Trends and State of Rotorua Major Streams, 2013

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Executive summary

Monitoring of stream inflows into Lake Rotorua has been undertaken as part of the Bay of Plenty Regional Council’s Rotorua Lakes Management Strategy, the wider integrated catchment management and previously as part of the Catchment Boards programme.

Monitoring of these inflows provides valuable insight into the potential sources of lake water quality degradation and helps indicate if lake restoration methods are successful. Stream monitoring also provides on-going data to be used in modelling of present and future scenarios of nutrient exports to the lake and for modelling lake water quality. The objective of this report is to examine the state and trends of water quality (and in particular nutrients) in the major streams to Lake Rotorua and test these against some of the Rotorua Lake Management Strategies’ targets.

Changes in stream load nutrients are influenced by land use change within the catchment. Nitrate or nitrate-nitrite-nitrogen (NNN) is the dominant form of nitrogen entering Lake Rotorua that is readily available to phytoplankton in the lake, and is the most useful indicator of nitrogen inputs due to its soluble nature and movement through soils. These features make it one of the best indicators to show how quickly catchments respond to changes in land use.

As Rutherford found in 2003, nitrate concentrations in Rotorua streams continue to show an increasing trend. Trend analysis shows that from 1992 to 2012 eight of the nine major inflows to Rotorua have a significant increasing trend in NNN. However, this trend is not apparent in three streams (the Puarenga, Waiohewa and Waiowhiro Streams) over the last decade, where concentrations have stabilised. With the exception of the Waiowhiro Stream, concentrations of NNN in most streams have doubled over the past 37 years. The Waiohewa Stream stands out as a significant contributor of nitrogen to Lake Rotorua due to geothermal fluids from the Tikitere geothermal field.

Nitrogen contributions to the lake are now fairly well understood. Rutherford (2009, 2011) has thoroughly explored the relationships of land use change, and particularly pastoral farming’s role and contribution of nitrogen in the Rotorua catchment. Prioritisation of nitrogen sources can be undertaken with the ROTAN model at the catchment scale by examination of various land use change scenarios. The potential for nitrate leaching from various land uses can also provide a priority mechanism for change and generally follows the order (Meener et al., 2004):

- vegetable cropping> dairy farming>< arable/mixed cropping> sheep/beef/deer farming> forestry.

Of the nine major inflows analysed, five show significant decreasing trends in dissolved reactive phosphorus concentration over 1992 to 2012 and likewise for four streams over 2002 to 2012. Utuhina’s downward trend can be explained by recent alum treatment to the stream, but explanations for the decreasing trends in other streams are not so obvious. These trends are likely to be a combination of land-use changes, possible changes in the rate of change of DRP in groundwater under differing groundwater conditions, and increased buffering of DRP in stream waters.

The annual nitrogen loadings from the nine major inflows into Lake Rotorua has increased over the last two decades. Dissolved nutrient loads increase with flow, such that in wetter years higher nutrient loadings can be expected, along with an increasing component of particulate and organic nutrients.

Arresting storm flow components of the particulate forms of phosphorus and nitrogen will play a valuable part in reducing total nutrient load to Lake Rotorua, but measuring and monitoring restoration efforts in reducing these nutrient contributions is problematic and costly. Nutrient loads based on monthly sampling data can often underestimate total loading contributions to the lake. For example, underestimates from the Ngongotahā catchment for phosphorus could be in the order of 50%, depending on the storm events in a given year.

Phosphorus load figures generated by Abell (2012) and others show that flood flow phosphorus is a major source, and work of Rutherford (2009) and Abell (2012) shows which Rotorua stream catchments generate the greatest phosphorus loads. A priority catchment list was created for the reduction of particulate phosphorus from the flood flow percentage calculations from Rutherford (2008):

- Ngongotahā>Waiohewa>Puarenga>Utuhina>Waitetī>Waiowhiro>Waingaehe~Awahou>Hamurana.

Here, the Ngongotahā catchment should be the highest priority for reducing export of particulate phosphorus, and the Hamurana the lowest.

Examination of annual average loads from the 9 major Rotorua Streams was compared to the annual average nutrient load exiting Lake Rotorua via the Ōhau Channel. Data shows that net import of phosphorous to the lake is similar to net export. Exceptions occurred in 2004 when severe algal blooms occurred, increasing the export of phosphorus out of the lake due to uptake by algae; and 2011 where intense storm events have resulted in increased particulate phosphorus entering the lake. Much of this particulate phosphorus will remain in the lake to be incorporated in sediment or released in a soluble form under anoxic conditions.

Continued increasing trends in nitrogen and the risk of continued sustained internal nutrient releases from potentially anoxic sediments requires that external nutrient reduction targets are strived for if a sustained water quality in line with community objectives is to be sustained. Maintaining the lake in its current trophic status or improving the trophic status will depend on the lakes ability to assimilate an increasing load of labile nitrogen. Restoration techniques and land management options will also need to address the increasing nitrogen load to the lake, as well as manage phosphorus. The ability to address particulate phosphorus on the land with increasingly extreme climatic conditions predicted could pose an increased challenge to reaching lake water quality objectives.

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Part 1: Introduction

1.1 Background

Lake Rotorua is the largest lake the Te Arawa/Rotorua lakes group and is a significant regional and national lake for recreation and tourism. From the early 1960s water quality of Lake Rotorua deteriorated because of excess of phytoplankton growths caused principally by increased levels of phosphorus and nitrogen.

Treated domestic sewage was discharged into the lake from the Rotorua sewage-treatment plant from 1973 to 1991. Together with nutrient inputs from septic tanks, horticulture and pastoral farming, urban stormwater, and other miscellaneous sources, the greatest nutrient input to Lake Rotorua occurred in the late 1980s. Nutrient load to the Lake was greatly reduced when land disposal from the Rotorua sewage-treatment plant was instigated, although nutrient losses from spray irrigation sites still occur. The Kaituna Catchment Control Scheme, which has been in place since the 1970s, has worked to fence off stream margins in lake margins as well as retire plant erosion-prone land. Although these measures have reduced inputs of sediment, total phosphorus and particulate nitrogen (Williams et al 1996), they have not controlled nitrate-nitrogen inputs.

Rutherford (2003, 2009) identified an increasing trend in mean baseflow concentrations of nitrate in eight of the nine major streams flowing into Lake Rotorua between 1977 and 2003. Stream data from as early as 1968 (Fish, 1975) as well as 1976/77 data from Hoare (1980) and Regional Council data was used in his analysis. A further finding from Rutherford’s analysis showed that reductions in nutrient flow to the lake from sewage diversion have been negated by increases in nitrogen load in streams.

Williams et al (1996) not only showed evidence that control measures undertaken by the Kaituna Catchment Control Scheme reduced loads of sediment, total phosphorus, and particulate nitrogen to the lake, but also found increasing nitrate concentrations in the Ngongotahā. There is also evidence to link increased nitrate stream concentrations with land clearance around the lake done in the 1940s (Rutherford 2003, 2011) followed by subsequent land use intensification and urbanisation.

Due to the complex volcanic nature surrounding the lake, there is a great variation in the range and size of aquifers which feed the Rotorua streams. Tritium dating of spring and groundwater has aged stream waters between 15 to 170 years (Morgenstern and Gordon, 2006), corresponding to a range of groundwater lag times before groundwater again reaches the surface. Increasing nitrate enrichment of aquifers with increasing land use intensification primarily from agricultural land can thus result in nitrate being retained within aquifers for many decades. Increasing trends in stream nitrate concentration have been shown to be inversely correlated with the age of groundwater in the Lake Taupo catchment (Rutherford, 2003). Hence, nitrate trends in streams may continue to increase for some years, potentially impacting on Lake Rotorua’s water quality.

Abell (2012) looked at spatial and temporal variations in nitrogen and phosphorus loading to lakes, and their impact on water quality. While nitrate was found to be diluted following the onset of storm flow, post event concentrations can be upwards of approximately 25% pre-event nitrate concentrations. Total phosphorus (TP) showed strong correlations with flow over storm events measured in the Puarenga and the Ngongotaha streams. Abell also stated that using averaging methods based on samples collected predominantly during base-flow conditions can lead to an under estimation of TP loads. Conversely there was little relationship found between flow and dissolved reactive phosphorus (DRP) reflecting a steady state nature between dissolution kinetics of phosphorus in soil and in stream water.

1.2 Policy, Strategy and Restoration context

Monitoring of Rotorua stream inflows has been undertaken as part of Bay of Plenty Regional Council's (BoPRC) wider integrated catchment management, and previously as part of the old Catchment Boards programme (now the Kaituna Catchment Control scheme) to maintain lake and stream water quality. Policies in the operative Bay of Plenty Regional Council Regional Water and Land Plan consolidate policies to manage land and water resources in an integrated catchment management framework. Policies relevant for this report center around key objectives such as:

1. the maintenance and enhancement of water quality for individual Rotorua lakes, as measured by the trophic level index (TLI);
2. the management of nitrogen and phosphorous in individual Rotorua lake catchments;
3. reducing cyanobacterial alagal blooms on the Rotorua Lakes by managing nutrient inputs in the lake catchments.

The BoPRC, the Rotorua District Council (RDC) and Te Arawa Māori Trust Board developed a Strategy for the Lakes of the Rotorua district in 2000. The Strategy identified four key elements (Lake Protection, Use, Enjoyment and Management), each of which identified specific key goals. Goals relevant to this project under the Lake Protection element included:

- address the causes of water pollution
- determine the extent of pollution from stormwater
- define and refine water quality standards

The strategy also identified a number of tasks that needed to be addressed as part of the long-term management of the Te Arawa/Rotorua lakes. The main objective of the Lake Protection element was to establish and maintain high water quality in lakes, rivers and streams in the area. The Strategy also highlighted that defining and refining water quality standards was critical to assess future discharges and to determine performance criteria, benefits and costs for upgrading current activities. It also emphasised that the BoPRC take a lead role in lake monitoring. Task relevant to this report in the protection and restoration programme are outlined below:

Task No.	Description	Objective
1	BoPRC and RDC to reach agreement on the relative sources of water quality degradation for each lake	To prioritise the causes of water quality degradation
2	Refine water quality standards applying to each lake	To encapsulate the existing natural state classifications for each lake with in a scientific index that enables more accurate assessment of changes in factors affecting the water quality
3	Identify all river and lake margins where grazing is no longer allowed, and all areas that are yet to be declared unavailable for grazing	Report on lake, stream and river buffer areas currently withdrawn and yet to be withdrawn from grazing, to determine the scale of the work, and the benefits and costs of present and future work

Monitoring stream inflows to Lake Rotorua and assessing their state and trend will play a part in determining causes of water quality degradation, and aligns with Task No.1 of the Strategy and the Regional Water and Land Plan policy. Data collected and reported here will also help inform Task No.2 but there is still not enough progress associated with Task No.3 to determine whether changes in areas grazed as a result of interventions to land management do indeed result in reductions in stream nutrient loads. Modelling undertaken by NIWA using the ROTAN model for nitrogen has explored land use change and contributions of individual catchment to lake nutrients, and this report will support future modelling and assessments of Rotorua Lake catchment nutrient inputs.

The non-statutory Rotorua-Rotoiti Action Plan also provides guidance on the management of Lake Rotorua. It lists that the reduction of nitrogen and phosphorus is the most important step to improved water quality. Nutrient inputs to the lake from land use as of 2009 are listed in the Action Plan as 556 t/yr nitrogen and 39.1 t/yr phosphorus. To reach the long-term TLI target of 4.2 TLI units, inputs to Lake Rotorua need to be reduced to 435 t/yr of nitrogen and 37 t/yr of phosphorus. A range of options for nutrient reduction are outlined in the Action Plan including: land use change; inflow nutrient treatments including geothermal treatments; methods for limiting internal nutrients; best land management practices; and wastewater reductions.

Changes in stream load nutrients will depend on how land-use has changed within the catchment and how quickly the catchment responds to these changes. Nitrate (or as measured here NNN) is the most useful indicator in this regard due to its soluble nature. Nitrates relatively quick movement through the landscape is captured by groundwater aquifers. The larger, deeper and possibly more complex aquifer system the more retarded the nitrate signal may become. Interpreting nitrate signals as they exit the catchment will depend on the history of catchment land use and the proportions of old groundwater to new ground water, as well as recent run-off.

Monitoring of inflows into Lake Rotorua provides valuable insight into potential causes of lake water quality degradation and helps indicate if restoration methods are being successful. Stream monitoring data also provides on-going data in modelling of present and future scenarios of nutrient exports to the lake and actual lake water quality. The objective of this report is to examine the state and trends in the major streams to Lake Rotorua and test these against some of the Management Strategies targets.

Part 2: Methods

2.1 Stream data sources

A range of data have been collected from streams flowing to Lake Rotorua (Figure 2.1), these include:

- Fish (1968 – 70) (eight major streams);
- Hoare (1976 – 77) (nine major plus several minor streams);
- Williams et al. (1987/89) (nine major plus several minor streams)
- Bay Of Plenty Regional Council (1991 – present) (nine major plus several minor streams);
- Abell (2012) (two major streams, storm flow monitoring).

BoPRC continues to monitor the nine major inflows to Lake Rotorua as well is some of the minor inflows. See Figure 2.1 for monitoring locations.

Rutherford (2003) noted that analytical methods have changed over time, and that variations occurred between laboratories and/or individual analysts. This remains true today, and while much of the focus of this report will be on the data collected by BoPRC, analyses has been undertaken by the Council laboratory as well is external laboratories (most notably Hills Laboratory, Hamilton).

A laboratory analysis change from Antimony – Phosphate Molybdate derived Murphy-Riley Method (1962) (NWASCO Misc Pub. No38, 1982), to Molybdenum blue colorimetry by FIA (APHA 4500-P G) has resulted in an observable difference in the data sets pre July 2008 and post July 2008 to present. The newer method is more sensitive to low concentrations and the older method has a higher top range. Modelling and adjustment of dissolved reactive phosphorus data has thus been undertaken on BoPRC data before July 2008 to take these differences into consideration.

There was also some bias for results for nitrogen, as nitrate-nitrite-nitrogen can be found to be higher than total nitrogen in some streams. This is potentially because of interference in the analysis method (Adrian Spence, BoPRC Laboratory Leader pers comm 2013).

2.2 Stream Nutrients and Hydrological Considerations

Rutherford's 2003 report on nutrient load targets in Lake Rotorua highlighted the importance of hydrology when calculating nutrient loads in streams. One relationship found by Hoare (1980) and Abell (2012) was that event mean concentrations of particulate nutrients often increased with flow, and Abell noted that nitrate concentrations were diluted during periods of maximum flow. In contrast, Hoare noted that soluble nutrient (nitrogen and phosphorus) concentrations showed no significant variation with flow.

While Hoare (1980) found that greater than 90% of total annual stream inflow to Lake Rotorua was supplied under base flow conditions, Abell showed that significant particulate nutrient loads could be transported over one storm event, when compared to base flow derived particulate nutrient exports. For example, in one catchment he found that over 4 months of sampling, 20% of total phosphorus load was exported to the lake over just 10 days. Catchment hydrology can also vary over time dependent on climatic conditions and land use, hence any comparison of nutrient data over time should account for changes in flow.

Data used in this report is based on monthly monitoring of streams and for the majority of streams flow is measured by physical gauging around the time of monitoring. The Ngongotahā, Utuhina and Puarenga Streams have stage high rate sampling of since 1975, providing a long term continuous flow record in these streams. There are a number of gaps in these records. For streams with continuous flow data daily average flows have been used. Missing flow data has been calculated form rating curves where possible. Comparison of monthly gauged flow data with streams with flow/level recordings has been used to create a monthly baseflow record. Approximately 95% of the 1990 to 2012 BoPRC monthly monitoring has been undertaken during baseflow conditions.

2.3 Trend Analysis

Stream water quality data sets have been assessed for trends using the methods described below. Two sets of analyses have been undertaken because of the a gap in temporal data: firstly using the entire data set from 1992 – 2012 and then from 2002 – 2012.

Trend analysis was undertaken on sites with five or more years of data where the data offers reasonable continuity. Analysis was undertaken taking into account both temporal trends and flow adjusted trends where appropriate. The approach to trend analysis follows the non-parametric methods of Helsel and Hirsch (1992) which have been utilised by Vant and Smith (2004), and more recently have been used to analyse New Zealand's National River Water Quality Network (Ballantine and Davies-Colley, 2009).

To accurately detect trends in water quality data, it was necessary to look at the influence seasonal variability and flow variability has on the data. Seasonality affects many parameters such as rainfall (and subsequent flow), temperature, or land use activities that may impact some water quality parameters. Likewise, flow adjustment may be necessary as some water quality parameters change with variation in flow.

Trend analysis involved computation of each parameter either with the seasonal-Kendall test or Mann-Kendall test using the Time Trends software (Jowatt, 2012). Flow adjustment was performed for each test where necessary and where this was done adjustment utilised Locally Weighted Scatterplot Smoothing (LOWESS) with a 30% span, which is the adjustment method recommended for the national rivers monitoring set.

The Sen Slope Estimator (SEN) was used to represent the direction and magnitude of trends in data. This approach involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope.

Positive slopes indicate an increase in the values of a water quality parameter and negative slopes indicate an overall decrease. For each trend slope the probability of the slope occurring due to chance was also calculated. The *p*-value indicates if the trend detected is statistically significant. Conventionally, *p*-values of 5% (or $p<0.05$) or less are regarded as statistically significant (i.e. the 95% confidence level, unlikely to occur due to chance).

Results for trend analysis over the relative dataset record have been by their percentage trend slope and then by their 'p' value. The trend slope is expressed by the relevant parameters units/year.

Values of the SEN were also normalised by dividing through by the raw data median to give the *relative* SEN (RSEN). Expressed is a percentage change per year (%/year), this standardisation of the slopes allows for easier comparison between sites (and parameters). *Meaningful* trends have been categorised by Scarsbrook (2006) and Ballantine and Davies-Colley (2009) as being those with RSEN greater than 1% per year with the null hypothesis for the Kendall test rejected ($p<0.05$). RSEN results with a greater than 1% per year increase or decrease are marked in bold type in trend results tables.

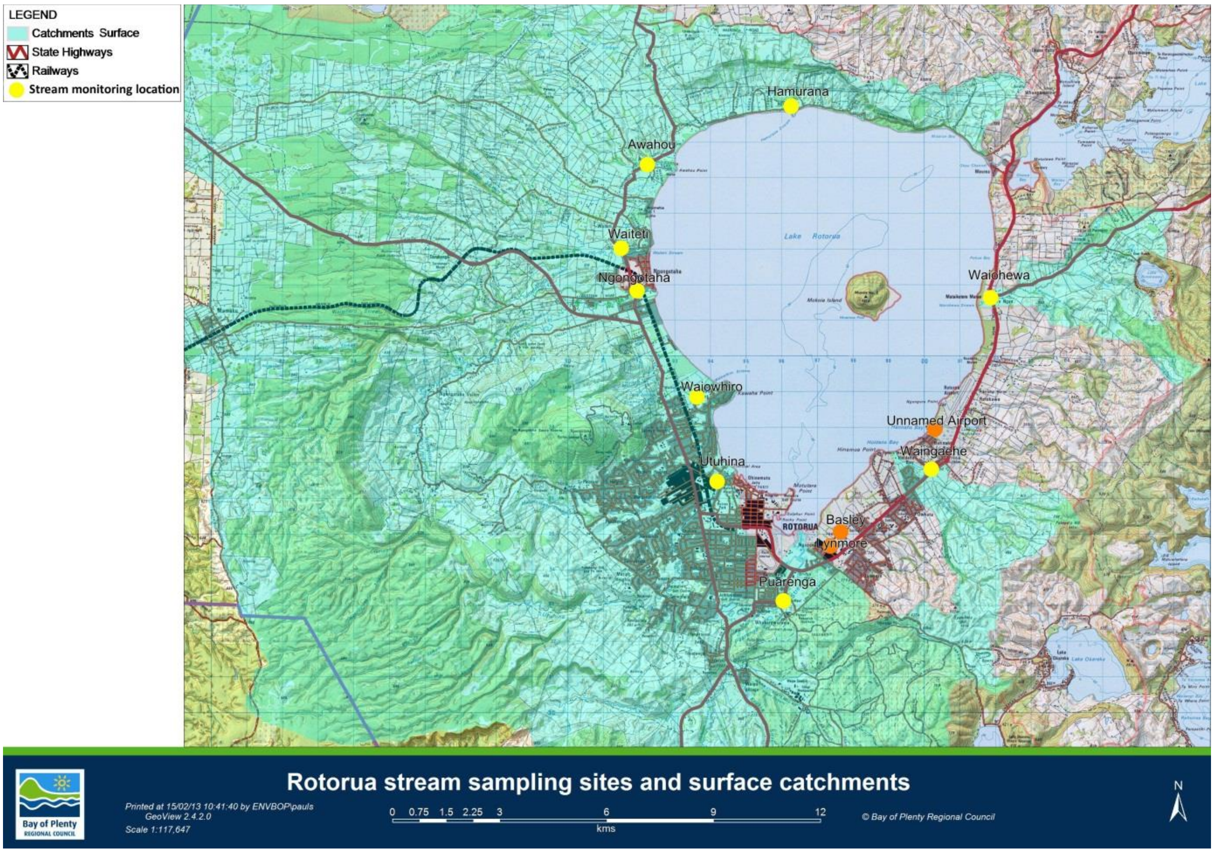


Figure 2.1 *Stream monitoring locations in the surface catchments (orange circles are the location of minor inflows monitored by BoPRC).*

Part 3: Rotorua Streams Results and Discussion

3.1 Stream Flow

Flow data collected by BoPRC and NIWA show that seven of the nine streams monitored have significantly increasing flow (seasonal Kendal test $p<0.05$) over the period 1992 to 2012 reflecting recent high rainfall events. Particularly high rainfall was experienced over the last two summers, with some of the highest flood flows recorded in some streams over the past two decades. These high flows have resulted in high lake levels in many of the Rotorua Lakes.

Regional Council monthly data for average annual flows based for the major streams are given in Table 3.1 and Figure 3.1 displays median and interquartile ranges. Further monthly flow statistics are given in Appendix 1.

Table 3.1 Annual average flow for nine Rotorua Streams (m^3/s)

	1992	1993	1994	2003	2004	2005	2006	2007	2008	2009	2010	2011
Awahou Stream	1.55	1.49	1.73	1.52	1.51	1.53	1.67	1.65	1.59	1.65	1.67	1.89
Hamurana Stream	2.59	2.49	2.35	2.40	2.47	2.51	2.71	2.46	2.40	2.43	2.55	2.80
Ngongotaha Stream	1.34	1.30	1.17	1.16	1.58	1.57	1.66	1.32	1.95	1.69	1.53	2.00
Puarenga Stream	1.76	1.46	1.51	1.50	1.88	1.78	1.72	1.52	1.63	1.56	1.48	2.29
Utuhina Stream	2.79	1.65	2.11	1.44	1.62	1.59	1.84	1.53	1.67	1.77	1.88	1.91
Waingaehe Stream	0.24	0.21	0.23	0.20	0.22	0.25	0.28	0.25	0.25	0.25	0.24	0.28
Waiohewa Stream	0.47	0.31	0.26	0.30	0.33	0.35	0.41	0.32	0.44	0.33	0.33	0.49
Waiowhiro Stream	0.51	0.26	0.29	0.28	0.32	0.29	0.35	0.32	0.32	0.30	0.32	0.34
Waiteti Stream	1.05	1.05	0.92	0.89	0.97	1.15	1.33	1.11	1.06	1.20	1.11	1.42
Total	**12.3**	**10.2**	**10.6**	**9.7**	**10.9**	**11.0**	**12.0**	**10.5**	**11.3**	**11.2**	**11.1**	**13.4**

There was little flow variability in the Rotorua inflow streams based on monthly sampling data i.e. coefficient of variation was less than one; however, Rutherford (2008) found that flood flows can make up a considerable volume of the total annual flow in some streams. In recent wetter years (2011 and 2012) monitoring has been undertaken during baseflow conditions just over 80% of the time (compared to 95% on average from 1992 to 2012). Hence, average annual flows for most streams are below what Hoare measured by continuous flow recording in 1976, and these are lower than what Fish reported in 1968/70 (Table 3.2). It is unclear whether Fish's flow data is baseflow or baseflow/floodflow.

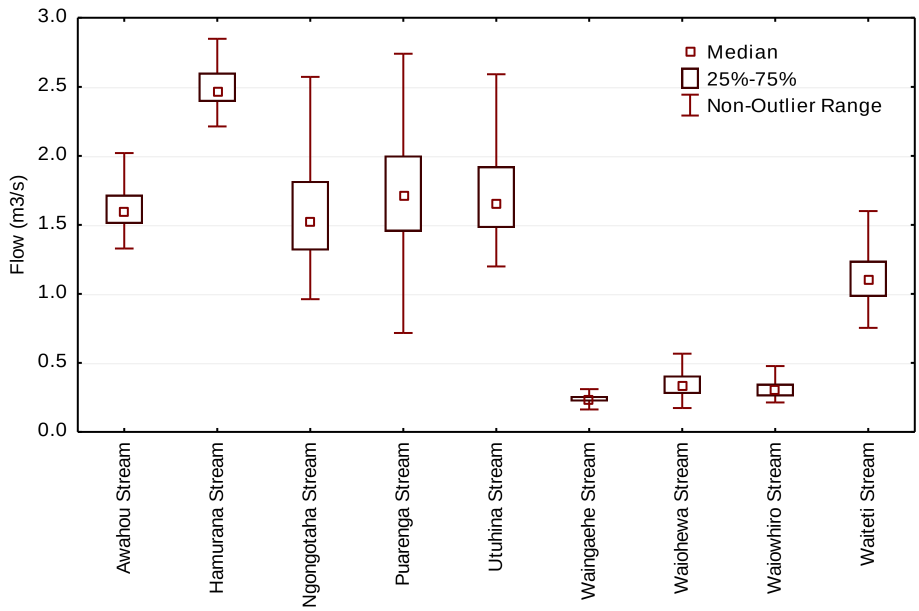


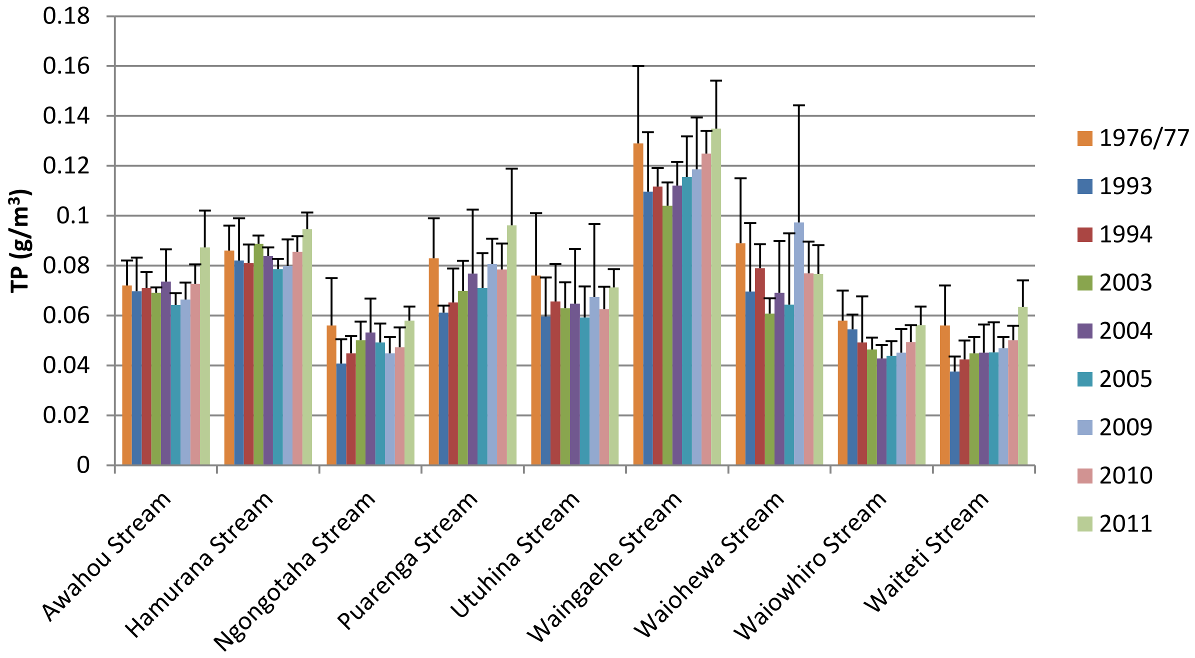
Figure 3.1 Box-whisker plot of monthly flow, 1992 to 2012.

Table 3.2 Annual average baseflow for nine Rotorua Streams (m^3/s) from previous studies (from Rutherford, 2003).

	Fish 1968-70	Hoare 1976	Williamson 1987-89
Awahou Stream	1.79	1.66	
Hamurana Stream	2.96	3.08	
Ngongotaha Stream	2.29	1.98	1.38
Puarenga Stream	1.92	2.05	
Utuhina Stream	2.22	2.04	
Waingaehe Stream	0.48	0.41	
Waiohewa Stream	0.29	0.27	
Waiowhiro Stream	1.51	1.39	
Waiteti Stream	-	0.41	

3.2 Phosphorus

The Waingaehe Stream has the highest concentration of total phosphorus (TP) (Figure 3.2), composed primarily of dissolved reactive phosphorus (DRP). Ngongotahā, Waiwhiro and Waitetī Streams have the lowest concentrations of TP reflecting their different geology, mix of springs and catchment types. Annual average TP levels are fairly consistent over most of the nine major streams at baseflow, but average TP concentrations were consistently elevated in 2011 due to the higher frequency of intense storm events.



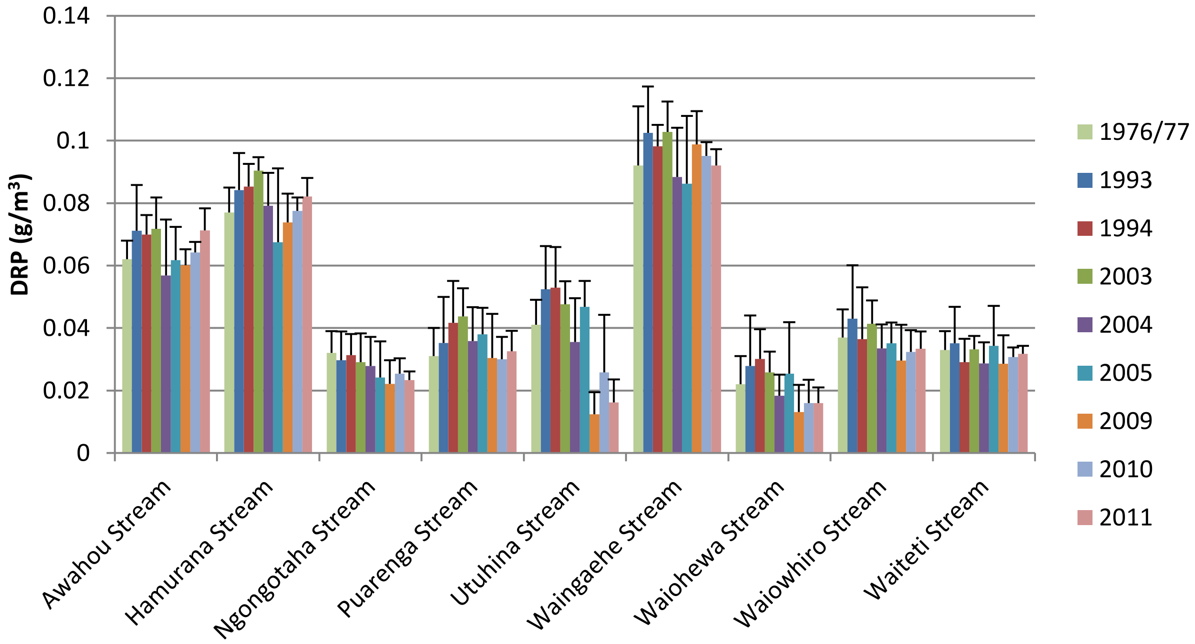


Figure 3.2 Average annual TP & DRP concentrations for selected years (bar is one standard deviation). 1976/77 data is from Hoare (1980).

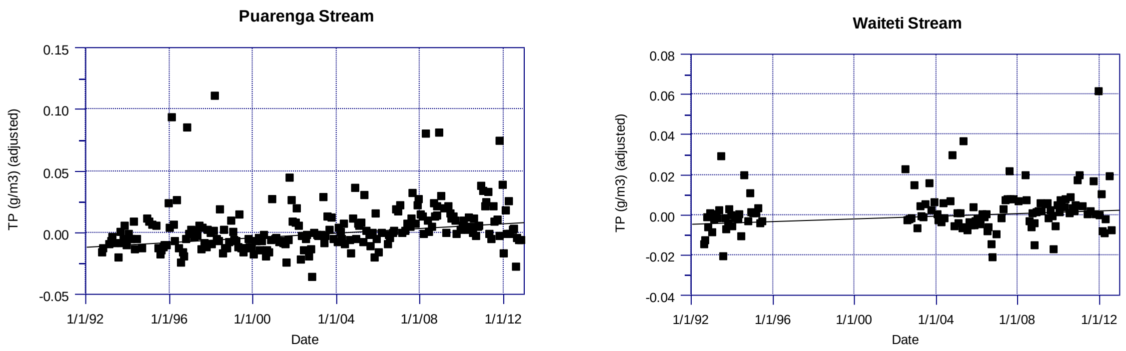


Figure 3.3 Seasonal Kendal trend slope for TP in Puarenga and Waitetī Streams, 1992 to 2012 (flow adjusted).

Puarenga Stream (Figure 3.3) and Waiteti streams are the only ones to display a significant upward trend in TP over the longer term Regional Council record (1992 to 2012). Puarenga trend was increasing at 1.52% per annum with a $p<0.001$, and the Waitetī was increasing at 0.67% per annum with $p=0.004$ (data gap in the Waitetī data from 1995 to 2002).

The Waitetī Stream observed trend for 2002 to 2012 had a higher rate of increase at 1.67% per annum (Table 3.3) than the 1992 to 2012 period. Other streams also have more recent significant increasing trends as shown in Table 3.3. Even though the trend analysis has adjusted for seasonality and flow, some bias from the increased flood flow events in the past few years may be the underlying cause in the upward trend. This could be due to increased pools of available phosphorous in the streams due to the intermittent actions of intense storm events.

Table 3.3 TP trend statistics for several Rotorua Streams, analysis period 2002-2012 (Bold values are meaningful and significant).

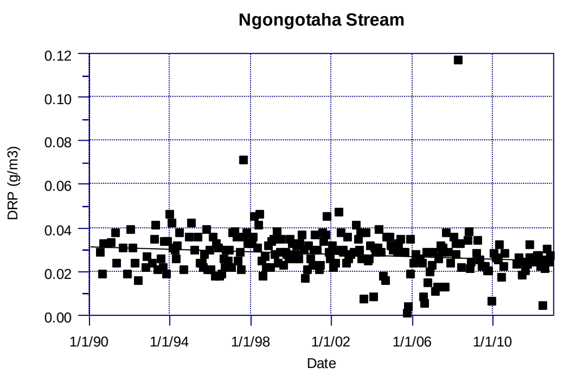
Stream	n	%/yr (RSEN)	p-value	median
Utuhina Stream	108	**1.60**	0.003	0.062
Waingaehe Stream	107	0.80	0.040	0.112
Waiowhiro Stream	103	**1.92**	0.0001	0.047
Waitetī Stream	96	**1.67**	0.023	0.048
Puarenga Stream	117	**2.24**	0.0002	0.071

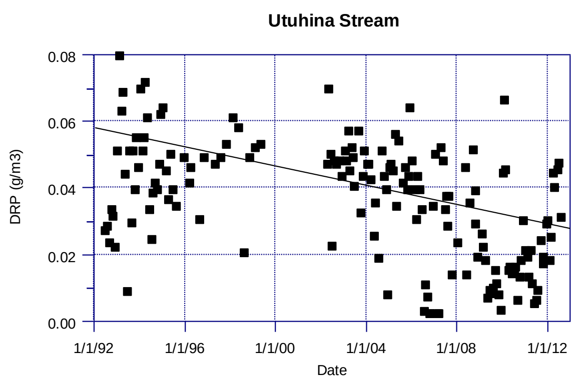
Several streams have lower annual average DRP concentrations in the last three years compared to earlier averages (Figure 3.2), notably: Ngongotahā; Puarenga; Utuhina; and Waiohewa Streams. The Utuhina stream has been treated with aluminium sulphate (alum) since 2006 explaining the strongly significant decreasing DRP trend (Tables 3.4 & 3.5, Figure 3.4 & 3.5). Alum dosing has also been undertaken in the Puarenga Stream since 2010, downstream of the monitoring site which provides the data used in this report.

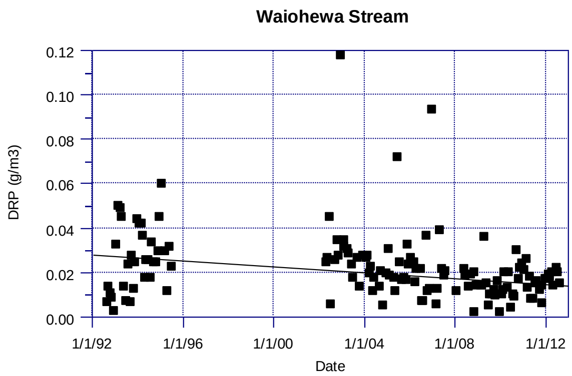
Of the nine major inflows analysed, five show significant ($p>0.05$) decreasing trends in DRP concentration over the 1992 to 2012 analysis period and likewise for four streams over the 2002 to 2012 analysis period. Apart from the Utuhina, there are no obvious explanations as to the reason for these trends. It is likely to be a combination of land-use changes, possibly changes in dissolution kinetic in groundwater under differing groundwater conditions, and increased buffering of DRP in stream waters (Abell, 2012). All streams with significant trends have a moderate negative correlation with flow (Utuhina a weak correlation), with the exception of the Ngongotahā Stream which has a weak positive correlation. Hence, oscillating groundwater conditions may be influencing these trends with possibly some dilution occurring with greater flows. The Ngongotahā Stream has had increasing trends in suspended sediments and indicator bacteria, thus increasing DRP may be a symptom of contamination events.

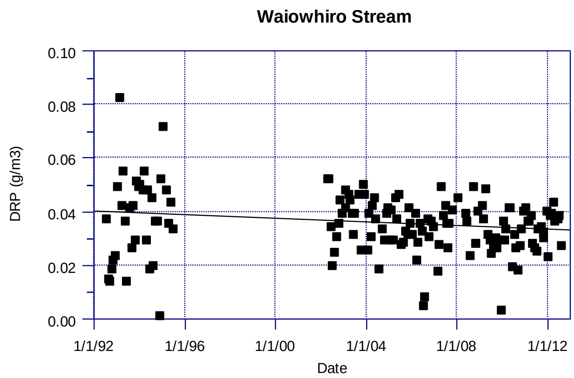
Table 3.4 DRP trend statistics for several Rotorua Streams, analysis period 1992-2012 (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Ngongotahā Stream	230	**-1.07**	0.0004	0.028
Utuhina Stream	163	**-3.58**	<0.0001	0.039
Waingaehe Stream	143	-0.32	0.004	0.093
Waiohewa Stream	140	**-3.70**	0.0002	0.019
Waiowhiro Stream	150	**-0.84**	0.024	0.036









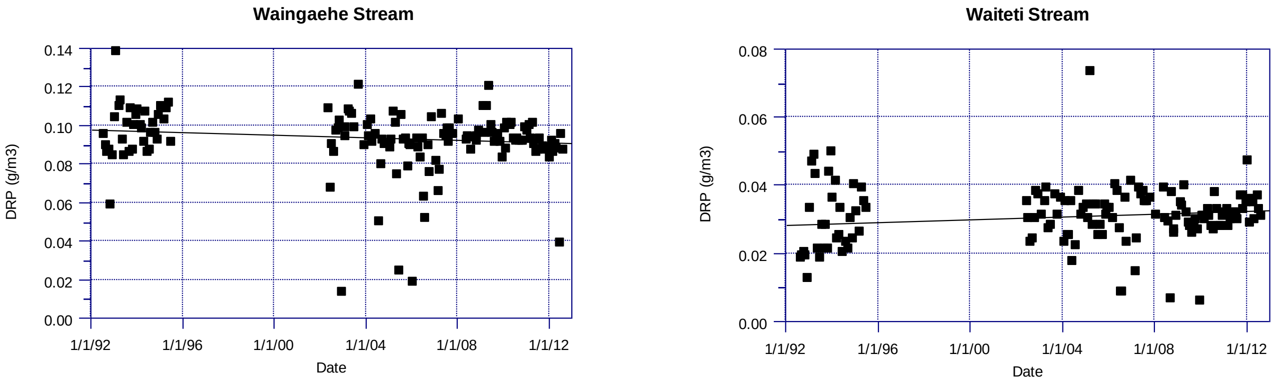


Figure 3.4 Seasonal Kendal trend slope for DRP in six Rotorua Streams, 2002 to 2012.

Table 3.5 DRP trend statistics for several Rotorua Streams, analysis period 2002-2012 (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Ngongotahā Stream	112	**-2.6**	0.0004	0.027
Puarenga Stream	118	**-4.58**	0.0004	0.037
Utuhina Stream	113	**-9.94**	<0.0001	0.033
Waiohewa Stream	106	**-5.56**	0.0009	0.018

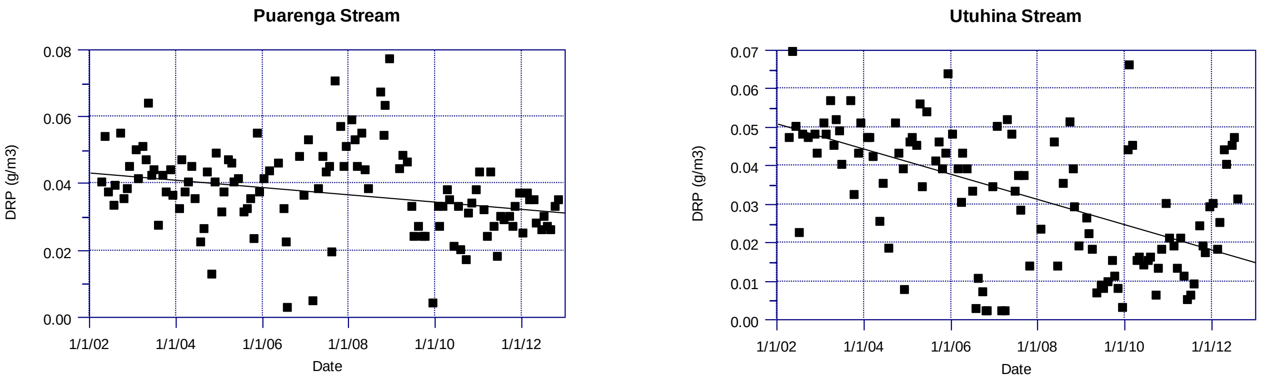


Figure 3.5 Seasonal Kendal trend slope for DRP in Puarenga and Utuhina Streams, 2002 to 2012.

3.3 Nitrogen

The Waiohewa Stream stands out as a significant contributor of nitrogen to Lake Rotorua (Figure 3.6) due to geothermal fluids from the Tikitere geothermal field. Most of the nitrogen is in the form of dissolved inorganic nitrogen (DIN), with ammonium (NH_4-N) being oxidised to nitrate-nitrite-nitrogen (NNN) in the stream, resulting in a similar ratio of ammonium and nitrate-nitrite-nitrogen as the stream enters the lake.

Observationally, other cold water streams appear to have increasing concentrations of nitrogen, with the exception of the Utuhina and Waiowhiro Streams. Most of the nitrogen in the cold water streams is in the NNN form with ammonium and organic nitrogen only a small component of the nitrogen load to the lake from these sources (see Figure 3.7).

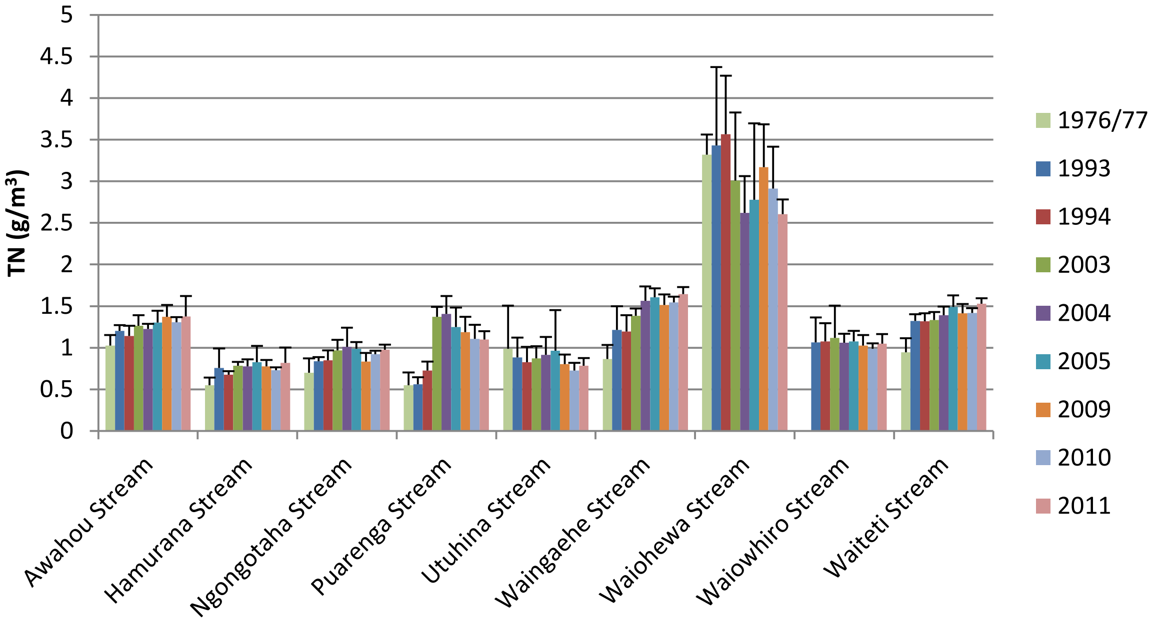


Figure 3.6 Average annual TN concentrations for selected years (bar is one standard deviation). 1976/77 data is from Hoare (1980).

Trends analyses of the longer term BoPRC data set (deseasonalised and adjusted for flow) show three significant increasing trends and two decreasing for TN (Table 3.6, Figure 3.8). Although the Utuhina and Waiohewa streams display negative trends, the reasons for these are probably for quite different reasons. The Utuhina has a decreasing total nitrogen trend due to increasing urbanisation which has been encroaching into mostly low intensity pastoral agriculture, whereas the geothermally dominated Waiohewa has a large proportion of its nitrogen as ammonium, which also displays a decreasing trend. Geothermal waters may have decreased in ammonium content in the Waiohewa and/or a greater conversion of ammonium to nitrate-nitrogen is occurring in the stream contributing to the increasing NNN trend.

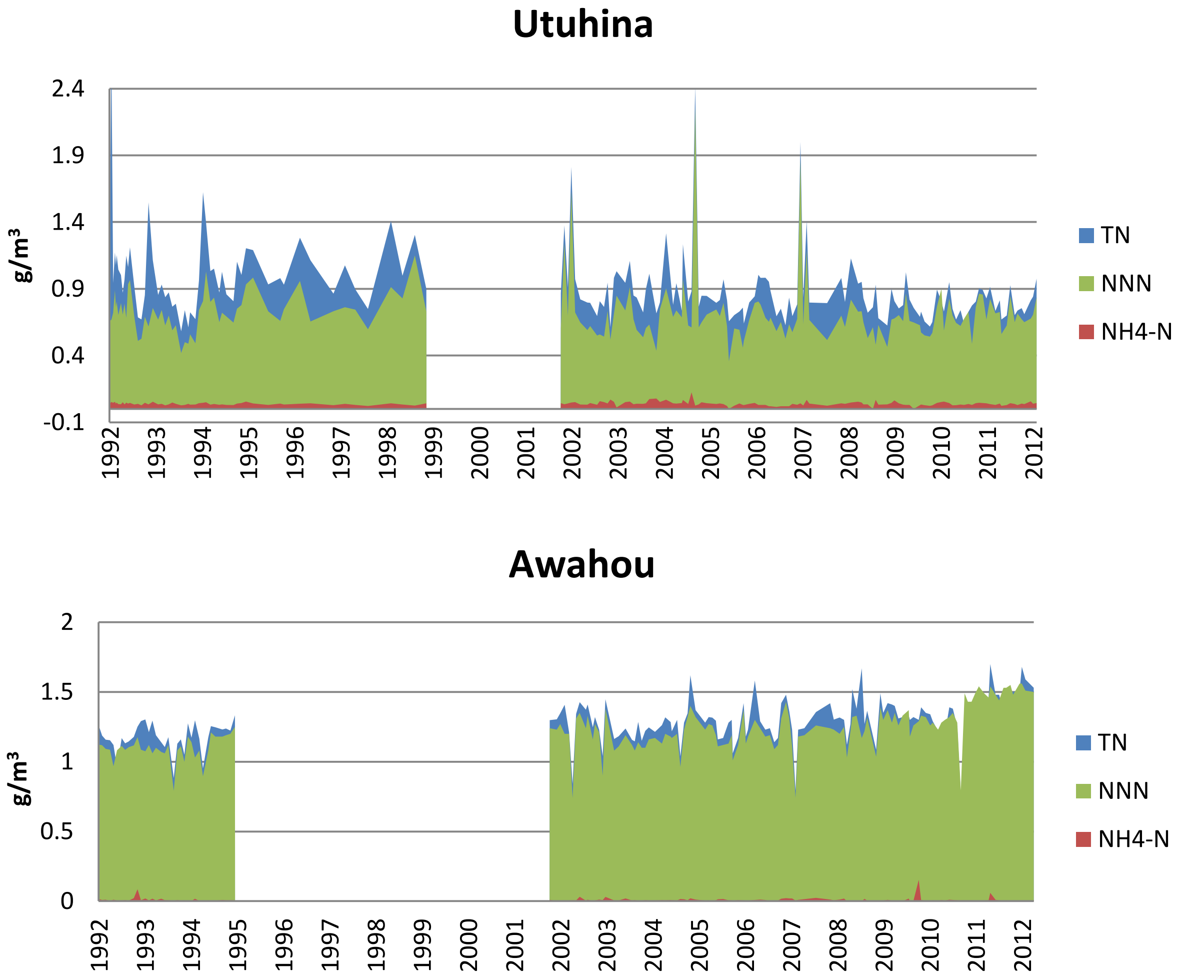


Figure 3.7 TN, NNN and NH4-N concentrations in the Utuhina and Awahou Streams, showing the dominance of NNN at both streams.

Increasing intensive land use is a likely contributor to the rising TN trend in the Awahou and Waingaehe Streams and these trends are driven by the underlying increasing concentration of NNN in many of the major Rotorua Streams (Tables 3.6, 3.7). Puarenga Stream has a different nitrogen profile due to the influence of Rotorua District Council's and Red Stag's wastewater effluent spray irrigation. There is a longer term increasing trend in TN but a decreasing trend from 2002 to 2012 (Table 3.7) reflecting the improvements in spray irrigation and nitrogen reduction at the wastewater treatment plant. The trend is repeated with respect to NNN.

Table 3.6 TN trend statistics for several Rotorua Streams, analysis period 1992-2012 (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Awahou Stream	137	0.43	0.0002	1.282
Puarenga	210	**1.1**	0.0001	1.147
Utuhina Stream	155	**-1.22**	<0.0001	0.834
Waingaehe Stream	140	0.56	0.0014	1.508
Waiohewa Stream	129	**-1.25**	0.0019	2.721

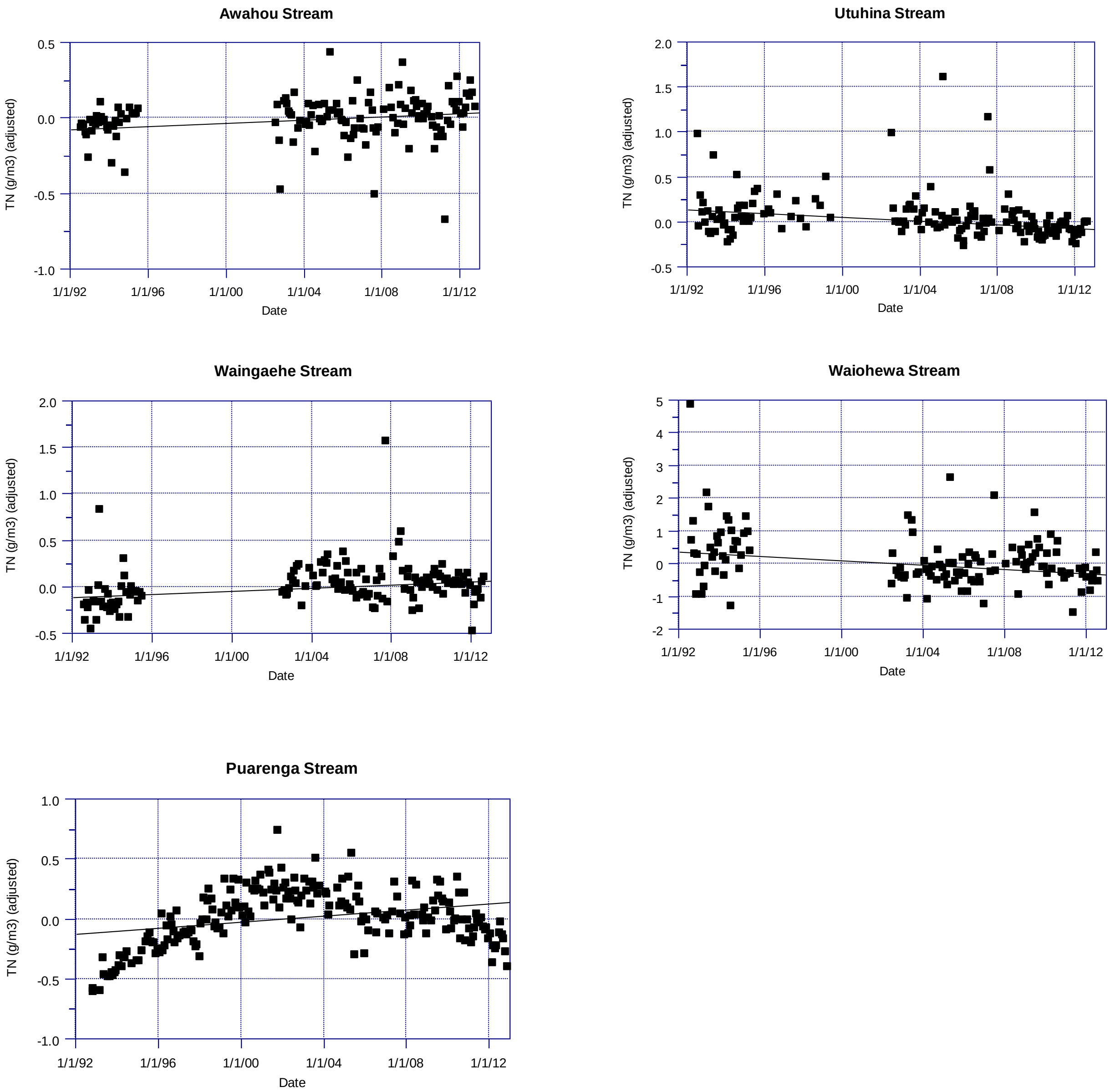
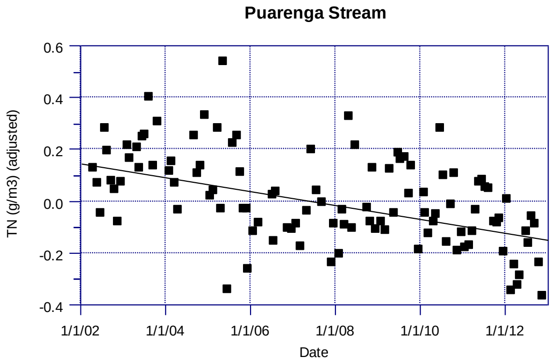


Figure 3.8 *Seasonal Kendal trend slope for TN in Rotorua Streams, 1992 to 2012.*

Table 3.7 *TN trend statistics for several Rotorua Streams, analysis period 2002-2012 (Bold values are meaningful and significant).*

Stream	**n**	**%/yr (RSEN)**	**p-value**	**median**
Awahou Stream	104	0.67	0.007	1.321
Puarenga Stream	108	**-2.28**	<0.0001	1.173
Utuhina Stream	106	**-1.51**	0.0008	0.808



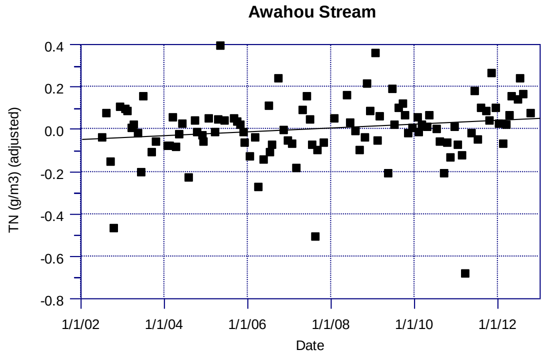


Figure 3.9 Seasonal Kendal trend slope for TN in Rotorua Streams, 2002 to 2012

The influence of geothermal fluids is expressed in the Waiohewa Stream as having the greatest annual average concentrations of ammonium of all the streams followed by other the geothermally influenced streams, the Puarenga and Utuhina (Figure 3.10) respectively. Ammonium content is only a minor contribution to the overall nitrogen loading to the lake in most other streams as demonstrated in Figure 3.7.

Ammonium levels significantly decreased in the Hamurana, Wainagehe, Waiowhiro and Waitetī Streams between 1992 and 2012, and also decreased in the Hamurana and Waitetī streams between 2002 and 2012 (Tables 3.8 and 3.9). The Waitetī Stream displays the greatest change with over a 7% per annum decrease over the 2002 to 2012 period, which may be due to improvements in agricultural management practices over the period as well as increasing subdivision. Recent increased discharge volumes may also be affecting ammonium trends although little correlation between flow and ammonium is apparent in most streams. Abell (2012) in measurements of ammonium concentrations and flow in several storm events in the Puarenga and Ngongotahā Streams found that there was no clear relationship between flow and ammonium. However, increased baseflow in streams as a result of recent intense storm events may be impacting on in-stream nitrogen fluxes and changes in flushing of ammonium from land with.

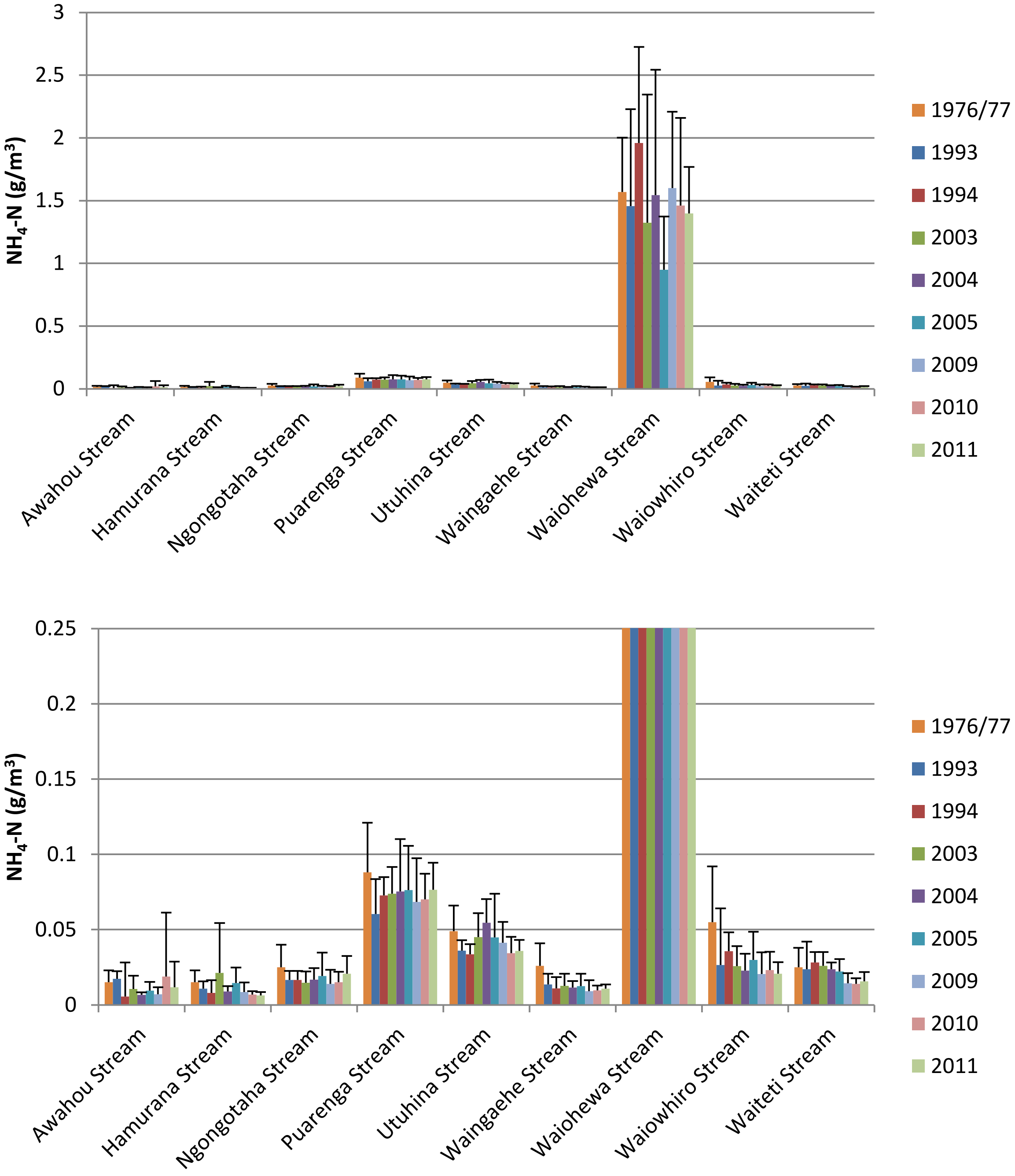


Figure 3.10 Average annual NH4-N concentrations for selected years (bar is one standard deviation). 1976/77 data is from Hoare (1980). Note the expanded y-axis scale in the lower Figure

Table 3.8 NH_4-N trend statistics for several Rotorua Streams, analysis period 1992-2012 (not flow adjusted) (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Hamurana Stream	143	**-2.5**	0.0007	0.008
Waiohewa Stream	123	**-1.31**	0.038	1.370
Waingaehe Stream	143	**-2.0**	0.011	0.010
Waiowhiro Stream	149	**-2.0**	0.013	0.020
Waitetī Stream	140	**-3.16**	<0.0001	0.019

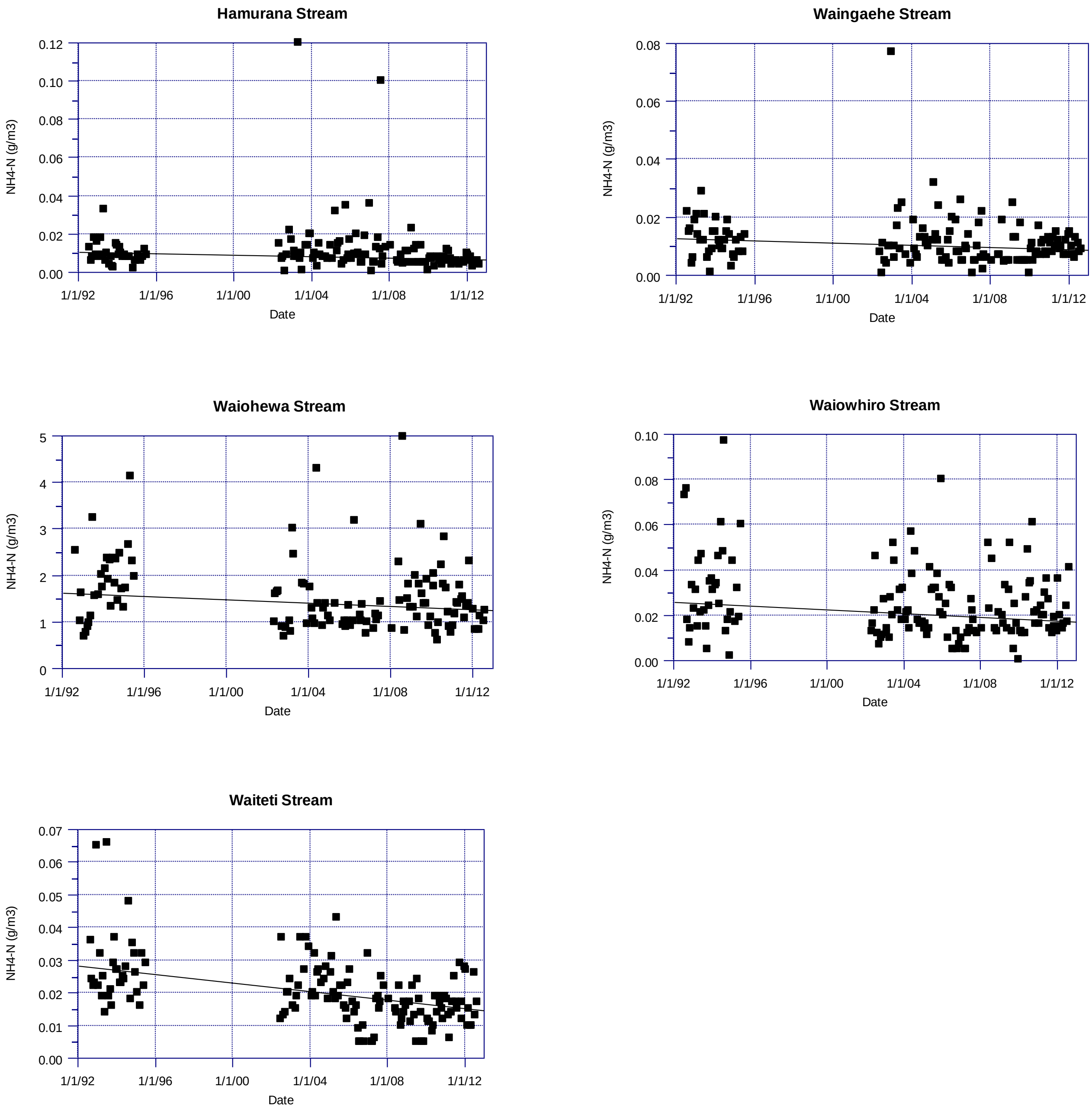
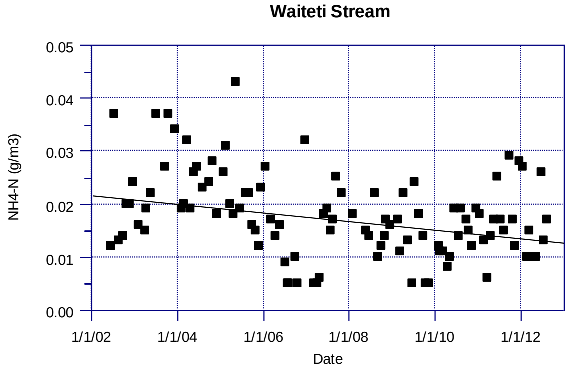


Figure 3.11 Sen slope trends for NH_4-N four Rotorua Streams, 1992 to 2012.

Table 3.9 NH_4-N trend statistics for several Rotorua Streams, analysis period 2002-2012 (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Hamurana Stream	109	**-5**	0.0001	0.008
Ngongotahā Stream	112	**2.67**	0.015	0.015
Utuhina Stream	111	**-3.68**	0.026	0.038
Waitetī Stream	107	**-7.65**	0.002	0.017



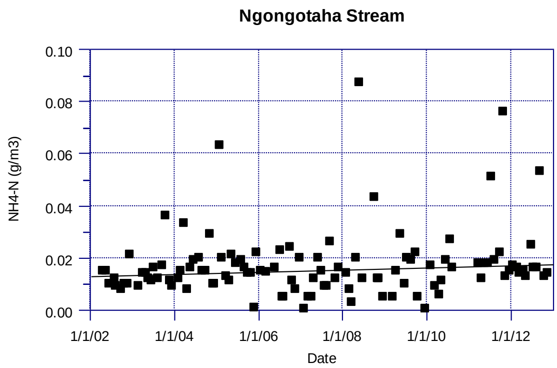


Figure 3.12 Sen slope trends for NH4-N for Waitete and Ngongotahā Stream, 2002 to 2012.

Nitrate-nitrite-nitrogen (NNN) is the dominant form of nitrogen entering Lake Rotorua that is readily available to lake phytoplankton. Average annual concentrations of NNN are displayed in Figure 3.13 with the BoPRC data shown alongside that from Fish (1975) and Hoare (1980), similar to that presented by Rutherford (2003). NNN concentrations in most streams have doubled over the past 37 years, with the exception of Waiowhiro Stream. Several streams also appear to show a continued increasing NNN average annual concentration: the Awahou; Hamurana; Ngongotahā; and Waitetī. The Waiohewa, Utuhina and Waowhiro streams appear to have a more stable NNN signature particularly in the last 20 years, whereas the Puarenga stream although strongly elevated in NNN since the mid-1990s has shown a recent decline in annual average NNN concentration.

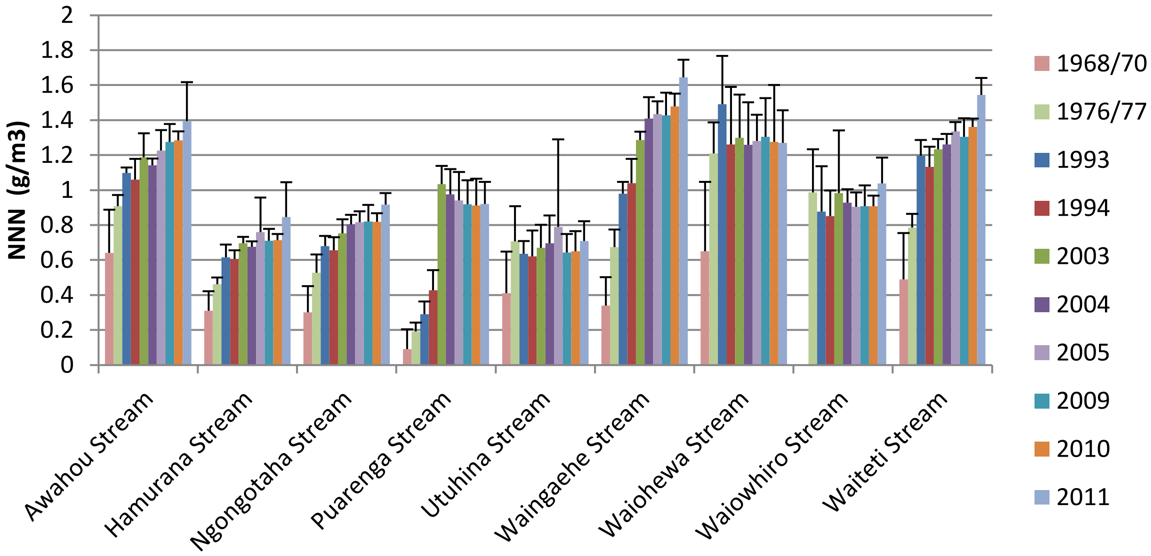


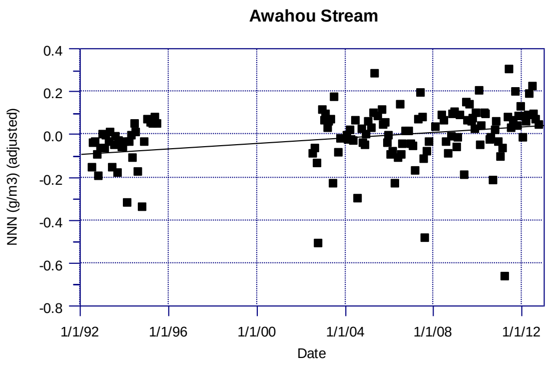
Figure 3.13 *Average annual NNN concentrations for selected years (bar is one standard deviation). 1976/77 data is from Hoare (1980), 1968/70 from Rutherford (2003).*

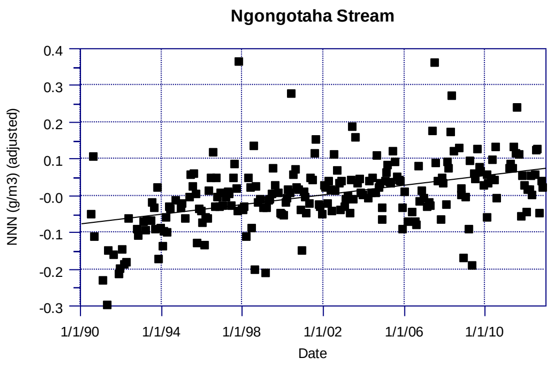
Trend analysis shows that from 1992 to the present, eight of the nine major inflows to Rotorua have a significant increasing trend in NNN (Table 3.10, Figure 3.14). In contrast, the Utuhina Stream displayed a decreasing trend over the same analysis period, but trend analysis over the more recent period (2002 to 2012) shows that NNN concentrations here are significantly increasing (Table 3.11). This pattern is reversed in Puarenga Stream as it shows a long-term (1992-2012) increasing NNN trend and a recent (2002-2012) decreasing NNN concentration (Figure 3.15).

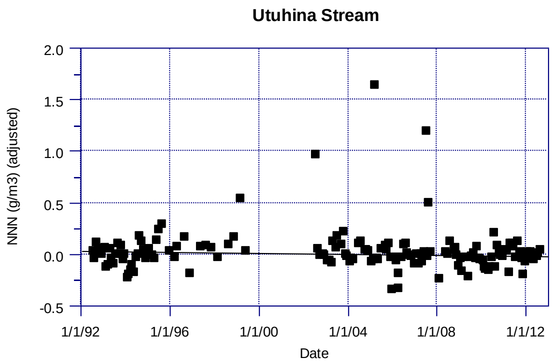
Table 3.10 *NNN trend statistics for several Rotorua Streams, analysis period 1992-2012 (Bold values are meaningful and significant).*

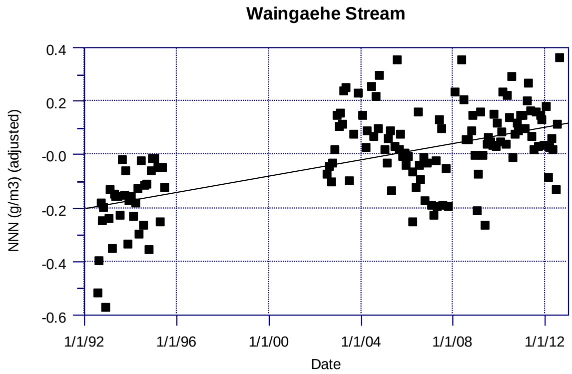
Stream	n	%/yr (RSEN)	p-value	median
Awahou Stream	137	0.52	<0.0001	1.197
Hamurana Stream#	140	0.97	<0.0001	0.692
Ngongotahā Stream	226	0.83	<0.0001	0.786
Puarenga Stream	215	**2.27**	<0.0001	0.884
Utuhina Stream	155	-0.39	0.043	0.67
Waingaehe Stream	140	**1.08**	<0.0001	1.403
Waiohewa Stream	*129*	*0.33*	*0.17*	*1.348*
Waiowhiro Stream	136	0.41	0.013	0.926
Waitetī Stream	128	0.5	<0.0001	1.305

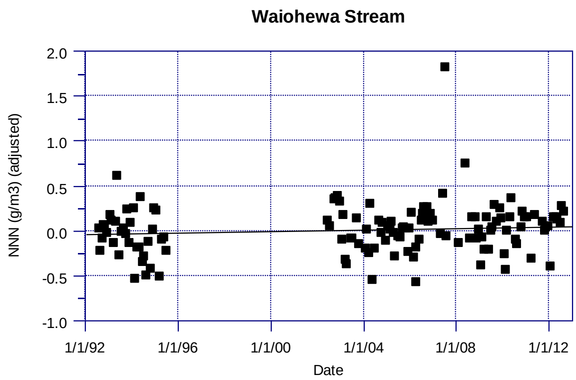
not flow adjusted

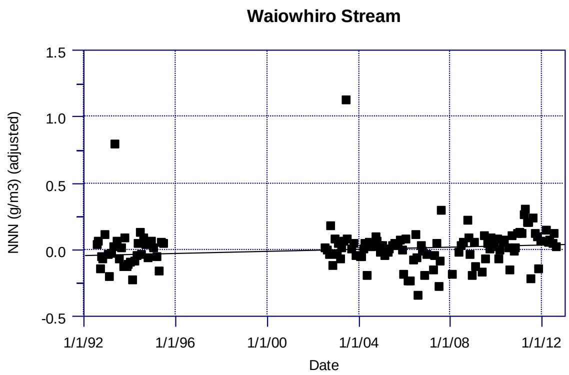

Awahou Stream
NNN (g/m3) (adjusted)
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date

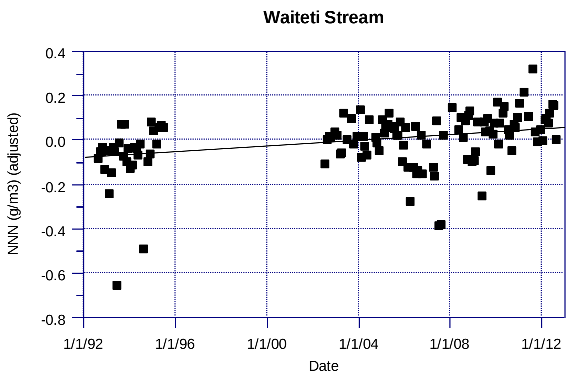

Ngongotaha Stream
NNN (g/m3) (adjusted)
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
1/1/90
1/1/94
1/1/98
1/1/02
1/1/06
1/1/10
Date

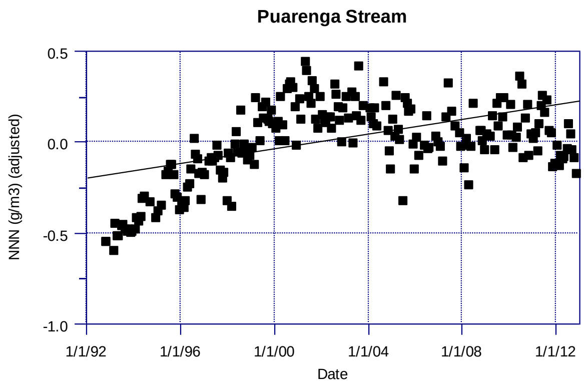

Utuhina Stream
NNN (g/m3) (adjusted)
2.0
1.5
1.0
0.5
0.0
-0.5
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date


Waingaehe Stream
NNN (g/m3) (adjusted)
0.4
0.2
-0.0
-0.2
-0.4
-0.6
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date


Waiohewa Stream
NNN (g/m3) (adjusted)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date


Waiowhiro Stream
NNN (g/m3) (adjusted)
1.5
1.0
0.5
0.0
-0.5
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date


Waiteti Stream
NNN (g/m3) (adjusted)
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date


Puarenga Stream
NNN (g/m3) (adjusted)
0.5
0.0
-0.5
-1.0
1/1/92
1/1/96
1/1/00
1/1/04
1/1/08
1/1/12
Date

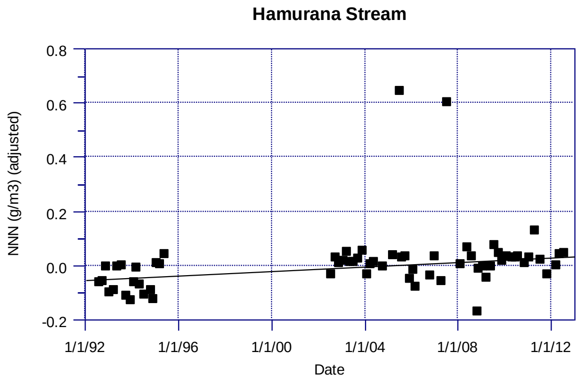


Figure 3.14 Sen slope trends for NNN for Rotorua Stream, 1992 to 2012.

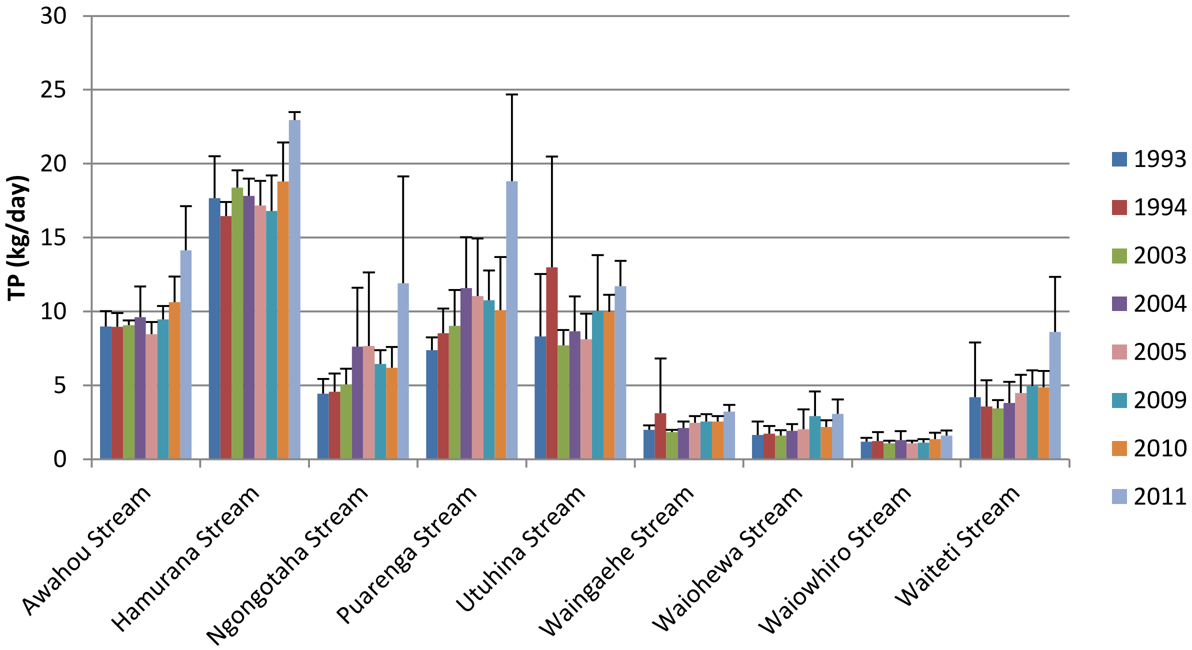
Table 3.11 NNN trend statistics for several Rotorua Streams, analysis period 2002-2012 (Bold values are meaningful and significant).

Stream	n	%/yr (RSEN)	p-value	median
Awahou Stream	104	**1.07**	0.0001	1.275
Hamurana Stream[#]	106	**1.39**	<0.0001	0.71
Ngongotahā Stream	111	0.6	0.016	0.818
Puarenga Stream	111	**-1.51**	<0.0001	0.94
Utuhina Stream	72	0.87	0.013	0.709
Waingaehe Stream	105	**1.03**	0.0004	1.48
Waitetī Stream	96	0.07	0.0001	1.343

not flow adjusted

Part 4: Nutrient loads and catchment yields; implications for lake management

Annual average daily loads for TP and TN based on monthly data are presented in Figure 4.1. Hamarana Stream has the highest phosphorus load of all the streams while the Waiowhiro Stream has the lowest. Nutrient loads in 2011 have been influenced by intense rain events of this time, and give some indication of the contribution of phosphorus and to a lesser extent nitrogen, during flood flow. As monthly sampling conducted by the Regional Council is typically taken during baseflow conditions, nutrient loading to the lake is likely to be underestimated. Rutherford (2008) estimated that flood flows in the Puarenga and Ngongotahā Streams makes up 36% and 44% of the total flow respectively. For other streams such as the spring fed Awahou and Hamurana, flood flow is only a minor component of the overall hydrograph. Abell (2012) modelled that 50% of the estimated TP load to the lake occurred over 10% of the time for the Ngongotahā Stream, and 17% of the time for the Puarenga. Hence, the load estimates provided in Figure 4.1 for at least these 2 streams may have underestimated total loads.



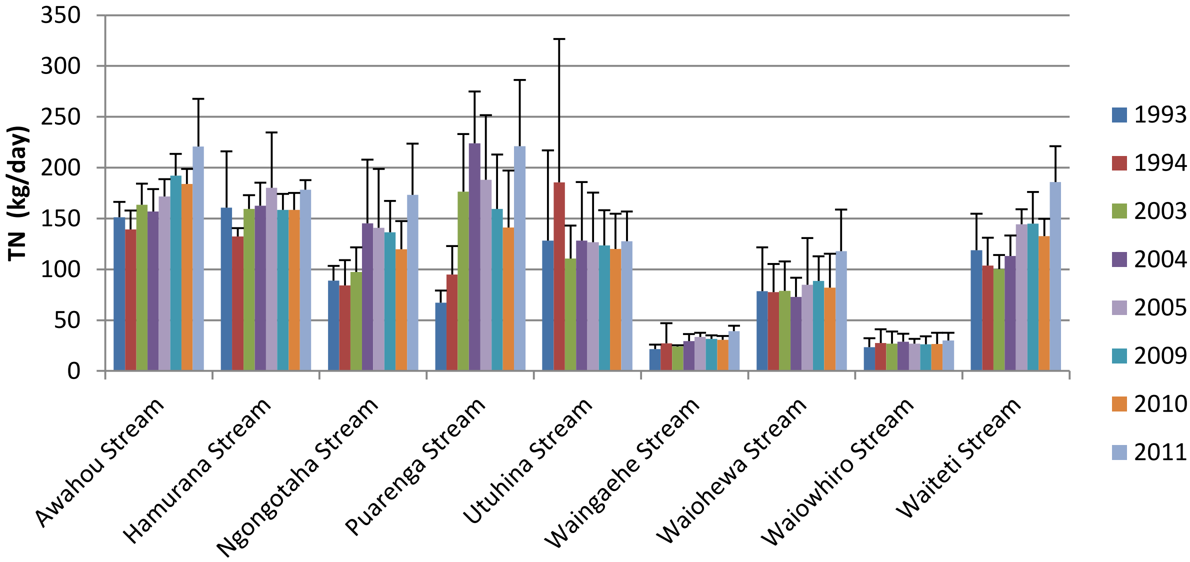
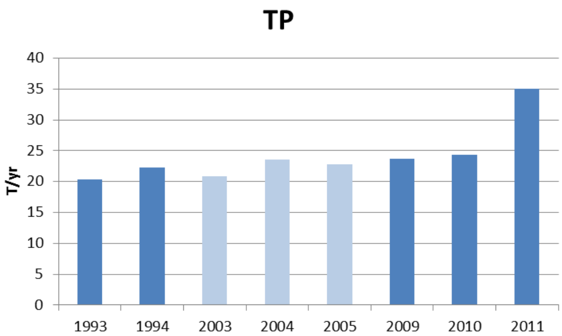


Figure 4.1 *Daily annual average phosphorus and nitrogen load for major Rotorua inflows (bar is one standard deviation).*

The annual combined loading of nitrogen to Lake Rotorua from the nine major inflows shows an increase over the last two decades (Figure 4.2). Further nutrient load will also come from groundwater directly to the lake, other inflows, and further floodflow. Looking for changes in loading to Lake Rotorua is better expressed by changes/trends in NNN, as shown in the previous section. This is because NNN trends are adjusted for flow and seasonality and provide a more reliable estimate of increasing nitrogen over time than comparing annual load estimates of TN which can be influenced by changing annual rainfall totals. The effect of flow on loads is apparent when comparing load estimates from Hoare who sampled during years (1976/77) of elevated flow in the major streams. Hoare found TN in the major streams to be around 255 T/yr for 1976 and 236 T/yr for 1977, and for TP 29.5 T/yr and 28.5 T/yr respectively. Flood flow TN was an additional 50 T/yr for both years and 10 T/yr for TP, again for both years. Comparison of these figures with the loads shown in Figure 4.2 indicates that nitrogen loads are increasing and that phosphorus loads are more stable, although floodflow and possibly greater groundwater recharge has impacted phosphorus loads as seen in Figure 4.2 in 2011.



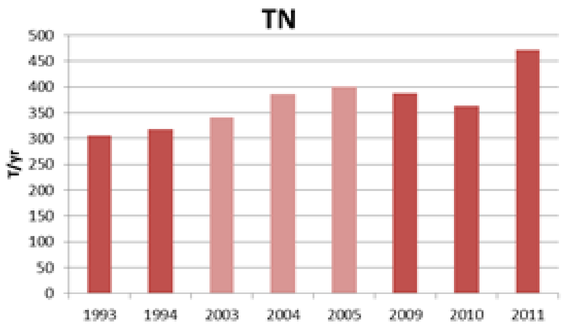


Figure 4.2 *Phosphorus and nitrogen estimated annual load from 9 major Rotorua Streams (note annual figures are not continuous).*

More particulate nutrient is exported with increasing flow, decreasing the relative contribution of dissolved inorganic nutrients to total nutrient loads (Abell, 2012). Figure 4.3 illustrates this for nitrogen in the Ngongotahā and Puarenga Streams. The load of TN increases more quickly with flow than the NNN load, reflecting storm events ability to mobilise particulate nitrogen (as well as phosphorus). Dissolved nutrients loads still increase with flow contributing to the higher nutrient loadings in wetter years, but with an increasing component of particulate and organic nutrient.

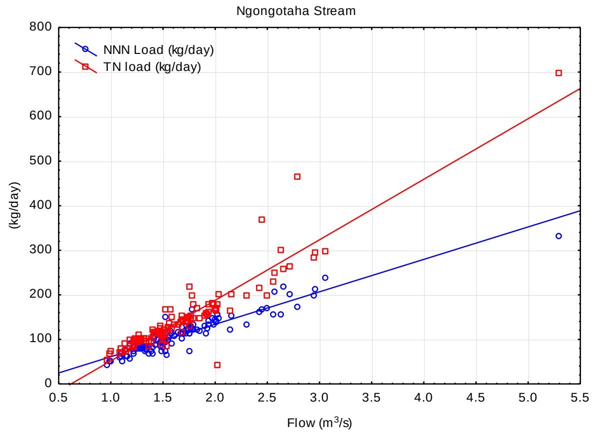
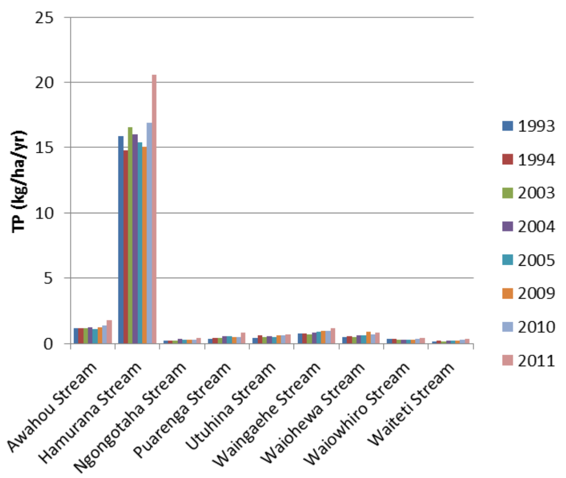
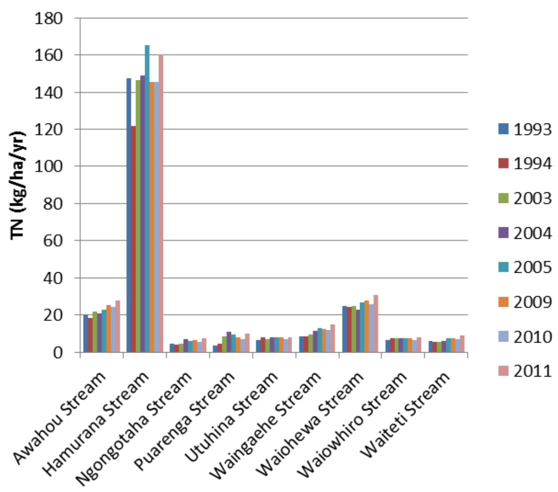


Figure 4.3 Flow vs TN and NNN daily average loads for Ngongotahā and Puarenga Streams, 2002 to 2012.

Arresting storm flow components of particulate exports of phosphorus and nitrogen will play a valuable part in reducing the total nutrient inputs to Lake Rotorua. However, measuring and monitoring the efficacy of restoration efforts to reduce particulate export is difficult and costly. Several studies have quantified differing nitrogen and phosphorus components with storm flow (Hoare (1980), Williams (1996), Abell (2012)), but relating these to changes in catchment management requires some measure of nutrient with respect to the changes made to catchment conditions.

Yield estimates can provide nutrient loading on a per catchment basis. For the purposes of this report, catchment yield estimates for baseflow data has been calculated and presented in Figures 4.4 and 4.5. For phosphorus, catchment yields appear to be increasing over time but Figure 4.5 shows that since 2005 the difference between dissolved phosphorus (DRP) catchment yields compared to the total phosphorus (TP) catchment yields has increased. DRP concentrations do not vary significantly with flow whereas particulate phosphorus does. Thus the increased difference between measured DRP and TP post 2005 suggests that there has been a greater influence of floodflows on TP catchment yields.





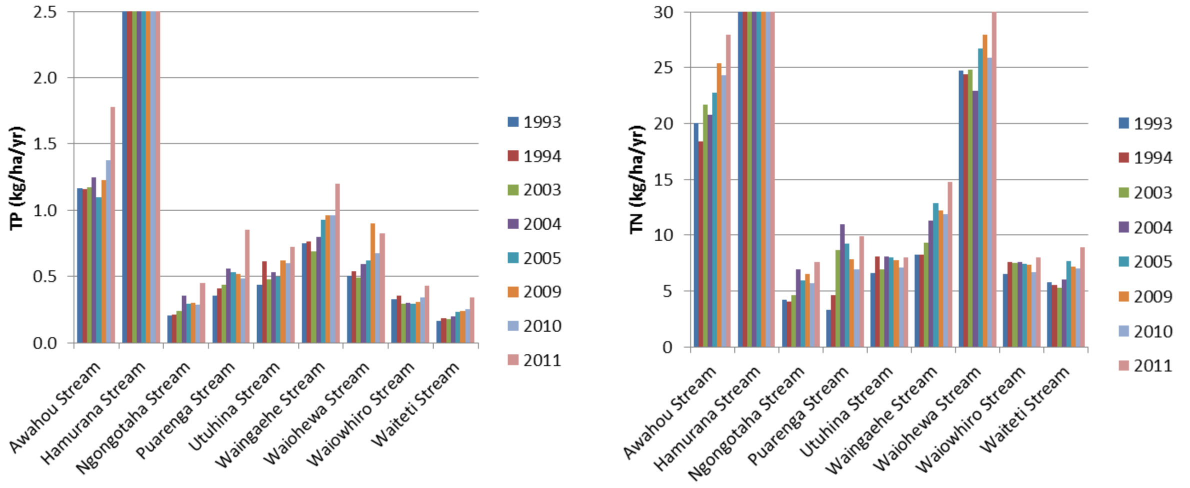


Figure 4.4 Annual baseflow catchment yields for phosphorus and nitrogen for major Rotorua Streams. Note the expanded y-axis scale in the lower Figure

The opposite is true for catchment yields of TN and NNN, where the difference between these parameters has decreased between 1992 and 2011, suggesting that NNN is increasing even if flow regimes between years are different. The observed increasing trends in NNN concentrations in the previous section, confirms that this increasing nitrogen load is not merely an artefact of increased flows.

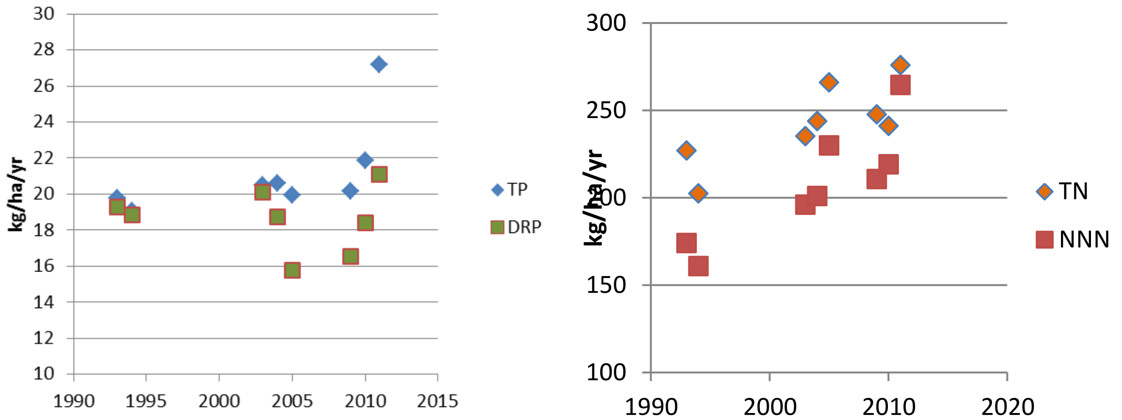


Figure 4.5 Combined major Rotorua Stream annual catchment yeilds for total and dissolved phosphorus, total nitrogen and nitrate-nitrite-nitrogen.

Abell (2012) derived TP and TN catchment yields for the Puarenga and Ngongotahā Streams both with, and without floodflow. Table 4.1 compares catchment yields calculated by Abells' regression models for May 2010 to May 2012 with estimated yields from this study for 2011 derived from monthly baseflow load and catchment area data (data with floodflow not removed is also shown).

For the Ngongotahā Stream in 2011, baseflow TP catchment yields can be less that 50% of the total catchment phosphorus yield and less than 60% of the total nitrogen catchment yield. Baseflow yield is more dominant in the slightly smaller Puarenga catchment than the Ngongotahā, with c. 65% of TP yield, and c. 80% of TN yield respectively.

Table 4.1 Estimated catchment yields (kg/ha/yr) of TP and TN from Abell (2012) compared with 2011 baseflow yields this study, and estimated percentage baseflow yields for TP & TN of total estimated yields (baseflow + floodflow).

	TP Yield Abell – 2010/12 data (Jan 11 storms not included)	**TN Yield Abell – 2010/12 data** (Jan 11 storms not included)	**TP Yield 2011 baseflow** [includes some floodflow]	**TN Yield 2011 baseflow** [includes some floodflow]	**TP % baseflow yields of total** (Jan 11 storms not included)	**TN % baseflow yields of total** (Jan 11 storms not included)
Ngongotahā Stream	1.01 (0.90)	12.73 (11.90)	0.45 [0.56]	7.6 [8.1]	44.6% (50%)	59.7% (63.9%)
Puarenga Stream	1.34 (1.22)	12.71 (12.00)	0.86 [0.91]	9.9 [10.6]	64.2% (70.5%)	77.9% (82.5%)

Examination of annual average loads from the 9 major Rotorua Streams compared to the annual average nutrient load exiting Lake Rotorua via the Ōhau Channel shows that net import of phosphorous to the lake is similar to net export (Figure 4.6). Exceptions to this were in 2004 when severe algal blooms occurred increasing the export of phosphorus out of the lake due to uptake by algae; and 2011 where intense storm events have resulted in increased particulate phosphorus entering the lake. Much of this particulate phosphorus is likely to remain in the lake to be incorporated in sediment or released in a soluble form under anoxic conditions. Nitrogen annual average loads to the lake are greater than nitrogen discharged via than the Ōhau Channel indicating that a large proportion of nitrogen is transformed in the lake (not including the nitrogen from other sources).

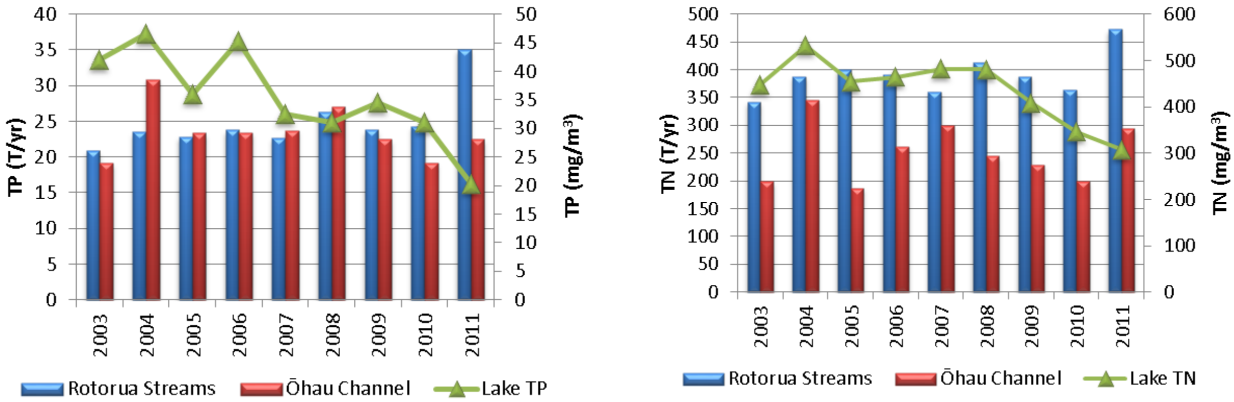


Figure 4.6 Comparison of annual average phosphorus and nitrogen loads entering Lake Rotorua from 9 major streams and leaving via the Ōhau Channel, and annual average lake water nutrient concentrations.

The latest TLI assessment for Lake Rotorua (2011/2012) showed it to be below its target trophic level index of 4.2 TLI units. This reduction in TLI reflected observed reductions in both phosphorus and nitrogen. McIntosh (2012) calculated that approximately 37 tonne of phosphorous in the lake was bound by aluminium sulphate additions via the Utuhina and Puarenga Streams over 2007 to 2011. Remediation of phosphorus by alum dosing, and an 2011/12 summer characterised by cold, wet conditions that saw the lake only have one minor anoxic event, appears to have been the stimulus for achieving a reduced lake TLI. The consequent reduction in algal biomass is also likely to have reduced microbial activity in the lake sediments due to reduced organic matter deposition. This would also have contributed to a reduction in nutrient release from lake sediments.

Prior to 2011/12, the TN:TP ratio suggested co-limitation for algal productivity, but with the improvement in TLI there is some movement towards P-limitation of algal growth. Rutherford (1996) modelled lake phosphorus fluxes, and suggested that lake water quality would improve at a similar rate to reductions in lake water TP concentration. While only one year's result in lake improvement is not evidence yet of a sustainable long term impact on lake water quality, there is evidence that reducing the lakes internal phosphorus and nitrogen releases will improve lake water quality. As nitrogen input to the lake continues to increase and as phosphorous continues to be reduced or maintained at current levels, there will be an increased trend towards P- limitation of algal growth.

If high diffusion rates of ammonium and phosphorus occur due to periods of stratification and anoxia in the lake, this will favour the development of cyanobacteria. Alum dosing may have provided the inertia for some water quality gains but these are likely to be short lived without further continued nutrient reductions (Hamilton et al., 2012). Increased temperatures due to climate change are also likely to increase stratification and anoxic events in the lake, further increasing the possibilities of cyanobacteria blooms and increased trophic status.

Nutrient enrichment experiments have shown that the addition of either phosphorus or nitrogen has potential to promote undesirable cyanobacteria growth (Abell, 2012). Hence the management of both nutrients should remain a management focus for the lake. Maintaining the lake in its current trophic status or improving the trophic status will depend on the lakes ability to assimilate an increasing load of labile nitrogen. Restoration techniques and land management options will also need to address the increasing nitrogen load to the lake, as well as managing phosphorus. The ability to address particulate phosphorus on the land with increasingly extreme climatic conditions predicted could pose an increased challenge to reaching lake water quality objectives.

Part 5: Summary Discussion

As Rutherford found in 2003, nitrate concentrations in Rotorua streams have been shown to be increasing over time. However, this trend is not apparent in three streams over the last decade, the Puarenga, Waiohewa and Waiowhiro Streams (Table 5.1), which show either a decline in nitrate, or no trend. Declining nitrogen yields from the Puarenga Stream is likely to reflect impacts of different land management regimes. Here nitrate responds more quickly to catchment changes due to its younger groundwaters (MRT = 37 years) and lower lag time, hence a quicker reaction to the changing intensity of nitrate placed on the land. Waiohewa and Waiowhiro streams are thought to be near steady state nitrogen concentrations (inputs equal outputs; Morgenstern & Gordon, 2006), but Waiohewa stream's nitrogen levels will be influenced by fluxes in geothermal inputs.

Table 5.1 Significant trends in nitrogen in major Rotorua streams, percent change per year (Bold values are meaningful and significant).

Stream	TN	1992-2012 NH_4-N	NNN	TN	2002-2012 NH_4-N	NNN
Awahou Stream	0.43		0.52	0.67		**1.07**
Hamurana Stream		**-2.50**	0.97[#]		-5.0	**1.39**[#]
Utuhina Stream	**-1.22**		-0.39	**-1.51**	**-3.68**	0.87
Ngongotahā Stream			0.83		**2.67**	0.6
Puarenga Stream	**1.1**		**2.27**	**-2.28**		**-1.51**
Waingaehe Stream	0.56	**2.00**	**1.08**			**1.03**
Waiohewa Stream	**-1.25**	**-1.31**	0.33			
Waiowhiro Stream		**-2.00**	0.41			
Waitetī Stream		**-3.16**	0.50		**-7.65**	0.07

not flow adjusted

Despite reductions in nitrate levels in the Puarenga, and lack of increases in the Waiohewa and Waiowhiro, we did not observe any levelling off of total combined nitrogen inputs via streams into the lake. Indeed, nitrogen loads continue to increase, albeit despite smaller random temporal fluctuations.

Nitrogen response to land use change may be gauged from catchments such as the Waingaehe which has undergone a change from dairy to drystock farming potentially influencing stream nutrient concentrations. The nitrogen response to land use change in the Waingaehe catchment is expected to be slow as the catchment has large, deep aquifers of old groundwater (127 years mean residence time (MRT)) (Morgenstern and Gordon, 2006). The presence of this large amount of old groundwater is likely to complicate any assessments as to whether land use change has brought about a requisite target reduction, especially as the old groundwater continuously adjusts to new inputs before a steady state is obtained.

Little change was observed in the adjusted NNN trends for the Waingaehe Stream between the two analysis periods (1992-2012, and 2002-2012). From 2003 to 2010 there has been an approximate 35% increase in the nitrogen load in the Waingaehe, but in the same period, the annual average NNN load has not significantly changed. Morgenstern and Gordon (2006) predicted a doubling of the NNN load from the stream in from 2006 to 2050. However, under the current trend slope (c. 1.08) it seems unlikely that the NNN load will double by 2050, but could instead increase by around a quarter of the 2005 load.

The Awahou and Hamarana catchments, which also have old groundwater contributions (MRT's of 61 and 110 years respectively (Morgenstern and Gordon, 2006)), both display increasing positive NNN concentration slope trends between the 1992 to 2012 and 2002 to 2012 analysis periods. Being large contributors of flow to Lake Rotorua, these catchments have a strong influence on the nitrogen (and phosphorus) loading, and together with the Ngongotahā and Waitetī catchments help drive increasing nitrogen loading to the lake.

Nitrogen contributions to the lake are now fairly well understood. Rutherford (2009, 2011) has thoroughly explored the relationships of land use change and particularly pastoral farming's role and its contribution of nitrogen in the Rotorua catchment. Other nitrogen contributions such as the disposal of sewage directly to the lake until 1991, and contributions from communities with on-site wastewater treatment have been and continue to be progressively addressed. The farming community has also recently signed a memorandum of understanding (February, 2013) along with the Lakes Water Quality Society and BoPRC (the 'Oturoa Agreement'), recognising the impact of nutrients (and in particular from pastoral farming) has on lake water quality. Hence, the goal of identifying causes of water quality pollution as outlined in the Lakes Management Strategy have been well met.

The ROTAN model provides a vehicle with which to look at various land use change scenarios and its impact on nitrogen loads. While the ROTAN model provides one method to prioritise catchment scale land use change, priorities can also be looked by land use as shown by Meener et al. (2004) which ranked the potential for nitrate leaching from various land uses and generally follows the order:

- vegetable cropping> dairy farming> arable/mixed cropping> sheep/beef/deer farming> forestry.

Causes of nitrate leaching within each farming system have also been examined and form the basis for best land management practices to reduce nitrate leaching. Nitrate from urine patches is the greatest nitrogen contributor on pastoral farming system, while residual fertiliser in soil contributes the most nitrate to groundwater in cropping systems. Strategies to addressing these main contribution sources form the priority for on farm best management practices.

Best on farm management options that work towards addressing nitrogen sources will often also address phosphorus (Meener et al, 2004). Phosphorus from the major Rotorua inflows has remained similar to those of two decades ago with the exception of 2011 and 2012 where intense storm events have increased the annual average phosphorus loading to the lake. This highlights the importance of storm-induced phosphorus generation in some catchments. Although the phosphorus generated in these events is mostly particulate phosphorus which may not be directly available to lake phytoplankton, it increases the lakes phosphorus reservoir which can be released with thermal stratification and anoxia. Phosphorus load figures generated by Abell (2012) and others show that flood flow phosphorus is a priority source, and work of Rutherford (2009) and Abell (2012) shows which Rotorua stream catchments generate the greatest loads.

Several streams show clear decreasing trends in soluble phosphorus (DRP) over the past two decades. In particular, the Utuhina Stream has the largest decreasing trend (Table 5.2), and this is thought to reflect alum dosing in this stream. Furthermore, the rate of declining DRP trends has increased from 1992-2012 to 2002-2012 in the Ngongotaha and Waiohewa streams. Lack of a significant trend in TP for these streams suggests that it is only the DRP fraction that has decreased, whereas it is likely that the particulate phosphorus (or TP) loads in these catchments has not changed, or even increased.

Table 5.2 Significant trends in phosphorus in major Rotorua streams, percentage change per year (Bold values are meaningful and significant).

	1992-2012		2002-2012	
Stream	**TP**	**DRP**	**TP**	**DRP**
Awahou Stream	-	-	-	-
Hamurana Stream	-	-	-	-
Utuhina Stream	-	**-3.58**	**1.60**	**-9.94**
Ngongotahā Stream	-	**-1.07**	-	**-2.60**
Puarenga Stream	**1.67**	-	**2.24**	**-4.58**
Waingaehe Stream	-	-0.32	0.80	-
Waiohewa Stream	-	**-3.70**	-	**-5.56**
Waiowhiro Stream	-	**-0.84**	**1.92**	-
Waitetī Stream	0.67	-	**1.46**	-

Given the strong correlation between particulate phosphorus and flow during floodflow (Rutherford, 2009; Abell, 2012), it is possible to create a priority catchment list for the reduction of particulate phosphorus from the Rutherford (2008) flood flow percentage calculations such that:

- Hamurana<Awahou~Waingaehe<Waiowhiro<Waitetī<Utuhina<Puarenga<Waiohewa <Ngongotahā.

Here, the Ngongotahā catchment should be the highest priority for reducing export of particulate phosphorus, and the Hamurana the lowest. Furthermore, the Ngongotahā catchment is a much larger contributor of phosphorus to the lake than the Waiohewa, further emphasising that priorities to reduce particulate phosphorus or flood flow phosphorus should lie in the this catchment.

Work and research by BoPRC and others (e.g. University of Waikato's Dylan McCasgill research into P-retention dams) is targeting critical source areas where phosphorus might be generated, and where it might be intercepted in flood flow. As this work is progressed, priority areas within catchments will be identified and this information will help create future phosphorus management strategies in line with the Rotorua Lakes Management Strategy Task 1. To some extent this also answers the Strategies goal of understanding the extent of stormwater nutrient loading.

Although we have a good understanding of the contribution of nutrients in some Rotorua catchment streams from stormwater or flood flows, it may be some time before quality high intensity data needed to delineate such events will be collected. This reflects the inherent intensity of monitoring required to understand flood flows which are unique to each catchment. Work by Abell (2012) and Williams (1996) clearly demonstrate that nutrient loads based on monthly sampling data underestimate total loading contributions to the lake – indeed underestimates from catchments such as the Ngongotahā for phosphorus could be in the order of 50% depending on the storm events in a given year.

As the dissolved component of phosphorus appears to be in a steady state, or decreasing in the case of some catchments, the balance of phosphorus entering the lake is largely determined by climate and land use. Controlling phosphorus input to achieve the Rotorua Lake water quality objective and the Action Plan target of 10 tonnes per year is currently being achieved by alum doing of the Utuhina and Puarenga Streams. As internal phosphorus loads reduce, replacing gains made by alum treatment with phosphorus reduction by a range of land management options will play a role in a sustainable solution towards achieving the lake water quality objective.

However, phosphorus management will play only one part in maintaining lake water quality. Nitrogen reductions will also play a significant part in this co-nutrient limited lake. While there is a recent movement towards P-limitation in Lake Rotorua, future phytoplankton responses to changing nutrient balance will be dependant on phytoplankton assemblages and their physiological and competition status. Continued increasing trends in nitrogen and the risk of continued sustained internal nutrient releases from potentially anoxic sediments requires that external nutrient reduction targets are strived for if a sustained water quality in line with community objectives is to be sustained. Recent water quality gains in the nearby Lake Rotoehu by the harvesting of the aquatic pest weed hornwort, provides an example of how a reduction in lake water column nitrogen reduces phytoplankton growth. It is likely that management techniques such as used in Lake Rotoehu and a range of others may need to be implemented in the Lake Rotorua catchment to help achieve reductions in nutrients.

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Appendices

Appendix 1 – Seasonal Flow Statistics

Awahou Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	13	9	12	11	13	12	14	11	13	14	11	10
Mean	1.653	1.613	1.598	1.586	1.562	1.534	1.710	1.665	1.647	1.679	1.619	1.605
Med	1.534	1.601	1.557	1.560	1.528	1.567	1.667	1.657	1.676	1.607	1.606	1.618
25%	1.504	1.514	1.444	1.512	1.477	1.478	1.567	1.536	1.576	1.559	1.548	1.518
75%	1.655	1.720	1.669	1.609	1.643	1.625	1.792	1.738	1.740	1.730	1.661	1.681
Min	1.389	1.367	1.382	1.398	1.379	1.130	1.435	1.416	1.369	1.466	1.398	1.400
Max	2.329	1.929	1.978	2.075	1.793	1.783	2.151	1.996	1.930	2.282	1.952	1.800

Hamurana Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	10	5	11	10	8	9	12	7	7	10	9	7
Mean	2.456	2.416	2.578	2.467	2.448	2.412	2.611	2.573	2.448	2.591	2.474	2.523
Med	2.433	2.398	2.495	2.441	2.428	2.427	2.629	2.585	2.501	2.567	2.472	2.496
25%	2.364	2.329	2.392	2.401	2.282	2.349	2.449	2.479	2.333	2.525	2.444	2.409
75%	2.460	2.469	2.687	2.490	2.550	2.453	2.723	2.638	2.567	2.624	2.499	2.587
Min	2.328	2.327	2.306	2.244	2.216	2.241	2.361	2.403	2.213	2.397	2.305	2.365
Max	2.700	2.559	3.046	2.801	2.848	2.617	2.957	2.790	2.621	2.998	2.655	2.810

Ngongotaha Stream Flow (m^3/s): 1990 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	19	19	21	20	22	20	19	20	20	19	20	20
Mean	1.529	1.409	1.420	1.672	1.521	1.721	1.800	2.004	1.743	1.852	1.743	1.559
Med	1.431	1.344	1.431	1.474	1.459	1.770	1.643	1.613	1.610	1.766	1.700	1.567
25%	1.256	1.235	1.224	1.197	1.241	1.439	1.415	1.495	1.387	1.529	1.460	1.377
75%	1.500	1.575	1.562	1.599	1.702	1.891	2.069	2.097	1.838	2.116	2.030	1.730
Min	0.962	0.999	0.983	1.093	1.047	1.096	1.213	1.030	1.154	1.095	1.063	1.113
Max	3.918	1.916	1.972	6.568	2.644	2.786	2.962	5.295	3.221	2.721	2.497	2.296

Puarenga Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	19	17	18	18	20	20	17	18	20	20	20	19
Mean	1.598	1.630	1.645	1.545	1.629	1.897	1.984	2.100	1.912	1.976	1.726	1.627
Med	1.437	1.405	1.588	1.479	1.625	1.825	1.810	2.004	1.769	1.953	1.796	1.564
25%	1.341	1.262	1.277	1.390	1.369	1.743	1.607	1.642	1.720	1.636	1.491	1.465
75%	1.631	1.774	1.853	1.665	1.774	2.033	2.157	2.336	2.057	2.289	2.036	1.704
Min	1.277	1.195	1.209	1.185	0.578	1.253	1.367	0.962	1.457	1.377	0.717	1.330
Max	3.844	2.913	2.862	2.164	2.663	3.159	2.987	3.621	2.935	3.310	2.560	2.204

Utuhina Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	14	13	13	12	14	13	15	17	14	13	16	13
Mean	1.686	1.551	1.638	1.668	1.702	2.031	2.126	2.245	1.623	1.857	1.789	2.239
Med	1.491	1.490	1.535	1.561	1.636	1.905	1.889	2.059	1.542	1.759	1.642	1.794
25%	1.365	1.310	1.406	1.463	1.526	1.548	1.612	1.745	1.466	1.653	1.518	1.425
75%	1.727	1.802	1.804	1.785	1.828	2.273	2.030	2.455	1.688	1.932	1.895	1.836
Min	1.199	1.251	1.314	1.217	1.425	1.276	1.382	1.365	1.300	1.282	0.687	1.268
Max	3.755	2.008	2.591	2.670	2.209	4.150	5.372	4.367	2.169	2.519	3.952	9.586

Waingaehe Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	13	10	13	12	12	12	14	12	14	12	11	9
Mean	0.244	0.232	0.222	0.231	0.236	0.244	0.261	0.258	0.248	0.249	0.238	0.238
Med	0.237	0.234	0.227	0.233	0.231	0.235	0.243	0.251	0.252	0.253	0.238	0.234
25%	0.212	0.202	0.193	0.218	0.217	0.225	0.232	0.236	0.225	0.228	0.223	0.223
75%	0.266	0.256	0.235	0.248	0.259	0.261	0.276	0.279	0.268	0.262	0.254	0.263
Min	0.194	0.177	0.163	0.192	0.197	0.175	0.213	0.207	0.192	0.207	0.204	0.194
Max	0.376	0.302	0.289	0.260	0.286	0.310	0.397	0.310	0.298	0.292	0.279	0.271

Waiohewa Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	12	8	11	11	12	11	12	8	12	11	10	11
Mean	0.280	0.283	0.325	0.327	0.360	0.381	0.377	0.405	0.370	0.390	0.371	0.318
Med	0.285	0.284	0.252	0.290	0.303	0.376	0.366	0.401	0.353	0.395	0.353	0.312
25%	0.252	0.244	0.225	0.258	0.275	0.330	0.318	0.349	0.321	0.362	0.298	0.260
75%	0.314	0.307	0.375	0.365	0.438	0.444	0.414	0.447	0.403	0.414	0.392	0.364
Min	0.215	0.210	0.173	0.200	0.203	0.254	0.202	0.266	0.240	0.238	0.217	0.223
Max	0.330	0.372	0.699	0.620	0.665	0.513	0.621	0.540	0.567	0.552	0.612	0.489

Waiowhiro Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	10	8	12	11	13	12	14	12	12	13	12	11
Mean	0.258	0.276	0.263	0.299	0.291	0.318	0.368	0.373	0.356	0.351	0.306	0.313
Med	0.256	0.276	0.259	0.264	0.275	0.308	0.330	0.374	0.313	0.359	0.304	0.300
25%	0.239	0.233	0.234	0.254	0.237	0.292	0.288	0.302	0.294	0.316	0.283	0.251
75%	0.263	0.305	0.289	0.324	0.292	0.334	0.385	0.414	0.362	0.388	0.333	0.318
Min	0.215	0.219	0.214	0.220	0.220	0.247	0.260	0.251	0.260	0.219	0.241	0.230
Max	0.347	0.350	0.307	0.531	0.501	0.403	0.892	0.520	0.580	0.484	0.375	0.613

Waiteti Stream Flow (m^3/s): 1992 to 2012

Season	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
N	12	7	13	10	12	11	9	12	12	13	8	11
Mean	1.114	1.087	1.109	1.088	1.056	1.223	1.164	1.239	1.142	1.199	1.046	1.093
Med	0.961	1.057	1.075	1.055	1.063	1.242	1.166	1.159	1.079	1.132	1.059	1.074
25%	0.884	1.010	0.971	0.965	0.929	1.001	1.113	1.099	1.013	1.042	1.003	0.982
75%	1.073	1.125	1.210	1.141	1.160	1.317	1.263	1.366	1.290	1.239	1.110	1.118
Min	0.754	0.824	0.811	0.830	0.759	0.863	0.853	0.944	0.849	0.924	0.888	0.812
Max	2.869	1.459	1.505	1.505	1.337	1.848	1.391	1.788	1.509	1.770	1.135	1.541

Appendix 2 – Stream Statistics

Awahou Stream 1992 - 2012						
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
TN (g/m^3)	149	1.282	1.285	0.756	1.700	0.156
TP (g/m^3)	152	0.071	0.069	0.041	0.117	0.010
DRP (g/m^3)	151	0.064	0.065	0.015	0.108	0.011
NH4-N (g/m^3)	151	0.010	0.006	0.001	0.153	0.015
NNN (g/m^3)	149	1.217	1.200	0.740	1.560	0.161
Flow (m^3/s)	143	1.627	1.601	1.329	2.329	0.187

Hamurana Stream 1992 - 2012						
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
TN (g/m^3)	142	0.777	0.752	0.542	2.170	0.174
TP (g/m^3)	146	0.084	0.083	0.063	0.120	0.009
DRP (g/m^3)	145	0.078	0.080	0.014	0.111	0.013
NH4-N (g/m^3)	145	0.011	0.008	0.001	0.120	0.013
NNN (g/m^3)	142	0.714	0.692	0.492	2.120	0.168
Flow (m^3/s)	105	2.507	2.469	2.213	3.046	0.175

Ngongotaha Stream 1990 - 2012						
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
TN (g/m^3)	226	0.972	0.955	0.189	1.975	0.196
TP (g/m^3)	234	0.052	0.047	0.016	0.257	0.026
DRP (g/m^3)	232	0.028	0.028	0.001	0.117	0.010
NH4-N (g/m^3)	232	0.018	0.015	0.001	0.159	0.015
NNN (g/m^3)	228	0.783	0.781	0.490	1.230	0.104
Flow (m^3/s)	239	1.663	1.529	0.962	6.568	0.605

Puarenga Stream 1992 - 2012						
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
TN (g/m^3)	216	1.136	1.146	0.389	2.015	0.261
TP (g/m^3)	227	0.073	0.068	0.035	0.193	0.021
DRP (g/m^3)	224	0.037	0.037	0.003	0.077	0.011
NH4-N (g/m^3)	225	0.070	0.069	0.001	0.176	0.022
NNN (g/m^3)	221	0.844	0.875	0.153	1.280	0.234
Flow (m^3/s)	226	1.773	1.716	0.578	3.844	0.471

Utuhina Stream 1992 - 2012						
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
TN (g/m^3)	168	0.917	0.848	0.582	2.712	0.284
TP (g/m^3)	171	0.066	0.063	0.031	0.293	0.024
DRP (g/m^3)	169	0.035	0.039	0.002	0.079	0.017
NH4-N (g/m^3)	168	0.039	0.038	0.011	0.124	0.013
NNN (g/m^3)	168	0.717	0.683	0.357	2.260	0.215
Flow (m^3/s)	165	1.855	1.653	0.687	9.586	0.848

Waingaehe Stream 1992 - 2012						
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
TN (g/m^3)	144	1.486	1.497	0.974	3.110	0.270
TP (g/m^3)	146	0.117	0.112	0.068	0.433	0.030
DRP (g/m^3)	144	0.092	0.093	0.014	0.138	0.017
NH4-N (g/m^3)	144	0.011	0.010	0.001	0.077	0.008
NNN (g/m^3)	144	1.342	1.385	0.870	1.880	0.228
Flow (m^3/s)	143	0.242	0.238	0.163	0.397	0.035

Waiohewa Stream 1992 - 2012						
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
TN (g/m^3)	145	3.018	2.800	1.530	8.822	0.883
TP (g/m^3)	145	0.075	0.069	0.019	0.330	0.035
DRP (g/m^3)	141	0.022	0.019	0.002	0.118	0.015
NH4-N (g/m^3)	132	1.433	1.300	0.006	4.980	0.811
NNN (g/m^3)	145	1.328	1.330	0.573	3.090	0.299
Flow (m^3/s)	130	0.350	0.330	0.173	0.699	0.105

Waiowhiro Stream 1992 - 2012						
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
TN (g/m^3)	147	1.054	1.019	0.623	2.260	0.203
TP (g/m^3)	150	0.049	0.048	0.007	0.104	0.012
DRP (g/m^3)	150	0.035	0.036	0.001	0.082	0.011
NH4-N (g/m^3)	150	0.025	0.020	0.001	0.097	0.016
NNN (g/m^3)	147	0.917	0.911	0.482	2.040	0.170
Flow (m^3/s)	140	0.315	0.298	0.214	0.892	0.089

Waiteti Stream 1992 - 2012						
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
TN (g/m^3)	141	1.407	1.401	1.070	1.850	0.125
TP (g/m^3)	142	0.048	0.046	0.020	0.120	0.013
DRP (g/m^3)	142	0.031	0.031	0.006	0.073	0.008
NH4-N (g/m^3)	141	0.020	0.019	0.005	0.066	0.010
NNN (g/m^3)	141	1.291	1.300	0.841	1.680	0.144
Flow (m^3/s)	130	1.134	1.101	0.754	2.869	0.263