 (0.0)	<1 (–0.5)	**<1 (–1.7)**	51 (–1.0)	**2 (–4.2)**	62 (0.7)	81 (0.6)	**<1 (–4.2)**	**<1 (–9.5)**	**1 (–3.7)**	7 (–10.3)	17 (–11.7)
Waiwawa (95)	6 (0.3)	<1 (–0.2)	98 (0.0)	58 (–0.2)	83 (–0.1)	99 (0.0)	**3 (–1.9)**	10 (–0.1)	19 (–0.7)	<1 (–0.4)	12 (–2.9)	65 (0.6)
	5 (0.9)	35 (–0.1)	<1 (–0.5)	30 (–1.3)	**3 (–2.3)**	**2 (–4.0)**	18 (–2.9)	11 (0.0)	**<1 (–5.8)**	18 (–0.1)	17 (–5.6)	82 (0.8)
Wharekawa (97)	3 (0.4)	8 (–0.1)	<1 (0.3)	**2 (1.5)**	22 (–0.7)	**<1 (2.2)**	**<1 (2.9)**	<1 (–0.6)	8 (–1.3)	**<1 (–1.0)**	47 (–1.3)	41 (2.4)
	24 (0.4)	11 (0.2)	29 (–0.2)	24 (1.9)	57 (–1.0)	**3 (–2.0)**	**<1 (3.6)**	3 (–0.1)	**<1 (–11.4)**	**<1 (–2.5)**	**2 (–8.4)**	67 (–1.6)

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Hauraki												
Mangawhero (32)	1 (–0.4) 53 (0.3)	<1 (–0.2) 83 (0.0)	<1 (0.4) 2 (–0.2)	67 (–0.2) 75 (0.5)	99 (0.0) 93 (–0.1)	1 (0.6) 53 (0.4)	<1 (0.7) 7 (1.3)	**<1 (–1.1)** 8 (–0.5)	25 (–0.4) **<1 (–4.2)**	<1 (0.8) **<1 (–2.5)**	35 (–4.1) 27 (9.0)	12 (–2.8) 99 (–0.6)
Oraka (35)	10 (0.1) 98 (–0.1)	48 (0.0) 62 (0.0)	**<1 (1.1)** 66 (0.2)	**<1 (3.4)** 25 (1.3)	21 (–0.5) **3 (–2.0)**	<1 (0.9) 19 (0.5)	<1 (0.9) 1 (0.9)	25 (–1.4) 19 (–4.3)	**1 (–1.0)** **<1 (–3.0)**	3 (–0.9) **<1 (–3.5)**	**2 (–7.4)** 26 (–7.9)	53 (–1.5) 14 (–4.2)
Piako (83)	3 (0.4) 86 (0.2)	<1 (–0.4) 2 (0.9)	<1 (0.5) 78 (–0.1)	**<1 (–1.7)** **<1 (3.1)**	99 (0.0) **<1 (–6.4)**	10 (–0.4) **<1 (–3.0)**	23 (–0.5) **1 (–2.9)**	**<1 (–5.3)** **<1 (–6.6)**	**<1 (–1.5)** **<1 (–3.8)**	37 (–0.4) 6 (–1.8)	29 (4.6) 96 (–3.7)	15 (7.2) 96 (2.7)
Piako (79)	16 (0.3) 99 (0.0)	<1 (0.3) **<1 (1.0)**	<1 (0.7) 43 (–0.2)	55 (–0.5) 26 (–2.3)	**<1 (–1.5)** 19 (–3.1)	<1 (–0.8) **<1 (–2.6)**	**1 (–1.0)** **3 (–2.5)**	**<1 (–4.1)** **<1 (–8.0)**	3 (–0.9) **2 (–2.6)**	61 (–0.3) 50 (0.6)	61 (–1.1) 76 (–2.1)	8 (4.4) 84 (1.6)
Piakonui (82)	6 (0.3) 19 (0.6)	<1 (–0.2) 12 (–0.3)	96 (0.0) <1 (–0.6)	**<1 (–2.4)** 70 (–0.6)	**<1 (1.7)** 71 (0.4)	35 (–0.2) **1 (–1.6)**	10 (–0.7) **5 (–2.1)**	**<1 (–1.3)** 21 (–0.5)	**<1 (–2.1)** **<1 (–5.6)**	**<1 (–1.7)** **<1 (–3.0)**	67 (–1.2) 56 (–3.7)	96 (0.3) 45 (6.0)
Waihou (33)	87 (0.0) 25 (0.3)	53 (0.0) 29 (0.1)	<1 (0.7) 27 (–0.2)	**<1 (2.1)** **1 (3.6)**	14 (–0.4) 48 (–0.7)	**<1 (1.0)** 62 (0.3)	**<1 (1.0)** 10 (0.6)	**1 (–2.3)** **4 (–4.7)**	<1 (–0.6) **1 (–1.0)**	**<1 (–1.0)** **<1 (–1.7)**	41 (1.8) 40 (–2.6)	56 (1.3) 62 (3.5)
Waihou (3)	67 (0.1) 98 (0.0)	<1 (–0.1) 59 (0.0)	<1 (0.5) 1 (0.4)	**1 (1.4)** 6 (3.0)	22 (–0.5) 27 (1.2)	<1 (0.5) 31 (0.3)	1 (0.4) 19 (0.5)	46 (0.6) 37 (–2.3)	59 (–0.1) **1 (–1.5)**	<1 (–0.9) **<1 (–2.3)**	– 35 (3.1)	– –
Waihou (37)	<1 (0.1) 59 (0.1)	<1 (–0.1) 78 (0.0)	<1 (0.5) 1 (0.2)	88 (0.1) **<1 (6.6)**	77 (–0.1) **<1 (–4.7)**	**<1 (1.7)** **<1 (1.7)**	**<1 (1.7)** **<1 (2.2)**	<1 (–0.3) 7 (–0.4)	<1 (–0.6) **<1 (–1.4)**	<1 (–0.5) **<1 (–1.8)**	82 (0.7) 12 (4.8)	10 (3.5) 56 (2.4)
Waiohotu (36)	<1 (0.7) **2 (1.1)**	5 (–0.1) <1 (–0.6)	35 (0.0) <1 (–0.5)	**<1 (2.0)** 39 (–1.1)	– –	**<1 (1.4)** **<1 (–1.6)**	<1 (0.9) **<1 (–1.7)**	16 (0.1) 45 (–0.2)	70 (0.0) **<1 (–3.7)**	**<1 (–2.5)** **<1 (–6.2)**	67 (2.3) 50 (–7.1)	**4 (13.5)** 82 (–1.2)
Waiomou (34)	42 (0.1) 62 (0.3)	40 (0.0) 94 (0.0)	<1 (0.4) <1 (–0.6)	**<1 (2.0)** **<1 (3.7)**	6 (–0.8) **<1 (–2.5)**	**<1 (1.5)** 49 (0.5)	**<1 (1.0)** 39 (–0.7)	65 (–0.3) **<1 (–8.3)**	16 (0.5) **<1 (–3.6)**	**<1 (–1.3)** **<1 (–4.8)**	36 (1.0) 56 (–2.1)	24 (1.6) 96 (–0.1)
Waitakaruru (31)	7 (0.3) 6 (0.8)	13 (–0.1) 53 (0.2)	**<1 (1.5)** <1 (0.7)	**4 (–1.3)** 16 (1.9)	83 (0.1) **2 (–2.3)**	**<1 (–1.1)** **3 (–1.6)**	**<1 (–1.7)** 19 (–1.7)	**<1 (–2.6)** 11 (–3.4)	10 (–0.6) **<1 (–3.5)**	72 (0.0) 79 (–0.3)	67 (0.6) 99 (0.1)	7 (5.0) 71 (1.4)
Waitoa (81)	10 (0.3) 45 (0.2)	17 (0.1) 90 (0.0)	<1 (0.7) 59 (–0.1)	8 (–0.9) 10 (–2.0)	**1 (–1.7)** 96 (0.1)	85 (–0.1) 10 (–1.1)	24 (–0.4) 22 (–0.8)	**<1 (–4.5)** **<1 (–16.4)**	**<1 (–1.5)** **<1 (–6.4)**	**2 (–1.4)** **2 (–3.0)**	94 (0.9) 75 (3.5)	51 (2.2) 62 (5.9)
Waitoa (80)	61 (0.1) 39 (–0.6)	<1 (0.6) **<1 (1.0)**	22 (0.2) **<1 (–3.2)**	6 (0.9) **<1 (4.1)**	**<1 (–1.4)** **<1 (–4.7)**	<1 (–0.8) 31 (0.9)	<1 (–0.8) 29 (0.9)	**<1 (–4.6)** **2 (–4.6)**	**<1 (–18.0)** **<1 (–11.6)**	**<1 (–27.9)** **<1 (–21.0)**	29 (4.4) 40 (3.9)	18 (2.0) 62 (3.3)

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Inflows to Lake Taupo												
Hinemaiaia (55)	52 (0.1)	<1 (–0.2)	1 (0.2)	**<1 (1.5)**	**<1 (–1.2)**	**<1 (1.1)**	**<1 (–1.4)**	20 (0.0)	<1 (–0.5)	<1 (–0.7)	6 (–4.2)	99 (0.1)
	11 (0.8)	3 (–0.4)	16 (0.2)	**1 (2.2)**	**<1 (–3.6)**	**<1 (2.2)**	14 (1.0)	1 (–0.4)	21 (–0.6)	**<1 (–1.9)**	49 (–3.5)	78 (6.5)
Kuratau (58)	<1 (0.6)	1 (–0.1)	11 (0.1)	42 (0.4)	**5 (–1.0)**	77 (0.1)	**<1 (–1.9)**	1 (–0.5)	**3 (–1.5)**	**<1 (–1.4)**	–	–
	5 (0.9)	99 (0.0)	32 (–0.2)	**5 (2.5)**	**<1 (–4.4)**	**5 (1.8)**	**4 (2.0)**	11 (–1.1)	12 (–3.0)	**<1 (–5.0)**	–	–
Kuratau (101)	4 (0.5)	52 (–0.1)	78 (0.0)	16 (0.9)	–	**<1 (2.5)**	**<1 (3.0)**	5 (0.0)	9 (–1.3)	**<1 (–16.0)**	–	–
	10 (0.8)	26 (–0.1)	99 (0.0)	10 (1.3)	–	**<1 (2.5)**	**<1 (3.1)**	3 (0.0)	6 (–2.1)	**<1 (–15.0)**	93 (0.2)	86 (0.0)
Mapara (53)	1 (0.2)	4 (0.1)	<1 (0.6)	**<1 (–1.4)**	18 (0.4)	**<1 (1.1)**	**<1 (1.2)**	**<1 (–4.1)**	<1 (–0.8)	1 (–0.3)	6 (–3.5)	99 (0.0)
	10 (0.4)	58 (–0.1)	<1 (0.4)	8 (1.5)	34 (–1.1)	**<1 (1.3)**	1 (0.8)	**<1 (–11.9)**	**<1 (–2.3)**	**<1 (–2.2)**	99 (0.0)	46 (2.9)
Tauranga–Taup (56)	<1 (0.7)	<1 (–0.1)	98 (0.0)	**2 (1.2)**	**<1 (–1.5)**	**<1 (1.6)**	**<1 (1.3)**	25 (0.0)	1 (–0.7)	**<1 (–1.3)**	–	–
	<1 (1.7)	7 (–0.2)	<1 (–0.8)	**<1 (5.0)**	**<1 (–4.2)**	**1 (3.1)**	**<1 (4.0)**	21 (0.0)	**<1 (–3.5)**	**<1 (–5.1)**	–	–
Tokaanu (57)	<1 (0.1)	<1 (–0.2)	<1 (0.3)	**1 (2.1)**	–	**<1 (1.4)**	**<1 (1.3)**	<1 (0.0)	8 (–0.1)	27 (0.1)	–	–
	<1 (0.4)	13 (0.2)	79 (0.0)	**<1 (10.2)**	–	**<1 (1.8)**	**<1 (2.3)**	<1 (0.0)	**<1 (–1.3)**	<1 (–0.8)	–	–
Tokaanu Pwr (103)	61 (0.2)	4 (0.3)	11 (–0.4)	**<1 (5.0)**	–	16 (1.7)	36 (0.0)	73 (0.0)	10 (–1.4)	**<1 (–25.0)**	–	–
	25 (0.4)	2 (0.5)	12 (–0.4)	**<1 (4.4)**	–	83 (–0.5)	25 (0.0)	57 (0.0)	**1 (–2.1)**	**<1 (–15.0)**	–	–
Tongariro (5)	5 (–0.2)	38 (0.0)	<1 (–0.6)	**<1 (–2.9)**	**<1 (1.2)**	**1 (1.0)**	**<1 (2.3)**	**<1 (–5.0)**	65 (0.0)	1 (0.7)	–	–
	70 (–0.2)	<1 (–0.3)	14 (–0.3)	66 (0.8)	**<1 (3.9)**	59 (0.7)	**2 (3.4)**	**<1 (6.0)**	7 (–0.5)	78 (0.0)	19 (–6.4)	–
Waihaha (59)	<1 (0.9)	9 (–0.1)	<1 (0.3)	69 (0.3)	**<1 (–1.8)**	<1 (0.7)	37 (0.2)	39 (0.0)	26 (0.4)	72 (0.0)	29 (–5.3)	9 (3.6)
	8 (0.9)	12 (–0.3)	8 (–0.3)	**1 (4.1)**	**<1 (–6.7)**	**3 (1.2)**	**3 (1.6)**	35 (0.0)	71 (–1.3)	**2 (–1.6)**	50 (–5.8)	89 (0.4)
Waitahanui (54)	3 (0.2)	4 (–0.1)	<1 (0.6)	13 (0.9)	**<1 (–1.4)**	**<1 (2.6)**	**<1 (2.5)**	10 (0.0)	<1 (–0.8)	<1 (–0.6)	**2 (–7.2)**	6 (4.4)
	1 (0.7)	37 (–0.1)	<1 (0.3)	**<1 (4.4)**	**<1 (–3.6)**	**<1 (2.1)**	**<1 (2.1)**	18 (0.0)	**<1 (–1.5)**	**<1 (–1.6)**	26 (–6.0)	7 (11.4)
Whanganui (104)	**1 (1.2)**	1 (–0.3)	41 (–0.2)	36 (1.2)	–	**<1 (–2.5)**	**<1 (–2.7)**	47 (0.0)	18 (–0.6)	**<1 (–3.3)**	–	–
	<1 (1.4)	3 (–0.3)	46 (–0.2)	22 (1.4)	–	**<1 (–2.2)**	**<1 (–2.5)**	80 (0.0)	31 (–0.9)	**1 (–3.2)**	92 (1.7)	92 (–1.3)
Whareroa (102)	42 (0.3)	7 (–0.2)	27 (0.1)	54 (–0.5)	–	**<1 (1.4)**	**<1 (2.1)**	24 (–0.1)	**<1 (–2.8)**	**<1 (–2.3)**	–	–
	35 (0.4)	9 (–0.2)	62 (0.0)	87 (–0.2)	–	**<1 (1.8)**	**<1 (2.2)**	14 (–0.2)	**<1 (–2.3)**	**<1 (–2.4)**	39 (–3.7)	50 (6.7)

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Upland tributaries of the Waikato River												
Kawaunui (48)	2 (0.3)	<1 (–0.2)	**<1 (1.6)**	64 (–0.3)	98 (0.0)	**<1 (5.1)**	**<1 (6.0)**	86 (0.4)	9 (0.9)	**<1 (1.6)**	40 (–5.5)	36 (2.0)
	9 (0.5)	10 (0.3)	<1 (–0.8)	29 (–1.7)	45 (1.5)	**2 (1.3)**	**<1 (2.8)**	**<1 (–29.8)**	**<1 (–9.1)**	**<1 (–8.7)**	40 (–12.7)	85 (–2.7)
Mangaharakeke (43)	<1 (0.7)	44 (0.0)	<1 (0.7)	86 (–0.1)	83 (0.1)	**<1 (6.0)**	**<1 (10.5)**	**<1 (–4.1)**	51 (0.2)	4 (0.6)	98 (0.2)	82 (–0.5)
	<1 (1.0)	86 (0.1)	6 (0.2)	37 (0.9)	54 (–0.5)	**<1 (4.2)**	**<1 (7.1)**	**<1 (–10.9)**	**<1 (–3.0)**	**<1 (–2.6)**	**2 (–14.3)**	26 (–11.9)
Mangakara (49)	68 (0.0)	24 (0.0)	**<1 (1.2)**	**5 (1.6)**	61 (–0.2)	**<1 (3.2)**	**<1 (3.6)**	**<1 (–3.0)**	16 (–0.3)	<1 (–0.9)	59 (1.1)	**<1 (2.2)**
	8 (0.4)	68 (–0.1)	**<1 (1.1)**	59 (1.3)	93 (0.0)	**<1 (2.6)**	**<1 (3.1)**	**<1 (–4.0)**	**<1 (–2.8)**	**<1 (–2.9)**	31 (–3.8)	49 (1.5)
Mangakino (60)	<1 (0.5)	<1 (–0.1)	<1 (0.8)	**4 (1.3)**	11 (–0.1)	**<1 (3.0)**	**<1 (3.4)**	32 (0.0)	53 (–0.2)	92 (0.0)	–	–
	32 (0.3)	94 (0.0)	8 (0.4)	**2 (3.1)**	**<1 (–4.7)**	**<1 (1.6)**	**<1 (2.6)**	9 (–0.3)	**5 (–1.0)**	**<1 (–1.2)**	–	–
Otamakokore (46)	<1 (0.3)	<1 (0.3)	<1 (0.8)	**2 (1.3)**	**<1 (–1.3)**	**<1 (1.7)**	**<1 (2.3)**	**<1 (–4.6)**	20 (–0.4)	<1 (0.5)	70 (1.0)	52 (0.5)
	90 (0.1)	49 (0.2)	34 (–0.2)	55 (0.5)	14 (–0.8)	7 (–0.9)	59 (–0.4)	**4 (–2.5)**	**2 (–2.0)**	42 (–0.3)	34 (–3.5)	46 (3.8)
Pueto (52)	<1 (0.4)	14 (0.0)	<1 (0.5)	26 (0.4)	11 (0.4)	**<1 (1.9)**	**<1 (1.7)**	**<1 (–7.6)**	35 (–0.1)	<1 (0.5)	99 (–0.1)	34 (1.7)
	1 (0.7)	35 (–0.1)	84 (0.0)	**<1 (3.5)**	**<1 (–3.3)**	**<1 (2.1)**	**<1 (2.9)**	50 (–0.5)	**<1 (–1.2)**	**<1 (–1.5)**	42 (3.6)	81 (2.7)
Tahunaatara (44)	<1 (0.4)	15 (0.0)	<1 (0.6)	**4 (1.1)**	**<1 (–1.2)**	**<1 (2.1)**	**<1 (2.5)**	3 (–0.7)	50 (–0.2)	1 (–0.6)	11 (3.0)	41 (3.0)
	14 (0.7)	49 (–0.1)	62 (0.0)	12 (1.8)	**2 (–2.7)**	13 (0.5)	**5 (1.1)**	**1 (–2.4)**	**5 (–1.7)**	**<1 (–3.3)**	14 (–11.5)	17 (–8.6)
Torepatutahi (51)	<1 (0.3)	<1 (0.3)	<1 (0.8)	97 (0.0)	–	**<1 (3.7)**	**<1 (4.4)**	<1 (0.0)	<1 (–0.5)	86 (0.0)	–	–
	<1 (0.7)	15 (–0.3)	<1 (0.8)	**<1 (3.5)**	–	**<1 (3.0)**	**<1 (4.1)**	<1 (0.0)	**<1 (–1.8)**	**<1 (–1.2)**	–	–
Waiotapu (47)	19 (–0.1)	<1 (0.2)	<1 (0.4)	9 (0.8)	2 (0.6)	**<1 (1.9)**	**<1 (3.0)**	<1 (0.6)	44 (–0.4)	**<1 (–5.0)**	32 (5.1)	36 (8.3)
	<1 (–0.5)	82 (–0.1)	<1 (–0.7)	**<1 (4.7)**	10 (–1.4)	<1 (0.5)	**<1 (2.9)**	**<1 (–1.4)**	**<1 (–1.7)**	36 (0.0)	31 (–8.9)	**<1 (–27.5)**
Waiotapu (50)	71 (0.0)	<1 (0.3)	<1 (0.5)	8 (0.8)	5 (0.8)	**<1 (1.2)**	**<1 (1.3)**	5 (–0.5)	99 (0.0)	12 (–0.5)	–	–
	63 (–0.1)	<1 (0.9)	8 (–0.4)	78 (0.2)	12 (–2.8)	17 (–0.3)	29 (0.3)	**2 (–1.5)**	**5 (–3.1)**	**<1 (–2.8)**	–	–
Waipapa (42)	<1 (0.2)	1 (0.1)	**<1 (1.2)**	99 (0.0)	46 (–0.2)	**<1 (5.8)**	**<1 (6.3)**	<1 (–0.8)	1 (–0.7)	**<1 (1.6)**	75 (0.6)	**1 (7.8)**
	29 (0.2)	86 (0.1)	**<1 (1.2)**	**1 (2.6)**	**3 (–2.1)**	**<1 (5.2)**	**<1 (6.1)**	41 (0.0)	50 (–0.2)	**1 (1.1)**	23 (–6.2)	7 (11.1)
Whirinaki (45)	2 (0.1)	<1 (–0.1)	<1 (0.4)	23 (–1.1)	–	**<1 (2.2)**	**<1 (2.7)**	<1 (–0.5)	13 (–0.1)	7 (–0.2)	–	–
	8 (0.4)	82 (0.0)	55 (0.1)	98 (0.2)	–	**<1 (1.6)**	**<1 (2.4)**	7 (–0.2)	**<1 (–1.7)**	**<1 (–2.1)**	–	–

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Lowland tributaries of the Waikato River												
Awaroa-Otaua (27)	13 (0.2)	56 (–0.1)	1 (0.3)	**<1 (4.4)**	**<1 (–4.8)**	<1 (0.9)	4 (0.8)	83 (0.1)	**<1 (2.3)**	**<1 (–2.4)**	–	–
	22 (0.5)	9 (–0.7)	3 (0.6)	**3 (3.2)**	82 (–0.3)	**2 (1.3)**	**1 (2.8)**	94 (–0.2)	66 (–0.5)	**1 (–8.3)**	–	–
Awaroa-Rotowar (7)	<1 (0.5)	6 (–0.1)	**<1 (3.3)**	65 (0.4)	16 (–0.9)	**<1 (2.8)**	**<1 (3.6)**	18 (1.4)	**1 (–1.3)**	**<1 (–1.1)**	30 (–3.8)	61 (1.3)
	16 (0.5)	6 (–0.3)	**<1 (3.9)**	**<1 (6.9)**	**<1 (–10.0)**	**<1 (6.4)**	**<1 (7.6)**	6 (4.1)	57 (1.5)	**<1 (–1.1)**	12 (–5.5)	64 (–4.4)
Karapiro (85)	64 (-0.1)	<1 (–0.3)	<1 (0.6)	**<1 (3.2)**	**<1 (–2.0)**	**<1 (1.3)**	2 (0.9)	27 (–0.5)	1 (–0.8)	**<1 (–1.4)**	22 (3.1)	31 (2.9)
	12 (0.6)	86 (0.0)	5 (0.7)	49 (1.1)	**<1 (–5.1)**	27 (–1.1)	59 (–0.5)	8 (–3.8)	**<1 (–2.6)**	34 (1.0)	75 (–0.8)	96 (0.3)
Kirikiriroa (90)	46 (0.1)	1 (–0.2)	2 (–0.5)	**<1 (–2.0)**	50 (0.4)	**<1 (–4.1)**	<1 (–0.8)	**<1 (–11.8)**	**<1 (–2.7)**	29 (0.6)	33 (–4.2)	46 (4.0)
	42 (0.2)	19 (–0.3)	99 (0.0)	22 (–1.9)	98 (0.0)	**<1 (–2.8)**	**<1 (–2.8)**	**<1 (–3.1)**	**<1 (–4.0)**	42 (0.8)	10 (–9.9)	69 (–8.5)
Komakorau (6)	<1 (0.4)	<1 (–0.5)	<1 (0.6)	**1 (1.1)**	20 (0.4)	86 (0.0)	9 (0.4)	**<1 (–2.3)**	37 (–0.3)	**<1 (–3.1)**	14 (3.0)	**<1 (5.6)**
	5 (0.6)	**2 (–1.0)**	48 (–0.2)	79 (0.3)	21 (–1.0)	**<1 (–1.9)**	20 (–0.6)	**1 (–3.6)**	16 (–1.5)	41 (–0.9)	82 (–1.0)	64 (–3.7)
Little Waipa (38)	<1 (0.2)	<1 (0.3)	**<1 (1.0)**	**<1 (3.6)**	**<1 (–2.3)**	**<1 (2.3)**	**<1 (2.2)**	52 (–0.5)	34 (0.3)	79 (0.0)	36 (–2.3)	34 (–2.4)
	59 (0.1)	70 (0.1)	<1 (0.7)	34 (2.9)	**<1 (–3.4)**	**<1 (2.1)**	**<1 (2.4)**	**1 (–7.7)**	8 (–1.3)	**<1 (–1.8)**	10 (–6.6)	30 (–3.5)
Mangakotukutu (87)	14 (0.2)	<1 (–0.2)	<1 (0.5)	**<1 (–1.3)**	46 (0.4)	43 (–0.2)	22 (–0.4)	**<1 (–2.2)**	**1 (1.4)**	**<1 (3.2)**	44 (–2.5)	10 (4.6)
	41 (0.3)	17 (0.3)	1 (–0.7)	41 (–0.9)	30 (1.5)	**<1 (–4.4)**	**<1 (–4.2)**	**<1 (–7.8)**	**1 (–3.6)**	33 (1.3)	89 (–1.0)	56 (3.0)
Mangamingi (40)	13 (0.2)	22 (0.1)	65 (0.0)	**<1 (2.7)**	**<1 (–1.6)**	3 (0.5)	**<1 (1.4)**	**<1 (–9.9)**	**<1 (–3.5)**	**<1 (–3.6)**	41 (2.6)	82 (0.2)
	8 (0.6)	86 (0.0)	13 (–0.4)	**<1 (5.1)**	**<1 (–3.9)**	62 (0.2)	90 (–0.1)	**2 (10.3)**	**<1 (–5.9)**	**<1 (–6.6)**	17 (–6.5)	82 (–1.4)
Mangaone (77)	<1 (0.5)	**<1 (1.0)**	<1 (0.3)	**<1 (2.1)**	**<1 (–2.4)**	**<1 (–1.2)**	**<1 (–1.7)**	**<1 (–4.6)**	32 (–0.3)	<1 (–0.7)	44 (2.6)	**<1 (10.2)**
	29 (0.6)	<1 (0.8)	94 (0.0)	31 (–0.9)	99 (0.0)	1 (0.8)	**<1 (1.3)**	**<1 (–8.7)**	**<1 (–5.2)**	**1 (–1.2)**	45 (–3.4)	56 (–4.6)
Mangaonua (78)	16 (0.2)	<1 (0.4)	<1 (0.8)	81 (0.1)	**1 (–1.2)**	41 (0.2)	20 (0.3)	**3 (–1.2)**	**<1 (–1.8)**	**<1 (–2.4)**	31 (3.4)	**<1 (17.1)**
	59 (–0.2)	<1 (0.9)	<1 (0.6)	**1 (3.2)**	**<1 (–5.6)**	**1 (1.1)**	**<1 (1.7)**	**<1 (2.9)**	**<1 (–4.2)**	**1 (–2.7)**	62 (5.6)	99 (0.0)
Mangaonua (84)	2 (0.3)	3 (–0.1)	13 (0.1)	18 (–0.6)	79 (–0.1)	**<1 (–1.1)**	**<1 (–1.0)**	**<1 (–17.3)**	**<1 (–5.0)**	**<1 (–7.4)**	98 (0.1)	23 (3.2)
	16 (0.6)	49 (–0.1)	42 (–0.1)	21 (–1.4)	30 (–1.6)	27 (–0.9)	19 (–1.2)	10 (–1.7)	**<1 (–4.5)**	**<1 (–4.0)**	89 (0.7)	**4 (12.7)**
Mangatangi (30)	7 (0.3)	46 (–0.1)	62 (–0.1)	**<1 (5.8)**	**<1 (–4.2)**	**<1 (–1.2)**	**<1 (–3.1)**	**1 (–1.5)**	<1 (0.7)	33 (–0.4)	–	–
	<1 (1.3)	70 (0.2)	<1 (–0.8)	**<1 (9.5)**	**<1 (–13.2)**	29 (–1.3)	**2 (–3.0)**	19 (–2.5)	**3 (–1.4)**	21 (–1.5)	–	–
Mangatawhiri (29)	72 (0.0)	<1 (–0.4)	<1 (0.4)	18 (–0.8)	19 (–0.7)	**<1 (–2.1)**	**<1 (–7.3)**	**<1 (–2.7)**	24 (–0.4)	19 (–0.6)	–	–
	<1 (1.1)	98 (0.0)	22 (–0.2)	25 (–2.0)	**1 (–3.5)**	9 (–2.4)	7 (–4.0)	3 (–0.5)	12 (–2.8)	37 (1.1)	–	–

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Mangawara (19)	26 (0.2)	<1 (0.5)	<1 (0.6)	**1 (1.0)**	10 (–0.7)	96 (0.0)	81 (–0.1)	2 (–0.8)	10 (0.5)	65 (–0.4)	–	–
	12 (0.6)	**<1 (1.3)**	60 (–0.1)	60 (0.7)	71 (–0.4)	**2 (–1.5)**	**<1 (–2.3)**	**<1 (–4.0)**	**<1 (–2.2)**	8 (3.4)	–	–
Mangawhero (86)	2 (0.4)	80 (0.0)	<1 (0.9)	**<1 (1.7)**	**<1 (–1.3)**	69 (0.1)	63 (0.2)	**<1 (–4.1)**	10 (–0.8)	20 (0.9)	82 (–0.8)	**<1 (8.8)**
	7 (0.7)	44 (–0.1)	<1 (0.8)	**<1 (2.1)**	63 (–0.7)	**<1 (2.6)**	**<1 (4.4)**	48 (–1.0)	81 (–0.5)	41 (1.7)	64 (3.2)	6 (11.1)
Matahuru (20)	4 (0.4)	64 (0.0)	2 (0.2)	**<1 (3.0)**	**3 (–1.3)**	<1 (–0.9)	**<1 (–2.1)**	**<1 (–1.9)**	1 (0.8)	6 (–1.1)	–	–
	54 (0.3)	22 (0.3)	90 (–0.1)	7 (1.8)	9 (–2.0)	54 (–0.6)	41 (–1.5)	**2 (–5.4)**	**<1 (–2.8)**	7 (–1.9)	–	–
Ohaeroa (25)	69 (0.1)	99 (0.0)	<1 (0.4)	45 (–0.6)	**1 (1.1)**	**<1 (1.6)**	**<1 (1.9)**	**<1 (–3.6)**	10 (–0.6)	45 (0.2)	–	–
	31 (0.4)	82 (0.1)	14 (–0.2)	39 (1.6)	12 (–2.1)	**<1 (1.9)**	**<1 (2.4)**	**<1 (–9.0)**	9 (–2.7)	70 (–0.5)	–	–
Opuatia (24)	40 (0.1)	4 (–0.1)	<1 (0.5)	**<1 (4.1)**	**<1 (–3.2)**	**<1 (1.4)**	**<1 (1.4)**	**<1 (–2.7)**	**<1 (1.6)**	**<1 (–2.9)**	18 (4.3)	**<1 (15.8)**
	27 (0.4)	50 (–0.1)	37 (–0.1)	**<1 (5.5)**	**<1 (–5.7)**	7 (1.2)	12 (1.3)	38 (–1.0)	71 (–0.6)	**1 (–4.3)**	58 (4.0)	23 (9.3)
Pokaiwhenua (39)	5 (0.2)	6 (0.1)	<1 (0.9)	**<1 (2.9)**	**<1 (–1.6)**	**<1 (1.7)**	**<1 (1.5)**	**<1 (–1.5)**	**<1 (–1.9)**	**<1 (–2.4)**	39 (–2.1)	65 (0.6)
	31 (0.3)	9 (0.3)	<1 (0.6)	14 (1.8)	**1 (–3.2)**	**<1 (1.8)**	**<1 (2.1)**	**<1 (–13.2)**	**<1 (–4.5)**	**<1 (–4.3)**	**3 (–11.4)**	62 (–2.8)
Waerenga (21)	<1 (0.5)	11 (–0.1)	<1 (0.3)	**2 (2.4)**	**<1 (–1.5)**	**<1 (1.1)**	2 (0.8)	36 (–0.6)	7 (0.9)	69 (0.0)	11 (5.5)	7 (5.9)
	10 (0.8)	81 (–0.1)	18 (–0.2)	**<1 (5.3)**	**<1 (–5.4)**	12 (1.6)	9 (1.9)	**1 (–2.7)**	48 (–0.6)	15 (–2.2)	67 (–1.5)	42 (3.9)
Waitawhiriwhiri (89)	12 (0.2)	3 (–0.1)	36 (0.1)	71 (0.1)	6 (–1.0)	82 (–0.1)	<1 (0.9)	**<1 (–2.0)**	**2 (–1.0)**	32 (0.8)	94 (–0.2)	28 (7.2)
	70 (0.1)	99 (0.0)	82 (0.1)	31 (–1.1)	73 (0.4)	13 (–0.6)	70 (0.2)	25 (–0.9)	**<1 (–4.2)**	99 (0.0)	96 (0.9)	99 (–0.2)
Whakapipi (26)	8 (0.2)	1 (0.2)	**<1 (1.2)**	**<1 (–1.6)**	91 (0.0)	**<1 (1.4)**	**<1 (1.5)**	**<1 (–4.7)**	**<1 (1.7)**	**<1 (4.3)**	–	–
	27 (0.4)	99 (0.0)	49 (0.2)	21 (1.5)	**<1 (–5.9)**	86 (0.1)	90 (0.1)	6 (–2.8)	45 (–1.1)	**4 (3.5)**	–	–
Whakauru (41)	71 (0.0)	58 (0.0)	<1 (0.5)	**<1 (4.7)**	**<1 (–2.6)**	**<1 (5.7)**	**<1 (9.4)**	32 (0.0)	**<1 (2.3)**	83 (0.0)	**2 (5.8)**	**1 (6.0)**
	57 (0.2)	5 (0.3)	<1 (0.8)	**<1 (8.6)**	**<1 (–7.3)**	**<1 (9.5)**	**<1 (19.0)**	16 (–3.1)	**<1 (3.6)**	84 (–0.6)	46 (3.7)	40 (7.9)
Whangamarino (28)	<1 (0.6)	89 (–0.1)	1 (0.3)	**<1 (–3.0)**	50 (0.4)	**<1 (2.1)**	**<1 (–8.1)**	33 (–1.3)	40 (0.4)	**<1 (–2.9)**	–	–
	5 (0.9)	**<1 (5.8)**	10 (–0.5)	28 (2.2)	60 (0.9)	**3 (2.3)**	73 (–1.2)	8 (–5.5)	35 (–1.0)	99 (0.0)	–	–
Whangamarino (22)	1 (0.4)	10 (–0.2)	<1 (0.4)	50 (0.7)	6 (–0.9)	**<1 (–1.8)**	**<1 (–2.8)**	**<1 (–2.8)**	18 (0.4)	26 (0.3)	–	–
	24 (0.5)	**1 (1.0)**	15 (–0.3)	6 (2.4)	**<1 (–5.6)**	44 (–1.2)	90 (0.0)	**<1 (–12.5)**	58 (–0.3)	**<1 (–2.9)**	–	–
Whangape (23)	66 (0.0)	<1 (0.4)	<1 (0.5)	**<1 (13.4)**	**<1 (–5.5)**	**<1 (5.4)**	3 (–0.9)	29 (0.0)	**<1 (4.5)**	<1 (0.0)	–	–
	99 (0.0)	88 (–0.1)	18 (–0.5)	**<1 (6.8)**	8 (–3.1)	**1 (2.8)**	7 (0.0)	70 (0.0)	21 (–1.5)	77 (0.0)	–	–

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Waipa River and tributaries												
Kaniwhaniwha (11)	<1 (0.5)	<1 (–0.2)	<1 (0.2)	97 (0.0)	9 (–0.8)	6 (0.6)	32 (0.4)	**5 (–1.7)**	20 (0.6)	33 (0.0)	–	–
	<1 (1.2)	62 (–0.2)	96 (0.0)	9 (2.7)	**<1 (–4.8)**	**5 (–1.4)**	**2 (–2.6)**	**2 (–4.5)**	96 (0.0)	57 (–1.4)	–	–
Mangaohoi (74)	59 (0.1)	23 (0.0)	30 (–0.1)	**3 (–1.5)**	**<1 (1.0)**	<1 (–0.8)	**<1 (–1.1)**	**<1 (–2.7)**	1 (–0.7)	1 (–0.5)	62 (–3.5)	92 (–0.8)
	4 (0.6)	70 (0.0)	86 (0.0)	29 (–1.9)	**1 (2.2)**	**<1 (–1.5)**	**<1 (–1.3)**	45 (–0.6)	**<1 (–2.5)**	37 (–0.5)	89 (1.9)	46 (2.8)
Mangaokewa (65)	20 (0.2)	2 (–0.1)	<1 (0.5)	54 (–0.4)	29 (0.4)	**<1 (1.3)**	**<1 (2.1)**	**<1 (–12.3)**	7 (–0.9)	39 (–0.7)	–	–
	35 (0.3)	64 (0.1)	<1 (0.5)	75 (0.7)	**3 (–2.6)**	**1 (1.6)**	**1 (1.8)**	6 (–3.0)	**<1 (–3.2)**	11 (–2.0)	–	–
Mangapiko (76)	15 (–0.2)	13 (0.1)	95 (0.0)	**<1 (2.4)**	**1 (–1.3)**	1 (–0.9)	**1 (–1.1)**	**<1 (–5.5)**	9 (–0.6)	**1 (–1.7)**	–	–
	14 (0.6)	**<1 (1.5)**	98 (0.0)	45 (0.6)	89 (–0.3)	12 (–1.0)	9 (–1.5)	**<1 (–6.7)**	17 (–1.0)	59 (0.8)	–	–
Mangapu (63)	76 (0.0)	<1 (–0.2)	<1 (0.7)	12 (0.7)	32 (–0.4)	**<1 (1.3)**	**<1 (1.5)**	33 (–0.9)	73 (0.2)	**2 (1.2)**	15 (4.7)	65 (2.0)
	33 (0.4)	58 (–0.1)	50 (0.1)	**1 (2.4)**	**<1 (–3.9)**	**<1 (2.4)**	**<1 (2.3)**	**<1 (4.6)**	**<1 (–3.1)**	**<1 (–5.1)**	71 (3.4)	20 (21.7)
Mangatutu (73)	44 (0.1)	16 (–0.1)	<1 (0.6)	**4 (1.0)**	**<1 (–1.0)**	**<1 (2.0)**	**<1 (2.0)**	**5 (–1.5)**	90 (0.0)	52 (0.0)	34 (–3.8)	66 (–1.1)
	70 (0.2)	19 (0.2)	99 (0.0)	98 (–0.1)	41 (–1.2)	45 (1.2)	14 (2.1)	**1 (–3.8)**	**<1 (–4.3)**	**2 (–2.7)**	56 (–4.3)	99 (–1.3)
Mangauika (13)	<1 (0.5)	<1 (–0.1)	39 (0.1)	**<1 (3.6)**	75 (0.1)	**<1 (3.5)**	**<1 (4.1)**	<1 (–0.2)	59 (0.0)	**<1 (–2.5)**	94 (–1.4)	24 (4.4)
	<1 (1.6)	28 (–0.3)	45 (0.1)	**<1 (6.5)**	**4 (–3.0)**	**1 (1.9)**	**4 (1.8)**	93 (0.0)	69 (1.2)	**<1 (–15.0)**	31 (16.5)	52 (3.7)
Ohote (88)	91 (0.0)	9 (0.5)	<1 (–0.5)	11 (0.9)	**<1 (–2.6)**	12 (–0.5)	**1 (–1.3)**	74 (0.0)	48 (–0.3)	**<1 (2.4)**	7 (4.8)	25 (1.2)
	68 (0.1)	6 (1.0)	**<1 (–1.4)**	23 (1.5)	**<1 (–5.1)**	49 (–0.5)	21 (–1.7)	88 (0.0)	**1 (–2.4)**	**1 (2.6)**	13 (8.4)	62 (–1.3)
Puniu (75)	12 (–0.2)	<1 (–0.3)	<1 (0.7)	**<1 (3.6)**	**<1 (–2.7)**	**<1 (2.0)**	**<1 (1.9)**	**1 (1.4)**	8 (0.6)	65 (0.0)	–	–
	78 (0.2)	99 (0.0)	59 (–0.1)	5 (2.3)	**2 (–3.7)**	13 (1.4)	**2 (1.9)**	27 (–1.2)	**1 (–2.0)**	**1 (–2.2)**	–	–
Waipa (61)	<1 (0.7)	46 (0.0)	<1 (0.8)	36 (–0.4)	4 (–0.9)	**<1 (2.6)**	**<1 (3.5)**	49 (0.2)	42 (–0.5)	**<1 (–1.9)**	–	–
	1 (1.3)	32 (–0.1)	6 (–0.3)	39 (1.6)	**<1 (–5.9)**	10 (0.7)	21 (0.7)	42 (–1.1)	**1 (–3.3)**	**<1 (–11.4)**	–	–
Waipa (12)	51 (0.1)	<1 (–0.1)	<1 (0.5)	10 (1.0)	**2 (–1.3)**	**<1 (1.2)**	**<1 (1.3)**	6 (–1.4)	84 (0.0)	78 (0.0)	99 (0.3)	**4 (4.6)**
	35 (0.3)	54 (–0.1)	88 (0.0)	**<1 (3.6)**	8 (–2.5)	35 (0.6)	5 (1.4)	**2 (–4.8)**	**2 (–2.4)**	**1 (–2.5)**	31 (3.2)	52 (6.2)
Waipa (2)	43 (0.1)	<1 (0.0)	<1 (0.2)	**<1 (–3.6)**	**<1 (2.1)**	**<1 (1.0)**	<1 (0.9)	51 (0.0)	**1 (–1.3)**	48 (0.0)	–	–
	99 (0.0)	4 (–0.1)	40 (–0.1)	64 (1.1)	12 (1.8)	16 (–1.0)	50 (–0.5)	8 (–4.0)	8 (–2.2)	32 (–1.1)	71 (2.1)	–
Waipa (64)	51 (0.1)	<1 (–0.2)	<1 (0.4)	**2 (–1.5**)	50 (–0.2)	**<1 (1.9)**	**<1 (2.0)**	**<1 (–1.5)**	**4 (–1.0)**	**1 (–1.6)**	90 (0.8)	85 (0.8)
	32 (0.5)	13 (0.2)	19 (0.2)	22 (–1.7)	**1 (–2.4)**	49 (0.5)	21 (1.0)	12 (–4.3)	**<1 (–4.1)**	**<1 (–5.4)**	17 (–9.6)	62 (–5.3)

Appendix 3 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Waipa (1)	80 (0.0)	5 (–0.1)	<1 (0.3)	**<1 (1.7)**	**1 (–1.2)**	**<1 (1.0)**	**<1 (1.0)**	43 (0.5)	**<1 (1.2)**	**<1 (–1.0)**	–	–
	28 (–0.5)	11 (–0.2)	51 (–0.2)	**1 (3.1)**	65 (–0.2)	**<1 (2.0)**	**<1 (2.4)**	18 (1.4)	15 (1.2)	8 (–1.0)	**4 (9.2)**	–
Waitomo (18)	94 (0.0)	<1 (–0.4)	<1 (0.2)	**2 (1.0)**	26 (–0.5)	<1 (0.9)	<1 (0.8)	**<1 (–2.3)**	34 (0.3)	99 (0.0)	52 (–2.5)	85 (–0.5)
	24 (0.4)	25 (–0.2)	52 (–0.1)	**4 (1.5)**	6 (–3.2)	87 (0.1)	63 (–0.2)	15 (–3.4)	52 (–0.5)	79 (0.0)	36 (6.3)	89 (4.1)
Waitomo (17)	49 (0.1)	<1 (–0.1)	<1 (0.3)	64 (0.3)	12 (–0.6)	<1 (0.9)	**<1 (1.1)**	**<1 (–7.2)**	35 (0.4)	**<1 (1.2)**	78 (–3.6)	97 (–0.3)
	6 (0.5)	63 (0.1)	90 (0.0)	48 (0.9)	16 (–1.8)	26 (0.4)	41 (0.4)	<1 (–0.8)	**2 (–1.4)**	98 (0.0)	74 (–2.6)	31 (–3.1)
West Coast												
Awakino (70)	87 (0.0)	<1 (–0.2)	<1 (–0.2)	16 (–1.6)	13 (–0.6)	**<1 (–1.2)**	**<1 (–1.9)**	<1 (–0.3)	23 (–0.6)	<1 (–0.8)	43 (–3.3)	63 (–1.6)
	1 (1.1)	21 (0.1)	52 (–0.1)	10 (–4.2)	41 (–1.2)	**<1 (–4.8)**	**<1 (–5.5)**	82 (0.0)	**<1 (–4.4)**	**<1 (–3.7)**	50 (–8.1)	62 (3.6)
Awakino (69)	52 (–0.1)	15 (–0.1)	29 (0.1)	88 (–0.1)	10 (–0.8)	**<1 (1.0)**	11 (0.6)	**<1 (–2.5)**	41 (0.5)	37 (0.0)	94 (0.3)	38 (3.4)
	<1 (1.3)	2 (0.7)	10 (0.6)	7 (–3.9)	94 (0.1)	**1 (–2.1)**	**2 (–3.3)**	31 (–1.8)	**<1 (–6.2)**	**1 (–4.3)**	40 (–8.0)	35 (–14.6)
Manganui (67)	66 (–0.1)	1 (–0.2)	59 (0.0)	13 (1.5)	24 (–0.6)	**1 (1.0)**	15 (–0.6)	**<1 (–1.1)**	76 (0.0)	35 (0.0)	99 (–0.1)	68 (–2.0)
	5 (1.0)	25 (0.2)	7 (0.5)	**5 (–5.1)**	**2 (2.4)**	**<1 (–3.7)**	**<1 (–6.0)**	8 (–0.4)	**<1 (–7.7)**	**<1 (–4.4)**	42 (–15.6)	20 (–14.8)
Mangaotaki (66)	18 (0.2)	26 (0.0)	<1 (0.2)	59 (–0.3)	57 (0.2)	**<1 (1.3)**	<1 (0.8)	**<1 (–3.0)**	44 (0.3)	11 (0.9)	–	–
	74 (0.1)	78 (0.0)	5 (–0.2)	34 (–1.5)	65 (–0.8)	86 (–0.2)	27 (–0.5)	59 (–0.5)	**<1 (–5.4)**	**<1 (–3.0)**	–	–
Marokopa (15)	18 (0.2)	<1 (–0.1)	2 (0.2)	74 (0.1)	4 (–0.7)	**<1 (1.1)**	**<1 (1.1)**	**<1 (–2.0)**	96 (0.0)	27 (0.0)	**1 (–7.9)**	62 (2.4)
	24 (0.4)	81 (–0.1)	62 (0.1)	28 (1.0)	**3 (–2.9)**	44 (–0.4)	30 (0.9)	13 (–0.3)	**<1 (–4.1)**	6 (–1.6)	35 (–8.9)	58 (4.0)
Mokau (68)	52 (0.1)	35 (0.1)	<1 (0.4)	32 (–0.7)	**<1 (1.2)**	**<1 (1.1)**	**<1 (1.3)**	**<1 (–1.9)**	**4 (–1.2)**	17 (0.0)	56 (–1.1)	49 (2.5)
	66 (0.1)	27 (0.2)	13 (–0.3)	10 (–2.4)	35 (1.5)	23 (–0.6)	62 (0.3)	**2 (–6.8)**	**<1 (–6.4)**	**3 (–4.0)**	62 (–3.0)	50 (–12.9)
Mokau (62)	76 (0.0)	<1 (–0.3)	<1 (0.6)	41 (0.4)	5 (–0.9)	**<1 (1.7)**	**<1 (2.1)**	15 (–0.1)	3 (0.9)	28 (0.7)	57 (2.9)	87 (0.5)
	92 (0.1)	8 (–0.3)	17 (–0.2)	23 (1.1)	**<1 (–5.3)**	62 (–0.1)	86 (0.1)	45 (–0.1)	**4 (–2.3)**	**<1 (–3.1)**	**5 (–16.8)**	40 (–4.3)
Mokau (71)	31 (0.1)	<1 (–0.1)	<1 (0.4)	**2 (–1.5)**	16 (0.6)	**<1 (1.3)**	**<1 (1.4)**	**<1 (–2.9)**	19 (–0.8)	61 (0.0)	98 (0.1)	22 (7.5)
	34 (0.3)	49 (–0.1)	13 (–0.2)	31 (–1.0)	51 (–0.9)	31 (–0.6)	90 (–0.1)	**<1 (–8.4)**	**<1 (–5.3)**	**<1 (–4.3)**	79 (3.9)	82 (–1.6)
Mokauiti (72)	78 (0.1)	<1 (–0.2)	<1 (0.2)	**1 (–1.6)**	**<1 (1.6)**	<1 (0.8)	3 (0.8)	**3 (–1.3)**	7 (–0.8)	82 (0.0)	90 (0.3)	15 (6.3)
	49 (0.4)	82 (0.0)	<1 (–0.8)	78 (0.6)	49 (–0.5)	74 (0.6)	78 (0.3)	**1 (–6.3)**	**<1 (–4.3)**	62 (–1.3)	65 (–3.6)	99 (0.0)
Ohautira (9)	81 (0.0)	29 (0.0)	32 (0.1)	38 (–0.6)	**<1 (1.0)**	**<1 (1.5)**	**<1 (2.1)**	**<1 (–5.3)**	30 (–0.5)	5 (–0.5)	12 (–4.5)	35 (4.6)
	33 (0.6)	65 (0.1)	94 (0.0)	10 (–2.7)	**4 (2.1)**	15 (–1.2)	51 (–0.8)	**<1 (–6.2)**	**<1 (–4.2)**	**<1 (–1.8)**	14 (–9.9)	71 (2.0)

Appendix 3 continued

	Temperature	**Dissolved oxygen**	**Conductivity**	**Turbidity**	**Visual clarity**	**Total nitrogen**	**Nitrate-N**	**Ammonia**	**Total phosphorus**	**Dissolved reactive P**	***Escherichia coli***	**Enterococci**
Oparau (14)	25 (0.2)	27 (–0.1)	76 (0.0)	81 (0.2)	1 (–0.9)	**1 (1.0)**	12 (0.9)	3 (–0.3)	45 (–0.6)	**1 (–1.7)**	–	–
	19 (0.5)	21 (0.3)	2 (–0.6)	94 (–0.1)	8 (–1.8)	13 (–2.1)	38 (–1.6)	2 (–0.8)	**4 (–4.4)**	**<1 (–7.6)**	–	–
Tawarau (16)	9 (0.2)	<1 (–0.1)	5 (0.1)	62 (–0.4)	41 (–0.3)	<1 (0.9)	<1 (0.8)	**<1 (–1.7)**	78 (0.0)	59 (0.0)	–	–
	43 (0.3)	22 (–0.1)	50 (–0.2)	47 (1.1)	**2 (–2.5)**	84 (–0.2)	40 (0.7)	<1 (–0.3)	**<1 (–3.8)**	**<1 (–1.7)**	–	–
Waingaro (8)	10 (–0.2)	<1 (0.2)	14 (0.1)	16 (1.0)	8 (–0.6)	**<1 (1.1)**	**<1 (1.5)**	**2 (–1.8)**	54 (–0.2)	**<1 (–1.8)**	–	–
	90 (–0.1)	<1 (0.6)	13 (0.2)	12 (–2.5)	78 (–0.7)	85 (–0.3)	33 (1.2)	**<1 (–10.6)**	**<1 (–4.8)**	**1 (–2.5)**	–	–
Waitetuna (10)	87 (0.0)	19 (–0.1)	5 (0.1)	**<1 (2.1)**	**1 (–1.1)**	**<1 (1.5)**	**<1 (1.9)**	19 (–0.9)	70 (0.3)	2 (–0.8)	46 (–1.5)	11 (3.5)
	85 (0.1)	90 (0.0)	36 (–0.1)	49 (0.9)	26 (–1.4)	98 (0.0)	16 (1.1)	**1 (–7.6)**	13 (–2.3)	99 (0.0)	17 (–4.6)	99 (0.3)