Trend and State of nutrients in Lake Rotorua Streams 2002 - 2022

Prepared for:

Bay of Plenty Regional Council

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Prepared by:

Keith Hamill (River Lake Ltd)

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Bay of Plenty Regional Council

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Keith Hamill

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River Lake Ltd
Whakatane
New Zealand
Mobile: +64 27 308 7224
Email: keith@riverlake.co.nz
Web: www.riverlake.co.nz

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Executive summary

Introduction

This report describes the state and trends in nutrients of the nine major streams flowing to Lake Rotorua. It is part of a package of reports to support the Science Review required as part of the Regional Natural Resources Plan.

The confidence and direction of lake water quality trends were determined using the seasonal Kendall test routine. The trend analysis was undertaken over three different time periods determined by the period of water quality sampling for all streams and when there were changes in analytical method used for phosphorus (P). The time periods used were: July 2002 to June 2022 (Long term -), July 2002 to June 2010 (pre-2010 P-method change), and September 2010 to August 2019 (post-2010 P-method change).

Nutrient loads were estimated using the numeric integration method. This method tends to under-estimate annual loads because flood events are often missed, but is useful for analysing trends. McBride (2022) has recently updated estimates of long-term annual loads to Lake Rotorua which provides comprehensive annual estimates for the nine monitored streams, plus additional inflows including ungauged catchments, groundwater and geothermal.

State

The mean flow to Lake Rotorua from the main streams the period 2002-2022 was, in order of size: Hamurana (2.63 m^3/s), Puarenga (2.0 m^3/s), Utuhina (1.76 m^3/s), Ngongotaha (1.74 m^3/s) and Awahou (1.60 m^3/s), Waiteti (1.19 m^3/s), Waiohewa (0.33 m^3/s), Waiowhiro (0.32 m^3/s) and Waingaehe (0.25). In total, these streams contributed 11.8 m^3/s; this is 5.5 m^3/s less than the 17.32 m^3/s mean flow down the Ōhau Channel outlet, the difference includes inflows from groundwater and ungauged streams. Since 2002, the years with the highest total stream inflow to Lake Rotorua were 2011/12 and 2017/18, and the years with the lowest stream inflow were 2002/03, 2020/21 and 2021/22.

Lake Rotorua catchment streams with the highest concentration of total nitrogen (TN) were Waiohewa (2839 mg/m^3), Waingaehe (1544 mg/m^3), Waiteti (1484 mg/m^3), Awahou (1365 mg/m^3). The streams with the highest concentration of total phosphorus (TP) were Waingaehe (123 mg/m^3), Hamurana (89.5 mg/m^3), Puarenga (81.8 mg/m^3), Waiohewa (80.3 mg/m^3) and Awahou (74.6 mg/m^3).

Hamurana, Awahou and Waingaehe is characterised by having particularly high concentrations of dissolved reactive phosphorus (DRP) and a high ration of DRP to TP (80 to 90%). Waiowhero is characterised by having a strong geothermal influence, very high concentrations of ammoniacal nitrogen (NH4-N) and relatively low concentrations of DRP relative to TP (25%).

Trends

Over the period of 2002 to 2022, the concentration of TN increased in Hamurana, Awahou and Waiteti due to increasing nitrate-nitrite-nitrogen (NNN). These increasing trends have continued in each of these streams since 2010 and was particularly large in the Awahou and Waiteti. Over the 2002-2022 period, there is reliable evidence of TN decreasing in the Puarenga and possibly in the Ngongotaha, but this decrease does not appear to have continued since 2010.

NH4-N concentrations decreased in five streams (Hamurana, Awahou, Waiteti, Waiowhiro, and Waingaehe) over the 2002 to 2022 period. In contrast, the Waiohewa had a strong increase in NH4-N from 2002-2022.

There is reliable evidence that, over the period of 2002 to 2022, the concentration of TP increased in the Hamurana, Ngongotaha, Utuhina, Puarenga, Waingaehe, and Waiohewa; with this trend continuing since 2010 in each stream except the Waingaehe.

DRP concentrations appear to have decreased in the Waiowhiro, Puarenga and (with lesser confidence) the Utuhina in the period 2002-2022; but DRP loads have increased in the Hamurana. Over the more recent period of 2010-2019, most streams (except Waiowhiro) had a likely increasing concentration of DRP.

Loads

The nine main streams flowing to Lake Rotorua transport 410 t/y of nitrogen and 28 t/yr of phosphorus (average for 2002-2022). Additional nutrient load also enters the lake via ungauged streams, stormflows, geothermal, and groundwater (McBride 2022). There is considerable variation in nutrient loads between years, which largely reflects difference in stream flows between years. Years with particularly high nutrient loads were 2011/12 and 2017/18.

The streams contributing most of the TN load are Awahou (71.1 t/yr), Puarenga (67.4 t/yr), Hamurana (66.5 t/yr) and Waiteti (55.8 t/yr). Waiohewa has high NH4-N loads due high concentrations from the geothermal activity. The streams contributing most of the TP load are the Hamurana (7.5 t/yr), Puarenga (5.1 t/yr), Awahou (3.9 t/yr) and Utuhina (3.8 t/yr).

The trends in nutrient loads were very similar to trends in nutrient concentrations. For the period 2002 to 2022, the load of TN increased in Hamurana, Awahou and (with less confidence) Waiteti. This increasing trend has continued in the Hamurana and Awahou since 2010. There is reasonable evidence that TN loads in the Puarenga decreased from 2002-2022, but not since 2010.

There was reasonable evidence of increasing TP load from the Waiteti, Utuhina, Puarenga, Waingaehe, Waiohewa, and possibly from the Hamurana due to increased flows over the 2002-2022 period.

Contents

1. Introduction

1.1 Background

In 2017 the Bay of Plenty Regional Council (Toi Moana) (**BOPRC**) notified Plan Change 10 (**PC10**) which introduced rules into the Regional Natural Resources Plan (**RNRP**) to limit the amount of nitrogen entering Lake Rotorua from land use. This was part of an integrated programme to improve the water quality of Lake Rotorua. The overarching objective of PC10 is to meet the sustainable lake load of 435 tonne of nitrogen per annum by 2032, which is set to maintain the trophic level index (**TLI**) at 4.2 TLI units.

The Lake Rotorua Nutrient Rules introduced with PC10 include a requirement that BOPRC undertake a five-yearly review of the science supporting decisions associated with Lake Rotorua. The first Science Review was undertaken in 2018, and the second Science Review was undertaken in 2022. This report is one of package of reports that support the 2022 Science Review.

The aim of this report is to describe the state and trends of water quality (and particularly nutrients) in streams entering Lake Rotorua. It updates the analysis undertaken by Dare (2018) on the state and trend of nutrients in Lake Rotorua streams.

While this report focuses on trends in water quality, a more comprehensive and long-term analysis of nutrient loads to Lake Rotorua has been undertaken by McBride (2022).

1.2 Lake Rotorua

1.2.1 *Lake*

Lake Rotorua is a large (80.6 km^2) but relatively shallow polymictic lake with an average depth and maximum depth of 10 m and 45m respectively. Lake Rotorua is eutrophic but the water quality has considerably improved since 2002 with reductions in nutrient concentrations, fewer algae blooms and increased water clarity. The Trophic Level Index (**TLI**) is now tracking close to the target of TLI 4.2 set in the RNRP (i.e. annual average for 2019-2021 was 4.2 in 2022 (Hamill 2022, Stephens et al. 2018)).

1.2.2 *Lake Rotorua catchment*

There are nine major streams that enter Lake Rotorua that contribute about two thirds (64%) of the inflow to the lake. The remainder of the lake inflows comes from small streams, spring, groundwater upwelling to the lake bed, and rainfall direct to the lake surface. Lake Rotorua discharges to Lake Rotoiti via the Ōhau channel, although the diversion wall results in most of the Ōhau channel flow being diverted directly to the outlet and down the Kaituna River.

Lake Rotorua has a topographical surface water catchment of 502.1 km^2 and a total groundwater catchment of 537.9 km^2. Groundwater contribution from outside the surface water catchment mostly comes from the Mamaku plateau west of the lake and contributes to a substantial baseflow in the Hamurana Stream and, to a less extent, Awahou Stream (White et al. 2014). A large proportion of the catchment is forested with an even mix of exotic and indigenous vegetation, and there is a similar amount of pastoral land used for dairy. Rotorua city lies within the catchment.

The nutrient losses from the various sources in the Lake Rotorua catchment were estimated based on land use coefficients (Bay of Plenty Regional Council, Rotorua District Council and Te Arawa Lakes Trust 2007). The catchment land uses estimated to contribute most to nitrogen load were: Pasture (72%), urban (6.4%), geothermal (5.4%) and native forest (5.4%). The catchment land uses estimated to contribute most to phosphorus load were: Pasture (42%), urban (9.6%), geothermal (3.5%) and native forest (3.3%). Geothermal inputs primarily enter via springs or direct within the lake near Rotorua township, Puarenga Stream and the Waiohewa Stream.

1.2.3 *Lake and catchment nutrient targets*

The RNRP sets a water quality target for Lake Rotorua corresponding to a TLI of 4.2. To reach the TLI target of 4.2, the 'sustainable loads' of nitrogen and phosphorus to Lake Rotorua are estimated to be 435 tonnes N/yr and 37 tonnes P/yr (BOPRC 2009). This was set as roughly commensurate with catchment loads prior to substantial degradation of water quality in the lake but does not fully include stormflow particulates (Rutherford et al. 1989, McBride et al. 2019). However, McBride (2022) found that the nitrogen catchment target load of 435 t N /yr was higher than his estimated loading for the 1960s (the period to which water quality targets were set).

Management interventions to improve the water quality of Lake Rotorua include: land disposal of the city's wastewater since 1991 onto parts of the Whakarewarewa Forest in the Puarenga Stream catchment), sewage reticulation of smaller communities around the lake, trial of nitrogen removal from Tikitere geothermal inflows to Waiohewa Stream (2011), alum dosing to lock phosphorus from the Utuhina Stream (2006) and the Puarenga Stream (2010), and regional rules to cap land-based nutrient inputs (Rule 11 of Regional Land and Water Plan).

Active management by alum dosing appears to be an effective intervention associated with improved water quality of Lake Rotorua in recent years (McBride et al. 2018). However, relying on alum dosing in the long term is not preferred from a cultural perspective, thus reduction of nutrients in catchments of Lake Rotorua is being pursue to achieve lake water quality targets.

2. Method

2.1 Water quality sampling site and variables

Water quality monitoring is carried out monthly on the nine major inflows to Lake Rotorua: the Hamurana at Hamurana Road, Awahou at SH36, Ngongotahā at SH 36, Puarenga at FRI, Utuhina at Lake Road, Waingaehe at SH 30, Waiohewa at Rangiteaorere Road, Waiowhero at Bonningtons Farm, and Waitetī at SH 36. These sites are located on the mainstem at the lower end of the catchment. It should be noted that the Utuhina Stream site has alum dosing occurring upstream of the monitoring site which will influence DRP measurements. The stream water quality monitoring sites and groundwater catchment associated with the streams is shown in **Figure 2.1**.

In addition, one site in the upper Waitetī Catchment, 'Waitetī at Oturoa Road', has been monitored since 2015, and the Rotorua District Council has a long-term monitoring site on the Waipa Stream at Mill Road (a tributary to the Puarenga Stream). The 'Waitetī at Oturoa Road' site was identified as having relatively high particulate nutrients (Dare 2018), however the results are not included in this report due to the relatively short record and focus on water quality entering Lake Rotorua.

Monitoring consists of water quality analysis and flow gauging, with the intention of providing a long-term dataset for nutrient trend analysis. The associated flow measurement allows for the calculation of loads, although load calculations from monthly sampling tend to underestimate actual loads without specific methods and sampling to account for storm flows.

Water quality variables collected at each water quality monitoring site are: water temperature (**TEMP**), pH, dissolved oxygen (**DO**), electrical conductivity (**EC**), ammoniacal nitrogen (**NH4-N**), total oxidised nitrogen (**NNN**), total nitrogen (**TN**), dissolved reactive phosphorus (**DRP**), total phosphorus (**TP**), turbidity (**TURB**), and total suspended solids (**TSS**).

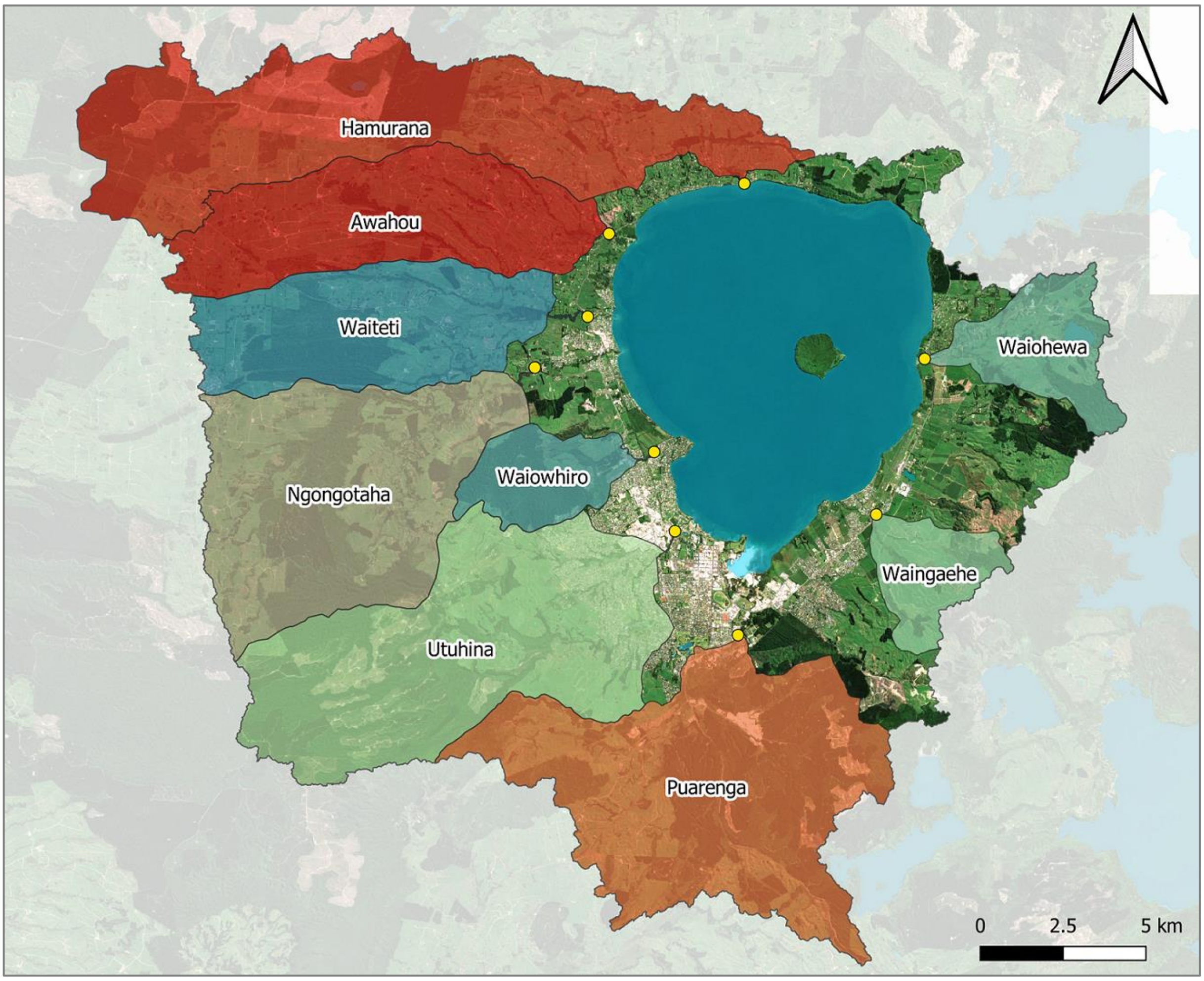

Figure 2.1: Lake Rotorua groundwater catchment extent and the catchment of major inflow streams upstream of the downstream water quality monitoring sites (yellow dots).

2.2 Data extraction and preening

2.2.1 *Water quality and flow*

Water quality datasets was obtained from the BOPRC Aquarius database for BOPRC monitoring of the nine inflow streams to Lake Rotorua. Inconsistency in units of measurement in flow recordings were corrected prior to analysis.

The majority of the dataset consisted of monthly sampling associated with a systematic random sampling approach, however on some occasions there was a higher sampling frequency. Where multiple data were collected from a single site in a single month, then this data was averaged to provide a single data value per month. This was done to avoid the risk of periods of higher sample frequency causing a seasonal of flow bias in the dataset.

Overall, instantaneous flow was measured for about 81% of samples[1], with a range from 68% of samples from Hamurana and 90% of samples from Puarenga. The majority of the gaps in the flow records were for years 2013 to 2015. Gaps in the flow record were filled by applying mean annual flow calculated from continuous flow records, and where this was not available an estimate of mean daily annual flow was used from a composite synthetic record developed by McBride (2022). This approach provided a measured or estimated flow paired to all water quality records.

2.3 Outliers

The dataset was examined for outliers for each site/variable combination. Outliers were examined in the context of other variables to determine whether they may be data errors. This identified inconsistencies in the units used to record flow.

Extreme outliers were identified for two occasions, these were:

- Waingaehe Stream on 1/10/2013 with NH4-N of 1370ppb - about 100 times. Normal flows
- Waingaehe Stream on 20/8/2014 with NH4-N of 190ppb and TP of 852 ppb - about 20 times and 8 times median respectively). Small flood event.
- Waiowhiro Stream on 11/10/12 with TN of 11500ppb, NH4-N of 71400ppb and TP of 612 ppb – about 10 times, 200 times and 20 times median respectively). Normal flows.

These outliers are sufficiently extreme to significantly change the annual nutrient loads determined from monthly sampling. The extreme outliers for Waingaehe Stream on 1/10/2013 and Waiowhiro Stream on 11/10/12 were excluded from the analysis.

2.4 Detection limits

Changes in analytical procedures during the course of the monitoring programme also resulted in changes in detection limits at different times (**Appendix A**).

Measurements that are less than the laboratory detection limit are currently recorded as uncensored values. The dataset had very few results were at of less than detection limits, these results consisted of nine occasions of NH4-N (six on Awahou Stream) and two occasions for DRP.

2.5 Changes in analytical methods

The laboratory methods used for analysing TN, TP and DRP changed over the period between August 2008 and September 2010 (**Appendix A**). These analytical changes resulted in lower detection limits and much less variability in results. However, in some waterbodies, the laboratory changes resulted in

[1] i.e. 1686 flow records for 2070 paired TP records for the period January 2002 to May 2022.

a step change decrease in TN results and a step change increase in TP, which complicates the assessment of water quality trends and caused uncertainty when reporting state.

2.5.1 *Phosphorus*

Subsequent investigations found that phosphorus results from the TP and DRP analytical method introduced in September 2010 were elevated due to interference by silica and arsenic in some waterbodies. To address this issue, BOPRC laboratory trialled a new analytical method (starting October 2018) and adopted this new method in October 2019. Hamill (2022) described the development of correction factors for individual Rotorua Te Arawa lakes to correct the lake TP and DRP data collected during the period September 2010 to September 2019 (inclusive).

The analytical method for TP and DRP used between 2010 and 2019 also affected results from the streams flowing into Lake Rotorua. A comparison of paired samples during the trial found the 2019 method (used in the trial) had consistently lower results than the 2010 method (**Figure 2.2**). However, compared lakes (e.g. Ōhau Channel outlet of Lake Rotorua), the difference between the two analytical methods had high variability and a poor correlation for all inflow streams except Ngongotaha Stream. This was due to high variability in TP and DRP results using the 2010 method, while results from paired samples using the 2019 method were relatively constant over the sample occasions. It suggests that the inflow streams may have high variability in the substances (e.g. silicate) causing additive interference of the 2010 method.

The high variability and a poor correlation between the results of the two phosphorus (**P**) analytical methods on samples from streams entering Lake Rotorua means that a reliable correction factor cannot be derived. Unlike the Rotorua Te Arawa lakes, it cannot be assumed that the median difference measured during the trial in 2018/19 can be used to adjust results of samples collected in previous years[2].

Trend analysis of TP and DRP from Lake Rotorua streams spanning mid-2010 or mid-2019 needs to be treated with caution. In the absence of a reliable correction formula, this report has taken the approach of analysing individual time periods determined according to when the TP and DRP analytical methods changed. These periods are: July 2002 to June 2022; July 2002 to June 2010; and September 2010 to August 2019. For this report, a decreasing trend in TP or DRP over the 20-year period is considered reliable because the silicate interference of the 2010 analytical method is additive. However, an increasing trend in TP or DRP over the 20-year period is only considered reliable if it is supported by statistically increasing trends in the separate periods before and/or afterward 2010.

[2] Note that this approach differs from that used by Dare (2018) before trial data was available.

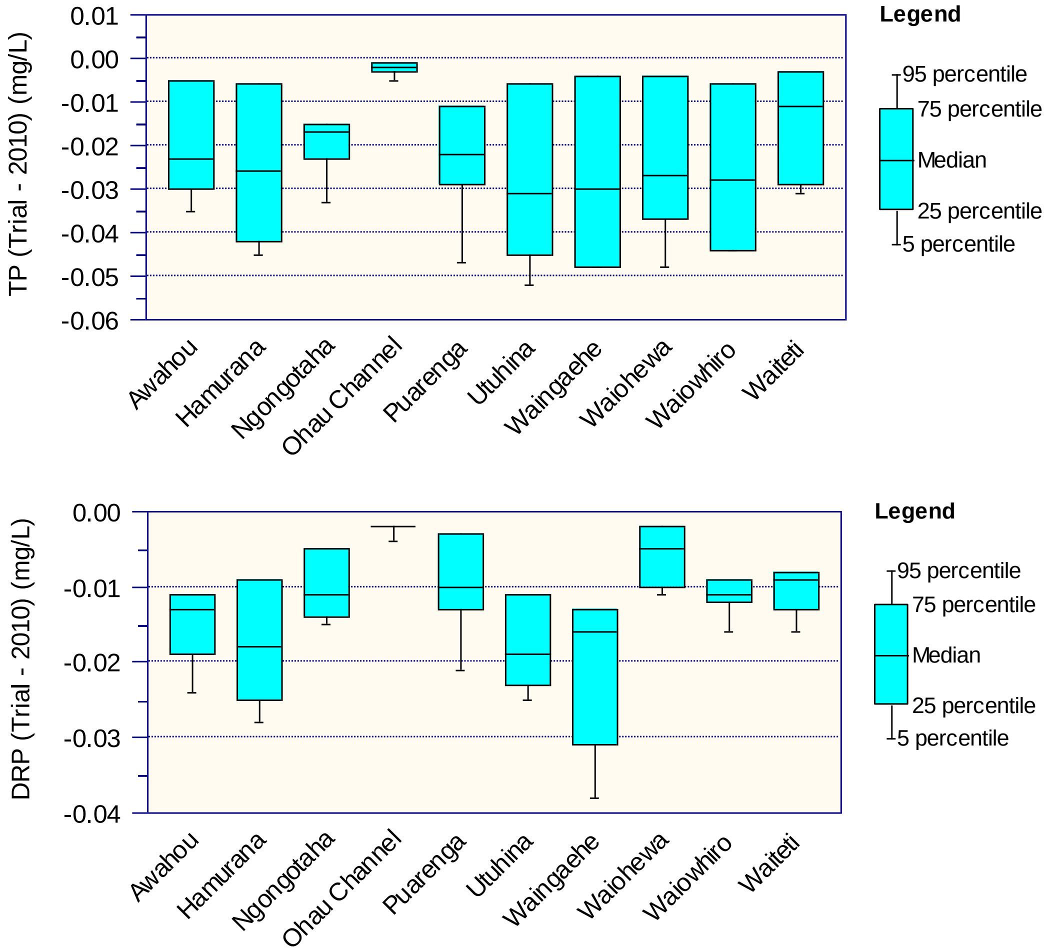

Figure 2.2: Difference in results for total phosphorus and dissolved reactive phosphorus between BOPRC laboratory analytical methods used since 2019 (Trial) and between 2010 and 2019 (2010).

2.5.2 *Total nitrogen*

In November 2009 the BOPRC laboratory changed its method for analysing TN in water samples from calculation of TKN plus NNN (called here **TN-K**), to a direct measurement by alkaline persulphate digestion (called here **TN-A**). The TN-A method has more precise results and has a lower detection limit than the TN-K method, making it better suited to lake water samples (Davies-Colley et al. 2012, NEMS 2019). However, the TN-A method is known to under-report results compared to TN-K when the concentration of TSS is elevated (e.g. >10 mg/L) (Davies-Colley and McBride 2016, NEMS 2019).

Hamill and Scholes (2016) compared mean TN in Rotorua lakes over four years before and after the laboratory change and found the TN-A method about 50 ppb lower. However, this work could not fully exclude the influence of other factors causing the change and did not include streams. Further discussion of laboratory method changes is provided in Hamill (2022).

This report has not applied any adjustment of TN laboratory method changes, however interpreting trend analysis spanning November 2009 should be cognitive of a potential step change decline in TN due to analytical method change. A decreasing TN trend over this period should be treated with caution unless it is also associated with a declining trend in NNN, or a declining trend in TN in the before and/or after November 2009.

2.6 Analysis

2.6.1 *Trend analysis method*

Trend analysis was performed using Time Trends v 8.0: Trend and Equivalence Analysis (Jowett, 2016).

Trends in water quality and flow were analysed for the following periods:

- Long term - July 2002 to June 2022;
- Pre-2010 P-method change - July 2002 to June 2010; and
- Post-2010 P-method change - September 2010 to August 2019.

These periods were chosen because July 2002 is when regular monthly sampling began on the nine Rotorua streams; although most streams were also sampled between July 1992 and June 1995, and Ngongotaha, Puarenga and Utuhina have been sampled monthly since 1990 and 1992 respectively. As discussed above, the period of September 2010 to August 2019 was when the analytical method used for TP and DRP had potential additive interference from silicate.

The trends were statistically determined using the seasonal Kendall test routine taking the median of monthly seasons (Helsel and Hirsch 1992). This is a non-parametric method of detecting trends that produces two key results: a Kendal statistic P-value and a Sen Slope Estimator (**SEN**). The Kendall statistic P-value is used to assess the confidence in the direction of a trend. The Sen Slope Estimator is the median of all possible inter-observation slopes and is used to represent the direction and magnitude of trends. It is normalised to be expressed as a Percent Annual Change (**PAC**).

The lower the P-value the more likely it is that the trend is real (not due to chance), and the larger the PAC the larger the magnitude of the trend. Trends were considered statistically significant ("established with confidence") if the P-value was <0.05, and the SEN slope 95% confidence interval did not contain zero. If the SEN slope 95 percent confidence interval spanned zero, then the trend has insufficient data to confidently determine direction and is "indeterminant" (McBride 2019, Larned et al 2016).

Trend interpretation

Trends were declared to be "confidently" detected when direction is established with 95% certainty (P-value <0.05). In addition, the likelihood of a water quality trend was expressed using categories reflecting the of "likelihood" and direction of a trend as determined with different levels of confidence.

Summary tables used in this report show the trend confidence as "very likely", "likely" "possible" and "uncertain/unlikely/indeterminant" as described in **Table 2.1**. The tables use arrows to indicate the trend confidence and direction as follows: “very likely increase” , “likely increase” , “possible increase” , “uncertain” , “possible decrease” , “likely decrease” , and “very likely decrease” .

Table 2.1: Confidence categories used to express the probability of a trend in water quality (from Time Trends and consistent with Stocker et al., 2014, Snelder and Fraser 2018)

Likelihood summary	**Likelihood (TimeTrends)**	**Kendall P-value**	**Confidence limits (%)**	**Slope Direction Likelihood**
Very Likely	Virtually certain	≤0.01	99	≥0.995
	Very likely	≤0.05	95	≥0.975
Likely / Possible	Likely	≤0.1	90	≥0.95
	Possible	0.33	0.67	≥0.835
Uncertain / Unlikely	About as likely as not	≤0.67	33	≥0.665
	Unlikely	≤0.9	10	≥0.55
	Extremely unlikely	≤0.95	5	≥0.525
	Exceptionally unlikely	0.99	1	≥0.505

Flow adjustment

Most variables had some correlation with flow; thus, the data was also analysed with flow as a covariate. Covariate adjustment used the LOWESS method with a 30% span, on monthly median values. Unadjusted trends give a better indication of the influence on Lake Rotorua, while flow adjusted trends can give insight into changes in in nutrient concentrations independent of changes in flow.

Exclusion of series

The trend method is robust to the occasional missing data of censored data (Hirsch and Slack 1984), but it is good practice in trend analysis to exclude time-series that offer insufficient temporal span or frequency of detection. Helsel (1990) estimated that the impact of censored values on the Sen slope is negligible when fewer than 15% of the values are censored.

The dataset had very few values at detection limit (at most 2.5% of NH4-N samples from Awahou Stream). Sampling occurred on greater than 97% of months at most sites except Waingaehe and Waohewa where sampling occurred on >96 and >95.5% of months respectively.

2.6.2 *Load estimates*

Loads were estimated by multiplying discrete monthly water quality values by flow measurements on that day. These loads were then expressed as tonnes per year (t/yr). This method is a form of numeric integration where the instantaneous flux calculated at the time of sampling is assumed to represent the entire period up to when the next sample is taken. The annual load was calculated as the monthly average multiplied by 12 months. This approach avoided under-estimating loads due to occasional missed months of sampling in a year.

The numeric integration method of calculating loads tends to under-estimate annual loads unless the sampling frequency is very high (>100 per year) (Meals et al. 2013). This is because standard monthly sampling can easily miss the load variability due to flood events.

To provide more accurate estimation of annual loads, Dare et al. (2018) calculated loads using two regression methods (i.e. LOADEST and WRTDS) based on the relationship between flow and concentration. Regression methods were not used for this report because McBride (2022) has recently updated estimates of long-term annual loads to Lake Rotorua, and the focus of this report is on the statistical trend analysis of the measured nutrient concentrations and loads. While regression models provide a more accurate estimate of loads, they can introduce additional assumptions that make distinguishing the drivers of trends opaque.

McBride (2022) has recently updated estimates of long-term annual loads to Lake Rotorua which provides comprehensive annual estimates of total catchment load to Lake Rotorua including the nine major streams (estimated using the regression approach), and inflows from ungauged catchments, groundwater, rainfall and geothermal.

3. Results and Discussion

3.1 Stream Flows

3.1.1 *Daily mean flow*

The composite record of daily mean flow to Lake Rotorua shows that the mean flow to Lake Rotorua from the main streams the period 2002-2022 was, in order of size: Hamurana (2.63 m³/s), Puarenga (2.0 m³/s), Utuhina (1.76 m³/s), Ngongotaha (1.74 m³/s) and Awahou (1.60 m³/s), Waiteti (1.19 m³/s), Waiohewa (0.33 m³/s), Waiowhiro (0.32 m³/s) and Waingaehe (0.25). In total these streams contributed 11.8 m³/s. This is 5.5 m³/s less than the 17.32 m³/s mean flow down the Ōhau Channel outlet, with the difference representing the combined inflow from ungauged streams, groundwater and direct rainfall to the lake (**Figure 3.1**).

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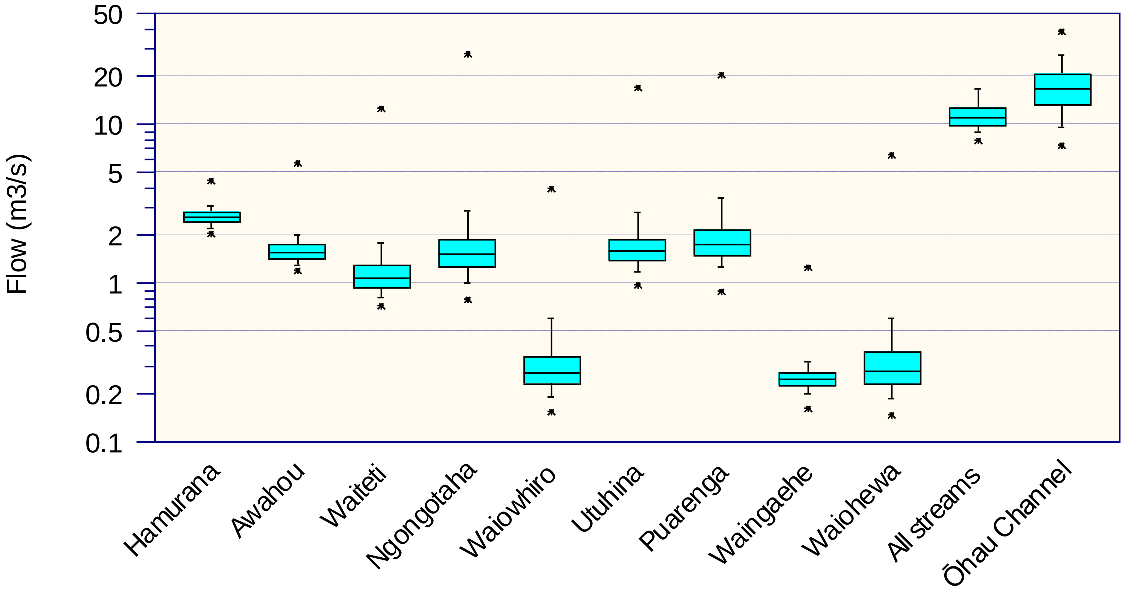

Figure 3.1: Flow of Lake Rotorua inflow streams and Ōhau Channel outlet from composite record of mean daily flow. Boxes indicate minimum, 5%ile, 25%ile, median, 75%ile, 95%ile and maximum over the period 2002-2022.

Over the last 20-years (2002-2022) the stream flows to Lake Rotorua were highest in April 2017 (22.8 m³/s). Wet years with generally high inflow volumes occurred during the calendar years of 2011, 2012, 2017, and 2018. Dry years with generally low inflow volumes occurred in 2002 to 2004, 2013 to 2016, and late 2019 to early 2022. The precise timing of high inflow varied between the different streams, likely due to the differing extents of groundwater influence (**Figure 3.2**).

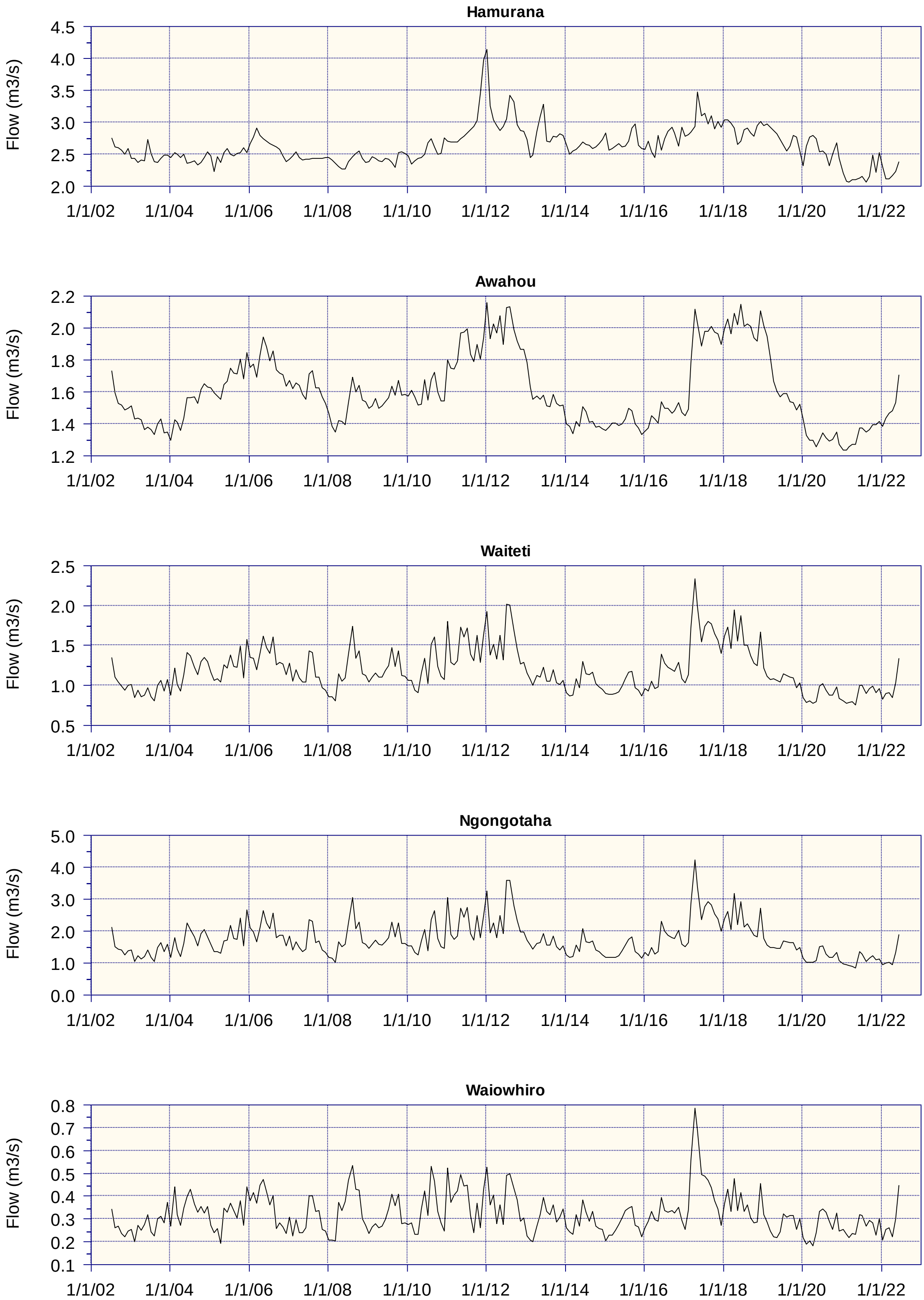

Figure 3.2a: Mean monthly flows of monitored streams flowing to Lake Rotorua, 2002-2022.

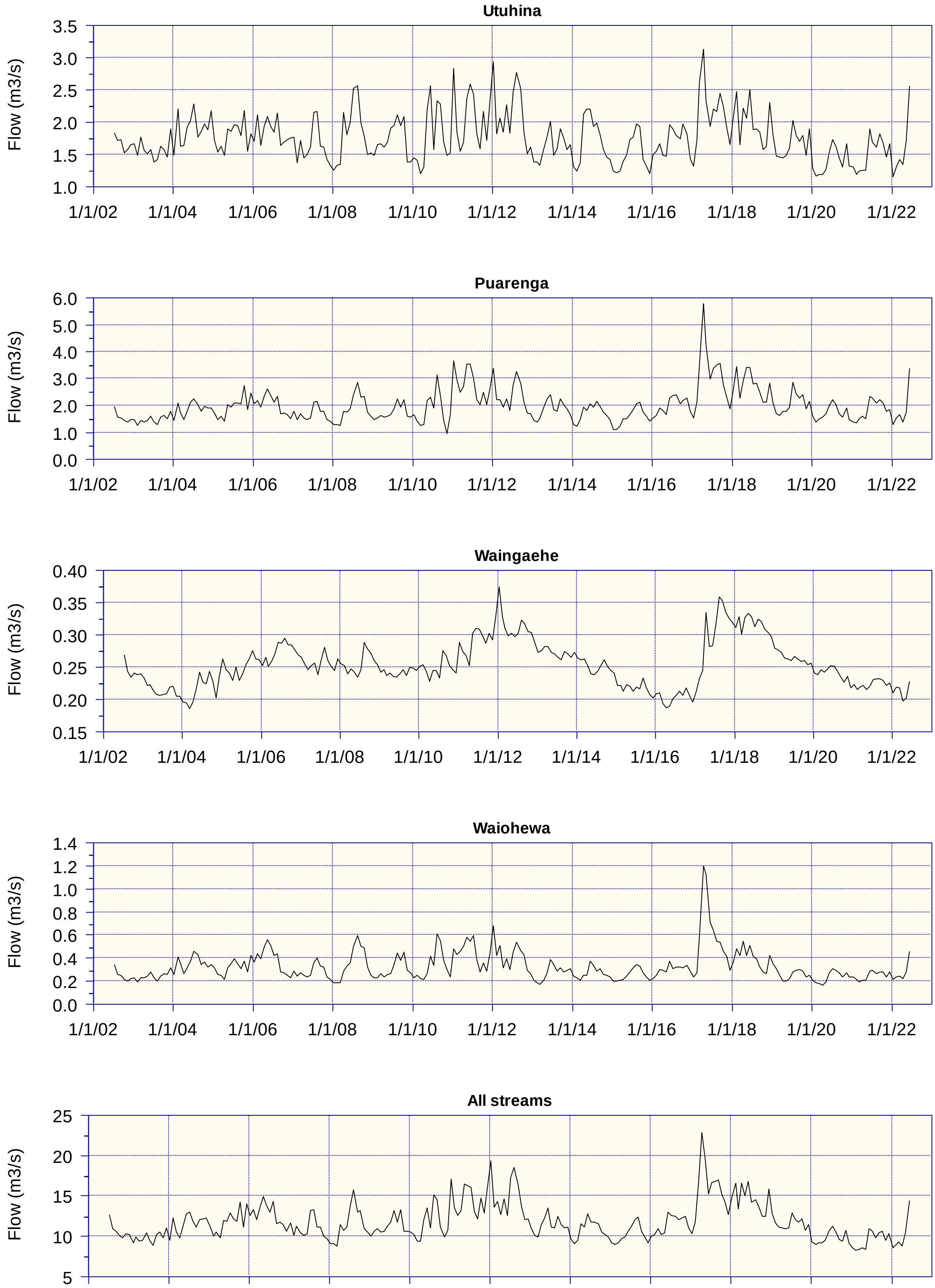

Figure 3.2b: Mean monthly flows of monitored streams flowing to Lake Rotorua, 2002-2022.

Trends in flow

The statistical trends in flow were assessed from two datasets, one using the flow measured on the day of (usually monthly) water quality sampling (Q spot), and the other using the mean monthly flow calculated from the composite mean daily flow record for each stream. For the period 2002-2022, the analysis found a trend of increasing flow in Hamurana and Puarenga, and evidence in the mean monthly dataset of a decrease in flows of the Waiteti, Ngongotaha and Utuhina. Many streams had increasing flows for the period 2002-2010, but there was no evidence of a trend in flows over the period 2010-2019 (**Table 3.1**). Flow is a major factor in determining nutrient loads, so the trend in flow measured at the time of sampling (Q spot) are important for interpreting any trends observed in the load calculations.

Table 3.1: Trend in flow for each time period as measured at time of sampling (Q spot) and as calculated as mean monthly flow. Arrows indicate the trend confidence and direction as follows: “very likely increase” ↑ , “likely increase” ↗, “possible increase” ↗, “uncertain” →, “possible decrease” ↘, “likely decrease” ↘, and “very likely decrease” ↓.

Period	Variable	Site	Hamurana	Awahou	Waiteti	Ngongotaha	Waiowhiro	Utuhina	Puarenga	Waingaehe	Waiohewa
2002-2022	Q spot	Confidence	↑	→	→	→	↘	↘	↑	→	↗
2002-2022	Q spot	PAC	0.43	-0.09	-0.10	-0.11	-0.34	-0.29	0.68	0.09	0.26
2002-2010	Q spot	Confidence	↘	↑	↑	↑	→	↑	↘	↑	↗
2002-2010	Q spot	PAC	-0.40	0.74	1.83	2.60	0.21	3.29	-0.54	1.52	1.52
2010-2019	Q spot	Confidence	→	→	→	→	↗	↘	↗	→	↗
2010-2019	Q spot	PAC	0.31	0.64	0.55	-0.64	1.08	-0.70	1.16	-0.57	1.53
2002-2022	Q monthly mean	Confidence	↑	↘	↓	↓	↘	↓	↑	→	↘
2002-2022	Q monthly mean	PAC	0.47	-0.31	-0.51	-0.73	-0.29	-0.50	0.90	0.17	-0.44
2002-2010	Q monthly mean	Confidence	↓	↑	↑	↑	↑	→	↑	↑	↗
2002-2010	Q monthly mean	PAC	-0.37	0.88	2.25	3.37	2.12	0.32	1.90	1.73	2.22
2010-2019	Q monthly mean	Confidence	→	→	→	→	→	↘	→	↘	→
2010-2019	Q monthly mean	PAC	0.32	0.23	-0.18	0.04	-0.44	-0.75	0.95	-1.59	-1.13

3.2 Stream Nutrient Concentrations

3.2.1 *Annual average concentrations*

The TN concentration in the nine Lake Rotorua catchment streams was, in order of mean TN concentration[3]: Waiohewa (2839 mg/m^3), Waingaehe (1544 mg/m^3), Waiteti (1484 mg/m^3), Awahou (1365 mg/m^3), Waiowhiro (1014 mg/m^3), Puarenga (1096 mg/m^3), Ngongotaha (935 mg/m^3), Utuhina (816 mg/m^3) and Hamurana (795 mg/m^3). For most streams the nitrogen is primarily (80% - 95%) in the form of NNN, but Waiohewa is an exception, with the nitrogen predominantly in the form of NH4-N due to a strong geothermal influence (**Figure 3.3**, **Appendix B**).

The TP concentration in the nine Lake Rotorua catchment streams was, in order of mean TP concentration [3]: Waingaehe (123 mg/m^3), Hamurana (89.5 mg/m^3), Puarenga (81.8 mg/m^3), Waiohewa (80.3 mg/m^3), Awahou (74.6 mg/m^3), Utuhina (71.5 mg/m^3), Ngongotaha (58.3 mg/m^3), Waiteti (55.4 mg/m^3) and Waiowhiro (51.5 mg/m^3) (**Figure 3.4, Appendix B**).

The ratio of DRP to TP in each stream was: Hamurana (90%), Awahou (90%), Waingaehe (80%), Waiowhiro (69%), Waiteti (64%), Ngongotaha (50%), Puarenga (45%), Utuhina (41%), and Waiohewa (25%) (**Appendix D**). Phosphorus concentrations in Rotorua groundwater is positively correlated with mean residence time due to natural leaching (Morgenstern et al. 2015), and the high concentration of DRP in Waingaehe, Hamurana, Awahou corresponds to the strong influence of groundwater with a long residence time (i.e. 145 years, 125 years and 75 years respectively). The low relative concentration of DRP to TP in the Waiohewa is likely due to the binding of DRP to metals (e.g. aluminium) in geothermal inputs. Geothermal influence in the Puarenga may have a similar effect. The monitoring site on the Utuhina is downstream of the alum dosing, which has reduced DRP concentrations since beginning in 2006.

The flow weighted annual average concentrations of nitrogen and phosphorus of the nine monitored streams entering Lake Rotorua are shown in **Figure 3.5**. Periods of low TN concentration occurred in hydrological years of 2013/14, 2014/15, 2015/16 and 2019/20, while TP had highest flow weighted concentrations in 2014/15.

The annual average TP concentrations for the period of 2010/11 to 2018/19 were higher than all years before and after this period. A student t-test found that TP in streams was significantly (*p*-value <0.05) higher in the period 2010-2019 compared to 2002-2010. The increase in TP in the 2010-2019 period also appeared to cause a statistically significant drop in the ratio of DRP:TP (**Appendix D**). Dare (2018) observed similar patterns and raised concerns about a possible increase in particulate phosphorus from streams. However, in the light of more recent data, it appears that these observations were likely due to additive interference if the analytical method for TP used over the 2010-2019 period, although to a different extents for different streams and to a stronger extent for TP than for DRP (also see discussion in method section).

[3] Mean concentration for period 2002-2022 (see Appendix B, and Appendix C).

In most streams, the relative concentration of NNN:TN increased after the analytical method change in late 2009, due to a decrease in TN. However, the opposite pattern occurred in Waiohewa (which as high concentrations of NH4-N). An independent student t-test found the change in the ratio of NNN:TN between 2002-2010 and 2010-2022 was statistically significant in every stream (**Appendix D**).

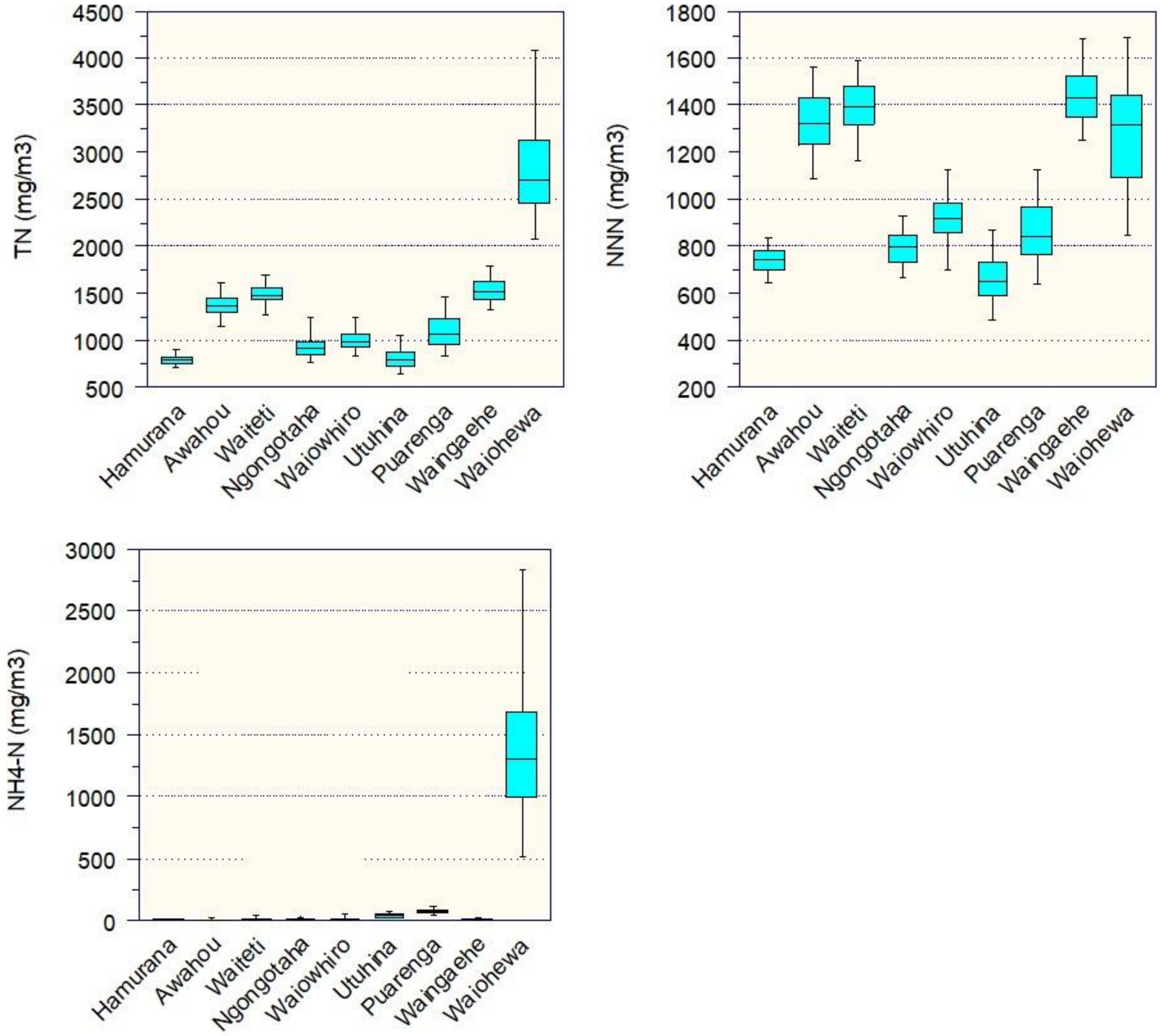

Figure 3.3: Average monthly nitrogen concentrations from the nine monitored streams entering Lake Rotorua. Boxes indicate minimum, 5%ile, 25%ile, median, 75%ile, 95%ile and maximum over the period 2002-2022.

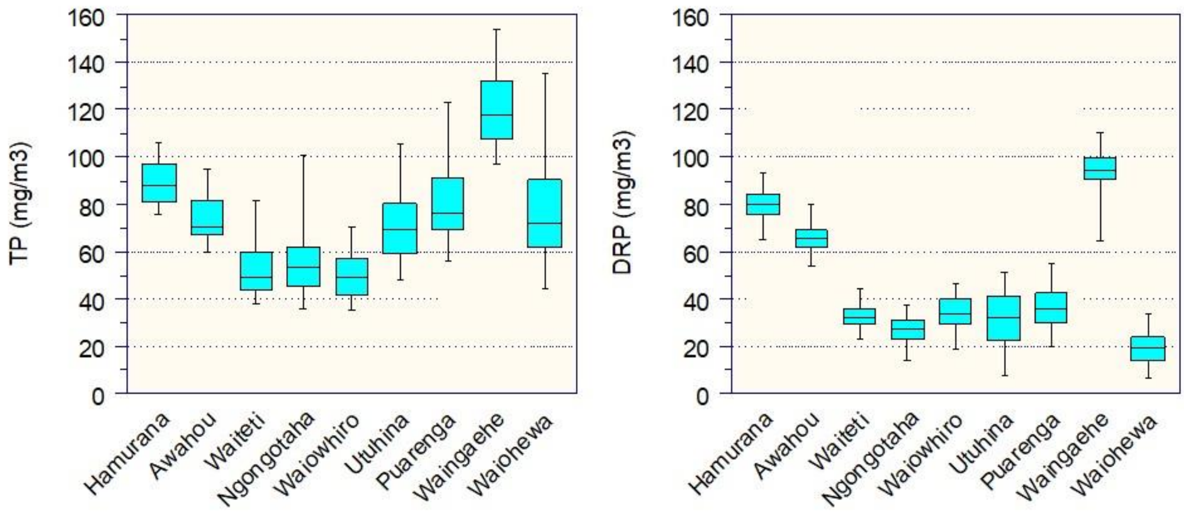

Figure 3.4: Average monthly phosphorus concentrations from the nine monitored streams entering Lake Rotorua. Boxes indicate minimum, 5%ile, 25%ile, median, 75%ile, 95%ile and maximum over the period 2002-2022.

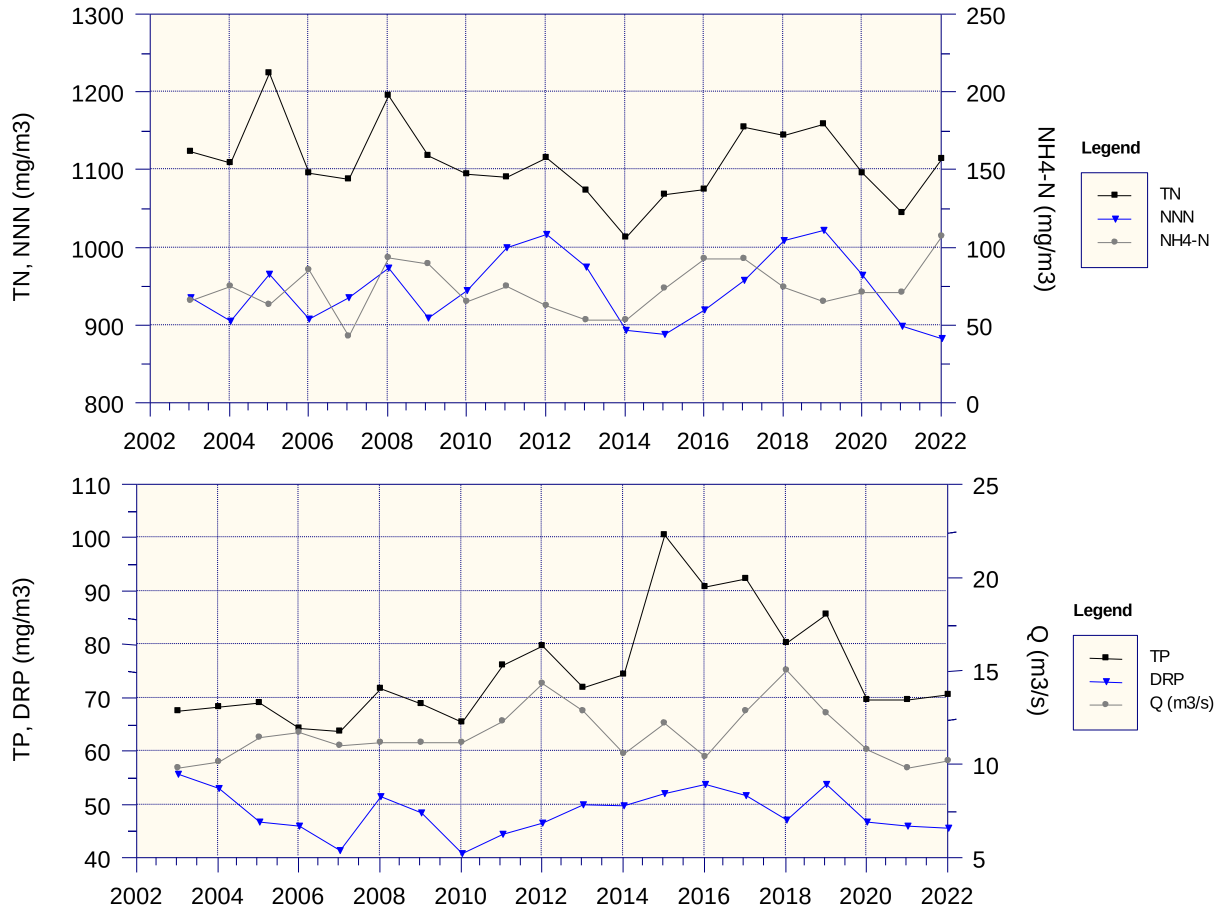

Figure 3.5: Annual average flow-weighted concentration of all nine stream inflows to Lake Rotorua. Dates are the hydrological year end.

3.2.2 *Trends in nutrient concentrations*

Changes in the concentration of nitrogen and phosphorus in each stream over time is shown in **Figure 3.6** and **Figure 3.7**, and a summary of the statistical analysis of trends is in **Table 3.2** and **Table 3.3** (with more details provided in **Appendix C**).

For the period 2002 to 2022, the concentration of TN increased in Hamurana, Awahou and Waiteti due to increasing NNN. This increasing trend has continued since 2010 and was particularly large in the Awahou and Waiteti.

TN shows a decrease in Ngongotaha, Waiowhiro, Utuhina and Puarenga, however only in the Puarenga, and to a weaker extent the Ngongotaha, was the decreasing TN trend confirmed with a decreasing trend in NNN and in time period before 2010. Flow adjusted trends analysis (**Table 3.3**) indicates that Utuhina may also have had a confirmed reduction in TN - although mostly occurring in prior to 2010 (and with a subsequent increase since 2010).

NNN concentrations have increased in the Hamurana, Awahou and Waiteti since 2002, and decreased in the Puarenga. These trends appear to have continued since 2010.

Changes in the ratio of NNN:TN provides some evidence that the change in analytical method from TN-K to TN-A in November 2009 reduce the TN results in some streams (**Figure 3.6**, **Appendix D**). Thus, weakening increasing trends and causing decreasing trends of TN data in some streams.

For the period 2002 to 2022, NH4-N concentrations decreased in five streams (Hamurana, Awahou, Waiteti, Waiowhiro, and Waingaehe) (although evidence of a decrease in NH4-N in the Hamurana was weak after flow adjusting). In contrast, the Waiohewa had a strong increase in NH4-N from 2002-2022.

TP data showed an apparent increase at all stream sites from 2002-2022, but this was largely due to the analytical method used between 2010 and 2019. On the basis of TP trends in periods before and after 2010, it is likely that the increasing TP trend is real for the Hamurana, Ngongotaha, Utuhina, Puarenga, Waingaehe, Waiohewa. There is evidence of recent (since 2010) increases in TP for the Hamurana, Ngongotaha, Utuhina, Puarenga and Waiohewa.

DRP concentrations appear to have decreased in the Waiowhiro, Puarenga and (with lesser confidence) the Utuhina in the period 2002-2022, and increased in the Hamurana. In the short time period 2010-2019, most streams had likely increased DRP (the exception being Waiowhiro).

Figure 3.6 a: Annual average nitrogen concentrations in the main streams entering Lake Rotorua.

Figure 3.6 b: Annual average nitrogen concentrations in the main streams entering Lake Rotorua.

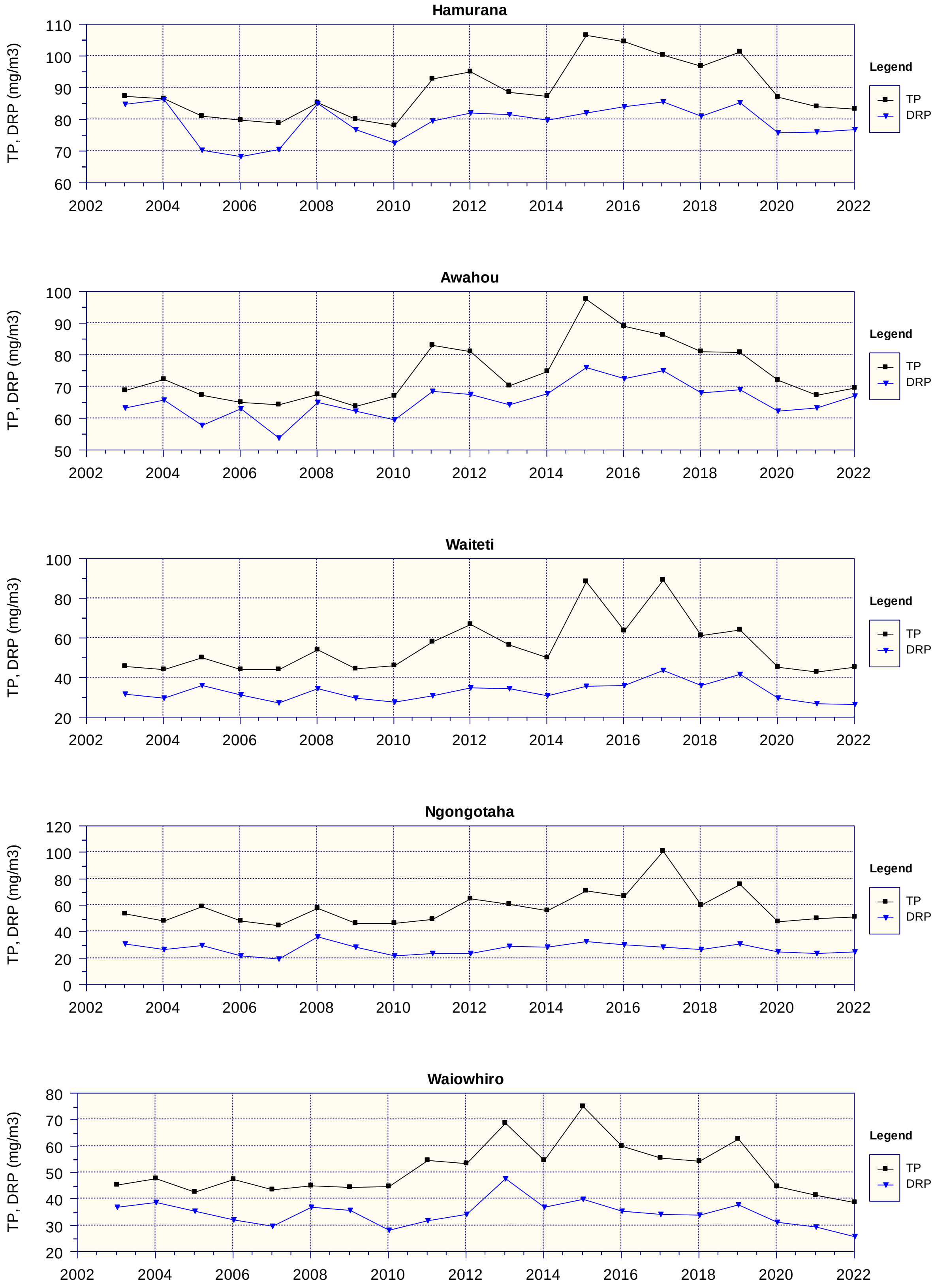

Figure 3.7 a: Annual average phosphorus concentrations in the main streams entering Lake Rotorua.

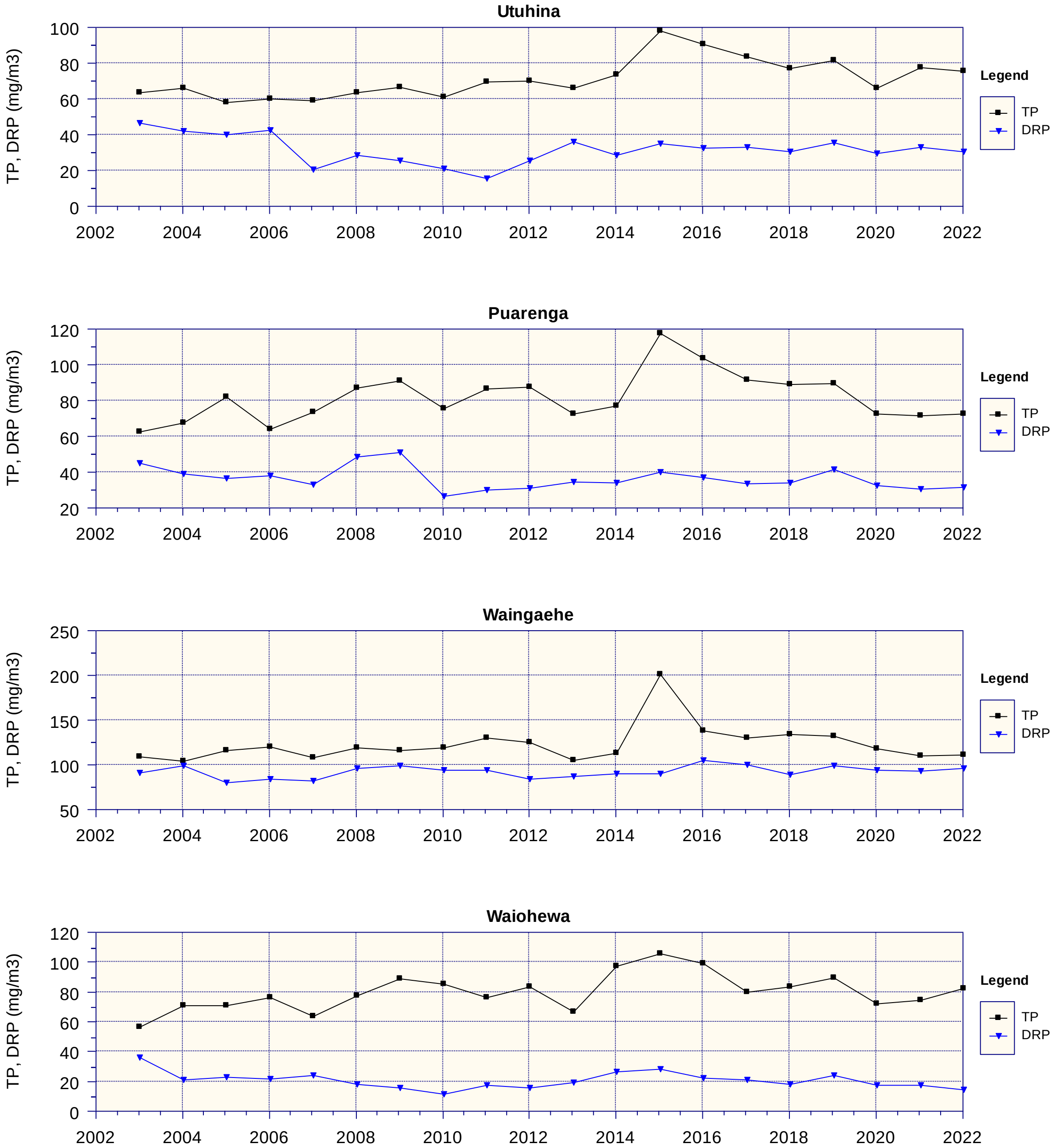

Figure 3.7 b: Annual average phosphorus concentrations in the main streams entering Lake Rotorua.

Table 3.2: Trends in nutrient concentrations for each time period and stream without any flow adjustment. Arrows indicate the trend confidence and direction as follows: "very likely increase" , "likely increase" , "possible increase" , "uncertain" , "possible decrease" , "likely decrease" , and "very likely decrease" .

Period	Variable	Site	Hamurana	Awahou	Waiteti	Ngongotaha	Waiowhiro	Utuhina	Puarenga	Waingaehe	Waiohewa
2002-2022	TN	Confidence	very likely increase	very likely increase	very likely increase	very likely decrease	very likely decrease	very likely decrease	very likely decrease	uncertain	uncertain
2002-2022	TN	PAC	0.33	0.77	0.63	-0.74	-0.39	-0.45	-1.62	-0.05	0.13
2002-2010	TN	Confidence	uncertain	likely increase	possible increase	possible decrease	uncertain	possible decrease	very likely decrease	likely increase	possible increase
2002-2010	TN	PAC	-0.10	1.10	0.39	-0.88	-0.27	-0.77	-3.02	1.15	0.98
2010-2019	TN	Confidence	very likely increase	very likely increase	very likely increase	uncertain	uncertain	very likely increase	uncertain	uncertain	uncertain
2010-2019	TN	PAC	0.64	1.32	1.11	-0.13	0.00	1.22	-0.24	0.23	0.35
2002-2022	NNN	Confidence	very likely increase	very likely increase	very likely increase	likely decrease	uncertain	uncertain	very likely decrease	possible increase	likely decrease
2002-2022	NNN	PAC	0.56	1.01	0.86	-0.23	-0.07	-0.14	-1.40	0.13	-0.45
2002-2010	NNN	Confidence	uncertain	very likely increase	very likely increase	very likely increase	uncertain	uncertain	very likely decrease	very likely increase	uncertain
2002-2010	NNN	PAC	0.19	1.39	0.77	1.14	0.09	-0.45	-2.23	1.50	-0.88
2010-2019	NNN	Confidence	possible decrease	very likely increase	very likely increase	uncertain	possible decrease	likely increase	possible decrease	uncertain	likely decrease
2010-2019	NNN	PAC	-0.33	0.70	0.64	-0.24	-0.57	1.08	-0.41	-0.19	-1.25
2002-2022	NH4-N	Confidence	very likely decrease	very likely decrease	very likely decrease	uncertain	very likely decrease	possible increase	likely increase	very likely decrease	very likely increase
2002-2022	NH4-N	PAC	-1.32	-5.33	-1.44	0.00	-2.14	0.51	0.58	-3.17	1.43
2002-2010	NH4-N	Confidence	very likely decrease	uncertain	very likely decrease	uncertain	possible decrease	very likely decrease	uncertain	very likely decrease	possible increase
2002-2010	NH4-N	PAC	-5.55	0.00	-9.72	0.00	-4.17	-5.26	-0.30	-7.50	1.72
2010-2019	NH4-N	Confidence	likely increase	very likely decrease	uncertain	very likely decrease	very likely decrease	likely increase	uncertain	very likely decrease	likely increase
2010-2019	NH4-N	PAC	2.64	-8.34	0.00	-3.57	-5.26	2.63	-0.31	-9.52	2.48
2002-2022	TP	Confidence	very likely increase	very likely increase	very likely increase	very likely increase	very likely increase	very likely increase	very likely increase	very likely increase	very likely increase
2002-2022	TP	PAC	0.71	0.85	1.02	0.81	0.77	1.73	0.93	0.43	1.39
2002-2010	TP	Confidence	very likely decrease	very likely decrease	possible increase	possible decrease	uncertain	possible decrease	very likely increase	very likely increase	likely increase
2002-2010	TP	PAC	-1.46	-0.75	1.09	-1.22	0.00	-1.33	3.57	1.28	3.90
2010-2019	TP	Confidence	very likely increase	possible increase	possible increase	very likely increase	uncertain	very likely increase	very likely increase	possible increase	very likely increase
2010-2019	TP	PAC	1.03	0.62	0.74	1.47	0.44	2.41	1.64	0.53	2.06
2002-2022	DRP	Confidence	uncertain	very likely increase	uncertain	uncertain	very likely decrease	likely decrease	very likely decrease	possible increase	uncertain
2002-2022	DRP	PAC	-0.05	0.49	0.01	-0.09	-0.55	-0.98	-1.09	0.21	-0.44
2002-2010	DRP	Confidence	very likely decrease	very likely decrease	uncertain	very likely decrease	likely decrease	very likely decrease	uncertain	uncertain	very likely decrease
2002-2010	DRP	PAC	-1.93	-0.85	-0.53	-2.63	-2.80	-10.16	-1.60	-0.01	-10.67
2010-2019	DRP	Confidence	likely increase	very likely increase	very likely increase	very likely increase	possible increase	very likely increase	very likely increase	very likely increase	likely increase
2010-2019	DRP	PAC	0.43	0.74	2.94	2.04	0.68	4.44	2.60	1.05	2.25

Table 3.3: Flow adjusted trends in nutrient concentrations for each time period and. Arrows indicate the trend confidence and direction as follows: "very likely increase" ↑, "likely increase" ↗, "possible increase" ↗, "uncertain" →, "possible decrease" ↘, "likely decrease" ↘, and "very likely decrease" ↓.

Period	Variable	Site	Hamurana	Awahou	Waiteti	Ngongotaha	Waiowhiro	Utuhina	Puarenga	Waingaehe	Waiohewa
2002-2022	TN	Confidence	↑	↑	↑	↓	↓	↘	↓	→	→
2002-2022	TN	PAC	0.19	0.57	0.59	-0.59	-0.20	-0.30	-1.66	-0.09	0.14
2002-2010	TN	Confidence	→	↗	→	↓	↘	↓	↓	↗	→
2002-2010	TN	PAC	-0.43	0.29	0.17	-1.23	-0.79	-1.75	-1.85	0.55	0.76
2010-2019	TN	Confidence	↑	↗	↑	→	↘	↑	↘	→	→
2010-2019	TN	PAC	0.52	0.84	0.94	-0.12	-0.43	1.56	-0.62	0.20	0.25
2002-2022	NNN	Confidence	↑	↑	↑	↘	→	→	↓	→	→
2002-2022	NNN	PAC	0.38	0.80	0.77	-0.11	0.08	0.10	-1.36	0.08	-0.21
2002-2010	NNN	Confidence	→	↗	↗	↗	→	↓	↓	↗	→
2002-2010	NNN	PAC	0.00	0.49	0.61	0.33	-0.28	-1.86	-1.28	0.85	0.22
2010-2019	NNN	Confidence	→	↗	↑	↘	↓	↑	↓	↘	→
2010-2019	NNN	PAC	-0.20	0.44	0.70	-0.47	-0.76	1.14	-1.38	-0.31	-0.47
2002-2022	NH4-N	Confidence	↘	↓	↓	→	↓	↗	↗	↓	↑
2002-2022	NH4-N	PAC	-0.64	-4.36	-1.27	0.30	-2.06	0.59	0.42	-2.94	1.18
2002-2010	NH4-N	Confidence	↓	→	↓	→	↘	↓	→	↓	→
2002-2010	NH4-N	PAC	-5.15	-3.21	-8.13	-1.83	-4.46	-4.15	0.76	-5.50	1.78
2010-2019	NH4-N	Confidence	↑	↓	→	↓	↓	↑	→	↓	→
2010-2019	NH4-N	PAC	3.80	-7.18	-0.31	-3.31	-5.23	2.83	-0.30	-8.74	1.01
2002-2022	TP	Confidence	↑	↑	↑	↑	↑	↑	↑	↑	↑
2002-2022	TP	PAC	0.35	0.53	0.77	0.72	0.82	1.72	0.83	0.38	1.34
2002-2010	TP	Confidence	↓	↘	→	→	→	→	↑	↑	↑
2002-2010	TP	PAC	-1.35	-0.40	0.74	-0.66	-0.17	0.45	3.13	1.07	4.16
2010-2019	TP	Confidence	↑	↗	→	↑	↗	↑	↑	→	↑
2010-2019	TP	PAC	1.03	0.67	0.80	1.54	0.92	1.96	1.97	0.37	2.64
2002-2022	DRP	Confidence	→	↑	↗	→	↓	↘	↓	↗	→
2002-2022	DRP	PAC	0.01	0.32	0.21	-0.09	-0.65	-0.83	-0.73	0.16	-0.13
2002-2010	DRP	Confidence	↓	↘	→	↘	↓	↓	↘	↗	↓
2002-2010	DRP	PAC	-1.51	-0.69	-0.84	-1.91	-2.10	-5.18	-1.48	0.76	-8.26
2010-2019	DRP	Confidence	↑	↑	↑	↗	↗	↑	↑	↗	↑
2010-2019	DRP	PAC	0.40	0.52	1.91	1.35	0.59	3.48	2.73	0.50	3.12

3.3 Stream Nutrient Loads

3.3.1 *Stream loads*

The nitrogen and phosphorus loads entering Lake Rotorua from the nine monitored streams are shown in **Figures 3.8** and **Figure 3.9**. The streams contributing most of the TN load are Awahou (71.1 t/yr), Puarenga (67.4 t/yr), Hamurana (66.5 t/yr) and Waiteti (55.8 t/yr). Waiohewa has high NH4-N loads due high concentrations from the geothermal activity. The streams contributing most of the TP load are the Hamurana (7.5 t/yr), Puarenga (5.1 t/yr), Awahou (3.9 t/yr) and Utuhina (3.8 t/yr). The phosphorus from Hamurana and Awahou is mostly in the form of DRP (6.6 t/yr and 3.4 t/yr respectively), and together they contribute about 56% of the total DRP load from streams entering Lake Rotorua.

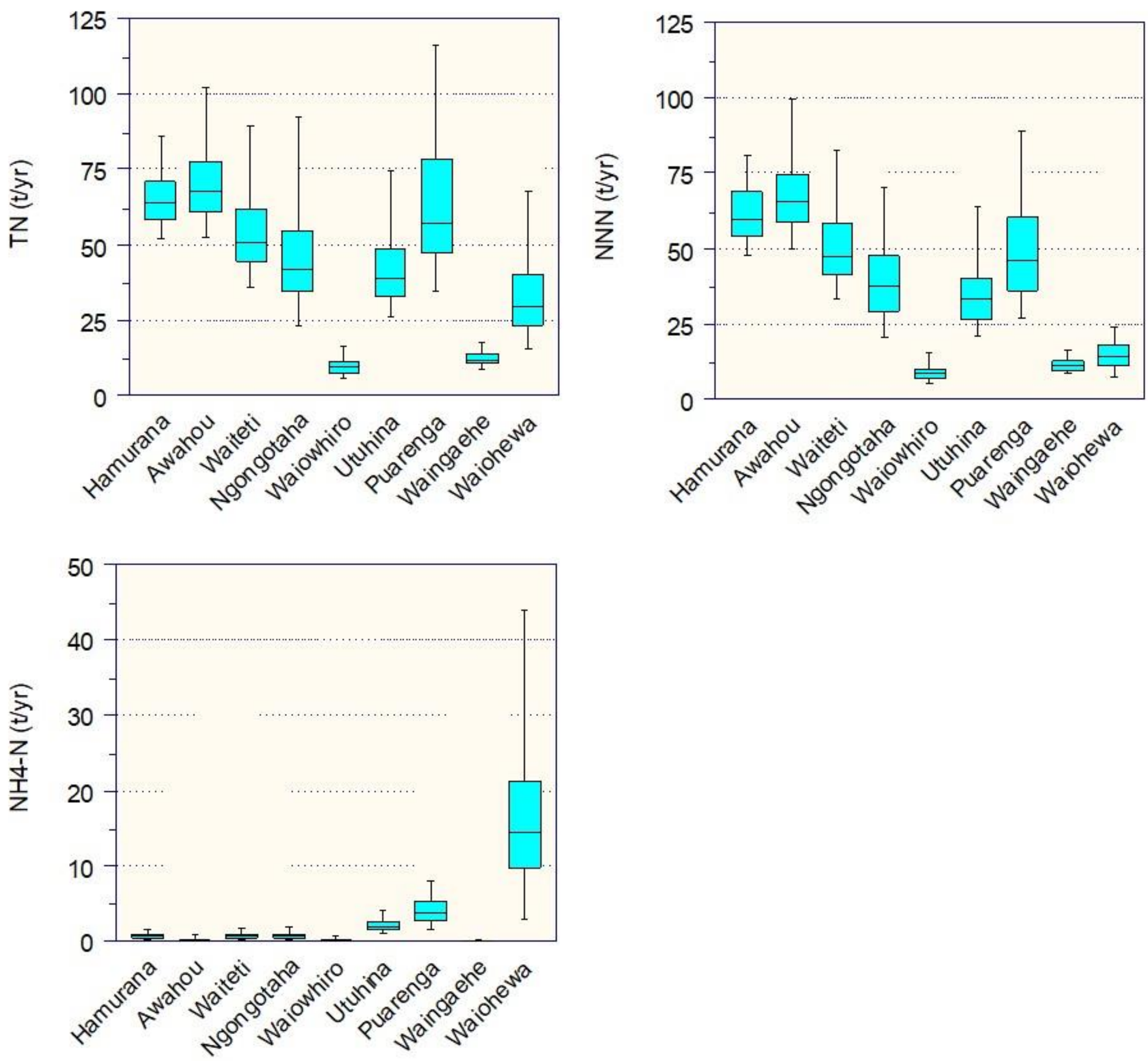

Figure 3.8: Average monthly nitrogen loads from the nine monitored streams entering Lake Rotorua. Boxes indicate minimum, 5%ile, 25%ile, median, 75%ile, 95%ile and maximum over the period 2002-2022.

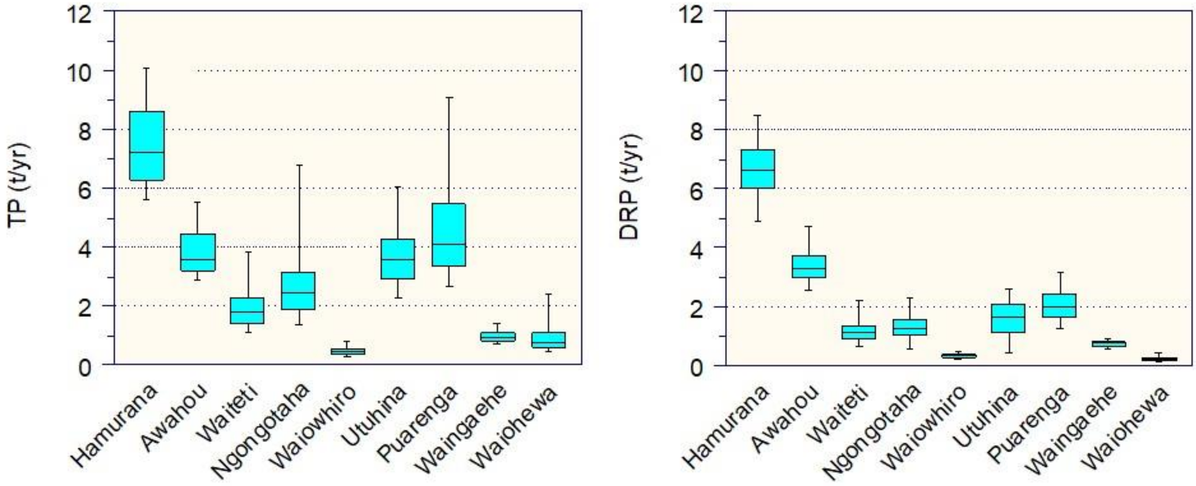

Figure 3.9: Average monthly phosphorus loads from the nine monitored streams entering Lake Rotorua. Boxes indicate minimum, 5%ile, 25%ile, median, 75%ile, 95%ile and maximum over the period 2002-2022.

3.3.2 *Total nutrient load from all streams*

The total nutrient loads entering Lake Rotorua from the nine monitored streams are shown for each year in **Table 3.4** and **Figure 3.10**. This analysis found that the nine stream inflows transport, on average, about 410 t/y of nitrogen and 28 t/yr of phosphorus. The results are very similar to those estimated by Dare (2018) using both the numeric integration method and the LOADEST method. However, these load estimates are considerably less than the total catchment load to the lake as calculated by McBride (2022) which included stream base flow, stormflows, geothermal, and groundwater.

The years with higher-than-normal loading of TN and/or TP were 2004/05, 2010/11, 2011/12, 2012/13, 2014/15, 2016/17, 2017/18 and 2018/19. These years corresponded to elevated flows on sampling occasions. Comparing annual average flow calculated from the time of sampling with the annual flows calculated from the daily composite dataset shows that load calculations for 2004/05 are likely underestimated and that load calculations from 2014/15 may be over-estimated (**Table 3.4**, **Figure 3.10**).

Nutrient loads from streams to Lake Rotorua vary between years according to inter-annual variability in rainfall and stream flows. In the long term, catchment nutrient loads effect the water quality of Lake Rotorua (Rutherford et al 1989, Burger et al. 2008, Hamilton et al. 2015), but on an annual time scale, the wet years with high nutrient loading from the catchment do not correspond to worse lake water quality. Hamill (2022) investigated the relationship between annual rainfall and the water quality of Rotorua Te Arawa Lake (as measured using the trophic level index (**TLI**)). Most of the Te Arawa lakes had a strong positive relationship between rainfall and TLI, but Lake Rotorua had a negative correlation between rainfall and TLI. McBride (2022) attributed the disconnect between annual catchment loads and annual TLI in Lake Rotorua to the influence of internal nutrient loading during periods of intermittent stratification. Long periods of stratification can lead to anoxic conditions and the release of DRP and NH4-N from sediments. The period of stratification in Lake Rotorua is highly variable between years and sustained periods (e.g. >four weeks) of stratification are relatively rare

(McBride 2022b). Annual variability of water quality in Lake Rotorua may reflect a complex interaction between climatic conditions, catchment nutrient loads, stratification and internal nutrient loads, with time-lags in the release of nutrients deposited to lake sediments from previous years.

Table 3.4: Total annual nutrient load and flow (Q) from the nine monitored streams entering Lake Rotorua. Years with shading indicate high flows on sampling occasions.

Hydraulic Year	TN (t/yr)	NNN (t/yr)	NH4-N (t/yr)	TP (t/yr)	DRP (t/yr)	Q spot (m3/s)	Q monthly mean (m3/s)
2002/03	350	291	20.5	20.8	17.0	9.8	10.3
2003/04	356	290	23.9	21.8	16.9	10.1	10.5
2004/05	450	348	23.6	25.3	16.6	11.4	11.5
2005/06	406	336	35.1	23.8	16.8	11.7	13.1
2006/07	378	324	14.9	21.9	14.1	11.0	11.4
2007/08	428	344	22.0	26.7	19.3	11.1	10.7
2008/09	397	323	31.9	24.1	17.2	11.2	11.8
2009/10	388	334	23.5	22.8	14.2	11.1	11.4
2010/11	425	390	30.2	29.5	17.0	12.3	13.5
2011/12	507	458	28.9	36.3	21.1	14.3	14.4
2012/13	443	396	23.8	29.4	19.9	12.8	13.2
2013/14	339	299	17.5	24.7	16.5	10.6	11.0
2014/15	452	332	40.4	45.2	19.4	12.2	10.3
2015/16	354	302	30.4	29.9	17.6	10.4	10.8
2016/17	479	392	38.2	38.5	20.6	12.8	14.1
2017/18	543	478	35.4	37.9	22.2	15.0	15.5
2018/19	468	412	26.9	34.6	21.6	12.7	12.7
2019/20	374	330	24.4	23.7	15.8	10.8	10.7
2020/21	326	277	23.7	22.1	14.1	9.8	9.5
2021/22	346	270	35.3	21.8	14.1	10.2	10.2
Median	401	333	25.7	25.0	17.0	11.2	11.4
Average	410	346	28	28	18	12	12

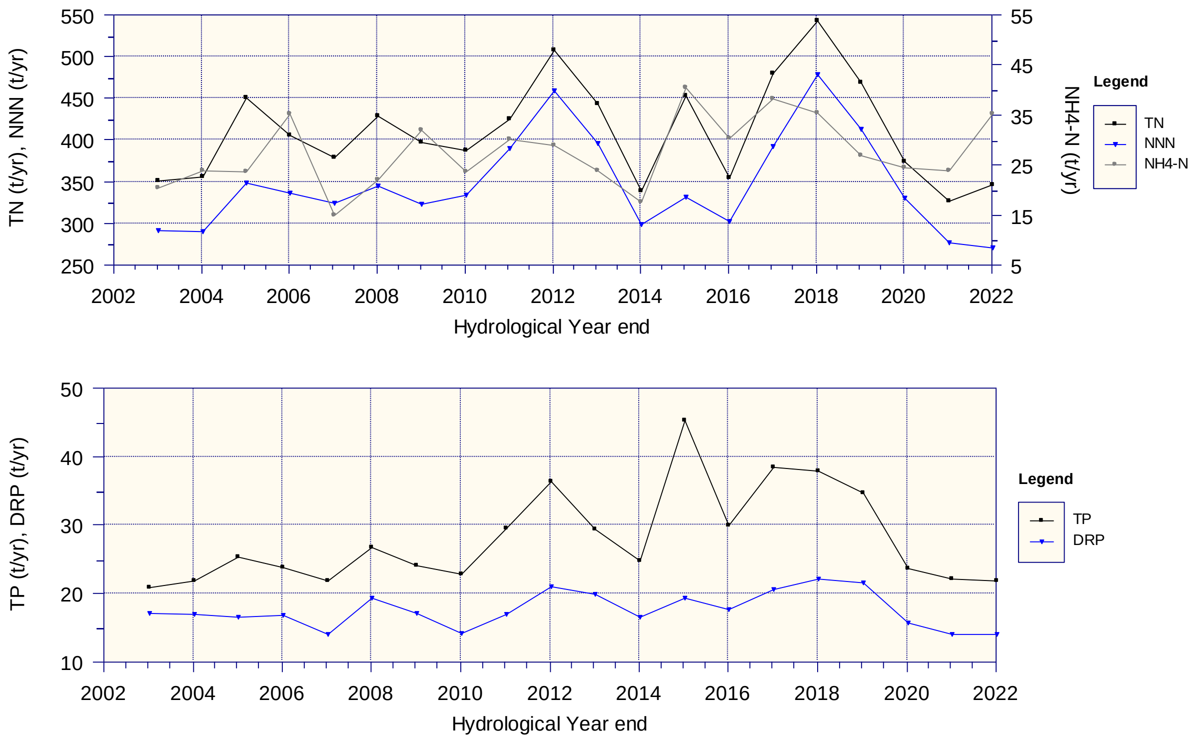

Figure 3.10: Total annual nutrient load from the nine monitored streams entering Lake Rotorua.

3.3.3 *Trends in nutrient loads*

Changes in the concentration of nitrogen and phosphorus loads over time is shown in **Figure 3.11** and **Figure 3.12**, and a summary of the statistical trend analysis is in **Table 3.5** (more details provided in **Appendix C)**.

The trends in nutrient loads were very similar to trends in nutrient concentrations. For the period 2002 to 2022, the load of TN increased in Hamurana, Awahou and (with less confidence) Waiteti due to increasing NNN. This increasing trend has likely continued in the Hamurana and Awahou since 2010.

TN loads appeared to decrease in Waiowhiro, Utuhina and Puarenga, however only in the Puarenga, was the decreasing TN trend confirmed with a decreasing trend in NNN and in time period before 2010. The decrease of TN and NNN load in the Puarenga occurred despite a trend of increasing flow over the same time period.

For the period 2002 to 2022, NH4-N loads decreased in five streams (Hamurana, Awahou, Waiteti, Waiowhiro, and Waingaehe). In contrast, the Puarenga and Waiohewa had a strong increase in NH4-N loads – in part due to an increasing trend in stream flow.

TP load data showed an apparent increase at all stream sites from 2002-2022. On the basis of TP trends in periods before and after 2010, it is likely that the increasing TP trend is real for the Waiteti, Utuhina, Puarenga, Waingaehe, and Waiohewa. It may also be real for Hamurana due to increased flows over this period.

DRP loads appear to have decreased in the Waiowhiro, in the period 2002-2022, and increased in the Waingaehe.

Table 3.5: Trends in nutrient loads and flow for each time period and stream. Arrows indicate the trend confidence and direction as follows: "very likely increase" , "likely increase" , "possible increase" , "uncertain" , "possible decrease" , "likely decrease" , and "very likely decrease" .

Period	Variable	Site	Hamurana	Awahou	Waiteti	Ngongotaha	Waiowhiro	Utuhina	Puarenga	Waingaehe	Waiohewa
2002-2022	Q spot	Confidence	very likely increase	uncertain	uncertain	uncertain	possible decrease	possible decrease	very likely increase	uncertain	possible increase
2002-2022	Q spot	PAC	0.43	-0.09	-0.10	-0.11	-0.34	-0.29	0.68	0.09	0.26
2002-2010	Q spot	Confidence	possible decrease	very likely increase	very likely increase	very likely increase	uncertain	very likely increase	possible decrease	very likely increase	possible increase
2002-2010	Q spot	PAC	-0.40	0.74	1.83	2.60	0.21	3.29	-0.54	1.52	1.52
2010-2019	Q spot	Confidence	uncertain	uncertain	uncertain	uncertain	possible increase	possible decrease	possible increase	uncertain	possible increase
2010-2019	Q spot	PAC	0.31	0.64	0.55	-0.64	1.08	-0.70	1.16	-0.57	1.53
2002-2022	TN (t/yr)	Confidence	very likely increase	very likely increase	likely increase	likely decrease	very likely decrease	very likely decrease	very likely decrease	uncertain	possible increase
2002-2022	TN (t/yr)	PAC	0.68	0.63	0.49	-0.73	-0.68	-0.88	-0.88	-0.04	0.68
2002-2010	TN (t/yr)	Confidence	possible decrease	very likely increase	likely increase	possible increase	uncertain	likely increase	very likely decrease	very likely increase	very likely increase
2002-2010	TN (t/yr)	PAC	-0.65	2.58	1.69	2.04	-0.28	1.78	-3.17	2.48	3.43
2010-2019	TN (t/yr)	Confidence	likely increase	likely increase	possible increase	uncertain	uncertain	uncertain	possible increase	uncertain	likely increase
2010-2019	TN (t/yr)	PAC	0.95	2.15	1.74	-0.62	0.74	1.17	1.84	-1.03	3.65
2002-2022	NNN (t/yr)	Confidence	very likely increase	very likely increase	very likely increase	uncertain	uncertain	likely decrease	very likely decrease	uncertain	uncertain
2002-2022	NNN (t/yr)	PAC	0.99	0.96	0.88	-0.25	-0.36	-0.56	-0.76	0.25	0.03
2002-2010	NNN (t/yr)	Confidence	uncertain	very likely increase	very likely increase	very likely increase	uncertain	very likely increase	very likely decrease	very likely increase	possible increase
2002-2010	NNN (t/yr)	PAC	-0.09	2.19	2.51	3.13	0.17	2.94	-3.18	2.68	1.14
2010-2019	NNN (t/yr)	Confidence	uncertain	likely increase	possible increase	uncertain	uncertain	uncertain	uncertain	possible decrease	possible increase
2010-2019	NNN (t/yr)	PAC	0.13	1.78	1.75	-0.55	0.40	0.66	1.59	-1.48	1.39
2002-2022	NH4-N (t/yr)	Confidence	very likely decrease	very likely decrease	very likely decrease	uncertain	very likely decrease	possible increase	very likely increase	very likely decrease	very likely increase
2002-2022	NH4-N (t/yr)	PAC	-1.62	-5.69	-1.57	-0.03	-2.37	0.46	1.51	-2.88	2.03
2002-2010	NH4-N (t/yr)	Confidence	very likely decrease	uncertain	very likely decrease	uncertain	possible decrease	uncertain	possible decrease	likely decrease	uncertain
2002-2010	NH4-N (t/yr)	PAC	-5.61	-1.08	-7.31	0.08	-3.55	-0.69	-2.14	-5.85	3.34
2010-2019	NH4-N (t/yr)	Confidence	likely increase	very likely decrease	uncertain	very likely decrease	very likely decrease	uncertain	likely increase	very likely decrease	very likely increase
2010-2019	NH4-N (t/yr)	PAC	3.28	-10.06	0.15	-4.26	-4.56	1.19	1.65	-11.82	5.51
2002-2022	TP (t/yr)	Confidence	very likely increase	very likely increase	very likely increase	very likely increase	likely increase	very likely increase	very likely increase	very likely increase	very likely increase
2002-2022	TP (t/yr)	PAC	1.17	1.23	1.27	1.40	0.64	1.78	1.71	0.70	1.71
2002-2010	TP (t/yr)	Confidence	very likely decrease	uncertain	very likely increase	possible increase	uncertain	very likely increase	very likely increase	very likely increase	very likely increase
2002-2010	TP (t/yr)	PAC	-1.73	0.26	2.46	2.04	0.41	3.02	2.52	3.15	4.44
2010-2019	TP (t/yr)	Confidence	very likely increase	likely increase	possible increase	possible increase	possible increase	possible increase	very likely increase	uncertain	very likely increase
2010-2019	TP (t/yr)	PAC	1.20	1.44	1.26	1.27	1.24	1.10	3.61	0.65	3.84
2002-2022	DRP (t/yr)	Confidence	likely increase	very likely increase	possible increase	uncertain	very likely decrease	possible decrease	uncertain	very likely increase	uncertain
2002-2022	DRP (t/yr)	PAC	0.46	0.50	0.47	-0.30	-0.79	-0.61	-0.20	0.43	0.11
2002-2010	DRP (t/yr)	Confidence	very likely decrease	uncertain	possible increase	uncertain	possible decrease	very likely decrease	possible decrease	very likely increase	very likely decrease
2002-2010	DRP (t/yr)	PAC	-1.87	-0.15	1.41	-1.56	-1.79	-7.46	-2.62	1.87	-8.02
2010-2019	DRP (t/yr)	Confidence	possible increase	possible increase	very likely increase	possible increase	possible increase	very likely increase	very likely increase	uncertain	very likely increase
2010-2019	DRP (t/yr)	PAC	0.81	1.24	2.66	1.65	1.27	4.06	4.21	0.58	5.00

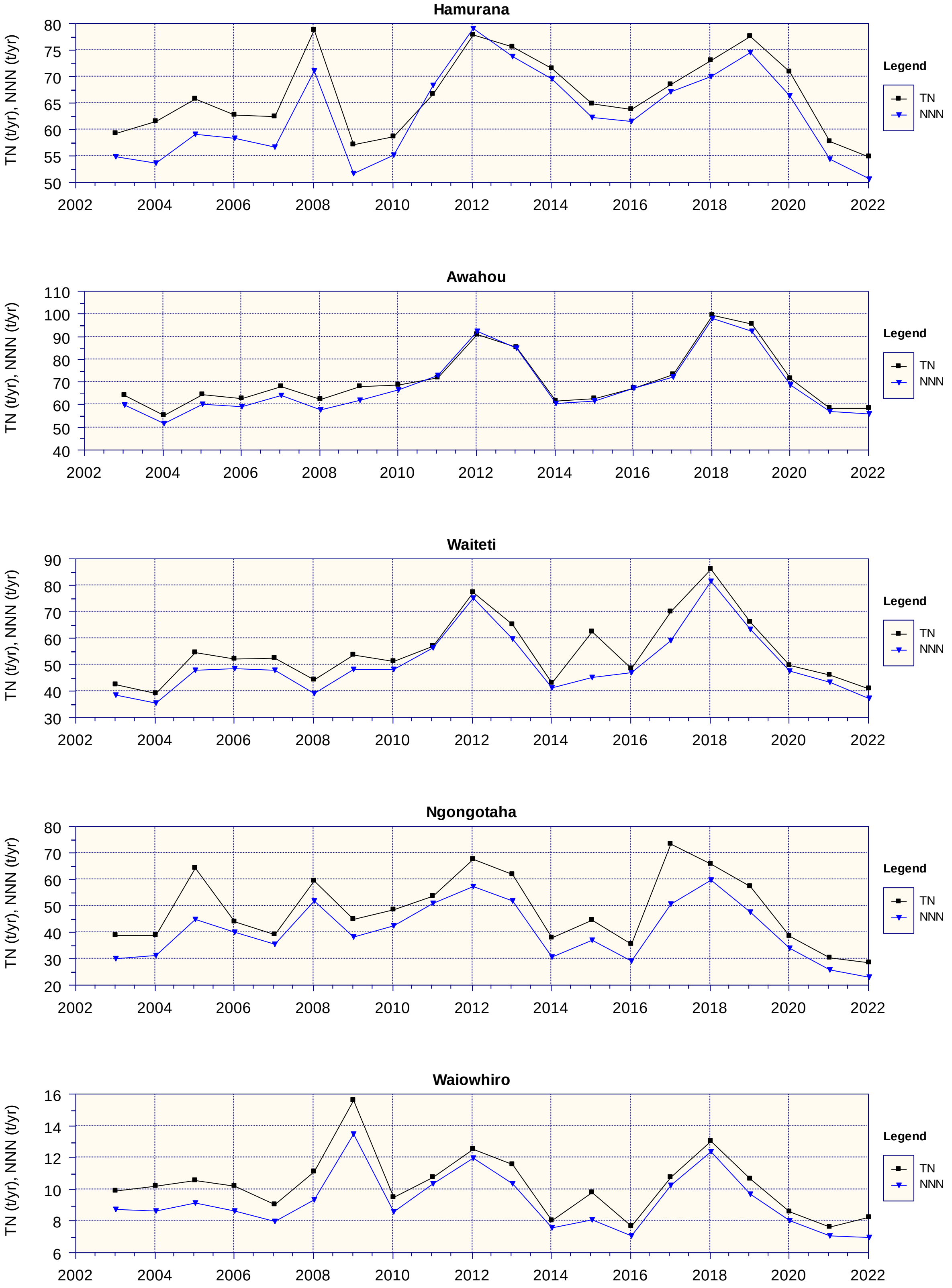

Figure 3.11a: Annual average TN and NNN loads for streams entering Lake Rotorua. Dates are the hydrological year end.

Figure 3.11b: Annual average TN and NNN loads for streams entering Lake Rotorua. Dates are the hydrological year end.

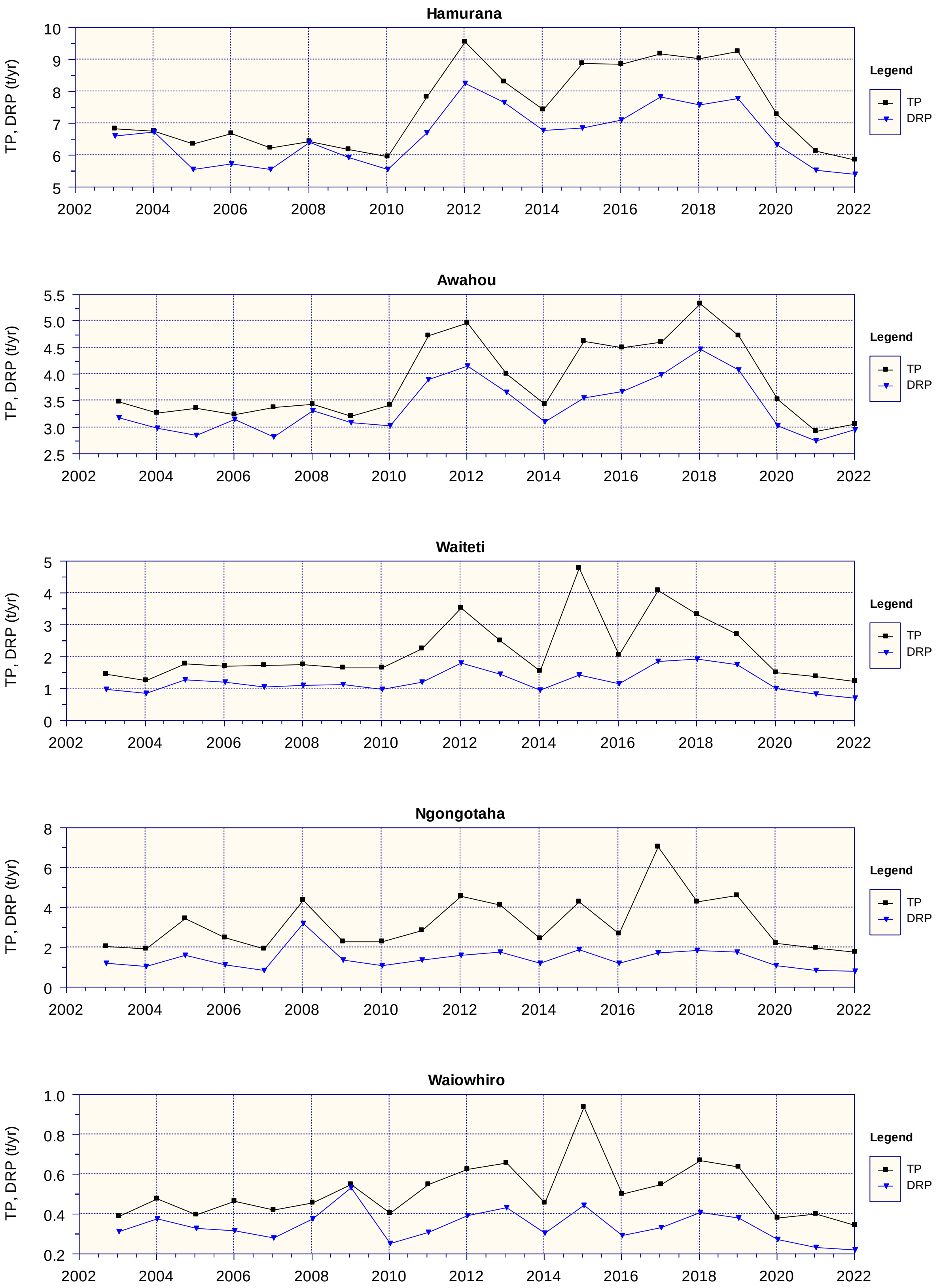

Figure 3.12a: Annual average phosphorus loads for streams entering Lake Rotorua. Dates are the hydrological year end.

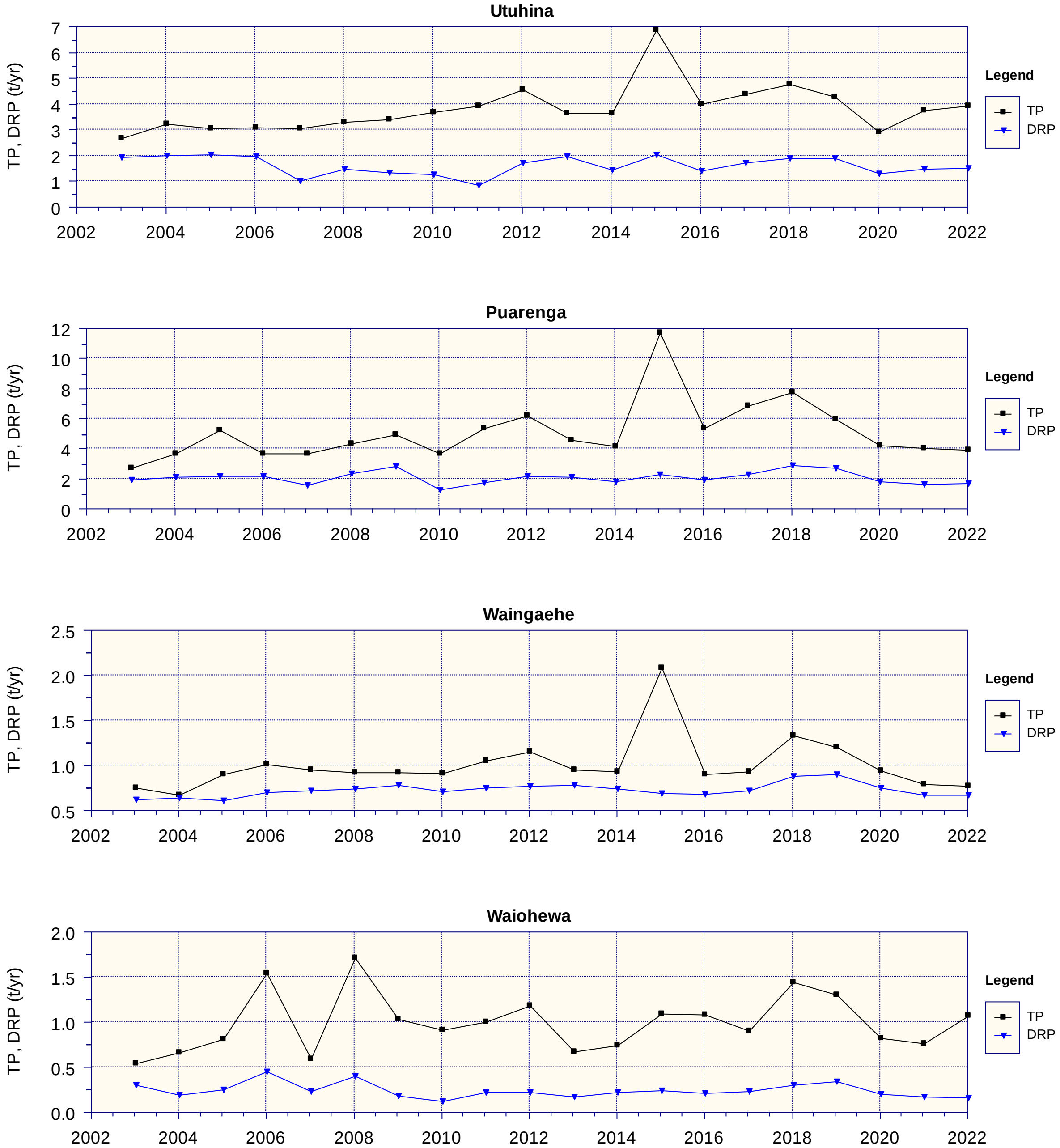

Figure 3.12b: Annual average phosphorus loads for streams entering Lake Rotorua. Dates are the hydrological year end.

4. Conclusion

This report updates previous analysis on the state and trends in nutrients of the nine major streams flowing to Lake Rotorua. The total volume of stream inflow to Lake Rotorua varies between years and this has a considerable effect on the stream nutrient loads entering the Lake as well as the concentration of nutrients in the streams. The effect of interannual climate variability on trend analysis can be minimised by using long time periods (>10 years). However, long term trend analysis of the

Rotorua Stream inflows is complicated by change in analytical methods that occurred around 2010. Analysis in this report addressed this issue by interpreting trend analysis from multiple time periods.

Over the period of 2002 to 2022, the concentration of TN increased in Hamurana, Awahou and Waiteti, with this trend continuing since 2010. Over the period of 2002 to 2022, the concentration of TP increased in the Hamurana, Ngongotaha, Utuhina, Puarenga, Waingaehe and Waiohewa; with this trend continuing after 2010 in each stream except the Waingaehe.

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Appendices

Appendix A – Laboratory Analysis Methods and Changes

Table A1.1 *Current methods used for chemical/biological analysis of water samples*

Parameter (abbreviation)	Method	Detection Limit/ Units
Ammonium Nitrogen (NH_4-N)	Phenyl/hypochlorite colorimetry. FIA APHA 4500-NH3 G.	1 mg/m^3
Total Oxidised Nitrogen (NOx)	Flow injection analyser. APHA 4500 NO3-I	1 mg/m^3
Total Nitrogen (TN)	Persulphate digestion, auto cadmium reduction. FIA	
Total Phosphorus (TP)	Acid persulphate digestion, molybdate colorimetry. FIA. Apha 4500-P H	1 mg/m^3
Dissolved Reactive Phosphorus (DRP)	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	1 mg/m^3
Water clarity – Secchi disc	Secchi disc visibility measured in metres (to 0.1m increments) with a viewing tube.	0.1 m
Turbidity	APHA Method 2130B-HACH 2100N ratio and signal averaging on.	0.01 NTU
pH	APHA method 4500-H+ measurement at 25^{o}C	
Temperature	Seabird 19Plus or 19PlusV2 CTD	0.1 deg C
Electrical conductivity	Seabird 19Plus or 19PlusV2 CTD	0. 05 µS/m
Dissolved oxygen	Seabird 19Plus or 19PlusV2 CTD (accuracy 2% of saturation)	
PAR Light Sensor	Biospherical QSP-2300	µmol photons/m^2.s
Escherichia coli (E.coli)	Membrane filtration, Standard Methods for the Examination of Water & Wastewaters (2005)	1 cfu/100ml

Table A1.2: *Historical laboratory method changes of TN, TP and DRP*

Internal Method Ref:	Date in use	Description	Lab	Detection Limit (g/m^3)
TKN-1	Up to Oct 08	APHA Method 4500B NIWA mod., Oct 1990	BOPRC (EBOP)	0.09 (mostly recorded as actual values)
TKN-7	Oct 08 – Oct 09 (some intermittent use 05/06	Kjeldahl Digestion. Phenol/hypchlorite colorimetry (discrete Analyser) APHA 4500-Norg C (modified)	RJH	0.1
TN-2	Project use 92	Persulphate digestion, AA hydrazine reduction	NIWA	0.001
TN-5	Nov 09 – present NIWA (intermittent 05/06)	Persulphate digestion, auto cadmium reduction. FIA	BOPRC (20.08.10) NIWA	0.001
TP-1	Up to July 08	NWASCO Misc Pub. No38, 1982 Antimony – Phosphate Molybdate, derived Murphy-Riley Method (1962)	BOPRC (EBOP)	*listed as* 0.008 recorded as 0.001
TP-6	Aug 08 – Oct 09	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. Apha 4500-P E(modified)		0.004
TP-2	Nov 09 – Aug 10	Acid persulphate digestion/ molybdenum blue colorimetry	NIWA	0.001
TP-5	Aug 10 – Sept 2019	Acid persulphate digestion, molybdate colorimetry. FIA. Apha 4500-P H	BOPRC (20.08.10)	0.001
TP	Oct 2019 - present	Acid persulphate digestion, molybdate colorimetry. FIA. Apha 4500-P H New channel	BOPRC (Oct 2019)	0.001
DRP-1	Up to Sept 08	NWASCO Misc Pub. No38, 1982 Antimony – Phosphate Molybdate, derived Murphy-Riley Method (1962)	BOPRC (Env. BOP)	*historically listed as* 0.004 recorded as 0.001
DRP-6	Oct 08 – Oct 09	Molybdenum blue colorimetry, discrete analyser, APHA 4500 P – E (Modified)	Hills	0.004
DRP-5	Nov 09 – Aug 10	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	NIWA (08.12.09)	0.001
DRP-5	Aug 10 – Sept 2019	Molybdenum blue colorimetry, FIA, APHA 4500-P G.	BOPRC (20.08.10)	0.001
DRP	Oct 2019 - present	Molybdenum blue colorimetry, FIA, APHA 4500-P G. new channel	BOPRC (Oct 2019)	0.001

Appendix B – Annual concentrations and loads

Table App. B: Annual mean concentration (mg/m³) and loads in streams inflows to Lake Rotorua.

Stream	Year	TN	NNN	NH4-N	TP	DRP	Q (m3/s	TN (t/yr)	NNN (t/yr)	NH4-N	TP (t/yr)	DRP (t/yr)
Hamurana	2016/17	748	732	8.7	100.3	85.4	2.90	68.4	67.1	0.82	9.17	7.82
Hamurana	2017/18	782	751	5.9	96.8	81.0	2.96	73.0	69.9	0.56	9.04	7.58
Hamurana	2018/19	850	817	7.9	101.3	85.2	2.89	77.6	74.6	0.73	9.25	7.78
Hamurana	2019/20	843	791	7.5	87.0	75.7	2.65	70.9	66.4	0.62	7.27	6.32
Hamurana	2020/21	793	747	8.5	84.1	75.9	2.31	57.7	54.4	0.62	6.12	5.54
Hamurana	2021/22	779	718	8.1	83.1	76.7	2.22	54.9	50.7	0.58	5.85	5.40
Awahou	2016/17	1370	1354	12.4	86.3	74.9	1.69	73.1	72.2	0.68	4.60	3.99
Awahou	2017/18	1517	1493	2.1	81.0	68.0	2.08	99.5	98.0	0.14	5.32	4.46
Awahou	2018/19	1615	1564	4.0	80.7	68.9	1.87	95.4	92.4	0.24	4.72	4.07
Awahou	2019/20	1465	1406	3.4	72.1	62.3	1.54	71.4	68.7	0.16	3.53	3.03
Awahou	2020/21	1350	1315	3.7	67.3	63.3	1.37	58.4	56.9	0.16	2.92	2.74
Awahou	2021/22	1329	1274	4.5	69.6	67.1	1.42	58.4	56.0	0.20	3.06	2.95
Waiteti	2016/17	1677	1469	47.8	89.3	43.7	1.29	70.0	59.1	2.32	4.08	1.85
Waiteti	2017/18	1602	1521	14.3	61.3	35.8	1.70	86.1	81.6	0.80	3.33	1.93
Waiteti	2018/19	1590	1534	19.6	64.1	41.7	1.31	65.9	63.3	0.83	2.70	1.74
Waiteti	2019/20	1499	1439	12.2	45.2	29.8	1.05	49.6	47.7	0.40	1.50	0.99
Waiteti	2020/21	1489	1403	16.2	42.9	26.8	0.98	46.2	43.2	0.53	1.37	0.84
Waiteti	2021/22	1538	1410	20.4	45.4	26.4	0.87	40.8	37.3	0.56	1.22	0.70
Ngongotaha	2016/17	1147	829	26.0	100.8	28.2	1.92	73.3	50.5	1.91	7.03	1.72
Ngongotaha	2017/18	923	839	12.5	60.1	26.2	2.26	65.7	59.7	0.90	4.26	1.85
Ngongotaha	2018/19	973	819	13.8	75.5	30.9	1.83	57.2	47.5	0.84	4.62	1.76
Ngongotaha	2019/20	851	762	13.7	47.6	24.9	1.41	38.6	34.1	0.64	2.19	1.09
Ngongotaha	2020/21	809	708	16.5	49.6	23.5	1.15	30.2	25.7	0.61	1.98	0.84
Ngongotaha	2021/22	861	700	16.2	51.0	24.7	1.10	28.6	22.9	0.54	1.74	0.81
Waiowhiro	2002/03	1108	986	20.8	45.1	36.8	0.28	9.9	8.7	0.19	0.39	0.31
Waiowhiro	2016/17	1055	1005	20.0	55.3	34.2	0.32	10.7	10.2	0.21	0.55	0.33
Waiowhiro	2017/18	1052	995	18.6	54.3	33.8	0.39	13.0	12.3	0.24	0.67	0.41
Waiowhiro	2018/19	1034	942	16.9	62.5	37.6	0.32	10.6	9.7	0.19	0.63	0.38
Waiowhiro	2019/20	1004	915	15.2	44.7	31.2	0.27	8.6	8.0	0.14	0.38	0.27
Waiowhiro	2020/21	884	830	15.6	41.2	29.3	0.29	7.6	7.0	0.19	0.40	0.23
Waiowhiro	2021/22	935	805	18.4	38.5	25.6	0.31	8.2	7.0	0.17	0.34	0.22
Utuhina	2016/17	871	760	46.7	83.4	33.0	1.66	49.1	42.9	2.65	4.37	1.71
Utuhina	2017/18	865	759	41.2	77.2	30.5	1.97	54.1	47.5	2.60	4.76	1.88
Utuhina	2018/19	817	709	38.8	81.7	35.6	1.67	43.4	37.6	2.08	4.28	1.88
Utuhina	2019/20	753	655	53.0	66.0	29.3	1.38	32.9	29.1	2.42	2.89	1.29
Utuhina	2020/21	739	571	61.8	77.6	33.1	1.48	34.9	26.5	2.95	3.75	1.48
Utuhina	2021/22	798	588	43.3	75.4	30.7	1.70	40.4	29.1	2.21	3.91	1.52
Puarenga	2016/17	1078	820	87.3	91.4	33.3	2.41	86.0	64.1	6.68	6.85	2.29
Puarenga	2017/18	1028	851	65.4	89.2	33.8	2.78	91.1	75.4	5.80	7.73	2.88
Puarenga	2018/19	986	808	63.8	89.6	41.4	2.10	66.1	54.7	4.31	5.95	2.72
Puarenga	2019/20	990	836	55.2	72.6	32.4	1.82	57.8	49.1	3.21	4.21	1.83
Puarenga	2020/21	949	750	62.1	71.7	30.6	1.69	52.0	40.0	3.35	4.04	1.60
Puarenga	2021/22	1059	791	77.7	72.6	31.7	1.95	57.8	43.0	4.15	3.88	1.67
Waiohewa	2016/17	3025	1197	1822	79.9	20.7	0.40	37.4	14.5	22.85	0.90	0.23
Waiohewa	2017/18	2516	1051	1402	83.3	17.8	0.55	43.2	17.8	24.33	1.44	0.30
Waiohewa	2018/19	2592	1296	1210	89.6	23.7	0.45	37.1	18.3	17.68	1.30	0.34
Waiohewa	2019/20	2749	1286	1422	71.8	17.1	0.37	32.1	15.4	16.78	0.82	0.20
Waiohewa	2020/21	2869	1376	1412	74.5	17.5	0.31	28.7	13.1	15.27	0.76	0.17
Waiohewa	2021/22	3494	1247	1979	82.4	14.5	0.40	46.2	14.8	26.79	1.07	0.16

Appendix C –Trend Analysis Results

Trend analysis results from raw data without flow adjustment.

Seasonal Kendall trend and slope analysis for period July 2002-June 2022.

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Hamurana	TN	795	774	0.0001	0.332	1.00	Increasing trend virtually certain
Hamurana	NNN	753	740	0	0.560	1.00	Increasing trend virtually certain
Hamurana	NH4-N	9.1	7	0.0257	-1.319	0.99	Decreasing trend very likely
Hamurana	TP	89.5	88	0	0.712	1.00	Increasing trend virtually certain
Hamurana	DRP	79.2	80	0.4109	-0.047	0.80	Decreasing trend about as likely as not
Hamurana	TN (t/yr)	66.5	64	0.0003	0.682	1.00	Increasing trend virtually certain
Hamurana	NNN (t/yr)	63.1	60	0	0.994	1.00	Increasing trend virtually certain
Hamurana	NH4-N (t/yr)	0.7	1	0.0304	-1.616	0.99	Decreasing trend very likely
Hamurana	TP (t/yr)	7.5	7	0	1.167	1.00	Increasing trend virtually certain
Hamurana	DRP (t/yr)	6.6	7	0.0525	0.461	0.97	Increasing trend likely
Awahou	TN	1365	1363	0	0.765	1.00	Increasing trend virtually certain
Awahou	NNN	1323	1327	0	1.005	1.00	Increasing trend virtually certain
Awahou	NH4-N	7.2	5	0	-5.333	1.00	Decreasing trend virtually certain
Awahou	TP	74.6	70	0	0.852	1.00	Increasing trend virtually certain
Awahou	DRP	65.5	66	0	0.487	1.00	Increasing trend virtually certain
Awahou	TN (t/yr)	71.1	68	0.0064	0.630	1.00	Increasing trend virtually certain
Awahou	NNN (t/yr)	68.9	66	0.0001	0.961	1.00	Increasing trend virtually certain
Awahou	NH4-N (t/yr)	0.4	0	0	-5.689	1.00	Decreasing trend virtually certain
Awahou	TP (t/yr)	3.9	4	0.0002	1.228	1.00	Increasing trend virtually certain
Awahou	DRP (t/yr)	3.4	3	0.0302	0.499	0.98	Increasing trend very likely
Waiteti	TN	1484	1480	0	0.633	1.00	Increasing trend virtually certain
Waiteti	NNN	1383	1390	0	0.863	1.00	Increasing trend virtually certain
Waiteti	NH4-N	20.6	16	0.0097	-1.442	1.00	Decreasing trend virtually certain
Waiteti	TP	55.4	49	0.0018	1.020	1.00	Increasing trend virtually certain
Waiteti	DRP	32.7	32	0.7422	0.006	0.63	Trend unlikely
Waiteti	TN (t/yr)	55.8	51	0.0739	0.492	0.96	Increasing trend likely
Waiteti	NNN (t/yr)	51.3	47	0.0076	0.878	1.00	Increasing trend virtually certain
Waiteti	NH4-N (t/yr)	0.9	1	0.0071	-1.570	1.00	Decreasing trend virtually certain
Waiteti	TP (t/yr)	2.2	2	0.0096	1.270	1.00	Increasing trend virtually certain
Waiteti	DRP (t/yr)	1.2	1	0.3044	0.472	0.85	Increasing trend possible
Ngongotaha	TN	935	905	0	-0.737	1.00	Decreasing trend virtually certain
Ngongotaha	NNN	790	796	0.0857	-0.230	0.96	Decreasing trend likely
Ngongotaha	NH4-N	16.2	14	0.8007	0.000	0.60	Trend unlikely
Ngongotaha	TP	58.3	53	0.0028	0.809	1.00	Increasing trend virtually certain
Ngongotaha	DRP	27.0	27	0.4133	-0.087	0.80	Decreasing trend about as likely as not
Ngongotaha	TN (t/yr)	48.5	42	0.0935	-0.728	0.96	Decreasing trend likely
Ngongotaha	NNN (t/yr)	40.4	38	0.5	-0.254	0.76	Decreasing trend about as likely as not
Ngongotaha	NH4-N (t/yr)	0.9	1	0.9833	-0.028	0.52	Trend exceptionally unlikely
Ngongotaha	TP (t/yr)	3.2	2	0.0246	1.401	0.99	Increasing trend very likely
Ngongotaha	DRP (t/yr)	1.4	1	0.645	-0.299	0.69	Decreasing trend about as likely as not
Waiowhiro	TN	1014	987	0.001	-0.392	1.00	Decreasing trend virtually certain
Waiowhiro	NNN	919	916	0.7152	-0.072	0.65	Trend unlikely
Waiowhiro	NH4-N	22.4	18	0.0006	-2.143	1.00	Decreasing trend virtually certain
Waiowhiro	TP	51.5	49	0.0015	0.769	1.00	Increasing trend virtually certain
Waiowhiro	DRP	34.5	34	0.0251	-0.553	0.99	Decreasing trend very likely
Waiowhiro	TN (t/yr)	10.2	9	0.0112	-0.684	0.99	Decreasing trend very likely
Waiowhiro	NNN (t/yr)	9.2	8	0.3537	-0.355	0.83	Decreasing trend about as likely as not
Waiowhiro	NH4-N (t/yr)	0.2	0	0.0024	-2.370	1.00	Decreasing trend virtually certain
Waiowhiro	TP (t/yr)	0.5	0	0.0837	0.637	0.96	Increasing trend likely
Waiowhiro	DRP (t/yr)	0.3	0	0.0194	-0.787	0.99	Decreasing trend very likely

Seasonal Kendall trend and slope analysis for period July 2002-June 2022.

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Utuhina	TN	816	779	0.0024	-0.446	1.00	Decreasing trend virtually certain
Utuhina	NNN	677	651	0.5159	-0.137	0.75	Decreasing trend about as likely as not
Utuhina	NH4-N	42.1	38	0.141	0.510	0.93	Increasing trend possible
Utuhina	TP	71.5	69	0	1.733	1.00	Increasing trend virtually certain
Utuhina	DRP	31.5	32	0.099	-0.978	0.95	Decreasing trend likely
Utuhina	TN (t/yr)	44.0	39	0.0101	-0.879	1.00	Decreasing trend very likely
Utuhina	NNN (t/yr)	36.3	33	0.0839	-0.564	0.96	Decreasing trend likely
Utuhina	NH4-N (t/yr)	2.3	2	0.3104	0.455	0.84	Increasing trend possible
Utuhina	TP (t/yr)	3.8	4	0	1.778	1.00	Increasing trend virtually certain
Utuhina	DRP (t/yr)	1.6	2	0.2732	-0.606	0.87	Decreasing trend possible
Puarenga	TN	1096	1068	0	-1.618	1.00	Decreasing trend virtually certain
Puarenga	NNN	860	843	0	-1.398	1.00	Decreasing trend virtually certain
Puarenga	NH4-N	71.7	68	0.0567	0.585	0.97	Increasing trend likely
Puarenga	TP	81.8	77	0.0001	0.934	1.00	Increasing trend virtually certain
Puarenga	DRP	36.3	36	0	-1.094	1.00	Decreasing trend virtually certain
Puarenga	TN (t/yr)	67.4	57	0.0117	-0.884	0.99	Decreasing trend very likely
Puarenga	NNN (t/yr)	51.9	46	0.0435	-0.763	0.98	Decreasing trend very likely
Puarenga	NH4-N (t/yr)	4.5	4	0.0002	1.510	1.00	Increasing trend virtually certain
Puarenga	TP (t/yr)	5.1	4	0	1.712	1.00	Increasing trend virtually certain
Puarenga	DRP (t/yr)	2.1	2	0.589	-0.201	0.71	Decreasing trend about as likely as not
Waingaehe	TN	1544	1510	0.5918	-0.053	0.71	Decreasing trend about as likely as not
Waingaehe	NNN	1434	1430	0.2584	0.126	0.87	Increasing trend possible
Waingaehe	NH4-N	9.7	7	0	-3.175	1.00	Decreasing trend virtually certain
Waingaehe	TP	123.2	118	0.0041	0.426	1.00	Increasing trend virtually certain
Waingaehe	DRP	92.2	94	0.1162	0.206	0.94	Increasing trend possible
Waingaehe	TN (t/yr)	12.5	12	0.9061	-0.036	0.56	Trend extremely unlikely
Waingaehe	NNN (t/yr)	11.5	11	0.482	0.254	0.76	Increasing trend about as likely as not
Waingaehe	NH4-N (t/yr)	0.1	0	0.0001	-2.877	1.00	Decreasing trend virtually certain
Waingaehe	TP (t/yr)	1.0	1	0.0136	0.702	0.99	Increasing trend very likely
Waingaehe	DRP (t/yr)	0.7	1	0.0307	0.428	0.98	Increasing trend very likely
Waiohewa	TN	2839	2700	0.5669	0.134	0.72	Increasing trend about as likely as not
Waiohewa	NNN	1288	1320	0.0542	-0.455	0.97	Decreasing trend likely
Waiohewa	NH4-N	1417.6	1300	0.0012	1.431	1.00	Increasing trend virtually certain
Waiohewa	TP	80.3	72	0.0001	1.389	1.00	Increasing trend virtually certain
Waiohewa	DRP	20.5	19	0.4294	-0.439	0.79	Decreasing trend about as likely as not
Waiohewa	TN (t/yr)	35.2	30	0.1148	0.678	0.94	Increasing trend possible
Waiohewa	NNN (t/yr)	15.3	14	0.9397	0.034	0.53	Trend extremely unlikely
Waiohewa	NH4-N (t/yr)	17.7	14	0.0028	2.030	1.00	Increasing trend virtually certain
Waiohewa	TP (t/yr)	1.0	1	0.0018	1.708	1.00	Increasing trend virtually certain
Waiohewa	DRP (t/yr)	0.2	0	0.8608	0.115	0.57	Trend unlikely
Hamurana	Q (m3/s)	2.6	3	0.0021	0.427	1.00	Increasing trend virtually certain
Awahou	Q (m3/s)	1.6	2	0.7555	-0.086	0.63	Trend unlikely
Waiteti	Q (m3/s)	1.2	1	0.6799	-0.104	0.67	Trend unlikely
Ngongotaha	Q (m3/s)	1.6	1	0.8009	-0.106	0.61	Trend unlikely
Waiowhiro	Q (m3/s)	0.3	0	0.2452	-0.336	0.88	Decreasing trend possible
Utuhina	Q (m3/s)	1.7	2	0.1495	-0.293	0.93	Decreasing trend possible
Puarenga	Q (m3/s)	1.9	2	0.0031	0.684	1.00	Increasing trend virtually certain
Waingaehe	Q (m3/s)	0.3	0	0.5128	0.095	0.74	Increasing trend about as likely as not
Waiohewa	Q (m3/s)	0.4	0	0.3299	0.260	0.84	Increasing trend possible

Seasonal Kendall trend and slope analysis for period July 2002 to June 2010.

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Hamurana	TN	795	756	0.7488	-0.099	0.66	Trend unlikely
Hamurana	NNN	723	693	0.4647	0.192	0.77	Increasing trend about as likely as not
Hamurana	NH4-N	12.8	9	0.011	-5.552	1.00	Decreasing trend very likely
Hamurana	TP	81.9	81	0	-1.460	1.00	Decreasing trend virtually certain
Hamurana	DRP	76.6	79	0.0016	-1.927	1.00	Decreasing trend virtually certain
Hamurana	TN (t/yr)	62.3	59	0.2178	-0.651	0.91	Decreasing trend possible
Hamurana	NNN (t/yr)	56.7	54	0.8911	-0.087	0.58	Trend unlikely
Hamurana	NH4-N (t/yr)	1.0	1	0.0144	-5.606	0.99	Decreasing trend very likely
Hamurana	TP (t/yr)	6.4	6	0.0001	-1.732	1.00	Decreasing trend virtually certain
Hamurana	DRP (t/yr)	6.0	6	0.003	-1.866	1.00	Decreasing trend virtually certain
Awahou	TN	1287	1297	0.0621	1.099	0.97	Increasing trend likely
Awahou	NNN	1206	1200	0.0154	1.389	0.99	Increasing trend very likely
Awahou	NH4-N	10.5	7	0.451	0.000	0.80	Decreasing trend about as likely as not
Awahou	TP	66.8	67	0.0082	-0.746	1.00	Decreasing trend virtually certain
Awahou	DRP	61.0	62	0.0478	-0.848	0.98	Decreasing trend very likely
Awahou	TN (t/yr)	64.5	65	0.0023	2.577	1.00	Increasing trend virtually certain
Awahou	NNN (t/yr)	60.5	61	0.0004	2.194	1.00	Increasing trend virtually certain
Awahou	NH4-N (t/yr)	0.5	0	0.7738	-1.083	0.65	Trend unlikely
Awahou	TP (t/yr)	3.3	3	0.5722	0.265	0.70	Increasing trend about as likely as not
Awahou	DRP (t/yr)	3.0	3	0.7738	-0.145	0.64	Trend unlikely
Waiteti	TN	1401	1410	0.1173	0.392	0.94	Increasing trend possible
Waiteti	NNN	1278	1300	0.0123	0.770	0.99	Increasing trend very likely
Waiteti	NH4-N	18.1	18	0	-9.722	1.00	Decreasing trend virtually certain
Waiteti	TP	46.1	46	0.2781	1.086	0.86	Increasing trend possible
Waiteti	DRP	30.7	31	0.3568	-0.528	0.84	Decreasing trend about as likely as not
Waiteti	TN (t/yr)	49.1	49	0.0676	1.688	0.97	Increasing trend likely
Waiteti	NNN (t/yr)	44.7	45	0.0028	2.507	1.00	Increasing trend virtually certain
Waiteti	NH4-N (t/yr)	0.6	1	0.0005	-7.309	1.00	Decreasing trend virtually certain
Waiteti	TP (t/yr)	1.6	2	0.0253	2.462	0.99	Increasing trend very likely
Waiteti	DRP (t/yr)	1.1	1	0.2562	1.410	0.86	Increasing trend possible
Ngongotaha	TN	953	946	0.2301	-0.881	0.90	Decreasing trend possible
Ngongotaha	NNN	802	791	0.0074	1.138	1.00	Increasing trend virtually certain
Ngongotaha	NH4-N	15.6	14	0.9022	0.000	0.58	Trend extremely unlikely
Ngongotaha	TP	50.4	49	0.201	-1.225	0.91	Decreasing trend possible
Ngongotaha	DRP	26.7	28	0.0047	-2.631	1.00	Decreasing trend virtually certain
Ngongotaha	TN (t/yr)	47.1	42	0.2639	2.036	0.87	Increasing trend possible
Ngongotaha	NNN (t/yr)	39.3	36	0.001	3.129	1.00	Increasing trend virtually certain
Ngongotaha	NH4-N (t/yr)	0.7	1	1	0.083	0.50	Trend exceptionally unlikely
Ngongotaha	TP (t/yr)	2.6	2	0.1322	2.044	0.93	Increasing trend possible
Ngongotaha	DRP (t/yr)	1.4	1	0.3711	-1.558	0.84	Decreasing trend about as likely as not
Waiowhiro	TN	1039	1005	0.6716	-0.265	0.71	Trend unlikely
Waiowhiro	NNN	905	900	0.8987	0.089	0.55	Trend unlikely
Waiowhiro	NH4-N	22.1	18	0.1166	-4.167	0.95	Decreasing trend possible
Waiowhiro	TP	45.0	45	0.9663	0.000	0.55	Trend exceptionally unlikely
Waiowhiro	DRP	33.8	35	0.0642	-2.797	0.97	Decreasing trend likely
Waiowhiro	TN (t/yr)	10.6	10	0.7345	-0.283	0.68	Trend unlikely
Waiowhiro	NNN (t/yr)	9.2	8	0.6716	0.175	0.65	Trend unlikely
Waiowhiro	NH4-N (t/yr)	0.2	0	0.3047	-3.552	0.87	Decreasing trend possible
Waiowhiro	TP (t/yr)	0.4	0	0.8046	0.405	0.61	Trend unlikely
Waiowhiro	DRP (t/yr)	0.3	0	0.1288	-1.788	0.94	Decreasing trend possible

Seasonal Kendall trend and slope analysis for period July 2002 to June 2010.

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Utuhina	TN	885	815	0.1337	-0.765	0.94	Decreasing trend possible
Utuhina	NNN	704	651	0.5204	-0.450	0.77	Decreasing trend about as likely as not
Utuhina	NH4-N	40.3	38	0.0007	-5.263	1.00	Decreasing trend virtually certain
Utuhina	TP	62.0	60	0.2948	-1.333	0.87	Decreasing trend possible
Utuhina	DRP	33.2	39	0	-10.159	1.00	Decreasing trend virtually certain
Utuhina	TN (t/yr)	45.9	41	0.0947	1.779	0.95	Increasing trend likely
Utuhina	NNN (t/yr)	36.6	33	0.0358	2.936	0.98	Increasing trend very likely
Utuhina	NH4-N (t/yr)	2.1	2	0.3821	-0.689	0.82	Decreasing trend about as likely as not
Utuhina	TP (t/yr)	3.2	3	0.0121	3.018	0.99	Increasing trend very likely
Utuhina	DRP (t/yr)	1.6	2	0.0192	-7.463	0.99	Decreasing trend very likely
Puarenga	TN	1231	1241	0	-3.023	1.00	Decreasing trend virtually certain
Puarenga	NNN	938	959	0.0002	-2.226	1.00	Decreasing trend virtually certain
Puarenga	NH4-N	66.0	66	0.7803	-0.303	0.64	Trend unlikely
Puarenga	TP	75.4	72	0	3.571	1.00	Increasing trend virtually certain
Puarenga	DRP	39.8	41	0.361	-1.597	0.84	Decreasing trend about as likely as not
Puarenga	TN (t/yr)	65.2	61	0.0069	-3.169	1.00	Decreasing trend virtually certain
Puarenga	NNN (t/yr)	49.3	48	0.0168	-3.176	0.99	Decreasing trend very likely
Puarenga	NH4-N (t/yr)	3.5	3	0.3029	-2.139	0.87	Decreasing trend possible
Puarenga	TP (t/yr)	4.0	4	0.0382	2.516	0.98	Increasing trend very likely
Puarenga	DRP (t/yr)	2.0	2	0.2346	-2.615	0.90	Decreasing trend possible
Waingaehe	TN	1551	1520	0.0556	1.151	0.97	Increasing trend likely
Waingaehe	NNN	1404	1430	0.0024	1.498	1.00	Increasing trend virtually certain
Waingaehe	NH4-N	11.0	8	0.0091	-7.501	1.00	Decreasing trend virtually certain
Waingaehe	TP	114.0	111	0.0277	1.276	0.99	Increasing trend very likely
Waingaehe	DRP	90.3	94	0.9287	-0.014	0.57	Trend extremely unlikely
Waingaehe	TN (t/yr)	12.0	12	0.0129	2.478	0.99	Increasing trend very likely
Waingaehe	NNN (t/yr)	10.9	11	0.0005	2.678	1.00	Increasing trend virtually certain
Waingaehe	NH4-N (t/yr)	0.1	0	0.0741	-5.853	0.97	Decreasing trend likely
Waingaehe	TP (t/yr)	0.9	1	0.0016	3.150	1.00	Increasing trend virtually certain
Waingaehe	DRP (t/yr)	0.7	1	0.0004	1.872	1.00	Increasing trend virtually certain
Waiohewa	TN	2865	2750	0.2438	0.976	0.88	Increasing trend possible
Waiohewa	NNN	1343	1330	0.6863	-0.877	0.69	Trend unlikely
Waiohewa	NH4-N	1308.2	1105	0.2622	1.721	0.86	Increasing trend possible
Waiohewa	TP	73.9	64	0.0647	3.904	0.97	Increasing trend likely
Waiohewa	DRP	21.3	18	0.0005	-10.672	1.00	Decreasing trend virtually certain
Waiohewa	TN (t/yr)	35.9	29	0.0198	3.426	0.99	Increasing trend very likely
Waiohewa	NNN (t/yr)	16.3	13	0.324	1.142	0.84	Increasing trend possible
Waiohewa	NH4-N (t/yr)	16.0	12	0.359	3.341	0.81	Increasing trend about as likely as not
Waiohewa	TP (t/yr)	0.9	1	0.0198	4.444	0.99	Increasing trend very likely
Waiohewa	DRP (t/yr)	0.3	0	0.0184	-8.021	0.99	Decreasing trend very likely
Hamurana	Q (m3/s)	2.5	2	0.1574	-0.396	0.93	Decreasing trend possible
Awahou	Q (m3/s)	1.6	2	0.0193	0.739	0.99	Increasing trend very likely
Waiteti	Q (m3/s)	1.1	1	0.0126	1.832	0.99	Increasing trend very likely
Ngongotaha	Q (m3/s)	1.5	1	0.0013	2.601	1.00	Increasing trend virtually certain
Waiowhiro	Q (m3/s)	0.3	0	0.6852	0.208	0.66	Trend unlikely
Utuhina	Q (m3/s)	1.6	2	0.0001	3.293	1.00	Increasing trend virtually certain
Puarenga	Q (m3/s)	1.6	2	0.2123	-0.545	0.91	Decreasing trend possible
Waingaehe	Q (m3/s)	0.2	0	0.0195	1.517	0.99	Increasing trend very likely
Waiohewa	Q (m3/s)	0.4	0	0.1275	1.516	0.93	Increasing trend possible

Seasonal Kendall trend and slope analysis for period September 2010 to August 2019

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Hamurana	TN	792	783	0.0137	0.638	0.99	Increasing trend very likely
Hamurana	NNN	777	768	0.2893	-0.326	0.87	Decreasing trend possible
Hamurana	NH4-N	6.5	6	0.0581	2.639	0.97	Increasing trend likely
Hamurana	TP	96.9	97	0.0054	1.032	1.00	Increasing trend virtually certain
Hamurana	DRP	82.3	82	0.0544	0.432	0.97	Increasing trend likely
Hamurana	TN (t/yr)	71.3	70	0.0707	0.949	0.96	Increasing trend likely
Hamurana	NNN (t/yr)	69.8	69	0.6626	0.128	0.67	Increasing trend about as likely as not
Hamurana	NH4-N (t/yr)	0.6	1	0.0687	3.280	0.97	Increasing trend likely
Hamurana	TP (t/yr)	8.7	9	0.0207	1.202	0.99	Increasing trend very likely
Hamurana	DRP (t/yr)	7.4	7	0.2414	0.807	0.88	Increasing trend possible
Awahou	TN	1425	1430	0.0013	1.322	1.00	Increasing trend virtually certain
Awahou	NNN	1416	1430	0.041	0.700	0.98	Increasing trend very likely
Awahou	NH4-N	5.5	4	0.0004	-8.339	1.00	Decreasing trend virtually certain
Awahou	TP	82.5	81	0.2982	0.617	0.85	Increasing trend possible
Awahou	DRP	69.6	68	0.0105	0.735	0.99	Increasing trend very likely
Awahou	TN (t/yr)	79.0	77	0.0897	2.145	0.95	Increasing trend likely
Awahou	NNN (t/yr)	78.4	76	0.0825	1.775	0.96	Increasing trend likely
Awahou	NH4-N (t/yr)	0.3	0	0.0006	-10.060	1.00	Decreasing trend virtually certain
Awahou	TP (t/yr)	4.5	4	0.0723	1.443	0.96	Increasing trend likely
Awahou	DRP (t/yr)	3.8	4	0.1596	1.245	0.92	Increasing trend possible
Waiteti	TN	1541	1512	0.0003	1.111	1.00	Increasing trend virtually certain
Waiteti	NNN	1456	1480	0.0124	0.642	0.99	Increasing trend very likely
Waiteti	NH4-N	23.7	15	0.9754	0.000	0.51	Trend exceptionally unlikely
Waiteti	TP	66.1	58	0.3219	0.739	0.84	Increasing trend possible
Waiteti	DRP	35.8	34	0	2.935	1.00	Increasing trend virtually certain
Waiteti	TN (t/yr)	64.1	56	0.1471	1.742	0.92	Increasing trend possible
Waiteti	NNN (t/yr)	59.0	54	0.1522	1.749	0.92	Increasing trend possible
Waiteti	NH4-N (t/yr)	1.2	1	0.9757	0.152	0.50	Trend exceptionally unlikely
Waiteti	TP (t/yr)	3.0	2	0.1846	1.257	0.91	Increasing trend possible
Waiteti	DRP (t/yr)	1.5	1	0.0265	2.660	0.99	Increasing trend very likely
Ngongotaha	TN	949	904	0.7409	-0.129	0.65	Trend unlikely
Ngongotaha	NNN	802	828	0.4881	-0.242	0.77	Decreasing trend about as likely as not
Ngongotaha	NH4-N	16.9	14	0.0112	-3.571	1.00	Decreasing trend very likely
Ngongotaha	TP	68.4	60	0.0369	1.468	0.98	Increasing trend very likely
Ngongotaha	DRP	28.2	28	0.0216	2.041	0.99	Increasing trend very likely
Ngongotaha	TN (t/yr)	55.3	47	0.8172	-0.624	0.61	Trend unlikely
Ngongotaha	NNN (t/yr)	45.8	44	0.7664	-0.553	0.63	Trend unlikely
Ngongotaha	NH4-N (t/yr)	1.1	1	0.027	-4.257	0.99	Decreasing trend very likely
Ngongotaha	TP (t/yr)	4.2	3	0.3061	1.272	0.85	Increasing trend possible
Ngongotaha	DRP (t/yr)	1.6	1	0.1207	1.650	0.94	Increasing trend possible
Waiowhiro	TN	1019	1000	1	-0.005	0.50	No detectable trend
Waiowhiro	NNN	952	948	0.3147	-0.575	0.86	Decreasing trend possible
Waiowhiro	NH4-N	24.1	19	0.0071	-5.264	1.00	Decreasing trend virtually certain
Waiowhiro	TP	59.7	57	0.4437	0.439	0.78	Increasing trend about as likely as not
Waiowhiro	DRP	36.8	37	0.3247	0.676	0.84	Increasing trend possible
Waiowhiro	TN (t/yr)	10.5	10	0.7839	0.741	0.61	Trend unlikely
Waiowhiro	NNN (t/yr)	9.8	9	0.7839	0.400	0.61	Trend unlikely
Waiowhiro	NH4-N (t/yr)	0.3	0	0.0477	-4.556	0.98	Decreasing trend very likely
Waiowhiro	TP (t/yr)	0.6	1	0.2116	1.240	0.89	Increasing trend possible
Waiowhiro	DRP (t/yr)	0.4	0	0.1522	1.274	0.93	Increasing trend possible

Seasonal Kendall trend and slope analysis for period September 2010 to August 2019

Site	Variable	Mean	Median	P	PAC	Slope Likelihood	Trend direction and confidence
Utuhina	TN	780	755	0.001	1.222	1.00	Increasing trend virtually certain
Utuhina	NNN	677	674	0.067	1.082	0.97	Increasing trend likely
Utuhina	NH4-N	40.3	38	0.076	2.629	0.96	Increasing trend likely
Utuhina	TP	78.9	77	0.002	2.412	1.00	Increasing trend virtually certain
Utuhina	DRP	30.3	30	0.002	4.443	1.00	Increasing trend virtually certain
Utuhina	TN (t/yr)	44.7	40	0.377	1.169	0.82	Increasing trend about as likely as not
Utuhina	NNN (t/yr)	38.2	35	0.605	0.658	0.69	Increasing trend about as likely as not
Utuhina	NH4-N (t/yr)	2.3	2	0.446	1.190	0.78	Increasing trend about as likely as not
Utuhina	TP (t/yr)	4.4	4	0.260	1.097	0.86	Increasing trend possible
Utuhina	DRP (t/yr)	1.7	2	0.005	4.063	1.00	Increasing trend virtually certain
Puarenga	TN	1023	1020	0.715	-0.243	0.67	Trend unlikely
Puarenga	NNN	823	820	0.273	-0.412	0.88	Decreasing trend possible
Puarenga	NH4-N	79.0	72	0.691	-0.313	0.68	Trend unlikely
Puarenga	TP	90.4	85	0.013	1.640	0.99	Increasing trend very likely
Puarenga	DRP	35.0	35	0.001	2.596	1.00	Increasing trend virtually certain
Puarenga	TN (t/yr)	73.1	57	0.212	1.840	0.89	Increasing trend possible
Puarenga	NNN (t/yr)	56.9	48	0.484	1.588	0.75	Increasing trend about as likely as not
Puarenga	NH4-N (t/yr)	5.7	5	0.072	1.648	0.96	Increasing trend likely
Puarenga	TP (t/yr)	6.4	5	0.005	3.614	1.00	Increasing trend virtually certain
Puarenga	DRP (t/yr)	2.2	2	0.000	4.212	1.00	Increasing trend virtually certain
Waingaehe	TN	1563	1527	0.775	0.227	0.61	Trend unlikely
Waingaehe	NNN	1474	1477	0.755	-0.193	0.65	Trend unlikely
Waingaehe	NH4-N	9.2	7	0.000	-9.522	1.00	Decreasing trend virtually certain
Waingaehe	TP	133.9	131	0.278	0.527	0.86	Increasing trend possible
Waingaehe	DRP	93.3	95	0.014	1.053	0.99	Increasing trend very likely
Waingaehe	TN (t/yr)	13.4	13	0.466	-1.029	0.79	Decreasing trend about as likely as not
Waingaehe	NNN (t/yr)	12.5	12	0.248	-1.482	0.89	Decreasing trend possible
Waingaehe	NH4-N (t/yr)	0.1	0	0.000	-11.819	1.00	Decreasing trend virtually certain
Waingaehe	TP (t/yr)	1.2	1	0.371	0.653	0.82	Increasing trend about as likely as not
Waingaehe	DRP (t/yr)	0.8	1	0.441	0.575	0.78	Increasing trend about as likely as not
Waiohewa	TN	2757	2647	0.365	0.348	0.81	Increasing trend about as likely as not
Waiohewa	NNN	1243	1281	0.056	-1.250	0.98	Decreasing trend likely
Waiohewa	NH4-N	1428.8	1343	0.065	2.480	0.97	Increasing trend likely
Waiohewa	TP	86.2	81	0.045	2.057	0.98	Increasing trend very likely
Waiohewa	DRP	21.2	20	0.058	2.249	0.97	Increasing trend likely
Waiohewa	TN (t/yr)	34.7	31	0.065	3.649	0.97	Increasing trend likely
Waiohewa	NNN (t/yr)	14.9	14	0.280	1.395	0.86	Increasing trend possible
Waiohewa	NH4-N (t/yr)	18.3	15	0.002	5.512	1.00	Increasing trend virtually certain
Waiohewa	TP (t/yr)	1.0	1	0.013	3.837	0.99	Increasing trend very likely
Waiohewa	DRP (t/yr)	0.2	0	0.003	4.998	1.00	Increasing trend virtually certain
Hamurana	Q (m3/s)	2.8	3	0.422	0.312	0.79	Increasing trend about as likely as not
Awahou	Q (m3/s)	1.7	2	0.522	0.644	0.73	Increasing trend about as likely as not
Waiteti	Q (m3/s)	1.3	1	0.605	0.550	0.70	Increasing trend about as likely as not
Ngongotaha	Q (m3/s)	1.8	2	0.770	-0.640	0.64	Trend unlikely
Waiowhiro	Q (m3/s)	0.3	0	0.235	1.085	0.89	Increasing trend possible
Utuhina	Q (m3/s)	1.8	2	0.315	-0.705	0.86	Decreasing trend possible
Puarenga	Q (m3/s)	2.1	2	0.321	1.163	0.84	Increasing trend possible
Waingaehe	Q (m3/s)	0.3	0	0.644	-0.575	0.71	Decreasing trend about as likely as not
Waiohewa	Q (m3/s)	0.4	0	0.280	1.529	0.86	Increasing trend possible

Appendix D – Graphs of NNN:TN and DRP:TP

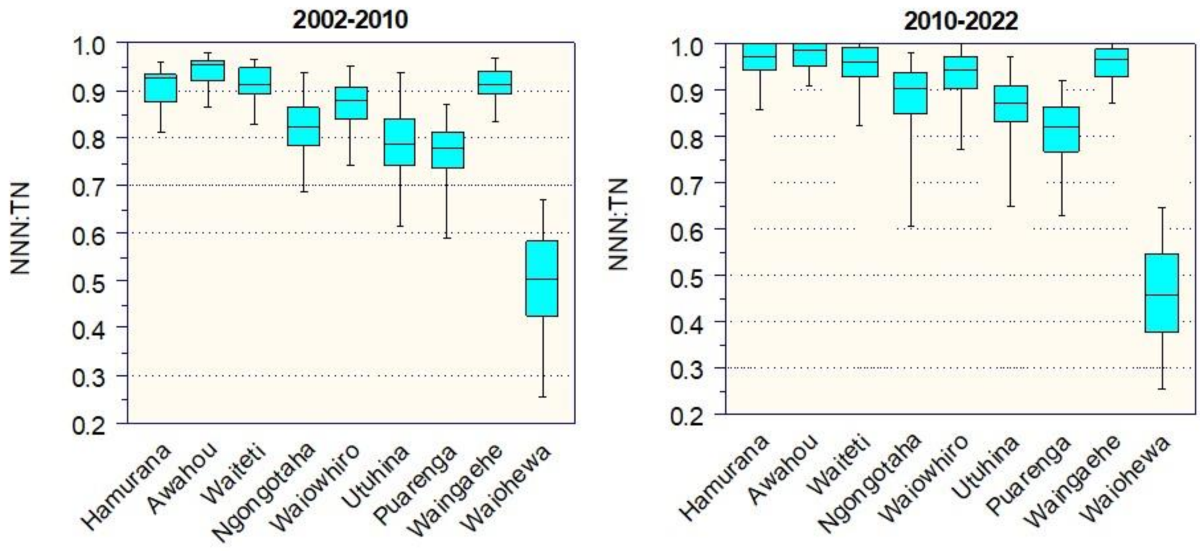


Figure D.1: Ratio of NNN:TN in Lake Rotorua catchment streams before 2010 and after 2010.

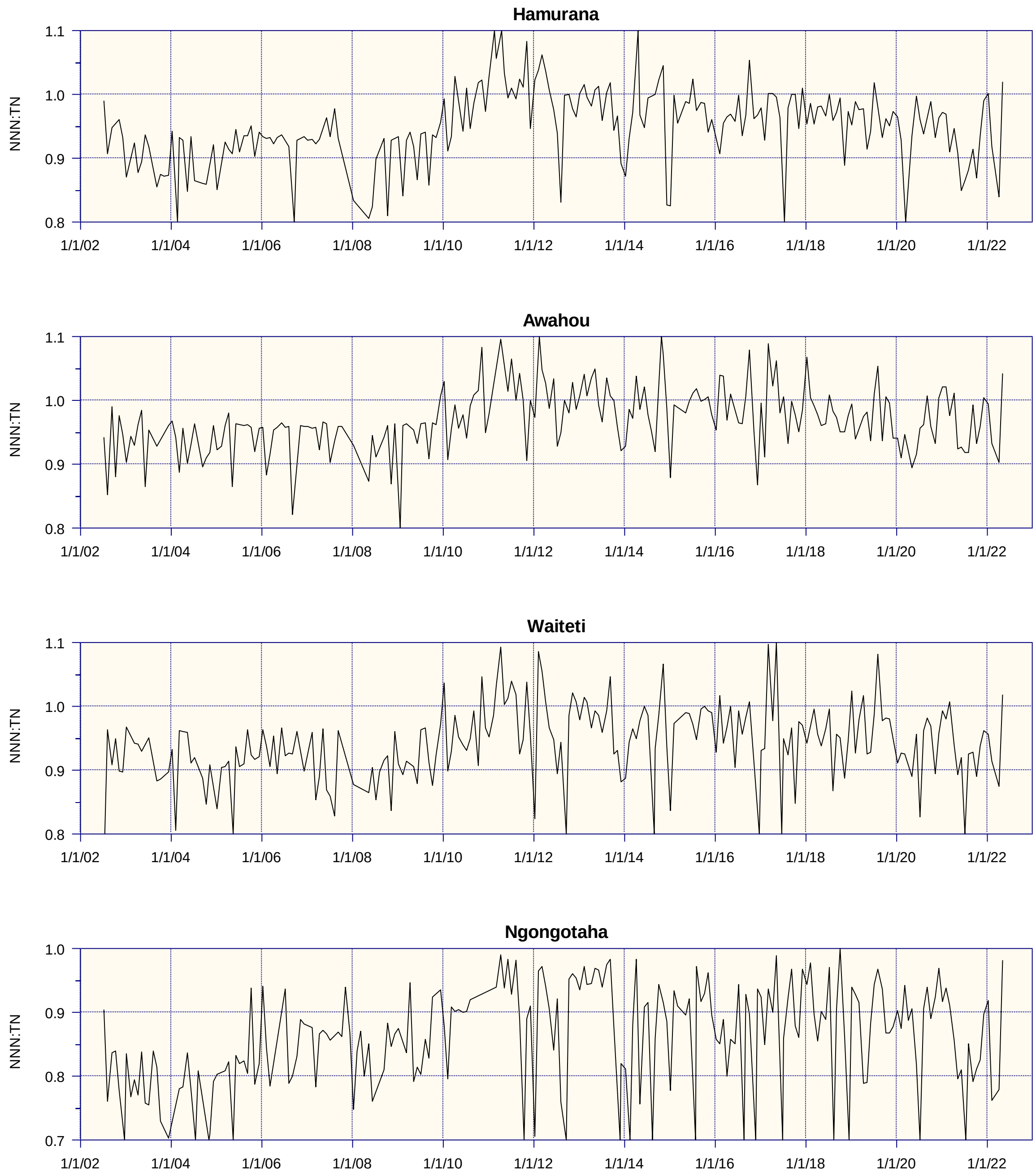


Figure D.2a: Ratio of NNN:TN in Lake Rotorua catchment streams. Many streams had an increase in the NNN:TN ratio in late 2009 due to lower concentrations of TN.

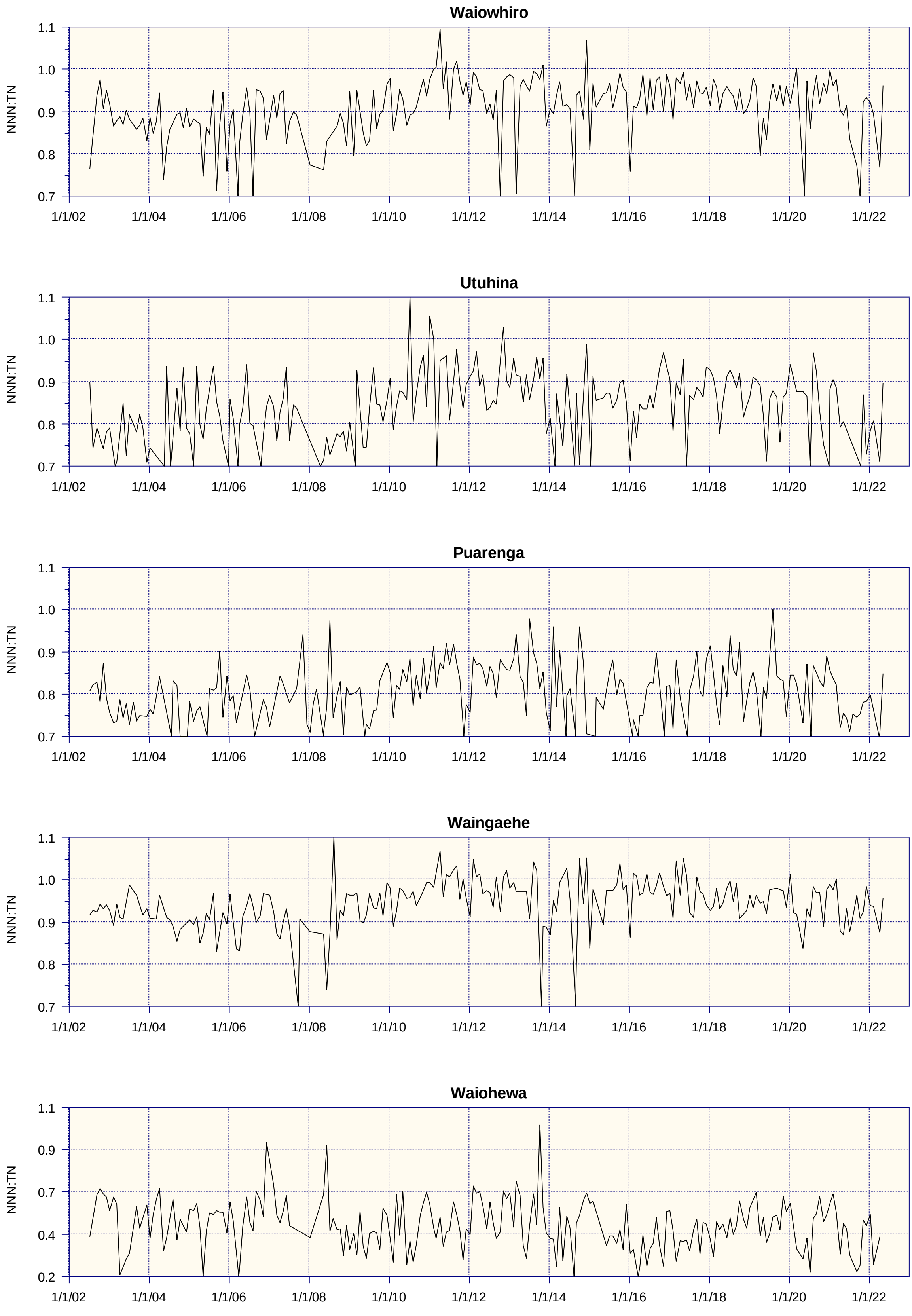


Figure D.2b: Ratio of NNN:TN in Lake Rotorua catchment streams. Many streams had an increase in the NNN:TN ratio in late 2009 due to lower concentrations of TN.

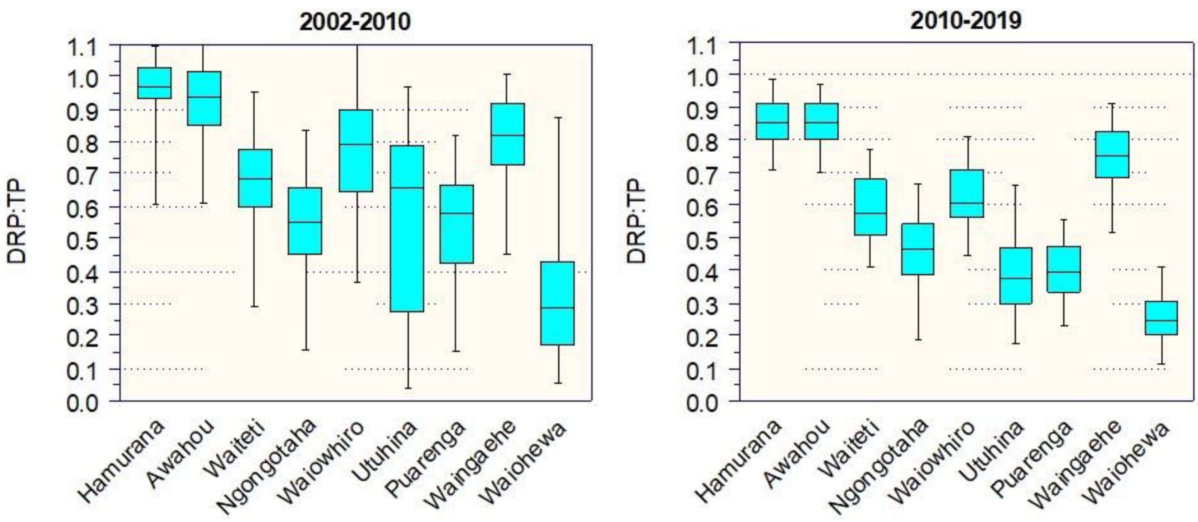


Figure D.3: Ratio of DRP:TP in Lake Rotorua catchment streams for periods before and after the analytical method change.

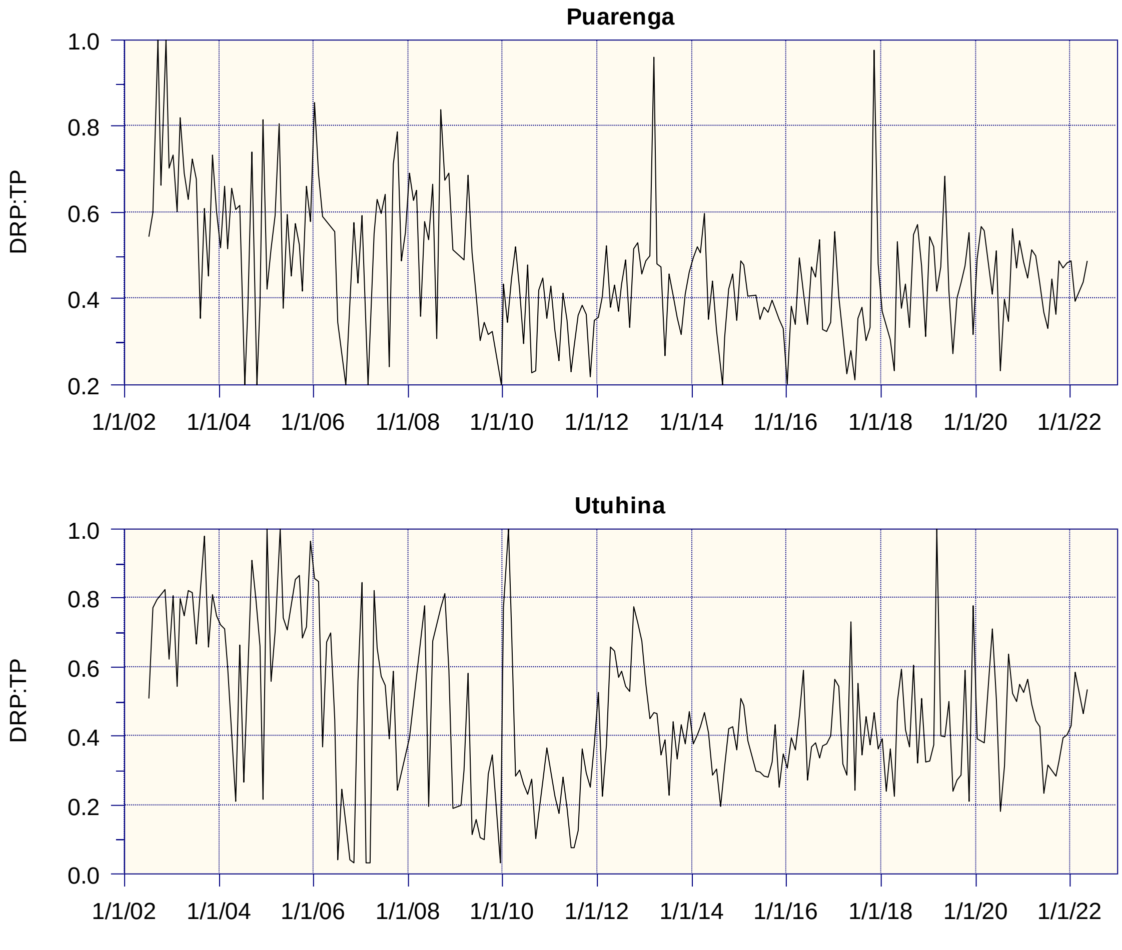


Figure D4: Changes in ratio of DRP:TP in the Puarenga Stream and Utuhina Stream. Puarenga showed a decrease in the DRP:TP ratio in about 2010 due to lower concentrations of DRP. Utuhina showed a decrease in DRP:TP ratio after alum dosing began in 2006.

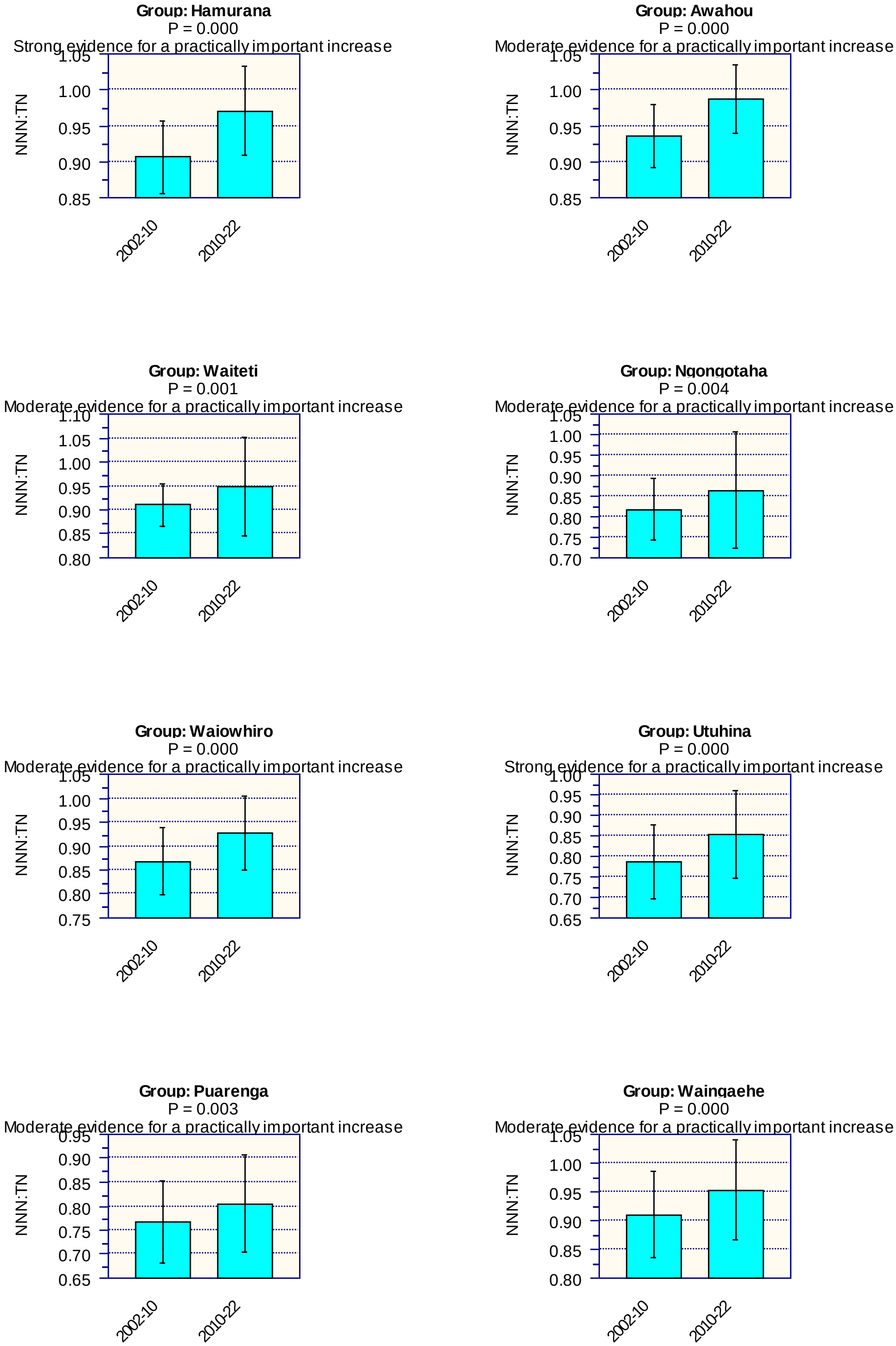


Figure D.5a: Equivalence test results comparing NNN:TN in Lake Rotorua catchment streams before and after 2010.

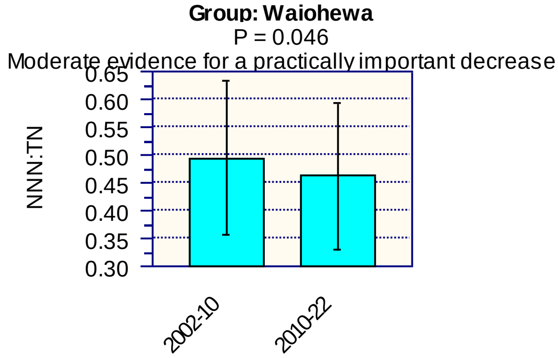


Figure D.5b: Equivalence test results comparing NNN:TN in Lake Rotorua catchment streams before and after 2010. A “practically important difference” was set at a 5% change.

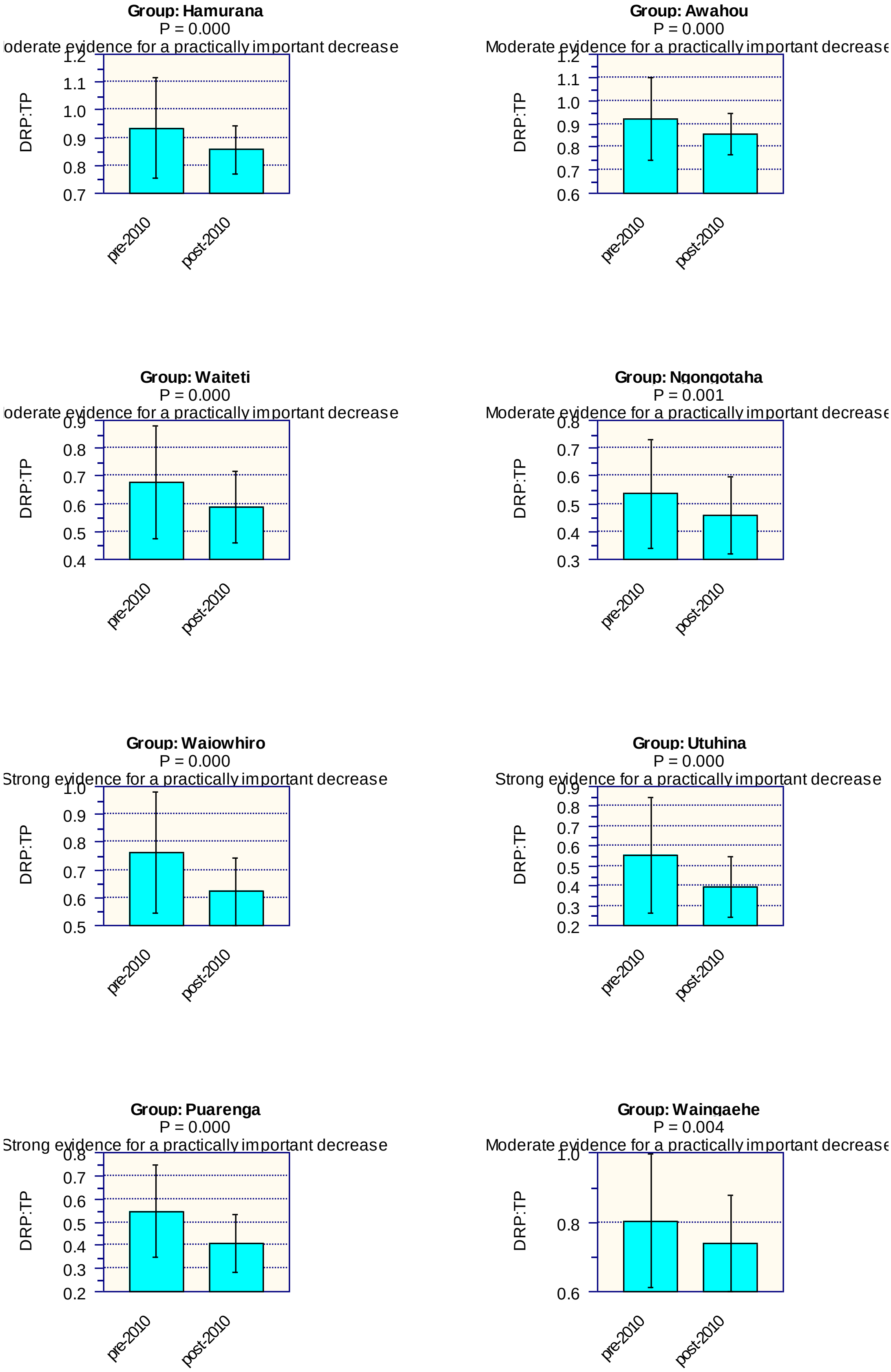


Figure D.6a: Equivalence test results comparing DRP:TP in Lake Rotorua catchment streams for hydrological years 2002-2010 and 2010-2019. A lower DRP:TP ratio due to relatively higher TP.

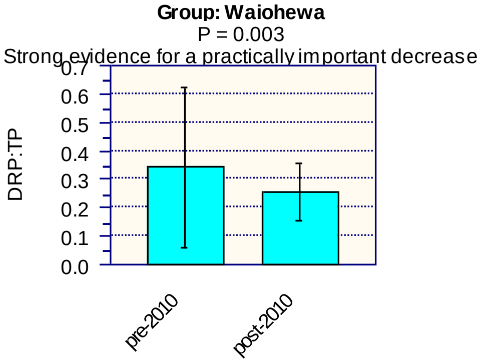


Figure D.6b: Equivalence test results comparing DRP:TP in Lake Rotorua catchment streams for hydrological years 2002-2010 and 2010-20190.

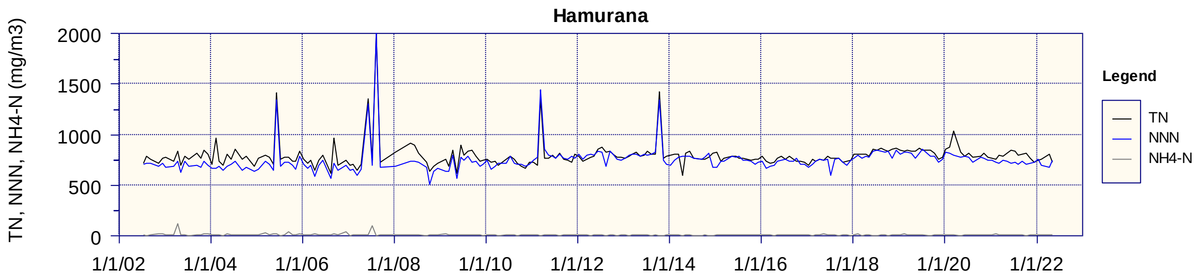
Appendix E: Catchment Specific Information and Graphs

Hamurana

Background

The Hamurana Catchment has a groundwater catchment area of 16.07 km^2. Groundwater from Hamurana spring has a residence time of about 125 years (Morgenstern et al. (2015).

Graphs of monthly data



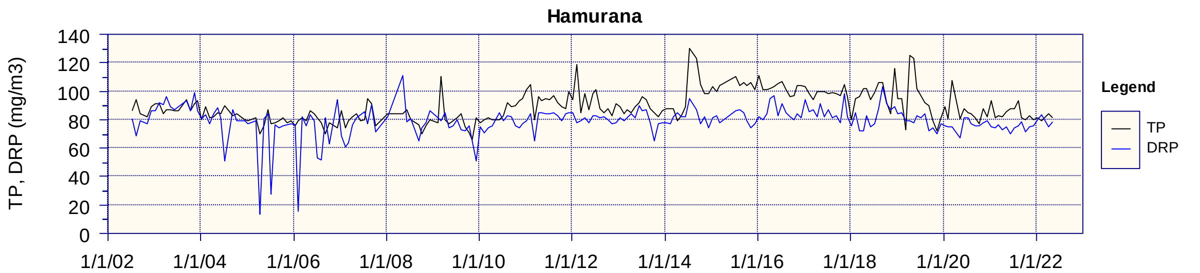
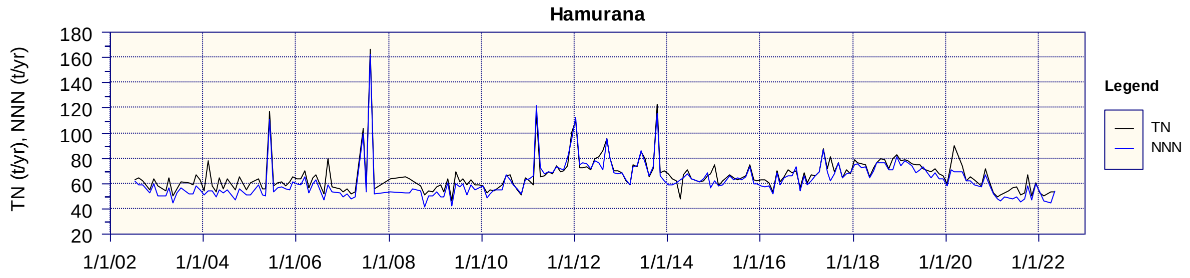


Figure E.1: Monthly nitrogen and phosphorus concentrations in Hamurana Stream.



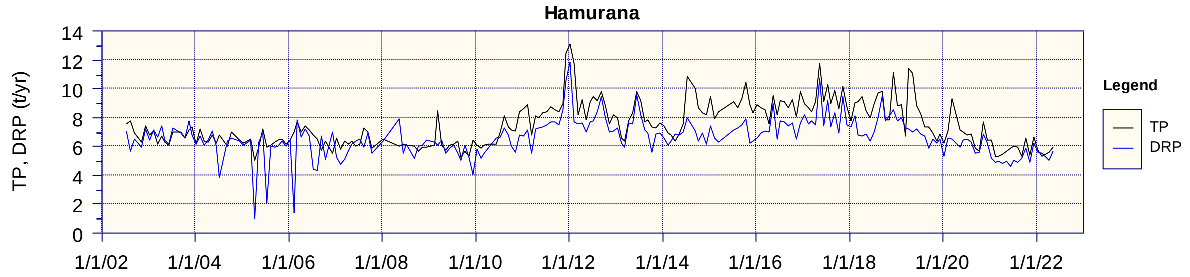


Figure E.2: Monthly nitrogen and phosphorus loads in Hamurana Stream.

Awahou

Background

The Awahou Catchment is located on Lake Rotorua's North West shore and as a groundwater catchment area of 19.92 ha. Groundwater is a significant contributor to the Awahou Stream and estimate the mean residence time to be 75 years (Morgenstern et al. (2015).

Dairy has become more prevalent in this catchment over time, with the greatest increase in this land use occurring in the late 1970's and 1980's (Rutherford, et al. 2011).

Graphs of monthly data

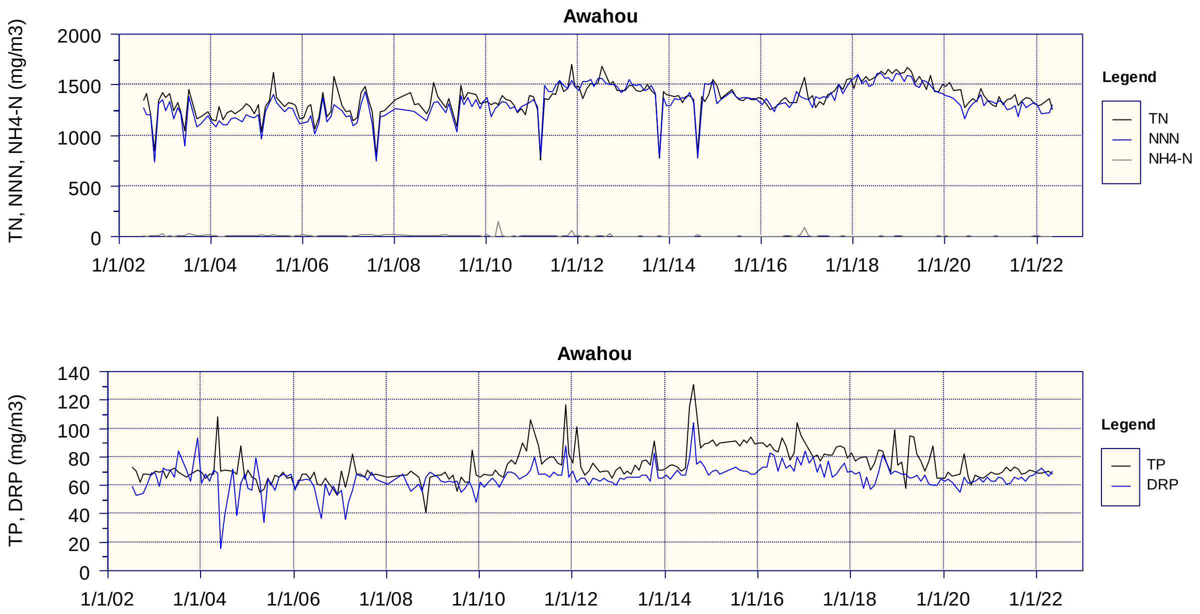


Figure E.3: Monthly nitrogen and phosphorus concentrations in Awahou Stream.

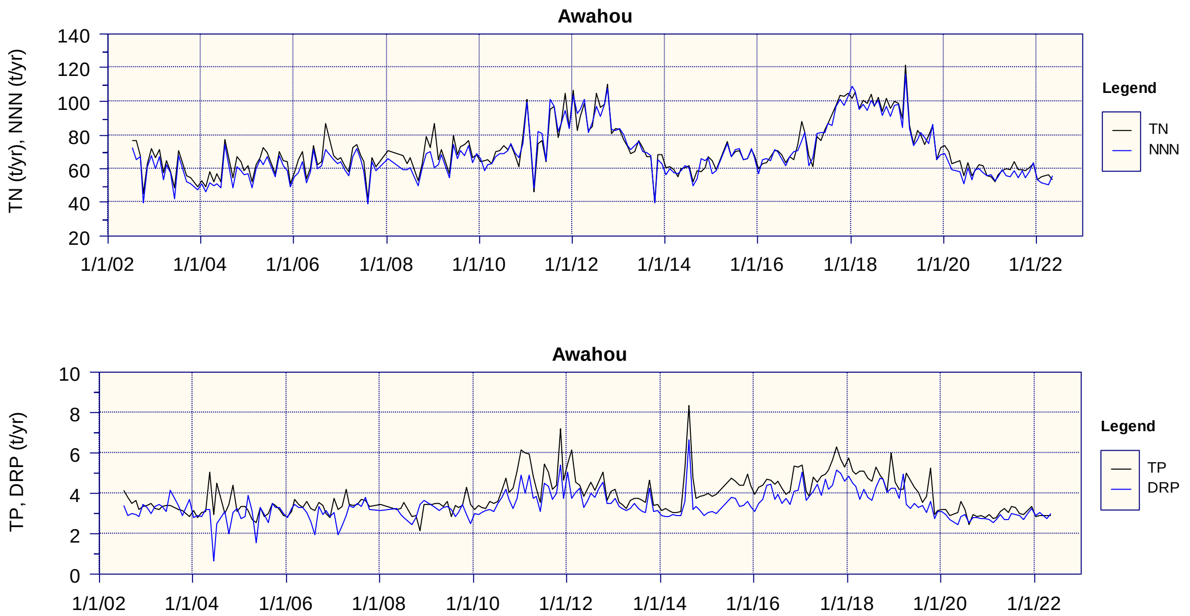


Figure E.4: Monthly nitrogen and phosphorus loads in Awahou Stream.

Waitetī

Background

The Waitetī Stream has a catchment area of 61.88 km^2 located on the west shore of Lake Rotorua. The catchment is dominated by pasture and arable land (60%) and native forest and scrub (23%).

Graphs of monthly data

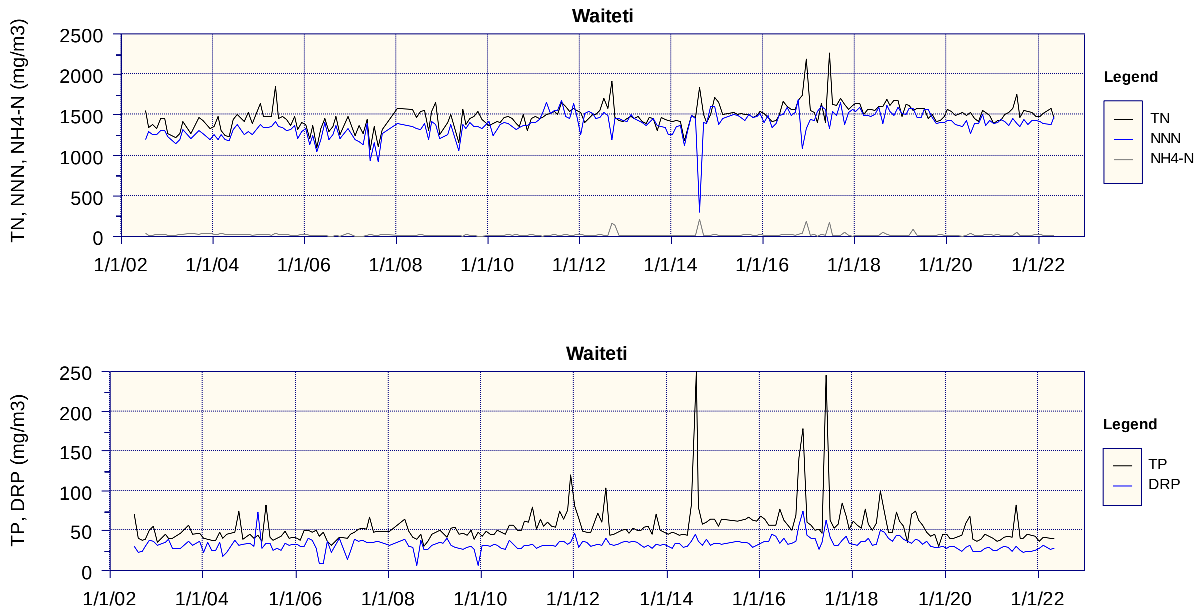


Figure E.5: Monthly nitrogen and phosphorus concentrations in Waitetī Stream.

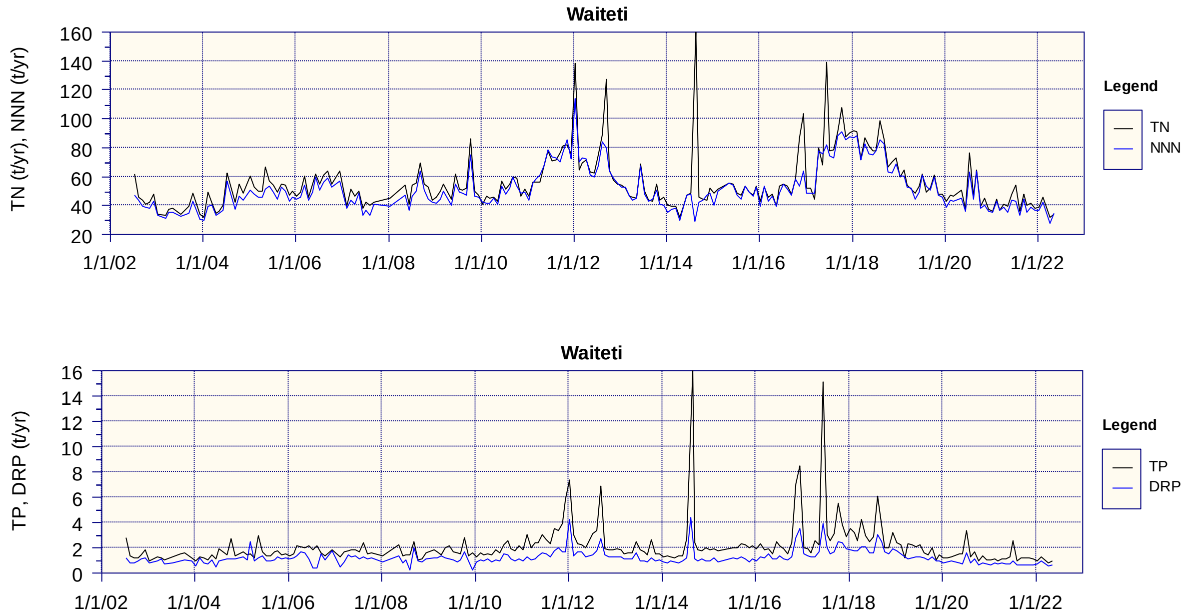


Figure E.6: Monthly nitrogen and phosphorus loads in Waitetī Stream. Y-axis is truncated.

Ngongotaha

Background

Ngongotahā Stream is located on the west side of Lake Rotorua has a catchment area of 77.41 km^2. The catchment is composed primarily of pasture and arable land (43%), native forest or scrub (33%), and exotic forest (13%). Approximately 1% of the catchment is occupied by the urban township of Ngongotahā which has a population of approximately 4,000 people.

Flow in the Ngongotahā Stream is variable compared to other streams draining to Lake Rotorua, suggesting that surface water input is likely to be an important contributor. The mean residence time for groundwater in this catchment is 30 years which is the youngest of all Lake Rotorua's sub-catchments (Morgenstern et al. 2015).

Graphs of monthly data

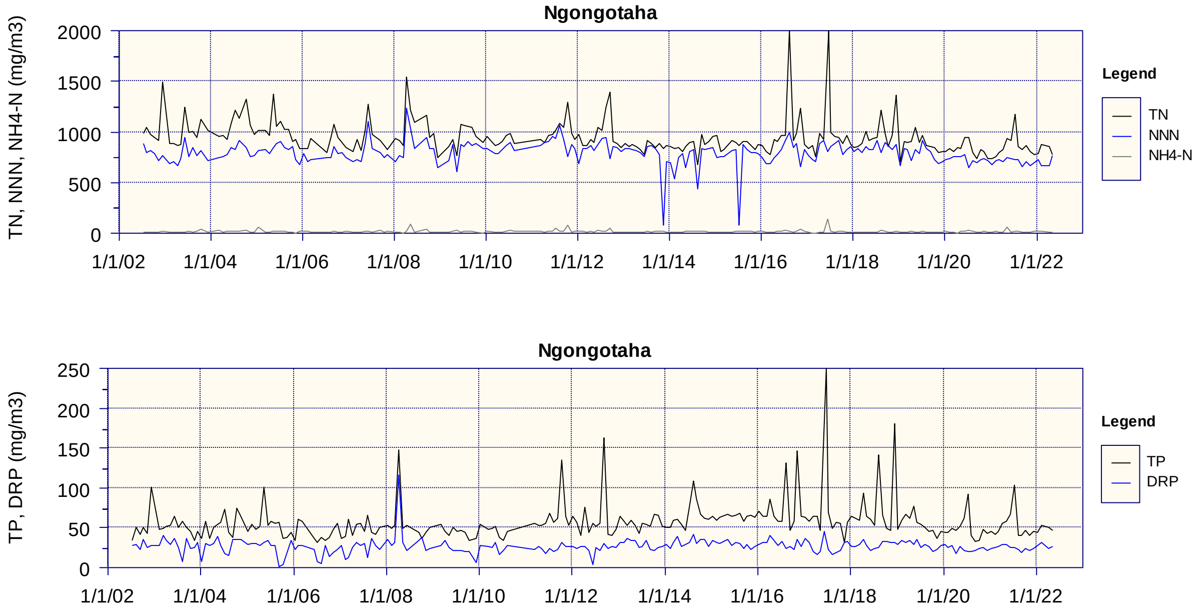


Figure E.7: Monthly nitrogen and phosphorus concentrations in Ngongotaha Stream.

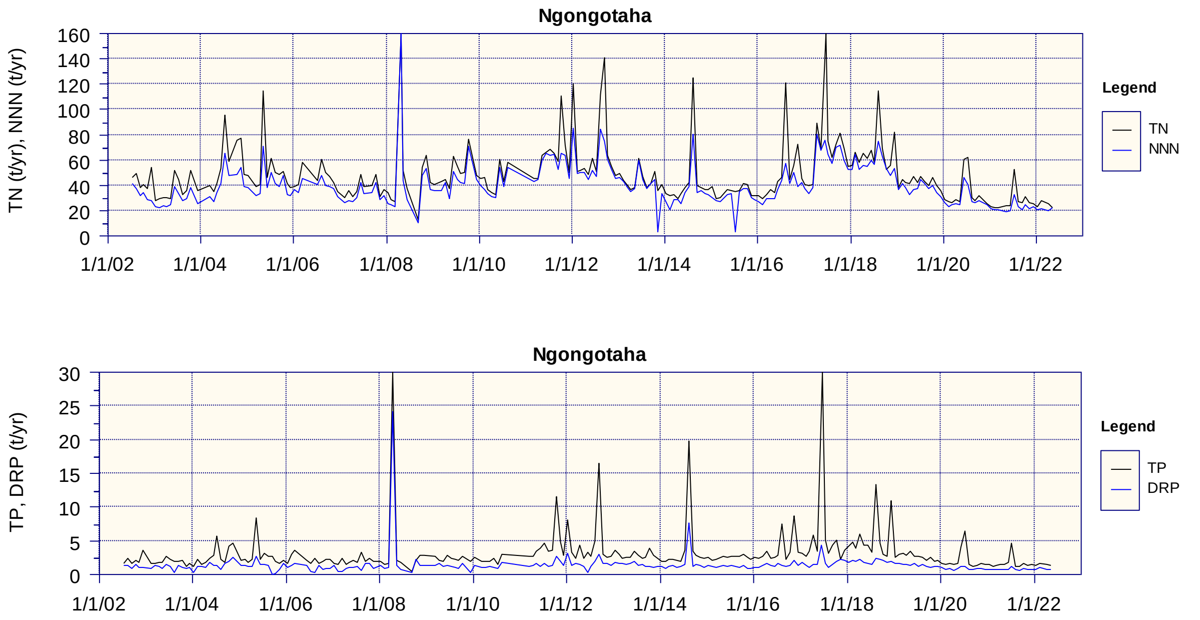


Figure E.8: Monthly nitrogen and phosphorus loads in Ngongotaha Stream. Y-axis is truncated.

Waiowhiro

Background

The Waiowhiro is a small (13.63 km^2) catchment on the western shore of Lake Rotorua. It originates on the north eastern aspect of Mt Ngongotahā and includes Fairy and Paradise springs. The catchment is dominated by urban land use (40%), with native forest and scrub, and pasture and arable land both comprising 20% of the land use.

Graphs of monthly data

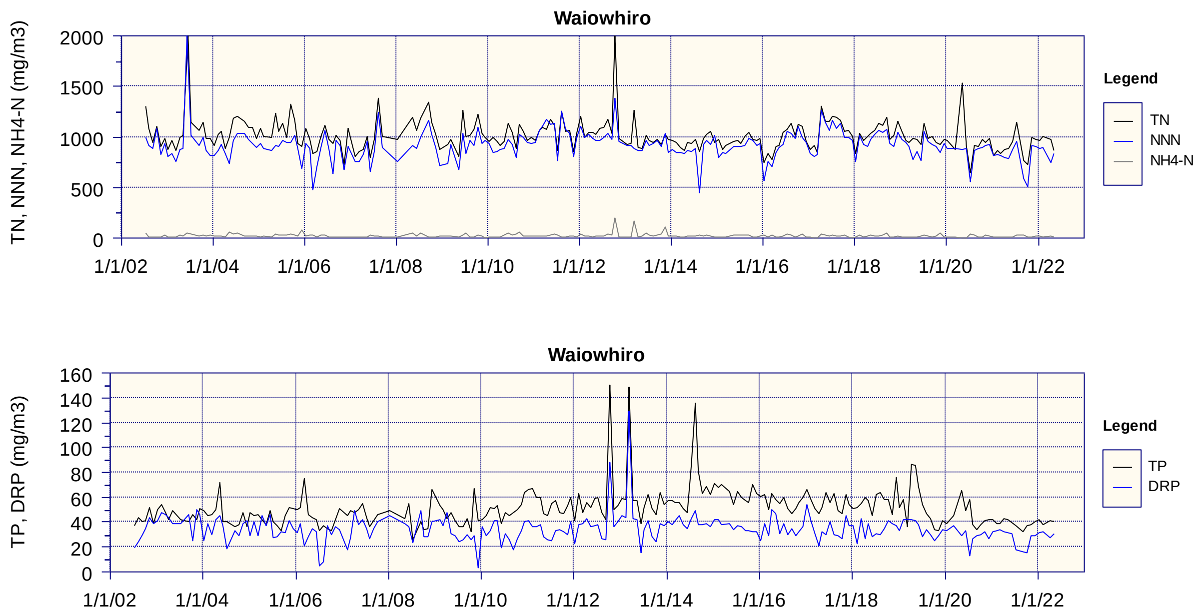


Figure E.9: Monthly nitrogen and phosphorus concentrations in Waiohwiro Stream.

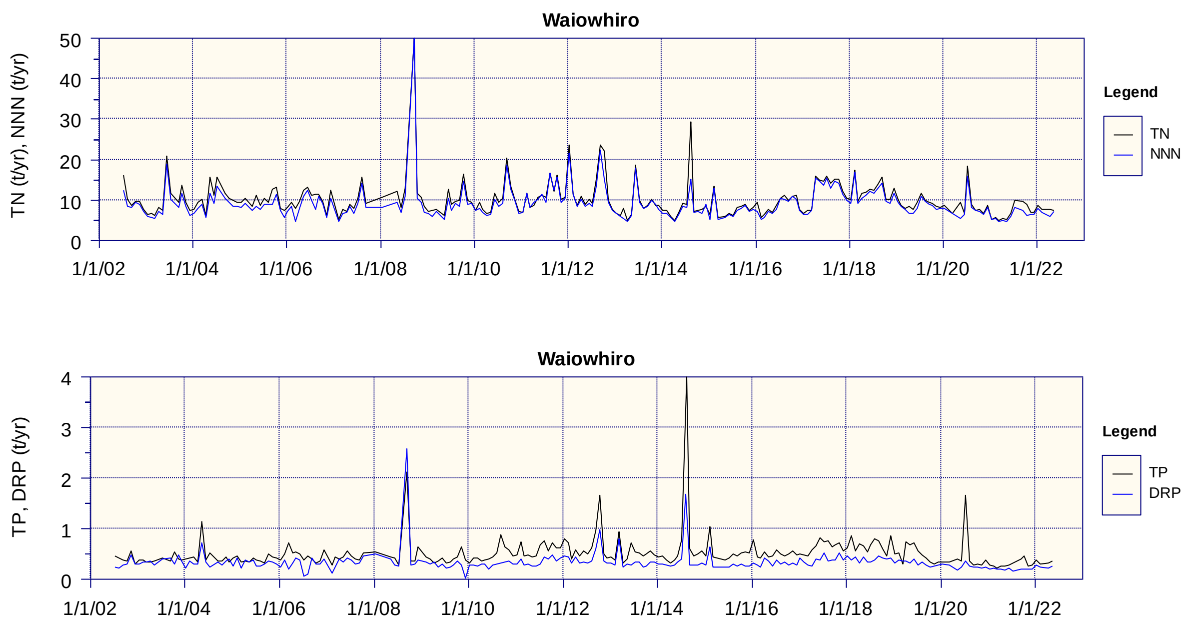


Figure E.10: Monthly nitrogen and phosphorus loads in Waiohwiro Stream. Y-axis is truncated

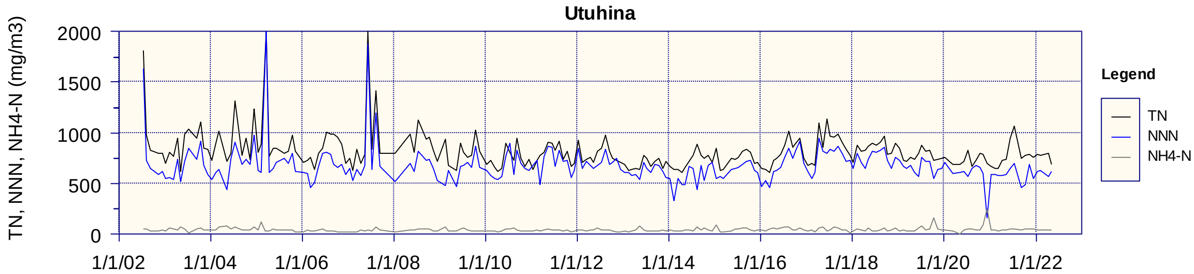
Utuhina

Background

Utuhina Stream enters Lake Rotorua at Te Ruapeka Bay near Ohinemutu. It has a catchment area of 61 km^2, a mean baseflow of about 1.8 m^3/s and supplies a relatively large load of phosphorus to the lake (4.9 t/yr as TP) (Rutherford and Timpany 2008). The main landuses in the catchment are forest and scrub (27%), pasture (22%), urban (22%) and exotic forest (18%). Groundwater inputs to the Utuhina Stream have a mean residence time of 60 years.

Dosing of the Utuhina Stream with alum to bind dissolved phosphorus began in July 2006. The Utuhina Stream monitoring site at Lake Road is downstream of the alum dosing location, so DRP results are affected by the dosing regimen.

Graphs of monthly data



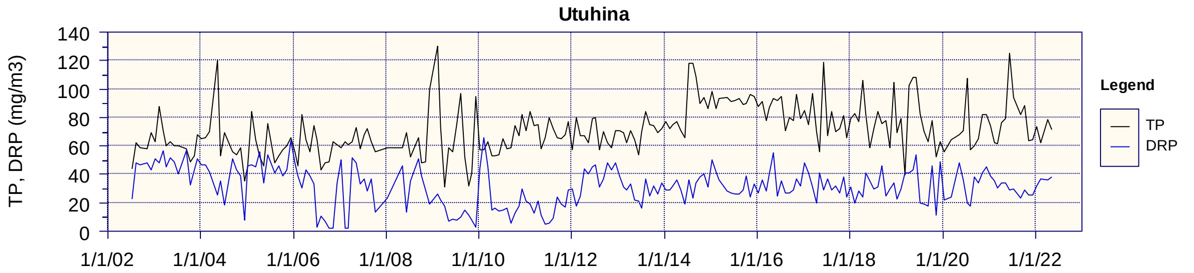
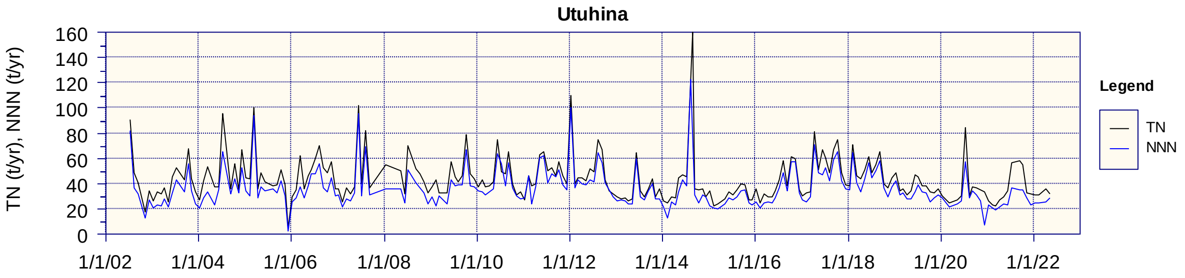


Figure E.11: Monthly nitrogen and phosphorus concentrations in Utuhina Stream.



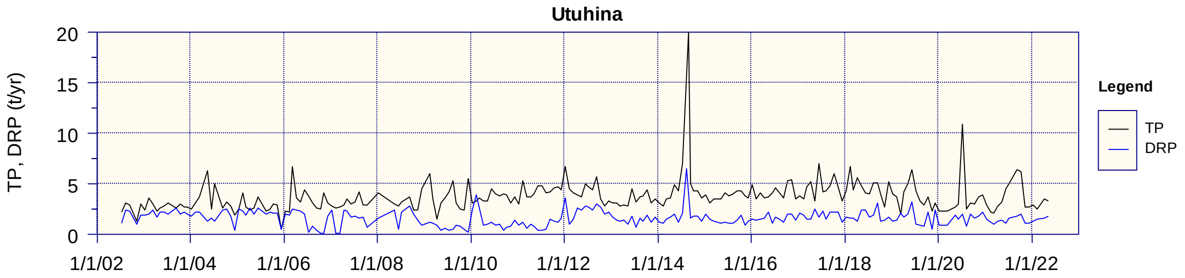


Figure E.12: Monthly nitrogen and phosphorus loads in Utuhina Stream. Y-axis is truncated

Puarenga

Background

Puarenga Stream enters Lake Rotorua at Sulphur Bay. It has a catchment area of 82.3 km^2, a mean baseflow of about 1.711 m^3/s. The Puarenga Stream catchment landuse consists of 46.2% in forestry, 30.3% in pasture and 16.9% in indigenous vegetation. There are a number of landuse and industrial activities in the catchment including the Red Stag Timber Mill, and land discharge of the Rotorua wastewater to the Whakarewarewa Forest.

Two main tributaries enter the Puarenga Stream about 5.4km upstream of the lake, the Waipa Stream and the Kauaka Stream. The Waipa Stream is a spring fed stream with a catchment area of ca. 23 km^2 and a median flow of 620 L/s. It contributes about 38% of the total Puarenga Stream flow (25% via the natural stream catchment and 13% due to the irrigated wastewater). The Kauaka Stream has a catchment area of 12.8 km^2.

Natural geothermal water enters the Puarenga Stream near Whakarewarewa Village about 4.2km from the lake. This causes changes in water quality and ecology it becomes acidic (pH 4), warm (14-22^{o}C), turbid, and with elevated metal concentrations. Downstream of Whakarewarewa the Puarenga Stream is considered a thermal stream (Scholes 2012). Alum dosing of the Puarenga Stream to bind DRP began in 2010, but this occurs downstream of the water quality monitoring site, so does not affect monitoring results.

Groundwater in this catchment has a mean residence time of approximately 40 years (Morgenstern et al. 2015).

Water quality trends in the Puarenga Stream (and its tributary the Waipa Stream) should be understood in the context of long-term trends during the 1990's. The concentration of nitrogen (TN, NNN, NH4-N) in the Waipa Stream substantially increased from about 1993 to 2000 after the commencement of discharges of Rotorua treated wastewater in October 1991. Since about 2000 the nitrogen concentration has substantially reduced (improved) reflecting improvements to the waste water treatment and the management of the land treatment system, in particular improve irrigation scheduling began in January 2002, carbon dosing in 2006 and instillation of the membrane bioreactor in 2012 (Hamill 2020).

There is evidence of the land treatment system having break-through of phosphorus since 2001 (Scholes 2013, Hamill 2013).

Graphs of monthly data

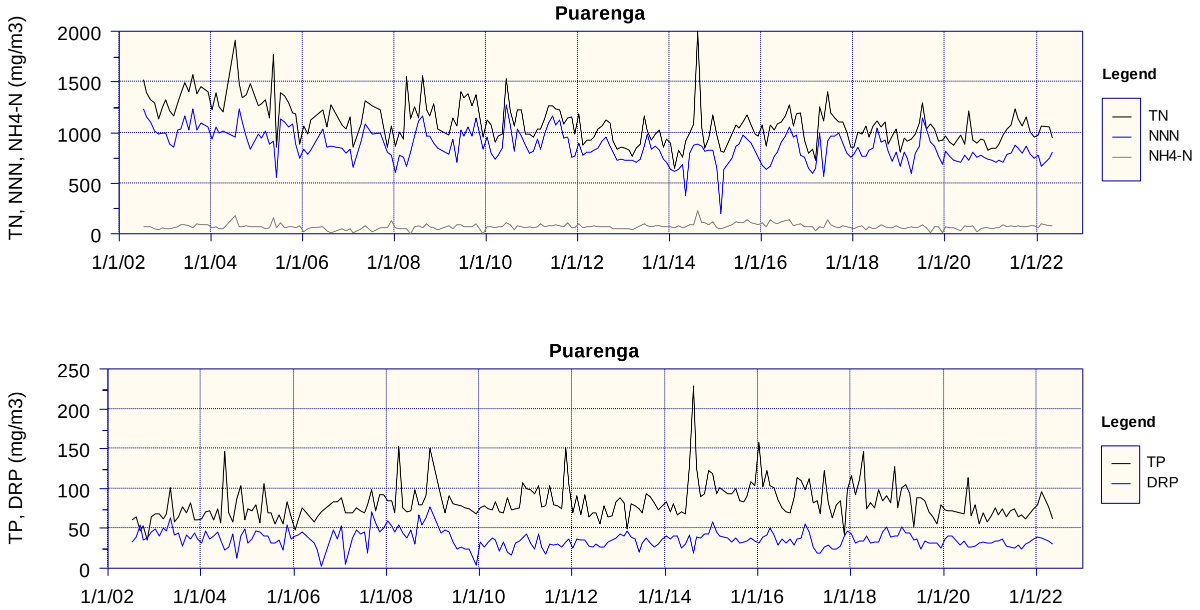


Figure E.13: Monthly nitrogen and phosphorus concentrations in Puarenga Stream.

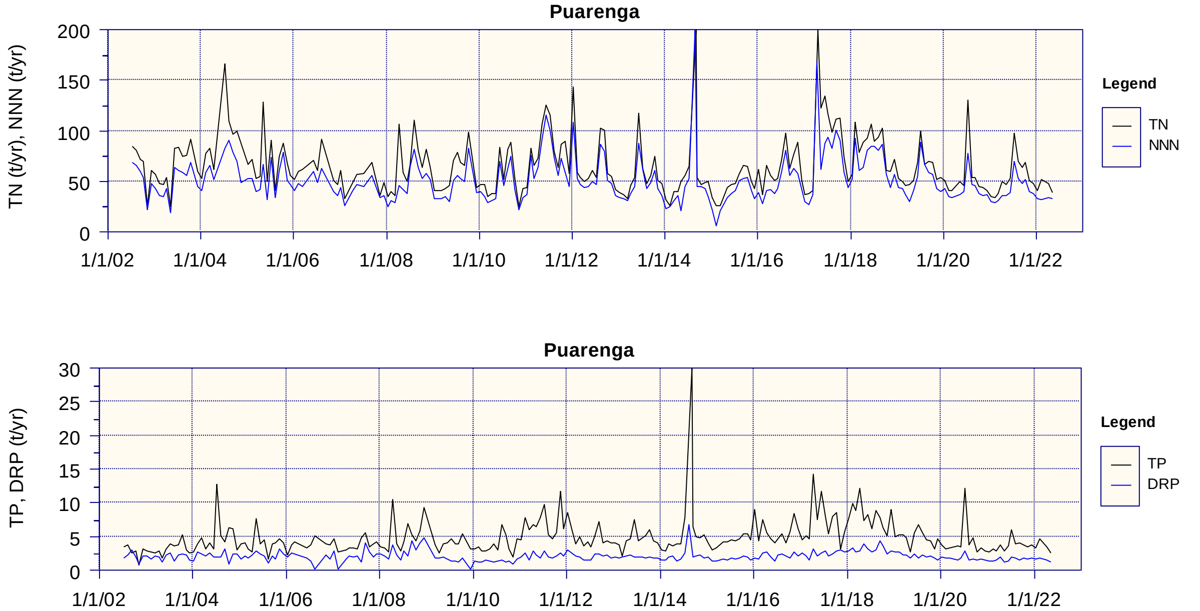


Figure E.14: Monthly nitrogen and phosphorus loads in Puarenga Stream. Y-axis is truncated

Waingaehe

Background

The Waingaehe Catchment is located on the eastern side of Lake Rotorua with a small 11.06 km^2 catchment. The catchment is dominated by pasture and arable land (59%) and exotic forest (28%), with minor contributions from other sources. The groundwater in the catchment is old, with an average mean residence time of 145 years (Morgenstern et al. 2015).

Graphs of monthly data

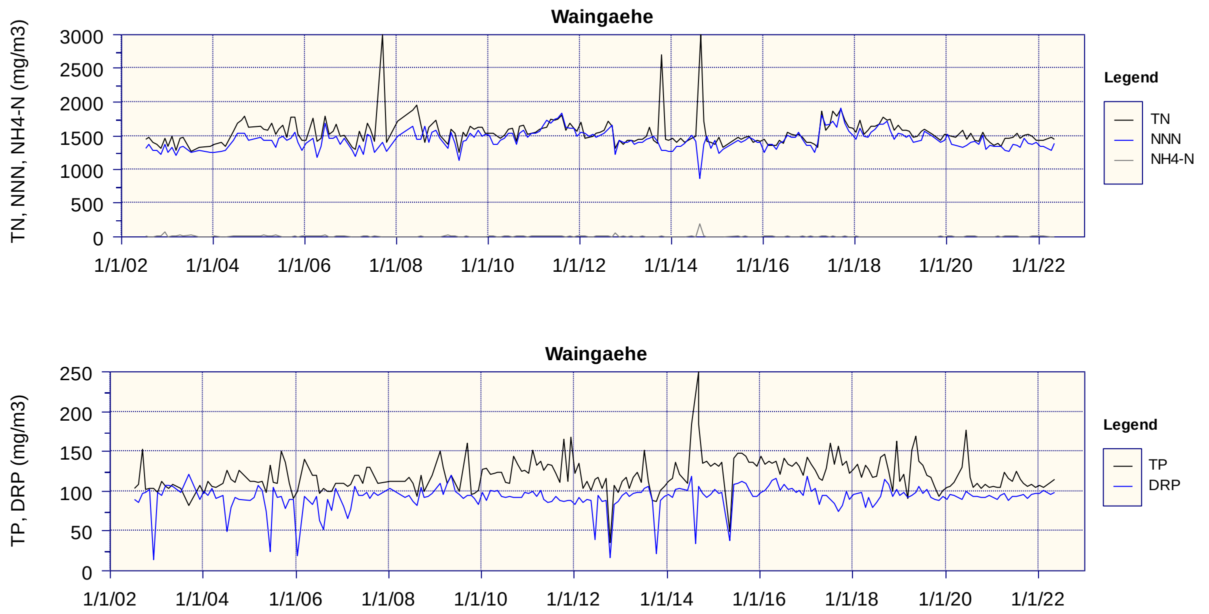


Figure E.15: Monthly nitrogen and phosphorus concentrations in Waingaehe Stream.

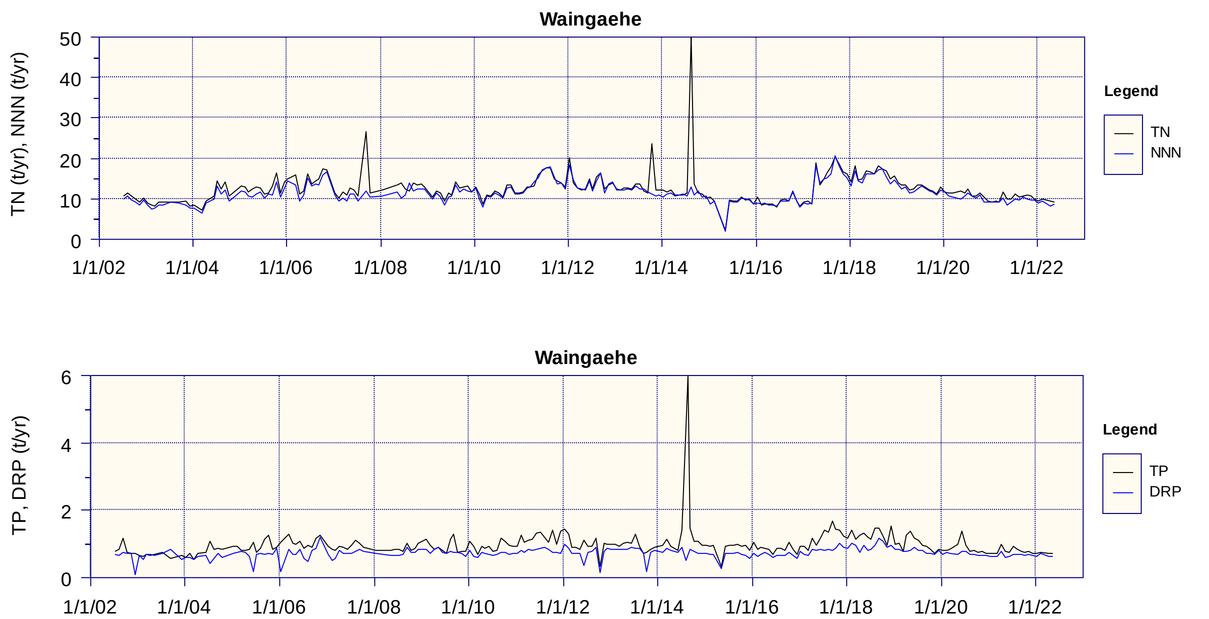


Figure E.16: Monthly nitrogen and phosphorus loads in Waingaehe Stream. Y-axis is truncated

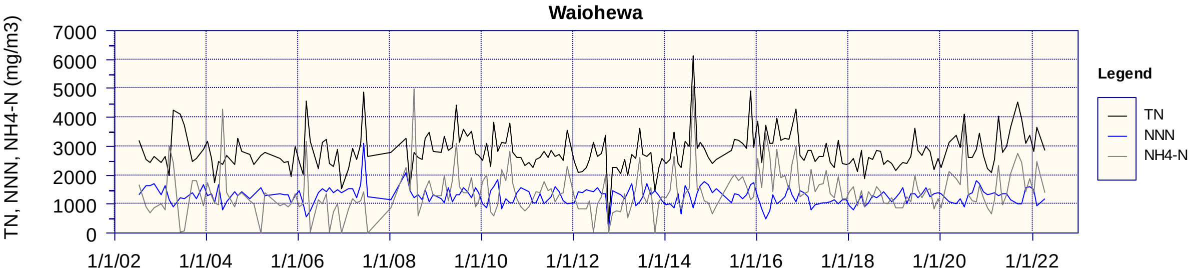
Waiohewa

Background

The Waiohewa Catchment is a small (11.69 km^2) catchment draining from the eastern hills of Lake Rotorua. Land cover within this catchment is comprised primarily of pasture and arable land (30%), lifestyle blocks and mixed land use (19%), native forest and scrub (18%), 'other' land uses (16%), and exotic forest (12%). It receives water from the Tikitere geothermal field near Hell's Gate, which has a strong influence on the water quality, including elevating NH4-N to high concentrations.

Lake Rotokawau discharges to the Waiohewa catchment via groundwater.

Graphs of monthly data



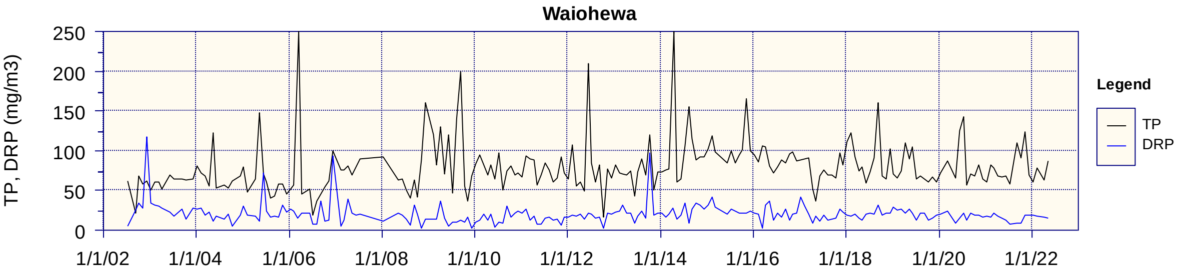
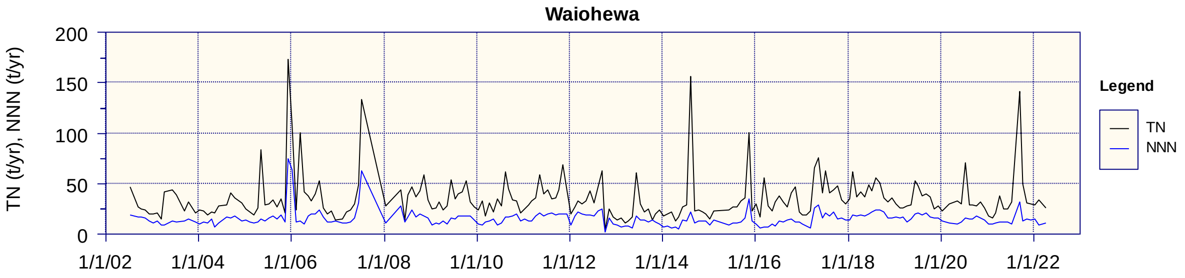


Figure E.17: Monthly nitrogen and phosphorus concentrations in Waiohewa Stream. Y-axis is truncated.



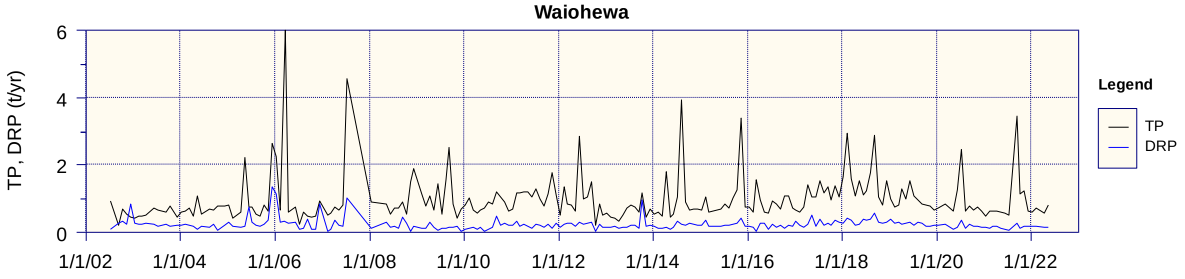


Figure E.18: Monthly nitrogen and phosphorus loads in Waiohewa Stream. Y-axis is truncated.