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Sources of nitrogen and phosphorus in the Waikato and Waipa Rivers, 2003–12

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Abstract

Mass flows of nitrogen and phosphorus transported by rivers during 2003–12 were determined at 20 sites in the Waikato and Waipa catchments. The combined mass flow of nitrogen was about 11,200 t/yr, while that of phosphorus was about 950 t/yr. The outflow from Lake Taupo contributed about 3% of the combined mass flow of nitrogen, and about 2% of the phosphorus. Background or natural sources within the catchment were estimated to contribute about 29% of the combined mass flow of nitrogen and 35% of the phosphorus.

Some 19 moderate-to-large consented point sources discharged loads of nitrogen and phosphorus to the river system. These point sources contributed about 7% of the nitrogen and 18% of the phosphorus that was carried by the rivers. Diffuse agricultural sources in the rivers' catchments are likely to have contributed 61% of the combined mass flow of nitrogen and 45% of the phosphorus (with natural sources contributing the remaining proportions). During 2003–12 the combined loads of phosphorus discharged by the point sources fell by about 30%, and the loads of nitrogen fell by about 7%.

Executive summary

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 mass flows or loads of the plant nutrients nitrogen and phosphorus at several locations in each sub-catchment during 2003–12. Each of the three sub-catchments contributed similar proportions—about one-third—of the mass flows of each nutrient. The combined mass flow of nitrogen was similar to that observed during the 1990s, but that of phosphorus was about 12% lower (due to the lower average river flow during 2003–12).

2. Some 19 moderate-to-large consented point sources discharge a variety of contaminants—including nitrogen and phosphorus—to waterbodies in the catchment. These sources include 11 sewage treatment plants of widely-varying size, and 8 industrial discharges—dairy factories, meatworks, power stations and a pulp and paper mill. Consent monitoring data were used to calculate the mass flows of nitrogen and phosphorus from these operations during 2003–12. 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.

3. More than half of the combined mass flow of nitrogen from these point sources was contributed by just three operations, namely Hamilton sewage (26% of the total), Kinleith pulp and paper mill (20%) and Horotiu meatworks (12%). And nearly half of the combined mass flow of phosphorus was contributed by just two of these, namely Hamilton sewage (37%) and the Kinleith mill (11%).

4. The mass flows of nitrogen and phosphorus discharged from several of the point sources fell over the decade. The available data showed a drop of about 30% in the combined mass flow of phosphorus, and a 7% drop in nitrogen. These reductions were mostly due to ongoing improvements in wastewater treatment at the sites.

5. Altogether, the 19 point sources contributed about 7% of the mass flow of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2003–12. They also contributed about 18% of the mass flow of phosphorus. The greatest concentration of point sources is found in the Lower Waikato sub-catchment, where they contributed 12% of the nitrogen and 31% of the phosphorus.

6. Naturally-occurring processes within the catchments also contribute to the nutrient mass flows in the rivers; and these processes would have operated prior to human development of the catchments. About one-third of the current mass flows of both nutrients is estimated to be due to these natural or “background” processes. A proportion of the mass flows from land that has been developed by people can be regarded as natural and essentially un-manageable.

7. Subtracting the contributions from point and natural sources from the overall mass flows carried by the rivers provides an estimate of the nutrient loads caused by development of the land—and in these catchments this largely means development of the land for pastoral farming. These diffuse, man-made sources contributed about 61% of the mass flow of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2003–12, and about 45% of the phosphorus.

1 Introduction

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 mass flows 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 mass flows from these data (e.g. Littlewood 1992).

The mass flows of sediment in rivers have been studied for many years (e.g. Griffiths 1981). More recently, attention has turned to other water quality contaminants, including the plant nutrients nitrogen and phosphorus, heavy metals and pesticides (e.g. Littlewood et al. 1998). Many waterbodies in New Zealand experience some degree of contamination with plant nutrients, which are found in discharges from sewage works, dairy factories and meatworks, for example, as well as the diffuse discharges from land that has been developed (e.g. for pastoral farming).

Many other 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.

In New Zealand waters, the main sources of plant nutrients are (Rutherford et al. 1987): (i) the background or "natural" losses from land, (ii) discharges from point sources such as those mentioned above, and (iii) runoff and leaching from land used for pastoral farming—that is, the additional losses that depend on the nature and intensity of land development. Apart from a few exceptions (e.g. Auckland city), urban stormwater is generally a relatively minor source of plant nutrients in New Zealand, including in the Waikato region (Williamson 1999). It is often feasible to prepare a "nutrient budget", which identifies and compares the mass flows of nutrients from these various sources. Accounting for all significant sources of contaminants in such a budget is now required by the National Policy Statement for Freshwater Management (2014).

The Waikato and Waipa Rivers drain a large part of the central North Island of New Zealand (Figure 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 moderate-to-large point sources of contaminants in each of the sub-catchments. The majority 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.

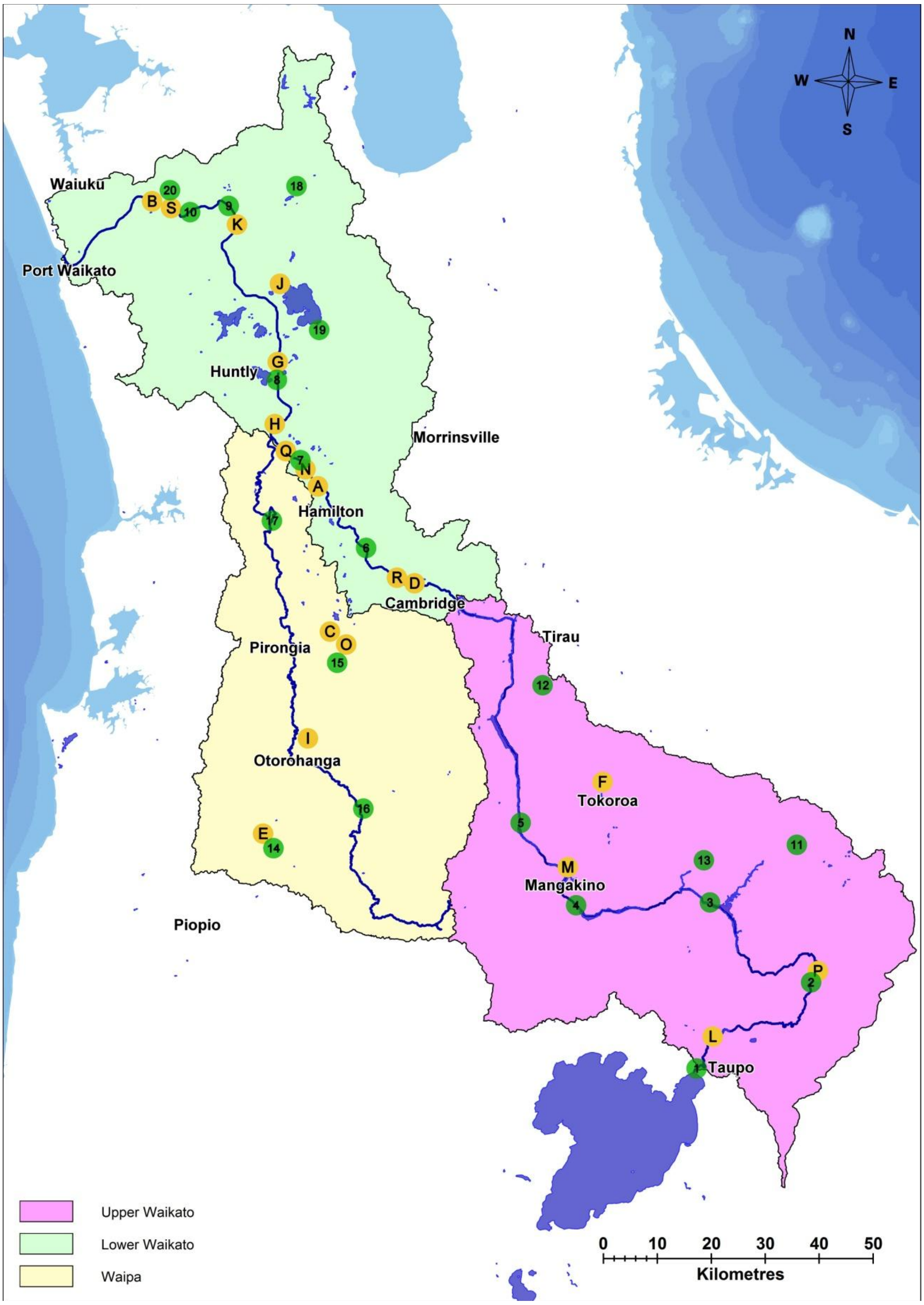

Figure 1: The catchments of the Waikato and Waipa Rivers, showing 20 sites at which water quality and river flows are monitored (green circles, see Table 2 for site names) and 19 consented discharges of wastewaters (orange circles, see Table 3 for site names). The boundary between the Upper and Lower sections of the Waikato River is at Karapiro dam.

Table 1: Landcover in three sections of the Waikato-Waipa catchments, 2008–09 (LCDB3.3; see Appendix 1 for further details). The number of moderate-to-large point sources discharges in each section is also shown (see text).

	Upper Waikato	Waipa	Lower Waikato	Combined
Area (km^2)	4380	3093	3516	10,989
Indigenous vegetation	13%	19%	12%	15%
Exotic forest	37%	5%	5%	17%
Pasture, crops	49%	74%	75%	64%
Lakes, wetlands	1%	<1%	5%	2%
Urban, other	1%	1%	3%	2%
Point source discharges	4	4	11	19

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 (Tulagi 2013a,b). 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 rivers in the 1990s. This was subsequently updated for the decade 1998–2007 (Vant 2010). This report refines and updates these earlier analyses for the decade 2003–12.

2 Mass flows carried by the rivers

Mass flows of nitrogen and phosphorus in the catchments of the Waikato and Waipa Rivers during 2003–12 were determined at a total of 20 sites (Figure 1). In each case the mass flows were calculated using monthly measurements of total N and total P concentrations, together with continuous records of river flow. Apart from three sites, the monthly samples were collected at or close to the location of the flow recorder. However, the Waikato River samples from Narrows (site 6), Horotiu (site 7) and Tuakau (site 10) were collected from locations that were about 23 km, 14 km and 12 km downstream of the corresponding flow recorder, respectively (Vant 2013).

The following procedure was used to calculate the mass flows at each site: (1) identify the river flow at the time each of the monthly water quality samples was collected (n=120 in most cases), (2) determine the relationships between river flow and the concentrations of total N and total P, (3) use these relationships to calculate the mass flow at each half-percentile interval (i.e. 0.5%) of the site's flow distribution curve, and (4) add the 200 estimates of mass flow thus obtained to give the combined mass flow at all river flows. These calculations were made with the "Sedrate" software, using its bias correction procedures.

In most cases there was a statistically significant relationship between the logarithms of river flow and nutrient concentration, with the correlation coefficients being between about 0.2 and 0.9. The exceptions were Waikato River sites at Taupo Gates (total P), Ohaaki (total N), Ohakuri (total N) and Narrows (total P) where correlation coefficients were in the range 0.1–0.2. Figure 2 shows how the concentrations of total N and total P varied with flow in the Waikato at Tuakau (Fig. 2A,B) and the Waipa at Whatawhata (Fig. 2C,D). In each case, increased flows tended to be associated with higher concentrations, with the log-log correlation coefficients in both cases being about 0.8 for total N and 0.5 for total P.

The extent to which the mass flows 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, high flow (95%ile) in the Waipa River at Whatawhata was about 13 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 mass flows of total N and total P at these two sites is shown in Figure 3 (noting that the average mass flows of each nutrient were similar at the two sites: Table 2). Mass flows 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 mass flows at the Waikato River site showed much less seasonal variability.

Table 2 shows the average mass flows of nitrogen and phosphorus transported through the three sections of the catchment during 2003–12. The overall river flow averaged about 402 m^3/s, with the combined mass flows of total N and total P being about 11,200 t/yr and 950 t/yr, respectively.

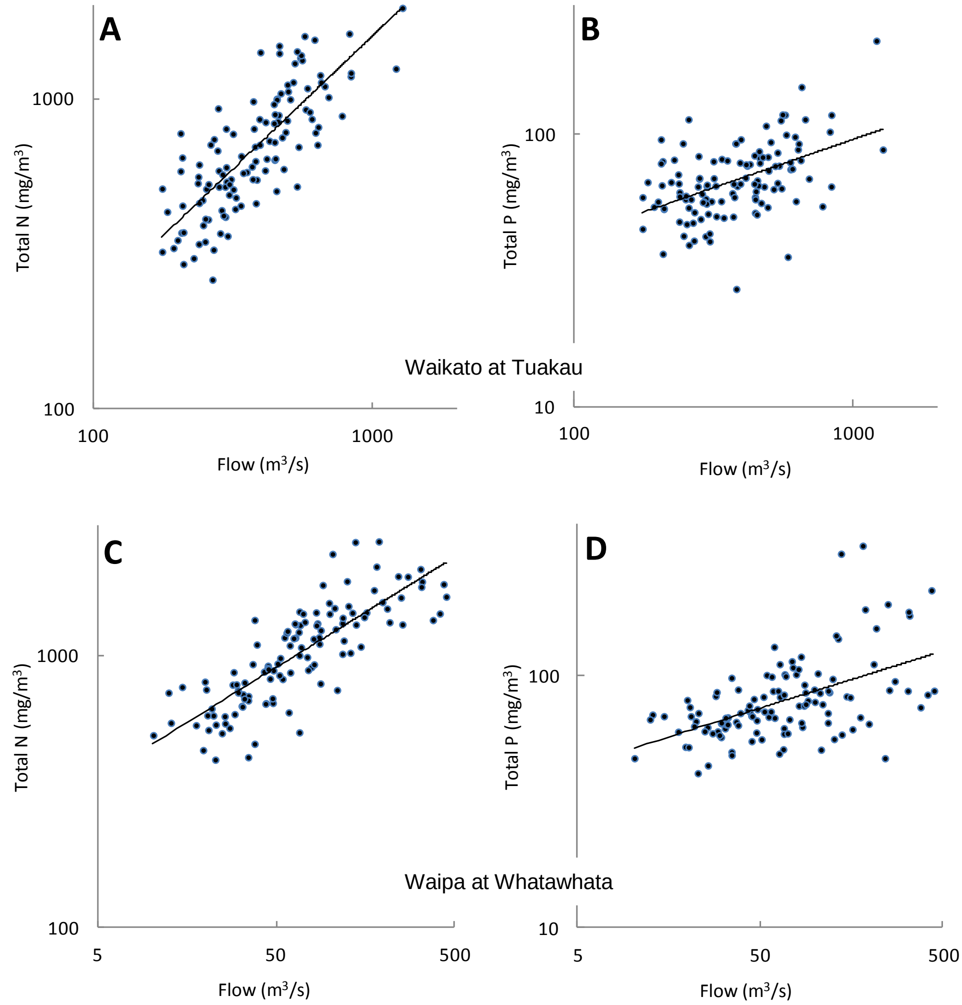

Figure 2: Monthly measurements of flow and nutrient concentration in the Waikato and Waipa Rivers, 2003–12. **A**, total nitrogen, and **B**, total phosphorus, at Waikato at Tuakau (site 10). **C**, total nitrogen, and **D**, total phosphorus, at Waipa at Whatawhata (site 17; data from NIWA).

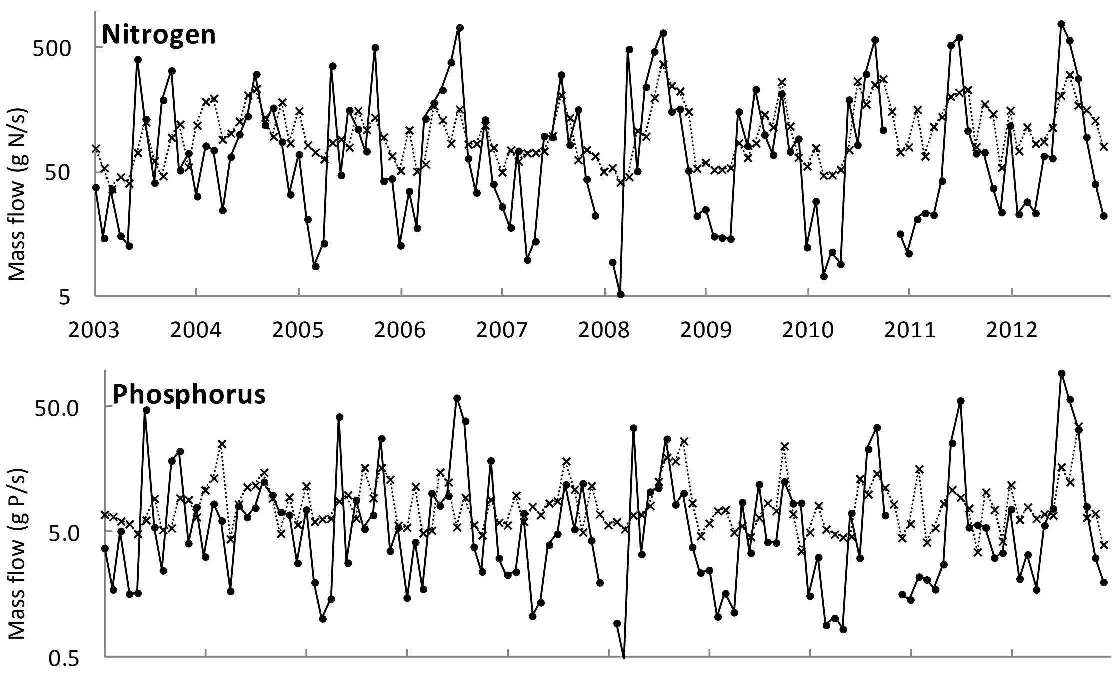

Figure 3: Mass flows of nitrogen and phosphorus in the Waikato River at Narrows (site 6; crosses, dotted line) and the Waipa River at Whatawhata (site 17; circles, solid line) at monthly intervals during 2003–12.

Table 2: Average flows, and mass flows of nitrogen and phosphorus in three sections of the Waikato-Waipa catchment, 2003–12 (site locations in Fig. 1). The most downstream sites in each section are underlined.

#	Site	Flow (m^3/s)		Nitrogen (t/yr)		Phosphorus (t/yr)	
	Upper Waikato						
11	Otamakokore at Hossack Rd	1		52		6	
12	Pokaiwhenua, Arapuni-Putararu	5		329		22	
13	Tahunaatara at Ohakuri Rd	5		146		8	
1	Waikato at Taupo Gates	158	(39%)	339*	(3%)	23	(2%)
2	Waikato at Ohaaki	167		726		59	
3	Waikato at Ohakuri	175		1185		119	
4	Waikato at Whakamaru	190		1604		132	
5	Waikato at Waipapa	219		2177		208	
6	<u>Waikato at Narrows</u>§	235	(58%)	3695	(33%)	280	(29%)
	Waipa						
14	Mangaokewa at Te Kuiti	5		192		10	
15	Puniu at Bartons Corner Rd	15		727		36	
16	Waipa at Otewa†	13		240		19	
17	<u>Waipa at Whatawhata</u>†	88	(22%)	4069	(36%)	273	(29%)
	Lower Waikato						
18	Mangatangi at Maramarua	3		185		12	
19	Matahuru at Waiterimu Rd	2		174		12	
20	Whakapipi at SH22	1		132		3	
7	Waikato at Horotiu	257		4220		385	
8	Waikato at Huntly	360		9408		758	
9	Waikato at Mercer	402		11,527		964	
10	<u>Waikato at Tuakau</u>	402	(100%)	11,193	(100%)	951	(100%)

*Result for Waikato @ Reids Farm (NIWA), as NIWA's analyses for total N are more accurate than those used by WRC.
§See the discussion in section 4 about how the information from this site was used.
†Sites operated by NIWA.

The flows and mass flows carried by the various tributaries—e.g. Otamakokore, Mangatangi, Whakapipi—were substantially lower than those in the main stem of the rivers. However, while the outflow from Lake Taupo (i.e. site 1) also contributed just a minor proportion (2–3%) of the mass flows, it was a major source of the combined river flow (39%). This highlights the fact that nutrient concentrations in Lake Taupo are much lower than those in the streams draining other parts of the Waikato and Waipa catchments.

Each of the three sections of the catchment—Upper Waikato, Lower Waikato and Waipa—contributed about 30–40% of the combined mass flow of nitrogen and phosphorus carried by the river as a whole (Table 2). The majority (58%) of the river flow, however, came from the Upper Waikato section.

The combined mass flow of nitrogen transported during 2003–12 was within 1% of that carried during 1990–2004 (WRC unpublished results). However, average river flow during 2003–12 was about 10% lower than during 1990–2004 (when it averaged 444 m^3/s). So the lower flow during 2003–12 was offset by higher total N concentrations then (Vant 2013), such that the overall mass flow of nitrogen was largely stable. Average total P concentrations, however, were largely unchanged between the two periods, so that the combined mass flow of phosphorus transported during 2003–12 (namely 951 t/yr) was about 12% lower than during 1990–2004 (namely 1083 t/yr).

3 Mass flows from point sources

Figure 1 shows the location of 19 sites where contaminants are discharged to the Waikato and Waipa Rivers. Each can be regarded as a moderate-to-large point source of nitrogen and phosphorus. Eleven of these locations are sites where sewage wastewaters from urban areas are treated, while the remaining eight are various industrial sites, including dairy factories, meatworks and a pulp and paper mill (Table 3).

Table 3: Summary of consent monitoring information held by Waikato Regional Council on the flow rate and nutrient concentration for 19 point source discharges to the Waikato and Waipa Rivers, 2003–12.

	Site	Document number	Period	Flow frequency[1]	Number of samples (N, P)
	Sewage wastewater				
A	Hamilton	2997812	2003-12	Daily	2113, 980
B	Tuakau/Pukekohe	3005898	2008-12	Daily	151, 152
C	Te Awamutu	3003150	2003-12[2]	Weekly	349, 498
D	Cambridge	2999258	2003-12	Weekly	303, 304
E	Te Kuiti	2992631	2011-13	Varied[3]	59, 59
F	Tokoroa	2848728	2006-11	Daily	–[4]
G	Huntly	3001573	2007-12	Daily	44, 44
H	Ngaruawahia	2999392	2010-12	Daily	27, 27
I	Otorohanga	3002857	2011-12	Monthly[5]	24, 23
J	Te Kauwhata	3005158	2008-12	Monthly[6]	49, 49
K	Meremere	3005519	2010-12	Daily	33, 33
	Industrial wastewater				
L	Wairakei power station	3006729	2010-12	Daily[7]	20, –
M	Kinleith pulp and paper mill	2998292	2003-12	Daily	120, 120
N	Te Rapa dairy factory	2985852	2007-12	Daily	337, 337
O	Te Awamutu dairy factory	2993237	2008-13	Daily	264, 265
P	Ohaaki power station	2330498	1996-2004	–[8]	3, 3
Q	Horotiu meatworks	2999040	2003-12	Daily	480, 481
R	Hautapu dairy factory	3003420	2006-11	Weekly	132, 132
S	Tuakau rendering plant	3004396	2004-12	Daily	169, 119

Notes
1. Interval during which continuously-recorded discharge rates were averaged.
2. Total N from 2006
3. Weekly-to-fortnightly
4. Calculated as the product of the 5-year averages of flow and nutrient concentrations
5. More frequent measurements at times
6. Daily from July 2012
7. Averaged quarterly
8. Maximum consented stormwater flow

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 mass flows of nitrogen and phosphorus that were discharged from each of the point sources during 2003–12. 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. In two cases, however, routine monitoring results were not available, so information from the consent holder's assessments of environmental effects was used instead. Table 3 summarises the information available on flows and nutrient concentrations for each of the discharges during 2003–12.

Comprehensive records were available for some sites (Table 3), with daily wastewater flow rates being available for more than half 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. However, records spanning the full decade were available for just five of the sites (Hamilton, Te Awamutu and Cambridge sewage; Kinleith mill and Horotiu meatworks; for example, see Fig. 4). In most cases samples of the wastewaters had been analysed for total nitrogen and total phosphorus, but in some cases only the concentrations of dissolved nitrogen or phosphorus were available (Tuakau/Pukekohe until mid-2010, Cambridge, Tokoroa and the Wairakei power station).

Following Vant (2011), in most cases unbiased estimates of nutrient mass flow were obtained by averaging the products of effluent flow and nutrient concentration that were determined at regular intervals, typically daily, weekly or monthly. That is, mass flows were calculated as the “average of the products”, rather than as the “product of the averages”. Throughout 2003–12, daily nitrogen mass flows for Hamilton sewage were available on weekdays (i.e. about 20 per month). The decadal-average of these was regarded as being relatively unbiased. Similarly for Horotiu meatworks, nutrient mass flows were available at weekly intervals, and these were simply averaged over the decade.

However, for phosphorus in Hamilton sewage, and for both nutrients in Cambridge sewage, the Te Rapa, Te Awamutu and Hautapu dairy factories and the Tuakau rendering plant, changes to the respective sampling intervals during 2003–12 meant that the raw data had to first be summarised as monthly means (e.g. Fig. 4A), with the decadal-average then being calculated from these. In most other cases the decadal-averages were calculated as the average of the products of each monthly nutrient concentration and the corresponding monthly average flow rates (e.g. Fig. 4C).

Table 4 summarises the information on wastewater flows, and nitrogen and phosphorus concentrations and mass flows in the 19 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).

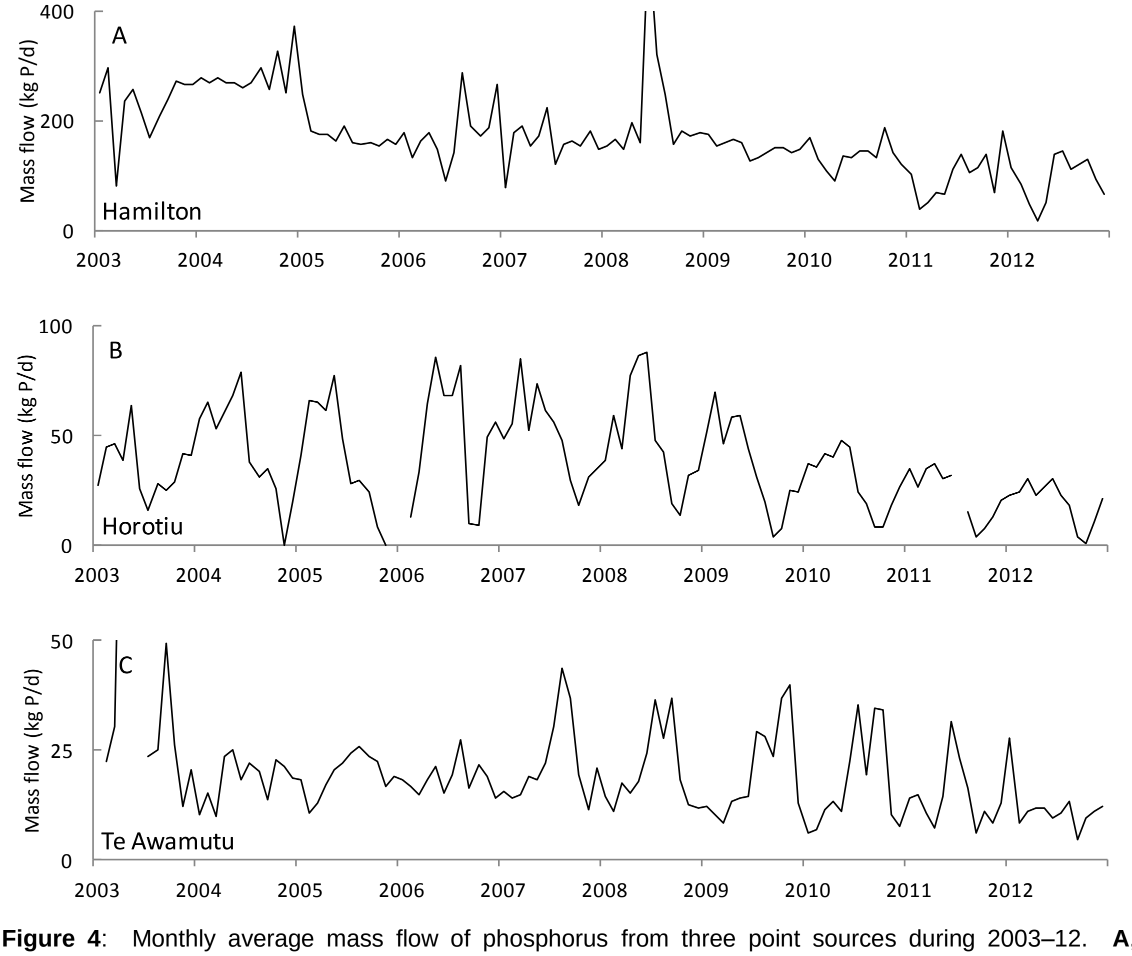

Figure 4: Monthly average mass flow of phosphorus from three point sources during 2003–12. **A**, Hamilton sewage (site A), **B**, Horotiu meatworks (site Q), and **C**, Te Awamutu sewage (site C).

Table 4: Average flows of wastewater, and average concentrations and mass flows of nitrogen (N) and phosphorus (P) from 19 consented discharges to the Waikato and Waipa Rivers, 2003–12. "Δ" denotes sites where there was sufficient information to assess changes in average mass flows over the decade: see text.

	Site	Flow	Concentration (g/m^3)		Mass flow (t/yr)	
		(m^3/day)	Total N	Total P	Total N	Total P
	Sewage wastewater					
A	Hamilton (Δ)	41,460	12	2.8	189	63.1
B	Tuakau-Pukekohe (Δ)	6580	9	5.9	21	13.7
C	Te Awamutu (Δ)	4500	6	4.2	11	7.0
D	Cambridge (Δ)	4110	38	6.5	54	8.5
E	Te Kuiti	3430	33	4.6	26	4.0
F	Tokoroa	3060	29	5.8	32	6.5
G	Huntly (Δ)	2660	15	5.0	14	4.2
H	Ngaruawahia	1670	14	4.4	8	2.5
I	Otorohanga	1510	25	3.8	14	2.1
J	Te Kauwhata (Δ)	700	9	3.8	2	0.9
K	Meremere	310	11	2.7	1	0.2
	Sub-total sewage				**373**	**113**
	Industrial wastewater					
L	Wairakei power station	1,260,000	<1	–	50	–
M	Kinleith pulp and paper mill (Δ)	85,210	5	0.6	145	19.1
N	Te Rapa dairy factory (Δ)	15,450	2	1.9	11	10.8
O	Te Awamutu dairy factory (Δ)	4130	11	3.4	15	4.8
P	Ohaaki power station	3200	1	0.6	1	0.7
Q	Horotiu meatworks (Δ)	2160	114	17.2	90	13.8
R	Hautapu dairy factory	930	51	1.4	17	0.5
S	Tuakau rendering plant (Δ)	500	148	48.9	30	8.4
	Sub-total industrial				**357**	**58**
	Total				**730**	**171**

The combined mass flow of nitrogen discharged from the 19 moderate-to-large point sources during 2003–12 averaged about 730 t/yr (Table 4), with roughly half coming from sewage discharges and half from industrial discharges. Much (58%) of the combined mass flow of nitrogen came from just three sites: Hamilton sewage (26%), Kinleith pulp and paper mill (20%) and Horotiu meatworks (12%). By contrast, three other sites were small (Te Kauwhata and Meremere sewage, and Ohaaki power station), and together contributed less than 1% of the combined point source mass flow of nitrogen.

For phosphorus, the combined mass flow averaged about 170 t/yr, with two-thirds coming from sewage discharges and one-third from industrial discharges (Table 4). Nearly half (48%) of the combined mass flow came from just two sites: Hamilton sewage (37%) and the Kinleith pulp and paper mill (11%). Once again, Te Kauwhata and Meremere sewage and Ohaaki power station were minor contributors, as was the Hautapu dairy factory.

The nutrient mass flows at each site varied throughout the decade. Much of this appeared to be random variability, but several of the industrial discharges also showed marked seasonal variability. These included the Horotiu meatworks (Fig. 4B) and the three dairy factories. The seasonal nature of production at these sites undoubtedly accounts for much of this (e.g. no processing of milk during the winter).

In addition, there were overall trends—usually improvements—in mass flows at several sites. These generally resulted from improved treatment of wastewaters during the decade. Figure 4 shows the long-term improvements in mass flows of phosphorus from Hamilton and Te Awamutu sewage, and from the Horotiu meatworks. In each case the average mass flow during the last two years of the decade (i.e. 2011–12) was 40–50% lower than the average for the previous eight years. Over the decade, the combined mass flow of phosphorus from the three operations fell at an overall rate of about 9% per year.

There was sufficient information at 11 of the sites (Table 4) to broadly compare the mass flows during the earlier part of the decade with those in the last two years of it (i.e. in 2011–12). The combined mass flow of nitrogen from these sites during 2011–12 was about 7% lower than that in the period prior to 2011, while for phosphorus the combined mass flow was about 30% lower. This indicates that during 2003–12 there were moderate-to-large reductions in the point source mass flows of nitrogen and phosphorus that were discharged to the Waikato and Waipa Rivers.

4 Components of the total mass flows in the rivers

The mass flows of nitrogen and phosphorus discharged from the point sources (Table 4) can be directly compared with the total mass flows of these nutrients that were carried by the Waikato and Waipa Rivers during 2003–12 (Table 2). Furthermore, by estimating the contributions from background—that is, the mass flows that would have been carried by the rivers prior to development of their catchments—it is possible to also estimate the mass flows that have resulted from the development of the land.

The water quality monitoring site on the Waikato River at Narrows (site 6) is about 23 km downstream of the Karapiro dam (i.e. the downstream boundary of the Upper Waikato section: see Fig. 1). The discharges from Cambridge sewage (site D) and the Hautapu dairy factory (site R) enter the river between these locations, as do some small streams (e.g. the Mangawhero Stream)—the mass flows 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, and the nutrient mass flows at the dam were estimated as the mass flow at Narrows, minus the contributions from Cambridge sewage and the Hautapu dairy factory. That is, the mass flows 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. Note also that the mass flows calculated for the Lower Waikato section do not include the inputs from the two upstream catchments (i.e. Upper Waikato and Waipa).

Table 5 shows the average mass flows of nitrogen and phosphorus carried by the Waikato and Waipa Rivers during 2003–12. The combined contributions to these mass flows from the various point sources listed in Table 4 are also shown. Following Vant (1999, 2011), pre-development or background mass flows were calculated from the respective catchment areas (Table 1; but note that about 504 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 & 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 mass flows for this sub-catchment (Table 5).

Subtracting (1) the point source mass flows, and (2) the background mass flows from the total mass flow gives an estimate of the mass flow that is associated with the areas of the catchment that have been developed (generally for pastoral farming)—called “Landuse” in Table 5.

Tables 2 and 5 show that during 2003–12 the rivers carried about 11,200 t/yr of nitrogen and 950 t/yr of phosphorus to the Tasman Sea. Overall, point source discharges contributed 7% of the nitrogen and 18% of the phosphorus. Some 60% of the nitrogen load and 74% of the phosphorus load from point sources entered the main-stem of the Waikato River downstream of Karapiro dam (i.e. the Lower Waikato). By contrast, the Waipa River carried just 9–10% of the combined point source contributions of these nutrients.

Table 5: Mass flows of nitrogen and phosphorus in the Waikato River catchment during 2003–12. The combined mass flows from the various consented moderate-to-large point source discharges are shown, as are estimates of the pre-development or background mass flows, and the mass flows resulting from catchment land use.

	Upper Waikato	Waipa	Lower Waikato*	Combined
Nitrogen (t/yr)				
Overall	3623	4069	3501	11,193
LTaupo outflow	339 (9%)			339 (3%)
Point sources	227 (6%)	66 (2%)	437 (12%)	730 (7%)
Background	1453† (40%)	928 (23%)	904 (26%)	3284 (29%)
Landuse	1604 (44%)	3075 (75%)	2160 (62%)	6840 (61%)
Phosphorus (t/yr)				
Overall	271	273	408	951
LTaupo outflow	23 (9%)			23 (2%)
Point sources	26 (9%)	18 (7%)	127 (31%)	171 (18%)
Background	150† (55%)	93 (34%)	90 (22%)	333 (35%)
Landuse	71 (26%)	162 (59%)	191 (47%)	425 (45%)

*Results are for Karapiro to Tuakau (area 3012 km^2), rather than to Port Waikato

†Includes geothermal inputs (see text)

Within each section of the catchment, the proportion of the nutrient mass flows contributed by point sources also varied markedly. Just 2% of the nitrogen in the Waipa section came from point sources, compared with 12% in the Lower Waikato section (Table 5); similarly, 7% of the phosphorus in the Waipa section came from point sources, compared with 31% 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. So land that has been developed has both a “background” and a “landuse” contribution. That is, “landuse” 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 landuse-derived nitrogen and phosphorus.

Between 44% (Upper Waikato) and 75% (Waipa) of the mass flows 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 mass flow of nitrogen transported to the Tasman Sea (Table 5). However, background and point source mass flows of phosphorus were somewhat more important than those of nitrogen. So lesser amounts—between 26% (Upper Waikato) and 59% (Waipa)—of the mass flows of phosphorus carried by the rivers are estimated to have come from diffuse agricultural sources, with landuse accounting for about 45% of the combined load transported to the Tasman Sea (Table 5).

5 Summary and Conclusions

1. It is convenient to divide the catchment of the Waikato and Waipa Rivers into three roughly-equal sections (Figure 1): 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 mass flows or loads of the plant nutrients nitrogen and phosphorus at several locations in each sub-catchment during 2003–12. Each of the three sub-catchments contributed similar proportions—about one-third—of the mass flows of each nutrient (Table 2). The combined mass flow of nitrogen was similar to that observed during the 1990s, but that of phosphorus was about 12% lower (due to the lower average river flow during 2003–12).

2. Some 19 moderate-to-large consented point sources discharge a variety of contaminants—including nitrogen and phosphorus—to waterbodies in the catchment. These sources include 11 sewage treatment plants of widely-varying size, and 8 industrial discharges—dairy factories, meatworks, power stations and a pulp and paper mill. Consent monitoring data were used to calculate the mass flows of nitrogen and phosphorus from these operations during 2003–12 (Table 3). 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.

3. More than half of the combined mass flow of nitrogen from these point sources was contributed by just three operations (Table 4), namely Hamilton sewage (26% of the total), Kinleith pulp and paper mill (20%) and Horotiu meatworks (12%). And nearly half of the combined mass flow of phosphorus was contributed by just two of these, namely Hamilton sewage (37%) and the Kinleith mill (11%).

4. The mass flows of nitrogen and phosphorus discharged from several of the point sources fell over the decade. The available data showed a drop of about 30% in the combined mass flow of phosphorus, and a 7% drop in nitrogen. These reductions were mostly due to ongoing improvements in wastewater treatment at the sites.

5. Altogether, the 19 point sources contributed about 7% of the mass flow of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2003–12 (Table 5). They also contributed about 18% of the mass flow of phosphorus. The greatest concentration of point sources is found in the Lower Waikato sub-catchment, where they contributed 12% of the nitrogen and 31% of the phosphorus.

6. Naturally-occurring processes within the catchments also contribute to the nutrient mass flows in the rivers; and these processes would have operated prior to human development of the catchments. About one-third of the current mass flows of both nutrients is estimated to be due to these natural or "background" processes. A proportion of the mass flows from land that has been developed by people can be regarded as natural and essentially un-manageable.

7. Subtracting the contributions from point and natural sources from the overall mass flows carried by the rivers provides an estimate of the nutrient loads caused by development of the land—and in these catchments this largely means development of the land for pastoral farming. These diffuse, man-made sources contributed about 61% of the mass flow of nitrogen carried to the sea by the Waikato and Waipa Rivers during 2003–12, and about 45% of the phosphorus.

8. Figure 5 summarises these results. Figure 5A shows the relative contributions of the various sources (including the outflow from Lake Taupo) to the mass flows of nitrogen and phosphorus carried by the river as a whole. The mass flows for the three sub-catchments are shown in Figures 5B (nitrogen) and 5C (phosphorus).

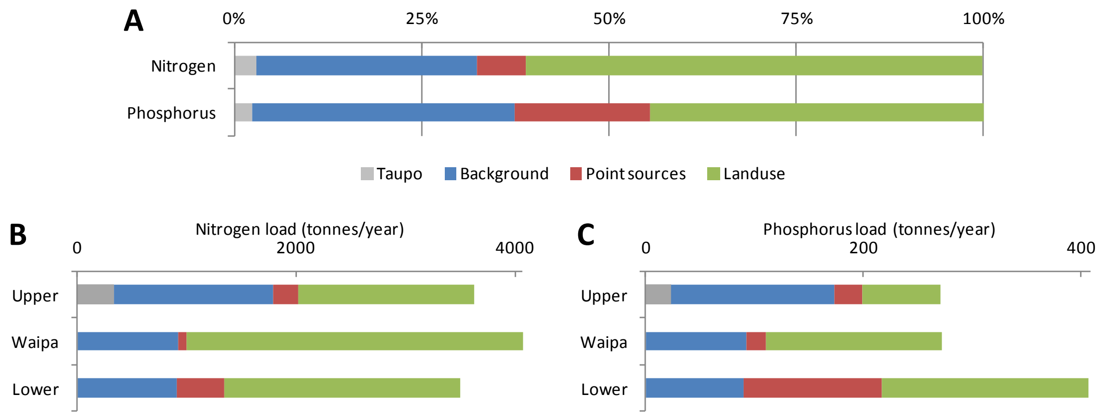

Figure 5: Sources of nitrogen and phosphorus to the Waikato and Waipa Rivers, 2003–12. **A**, relative contributions from the whole catchment (including the outflow from Lake Taupo); **B** and **C**, contributions of nitrogen and phosphorus from the three sub-catchments. See Table 5 for details.

6 References

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

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.

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.

National Policy Statement for Freshwater.Management 2014. Wellington, Ministry for the Environment.

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. pp. 139–165.

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 and Development.

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

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

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

Vant WN 2010. Water quality. In Collier KJ et al. (eds), The Waters of the Waikato. Hamilton, Waikato Regional Council and University of Waikato.

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 2013: Trends in river water quality in the Waikato region, 1993–2012. Waikato Regional Council Technical Report 2013/20. 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: Landcover in the Waikato and Waipa catchments, 2008–09 ([LCDB3.3]).