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Trends in river water quality in the Waikato region, 1991-2020

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Te Kaunihera ā Rohe o Waikato

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Abstract

Trends in long-term (up to 30-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 slope direction probability). At ten Waikato River sites, records of 15 water quality variables obtained during 1991–2020 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, ten of the 15 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 98 records. Trends that were very likely to have occurred (slope direction probabilities >95%) were found in 68 records. For 33 of these (34% 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 (a) statistically very likely, and (b) environmentally important. Well over half (21) of these important trends were improvements in water quality, while the remainder (12) were deteriorations.

Records of temperature and dissolved oxygen at Waikato River sites showed only slight trends. Records of turbidity and visual clarity showed only a small number of important trends, both improvements and deteriorations. Four important improvements and one deterioration occurred in concentrations of arsenic, and five improvements occurred in ammonia concentrations. Important improvements were also common in records of chlorophyll *a* (six) and total phosphorus (four; but note that the reliability of some of the underlying TP data is probably poor). Conversely, four important deteriorations occurred in *E. coli* concentrations. And important deteriorations occurred in records of total nitrogen at six of the ten sites. Intensification of pastoral farming in the Waikato catchment probably caused this deterioration in total nitrogen concentrations in the river.

For the other rivers and streams, records for eight key water quality variables were analysed at 77–104 sites, giving a total of 797records. Trends in water quality were found to be not very likely to have occurred in 263 (33%) of these records during 1991–2020. Trends were found to be very likely in the remaining records, with 234 records (29% of the total number) showing trends that were important. Some 124 (16%) of these latter trends represented important improvements in water quality, and the remainder (110, or 14%) represented important deteriorations.

Records of temperature and dissolved oxygen at these other river and stream sites showed only slight trends. Important improvements appeared to occur in records of total phosphorus at about 40% of the sites, and slight improvements at a further 32% of the sites; deteriorations occurred at only three sites. Important improvements were also common in records of ammonia (30%) and *E. coli* (17%), with smaller numbers of deteriorations in each case. Important deteriorations in turbidity were about twice as common (34 sites) as important improvements (15 sites); a similar pattern was found for visual clarity (18 sites and 10 sites, respectively). Important deteriorations in total nitrogen occurred at 38 of the sites (36%), while important improvements occurred at eight sites; slight deteriorations (28% of sites) were also more common than slight improvements (15%).

The reductions in concentrations of ammonia were more than offset by increases in concentrations of nitrate. The net result of this was for concentrations of total nitrogen to increase at 64% of sites 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. As a result, 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 2019, Tulagi and Salu 2021).

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, 2007, 2012 and 2017 (e.g. Vant 2018). This latest report describes a further extension of the analysis, covering the 30-year period 1991 to 2020.[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 (e.g. Tulagi 2019). 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 by 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 (e.g. Tulagi 2019). Since 1991 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]

<u>Faecal coliforms/enterococci</u>. 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).

<u>Turbidity</u>. 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.

[1] Note that this analysis only deals with <u>changes</u> in river water quality. It does not deal with the <u>state</u> (or condition) of water quality in rivers in the Waikato region, a matter that is dealt with elsewhere (e.g. Bates 2021).

[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. NIWA stopped monitoring the Ohinemuri and Waihou sites in 2017; since then they have been monitored by Waikato Regional Council.

[3] Results obtained prior to 1991, particularly at the Waikato River sites, are not described here, although the data are available and have been analysed previously.

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

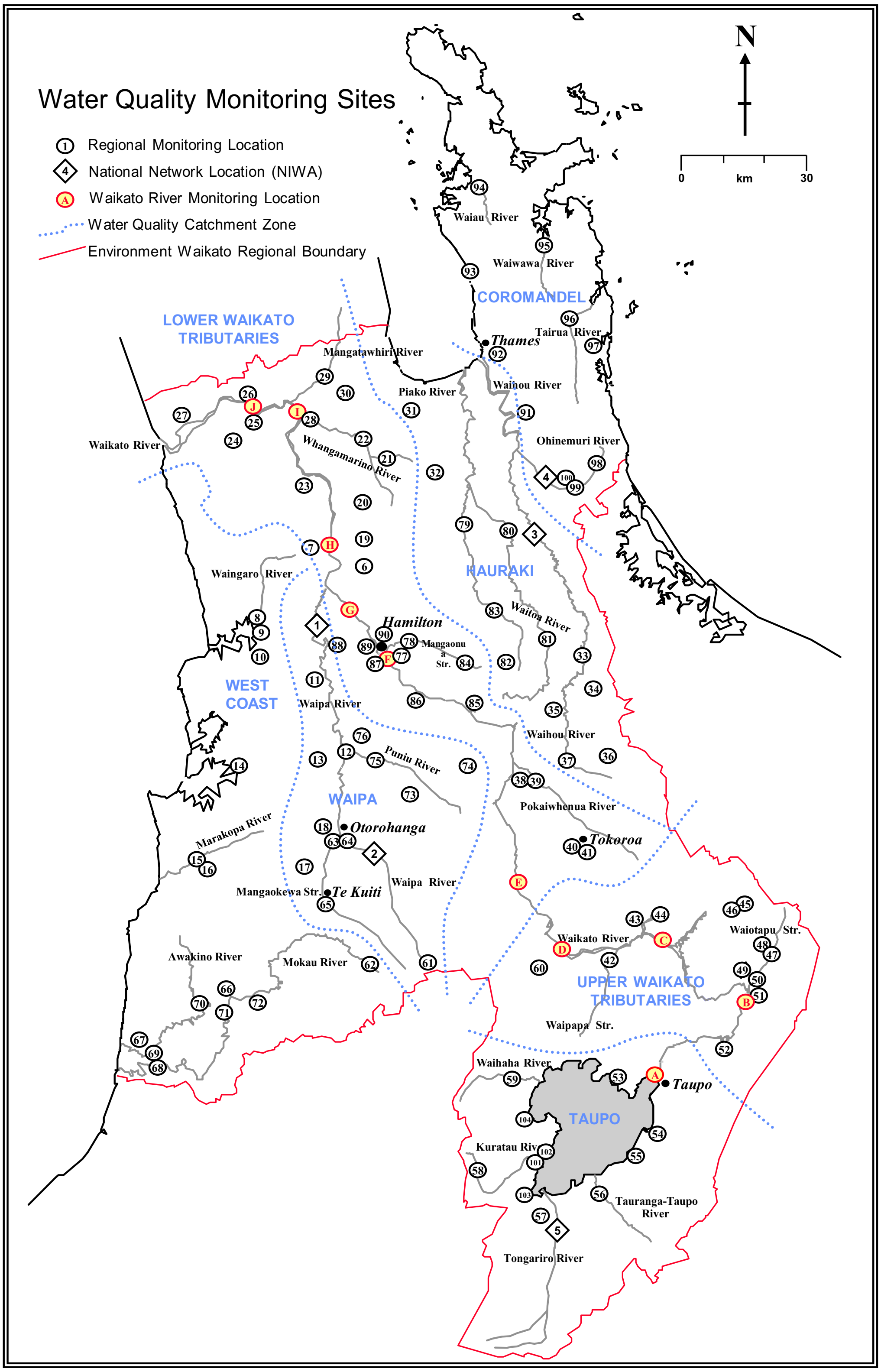

Figure 1: The Waikato region, showing the Waikato River and the ten routine water quality sampling sites (A-to-J), and the 104 sites on the other rivers and streams (see Tables 2 and 3 for site details). The dotted lines divide the region into seven water quality zones (see text).

Phosphorus. During 2004–12 changes were made to the laboratory methods used for analysing both total phosphorus (TP) and dissolved reactive phosphorus (DRP). For TP, in late 2004 a modified method was introduced which did not include the procedure for dealing with possible interferences caused by the presence of arsenic; this procedure was reinstated in 2012. Furthermore, in 2005 the reagent used to digest particulate forms of phosphorus was changed from potassium persulphate to ammonium persulphate. For DRP, the change—in 2005—involved sample handling rather than chemical reactions, with sample handling changing from "flow injection" analysis to "discrete" analysis.

Inspection of the datasets showed that at some sites these changes to laboratory procedures had noticeably affected the long-term records of TP and DRP. At other sites, changes in the long-term records were apparent, but the reasons for these was not clear. The effects of the changes were investigated in studies undertaken during 2012–13 (Vant 2014) and 2017–18 (WRC documents #11214122 and 11735651).

The first study produced a method that has been used to adjust the reported total phosphorus results from 2004–12 for the Waikato River sites for the interference by arsenic. The second study suggested that the ammonium persulphate digestant could be less effective than the potassium persulphate digestant, but the conditions under which this occurred were unclear. However, it did show that reanalysis of the same sample for total phosphorus at different times could produce erratic results.

At this point, the reliability of the long-term records of total phosphorus at the monitoring sites is uncertain. These records have been analysed for trends, and the results are presented in this report; however, these results should be regarded as being provisional.

Escherichia coli. *E. coli* concentrations have been determined in monthly samples from the ten Waikato River sites since 1998; they have also been determined in monthly samples from the five NIWA sites since 2005. At 72 regional river sites, however, concentrations were determined in samples collected quarterly during 1998–2012 (in March, June, September and December each year), and monthly during 2013–20. To avoid biasing the trend analyses for these 72 sites, only the results from March, June, September and December during 1998–2020 were analysed for long-term trends.[5] The records of monthly samples collected at all 104 regional river sites during 2011–20, however, were analysed.

At times, the laboratory method used to determine any water quality variable may not be sufficiently-sensitive to accurately determine very low concentrations of the material; in this case results are routinely reported as being below some laboratory detection level. The standard procedure at WRC is to set such "non-detect" results as being equivalent to half of the detection level prior to statistical analysis. During 2017–20 the laboratory detection level for *E. coli* varied markedly between sites and sampling occasions. In particular, at certain Waikato River sites the detection level varied from <1 cfu/100 mL to <10 cfu/100 mL (and on rare occasions was as large as <100 cfu/100 mL and even <1000 cfu/100 mL). Because typical *E. coli* concentrations are relatively-low at sites in the Upper Waikato River, whether non-detects were replaced by 0.5 cfu/100 mL or 5 cfu/100 mL (or an even larger value) introduced an important uncertainty into the trend analysis. In fact, at one site this procedure biased the record such that an increasing trend appeared to occur. As a result, an alternative approach was used for the *E. coli* records at Waikato River sites (only): the seasonal Kendall trend test was determined for the raw datasets including all non-detects (e.g. E. coli <1 cfu/100 mL, E. coli <10 cfu/100 mL) using TimeTrends (see later).

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

[5] An alternative procedure involving the use of the quarterly median concentration for each of the quarters during 2013–20 was considered, but was not continued with as it was clear that summarizing the monthly data this way reduced the overall variability in this part of the long-term records.

Table 1: Median numbers of samples in the 30-year (1991–2020) 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	357	(316, 359)	330	(206, 359)
Dissolved oxygen	357	(316, 358)	329	(204, 355)
Conductivity	358	(317, 359)	330	(206, 357)
Turbidity†	305	(295, 306)	303	(206, 357)
Visual clarity	306	(290, 307)	321	(199, 358)
Arsenic	326	(313, 337)	–	
Boron	326	(317, 338)	–	
Total nitrogen	357	(317, 358)	329	(206, 359)
Nitrate-N	357	(317, 358)	330	(206, 359)
Ammonia	357	(317, 358)	330	(206, 359)
Total phosphorus	357	(317, 359)	329	(206, 359)
Dissolved reactive P	358	(317, 359)	330	(206, 359)
Chlorophyll *a*	357	(317, 359)	–	
Escherichia coli§	272	(263, 273)	91	(69, 190)
Enterococci	355	(318, 357)	100	(69, 118)

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

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

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 deal satisfactorily 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 the records of New Zealand's National River Water Quality Network (e.g. Smith et al. 1996), and the records for several hundred New Zealand rivers (Larned et al. 2004, 2016).

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

- the "seasonal Kendall slope estimator" (SKSE) or "Sen slope" which measures the magnitude of the trend, and
- the associated "slope direction probability" which determines the probability that the trend slope is different from zero.

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).

Jowett Consulting has developed software that both adjusts water quality records for changes in flow, and calculates the SKSE and the slope direction probability (TimeTrends, version 6.30, 2017), and this was used in the analyses reported here.

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 $\times$ 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 Slope direction probability

The slope direction probability calculates the probability that the slope is different from zero—that is, that the trend is "real". A recently-proposed convention is to use the terminology adopted by the Intergovernmental Panel on Climate Change, IPCC (Mastrandrea 2010), to describe the likelihood of the trend being real. The TimeTrends software now includes a table of slope confidence limits and slope direction probabilities, along with recommended descriptions of the likelihood of the trend being real. That terminology has been adopted in this report, with trends where the slope probability was greater than 95% being described as being "very likely" to have occurred (and slopes where the slope probability was greater than 99.5% being described as being "virtually certain" to have occurred).[6]

It is important to note that a trend that is "very likely" to have occurred is not necessarily an <u>important</u> one (Vant and Wilson 1998). That is, the slope direction probability 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 high slope probability. 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, trends that (a) are very likely, and (b) 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 adjusting-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.

[6] Although the terms are not used here, TimeTrends also suggests that trends where the slope direction probability is in the range 83.5-to-95% can be described as being "likely" to have occurred, while those where the slope direction probability is less than 66.5% would be no better than "about as likely as not".

Note, however, that Hirsch et al. (2010) pointed out that the relationships between flow and water quality can change over time, particularly where point source discharges of contaminants to rivers change markedly. A good example from the Waikato region is the changing relationship between flow and total phosphorus in the Waitoa River at Mellon Rd. In the 1990s, concentrations of total phosphorus in the river were dominated by the load from a factory discharge, such that as river flow increased, the concentrations in the river fell, due to dilution there. Since then the factory discharge has been much smaller (see later), and diffuse sources in the catchment now dominate the phosphorus load carried by the river. As a result, phosphorus concentrations now increase as river flows increase, due to increased loads from the catchment at times of high flow. Examination of the flow-concentration relationships for rivers in the Waikato region has indicated that situations like this are not common here, so the assumption has been made that the various relationships between flow and concentration were broadly stable during 1991–2020.

Most of the water quality records were 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.

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 five primary and the five 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 (Table 3), 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.

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*	Reids Farm	1131-119
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

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 @ Myjers Farm Br	516-22
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 @ Myjers Farm Br	516-22
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 @ Myjers Farm Br	516-22
22	*Whangamarino @ Jefferies Rd*	Matahuru @ Myjers Farm Br	516-22
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 @ Bartons Corner Rd	818-2
65	Mangaokewa @ Te Kuiti	Mangaokewa @ Te Kuiti	414-13
76	*Mangapiko @ Bowman Rd*	Puniu @ Bartons Corner Rd	818-2
63	*Mangapu @ Otorohonga*	Waipa @ SH31 Otorohanga	1191-13
73	*Mangatutu @ Walker Rd*	Puniu @ Bartons Corner Rd	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 @ Bartons Corner Rd	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 @ SH31 Otorohanga	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*	Marokopa @ Falls	513-7
8	*Waingaro @ Ruakiwi Rd*	Marokopa @ Falls	513-7
10	*Waitetuna @ Te Uku-Waingaro Rd*	Marokopa @ Falls	513-7

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).

3 Results and discussion

3.1 Waikato River

Appendix 1 lists the trend slopes and slope probabilities for the water quality records at the ten Waikato River sites for two time periods: 1991–2020 (30-years) and 2011–20 (10-years). In each case, a total of 148 separate water quality records were analysed. Table 4 lists the trend slopes (RSKSE) for 10 key variables over the past 30 years. In this report, trends where the slope probabilities are greater than 95% are regarded as being very likely (section 2.4). Furthermore, in both Appendix 1 and Table 4 a distinction is made between very likely 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 10 key variables for the 30-year period 1991–2020 are described below. Some of the more striking trends are shown in Figure 2.[7]

Table 4: Slopes (% per year) of very likely trends (slope direction probability >95%) in flow-adjusted water quality at ten Waikato River sites during 1991–2020 (see Appendix 1 for further details). Secondary sites (see section 2.6) are shown in italics. Important improvements are shown in bold blue type; important deteriorations are bold red underlined; "nvl", not very likely (trend slope probability <95%).

	Temperature	**Dissolved oxygen**	**Turbidity**	**Visual clarity**	**Arsenic**	**Total nitrogen**	**Ammonia**	**Total phosphorus**	**Chlorophyll *a***	***Escherichia coli***
Taupo	0.3	nvl	0.9	–	**<u>1.0</u>**	nvl	nvl	**–1.6**	nvl	**<u>5.1</u>**
Ohaaki	–0.1	0.1	0.9	–0.7	**–1.4**	0.8	**–5.1**	**–1.4**	nvl	nvl
Ohakuri	0.2	nvl	0.4	–0.5	–0.5	0.9	**–2.0**	nvl	nvl	nvl
Whakamaru	nvl	–0.1	nvl	nvl	–0.5	**<u>1.9</u>**	–0.2	nvl	nvl	**<u>4.9</u>**
Waipapa	0.1	–0.1	nvl	nvl	–0.7	**<u>1.6</u>**	nvl	nvl	**–1.5**	nvl
Narrows	0.2	–0.2	**–1.0**	**1.1**	–0.7	**<u>1.6</u>**	**–1.5**	–0.7	**–2.8**	nvl
Horotiu	nvl	–0.1	–0.5	0.6	–0.8	**<u>1.1</u>**	**–4.3**	–0.9	**–3.2**	nvl
Huntly	nvl	–0.1	nvl	nvl	**–1.1**	0.9	**–3.3**	**–1.5**	**–3.5**	nvl
Mercer	–0.4	–0.2	**<u>1.2</u>**	–	**–1.4**	**<u>1.4</u>**	nvl	–0.9	**–3.4**	**<u>1.6</u>**
Tuakau	–0.3	–0.2	nvl	–0.5	**–1.3**	**<u>1.2</u>**	nvl	**–1.2**	**–3.4**	**<u>2.6</u>**
Total numbers of important trends										
Improvements	0	0	1	1	4	0	5	4	6	0
Deteriorations	0	0	1	0	1	6	0	0	0	4

[7] Many of the trends illustrated in this report were virtually certain to have occurred (slope probability >99.5%). In such cases the trends are usually visually striking. Trends that are less certain (90%< slope probability <95%), however, can be less visually striking.

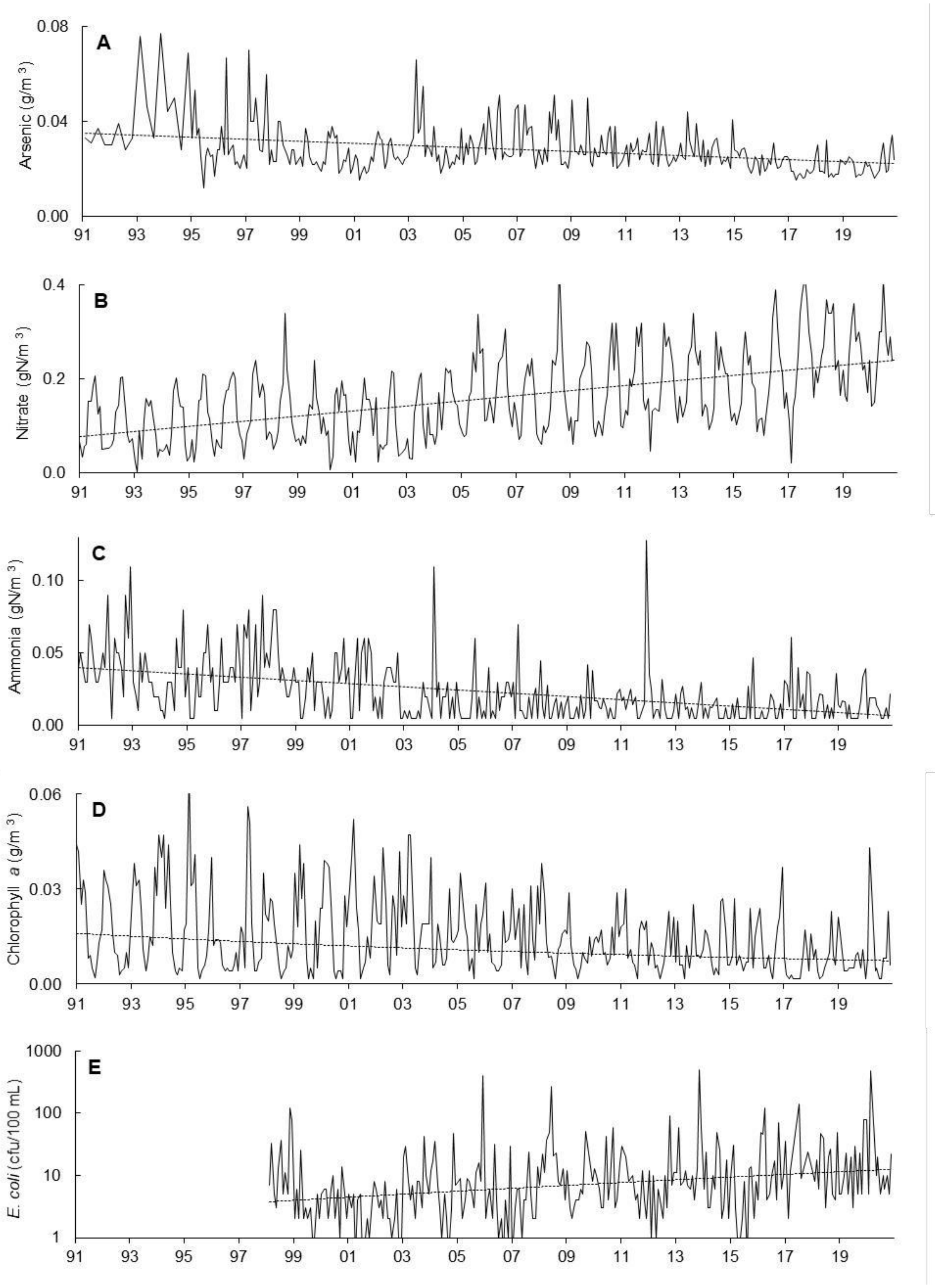

Figure 2: Water quality at Waikato River sites during 1991–2020: **A**, Arsenic at Ohaaki (site B); **B**, nitrate at Waipapa (site E); **C**, ammonia at Horotiu (site G); **D**, chlorophyll *a* at Mercer (site I); and **E**, *E. coli* (logarithmic scale) at Whakamaru (site D). The dashed lines broadly indicate the overall trends in the records.

<u>Temperature</u>. Very likely trends in water temperature were observed at seven sites, being four increases and three decreases (Table 4). However, all these trends were slight, being no larger than ±0.4% per year (or about ±0.06°C per year). However, the largest of the four observed increases (0.3% per year at Taupo Gates, site A) corresponds to an increase in average water temperature of about 1°C over the entire 30-year period. 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.

<u>Dissolved oxygen</u>. There were very likely trends in dissolved oxygen levels at eight sites (Table 4), namely decreases at seven sites, and an increase at one site. However, the slopes or rates of change were all slight (with none being larger than ±0.2% per year). The observed increase can be regarded as a slight improvement, and the decreases as slight deteriorations.

<u>Turbidity</u>. The turbidity records began in the middle of 1995 (i.e. 25-year records). Very likely trends in turbidity were observed at six sites (Table 4). One of these (at Narrows, site F, –1.0% per year) was an important improvement, and one (at Mercer, site I, 1.2% per year) was an important deterioration. There were also slight deteriorations at a further three sites, and a slight improvement at one site. It is not clear why these changes have occurred.

<u>Visual clarity</u>. The visual clarity disc records began in early 1995 (i.e. 26-year records); but clarity was not measured at Taupo Gates (site A) or Mercer (site I). Very likely trends in visual clarity were observed at five of the eight monitored sites (Table 4). An important improvement occurred at Narrows (site F, 1.1% per year)—where an important improvement in turbidity was also seen (see above). However, there were also three slight deteriorations in visual clarity.

During the last 10 years (2011–20; see Appendix 1), important improvements in visual clarity were observed at five of the eight of the sites where visual clarity was monitored, with the average value of the slopes at the five sites being 2.8% per year. It is not clear why these improvements occurred, but the recent reduction in chlorophyll *a* concentrations—particularly at Waipapa and Narrows (see later)—may well have contributed to them.

<u>Arsenic</u>. Very likely trends in arsenic concentration were observed at all ten sites, with five of these being important (Table 4). Important improvements were observed at Ohaaki (site B; see Figure 2A), and at Huntly, Mercer and Tuakau (sites H, I and J). Slight improvements were also observed at sites C to G. Furthermore, during the last 10 years (2011–20; see Appendix 1), important improvements were observed at all nine sites between Ohaaki and Tuakau (sites B-J), with slopes ranging from –1.1% per year to –3.8% per year (average value –2.0% per year). The improvements are likely to be related to recent reductions in the load of arsenic that is discharged to the river from the Wairakei Power Station, upstream of the Ohaaki site.

Important improvements in concentrations of boron, another geothermal contaminant that is discharged to the upper river, were also observed at most sites during 2011–20 (Appendix 1).

An important deterioration in arsenic concentrations during 1991–2020 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 (as the monitoring site is <u>upstream</u> of the natural and industrial geothermal discharges to the river itself).

<u>Total nitrogen</u>. Very likely trends in total nitrogen concentration were observed at nine sites (Table 4), namely all except for Taupo Gates (site A). Six of these were important deteriorations, with slopes in the range 1.1% per year to 1.9% per year. No decreases in total nitrogen occurred.

Since the 1990s, the moderate-to-large point source discharges of nitrogen to the river have either remained constant or have decreased, such that the combined load from these point sources is now less than half what it was during the 1990s (Vant 1999, 2014). This implies that the increased total nitrogen 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 nitrogen occurred in many of the river's tributaries during 1991–2020, particularly those in the catchment of the upper river where point source discharges are uncommon.

At many of the monitoring sites, a similar pattern was observed in the 1991–2020 trends in concentrations of nitrate (Appendix 1), the main inorganic component of total nitrogen. Important deteriorations in nitrate occurred at nine sites (e.g. Figure 2B); but the rates of increase were generally higher than for total nitrogen, with the average for the nine sites being 2.7% per year, compared with an average of 1.3% per year for total nitrogen. Over the past ten years (2011–20) the increase in nitrate at sites other than Taupo Gates has continued apace, with slopes in the range 2.4% per year to 6.1% per year (average 3.7% per year).

<u>Ammonia</u>. Very likely trends in ammonia concentration were observed at six of the sites (e.g. Figure 2C). Five of these were important improvements, with rates of change in the range –1.5% per year to –5.1% per year (Table 4). The lower concentrations in the river probably result from improvements in the treatment of wastewaters from a variety of sources, including municipal sewage, industrial wastewaters and dairy shed discharges. For example, major loads of treated wastewater from Hamilton sewage and the Horotiu meatworks are discharged to the river just upstream of the Horotiu monitoring site (site G), and these loads have reduced markedly since about 2010 (Vant 2014 and WRC unpublished results).

<u>Total phosphorus</u>. As noted above (section 2.1), the results presented here for the trends in total phosphorus are provisional. Very likely trends in total phosphorus were observed at seven of the sites, being all except for Ohakuri, Whakamaru and Waipapa (sites C, D and E). All were improvements, and four of the seven were important improvements (with rates of change in the range –1.2% per year to –1.6% per year).

At the time of writing, questions remain about the reliability of the laboratory procedures that have been used to determine the concentrations of total phosphorus in the routinely-collected water samples. As a result, the trends reported here will not be discussed further.

<u>Chlorophyll *a*</u>. Very likely 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 –1.5% per year to –3.5% per year (e.g. Fig. 2D, Mercer). In each case, chlorophyll *a* concentrations have tended to decline from around 2003.

If the observed declines in total phosphorus described above are real, then the reductions in chlorophyll *a* in the river are likely to be associated with this (noting that at the same time concentrations of the other major plant nutrient—total nitrogen—have typically increased, implying that phytoplankton growth in the river is less dependent on the availability of nitrogen).

<u>*Escherichia coli*</u>. Important deteriorations in *E. coli* concentrations occurred at Taupo Gates, Whakamaru, Mercer and Tuakau (sites A, D, I and J). As noted above, there is some uncertainty about the robustness of the *E. coli* records due to changing laboratory detection limit in recent years.

<u>The summary rows</u> at the bottom of Table 4 provide an overview of the trend results for the 10 key water quality variables at the ten Waikato River sites during 1991–2020. The results can be summarized as follows:

- mixed results: records of water temperature and dissolved oxygen showed some slight improvements, slight deteriorations or little change; for both turbidity and visual clarity there was an important improvement and some deterioration; and four important improvements and one important deterioration occurred in concentrations of arsenic;
- general improvement: important improvements were observed in chlorophyll *a* concentrations at six sites and in ammonia at five sites; important improvements apparently occurred in total phosphorus concentrations as well;

- general deterioration: important deteriorations occurred in total nitrogen at six sites; and important deteriorations (and no improvements) occurred in E. coli at four sites.
- note also that over the last ten years of the period (2011–20), at many or most sites important improvements occurred in turbidity and visual clarity, and in concentrations of arsenic, boron and chlorophyll (Appendix 1); however, during this decade important deteriorations occurred in concentrations of total nitrogen, nitrate, *E. coli* and enterococci.

3.2 Other rivers and streams

Appendix 2 lists the trend slopes and slope probabilities for the water quality records at the 104 sites on the other rivers and streams for two time periods: 1991–2020 (30-years) and 2011–20 (10-years). About 1180 separate 30-year records were analysed (including quarterly records of *E. coli* and enterococci), and about 1350 separate 10-year records (monthly records of both *E. coli* and enterococci for most sites). Table 5 lists the trend slopes (RSKSE) from the 30-year records for eight key variables. As noted above, trends where the slope probabilities are greater than 95% are regarded as being very likely (section 2.4). Furthermore, in both Appendix 2 and Table 5 a distinction is made between very likely 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 30-year period 1991–2020 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, (2) for the very likely trends only, and (3) for the very likely 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 was an overall pattern of change across the region as a whole.

Temperature. Slope probabilities indicating very likely trends (i.e. >95%) in water temperature were found at 61 sites (Table 5). None of the absolute values of the slopes exceeded 1% per year, so all these trends were slight. Six of the trends were decreases, and thus represented improvements (Waihou @ Okauia and @ Te Aroha, sites #33 and 3, Waitoa @ Mellon Rd, site #80, Whareroa, site #102, and the two sites on the Waiotapu, sites #47 and 50), but most were slight deteriorations. The median rate of change for the very likely trends was 0.2% per year or about +0.03°C per year. The sites at which these trends occurred were distributed reasonably evenly across the seven water zones (Table 5).

Dissolved oxygen. Trends in dissolved oxygen classed as very likely were observed at three-quarters (78) of the sites; all of these were slight. Many (64) trends were decreases, so the overall pattern for sites in the region as a whole was a decrease in dissolved oxygen levels (Table 6). And decreases outweighed increases in all part of the region (Table 5). This represents a general deterioration in water quality. However, the median value of the slopes (RSKSE) for the very likely trends was low, being just –0.1% per year.

The largest rate of improvement in dissolved oxygen concentrations occurred at Whangamarino @ Island Block Rd (site #28), where the slope was 0.5% per year. The largest deterioration occurred at Awaroa @ Otaua Rd (site #27), where the slope was –0.35% per year.

It is unclear whether there's a common cause of the observed deteriorations; nor is it clear what the cause(s) might be.

Table 5: Slopes (% per year) of very likely trends (slope direction probability >95%) in flow-adjusted water quality at 104 Waikato region river sites during 1991–2020 (see Appendix 2 for further details). Important improvements are shown in bold blue type; important deteriorations are bold red underlined; "nvl", not very likely (trend slope probability <95%). 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)	nvl	nvl	**−1.1**	0.5	**−1.0**	**−6.1**	**−2.1**	nvl
Kauaeranga (92)	nvl	nvl	nvl	nvl	**1.0**	nvl	nvl	nvl
Ohinemuri (4)	0.3	−0.1	nvl	**1.2**	nvl	**−1.2**	**−3.1**	nvl
Ohinemuri (99)	nvl	−0.2	**−1.5**	0.7	0.7	**1.3**	**−6.8**	**−9.7**
Ohinemuri (98)	nvl	nvl	nvl	−0.8	nvl	−0.9	**−1.9**	**−4.4**
Tairua (96)	0.2	−0.1	**−1.7**	nvl	−0.4	nvl	**−1.6**	**−4.7**
Tapu (93)	0.2	0.0	nvl	nvl	nvl	nvl	nvl	**−4.3**
Waiau (94)	0.1	nvl	nvl	0.8	−0.6	nvl	**−1.8**	**−1.7**
Waitekauri (100)	0.2	nvl	−0.7	nvl	**−2.6**	**−2.7**	**−1.3**	**−5.2**
Waiwawa (95)	nvl	−0.1	nvl	0.9	−0.5	nvl	**−1.2**	**−4.3**
Wharekawa (97)	0.2	nvl	−0.9	**1.0**	0.5	nvl	**−1.8**	**−3.5**
Imp – Det	0 – 0	0 – 0	3 – 0	2– 0	2 – 1	3 – 1	9 – 0	8 – 0
Hauraki								
Mangawhero (32)	nvl	−0.1	0.6	−0.6	nvl	nvl	−0.5	nvl
Oraka (35)	nvl	−0.1	**1.8**	−0.8	0.8	nvl	−0.6	**−3.1**
Piako (83)	nvl	−0.2	**−1.3**	0.7	−0.7	**−5.0**	**−2.2**	nvl
Piako (79)	nvl	0.1	nvl	nvl	**−1.0**	**−3.3**	−0.9	nvl
Piakonui (82)	nvl	−0.1	−0.8	**1.6**	nvl	nvl	**−2.0**	**−2.2**
Waihou (33)	−0.1	nvl	**1.2**	−0.7	**1.0**	nvl	−0.5	**2.1**
Waihou (3)	−0.2	−0.2	nvl	0.9	0.6	nvl	nvl	nvl
Waihou (37)	nvl	−0.2	0.9	−0.4	**1.8**	nvl	−0.5	**3.6**
Waiohotu (36)	0.4	−0.1	0.7	–	0.7	nvl	−0.5	**−4.3**
Waiomou (34)	nvl	0.0	**1.6**	−0.7	**1.2**	nvl	−0.7	**1.9**
Waitakaruru (31)	0.2	−0.2	**−1.5**	**2.1**	**−1.3**	**−3.0**	**−1.6**	nvl
Waitoa (81)	nvl	0.1	−0.5	nvl	nvl	**−3.3**	**−1.9**	nvl
Waitoa (80)	−0.2	0.3	**1.2**	**−1.1**	−0.5	**−2.5**	**−10.9**	nvl
Imp – Det	0 – 0	0 – 0	2 – 4	2 – 1	2 – 3	5 – 0	5– 0	3 – 3
Inflows to Lake Taupo								
Hinemaiaia (55)	nvl	−0.1	0.7	−0.7	**1.6**	nvl	−0.7	nvl
Kuratau (58)	0.6	−0.1	nvl	nvl	**2.5**	nvl	−0.9	–
Kuratau (101)	0.3	−0.1	**1.2**	–	**1.4**	nvl	**−1.3**	nvl
Mapara (53)	0.2	nvl	nvl	nvl	0.6	**−1.6**	**−1.0**	nvl
Tauranga–Tau (56)	0.5	−0.2	**1.1**	−0.6	**1.0**	nvl	−0.9	–
Tokaanu (57)	0.1	−0.2	**2.1**	–	0.9	nvl	−0.1	–
Tokaanu Pow (103)	0.4	0.1	**1.4**	–	nvl	nvl	**−1.4**	–
Tongariro (5)	0.2	0.0	nvl	**1.0**	0.7	nvl	nvl	nvl
Waihaha (59)	0.7	nvl	0.9	**−1.5**	0.4	nvl	nvl	nvl
Waitahanui (54)	0.1	−0.1	**1.7**	−0.9	**1.4**	nvl	−0.6	**−3.4**
Whanganui (104)	nvl	−0.2	nvl	–	−0.9	nvl	**−1.3**	nvl
Whareroa (102)	−0.4	−0.1	**1.1**	–	0.3	nvl	−0.9	nvl
Imp – Det	0 – 0	0 – 0	0 – 6	1 – 1	0 – 5	1 – 0	4– 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)	0.2	–0.1	–0.7	nvl	3.1	–2.2	–1.7	nvl
Mangaharakek (43)	0.5	nvl	1.1	–0.7	4.7	–2.5	nvl	1.6
Mangakara (49)	nvl	–0.1	0.9	nvl	2.5	–0.4	–1.1	nvl
Mangakino (60)	0.2	–0.1	1.4	–0.9	2.4	nvl	–0.3	–
Otamakokore (46)	nvl	nvl	0.9	nvl	1.8	–0.4	–0.4	nvl
Pueto (52)	0.2	–0.1	1.3	nvl	2.3	–3.0	–0.9	nvl
Tahunaatara (44)	0.2	–0.1	1.1	–1.0	2.1	–0.1	nvl	2.5
Torepatutahi (51)	0.2	nvl	0.8	–	3.1	nvl	–0.6	–
Waiotapu (47)	–0.2	0.1	0.9	nvl	1.3	0.6	–2.0	3.7
Waiotapu (50)	–0.2	nvl	1.0	0.8	1.0	nvl	–1.1	–
Waipapa (42)	0.1	nvl	–0.6	0.4	4.2	nvl	–0.2	nvl
Whirinaki (45)	0.1	0.0	nvl	–	2.1	nvl	–0.6	–
Imp – Det	0 – 0	0 – 0	0 – 5	0 – 1	0 – 12	3 – 0	4 – 0	0 – 3
Lowland tributaries of the Waikato River								
Awaroa–Otau (27)	nvl	–0.3	2.0	–1.4	0.7	nvl	nvl	–
Awaroa–Rotowa (7)	0.5	–0.2	nvl	nvl	1.0	1.3	–1.6	–2.6
Karapiro (85)	nvl	–0.3	2.0	–1.8	1.0	nvl	–0.8	nvl
Kirikiriroa (90)	nvl	nvl	–1.8	1.2	–3.3	–6.7	–2.6	–2.0
Komakorau (6)	0.3	–0.2	1.1	–0.2	–0.3	–1.9	–0.5	nvl
Little Waipa (38)	nvl	nvl	2.1	–1.2	2.4	nvl	nvl	2.2
Mangakotukut (87)	0.1	–0.1	–1.1	1.2	–0.7	–2.1	0.7	nvl
Mangamingi (40)	nvl	–0.1	3.2	–2.1	nvl	nvl	–4.5	nvl
Mangaone (77)	0.4	0.4	0.5	–0.6	–1.1	–3.5	–1.3	–1.6
Mangaonua (78)	0.2	0.1	nvl	nvl	nvl	–0.9	–1.0	nvl
Mangaonua (84)	0.3	–0.1	–0.7	nvl	–0.8	–6.7	–3.6	–3.8
Mangatangi (30)	0.2	nvl	4.4	–5.1	–0.6	1.1	nvl	–
Mangatawhiri (29)	nvl	–0.2	nvl	nvl	–0.7	nvl	nvl	–
Mangawara (19)	0.2	0.2	0.9	–0.5	nvl	nvl	nvl	–
Mangawhero (86)	0.3	0.1	0.9	–0.9	nvl	–2.0	–0.9	nvl
Matahuru (20)	0.4	–0.2	2.1	–1.6	–0.7	nvl	nvl	–
Ohaeroa (25)	nvl	–0.2	nvl	0.6	1.7	–1.3	–0.9	–
Opuatia (24)	nvl	–0.2	2.7	–2.9	1.0	–1.3	nvl	nvl
Pokaiwhenua (39)	nvl	nvl	2.5	–1.3	1.9	nvl	–1.5	2.5
Waerenga (21)	0.5	–0.2	2.2	–1.6	0.8	0.4	nvl	nvl
Waitawhiriwhiri (89)	0.2	–0.1	nvl	nvl	–0.5	–1.6	–1.4	nvl
Whakapipi (26)	0.3	0.2	–1.4	1.2	1.0	–2.3	1.0	–
Whakauru (41)	nvl	–0.1	5.5	–3.8	10.0	0.8	3.6	5.0
Whangamarino (28)	0.5	0.5	–2.3	nvl	2.0	1.8	nvl	–
Whangamarino (22)	0.4	–0.1	2.8	–2.4	–0.7	nvl	0.7	–
Whangape (23)	nvl	nvl	6.6	–4.7	3.5	nvl	2.6	–
Imp – Det	0 – 0	0 – 0	4 – 13	3 – 12	2 – 10	10–3	8 – 3	4 – 3

Table 5 continued

	Temperature	Dissolved oxygen	Turbidity	Visual clarity	Total nitrogen	Ammonia	Total phosphorus	*Escherichia coli*
Waipa River and tributaries								
Kaniwhaniwha (11)	0.4	−0.1	nvl	−0.9	0.3	−0.6	nvl	–
Mangaohoi (74)	0.2	nvl	−0.7	0.8	**−1.1**	−0.8	−0.8	nvl
Mangaokewa (65)	0.2	−0.1	**1.0**	nvl	**1.2**	**−3.9**	−0.8	–
Mangapiko (76)	nvl	0.3	**1.2**	−0.7	−0.6	**−4.0**	**−1.8**	–
Mangapu (63)	nvl	−0.2	nvl	nvl	0.6	**−2.1**	**−1.9**	**2.4**
Mangatutu (73)	0.2	nvl	0.4	nvl	**1.1**	**−1.3**	−0.5	nvl
Mangauika (13)	0.4	−0.1	**1.6**	0.7	**2.1**	nvl	nvl	nvl
Ohote (88)	nvl	0.4	**1.2**	**−1.8**	−0.7	0.6	nvl	**3.3**
Puniu (75)	nvl	−0.3	**3.3**	**−2.5**	**1.5**	**1.0**	nvl	–
Waipa (61)	0.4	nvl	nvl	nvl	0.8	0.1	**−1.0**	–
Waipa (12)	nvl	−0.1	0.9	**−1.3**	0.9	−0.7	**−1.1**	nvl
Waipa (2)	0.2	nvl	nvl	0.9	0.8	nvl	nvl	nvl
Waipa (64)	0.2	−0.1	**−1.2**	nvl	**1.1**	**−1.1**	**−1.9**	nvl
Waipa (1)	nvl	−0.1	**2.4**	−0.9	0.7	nvl	0.4	**2.6**
Waitomo (18)	nvl	−0.3	0.8	−0.6	0.6	−0.7	nvl	nvl
Waitomo (17)	0.1	−0.1	nvl	nvl	0.4	−0.1	−0.4	nvl
Imp – Det	0 – 0	0 – 0	1 – 6	0– 3	1 – 5	5– 1	5 – 0	0 – 3
West Coast								
Awakino (70)	0.2	−0.1	**−1.2**	nvl	**−1.2**	nvl	−0.8	nvl
Awakino (69)	nvl	−0.1	**−1.3**	0.5	0.5	−0.7	**−1.0**	nvl
Manganui (67)	nvl	−0.1	nvl	nvl	nvl	nvl	**−1.1**	nvl
Mangaotaki (66)	nvl	0.0	nvl	nvl	0.8	**−2.9**	−0.7	–
Marokopa (15)	0.2	−0.1	nvl	−0.4	0.8	nvl	−0.5	nvl
Mokau (68)	nvl	nvl	**−1.3**	0.7	0.6	**−1.1**	**−2.3**	**−2.3**
Mokau (62)	nvl	−0.2	0.8	−0.8	**1.9**	nvl	nvl	nvl
Mokau (71)	nvl	−0.1	−0.8	0.7	**1.0**	**−1.2**	**−1.1**	nvl
Mokauiti (72)	nvl	−0.2	**−1.8**	**1.7**	0.7	−0.9	**−1.4**	nvl
Ohautira (9)	0.3	nvl	**−1.8**	**1.6**	0.4	**−1.1**	**−1.0**	nvl
Oparau (14)	0.2	−0.1	nvl	nvl	nvl	nvl	−0.8	–
Tawarau (16)	0.2	−0.1	nvl	nvl	0.6	nvl	−0.6	–
Waingaro (8)	nvl	0.2	nvl	nvl	0.6	−0.6	**−1.0**	–
Waitetuna (10)	0.2	nvl	nvl	nvl	0.7	−0.8	−0.7	**−2.1**
Imp – Det	0 – 0	0 – 0	5 – 0	2 – 0	1 – 2	4 – 0	7 – 0	2 –0
Total numbers of important trends								
Improvements	0	0	15	10	8	31	42	18
Deteriorations	0	0	34	18	38	5	3	12

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, 1991–2020. 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	Very likely records	Very likely and important records
Temperature	**0.1**	**0.2**	–
Dissolved oxygen	**−0.1**	**−0.1**	–
Turbidity	**0.5**	**0.9**	**1.2**
Visual clarity	**−0.2**	−0.6	−1.3
Total nitrogen	**0.7**	**0.8**	**1.4**
Ammonia	**−0.1**	**−1.2**	**−2.1**
Total phosphorus	**−0.8**	**−1.0**	**−1.5**
E. coli	**−0.4**	−2.1	−2.1

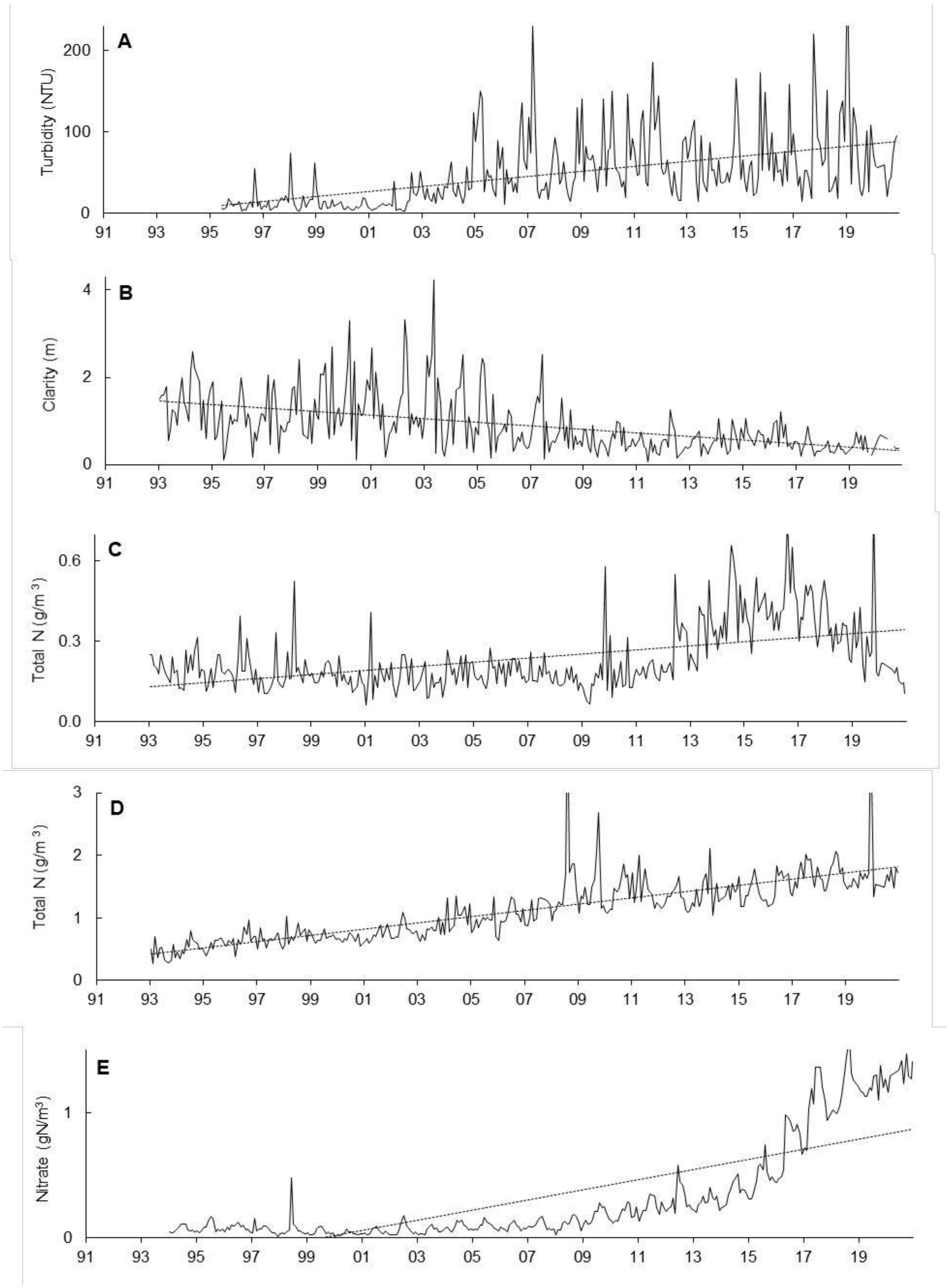

Figure 3: Water quality at various sites during 1991–2020: **A**, Turbidity at Whangape (site #18); **B**, visual clarity at Mangatangi (#30); **C**, total nitrogen at Kuratau (Moerangi, #58); **D**, total nitrogen at Waipapa (#42); and **E**, nitrate at Whakauru (#41). The dashed lines broadly indicate the overall trends in the records.

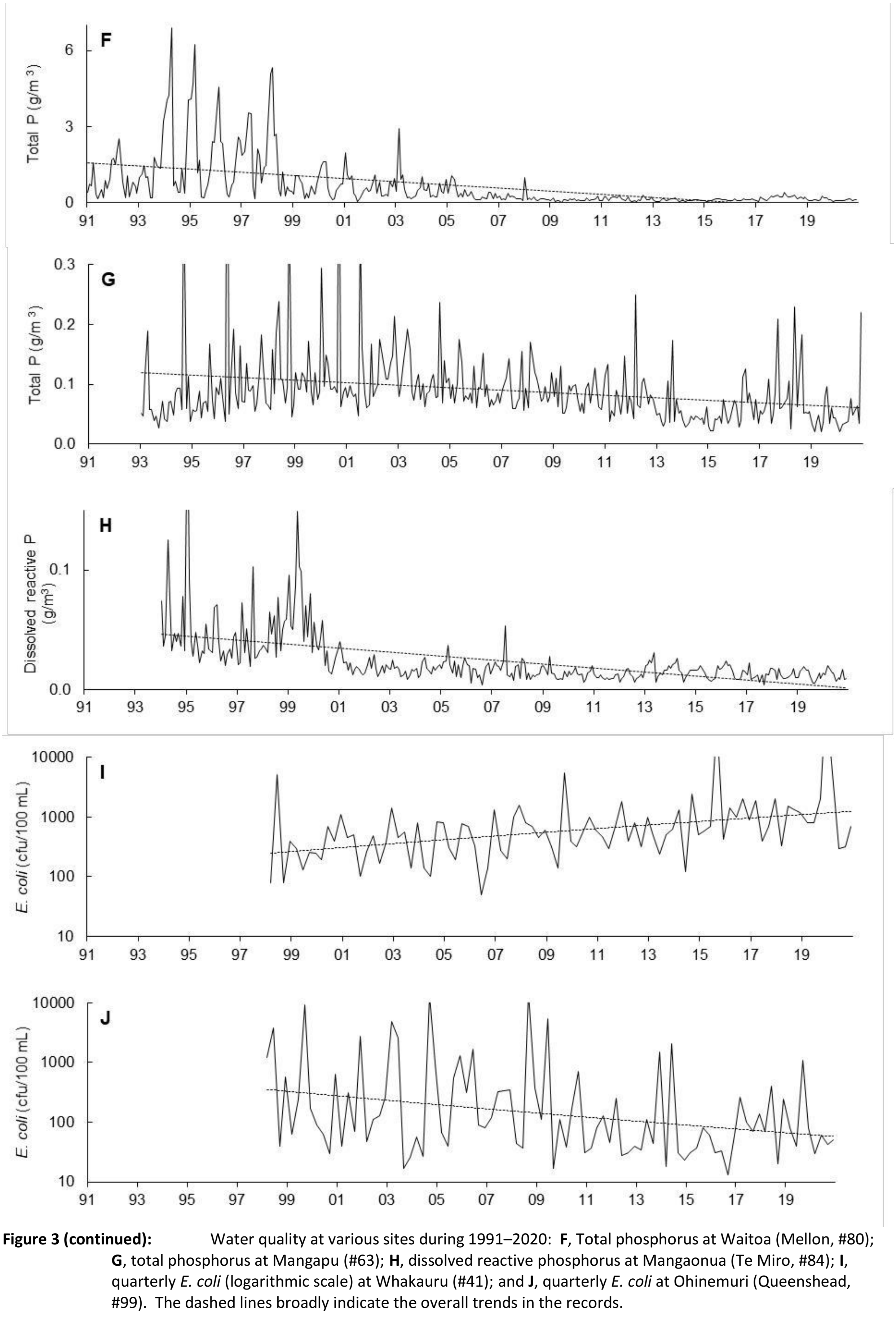

Figure 3 (continued): Water quality at various sites during 1991–2020: **F**, Total phosphorus at Waitoa (Mellon, #80); **G**, total phosphorus at Mangapu (#63); **H**, dissolved reactive phosphorus at Mangaonua (Te Miro, #84); **I**, quarterly *E. coli* (logarithmic scale) at Whakauru (#41); and **J**, quarterly *E. coli* at Ohinemuri (Queenshead, #99). The dashed lines broadly indicate the overall trends in the records.

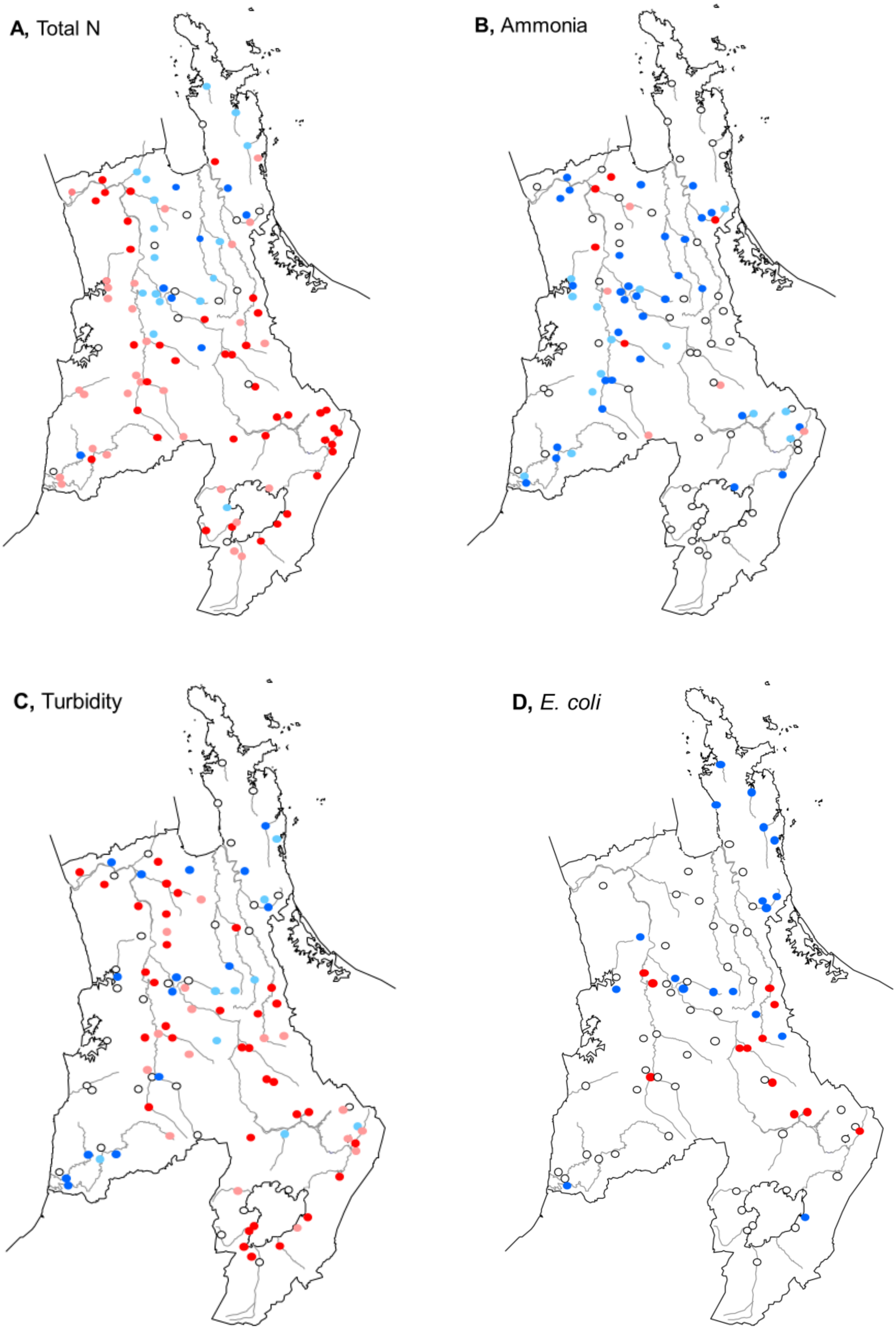

Figure 4: Nature of trends for selected water quality variables at regional river sites during 1991–2020. The symbols distinguish between records where slope probabilities were not very likely (open circles), and those showing one of the following very likely trends: important improvement (dark blue), slight improvement (pale blue); slight deterioration (pink) and important deterioration (red). **A**, total nitrogen; **B**, ammonia; **C**, turbidity; and **D**, *E. coli*; See Figure 1 and Table 5 for details.

Turbidity. Trends in turbidity classed as very likely were observed at 74 of the sites. Many (49) of these were important, and there were twice as many deteriorations (34) as improvements (15). As a result, 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 important trends was 1.2% per year. Deteriorations in turbidity tended to be less common in the Coromandel and West Coast zones (Figure 4C).

The largest rate of improvement in turbidity was –2.3% per year (Whangamarino @ Island Block Rd, #28), while the largest deterioration was 6.6% per year (Whangape, #23; see Figure 3A). 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 since about 2005. This has probably caused the increased turbidity in the water flowing out of the lake.

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.

Very likely trends in visual clarity were observed at two-thirds (64) of the sites at which it was measured (96). About half (28) of these were important, and there were twice as many deteriorations (18) as improvements (10). The median value of the slopes (RSKSE) for the important trends was –1.3% per year.

The largest rate of improvement in visual clarity was 2.1% per year (Waitakaruru, #72), while the largest deterioration was –5.1% per year (Mangatangi River, #31; see Figure 3B). Deteriorations outweighed improvements to a greater extent in the Lowland Waikato zone than elsewhere in the region.

Total nitrogen. Trends in total nitrogen concentrations classed as very likely were observed at many (91) of the sites; half (46) of them were important. Of these, deteriorations (38; e.g. Figures 3C and 3D) were nearly five times as common as improvements (8), so the overall pattern for sites in the region as a whole was a deterioration in total nitrogen (Table 6). The median value of the slopes (RSKSE) for the very likely and important trends was 1.4% per year.

Deteriorations in total nitrogen occurred in most parts of the region (Figure 4A), but improvements were more common in the northern part of the region (Coromandel, Hauraki and Lowland Waikato zones). Important deteriorations in total nitrogen were observed at all 12 sites in the Upland Waikato zone (e.g. Figure 3D), with the median rate of change there being 2.4% 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 can be several decades old (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 means that ongoing increases in stream nitrogen concentrations have been common in recent decades.

Some of the important improvements in total nitrogen 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 developed catchments, probably reflecting increased leaching losses from areas of pastoral farming following intensification in recent decades.

The recent felling of areas of plantation forest has probably also contributed to increasing concentrations of total nitrogen in at least two of the monitored streams. The small catchment (7 km^2) catchment in the headwaters of the Kuratau River (at Moerangi, site #58) is mostly covered in native bush/scrub and plantation forest, with no pasture being present. The marked increase in total nitrogen concentrations in the past decade at this site (Figure 3C) is likely to be due to activities associated with the harvesting of part of the plantation forest here (NZ Forest Managers, pers. comm.).

Similarly, the replacement of some plantation forest with pasture in the catchment of the Whakauru Stream (site #41) has been followed by increases in concentrations of total N, nitrate (Figure 3E) and several other variables over the past decade (Figure 3I, Appendix 2). Note that the rates of increase in total nitrogen (RSKSE) at this site, namely 10% per year during 1991–2020 and 17% per year during 2011–20 (Appendix 2), were the highest that occurred at any of the routinely-monitored locations. Nitrate concentrations in this stream have increased even more rapidly: 19% per year during 1991–2020 and 25% per year during 2011–20 (Appendix 2).

Ammonia. Trends in ammonia concentrations classed as very likely were observed at half (55) of the sites, and many of them (36) were important trends. Of these, all but five (sites #99, 7, 30, 28 and 75) were improvements, 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 4B), although fewer improvements were seen in the Taupo zone and on the Coromandel Peninsula—areas where ammonia concentrations have historically been low. The median value of the slopes (RSKSE) for the very likely and important trends was –2.1% per year.

At several sites substantial decreases in ammonia have occurred during the past 30 years as a result of the reduction or removal of loads from point source discharges further upstream: Waitekauri (#100; mining wastewaters), Kirikiriroa (#90; landfill leachate), and Mangaokewa (#65; stockyard runoff).

The median value of SKSE—that is, the slopes expressed in concentration units—for very likely trends in ammonia, namely –0.14 mg N/m^3/yr, was considerably smaller than the median value of SKSE for very likely trends in total nitrogen (+4.5 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, especially nitrate (e.g. Figure 3E; see Appendix 2), such that the overall outcome for rivers in general across the region was an increase in concentrations of total nitrogen (Figures 4A and 4B).

Total phosphorus. As noted above (section 2.1), the results presented here for the trends in total phosphorus are provisional. Trends in total phosphorus concentrations classed as very likely were observed at three-quarters (81) of the sites, and many of them (45) were important trends. Of these, improvements (some 42; e.g. Figures 3F and 3G; see also Figure 3H) were much more common than deteriorations (3), so the overall pattern for sites in the region as a whole was an improvement in total phosphorus concentrations (Table 6). The median value of the slopes (RSKSE) for the very likely and important trends was –1.5% per year. Improvements in total phosphorus occurred throughout the region, while the three deteriorations all occurred in the Lowland Waikato zone.

At the time of writing, questions remain about the reliability of the laboratory procedures that have been used to determine the concentrations of total phosphorus in the routinely-collected water samples. As a result, apart from those for two of the sites, the trends reported here will not be discussed further.

The ongoing improvement in total phosphorus concentrations in the lower Waitoa River (Figure 3F) follows major reductions over the past 25 years in the loads of P discharged to the river by some of the industries in the area, particularly one of the dairy factories (Vant 2016).

The record shown in Figure 3G for total phosphorus concentrations in the Mangapu River is also interesting. During the first 10 years of the record (1993–2002), flow-adjusted total phosphorus concentrations increased, with a slope probability of 99% and a slope of 6.8% per year. However, in the following 18 years of the record (2003–20) concentrations decreased, with a slope of –4.0% per year (slope probability 99%). Over the full 28-year period from 1993, the net effect of these changes was for total phosphorus concentrations in the river to decrease, with an overall slope of –1.9% per year (Table 5, Appendix 2).

Escherichia coli.[8] Trends in *E. coli* concentrations classed as very likely were observed at about 40% (30) of the 77 sites where records began during 1998–2006, and all were important. Of these, 12 were deteriorations (e.g. Fig. 3I) and 18 were improvements (e.g. Fig. 3J); the similarity of these totals meant there was no overall pattern for sites in the region as a whole (Table 6). The median value of the slopes was –2.1% per year. Improvements tended to be more common in the northern half of the region, particularly in the Coromandel zone where records at eight of the 11 sites improved (Figure 4D).

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 1991–2020. The results can be summarized as follows:

- slight changes only: records of both water temperature and dissolved oxygen showed slight trends—most of which were deteriorations—at between half (temperature) and two-thirds (dissolved oxygen) of the monitored sites;
- general improvement: important improvements in total phosphorus concentration apparently occurred at 40% of the sites (provisional result only);
- some improvement: important improvements occurred in ammonia concentration at one-third of the sites, and in *E. coli* at nearly one-quarter of the sites monitored;
- some deterioration: important deteriorations in turbidity occurred at about one-third of sites (while visual clarity deteriorated at about one-fifth of sites); however, appreciable numbers of important improvements occurred as well;
- general deterioration: important deteriorations in total nitrogen concentration occurred at more than one-third of the sites.

[8] Note that most of these records—obtained from quarterly sampling since 1998—contain fewer results than those for many other variables, so that the sample size is considerably smaller (median 91: Table 1). Care should thus be taken in comparing the trend results for *E. coli* with those reported for other variables. (For the five sites sampled by NIWA, however, monthly results since 2005 were analysed [n = 179–180]).

4 Conclusions

1. For the Waikato River, records for ten key water quality variables were analysed at 8–10 monitoring sites, giving a total of 98 records that were considered (Table 4). Trends in water quality were found to be not very likely to have occurred in 30 (31%) of these records during 1991–2020. Very likely trends (slope direction probability >95%) were found in the remaining records, with 33 records (34%) showing trends that were 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). Well over half (21) of these latter trends represented important improvements in water quality, and the remainder (12) represented important deteriorations. Figure 5A summarizes the changes in water quality in the Waikato River during 1991–2020.

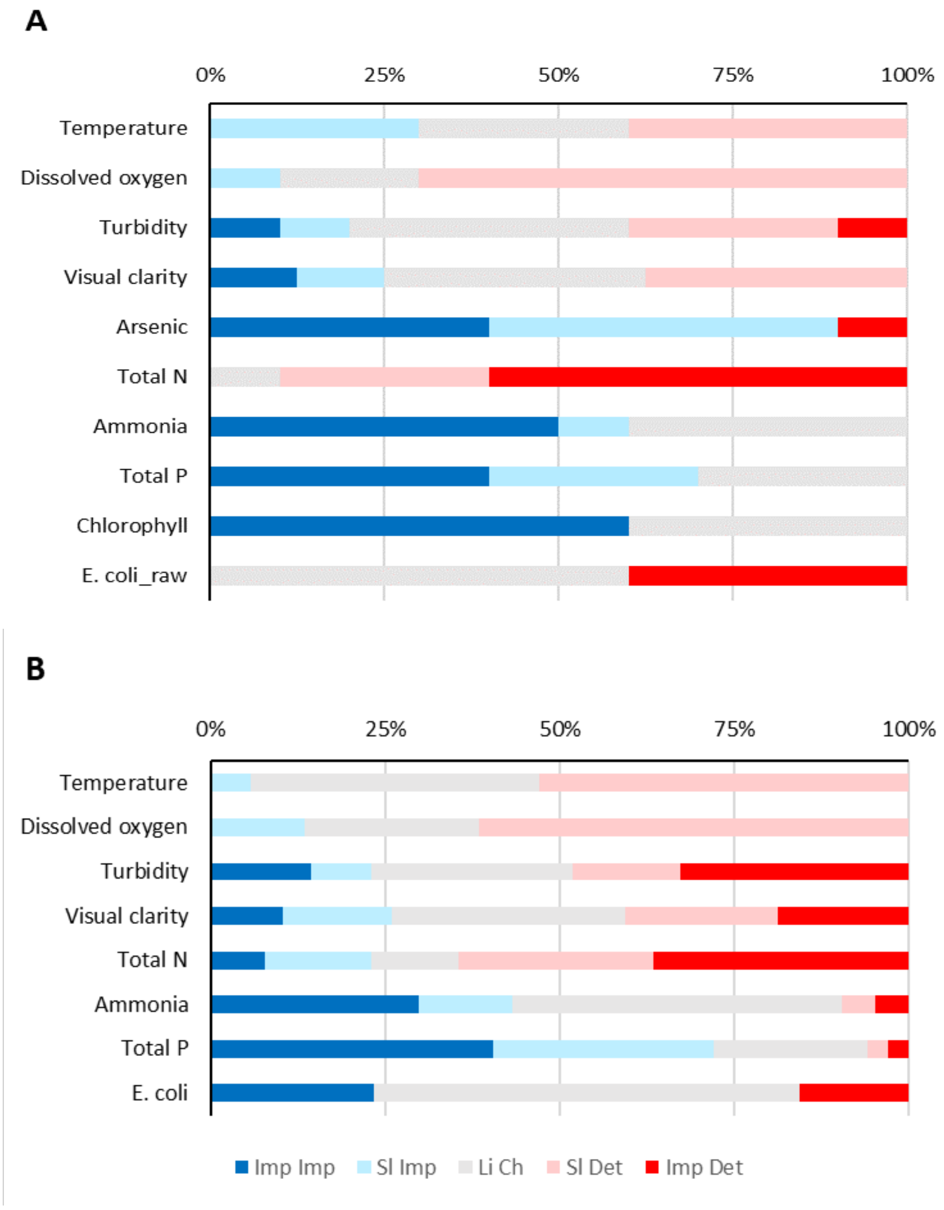

Figure 5: Proportion of records showing trends in key water quality variables at monitoring sites on rivers in the Waikato region, 1991–2020. A, Waikato River (see Table 4 for further details); B, other rivers and streams (see Table 5 for further details). The colours distinguish between records where slope probabilities indicated that trends were not very likely (grey), and those showing one of the following very likely trends: important improvement (dark blue), slight improvement (pale blue); slight deterioration (pink) and important deterioration (red).

2. Records of temperature and dissolved oxygen at the ten Waikato River sites showed only slight trends. Records of turbidity and visual clarity showed only a small number of important trends, both improvements and deteriorations. Four important improvements and one deterioration occurred in concentrations of arsenic, and five improvements occurred in ammonia concentrations. Important improvements were also common in records of chlorophyll *a* (six) and—apparently—total phosphorus (four). Conversely, four important deteriorations occurred in *E. coli* concentrations. And important deteriorations occurred in records of total nitrogen at six of the ten sites. Intensification of pastoral farming in the Waikato catchment probably caused this general deterioration in total nitrogen concentrations.

3. For the other rivers and streams, records for eight key water quality variables were analysed at 77–104 sites, giving a total of 797 records that were considered (Table 5). Trends in water quality were found to be not very likely to have occurred in 263 (37%) of these records during 1991–2020. Trends were found to be very likely in the remaining records, with 234 records (29% of the total number) showing trends that were important. Some 124 (16%) of these latter trends represented important improvements in water quality, and the remainder (110, or 14%) were important deteriorations. Figure 5B summarizes the changes in water quality in the other rivers and streams during 1991–2020.

4. Records of temperature and dissolved oxygen at these other river and stream sites showed only slight trends. Important improvements appeared to occur in records of total phosphorus at about 40% of the sites, and slight improvements at a further 32% of the sites; deteriorations occurred at only three sites. Important improvements were also common in records of ammonia (30%) and *E. coli* (17%), with smaller numbers of deteriorations in each case. Important deteriorations in turbidity were about twice as common (34 sites) as important improvements (15 sites); a similar pattern was found for visual clarity (18 sites and 10 sites, respectively). Important deteriorations in total nitrogen occurred at 38 of the sites (36%), while important improvements occurred at eight sites; slight deteriorations (28% of sites) were also more common than slight improvements (15%)

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 increase at 64% of sites across the region (Figure 4A). 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.

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Appendix 1

Trend slopes (% per year) and, in brackets, slope direction probabilities (%) for monthly records of flow-adjusted water quality variables at ten Waikato River sites. Results are shown for 1991–2020 (30-year record) and for 2011–20 (10-year record). Important improvements (see text) are shown in bold blue type; important deteriorations are bold red underlined. The names of sites for which a flow index was generated (see section 2.6) are shown in italics. Results for total phosphorus are provisional.

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Arsenic	Boron	Total nitrogen	Nitrate-N	Ammonia	Total phosphorus	Dissolved reactive P	Chlorophyll *a*	*Escherichia coli*	Enterococci
1991–2020															
Taupo	0.3 (99)	0.0 (93)	0.1 (99)	0.9 (99)	–	**1.0 (99)**	0.1 (99)	−0.2 (83)	**−1.4 (99)**	0.0 (50)	**−1.6 (99)**	−0.4 (99)	0.0 (50)	**4.2 (96)**	**2.4 (99)**
Ohaaki	−0.1 (99)	0.1 (99)	−0.4 (99)	0.9 (99)	−0.7 (99)	**−1.4 (99)**	−0.8 (99)	0.8 (99)	**1.0 (99)**	**−5.1 (99)**	**−1.4 (99)**	**−2.3 (99)**	0.0 (50)	0.5 (74)	−0.3 (75)
Ohakuri	0.2 (99)	0.0 (83)	−0.2 (99)	0.4 (97)	−0.5 (99)	−0.5 (99)	−0.2 (99)	0.9 (99)	**1.7 (99)**	**−2.0 (99)**	−0.2 (90)	−0.8 (99)	0.1 (71)	1.4 (92)	0.8 (97)
Whakamaru	0.0 (57)	−0.1 (97)	−0.1 (94)	0.0 (59)	0.0 (50)	−0.5 (99)	−0.2 (99)	**1.9 (99)**	**3.5 (99)**	−0.2 (99)	0.0 (56)	−0.1 (64)	−0.2 (77)	**4.9 (99)**	**4.7 (99)**
Waipapa	0.1 (99)	−0.1 (99)	−0.1 (95)	0.0 (53)	−0.4 (94)	−0.7 (99)	−0.3 (99)	**1.6 (99)**	**3.3 (99)**	−0.1 (59)	−0.2 (93)	0.3 (95)	**−1.5 (99)**	0.5 (72)	0.5 (83)
Narrows	0.2 (99)	−0.2 (99)	0.0 (66)	**−1.0 (99)**	**1.1 (99)**	−0.7 (99)	−0.3 (99)	**1.6 (99)**	**3.4 (99)**	**−1.5 (99)**	−0.7 (99)	0.3 (90)	**−2.8 (99)**	0.4 (75)	**1.9 (99)**
Horotiu	0.0 (81)	−0.1 (99)	−0.1 (99)	−0.5 (96)	0.6 (99)	−0.8 (99)	−0.4 (99)	**1.1 (99)**	**3.3 (99)**	**−4.3 (99)**	−0.9 (99)	−0.1 (69)	**−3.2 (99)**	0.7 (86)	−0.5 (75)
Huntly	0.0 (61)	−0.1 (98)	−0.1 (99)	0.3 (79)	0.1 (66)	**−1.1 (99)**	−0.6 (99)	0.9 (99)	**2.2 (99)**	**−3.3 (99)**	**−1.5 (99)**	**−1.0 (99)**	**−3.5 (99)**	0.0 (50)	0.3 (77)
Mercer	−0.4 (99)	−0.2 (99)	−0.1 (97)	**1.2 (99)**	–	**−1.4 (99)**	−0.8 (99)	**1.4 (99)**	**2.8 (99)**	0.0 (50)	−0.9 (99)	−0.6 (99)	**−3.4 (99)**	**1.6 (99)**	**2.2 (99)**
Tuakau	−0.3 (99)	−0.2 (99)	0.0 (72)	0.6 (93)	−0.5 (99)	**−1.3 (99)**	−0.7 (99)	**1.2 (99)**	**2.9 (99)**	0.0 (50)	**−1.2 (99)**	−0.8 (99)	**−3.4 (99)**	**2.6 (99)**	**1.7 (99)**
2011–2020															
Taupo	−0.1 (58)	0.0 (57)	0.1 (94)	**-3.7 (99)**	–	0.6 (99)	0.3 (97)	−0.6 (64)	0.0 (50)	0.0 (50)	−0.1 (56)	0.0 (50)	–	9.9 (92)	**17.9 (99)**
Ohaaki	−0.3 (79)	0.3 (99)	**−1.1 (99)**	**-2.0 (97)**	**3.5 (99)**	**−3.8 (99)**	**−1.4 (99)**	−0.6 (62)	**2.4 (97)**	0.0 (50)	1.7 (87)	**−2.8 (99)**	0.0 (50)	**13.8 (99)**	**5.9 (99)**
Ohakuri	0.1 (56)	0.2 (92)	**−1.0 (99)**	-0.5 (70)	1.4 (95)	**−2.3 (99)**	**−1.8 (99)**	1.3 (95)	**3.1 (99)**	1.2 (82)	**1.8 (99)**	**−3.1 (97)**	−1.9 (80)	**12.2 (97)**	**10.5 (99)**
Whakamaru	**−1.1 (98)**	−0.4 (99)	−0.7 (99)	**-2.2 (96)**	**4.1 (99)**	**−2.1 (99)**	**−1.8 (99)**	**2.8 (99)**	**6.1 (99)**	0.0 (50)	**1.6 (99)**	1.0 (72)	**−6.4 (99)**	10.6 (93)	2.8 (81)
Waipapa	−0.5 (97)	−0.2 (86)	−0.8 (99)	**-1.8 (99)**	**2.5 (99)**	**−2.5 (99)**	**−1.5 (99)**	**1.9 (99)**	**3.8 (99)**	1.0 (84)	1.1 (92)	−0.4 (70)	**−3.3 (98)**	6.2 (90)	5.6 (94)
Narrows	−0.4 (81)	−0.3 (97)	−0.3 (97)	**-2.5 (97)**	**1.8 (99)**	**−1.7 (99)**	−0.7 (99)	**2.8 (99)**	**4.6 (99)**	0.2 (60)	**1.5 (99)**	0.4 (71)	**−4.5 (99)**	5.5 (87)	**4.5 (97)**
Horotiu	0.7 (93)	−0.3 (90)	−0.3 (94)	-1.0 (88)	**2.0 (98)**	**−1.5 (99)**	**−1.1 (99)**	**1.8 (99)**	**2.8 (99)**	−0.4 (60)	0.4 (76)	**−1.3 (98)**	−4.1 (94)	**5.5 (98)**	**4.9 (99)**
Huntly	−0.5 (91)	0.1 (72)	−0.4 (99)	-0.2 (58)	0.8 (83)	**−1.6 (99)**	**−1.4 (99)**	**2.0 (99)**	**3.0 (99)**	0.0 (50)	0.0 (52)	−1.2 (92)	−4.2 (95)	0.7 (57)	3.2 (92)
Mercer	−0.6 (94)	0.2 (83)	−0.4 (99)	-1.5 (91)	–	**−1.1 (99)**	**−1.2 (99)**	0.9 (85)	**3.3 (99)**	0.0 (50)	−0.8 (80)	0.1 (58)	**−7.4 (99)**	4.0 (86)	0.8 (60)
Tuakau	−0.3 (82)	0.0 (51)	−0.3 (95)	**-1.7 (97)**	1.2 (94)	**−1.7 (99)**	**−1.2 (99)**	**2.1 (99)**	**4.2 (99)**	0.0 (50)	−0.9 (86)	0.1 (57)	**−5.4 (99)**	**6.1 (99)**	3.7 (91)

Appendix 2

Trend slopes (% per year) and, in brackets, slope direction probabilities (%) for monthly records of flow-adjusted water quality variables at 104 Waikato region sites. Results are shown for 1991–2020 (30-year record) and for 2011–20 (10-year record). Important improvements (see text) are shown in bold blue type; important deteriorations are bold red underlined. 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 generally contained considerably fewer results than those for the other variables (with median numbers being 91 and 100, respectively: Table 1). Results for total phosphorus are provisional.

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate–N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Coromandel												
1991–2020												
Hikutaia (91)	–0.1 (85)	0.0 (64)	0.0 (65)	**–1.1 (99)**	0.5 (96)	**–1.0 (99)**	**–1.6 (99)**	**–6.1 (99)**	**–2.1 (99)**	**–2.6 (99)**	–0.4 (55)	2.0 (89)
Kauaeranga (92)	–0.1 (68)	0.0 (81)	0.3 (99)	0.5 (89)	–0.3 (80)	**1.0 (99)**	0.6 (85)	0.0 (50)	0.1 (83)	0.0 (50)	–1 (88)	**2.2 (95)**
Ohinemuri (4)	0.3 (99)	–0.1 (99)	**1.1 (99)**	0.0 (67)	**1.2 (99)**	–0.1 (61)	–0.2 (78)	**–1.2 (97)**	**–3.1 (99)**	**–5.1 (99)**	0.0 (50)	–
Ohinemuri (99)	–0.1 (90)	–0.2 (99)	**1.9 (99)**	**–1.5 (99)**	0.7 (99)	0.7 (99)	0.8 (99)	**1.3 (99)**	**–6.8 (99)**	**–11.6 (99)**	**–9.7 (99)**	–0.7 (66)
Ohinemuri (98)	0.1 (74)	0.0 (69)	0.0 (76)	0.0 (57)	–0.8 (99)	0.1 (66)	0.0 (62)	–0.9 (99)	**–1.9 (99)**	**–3.0 (99)**	**–4.4 (99)**	–0.6 (72)
Tairua (96)	0.2 (99)	–0.1 (99)	0.0 (62)	**–1.7 (99)**	–0.3 (77)	–0.4 (96)	–0.8 (99)	0.0 (50)	**–1.6 (99)**	0.0 (50)	**–4.7 (99)**	–0.1 (53)
Tapu (93)	0.2 (97)	0.0 (99)	0.1 (99)	–0.3 (82)	0.3 (88)	0.0 (55)	**–1.7 (99)**	0.0 (50)	0.0 (66)	0.0 (50)	**–4.3 (99)**	–0.3 (58)
Waiau (94)	0.1 (95)	0.0 (54)	0.3 (99)	–0.6 (93)	0.8 (99)	–0.6 (99)	**–1.1 (99)**	0.0 (50)	**–1.8 (99)**	**–1.8 (99)**	**–1.7 (97)**	–0.2 (53)
Waitekauri (100)	0.2 (96)	0.0 (71)	**–1.4 (99)**	–0.7 (97)	–0.2 (71)	**–2.6 (99)**	**–3.1 (99)**	**–2.7 (99)**	**–1.3 (99)**	0.0 (99)	**–5.2 (99)**	–0.4 (67)
Waiwawa (95)	0.1 (95)	–0.1 (99)	–0.1 (95)	–0.3 (85)	0.9 (99)	–0.5 (96)	**–1.6 (99)**	0.0 (50)	**–1.2 (99)**	0.0 (50)	**–4.3 (99)**	–0.8 (78)
Wharekawa (97)	0.2 (99)	0.0 (89)	0.1 (99)	–0.9 (99)	**1.0 (99)**	0.5 (99)	**1.3 (99)**	0.0 (50)	**–1.8 (99)**	–0.1 (99)	**–3.5 (99)**	0.6 (66)
2011–2020												
Hikutaia (91)	–0.6 (90)	–0.4 (99)	0.2 (82)	1.3 (74)	**3.8 (99)**	**2.7 (96)**	2.0 (85)	0.0 (50)	1.9 (88)	0.0 (50)	**6.3 (99)**	4.9 (93)
Kauaeranga (92)	–0.3 (75)	–0.1 (74)	–0.8 (99)	–2.1 (87)	**4.7 (99)**	**–4.9 (99)**	**–3.5 (98)**	0.0 (50)	**–3.5 (96)**	0.0 (50)	**–6.7 (98)**	**–5.0 (98)**
Ohinemuri (4)	0.0 (51)	0.1 (84)	–0.8 (87)	**–3.2 (98)**	**2.5 (99)**	**2.0 (98)**	**1.9 (97)**	–1.5 (67)	**–2.9 (99)**	–0.2 (57)	–3 (83)	–
Ohinemuri (99)	–0.1 (61)	–0.1 (69)	–0.7 (87)	–2.2 (90)	**5.5 (99)**	–0.3 (55)	0.6 (65)	0.1 (59)	–0.1 (51)	0.0 (50)	3.1 (89)	1.8 (70)
Ohinemuri (98)	0.1 (55)	0.4 (99)	–0.1 (70)	–0.2 (55)	**4.5 (99)**	**1.2 (99)**	**2.2 (99)**	0.0 (50)	0.2 (54)	1.1 (76)	–0.5 (62)	2.0 (78)
Tairua (96)	–0.6 (87)	0.1 (77)	–0.3 (99)	–1.7 (83)	11.5 (95)	**2.0 (99)**	1.0 (84)	0.0 (50)	–0.3 (55)	0.0 (50)	**5.7 (99)**	6.3 (92)
Tapu (93)	–0.8 (96)	–0.1 (73)	–0.1 (75)	–1.1 (79)	**1.7 (96)**	0.7 (72)	**4.3 (96)**	0.0 (50)	1.1 (93)	0.0 (50)	3.1 (89)	**5.9 (96)**
Waiau (94)	–0.7 (95)	–0.1 (64)	0.4 (99)	–1.0 (80)	1.4 (92)	**3.0 (98)**	0.9 (70)	0.0 (50)	2.3 (91)	0.0 (50)	**5.8 (96)**	2.7 (80)
Waitekauri (100)	0.1 (69)	0.0 (60)	0.0 (51)	**–1.5 (97)**	**4.8 (99)**	0.3 (62)	**1.8 (96)**	0.0 (50)	1.0 (68)	0.0 (50)	**7.2 (96)**	0.5 (59)
Waiwawa (95)	–0.4 (79)	–0.1 (69)	–0.2 (75)	1.0 (83)	**3.1 (99)**	**3.9 (99)**	0.4 (65)	0.0 (50)	–0.3 (66)	0.0 (50)	**5.0 (97)**	2.9 (83)
Wharekawa (97)	–0.2 (71)	0.0 (55)	–0.3 (99)	**–1.8 (97)**	**3.4 (99)**	–0.2 (69)	–1.8 (94)	0.0 (50)	**1.7 (95)**	0.0 (50)	4.2 (87)	0.8 (56)

Appendix 2 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate–N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
Hauraki												
1991–2020												
Mangawhero (32)	0.0 (60)	−0.1 (99)	0.3 (99)	0.6 (98)	−0.6 (95)	0.1 (87)	0.3 (99)	0.0 (50)	−0.5 (99)	−0.2 (92)	−1.8 (86)	−1.4 (81)
Oraka (35)	0.0 (76)	−0.1 (99)	1.0 (99)	1.8 (99)	−0.8 (99)	0.8 (99)	0.8 (99)	0.6 (88)	−0.6 (99)	−0.8 (99)	−3.1 (98)	1.1 (88)
Piako (83)	0.1 (81)	−0.2 (98)	0.3 (99)	−1.3 (99)	0.7 (99)	−0.7 (99)	−0.5 (98)	−5.0 (99)	−2.2 (99)	−2.0 (99)	−0.4 (59)	2.5 (99)
Piako (79)	0.0 (65)	0.1 (99)	0.6 (99)	−0.6 (94)	0.3 (82)	−1.0 (99)	−1.0 (99)	−3.3 (99)	−0.9 (99)	−0.7 (99)	−0.4 (62)	3.7 (99)
Piakonui (82)	0.1 (87)	−0.1 (99)	0.0 (84)	−0.8 (99)	1.6 (99)	−0.2 (91)	0.0 (57)	0.0 (50)	−2.0 (99)	−1.6 (99)	−2.2 (99)	−0.5 (73)
Waihou (33)	−0.1 (99)	0.0 (75)	0.6 (99)	1.2 (99)	−0.7 (99)	1.0 (99)	1.0 (99)	−0.1 (63)	−0.5 (99)	−0.7 (99)	2.1 (96)	2.3 (99)
Waihou (3)	−0.2 (99)	−0.2 (99)	0.5 (99)	0.4 (94)	0.9 (99)	0.6 (99)	0.6 (99)	0.0 (56)	−0.1 (89)	−0.3 (99)	1.4 (89)	–
Waihou (37)	0.0 (90)	−0.2 (99)	0.4 (99)	0.9 (99)	−0.4 (99)	1.8 (99)	1.9 (99)	0.0 (50)	−0.5 (99)	−0.6 (99)	3.6 (99)	2.8 (99)
Waiohotu (36)	0.4 (99)	−0.1 (99)	−0.1 (98)	0.7 (99)	–	0.7 (99)	0.1 (86)	0.0 (50)	−0.5 (99)	−2.4 (99)	−4.3 (99)	3.1 (99)
Waiomou (34)	−0.1 (90)	0.0 (96)	0.3 (99)	1.6 (99)	−0.7 (99)	1.2 (99)	1.2 (99)	−0.1 (65)	−0.7 (99)	−2.0 (99)	1.9 (99)	2.0 (99)
Waitakaruru (31)	0.2 (99)	−0.2 (99)	0.9 (99)	−1.5 (99)	2.1 (99)	−1.3 (99)	−1.4 (99)	−3.0 (99)	−1.6 (99)	−1.4 (99)	−1.5 (88)	0.9 (85)
Waitoa (81)	0.1 (76)	0.1 (99)	0.5 (99)	−0.5 (96)	−0.2 (79)	0.0 (58)	0.1 (65)	−3.3 (99)	−1.9 (99)	−2.0 (99)	1.3 (88)	1.3 (84)
Waitoa (80)	−0.2 (99)	0.3 (99)	0.1 (92)	1.2 (99)	−1.1 (99)	−0.5 (99)	−0.3 (98)	−2.5 (99)	−10.9 (99)	−16.8 (99)	0.3 (59)	1.4 (98)
2011–2020												
Mangawhero (32)	0.8 (96)	0.2 (92)	0.5 (99)	−1.0 (81)	−2.3 (97)	−0.6 (73)	−1.1 (97)	0.0 (50)	1.1 (99)	−1.5 (99)	0.3 (58)	2.0 (72)
Oraka (35)	0.4 (90)	0.2 (87)	1.1 (99)	1.6 (81)	0.6 (78)	0.9 (99)	0.6 (99)	3.2 (91)	5.5 (99)	4.4 (99)	10.0 (99)	10.7 (99)
Piako (83)	−1.0 (93)	0.4 (85)	0.2 (92)	−1.1 (89)	4.0 (99)	−0.4 (71)	−0.3 (72)	0.0 (50)	−3.2 (99)	−7.2 (99)	10.0 (99)	9.2 (99)
Piako (79)	−0.6 (92)	−0.2 (71)	0.3 (87)	2.9 (96)	−1.8 (88)	0.5 (65)	0.8 (76)	3.8 (98)	−3.2 (98)	−6.7 (99)	14.2 (98)	14.0 (99)
Piakonui (82)	−0.6 (86)	0.2 (99)	0.0 (56)	−1.0 (80)	1.4 (90)	0.7 (89)	2.2 (99)	0.0 (50)	0.0 (54)	−2.1 (99)	2.3 (81)	1.7 (77)
Waihou (33)	−0.9 (99)	0.2 (93)	0.6 (99)	−0.2 (57)	−0.2 (66)	1.0 (99)	1.4 (99)	4.7 (99)	2.6 (99)	1.1 (94)	6.5 (99)	5.1 (99)
Waihou (3)	−1.2 (99)	−0.7 (99)	0.4 (97)	−1.3 (87)	3.4 (99)	1.9 (99)	1.2 (99)	7.6 (99)	1.4 (98)	4.1 (99)	2.7 (85)	–
Waihou (37)	−0.3 (99)	−0.4 (99)	0.6 (99)	0.8 (70)	0.6 (88)	2.2 (99)	2.2 (99)	0.0 (50)	0.0 (60)	−0.9 (99)	14.0 (99)	10.3 (99)
Waiohotu (36)	0.4 (77)	0.2 (93)	−0.2 (94)	−1.8 (95)	–	2.1 (99)	2.2 (99)	0.0 (50)	0.5 (83)	−2.0 (99)	−0.5 (59)	8.3 (98)
Waiomou (34)	−0.9 (99)	0.4 (99)	0.2 (96)	0.5 (71)	0.3 (68)	1.3 (99)	2.4 (99)	0.8 (91)	−0.1 (52)	−3.1 (99)	5.0 (99)	2.9 (97)
Waitakaruru (31)	−0.4 (79)	0.1 (67)	−0.4 (85)	−0.8 (78)	3.4 (99)	−1.5 (91)	−0.2 (67)	1.3 (94)	−1.4 (88)	−6.1 (99)	2.3 (84)	1.5 (69)
Waitoa (81)	−0.7 (95)	0.4 (98)	0.6 (99)	0.1 (56)	3.2 (99)	0.5 (73)	1.0 (92)	0.7 (77)	−1.0 (84)	−4.2 (99)	11.2 (99)	7.2 (99)
Waitoa (80)	−0.3 (66)	−0.2 (76)	1.2 (99)	3.6 (95)	−1.9 (88)	0.7 (85)	0.9 (84)	2.4 (94)	2.1 (93)	−1.8 (88)	15.3 (99)	7.6 (99)

Appendix 2 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												
1991–2020												
Hinemaiaia (55)	0.1 (79)	−0.1 (99)	0.1 (92)	0.7 (99)	−0.7 (99)	**1.6 (99)**	0.8 (99)	0.0 (50)	−0.7 (99)	−0.9 (99)	−0.9 (69)	**3.8 (99)**
Kuratau (58)	0.6 (99)	−0.1 (99)	0.1 (99)	0.4 (95)	−0.3 (85)	**2.5 (99)**	**2.6 (99)**	0.0 (50)	−0.9 (99)	0.0 (50)	–	–
Kuratau (101)	0.3 (99)	−0.1 (99)	0.0 (50)	**1.2 (99)**	–	**1.4 (99)**	**1.7 (99)**	0.0 (50)	**−1.3 (99)**	**−1.8 (99)**	1.6 (89)	0.8 (87)
Mapara (53)	0.2 (99)	0.0 (78)	0.5 (99)	−0.3 (94)	−0.1 (74)	0.6 (99)	0.8 (99)	**−1.6 (99)**	**−1.0 (99)**	−0.6 (99)	0.7 (73)	0.9 (78)
Tauranga–Taup (56)	0.5 (99)	−0.2 (99)	−0.2 (99)	**1.1 (99)**	−0.6 (99)	**1.0 (99)**	0.4 (99)	0.0 (50)	−0.9 (99)	**−1.2 (99)**	–	–
Tokaanu (57)	0.1 (99)	−0.2 (99)	0.2 (99)	**2.1 (99)**	–	0.9 (99)	**1.0 (99)**	0.0 (50)	−0.1 (96)	−0.1 (89)	–	–
Tokaanu Pwr (103)	0.4 (99)	0.1 (96)	−0.1 (88)	**1.4 (99)**	–	0.6 (87)	0.3 (71)	0.0 (50)	**−1.4 (99)**	**−2.0 (99)**	–	–
Tongariro (5)	0.2 (99)	0.0 (99)	0.0 (66)	0.0 (53)	**1.0 (99)**	0.7 (99)	**1.0 (99)**	0.6 (93)	0.1 (87)	0.3 (99)	0.8 (75)	–
Waihaha (59)	0.7 (99)	0.0 (94)	0.1 (99)	0.9 (99)	**−1.5 (99)**	0.4 (99)	−0.6 (99)	0.0 (50)	0.1 (67)	−0.6 (99)	1.2 (82)	2.0 (91)
Waitahanui (54)	0.1 (98)	−0.1 (99)	0.4 (99)	**1.7 (99)**	−0.9 (99)	**1.4 (99)**	**1.3 (99)**	0.0 (50)	−0.6 (99)	−0.7 (99)	**−3.4 (95)**	0.9 (80)
Whanganui (104)	0.2 (82)	−0.2 (99)	−0.2 (96)	0.7 (93)	–	−0.9 (99)	**−1.1 (99)**	0.0 (50)	**−1.3 (99)**	**−2.4 (99)**	0.5 (58)	0.7 (61)
Whareroa (102)	−0.4 (99)	−0.1 (99)	−0.1 (99)	**1.1 (98)**	–	0.3 (99)	0.5 (99)	0.0 (50)	−0.9 (99)	**−1.1 (99)**	0.6 (64)	−0.5 (52)
2011–2020												
Hinemaiaia (55)	−0.2 (72)	0.1 (74)	0.1 (64)	−2.0 (93)	**2.7 (99)**	**2.5 (99)**	**4.0 (99)**	0.0 (50)	0.1 (57)	**−1.3 (99)**	**7.3 (99)**	**7.8 (99)**
Kuratau (58)	0.5 (89)	0.0 (53)	−0.5 (99)	−1.5 (89)	**2.8 (99)**	1.7 (88)	2.4 (87)	0.0 (50)	2.6 (88)	0.0 (50)	**12.8 (99)**	**13.7 (99)**
Kuratau (101)	0.0 (50)	−0.1 (80)	0.2 (74)	1.3 (94)	–	−0.4 (79)	0.0 (50)	0.0 (50)	0.0 (50)	0.0 (50)	**9.7 (99)**	**8.3 (99)**
Mapara (53)	0.3 (87)	0.1 (66)	0.3 (99)	0.9 (84)	**−2.7 (99)**	−0.7 (99)	−0.7 (99)	**1.6 (98)**	−0.1 (71)	−0.9 (99)	**12.6 (99)**	**7.8 (99)**
Tauranga–Taup (56)	0.9 (97)	−0.1 (82)	0.0 (54)	−0.4 (56)	1.4 (94)	−1.3 (88)	**−2.5 (99)**	0.0 (50)	**1.7 (99)**	0.2 (76)	**8.2 (99)**	**11.3 (99)**
Tokaanu (57)	−0.1 (93)	−0.2 (95)	0.2 (99)	−3.3 (86)	–	0.0 (50)	0.0 (50)	0.0 (50)	0.6 (99)	−0.8 (99)	**10.9 (99)**	3.9 (89)
Tokaanu Pwr (103)	0.9 (90)	−0.2 (76)	0.4 (96)	−1.9 (93)	–	1.2 (86)	**4.5 (95)**	0.0 (50)	0.5 (74)	0.0 (50)	**11.6 (99)**	**14.5 (99)**
Tongariro (5)	1.3 (95)	0.0 (59)	**1.5 (99)**	0.0 (51)	0.2 (64)	0.3 (76)	−2.6 (92)	**5.4 (99)**	0.5 (87)	−0.6 (94)	**7.7 (99)**	–
Waihaha (59)	0.4 (71)	0.1 (69)	−0.3 (97)	−0.3 (64)	1.6 (93)	−0.2 (58)	**−3.3 (99)**	0.0 (50)	−0.5 (73)	**−2.6 (99)**	**10.9 (99)**	3.9 (90)
Waitahanui (54)	−0.1 (60)	0.0 (50)	0.2 (99)	1.6 (80)	**1.5 (96)**	**−1.3 (99)**	−0.9 (99)	0.0 (50)	0.1 (63)	**−1.3 (99)**	0.5 (67)	1.4 (63)
Whanganui (104)	−0.5 (74)	0.1 (68)	0.2 (79)	0.7 (72)	–	**1.5 (97)**	1.0 (95)	0.0 (50)	1.2 (86)	−1.2 (85)	**9.6 (99)**	4.4 (87)
Whareroa (102)	−0.5 (78)	0.1 (75)	0 (64)	**2.3 (99)**	–	−0.2 (81)	−0.5 (91)	0.0 (50)	0.8 (98)	−0.2 (64)	**7.9 (99)**	**6.0 (98)**

Appendix 2 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												
1991–2020												
Kawaunui (48)	0.2 (99)	–0.1 (99)	1.1 (99)	–0.7 (97)	0.3 (89)	3.1 (99)	3.8 (99)	–2.2 (99)	–1.7 (99)	–1.2 (99)	–4.2 (94)	0.7 (78)
Mangaharakeke (43)	0.5 (99)	0.0 (73)	0.5 (99)	1.1 (99)	–0.7 (99)	4.7 (99)	6.3 (99)	–2.5 (99)	–0.3 (91)	–0.3 (97)	1.6 (98)	3.1 (99)
Mangakara (49)	0.0 (50)	–0.1 (99)	1.1 (99)	0.9 (99)	0.2 (76)	2.5 (99)	2.8 (99)	–0.4 (99)	–1.1 (99)	–1.2 (99)	0.8 (80)	1.8 (99)
Mangakino (60)	0.2 (99)	–0.1 (99)	0.6 (99)	1.4 (99)	–0.9 (99)	2.4 (99)	2.7 (99)	0.0 (50)	–0.3 (99)	–0.5 (99)	–	–
Otamakokore (46)	0.0 (72)	0.0 (73)	0.4 (99)	0.9 (99)	–0.2 (86)	1.8 (99)	2.2 (99)	–0.4 (99)	–0.4 (99)	–0.1 (89)	1.4 (90)	2.2 (99)
Pueto (52)	0.2 (99)	–0.1 (99)	0.4 (99)	1.3 (99)	–0.1 (67)	2.3 (99)	2.3 (99)	–3.0 (99)	–0.9 (99)	–0.6 (99)	0.8 (74)	3.2 (99)
Tahunaatara (44)	0.2 (99)	–0.1 (99)	0.6 (99)	1.1 (99)	–1.0 (99)	2.1 (99)	2.5 (99)	–0.1 (97)	0.0 (57)	–0.3 (99)	2.5 (98)	2.5 (96)
Torepatutahi (51)	0.2 (99)	–0.1 (80)	0.7 (99)	0.8 (99)	–	3.1 (99)	3.6 (99)	0.0 (50)	–0.6 (99)	–0.3 (99)	–	–
Waiotapu (47)	–0.2 (99)	0.1 (99)	0.3 (99)	0.9 (99)	0.0 (58)	1.3 (99)	2.2 (99)	0.6 (99)	–2.0 (99)	0.0 (99)	3.7 (98)	2.2 (86)
Waiotapu (50)	–0.2 (99)	0.0 (85)	0.3 (99)	1.0 (99)	0.8 (98)	1.0 (99)	1.1 (99)	0.1 (73)	–1.1 (99)	–1.2 (99)	–	–
Waipapa (42)	0.1 (99)	0.0 (54)	1.3 (99)	–0.6 (98)	0.4 (99)	4.2 (99)	4.7 (99)	0.0 (50)	–0.2 (96)	0.9 (99)	0.7 (80)	2.7 (99)
Whirinaki (45)	0.1 (95)	0.0 (96)	0.4 (99)	0.4 (71)	–	2.1 (99)	2.4 (99)	0.0 (50)	–0.6 (99)	–0.8 (99)	–	–
2011–2020												
Kawaunui (48)	0.8 (98)	0.0 (64)	0.9 (99)	–0.4 (67)	–1.4 (90)	1.7 (99)	2.1 (99)	1.3 (77)	–1.4 (98)	–2.9 (99)	16.8 (99)	15.0 (99)
Mangaharakeke (43)	0.1 (74)	0.1 (85)	0.4 (99)	3.6 (99)	–1.4 (99)	3.1 (99)	2.6 (99)	0.2 (99)	1.5 (97)	–2.0 (99)	9.2 (99)	10.8 (99)
Mangakara (49)	0.3 (80)	0.0 (50)	1.0 (99)	0.9 (78)	–1.7 (91)	2.3 (99)	2.4 (99)	2.3 (95)	–0.2 (70)	–1.9 (99)	14.0 (99)	4.0 (99)
Mangakino (60)	–0.2 (64)	0.0 (61)	0.1 (78)	0.2 (55)	0.1 (57)	2.2 (99)	2.0 (99)	0.0 (50)	0.4 (86)	–1.4 (99)	13.2 (99)	9.0 (97)
Otamakokore (46)	–0.3 (77)	–0.6 (99)	0.0 (54)	–1.1 (84)	1.5 (89)	1.8 (99)	1.7 (99)	0.0 (50)	1.2 (99)	–1.4 (99)	11.0 (99)	12.2 (99)
Pueto (52)	–0.1 (57)	0.1 (75)	0.4 (99)	–0.5 (68)	0.2 (60)	4.3 (99)	4.9 (99)	–0.5 (98)	–1.3 (99)	–2.8 (99)	8.2 (99)	15.8 (99)
Tahunaatara (44)	–0.1 (55)	–0.1 (61)	0.7 (99)	1.1 (86)	–1.8 (99)	3.5 (99)	4.1 (99)	0.0 (50)	2.5 (99)	0.7 (83)	12.7 (99)	6.3 (99)
Torepatutahi (51)	0.1 (71)	–0.5 (95)	0.7 (98)	–2.6 (94)	–	2.9 (99)	2.7 (99)	0.0 (50)	–0.3 (78)	–1.5 (99)	23.5 (99)	14.9 (99)
Waiotapu (47)	–0.2 (85)	0.1 (82)	0.3 (88)	0.9 (88)	–1.5 (97)	0.4 (96)	1.2 (99)	0.2 (60)	–2.3 (94)	0.0 (50)	13.7 (99)	12.8 (99)
Waiotapu (50)	–0.2 (72)	–0.6 (98)	0.0 (55)	0.2 (59)	–	1.2 (99)	1.6 (99)	–1.3 (89)	0.1 (61)	–1.8 (97)	17.6 (99)	14.0 (99)
Waipapa (42)	–0.3 (89)	–0.1 (63)	1.0 (99)	–3.3 (99)	1.9 (99)	2.8 (99)	3.2 (99)	0.0 (50)	–0.1 (53)	–2.6 (99)	6.5 (99)	3.7 (94)
Whirinaki (45)	0.3 (92)	0.2 (96)	0.3 (99)	–1.0 (73)	–	1.1 (99)	1.0 (99)	0.0 (50)	–0.1 (60)	–1.1 (99)	12.5 (99)	20.8 (99)

Appendix 2 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 1991–2020												
Awaroa–Otaua (27)	0.1 (92)	–0.3 (99)	0.3 (99)	2.0 (99)	–1.4 (99)	0.7 (99)	1.0 (99)	0.2 (63)	0.1 (60)	–3.1 (99)	–	–
Awaroa–Rotowar (7)	0.5 (99)	–0.2 (99)	2.7 (99)	0.0 (52)	–0.5 (93)	1.0 (99)	1.6 (99)	1.3 (99)	–1.6 (99)	0.0 (50)	–2.6 (99)	–0.5 (70)
Karapiro (85)	–0.1 (82)	–0.3 (99)	0.4 (99)	2.0 (99)	–1.8 (99)	1.0 (99)	1.1 (99)	0.1 (68)	–0.8 (99)	–1.1 (99)	–1.3 (81)	0.3 (61)
Kirikiriroa (90)	0.1 (88)	0.1 (94)	–0.5 (99)	–1.8 (99)	1.2 (99)	–3.3 (99)	–1.6 (99)	–6.7 (99)	–2.6 (99)	–1.7 (99)	–2.0 (98)	–0.3 (56)
Komakorau (6)	0.3 (99)	–0.2 (99)	0.4 (99)	1.1 (99)	–0.2 (97)	–0.3 (99)	0.0 (50)	–1.9 (99)	–0.5 (99)	–2.8 (99)	0 (50)	2.5 (99)
Little Waipa (38)	0.0 (74)	0.0 (78)	1.0 (99)	2.1 (99)	–1.2 (99)	2.4 (99)	2.3 (99)	–0.2 (75)	0.0 (57)	–0.4 (99)	2.2 (98)	1 (87)
Mangakotukutu (87)	0.1 (95)	–0.1 (99)	0.3 (99)	–1.1 (99)	1.2 (99)	–0.7 (99)	–0.8 (99)	–2.1 (99)	0.7 (99)	2.3 (99)	–2.4 (91)	1.4 (80)
Mangamingi (40)	0.0 (65)	–0.1 (99)	–0.2 (99)	3.2 (99)	–2.1 (99)	0.2 (88)	0.3 (94)	0.4 (64)	–4.5 (99)	–5.1 (99)	2.2 (90)	1 (90)
Mangaone (77)	0.4 (99)	0.4 (99)	0.3 (99)	0.5 (97)	–0.6 (99)	–1.1 (99)	–1.3 (99)	–3.5 (99)	–1.3 (99)	–0.7 (99)	–1.6 (96)	3.7 (99)
Mangaonua (78)	0.2 (98)	0.1 (99)	0.6 (99)	–0.2 (76)	–0.2 (80)	–0.1 (83)	0.1 (70)	–0.9 (99)	–1 (99)	–2.3 (99)	1.1 (77)	5.6 (99)
Mangaonua (84)	0.3 (99)	–0.1 (99)	0.3 (99)	–0.7 (99)	0.3 (88)	–0.8 (99)	–0.6 (99)	–6.7 (99)	–3.6 (99)	–4.7 (99)	–3.8 (99)	1.5 (97)
Mangatangi (30)	0.2 (99)	0.0 (75)	0.0 (63)	4.4 (99)	–5.1 (99)	–0.6 (99)	–1.2 (99)	1.1 (98)	–0.2 (84)	–1.9 (99)	–	–
Mangatawhiri (29)	–0.1 (85)	–0.2 (99)	0.3 (99)	0.0 (55)	–0.3 (84)	–0.7 (99)	–2.0 (99)	0.0 (50)	–0.4 (94)	–0.4 (92)	–	–
Mangawara (19)	0.2 (99)	0.2 (99)	0.5 (99)	0.9 (99)	–0.5 (98)	0.0 (54)	0.0 (56)	–0.1 (64)	–0.2 (84)	–0.1 (65)	–	–
Mangawhero (86)	0.3 (99)	0.1 (97)	0.6 (99)	0.9 (99)	–0.9 (99)	0.1 (71)	0.2 (84)	–2.0 (99)	–0.9 (99)	–0.1 (62)	–0.2 (60)	1.7 (98)
Matahuru (20)	0.4 (99)	–0.2 (99)	0.2 (99)	2.1 (99)	–1.6 (99)	–0.7 (99)	–1.5 (99)	–0.3 (83)	–0.1 (61)	–1.5 (99)	–	–
Ohaeroa (25)	0.1 (84)	–0.2 (99)	0.3 (99)	0.1 (66)	0.6 (98)	1.7 (99)	1.9 (99)	–1.3 (99)	–0.9 (99)	0.1 (68)	–	–
Opuatia (24)	0.1 (88)	–0.2 (99)	0.5 (99)	2.7 (99)	–2.9 (99)	1.0 (99)	1.1 (99)	–1.3 (99)	0.1 (68)	–1.9 (99)	–1.2 (82)	2.6 (99)
Pokaiwhenua (39)	0 (77)	–0.1 (94)	0.9 (99)	2.5 (99)	–1.3 (99)	1.9 (99)	1.8 (99)	–0.2 (88)	–1.5 (99)	–2.0 (99)	2.5 (97)	3.3 (99)
Waerenga (21)	0.5 (99)	–0.2 (99)	0.2 (99)	2.2 (99)	–1.6 (99)	0.8 (99)	0.7 (99)	0.4 (95)	–0.1 (66)	–1.1 (99)	1.1 (89)	2.8 (99)
Waitawhiriwhiri (89)	0.2 (99)	–0.1 (98)	0.0 (60)	0.0 (56)	0.1 (68)	–0.5 (99)	0.2 (85)	–1.6 (99)	–1.4 (99)	–0.9 (97)	–1.3 (84)	0.9 (79)
Whakapipi (26)	0.3 (99)	0.2 (99)	0.8 (99)	–1.4 (99)	1.2 (99)	1.0 (99)	1.1 (99)	–2.3 (99)	1.0 (99)	3.8 (99)	–	–
Whakauru (41)	–0.1 (81)	–0.1 (99)	1.0 (99)	5.5 (99)	–3.8 (99)	10 (99)	18.6 (99)	0.8 (99)	3.6 (99)	2.7 (99)	5.0 (99)	4.6 (99)
Whangamarino (28)	0.5 (99)	0.5 (98)	0.3 (99)	–2.3 (99)	0.3 (83)	2.0 (99)	–1.5 (99)	1.8 (98)	–0.3 (92)	–2.7 (99)	–	–
Whangamarino (22)	0.4 (99)	–0.1 (99)	0.2 (99)	2.8 (99)	–2.4 (99)	–0.7 (99)	–1.3 (99)	–0.1 (62)	0.7 (99)	–0.2 (79)	–	–
Whangape (23)	0.1 (92)	0.0 (55)	0.7 (99)	6.6 (99)	–4.7 (99)	3.5 (99)	0.0 (50)	0.0 (50)	2.6 (99)	0.0 (50)	–	–

Appendix 2 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 2011–2020												
Awaroa–Otaua (27)	−0.7 (97)	−0.4 (84)	0.1 (65)	**−4.7 (99)**	**5.0 (99)**	**1.8 (98)**	**2.9 (99)**	2.0 (87)	**−4.0 (99)**	**−3.1 (99)**	0.9 (67)	−2.4 (82)
Awaroa–Rotowar (7)	0.2 (72)	0.2 (83)	−0.2 (62)	**−7.5 (99)**	**5.1 (99)**	**−4.9 (99)**	**−6.6 (99)**	1.8 (76)	**−3.7 (99)**	0.0 (50)	−1.1 (65)	−0.9 (63)
Karapiro (85)	−0.3 (65)	−0.3 (89)	**1.1 (99)**	0.2 (59)	**2.1 (96)**	0.5 (85)	0.3 (69)	**3.5 (97)**	**2.1 (99)**	−1.1 (89)	−2.3 (66)	2.2 (84)
Kirikiriroa (90)	−0.1 (61)	0.9 (99)	−0.5 (98)	**−1.7 (97)**	**3.2 (99)**	**−2.5 (99)**	**−2.9 (99)**	**−2.3 (96)**	−0.6 (72)	**−7.5 (99)**	1.3 (67)	−2.5 (66)
Komakorau (6)	0.0 (50)	**1.2 (99)**	0.1 (80)	**3.3 (99)**	**−4.7 (99)**	0.7 (78)	−0.2 (53)	−0.4 (70)	**2.1 (98)**	**−6.3 (99)**	**6.8 (99)**	**5.9 (99)**
Little Waipa (38)	0.0 (55)	−0.5 (97)	0.9 (99)	−0.7 (70)	**4.8 (99)**	**2.1 (99)**	**2.8 (99)**	−0.8 (86)	−1.2 (86)	**−1.7 (99)**	**8.4 (99)**	**7.1 (99)**
Mangakotukutu (87)	−0.1 (56)	−0.2 (92)	0.4 (97)	−1.3 (87)	1.7 (92)	0.6 (78)	0.3 (70)	**1.4 (95)**	1.3 (90)	0.0 (51)	**7.7 (97)**	5.9 (88)
Mangamingi (40)	0.2 (63)	−0.3 (93)	−0.3 (95)	**2.8 (98)**	−1.5 (88)	**−1.1 (98)**	**−1.7 (99)**	−1.2 (69)	**−3.4 (99)**	**−5.7 (99)**	**9.2 (98)**	**5.8 (97)**
Mangaone (77)	0.6 (83)	−0.3 (90)	0.3 (99)	1.4 (93)	**−2.5 (98)**	**−1.7 (99)**	**−2.2 (99)**	**2.7 (99)**	**1.5 (97)**	**−1.0 (97)**	2.3 (80)	**9.4 (99)**
Mangaonua (78)	0.2 (72)	0.2 (76)	0.2 (86)	**2.3 (99)**	−1.9 (93)	−0.5 (94)	**−1.0 (99)**	0.5 (68)	**3.9 (99)**	**−3.5 (99)**	**5.3 (96)**	**15.8 (99)**
Mangaonua (84)	−0.2 (61)	0.1 (81)	0.4 (98)	−0.2 (57)	0.8 (81)	0.5 (86)	0.6 (80)	0.0 (50)	0.9 (80)	**−2.0 (95)**	4.8 (94)	3.9 (89)
Mangatangi (30)	−0.2 (63)	−0.3 (86)	0.7 (99)	0.9 (76)	**−3.3 (99)**	**1.7 (98)**	**1.7 (95)**	**12.3 (99)**	0.4 (74)	**−4.2 (99)**	**9.5 (99)**	3.0 (83)
Mangatawhiri (29)	−0.7 (88)	−0.2 (80)	0.3 (98)	1.5 (86)	1.8 (89)	0.2 (59)	**2.8 (99)**	0.0 (50)	0.2 (67)	**−2.4 (99)**	**9.5 (99)**	6.8 (93)
Mangawara (19)	−0.3 (73)	−0.7 (97)	0.7 (99)	**2.2 (98)**	**−4.3 (98)**	**2.1 (99)**	**2.9 (99)**	**4.5 (99)**	0.8 (86)	−1.6 (93)	**12.3 (99)**	3.4 (88)
Mangawhero (86)	0.0 (53)	0.3 (99)	−0.2 (87)	**−1.5 (99)**	−1.6 (84)	−0.6 (88)	−1.1 (86)	**1.6 (97)**	**−1.2 (95)**	**−3.3 (98)**	**6.8 (99)**	−2.5 (83)
Matahuru (20)	0.5 (89)	−0.2 (82)	0.3 (95)	−1.0 (83)	**5.7 (97)**	−0.4 (69)	**−2.1 (96)**	**3.2 (99)**	**−1.6 (97)**	**−3.9 (99)**	**10.7 (99)**	**7.0 (99)**
Ohaeroa (25)	−0.3 (81)	−0.3 (92)	0.3 (98)	2.1 (92)	0.5 (67)	**1.6 (99)**	**1.6 (99)**	**5.4 (99)**	0.6 (76)	**−2.4 (97)**	**5.9 (99)**	−1.2 (71)
Opuatia (24)	−0.6 (96)	0.0 (58)	0.8 (99)	−2.3 (91)	−0.7 (72)	0.0 (51)	0.9 (86)	−0.2 (57)	**−2.4 (98)**	0.1 (57)	−2.9 (83)	−2.7 (80)
Pokaiwhenua (39)	0.2 (67)	−0.6 (99)	**1.0 (99)**	2.6 (91)	0.3 (71)	**1.8 (99)**	**2.0 (99)**	2.4 (77)	0.5 (86)	**−1.1 (99)**	**12.7 (99)**	**12.7 (99)**
Waerenga (21)	**1.1 (97)**	−0.3 (96)	0.4 (99)	−0.7 (74)	0.9 (76)	**−1.4 (99)**	**−1.9 (99)**	**3.8 (96)**	−1.7 (90)	−1.8 (91)	**8.7 (99)**	**9.5 (99)**
Waitawhiriwhiri (89)	−0.3 (74)	−0.2 (83)	−0.1 (57)	0.7 (70)	−1.4 (91)	−0.6 (91)	**−1.1 (97)**	−0.1 (54)	−0.3 (66)	**−5.7 (99)**	**9.0 (98)**	3.3 (87)
Whakapipi (26)	−0.2 (64)	0.4 (99)	0.4 (97)	**−3.3 (99)**	**7.1 (99)**	0.9 (93)	**1.4 (97)**	1.7 (92)	0.0 (53)	−0.8 (64)	−2.1 (76)	−5.3 (94)
Whakauru (41)	**1.1 (98)**	−0.2 (89)	**2.4 (99)**	**6.8 (99)**	**−7.2 (99)**	**17.1 (99)**	**25.1 (99)**	**3.8 (98)**	**8.2 (99)**	**6.4 (99)**	**6.4 (99)**	**10.2 (98)**
Whangamarino (28)	0.7 (93)	−0.1 (51)	0.6 (99)	**−2.9 (99)**	0.3 (61)	0.9 (90)	4.2 (93)	6.7 (88)	**−2.8 (99)**	**−4.7 (99)**	0.6 (61)	−0.6 (54)
Whangamarino (22)	0.9 (97)	−0.2 (73)	0.2 (80)	**4.0 (99)**	**−4.7 (99)**	−0.9 (79)	**−2.2 (98)**	**3.7 (99)**	0.4 (71)	**−2.5 (99)**	**6.2 (98)**	2.2 (68)
Whangape (23)	0.7 (98)	−0.3 (67)	**1.2 (99)**	0.9 (79)	**−5.3 (99)**	−0.1 (56)	0.0 (50)	0.0 (50)	0.8 (77)	0.0 (50)	**−9.9 (99)**	−0.6 (68)

Appendix 2 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												
1991–2020												
Kaniwhaniwha (11)	0.4 (99)	−0.1 (99)	0.2 (99)	0.6 (90)	−0.9 (99)	0.3 (98)	0.3 (87)	−0.6 (97)	−0.3 (76)	−0.2 (70)	–	–
Mangaohoi (74)	0.2 (99)	0.0 (84)	−0.1 (98)	−0.7 (96)	0.8 (99)	−1.1 (99)	−1.7 (99)	−0.8 (99)	−0.8 (99)	−0.8 (99)	1.5 (69)	0.4 (66)
Mangaokewa (65)	0.2 (96)	−0.1 (99)	0.5 (99)	1.0 (99)	−0.2 (80)	1.2 (99)	1.9 (99)	−3.9 (99)	−0.8 (99)	−0.7 (99)	–	–
Mangapiko (76)	0.2 (94)	0.3 (99)	0.2 (99)	1.2 (99)	−0.7 (99)	−0.6 (99)	−1.0 (99)	−4.0 (99)	−1.8 (99)	−2.5 (99)	–	–
Mangapu (63)	0.0 (52)	−0.2 (99)	0.6 (99)	0.3 (95)	−0.3 (82)	0.6 (99)	0.9 (99)	−2.1 (99)	−1.9 (99)	−1.5 (99)	2.4 (95)	1.9 (96)
Mangatutu (73)	0.2 (98)	0.0 (68)	0.4 (99)	0.4 (95)	−0.3 (86)	1.1 (99)	1.2 (99)	−1.3 (99)	−0.5 (97)	−0.6 (99)	−1.8 (90)	−1.0 (88)
Mangauika (13)	0.4 (99)	−0.1 (99)	0.1 (95)	1.6 (99)	0.7 (99)	2.1 (99)	2.3 (99)	0.0 (50)	−0.1 (59)	−1.8 (99)	0.2 (54)	1.1 (81)
Ohote (88)	0.1 (85)	0.4 (99)	−0.1 (93)	1.2 (99)	−1.8 (99)	−0.7 (99)	−1.2 (99)	0.6 (96)	−0.1 (60)	0.3 (91)	3.3 (99)	2.9 (99)
Puniu (75)	0.0 (57)	−0.3 (99)	0.5 (99)	3.3 (99)	−2.5 (99)	1.5 (99)	1.5 (99)	1.0 (99)	0.3 (92)	−0.5 (99)	–	–
Waipa (61)	0.4 (99)	0 (77)	0.4 (99)	−0.2 (75)	−0.2 (84)	0.8 (99)	1.3 (99)	0.1 (96)	−1.0 (99)	−2.1 (99)	–	–
Waipa (12)	0.1 (74)	−0.1 (99)	0.4 (99)	0.9 (99)	−1.3 (99)	0.9 (99)	0.9 (99)	−0.7 (96)	−1.1 (99)	−1.1 (99)	−0.3 (63)	2.7 (98)
Waipa (2)	0.2 (99)	0 (91)	0.2 (99)	−0.5 (93)	0.9 (99)	0.8 (99)	0.6 (99)	−0.1 (63)	−0.3 (92)	−0.1 (80)	−0.3 (61)	–
Waipa (64)	0.2 (96)	−0.1 (96)	0.3 (99)	−1.2 (99)	0.3 (94)	1.1 (99)	1.3 (99)	−1.1 (99)	−1.9 (99)	−1.4 (99)	0.5 (73)	−0.1 (54)
Waipa (1)	0.1 (81)	−0.1 (99)	0.3 (99)	2.4 (99)	−0.9 (99)	0.7 (99)	0.7 (99)	0.2 (80)	0.4 (99)	−1.2 (99)	2.6 (98)	–
Waitomo (18)	0.1 (87)	−0.3 (99)	0.3 (99)	0.8 (99)	−0.6 (99)	0.6 (99)	0.6 (99)	−0.7 (97)	−0.1 (75)	−0.4 (92)	−1.8 (86)	0.2 (59)
Waitomo (17)	0.1 (99)	−0.1 (99)	0.3 (99)	0.2 (76)	−0.3 (87)	0.4 (99)	0.6 (99)	−0.1 (99)	−0.4 (96)	0.3 (93)	−1.5 (90)	−0.3 (65)
2011–2020												
Kaniwhaniwha (11)	0.0 (57)	1.0 (99)	0.5 (99)	3.1 (91)	−1.6 (80)	1.9 (98)	3.0 (99)	0.8 (82)	0.8 (68)	−0.7 (65)	7.3 (92)	0.6 (67)
Mangaohoi (74)	0.1 (63)	0.0 (63)	−0.4 (96)	0.9 (78)	−2.0 (97)	−1.4 (99)	−2.5 (99)	0.0 (50)	−0.6 (93)	−2.5 (99)	−1.0 (70)	3.3 (76)
Mangaokewa (65)	0.3 (74)	−0.3 (95)	0.8 (99)	2.9 (99)	−2.5 (97)	1.5 (99)	1.8 (99)	5.1 (99)	1.3 (84)	−0.6 (80)	6.5 (97)	4.1 (96)
Mangapiko (76)	0.4 (89)	0.2 (86)	0.5 (89)	−0.5 (70)	−1.4 (77)	−0.5 (67)	0.2 (57)	−0.1 (54)	−4.6 (99)	−5.2 (99)	13.7 (99)	9.2 (99)
Mangapu (63)	0.1 (66)	−0.4 (99)	0.6 (99)	0.3 (59)	−1.6 (86)	0.3 (78)	0.8 (84)	−2.7 (99)	−2.4 (98)	−6.5 (99)	5.4 (97)	3.7 (92)
Mangatutu (73)	0.4 (79)	0.2 (89)	0.2 (64)	−1.7 (89)	2.0 (98)	−0.4 (58)	−0.9 (80)	0.0 (50)	−0.2 (53)	−0.6 (63)	2.5 (79)	0.6 (67)
Mangauika (13)	−0.3 (75)	−0.1 (61)	0.1 (79)	−7.1 (99)	2.6 (97)	−4.9 (99)	−5.5 (99)	0.0 (50)	−0.2 (55)	1.5 (95)	−8.8 (91)	−6.6 (92)
Ohote (88)	−0.1 (66)	0.4 (79)	1.5 (99)	3.2 (99)	−1.8 (90)	−0.5 (70)	0.0 (50)	2.8 (97)	2.2 (99)	−6.7 (99)	8.8 (99)	7.2 (99)
Puniu (75)	0.5 (78)	0.1 (73)	0.4 (97)	1.4 (88)	−1.2 (64)	1.5 (97)	1.7 (95)	3.4 (98)	1.0 (83)	−1.6 (99)	5.0 (95)	2.0 (56)
Waipa (61)	0.0 (50)	−0.1 (63)	0.3 (98)	1.3 (83)	1.9 (96)	−0.9 (93)	−1.0 (73)	0.3 (88)	1.5 (80)	−0.5 (63)	2.9 (85)	8.0 (94)
Waipa (12)	0.0 (53)	0.2 (92)	0.4 (99)	−0.3 (60)	2.0 (78)	1.6 (99)	1.0 (96)	2.0 (86)	−1.1 (79)	−3.0 (99)	2.9 (79)	2.8 (89)
Waipa (2)	0.0 (52)	0.2 (99)	0.4 (99)	4.9 (99)	−3.0 (99)	2.0 (99)	1.8 (93)	6.3 (99)	2.9 (99)	0.9 (90)	3.0 (80)	–
Waipa (64)	0.2 (68)	0.1 (71)	0.5 (96)	0.1 (56)	1.3 (90)	0.6 (81)	0.2 (57)	1.1 (92)	−0.4 (63)	−0.9 (74)	9.0 (99)	4.9 (96)
Waipa (1)	−0.2 (72)	0.0 (53)	0.3 (99)	4.2 (99)	−2.0 (92)	0.3 (82)	0.2 (62)	−0.1 (53)	0.6 (78)	−1.7 (98)	3.1 (95)	–
Waitomo (18)	0.6 (96)	−0.1 (68)	0.6 (99)	−0.1 (51)	−0.5 (66)	0.8 (93)	0.5 (84)	1.6 (85)	0.1 (55)	−0.7 (76)	10.3 (94)	0.7 (64)
Waitomo (17)	0.2 (79)	−0.3 (96)	0.3 (97)	−0.6 (78)	0.1 (60)	0.1 (61)	−0.1 (67)	0.0 (50)	0.0 (50)	−2.7 (99)	4.4 (96)	5.2 (96)

Appendix 2 continued

	Temperature	Dissolved oxygen	Conductivity	Turbidity	Visual clarity	Total nitrogen	Nitrate–N	Ammonia	Total phosphorus	Dissolved reactive P	*Escherichia coli*	Enterococci
West Coast												
1991–2020												
Awakino (70)	0.2 (97)	−0.1 (99)	0.0 (55)	**−1.2 (99)**	0.0 (57)	**−1.2 (99)**	**−2.0 (99)**	0.0 (50)	−0.8 (99)	−0.7 (99)	−1.5 (88)	−0.8 (79)
Awakino (69)	0.0 (60)	−0.1 (99)	0.5 (99)	**−1.3 (99)**	0.5 (96)	0.5 (99)	0.6 (99)	−0.7 (99)	**−1.0 (99)**	0.2 (80)	−1.3 (74)	0.5 (68)
Manganui (67)	0.1 (76)	−0.1 (99)	0.1 (99)	−0.2 (68)	0.1 (57)	0.1 (71)	−0.7 (99)	0.0 (50)	**−1.1 (99)**	−0.3 (92)	0.1 (53)	−1.1 (90)
Mangaotaki (66)	0.1 (94)	0.0 (97)	0.2 (99)	0.2 (82)	−0.1 (69)	0.8 (99)	0.7 (99)	**−2.9 (99)**	−0.7 (98)	−0.1 (61)	–	–
Marokopa (15)	0.2 (99)	−0.1 (99)	0.2 (99)	0.5 (94)	−0.4 (99)	0.8 (99)	0.7 (99)	0.0 (50)	−0.5 (99)	0.1 (73)	−0.8 (73)	0.9 (76)
Mokau (68)	0.1 (76)	0.0 (90)	0.4 (99)	**−1.3 (99)**	0.7 (99)	0.6 (99)	**1.0 (99)**	**−1.1 (99)**	**−2.3 (99)**	−0.5 (97)	**−2.3 (97)**	0.7 (72)
Mokau (62)	0.1 (89)	−0.2 (99)	0.5 (99)	0.8 (99)	−0.8 (99)	**1.9 (99)**	**2.4 (99)**	0.0 (50)	0.0 (50)	−0.3 (84)	−0.2 (52)	0.5 (73)
Mokau (71)	0.1 (80)	−0.1 (99)	0.4 (99)	−0.8 (99)	0.7 (99)	**1.0 (99)**	**1.1 (99)**	**−1.2 (99)**	**−1.1 (99)**	−0.1 (61)	−1.6 (94)	−0.1 (53)
Mokauiti (72)	0.0 (60)	−0.2 (99)	0.4 (99)	**−1.8 (99)**	**1.7 (99)**	0.7 (99)	0.7 (99)	−0.9 (99)	**−1.4 (99)**	−0.2 (66)	−2.2 (91)	0.1 (58)
Ohautira (9)	0.3 (99)	0.0 (60)	0.2 (99)	**−1.8 (99)**	**1.6 (99)**	0.4 (96)	0.8 (99)	**−1.1 (99)**	**−1.0 (99)**	−0.4 (99)	−0.4 (74)	**2.2 (99)**
Oparau (14)	0.2 (98)	−0.1 (99)	0.1 (94)	−0.3 (75)	−0.1 (60)	0.4 (94)	0.5 (97)	0.0 (50)	−0.8 (99)	**−1.2 (99)**	–	–
Tawarau (16)	0.2 (99)	−0.1 (99)	0.1 (99)	0.0 (56)	0.1 (61)	0.6 (99)	0.7 (99)	0.0 (50)	−0.6 (99)	0.0 (60)	–	–
Waingaro (8)	0.0 (62)	0.2 (99)	0.3 (99)	−0.1 (55)	−0.2 (84)	0.6 (99)	**1.0 (99)**	−0.6 (98)	**−1.0 (99)**	**−1.4 (99)**	–	–
Waitetuna (10)	0.2 (95)	0.0 (62)	0.2 (99)	0.1 (55)	−0.2 (80)	0.7 (99)	**1.1 (99)**	−0.8 (99)	−0.7 (99)	−0.6 (99)	**−2.1 (98)**	0.9 (93)
2011–2020												
Awakino (70)	0.1 (63)	−0.1 (83)	0.4 (99)	**2.6 (98)**	−0.3 (63)	0.8 (78)	−1.1 (90)	0.0 (50)	1.6 (92)	−0.2 (64)	1.2 (66)	−3.0 (83)
Awakino (69)	−0.2 (75)	−0.7 (99)	**1.4 (99)**	−0.9 (79)	1.2 (88)	0.0 (50)	**1.7 (96)**	0.0 (50)	0.8 (80)	0.3 (82)	1.5 (69)	0.6 (59)
Manganui (67)	−0.1 (62)	−0.4 (99)	0.4 (99)	−1.9 (85)	−1.2 (87)	0.4 (63)	−0.2 (60)	0.0 (50)	0.8 (60)	−1.0 (93)	2.9 (89)	3.0 (79)
Mangaotaki (66)	0.1 (56)	−0.3 (94)	0.5 (99)	0.1 (63)	−1.5 (92)	**1.5 (99)**	**1.8 (99)**	−0.1 (58)	**2.0 (96)**	−0.6 (61)	−0.8 (66)	0.3 (57)
Marokopa (15)	0.4 (75)	−0.2 (92)	0.1 (72)	1.4 (93)	0.5 (67)	**1.7 (99)**	0.8 (89)	0.0 (50)	0.2 (65)	**−1.4 (99)**	**8.8 (99)**	3.9 (95)
Mokau (68)	0.2 (76)	−0.2 (85)	**1.1 (99)**	−1.0 (73)	**−2.6 (99)**	**1.8 (99)**	**1.8 (98)**	3.6 (88)	−1.6 (91)	−0.3 (63)	2.2 (83)	1.7 (60)
Mokau (62)	0.4 (80)	−0.2 (92)	0.5 (99)	1.2 (85)	0.7 (76)	**3.2 (99)**	**5.2 (99)**	0.0 (50)	0.2 (54)	−1.7 (94)	**5.4 (99)**	**5.5 (99)**
Mokau (71)	0.1 (62)	−0.1 (67)	0.5 (99)	−0.4 (67)	0.8 (78)	**1.8 (99)**	**1.6 (99)**	**1.6 (97)**	1.7 (93)	−0.1 (54)	3.4 (82)	−0.3 (51)
Mokauiti (72)	0.1 (61)	−0.1 (77)	**1.3 (99)**	−2.4 (94)	0.3 (57)	**1.8 (99)**	**2.6 (99)**	0.5 (79)	0.2 (68)	**−2.8 (98)**	−3.4 (83)	0.1 (52)
Ohautira (9)	0.7 (92)	0.4 (99)	0.9 (99)	**−5.9 (99)**	**1.9 (96)**	−0.7 (84)	−0.7 (74)	0.0 (50)	0.0 (52)	−0.3 (66)	2.4 (79)	0.6 (64)
Oparau (14)	−0.1 (59)	−0.6 (99)	0.6 (99)	−1.2 (70)	1.7 (92)	−0.1 (52)	−0.1 (55)	0.0 (50)	0.5 (79)	**−1.3 (95)**	**7.0 (98)**	**7.6 (98)**
Tawarau (16)	0.3 (88)	0.0 (56)	0.1 (74)	0.8 (74)	0.3 (68)	**1.0 (99)**	0.7 (93)	0.0 (50)	0.5 (77)	**−1.6 (99)**	4.5 (83)	4.1 (87)
Waingaro (8)	0.6 (91)	0.6 (99)	**1.0 (99)**	−0.7 (68)	0.8 (76)	0.9 (77)	0.5 (63)	**2.2 (99)**	−0.7 (79)	**−1.8 (96)**	−2.2 (67)	−0.7 (57)
Waitetuna (10)	0.7 (89)	0.3 (99)	0.7 (99)	**−4.6 (99)**	1.3 (84)	−0.6 (72)	−0.2 (61)	−0.5 (69)	−0.9 (85)	**−1.9 (96)**	−1.5 (76)	0.7 (58)