Storm nutrient loads in Rotorua streams

NIWA Client Report: HAM2008-084
June 2008

NIWA Project: BOP05225

Storm nutrient loads in Rotorua streams

Kit Rutherford
Graham Timpany

Prepared for

Environment Bay of Plenty

NIWA Client Report: HAM2008-084
June 2008

NIWA Project: BOP05225

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

© All rights reserved. This publication may not be reproduced or copied in any form without the permission of the client. Such permission is to be given only in accordance with the terms of the client's contract with NIWA. This copyright extends to all forms of copying and any storage of material in any kind of information retrieval system.

Contents

Reviewed by:

C. C. Palliser

Chris Palliser

Approved for release by:

John Quinn

Formatting checked

A. Bartley

Executive Summary

This report was prepared at the request of the Lake Rotorua Technical Advisory Group and complements an earlier study of stream nutrient concentrations (Rutherford 2003). The principal objectives were to determine the fractions of flow and nutrient load carried into Lake Rotorua by baseflow and floodflow and to compare loads in 1992-2005 with those measured in 1976-1977 by Hoare (1980b). To do this it has been necessary to collate and edit a large quantity of archived water quality and flow data, determine the relationship between stream nutrient concentration and flow rate, use these relationships to estimate nutrient loads, identify and account for any time trends in nutrient concentration and/or flow, and estimate the uncertainty in load predictions.

Flows in 1976-1977, when Hoare measured loads, were ~15% higher than during 1992-2005. In order to make a comparison, 1992-2005 loads were 'adjusted' to 1976-1977 flows using the method described by Williamson et al. (1996).

For many samples particulate and organic nutrient concentrations were not measured but were estimated by difference (for phosphorus PP + DOP ~ TP – DRP and for nitrogen PN + DON ~ TN - TIN). For some samples this gave negative values indicating errors in the measurement of either inorganic or total nutrient, or both. Negative values were omitted from the flow and time regression analysis. Nevertheless the uncertainty in total and particulate nutrient loads is high.

Comparing 1976-1977 loads with flow-adjusted 1992-2005 loads there is evidence that:

1. DRP load has increased by 15% (range 10-20%);

2. PP + DOP load may have decreased by 10% but the uncertainty is high (range 39% decrease to 23% increase);

3. TP load has decreased by 11% (range 4-17%);

4. TIN load has increased by 27% (range 22-31%) from 276-295 t y^{-1} to 350-370 t y^{-1}. When scaled to the same flow the increase is 47% (range 42-47%). This is consistent with a significant increase in baseflow nitrate concentration in eight major streams identified by Rutherford (2003);

5. PN + DON load has decreased by 41% (range 23-55%) from 140 t y^{-1} in 1976-1977 to 64-108 t y^{-1}. When scaled to the same flow the decrease is smaller at 31% (range 11-47%). However, the uncertainty in both load estimates is high; and

6. TN has not changed – 416-435 t y^{-1} in 1976-1977 and 419-456 t y^{-1} in 1992-2005. When scaled to the same flow there is an increase of 19% (range 14-25%).

PP and PN concentrations are strongly correlated with flow. In springfed streams this is of little consequence because storm flows are rare. However, several streams have a significant floodflow component (notably the Ngongotaha, Utuhina and Puarenga) and in these streams floods carry a disproportionately large fraction of the particulate load. Whereas floods carry 36-44% of water in the Ngongotaha, Utuhina and Puarenga, they carry 68-89% of PP and 43-76% of PN. TP and TN concentrations vary with flow but, because they include DRP and TIN, flow variation is less strong than for PP and PN.

There is some evidence that particulate nutrient loads are lower now than in 1976-1977. There are three possible explanations. First, catchment control works may have resulted in lower particulate nutrient loads reaching streams. Second, these findings may be an artefact of the fact that there were fewer large floods in 1992-2005 than in 1976-1977. Third, the regression models developed using 1992-2005 data may be biased because of the small number of floods than in 1976-1977.

Intensive monitoring of two storms of similar magnitude in 2005 by the NIWA Rotorua field team demonstrates that TP and TN load can differ between similar storms by at least 100%. Factors such as rainfall intensity and duration, time since last storm, antecedent soil moisture and pasture condition probably determine this variability. However, there is not enough information available to quantify these factors.

DRP and TIN concentrations are either uncorrelated with flow or vary only slightly. Consequently the loads of these nutrients are proportional to flow and the fractions carried by baseflow and floodflow are almost the same as the proportions of water carried.

1. Introduction

This report complements an earlier study of stream nutrient concentrations (Rutherford 2003) which identified increasing time trends of nitrate concentration in 8 of the 9 major streams flowing into Lake Rotorua. The principal objective of this report is to determine the fractions of flow and nutrient load carried into Lake Rotorua by baseflow and floodflow.

Nutrient concentrations have been measured only intermittently but flow has been measured more regularly. Consequently a ‘rating curve’ approach is adopted which involves relating concentration and flow, predicting concentration for each value of flow, multiplying flow by concentration to give load, and summing to give load. In order to implement the ‘rating curve’ approach it is necessary to:

1. determine the relationship between stream nutrient concentration and flow rate;

2. use these relationships to estimate load;

3. identify and account for any time trends in nutrient concentration and/or flow; and

4. estimate the uncertainty in load predictions.

2. Methods

2.1 Flow time-series

Daily mean flows were extracted from the EBoP and NIWA databases. Continuous records for 1992-2005 were only available at the Ngongotaha Stream and there were gaps in the records at the other 8 stream sites. Linear regression equations were derived between sites and used to fill gaps.

15-minute flows were extracted and used to analyse data from storms sampled by NIWA during 2004-2005.

2.2 Baseflow separation

Baseflow was estimated following Pettyjohn & Henning (1979). The minimum daily flow in a 10-day moving average window was calculated, and provided flow did not exceed this minimum by more than 10% baseflow was assumed for that day. Figure 1 illustrates the separation for a 6 month period in the Ngongotaha. On days where stormflow occurred the entire flow was defined as stormflow and baseflow was zero.

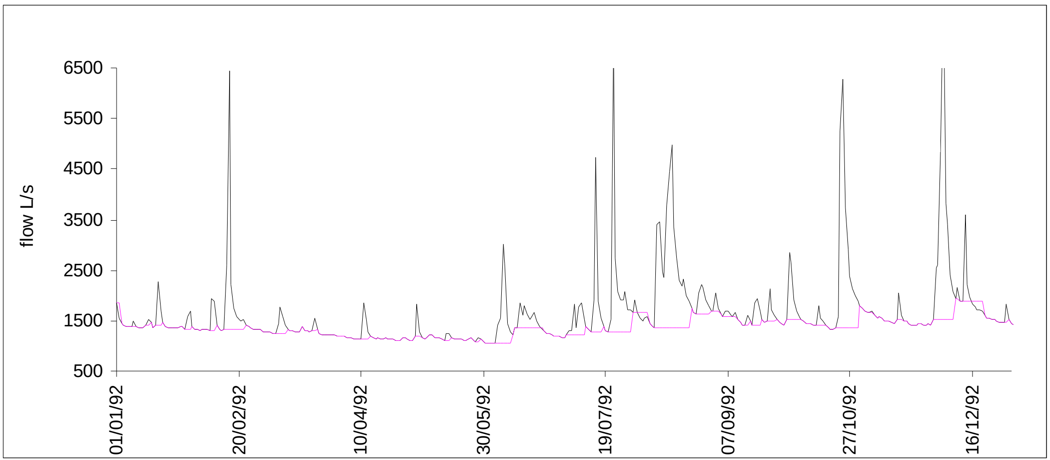


Figure 1: Daily mean stream flow (black) and the 10-day minimum (purple). Flow which exceeds the 10-day minimum by more than 10% is deemed to be stormflow.

2.3 Nutrient concentrations

Nutrient concentration data for the period 1992-2005 are collated from:

1. routine monitoring conducted by EBoP 1992-1995 – 9 major sites;
2. routine monitoring conducted by EBoP 2004-2005 – 9 major sites;
3. occasional sampling by EBoP 1996-2004 – 3 major sites;
4. storm sampling by NIWA 2004-2005 – 4 major sites.

Storm composite samples were collected by EBoP in 1992-1995. Many of these composites had significantly higher concentrations than grab samples collected during the same storms, and appeared as extreme outliers on flow versus concentration plots. They are omitted from this analysis.

Laboratory results include some or all of DRP, TP, NO_3N, NNN (NO_3N + NO_2N), NH_4N, TKN and TN. The EBoP monitoring does not include measurements of dissolved organic nutrient (DOP, DON) or particulate nutrient (PP, PN) concentration. We estimated PP + DOP = TP – DRP and PN + DON = TN – TIN for these datasets. For convenience we denote the sum of particulate and dissolved organic phosphorus and nitrogen as PP and PN respectively – strictly we should use PP + DOP and PN + DON. The NIWA storm samples include measurements of PP, DOP, PN and DON.

2.4 Concentration models

In each stream two regression models were fitted relating concentration and flow, and the 'better' model used in subsequent analysis. The linear model has the form

$$C_i = \alpha_0 + \alpha_1 Q_i + \alpha_2 T_i + \varepsilon_0 \qquad 1$$

where i = day number; C_i = concentration on day i (mg m^{-3}); Q_i = daily mean flow on day i (L s^{-1}); T_i = number of days since 1st January 1992; ε_0 = error term; and α_o, α_1, α_2 = regression Coeff. The log-linear model has the form

$$\ln C_i = \alpha_0 + \alpha_1 \ln Q_i + \alpha_2 T_i + \varepsilon_0 \qquad 2$$

The re-transformed concentration is

$$C_i = \beta \exp(\alpha_0 + \alpha_1 \ln Q_i + \alpha_2 T_i + \varepsilon_0) \qquad 3$$

where β = the bias correction coefficient estimated following Duan (1983) as

$$\beta = \frac{\sum_{i=1}^{N} \exp(e_i)}{N} \qquad 4$$

where e_i = residuals of the log-transformed model, and N = number of data pairs in the regression. The confidence interval on the predicted mean concentration on day i is

$$C_i = \hat{C}_i \pm tS\sqrt{\frac{1}{N} + \frac{(Q_i - \overline{Q})^2}{\sum_{j=1}^{N}(Q_j - \overline{Q})^2}} \qquad 5$$

For the log-linear model C_i = natural logarithm of the concentration on day i; $\hat{C}_i$ = predicted value of log concentration (Eq. 2); t = Student's t value; S = standard error of the regression; N = number of data pairs in the regression; Q_i = natural logarithm of flow on day i; $\overline{Q}$ = average flow in the regression. The mean, upper 95%ile and lower 95%ile of log(concentration) are re-transformed using Eq. 3.

Models were fitted using the REGRESSION add-in in EXCEL.

In the figures discussed below, observed C is plotted versus Q and T separately to give a visual impression of the univariate correlation. To show the marginal effect of Q in the multiple regression, predicted C is plotted setting T to its mean value. To show the marginal effect of T, predicted C is plotted setting Q to its mean value.

2.5 Nutrient load

Daily nutrient load is

$$L_i = KC_iQ_i \qquad 6$$

where L_i = nutrient load on day i (t y^{-1}); Q_i = daily mean flow (L s^{-1}); and K = unit conversion factor.

Mean daily loads are summed to give the mean load over the period 1992-2005. The upper 95%ile daily loads are summed to give the upper 95%ile for the period 1992-2005, and similarly for the lower 95%ile load. This assumes that uncertainties in load are independent (viz., there is no serial correlation).

One objective of this study is to estimate the average and 95%ile daily nutrient loads that are representative of current conditions. The most recent sampling period is 2004-2005 but flows during this period were below average. Consequently, using only data from this period would under-estimate current loads.

Following Williamson et al. (1996) we estimated average current loads by using flows for the 14 years period 1992-2005. As described above, multiple regression models were derived for concentration with flow and time using monitoring data collected over the period 1992-2005. When estimating current loads, the date was fixed at 1st January 2004 in the regression term involving time. However, the entire 14-year flow record was used. This approach assumes that after removing any time trends the concentration versus flow relationships derived using data from 1992-2005 apply during current conditions. It also assumes that after removing any flow dependence our model fitting successfully identifies any time trends during the period 1992-2005 and hence enables us to ‘correct’ the concentration versus flow relationships to current conditions. Both seem reasonable assumptions (Williamson et al. 1996).

2.6 Storm sampling

NIWA was commissioned by EBoP to measure storm loads in 4 of the major streams (Ngongotaha, Puarenga, Utuhina and Waingaehe) during 2004-2005. A total of ~50 samples were collected in each stream during this time but only 2 significant storms occurred. Eq. 1-5 were used to analyse results using 15-minute flows rather than daily flows. Model coefficients were estimated using the SOLVER add-in in EXCEL. This gives identical results to REGRESSION but has added flexibility. 95% confidence intervals on the estimates storm loads were calculated using a Monte-Carlo approach. For the log model, the mean concentration (and hence load) were estimated at each 15-minute interval using Eq. 3. An error term was then added which was the product of a normally distributed, serially uncorrelated, random number (range -1 to +1) multiplied by the 95% confidence interval on the mean load estimated from Eq. 5. Ten realisations were made and the average and 95% confidence interval on the storm load calculated.

3. Results

3.1 Stream flow

Current flows are significantly lower than those in 1976 when Hoare (1980a, 1980b) measured nutrient loads. Total flow at the major sites during 1992-2005 is 85% of the total from the same sites in 1976 (Table 1).

Cumulative flow frequency curves (Figure 2) show similar characteristics to 1976 (Hoare 1980a). Curves for the spring-fed Hamurana, Awahou and Waingaehe streams rise steeply and floods contribute <10% of total flow. The Ngongotaha Stream has high flow variability and 44% of total flow is delivered by storms.

Table 1: Mean flows for 1992-2005 and 1976 at the major flow sites.

SITE	TOTAL $L\ s^{-1}$	BASEFLOW $L\ s^{-1}$	FLOODFLOW $L\ s^{-1}$	BASE%	FLOOD%	1976 [1]
HAM	2495	2468	26	99%	1%	3080
AWA	1594	1468	127	92%	8%	1664
WNG	227	209	19	92%	8%	274
WWH	358	255	103	71%	29%	415
WTT	1156	788	368	68%	32%	1391
UTU	1845	1162	683	63%	37%	2040
PUA	1711	1099	612	64%	36%	2050
WHE	319	207	112	65%	35%	413
NGO	1734	963	771	56%	44%	1977
TOTAL	11439	8619	2821			13304

[1] Hoare (1980a)
HAM = Hamurana, AWA = Awahou, WNG = Waingaehe, WWH = Waiowhiro, UTU = Utuhina
PUA = Puarenga, WHE = Waiohewa, NGO = Ngongotaha, WTT = Waiteti

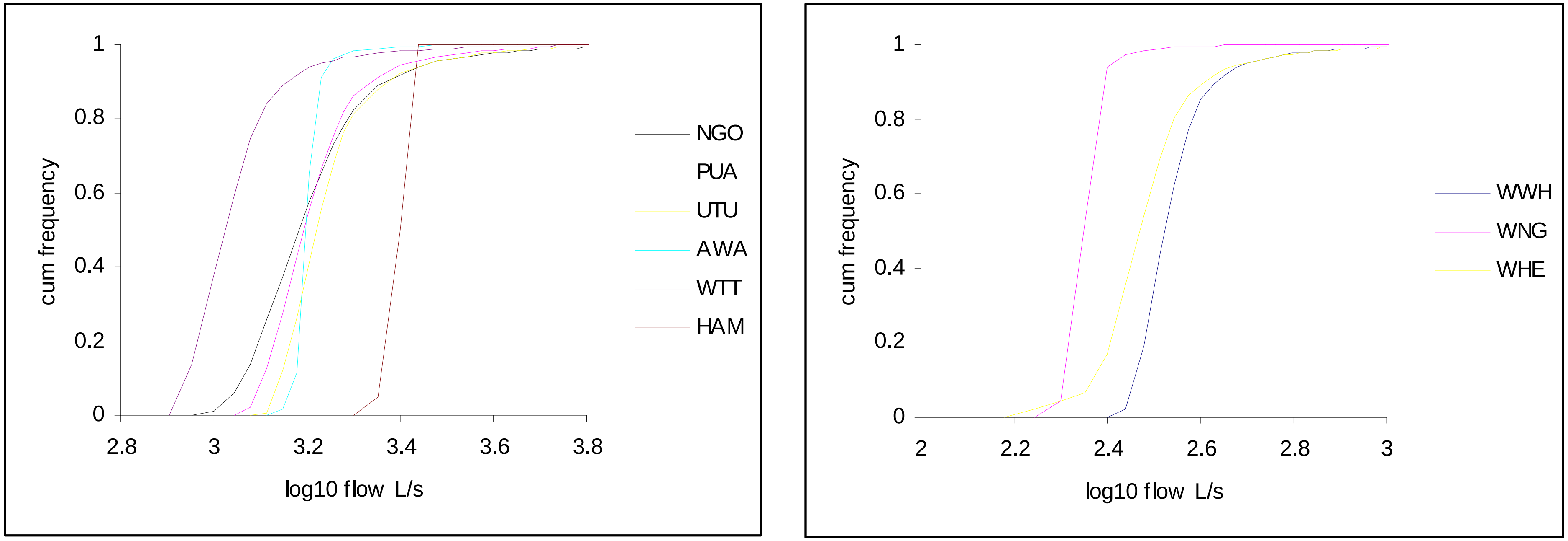


Figure 2: Cumulative flow distributions for the 9 major streams flowing into Lake Rotorua covering the period 1992-2005.

3.2 Awahou Stream

The Awahou is fed by several large springs just upstream from the sampling point and the majority of flow (92%) occurs as baseflow (Table 2).

TIN concentrations show no significant variation with flow rate ($p = 0.95$, Table 12) but there is evidence that DRP concentrations decrease with flow ($p = 0.13$, Table 11) although the trend is weak. Because the concentrations of these soluble nutrients do not vary significantly with flow, the proportions of water (92%) and DRP and TIN load (92-93%) delivered to the lake by baseflow are almost identical. There is evidence that DRP concentration is decreasing with time ($p = 0.05$). There is strong evidence that TIN is increasing with time ($p < 0.001$).

In the Awahou, TP is largely comprised of DRP with very low DOP and PP concentrations. In several samples DRP > TP which would give negative PP and where this occurs we omit the data. In contrast TIN < TN consistently, which implies detectable particulate and/or dissolved organic N concentrations and always results in non-negative PN. The Awahou rarely floods and only a small number of samples are at high flows. PP, TP, PN and TN concentrations are higher during floodflows than baseflows but because floodflows occur only rarely the majority (62-91%) of PP, TP, PN and TN load is delivered to the lake during baseflow.

Table 2: Summary of flow and nutrient mass flow in the Awahou Stream.

			total	baseflow	floodflow	baseflow	floodflow
AWA	Flow L s^{-1}	mean	1594	1468	127	92%	8%
AWA	DRP t y^{-1}	mean	3.69	3.41	0.27	93%	7%
AWA		UCL	3.80	3.50	0.30	92%	8%
AWA		LCL	3.57	3.32	0.25	93%	7%
AWA	PP t y^{-1}	mean	1.05	0.82	0.23	78%	22%
AWA		UCL	1.78	1.11	0.66	63%	37%
AWA		LCL	0.70	0.60	0.10	86%	14%
AWA	TP t y^{-1}	mean	3.62	3.24	0.38	90%	10%
AWA		UCL	3.75	3.34	0.41	89%	11%
AWA		LCL	3.50	3.15	0.34	90%	10%
AWA	TIN t y^{-1}	mean	60.9	56.1	4.8	92%	8%
AWA		UCL	61.9	56.9	5.1	92%	8%
AWA		LCL	59.9	55.3	4.6	92%	8%
AWA	PN t y^{-1}	mean	4.45	3.73	0.72	84%	16%
AWA		UCL	7.88	4.91	2.97	62%	38%
AWA		LCL	3.14	2.84	0.30	91%	9%
AWA	TN t y^{-1}	mean	65.8	59.8	5.95	91%	9%
AWA		UCL	67.3	61.0	6.28	91%	9%
AWA		LCL	64.4	58.7	5.64	91%	9%

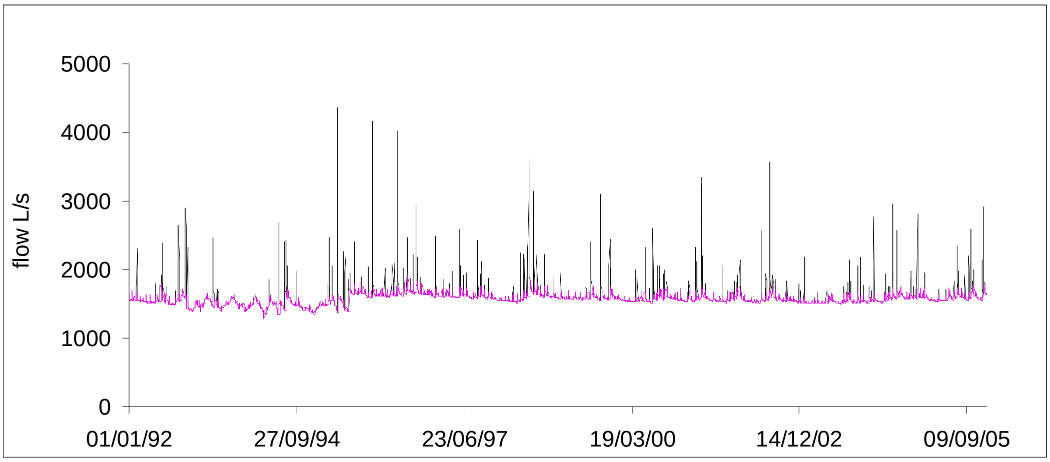
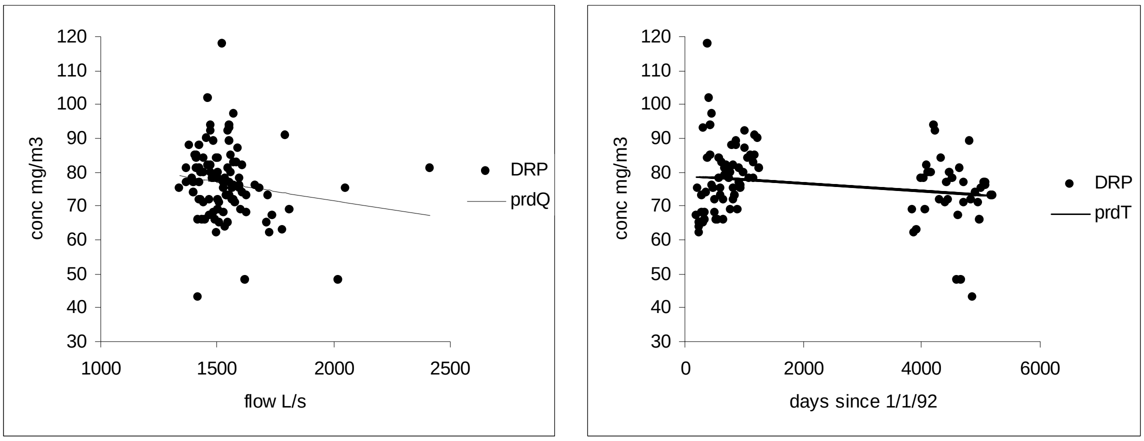
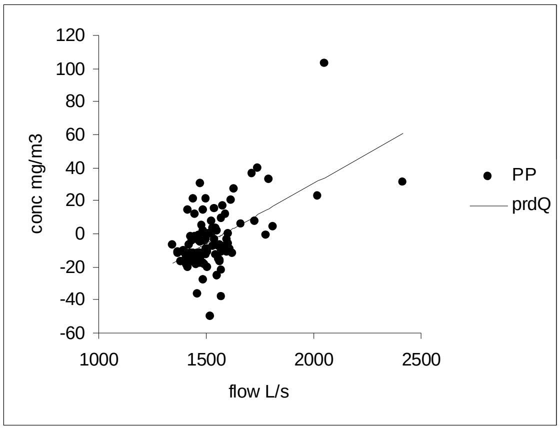
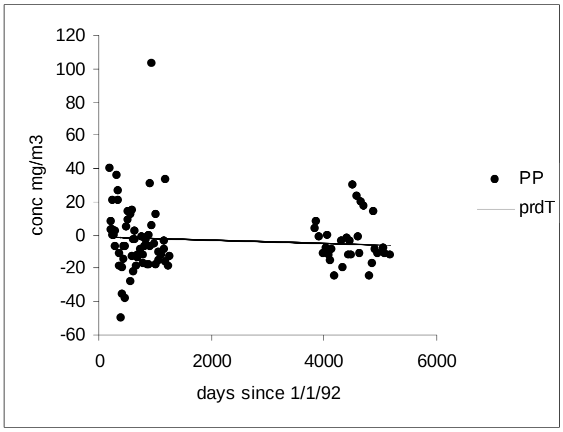


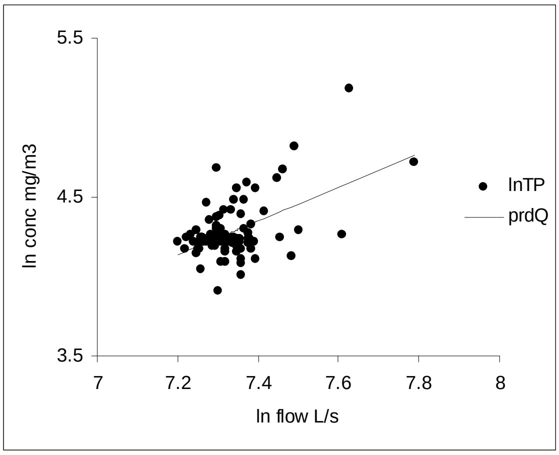
Figure 3: Daily mean flow (black) and baseflow (purple) in the Awahou Stream 1992-2005.

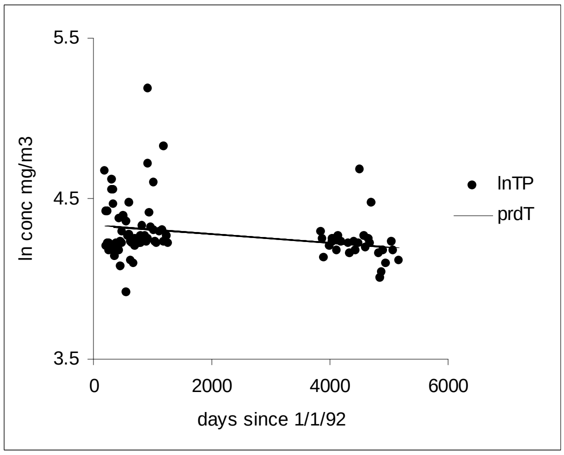
Figure 4: Concentration versus flow (left) and time (right) relationships in the Awahou Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON. Details of fitted models are given in Tables 11 & 12.

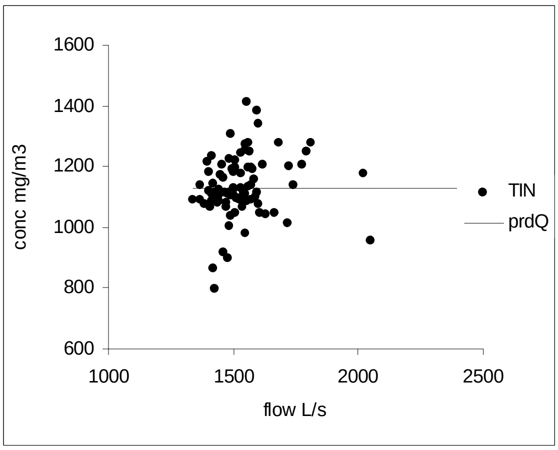


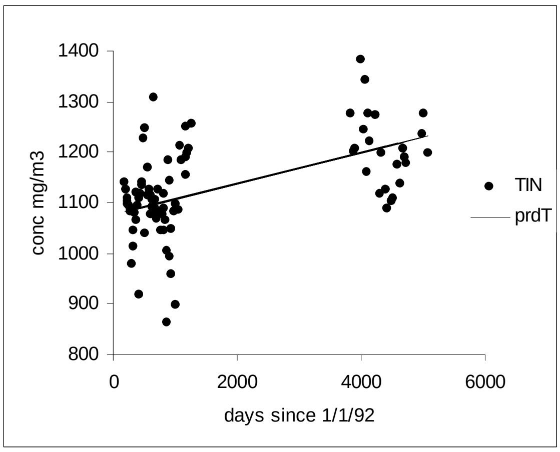

conc mg/m3
flow L/s
PP
prdQ

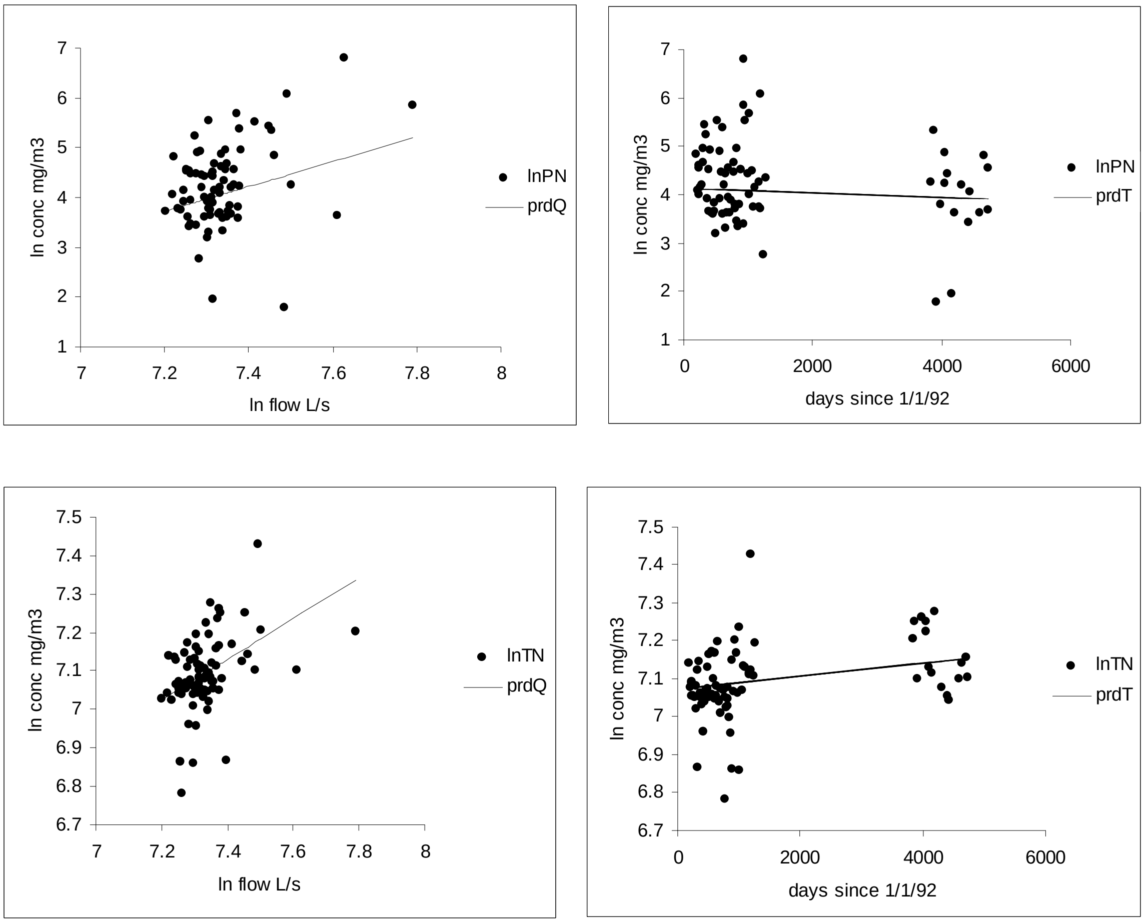

conc mg/m3
days since 1/1/92
PP
prdT


ln conc mg/m3
ln flow L/s
lnTP
prdQ


ln conc mg/m3
days since 1/1/92
lnTP
prdT


conc mg/m3
flow L/s
TIN
prdQ


conc mg/m3
days since 1/1/92
TIN
prdT



3.3 Hamurana Stream

Flow in the spring-fed Hamurana Stream shows almost no short-term response to rainfall (viz., floodflow is <1% of the total) (see Table 3). Flow varies seasonally and between years presumably in response to long-term changes in groundwater recharge. Flows were measured intermittently in 1992-1994 and 2002-2005. Predicted flows for 1995-2001 have a large uncertainty (Figure 5).

DRP concentration decreases with flow ($p = 0.01$) (Table 11), possibly because in wet years groundwater residence time is lower and there is less time for the dissolution of P from ignimbrites which comprise the aquifer. There is evidence of a weak increasing trend in DRP concentration ($p = 0.13$). TIN concentration increases with flow ($p = 0.05$) and increases significantly with time ($p = 0.0001$) (Table 12).

TP ~ DRP and as a result PP + DOP concentration is low and estimates are unreliable. PN + DON concentration estimates are more reliable but also low. PP, TP, PN and TN concentrations increase with flow ($p = 0.01$-0.30) but because flow variation is small, the majority of these nutrients (99%) are carried into the lake during baseflow.

Table 3: Summary of flow and nutrient mass flow in the Hamurana Stream.

			total	baseflow	floodflow	baseflow	floodflow
HAM	Flow L s^{-1}	mean	2495	2468	26	99%	1%
HAM	DRP t y^{-1}	mean	7.25	7.17	0.07	99%	1%
HAM		UCL	7.42	7.34	0.08	99%	1%
HAM		LCL	7.08	7.01	0.07	99%	1%
HAM	PP t y^{-1}	mean	0.00	0.00	0.00	100%	0%
HAM		UCL	0.27	0.26	0.00	100%	0%
HAM		LCL	-0.27	-0.26	0.00	100%	0%
HAM	TP t y^{-1}	mean	6.64	6.57	0.07	99%	1%
HAM		UCL	6.80	6.73	0.07	99%	1%
HAM		LCL	6.48	6.41	0.07	99%	1%
HAM	TIN t y^{-1}	mean	55.0	54.4	0.59	99%	1%
HAM		UCL	56.1	55.5	0.60	99%	1%
HAM		LCL	53.9	53.3	0.58	99%	1%
HAM	PN t y^{-1}	mean	5.35	5.28	0.07	99%	1%
HAM		UCL	6.85	6.77	0.08	99%	1%
HAM		LCL	3.84	3.79	0.05	99%	1%
HAM	TN t y^{-1}	mean	59.5	58.9	0.65	99%	1%
HAM		UCL	61.3	60.6	0.67	99%	1%
HAM		LCL	57.8	57.2	0.63	99%	1%

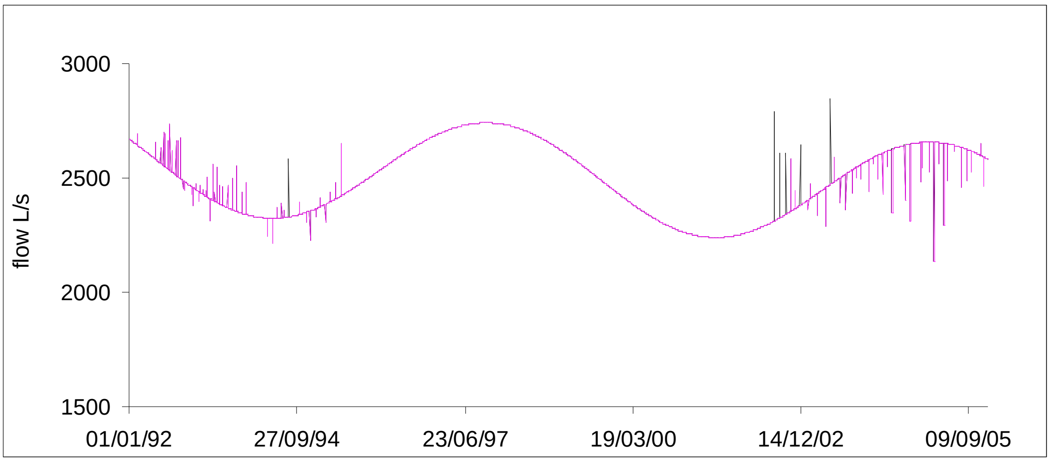
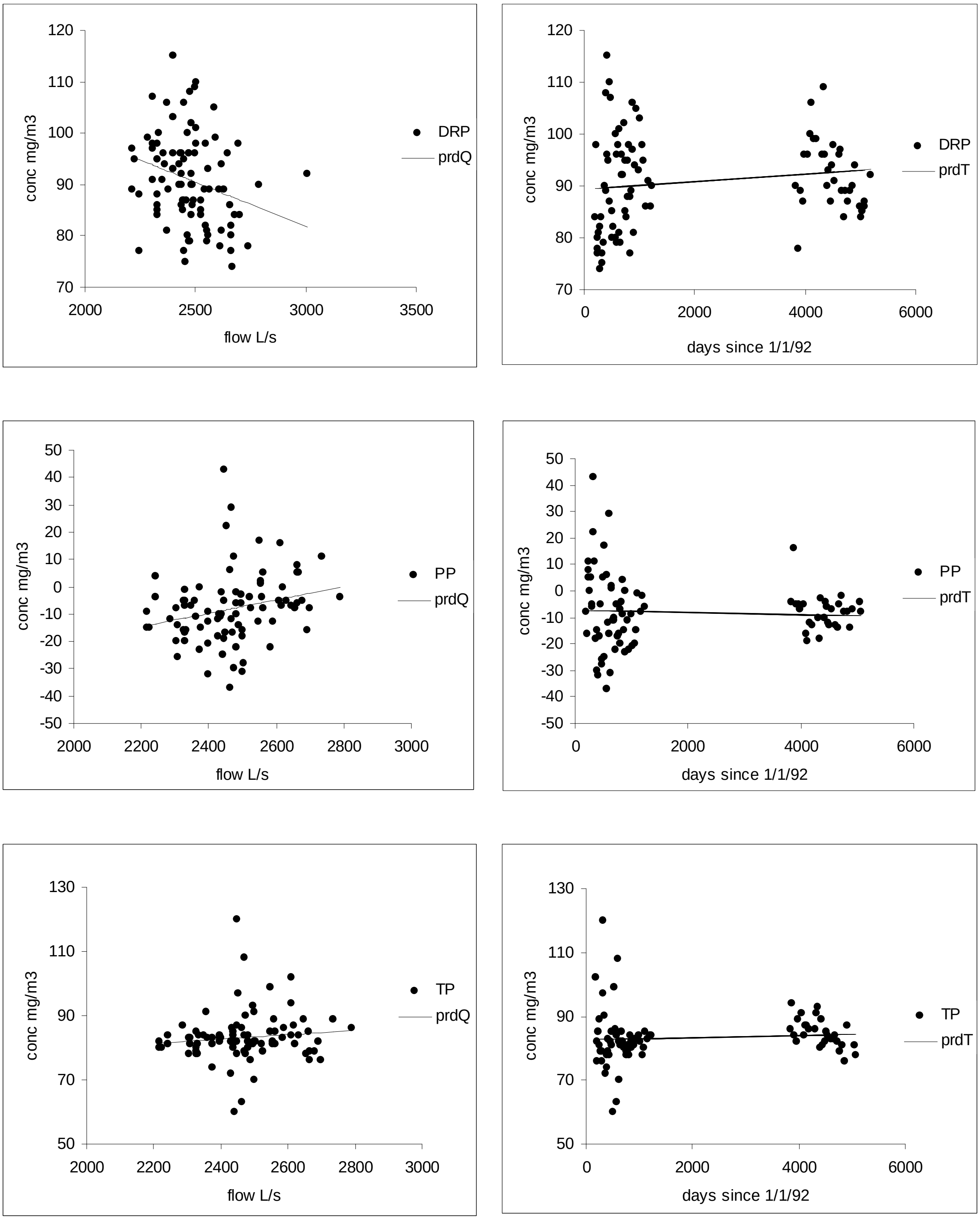
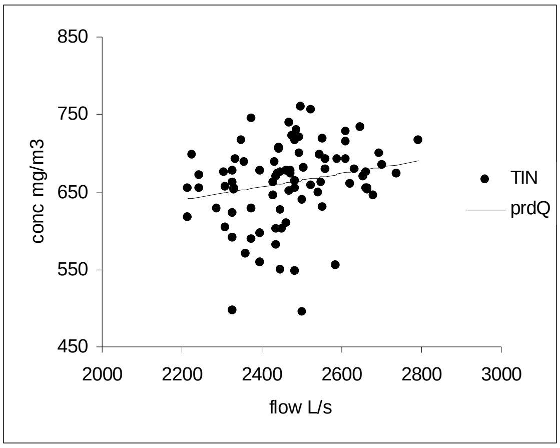
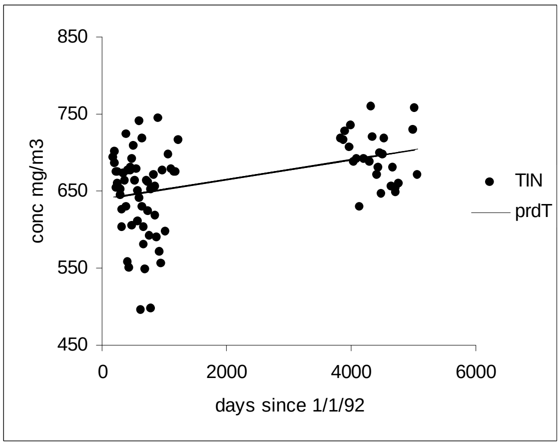


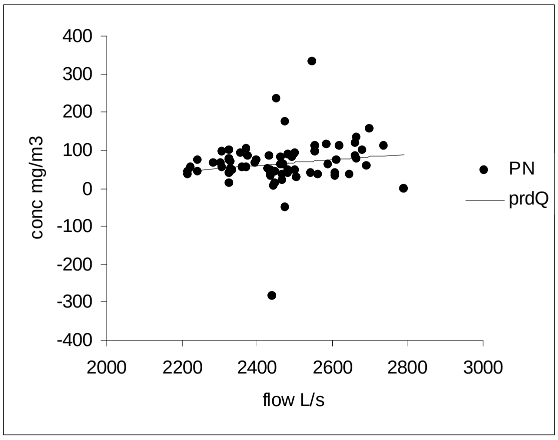
Figure 5: Estimated daily mean flow in the Hamurana Stream 1992-2005. Measured flows correspond to the ends of the vertical bars. The sine curve, which was fitted to the measured flows, is used to estimate 'missing' flows.

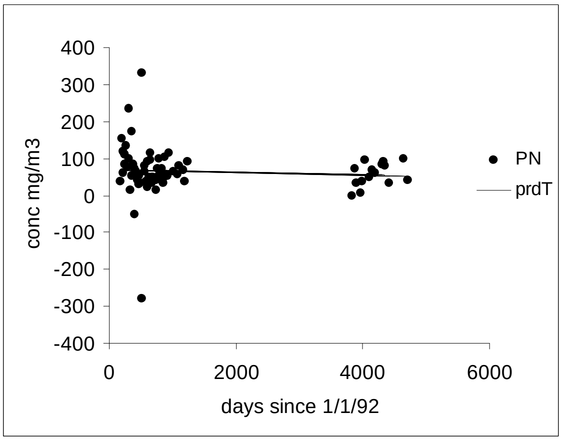
Figure 6: Concentration versus flow (left) and time (right) relationships in the Hamurana Stream derived from data from 1992-2005. The lines shown are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

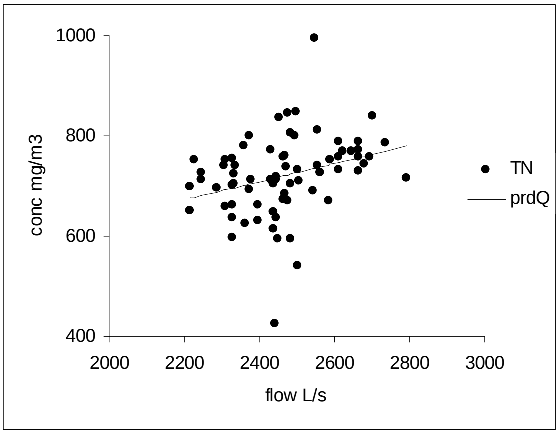


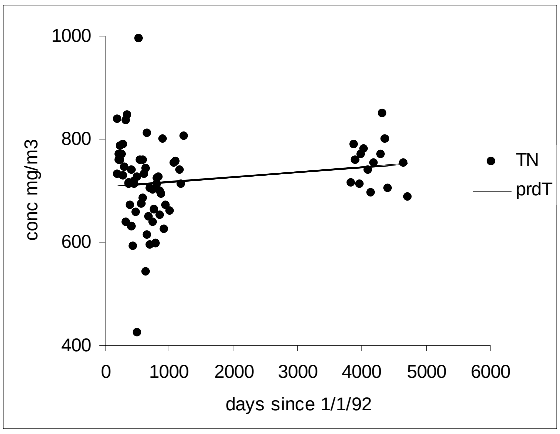












3.4 Waiohewa Stream

Floodflows carry a significantly larger proportion of the total flow in Waiohewa Stream (35%) (Table 4) than in the spring-fed Awahou (8%) and Hamurana (1%) Streams. DRP concentrations decrease with flow ($p < 0.001$) and floods carry a disproportionately small fraction of the total DRP load (flow 35% DRP 29-30%) (Table 11). TIN concentration increases with flow ($p < 0.001$) and floods carry a disproportionately large fraction of the total TIN load (flow 35% TIN 37-39%) (Table 12). PP, TP, PN and TN concentrations increase with flow ($p < 0.001$) and floods carry 40-60% of the load of these constituents.

The Waiohewa drains the Tikitere geothermal area and has unusually high TIN concentrations (dominated by NH_4N near the source and by NO_3N near the mouth). TIN concentration increases with flow ($p < 0.001$) and decreases with time ($p < 0.001$). In contrast DRP decreases with flow ($p < 0.001$) and increases with time ($p = 0.009$). TP increases with flow ($p < 0.001$) and decreases with time ($p < 0.001$). TN also increases with flow ($p < 0.001$) and decreases with time ($p = 0.02$). There is a collinearity problem with these data – flow was higher in 1992-1995 than 2004-2005 and this, in combination with the correlation between concentration and flow, may affect the apparent time trend.

Table 4: Summary of flow and nutrient mass flow in the Waiohewa Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
WHE	Flow L s^{-1}	mean	319	207	112	65%	35%
WHE	DRP t y^{-1}	mean	0.31	0.22	0.09	70%	30%
WHE		UCL	0.34	0.24	0.10	70%	30%
WHE		LCL	0.28	0.20	0.08	71%	29%
WHE	PP t y^{-1}	mean	0.48	0.21	0.27	44%	56%
WHE		UCL	0.59	0.24	0.35	40%	60%
WHE		LCL	0.39	0.19	0.21	47%	53%
WHE	TP t y^{-1}	mean	0.79	0.43	0.36	55%	45%
WHE		UCL	0.88	0.47	0.41	53%	47%
WHE		LCL	0.71	0.40	0.31	56%	44%
WHE	TIN t y^{-1}	mean	27.8	17.2	10.6	62%	38%
WHE		UCL	29.4	18.0	11.4	61%	39%
WHE		LCL	26.2	16.4	9.8	63%	37%
WHE	PN t y^{-1}	mean	4.99	2.56	2.43	51%	49%
WHE		UCL	6.89	3.20	3.69	46%	54%
WHE		LCL	3.72	2.06	1.66	55%	45%
WHE	TN t y^{-1}	mean	32.0	19.1	13.0	59%	41%
WHE		UCL	34.2	20.1	14.1	59%	41%
WHE		LCL	30.0	18.1	11.9	60%	40%

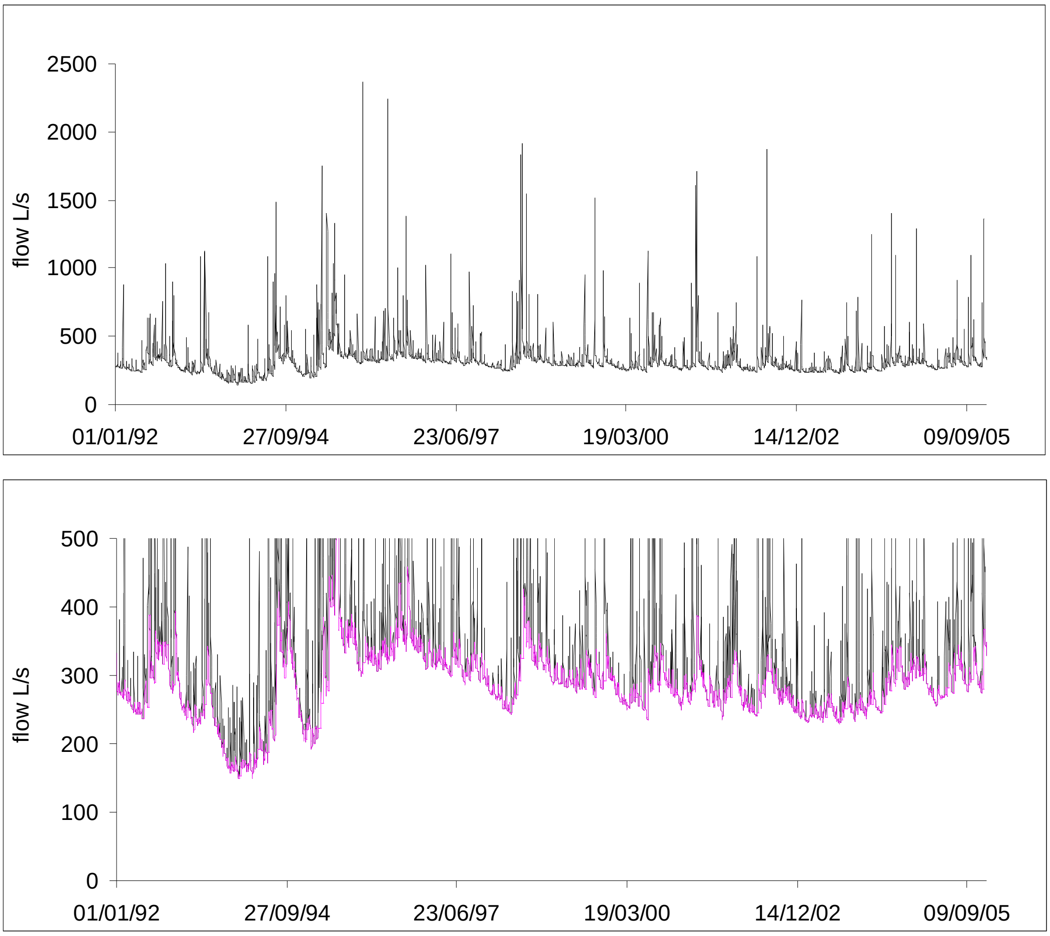
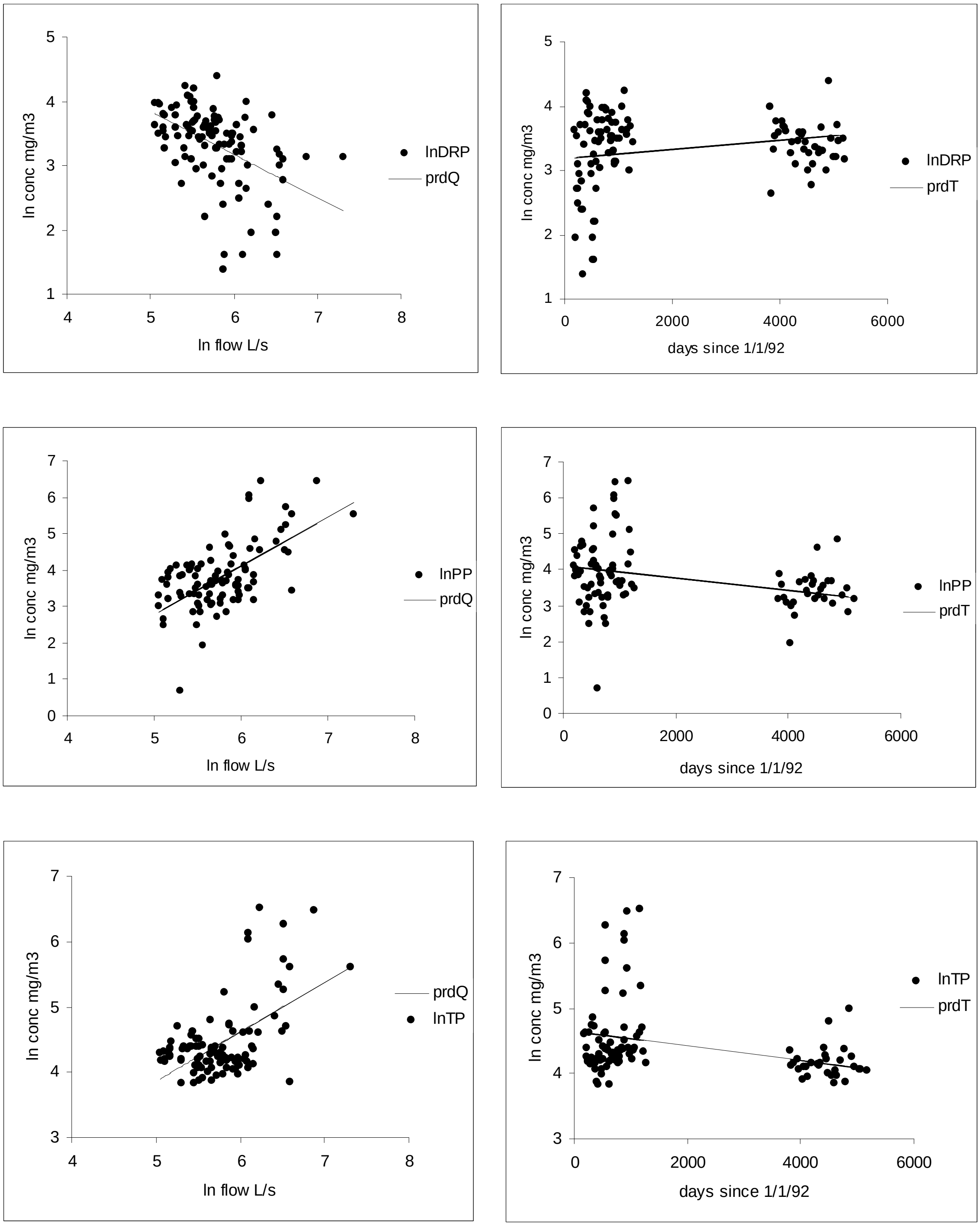
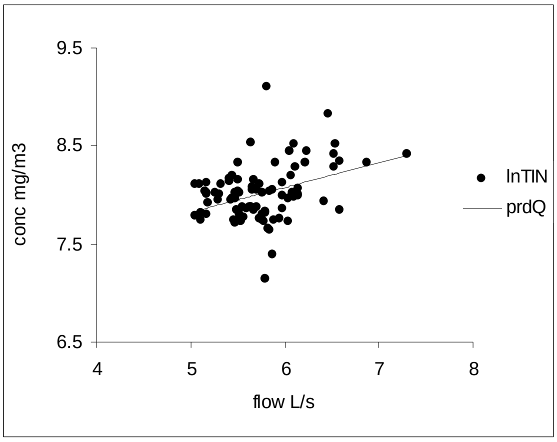
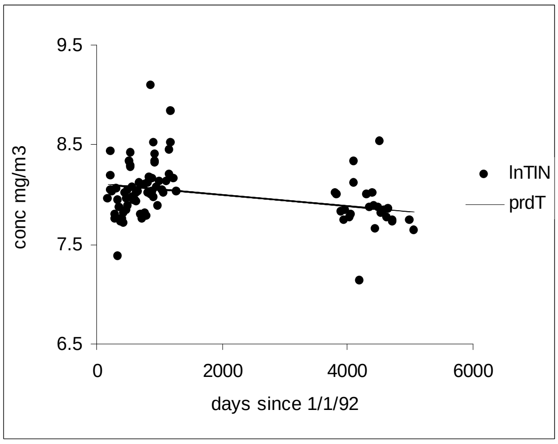


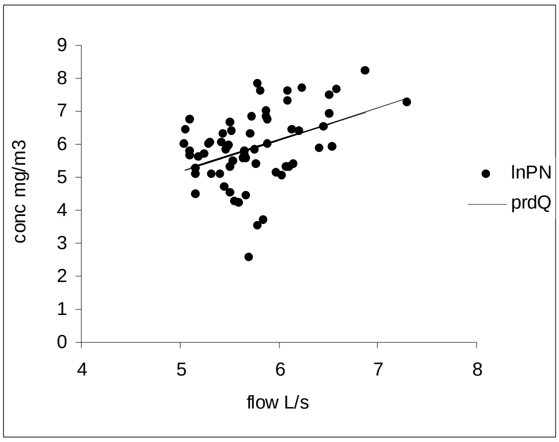
Figure 7: Estimated daily mean flow (black) and baseflow (purple) in the Waiohewa Stream 1992-2005.

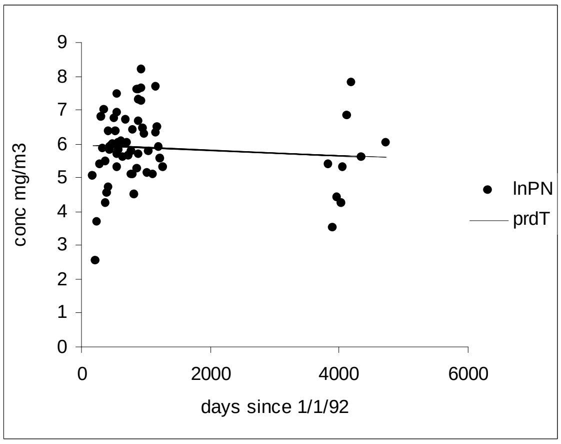
Figure 8: Concentration versus flow (left) and time (right) relationships in the Waiohewa Stream derived from data from 1992-2005. The lines shown are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

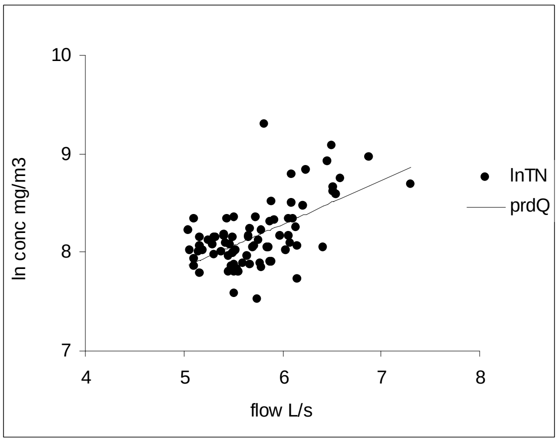


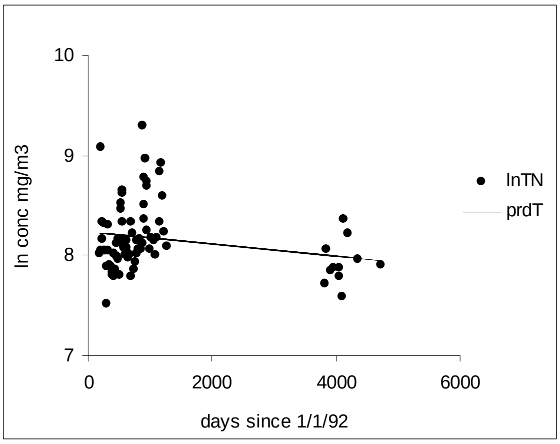












3.5 Waingaehe Stream

Flow in the Waingaehe is predominantly baseflow (92%) (Table 5). TIN concentration is independent of flow and increases significantly with time ($p << 0.001$) (Table 12). TIN load is dominated by baseflow. DRP concentration decreases with flow ($p < 0.001$)

(Table 11) and DRP load is also dominated by baseflow (92%). DRP concentration decreases with time ($p = 0.001$).

Several estimates of PP = TP – DRP and PN = TN – TIN are negative – these points are plotted as 0 in Figure 10. Omitting these points from the regression, PP and PN concentration increase with flow ($p << 0.001$). Storms were sampled in both 1992-1995 and 2004-2005 and consequently the regression models for the Waingaehe are not affected by collinearity as in the Waiohewa. Because PP, TP, PN and TN concentrations are correlated with flow, floods carry 12-35% of the load, even though they comprise only 8% of the flow.

Table 5: Summary of flow and nutrient mass flow in the Waingaehe Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
WNG	Flow L s^{-1}	mean	227	209	19	92%	8%
WNG	DRP t y^{-1}	mean	0.71	0.65	0.06	92%	8%
WNG		UCL	0.72	0.67	0.06	92%	8%
WNG		LCL	0.69	0.64	0.05	92%	8%
WNG	PP t y^{-1}	mean	0.33	0.22	0.10	69%	31%
WNG		UCL	0.41	0.27	0.14	65%	35%
WNG		LCL	0.26	0.19	0.07	72%	28%
WNG	TP t y^{-1}	mean	1.06	0.88	0.18	83%	17%
WNG		UCL	1.13	0.93	0.20	82%	18%
WNG		LCL	0.99	0.83	0.16	84%	16%
WNG	TIN t y^{-1}	mean	9.93	9.12	0.81	92%	8%
WNG		UCL	10.1	9.24	0.83	92%	8%
WNG		LCL	9.80	9.00	0.80	92%	8%
WNG	PN t y^{-1}	mean	1.21	0.90	0.31	74%	26%
WNG		UCL	1.46	1.05	0.42	72%	28%
WNG		LCL	1.02	0.78	0.24	77%	23%
WNG	TN t y^{-1}	mean	11.5	10.1	1.40	88%	12%
WNG		UCL	11.9	10.5	1.48	88%	12%
WNG		LCL	11.0	9.68	1.32	88%	12%

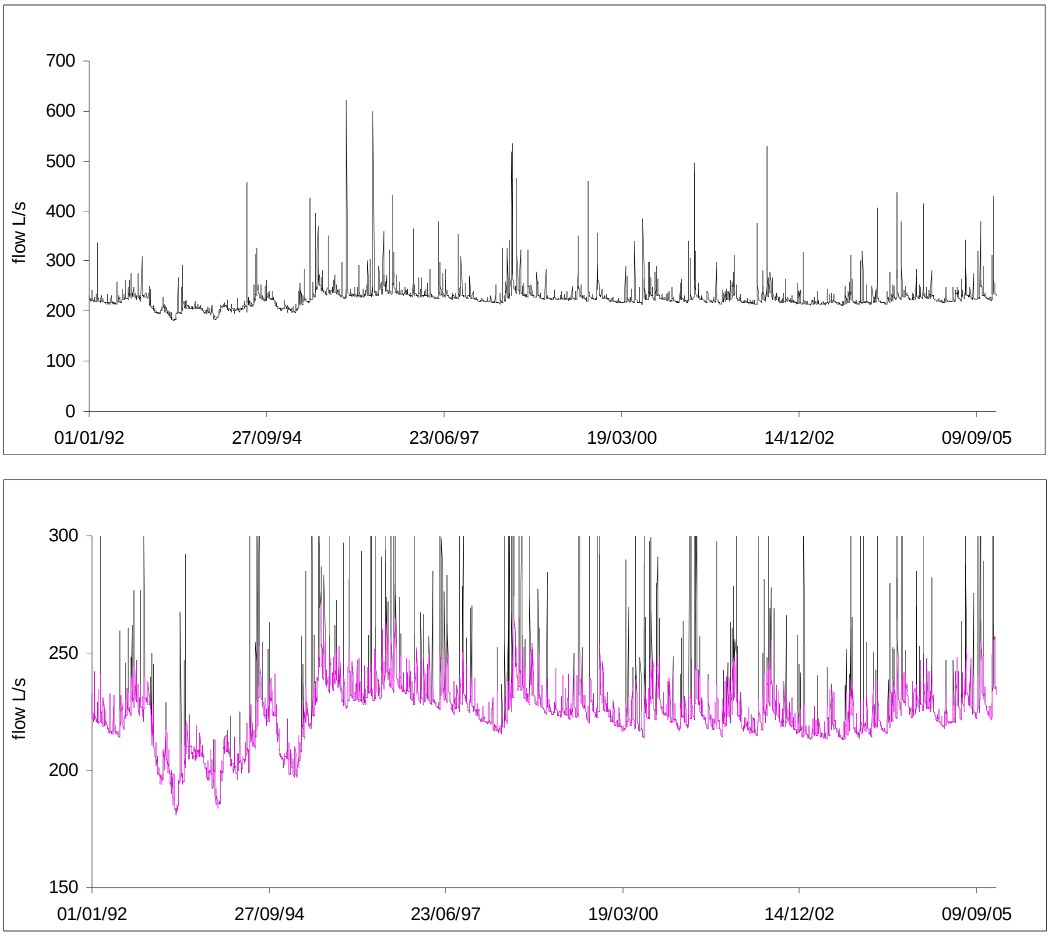
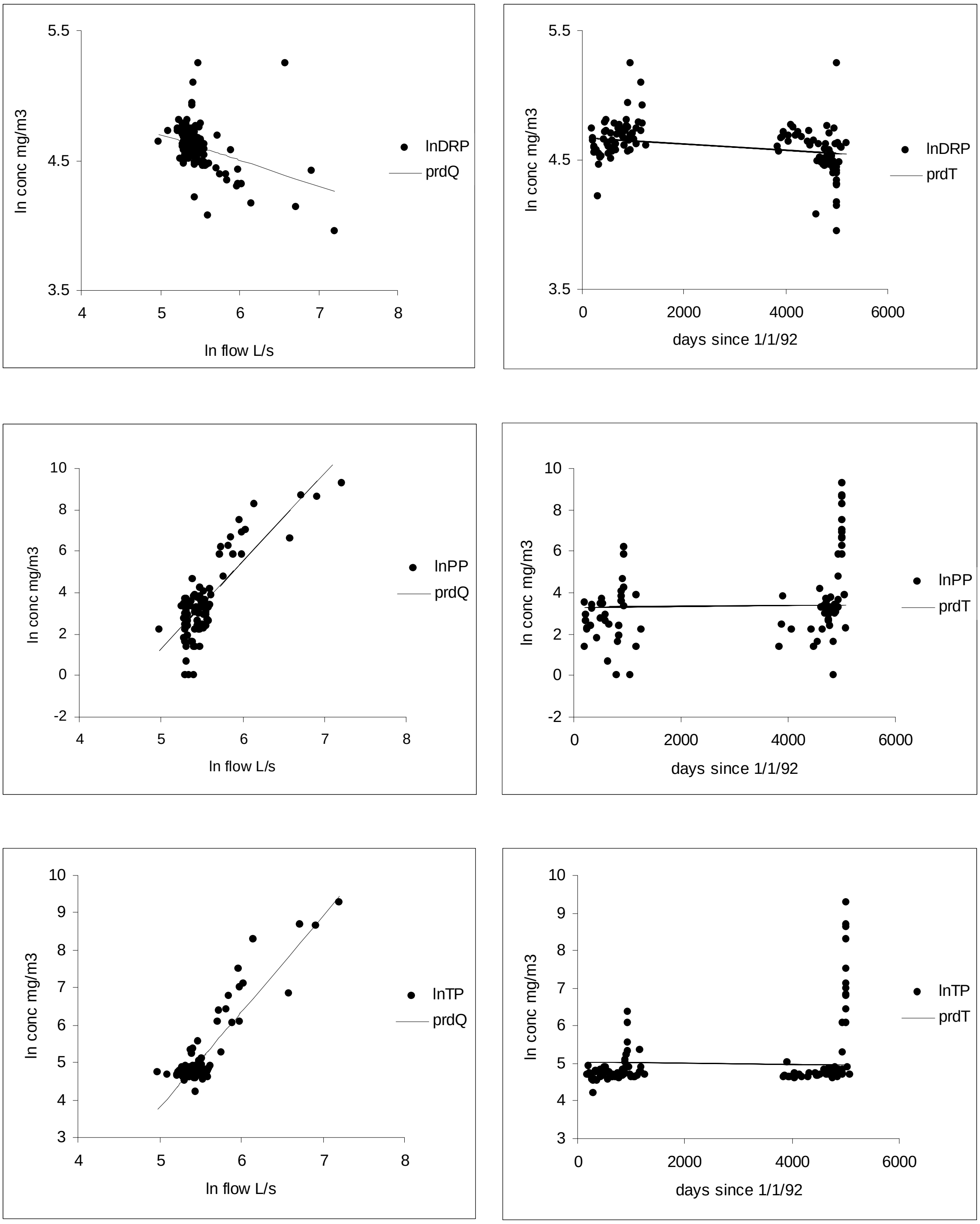
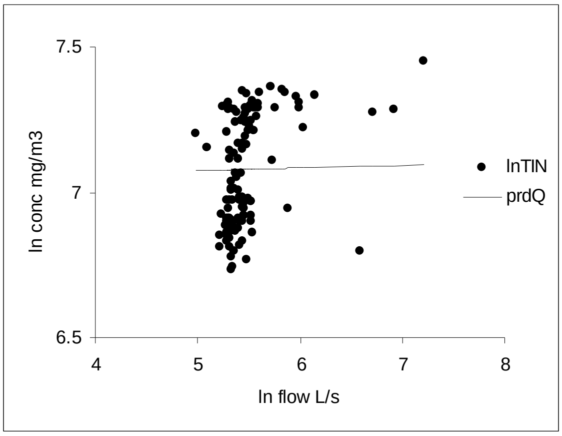
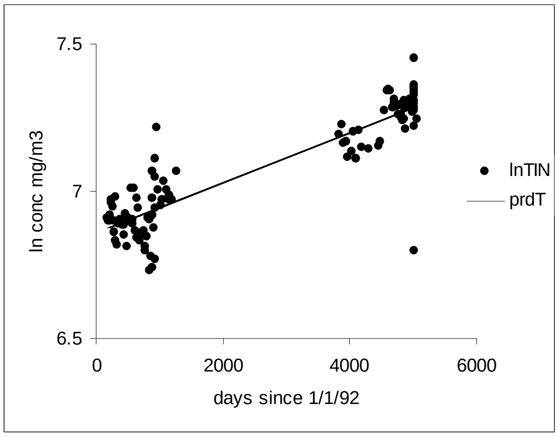


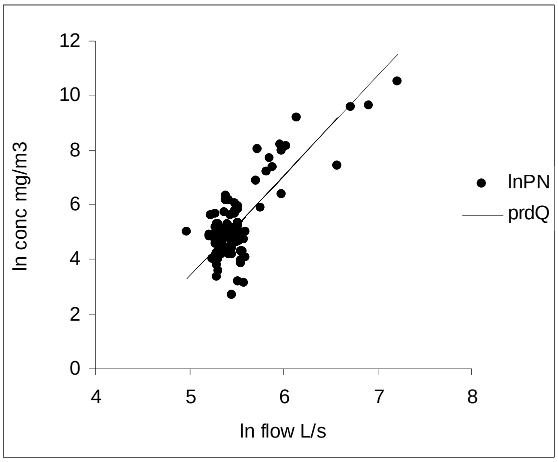
Figure 9: Estimated daily mean flow (black) and baseflow (purple) in the Waingaehe Stream 1992-2005.

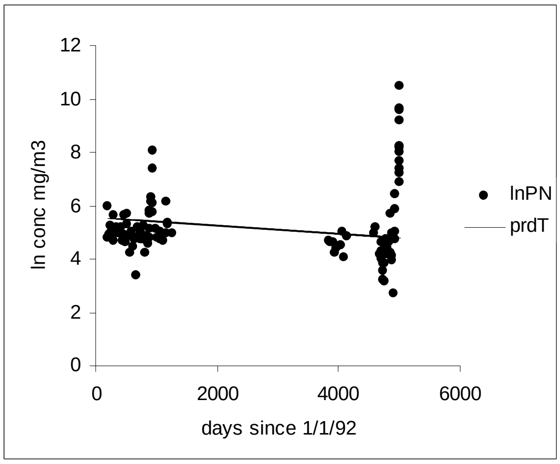
Figure 10: Concentration versus flow (left) and time (right) relationships in the Waingaehe Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

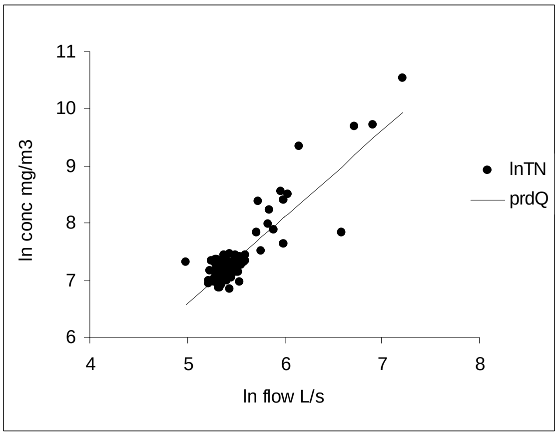


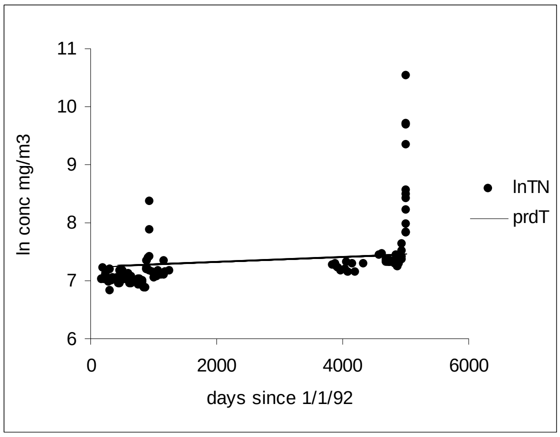












3.6 Waiteti Stream

Approximately 30% of the total flow in the Waiteti occurs during floods (Table 6). Only 2 samples are from flows above 2000 L s^{-1} which makes our estimates of flow/concentration relationships speculative. DRP and TIN do not vary significantly with flow (Tables 11 and 12). PP, TP, PN and TN concentrations show no consistent variation with flow which differs markedly from other streams. However, the vast majority of samples are at baseflow. DRP ($p = 0.01$), TP ($p = 0.005$) and TIN ($p < 0.001$) concentration increase with time.

Table 6: Summary of flow and nutrient mass flow in the Waiteti Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
WTT	Flow L s^{-1}	mean	1156	788	368	68%	32%
WTT	DRP t y^{-1}	mean	1.29	0.90	0.39	70%	30%
WTT		UCL	1.37	0.95	0.43	69%	31%
WTT		LCL	1.21	0.86	0.35	71%	29%
WTT	PP t y^{-1}	mean	0.12	0.08	0.04	68%	32%
WTT		UCL	0.21	0.14	0.07	68%	32%
WTT		LCL	0.03	0.02	0.01	68%	32%
WTT	TP t y^{-1}	mean	1.67	1.14	0.53	68%	32%
WTT		UCL	1.78	1.19	0.59	67%	33%
WTT		LCL	1.57	1.08	0.48	69%	31%
WTT	TIN t y^{-1}	mean	47.2	32.0	15.2	68%	32%
WTT		UCL	48.1	32.4	15.7	67%	33%
WTT		LCL	46.3	31.5	14.8	68%	32%
WTT	PN t y^{-1}	mean	5.52	4.2	1.33	76%	24%
WTT		UCL	6.24	4.7	1.51	76%	24%
WTT		LCL	4.79	3.6	1.16	76%	24%
WTT	TN t y^{-1}	mean	50.3	34.1	16.2	68%	32%
WTT		UCL	51.3	34.6	16.7	67%	33%
WTT		LCL	49.3	33.6	15.7	68%	32%

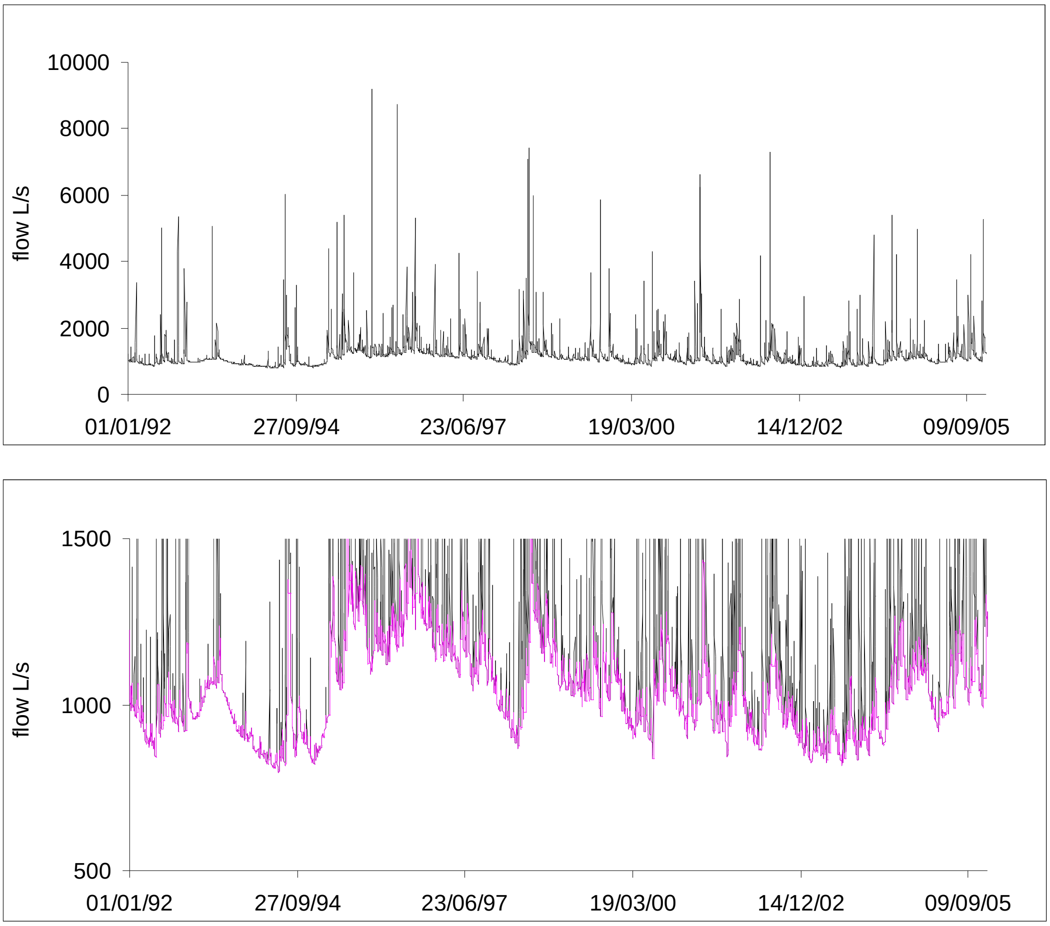
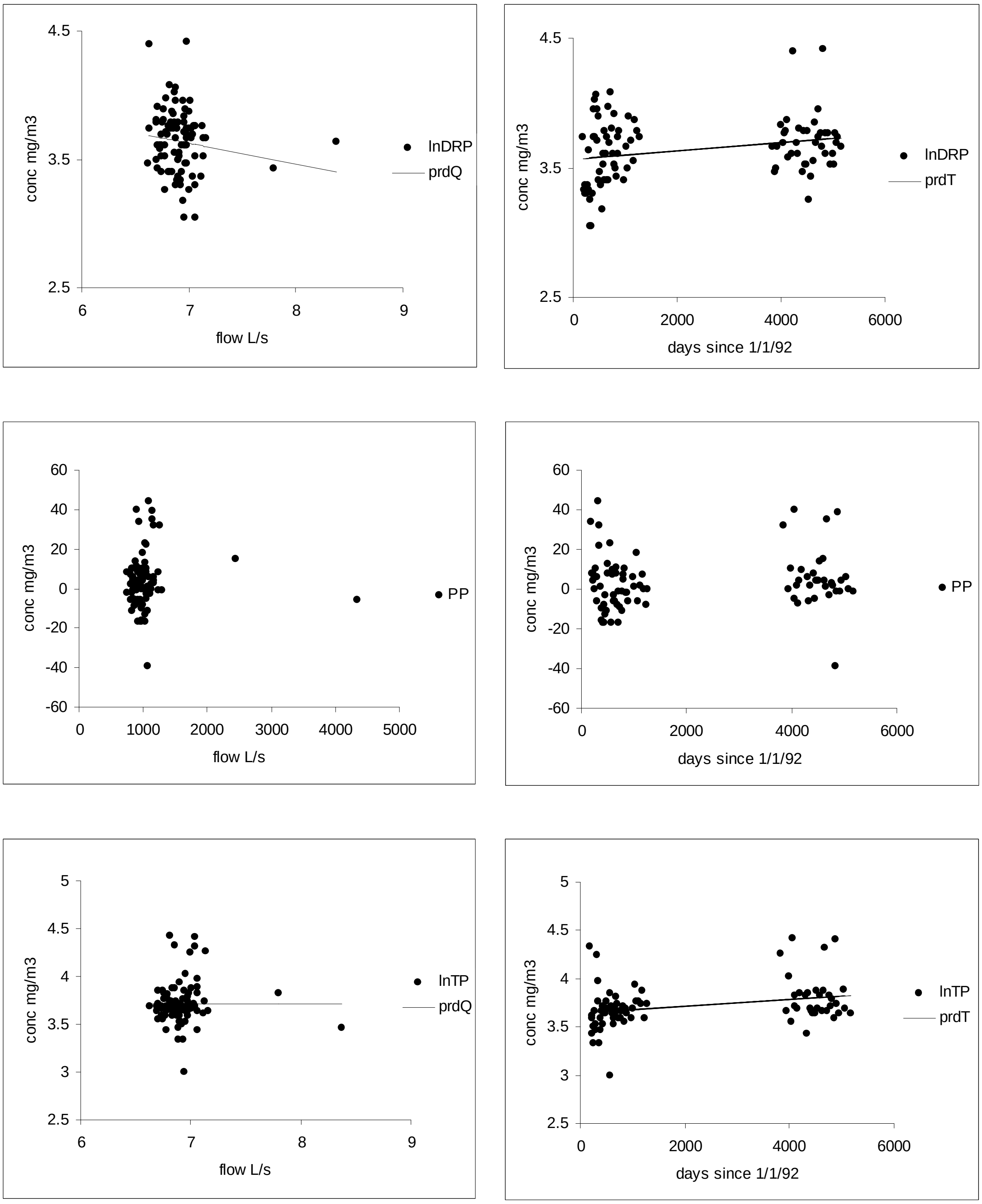
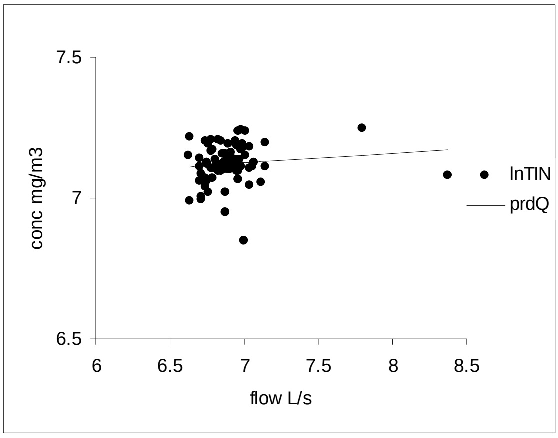
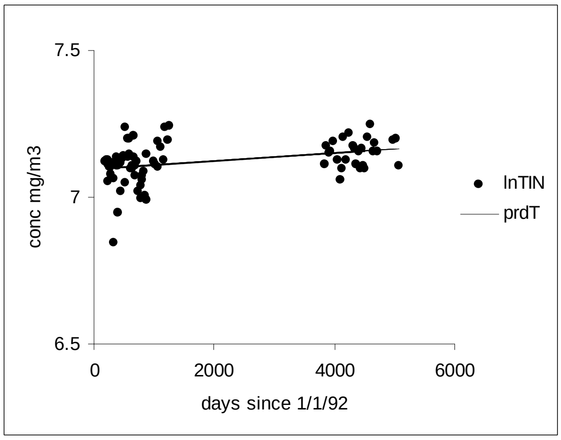


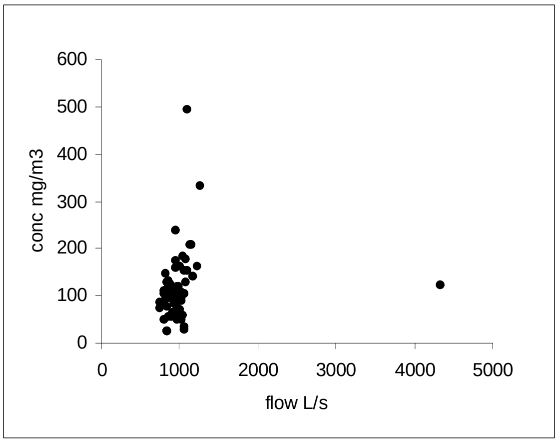
Figure 11: Estimated daily mean flow (black) and baseflow (purple) in the Waiteti Stream 1992-2005.

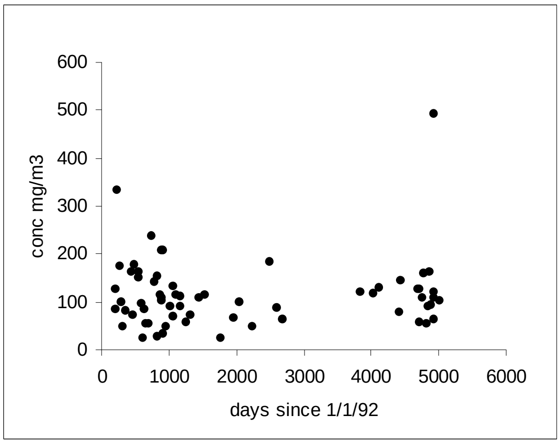
Figure 12: Concentration versus flow (left) and time (right) relationships in the Waiteti Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

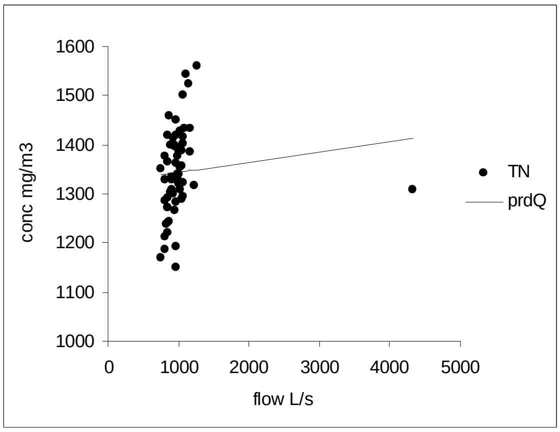


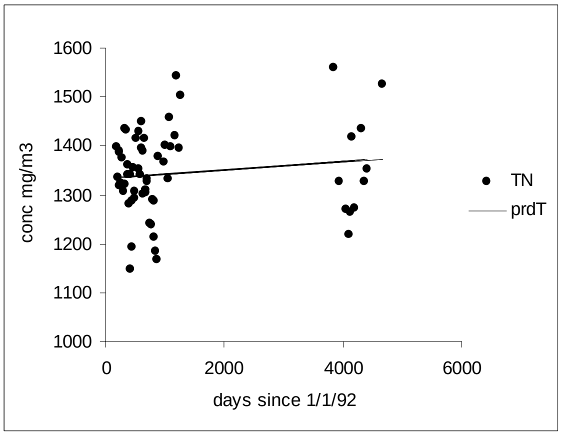












3.7 Waiowhiro Stream

Approximately 70% of total flow in the Waiwhiro occurs as baseflow (Table 7). TIN concentration is uncorrelated with flow (Table 12) and consequently TIN massflow is proportional to flow. DRP concentration decreases with flow ($p < 0.001$) (Table 11) and floods which carry 29% of total flow transport 26-27% of DRP massflow. DRP concentration is uncorrelated with time but TIN concentration increases ($p = 0.02$).

In several samples DRP > TP and, omitting these samples, PP concentration increases with flow ($p << 0.001$). PN concentration also increases with flow ($p << 0.001$). Consequently floods that carry 29% of total flow transport 47-62% of PP massflow and 38-43% of PN massflow. TP and TN concentrations increase with flow ($p << 0.001$) and floods that carry 29% of total flow transport 33-34% of TP massflow and 31-32% of TN massflow. PP and TP concentrations decease with time ($p = 0.006$-0.02) but neither PN or TN varies consistently with time.

Table 7: Summary of flow and nutrient mass flow in the Waiowhiro Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
WWH	Flow L s^{-1}	mean	358	255	103	71%	29%
WWH	DRP t y^{-1}	mean	0.50	0.37	0.13	74%	26%
WWH		UCL	0.53	0.38	0.14	73%	27%
WWH		LCL	0.47	0.35	0.12	74%	26%
WWH	PP t y^{-1}	mean	0.21	0.10	0.11	46%	54%
WWH		UCL	0.33	0.12	0.20	38%	62%
WWH		LCL	0.14	0.07	0.07	53%	47%
WWH	TP t y^{-1}	mean	0.64	0.42	0.21	66%	34%
WWH		UCL	0.68	0.45	0.23	66%	34%
WWH		LCL	0.60	0.40	0.20	67%	33%
WWH	TIN t y^{-1}	mean	10.68	7.60	3.08	71%	29%
WWH		UCL	11.12	7.88	3.24	71%	29%
WWH		LCL	10.25	7.33	2.93	71%	29%
WWH	PN t y^{-1}	mean	2.62	1.57	1.06	60%	40%
WWH		UCL	3.07	1.76	1.31	57%	43%
WWH		LCL	2.26	1.39	0.86	62%	38%
WWH	TN t y^{-1}	mean	12.53	8.61	3.92	69%	31%
WWH		UCL	13.08	8.94	4.14	68%	32%
WWH		LCL	12.00	8.29	3.71	69%	31%

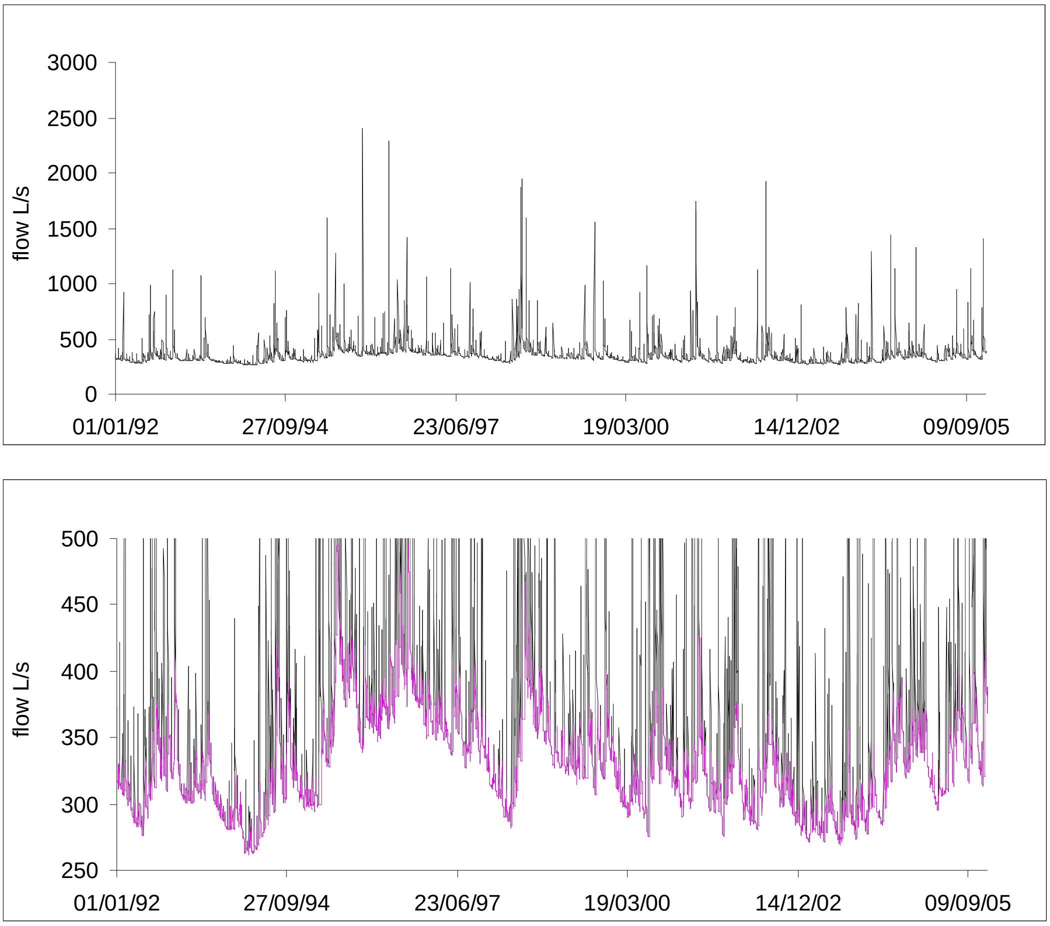
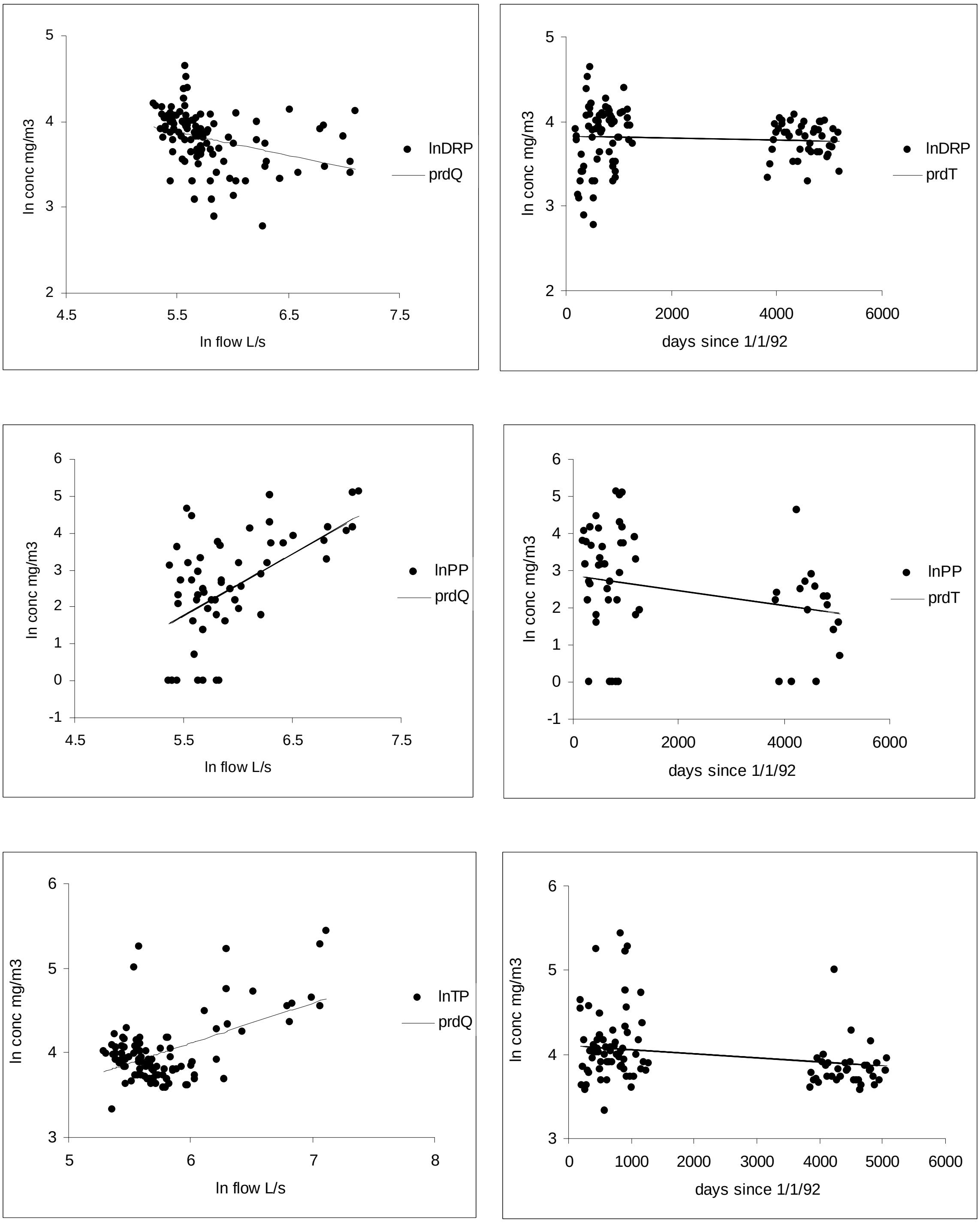
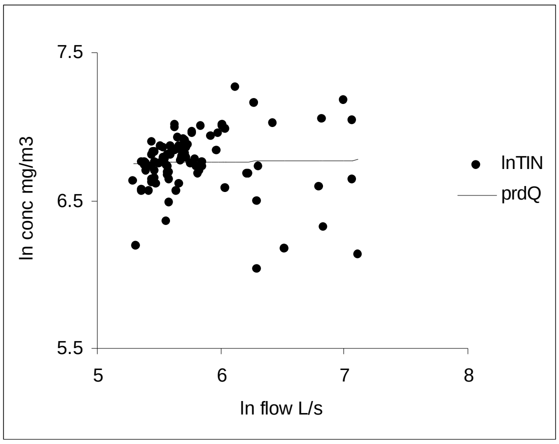
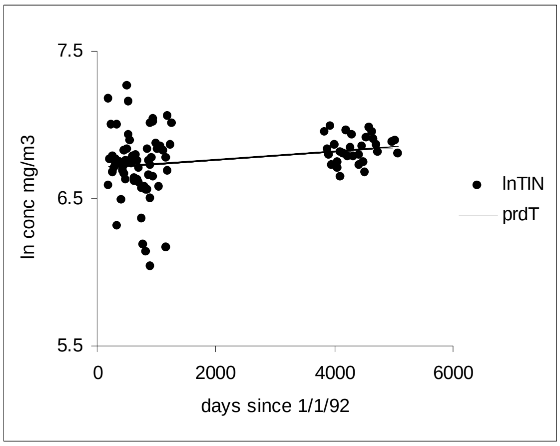


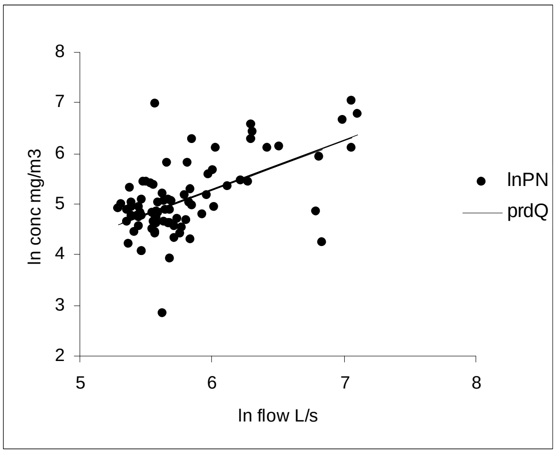
Figure 13: Estimated daily mean flow (black) and baseflow (purple) in the Waiowhiro Stream 1992-2005.

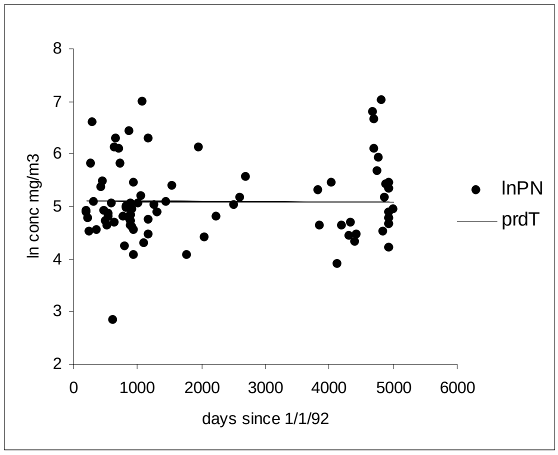
Figure 14: Concentration versus flow (left) and time (right) relationships in the Waiowhiro Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

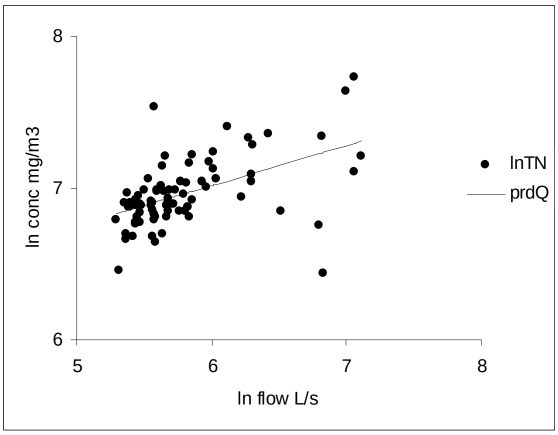


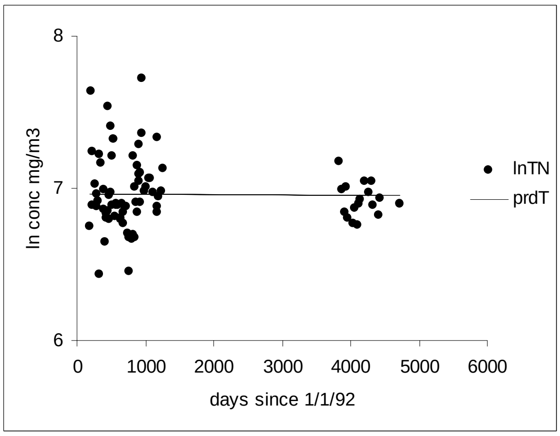












3.8 Utuhina Stream

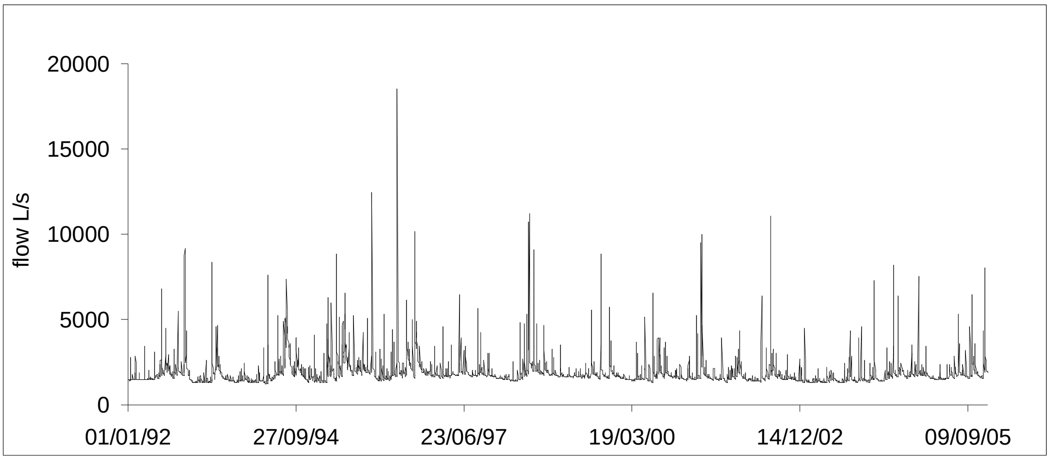
Approximately 60% of the total flow in the Utuhina occurs as baseflow (Table 8). DRP concentration decreases with flow ($p << 0.001$) (Table 11) and floods that account for 37% of flow carry only 32% of DRP massflow. In contrast TIN concentration is not strongly correlated ($p = 0.02$) with flow (Table 12).

PP and PN concentration increase with flow ($p << 0.001$) and floods that account for 37% of flow transport 70-80% of PP and 43-76% of PN massflow. The PP model used to derive these estimates is affected by the omission of several samples in which DRP > TP. TP and TN concentrations both increase with flow ($p << 0.001$) and floods that account for 37% of total flow transport 42-53% of TP and 39-45% of TN massflow.

PP ($p = 0.002$) concentration increases with time but DRP concentration decreases ($p < 0.001$). TIN, PN, TP and TN concentration are uncorrelated with time.

Table 8: Summary of flow and nutrient mass flow in the Utuhina Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
UTU	Flow $L\ s^{-1}$	mean	1845	1162	683	63%	37%
UTU	DRP $t\ y^{-1}$	mean	2.36	1.60	0.76	68%	32%
UTU		UCL	2.50	1.69	0.81	68%	32%
UTU		LCL	2.23	1.52	0.71	68%	32%
UTU	PP $t\ y^{-1}$	mean	3.97	1.00	2.96	25%	75%
UTU		UCL	5.91	1.19	4.71	20%	80%
UTU		LCL	2.78	0.84	1.94	30%	70%
UTU	TP $t\ y^{-1}$	mean	4.91	2.63	2.28	54%	46%
UTU		UCL	6.03	2.84	3.18	47%	53%
UTU		LCL	4.19	2.44	1.75	58%	42%
UTU	TIN $t\ y^{-1}$	mean	41.8	26.7	15.1	64%	36%
UTU		UCL	46.0	28.3	17.7	61%	39%
UTU		LCL	38.3	25.3	13.0	66%	34%
UTU	PN $t\ y^{-1}$	mean	14.9	6.7	8.26	45%	55%
UTU		UCL	32.9	8.0	24.83	24%	76%
UTU		LCL	9.8	5.6	4.21	57%	43%
UTU	TN $t\ y^{-1}$	mean	57.6	33.7	23.9	59%	41%
UTU		UCL	65.4	35.8	29.6	55%	45%
UTU		LCL	51.7	31.8	19.9	61%	39%



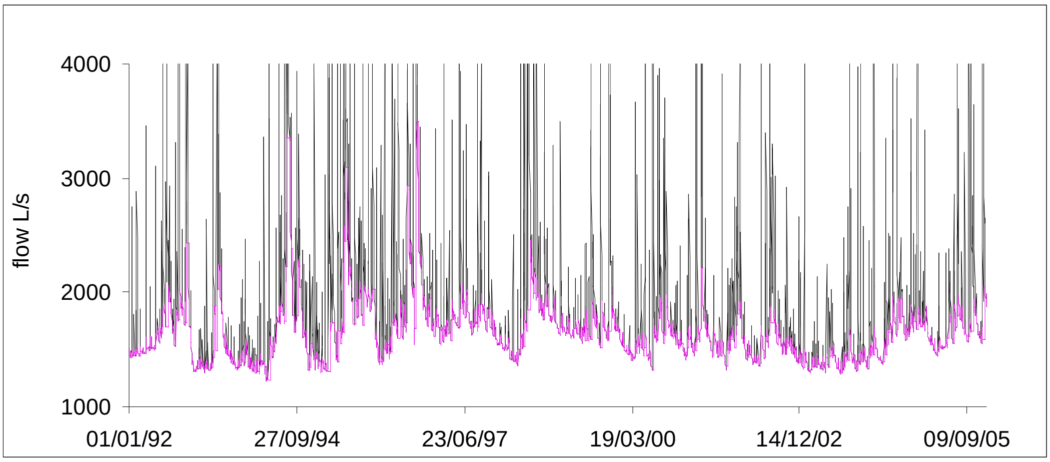
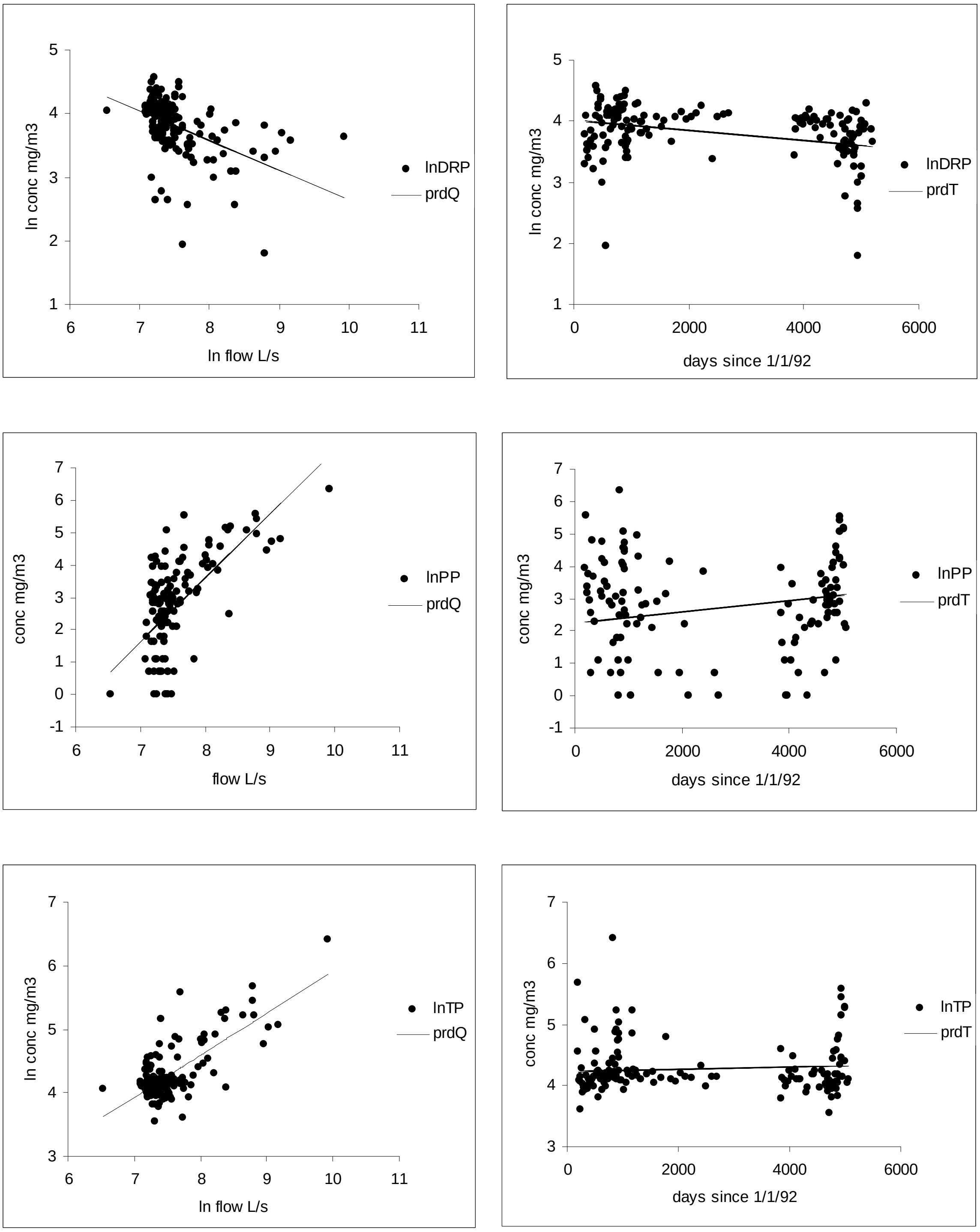
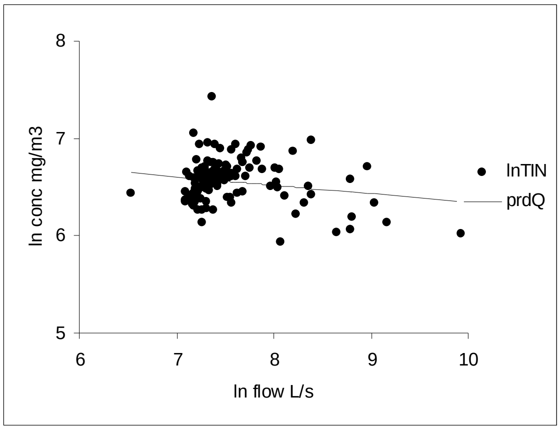
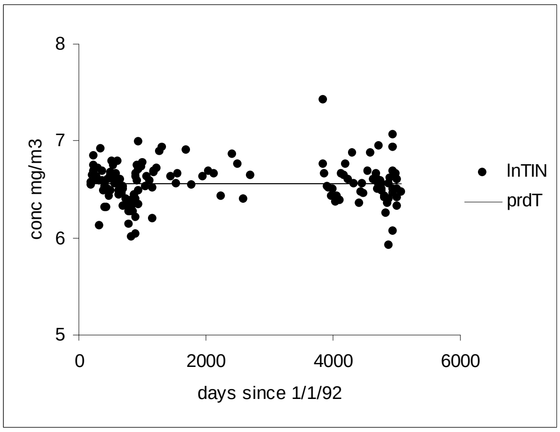


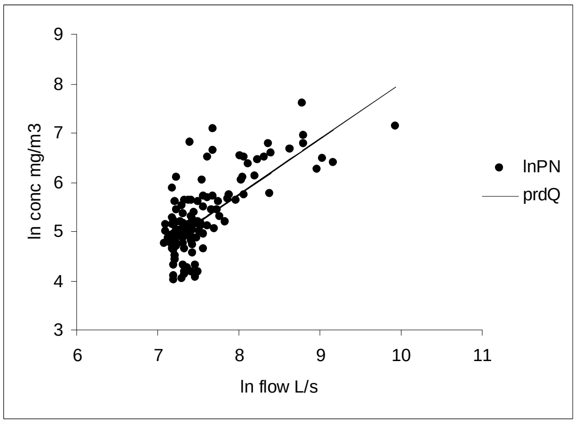
Figure 15: Estimated daily mean flow (black) and baseflow (purple) in the Utuhina Stream 1992-2005.

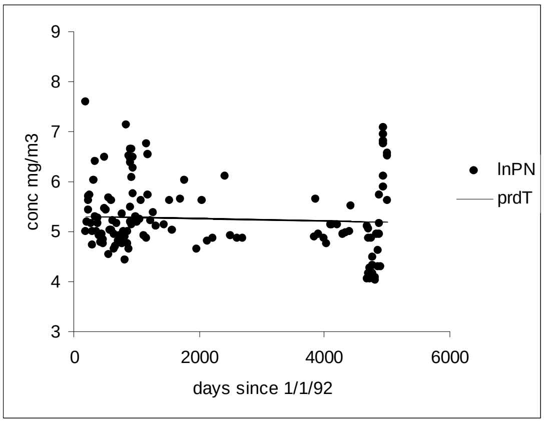
Figure 16: Concentration versus flow (left) and time (right) relationships in the Utuhina Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

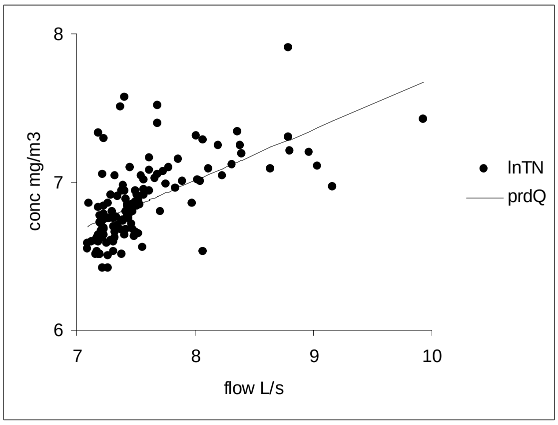


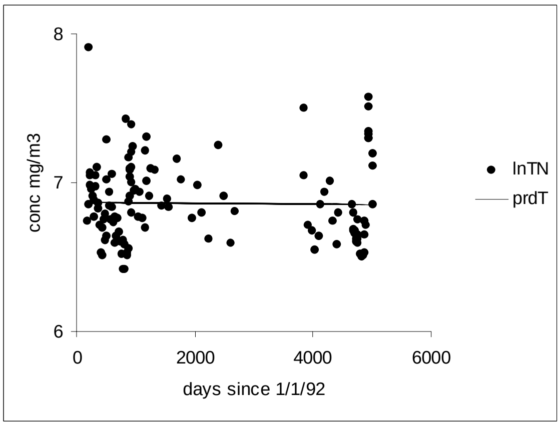












3.9 Ngongotaha Stream

Baseflow comprises 56% of total flow in the Ngongotaha (Table 9). DRP concentration decreases with flow and floods ($p << 0.001$, Table 11) that comprise 44% of total flow carry only 41-42% of total DRP massflow. TIN concentration also decreases with flow ($p = 0.002$) (Table 12). PP, TP, PN and TN concentrations all correlate strongly with flow and floods that comprise 44% of total flow carry 83-89% of PP massflow, 66-69% of TP massflow and 71-74% of PN massflow. For TN floods carry 53-54% of total massflow reflecting the fact that although PN concentration (which averages 40% of TN concentration) increases with flow, TIN concentration (which averages 60% of TN) decreases slightly with flow. DRP and PN concentration exhibit no time trends. PP and TP both increase with time but this may simply because the both correlate strongly with flow and the largest flows occurred near the end of the study. TIN shows a significant increase over time ($p << 0.001$) and this causes TN to increase over time, even though PN shows no trend.

Table 9: Summary of flow and nutrient mass flow in the Ngongotaha Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
NGO	Flow L s^{-1}	mean	1734	963	771	56%	44%
NGO	DRP t y^{-1}	mean	1.92	1.12	0.80	58%	42%
NGO		UCL	1.99	1.15	0.84	58%	42%
NGO		LCL	1.86	1.09	0.77	59%	41%
NGO	PP t y^{-1}	mean	4.91	0.68	4.23	14%	86%
NGO		UCL	7.04	0.77	6.27	11%	89%
NGO		LCL	3.52	0.60	2.91	17%	83%
NGO	TP t y^{-1}	mean	6.03	1.96	4.08	32%	68%
NGO		UCL	6.55	2.05	4.50	31%	69%
NGO		LCL	5.57	1.87	3.70	34%	66%
NGO	TIN t y^{-1}	mean	44.2	24.9	19.3	56%	44%
NGO		UCL	45.0	25.2	19.7	56%	44%
NGO		LCL	43.5	24.5	19.0	56%	44%
UTU	PN t y^{-1}	mean	23.0	6.35	16.6	28%	72%
UTU		UCL	25.8	6.74	19.0	26%	74%
UTU		LCL	20.5	5.99	14.6	29%	71%
NGO	TN t y^{-1}	mean	68.4	31.6	36.8	46%	54%
NGO		UCL	70.4	32.3	38.1	46%	54%
NGO		LCL	66.5	31.0	35.5	47%	53%

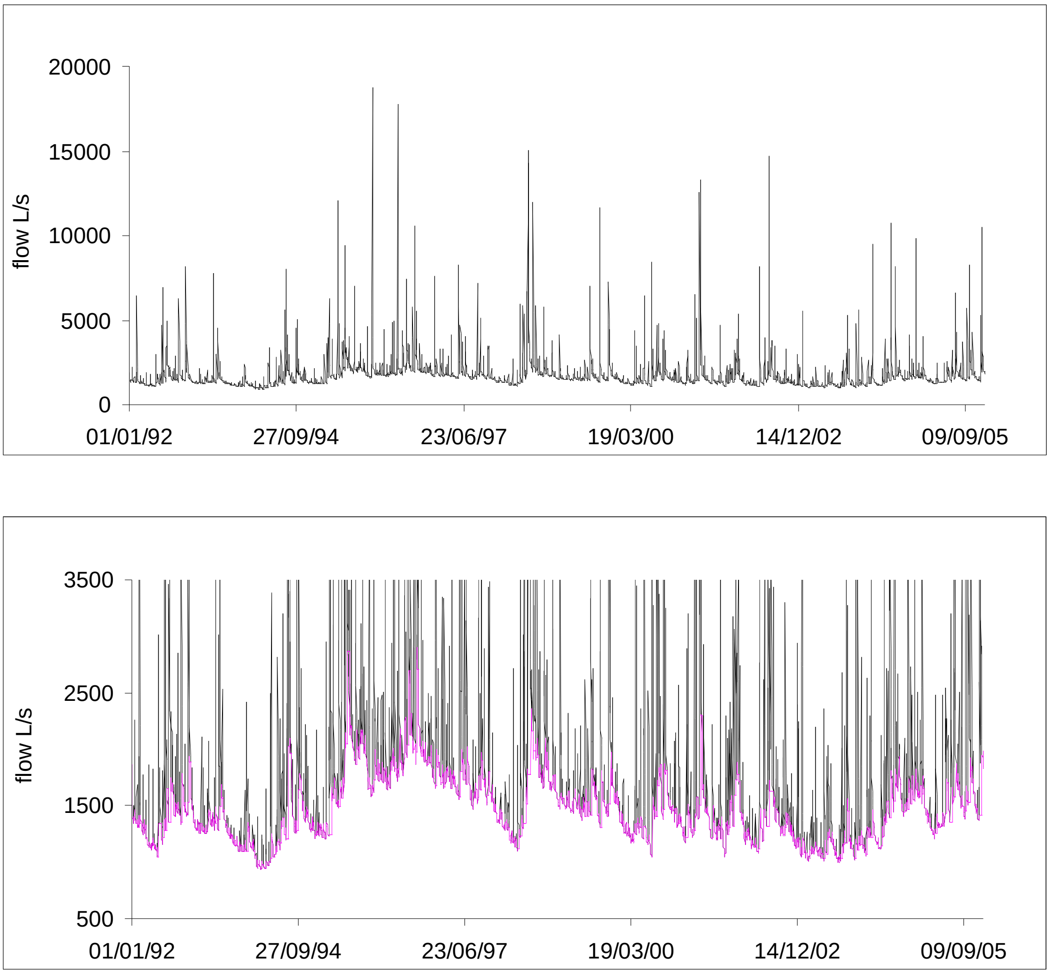
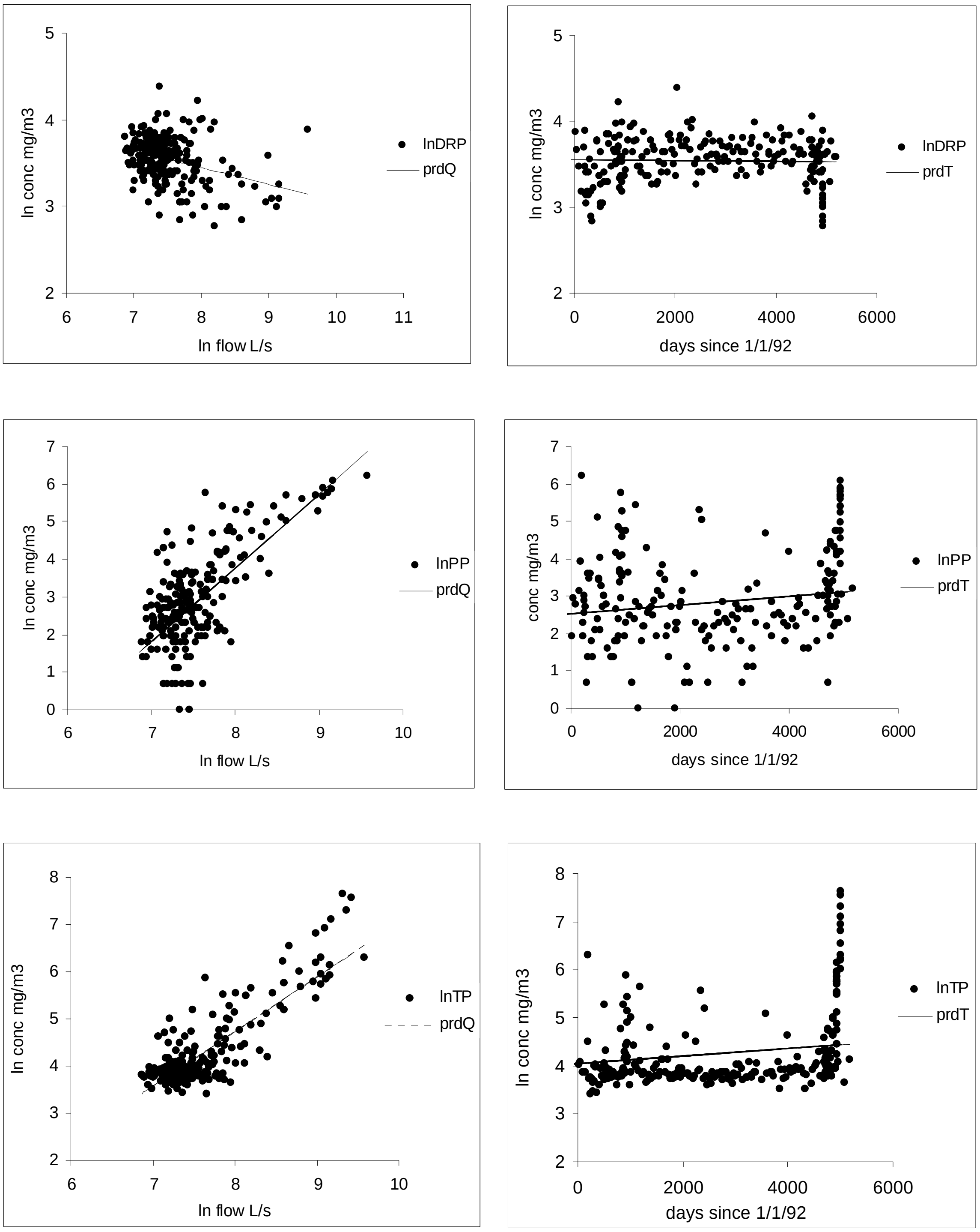
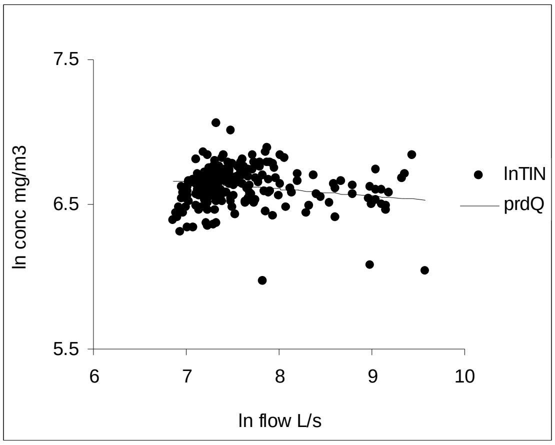
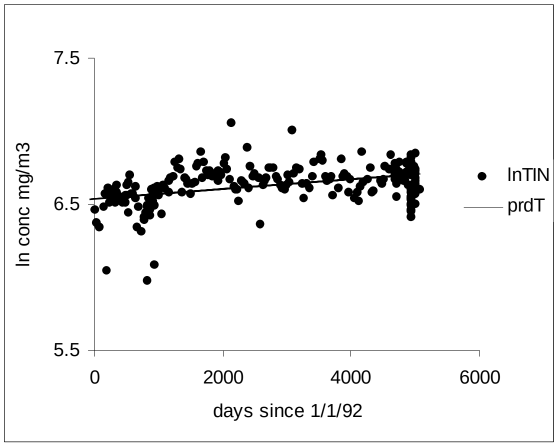


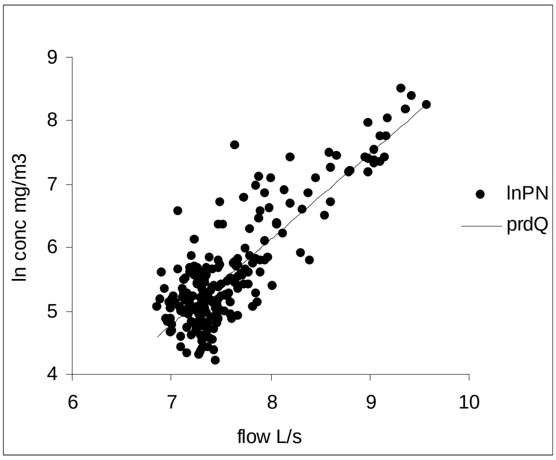
Figure 17: Estimated daily mean flow (black) and baseflow (purple) in the Ngongotaha Stream 1992-2005.

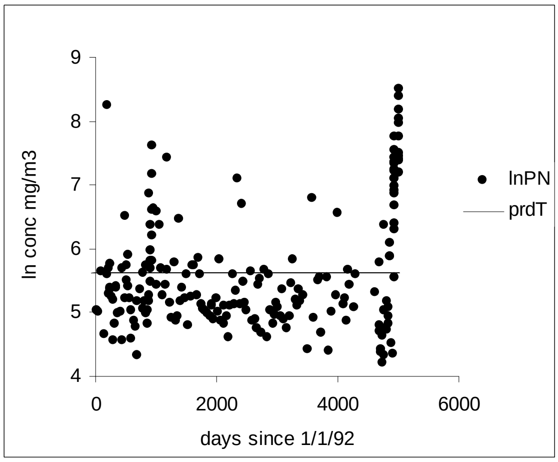
Figure 18: Concentration versus flow (left) and time (right) relationships in the Ngongotaha Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

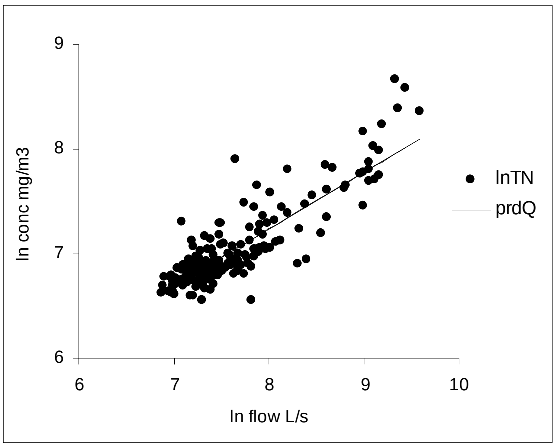


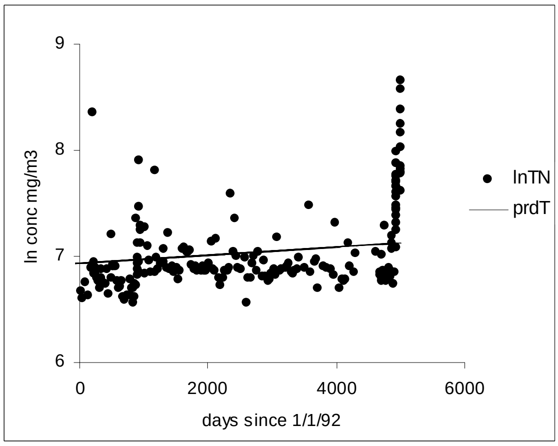












3.10 Puarenga Stream

Baseflow makes up 64% of the total flow in the Puarenga (Table 10). DRP concentration decreases with flow ($p < 0.001$) (Table 11) and floods that comprise 36% of flow carry only 32-35% of the DRP load. TIN concentration decreases slightly with flow ($p = 0.07$)

(Table 12). PP, TP, PN and TN concentrations all increase with flow. Consequently floods transport 68-75% of PP load, 50-51% of TP load and 52-54% of PN load. Floods transport only 40% of TN load because although PN concentration increases with flow, TIN concentration (which averages ~50% of TN concentration) decreases slightly with flow. DRP concentration decreases with time ($p < 0.001$) but this may be because DRP is inversely correlated with flow and the highest flows occurred near the end of the study. PP and TP show no time trend. TIN and TN concentrations show a dramatic increase over time – the result of increasing NO_3N loss from the RLTS in Whararewarewa Forest during the study period. PN shows no time trend.

Table 10: Summary of flow and nutrient mass flow in the Puarenga Stream.

			total	**baseflow**	**floodflow**	**baseflow**	**floodflow**
PUA	Flow $L\ s^{-1}$	mean	1711	1099	612	64%	36%
PUA	DRP $t\ y^{-1}$	mean	2.27	1.51	0.75	67%	33%
PUA		UCL	2.49	1.61	0.88	65%	35%
PUA		LCL	2.08	1.42	0.66	68%	32%
PUA	PP $t\ y^{-1}$	mean	2.90	0.83	2.07	29%	71%
PUA		UCL	3.61	0.91	2.70	25%	75%
PUA		LCL	2.36	0.76	1.60	32%	68%
PUA	TP $t\ y^{-1}$	mean	4.78	2.36	2.42	49%	51%
PUA		UCL	5.05	2.45	2.60	49%	51%
PUA		LCL	4.54	2.28	2.26	50%	50%
PUA	TIN $t\ y^{-1}$	mean	63.5	41.2	22.2	65%	35%
PUA		UCL	65.6	42.4	23.2	65%	35%
PUA		LCL	61.4	40.0	21.3	65%	35%
UTU	PN $t\ y^{-1}$	mean	15.5	7.2	8.27	47%	53%
UTU		UCL	16.7	7.6	9.11	46%	54%
UTU		LCL	14.4	6.9	7.52	48%	52%
PUA	TN $t\ y^{-1}$	mean	78.6	47.0	31.5	60%	40%
PUA		UCL	81.0	48.2	32.8	60%	40%
PUA		LCL	76.2	45.9	30.4	60%	40%

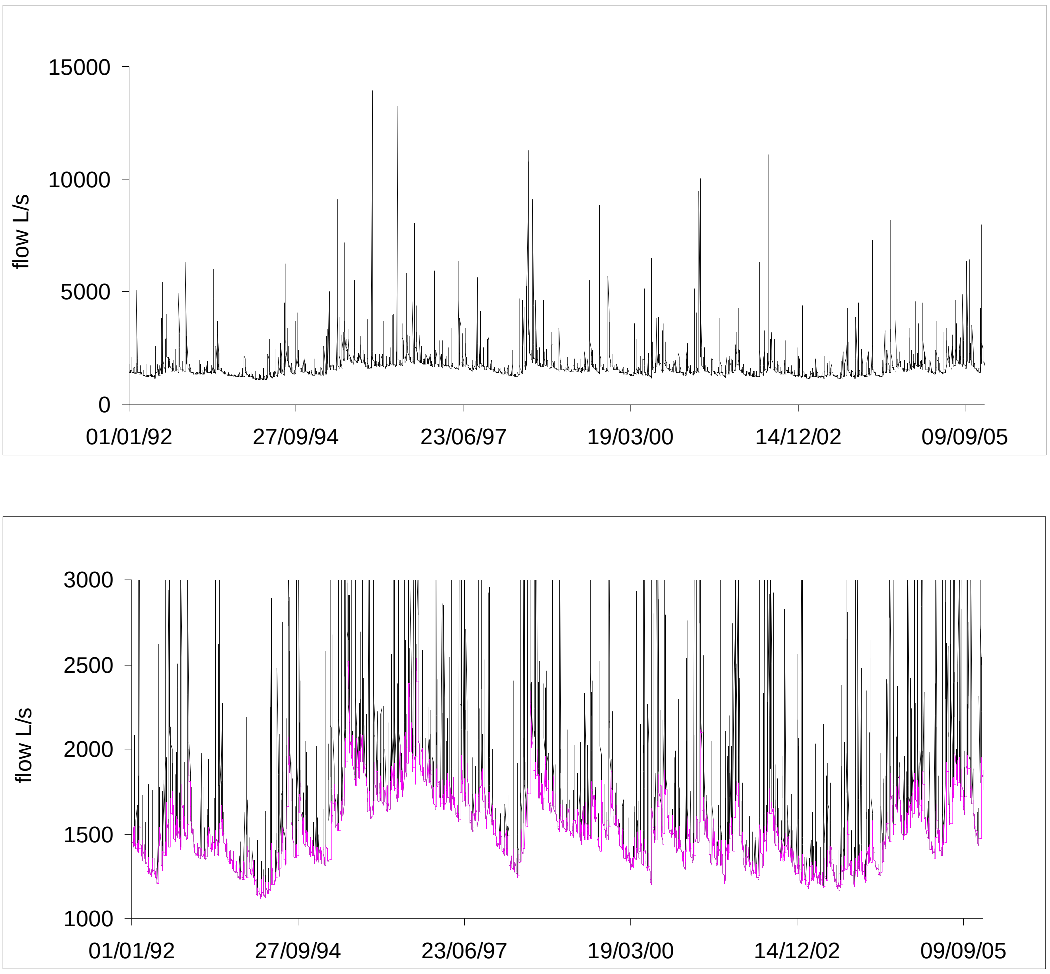
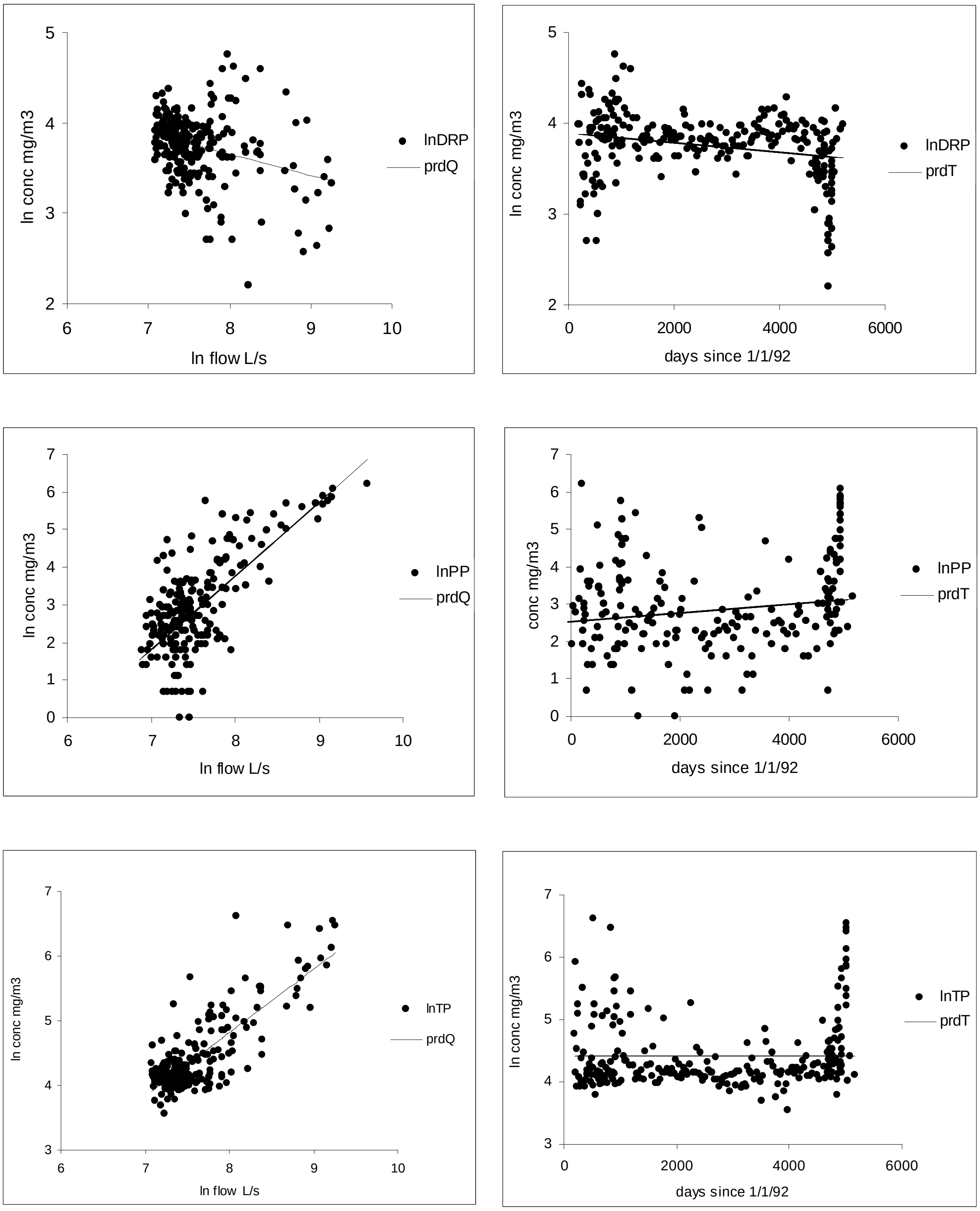
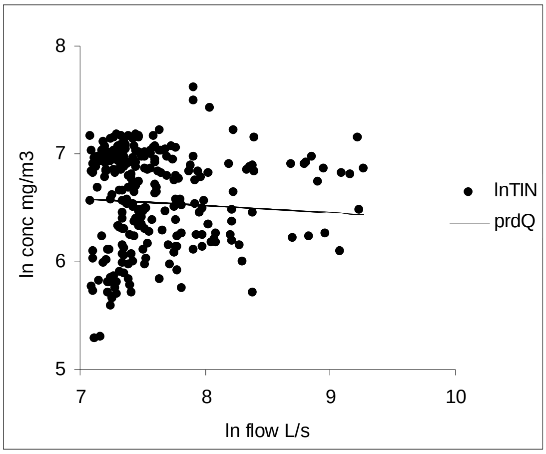
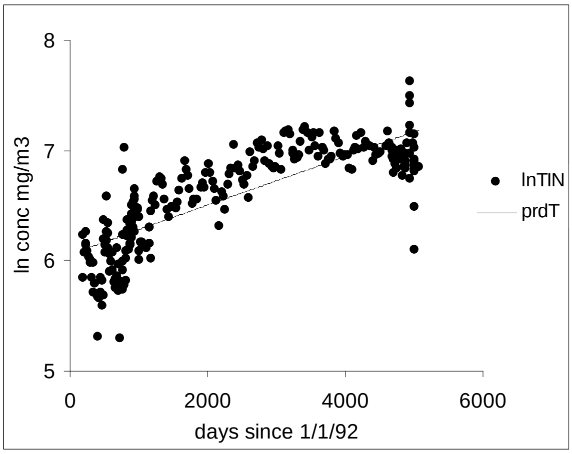


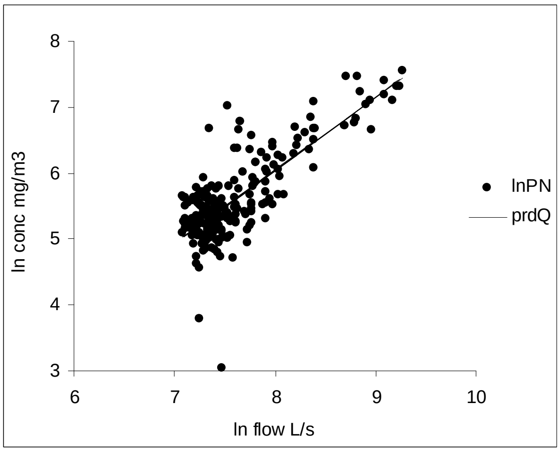
Figure 19: Estimated daily mean flow (black) and baseflow (purple) in the Puarenga Stream 1992-2005.

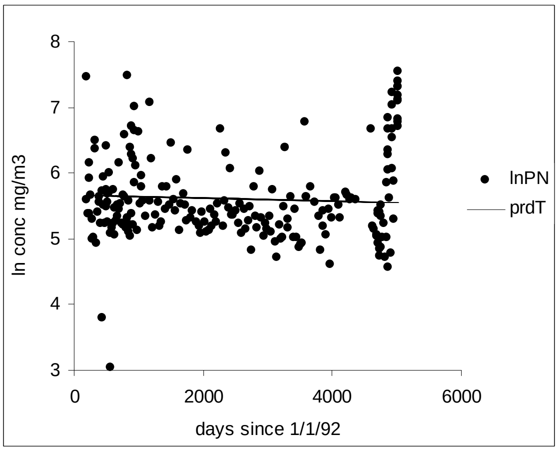
Figure 20: Concentration versus flow (left) and time (right) relationships in the Puarenga Stream derived from data from 1992-2005. Lines are estimated from fitted multiple regression models setting either time (left) or flow (right) to its mean value. PP = TP – DRP and hence includes DOP. PN = TN – TIN and includes DON.

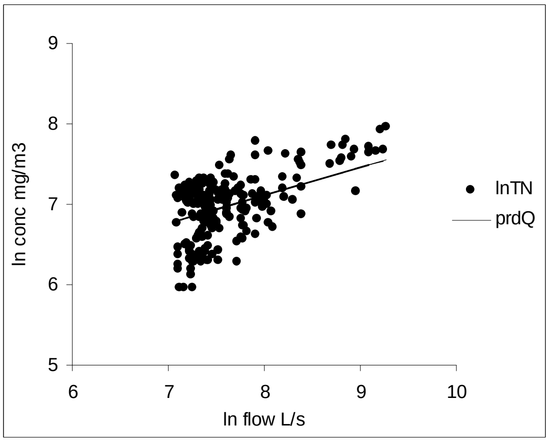



ln conc mg/m3
ln flow L/s
lnTIN
prdQ


ln conc mg/m3
days since 1/1/92
lnTIN
prdT


ln conc mg/m3
ln flow L/s
lnPN
prdQ


ln conc mg/m3
days since 1/1/92
lnPN
prdT


ln conc mg/m3
ln flow L/s
lnTN
prdQ

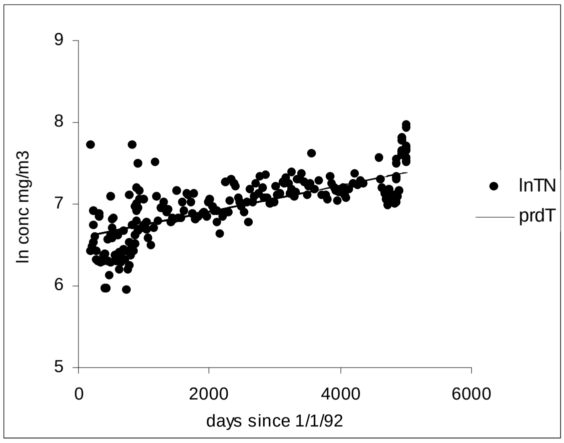

ln conc mg/m3
days since 1/1/92
lnTN
prdT

Table 11: Summary of regression model coefficients for DRP, PP + DOP and TP concentration in 9 major streams at Rotorua. R = regression coefficient, SE = standard error, N = number of samples, df = degrees of freedom, SS = sum of squares, MS = mean square, F = F ratio, Reg = regression, Res = residual, t Stat = Student's t value for the significance of the coefficient, P-value = probability that the coefficient is zero.

Site	DRP	DRP	DRP	DRP	DRP	PP	PP	PP	PP	PP	TP	TP	TP	TP	TP
WTT	R	0.28				R	0.09				R	0.31			
WTT	SE	0.24				SE	13.8				SE	0.22			
WTT	N	94				N	86				N	86			
WTT		df	SS	MS	F		df	SS	MS			df	SS	MS	F
WTT	Reg	2	0.448	0.224	4.01	Reg	2	142	70.9	0.372	Reg	2	0.399	0.199	4.28
WTT	Res	91	5.09	0.0559		Res	83	15800	190		Res	83	3.87	0.0467	
WTT	Total	93	5.54			Total	85	15600			Total	85	4.27		
WTT		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WTT	Intercept	4.67	0.784	5.98	4.27E-08	Intercept	1.14	4.39	0.259	0.795	Intercept	3.63	0.730	4.97	3.54E-06
WTT	lnQ	-0.163	0.114	-1.43	0.155	Q	0.000810	0.00365	0.221	0.825	lnQ	0.00124	0.105	0.0117	0.990
WTT	TIME	3.22-05	1.25-05	2.57	0.012	TIME	0.000644	0.000777	0.828	0.409	TIME	3.55E-05	1.22E-05	2.91	0.00460
WTT			Duan	1.028									Duan	1.024	
WNG	R	0.51				R	0.85				R	0.90			
WNG	SE	0.16				SE	0.97				SE	0.39			
WNG	N	129				N	84				N	125			
WNG		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WNG	Reg	2	1.06	0.533	21.9	Reg	2	192	96.1	101	Reg	2	76.4	38.2	257
WNG	Res	126	3.07	0.0243		Res	81	76	0.943		Res	122	18.1	0.148	
WNG	Total	128	4.13			Total	83	269			Total	124	94.6		
WNG		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WNG	Intercept	5.76	0.260	22.0	3.58E-45	Intercept	-19.9	1.73	-11.5	1.01E-18	Intercept	-8.98	0.643	-13.9	4.52E-27
WNG	lnQ	-0.199	0.0487	-4.07	7.99E-05	lnQ	4.22	0.321	13.1	7.53E-22	lnQ	2.56	0.120	21.3	6.07E-43
WNG	TIME	-2.39E-05	7.31E-06	-3.26	0.001391	TIME	1.87E-05	5.62E-05	0.332	0.740205	TIME	-1.77E-05	1.84E-05	-0.960	0.338767
WNG			Duan	1.01				Duan	1.56				Duan	1.08	

Site	DRP	DRP	DRP	DRP	DRP	PP	PP	PP	PP	PP	TP	TP	TP	TP	TP
WHE	R	0.51				R	0.68				R	0.65			
WHE	SE	0.51				SE	0.67				SE	0.43			
WHE	N	108				N	98				N	102			
WHE		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WHE	Reg	2	9.37	4.68	18.2	Reg	2	36.0	18.0	40.3	Reg	2	13.1	6.56	35.4
WHE	Res	105	26.9	0.256		Res	95	42.5	0.447		Res	99	18.3	0.185	
WHE	Total	107	36.3			Total	97	78.5			Total	101	31.4		
WHE		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WHE	Intercept	7.06	0.669	10.5	3.52E-18	Intercept	-3.53	0.916	-3.85	0.000210	Intercept	0.253	0.578	0.437	0.662
WHE	lnQ	-0.672	0.116	-5.76	8.4E-08	lnQ	1.32	0.159	8.30	6.80E-13	lnQ	0.761	0.100	7.56	2.04E-11
WHE	TIME	7.08E-05	2.67E-05	2.65	0.00920	TIME	-0.000171	3.86E-05	-4.42	2.52E-05	TIME	-0.000111	2.42E-05	-4.58	1.34E-05
WHE			Duan	1.11				Duan	1.25				Duan	1.11	
UTU	R	0.56				R	0.65				R	0.73			
UTU	SE	0.36				SE	1.12				SE	0.28			
UTU	N	159				N	127				N	153			
UTU		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
UTU	Reg	2	9.53	4.76	35.9	Reg	2	110	55.3	44.2	Reg	2	13.8	6.94	86.5
UTU	Res	156	20.6	0.132		Res	124	155	1.25		Res	150	12.0	0.0802	
UTU	Total	158	30.2			Total	126	265			Total	152	25.9		
UTU		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
UTU	Intercept	7.53	0.491	15.3	5.85E-33	Intercept	-12.5	1.63	-7.67	4.28E-12	Intercept	-0.754	0.384	-1.96	0.0517
UTU	lnQ	-0.468	0.0642	-7.29	1.44E-11	lnQ	1.96	0.210	9.35	4.59E-16	lnQ	0.662	0.0503	13.1	9.18E-27
UTU	TIME	-8.20-05	1.52E-05	-5.39	2.55E-07	TIME	0.000174	5.37E-05	3.23	0.00153	TIME	1.95E-05	1.22E-05	1.60	0.111
UTU			Duan	1.06				Duan	1.66				Duan	1.04	

Site	DRP	DRP	DRP	DRP	DRP	PP	PP	PP	PP	PP	TP	TP	TP	TP	TP
PUA	R	0.42				R	0.75				R	0.81			
PUA	SE	0.33				SE	0.80				SE	0.33			
PUA	N	248				N	233				N	243			
PUA		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
PUA	Reg	2	5.64	2.82	25.6	Reg	2	186	93.3	145	Reg	2	50.4	25.2	234
PUA	Res	245	26.9	0.109		Res	230	147	0.641		Res	240	25.7	0.107	0
PUA	Total	247	32.5			Total	232	334			Total	242	76.1	0	0
PUA		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
PUA	Intercept	5.67	0.347	16.3	5.17E-41	Intercept	-11.1	0.852	-13.0	2.00E-29	Intercept	-3.00	0.343	-8.75	3.71E-16
PUA	lnQ	-0.234	0.0461	-5.07	7.50E-07	lnQ	1.88	0.113	16.6	1.68E-41	lnQ	0.979	0.0456	21.4	1.18E-57
PUA	TIME	-5.25E-05	1.2E-05	-4.19	3.75E-05	TIME	2.71E-05	3.16E-05	0.856	0.392	TIME	-2.71E-06	1.26E-05	-0.214	0.830
PUA			Duan	1.05				Duan	1.34				Duan	1.06	
NGO	R	0.35				R	0.71				R	0.87			
NGO	SE	0.25				SE	0.98				SE	0.40			
NGO	N	235				N	217				N	241			
NGO		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
NGO	Reg	2	1.92	0.964	15.7	Reg	2	201	100	105	Reg	2	115	57.8	365
NGO	Res	232	14.2	0.0613		Res	214	203	0.952		Res	238	37.5	0.157	
NGO	Total	234	16.1			Total	216	405			Total	240	153		
NGO		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	*P-value*		Coeff	SE	t Stat	P-value
NGO	Intercept	5.01	0.263	19.0	2.68E-49	Intercept	-12.2	1.058	-11.5	2.54E-24	Intercept	-4.71	0.350	-13.4	3.64E-31
NGO	lnQ	-0.194	0.0350	-5.54	8.15E-08	lnQ	1.96	0.140	13.9	6.11E-32	lnQ	1.15	0.0468	24.6	2.06E-67
NGO	TIME	-4.67E-06	9.21E-06	-0.507	0.612	TIME	0.000116	3.76E-05	3.09	0.00225	TIME	7.91E-05	1.47E-05	5.38	1.76E-07
NGO			Duan	1.03				Duan	1.55				Duan	1.09	

Site	DRP	DRP	DRP	DRP	DRP	PP	PP	PP	PP	PP	TP	TP	TP	TP	TP
HAM	R	0.29				R	0.25				R	0.14			
HAM	SE	8.52				SE	12.60				SE	7.75			
HAM	N	92				N	87				N	88			
HAM		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
HAM	Reg	2	578	289	3.98	Reg	2	882	441	2.77	Reg	2	107	53.8	0.896
HAM	Res	89	6454	72.5		Res	84	1330-0	158		Res	85	5100	60.0	
HAM	Total	91	7030			Total	86	14200			Total	87	5210		
HAM		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
HAM	Intercept	132	16.2	8.15	2.07E-12	Intercept	-68.4	26.1	-2.61	0.0104	Intercept	66.0	15.9	4.14	8.12E-05
HAM	Q	-0.0173	0.00660	-2.62	0.0102	Q	0.0248	0.0106	2.33	0.0219	Q	0.00668	0.00647	1.03	0.304
HAM	TIME	0.0007233	0.000476	1.51	0.132	TIME	-0.000445	0.000751	-0.592	0.555	TIME	0.000341	0.000459	0.743	0.459
HAM															
WWH	R	0.34				R	0.64				R	0.59			
WWH	SE	0.31				SE	1.18				SE	0.31			
WWH	N	109				N	59				N	103			
WWH		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WWH	Reg	2	1.30	0.654	6.87	Reg	2	54.5	27.2	19.6	Reg	2	5.19	2.59	26.6
WWH	Res	106	10.0	0.0952		Res	56	77.9	1.39		Res	100	9.75	0.0975	
WWH	Total	108	11.4			Total	58	132			Total	102	14.9		
WWH		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WWH	Intercept	5.40	0.432	12.4	1.54E-22	Intercept	-7.02	2.08	-3.36	0.00139	Intercept	1.37	0.449	3.06	0.00283
WWH	lnQ	-0.272	0.0737	-3.69	0.000347	lnQ	1.66	0.342	4.88	9.14E-06	lnQ	0.472	0.0764	6.17	1.42E-08
WWH	TIME	-1.21E-05	1.56E-05	-0.778	0.438	TIME	-0.0002007	8.70E-05	-2.30	0.0247	TIME	-4.80E-05	1.70E-05	-2.81	0.00581
WWH			Duan	1.04				Duan	1.97				Duan	1.05	

Site	DRP	DRP	DRP	DRP	DRP	PP	PP	PP	PP	PP	TP	TP	TP	TP	TP
AWA	R	0.26				R	0.43				R	0.58			
AWA	SE	10.53				SE	0.93				SE	0.15			
AWA	N	99				N	27				N	93			
AWA		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
AWA	Reg	2	768	384	3.46	Reg	2	4.76	2.38	2.78	Reg	2	0.967	0.483	22.5
AWA	Res	96	10600	110		Res	24	20.5	0.856		Res	90	1.92	0.0214	
AWA	Total	98	11400			Total	26	25.3			Total	92	2.89		
AWA		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
AWA	Intercept	95.9	11.0	8.67	1.05E-13	Intercept	-22.1	10.9	-2.02	0.0542	Intercept	-3.51	1.28	-2.74	0.00734
AWA	Q	-0.0110	0.00715	-1.53	0.127	Q	3.32	1.48	2.24	0.0342	Q	1.07	0.174	6.11	2.41E-08
AWA	TIME	-0.00113	0.000561	-2.02	0.0457	TIME	4.93E-05	0.000102	0.479	0.636	TIME	-2.75E-05	8.434E-06	-3.26	0.00154
AWA															

Table 12: Summary of regression model coefficients for TIN, PN + DON and TN concentration in 9 major streams at Rotorua.

Site	TIN	TIN	TIN	TIN	TIN	PN	PN	PN	PN	PN	TN	TN	TN	TN	TN
WTT	R	0.38				R	0.12				R	0.16			
WTT	SE	0.063				SE	72.6				SE	86.4			
WTT	N	81				N	64				N	64			
WTT		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WTT	Reg	2	0.0531	0.0265	6.65	Reg	1	5102	5102	0.967	Reg	2	12319	6159	0.823
WTT	Res	78	0.311	0.00399		Res	62	326917	5272		Res	61	456305	7480	
WTT	Total	80	0.364			Total	63	332020			Total	63	468625		
WTT		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WTT	Int	6.85	0.214	31.8	1.66E-46	Int	93.6	23.2	4.03	0.000153	Int	1312	30.5	42.9	2.66E-47
WTT	lnQ	0.0349	0.0310	1.12	0.264	Q	0.0206	0.0209	0.983	0.329	Q	0.0205	0.0251	0.815	0.418
WTT	TIME	1.36E-05	3.91E-06	3.47	0.000825						TIME	0.00859	0.00792	1.08	0.282
WTT			Duan	1.00									Duan	1.02	
WNG	R	0.90				R	0.78				R	0.91			
WNG	SE	0.0844				SE	0.912				SE	0.244			
WNG	N	119				N	109				N	111			
WNG		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WNG	Reg	2	3.55	1.77	244	Reg	2	133	66.6	80.0	Reg	2	31.5	15.7	262
WNG	Res	116	0.827	0.00713		Res	106	88.2	0.832		Res	108	6.47	0.0599	
WNG	Total	118	4.38			Total	108	221			Total	110	37.9		
WNG		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WNG	Int	6.80	0.142	47.7	4.73E-67	Int	-14.7	1.59	-9.23	2.91E-15	Int	-1.02	0.425	-2.41	0.0175
WNG	lnQ	0.00902	0.0266	0.338	0.0732	lnQ	3.69	0.298	12.3	2.93E-22	LOGQ	1.50	0.0796	18.8	4.94E-36
WNG	TIME	8.48E-05	4.17E-06	20.3	3.36E-61	TIME	-0.000152	4.86E-05	-3.12	0.00225	TIME	4.31E-05	1.28E-05	3.34	0.001130
WNG			Duan	1.00				Duan	1.40				Duan	1.03	

Site	TIN	TIN	TIN	TIN	TIN	PN	PN	PN	PN	PN	TN	TN	TN	TN	TN
WHE	R	0.48				R	0.42				R	0.62			
WHE	SE	0.251				SE	1.01				SE	0.266			
WHE	N	89				N	64				N	80			
WHE		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WHE	Reg	2	1.64	0.823	12.9	Reg	2	13.1	6.57	6.38	Reg	2	3.50	1.75	24.6
WHE	Res	86	5.45	0.0634		Res	61	62.7	1.02		Res	77	5.46	0.0710	
WHE	Total	88	7.10			Total	63	75.9			Total	79	8.97		
WHE		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WHE	Int	6.64	0.357	18.5	7.46E-32	Int	0.512	1.56	0.328	0.744	Int	5.72	0.379	15.0	1.03E-24
WHE	lnQ	0.254	0.0624	4.07	0.000102	lnQ	0.952	0.270	3.51	0.000834	LOGQ	0.438	0.0659	6.65	3.7E-09
WHE	TIME	-5.59E-05	1.60E-05	-3.49	0.000751	TIME	-7.92E-05	0.000103	-0.766	0.446	TIME	-6.04E-05	2.44E-05	-2.47	0.0155
WHE			Duan	1.03				Duan	1.50				Duan	1.03	
UTU	R	0.19				R	0.64				R	0.62			
UTU	SE	0.207				SE	0.682				SE	0.216			
UTU	N	147				N	127				N	127			
UTU		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
UTU	Reg	2	0.238	0.119	2.77	Reg	2	39.1	19.5	41.9	Reg	2	3.58	1.79	38.4
UTU	Res	144	6.19	0.043		Res	124	57.8	0.466		Res	124	5.78	0.0466	
UTU	Total	146	6.43			Total	126	96.9			Total	126	9.37		
UTU		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
UTU	Int	7.20	0.282	25.5	2.36E-55	Int	-3.24	0.960	-3.37	0.000981	Int	4.26	0.303	14.0	2.30E-27
UTU	lnQ	-0.0861	0.0368	-2.33	0.0207	lnQ	1.12	0.125	9.01	3.02E-15	lnQ	0.344	0.0396	8.69	1.79E-14
UTU	TIME	-4.76E-07	9.15E-06	-0.0520	0.958	TIME	-2.24E-05	3.31E-05	-0.676	0.499	TIME	-2.50E-06	1.04E-05	-0.239	0.811
UTU			Duan	1.02				Duan	1.19				Duan	1.02	

Site	TIN	TIN	TIN	TIN	TIN	PN	PN	PN	PN	PN	TN	TN	TN	TN	TN
PUA	R	0.81				R	0.79				R	0.85			
PUA	SE	0.266				SE	0.411				SE	0.210			
PUA	N	260				N	218				N	218			
PUA		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
PUA	Reg	2	34.6	17.3	244	Reg	2	60.3	30.1	177	Reg	2	25.3	12.6	286
PUA	Res	257	18.2	0.0710		Res	215	36.4	0.169		Res	215	9.50	0.0442	
PUA	Total	259	52.9			Total	217	96.8			Total	217	34.8		
PUA		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
PUA	Int	6.55	0.274	23.8	4.73E-67	Int	-2.79	0.447	-6.24	2.24E-09	Int	3.93	0.228	17.2	1.91E-42
PUA	lnQ	-0.0655	0.0364	-1.79	0.0732	lnQ	1.11	0.0595	18.6	8.31E-47	lnQ	0.348	0.0304	11.4	5.06E-24
PUA	TIME	0.000222	1.00E-05	22.0	3.36E-61	TIME	-2.22E-05	1.73E-05	-1.27	0.202	TIME	0.000159	8.87E-06	18.0	7.84E-45
PUA			Duan	1.03				Duan	1.08				Duan	1.02	
NGO	R	0.44				R	0.85				R	0.89			
NGO	SE	0.122				SE	0.487				SE	0.172			
NGO	N	233				N	212				N	213			
NGO		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
NGO	Reg	2	0.813	0.406	26.9	Reg	2	130	65.0	273	Reg	2	24.7	12.3	414
NGO	Res	230	3.47	0.0150		Res	209	49.7	0.238		Res	210	6.27	0.0298	
NGO	Total	232	4.28			Total	211	179			Total	212	31.0		
NGO		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
NGO	Int	6.90	0.109	63.1	2.62E-147	Int	-4.65	0.450	-10.3	1.68E-20	Int	2.80	0.158	17.6	1.83E-43
NGO	lnQ	-0.0481	0.0146	-3.28	0.00118	lnQ	1.34	0.0605	22.2	4.62E-57	lnQ	0.541	0.0213	25.3	6.65E-66
NGO	TIME	3.35E-05	4.67E-06	7.17	9.97E-12	TIME	1.92E-07	1.99E-05	0.00961	0.992	TIME	3.82E-05	7.05E-06	5.41	1.67E-07
NGO			Duan	1.00				Duan	1.14				Duan	1.01	

Site	TIN	TIN	TIN	TIN	TIN	PN	PN	PN	PN	PN	TN	TN	TN	TN	TN
HAM	R	0.46				R	0.17				R	0.35			
HAM	SE	51.7				SE	66.1				SE	75.2			
HAM	N	85				N	72				N	72			
HAM		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
HAM	Reg	2	58452	29226	10.8		2	9472	4736	1.08	Reg	2	55858	27929	4.92
HAM	Res	82	219998	2682			69	301536	4370		Res	69	391041	5667	
HAM	Total	84	278450				71	311008			Total	71	446899		
HAM		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
HAM	Int	426	108	3.92	0.000181	Int	-116	144	-0.809	0.420	Int	261	164	1.59	0.115
HAM	Q	0.0860	0.0441	1.95	0.0545	Q	0.0757	0.0583	1.29	0.198	Q	0.180	0.0664	2.72	0.00818
HAM	TIME	0.0128	0.00316	4.06	0.000111	TIME	-0.00361	0.005269	-0.685	0.495	TIME	0.00949	0.00600	1.58	0.118
WWH	R	0.24				R	0.58				R	0.52			
WWH	SE	0.203				SE	0.614				SE	0.195			
WWH	N	95				N	81				N	82			
WWH		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
WWH	Reg	2	0.226	0.113	2.74		2	14.7	7.37	19.5	Reg	2	1.11	0.558	14.5
WWH	Res	92	3.80	0.0413			78	29.4	0.377		Res	79	3.03	0.0383	
WWH		94	4.03				80	44.1			Total	81	4.14		
WWH		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
WWH	Int	6.63	0.296	22.4	4.73E-39	Int	-0.490	0.897	-0.546	0.586	Int	5.44	0.290	18.7	8.62E-31
WWH	Q	0.0116	0.0503	0.231	0.817	lnQ	0.963	0.155	6.18	2.70E-08	LOGQ	0.262	0.0493	5.32	9.22E-07
WWH	TIME	2.84E-05	1.21E-05	2.33	0.0215	TIME	-2.80E-06	3.91E-05	-0.0718	0.942	TIME	-1.75E-06	1.52E-05	-0.115	0.908
WWH			Duan	1.01				Duan	1.20				Duan	1.01	

Site	TIN	TIN	TIN	TIN	TIN	PN	PN	PN	PN	PN	TN	TN	TN	TN	TN
AWA	R	0.51				R	0.18				R	0.54			
AWA	SE	90.2				SE	1.31				SE	0.0923			
AWA	N	87				N	78				N	79			
AWA		df	SS	MS	F		df	SS	MS	F		df	SS	MS	F
AWA	Reg	2	235206	117603	14.4	Reg	2	4.30	2.15	1.23	Reg	2	0.265	0.132	15.5
AWA	Res	84	683674	8138		Res	75	130	1.74		Res	76	0.648	0.00853	
AWA	Total	86	918881			Total	77	134			Total	78	0.913		
AWA		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value		Coeff	SE	t Stat	P-value
AWA	Int	1082	97.2	11.1	3.23E-18	Int	-14.2	11.8	-1.20	0.233	Int	3.18	0.830	3.84	0.0002513
AWA	Q	-0.00371	0.0629	-0.0591	0.953	lnQ	2.50	1.61	1.54	0.125	LOGQ	0.529	0.113	4.67	1.26E-05
AWA	TIME	0.0305	0.00570	5.35	7.20E-07	TIME	-4.8E-05	0.000102	-0.476	0.635	TIME	1.72E-05	7.1E-06	2.42	0.0178

4. Intensive storm surveys

4.1 Ngongotaha

Two storms occurred during the sampling period: Storm1 on 12th-13th July 2005 and Storm2 on 18th-21st September 2005. Regression models fitted to data from each storm separately furnished significantly different model coefficients (Table 13). Despite the two storms having carrying a similar total volume of water (1.04 and 1.08 GL), the total nutrient loads estimated using the separate models differed by a factor of ~3 for DRP, PP and TP (Table 14). DRP concentration was almost constant during Storm 1 but increased with flow during Storm 2. PP increased with flow in both storms but for a given flow concentrations were higher during Storm 2. TP being the sum of DRP and PP reflected this behaviour. TIN loads were similar in both storms because TIN concentration varied with flow in a similar manner. PN concentration varied with flow in both storms but for a given flow, PN concentrations were higher during Storm 2 although by a smaller percentage than was the case for PP.

The uncertainty in total load for each storm was estimated using the Monte Carlo simulation approach. The 95% confidence limit *for a given storm* is <5%. However, the difference *between storms* is 160-180% for phosphorus and 0-30% for nitrogen.

Loads were estimated for both storms using the regression coefficients fitted to the 1992-2005 dataset (termed 'global'). Using the global coefficients, similar loads were estimated for Storm1 and Storm2 (Table 15). The coefficients fitted only to Storm1 data give the most reliable load estimate for Storm1. Comparing loads for Storm1 predicted using coefficients fitted to Storm1 data (Storm1 in Table 15) with loads predicted using the global coefficients (Storm1 Global) the difference varies between -59% (PP) and +2% (TIN). Comparing loads for Storm2 the difference varies between -9% (TIN) and +101% (DRP). Generally the differences are smaller for the nitrogen than for phosphorus.

Table 13: Summary of regression model coefficients for DRP, PP, TIN and PN in the Ngongotaha Stream for 2 storms in 2005.

Storm1	**DRP**	**PP**	**TIN**	**PN**
a_o	3.38	-6.80	8.22	-2.89
A_1	-0.0323	1.36	-0.184	1.10
Duan	1.02	1.07	1.00	1.10
SE reg	0.272	0.440	0.113	0.456
N	17	17	17	17
Storm2	**DRP**	**PP**	**TIN**	**PN**
a_o	0.0665	-10.6	5.21	-6.84
A_1	0.464	1.91	0.158	1.58
Duan	1.01	1.07	1.00	1.06
SE reg	0.24	0.43	0.09	0.41
N	11	11	11	11

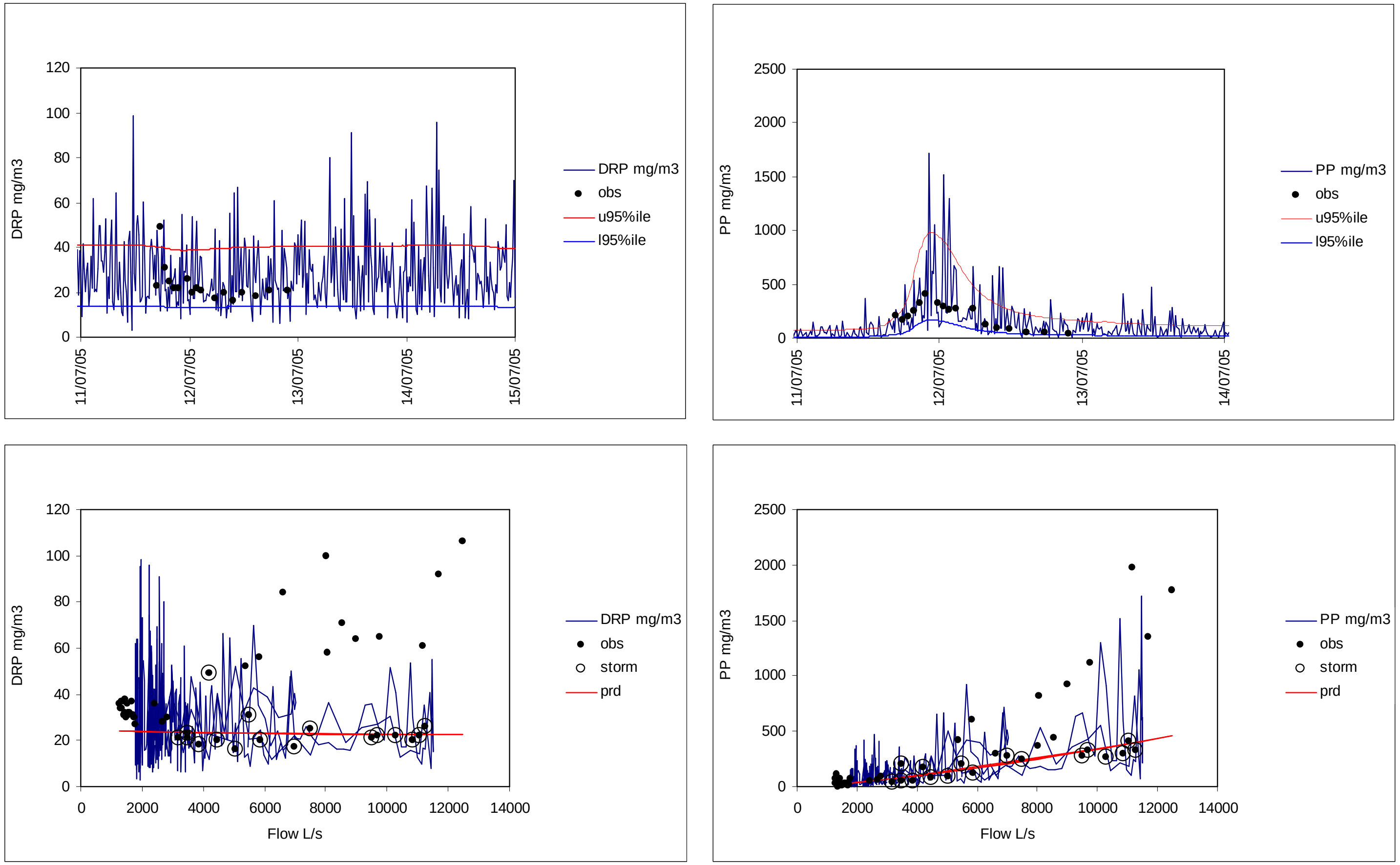
Table 14: Total nutrient load and water volume in the Ngongotaha Stream delivered by 2 storms in 2005.

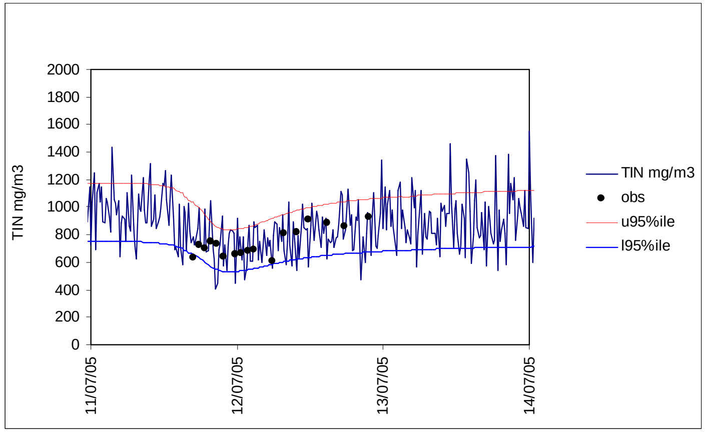
Storm1	**water GL**	**DRP kg**	**PP kg**	**TP**	**TIN kg**	**PN kg**	**TN**
mean	1.04	27.2	240	267	839	1270	2110
SD		0.9	22	23	10	115	125
95%ile		0.4	10	10	4	50	55
95%ile		1.4%	4.1%	3.8%	0.5%	4.0%	2.6%
Storm2	**water GL**	**DRP kg**	**PP kg**	**TP**	**TIN kg**	**PN kg**	**TN**
mean	1.08	70.2	681	752	774	1640	2412
SD		2.8	75	78	12	155	166
95%ile		1.2	33	34	5	68	73
95%ile		1.7%	4.8%	4.5%	0.6%	4.1%	3.0%
Storm1/Storm2	97%	39%	35%	36%	108%	78%	88%

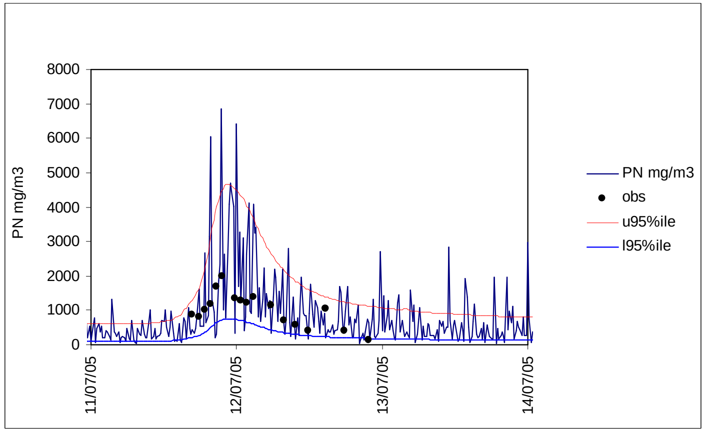
Table 15: Comparison of nutrient load in the Ngongotaha Stream for 2 storms in 2005 predicted using global and storm-specific coefficients. 'Storm1' denotes loads for Storm1 estimated using coefficients fitted to Storm1 data only. 'Storm1 Global' denotes loads for Storm1 estimated using coefficients fitted all data 1992-2005. Similarly for 'Storm2' and 'Storm2 Global'.

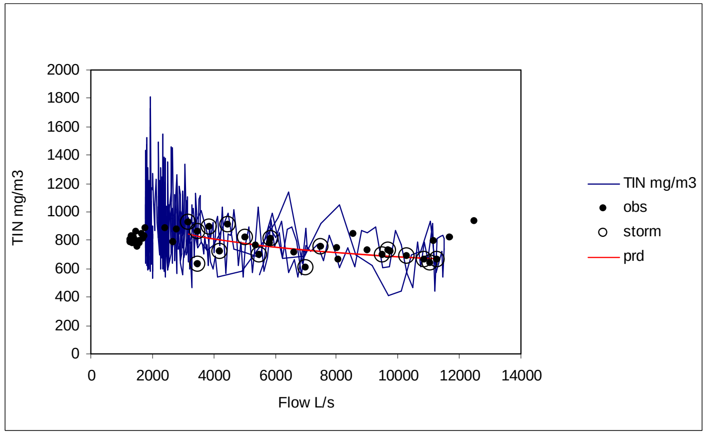
		GL	DRP kg	PP kg	TP kg	TIN kg	PN kg	TN kg
Storm1	mean	1.04	24.7	184	209	826	960	1786
Storm1	95%ile		0.2	4	4	3	20	23
Storm1 Global	mean	1.04	30.8	446	477	807	1465	2272
Storm1 Global	95%ile		0.1	19	19	1	19	21
Storm1/Global			80%	41%	44%	102%	66%	79%
Storm2	mean	1.08	65.0	546	611	764	1325	2089
Storm2	95%ile		0.4	14	14	2	27	27
Storm2 Global	mean	1.08	32.3	429	461	834	1413	2247
Storm2 Global	95%ile		0.1	17	17	1	14	15
Storm2/Global			201%	127%	132%	91%	94%	93%

Figure 21: Observed and predicted nutrient concentrations during Storm 1. Dark blue line = one realisation of predicted concentration including error. Red & light blue lines = upper & lower 95% confidence interval on the predicted mean concentration. Dots = all monitoring observations 1992-2005. Circled dots = intensive storm sampling 2004-2005.




TIN mg/m3
obs
u95%ile
l95%ile
11/07/05
12/07/05
13/07/05
14/07/05


PN mg/m3
obs
u95%ile
l95%ile
11/07/05
12/07/05
13/07/05
14/07/05


TIN mg/m3
obs
storm
prd
Flow L/s

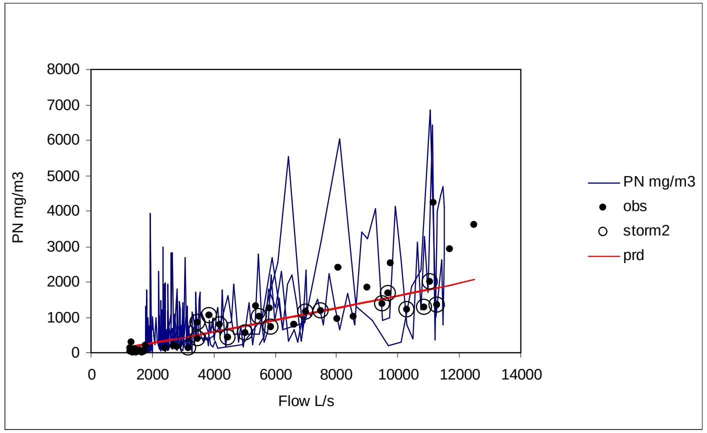
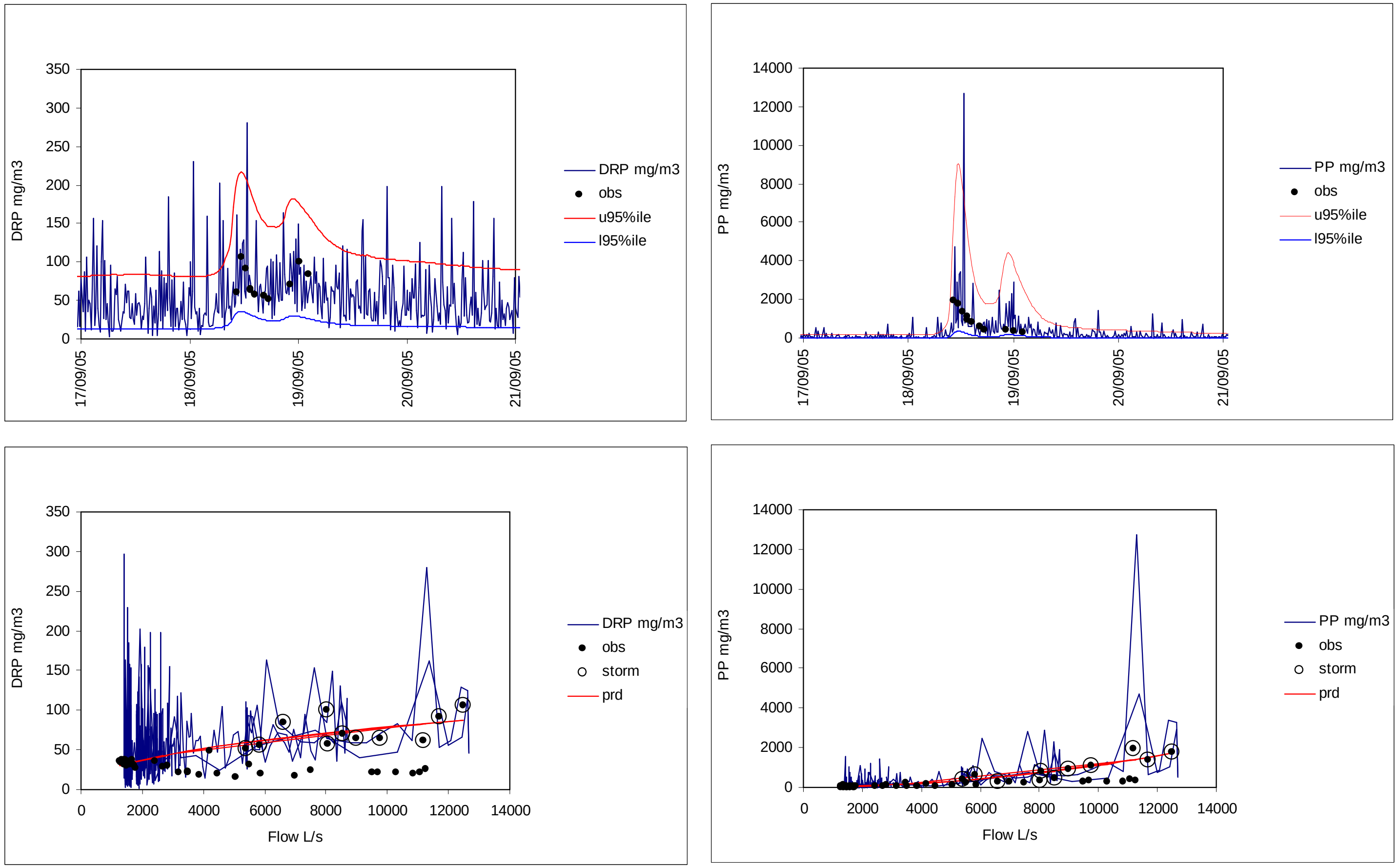
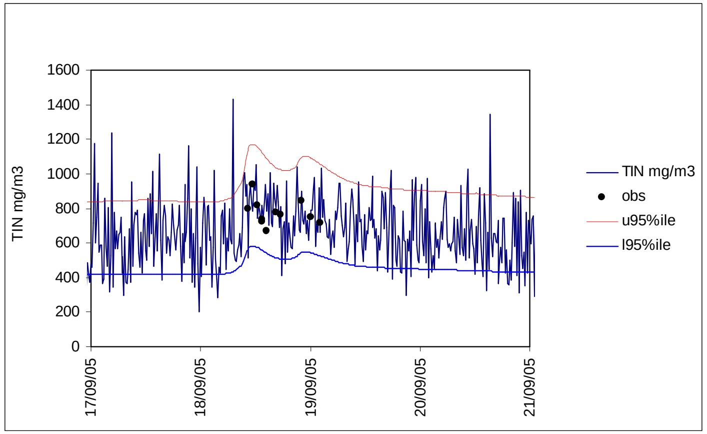
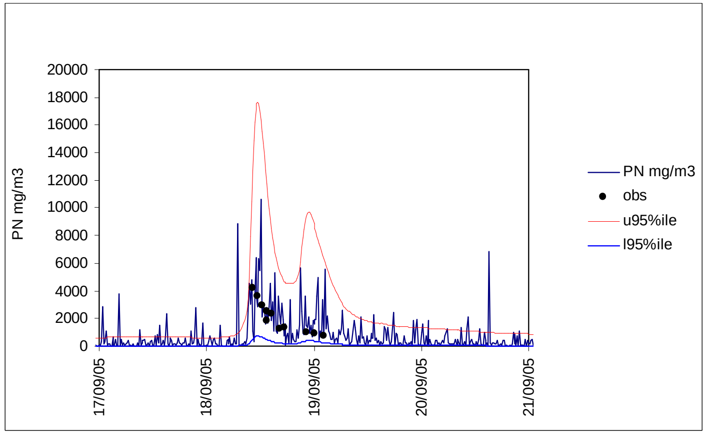
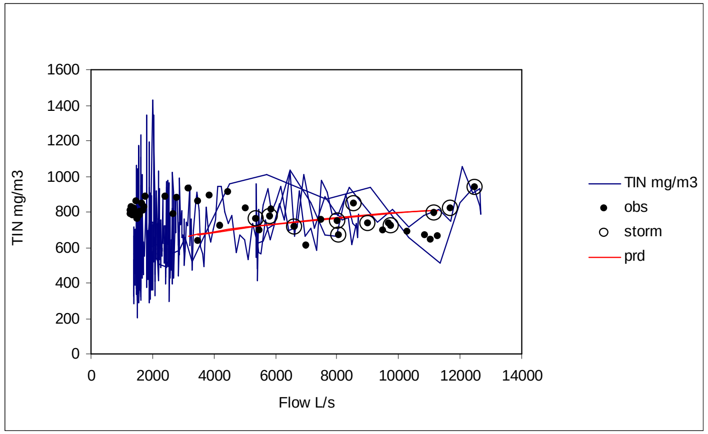

PN mg/m3
obs
storm2
prd
Flow L/s

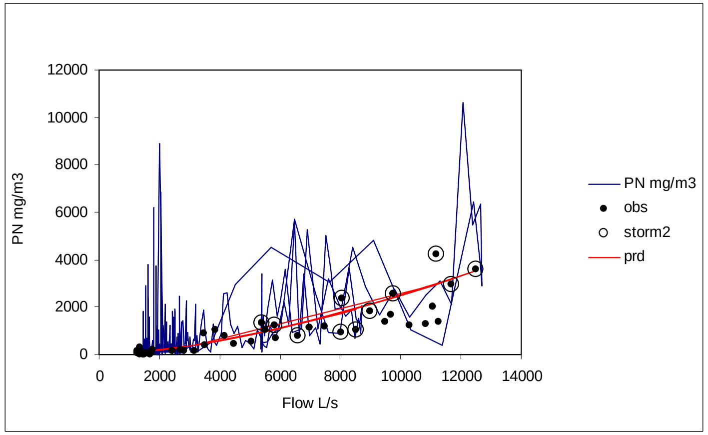
Figure 22: Observed and predicted nutrient concentrations during Storm 2.




TIN mg/m3
obs
u95%ile
l95%ile
17/09/05
18/09/05
19/09/05
20/09/05
21/09/05


PN mg/m3
obs
u95%ile
l95%ile
17/09/05
18/09/05
19/09/05
20/09/05
21/09/05


TIN mg/m3
obs
storm
prd
Flow L/s


PN mg/m3
obs
storm2
prd
Flow L/s

5. Discussion & conclusions

This study shows that the load of nutrient generated and delivered to the stream can differ between storms of similar magnitude by as much as 100%. Hoare (1980b) also found significant differences in load between similar storms. Factors such as rainfall intensity and duration, time since last storm, antecedent soil moisture and pasture condition probably determine this variability. However, for the storms studied in 2004-2005 there is not enough information about these factors to attempt to develop predictive models.

In this study regression models have been fitted to all the available data for 1992-2005. There is evidence that the actual load for a given storm may differ significantly from the predicted load – as is the case for Storm2 phosphorus. However, we are principally interested in the long-term average load. If the available monitoring data encompass the complete range of the factors that determine nutrient load (viz., rainfall intensity and duration, time since last storm, antecedent soil moisture, pasture condition etc.) then we would expect our global model (viz., the model fitted to all the monitoring data) to give an unbiased estimate of the long-term load. In the absence of evidence to the contrary, this assumption seems reasonable.

Estimated nutrient loads at the major sites can be compared with previous measurements in 1976-1977 Hoare (1980a, 1980b) (Table 16-17).

Total flow at the major sites currently averages 11.4 $m^3 s^{-1}$ which is only 86% of the total flow at the same sites of 13.3 m^3 s^{-1} in 1976 (Hoare 1980a). To facilitate load comparisons, 1992-2005 nutrient loads are adjusted to the 1976 flow using the method described by Williamson et al. (1996).

DRP load is currently 19-21 t y^{-1} which is very similar to the 20-21 t y^{-1} measured in 1976-1977 (Hoare 1980b). If the current load is 'adjusted' to the 1976 flow, however, current load is 10-20% higher than in 1976-1977.

PP and DOP concentrations were measured in 2004-2005 but for the 1992-2005 EBoP dataset were estimated by difference (viz., PP + DOP = TP – DRP). In several baseflow samples DRP > TP although at high flows TP > DRP. Samples where DRP > TP were omitted and this may have introduced a slight bias into the regression models for PP + DOP versus flow or time. Nevertheless the clear inference is that baseflow PP and/or DOP concentrations are low while floods carry measurable concentrations of PP and/or DOP. There is higher uncertainty in the regression models for PP + DOP than for other constituents. As a result predicted PP + DOP loads have a large 95%ile range (10-20 t y^{-1}). The current mean load (15 t y^{-1}) is smaller than that reported of 19 t y^{-1} for 1976-1977

(Hoare 1980b). After adjusting the current load to 1976 flows, current loads are on average 10% lower (range 39% lower to 23% higher) than in 1976. However, given the uncertainty in load estimates it might be unwise to conclude solely from this analysis that PP + DOP loads are currently significantly lower than in 1976-1977. On the other hand, a similar trend in TP and PN loads lends support to this suggestion.

TP loads are currently 28-33 t y^{-1} which is significantly lower than the 39-40 t y^{-1} reported for 1976-1977 by Hoare (1980b). Even after adjusting current loads to 1976 flows, current loads are on average 11% lower (range 4-17% lower) than 1976 values.

TIN load is currently 350-370 t y^{-1} which is significantly higher than the load of 276-295 t y^{-1} in 1976-1977. This is consistent with a significant increase in baseflow nitrate concentration in 8 of these major streams identified by Rutherford (2003). The scaled TIN load is 47% higher than in 1976-1977 (range 42-52%). TN load is currently 419-456 t y^{-1} compared with 416-435 t y^{-1} in 1976-1977. The scaled TN load is 19% higher than in 1976-1977 (range 14-25%).

In contrast PN + DON load appears to have decreased significantly since 1976-1977. The current PN + DON load is 64-108 t y^{-1} compared with 140 t y^{-1} in 1976-1977. There is a large uncertainty in our estimates of PN + DON load but even so the reduction is substantial. The scaled PN + DON load is 31% lower (range 11-47%) than in 1976-1977.

Overall there is evidence that PP + DOP and TP loads are lower now than in 1976-1977 by ~10%. The TP load is lower despite an increase in DRP load – evidence that particulate and/or dissolved organic phosphorus loads have decreased. There is also evidence that PN + DON loads are lower now than in 1976-1977 by ~30% although load estimates for particulate nutrients have a large uncertainty.

There are three possible explanations for these findings. Firstly, they may arise simply because there were fewer large floods in 1992-2005 than in 1976-1977. Although we scaled current loads to 1976 flows our scaling method assumes that load is proportional to flow. For PP, TP, PN and TN *concentration* increases with flow and so *load* increases non-linearly with flow. Had there been more floods during 1992-2005 then using the regression models developed during this study, the loads of PP, TP, PN and TN may have been higher than the scaled estimates in Table 16-17. It would be possible to address this issue by making a more detailed comparison of flood flows in 1976-1977 and 1992-2005. Secondly, the regression models developed using 1992-2005 data may be biased because of the small number of floods. Had larger floods occurred and been sampled in 1992-2005 it is possible that different flow versus concentration relationships would have been derived. If so then estimated loads would be different. It may be possible to investigate this possibility by comparing concentration versus flow relationships from 1976-1977 with those from 1992-2005. Thirdly, catchment control works may have resulted in lower particulate nutrient loads reaching streams. Williamson et al. (1996) showed that in the Ngongotaha Stream catchment control works (including riparian fencing and the retirement of some erosion-prone land) resulted in a significant decrease in suspended sediment (85%), particulate P (27%) and particulate N (40%) loads. The results of this study suggest that when all the major streams are considered, the average reduction in particulate P load is 10% and in particulate N is ~30%. Williamson et al. (1996) found that catchment control works also decreased soluble P load (26%). Our study suggests, however, that DRP load has increased by ~10-20% since 1976.

DRP and TIN concentrations are either uncorrelated with flow or vary only slightly. Consequently the loads of these nutrients are proportional to flow and the fractions carried by baseflow and floodflow are almost the same as the proportions of water carried (Table 18).

In contrast PP and PN concentrations are strongly correlated with flow. In springfed streams (notably the Hamurana) this correlation is of little consequence because storm flows are very rare. Consequently in streams with a very high baseflow component, the proportions of PP and PN load carried by storms are similar to the proportions of water (Table 18). Several streams have a significant floodflow component (notably the Ngongotaha, Utuhina and Puarenga). In these streams floods carry a disproportionately large fraction of the particulate load (Table 18). Whereas floods carry 36-44% of water in the Ngongotaha, Utuhina and Puarenga, they carry 68-89% of PP and 43-74% of PN.

TP and TN are the sum of DRP and TIN, that do not vary significantly with flow, and PP and PN that do. In few streams is TN dominated by TIN or TP by DRP. However, in most streams DRP and DIN are a substantial fraction of TP and TN (typically ~50%). Consequently floods do not carry as high a percentage of the total load for TP and TN as for PP and PN.

Table 18: Summary of the percentage of water and nutrient load carried by storms.

Site	WATER	DRP	TIN	PP	PN
HAM	1	1	1	0	1
AWA	8	7-8	8	14-37	9-38
WNG	8	8	8	28-35	23-28
WWH	29	26-27	29	47-62	38-43
WTT	32	29-31	24-33	(32)	(24)
WHE	35	29-30	37-39	53-60	45-54
PUA	36	32-35	35	68-75	52-54
UTU	37	32	34-39	70-80	43-76
NGO	44	41-42	44	83-89	71-74

Table 16: Summary of flow and phosphorus load in the major streams 1992-2005 and 1976.

	1976 [1] flow L s^{-1}	1992-2005 flow L s^{-1}	mean DRP t y^{-1}	upper 95%ile DRP t y^{-1}	lower 95%ile DRP t y^{-1}	mean PP+DOP t y^{-1}	upper 95%ile PP+DOP t y^{-1}	lower 95%ile PP+DOP t y^{-1}	mean TP t y^{-1}	upper 95%ile TP t y^{-1}	lower 95%ile TP t y^{-1}
AWA	1664	1594	3.7	3.8	3.6	1.2	1.8	0.7	3.6	3.8	3.5
HAM	3080	2495	7.2	7.4	7.1	0.0	0.3	-0.3	6.6	6.8	6.5
NGO	1977	1734	1.9	2.0	1.9	5.2	7.0	3.5	6.0	6.5	5.6
PUA	2050	1711	2.3	2.5	2.1	3.0	3.6	2.4	4.8	5.1	4.5
UTU	2040	1845	2.4	2.5	2.2	4.2	5.9	2.8	5.0	6.0	4.2
WHE	413	319	0.3	0.3	0.3	0.5	0.6	0.4	0.8	0.9	0.7
WNG	274	227	0.7	0.7	0.7	0.3	0.4	0.3	1.1	1.1	1.0
WTT	1391	1156	1.3	1.4	1.2	0.1	0.2	0.0	1.7	1.8	1.6
WWH	415	358	0.5	0.5	0.5	0.2	0.3	0.1	0.6	0.7	0.6
TOTAL		**11439**	**20.3**	**21.2**	**19.5**	**14.7**	**20.1**	**9.9**	**30.3**	**32.6**	**28.1**
1976 [2]	13304		20.5			19.0			39.5		
1977 [2]			19.7			18.8			38.5		
92-05/76		86%	99%	103%	95%	77%	106%	52%	77%	83%	71%
ADJUSTED [3]		**100%**	**115%**	**120%**	**110%**	**90%**	**123%**	**61%**	**89%**	**96%**	**83%**

[1] Hoare (1908a)
[2] Hoare (1980b)
[3] scaled to 1976 flow

Table 17: Summary of flow and nitrogen load in the major streams 1992-2005 and 1976.

	1976 [1] flow L s^{-1}	**1992-2005 flow L s^{-1}**	**mean TIN t y^{-1}**	**upper 95%ile TIN t y^{-1}**	**lower 95%ile TIN t y^{-1}**	**mean PN+DON t y^{-1}**	**upper 95%ile PN+DON t y^{-1}**	**lower 95%ile PN+DON t y^{-1}**	**mean TN t y^{-1}**	**upper 95%ile TN t y^{-1}**	**lower 95%ile TN t y^{-1}**
AWA	1664	1594	61	62	60	5	8	3	66	67	64
HAM	3080	2495	55	56	54	5	7	4	60	61	58
NGO	1977	1734	44	45	43	23	26	21	68	70	67
PUA	2050	1711	63	66	61	16	17	14	79	81	76
UTU	2040	1845	42	46	38	19	33	10	58	65	52
WHE	413	319	28	29	26	5	7	4	32	34	30
WNG	274	227	10	10	10	1	1	1	11	12	11
WTT	1391	1156	47	48	46	6	6	5	50	51	49
WWH	415	358	11	11	10	3	3	2	13	13	12
TOTAL		**11439**	**361**	**373**	**350**	**83**	**108**	**64**	**437**	**456**	**419**
1976 [2]	13304		295			140			435		
1977 [2]			276			140			416		
92-05/76		86%	127%	131%	122%	59%	77%	45%	103%	107%	98%
ADJUSTED [3]		**100%**	**147%**	**152%**	**142%**	**69%**	**89%**	**53%**	**119%**	**125%**	**114%**

[1] Hoare (1908a)
[2] Hoare (1980b)
[3] scaled to 1976 flow

6. References

Duan, N. (1983). Smearing estimate: a non-parametric retransformation method. *Journal of the American Statistical Association 78(383)*: 605-610.

Hoare, R.A. (1980a). The sensitivity to phosphorus and nitrogen of Lake Rotorua, New Zealand. *Progress in Water Technology 12*: 897-904.

Hoare, R.A. (1980b). Inflows to Lake Rotorua. *Journal of Hydrology (New Zealand) 19(1):* 49-59.

Pettyjohn, W.A.; Henning, R. (1979). Preliminary estimates of ground-water recharge rates relating to streamflow and water quality in Ohio. Ohio State University Water Resources Centre Project Report No 552, 323 pp.

Rutherford, J.C. (2003). Lake Rotorua Nutrient Load Targets. NIWA Client Report: HAM2003-155. NIWA, Hamilton. October 2003.

Williamson, R.B.; Smith, C.M.; Cooper, A.B. (1996). Watershed riparian management and its benefits to a eutrophic lake. *Journal of Water Resources Planning and Management 122:* 24-32.