Healthy Rivers Hearing-PC1

Day 27

17 June 2019

10.34am

Reports requested by Panel, tabled by Matthew McCallum-Clark

- Trends in River Water Quality in the Waikato Region, 1980-97

    Pub: 1998 (not online)

Hard copy only (scanned version follows this listing).

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

    Pub: March 2004

https://www.waikatoregion.govt.nz/assets/PageFiles/2651/TR04-02.pdf

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

    Pub: August 2013

https://www.waikatoregion.govt.nz/assets/PageFiles/10004/TR0833.pdf

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

    Pub: August 2013

http://www.waikatoregion.govt.nz/assets/PageFiles/26868/TR201320.pdf

- Trends in river water quality in the Waikato Region, 1993-2017

    Pub: December 2018

https://www.waikatoregion.govt.nz/assets/WRC/Services/publications/technical-reports/2018/TR201830.pdf

Environment Waikato Technical Report 1998/13

Trends in River Water Quality in the Waikato Region, 1980-97

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Summary

We analysed trends in river water quality at 109 sites in the Waikato region using modern non-parametric statistical methods (seasonal Kendall Sen slope estimator and trend test). Records of 15 variables measured at nine (of ten) Waikato River sites were analysed; many of these began as long ago as 1980. Rather shorter records—the majority beginning in either 1993 or 1994—of ten variables at 100 other sites on rivers and streams in the region were also analysed. The data were generally obtained at monthly intervals, but some records contain extended periods of quarterly sampling only. Most of the records were adjusted to remove the effects of flow, and both raw and flow-adjusted records were analysed for trends. In many cases flow records were not available at or near the water quality sampling site, so "flow indexes" generated from other suitable flow records were used instead.

A total of 133 Waikato River water quality records were considered. Significant trends (p-value $\leq$ 10%) were found in 69 of these (52% of the total number of records); 48 were improving trends (36% of total), and 21 were deteriorating trends (16% of total). Particularly noteworthy were the improvements in total nitrogen levels at five of the nine sites, in dissolved colour at seven sites, and in biochemical oxygen demand at all nine sites. There are other records showing improvements in river water quality prior to 1980, but the records analysed in this study did not encompass that earlier period.

A total of 966 water quality records from the other rivers and streams were considered. Significant trends were found in 226 of these (23% of total); 9% of the records showed an improvement, and 14% deteriorated. Because these particular records are all rather shorter than those from the Waikato River, it's unclear whether the observed changes represent a continuation of earlier trends, or simply reflect some relatively short-term change (including transitory changes). As further information is obtained, and the records are extended, the true nature of these early indications of change will become clearer.

While many of the trends involved moderately-high rates of change, about 20% of them were regarded as being "slight" (including most of the trends—mainly deteriorations—in pH and dissolved oxygen). While there are clear standards for identifying the <u>statistical</u> significance of trends, it was sometimes difficult to assess their <u>practical</u> importance. A simple, but slightly flawed, guideline adopted here was that trends where the absolute rate of change was less than 1% of the median value per year were considered to be relatively unimportant.

Contents

Acknowledgments

Many Environment Waikato staff have been involved in obtaining the water quality records described here (e.g., see Wilson et al. 1998). As well as Environment Waikato's own flow records, we also used those kindly provided by ECNZ and Contact Energy (through their agents NIWA and Opus), and NIWA (funded by the Foundation for Research, Science and Technology). NIWA (Graham Bryers) kindly provided the results for the five sites sampled as part of its National River Water Quality Network. And Graham McBride (NIWA) made useful comments on a draft version of this report.

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. Conditions are 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). Results are reported in annual data reports (e.g., Huser & Wilson 1997, Wilson et al. 1998). In 1993, monthly monitoring of the water quality of other rivers and streams in the region began. Water quality is now measured at 100 sites on these other rivers and streams (Figure 1), with results being summarized by Huser & Wilson (1996) and Wilson (1998a,b).

There are generally two important aims of routine water quality monitoring programmes:

- to determine the condition of the waterbody, and
- to determine long-term changes, or "trends" in water quality conditions

Until recently, analyses of the results of Environment Waikato's monitoring programmes focussed on the first of these aims. However, in 1994 modern statistical methods were used to identify trends in water quality at four sites on the Waikato River (NIWA 1994). This was followed in 1997 by a similar analysis of trends in microbiological water quality at 14 sites on the river (NIWA 1997).[1] Both studies found relatively-large improvements in river water quality over the previous 20 years. This report extends those initial analyses, and describes the results of a comprehensive analysis of many of the region's routine river water quality records—from both the Waikato River and the numerous other rivers and streams.

It is important to note that the records are of different length. Many of the Waikato River records began in 1980 (i.e., producing 18-year records to the end of 1997), but others did not start until late in the 1980s; while records of black disc visibility at (seven) river sites did not begin until 1995. The sampling of the 100 sites on the other rivers and streams also started at different times: 68 began in 1993 (i.e., 5-year records), 27 began a year later in 1994, while the five sites sampled as part of NIWA's National River Water Quality Network have been sampled since 1989–90 (i.e., 7- or 8-year records to the end of 1996, the endpoint of the data available at the time we undertook the analysis). We chose to ignore these differences, and instead simply report the overall trend for the whole of each record (i.e., to the end of 1997 for the Environment Waikato records, and to the end of 1996 for the NIWA records).

[1] note that whereas the 1997 analysis looked for trends in both the raw and flow-adjusted records, the 1994 analysis considered trends in the raw records only (although the likely effects of the observed long-term changes in river flow on water quality were commented on).

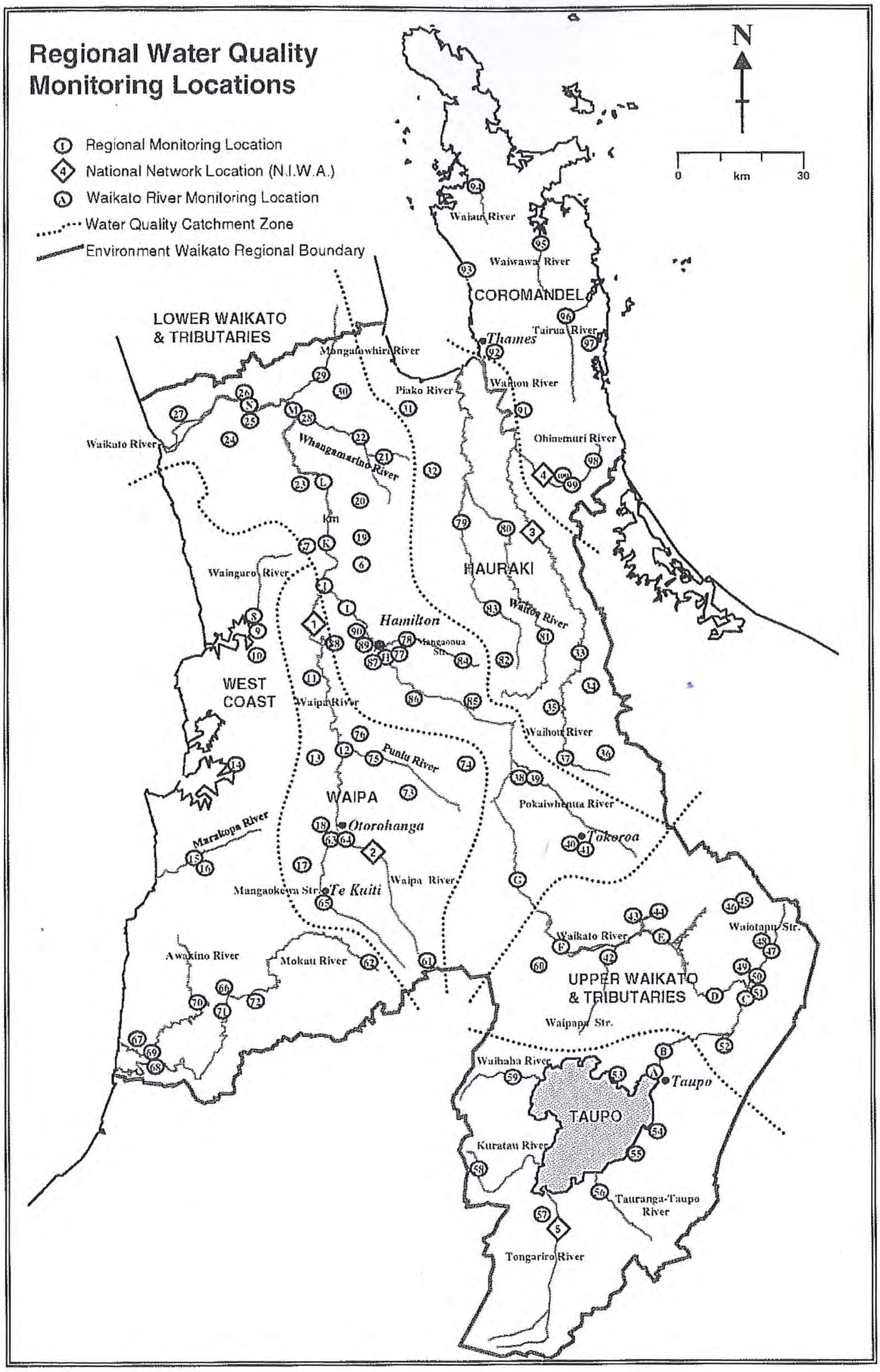

Figure 1: The Waikato Region, showing the Waikato River and the 10 routine water quality sampling sites, and the 100 sites on the other rivers and streams (see Tables 1 and 2 for site details). The dotted lines divide the region into seven water quality zones (see text).

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 (Wilson 1998a,b, Wilson et al. 1998). Note that the information for five of the 100 non-Waikato River sites was obtained by NIWA as part of its National River Water Quality Network (Smith et al. 1996, and unpublished results). These were: Ohinemuri @ Karangahake, Waihou @ Te Aroha, Tongariro @ Turangi, Waipa @ Otewa, and Waipa @ Whatawhata. (Note that we did not, however, consider the results from the three Waikato River sites which are also sampled as part of the National Network.)

2.1 Statistical analyses—general approach

It's generally not appropriate to analyse water quality records for trends using methods involving simple linear regression. This is because many water quality variables are not normally distributed, and so neither are their regression residuals. As a result, the necessary assumptions for using linear regression methods are generally not met. Nor do these methods satisfactorily deal with the marked seasonal variability which is often a major feature of water quality records. Modern seasonally-adjusted non-parametric methods are therefore increasingly being used to determine trends in water quality records (Gilbert 1987, Harcum et al. 1992, Helsel & Hirsch 1992; see NIWA 1994 for a useful discussion). These techniques were recently used to analyse the records of New Zealand's National River Water Quality Network (Smith et al. 1996).

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

- the "seasonal Kendall Sen slope estimator" which measures the magnitude of the trend, and
- the associated "seasonal Kendall trend test" which determines whether the trend is significant.

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

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

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

2.2 Seasonal Kendall trend slope

The Environment Waikato water quality samples were generally collected at monthly intervals (although some variables were only measured at quarterly intervals). For monthly samples the seasonal Kendall Sen 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 Sen 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.

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

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

Here we generally adopt the conventional procedure, and report slopes in water quality units/yr. Occasionally, however, we also refer to the percentage change per year (compared to the median level). Note that for many water quality variables, the numeric values of slopes expressed in common units are very small (e.g., 0.0001 $[g/m^3]$/yr). To avoid using large numbers of zeroes, we therefore often express the slopes in modified units (e.g., giving 0.1×10^{-3} $[g/m^3]$/yr for the previous example).

2.3 Seasonal Kendall trend test

The trend test assesses whether the trend slope is significant or not (i.e., the probability of the observed trend being due to chance). This is often called the *p*-value. It 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 of 5% or less are conventionally regarded as indicating that a trend is statistically significant (i.e., unlikely to be due to chance). In this analysis we adopted the more conservative criterion that significant trends were indicated by *p*-values of 10% or less, thus providing an earlier indication that important environmental changes may be occurring. Although we recognise that the magnitude of the *p*-value depends on the number of samples—ranging here from about 50 (or less) to more than 200—we have chosen to disregard this.

Note that the trend test says nothing about whether the trend is of any <u>practical</u> importance. Even though a given trend may be highly significant statistically, its magnitude may be so small that it is unlikely to be of much practical importance. One guideline is that if the absolute value of the (standardized) slope is much less than 1 percent of the median value per year, then any observed trends are often too small to be of much practical importance.

Depending on the water quality variable, positive or increasing slopes were identified as either being an improvement (e.g., for dissolved oxygen and visual clarity records) or a deterioration (most other variables), and vice versa for negative or decreasing slopes. We thus use the terms "improving" or "deteriorating" to decribe the observed trends.

The Wqstat II package (Colorado State University 1989) has been widely-used to calculate the seasonal Kendall trend estimator and test (e.g., Smith et al. 1996). However, due to its acknowledged shortcomings—particularly in dealing with missing values—we chose instead to simply evaluate the relevant formulae using widely-available software (Microsoft Excel 97).

2.4 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 a more-or-less predictable fashion. As a result, identifying and allowing-for the effect of flow can usefully reduce the overall variability in a water quality record, and thus permit any underlying trend to be more readily observed.

Most of the water quality records were therefore examined for trends both before and after being flow-adjusted (but see below for exceptions to this). Flow-adjustment was done by identifying a flow corresponding to each sampling occasion (see below), and determining a relationship between flow and water quality for each variable (at each site). Following standard procedures (see Smith et al. 1996), we used the LOWESS smoothing technique with a 30% span to compute these relationships (software: Data Desk, version 6.0.1; Data Description Inc.). In each case, the LOWESS relationship identified the expected value of the water quality variable corresponding to the flow at the time of sampling. The difference between this expected value and that actually measured was the flow-dependent residual. The "flow-adjusted" value of the variable was given by the sum of the median of the raw data and the residual.

2.5 Flow records

For nine of the routinely-monitored Waikato River sites, there were flow records at nearby sites. There is also a flow record at the tenth site—Tuakau Bridge ("N" in Figure 1), but it is affected by the tidal nature of the river at this point, so we have chosen not to analyse the corresponding water quality records. Here we distinguish between sites with "primary" flow records, where the flow recorder was located at or near the water quality sampling site, and "secondary" sites, where the flow recorder was some distance from the sampling site. Table 1 lists the flow records used for the six primary and the three secondary Waikato River sites.

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

Map	Water quality site	Flow record	TIDEDA	HYDROL
A	*Taupo Gates*	Reids Farm	1145444	1131-119
C	Ohaaki Bridge	Ohaaki Bridge[†]	1543447	1131-159
E	Ohakuri tailrace	Ohakuri total	2774	1131-163
F	Whakamaru tailrace	Whakamaru total	2754	1131-162
G	Waipapa tailrace	Waipapa total	2734	1131-161
H	*Narrows Bridge*	Karapiro total	2714	1131-160
I	*Horotiu Bridge*	Hamilton Traffic	43466	1131-64
K	Huntly Bridge	Huntly North[§]	1443467	1131-73
		Huntly Power Station	1543495	1131-74
M	Mercer Bridge	Mercer	1043446	1131-91

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

[§] record to January 1983; Power Station record used thereafter

Table 2: Flow records used to flow-adjust water quality records for 100 Waikato region sites. Sites for which a flow index was generated are shown in italics. TIDEDA and HYDROL numbers for the flow recorder sites are given.

Map	Water quality site	Flow record	TIDEDA	HYDROL
Coromandel (11 sites)				
91	*Hikutaia @ off Maratoto Rd*	Kauaeranga @ Smiths	9301	234-11
92	Kauaeranga @ Smiths	Kauaeranga @ Smiths	9301	234-11
4	Ohinemuri @ Karangahake (NIWA)	Ohinemuri @ Karangahake	9213	619-16
99	Ohinemuri @ Queens Head	Ohinemuri @ Queens Head	1009235	619-19
98	*Ohinemuri @SH25*	Ohinemuri @ Queens Head	1009235	619-19
96	*Tairua @ Morrisons*	Tairua @ Broken Hills	12301	940-2
93	Tapu @ Tapu-Coroglen Rd	Tapu @ Tapu-Coroglen Rd	9701	954-5
94	*Waiau @ E309 Rd*	Tapu @ Tapu-Coroglen Rd	9701	954-5
100	*Waitekauri u/s Ohinemuri*	Ohinemuri @ Queens Head	1009235	619-19
95	*Waiwawa @ SH25*	Waiwawa @ Rangihau Rd	11807	1257-2
97	*Wharekawa @ SH25*	Wharekawa @ Adams Farm	12509	1312-1
Hauraki (13 sites)				
32	*Mangawhero @ Mangawara Rd*	Waitakaruru @ Quarry Rd	9009	1230-4
35	*Oraka @ Lake Rd*	Waihou @ Okauia	9224	1122-18
83	Piako @ Kiwitahi	Piako @ Kiwitahi	9175	749-10
79	Piako @ Paeroa-Tahuna Rd	Piako @ Paeroa-Tahuna Rd	9140	749-15
82	*Piakonui @ Piakonui Rd*	Piako @ Kiwitahi	9175	749-10
33	Waihou @ Okauia	Waihou @ Okauia	9224	1122-18
3	Waihou @ Te Aroha (NIWA)	Waihou @ Te Aroha	9205	1122-34
37	*Waihou @ Whites Rd*	Oraka @ Pinedale	1009213	669-13
36	*Waiohotu @ Waiohotu Rd*	Oraka @ Pinedale	1009213	669-13
34	*Waiomou @ Matamata-Tauranga Rd*	Waihou @ Okauia	9224	1122-18
31	*Waitakaruru @ Coxhead Rd*	Waitakaruru @ Quarry Rd	9009	1230-4
81	Waitoa @ Landsdowne Rd	Waitoa @ Waharoa Control	9112	1249-38
80	Waitoa @ Mellon Rd	Waitoa @ Mellon Rd	9179	1249-18
Inflows to Lake Taupo (8 sites)				
55	*Hinemaiaia @SH1*	Hinemaiaia @ Maungatera	2743464	171-4
58	*Kuratau @ SH41 Moerangi*	Tauranga-Taupo @ Te Kono	1543413	971-4
53	*Mapara @ off Mapara Rd*	Tauranga-Taupo @ Te Kono	1543413	971-4
56	Tauranga-Taupo @ Te Kono	Tauranga-Taupo @ Te Kono	1543413	971-4
57	Tokaanu @ off SH41 Turangi	flow reasonably steady—don't adjust		
5	Tongariro @ Turangi (NIWA)	Tongariro @ Turangi	1043459	1050-2
59	*Waihaha @ SH32*	Tauranga-Taupo @ Te Kono	1543413	971-4
54	*Waitahanui @ Blake Rd*	Hinemaiaia @ Maungatera	2743464	171-4
Upland tributaries of the Waikato River (12 sites)				
48	*Kawaunui @ SH5*	Waiotapu @ Campbell Rd	2043493	1186-2
43	*Mangaharakeke @ SH30*	Tahunaatara @ Ohakuri Rd	1043428	934-1
49	Mangakara @ SH5	flow reasonably steady—don't adjust		
60	*Mangakino @ Sandel Rd*	Mangakino @ Dillon Rd	1043427	388-2
46	Otamakokore @ Hossack Rd	Otamakokore @ Hossack Rd	2143401	683-4
52	*Pueto @ Broadlands Rd*	Waiotapu @ Reporoa	43472	1186-9
44	Tahunaatara @ Ohakuri Rd	Tahunaatara @ Ohakuri Rd	1043428	934-1
51	Torepatutahi @ Vaile Rd	flow reasonably steady—don't adjust		
47	Waiotapu @ Campbell Rd	Waiotapu @ Campbell Rd	2043493	1186-2
50	*Waiotapu @ Homestead Rd*	Waiotapu @ Reporoa	43472	1186-9
42	*Waipapa @Tirohanga Rd*	Tahunaatara @ Ohakuri Rd	1043428	934-1
45	*Whirinaki @ Corbett Rd*	Otamakokore @ Hossack Rd	2143401	683-4
Lowland tributaries of the Waikato River (26 sites)				
7	Awaroa @ Rotowaro-Huntly Rd	Awaroa @ Sansons	1143450	39-11
27	*Awaroa @ Otaua Rd*	Whakapipi @ SH22	1643457	1282-8
85	*Karapiro @ Hickey Rd*	Pokaiwhenua @ Puketurua	1043419	786-2

Table 2 (continued)

Map	Water quality site	Flow record	TIDEDA	HYDROL
90	*Kirikiriroa @ Tauhara Dr*	Mangaonua @ Dreadnought	1543497	421-4
6	Komakorau @ Henry Rd	flow reasonably steady—don't adjust		
38	*Little Waipa @ Arapuni-Putararu Rd*	Pokaiwhenua @ Puketurua	1043419	786-2
87	*Mangakotukutuku @ Peacock Rd*	Mangaonua @ Dreadnought	1543497	421-4
40	*Mangamingi @ Paraonui Rd*	Pokaiwhenua @ Puketurua	1043419	786-2
77	*Mangaone @ Annebrooke Rd*	Mangaonua @ Dreadnought	1543497	421-4
78	*Mangaonua @ Hoeka Rd*	Mangaonua @ Dreadnought	1543497	421-4
84	*Mangaonua @ Te Miro Rd*	Mangaonua @ Dreadnought	1543497	421-4
30	Mangatangi @ SH2	Mangatangi @ SH2	1243414	453-6
29	*Mangatawhiri @ Lyons Rd*	Mangatangi @ SH2	1243414	453-6
19	*Mangawara @ Rutherford Rd*	Mangawara @ McConnells	1443498	481-4
86	*Mangawhero @ Cambridge-Ohaupo Rd*	Mangaonua @ Dreadnought	1543497	421-4
20	Matahuru @ Waiterimu Rd	Matahuru @ Waiterimu Rd	43489	516-5
25	*Ohaeroa @ SH22*	Whakapipi @ SH22	1643457	1282-8
24	*Opuatia @ Ponganui Rd*	Whakapipi @ SH22	1643457	1282-8
39	Pokaiwhenua @ Arapuni-Putararu Rd	Pokaiwhenua @ Puketurua	1043419	786-2
21	*Waerenga @ Taniwha Rd*	Matahuru @ Waiterimu Rd	43489	516-5
89	*Waitawhiriwhiri @ Edgecumbe St*	Mangaonua @ Dreadnought	1543497	421-4
26	Whakapipi @ SH22	Whakapipi @ SH22	1643457	1282-8
41	*Whakauru @ SH1*	Pokaiwhenua @ Puketurua	1043419	786-2
28	*Whangamarino @ Island Block Rd*	Matahuru @ Waiterimu Rd	43489	516-5
22	*Whangamarino @ Jefferies Rd*	Matahuru @ Waiterimu Rd	43489	516-5
23	Whangape @ Rangiriri-Glen Murray Rd	flow reasonably steady—don't adjust		
Waipa River and tributaries (16 sites)				
11	*Kaniwhaniwha @ Wright Rd*	Te Tahi @ Puketotara	1143427	1020-2
74	*Mangaohoi @ Maru Rd*	Puniu @ Pokuru	43431	818-2
65	Mangaokewa @ Te Kuiti	Mangaokewa @ Te Kuiti	1643462	414-13
76	*Mangapiko @ Bowman Rd*	Puniu @ Pokuru	43431	818-2
63	*Mangapu @ Otorohonga*	Waipa @ Honikiwi	43468	1191-13
73	*Mangatutu @ Walker Rd*	Puniu @ Pokuru	43431	818-2
13	*Mangauika @ Te Awamutu*	Te Tahi @ Pukeotara	1143427	1020-2
88	Ohote @ Whatawhata-Horotiu Rd	flow reasonably steady—don't adjust		
75	Puniu @ Bartons Corner Rd	Puniu @ Pokuru	43431	818-2
61	*Waipa @ Mangaokewa Rd*	Waipa @ Otewa	43481	1191-7
12	*Waipa @ Pirongia-Ngutunui Rd*	Waipa @ Whatawhata	43433	1191-11
2	Waipa @ Otewa (NIWA)	Waipa @ Otewa	43481	1191-7
64	*Waipa @ SH3 Otorohonga*	Waipa @ Honikiwi	43468	1191-13
1	Waipa @ Whatawhata (NIWA)	Waipa @ Whatawhata	43433	1191-11
18	*Waitomo @ SH31 Otorohonga*	Waitomo @ Aranui/Ruakuri	1943481	1253-3
17	*Waitomo @ Tumutumu Rd*	Waitomo @ Aranui/Ruakuri	1943481	1253-3
West Coast (14 sites)				
70	*Awakino @ Gribbon Rd*	Awakino @ Gorge	40810	33-14
69	*Awakino @ SH3-Awakau Rd*	Awakino @ Gorge	40810	33-14
67	*Manganui @ off Manganui Rd*	Awakino @ Gorge	40810	33-14
66	*Mangaotaki @ SH3*	Mokau @ Totoro	40708	556-9
15	*Marokopa @ Speedies Rd*	Marokopa @ Falls	41301	513-7
68	*Mokau @ Awakau Rd*	Mokau @ Totoro	40708	556-9
62	*Mokau @ Mangaokewa Rd*	Mangaokewa @ Te Kuiti	1643462	414-13
71	Mokau @ Totoro Rd	Mokau @ Totoro	40708	556-9
72	*Mokauiti @ Three Way Point*	Mokau @ Totoro	40708	556-9
9	*Ohautira @ Waingaro-Te Uku Rd*	Marokopa @ Falls	41301	513-7
14	*Oparau @ Langdon Rd*	Marokopa @ Falls	41301	513-7
16	*Tawarau @ off Speedies Rd*	Tawarau @ Te Anga	41302	976-2
8	*Waingaro @ Ruakiwi Rd*	Marokopa @ Falls	41301	513-7
10	*Waitetuna @ Te Uku-Waingaro Rd*	Marokopa @ Falls	41301	513-7

At the six sites with primary flow records, the flow at the time of sampling was retrieved from the relevant flow record (usually by interpolation). For the secondary sites the daily mean flow on the day of sampling was calculated. These various flows were used to flow-adjust all the water quality records.

For the 100 water quality sites on the region's other rivers and streams, the situation was less straight-forward. At six of the sites, flows were considered to be reasonably steady, so no flow-adjustment was undertaken. Flows were recorded at or near 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 69 sites a "flow index" was calculated, based on the mean flow calculated for each sampling day elsewhere on the relevant stream, or on a similar stream nearby. 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 2 lists the relevant flow records for each of the sites. These were used to flow-adjust the water quality records.

The 100 sites in Table 2 are reasonably-evenly distributed across the whole Waikato region. We chose to divide the region into seven different zones (Table 2, Figure 1). These were based largely on river catchments and some broad ecological features, including geology, altitude, winter temperatures, and vegetation cover and land use.

3 Results and Discussion

3.1 Waikato River

Table 3 lists the *p*-values and trend slopes for the water quality records at the nine Waikato River sites. Altogether we analysed 133 water quality records; 69 of these showed trends which were significant (p-value $\leq 10\%$). Of these, 48 were improving trends, and 21 were deteriorating trends (36% and 16% of the total number of records, respectively). A total of 54, or about three-quarters of the trends were actually significant at a p-value of $\leq 5\%$, while more than half of these (i.e., 38 trends) were significant at $p \leq 1\%$.

Of the 69 significant trends in the flow-adjusted records, a total of 11—or 16%—were not seen in the raw records. That is, flow-adjusting reduced the overall variability of these datasets to the extent that the underlying trends became apparent. Conversely, 23 of the raw records showed significant trends which were not seen in the corresponding flow-adjusted records. This means that 28% ($= 100 \times 23/[23 + \{69 - 11\}]$) of the trends apparent in the raw records disappeared following flow-adjustment.

Table 3: *p*-values (%) and trend slopes (in brackets) for records of flow-adjusted water quality variables at nine Waikato River sites during 1980–97. Trends shown in bold (and underlined) are significant ($p \leq 10\%$). Of these, improving trends are shown in plain text; and deteriorating trends are shown in italics.

	Turbidity (10^{-3} NTU/yr)	Black disc (10^{-3} m/yr)	Temperature (10^{-3} °C/yr)	pH (10^{-3}/yr)	Dissolved oxygen (10^{-3} % of saturation/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Ammoniacal N (10^{-3} [g/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Enterococci ([no./100 mL]/yr)	Faecal coliforms ([no./100 mL]/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)	Chlorophyll *a* (10^{-3} [g/m^3]/yr)	BOD$_5$ (10^{-3} [g/m^3]/yr)	Arsenic (10^{-3} [g/m^3]/yr)	Boron (10^{-3} [g/m^3]/yr)
Taupo	**0 (–6)**	–	**9 (–24)**	***0 (24)***	28 (90)	**5 (–3.4)**	**1 (–0.5)**	**0 (–0.1)**	14 (0.1)	**10 (–0.04)**	11 (0.0)	§0 (0.1)	**0 (–25)**	34 (0.0)	**3 (–1.2)**
Ohaaki	19 (–23)	**5 (380)**	***1 (251)***	30 (16)	***9 (–232)***	12 (–5.5)	89 (0.0)	**0 (–1.0)**	35 (–0.4)	**5 (–3.8)**	**8 (–0.1)**	§0 (0.0)	**0 (–113)**	51 (0.7)	71 (4.0)
Ohakuri	**7 (–7)**	**5 (248)**	18 (20)	***0 (16)***	**9 (237)**	**4 (–8.6)**	81 (0.0)	72 (0.0)	37 (0.0)	21 (–0.1)	48 (0.0)	38 (0.0)	**1 (–20)**	**7 (–0.4)**	11 (–2.5)
Whakamaru	40 (18)	**1 (332)**	23 (–83)	***8 (22)***	11 (310)	**6 (–13.3)**	**4 (–1.0)**	14 (–0.4)	78 (–0.1)	38 (–0.3)	**10 (–0.2)**	23 (0.1)	**3 (–28)**	73 (–0.2)	56 (–1.9)
Waipapa	**3 (–12)**	**5 (312)**	51 (8)	***0 (17)***	16 (253)	19 (–4.6)	13 (–0.5)	76 (0.0)	**1 (–0.4)**	**0 (–2.0)**	**0 (–0.4)**	74 (0.0)	**0 (–24)**	**3 (–0.6)**	**1 (–3.3)**
Narrows	***1 (24)***	64 (57)	16 (–30)	***0 (64)***	15 (–151)	58 (–3.5)	**0 (–1.7)**	***0 (0.2)***	53 (–0.7)	89 (–0.3)	**0 (–0.4)**	68 (–0.1)	**10 (–21)**	**0 (–0.5)**	**0 (–4.0)**
Horotiu	13 (20)	65 (66)	***3 (41)***	***0 (47)***	59 (–137)	94 (1.0)	36 (–0.5)	13 (0.2)	***2 (3.5)***	***0 (10.3)***	**0 (–0.4)**	71 (0.0)	**6 (–20)**	99 (0.1)	11 (–1.8)
Huntly	24 (45)	88 (22)	***1 (61)***	***0 (44)***	52 (–108)	**4 (–12.0)**	81 (–0.3)	***0 (0.9)***	95 (0.4)	35 (4.7)	**0 (–0.4)**	47 (0.1)	**2 (–28)**	90 (0.0)	**4 (–3.2)**
Mercer	37 (95)	–	***2 (130)***	***0 (51)***	54 (80)	**0 (–24.0)**	**0 (–1.1)**	***0 (1.4)***	***8 (1.4)***	†**0 (–14.2)**	**0 (–1.3)**	***0 (0.8)***	**9 (–27)**	99 (0.0)	56 (1.0)
Improvements	3	4	1	–¶	1	5	4	2	1	4	7	0	9	3	4
Deteriorations	*1*	*0*	*4*	*8*	*1*	*0*	*0*	*3*	*2*	*1*	*0*	*1*	*0*	*0*	*0*

§ some parts of these records appear dubious, perhaps because values were frequently near the detection limit of the analytical method used

† our 1987–97 record of faecal coliforms at this site was extended back to 1980 using information from Watercare Services (see NIWA 1997)

¶ all significant trends in pH were regarded as deteriorations, since both increasing and decreasing trends tend to shift levels outside the preferred range of values

These latter results are therefore likely to have reflected trends in the flow records, rather than being real trends in water quality.

In the majority of cases (52, or 75% of the significant trends), the absolute value of the slope exceeded 1% of the median per year, so the trends could be regarded as being "important". However, all the trends in pH and dissolved oxygen, and four of the five trends in temperature had smaller slopes. Most of the important deteriorating trends occurred at sites in the lower river (i.e., Horotiu, Huntly and Mercer).

Marked improvements were observed in several of the (3-year-long) records of black disc visibility. However, corresponding trends in levels of turbidity at these sites during the same period (1995–97) were not observed (although trends in certain of the complete turbidity records were: Table 3). The trends in the black disc records arose because the observed black disc visibilities were generally lower during the first year of measurement (1995), even though measured turbidities were normal then. It is possible that these early black disc results were in fact under-estimates caused by initial difficulties in establishing satisfactory measurement protocols. At this stage, the overall trends in turbidity (Table 3) therefore provide a more reliable measure of long-term changes in water clarity in the river. And the 1995 black disc results should be treated with caution.

Particularly noteworthy were the falls (i.e., improvements) in total nitrogen concentrations at five of the sites, in dissolved colour at seven sites, and in biochemical oxygen demand (BOD_5) at all nine sites. During the period of these records, general pressures on river water quality such as the total number of people living in communities near the river, and total stock numbers in the catchment have increased. Under these circumstances the observed improvements are pleasing.

Figure 2 shows some representative examples of the observed trends, namely the declines in dissolved colour, arsenic and boron at the Waipapa site during 1980–97.[2] The reduction in colour results from the substantial improvement in the quality of the wastewater discharged from the pulp and paper mill at Kinleith (Nagels & Davies-Colley 1997). Since 1991 the concentration of coloured material in the wastewater has been roughly half of that discharged previously.

By contrast, it's not clear why the concentrations of arsenic and boron fell during 1983–97. There was no overall decline in the load of contaminated geothermal fluid discharged to the river from the

[2] there are a number of gaps in these records, particularly those for arsenic and boron which were monitored at quarterly intervals only during 1987–94: monthly observations (only) are connected by straight lines; the units are absorbance @ 340 nm/cm (dissolved colour), and g/m^3 (all other variables in Figures 2 and 3)

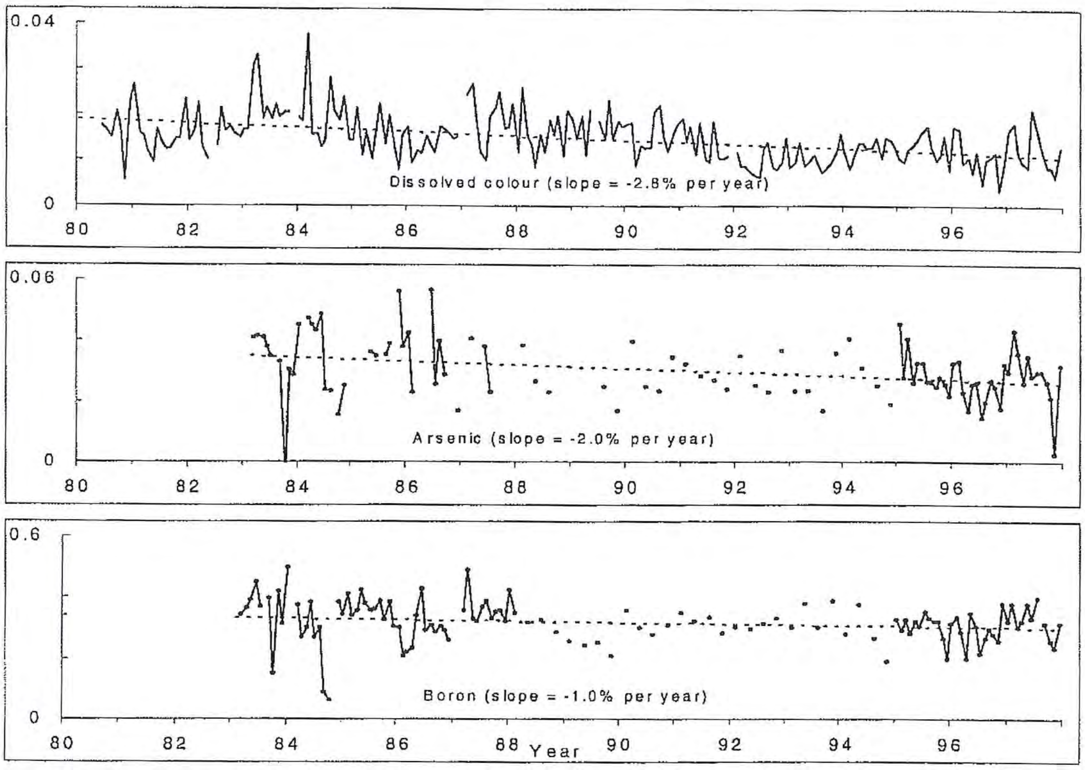

Figure 2: Flow-adjusted levels of dissolved colour, arsenic and boron in the Waikato River at Waipapa during 1980–97. The dashed lines show the overall trends in the records.

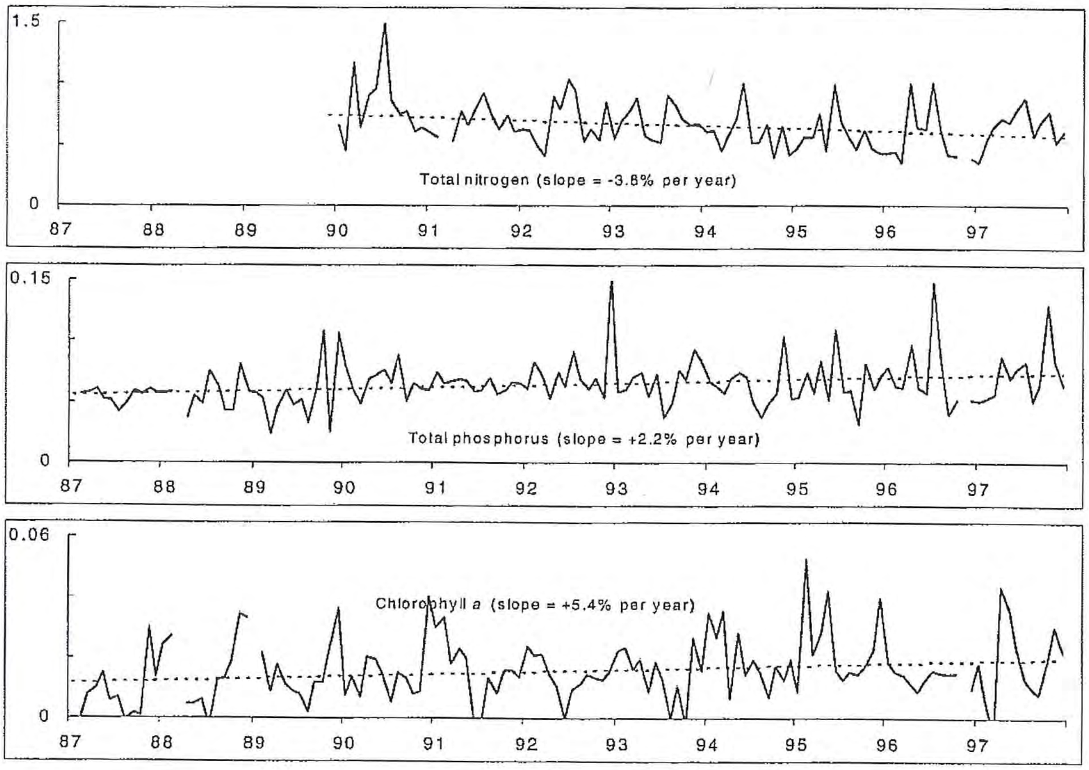

Figure 3: Flow-adjusted levels of total nitrogen, total phosphorus and chlorophyll *a* in the Waikato River at Mercer during 1987–97. The dashed lines show the overall trends in the records.

power station at Wairakei during the period, although since then loads have begun to fall appreciably (Contact Energy, unpublished results).

The changes observed at Mercer Bridge are also important. Figure 3 shows that concentrations of total nitrogen declined during 1990–97, at an overall rate of about 4% per year. However, the records of total phosphorus and chlorophyll *a* during 1987–97 both showed an overall increase—by about 2 and 5% per year, respectively. The fact that chlorophyll *a* levels tended to increase suggests they were largely unaffected by the decrease in nitrogen, but instead they increased in response to the increase in phosphorus. The combined effect of the increase in phosphorus and the decrease in nitrogen is that the nitrogen:phosphorus ratio of the water has declined. This means the lower river has become more suitable for the growth of nitrogen-fixing blue-green algae than it was previously.

As well as the various long-term changes, several short-term changes in river water quality have also occurred. The most striking of these is the recent improvement in levels of bacteria at the Ohaaki Bridge site. The discharge of sewage wastewater from the town of Taupo ceased towards the end of 1995. The median level of faecal coliforms in the period since then (20/100 mL during 1996–97) was about one-third of that for the previous five years (60/100 mL during 1991–95); and median levels of enterococci have halved (from 14 to 7/100 mL). Median levels of total nitrogen and total phosphorus at the Ohaaki Bridge site have also fallen since late 1995, by 23% and 40%, respectively.

3.2 Other rivers and streams

Table 4 lists the p-values and trend slopes for the water quality records at the 100 sites on the other rivers and streams. It is important to appreciate that the records for these sites are relatively short (mostly 4–5 years long), so it's unclear whether the observed changes represent a continuation of earlier trends, or simply reflect some relatively short-term change (including transitory changes). As further information is obtained, and the records are extended, the true nature of these early indications of change will become clearer.

We analysed records of (i) eight different water quality variables at all 100 sites, (ii) records of black disc visibility at 97 sites, and (iii) records of enterococci at 69 sites, giving a total of 966 records. Altogether 226 significant trends ($p \leq 10\%$) were observed—91 improving, and 135 deteriorating (i.e., about 9% and 14% of the total number of records, respectively). A total of 154, or about two-thirds of the trends were actually significant at a p-value of $\leq 5\%$, while about half of these (i.e., 73 trends) were significant at $p \leq 1\%$.

Table 4: *p*-values (%) and trend slopes (in brackets) for records of flow-adjusted water quality variables at 100 Waikato region sites (mostly during 1993–97; five records began in 1989–90: see text for details). Trends shown in bold (and underlined) are significant ($p \leq 10\%$). Of these, improving trends are shown in plain text; and deteriorating trends are shown in italics.

	Turbidity (10^{-3} NTU/yr)	Black disc (10^{-3} m/yr)	Temperature (10^{-3} °C/yr)	pH (10^{-3}/yr)	Dissolved oxygen (10^{-3} % of saturation/yr)	Total nitrogen (10^{-3} [g/m^3]/yr)	Ammoniacal N (10^{-3} [g/m^3]/yr)	Total phosphorus (10^{-3} [g/m^3]/yr)	Enterococci ([no./100 mL]/yr)	Dissolved colour (10^{-3} [absorbance @ 340 nm/cm]/yr)
Coromandel										
Hikutaia @ off Maratoto Rd	92 (–4)	42 (213)	38 (508)	92 (6)	28 (–293)	14 (–19.3)	49 (1.8)	62 (–0.5)	46 (14.0)	49 (–0.7)
Kauaeranga @ Smiths	49 (27)	14 (341)	28 (422)	49 (–25)	38 (–396)	92 (–0.3)	62 (0.4)	62 (–0.1)	14 (20.8)	77 (–0.1)
Ohinemuri @ Karangahake (NIWA)	96 (–3)	30 (–62)	80 (26)	69 (–7)	52 (132)	66 (3.1)	***2 (2.3)***	30 (–0.3)	–	20 (0.9)
Ohinemuri @ Queens Head	16 (110)	69 (–83)	23 (358)	11 (–60)	***4 (–1846)***	99 (–2.2)	***0 (17.2)***	55 (–6.0)	99 (2.8)	31 (–0.5)
Ohinemuri @ SH25	***8 (169)***	26 (–270)	61 (101)	47 (–28)	61 (–152)	92 (–10.2)	61 (–1.1)	92 (0.1)	***3 (56.8)***	61 (0.6)
Tairua @ Morrisons	38 (88)	62 (66)	62 (248)	***10 (–59)***	***1 (–752)***	49 (1.6)	92 (0.1)	92 (0.0)	46 (4.9)	49 (–0.2)
Tapu @ Tapu–Coroglen Rd	92 (23)	14 (310)	49 (319)	38 (8)	***6 (–513)***	38 (4.9)	14 (–0.4)	92 (0.0)	27 (16.4)	77 (–0.1)
Waiau @ E309 Rd	**10 (–394)**	**6 (203)**	38 (375)	92 (7)	62 (–102)	38 (2.5)	49 (–0.6)	**10 (–0.7)**	***3 (32.4)***	14 (–1.2)
Waitekauri u/s Ohinemuri	53 (44)	21 (130)	***3 (496)***	64 (–5)	**8 (301)**	64 (–12.2)	16 (7.3)	35 (–0.4)	31 (8.6)	64 (0.2)
Waiwawa @ SH25	38 (–125)	14 (142)	92 (132)	***0 (–71)***	***0 (–728)***	20 (–5.8)	92 (0.0)	62 (–0.2)	***0 (61.0)***	38 (–1.7)
Wharekawa @ SH25	14 (80)	92 (5)	14 (420)	***1 (–42)***	***6 (–752)***	20 (8.1)	77 (0.0)	92 (–0.2)	***7 (31.5)***	62 (0.5)
Hauraki										
Mangawhero @ Mangawara Rd	59 (106)	12 (103)	90 (55)	11 (51)	67 (128)	99 (2.0)	20 (–0.6)	40 (–1.2)	31 (21.2)	52 (1.3)
Oraka @ Lake Rd	11 (–515)	**0 (111)**	***6 (291)***	52 (14)	44 (94)	94 (6.5)	94 (0.1)	94 (1.2)	23 (–38.0)	**2 (–0.7)**
Piako @ Kiwitahi	14 (–609)	**7 (37)**	92 (–39)	92 (–2)	92 (249)	49 (34.0)	92 (–0.6)	38 (3.7)	71 (36.5)	28 (–2.9)
Piako @ Paeroa–Tahuna Rd	69 (–214)	55 (31)	99 (31)	99 (0)	23 (1942)	**3 (–86.2)**	**7 (–10.5)**	11 (–30.3)	44 (57.8)	**0 (–6.1)**
Piakonui @ Piakonui Rd	92 (20)	28 (90)	62 (199)	92 (2)	77 (–132)	38 (–14.5)	62 (0.1)	62 (–1.3)	70 (15.8)	38 (–1.2)
Waihou @ Okauia	**1 (–600)**	**0 (123)**	***3 (216)***	62 (5)	***8 (–166)***	29 (–17.4)	**8 (–0.9)**	72 (1.6)	23 (–39.7)	**8 (–0.8)**
Waihou @ Te Aroha (NIWA)	**2 (–359)**	**1 (26)**	**7 (–127)**	19 (–5)	69 (–40)	41 (–6.4)	36 (0.7)	**2 (–2.4)**	–	83 (0.1)
Waihou @ Whites Rd	43 (–35)	**7 (107)**	72 (3)	94 (5)	43 (–288)	94 (–0.4)	43 (–0.3)	**3 (–1.0)**	71 (–4.1)	22 (0.2)
Waiohotu @ Waiohotu Rd	61 (122)	–	***0 (405)***	94 (–3)	83 (–61)	61 (–2.7)	42 (0.1)	94 (–1.0)	71 (–4.1)	34 (–0.8)
Waiomou @ Matamata–Tauranga Rd	36 (–238)	**0 (139)**	***2 (333)***	72 (9)	11 (–358)	**8 (–22.8)**	62 (0.6)	29 (–1.0)	99 (–4.1)	29 (–0.5)
Waitakaruru @ Coxhead Rd	33 (674)	***1 (–53)***	44 (286)	33 (–11)	36 (–709)	26 (15.0)	11 (5.3)	***1 (5.4)***	99 (–0.1)	50 (1.6)
Waitoa @ Landsdowne Rd	69 (–243)	69 (20)	99 (–72)	84 (2)	23 (700)	55 (–60.2)	42 (–1.7)	69 (–1.0)	46 (34.5)	99 (–0.4)
Waitoa @ Mellon Rd	77 (–167)	49 (13)	92 (36)	77 (11)	77 (–467)	28 (251.9)	38 (15.4)	**6 (–175.6)**	***1 (264.5)***	14 (–1.3)

Table 4 (continued)

	Turbidity	Black disc	Temperature	pH	Dissolved oxygen	Total nitrogen	Ammoniacal N	Total phosphorus	Enterococci	Dissolved colour
Inflows to Lake Taupo										
Hinemaiaia @ SH1	94 (1)	29 (108)	94 (51)	62 (–5)	36 (–200)	94 (–0.8)	94 (0.0)	18 (0.5)	87 (–0.1)	11 (–0.2)
Kuratau @ SH41 Moerangi	34 (–64)	60 (78)	42 (188)	*1 (–34)*	51 (–161)	1 (–16.7)	*5 (0.7)*	51 (–0.2)	–	71 (0.3)
Mapara @ off Mapara Rd	*3 (197)*	16 (–25)	*2 (197)*	22 (10)	2 (515)	*0 (41.8)*	61 (0.0)	72 (–0.7)	61 (–3.1)	*0 (4.2)*
Tauranga–Taupo @ Te Kono	94 (5)	71 (39)	34 (155)	*9 (–28)*	*1 (–561)*	21 (–2.4)	*7 (0.2)*	94 (0.1)	–	61 (–0.3)
Tokaanu @ off SH41 Turangi	1 (–32)	–	48 (0)	99 (0)	83 (50)	*1 (13.8)*	48 (0.0)	18 (–1.0)	–	*0 (0.3)*
Tongariro @ Turangi (NIWA)	*0 (83)*	20 (75)	21 (79)	43 (–1)	41 (–72)	7 (–3.8)	5 (–0.3)	39 (–0.2)	–	12 (0.2)
Waihaha @ SH32	22 (–45)	9 (446)	28 (152)	*4 (–19)*	*7 (–476)*	94 (–0.4)	52 (0.1)	94 (0.1)	87 (–2.7)	72 (0.2)
Waitahanui @ Blake Rd	83 (–4)	23 (–107)	14 (75)	14 (–23)	*2 (–368)*	*4 (5.1)*	44 (0.0)	94 (–0.1)	61 (–1.2)	94 (0.0)
Upland tributaries of the Waikato River										
Kauwanui @ SH5	83 (46)	11 (58)	*1 (217)*	23 (38)	23 (–168)	18 (18.0)	94 (0.9)	94 (0.7)	61 (–21.1)	11 (–1.4)
Mangaharakeke @ SH30	62 (294)	7 (71)	*1 (308)*	29 (–11)	36 (–150)	36 (9.2)	62 (0.6)	18 (1.2)	87 (–1.1)	18 (0.9)
Mangakara @ SH5	20 (267)	99 (2)	36 (71)	32 (17)	32 (–238)	*1 (52.3)*	99 (0.0)	7 (–3.6)	1 (–20.0)	78 (0.0)
Mangakino @ Sandel Rd	62 (–39)	62 (24)	29 (181)	36 (–8)	*0 (–468)*	44 (7.6)	14 (0.2)	14 (0.7)	–	83 (–0.3)
Otamakokore @ Hossack Rd	21 (–134)	20 (69)	*1 (355)*	12 (25)	16 (1268)	83 (–3.8)	21 (–1.7)	34 (–1.1)	87 (–6.3)	16 (–1.6)
Pueto @ Broadlands Rd	18 (–111)	28 (30)	*1 (272)*	*1 (33)*	36 (179)	36 (–5.7)	6 (–0.5)	83 (–0.5)	87 (2.3)	*3 (0.6)*
Tahunaatara @ Ohakuri Rd	52 (–31)	10 (98)	52 (48)	83 (–5)	94 (42)	62 (3)	44 (0.5)	29 (–0.8)	61 (–6.4)	6 (–1.4)
Torepatutahi @ Vaile Rd	89 (–35)	0 (338)	99 (0)	67 (0)	44 (–217)	*4 (8.8)*	44 (0.0)	0 (–5.8)	–	*0 (1.7)*
Waiotapu @ Campbell Rd	44 (155)	94 (6)	11 (164)	11 (32)	52 (177)	18 (20.0)	8 (–15.5)	36 (1.4)	13 (–0.8)	18 (–0.2)
Waiotapu @ Homestead Rd	29 (–371)	3 (40)	*2 (417)*	52 (15)	11 (524)	94 (12.3)	0 (–20.4)	72 (–1.4)	–	44 (–0.5)
Waipapa @ Tirohanga Rd	*2 (644)*	34 (–26)	62 (140)	62 (3)	29 (282)	*0 (29.7)*	52 (0.3)	72 (–0.5)	61 (–7.4)	94 (0.0)
Whirinaki @ Corbett Rd	82 (–40)	–	83 (21)	71 (–14)	71 (–218)	*3 (14.1)*	27 (–0.7)	94 (0.0)	–	94 (0.0)

Table 4 (continued)

	Turbidity	Black disc	Temperature	pH	Dissolved oxygen	Total nitrogen	Ammoniacal N	Total phosphorus	Enterococci	Dissolved colour
Lowland tributaries of the Waikato River										
Awaroa @ Rotowaro–Huntly Rd	44 (–373)	8 (57)	44 (126)	52 (22)	72 (–90)	11 (17.0)	94 (–0.2)	52 (–0.4)	7 (–15.1)	29 (–1.0)
Awaroa @ Otaua Rd	11 (428)	*4 (–69)*	*5 (389)*	62 (–20)	*3 (–2250)*	36 (34.5)	52 (1.2)	18 (1.8)	–	*8 (3.3)*
Karapiro @ Hickey Rd	5 (–660)	17 (49)	43 (–112)	*7 (–20)*	*5 (–919)*	35 (–25.9)	28 (–1.5)	43 (2.3)	87 (–3.5)	52 (1.1)
Kirikiriroa @ Tauhara Dr	92 (217)	47 (19)	61 (–166)	76 (10)	47 (–951)	92 (3.5)	76 (–13.0)	92 (–0.1)	18 (67.9)	61 (–1.9)
Komakorau @ Henry Rd	*6 (5030)*	16 (4)	11 (188)	12 (–42)	89 (–133)	83 (–10.0)	62 (2.9)	*1 (5.8)*	87 (–14.3)	52 (4.5)
Little Waipa @ Arapuni–Putararu Rd	17 (–121)	13 (157)	*3 (170)*	52 (9)	22 (–888)	10 (–40.8)	10 (–1.6)	35 (–2.0)	40 (16.7)	43 (–0.6)
Mangakotukutuku @ Peacock Rd	76 (216)	12 (17)	8 (–317)	35 (28)	61 (136)	92 (6.9)	18 (7.5)	47 (–16.5)	18 (148.4)	35 (–12.2)
Mangamingi @ Paraonui Rd	31 (–225)	1 (88)	69 (101)	*2 (70)*	23 (454)	55 (–90.9)	0 (–154.3)	23 (24.7)	37 (–136.0)	55 (–0.5)
Mangaone @ Annebrooke Rd	92 (–10)	8 (90)	8 (–415)	18 (39)	0 (3911)	47 (118.0)	47 (–1.3)	76 (0.3)	99 (52.5)	76 (–0.9)
Mangaonua @ Hoeka Rd	47 (–1013)	61 (31)	76 (–230)	61 (13)	92 (–21)	18 (–48.2)	26 (–4.2)	92 (–0.4)	18 (66.5)	47 (2.1)
Mangaonua @ Te Miro Rd	8 (–501)	25 (105)	35 (–393)	35 (37)	76 (161)	76 (–12.3)	47 (–2.3)	47 (–5.3)	99 (14.2)	18 (–1.8)
Mangatangi @ SH2	72 (–76)	*9 (–69)*	*3 (317)*	11 (–17)	28 (–566)	52 (6.3)	*4 (3.2)*	*0 (6.2)*	–	44 (1.4)
Mangatawhiri @ Lyons Rd	8 (–332)	7 (86)	*10 (469)*	94 (–2)	35 (–1467)	23 (–16.3)	*1 (1.8)*	23 (–0.8)	–	23 (–1.0)
Mangawara @ Rutherford Rd	*1 (3787)*	19 (–13)	82 (–213)	19 (16)	0 (1446)	94 (10.9)	*3 (26.1)*	*0 (15.5)*	–	59 (–5.0)
Mangawhero @ Cambridge–Ohaupo Rd	61 (–366)	47 (7)	18 (–305)	92 (–2)	35 (–497)	61 (68.5)	12 (–10.9)	61 (–12.8)	65 (39.3)	35 (–2.6)
Matahuru @ Waiterimu Rd	14 (–1371)	6 (19)	35 (140)	62 (25)	83 (250)	29 (–41.3)	40 (4.2)	83 (–0.7)	–	4 (–3.0)
Ohaeroa @ SH22	2 (–1341)	1 (69)	42 (211)	94 (–4)	27 (379)	83 (14.3)	43 (0.1)	28 (–1.7)	–	61 (–0.2)
Opuatia @ Ponganui Rd	83 (62)	61 (–13)	52 (126)	*8 (39)*	28 (455)	14 (20.3)	62 (–0.2)	36 (1.1)	87 (0.0)	72 (–0.3)
Pokaiwhenua @ Arapuni–Putararu Rd	72 (–32)	3 (103)	*4 (145)*	28 (15)	77 (110)	10 (–49.3)	35 (–1.2)	13 (–6.9)	84 (4.4)	61 (–0.4)
Waerenga @ Taniwha Rd	4 (–297)	8 (57)	13 (263)	94 (0)	72 (–243)	44 (25.6)	72 (0.1)	83 (0.3)	14 (–19.9)	94 (–0.3)
Waitawhiriwhiri @ Edgecumbe St	61 (1186)	35 (19)	76 (–143)	12 (23)	61 (–241)	47 (48.9)	35 (16.7)	92 (0.1)	65 (69.0)	47 (–5.7)
Whakapipi @ SH22	3 (–626)	5 (79)	21 (295)	61 (3)	27 (–367)	52 (112.4)	94 (0.0)	83 (0.6)	–	52 (1.0)
Whakauru @ SH1	99 (–5)	5 (103)	84 (79)	99 (–3)	31 (321)	23 (–19.7)	84 (0.0)	69 (–1.2)	84 (37.1)	16 (–1.4)
Whangamarino @ Island Block Rd	*0 (18,036)*	*1 (–31)*	31 (408)	49 (43)	4 (4580)	38 (37.8)	20 (5.5)	*0 (21.8)*	–	20 (–5.8)
Whangamarino @ Jefferies Rd	61 (–701)	94 (0)	61 (151)	43 (9)	82 (91)	4 (–67.6)	*3 (4.1)*	22 (2.6)	–	35 (–1.4)
Whangape @ Rangiriri–Glen Murray Rd	0 (–6009)	0 (87)	99 (0)	*0 (200)*	89 (300)	3 (–69.9)	72 (0.0)	0 (–10.5)	–	32 (–3.8)

Table 4 (continued)

	Turbidity	Black disc	Temperature	pH	Dissolved oxygen	Total nitrogen	Ammoniacal N	Total phosphorus	Enterococci	Dissolved colour
Waipa River and tributaries										
Kaniwhaniwha @ Wright Rd	71 (–232)	7 (55)	61 (103)	*2 (–44)*	34 (–262)	34 (13.9)	*1 (3.3)*	71 (0.4)	–	51 (0.1)
Mangaohoi @ Maru Rd	*4 (238)*	2 (147)	92 (63)	92 (1)	77 (–41)	92 (–2.2)	92 (0.0)	28 (1.2)	71 (–2.7)	77 (–0.3)
Mangaokewa @ Te Kuiti	94 (27)	10 (32)	52 (165)	72 (–11)	*4 (–294)*	*1 (52.9)*	*1 (30.3)*	*1 (4.6)*	–	94 (0.1)
Mangapiko @ Bowman Rd	62 (–466)	1 (44)	72 (83)	94 (5)	*8 (–1164)*	*1 (263.7)*	94 (3.2)	*4 (16.4)*	–	14 (–3.0)
Mangapu @ Otorohonga	36 (575)	11 (–43)	83 (97)	62 (–9)	*0 (–2056)*	*0 (66.0)*	*0 (9.0)*	*1 (6.6)*	46 (–42.9)	44 (–0.9)
Mangatutu @ Walker Rd	14 (–131)	0 (164)	18 (147)	29 (–29)	*0 (–685)*	8 (–16.1)	23 (1.4)	29 (–0.9)	87 (–3.3)	62 (0.3)
Mangauika @ Te Awamutu	21 (85)	93 (12)	21 (153)	42 (–23)	*0 (–388)*	71 (4.8)	94 (0.0)	2 (–0.7)	31 (1.4)	71 (0.2)
Ohote @ Whatawhata–Horotiu Rd	20 (643)	69 (20)	99 (0)	38 (–30)	*0 (–2683)*	92 (41.6)	99 (0.0)	*0 (9.5)*	46 (7.7)	24 (15.3)
Puniu @ Bartons Corner Rd	72 (49)	7 (85)	35 (148)	13 (–20)	72 (79)	43 (18.1)	*4 (1.9)*	22 (1.9)	–	17 (1.3)
Waipa @ Mangaokewa Rd	*3 (173)*	35 (–89)	35 (153)	*4 (–28)*	61 (–248)	*4 (15.5)*	*2 (0.5)*	*4 (2.3)*	–	*5 (2.8)*
Waipa @ Pirongia–Ngutunui Rd	94 (–47)	50 (19)	60 (–72)	33 (–18)	*6 (–294)*	26 (21.3)	*1 (3.6)*	60 (1.3)	99 (2.8)	41 (–1.0)
Waipa @ Otewa (NIWA)	*7 (124)*	*1 (–40)*	64 (–69)	16 (–6)	*3 (–142)*	0 (–16.1)	32 (0.0)	91 (–0.1)	–	*5 (1.3)*
Waipa @ SH3 Otorohonga	94 (–134)	29 (37)	36 (110)	52 (–9)	*10 (–612)*	94 (–1.6)	29 (0.9)	94 (0.5)	40 (–30.5)	62 (0.4)
Waipa @ Whatawhata (NIWA)	11 (–447)	17 (13)	41 (113)	91 (0)	75 (–35)	23 (–13.6)	0 (–2.4)	94 (–0.1)	–	31 (0.4)
Waitomo @ SH31 Otorohonga	24 (–1037)	9 (28)	94 (45)	94 (–5)	58 (–499)	48 (8.8)	31 (–0.5)	94 (0.0)	99 (–2.6)	70 (–0.3)
Waitomo @ Tumutumu Rd	26 (142)	82 (14)	20 (120)	40 (9)	60 (–200)	94 (–5.3)	1 (–1.8)	*3 (1.1)*	46 (7.8)	32 (0.3)

Table 4 (continued)

	Turbidity	Black disc	Temperature	pH	Dissolved oxygen	Total nitrogen	Ammoniacal N	Total phosphorus	Enterococci	Dissolved colour
West Coast										
Awakino @ Gribbon Rd	52 (50)	3 (109)	44 (91)	8 (–23)	1 (–327)	94 (0.0)	29 (0.3)	14 (–0.5)	40 (–4.8)	29 (0.3)
Awakino @ SH3–Awakau Rd	72 (–108)	0 (111)	44 (140)	36 (–43)	0 (–816)	44 (–7.4)	94 (0.0)	72 (–0.6)	40 (–9.5)	83 (0.2)
Manganui @ off Manganui Rd	35 (–136)	2 (75)	10 (241)	1 (–54)	22 (–362)	83 (–2.7)	1 (1.2)	72 (–0.3)	99 (1.0)	61 (0.2)
Mangaotaki @ SH3	62 (–228)	3 (79)	29 (222)	44 (–17)	2 (–350)	94 (–1.0)	11 (0.9)	44 (–0.9)	–	62 (0.3)
Marokopa @ Speedies Rd	49 (80)	40 (48)	82 (24)	3 (–33)	0 (–787)	11 (16.2)	70 (0.1)	82 (0.1)	14 (11.8)	14 (0.5)
Mokau @ Awakau Rd	94 (–82)	94 (0)	18 (482)	62 (–5)	11 (–360)	23 (16.2)	2 (1.7)	83 (0.6)	40 (–11.2)	8 (1.7)
Mokau @ Mangaokewa Rd	2 (283)	59 (–23)	71 (83)	5 (–23)	2 (–732)	7 (15.0)	94 (0.1)	16 (1.5)	99 (–38.0)	21 (2.0)
Mokau @ Totoro Rd	62 (378)	44 (17)	36 (272)	29 (–24)	0 (–506)	94 (1.8)	8 (0.3)	6 (2.7)	40 (–4.2)	14 (0.9)
Mokauiti @ Three Way Point	62 (267)	8 (25)	11 (426)	36 (–20)	23 (–358)	94 (1.9)	14 (2.5)	14 (2.8)	87 (–11.3)	8 (2.7)
Ohautira @ Waingaro–Te Uku Rd	94 (–196)	4 (43)	70 (58)	32 (–25)	49 (–116)	40 (11.0)	94 (0.1)	82 (–0.1)	71 (–3.2)	70 (0.4)
Oparau @ Langdon Rd	94 (1)	13 (128)	59 (124)	32 (–35)	1 (–982)	94 (–0.2)	11 (0.6)	59 (0.3)	–	40 (0.6)
Tawarau @ off Speedies Rd	83 (71)	21 (45)	52 (178)	17 (–24)	0 (–715)	13 (8.9)	22 (–0.7)	43 (–0.4)	–	35 (0.3)
Waingaro @ Ruakiwi Rd	49 (–352)	1 (80)	82 (86)	82 (–14)	49 (313)	70 (–3.8)	82 (0.1)	82 (–0.6)	–	70 (0.4)
Waitetuna @ Te Uku–Waingaro Rd	49 (–318)	14 (50)	70 (71)	59 (–23)	0 (–600)	25 (–9.8)	82 (0.3)	94 (0.1)	71 (5.7)	70 (0.7)
Total improvements	**11**	**37**	**3**	**–§**	**5**	**10**	**10**	**8**	**2**	**5**
Total deteriorations	*11*	*5*	*17*	*17*	*30*	*12*	*17*	*12*	*5*	*9*

§ all significant trends in pH were regarded as deteriorations, since both increasing and decreasing trends tend to shift levels outside the preferred range of values

As noted earlier for the Waikato River records, flow-adjusting made some trends more apparent than in the raw data, while in other cases trends in the raw data disappeared following flow-adjustment. For example, 44% of the underlying trends in total nitrogen only became apparent after flow-adjustment, while 65% of the trends in the raw records disappeared. For the black disc records the proportions were 67% and 43%, respectively.

Once again, the absolute value of the slope of the majority (180, or 80%) of the trends was ≥ 1% of the median per year; and almost all the trends in pH, and the majority of those in dissolved oxygen, had slopes which were smaller than this (but note that in this case all but one of the trends in temperature had larger slopes). Furthermore, the absolute value of the slope of 147 of the trends was ≥ 2% per year, while more than half exceeded 5% per year.

A total of 37 records of black disc visibility improved, 11 of these being from sites on lowland tributaries of the Waikato River. By contrast, only 5 records deteriorated. At the same time there were fewer changes in turbidity: 11 records improved, and the same number deteriorated. Although there was no obvious evidence of bias in the black disc records (cf. the situation for the Waikato River records), it is noteworthy that the agreement between trends in these, and those in the corresponding turbidity records was generally poor (Table 4). We therefore suggest that, in the meantime, the trends in these non-Waikato River black disc records also be treated with caution.

Apart from the changes in the black disc visibility records, the variable which showed the greatest number of important changes (i.e., slope ≥ 1% per year) was ammoniacal-N. Records deteriorated at 17 sites, most of which were in the Waipa catchment or on lowland tributaries of the Waikato River. Records of ammoniacal-N showed improvements at 10 sites. Water temperatures also deteriorated at 17 sites (i.e., temperatures increased), most of which were in the Hauraki zone or on tributaries of the Waikato River. As noted above, the records of pH, by contrast, showed few important changes. While 17 records were significant ($p \leq 10\%$), most of these had slopes lower than 0.3% per year. Only one record of pH changed by ≥ 1% per year.

The proportion of the water quality records in each zone which improved varied from 4% (Coromandel) to 15% (Hauraki); the proportion which deteriorated varied from 6% (Hauraki) to 21–22% (both Taupo and Waipa). The Hauraki zone thus experienced the highest rate of improvement, and the lowest rate of deterioration. As noted above, however, these records are relatively short at this stage, so it may be some time before reliable patterns emerge and clear conclusions can be drawn.

4 Conclusions

1. Several water quality variables were found to vary markedly with flow, and most records were routinely flow-adjusted (the exceptions being those for six sites where flows were judged to be reasonably steady). Variability associated with flow can obscure any underlying trend, so flow-adjustment can help identify the existence of a trend earlier than would otherwise be the case. Conversely, trends which are apparent in the raw records can disappear following flow-adjustment, suggesting they actually reflected an underlying trend in flow. This study has identified data-handling and analysis protocols for flow-adjusting the regions' water quality records, and we recommend that these procedures be adopted in future trend analyses.

2. Only some of the regions' water quality sites are located at or near the site of a flow recorder: six of the relevant nine Waikato River sites, and 25 of the 94 "non-steady flow" sites on the other rivers and streams. However, we have identified flow records which may be used in conjunction with the water quality records for the other 72 (= [9 – 6] + [94 – 25]) sites to generate a suitable "flow index" for each of them (Tables 1, 2). In these cases we have used the daily mean flow at the index site on each sampling date as a surrogate for the instantaneous flow at the time of each sampling at the water quality site. We consider this procedure to be generally satisfactory, and recommend that it be adopted (although we recognize that the flow records used to adjust the water quality records for particular sites may change in the future).

3. This analysis has confirmed and extended the results of the earlier analyses on Waikato River records from selected sites (NIWA 1994) or for specific variables (NIWA 1997). Many of these records began in 1980, and are among the longest available water quality records in the region. Significant improvements in river water quality have been more common (36% of records) than deteriorations (16%).

4. At the same time, this is the first comprehensive analysis of trends in water quality records from the 100 sites on other rivers and streams in the region (although Smith et al. analysed the 1989–93 records for five of these). These records generally began in 1993 or 1994, and are thus substantially shorter than those for the Waikato River. It would therefore be premature to draw firm conclusions now about the possible relevance of the observed changes.

5. Although there are rigorous statistical standards for determining the significance of trends, there is less guidance as to whether observed trends are important or not. About 20% of the statistically significant trends in this analysis can be described as being "slight"—because the overall rate of change was less than 1% per year. A low rate of change means there is a greater chance that

circumstances may change in the future so that an historic trend, while still being statistically significant, becomes unimportant in any practical sense. And there are certain difficulties inherent in attempts to standardize trends to permit comparison between records from different sites, and between different variables. At this stage we have adopted a rate of change of 1% of the median per year as a threshold below which trends can be regarded as being of relatively low importance. Many of the observed changes—mostly deteriorations—in pH and dissolved oxygen had slopes which were lower than this.

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