Waikato Regional Council Technical Report 2022/05

Sources of nitrogen and phosphorus in two major catchments in the Waikato Region, 2011–20

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

Prepared by:
Bill Vant

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

Doc Publication date April 2023

Document #: 21993338

Peer reviewed by: Drs Coral Grant and Sandy Elliott	Date	May 2022
Approved for release by: Mike Scarsbrook	Date	April 2023

Acknowledgement

Many members of Waikato Regional Council's Environmental Monitoring team have helped with the collection of surface water quality and river flow information that is reviewed and analysed here. Justin Wyatt assembled the databases used in the Sedrate analysis of the nutrient loads carried by the rivers. Alyx McDonald, Ben Murphy, David Stagg and Hugh Keane helped locate and retrieve the consent monitoring information that is analysed here. Andrew Hoffmann and Richard Glass prepared the maps and Dan Borman updated the land-cover analyses used in this report. And Drs Coral Grant (Auckland Council) and Sandy Elliott (NIWA Hamilton) made helpful comments on a draft of it.

Table of Contents

Figures

Tables

Executive summary

Rivers in two large catchments drain much of the Waikato Region. The Waikato and Waipa Rivers drain an area of about 11,400 km^2, and flow to the Tasman Sea to the west of the Region. Four smaller rivers collectively called the "Hauraki rivers" drain an area of about 4200 km^2, and flow to the Firth of Thames to the northeast of the Region. In each of these catchments much of the land has been developed for pastoral farming, with smaller areas in native and exotic forest. There are also about two dozen consented point source discharges of wastewaters in each catchment, both of sewage wastewaters from urban areas and industrial wastewaters from dairy factories, meatworks and other operations.

This report uses water quality and flow data from the routine monitoring of both the rivers and the consented discharges to determine the loads of the plant nutrients nitrogen and phosphorus in the rivers and discharges, and thereby establish the relative importance of the different sources of these nutrients. In doing so it updates previous analyses of these records for the decade 2011–20. The report is divided into two sections, with Section 1 dealing with the loads carried by the Waikato and Waipa Rivers and Section 2 dealing with the loads carried by the Hauraki rivers.

Waikato and Waipa Rivers

1. It is convenient to divide the catchment of the Waikato and Waipa Rivers into three roughly-equal sections: Upper Waikato, from the outflow of Lake Taupo to the Karapiro dam; Lower Waikato, from the Karapiro dam to the sea; and Waipa, the catchment of this major tributary of the Waikato River. Routine water quality and flow monitoring data were used to determine the loads of the plant nutrients nitrogen and phosphorus in each sub-catchment during 2011–20. Each of the three sub-catchments contributed similar proportions—about one-third—of the loads of each nutrient.

2. Average river flow at the most downstream site during 2011–20 was 371 m^3/s; this was 8% lower than in 2003–12. The average load of phosphorus carried by the river during 2011–20, namely c. 730 t/yr, was also lower (25%), partly because of substantial reductions in the loads discharged at several of the important point source discharges in the catchment over the past 20 years. However, the average load of nitrogen carried by the river, namely c. 10,980 t/yr, was only slightly lower (3%) than during 2003–12, probably because the increases in concentrations of nitrogen observed in the river since 2001 largely-offset the lower river flows that occurred during the past decade.

3. Some 20 consented point sources discharge a variety of contaminants—including nitrogen and phosphorus—to waterbodies in the catchment. These sources include 12 sewage treatment plants of widely-varying size, and eight industrial discharges—dairy factories, meatworks, power stations and a pulp and paper mill. Consent monitoring data were used to calculate the loads of nitrogen and phosphorus from these operations during 2011–20. Wastewater flows and nutrient concentrations varied widely, depending on the size and nature of the operations. For example, the pulp and paper mill discharged a large volume of low-nutrient wastewater, while the two meatworks discharged much smaller volumes that contained relatively high nutrient concentrations.

4. The combined load of nitrogen discharged from the 20 point sources was about 682 t/yr, while that of phosphorus was about 108 t/yr. The load of nitrogen was about 7% lower than that discharged during 2003–12 (namely 730 t/yr); while the load of phosphorus was about 37% lower (171 t/yr in 2003–12). These reductions were mostly due to ongoing improvements in wastewater treatment at the sites.

5. Much (70%) of the combined point source load of nitrogen came from just four sites: Hamilton sewage (28%), Kinleith pulp and paper mill (22%), Horotiu meatworks and dairy factory (10%) and Cambridge sewage (10%). And more than half (54%) of the combined point source load of phosphorus came from just three sites: Hamilton sewage (24%), Kinleith pulp and paper mill (19%) and Horotiu meatworks and dairy factory (12%).

6. Altogether, the 20 point sources contributed about 6% of the load of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2011–20. They also contributed about 15% of the load of phosphorus. The largest number of point sources was found in the Lower Waikato sub-catchment, where they contributed 12% of the nitrogen and 26% of the phosphorus.

7. Naturally-occurring processes within the catchments also contribute to the nutrient loads in the rivers; and these processes would have operated prior to human use of the catchments. Between about one-third and one-half of the current loads of both nutrients is estimated to be due to these natural or "background" processes. A proportion of the loads from land that has been developed can be regarded as natural and essentially un-manageable.

8. Subtracting the contributions from point and natural sources from the overall loads carried by the rivers provides an estimate of the nutrient loads caused by human use of the land—and in these catchments this largely means use of the land for pastoral farming. These diffuse, man-made sources contributed about 61% of the load of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2011–20, and about 35% of the phosphorus.

Hauraki rivers

1. Four rivers in the Hauraki area flow in a generally northerly direction into the Firth of Thames. In order of size, they are the Waihou/Ohinemuri, the Piako/Waitoa, the Kauaeranga and the Waitakaruru Rivers. Water quality has been monitored monthly at nearly 20 sites on these rivers since the early 1990s. Information is also available for the 24 discharges of sewage or industrial wastewaters into the rivers. Routine monitoring data for water quality and flow were used to determine the loads of nitrogen and phosphorus carried by these rivers during 2011–20.

2. Loads of nitrogen and phosphorus were determined at seven sites on the Hauraki rivers. Altogether the rivers carried at least 3730 t/yr of nitrogen and 207 t/yr of phosphorus to the Firth of Thames. The Waihou River carried 60–61% of the combined loads while the Kauaeranga and Waitakaruru Rivers each carried 1–2%; the Piako/Waitoa River carried about 36–38%.

3. The combined average flow of the Hauraki rivers during 2011–20 (c. 70 m^3/s) was similar to that seen in 2000–09. However, the combined load of nitrogen transported during 2011–20 was about 10% higher than in 2000–09, while the load of phosphorus was about 27% lower. Nitrogen concentrations increased in the Waihou and Ohinemuri Rivers during 2001–20, but decreased in the Piako River (and in the smaller Hikutaia and Waitakaruru Rivers). Substantial decreases in phosphorus concentrations apparently occurred in most rivers, but not in the Waihou (which carried the largest share of the combined load). However, the laboratory methods for phosphorus concentrations changed during the period, so the reliability of these trend results is uncertain.

4. The combined load of nitrogen discharged from the 24 point sources was about 214 t/yr, while that of phosphorus was about 48 t/yr. The load of nitrogen was about 18% lower than that discharged during 2000–09 (namely 262 t/yr); while the load of phosphorus was about 30% lower (68 t/yr in 2000–09).

5. The 24 point source discharges contributed about 6% of the nitrogen and 23% of the phosphorus that was carried by the rivers during 2011–20. Background sources in the river catchments were estimated to contribute about 21% of the combined load of nitrogen and 37% of the phosphorus. The remaining 73% of the nitrogen and 40% of the phosphorus is likely to have come from diffuse agricultural sources in the rivers' catchments.

General Introduction

Rivers in two relatively-large catchments drain much of the Waikato Region. The Waikato and Waipa Rivers drain an area of about 11,400 km^2, and flow to the Tasman Sea to the west of the Region. Four smaller rivers collectively called the "Hauraki rivers" drain an area of about 4200 km^2, and flow to the Firth of Thames to the northeast of the Region. In each of these catchments much of the land has been developed for pastoral farming, with smaller areas in native and exotic forest. There are also 20–24 consented point source discharges of wastewaters in each catchment, both of sewage wastewaters from urban areas and industrial wastewaters from dairy factories, meatworks and other operations.

The aquatic plant nutrients nitrogen and phosphorus are carried into rivers from the surrounding land by runoff and leaching. Larger amounts are usually transported from land that has been developed for farming. Wastewaters can also contribute substantial amounts of these nutrients to the rivers (with the concentrations in many wastewaters typically being much higher than those found in natural waters). This study uses routine monitoring data to determine the relative amounts of each nutrient that are contributed by the point sources and by runoff and leaching from the land (often referred to as "non-point" or "diffuse" sources). The contributions from the land can be further separated into (i) the "background" or "natural" contribution, and (ii) the additional contribution from areas of land that have been developed (noting that in the Waikato Region much of the land that has been developed is used for pastoral farming).[1]

The mass flow or flux of a material transported by a river—often called the "load"—is defined as being the product of river flow (m^3/s) and concentration (g/m^3); its units are mass per time (e.g. g/s, t/yr). In principle, it is calculated by integrating an infinite number of instantaneous loads over the period of interest. In practice, it is usually obtained from frequent estimates of river flow and rather less frequent measurements of concentrations obtained from water quality surveys. Various methods have been developed to estimate loads from these data (e.g. Littlewood 1992). The loads of sediment in rivers have been studied for many years (e.g. Griffiths 1981, Hoyle 2014). More recently, attention has turned to other water quality contaminants, including the plant nutrients, heavy metals and pesticides (e.g. Littlewood et al. 1998).

Many common contaminants, such as organic carbon (measured as biochemical oxygen demand), ammonia and faecal bacteria can decay or be transformed once they have entered a waterbody. By contrast, total phosphorus acts conservatively: it is neither destroyed nor created, but simply passes through, or is retained within, aquatic systems. In principle, inputs of phosphorus may therefore be tracked through a river system.

Total nitrogen, however, acts less conservatively in waterbodies, as it can exchange with atmospheric nitrogen via the processes of nitrogen fixation and denitrification. Even so, as a first approximation, for large river systems these atmospheric gains and losses may be ignored, and both nutrients may be regarded as being conservative or "quasi-conservative" contaminants. It is therefore often feasible to prepare a "nutrient budget", which identifies and compares the loads of nutrients from these various sources (Rutherford et al. 1987). Accounting for all significant sources of contaminants in such a budget is now required by the National Policy Statement for Freshwater Management (2020).

Vant (1999) made preliminary estimates of the loads of nitrogen and phosphorus caried by several rivers in the Waikato Region during the early 1990s. Since then, the loads

[1] In this region urban stormwater is generally a relatively minor source of nitrogen and phosphorus (Williamson 1999).

carried by the Waikato and Waipa Rivers and the Hauraki rivers have been determined for various 10-year periods (e.g. Vant 2014, 2016). This report updates these earlier analyses by determining the loads of nitrogen and phosphorus carried by rivers in the Region during 2011–20. Section 1 deals with the loads carried to the west by the Waikato and Waipa Rivers and Section 2 deals with the loads carried to the north-east by the Hauraki rivers.

1 Section 1, Waikato and Waipa Rivers

1.1 Introduction

The Waikato and Waipa Rivers drain a large part of the central North Island of New Zealand (Fig. 1). Table 1 summarises the landcover of three distinct sub-catchments: (i) Upper Waikato, from Taupo Gates to Karapiro dam—where the river water is impounded in eight large hydroelectric reservoirs, (ii) Lower Waikato, from Karapiro dam to the sea, a lowland area containing the river's floodplain and its many shallow lakes and wetlands, and (iii) Waipa, an area with more-erodible soils that contributes a disproportionate share of the sediment lost from the catchment (Hicks and Hill 2010). Table 1 also lists the number of non-trivial point sources of contaminants in each of the sub-catchments. Most of these discharges are found in the Lower Waikato sub-catchment. Discharges of farm dairy effluent are regarded here as being "minor" point sources, and form part of the general diffuse loads of contaminants entering the rivers from farmland.

The Waikato Regional Council operates a routine river water quality monitoring programme that includes more than 60 sites in the catchments of the Waikato and Waipa Rivers (Bates 2021, Salu 2021). It also issues the resource consents that permit the discharge of treated wastewaters to these rivers; consent holders are required to monitor the flow and water quality of these discharges and to provide the information to the Council. Vant (1999) used this information to estimate the relative importance of the various sources of the nitrogen and phosphorus that was carried by several rivers in the 1990s. The analyses for the Waikato and Waipa Rivers were subsequently updated for the decade 2003–12 (Vant 2014). This section refines and updates these earlier analyses for the decade 2011–20.

Table 1: Landcover in three sections of the Waikato-Waipa catchments, 2018 (LCDB5.1, WRC doc #3219468). The number of non-trivial point sources discharges in each section is also shown (see text).

	Upper Waikato†	Waipa	Lower Waikato*	Combined
Area (km^2)	4414	3092	3529	11,035
Indigenous vegetation	13%	19%	13%	15%
Exotic forest	30%	4%	5%	15%
Pasture, crops	55%	75%	74%	67%
Lakes, wetlands	1%	<1%	4%	2%
Urban, other	1%	1%	4%	2%
Point source discharges	4	5	11	20

†Excludes the catchment of Lake Taupo

*Excludes the Upper Waikato and Waipa subcatchments

Figure 1: The catchments of the Waikato and Waipa Rivers, showing four sites at which river-borne nutrient loads were calculated (green circles, see text and Table 2 for site names) and 20 consented discharges of wastewaters (orange circles, see Table 4 for site names). The boundary between the Upper and Lower sections of the Waikato River is at Karapiro dam.

1.2 Loads carried by the rivers

Vant (2014) determined the loads of nitrogen (N) and phosphorus (P) at a total of 20 sites in the catchments of the Waikato and Waipa Rivers during 2003–12. In this update for 2011–20, where the focus is on the overall loads carried by the rivers, only the results for four key sites were considered (Fig. 1). These were the outflow from Lake Taupo (Waikato River at Reids Farm, site 1) and the most downstream sites in each of the three main sub-catchments (Waikato River at Narrows, site 6; Waipa River at Whatawhata, site 17; and Waikato River at Tuakau, site 10).[2] In each case the loads were calculated using monthly measurements of total N and total P concentrations, together with continuous records of river flow. At sites 1 and 17, the monthly samples were collected close to the location of the flow recording site. However, for sites 6 and 10 the relevant flow recorders were upstream of the water quality sampling sites (by 23 km and 12 km, respectively*).*[3]

The following procedure was used to calculate the loads at each site (Vant 2016; see also WRC document #917875): (i) identify the near-instantaneous river flow at the time each of the monthly water quality samples was collected (*n*=120 in most cases),[4] (ii) determine the relationships between river flow and the concentrations of total N and total P (i.e. "nutrient rating curves"),[5] (iii) use these relationships to calculate the load at each half-percentile interval (i.e. 0.5%) of the site's flow duration curve, and (iv) add the 200 estimates of load thus obtained to give the combined load at all river flows. These calculations were made with the "Sedrate" software (v2.21a), using the LOWESS curve-fitting and Smearing bias correction procedures (as recommended by the software developer, Dr M Hicks, NIWA; pers. comm. August 2015).

Apart from site 1 (Waikato River at Reids Farm), there were statistically significant relationships between the logarithms of river flow and nutrient concentration, with the correlation coefficients being between about 0.3 and 0.9. Figure 2 shows how the concentrations of total N and total P varied with flow at the Waikato at Tuakau (Figs 2A and B) and the Waipa at Whatawhata sites (Figs 2C and D). Flow and concentration tended to covary (Fig. 2), with each of the log-log correlation coefficients (*r* values) being about 0.8–0.9 for total N and 0.7 for total P.

The extent to which the loads of total N and total P varied at each site also depended on the extent to which flows themselves varied, with some sites exhibiting less flow variability than others. For example, during 2011–20 high flow (95%ile) in the Waipa River at Whatawhata was about 17 times higher than low flow (5%ile); but in the Waikato River at Narrows high flow was just 2–3 times higher than low flow. The seasonal variation in loads of total N and total P at these two sites is shown in Figure 3.[6] Loads of both total N and total P tended to be 10–100 times higher in the winter than in the summer at the Waipa River site, whereas the loads at the Waikato River site showed much less seasonal variability.

[2] Sites 1 and 17 are operated by the National Institute of Water and Atmospheric Research (NIWA): see hydrowebportal.niwa.co.nz

[3] Both flow and water quality are assumed to be relatively-stable over each of these reaches, so the loads are likely to be as well.

[4] Flows recorded at 5-minute intervals at sites 10 and 17, at 15-minute intervals at site 1 and at 60-minute intervals near site 6.

[5] Note that there were trends in the nutrient concentrations at some sites (see later) which implies that the corresponding ratings also varied over time. However, the uncertainty associated with this is regarded as being less important than the value of basing the ratings on as large a dataset as possible.

[6] Note that the average loads of total N at the two sites were similar (Table 2); likewise for the loads of total P.

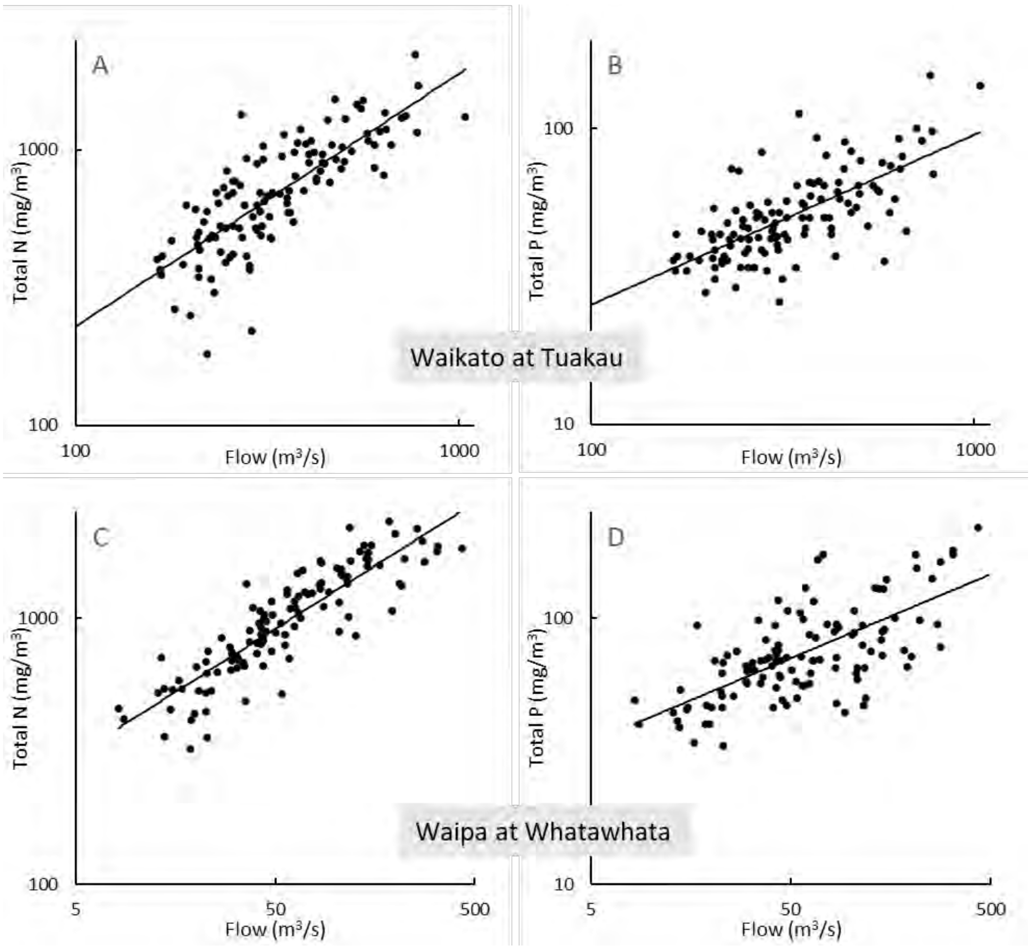

Figure 2: Monthly measurements of nutrient concentration and flow at the time of sampling in the Waikato and Waipa Rivers, 2011–20. A, total N, and B, total P at Waikato at Tuakau (site 10). C, total N, and D, total P at Waipa at Whatawhata (site 17; data from NIWA). Note that the lines indicate the simple linear relationships (in log-log space) between flow and concentration and not the LOWESS curvilinear relationships used in Sedrate.

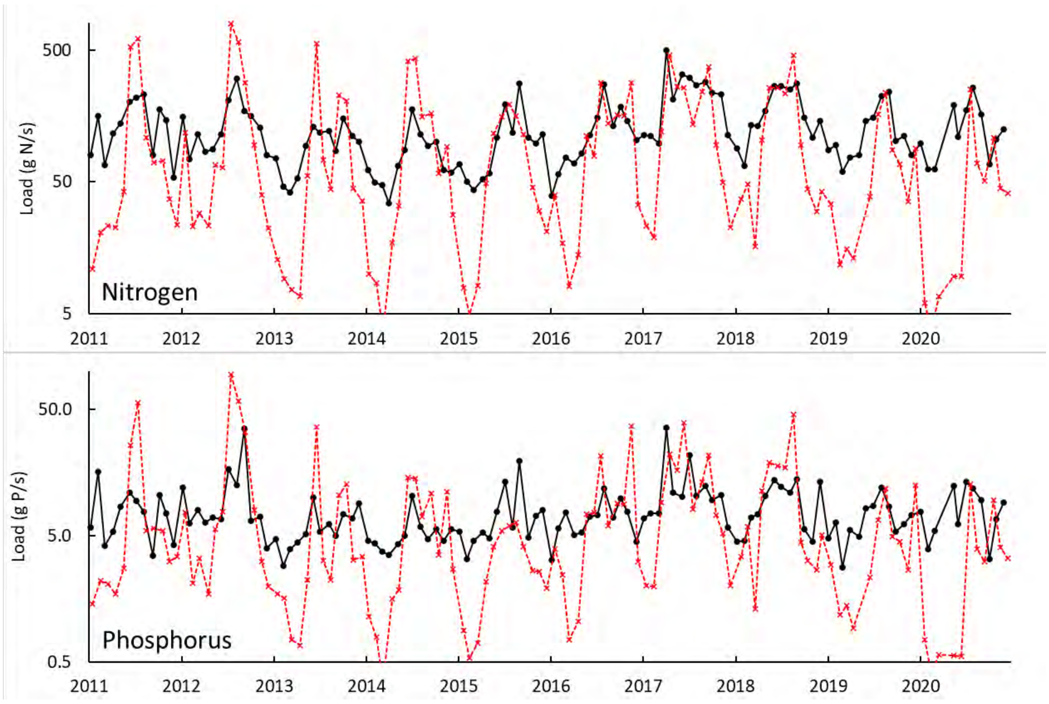

Figure 3: Instantaneous loads of nitrogen and phosphorus in the Waikato River at Narrows (site 6; circles, solid line) and the Waipa River at Whatawhata (site 17; red crosses, dotted line) at monthly intervals during 2011–20.

Table 2 shows the average loads of nitrogen and phosphorus transported through the three sections of the catchment during 2011–20. The overall river flow averaged about 371 m^3/s, while the average loads of total N and total P were about 10,940 t/yr and 715 t/yr, respectively.

Although the outflow from Lake Taupo (i.e. site 1) was a major source of the combined river flow (40%), it contributed just a minor proportion (2–3%) of the average loads of nitrogen and phosphorus. This highlights the fact that nutrient concentrations in Lake Taupo were much lower than those in the streams draining other parts of the Waikato and Waipa catchments. On average, each of the three sections of the catchment—Upper Waikato, Lower Waikato and Waipa—contributed about one-third (31–36%) of the combined loads of nitrogen and phosphorus carried by the river as a whole (Table 2). The majority (64%) of the river flow, however, came from the Upper Waikato section.

Vant (2014) described the average flows and average loads of nitrogen and phosphorus in the Waikato and Waipa Rivers during 2003–12.[7] For example, the average load of nitrogen at the most downstream site in the Waikato/Waipa catchment (i.e. at Tuakau Bridge) in 2011–20 was 3% lower than the corresponding value in 2003–12, while the load of phosphorus was 25% lower. The average river flow at this location was also lower during 2011–20 (371 m^3/s) than in 2003–12 (402 m^3/s),[8] which presumably contributed to the loads of nitrogen and phosphorus being lower then. However, changes in the nutrient concentrations at the various sites are also likely to have affected the loads.

Figure 4 shows the changes in the concentrations of total N and total P at the three key sites during 2001–20, while Table 3 shows the rates at which concentrations changed over this 20-year period. Trends in total N concentration were very likely to have occurred at each of the sites; all were increases, with rates of change ranging from 0.5% per year to 1.6% per year.

Table 2: Average flows and loads of nitrogen and phosphorus passing through monitoring sites in three sections of the Waikato-Waipa catchment, 2011–20 (site locations in Fig. 1). The proportions (%) of the combined values at Tuakau are shown in brackets.

#	Site	Flow (m^3/s)		Nitrogen (t/yr)		Phosphorus (t/yr)	
	Upper Waikato						
1	Waikato at Reids Farm	149	(40%)	313	(3%)	23	(2%)
6	Waikato at Narrows§	238	(64%)	3870	(35%)	230	(32%)
	Waipa						
17	Waipa at Whatawhata	79	(21%)	3621	(33%)	240	(34%)
	Lower Waikato						
10	Waikato at Tuakau	371	(100%)	10,938	(100%)	715	(100%)

§See the discussion in section 1.4 about how the information from this site was used.

[7] The loads reported there, however, were the average of those calculated using all of Sedrate's bias correction procedures, whereas the values reported here are those obtained from just one of those procedures (namely that based on LOWESS curve-fitting and Smearing bias correction). Appendix 1 shows the results for 2011–20 (from Table 2) and the corresponding results for 2003–12 (from WRC doc #4081893).

[8] Jenkins and Koh (2022) described the long-term decline in flow in rivers in the Waikato Region.

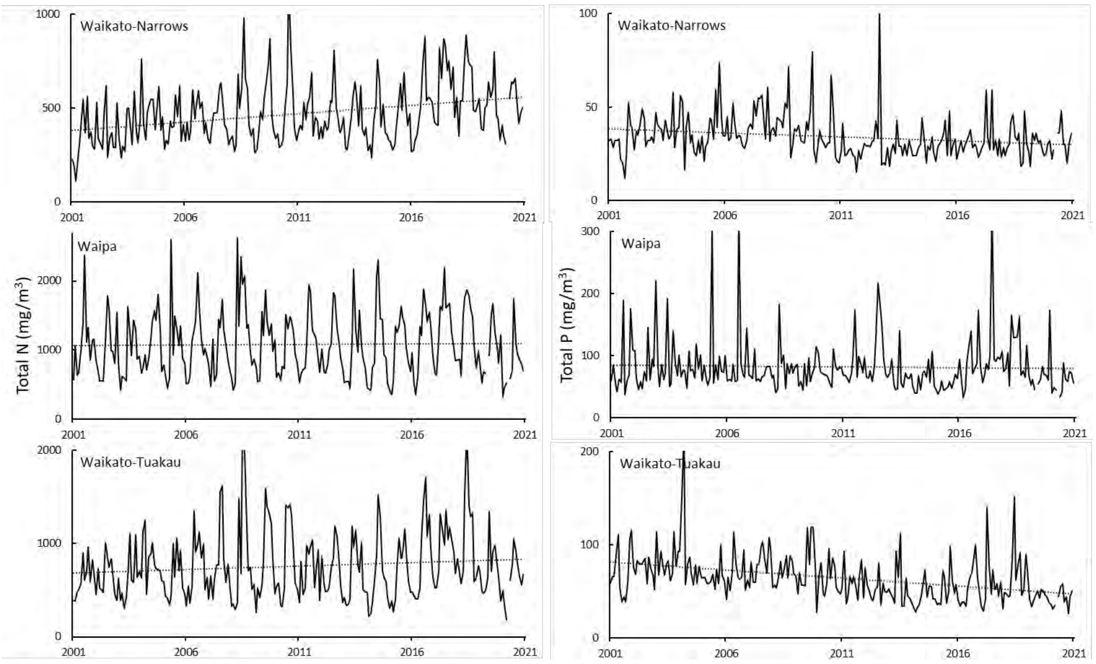

Figure 4: Concentrations of total N and total P at three downstream sites in the Waikato and Waipa catchments, 2001–20. Note the different vertical scales. The dashed lines broadly indicate the overall trends in the records; see also Table 3.

Table 3: Changes in flow-adjusted concentrations of total N and total P at three Waikato-Waipa water quality monitoring sites during 2001–20. Values are trend slopes (% per year) and, in brackets, probabilities (%) that the slopes are different from zero. Trends that are very likely to have occurred (slope probability >95%) are shown in bold type, with decreases in blue and increases in red. See Vant (2018) for further details.

Site	Total N	Total P
Waikato River at Narrows (site 6)	**1.4 (>99)**	**–1.2 (>99)**
Waipa River at Whatawhata (site 17)	**0.5 (99)**	–0.1 (69)
Waikato River at Tuakau (site 10)	**1.6 (>99)**	**–2.4 (>99)**

By contrast, decreases in total P concentration were found to have been very likely to have occurred at two of the sites, with rates of change of –1.2% per year (Waikato at Narrows) and –2.4% per year (Waikato at Tuakau), respectively. However, the laboratory methods used to analyse total P in samples from these sites have changed over the past 20 years, so these results are provisional only.[9,10] Furthermore, there was little overall change in total P concentration at the third site (Waipa at Whatawhata) where monitoring and sample analysis was undertaken by NIWA Hamilton, using methods that did not change over the 20-year period. At this stage it is unclear whether the records of total P concentrations and loads in this period at the sites monitored by WRC are entirely reliable.

At the Waikato River at Narrows site, the average flow during 2011–20 was within about 1% of that in 2003–12 (namely 235 m^3/s). And the average loads of nitrogen and phosphorus were 5% higher and 19% lower, respectively. This implies that much of the difference in the nutrient loads at this site was due to the increase in nitrogen concentration and decrease in phosphorus concentration there (Table 3). At the Waipa

[9] See WRC doc #11735651 for a summary of the investigations of these method changes up to early 2018. And see Vant (2018) for more information on the apparent trends in records of total P at WRC monitoring sites.

[10] Note also that the monthly records in Figure 4 at both the Narrows and Tuakau sites appear to show a drop in total P concentrations beginning around the year 2011. Although there were substantial reductions in several of the major point source loads of phosphorus discharged to the lower river between the first and second halves of the 20-year period (see later), calculations show that these were not sufficient to account for all the apparent drop in the concentrations in the river at Tuakau. Furthermore, the combined reduction in the loads discharged by the point sources upstream of the site at Narrows was relatively-small.

River at Whatawhata site, average river flows during 2011–20 were about 10% lower than in 2003–12; and the nutrient loads at this site fell by a similar amount (10% for nitrogen and 12% for phosphorus). In this case, changes in river flow appear to have been responsible for much of the change in nutrient loads (as the changes in concentration were slight: Table 3).

Finally, as noted above, at the whole-of-catchment Waikato River at Tuakau Bridge site the average flow during 2011–20 was about 8% lower than in 2003–12. Phosphorus concentrations were also lower, with both factors probably contributing to the markedly-lower (25%) phosphorus loads. Nitrogen concentrations, however, increased over the period (Table 3). This appears to have partly-offset the lower flows so that the average load of nitrogen was just 3% lower during 2011–20. An important contributor to these lower loads has been the reductions the nutrient loads to the river from point sources, particularly those of phosphorus (see below).

1.3 Loads from point sources

Figure 1 shows the location of 20 sites where contaminants are discharged to the Waikato and Waipa Rivers. Each can be regarded as a non-trivial point source of nitrogen and phosphorus (Table 4). Twelve of these locations are sites where sewage wastewaters from urban areas are treated, while industrial wastewaters are treated at the other eight sites (including dairy factories, meatworks and a pulp and paper mill).

In each case the discharge of treated wastewater is permitted by a resource consent issued by the Regional Council. The terms of these consents generally limit both the volume and the quality of the effluent that may be discharged. They also require the consent holder to regularly monitor these variables and to provide this information to the Council.

This consent monitoring information was used to determine the average loads of nitrogen and phosphorus that were discharged from each of the point sources during 2011–20. In most cases electronic copies of the monitoring information were available in the Council's document management system. These records were retrieved, collated and checked for errors. Table 4 summarises the information available on flows and nutrient concentrations for each of the discharges during the decade.

Comprehensive records were available for several sites (Table 4), with daily wastewater flow rates being available for more than three-quarters of the sites. Nutrient results were generally available at no less than monthly intervals, with weekly results being available for about one-third of the sites. Complete, or nearly-complete records were available for eight sites (namely A, B, C, D, M, N, O and Q); while those for a further five sites (E, F, G, J and L) were largely-complete (c. 80%). Other records had moderately-large gaps. In most cases samples of the wastewaters had been analysed for total N and total P, but in some cases only the concentrations of dissolved nitrogen or phosphorus were available (Cambridge, Tokoroa and the Wairakei power station: Table 4).

In most cases, average values of wastewater flow and nutrient concentration were calculated for each month. Multiplying these values together gave the average nutrient load discharged in that month. Following Vant (2011), unbiased estimates of the average nutrient load over the decade 2011–20 were obtained by averaging these individual monthly loads. That is, loads were calculated as the "average of the products", rather than as the "product of the averages" (i.e. decadal-average flow times decadal-average concentration). The average number of separate monthly products of flow and nitrogen concentration available for the various discharges during the decade (i.e. 120 months) was about 99 (range 41–120); for phosphorus the average number was 94 (range 0–120).

Table 4: Summary of consent monitoring information held by Waikato Regional Council on the flow rate and nutrient concentration for 20 point source discharges to the Waikato and Waipa Rivers, 2011–20. The catchment where each discharge is located is also shown: "UW", Upper Waikato; "LW", Lower Waikato; "Wp", Waipa.

	Site	Document number	Period	Number of samples (N, P)
	Sewage wastewater			
A	Hamilton (LW)	3329218	2011-20	2394, 2389
B	Tuakau/Pukekohe (LW)	3344887	2011-20	514, 509
C	Te Awamutu (Wp)	3339589	2011-20[a]	492, 492
D	Cambridge (LW)	3332120	2011-20[b]	241[f], 245[g]
E	Te Kuiti (Wp)	3319729	2011-20[a]	375, 375
F	Tokoroa (UW)	3331780	2011-20	232, 232[g]
G	Huntly (LW)	3336516	2011-20[c]	104, 106
H	Ngaruawahia (LW)	3332264	2011-20[c]	98, 112
I	Otorohanga (Wp)	3339084	2011-20	83, 86
J	Te Kauwhata (LW)	3343436	2011-20[c]	129, 122
T	Waikeria (Wp)	21143792	2012–19[d]	27, 27
K	Meremere (LW)	3344114	2011-20[c]	125, 125
	Industrial wastewater			
L	Wairakei power station (UW)	3346600	2011-20	101[h], –
M	Kinleith pulp and paper mill (UW)	3330240	2011-20	119, 119
N	Te Rapa dairy factory (LW)	3306593	2011-20	516, 494
O	Te Awamutu dairy factory (Wp)	3320878	2011-20	429, 516
Q	Horotiu meatworks/dairy (LW)	3331604	2011-20	506, 506
P	Ohaaki power station (UW)	21746333	2011-20	18, 18
R	Hautapu dairy factory (LW)	3340070	2012-20[e]	323, 323
S	Tuakau rendering plant (LW)	3341833	2011-20[e]	422, 105

Notes
a, weekly flows
b, weekly flows during 2011–12
c, 2013–15 missing
d, Several large gaps
e, Some gaps
f, Dissolved inorganic N only
g, Dissolved reactive P only
h, Ammoniacal-N only

Table 5 summarises the information on wastewater flows, and nitrogen and phosphorus concentrations and loads in the 20 discharges. The flows and concentrations varied markedly between the different sites, depending on the size (e.g. large vs. small urban areas) and nature of the different operations (e.g. meatworks vs. pulp and paper mill).

The combined load of nitrogen discharged from the 20 point sources during 2011–20 averaged 682 t/yr (Table 5), with over half (58%) coming from sewage discharges and the rest from industrial discharges. Much (70%) of the combined load of nitrogen came from just four sites: Hamilton sewage (28%), Kinleith pulp and paper mill (22%), Horotiu meatworks and dairy factory (10%) and Cambridge sewage (10%). By contrast, small loads were discharged from five sites (J, T, K, N, P); together these contributed just 2% of the combined point source load of nitrogen.

For phosphorus, the combined load averaged 108 t/yr, with over half (56%) coming from sewage discharges and the rest from industrial discharges (Table 5). More than half (54%) of the combined load came from just three sites: Hamilton sewage (24%), Kinleith pulp and paper mill (19%) and Horotiu meatworks and dairy factory (12%). The loads discharged from four sites were small (H, K, P and R), and together contributed less than 2% of the combined point source load of phosphorus.

Table 5: Average flows of wastewater, and average concentrations and loads of nitrogen and phosphorus from 20 consented discharges to the Waikato and Waipa Rivers, 2011–20.

	Site	Flow (m^3/day)	Concentration (g/m^3) Total N	Total P	Load (t/yr) Total N	Total P
	Sewage wastewater					
A	Hamilton	46,840	11	1.5	193	25.5
B	Tuakau-Pukekohe	8260	7	3.0	22	8.7
C	Te Awamutu	4510	9	2.5	15	4.2
D	Cambridge	4320	40	3.4	67	5.8
E	Te Kuiti	3370	17	2.4	18	2.5
F	Tokoroa	3290	30	4.6	36	5.5
G	Huntly	2260	16	3.0	13	2.3
H	Ngaruawahia	1660	18	1.2	11	0.7
I	Otorohanga	1290	12	3.4	9	1.7
J	Te Kauwhata	800	12	4.5	4	1.3
T	Waikeria	580	19	5.2	4	1.1
K	Meremere	220	10	3.7	1	0.2
	Sub-total sewage				**392**	**60**
	Industrial wastewater					
L	Wairakei power station	1,122,000	<1	–	23	–
M	Kinleith pulp and paper mill	87,730	5	0.6	147	20.2
N	Te Rapa dairy factory	17,350	1	1.2	5	7.2
O	Te Awamutu dairy factory	3660	8	2.1	8	2.2
Q	Horotiu meatworks/dairy	2310	82	14.5	70	12.6
P	Ohaaki power station	1140	<1	<0.1	<1	<0.1
R	Hautapu dairy factory	1080	33	1.4	15	0.5
S	Tuakau rendering plant	460	112	30.5	21	5.2
	Sub-total industrial				**290**	**48**
	Total				**682**	**108**

The nutrient loads at each site varied throughout the decade. Much of this appeared to be random variability, but several of the discharges also showed marked seasonal variability. This included Hamilton sewage, the Te Rapa dairy factory and the Horotiu meatworks and dairy factory; Figure 5 shows the variation in phosphorus loads from these sites. The seasonal nature of production at the factories accounts for some of this, as do the conditions of the individual consents which often require that loads be reduced during the summer, when phytoplankton growth rates in the river are high.

Following Vant (2018), the monthly-average records of nutrient loads at each of the sites during 2011–20 were analysed for trends. Table 6 shows the trend slopes—or overall rates of change in nutrient loads across the decade—and the probability that the slopes were different from zero. Altogether 21 of the trends were improvements (i.e. loads decreased), with 11 of these occurring at industrial sites. And eight of the records deteriorated, with six of these being at sewage sites.

At Hamilton, the reductions in the loads of nitrogen (2% per year) and phosphorus (8% per year, Fig. 5A) discharged in sewage wastewaters are noteworthy, particularly since this site contributed much (24–28%) of the combined loads from all the point sources. The phosphorus load from Hamilton sewage has decreased markedly over recent decades (e.g. Fig. 5A), and is now less than one-fifth of what it was in the early 1990s (Vant 1999)—despite the continued growth in the city's population and wastewater volumes since then.[11]

[11] Major upgrades of the treatment processes used at Hamilton's Pukete Wastewater Treatment Plant were carried out in both 2001 and 2014: see Pukete Wastewater Treatment Plant - Hamilton City Council.

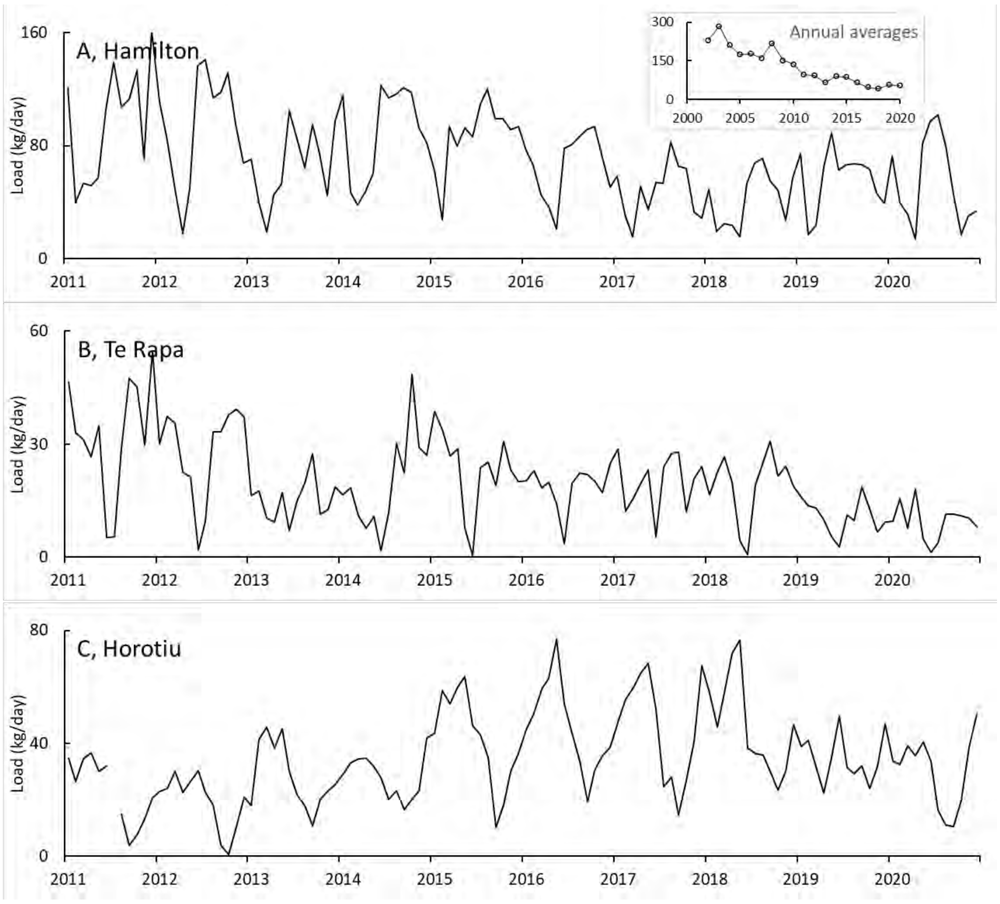

Figure 5: Monthly-average loads of phosphorus discharged to the Lower Waikato River at three locations during 2011–20. A, Hamilton sewage (site A), B, Te Rapa dairy factory (site N), and C, Horotiu meatworks and dairy factory (site Q). Inset: annual average loads discharged at Hamilton during 2002–20. See also Table 6.

Table 6: Slopes (% per year) and, in brackets, slope direction probabilities (%) of monthly records of the nitrogen and phosphorus loads discharged from 20 point sources during 2011–20. Trends that are very likely to have occurred (slope probability >95%) are shown in bold type, with decreases in blue and increases in red. The contributions (%) of each site to the combined nutrient load from point sources are also shown. "id", insufficient data (*n*<60).

	Site	N slope	P slope	Load N (%)	Load P (%)
	Sewage wastewater				
A	Hamilton	**−2.0 (>99)**	**−8.2 (>99)**	28	24
B	Tuakau-Pukekohe	1.0 (69)	−3.0 (94)	3	8
C	Te Awamutu	**12.8 (>99)**	**−3.4 (95)**	2	4
D	Cambridge	**5.1 (>99)**	1.2 (88)	10	5
E	Te Kuiti	**−5.7 (96)**	**−13.3 (>99)**	3	2
F	Tokoroa	**1.5 (>99)**	0.6 (93)	5	5
G	Huntly	**−5.3 (>99)**	**−11.5 (>99)**	2	2
H	Ngaruawahia	**6.0 (>99)**	**−131 (>99)**	2	1
I	Otorohanga	**−14.9 (>99)**	**−4.1 (95)**	1	2
J	Te Kauwhata	**20.2 (>99)**	**5.0 (99)**	1	1
T	Waikeria	id	id	1	1
K	Meremere	**−5.7 (>99)**	−1.0 (59)	<1	<1
	Industrial wastewater				
L	Wairakei power station	**−5.6 (>99)**	no data	3	–
M	Kinleith pulp and paper mill	**−1.5 (96)**	−0.3 (61)	22	19
N	Te Rapa dairy factory	**−2.5 (98)**	**−9.3 (>99)**	1	7
O	Te Awamutu dairy factory	−2.5 (78)	**−21.1 (>99)**	1	2
Q	Horotiu meatworks/dairy	−0.9 (67)	**6.8 (>99)**	10	12
P	Ohaaki power station	**−4.7 (>99)**	**50.7 (>99)**	<1	<1
R	Hautapu dairy factory	**−2.8 (>99)**	**−5.6 (99)**	2	<1
S	Tuakau rendering plant	**−6.0 (98)**	**−15.3 (>99)**	3	5

Reductions in the loads of both nutrients also occurred at both Huntly and Otorohanga, while there was a very large reduction in the load of phosphorus from Ngaruawahia. However, each of these sites represented just a modest contribution (1–2%) of the combined point source loads (Table 6). Conversely, the increase (5% per year) in the nitrogen load discharged from Cambridge was important because this site contributed a moderately-large proportion (10%) of the combined load.

Three of the changes in the loads discharged from the industrial sites were also noteworthy. There was a modest reduction (1.5% per year) in the load of nitrogen discharged from the Kinleith pulp and paper mill—which contributed a major proportion (22%) of the combined load from point sources. And at both the Te Rapa dairy factory and the Tuakau rendering plant there were important reductions in phosphorus loads (9% per year [Fig. 5B] and 15% per year, respectively), with both of these sites contributing a moderately-large proportion of the combined load (7% and 5%, respectively).

For any given month in the decade, the number of sites for which a nutrient load could be determined varied markedly: from 10-to-20 sites for nitrogen loads (average 17 per month), and from 9-to-19 sites for phosphorus loads (average 16 per month). As a result, it was not possible to calculate reliable values of the combined nutrient load from point sources for many of the months. Neither could changes over time in the combined load be determined this way. Instead, the overall changes in the combined loads of nitrogen and phosphorus discharged from the 20 point sources during 2011–20 were determined by taking account of both the change in load at each site and each site's contribution to the combined loads (Table 6).

Upper and lower bounds to the changes were determined as follows:

- upper bound: use all available trend slopes regardless of slope probability to calculate the load-weighted average rate of change in nutrient loads; and
- lower bound: set trend slopes that were "not very likely" (i.e. slope probability <95%) equal to zero, and calculate the load-weighted average rate of change in nutrient loads.

The combined load of point source nitrogen that was discharged was thus calculated to have decreased by between 0.7% per year and 0.8% per year during 2011–20. And the combined load of phosphorus decreased by between 4.5% per year and 4.8% per year.

The nutrient loads discharged to the Waikato and Waipa Rivers during 2011–20 can be compared with those reported by Vant (2014) for the period 2003–12 (see Appendix 2). The combined load of nitrogen discharged from the point sources during 2011–20 (682 t/yr) was about 7% lower than that discharged during 2003–12 (namely 730 t/yr); more strikingly, the combined load of phosphorus was 37% lower (loads of 108 t/yr and 171 t/yr, respectively).

1.4 Components of the total loads in the rivers

The loads of nitrogen and phosphorus discharged from the point sources during 2011–20 (Table 5) can be directly compared with the total loads of these nutrients that were carried by the Waikato and Waipa Rivers (Table 2). Furthermore, by estimating the contributions from background—that is, the loads that would have been carried by the rivers prior to use of their catchments—it is possible to also estimate the loads that have resulted from use of the land.[12]

[12] As noted above, this amounts to a form of "contaminant accounting" as is now required by the National Policy Statement for Freshwater Management (2020).

The division of the whole catchment into the three sections shown in Table 1 and Figure 1 doesn't entirely match the location of the monitoring sites. In particular, the Karapiro dam marks the change in the nature of the river from impounded water upstream of the dam to freely-flowing downstream of it. But the water quality monitoring site with the longest continuous record in the vicinity is at Narrows, 23 km downstream of the dam (Figure 1). The discharges from Cambridge sewage (site D) and the Hautapu dairy factory (site R) enter the river between the Karapiro dam and the site at Narrows, as do some small streams (e.g. the Mangawhero Stream)—the loads from which are not monitored.

In this analysis, the Karapiro dam is regarded as being the boundary between the Upper and Lower sections of the Waikato River, with the nutrient loads at the dam being estimated as the load at Narrows, minus the contributions from Cambridge sewage and the Hautapu dairy factory. That is, the loads carried by the small streams mentioned above were regarded as entering the river upstream of Karapiro dam and were thus included in the "Upper Waikato" section.[13]

Furthermore, the discharges from the Tuakau-Pukekohe sewage treatment plant and the Tuakau rendering plant enter the Waikato River downstream of the routine water quality monitoring site at Tuakau Bridge (see Fig. 1). So, the overall nutrient loads carried by the Waikato River can be calculated as the loads at Tuakau Bridge plus the loads from these point sources (sites B and S). Note that the loads calculated for the Lower Waikato section do not include the inputs to it from the two upstream catchments (i.e. Upper Waikato and Waipa).

Table 7 shows the average loads of nitrogen and phosphorus carried by the Waikato and Waipa Rivers during 2011–20. The combined contributions to these loads from the various point sources listed in Table 5 are also shown. Following Vant (1999, 2014), pre-development or background loads were calculated from the respective catchment areas (Table 1; but note that about 357 km^2 of the Lower Waikato sub-catchment is downstream of the Tuakau monitoring site) and estimates of the specific yields from undeveloped land, namely 3 kg/ha/yr for nitrogen and 0.3 kg/ha/yr for phosphorus, based on the information in Jenkins and Vant (2007, see their Table 2). Geothermal areas also contribute about 140 t/yr of nitrogen and 20 t/yr of phosphorus to the Upper Waikato River (Vant 1999). These values have been added to the specific yield-based estimates for the Upper Waikato, and are included in adjusted estimates of the background loads for this sub-catchment (Table 7).

Table 7: Loads of nitrogen and phosphorus in the Waikato River catchment during 2011–20. The combined loads from the various consented non-trivial point source discharges are shown, as are estimates of the pre-development or background loads, and the loads resulting from the use of land in the catchment.

	Upper Waikato		Waipa		Lower Waikato*		Combined	
Nitrogen (t/yr)								
Overall	3788		3621		3572		10,981	
Lake Taupo outflow	313	(8%)					313	(3%)
Point sources	207	(5%)	54	(1%)	421	(12%)	682	(6%)
Background	1463†	(39%)	927	(26%)	952	(27%)	3342	(30%)
Land use	1805	(48%)	2639	(73%)	2199	(62%)	6644	(61%)
Phosphorus (t/yr)								
Overall	224		240		266		729	
Lake Taupo outflow	23	(10%)					23	(3%)
Point sources	26	(12%)	12	(5%)	70	(26%)	108	(15%)
Background	151†	(68%)	93	(39%)	95	(36%)	339	(47%)
Land use	23	(10%)	135	(56%)	100	(38%)	259	(35%)

*Results are for Karapiro to Tuakau Bridge (area 3172 km^2), rather than to Port Waikato

†Includes geothermal inputs (see text)

[13] While the Cambridge and Hautapu discharges were included in the Lower Waikato section.

Subtracting (i) the point source loads, and (ii) the background loads from the total load gives an estimate of the load that is associated with the areas of the catchment that have been developed (generally for pastoral farming)—called “Land use” in Table 7.

Tables 2 and 7 show that during 2011–20 the rivers carried at least 10,980 t/yr of nitrogen and 730 t/yr of phosphorus to the Tasman Sea.[14] Overall, point source discharges contributed 6% of the nitrogen and 15% of the phosphorus that entered the sea. Most of the point source load of nitrogen was discharged to the main-stem of the Waikato River, with 30% to the Upper Waikato and 62% to the Lower Waikato. Similarly, 24% of the point source phosphorus was discharged to the Upper Waikato sub-catchment and 65% to the Lower Waikato.

Within each section of the catchment, the proportion of the nutrient loads contributed by point sources also varied markedly. Just 1% of the nitrogen in the Waipa section came from point sources, compared with 12% in the Lower Waikato section (Table 7); similarly, 5% of the phosphorus in the Waipa section came from point sources, compared with 26% in the Lower Waikato section.

As noted above, runoff and leaching from all land in the catchment—both developed and undeveloped—contributes nutrients to the rivers. In the absence of other information, the background contribution from land that has been developed is assumed in this analysis to be the same as that from an equivalent area of undeveloped land.[15] So land that has been developed has both a “background” and a “land use” contribution. That is, “land use” refers to the part of the contribution from developed land that results from human activity and that is thus, in principle, manageable. By contrast, the “background” component from developed land can be regarded as being un-manageable or “natural”.

Exotic forestry is common in the Upper Waikato, but not in the Lower Waikato or the Waipa sub-catchments (Table 1). Nutrient loads from areas of forestry in the Waikato catchment are typically low, being similar to those from undeveloped areas (e.g. Schouten et al. 1981; Jenkins and Vant 2007). Pastoral agriculture is common in the Waikato catchment (Table 1), and typically has a higher nutrient yield than forestry (e.g. Vant 1999), so is likely to be the source of much of the development-derived nitrogen and phosphorus.

Between 48% (Upper Waikato) and 73% (Waipa) of the loads of nitrogen carried by the rivers is estimated to have come from diffuse agricultural sources, with these sources accounting for about 61% of the combined load of nitrogen transported to the Tasman Sea (Table 7). However, background and point source loads of phosphorus were somewhat more important than those of nitrogen. So lesser amounts—between 10% (Upper Waikato) and 56% (Waipa)—of the loads of phosphorus carried by the rivers are estimated to have come from diffuse agricultural sources, with land use accounting for about 35% of the combined load transported to the Tasman Sea (Table 7).

1.5 Summary and Conclusions

1. It is convenient to divide the catchment of the Waikato and Waipa Rivers into three roughly-equal sections: Upper Waikato, from the outflow of Lake Taupo to the Karapiro dam; Lower Waikato, from the Karapiro dam to the sea; and Waipa, the catchment of this major tributary of the Waikato River. Routine water quality and flow monitoring data were used to determine the loads of the plant nutrients nitrogen and

[14] As noted above, 357 km^2 of the catchment is downstream of the Tuakau Bridge monitoring site, and the nutrient loads from this area are not included in this analysis.

[15] The results obtained should therefore be regarded as indicative rather than definitive, as the extent to which these estimates accurately quantify the loads from all areas of undeveloped land in the catchment is unknown.

phosphorus in each sub-catchment during 2011–20. Each of the three sub-catchments contributed similar proportions—about one-third—of the loads of each nutrient.

2. Average river flow at the most downstream site during 2011–20 was 371 m^3/s; this was 8% lower than in 2003–12. The average load of phosphorus carried by the river during 2011–20, namely c. 730 t/yr, was also lower (25%), partly because of substantial reductions in the loads discharged at several of the important point source discharges in the catchment over the past 20 years. However, the average load of nitrogen carried by the river, namely c. 10,980 t/yr, was only slightly lower (3%) than during 2003–12, probably because the increases in concentrations of nitrogen observed in the river since 2001 largely-offset the lower river flows that occurred during the past decade.

3. Some 20 consented point sources discharge a variety of contaminants—including nitrogen and phosphorus—to waterbodies in the catchment. These sources include 12 sewage treatment plants of widely-varying size, and eight industrial discharges—dairy factories, meatworks, power stations and a pulp and paper mill. Consent monitoring data were used to calculate the loads of nitrogen and phosphorus from these operations during 2011–20. Wastewater flows and nutrient concentrations varied widely, depending on the size and nature of the operations. For example, the pulp and paper mill discharged a large volume of low-nutrient wastewater, while the two meatworks discharged much smaller volumes that contained relatively high nutrient concentrations.

4. The combined load of nitrogen discharged from the 20 point sources was about 682 t/yr, while that of phosphorus was about 108 t/yr. The load of nitrogen was about 7% lower than that discharged during 2003–12 (namely 730 t/yr); while the load of phosphorus was about 37% lower (171 t/yr in 2003–12). These reductions were mostly due to ongoing improvements in wastewater treatment at the sites.

5. Much (70%) of the combined point source load of nitrogen came from just four sites: Hamilton sewage (28%), Kinleith pulp and paper mill (22%), Horotiu meatworks and dairy factory (10%) and Cambridge sewage (10%). And more than half (54%) of the combined point source load of phosphorus came from just three sites: Hamilton sewage (24%), Kinleith pulp and paper mill (19%) and Horotiu meatworks and dairy factory (12%).

6. Altogether, the 20 point sources contributed about 6% of the load of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2011–20 (Table 7). They also contributed about 15% of the load of phosphorus. The largest number of point sources was found in the Lower Waikato sub-catchment, where they contributed 12% of the nitrogen and 26% of the phosphorus.

7. Naturally-occurring processes within the catchments also contribute to the nutrient loads in the rivers; and these processes would have operated prior to human use of the catchments. Between about one-third and one-half of the current loads of both nutrients is estimated to be due to these natural or “background” processes. A proportion of the loads from land that has been developed can be regarded as natural and essentially un-manageable.

8. Subtracting the contributions from point and natural sources from the overall loads carried by the rivers provides an estimate of the nutrient loads caused by use of the land—and in these catchments this largely means use of the land for pastoral farming. These diffuse, man-made sources contributed about 61% of the load of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2011–20, and about 35% of the phosphorus.

9. Figure 6 summarises these results. Figure 6A shows the relative contributions of the various sources (including the outflow from Lake Taupo) to the loads of nitrogen and phosphorus carried by the river as a whole. The loads for each of the three sub-catchments are shown in Figures 6B (nitrogen) and 6C (phosphorus).

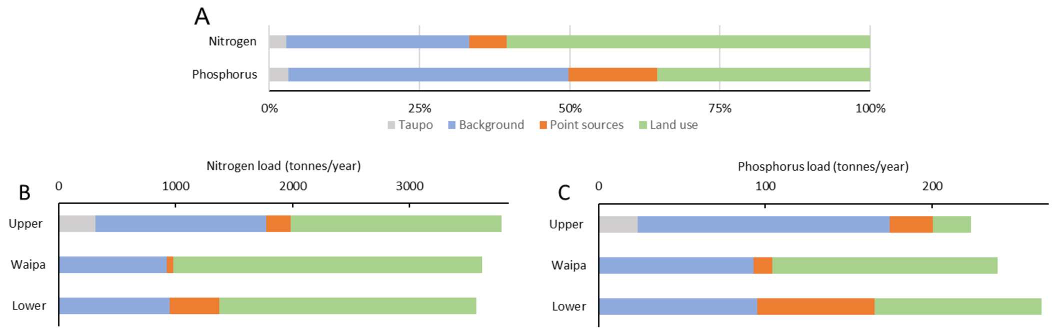

Figure 6: Sources of nitrogen and phosphorus to the Waikato and Waipa Rivers, 2011–20. A, relative contributions from the whole catchment (including the outflow from Lake Taupo); B and C, contributions of nitrogen and phosphorus from the three sub-catchments. See Table 7 for details.

2 Section 2, Hauraki rivers

2.1 Introduction

Four small-to-moderate rivers flow into the Firth of Thames: the Waitakaruru, Piako, Waihou and Kauaeranga Rivers (Fig. 7). These are collectively called the "Hauraki rivers". The Waitoa River, a major tributary of the Piako, enters about 40 km upstream of its mouth, while the Ohinemuri River enters the Waihou a similar distance from its mouth (Fig. 7). Altogether the area of the land that drains to the Firth is about 4200 km^2; about 65% of it is in pasture, with about 20% in native bush (Turner et al. 2006).[16] Some 60,000 people live here, many (c. 60%) in one of seven moderate-sized towns (c. 3500–7000 people each).[17] Table 8 lists some important characteristics of the catchments of the Hauraki rivers, showing that the pressures on them differ markedly. At one extreme the catchment of the Kauaeranga River is mostly covered by indigenous vegetation (90%). By contrast, the catchments of the Piako River and its Waitoa tributary are mostly covered in pasture (>90%; mainly dairy), and 11 treatment plants discharge wastewaters to these rivers (see later).

The Waikato Regional Council operates a routine river water quality monitoring programme that includes 19 sites in the catchments of the Hauraki rivers (Salu 2021). It also issues the resource consents that permit the discharge of treated wastewaters to these rivers; consent holders are required to monitor the flow and water quality of these discharges and to provide the information to the Council. Vant (1999) used this information to make some preliminary estimates of the relative importance of the various sources of the N and P that was carried by the Hauraki rivers in the 1990s. This was subsequently updated for the periods 2000–09 and 2006–15 (Vant 2011, 2016). This section refines and updates these earlier analyses for the decade 2011–20.

2.2 Loads carried by the rivers

The analysis of nutrient loads during 2006–15 was based on measurements made at 11 monitoring sites. In this update for 2011–20, where the focus is on the overall loads carried by the rivers, only the results for the seven most downstream sites on the main systems were considered (Fig. 7). These were Kauaeranga River at Smiths, Piako River at Paeroa-Tahuna Rd, Waitoa River at Mellon Rd, Ohinemuri River at Karangahake, Waihou River at Te Aroha, Hikutaia River at Maratoto Rd and Waitakaruru River at Coxhead Rd (Fig. 7). At the first five of these, the loads were calculated using monthly measurements of total N and total P concentrations, together with continuous records of river flow. At the remaining two sites less information was available, however, and the loads were estimated (see later).

Table 8: Landcover at selected sites on the Hauraki rivers in 2018 (LCDB5.1, WRC doc #3219468).

	Kauaeranga at Smiths	Waitoa at Mellon Rd	Piako at Paeroa-Tahina Rd	Ohinemuri at Karangahake	Waihou at Te Aroha
Area (km^2)	120	409	539	286	1107
Indigenous vegetation	90%	3%	5%	46%	24%
Exotic forest	5%	1%	1%	4%	16%
Pasture, crops	5%	94%	92%	47%	59%
Urban, water, other	<1%	2%	2%	3%	1%

[16] Note that the catchment drained by the Waikato and Waipa Rivers is 2–3 times larger than that of the Hauraki rivers. The average flows are thus considerably larger as well.

[17] Results of 2006 census, http://www.stats.govt.nz/Census/2006CensusHomePage/QuickStats/AboutAPlace.aspx

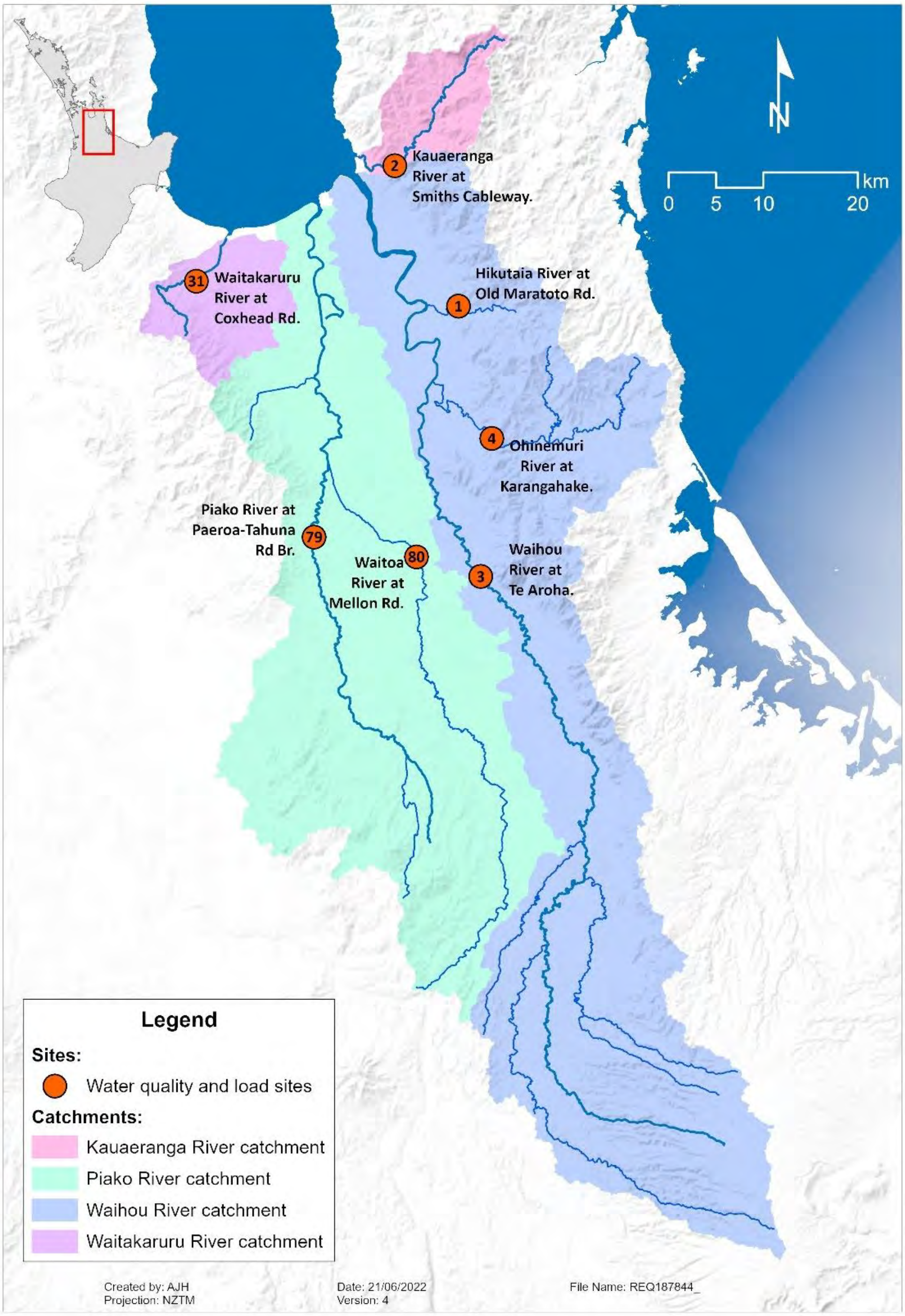

Figure 7: The four Hauraki river catchments, showing the seven sites at which nutrient loads were determined.

At each of the five sites with continuous flow records,[18] the nutrient loads were calculated by applying "nutrient ratings" to the flow duration curves as described above for the Waikato and Waipa sites. In each case there was a statistically significant relationship between the logarithms of flow and total N concentration, with the correlation coefficients being between about 0.4 and 0.8. And at three of these there were significant relationships with total P concentration as well (r=0.5–0.7). However, at Waihou River at Te Aroha total P showed little dependence on flow (r=0.1), while at Piako River at Paeroa-Tahuna Rd there was an inverse relationship (r=–0.5). Figure 8 shows how the concentrations of total N and total P varied with flow at the Waitoa at Mellon Rd site. In each case, higher flows were associated with higher concentrations, with the log-log correlation coefficients being 0.8 and 0.7 for total N and total P, respectively.

The extent to which the loads of total N and total P varied at each site also depended on the extent to which flows themselves varied, with some sites exhibiting less flow variability than others. For example, during 2011–20 high flow (95-percentile) in the Piako River at Paeroa-Tahuna Rd was about 60 times higher than low flow (5-percentile); but in the Waihou River at Te Aroha, high flow was less than four times higher than low flow. The seasonal variation in the loads of total N and total P at these two sites is shown in Figure 9. Loads of both total N and total P tended to be 10–100 times higher during the winter than in the summer at the Piako River site, whereas the loads at the Waihou River site showed much less seasonal variability.

There was no record of river flow at the Hikutaia River site (catchment area 73 km^2). In this case, the flow at the time of each monthly sampling visit was estimated from the corresponding flow in the Kauaeranga River, taking account of the catchment areas at the two locations. The estimated flows and measured concentrations were used to calculate flow-weighted average concentrations of total N and total P at the Hikutaia River site. Following Littlewood et al. (1998), loads were then calculated by multiplying the flow-weighted average concentrations by the average flow in the Hikutaia River during 2011–20; this was estimated from the average flow in the Kauaeranga (Table 9), taking account of the respective areas.[19]

A similar approach was used to calculate the loads during 2011–20 at the Waitakaruru site (catchment area 50 km^2). In this case the flow record used was from the Jefferis site on the Mangawara River (catchment area 98 km^2), 25 km to the south, where the average flow during 2011–20 was 1.7 m^3/s.

Table 9 shows the average loads of nitrogen and phosphorus at the seven river monitoring sites during 2011–20. The combined flow of the Hauraki rivers averaged about 70 m^3/s, with the combined loads of nitrogen and phosphorus averaging about 3670 t/yr and 200 t/yr, respectively (but see later for more comprehensive estimates). The Waihou River was the largest and carried the greatest share of the nutrients (c. 60%), while the Kauaeranga and Waitakaruru Rivers carried just 1–2% of the loads of nitrogen and phosphorus. Conversely, the Piako River carried 17% of the combined river flow, but 37–39% of the loads of nitrogen and phosphorus. These differences largely reflected the lower nutrient concentrations found in the Kauaeranga River. The Ohinemuri River also had relatively low nutrient concentrations and carried a disproportionately-low share of the nutrient loads.

[18] At all five sites flows were recorded at 5-minute intervals.

[19] This method of calculating loads is less precise than Sedrate's site-specific rating-based approach. However, the nutrient loads carried by the relatively-small Hikutaia River—and by the Waitakaruru River where the same method was used—are only a minor fraction of the loads carried by the Hauraki rivers as a whole.

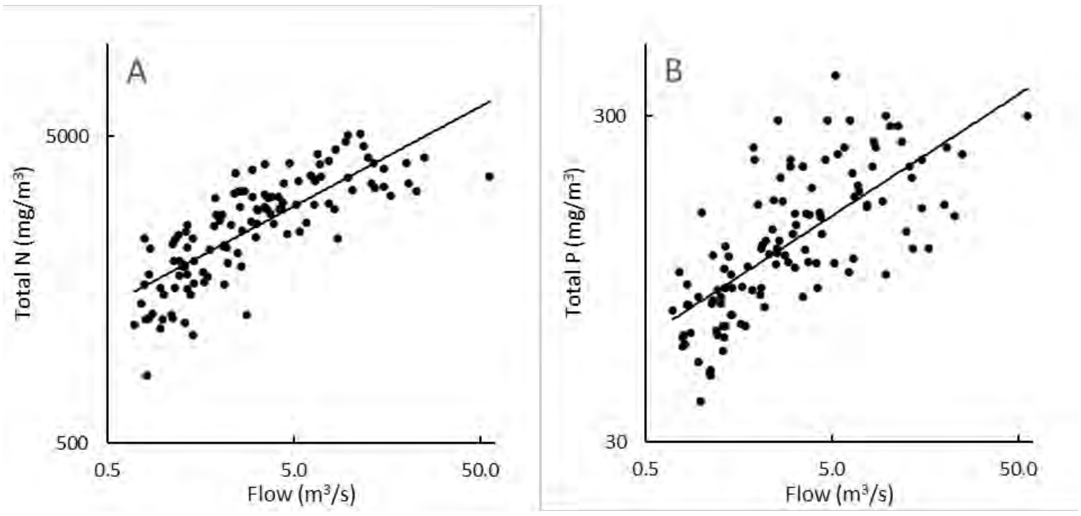

Figure 8: Monthly measurements of flow and A, total N, and B, total P at the Waitoa at Mellon Rd site, 2011–20. Note that the lines indicate the simple linear relationships (in log-log space) between flow and concentration and not the LOWESS curvilinear relationships used in Sedrate.

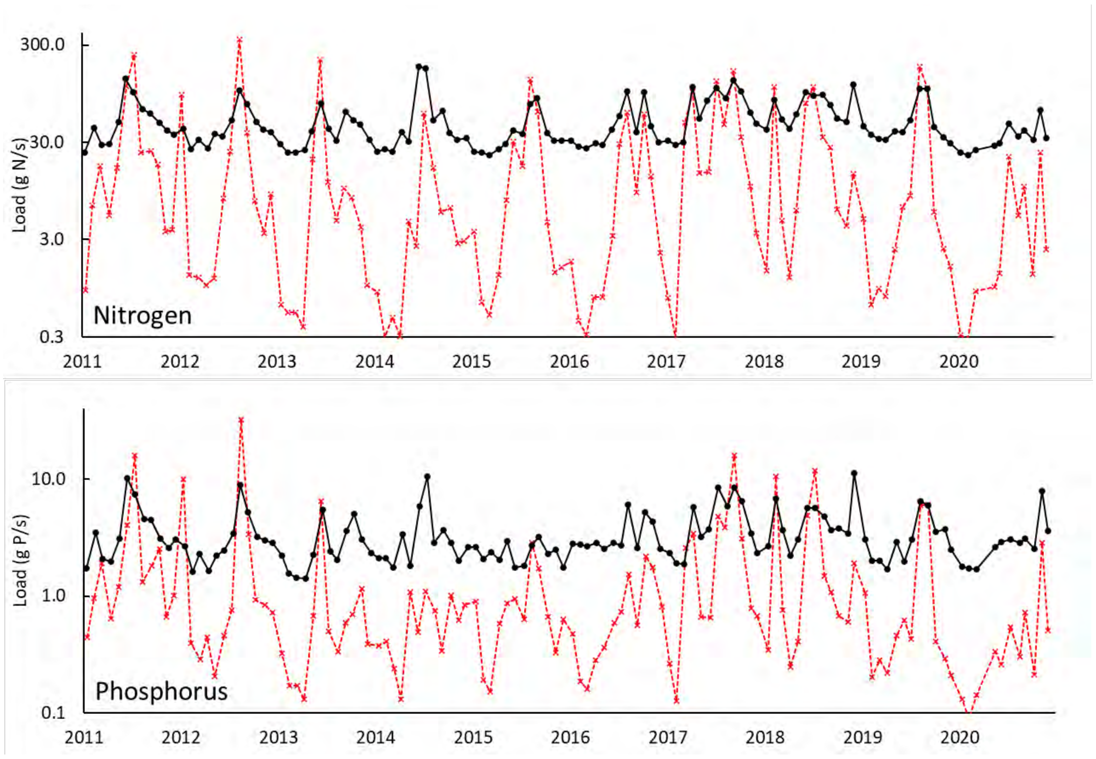

Figure 9: Instantaneous loads of nitrogen and phosphorus in the Waihou River (Te Aroha; black circles, solid line) and the Piako River (Paeroa-Tahuna Rd; red crosses, dotted line) at monthly intervals during 2011–20.

Table 9: Average flows and loads of nitrogen and phosphorus in four Hauraki river systems, 2011–20 (site locations in Fig. 7). Values in italics are estimated: see text. Note that the totals are lower than the more comprehensive values shown in Table 14.

	Flow (m^3/s)		Nitrogen (t/yr)		Phosphorus (t/yr)	
Kauaeranga						
Kauaeranga at Smiths	5.9	(8%)	55	(2%)	3	(2%)
Piako						
Piako at Paeroa-Tahuna Rd	7.2		882		45	
Waitoa at Mellon Rd	4.7		533		29	
Piako combined	11.9	(17%)	1415	(39%)	74	(37%)
Waihou						
Hikutaia at Maratoto Rd	*3.6*		*49*		*3*	
Ohinemuri at Karangahake	11.9		426		8	
Waihou at Te Aroha	35.6		1693		109	
Waihou combined	51.1	(73%)	2168	(59%)	121	(60%)
Waitakaruru						
Waitakaruru at Coxhead Rd	*0.9*	*(1%)*	*32*	*(1%)*	*3*	*(1%)*
All four rivers	69.7	(100%)	3669	(100%)	200	(100%)

Vant (2011) described the average flows and average loads of nitrogen and phosphorus at these Hauraki river monitoring sites during 2000–09.[20] The combined river flow in the two periods was similar (namely about 70 m^3/s). However, the combined load of nitrogen transported during 2011–20 was about 10% higher than that carried during 2000–09, while the combined load of phosphorus was about 27% lower.[21] This implies that changes in the nutrient concentrations at the various sites have probably affected the loads carried. Figure 10 shows the changes in the concentrations of total N and total P at the four largest downstream sites during 2001–20. And Table 10 shows the rates at which concentrations changed over this 20-year period.

Trends in total N concentration were very likely to have occurred at all the sites apart from those on the Kauaeranga and Waitoa Rivers (Table 10). Slight increases (0.7 to 0.8% per year) occurred at two sites, and decreases (0.8 to 1.5% per year) occurred at three sites. Substantial decreases in total P concentrations apparently occurred at all sites apart from that on the Waihou River (but note the earlier comments on the reliability of WRC's records of total P over this period). The large decreases in the Waitoa and Ohinemuri Rivers were partly due to the major reductions in the phosphorus loads discharged from one of the point sources in each of those catchments since 2000 (Vant 2011, 2016).[22]

The average rates of change in the nitrogen and phosphorus concentrations in the Hauraki rivers were determined using a load-weighted approach similar to that described above for the combined point source nutrient loads discharged to the Waikato and Waipa Rivers. Table 10 shows the average nutrient loads determined at each monitoring site during 2011–20; these were used to weight the rate of change in concentration observed at each site.

[20] The loads reported there, however, were the average of those calculated using all of Sedrate's bias correction procedures, whereas the values reported here are those obtained from just one of those procedures (namely that based on LOWESS curve-fitting and Smearing bias correction). Appendix 1 shows the results for 2011–20 and the corresponding results for 2000–09 (from WRC doc #4081893).

[21] As noted above for the Waikato and Waipa Rivers, an important contributor to these lower loads of phosphorus has been the reductions the loads discharged from point sources.

[22] Namely the Waitoa dairy factory (site P) and Waihi sewage (site F): see later.

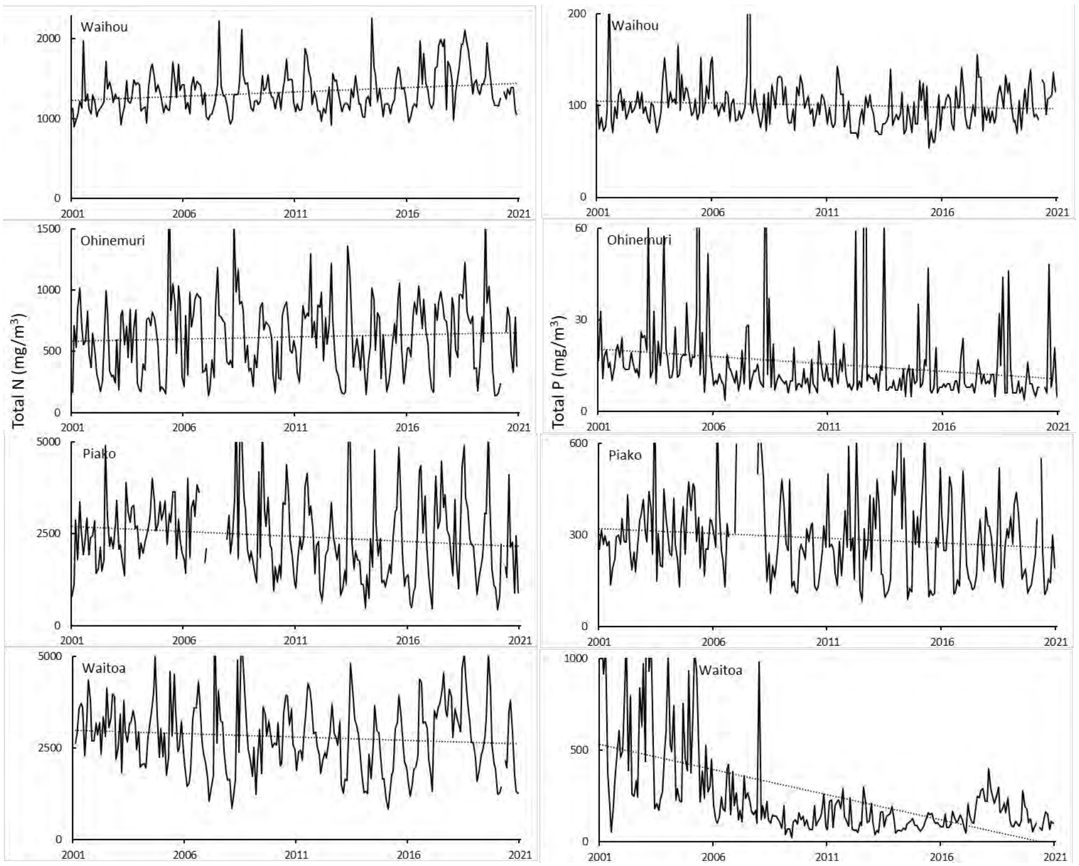

Figure 10: Concentrations of total N and total P at four sites on the Hauraki rivers, 2001–20. Note the different vertical scales. The dashed lines broadly indicate the overall trends in the records; see also Table 10.

Table 10: Changes in flow-adjusted concentrations of total N and total P at seven water quality monitoring sites on the Hauraki rivers during 2001–20. Values are trend slopes (% per year) and, in brackets, probabilities that the slopes are different from zero (%). Trends that are very likely to have occurred (slope probability >95%) are shown in bold type, with decreases in blue and increases in red. See Vant (2018) for further details. The average loads of each nutrient transported during 2011–20 (see Table 9) are also shown. These were used to determine the load-weighted average rates of change in the concentrations during 2001–20 (see text).

Site	Total N		Total P	
	Rate of change	Load (t/yr)	Rate of change	Load (t/yr)
Waihou at Te Aroha	**0.8 (>99)**	1693	–0.2 (85)	109
Piako at P-T Rd	**–0.8 (99)**	882	**–1.6 (>99)**	45
Waitoa at Mellon Rd	0.1 (71)	533	**–5.6 (>99)**	29
Ohinemuri at Karangahake	**0.7 (99)**	426	**–4.0 (>99)**	8
Kauaeranga at Smiths	–0.5 (76)	55	**–1.0 (99)**	3
Hikutaia at Maratoto Rd	**–1.3 (99)**	*49*	**–3.7 (>99)**	*3*
Waitakaruru at Coxhead Rd	**–1.5 (>99)**	*32*	**–2.9 (>99)**	*3*
Average (load-weighted)	+0.2		–1.5	

The upper and lower bounds to the changes in the nutrient concentrations in the Hauraki rivers as a whole were determined as follows:

- upper bound: use all available trend slopes regardless of slope probability to calculate the load-weighted average rate of change in nutrient concentrations; and
- lower bound: set trend slopes that were "not very likely" (i.e. slope probability <95%) equal to zero, and calculate the load-weighted average rate of change in nutrient concentrations.

Even though there were relatively large changes in nutrient concentrations in individual rivers during 2001–20—both increases and decreases (Table 10), the overall, load-weighted average rate of change in total N concentration in the Hauraki rivers during was small, being an increase of between 0.22 and 0.23% per year. The equivalent change in total P concentration, however, was a decrease of between 1.4 and 1.6% per year (but note the earlier comments about the reliability of WRC's long-term records of total P).[23]

2.3 Loads from point sources

2.3.1 Monitoring information

Figure 11 shows the location of 24 sites where contaminants are discharged to the Hauraki rivers: 11 in the greater Piako catchment, 12 in the greater Waihou catchment and one to the Waitakaruru River. Each can be regarded as being a non-trivial point source of nitrogen and phosphorus.[24] Some 14 of these locations are sites where sewage wastewaters from towns and other smaller settlements are treated, while the remaining ten are various industrial sites, mainly dairy factories and meatworks (Table 11). In each case the discharge of treated wastewater is permitted by a resource consent issued by the Waikato Regional Council. The terms of these consents generally limit both the volume and the water quality of the effluent that may be discharged; they also require the consent holders to regularly monitor these variables and to provide this information to the Council.

This consent monitoring information was used to determine the average loads of nitrogen and phosphorus that were discharged from each of the point sources during 2011–20. Electronic copies of the monitoring information were generally available in the Council's document management system. These records were retrieved, collated and checked for errors.

In most cases, daily wastewater volumes were recorded; samples of wastewater were often collected monthly, although fortnightly or weekly samples were collected in other cases (Table 11). However, the available records varied in their completeness: records covering 110 or more of the 120 months of the decade were available for 10 sites (B, F, G, K, N, O, S, T, V and W); and reasonably-complete records (100–109 months) were available for a further seven sites (Table 11). Although the amount of information available for the remaining sites was limited or patchy, it was regarded as being adequate for determining the decadal-average results used here.

The wastewater samples were usually analysed for total N and total P, but in some cases these variables needed to be estimated from the results of other analyses, including ammoniacal-N, Kjeldahl-N and dissolved reactive P (see Table 11).

---

[23] Similar calculations were made to determine the overall rates of change of nutrient concentrations during 2011–20 (using the trend slopes for just that decade: data not shown). These showed that total N concentration increased by between 1.1 and 1.3% per year then, while total P concentration showed little change (between –0.1 and 0.2% per year).

[24] As with the Waikato-Waipa catchments, the diminishing number of discharges of farm dairy effluent are not considered in this analysis. Rather they are regarded as part of the loads contributed by land that has been developed for farming.

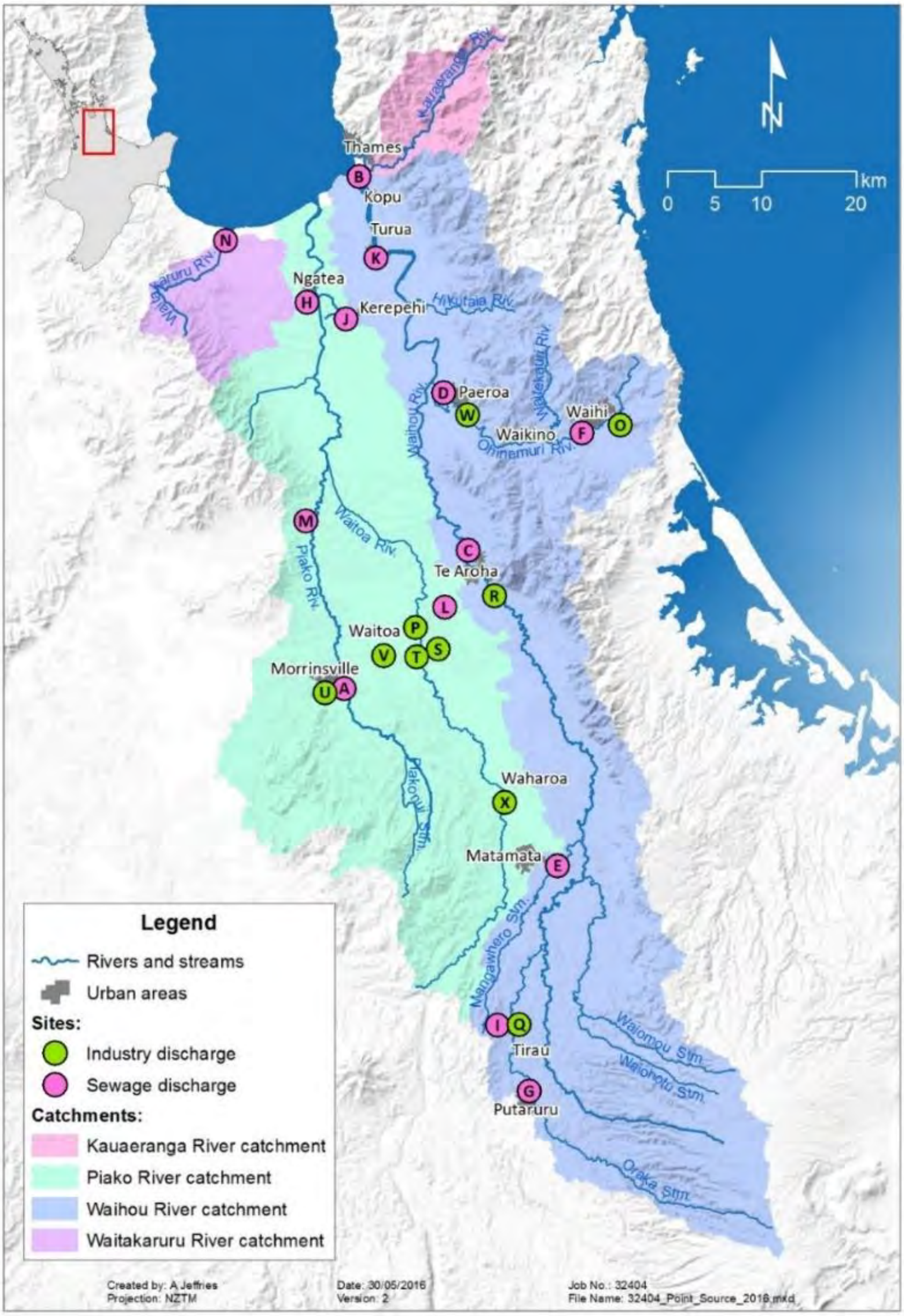

Figure 11: Location of 24 discharges of wastewaters discharging to the Hauraki rivers. See Table 11 for further details.

Table 11: Summary of consent monitoring information held by Waikato Regional Council for 24 point source discharges to the Hauraki rivers, 2011–20.

	Site	WRC document number	Period	Number of samples (N, P)
	Sewage wastewater			
A	Morrinsville	4103351	2011–20[a]	354, 354
B	Thames	4103630	2011–20	133, 134
D	Paeroa	4106251	2011–20	117, 117
F	Waihi	4105536	2011–20	122[d], 119
E	Matamata	4103427	2011–20[a]	148, 145
C	Te Aroha	4103413	2011–20[a]	124, 125
G	Putaruru	4078729	2011–20	133, 133
H	Ngatea	4109169	2011–20	116, 114[e]
I	Tirau	4079532	2011–20[a]	110, 99
J	Kerepehi	4108688	2011–20	116, 116
K	Turua	6119961	2011–20	121, 123
M	Tahuna	4103393	2011–20[b]	120, 117
N	Waitakaruru	6121490	2011–20	492, 492
L	Waihou	4103543	2012–18[c]	153, 153
	Industrial wastewater			
O	Waihi gold mine	4103172	2011–20	128[f], 123
P	Waitoa dairy factory	8338554	2011–20[a]	411, 411
Q	Tirau dairy factory	8412655	2011–20	428, 429
R	Te Aroha meatworks	4102479	2011–20[a]	207, 204
S	Waitoa poultry processor	4099776	2011–20	206, 276
T	Waitoa meatworks	3855752	2011–20	250, 210
U	Morrinsville dairy factory	8770554	2011–20[a]	204, 204
X	Waharoa dairy factory	3920447	2011–20[a]	116, 116
V	Tatuanui dairy factory	21360372	2011–20	116, 116
W	Paeroa meatworks	4102448	2011–17	134, 135

Notes
a, Some gaps
b, Flows for 2011–16 only
c, Flows for 2013–16 only
d, Total Kjeldahl N only
e, Dissolved reactive P only
f, Ammoniacal-N only

While many of the discharges were more-or-less continuous, six of the industrial discharges tended to be seasonal. These included the Tirau and Waitoa dairy factories, and three discharges in the Waitoa catchment where consent conditions prohibited discharge during low river flow in summer (sites S, T and X; see below also). In addition, the Paeroa meatworks generally only discharged during spring—until it closed in late 2017. The wastewater flows and nutrient loads described here were all averaged across the whole decade.

2.3.2 Wastewater flows and nutrient concentrations

Table 12 shows the average wastewater flows and average nitrogen and phosphorus concentrations in the 24 discharges of wastewater. Average flows of wastewater varied markedly between the different sites, reflecting differences in the number of people living in each town or settlement, and the nature and scale of the different industries. For example, large volumes of groundwater and stormwater collected in the pit at the Waihi gold mine and were pumped to a treatment plant. By contrast, for much of the decade there was no discharge from the Paeroa meatworks.

Table 12: Average flows of wastewater and average concentrations and loads of nitrogen and phosphorus from 24 consented discharges to Hauraki rivers, 2011–20 ("Pk", discharged in the Piako catchment; "Wh", discharged in the Waihou catchment). Site locations are shown in Figure 11.

	Site	Flow (m^3/day)	Concentration (g/m^3) Total N	Concentration (g/m^3) Total P	Load (t/yr) Total N	Load (t/yr) Total P
	Sewage wastewater					
A	Morrinsville (Pk)	4290	12	7.3	19	10.6
B	Thames (Wh)	3510	21	2.6	27	3.0
D	Paeroa (Wh)	2140	11	2.8	9	2.0
F	Waihi (Wh)	1790	11	0.2	7	0.1
E	Matamata (Wh)	1760	17	6.2	12	4.0
C	Te Aroha (Wh)	1560	28	1.7	16	1.0
G	Putaruru (Wh)	1150	29	5.5	12	2.3
H	Ngatea (Pk)	340	18	3.8	2	0.4
I	Tirau (Wh)	250	37	5.1	3	0.4
J	Kerepehi (Pk)	190	15	4.7	1	0.3
K	Turua (Wh)	100	17	7.0	1	0.2
M	Tahuna (Pk)	30	5	0.5	<1	<0.1
N	Waitakaruru	20	23	7.4	<1	0.1
L	Waihou (Pk)	20	23	6.2	<1	<0.1
	Sub-total sewage				**109**	**24**
	Industrial wastewater					
O	Waihi gold mine (Wh)	11,770	3	<0.1	12	<0.1
P	Waitoa dairy factory (Pk)	6610	4	0.3	9	0.6
Q	Tirau dairy factory (Wh)	2300	26	12.0	25	9.7
R	Te Aroha meatworks (Wh)	830	74	24.1	24	7.6
S	Waitoa poultry processor (Pk)	680	11	2.6	3	0.5
T	Waitoa meatworks (Pk)	480	160	22.1	28	3.8
U	Morrinsville dairy factory (Pk)	470	1	0.2	<1	<0.1
X	Waharoa dairy factory (Pk)	310	20	9.1	2	0.8
V	Tatuanui dairy factory (Pk)	200	12	0.4	1	<0.1
W	Paeroa meatworks (Wh)	70	35	6.3	1	0.1
	Sub-total industrial				**105**	**23**
	Total				**214**	**48**

The average concentrations of nitrogen and phosphorus in the different wastewaters also varied markedly, reflecting both the nature of the activity and the efficiency of wastewater treatment. For example, the wastewater from the Te Aroha and Waitoa meatworks contained much higher nutrient concentrations than those from the Waihi mine and the Morrinsville dairy factory, mainly due to the different nature of the operations at each site. Note that the much of the wastewater from the Morrinsville dairy factory was routed to the town's sewage treatment plant (and was thus included in the discharge from that site); only "low strength" condensate and boiler water was discharged directly from the factory. The wastewaters from the other dairy factories, by contrast, generally came from a wider range of factory processes.

2.3.3 Loads

In most cases, average values of wastewater flow and nutrient concentration were calculated for each month (as described above for the discharges to the Waikato and Waipa Rivers). Multiplying these values together gave the average nutrient load discharged in that month. The average number of separate monthly products of flow and concentration available for both nitrogen and phosphorus in the various discharges during the decade (i.e. 120 months) was 102 (range 38–120). Figure 12 shows the monthly-average loads of nitrogen (Figs 12A-to-C) and phosphorus (Figs 12D and 12E) at five selected sites.

The combined load of nitrogen discharged from the 24 point sources during 2011–20 averaged about 214 t/yr (Table 12). Nearly two-thirds of this came from six sites: Waitoa meatworks (13%), Thames sewage (12%; Fig. 12A), Tirau dairy factory (12%), Te Aroha meatworks (11%), Morrinsville sewage (9%) and Matamata sewage (6%). By contrast, nine sites each contributed less than 1% of the total. For phosphorus, the combined load averaged about 48 t/yr (Table 12). Three-quarters of this came from five sites: Morrinsville sewage (22%), Tirau dairy factory (20%; Fig. 12D), Te Aroha meatworks (16%), Matamata sewage (8%) and Waitoa meatworks (8%; Fig. 12E). By contrast, 13 sites each contributed less than 1% of the total.

The nutrient loads at each site varied throughout the decade. Although some of this appeared to be random variability, several of the discharges also showed marked seasonal variability (e.g. Figs 12A, 12C and 12E). Following Vant (2018), the monthly-average records of nutrient loads at each of the sites during 2011–20 were analysed for trends. Table 13 shows the trend slopes—or overall rates of change in nutrient loads across the decade—and the probability that the slopes were different from zero. Altogether, 15 of the records showed increasing nutrient loads (e.g. Figs 12B and 12D), with 10 of these occurring at sewage treatment sites. However, 11 records showed decreasing loads, with six of these at sewage treatment sites (e.g. Fig. 12A).

Large reductions in the loads of nitrogen occurred at the Waitoa meatworks and at both the Morrinsville and Te Aroha sewage sites (Table 13). In all three cases the rate of change in load was relatively-large (–7 to –13% per year) and the site contributed a relatively-large proportion of the combined nitrogen load (8–13%). Offsetting these improvements were the large increases in the loads discharged from the Waihi sewage site (Fig. 12B) and the Te Aroha meatworks. Although Waihi sewage only contributed a modest proportion of the combined load (3%), the rate at which the load increased was large (22% per year). At the Te Aroha meatworks both the proportion of the combined load and the rate of increase were relatively-large (11%, and 7% per year, respectively).

A large reduction in the load of phosphorus also occurred at the Morrinsville sewage site where the rate of change in load over the decade approached –5% per year, with the site contributing 22% of the combined load. Although the phosphorus load also fell rapidly at the Te Aroha sewage site (–18% per year), this site only contributed about 2% of the combined load. On the other hand, large increases in phosphorus loads occurred at the Tirau dairy factory (Fig. 12D) and the Te Aroha meatworks. In both cases the rate of increase was moderately-large (9–14% per year) and the site contributed a moderately-large proportion of the combined load (16–20%).

For any given month in the decade, the number of sites for which a nutrient load could be determined varied markedly: from 11-to-24 sites for both nitrogen and phosphorus loads (average 20 per month for both). As a result, it was not possible to calculate reliable values of the combined nutrient load from point sources for many of the months. Neither could changes over time in the combined load be determined this way. Instead, the overall changes in the combined loads of nitrogen and phosphorus discharged from the 24 point sources during 2011–20 were determined by taking account of both the change in load at each site and each site's contribution to the combined loads (Table 13).

Upper and lower bounds to the changes were determined as follows:

- upper bound: use all available trend slopes regardless of slope probability to calculate the load-weighted average rate of change in nutrient loads; and
- lower bound: set trend slopes that were "not very likely" (i.e. slope probability <95%) equal to zero, and calculate the load-weighted average rate of change in loads

The combined load of point source nitrogen that was discharged was thus calculated to have decreased by between 1.4% per year and 1.5% per year during 2011–20. And the combined load of phosphorus increased by between 3.3% per year and 3.4% per year.

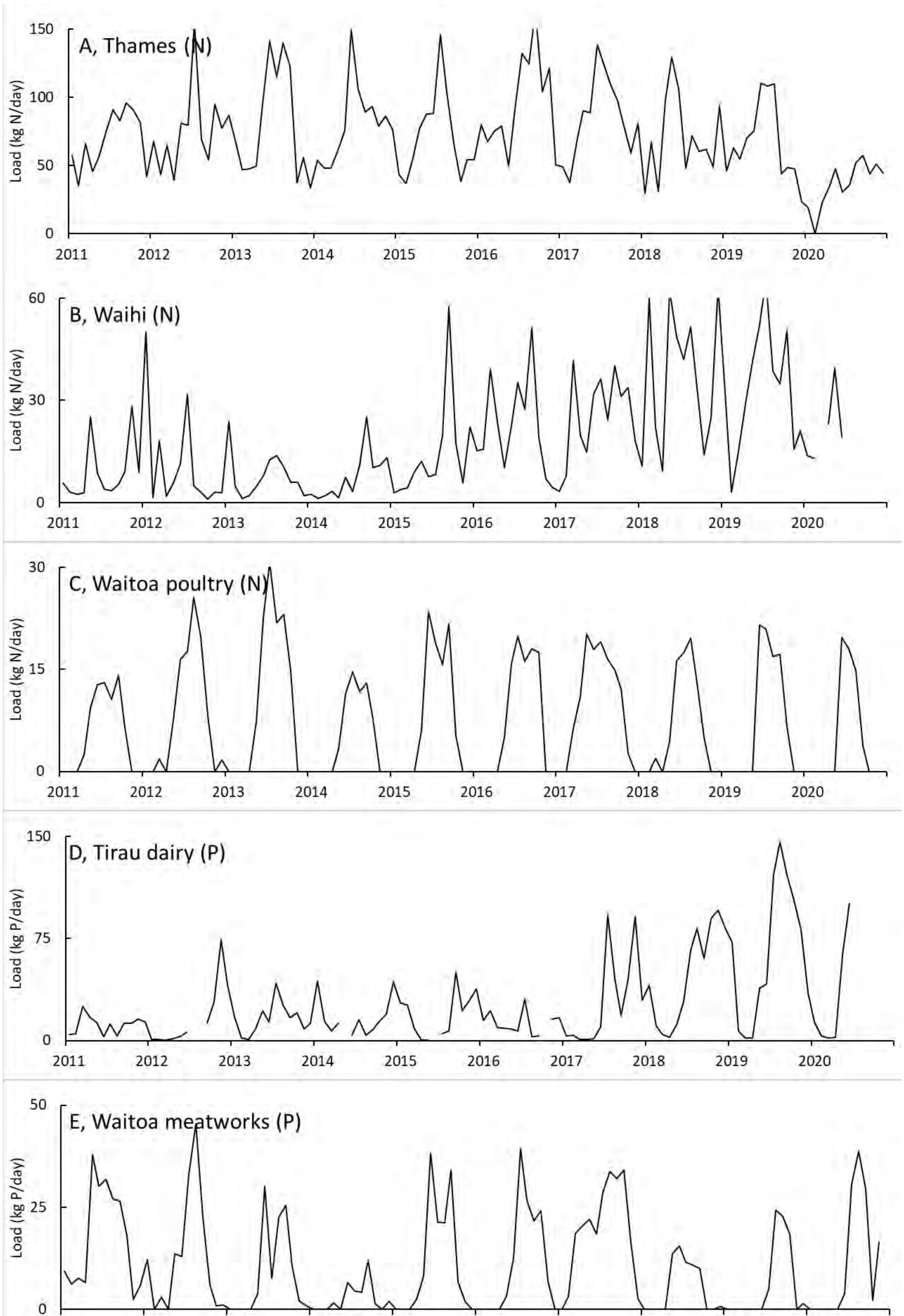

Figure 12: Monthly-average loads of nitrogen or phosphorus from five selected point sources during 2011–20. A, Thames sewage (N); B, Waihi sewage (N); C, Waitoa poultry processor (N); D, Tirau dairy factory (P); and E, Waitoa meatworks (P).

Table 13: Slopes (% per year) and, in brackets, slope direction probabilities (%) of monthly records of the nitrogen and phosphorus loads discharged from 24 point sources during 2011–20. Trends that are very likely to have occurred (slope probability >95%) are shown in bold type, with decreases in blue and increases in red. The contributions (%) of each site to the combined nutrient load from point sources are also shown. "id", insufficient data (*n*<60).

	Site	N slope	P slope	Load N (%)	Load P (%)
	Sewage wastewater				
A	Morrinsville	**−8.3 (99)**	**−4.6 (97)**	9	22
B	Thames	**−2.5 (97)**	−1.4 (92)	13	6
D	Paeroa	**8.6 (>99)**	**4.1 (>99)**	4	4
F	Waihi	**21.7 (>99)**	**20.3 (>99)**	3	<1
E	Matamata	−3.3 (93)	0.3 (56)	6	8
C	Te Aroha	**−12.9 (>99)**	**−17.9 (>99)**	8	2
G	Putaruru	**4.3 (>99)**	**1.3 (99)**	6	5
H	Ngatea	**12.3 (>99)**	**10.7 (>99)**	1	1
I	Tirau	−2.1 (92)	0.2 (60)	2	1
J	Kerepehi	**8.9 (>99)**	1.1 (70)	<1	1
K	Turua	−1.9 (87)	**−2.2 (98)**	<1	1
M	Tahuna	id	id	<1	<1
N	Waitakaruru	**7.8 (>99)**	−2.6 (92)	<1	<1
L	Waihou	id	id	<1	<1
	Industrial wastewater				
O	Waihi gold mine	**−7.7 (99)**	**−4.0 (97)**	6	<1
P	Waitoa dairy factory	**−6.3 (99)**	**4.9 (>99)**	4	1
Q	Tirau dairy factory	1.4 (67)	**14.4 (>99)**	12	20
R	Te Aroha meatworks	**7.5 (>99)**	**8.6 (>99)**	11	16
S	Waitoa poultry processor	0.0 (50)	0.0 (50)	1	1
T	Waitoa meatworks	**−7.4 (>99)**	0.0 (50)	13	8
U	Morrinsville dairy factory	**−6.0 (>99)**	**16.5 (>99)**	<1	<1
X	Waharoa dairy factory	0.0 (50)	0.0 (50)	1	2
V	Tatuanui dairy factory	0.8 (66)	1.5 (78)	<1	<1
W	Paeroa meatworks	0.0 (50)	0.0 (50)	1	<1

The nutrient loads discharged to the Hauraki rivers during 2011–20 can be compared with those reported by Vant (2011) for the period 2000–09 (see Appendix 2). The combined load of nitrogen discharged from the point sources during 2011–20 (214 t/yr) was about 18% lower than that discharged during 2000–09 (namely 262 t/yr); and the combined load of phosphorus was nearly 30% lower (loads of 48 t/yr and 68 t/yr, respectively).

2.4 Components of the total loads in rivers

The loads of nitrogen and phosphorus discharged from the point sources described above (Table 12) can be directly compared with the total loads of these nutrients that are carried by the Hauraki rivers (Table 9). Furthermore, by estimating the contributions from background—that is, the loads that would have been carried by the rivers prior to development of their catchments—it is possible to also estimate the loads that have resulted from the use of the land.[25]

The only information for the Kauaeranga River is for the monitoring site at Smiths (Fig. 7). The individual components of the overall load were therefore calculated for this site. The discharge of sewage wastewater from the settlement of Waitakaruru enters the Waitakaruru River downstream of the monitoring site at Coxhead Rd, so the wastewater load was added to that carried at Coxhead Rd. There are two downstream sites in the Piako catchment—Piako River at Paeroa-Tahuna Rd and Waitoa River at Mellon Rd—and the loads at these sites were combined. The discharges of sewage wastewater from Kerepehi, Ngatea and Tahuna enter the Piako River downstream of these monitoring sites,

[25] As noted above, this amounts to a form of "contaminant accounting" as is now required by the National Policy Statement for Freshwater Management (2020).

so the loads from these three point sources were added to those for the river sites to obtain the combined load for the Piako River.

The most downstream monitoring site on the Waihou River itself is at Te Aroha (noting that this site is more than 65 km from the mouth of the river). Various tributaries (Fig. 7)—including the moderately-large Ohinemuri River—and several point source discharges (Fig. 11) enter the river downstream of the monitoring site at Te Aroha. The nutrient loads carried by the Waihou River were therefore estimated as being (at least) the sum of the values for the following sites: Waihou River at Te Aroha, Ohinemuri River at Karangahake and Hikutaia Stream at Maratoto Rd, plus the wastewater from the Paeroa meatworks and the sewage wastewaters from Paeroa, Te Aroha, Thames and Turua.

Table 14 shows the average loads of nitrogen and phosphorus carried by the four Hauraki rivers during 2011–20. The contributions to these loads from the point source discharges listed in Table 12 are also shown. As described above for the Waikato and Waipa catchments, pre-development or background loads were calculated from the respective catchment areas (Table 14) and estimates of the specific yields from undeveloped land, namely 3 kg/ha/yr for nitrogen and 0.3 kg/ha/yr for phosphorus. Subtracting the point source and background loads from the total load gives an estimate of the load that is associated with the areas of the catchment that have been developed (generally for pastoral farming)—called "Land use" in Table 14.

Altogether, on average the four rivers carried about 3726 t/yr of nitrogen and 207 t/yr of phosphorus during 2011–20 (Table 14). The Waihou River carried 60–61% of the combined loads while the Piako carried 36–38%; the Kauaeranga and Waitakaruru Rivers each carried 1–2%.

Point source discharges contributed 5% of the nitrogen carried by the Piako River and 7% of that carried by the Waihou River. Overall, point sources contributed just 6% of the load of nitrogen that was carried by the Hauraki rivers. However, the discharges were important sources of the phosphorus load carried by the rivers, accounting for 23% of the load in the Piako River and 24% of that in the Waihou River. Overall, point sources contributed about 23% of the load of phosphorus that was carried by the Hauraki rivers.

Table 14: Loads of nitrogen and phosphorus in the lower reaches of four Hauraki rivers during 2011–20. The combined loads from the various non-trivial point source discharges are shown, as are estimates of the pre-development or background loads, and the loads resulting from the use of land in the catchment (see text). Values are rounded; note that the totals differ from those in the less comprehensive analysis in Table 9. The catchment area upstream of the monitoring site(s) on each river is also shown.

	Kauaeranga		Piako		Waihou		Waitakaruru		All four rivers	
Area (km^2)†	120		948		1466		50			
Nitrogen (t/yr)										
Overall	55		1418		2222		32		3726	
Point sources	0	(0%)	65	(5%)	149	(7%)	<1	(1%)	214	(6%)
Background	36*	(66%)	284	(20%)	440	(20%)	15*	(47%)	775	(21%)
Land use	19*	(34%)	1069	(75%)	1633	(73%)	17*	(53%)	2737	(73%)
Phosphorus (t/yr)										
Overall	3		74		127		3		207	
Point sources	0	(0%)	17	(23%)	31	(24%)	<1	(2%)	48	(23%)
Background	≥3*	(>90%)	28	(38%)	44	(35%)	2*	(53%)	78	(37%)
Land use	<1*	(<10%)	29	(39%)	53	(41%)	1*	(44%)	82	(40%)

†Piako = Piako at Paeroa-Tauna Rd (539 km2) plus Waitoa at Mellon Rd (409 km^2); Waihou = Waihou at Te Aroha (1107 km^2) plus Ohinemuri at Karangahake (286 km^2) plus Hikutaia at Maratoto Rd (73 km^2)

*Values imprecise, being dependent on the assumed nutrient yields for undeveloped land

As noted above, runoff and leaching from all land in the catchment—both developed and undeveloped—contributes nutrients to the rivers. In the absence of other information, the background contribution from land that has been developed is assumed in this analysis to be the same as that from an equivalent area of undeveloped land.[26] So land that has been developed has both a "background" and a "land use" contribution. That is, "land use" refers to the part of the contribution from developed land that results from human activity and that is thus, in principle, manageable. By contrast, the "background" component from developed land can be regarded as being un-manageable or "natural".

Exotic forestry is moderately-important in the Waihou catchment, but not in the other Hauraki catchments (Table 8). Furthermore, nutrient loads from areas of forestry in the Waikato region are typically low, being similar to those from undeveloped areas (e.g. Schouten et al. 1981; Jenkins and Vant 2007). However, pastoral agriculture occupies a much larger area in the Waihou catchment (Table 8), and typically has a much higher nutrient yield than forestry (e.g. Vant 1999), so is likely to be the source of much of the development-derived nitrogen and phosphorus.

Up to 75% (Piako River) of the nitrogen load carried by individual rivers is estimated to have come from diffuse agricultural sources, with these sources accounting for about 73% of the combined load of nitrogen carried by the Hauraki rivers. Background (37%) and point source (23%) loads of phosphorus were somewhat more important than those of nitrogen, so that diffuse agricultural sources accounted for a smaller proportion (40%) of the combined load of phosphorus carried by the Hauraki rivers.

2.5 Summary and conclusions

1. Four rivers in the Hauraki area flow in a generally northerly direction into the Firth of Thames. In order of size, they are the Waihou/Ohinemuri, the Piako/Waitoa, the Kauaeranga and the Waitakaruru Rivers. Water quality has been monitored monthly at nearly 20 sites on these rivers since the early 1990s. Information is also available for the 24 discharges of sewage or industrial wastewaters into the rivers. This section describes the loads of nitrogen and phosphorus carried by these rivers to the Firth of Thames during 2011–20.[27]

2. Loads of nitrogen and phosphorus were determined at seven sites on the Hauraki rivers. Altogether the rivers carried at least 3730 t/yr of nitrogen and 207 t/yr of phosphorus to the Firth of Thames. The Waihou River carried 60–61% of the combined loads while the Kauaeranga and Waitakaruru Rivers each carried 1–2%; the Piako/Waitoa River carried about 36–38%.

3. The combined flow of the Hauraki rivers during 2011–20 (c. 70 m^3/s) was similar to that seen in 2000–09. However, the combined load of nitrogen transported during 2011–20 was about 10% higher than in 2000–09, while the load of phosphorus was about 27% lower. Nitrogen concentrations increased in the Waihou and Ohinemuri Rivers during 2001–20, but decreased in the Piako River (and in the smaller Hikutaia and Waitakaruru Rivers). Substantial decreases in phosphorus concentrations apparently occurred in most rivers, but not in the Waihou (which carried the largest share of the combined load). However, the laboratory methods for phosphorus concentrations changed during the period, so these trend results are of uncertain reliability.

[26] The results obtained should therefore be regarded as indicative rather than definitive, as the extent to which these estimates accurately quantify the loads from all areas of undeveloped land in the catchment is unknown.

[27] Note that there is a considerable area of the Hauraki Plains downstream of the various monitoring sites (Fig. 7); the additional river flow and nutrient load contributed by this area is unknown.

4. The combined load of nitrogen discharged from the 24 point sources was about 214 t/yr, while that of phosphorus was about 48 t/yr. The point source load of nitrogen was about 18% lower than that discharged during 2000–09 (namely 262 t/yr), while the load of phosphorus was about 30% lower (68 t/yr in 2000–09).

5. The 24 point source discharges contributed about 6% of the nitrogen and 23% of the phosphorus that was carried by the rivers during 2011–20. Background sources in the river catchments were estimated to contribute about 21% of the combined load of nitrogen and 37% of the phosphorus. The remaining 73% of the nitrogen and 40% of the phosphorus is likely to have come from diffuse agricultural sources in the rivers' catchments.

6. Figure 13 summarises these results. Figure 13A shows the relative contributions of the various sources to the combined loads of nitrogen and phosphorus carried by the four Hauraki rivers. The loads for the two largest rivers are shown in Figures 13B (nitrogen) and 13C (phosphorus).

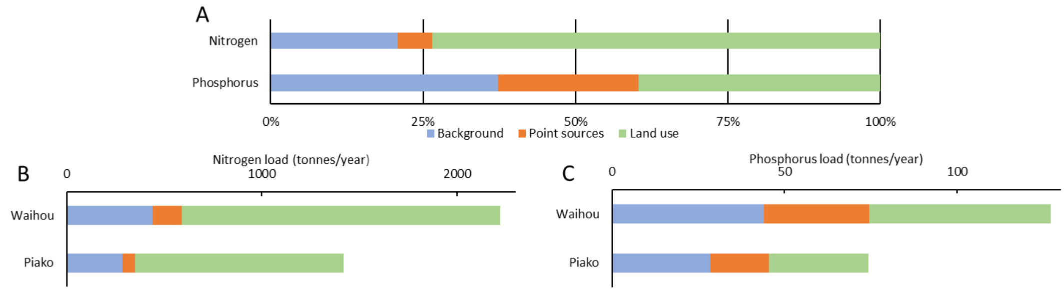

Figure 13: Sources of nitrogen and phosphorus to the Hauraki rivers, 2011–20. A, relative contributions from all four rivers; B and C, contributions of nitrogen and phosphorus from the Waihou and Piako catchments. See Table 14 for details.

References

Bates N 2021. Waikato River water quality monitoring programme: data report 2020. Waikato Regional Council Technical Report 2021/23. Hamilton, Waikato Regional Council.

Griffiths GA 1981. Some suspended sediment yields from South Island catchments, New Zealand. Journal of the American Water Resources Association 17: 662–671.

Hicks DM, Hill RB 2010. Sediment regime: sources, transport and changes in the riverbed. In Collier KJ, Hamilton DR, Vant, B, Howard-Williams C eds. The waters of the Waikato. Hamilton, Waikato Regional Council and University of Waikato. 71-91.

Hoyle J 2014. Waikato suspended sediment indicators: State and trend. Waikato Regional Council Technical Report 2014/43. Hamilton, Waikato Regional Council.

Jenkins B, Vant B 2007. Potential for reducing the nutrient loads from the catchments of shallow lakes in the Waikato region. Environment Waikato Technical Report 2006/54. Hamilton, Waikato Regional Council.

Jenkins B, Koh SS 2022 in preparation. Trend in water resource and quantity. Waikato Regional Council Technical Report 2022/06. Hamilton, Waikato Regional Council.

Littlewood IG 1992. Estimating contaminant loads in rivers: a review. Institute of Hydrology Report 117. Wallingford, Institute of Hydrology.

Littlewood IG, Watts CD, Custance JM 1998. Systematic application of United Kingdom river flow and quality databases for estimating annual river mass loads (1975–1994). The Science of the Total Environment 210/211:21–40.

Rutherford JC, Williamson RB, Cooper AB 1987. Nitrogen, phosphorus, and oxygen dynamics in rivers. In: Viner AB ed. Inland waters of New Zealand. DSIR Bulletin 241. Wellington, Department of Scientific and Industrial Research. 139–165.

Salu A 2021. Regional rivers water quality monitoring programme data report 2020. Waikato Regional Council Technical Report 2021/19. Hamilton, Waikato Regional Council.

Schouten CJ, Terzaghi W, Gordon Y 1981. Summaries of water quality and mass transport data for the Lake Taupo catchment, New Zealand. Water and Soil Miscellaneous Publication 24. Wellington, Ministry of Works, Water and Soil Division.

Turner S, Hume T, Gibberd B 2006. Waikato region estuaries—information and management issues. Environment Waikato Internal Series 2006/09. Hamilton, Waikato Regional Council.

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

Vant B 2011. Water quality of the Hauraki Rivers and Southern Firth of Thames, 2000–09. Waikato Regional Council Technical Report 2011/06. Hamilton, Waikato Regional Council.

Vant B 2014. Sources of nitrogen and phosphorus in the Waikato and Waipa Rivers, 2003–12. Waikato Regional Council Technical Report 2014/56. Hamilton, Waikato Regional Council.

Vant B 2016. Water quality and sources of nitrogen and phosphorus in the Hauraki rivers, 2006–15. Waikato Regional Council Technical Report 2016/17. Hamilton, Waikato Regional Council.

Vant B 2018. Trends in river water quality in the Waikato region, 1993–2017. Waikato Regional Council Technical Report 2018/30. Hamilton, Waikato Regional Council.

Williamson B 1999. Broad-scale assessment of urban stormwater issues in the Waikato region. NIWA Client Report EVW90213. Hamilton, National Institute of Water and Atmospheric Research.

Appendix 1: Average river flows (m^3/s) and loads (t/yr) of nitrogen and phosphorus at key sites in two major catchments in the Waikato Region, 2011–20. The corresponding results for earlier periods are also shown (using LOWESS curve-fitting and Smearing bias correction procedures; results from WRC doc #4081893).

Waikato and Waipa Rivers	2011–20			2003–12		
	Flow	N load	P load	Flow	N load	P load
Waikato, Reids Farm	149	313	23	159	339	26
Waikato, Narrows	238	3870	230	235	3700	280
Waikato, Tuakau Bridge	371	10,938	715	402	11,270	960
Waipa, Whatawhata	79	3621	240	88	4020	270

Hauraki rivers	2011–20			2000–09		
	Flow	N load	P load	Flow	N load	P load
Kauaeranga, Smiths	5.9	55	3	5.8	66	16
Piako, Paeroa-Tahuna Rd	7.2	882	45	6.9	769	56
Waitoa, Mellon Rd	4.7	533	29	4.8	533	58
Ohinemuri, Karangahake	11.9	426	8	11.1	297	10
Waihou, Te Aroha	35.6	1693	109	37.2	1577	126

Appendix 2: Average loads (t/yr) of nitrogen (N) and phosphorus (P) discharged to rivers from point sources during 2011–20. The corresponding results for earlier periods are also shown (from Vant 2011, 2014).

Waikato and Waipa Rivers	**2011–20**		**2003–12**	
	N load	**P load**	**N load**	**P load**
Sewage wastewater				
Hamilton	193	25.5	189	63.1
Tuakau-Pukekohe	22	8.7	21	13.7
Te Awamutu	15	4.2	11	7.0
Cambridge	67	5.8	54	8.5
Te Kuiti	18	2.5	26	4.0
Tokoroa	36	5.5	32	6.5
Huntly	13	2.3	14	4.2
Ngaruawahia	11	0.7	8	2.5
Otorohanga	9	1.7	14	2.1
Te Kauwhata	4	1.3	2	0.9
Waikeria	4	1.1	–	–
Meremere	1	0.2	1	0.2
Sub-total sewage	**392**	**60**	**373**	**113**
Industrial wastewater				
Wairakei power station	23	–	50	–
Kinleith pulp and paper mill	147	20.2	145	19.1
Te Rapa dairy factory	5	7.2	11	10.8
Te Awamutu dairy factory	8	2.2	15	4.8
Horotiu meatworks/dairy	70	12.6	90	13.8
Ohaaki power station	<1	<0.1	1	0.7
Hautapu dairy factory	15	0.5	17	0.5
Tuakau rendering plant	21	5.2	30	8.4
Sub-total industrial	**290**	**48**	**357**	**58**
Total	**682**	**108**	**730**	**171**

Hauraki rivers	**2011–20**		**2000–09**	
	N load	**P load**	**N load**	**P load**
Sewage wastewater				
Morrinsville	19	10.6	13	6.3
Thames	27	3.0	42	4.6
Paeroa	9	2.0	7	1.9
Waihi	7	0.1	8	2.9
Matamata	12	4.0	15	5.3
Te Aroha	16	1.0	16	1.6
Putaruru	12	2.3	11	3.2
Ngatea	2	0.4	1	0.2
Tirau	3	0.4	4	0.6
Kerepehi	1	0.3	1	0.4
Turua	1	0.2	<1	0.2
Tahuna	<1	<0.1	<1	<0.1
Waitakaruru	<1	0.1	<1	0.1
Waihou	<1	<0.1	<1	0.1
Sub-total sewage	**109**	**24**	**120**	**27**
Industrial wastewater				
Waihi gold mine	12	<0.1	9	–
Waitoa dairy factory	9	0.6	27	20.9
Tirau dairy factory	25	9.7	40	7.1
Te Aroha meatworks	24	7.6	27	6.5
Waitoa poultry processor	3	0.5	2	0.3
Waitoa meatworks	28	3.8	34	5.9
Morrinsville dairy factory	<1	<0.1	<1	<0.1
Waharoa dairy factory	2	0.8	–	–
Tatuanui dairy factory	1	<0.1	–	–
Paeroa meatworks	1	0.1	3	0.3
Sub-total industrial	**105**	**23**	**142**	**41**
Total	**214**	**48**	**262**	**68**