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Nitrogen concentrations and loads in the Hurunui River at SH1

Prepared for Ngai Tahu Farming Ltd

Report C16041/1

March 2016

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Quality Control			
Client:	Ngai Tahu Farming Ltd		
Report reference:	Title: Nitrogen concentrations and loads in the Hurunui River at SH1		No: 1
Prepared by:	Dr. Peter Brown		
Reviewed by:	Dr. Caroline Fraser	Approved for issue by:	Dr. Helen Rutter
Date issued:	March	Project No:	C16041

Document History							
Version:	1.0	Status:	Draft for discussion	Author: PB	Reviewer:		
Date:	16-03-04	Doc ID:	HurunuiNAnalysis_2016-03-04_DRAFT	Typist:	Approver:		
Version:	1.1	Status:	FINAL	Author: PB	Reviewer: CF		
Date:	16-03-09	Doc ID:	HurunuiNAnalysis_2016-03-09_FINAL	Typist:	Approver: HR		

www.aqualinc.com

CHRISTCHURCH PO Box 20-462, Bishopdale 8543, Christchurch ♦ Phone: (03) 964 6521 ♦ Fax: (03) 964 6520

HAMILTON PO Box 14-041, Enderley 3252, Hamilton ♦ Phone: (07) 858 4851 ♦

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Executive Summary

The Hurunui Waiau River Regional Plan (HWRRP - the Plan) specifies both load and concentration limits for the Hurunui River at SH1. The Plan limits were set to reflect the load and concentrations for the reference period from July 2005 to June 2011. Nitrogen was considered to be a secondary nutrient limiting periphyton growth, with Phosphorus being the primary limiting nutrient. The Plan allows for a 25% increase in the nitrogen load relative to the reference period: the reasoning was that provided Phosphorus did not increase, some increase in nitrogen should not increase the risk of periphyton growth.

Now that the plan is operative, a key question is how compliance with Plan limits should be assessed, given the uncertainty in measuring loads. The Plan provides little guidance on this matter. This report provides an analysis of the Dissolve Inorganic Nitrogen (DIN) data, including an analysis of the uncertainty, variability and underlying trends in concentrations and loads.

The conclusions from this study were:

Concentration

1. From 1984 to 2000 there is a trend of increasing DIN concentrations. The average concentration for the period 1984 to 2000 is 25% lower, compared to that from 2000 to 2015.
2. From 2000 to 2015 there is no statistically significant trend in DIN concentrations.
3. DIN concentrations in the Hurunui River at SH1 are well below Plan limits.
4. Concentrations tend to decrease with increasing flow. However the relationship is weak, and only explains 25% of variability.

Load sampling error

5. Load sampling error[1] is high, because sampling only occurs 1 day in 30.
6. The sampling error for the 6 year rolling average DIN load, calculated from monthly samples, is ±100 t-N/y[2].
7. Our estimate of the July 2005 to June 2011 Plan reference period DIN load, using all NIWA and ECan measurements, is 759±71 t-N/y[2].
8. Our estimate of the load for the last 6 seasons (Jul 2009 – Jun 2015) is 839±74 t-N/y[2].
9. The 6 year DIN load would need to exceed about 1,063 t-N/y before it could be concluded that a statistically significant breach of Schedule 1 Plan limits had occurred (not accounting for the influence of flow and climate variability).

[1] The sampling error is the uncertainty associated with the low sampling frequency. Sampling error does not include climate and other natural variability

[2] Two tail 90% confidence interval/one tail 95% confidence interval.

Climate variability and load

10. Annual DIN loads and river flows are strongly correlated, with high loads in wet years and low loads in dry years.
11. From July 2005 to June 2011 flows were below the long term average. Adjusting for the impact of flow on load, given long term average flows, the DIN load for the Plan reference period would be about 65 t-N/y higher.
12. The combined variability associated with both climate influences and sampling errors, for the 6 year DIN load, is over ±220 t-N/y.
13. The load variability reduces by about 50% if annual flow variability is corrected for. Correcting for flow makes it easier to separate out trends due to farming practices from climate influences.

Load trends

14. From 1989 (when monthly monitoring began) to 2000 there is a trend of increasing DIN loads. Average load for the period 1984 to 2000 was 17% lower, compared with those from 2000 to 2015.
15. From 2000 to 2015 there is a trend of increasing loads. However correcting for the impact of flow, there is no trend in loads. Neither trends (flow adjusted and unadjusted) are statistically significant.
16. From 2005 to 2015 there is a trend of increasing loads. However correcting for the impact of flow, there is a trend of decreasing loads. Neither trend is statistically significant.
17. Considering load, concentration and flow, it is likely nitrogen losses due to farming activities, for the Hurunui Catchment at SH1, have remained relatively unchanged since 2000. Our interpretation of this observation is land use intensification has been off-set by irrigation efficiency improvements.
18. Evaluating load trends with non-flow adjusted loads has a high degree of uncertainty; using load with an annual flow adjustment, or concentrations reduces the uncertainty in the evaluation of trends.

1 Planning context

The word 'nitrogen' occurs 72 times in the HWRRP Plan. The plan states that the control of the nitrogen load at SH1 is for the purpose of minimizing the risk of nuisance periphyton growth. The plan also specifies nitrogen concentration limits, which are set to limit chronic nitrate toxicity to aquatic species. The plan uses and promotes a number of tools to control this nutrient, some regulatory and some non-statutory. For our analysis we have focused solely on two of the regulatory tools used by the plan:

(1) The limit on the DIN load in the Hurunui River at SH1 (Schedule 1), and;

(2) The limit on the nitrate concentration in Policy 5.3 (e).

The Schedule 1 DIN load limit is 963 t-N/y, averaged over 6 years. The foot-note to this schedule states that this value is a 25% increase of the average load for the July 2005 to June 2011 reference period [i.e. the reference period load was assumed to be 770 t-N/y]. In the definitions section of the Plan on page 31 the DIN load is defined as being "The level, in tonnes per year, of dissolved inorganic nitrogen averaged over the last six years". The technique for calculating the loads is as set out in Norton and Kelly (2010).

The Plan provides little guidance on the level of statistical significance required when assessing non-compliance. Normal scientific practice would be to have a minimum confidence level of 95% for a single tail[3]. Using a value less than 95% means there is a high chance that over the life of the plan (typically 10 years), reported non-compliance is the result of pure chance. We have subsequently used a statistical significance value of 95% in our analysis.

Policy 5.3 (e) of the Plan states "*The annual median and 95th percentile nitrate-nitrogen concentrations in the mainstem of the Hurunui River…shall not exceed 2.3 and 3.6 mg NO_3-N/L respectively.*"

Policy 5.3 (e) concentration limits are set at over 4 times the maximum values recorded at SH1, and therefore are not a constraint on the Hurunui River main stem. While this policy is much less restrictive than load limits and therefore is not a direct constraint in the main stem, for some of the Hurunui tributaries it is a significant constraint.

2 Available data

Available water quality data at the Hurunui River SH1 Bridge is summarised in Table 1. The two key datasets of interest are the Environment Canterbury (ECan) site (SQ30064) and the NIWA National River Water Quality Network site (Hurunui at SH1 Br.). Both ECan and NIWA independently monitored water quality from April 2005 – June 2014, a total of 9 seasons. For the 2014/15 season onwards only NIWA data is available. The reason for duplicate data sets is that from 2005 until 2014 ECan was running a time bound investigation on water quality changes in the Hurunui Catchment that required water samples from multiple places within the study area on the same day. This finished in

[3] 95% confidence interval for 1 tail (e.g. highs) is equal to a 90% confidence interval for 2 tails (highs and lows).

2014 and ECan now relies on NIWA data for State of the Environment monitoring of water quality at Hurunui SH1.

DIN is made up of three components: nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3). Nitrate typically accounts for 96% of DIN, while nitrite and ammonia each account for about 1% and 3%, respectively.

Table 1: DIN and nitrate monitoring in the Hurunui River at SH1

Owner/ sampler	Site name/No.	Period of monitoring	No. samples	Source	Notes
ECan	SQ30064	May 1975 - Jun 2014	188	Link	Bi-monthly from May 1984 to April 1986 & monthly from Apr 2005 - Jun 2014
ECan	SQ34353	Mar to May 2011	2	Link	Spot sampling. Not used in analysis
NIWA	Hurunui at SH1 Br	Jan 1989 to Dec 2016	324		Monthly sampling for full record

A copy of the data from 2000 onwards is included in Appendix A.

3 Data distribution

Both the NIWA and ECan monthly sampling programs occurred/occur in a systematic manner independent of weather and river flows. We have analysed the flows on the day that the samples were taken and found there is minimal flow sampling bias (refer Figure 1 and Figure 2). Since flow and time of year are the primary factors correlated with nutrient load, the DIN load and concentration estimates should therefore be relatively unbiased (i.e. the sampling method has not introduced sampling bias).

There is a non-linear relationship between flow and concentration. DIN concentrations tend to reduce with increasing flow. However the relationship is weak, and only explains 25% of individual sample variability (refer Figure 3). The relationship is strongest in summer and autumn, when half the concentration variability can be explained by the flow, and lowest in winter and spring (refer Figure 4).

While the concentration data is skewed, the distribution does not include the isolated extremes that are evident with Phosphorus concentrations and loads. Annual DIN loads, calculating using the "ECan method" (the *average* of the Beale and averaging methods), are approximately normally distributed (refer Figure 7 and Figure 8). Consequently trends are not dominated by a few extreme events and standard analytical statistical techniques are more reliable compared with analysing Phosphorus (refer Brown 2015).

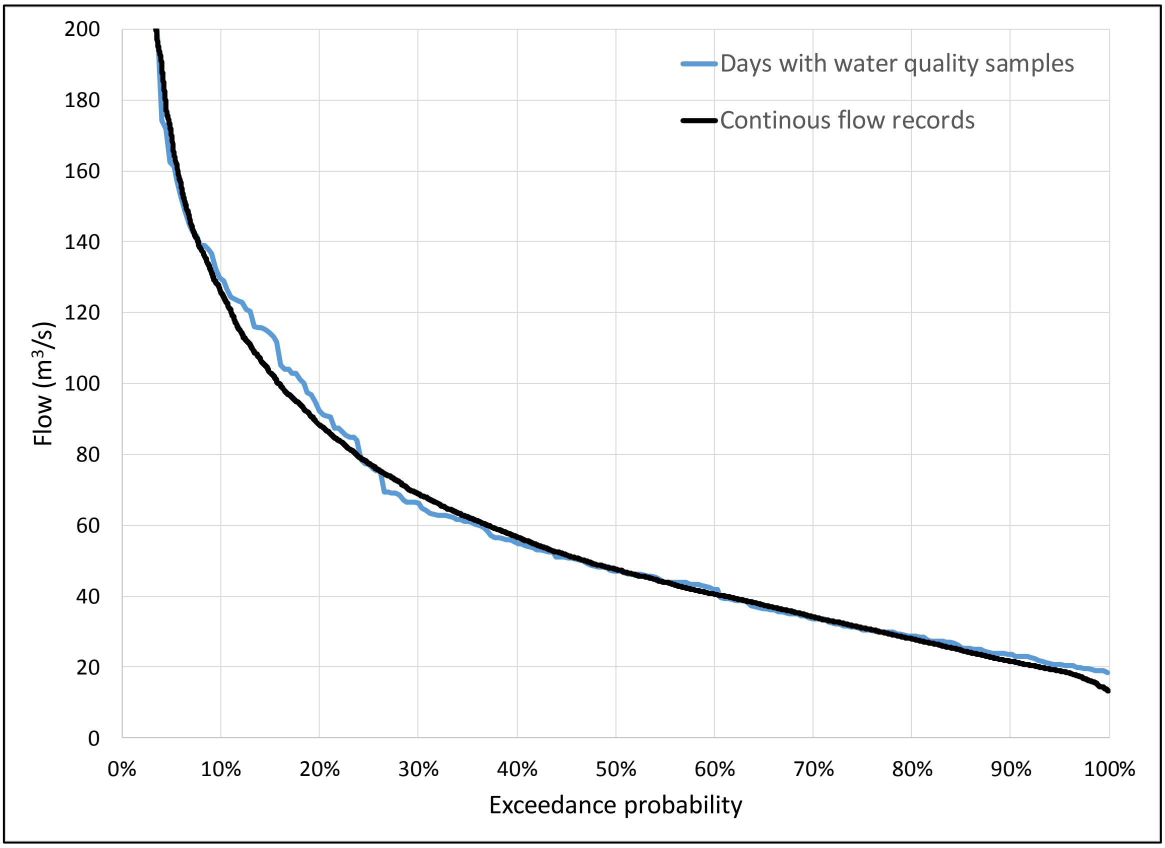

Figure 1: Flow exceedance probability: WQ samples and full record (2000-15)

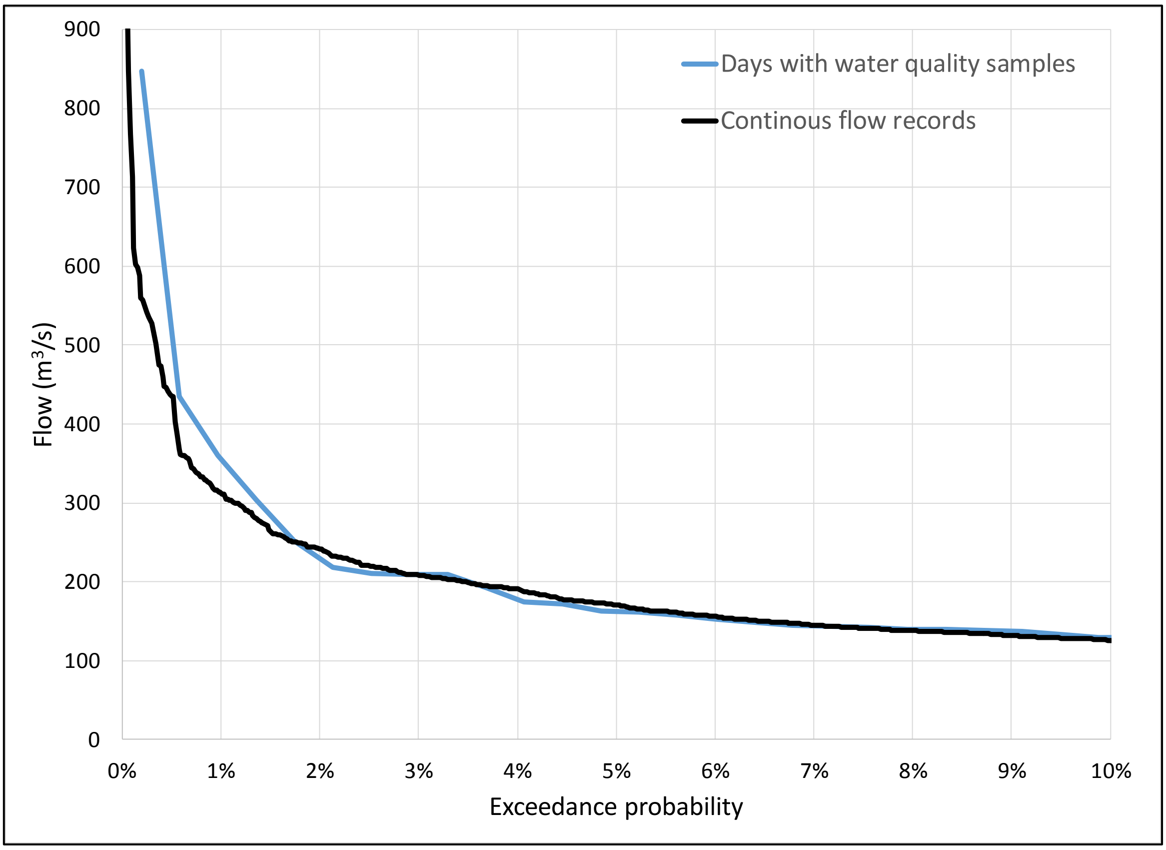

Figure 2: Flow exceedance probability: WQ samples and full record for high flows (2000-15)

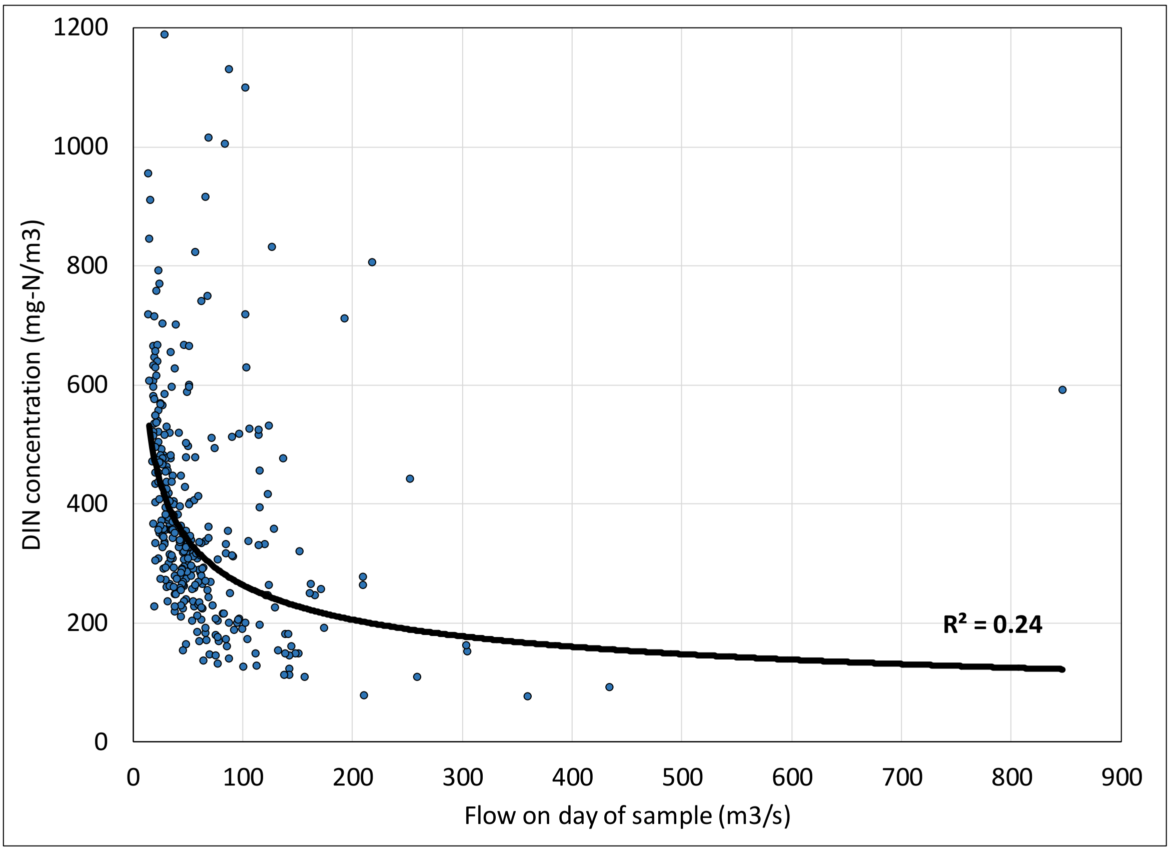

Figure 3: Flow vs concentration (2000-2015)

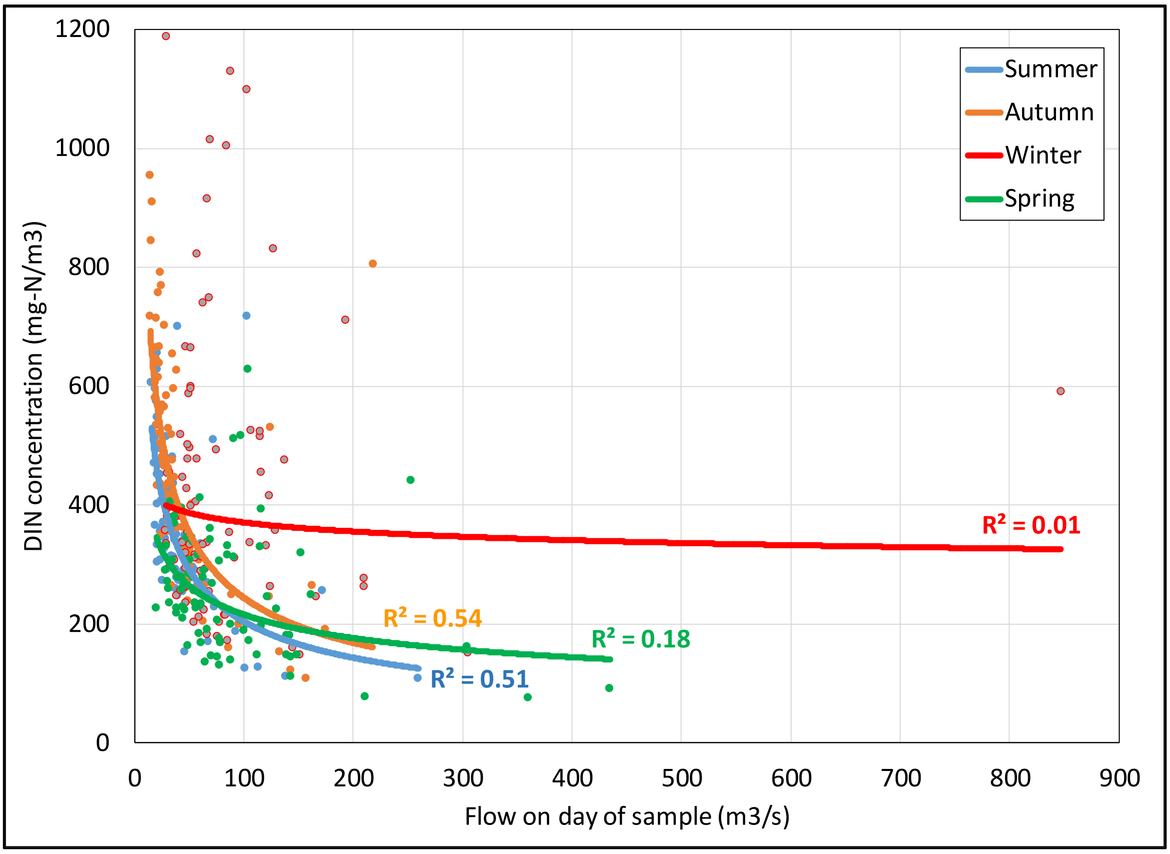

Figure 4: Flow vs concentration by season (2000-2015)

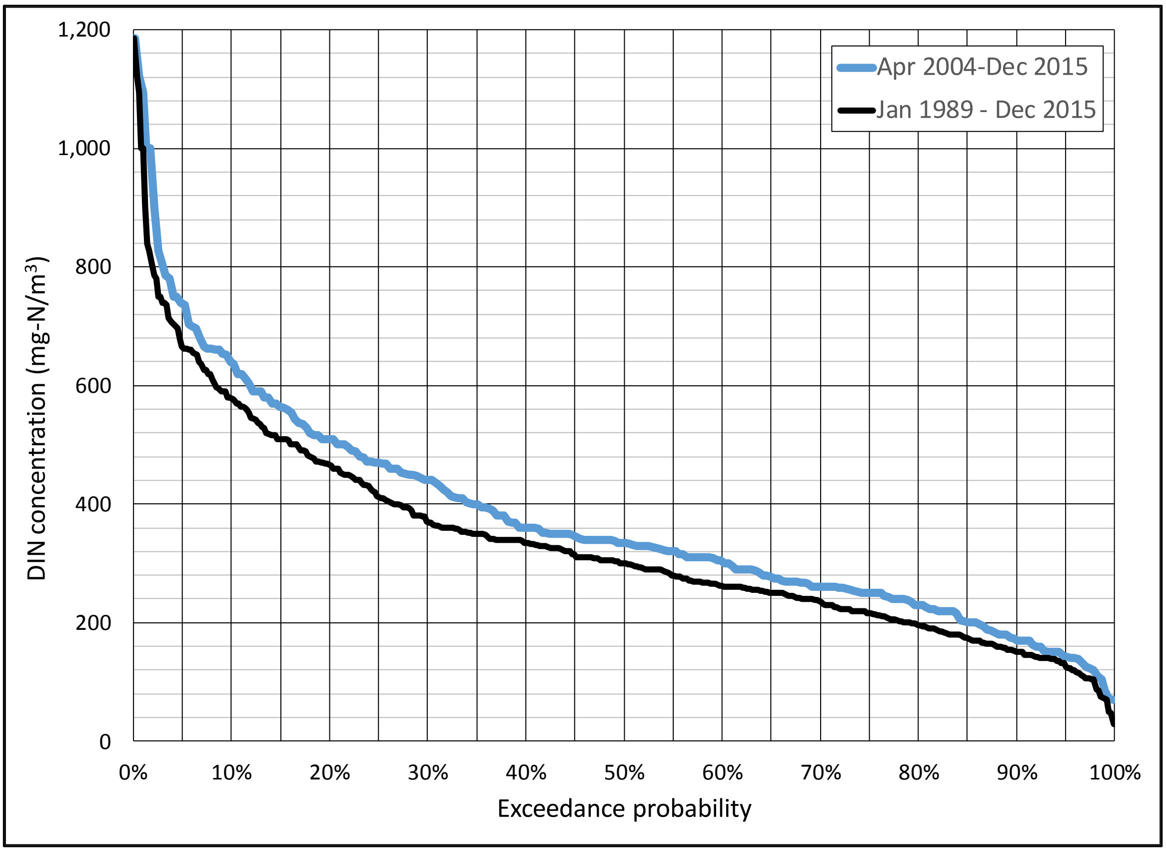

Figure 5: DIN concentration exceedance probability

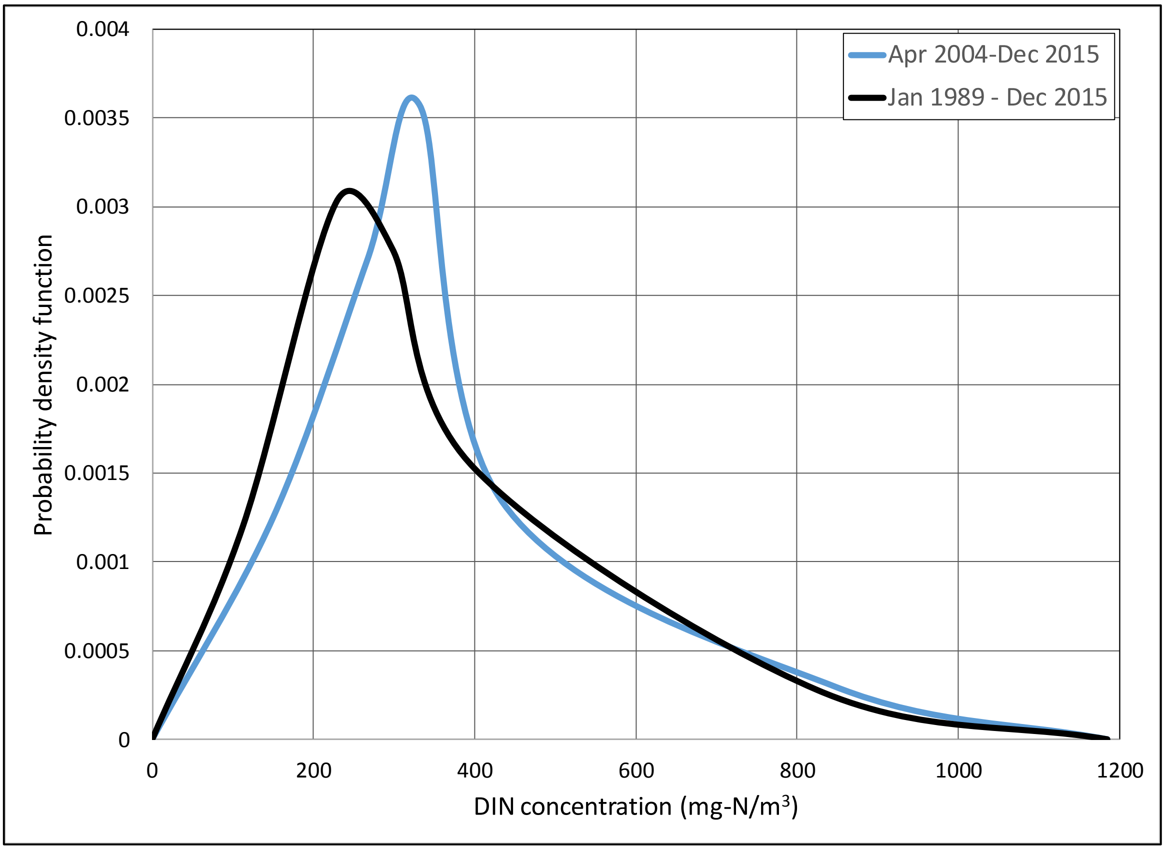

Figure 6: DIN concentration Probability Density Function

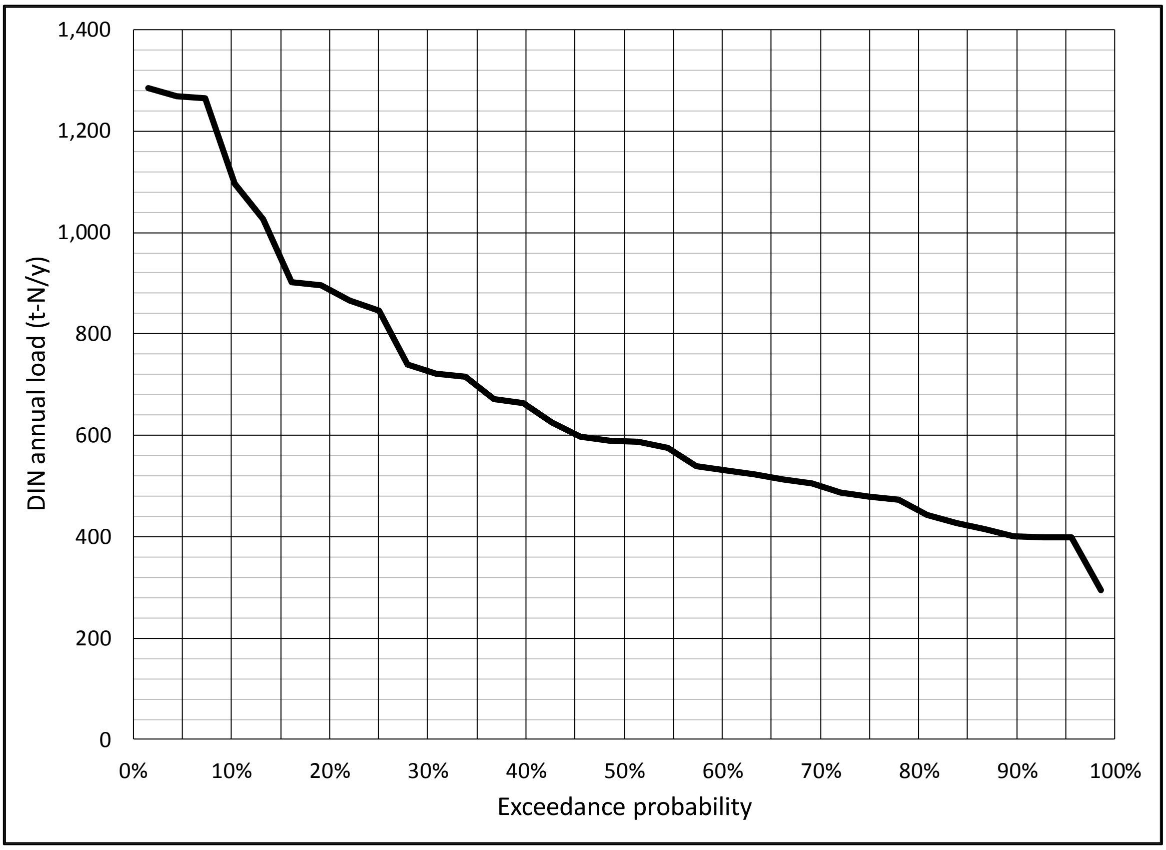

Figure 7: DIN load exceedance probability (1989-2015)

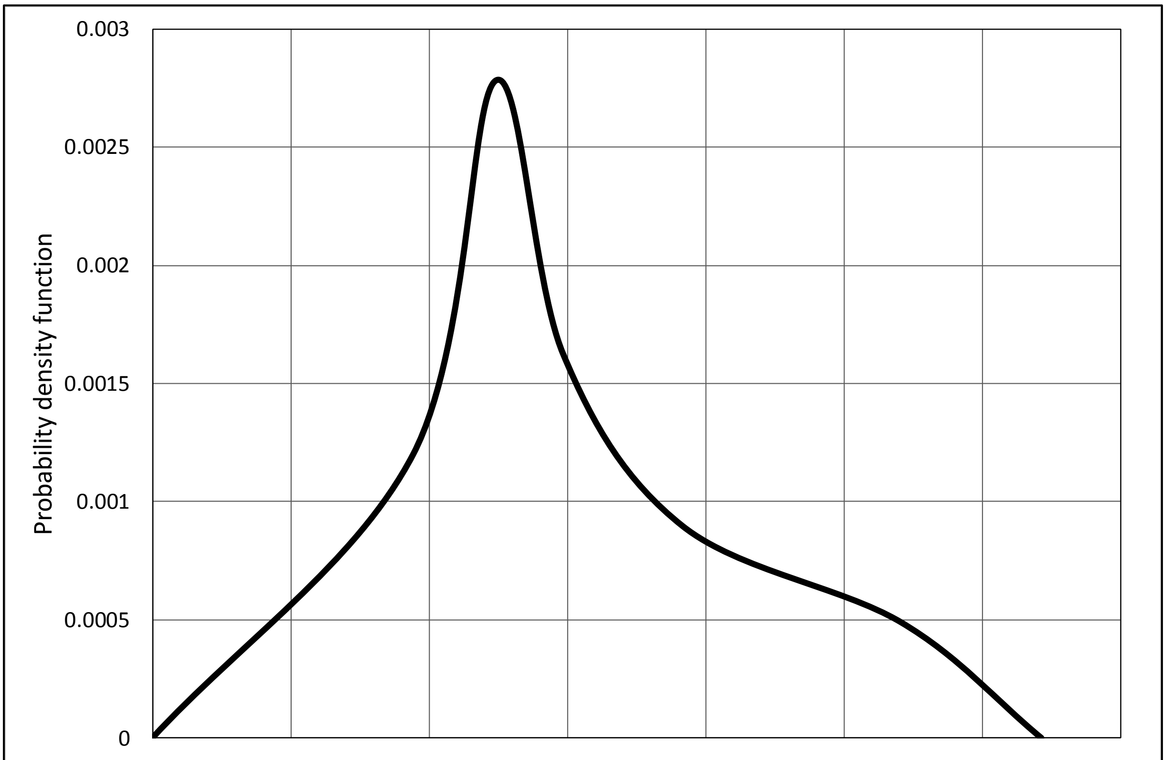

Figure 8: DIN load Probability Density Function (1989-2015)

Concentrations tend to decrease with increasing flow

Annual loads are approximately normally distributed

4 Concentration trends

DIN concentration trends over time are illustrated in Table 2, Figure 9, and Figure 10. Analysis includes a total of 511 samples, taken by both NIWA and ECan.

Table 2: Concentration time series (all flows) (mg/m^3)

Season (July to June)	No. samples	Median	Average
2000-01	16	436	496
2001-02	20	415	391
2002-03	12	215	273
2003-04	12	307	317
2004-05	15	291	315
2005-06	24	288	309
2006-07	24	309	305
2007-08	24	373	432
2008-09	24	432	475
2009-10	24	332	380
2010-11	23	370	473
2011-12	34	301	315
2012-13	33	355	413
2013-14	24	478	463
2014-15	12	248	255
2015-16 (half season)	6	230	223
Season average 00/01 - 05/06		**325**	**350**
Season average 05/06 - 10/11		**351**	**396**
Season average 09/10 - 14/15		**347**	**383**
Season average 10/11 - 15/16		**330**	**357**
Std. deviation 00/01 - 15/16		**75**	**84**

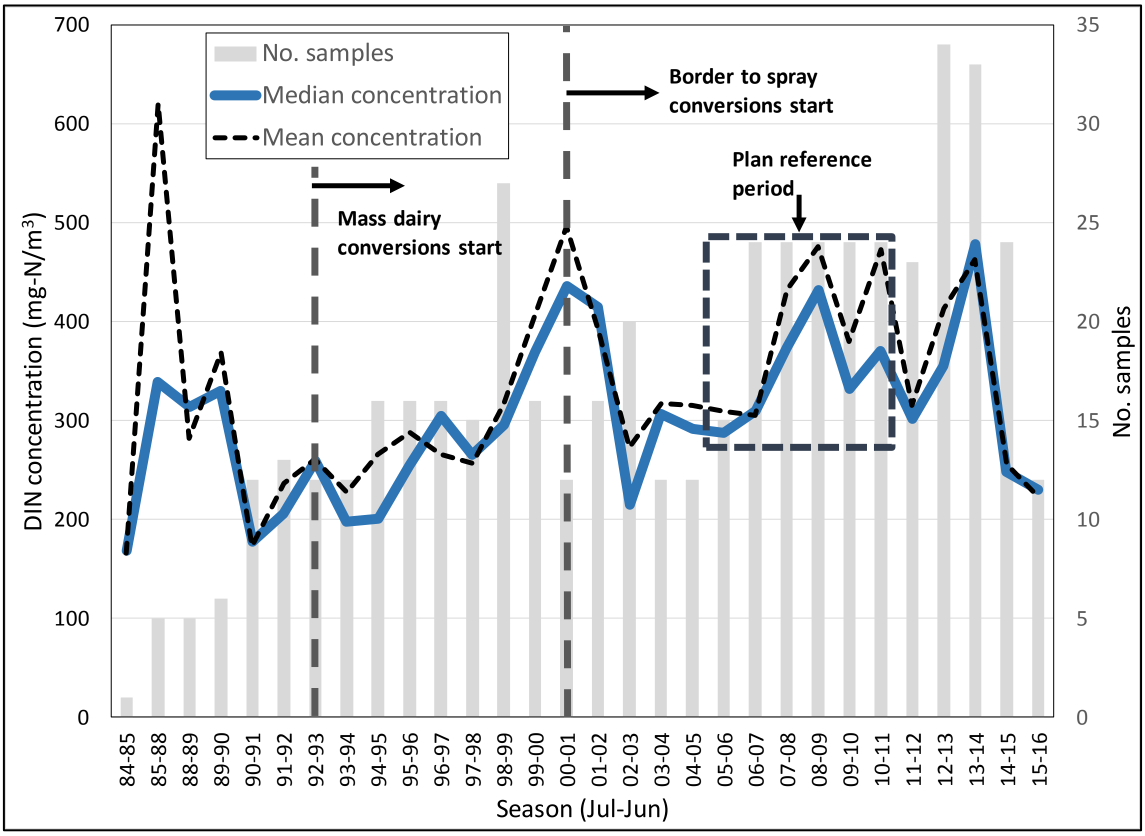

Figure 9: Median and mean annual concentration timeseries (all flows)

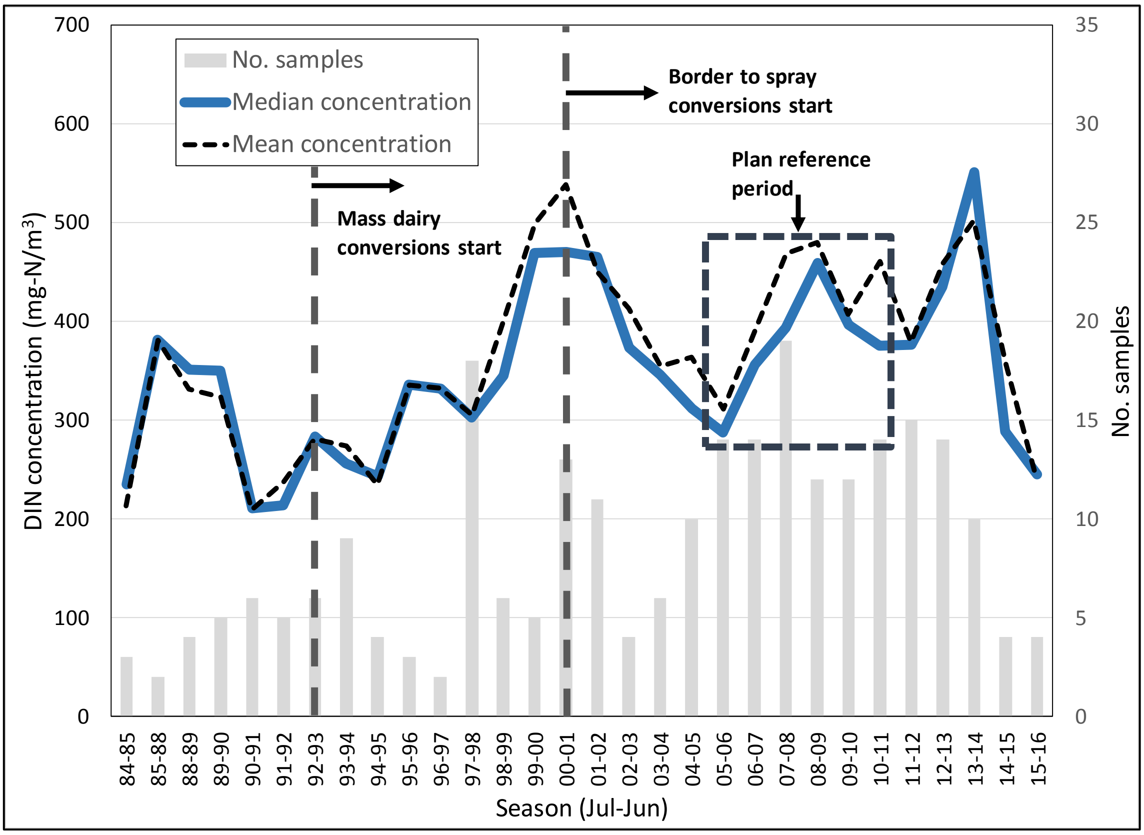

Figure 10: Median and mean annual concentration time series (for flows below median)

We analysed the trends in monthly concentration data using the non-parametric Seasonal Kendall Sen Slope Estimator (SKSE[4]) (Sen, 1968). We used NIWA's Trend and Equivalence Analysis software[5]; this software is widely used by regional councils for the purposes of trend evaluation for State of the Environment reporting.

We tested for trends both with and without a flow adjustment[6]. For analysis we combined both the ECan and NIWA datasets. Where more than one measurement was available for a month, we used the average concentration to represent the month. Results are presented in Table 3.

Table 3: SKSE trend analysis using monthly concentration data

Period	Mean conc. (mg-N/m3)	Rate of change (%/y)		Trend statistically significant?
		Unadjusted	Flow adjusted	
May 1984 to Dec 2015	328	1.5%	1.5%	Yes
May 1984 to Jun 2000	284	1.8%	3.0%	Yes
Jul 2000 to Dec 2015	364	0.5%	0.2%	No
Jul 2005 to Dec 2015	375	-0.1%	-0.2%	No

The key conclusion from Table 3 is that there is a statistically significant increase in the DIN concentration from 1984 to 2000, but after 2000 there is no statistically significant trend. The average concentration for the period 1984 to 2000 is 25% lower, compared to that from 2000 to 2015. Our interpretation is that the increase is probably primarily due to the large scale dairy conversions, which started around 1992.

From 2000 to 2015 there was no obvious trend in the DIN concentration, both for the full range of flows, and for flow below the median. While there is a small trend of increasing DIN concentration, the trend is not statistically significant. Our interpretation is that from 2000 the positive impact of border to spray irrigation conversions has been able to off-set the increases due to land use intensification and an increase in dairy cows.

From the start of the Plan reference period on July 2005, to December 2015, there is no statistically significant trend in DIN concentrations.

The maximum annual median concentration of 478 mg-N/m^3, recorded in the 2013-14 season, is almost five times below the Policy 5.3 (e) limit of 2.3mg-N/l (i.e. 2,300 mg-N/m^3). The maximum 95 percentile concentration of 808 mg-N/m^3, recorded during the 5 year period from July 2008 to June 2012, is over four times below the Policy 5.3 (e) limit of 3,600 mg-N/m^3. This policy is much less restrictive than load limits and therefore is not a direct constraint in the Hurunui main stem. However on some of Hurunui tributaries it is a significant constraint.

[4] The SKSE calculations were accompanied by a Seasonal Kendall test (Helsel & Frans, 2006) of the null hypothesis that there is no monotonic trend (for p=0.05).

[5] http://www.niwa.co.nz/our-science/freshwater/tools/analysis

[6] We included average daily flow as a covariate and parameterising these relationships by a GAM (generalized additive model) with three degrees of freedom.

The average concentration for the period 1984 to 2000 is 25% lower, compared to that from 2000 to 2015.

From 2000 to 2015 there is no statistically significant trend in concentrations.

DIN concentrations at SH1 are well below Plan limits

5 DIN Loads

5.1 Calculation methods

A good overview of nutrient calculation methods for annual loads is provided by Norton and Kelly (2010). In summary the three common methods used are:

1. Monthly average [conc. × average monthly flow];
2. Beale method; and
3. Regression method [i.e. nutrient vs flow rating curve]

Appendix 2 from Norton and Kelly, which describes each of these methods, is included in Appendix B.

The ‘monthly average’ is the simplest of the three methods to apply. The method works reasonably well because of the poor correlation between concentration and flow, although averaged over a long period of time the method may under-estimate load due to the slight positive relationship between these two variables.

The ‘Beale method’ attempts to address some of the limitations of the averaging method by accounting in part for the relationship between concentration and flow. The method is however more complex to apply.

The ‘regression method’ is an alternative approach than was not used in developing the Plan. In our view the method does not offer any significant advantages over the Beale and monthly average methods. The relationship between concentration and load is weak with a R^2 value of 0.25, which introduces a degree of subjectiveness when fitting the regression relationship.

5.2 Results

For DIN loads the Beale and monthly averaging methods both give similar results (refer Table 7). The methods used when developing the Plan was the *average* of the 'monthly average' and 'Beale' methods. In our view this is a reasonable approach, and there is no advantage in using alternative methods.

Load calculations, using both the ECan and NIWA datasets, using the Beale and averaging methods are presented in Table 4 to Table 6 and Figure 11. Further calculation details, for the period 2000 to 2015, are included in Appendix C and D.

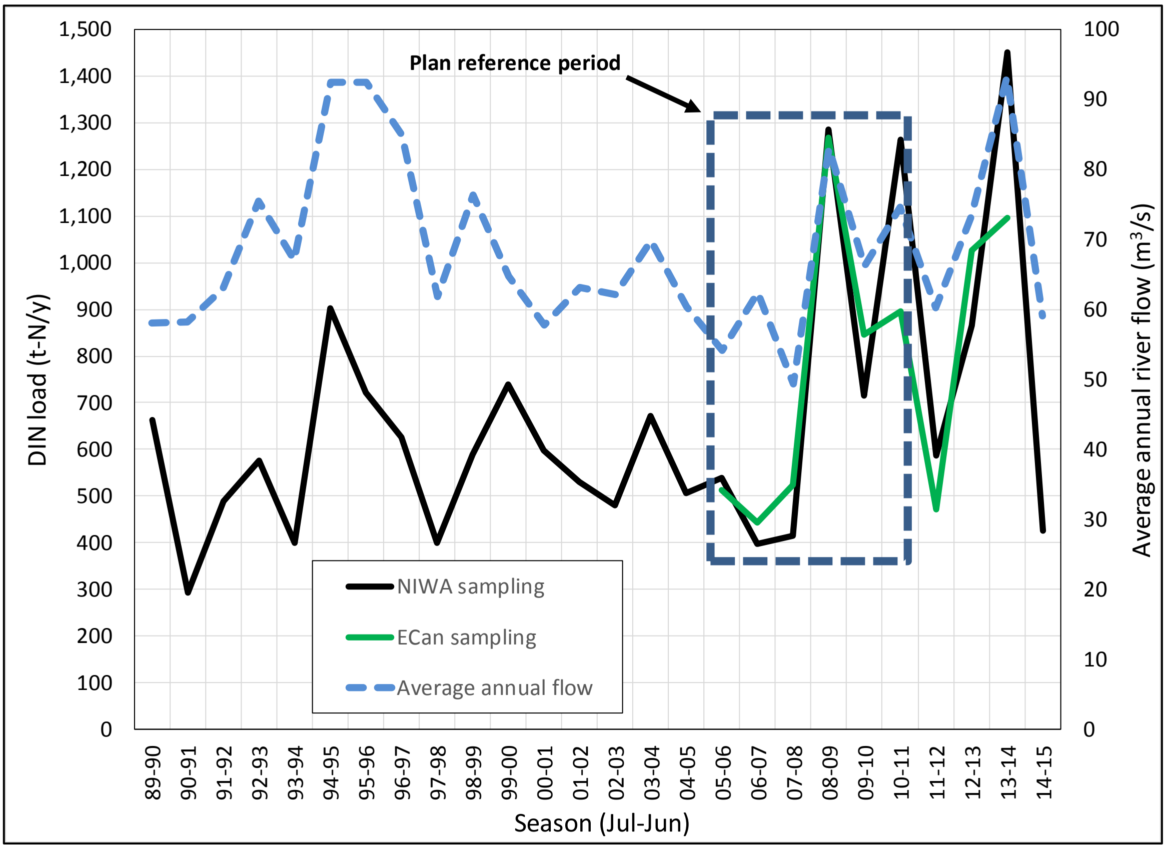

Figure 11: Load trends using the average of the Beale and monthly average methods

Table 4: DIN load calculated using the 'monthly average' method

Season (Jun-Jul)	Annual DIN load (t-N/y)			6 year rolling average (t-N/y)		
	ECan data*	NIWA data	Difference	ECan data	NIWA data	Difference
2000-01		610				
2001-02		615				
2002-03		491				
2003-04		675				
2004-05		511				
2005-06	533	519	14		570	
2006-07	436	448	-12		543	
2007-08	520	459	62		517	
2008-09	1,381	1,421	-40		672	
2009-10	806	782	24		690	
2010-11	862	1,283	-421	756	819	-62
2011-12	500	596	-96	751	831	-81
2012-13	1,078	861	217	858	900	-42
2013-14	1,124	1,433	-309	958	1,063	-104
2014-15		436			898	
Mean (Jul 05-Jun 11)	**756**	**819**	**-62**	**756**	**819**	**-62**
Mean (Jul 05-Jun 14)	**804**	**867**	**-62**	**831**	**734**	**-72**
Mean (Jul 00-Jun 15)		**743**				
Std. dev.	**315**	**340**	**183**	**85**	**171**	**23**

*When ECan sampled more than once in a month (e.g. July 2011 – March 2013), the average of the measurements was used in calculations.

Table 5: DIN load calculated using the 'Beale' method

Season (Jun-Jul)	Annual DIN load (t-N/y)			6 year rolling average (t-N/y)		
	ECan data*	NIWA data	Difference	ECan data	NIWA data	Difference
2000-01		586				
2001-02		446				
2002-03		468				
2003-04		669				
2004-05		499				
2005-06	491	559	-68		538	
2006-07	450	348	102		498	
2007-08	526	373	153		486	
2008-09	1,156	1,150	6		600	
2009-10	884	648	236		596	
2010-11	931	1,245	-314	740	721	19
2011-12	444	578	-133	732	724	8
2012-13	975	870	104	819	811	9
2013-14	1,070	1,470	-400	910	994	-84
2014-15		416			871	
Mean (Jul 05-Jun 11)	**740**	**721**	**19**	**740**	**721**	**19**
Mean (Jul 05-Jun 14)	**770**	**805**	**-35**	**800**	**663**	**-12**
Mean (Jul 00-Jun 15)		**688**				
Std. dev.	**272**	**331**	**203**	**72**	**161**	**42**

Table 6: DIN load calculated using the average of the Beale and monthly average methods

Season (Jun-Jul)	Annual DIN load (t-N/y)			6 year rolling average (t-N/y)		
	ECan data*	NIWA data	Difference	ECan data	NIWA data	Difference
2000-01		598				
2001-02		531				
2002-03		479				
2003-04		672				
2004-05		505				
2005-06	512	539	-27		554	
2006-07	443	398	45		521	
2007-08	523	416	108		502	
2008-09	1,268	1,285	-17		636	
2009-10	845	715	130		643	
2010-11	896	1,264	-368	748	770	-22
2011-12	472	587	-115	741	777	-36
2012-13	1,026	866	161	839	855	-17
2013-14	1,097	1,451	-355	934	1,028	-94
2014-15		426			885	
Mean (Jul 05-Jun 11)	**748**	**770**	**-22**	**748**	**770**	**-22**
Mean (Jul 05-Jun 14)	**787**	**836**	**-49**	**816**	**698**	**-42**
Mean (Jul 00-Jun 15)		**716**				
Std. dev.	**291**	**333**	**186**	**79**	**166**	**31**

Table 7: Correlation between NIWA and ECan annual load estimates

Variable 1	Variable 2	Correlation coefficient[7]
ECan Beale method	NIWA Beale method	0.86
ECan 'averaging' method	NIWA 'averaging' method	0.88
ECan ‘averaging’ method	ECan Beale method	0.97
NIWA ‘averaging’ method	NIWA Beale method	0.95

[7] Pearson’s correlation coefficient

5.3 Sampling error

The sampling error is the confidence a particular environmental value can be measured. Sampling error does not include climate and other natural variability. For DIN loads the sampling error is primarily due to sampling only occurring monthly. Load sampling error could be compared to trying to measure annual temperature changes, with a thermometer that is only accurate to ±5°C.

The sampling error can be calculated by comparing load estimates using NIWA and ECan datasets. For a period of 9 years both these organizations independently measured DIN concentrations on a monthly basis. The standard deviation in the difference in annual estimates was 186 t-N/y (refer Table 6). We estimate the sampling error for the 6 year rolling average, with one set on monthly monitoring data is approximately:

$$=\pm t \times se_{(s1\text{-}s2)} / (\sqrt{n} \times \sqrt{2})^{8}$$
$$=\pm 1.860 \times 186 \text{ t-N/y} / \sqrt{(6\times 2)}$$
$$=\pm 100 \text{ t-N/y}$$

For the Plan reference period July 2005 to June 2011, the sampling error is less, because we have twice the number of measurements, because both NIWA and ECan undertook monthly sampling. The sampling error for the plan reference period is therefore approximately:

$$=\pm 1.860\times 186 \text{ t-N/y} / (\sqrt{12}\ \sqrt{2})$$
$$=\pm 71 \text{ t-N/y}$$

We estimated the load for the reference period, as the average of the NIWA and ECan loads, which is 759 t-N/y (refer Table 6). Accounting for sampling error, the load is 759±71 t-N/y.

We estimate the load for the last six seasons (July 2009 to June 2015), using both NIWA and ECan data, is 839±74 t-N/y[9].

The Plan Schedule 1 limit is 963 t-N/y, averaged over 6 years. However, since the load can only be measured to an accuracy of ±100 t-N/y, the load would need to exceed about 1,063 t-N/y before it could be concluded with 95% confidence that the limit had actually been breached.

[8] Critical *t* value with 8 degrees of freedom (since standard error is calculated from 9 years of data), for a 90% CI 2 tail/95% CI 1 tail. $se_{(s1\text{-}s2)}$ = difference in annual load estimates from the two samples, and is assumed to be equal to the sample standard deviation. The $1/\sqrt{2}$ factor is the difference between the standard error of two samples vs the standard error of the true load (if it could be determined from continuous measurements) minus sample 1 or sample 2 data. *n* = number of annual load estimates. Confidence interval is 90% for two tail/95% for one tail.

[9] The measurement uncertainty is based on a total of 11 annual load estimates, 6 from NIWA and 5 from ECan. $839\pm 1.86\times 186 /\sqrt{11}$

With monthly sampling, the 6 year load can only be measured to an accuracy of ±100 t-N/y.

The load for the Plan reference period, using both NIWA and ECan data, is 759±71 t-N/y.

5.4 Trends and flow adjustment

In addition to the sampling error, the annual load has a high degree of variability because of the impact of flow and climate variability. Annual DIN loads and river flows are strongly correlated, with high loads in wet years and low loads in dry years (refer Figure 12).

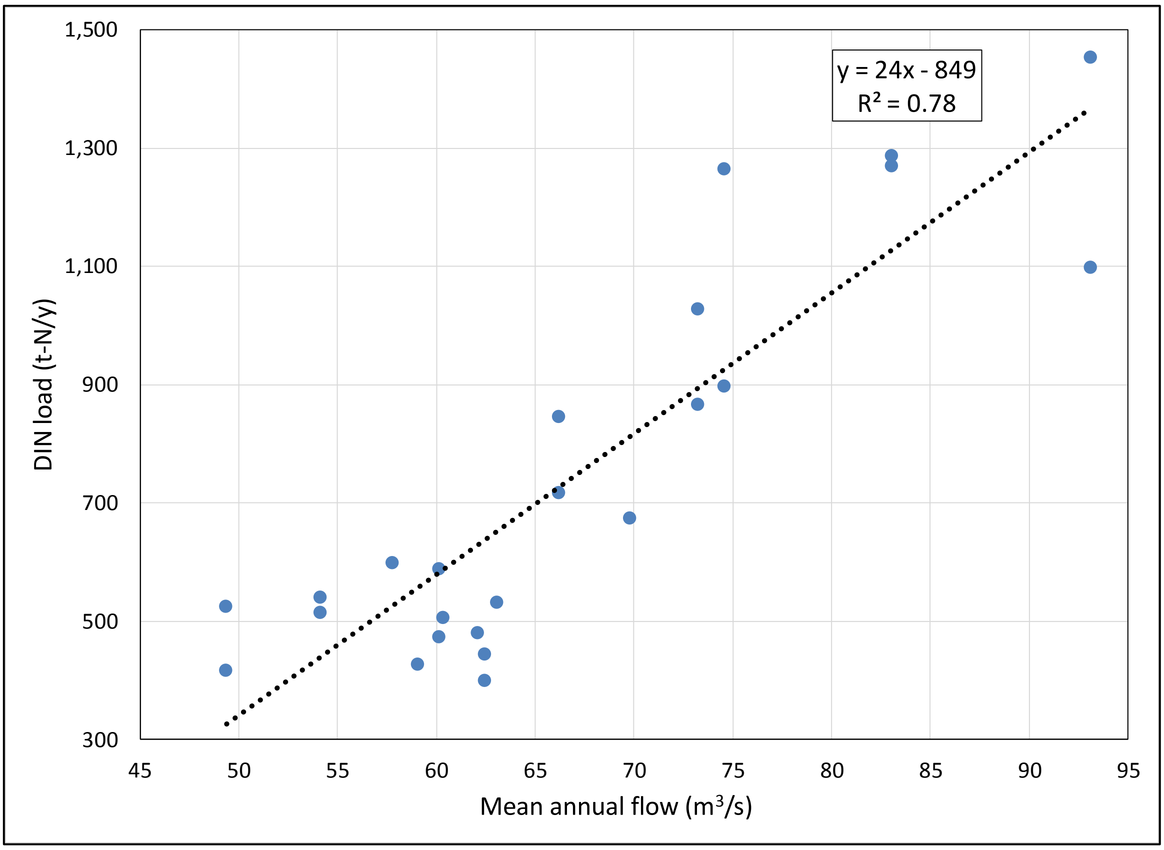

Figure 12: Relationship between mean annual flow and DIN load (Jul 2000 – Jun 2015)

The high degree of variability in annual rainfall and annual flows consequently leads to high year to year load variability. The standard deviation of this variability is about 310 t-N/y[10].

The implications of the high year to year variability are that the variability in the 6 year DIN load is over ±223. We estimated this as:

$= \pm t \times \text{se} / \sqrt{n}$[11]
$= \pm 1.761 \times 310$ t-N/y / $\sqrt{6}$
$= \pm 223$ t-N/y

The true 6 year variability will be greater than ±223 because long term climate cycles (particularly the Pacific Decadal Oscillation) means that there is auto-correlation from year to year with river flows and rainfall. For example the 1980's and 1990's were a wetter period, with higher river flows, while since about 2000 river flows have been on average lower. Auto-correlation means that consecutive periods of wet or dry years are more likely to occur than if the load for each year was independent of the previous year.

From July 2005 to June 2011 the average flow was 65.0 m^3/s, which is below the long term average from 1960 to 2015 of 67.7 m^3/s. Because the reference period flows were below average, this means that the long term load would have been under-estimated. Adjusting for the impact of flow on load, given long term average flows, the DIN load for the Plan reference period would be about 65[12] t-N/y higher.

We analysed the trends in annual DIN loads using the non-parametric Kendall Sen Slope Estimator. We used NIWA's Trend and Equivalence Analysis software. We tested for trends both with and without a flow adjustment[13]. For analysis we combined both the ECan and NIWA datasets. Where more than one estimate was available for a particular season, we used the average of the NIWA and ECan estimates. Results are presented in Table 8.

[10] Average of standard deviation of ECan and NIWA datasets, from Table 6.

[11] Critical *t* value with 14 degrees of freedom (since the standard error is calculated from 15 years of data), for a two tail 90% CI/one tail 95% CI. se = standard error in annual load estimates, and is assumed to be equal to the sample standard deviation. *n* = number of annual load estimates. Confidence interval is 90% for two tail/95% for one tail.

[12] (67.7 – 65.0)×24

[13] We included average annual flow as a covariate and parameterising these relationships by a GAM (generalized additive model) with three degrees of freedom.

Table 8: Annual load KSE trend analysis

Period	Mean load (t-N/y)	Rate of change (%/y)		Trend statistically significant?
		Unadjusted	Flow adjusted	
Jul 1989 - Jun 2015	650	1.21%	2.31%	Yes (for flow adjusted only)
Jul 2000 - June 2015	703	2.56%	0.20%	No
Jul 2005 to Dec 2015	748	6.55%	-1.47%	No

We also adjusted the DIN loads directly using the relationship between flow and load from Figure 12. Adjusted loads are presented in Figure 13.

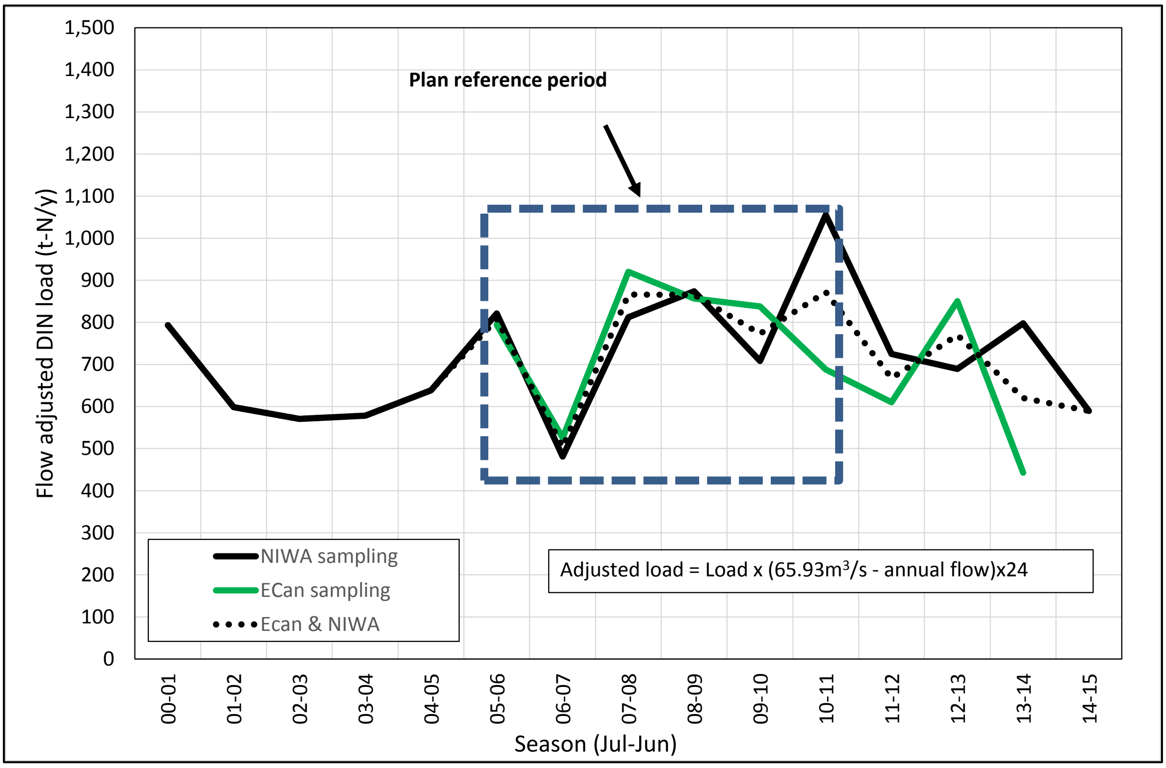

Figure 13: Load trends adjusted for flow (Jul 2000 – Jun 2015)

The conclusions from this trend analysis were:

1. From 1989 (when monthly monitoring began) to 2000 there is a trend of increasing DIN loads. Average load for the period 1984 to 2000 was 17% lower, compared with those from 2000 to 2015.
2. From 2000 to 2015 there is a trend of increasing loads. However correcting for the impact of flow, there is no trend in loads. Neither trends (flow adjusted and unadjusted) are statistically significant.
3. From 2005 to 2015 there is a trend of increasing loads. However correcting for the impact of flow, there is a trend of decreasing loads. Neither trend are statistically significant.

Considering load, concentration and flow, it is likely nitrogen losses due to farming activities, for the Hurunui Catchment at SH1, have remained relatively unchanged since

2000. Our interpretation of this observation is land use intensification has been off-set by irrigation efficiency improvements.

The load variability reduces by about 50% if annual flow variability is corrected for. Correcting for flow makes it easier to separate out trends due to farming practices from climate trends. Evaluating load trends with non-flow adjusted loads has a high degree of uncertainty; using load with an annual flow adjustment, or concentrations reduces the uncertainty in the evaluation of trends.

Average annual flow and DIN load are highly correlated.

Flows during the Plan reference period were below the long term average. Adjusted for long term average flows, the load is 824 ±71 t-N/y.

Average load for the period 1984 to 2000 was 17% lower, compared with those from 2000 to 2015.

Adjusting for flow, there is no statistically significant trend in the DIN load from 2000 to 2015.

Evaluating load trends with non-flow adjusted loads has a high degree of uncertainty; using load with an annual flow adjustment, or concentrations reduces the uncertainty in the evaluation of trends.

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Appendix A: Water quality data, 2000 - 2015

ECan data. Site SQ34353

Sample date		Flow (m^3/s)		DIN (mg-N/m^3)	Load (kg-N/d)	
Date	Season	Ave. daily flow	Ave. monthly flow		Ave. daily flow × conc.	Ave. monthly flow × conc.
2001-03-28	2000	16.1	17.1	910	1,267	1,346
2001-05-07	2000	14.3	24.1	954	1,179	1,985
2001-05-17	2000	15.4	24.1	844	1,126	1,756
2001-06-27	2000	40.9	45.0	382	1,349	1,486
2001-07-04	2001	37.5	45.4	380	1,230	1,489
2001-08-01	2001	51.0	48.4	599	2,642	2,507
2001-08-08	2001	42.3	48.4	519	1,896	2,172
2001-08-15	2001	48.7	48.4	478	2,013	2,000
2001-09-05	2001	33.2	29.4	405	1,162	1,027
2001-11-07	2001	71.4	98.0	268	1,652	2,269
2002-01-31	2001	30.7	145.8	425	1,126	5,354
2002-05-02	2001	26.9	23.3	465	1,079	934
2005-04-28	2004	31.4	43.8	529	1,433	2,003
2005-05-25	2004	43.9	44.8	363	1,375	1,402
2005-06-23	2004	46.2	43.8	263	1,049	994
2005-07-21	2005	115.9	66.0	455	4,557	2,594
2005-08-18	2005	66.4	51.8	183	1,048	817
2005-09-29	2005	45.6	47.0	223	877	904
2005-10-27	2005	34.4	53.7	308	917	1,429
2005-11-24	2005	44.8	33.3	264	1,022	761
2005-12-15	2005	33.5	33.1	261	756	745
2006-01-26	2005	43.9	69.5	283	1,073	1,699
2006-02-22	2005	26.6	36.2	371	854	1,160
2006-03-23	2005	28.8	29.9	476	1,183	1,229
2006-04-27	2005	142.9	80.3	123	1,512	850
2006-05-25	2005	46.9	56.2	280	1,135	1,358
2006-06-29	2005	50.5	92.7	496	2,166	3,974
2006-08-02	2006	64.2	47.6	293	1,623	1,203
2006-08-31	2006	38.7	47.6	247	826	1,016
2006-09-28	2006	78.6	61.5	169	1,148	899
2006-10-26	2006	139.0	105.3	181	2,174	1,647
2006-11-23	2006	138.9	186.3	147	1,764	2,366
2006-12-21	2006	45.3	86.5	288	1,128	2,152
2007-01-25	2006	27.6	39.1	326	776	1,102
2007-02-22	2006	18.5	25.3	514	821	1,122
2007-03-22	2006	24.5	20.0	350	742	605
2007-04-19	2006	23.6	22.8	520	1,061	1,026
2007-05-24	2006	94.9	43.6	200	1,640	753
2007-06-21	2006	28.3	50.9	358	876	1,576
2007-07-18	2007	29.9	51.1	393	1,017	1,735
2007-08-23	2007	42.0	51.7	256	928	1,144
2007-09-20	2007	43.8	42.1	209	791	760
2007-10-25	2007	148.6	208.3	147	1,887	2,645
2007-11-22	2007	30.5	41.8	260	684	940
2007-12-20	2007	45.9	28.0	348	1,380	841
2008-01-24	2007	19.2	19.8	365	605	625

2008-02-21	2007	39.1	39.7	700	2,364	2,401
2008-03-26	2007	21.9	28.1	757	1,431	1,840
2008-04-17	2007	23.9	21.4	770	1,591	1,426
2008-05-22	2007	19.8	23.5	714	1,223	1,452
2008-06-19	2007	29.8	34.7	453	1,164	1,355
2008-07-24	2008	128.9	143.3	357	3,975	4,420
2008-08-21	2008	69.0	199.4	1,015	6,054	17,488
2008-09-18	2008	90.6	128.1	513	4,010	5,674
2008-10-15	2008	69.3	80.9	343	2,050	2,394
2008-11-20	2008	53.6	68.8	338	1,565	2,008
2008-12-18	2008	35.6	61.7	436	1,339	2,323
2009-01-22	2008	22.9	36.0	472	932	1,468
2009-02-19	2008	20.3	39.6	629	1,105	2,155
2009-03-19	2008	29.1	38.8	418	1,051	1,400
2009-04-16	2008	25.2	41.5	480	1,043	1,719
2009-05-21	2008	123.2	106.3	245	2,609	2,251
2009-06-18	2008	43.8	46.8	447	1,693	1,806
2009-07-23	2009	120.3	72.8	331	3,440	2,082
2009-08-20	2009	63.2	81.0	223	1,218	1,561
2009-09-24	2009	42.7	82.5	279	1,030	1,990
2009-10-15	2009	104.2	92.1	171	1,539	1,361
2009-11-19	2009	38.3	44.6	226	747	870
2009-12-15	2009	137.7	79.4	113	1,339	771
2010-01-21	2009	43.9	64.6	255	966	1,424
2010-02-18	2009	23.8	23.8	356	732	733
2010-03-18	2009	23.6	30.0	503	1,023	1,303
2010-04-22	2009	27.0	34.5	431	1,004	1,284
2010-05-27	2009	218.1	77.6	806	15,186	5,402
2010-06-17	2009	56.6	107.8	823	4,021	7,666
2010-07-22	2010	66.4	83.8	916	5,253	6,630
2010-09-02	2010	104.1	168.3	629	5,655	9,149
2010-09-23	2010	152.4	168.3	319	4,199	4,640
2010-10-14	2010	84.7	108.0	331	2,423	3,089
2010-11-18	2010	36.3	41.0	381	1,196	1,350
2010-12-16	2010	20.5	57.6	333	588	1,655
2011-01-11	2010	29.8	55.4	293	754	1,400
2011-03-25	2010	34.5	36.9	476	1,418	1,518
2011-04-14	2010	30.3	43.4	476	1,247	1,783
2011-05-17	2010	132.5	93.4	153	1,746	1,231
2011-06-14	2010	46.2	45.8	318	1,270	1,260
2011-07-13	2011	209.7	92.5	277	5,019	2,213
2011-07-22	2011	62.7	92.5	333	1,802	2,657
2011-08-23	2011	56.6	51.2	477	2,332	2,111
2011-08-29	2011	61.7	51.2	312	1,664	1,381
2011-09-13	2011	55.3	48.1	235	1,124	977
2011-09-22	2011	43.9	48.1	228	865	948
2011-10-11	2011	60.3	87.0	231	1,203	1,736
2011-10-28	2011	100.2	87.0	189	1,636	1,420
2011-11-24	2011	210.4	109.4	77	1,400	728
2011-12-02	2011	67.0	62.5	170	983	917
2011-12-20	2011	59.9	62.5	268	1,387	1,446
2012-01-26	2011	33.7	42.5	315	916	1,157
2012-01-27	2011	36.1	42.5	343	1,069	1,258
2012-02-21	2011	24.2	32.1	407	851	1,126

2012-03-07	2011	52.5	41.5	315	1,429	1,130
2012-03-22	2011	31.7	41.5	373	1,021	1,337
2012-04-18	2011	32.8	31.7	376	1,066	1,030
2012-04-26	2011	24.9	31.7	469	1,010	1,285
2012-05-15	2011	41.8	38.7	256	926	856
2012-05-16	2011	48.2	38.7	239	995	799
2012-06-14	2011	77.4	84.1	203	1,353	1,471
2012-06-18	2011	55.8	84.1	405	1,953	2,942
2012-07-18	2012	144.9	82.4	159	1,990	1,133
2012-07-27	2012	54.8	82.4	316	1,495	2,251
2012-08-08	2012	115.2	150.9	523	5,204	6,818
2012-08-23	2012	68.4	150.9	748	4,422	9,751
2012-09-18	2012	84.8	96.6	316	2,315	2,637
2012-09-24	2012	59.5	96.6	413	2,121	3,446
2012-10-16	2012	141.9	129.2	180	2,206	2,009
2012-11-02	2012	75.4	54.0	206	1,342	961
2012-11-13	2012	53.8	54.0	256	1,190	1,194
2012-11-20	2012	49.2	54.0	285	1,212	1,329
2012-12-17	2012	27.4	35.0	345	817	1,044
2012-12-18	2012	27.2	35.0	345	809	1,044
2013-01-23	2012	53.2	89.4	295	1,355	2,279
2013-01-28	2012	36.7	89.4	355	1,125	2,742
2013-02-18	2012	20.6	24.6	495	882	1,052
2013-02-26	2012	19.5	24.6	575	968	1,222
2013-03-25	2012	20.0	19.8	645	1,113	1,104
2013-03-26	2012	19.0	19.8	665	1,091	1,138
2013-04-17	2012	21.3	30.7	615	1,132	1,631
2013-05-21	2012	35.0	40.9	355	1,075	1,254
2013-06-27	2012	83.9	121.3	1,005	7,287	10,537
2013-07-25	2013	114.5	138.3	515	5,093	6,154
2013-08-14	2013	51.1	78.0	595	2,628	4,011
2013-09-26	2013	121.0	126.6	245	2,562	2,679
2013-10-21	2013	129.7	203.0	225	2,522	3,947
2013-11-26	2013	43.3	65.0	395	1,477	2,219
2013-12-16	2013	35.5	42.7	355	1,088	1,311
2014-01-22	2013	43.4	57.0	335	1,256	1,651
2014-02-25	2013	19.0	21.2	595	978	1,092
2014-03-19	2013	27.0	25.4	565	1,317	1,242
2014-04-15	2013	35.3	80.3	595	1,813	4,126
2014-05-28	2013	162.6	114.2	265	3,723	2,616
2014-06-27	2013	123.0	161.1	415	4,411	5,778

NIWA data, Hurunui at SH1 Br.

Sample date		Flow (m^3/s)			DIN ($mg\text{-}N/m^3$)	Load (kg-N/d)		
Date	Season	Inst. Flow	Ave. daily flow	Ave. monthly flow		Inst. flow × conc.	Ave. daily flow × conc.	Ave. monthly flow × conc.
2000-01-19	1999	24.8	20.2	39.9	547	1172	955	1886
2000-02-23	1999	41.8	24.5	35.6	469	1694	994	1443
2000-03-22	1999	38.3	37.9	26.9	404	1337	1323	938
2000-04-26	1999	55.1	63.8	81.0	265	1262	1460	1856
2000-05-24	1999	78.2	86.3	49.8	160	1081	1193	689
2000-06-21	1999	129.0	151.2	110.9	148	1650	1933	1418
2000-07-19	2000	31.5	36.1	82.1	308	838	960	2185
2000-08-23	2000	127.3	106.3	118.2	525	5774	4821	5360
2000-09-19	2000	147.0	77.5	116.3	306	3886	2050	3076
2000-10-18	2000	195.0	142.3	146.2	111	1870	1365	1402
2000-11-22	2000	42.0	19.8	31.3	227	824	388	614
2000-12-13	2000	32.7	18.1	34.7	470	1328	737	1410
2001-01-23	2000	32.6	20.9	36.6	402	1132	726	1270
2001-02-21	2000	30.6	15.5	17.5	606	1602	810	914
2001-03-21	2000	13.7	14.2	17.1	718	850	884	1062
2001-04-18	2000	24.4	18.9	19.9	580	1223	948	996
2001-05-23	2000	36.5	29.6	24.1	356	1123	910	741
2001-06-20	2000	47.0	47.2	45.0	235	954	958	914
2001-07-18	2001	39.0	75.1	45.4	493	1661	3201	1932
2001-08-22	2001	53.0	55.0	48.4	311	1424	1479	1302
2001-09-19	2001	32.0	27.7	29.4	291	805	696	738
2001-10-24	2001	46.0	48.0	39.3	345	1371	1431	1172
2001-11-21	2001	41.5	142.8	98.0	145	520	1789	1227
2001-12-12	2001	239.0	259.3	105.9	108	2230	2420	988
2002-01-23	2001	60.0	72.3	145.8	510	2644	3184	6425
2002-02-20	2001	23.0	18.5	22.4	632	1256	1012	1225
2002-03-20	2001	72.0	50.6	39.4	297	1848	1299	1011
2002-04-17	2001	31.0	27.7	35.1	481	1288	1153	1460
2002-05-22	2001	25.0	19.0	23.3	521	1125	854	1047
2002-06-19	2001	255.0	305.1	121.8	151	3327	3980	1589
2002-07-24	2002	80.0	83.5	61.7	215	1486	1551	1147
2002-08-21	2002	52.0	59.3	51.1	211	948	1081	931
2002-09-18	2002	56.0	58.4	83.9	184	890	929	1333
2002-10-30	2002	69.0	69.8	76.4	146	870	881	964
2002-11-20	2002	90.1	102.4	105.2	200	1557	1770	1817
2002-12-18	2002	87.0	96.3	67.4	204	1533	1697	1188
2003-01-22	2002	45.0	38.3	46.9	279	1083	922	1129
2003-02-19	2002	42.0	35.3	41.2	313	1136	956	1113
2003-03-19	2002	28.0	20.6	27.7	433	1048	772	1037
2003-04-16	2002	28.8	38.6	54.6	627	1560	2091	2958
2003-05-21	2002	75.0	89.0	56.9	249	1614	1914	1225
2003-06-18	2002	76.1	82.2	72.6	215	1414	1527	1348
2003-07-23	2003	41.2	46.6	71.2	294	1047	1184	1808
2003-08-20	2003	29.0	37.1	49.9	398	997	1274	1716
2003-09-17	2003	78.0	114.9	154.7	329	2217	3267	4397
2003-10-22	2003	72.0	63.8	124.8	291	1810	1605	3139
2003-11-19	2003	32.0	46.4	51.3	306	846	1227	1356
2003-12-17	2003	48.0	48.3	30.4	327	1356	1364	859

2004-01-21	2003	75.0	66.5	41.8	270	1750	1551	976
2004-02-11	2003	73.0	73.0	74.6	228	1438	1439	1470
2004-03-17	2003	40.0	33.4	41.5	365	1261	1052	1308
2004-04-21	2003	28.0	23.4	30.8	437	1057	884	1162
2004-05-19	2003	53.0	58.9	67.9	308	1410	1567	1808
2004-06-16	2003	50.0	68.4	101.4	254	1097	1500	2225
2004-07-21	2004	30.0	33.1	45.8	298	772	851	1179
2004-08-18	2004	130.0	166.1	105.2	245	2752	3517	2227
2004-09-15	2004	73.0	88.0	85.5	200	1261	1521	1477
2004-10-27	2004	70.0	77.9	102.9	131	792	881	1164
2004-11-17	2004	56.0	60.7	57.2	169	818	886	835
2004-12-15	2004	38.0	45.3	58.0	291	955	1138	1458
2005-01-19	2004	36.0	40.4	45.7	273	849	952	1078
2005-02-16	2004	27.0	29.4	36.4	516	1204	1309	1623
2005-03-16	2004	43.0	50.8	52.8	343	1274	1504	1565
2005-04-20	2004	27.0	33.6	43.8	518	1208	1504	1961
2005-05-18	2004	35.0	46.1	44.8	325	983	1296	1257
2005-06-22	2004	39.2	46.5	43.8	261	884	1048	988
2005-07-20	2005	67.7	136.7	66.0	476	2784	5623	2713
2005-08-24	2005	46.9	54.1	51.8	203	821	946	907
2005-09-21	2005	36.0	45.7	47.0	269	835	1059	1091
2005-10-26	2005	31.0	39.3	53.7	278	745	945	1290
2005-11-16	2005	27.5	29.4	33.3	331	786	842	954
2005-12-14	2005	29.9	37.4	33.1	292	754	943	834
2006-01-18	2005	57.0	62.7	69.5	225	1108	1218	1351
2006-02-15	2005	35.0	38.6	36.2	351	1061	1171	1097
2006-03-16	2005	29.5	30.5	29.9	372	948	981	960
2006-04-19	2005	49.5	55.8	80.3	257	1099	1240	1783
2006-05-17	2005	32.5	50.7	56.2	326	915	1429	1582
2006-06-21	2005	68.5	91.2	92.7	311	1841	2451	2492
2006-07-19	2006	50.8	66.6	59.5	336	1475	1932	1726
2006-08-09	2006	39.5	48.7	47.6	354	1208	1490	1456
2006-09-27	2006	67.2	87.3	61.5	140	813	1056	744
2006-10-18	2006	96.0	111.7	105.3	148	1228	1428	1347
2006-11-15	2006	290.0	359.7	186.3	76	1904	2362	1223
2006-12-13	2006	69.0	92.4	86.5	187	1115	1492	1398
2007-01-17	2006	36.5	39.2	39.1	248	782	840	838
2007-02-14	2006	30.0	25.1	25.3	363	941	788	792
2007-03-14	2006	22.5	19.5	20.0	534	1038	899	922
2007-04-18	2006	27.0	24.9	22.8	568	1325	1223	1121
2007-05-07	2006	30.6	31.1	43.6	437	1155	1175	1645
2007-06-20	2006	31.0	28.8	50.9	335	896	832	1472
2007-07-18	2007	29.5	29.9	51.1	382	972	987	1684
2007-08-15	2007	79.2	85.4	51.7	171	1170	1261	764
2007-09-19	2007	51.7	48.6	42.1	164	733	689	596
2007-10-17	2007	389.7	434.8	208.3	91	3064	3419	1638
2007-11-21	2007	34.7	32.2	41.8	236	708	656	853
2007-12-19	2007	53.2	61.0	28.0	335	1541	1765	809
2008-01-16	2007	34.5	23.1	19.8	308	918	615	527
2008-02-13	2007	53.1	102.8	39.7	717	3290	6367	2459
2008-03-12	2007	29.9	27.2	28.1	703	1818	1654	1709
2008-04-16	2007	21.0	23.9	21.4	792	1437	1633	1467
2008-05-14	2007	21.6	22.9	23.5	639	1193	1265	1300
2008-06-18	2007	33.1	32.1	34.7	455	1301	1263	1363

2008-07-16	2008	84.1	105.1	143.3	336	2442	3050	4160
2008-08-13	2008	60.0	87.3	199.4	1129	5853	8516	19452
2008-09-17	2008	82.7	96.8	128.1	517	3690	4318	5719
2008-10-15	2008	66.9	69.3	80.9	361	2087	2161	2523
2008-11-19	2008	59.4	58.2	68.8	316	1620	1587	1874
2008-12-17	2008	38.8	35.0	61.7	480	1609	1450	2557
2009-01-14	2008	36.6	29.8	36.0	414	1309	1065	1288
2009-02-18	2008	17.8	20.7	39.6	656	1010	1175	2247
2009-03-18	2008	31.4	31.7	38.8	403	1092	1102	1350
2009-04-15	2008	26.9	26.2	41.5	491	1141	1113	1759
2009-05-19	2008	171.2	174.1	106.3	190	2810	2859	1746
2009-06-17	2008	41.9	47.2	46.8	427	1546	1743	1725
2009-07-15	2009	38.8	47.2	72.8	667	2238	2718	4195
2009-08-12	2009	47.8	50.7	81.0	333	1374	1458	2331
2009-09-16	2009	52.9	56.2	82.5	228	1040	1105	1622
2009-10-14	2009	78.8	97.5	92.1	207	1409	1743	1647
2009-11-11	2009	40.5	43.1	44.6	257	899	956	990
2009-12-16	2009	108.2	113.3	79.4	128	1197	1253	878
2010-01-13	2009	91.5	101.1	64.6	125	988	1092	698
2010-02-10	2009	22.5	20.5	23.8	451	878	797	928
2010-03-17	2009	19.5	22.5	30.0	540	911	1049	1401
2010-04-14	2009	25.5	23.1	34.5	557	1227	1113	1659
2010-05-12	2009	34.8	39.7	77.6	362	1088	1241	2426
2010-06-16	2009	48.5	62.3	107.8	740	3098	3986	6893
2010-07-14	2010	30.5	29.3	83.8	1188	3131	3005	8599
2010-08-11	2010	58.2	103.0	107.9	1099	5530	9775	10246
2010-09-15	2010	89.5	115.8	168.3	394	3043	3937	5723
2010-10-13	2010	73.2	90.8	108.0	312	1973	2447	2912
2010-11-17	2010	40.3	36.6	41.0	370	1288	1170	1311
2010-12-15	2010	21.5	20.7	57.6	548	1018	982	2727
2011-01-12	2010	38.0	28.4	55.4	343	1126	842	1641
2011-02-16	2010	40.7	43.4	51.5	338	1187	1264	1502
2011-03-16	2010	27.5	28.6	36.9	584	1388	1445	1863
2011-04-13	2010	23.3	31.3	43.4	462	930	1251	1731
2011-05-11	2010	47.5	61.7	93.4	283	1161	1508	2284
2011-06-15	2010	40.2	44.0	45.8	336	1167	1276	1331
2011-07-13	2011	130.0	209.7	92.5	263	2954	4765	2101
2011-08-17	2011	31.0	48.2	51.2	502	1345	2090	2222
2011-09-14	2011	42.0	53.2	48.1	278	1009	1277	1156
2011-10-12	2011	56.0	66.5	87.0	191	924	1098	1435
2011-11-16	2011	65.2	77.3	109.4	176	991	1175	1664
2011-12-14	2011	43.0	54.8	62.5	290	1077	1374	1565
2012-01-11	2011	51.5	33.7	42.5	404	1798	1175	1484
2012-02-15	2011	24.5	25.0	32.1	567	1200	1225	1570
2012-03-14	2011	27.6	36.2	41.5	447	1067	1398	1604
2012-04-11	2011	26.5	27.4	31.7	476	1090	1125	1304
2012-05-16	2011	48.8	48.2	38.7	273	1151	1136	912
2012-06-13	2011	66.0	86.6	84.1	353	2013	2642	2565
2012-07-11	2012	35.0	51.0	82.4	398	1204	1754	2835
2012-08-15	2012	86.5	192.6	150.9	711	5314	11832	9268
2012-09-12	2012	140.0	161.3	96.6	249	3012	3470	2078
2012-10-17	2012	112.0	116.1	129.2	195	1887	1957	2177
2012-11-14	2012	45.0	50.2	54.0	307	1194	1331	1431
2012-12-12	2012	36.5	37.1	35.0	260	818	832	785

2013-01-16	2012	114.0	172.0	89.4	256	2521	3805	1978
2013-02-13	2012	27.4	23.8	24.6	452	1069	928	960
2013-03-13	2012	19.2	19.0	19.8	606	1005	997	1037
2013-04-23	2012	42.3	52.7	30.7	402	1469	1831	1066
2013-05-15	2012	29.1	32.5	40.9	418	1051	1173	1477
2013-06-12	2012	55.5	60.9	121.3	289	1386	1522	3030
2013-07-17	2013	62.0	126.8	138.3	831	4452	9101	9930
2013-08-14	2013	52.0	51.1	78.0	664	2983	2933	4476
2013-09-11	2013	65.0	252.3	126.6	441	2477	9612	4823
2013-10-16	2013	230.0	303.7	203.0	162	3219	4250	2842
2013-11-13	2013	70.2	52.6	65.0	345	2088	1566	1935
2013-12-11	2013	62.0	42.5	42.7	326	1746	1198	1204
2014-01-15	2013	51.5	57.2	57.0	262	1166	1295	1291
2014-02-12	2013	24.9	21.5	21.2	536	1154	995	984
2014-03-12	2013	22.8	22.7	25.4	666	1314	1306	1464
2014-04-16	2013	28.1	34.9	80.3	654	1590	1972	4535
2014-05-14	2013	63.0	124.5	114.2	531	2890	5710	5241
2014-06-11	2013	793.0	847.1	161.1	590	40424	43180	8215
2014-07-16	2014	49.9	49.9	55.7	587	2533	2533	2825
2014-08-13	2014	124.4	123.8	74.7	262	2816	2802	1691
2014-09-17	2014	54.7	62.8	49.8	279	1319	1513	1200
2014-10-15	2014	57.7	61.1	69.9	233	1162	1229	1407
2014-11-12	2014	85.1	75.4	90.1	145	1066	945	1128
2014-12-10	2014	62.0	63.4	53.5	223	1194	1222	1032
2015-01-14	2014	28.9	20.9	24.6	304	759	549	646
2015-02-11	2014	31.2	25.2	19.0	273	737	595	448
2015-03-11	2014	37.0	34.0	24.0	265	847	778	550
2015-04-15	2014	52.0	62.4	39.9	204	917	1100	703
2015-05-13	2014	131.1	157.1	91.4	108	1223	1466	853
2015-06-17	2014	79.5	76.1	114.6	178	1223	1170	1763
2015-07-15	2015	42.4	46.9	61.7	319	1169	1294	1701
2015-08-12	2015	72.1	69.1	83.6	242	1507	1444	1748
2015-09-16	2015	35.3	38.6	58.4	218	666	727	1100
2015-10-14	2015	68.5	64.9	56.9	135	799	757	664
2015-11-11	2015	30.3	30.1	37.1	271	709	706	869
2015-12-16	2015	50.4	46.2	37.2	153	666	610	492

Appendix B: Methods for estimating nutrient mass loads

From Norton and Kelly (2010).

Appendix C: Averaging load estimation method

Monthly DIN load (t-N/month) = average monthly flow (m^3/s) × concentration ($mg\text{-}N/m^3$) × No. days per month (d) × 86400/1E9 (units conversion)

ECan data.

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
2005-06	80.4	25.3	27.1	44.3	22.8	23.1	52.7	32.5	38.1	25.5	42.1	119.2	**533**
2006-07	0.0	34.4	27.0	51.1	71.0	66.7	34.2	31.4	18.7	30.8	23.3	47.3	**436**
2007-08	53.8	35.5	22.8	82.0	28.2	26.1	19.4	67.2	57.0	42.8	45.0	40.7	**520**
2008-09	137.0	542.1	170.2	74.2	60.2	72.0	45.5	60.3	43.4	51.6	69.8	54.2	**1381**
2009-10	64.5	48.4	59.7	42.2	26.1	23.9	44.2	20.5	40.4	38.5	167.5	230.0	**806**
2010-11	205.5	0.0	206.8	95.8	40.5	51.3	43.4	42.1	47.1	53.5	38.2	37.8	**862**
2011-12	75.5	54.1	28.9	48.9	21.8	36.6	37.4	31.5	38.2	34.7	25.6	66.2	**500**
2012-13	52.4	256.8	91.3	62.3	34.8	32.4	77.8	31.8	34.7	48.9	38.9	316.1	**1078**
2013-14	190.8	124.3	80.4	122.4	66.6	40.6	51.2	30.6	38.5	123.8	81.1	173.3	**1124**
Average	**95.6**	**124.6**	**79.3**	**69.2**	**41.3**	**41.4**	**45.1**	**38.7**	**39.6**	**50.0**	**59.1**	**120.5**	804

NIWA data.

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
2000-01	67.7	166.2	92.3	43.5	18.4	43.7	39.4	25.6	32.9	29.9	23.0	27.4	**610**
2001-02	59.9	40.3	22.1	36.3	36.8	30.6	199.2	34.3	31.4	43.8	32.5	47.7	**615**
2002-03	35.6	28.9	40.0	29.9	54.5	36.8	35.0	31.2	32.2	88.7	38.0	40.5	**491**
2003-04	56.1	53.2	131.9	97.3	40.7	26.6	30.2	41.1	40.5	34.9	56.0	66.8	**675**
2004-05	36.6	69.0	44.3	36.1	25.0	45.2	33.4	45.4	48.5	58.8	39.0	29.7	**511**
2005-06	84.1	28.1	32.7	40.0	28.6	25.9	41.9	30.7	29.8	53.5	49.0	74.7	**519**
2006-07	53.5	45.1	22.3	41.7	36.7	43.3	26.0	22.2	28.6	33.6	51.0	44.2	**448**
2007-08	52.2	23.7	17.9	50.8	25.6	25.1	16.3	68.9	53.0	44.0	40.3	40.9	**459**
2008-09	129.0	603.0	171.6	78.2	56.2	79.3	39.9	62.9	41.8	52.8	54.1	51.8	**1421**
2009-10	130.1	72.3	48.7	51.1	29.7	27.2	21.6	26.0	43.4	49.8	75.2	206.8	**782**
2010-11	266.6	317.6	171.7	90.3	39.3	84.5	50.9	42.1	57.7	51.9	70.8	39.9	**1283**
2011-12	65.1	68.9	34.7	44.5	49.9	48.5	46.0	44.0	49.7	39.1	28.3	76.9	**596**
2012-13	87.9	287.3	62.3	67.5	42.9	24.3	61.3	26.9	32.1	32.0	45.8	90.9	**861**
2013-14	307.8	138.7	144.7	88.1	58.1	37.3	40.0	27.5	45.4	136.1	162.5	246.4	**1433**
2014-15	87.6	52.4	36.0	43.6	33.8	32.0	20.0	12.6	17.1	21.1	26.4	52.9	**436**
2015-16	52.7	54.2	33.0	20.6	26.1	15.3	46.7	36.1	38.9	51.3	52.8	75.8	**504**
Average	**98.3**	**128.1**	**69.1**	**53.7**	**37.7**	**39.1**	**46.7**	**36.1**	**38.9**	**51.3**	**52.8**	**75.8**	**728**

Appendix D: Beale load estimation method

Beale estimator using ECan data

Month	2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013	
	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)
July	115.9	4,557	64.2	1,623	29.9	1,017	128.9	3,975	120.3	3,440	66.4	5,253	136.2	3,587	99.8	2,048
August	66.4	1,048	38.7	826	42.0	928	69.0	6,054	63.2	1,218	104.1	5,655	59.2	2,016	91.8	5,040
September	45.6	877	78.6	1,148	43.8	791	90.6	4,010	42.7	1,030	152.4	4,199	49.6	992	72.1	2,271
October	34.4	917	139.0	2,174	148.6	1,887	69.3	2,050	104.2	1,539	84.7	2,423	80.2	1,455	141.9	2,206
November	44.8	1,022	138.9	1,764	30.5	684	53.6	1,565	38.3	747	36.3	1,196	210.4	1,400	59.5	1,279
December	33.5	756	45.3	1,128	45.9	1,380	35.6	1,339	137.7	1,339	20.5	588	63.4	1,200	27.3	813
January	43.9	1,073	27.6	776	19.2	605	22.9	932	43.9	966	29.8	754	34.9	991	44.9	1,261
February	26.6	854	18.5	821	39.1	2,364	20.3	1,105	23.8	732	43.4	1,264	24.2	851	20.1	927
March	28.8	1,183	24.5	742	21.9	1,431	29.1	1,051	23.6	1,023	34.5	1,418	42.1	1,251	19.5	1,102
April	142.9	1,512	23.6	1,061	23.9	1,591	25.2	1,043	27.0	1,004	30.3	1,247	28.9	1,054	21.3	1,132
May	46.9	1,135	94.9	1,640	19.8	1,223	123.2	2,609	218.1	15,186	132.5	1,746	45.0	962	35.0	1,075
June	50.5	2,166	28.3	876	29.8	1,164	43.8	1,693	56.6	4,021	46.2	1,270	66.6	1,748	83.9	7,287
Average daily load obs.	**56.7**	**1425.0**	**60.2**	**1214.9**	**41.2**	**1255.4**	**59.3**	**2285.5**	**74.9**	**2687.0**	**65.1**	**2251.3**	**70.1**	**1458.9**	**59.8**	**2203.6**
Annual ave. flow (m^3/s)		54.2		62.5		49.4		83.1		66.2		74.6		60.2		73.3
Covariance (Load/Flow)		21,143		17,303		6,688		36,428		178,503		44,455		17,990		36,011
Variance	1,301	1,115,352	1,916	221,903	1,231	265,946	1,442	2,567,575	3,520	16,615,233	1,918	3,130,685	2,837	568,442	1,516	3,896,374
bias correction		0.989		0.977		0.955		0.989		1.020		0.988		0.969		0.988
Ave daily load (kg-N/d)		1346.5		1232.6		1437.1		3167.4		2422.1		2550.6		1214.2		2670.3
Annual load (t-N/y)	0.081	**491**	0.081	**450**	0.081	**526**	0.081	**1156**	0.081	**884**	0.081	**931**	0.081	**444**	0.081	**975**

Month	2013-2014	
	Av. daily flow obs (m^3/s)	Load obs (kg-N/day)
July	114.5	5,093
August	51.1	2,628
September	121.0	2,562
October	129.7	2,522
November	43.3	1,477
December	35.5	1,088
January	43.4	1,256
February	19.0	978
March	27.0	1,317
April	35.3	1,813
May	162.6	3,723
June	123.0	4,411
Average daily load obs.	**75.4**	**2405.6**
Annual ave. flow (m^3/s)		93.2
Covariance (Load/Flow)		49,956
Variance	2,527	1,868,859
bias correction		0.987
Ave daily load (kg-N/d)		2931.8
Annual load (t-N/y)	0.081	**1070**

Beale estimator using NIWA data

Month	2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008	
	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)
July	36.1	960	75.1	3,201	83.5	1,551	46.6	1,184	33.1	851	136.7	5,623	66.6	1,932	29.9	987
August	106.3	4,821	55.0	1,479	59.3	1,081	37.1	1,274	166.1	3,517	54.1	946	48.7	1,490	85.4	1,261
September	77.5	2,050	27.7	696	58.4	929	114.9	3,267	88.0	1,521	45.7	1,059	87.3	1,056	48.6	689
October	142.3	1,365	48.0	1,431	69.8	881	63.8	1,605	77.9	881	39.3	945	111.7	1,428	434.8	3,419
November	19.8	388	142.8	1,789	102.4	1,770	46.4	1,227	60.7	886	29.4	842	359.7	2,362	32.2	656
December	18.1	737	259.3	2,420	96.3	1,697	48.3	1,364	45.3	1,138	37.4	943	92.4	1,492	61.0	1,765
January	20.9	726	72.3	3,184	38.3	922	66.5	1,551	40.4	952	62.7	1,218	39.2	840	23.1	615
February	15.5	810	18.5	1,012	35.3	956	73.0	1,439	29.4	1,309	38.6	1,171	25.1	788	102.8	6,367
March	14.2	884	50.6	1,299	20.6	772	33.4	1,052	50.8	1,504	30.5	981	19.5	899	27.2	1,654
April	18.9	948	27.7	1,153	38.6	2,091	23.4	884	33.6	1,504	55.8	1,240	24.9	1,223	23.9	1,633
May	29.6	910	19.0	854	89.0	1,914	58.9	1,567	46.1	1,296	50.7	1,429	31.1	1,175	22.9	1,265
June	47.2	958	305.1	3,980	82.2	1,527	68.4	1,500	46.5	1,048	91.2	2,451	28.8	832	32.1	1,263
Average daily load obs.	**45.5**	**1296.4**	**91.8**	**1874.7**	**64.5**	**1341.0**	**56.7**	**1492.8**	**59.8**	**1367.3**	**56.0**	**1570.6**	**77.9**	**1293.0**	**77.0**	**1797.7**
Annual ave. flow (m^3/s)		57.8		63.1		62.1		69.8		60.4		54.2		62.5		49.4
Covariance (Load/Flow)		28,606		67,110		6,507		12,157		20,929		35,541		32,703		78,922
Variance	1,731	1,396,885	9,151	1,144,605	723	216,140	569	360,807	1,436	522,909	929	1,811,403	8,810	231,881	13,381	2,636,409
bias correction		0.974		0.948		0.992		0.997		0.989		1.008		0.919		0.885
Ave daily load (kg-N/d)		1601.7		1222.3		1281.6		1833.3		1364.5		1532.1		952.6		1020.7
Annual load (t-N/y)	0.081	**586**	0.081	**446**	0.081	**468**	0.081	**669**	0.081	**499**	0.081	**559**	0.081	**348**	0.081	**373**

Month	2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016	
	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)	Av. daily flow obs (m3/s)	Load obs (kg-N/day)
July	105.1	3,050	47.2	2,718	29.3	3,005	209.7	4,765	51.0	1,754	126.8	9,101	49.9	2,533	46.9	1,294
August	87.3	8,516	50.7	1,458	103.0	9,775	48.2	2,090	192.6	11,832	51.1	2,933	123.8	2,802	69.1	1,444
September	96.8	4,318	56.2	1,105	115.8	3,937	53.2	1,277	161.3	3,470	252.3	9,612	62.8	1,513	38.6	727
October	69.3	2,161	97.5	1,743	90.8	2,447	66.5	1,098	116.1	1,957	303.7	4,250	61.1	1,229	64.9	757
November	58.2	1,587	43.1	956	36.6	1,170	77.3	1,175	50.2	1,331	52.6	1,566	75.4	945	30.1	706
December	35.0	1,450	113.3	1,253	20.7	982	54.8	1,374	37.1	832	42.5	1,198	63.4	1,222	46.2	610
January	29.8	1,065	101.1	1,092	28.4	842	33.7	1,175	172.0	3,805	57.2	1,295	20.9	549		
February	20.7	1,175	20.5	797	43.4	1,264	25.0	1,225	23.8	928	21.5	995	25.2	595		
March	31.7	1,102	22.5	1,049	28.6	1,445	36.2	1,398	19.0	997	22.7	1,306	34.0	778		
April	26.2	1,113	23.1	1,113	31.3	1,251	27.4	1,125	52.7	1,831	34.9	1,972	62.4	1,100		
May	174.1	2,859	39.7	1,241	61.7	1,508	48.2	1,136	32.5	1,173	124.5	5,710	157.1	1,466		
June	47.2	1,743	62.3	3,986	44.0	1,276	86.6	2,642	60.9	1,522	847.1	43,180	76.1	1,170		
Average daily load obs.	**65.1**	**2511.5**	**56.4**	**1542.6**	**52.8**	**2408.7**	**63.9**	**1706.8**	**80.8**	**2619.2**	**161.4**	**6926.6**	**67.7**	**1325.2**	**49.3**	**922.9**
Annual ave. flow (m^3/s)		83.1		66.2		74.6		60.2		73.3		93.2		59.1		55.9
Covariance (Load/Flow)		42,704		3,877		51,511		44,474		136,419		2,434,844		13,073		2,343
Variance	2,011	4,568,186	1,008	844,942	1,060	6,241,618	2,471	1,145,356	3,897	9,314,065	55,000	########	1,530	488,171	226	123,935
bias correction		0.983		0.979		1.002		0.985		1.004		1.005		0.985		0.997
Ave daily load (kg-N/d)		3151.4		1771.8		3410.4		1582.9		2384.6		4016.9		1140.3		1043.0
Annual load (t-N/y)	0.081	**1150**	0.081	**648**	0.081	**1245**	0.081	**578**	0.081	**870**	0.081	**1470**	0.081	**416**	0.081	**381**

Appendix 2: Methods for estimating nutrient mass loads

1) Averaging approach

This method uses the means of concentration and flow from the days on which concentration was measured to calculate load for a specific time interval. The method was previously used by Ausseil (2010) to estimate nutrient loads for the Culverden Basin. Monthly load was estimated by factoring the monthly average concentration by the monthly average flow volume

$$Load(month_i) = [Pollut](month_i) \cdot \int_{01/month_i}^{31/month_i} Flow(t) \cdot dt$$

Water quality measurements are made only once per month, therefore each monthly measurement was used to represent the monthly average concentration. The average flow volume per month is given as:

Average daily flow over the month (m^3/s)

$$\left(\sum_{month_i}^{n} DailyVolume \right) /n$$

Where: *n* = days in month

Then convert to average flow volume per month (m^3) by factoring *n* by total seconds per day. For example, if the monthly average nutrient concentration is 0.455 g/ m^3 and the average daily flow over the month is 66 m^3/s then:

$Load(month_i)$ = 0.455g/m^3 * 66 (30days * 86400s)

= 77837760g = 77.83 tonnes

This leads to the estimator

$$Load(year_i) = \sum_i [Pollut]_{monthi} \cdot Monthly\_average\_flow_{monthi} \cdot \Delta t$$

Where: $[Pollut]_{month}$ = the time series of observed monthly concentrations

Because averaging methods assume that concentration and flow are independent variables, this was first checked by regressing flow against concentration for both DIN and DRP. If both variables are correlated, the method will underestimate load particularly during periods of high flow (Quilbe *et al.* 2006). Generally if $r^2 < 0.5$, averaging methods can be used.

2) Regression approach

Where there is a strong regression between concentration and flow, one is able to estimate the value for the unknown variable (most likely concentration) for the days on which it was not sampled. Concentration data are often Log10 transformed and the resultant regression is applied to obtain values for unknown days (Richards 1998).

NB The regression approach is used only if concentration and flow are strongly correlated (i.e. *r* >0.5 or <-0.5) and thus inter-dependent.

3) The Beale ratio estimator

Ratio estimators assume that the ratio of load to flow for the entire year equals that for load to flow on the days on which concentration was measured:

$$\frac{Avg.\_daily\_load_{yr}}{Avg.\_daily\_flow_{yr}} = \frac{Avg.\_daily\_load_{obs.}}{Avg.\_daily\_flow_{obs.}}$$

where yr = average for a year, and obs. = average over the days on which concentration was measured

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An average daily load is first calculated for the days on which concentration was measured

$$Avg.\_daily\_load_{obs.} = \sum_{obs.i-j}[Pollut \cdot Avg.\_daily\_flow_{obs.}] \ / \ n$$

Where n = number of months on which concentration data is available

The average daily load is then adjusted by a flow ratio derived from the mean flow for the days that lack concentration data:

Flow ratio = $Avg.\_daily\_flow_{yr} \ / \ Avg.\_daily\_flow_{obs.}$

The method assumes that flux and flow are correlated, but if this is so, the ratio estimator is biased. Therefore, a bias correction factor is required to adjust the daily load; here, the Beale ratio estimator is used for this purpose:

The Beale Ratio Estimator

$$Avg.\_daily\_load_{yr} = Avg.\_daily\_load_{obs.} \cdot \frac{Avg.\_daily\_flow_{yr}}{Avg.\_daily\_flow_{obs.}} \left[\frac{1+\left(\frac{1}{n}-\frac{1}{N}\right)\frac{s_{lq}}{\overline{\overline{l_o q_o}}}}{1+\left(\frac{1}{n}-\frac{1}{N}\right)\frac{s_{qq}}{q_o^{\,2}}} \right]$$

For the term in the box brackets:

Slq = the covariance between flow and pollutant flux
Sqq = the variance of flow based on the days on which concentration was measured
N is the expected population size (365 for a year; 366 on leap years)
N = the number of measures of the pollutant concentration (e.g. 12 for monthly sampling)
Lo = average load flux on days when concentration was measured
Qo = average flow on days when concentration was measured
(See Richards 1998)

Annual pollutant load can then be estimated by multiplying the adjusted daily load by 365 (or 366 for leap years; Richards 1998). The Root Mean Square Error approximates the standard error of the annual load estimate and can be used to calculate 95% confidence limits as follows:
Load estimate ± (SE * 1.96)