Nutrient load estimates for Lake Brunner

NIWA Client Report: HAM2008-060
May 2008

NIWA Project: ELF07202/WCRC17

Nutrient load estimates for Lake Brunner

Kit Rutherford
Catherine Chagué-Goff
Alistair McKerchar

Prepared for

West Coast Regional Council

NIWA Client Report: HAM2008-060
May 2008

NIWA Project: ELF07202/WCRC17

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

Contents

Executive Summary		iv
1.	Background	1
1.1	Introduction	1
1.2	Context	1
2.	Results	3
2.1	Catchment area	3
2.2	Lake and tributary flow	3
2.3	Tributary nutrients	7
2.4	Land use	14
2.5	Nutrient yield	17
2.6	Relationship between yield and land use	18
2.7	Predicting lake inflows	20
3.	References	22
4.	Appendix 1: Dairy farms in the Brunner catchment. Source WCRC.	23

Reviewed by: *Approved for release by:*

Dr R.J. Wilcock Dr A.H. Elliott

Formatting checked

Executive Summary

The WCRC has sought assistance to incorporate existing monitoring data for the Brunner catchment into a model predicting flow and nutrient delivery. The model will be used to make quantitative predictions of nutrient loadings on the lake under future land use development scenarios.

Tributary water quality and flow have been measured on 14-27 occasions 2003-2007. In this report only total nutrient concentrations (TP and TN) are analysed and further work may be required on the soluble and particulate inorganic and organic components.

Flow is not measured continuously in any of the main inflows. A method was developed to estimate total daily flow of water into the lake from continuous measurements of lake outflow rate and lake level, with corrections for rainfall and evaporation, and to apportion total inflow between tributaries based on the average of measured flows. In this way it is possible to estimate daily flow in each tributary.

TP and TN concentrations vary only weakly with flow in the forested catchment (Carew) and in lake outflows (Poerua). TP concentrations vary strongly with flow in tributaries draining farmland as is commonly found elsewhere. TN concentrations vary less strongly with flow than TP in tributaries draining farmland. DON makes a major contribution to TN concentration but this DON may not be bioavailable to plants in the lake, although its colour may affect light penetration and primary productivity.

Correlations have been established between TP and TN concentration and flow in each of the tributaries. Using correlations between concentration and flow, estimates have been made of annual mass flows of TP and TN into the lake.

Land-use has been estimated in each sub-catchment from LCDB2 which is based on satellite imagery of ground cover. LCDB2 indicates that 19% of the total catchment area is high producing exotic grassland (6414 ha), while 75% of the catchment is forest, scrub, undeveloped grassland, rock or water. However, the total area in dairy farming is 3432 ha which is only 8% of the total catchment compared with 19% classified as high producing exotic grassland by LCDB2. It is desirable to compare the actual land use with the LCDB2 classification.

Specific yields of TN and TP for the whole catchment estimated from tributary monitoring data are 11.3 kg N ha^{-1} yr^{-1} and 0.54 kg P ha^{-1} yr^{-1}. Yields are highest in the Orangipuku (21 kg N ha^{-1} yr^{-1} and 0.93 kg P ha^{-1} yr^{-1}) the most intensively farmed catchment.

Independent estimates of specific yield for the catchment were made from measured lake concentrations, corrected for nutrient retention in the lake. The estimates for TN (11.3 kg N ha^{-1} yr^{-1}

from tributary sampling and 11.2 kg N ha^{-1} yr^{-1} from lake sampling) are indistinguishable. The estimates for TP (0.54 kg P ha^{-1} yr^{-1} from tributary sampling and 0.38 kg P ha^{-1} yr^{-1} from lake sampling) are similar within the likely errors of estimation.

Specific yields for high producing exotic grassland estimated in this study are 50.4 kg N ha^{-1} yr^{-1}. These match closely the unattenuated (edge of field) yield of c. 50 kg N ha^{-1} yr^{-1} for a typical New Zealand dairy farm (Meneer et al. 2003) which suggests that there is very little attenuation of nitrogen between where it is generated and where it is measured close to the lake. The yield for high producing exotic grassland of 2.4 kg P ha^{-1} yr^{-1} is slightly higher than the typical yield of 1 kg P ha^{-1} yr^{-1}.

The available tributary monitoring data are consistent with our expectations of the likely nutrient yields from intensive agriculture. The methods developed are suitable for estimating the effects of land use change on nutrient inflows to the lake and the available data will provide a good basis for the development of a lake water quality model.

1. Background

1.1 Introduction

The WCRC needs to predict nutrient loadings in Lake Brunner to aid with land use management and future planning. The WCRC has sought assistance from NIWA through an Envirolink medium advice Grant to incorporate existing monitoring data for the Brunner catchment, together with information from catchments elsewhere in New Zealand, into a model predicting flow and nutrient delivery.

The model will be used to make quantitative predictions of nutrient loadings on the lake under future land use development scenarios. Farm plans have been developed with 79% of the Brunner catchment's farming community. The model will be used to examine whether the forecast changes in farm land management are likely to achieve the desired environmental outcomes.

The nutrient loading model for the catchment will be the basis for the development of a water quality ecosystem model for the lake to predict water quality variables such as water clarity and hypolimnetic deoxygenation. The lake model is described in a separate report.

1.2 Context

Water quality monitoring in Lake Brunner, and associated investigations into managing best dairy practices, have found that the Lake Brunner catchment has undergone significant increases in nutrient loading. Nutrient concentrations (median nitrate and dissolved reactive phosphorus) of tributaries feeding the lake are approximately 6 to 10 fold higher in dairy farming dominated catchments compared with those of predominantly native forest.

The Lake Brunner catchment has been gazetted in the WCRC Water Plan as a special management area in recognition of its ecological, cultural and economic importance to the region and the country. It is WCRC's highest priority for water quality and catchment management. Several programs are focusing on sustainable land use practices within the catchment. They represent a sizeable investment made by a large group of organizations including FRST, MAF Sustainable Farming Fund, MfE, NZ Landcare Trust, NIWA, AgResearch, DairyNZ (formerly Dexcel and Dairy Insight), Westland Milk Products, and the West Coast Regional Council.

Finding the right solutions to managing water quality degradation in the catchment will take time, but WCRC sees it as important that these solutions are effective and sustainable, therefore worth the wait. There is still progress to be made in the region regarding attitudes towards the environment, both amongst landowners and industry, and at a political level. Clarifying and quantifying linkages between environmental pressures and responses are proven ways to improve buy-in from the community, including local council.

The Brunner catchment and lake comprise a complex system and modelling will potentially provide a means of tying together components of this system to predict quantitatively effects arising from different land use scenarios. This will provide the accurate information the WCRC requires for confident long-term planning, and regulation that is efficient, fair and effective in achieving water quality objectives. It will also assist the WCRC in identifying information gaps, and guide future research prioritisation.

The WCRC and the New Zealand Landcare Trust have recently developed farm plans with 79% of the Brunner catchment's farming community. The nutrient load model will be used to quantitatively examine whether forecast changes in farm land management are likely to result in the desired environmental outcomes. These include activities such as fencing of riparian corridors, bridge crossings, and winter standoff pads. It is hoped that a more quantitative framework of the model will allow the council to predict land use improvements over a much broader catchment scale. This will involve continued monitoring in the Orangipuku and Crooked River catchments, with data directly feeding into the nutrient-loading model.

2. Results

2.1 Catchment area

Three catchments make up 78% of the total catchment at the outlet – Crooked (which includes the Poerua), Hohonu and Orangipuku (Table 1, Figure 1). The lake occupies another 9% of the catchment. The Carew is a small undeveloped catchment that has been sampled on a few occasions. The Poerua River flows into the Crooked River from Lake Poerua and is also monitored.

Table 1: Catchment area and estimated mean flows for the Brunner catchment.

River	Area km^2	Area %total	Mean gauged flow[1] $m^3\ s^{-1}$	Mean flow[2] $m^3\ s^{-1}$	Mean flow % total
Crooked + Poerua	243	57	25.1	30.5	49
Hohonu	46	10	3.5	4.2	7
Orangipuku	45	10	6.6	8.0	13
Ungauged	106	15	-	15.2	24
Lake	40.6	9	-	3.6	7
			-		
Total	**440**	**100**	**-**	**61.5**	**100**
Carew	4.5	1	-	0.59	1.1
Poerua	38.1	9	-	5.0	11

[1] measured when water samples were collected

[2] long-term average estimated from a daily water balance 1998-2006

2.2 Lake and tributary flow

Lake level and lake outflow (via the Arnold River) are recorded continuously (Site 91405). However, there are no continuous flow recorders on any of the tributaries flowing into the lake. Average lake outflow for the period 1st August 1989 to 2nd November 2007 was 61.5 m^3/s. Total inflows to the lake were estimated using the continuity equation where:

$$\text{Rate of change of lake volume} = \text{inflow} - \text{outflow} \quad (1)$$

Rate of change of volume is estimated as rate of change of lake level times lake area. As the levels are recorded only with a resolution of ±1 mm, the calculation is sensitive to wind and seiching effects and some smoothing is necessary to achieve realistic inflow hydrographs.

Average rainfall over the lake area of 40.6 km^2 was assessed as 3500 mm yr^{-1} using a fitted rainfall surface. Evaporation was assumed constant at 700 mm yr^{-1}. This yields an average contribution to the outflow from net rainfall on the lake of 3.6 m^3 s^{-1}. Thus inflow to the lake from tributary rivers averaged 57.9 m^3 s^{-1} over the period considered (Table 1). A sample of the time-series of daily inflow (including rain on the lake surface), for 2003-2006, is shown in Figure 2. Figure 3 present a bar chart showing the proportion of the inflow from each of the sources listed in Table 1.

Flows have been measured in the three main tributaries on 14-27 occasions when collecting water quality samples between 2003-2007. Gaps were filled by correlation with flow at another site. It was found that tributary flow yield (L s^{-1} km^{-2}) varied between catchments (Table 1). Consequently the three main tributaries do not contribute inflow in proportion to their catchments area. The percentage of the total inflow from each tributary was estimated by scaling tributary catchment area by the ratio of tributary flow yield to flow yield for the lake (Table 1).

The three main tributaries – Crooked, Hohonu and Orangipuku – contribute 69% of the total lake inflow. Water quality and flow have been measured approximately monthly since 2003 in these three tributaries. Water quality and flow have also been measured in two other tributaries - the Carew (a small undeveloped catchment) and the Poerua (which flows into the Crooked).

Table 1 includes the average gauged flows and the long-term mean flows estimated from the daily total inflow. The gauged tributary averages are less than the long term means because the gaugings tend not to include flood flows.

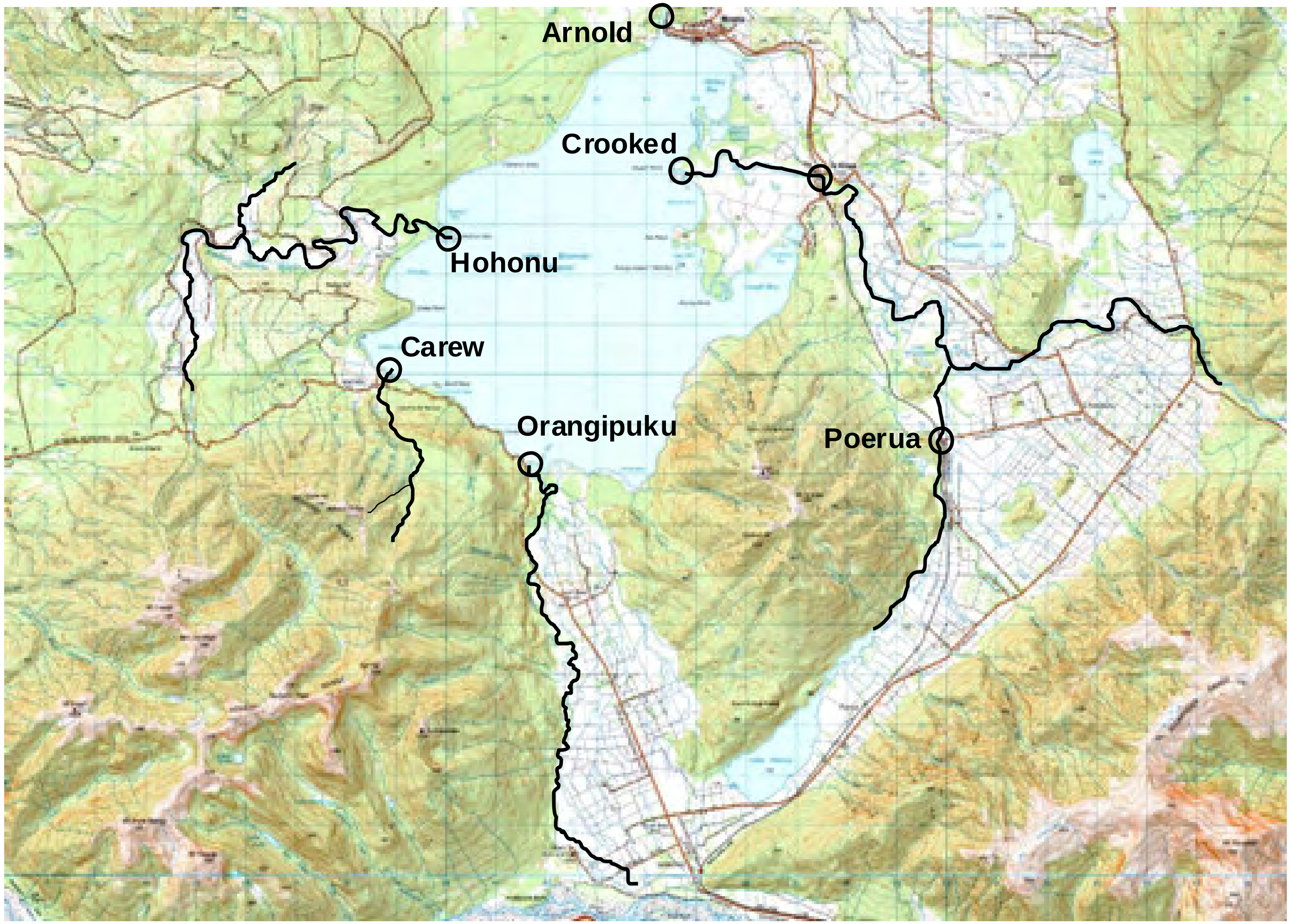


Figure 1: Map of the catchment showing sampling sites (circles) and the major inflows.

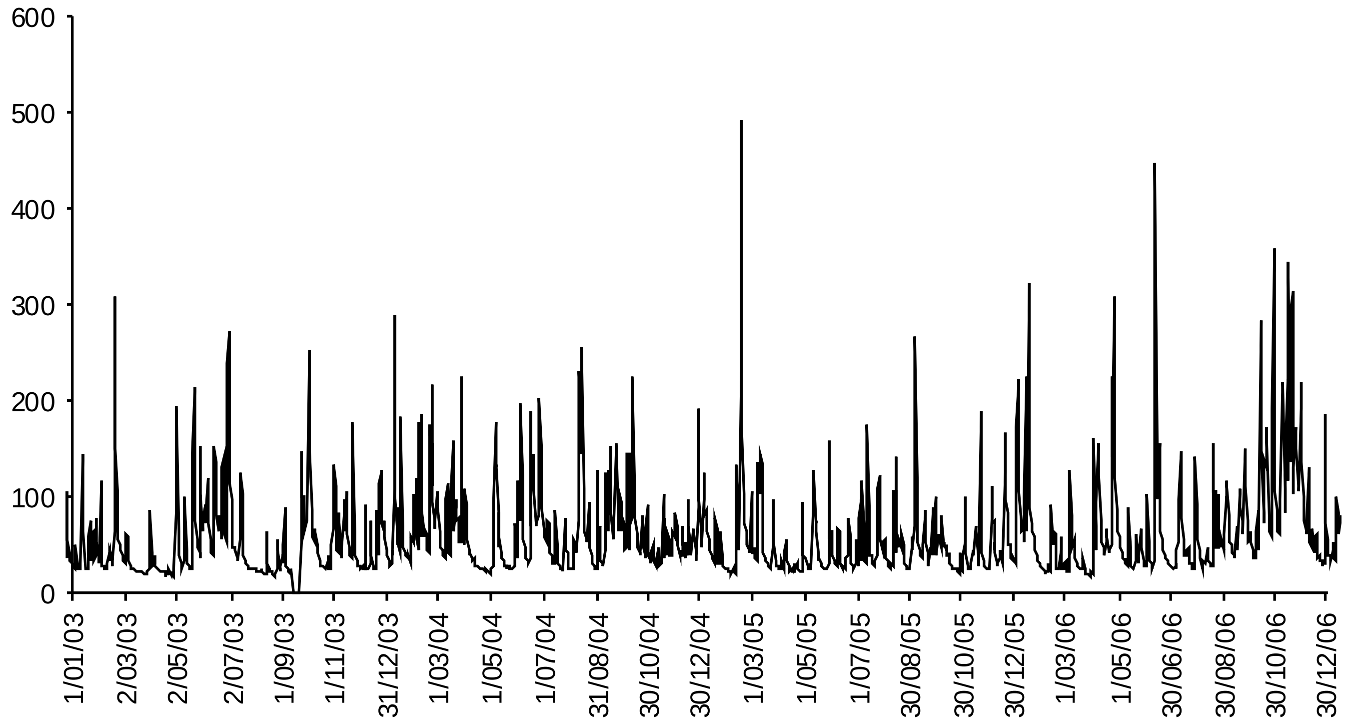


Figure 2: Daily total inflows (L/s), including rain on the lake, to Lake Brunner for 2003-2006 estimated from measured outflows and rate of change of lake level.

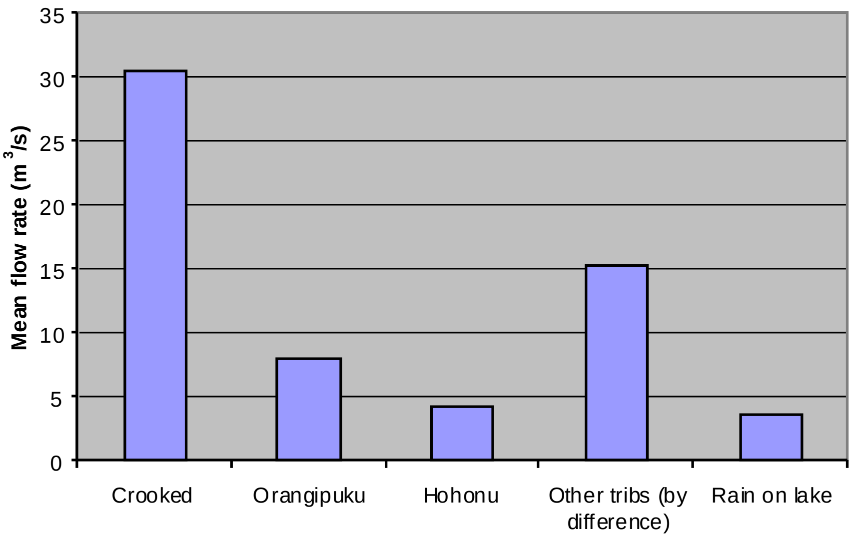


Figure 3: Estimated mean flow in the major tributaries flowing into Lake Brunner.

2.3 Tributary nutrients

TN concentrations in the tributaries vary from 100 to 500 mg N m^{-3} (Figure 4). In forested catchments (e.g., the Carew) TN is largely DON (c. 100 mg N m^{-3}) and TIN concentrations are low (c. 10 mg N m^{-3}). DON from forested generally has low bioavailability to plants. In the farmed catchments DON varies from 10 to 100 mg N m^{-3}. DON from dairying catchments may well be un-oxidised urea (Dr R.J. Wilcock, pers. comm., data from the Inchbonnie catchment study) and hence be 'available' to aquatic plants, since it is readily mineralised to ammonia and then nitrified. In the Crooked and Orangipuku catchments which are most intensively farmed DIN concentrations commonly exceed 100 mg N m^{-3}.

TP concentrations in the tributaries vary from 2 to 50 mg m^{-3} (Figure 5). TP comprises roughly equal proportions of FRP, DOP and PP. Phosphorus concentrations are low in forested catchments (e.g., the Carew) and high in the farmed catchments (e.g., the Orangipuku and Crooked) as expected. In Pigeon Creek, Inchbonnie, FRP is 61% of TP, which is high but not unusual for a dairy stream (Dr R.J. Wilcock, pers. comm.)

DIN and SRP are immediately bioavailable to plants in the lake. A proportion of PN and PP is potentially bioavailable, although they must first be mineralised and broken down to DIN and SRP by bacteri and fungi. DON from forested catchments and DOP are unlikely to stimulate plant growth in the lake because of low bioavailability (Hall et al. 2005). However, their colour may affect light levels in the lake. DON from dairying catchments may be derived from urea and hence be bioavailable, as discussed above.

Tributary TP concentrations vary strongly with flow in most of the tributaries (Figure 6). This behaviour is commonly observed elsewhere. The exception is the Carew probably because the catchment is bush-covered which reduces the effects of rain on mobilising phosphorus. In the Poerua TN concentration is not correlated with flow. The Poerua drains Lake Poerua which may buffer the effects of rain on nitrogen generation and transport. The correlation between TN concentration and flow is also weak in Crooked. The Poerua drains into the Crooked and this may affect the flow relationship. However, the Poerua contributes only 16% of the mean flow and so one would not expect it to unduly influence nutrients in the Crooked. The high variability in the Crooked TN data may disguise a flow relationship. It is not clear why TP and TN respond differently to flow in the Poerua and Crooked and further investigations are desirable. Flow relationships for dissolved inorganic and particulate forms have not yet been investigated but this can be done if required (e.g., as input for a lake water quality model). In small dairy catchments one usually gets a good relationship between TN concentration and flow, typically a semilog plot with an r^2 of 0.8 (Dr R.J. Wilcock, pers. comm.). In the Crooked River much of the catchment is in bush (with a low TN yield) and at high flows this may dilute high TN concentrations in dairy runoff.

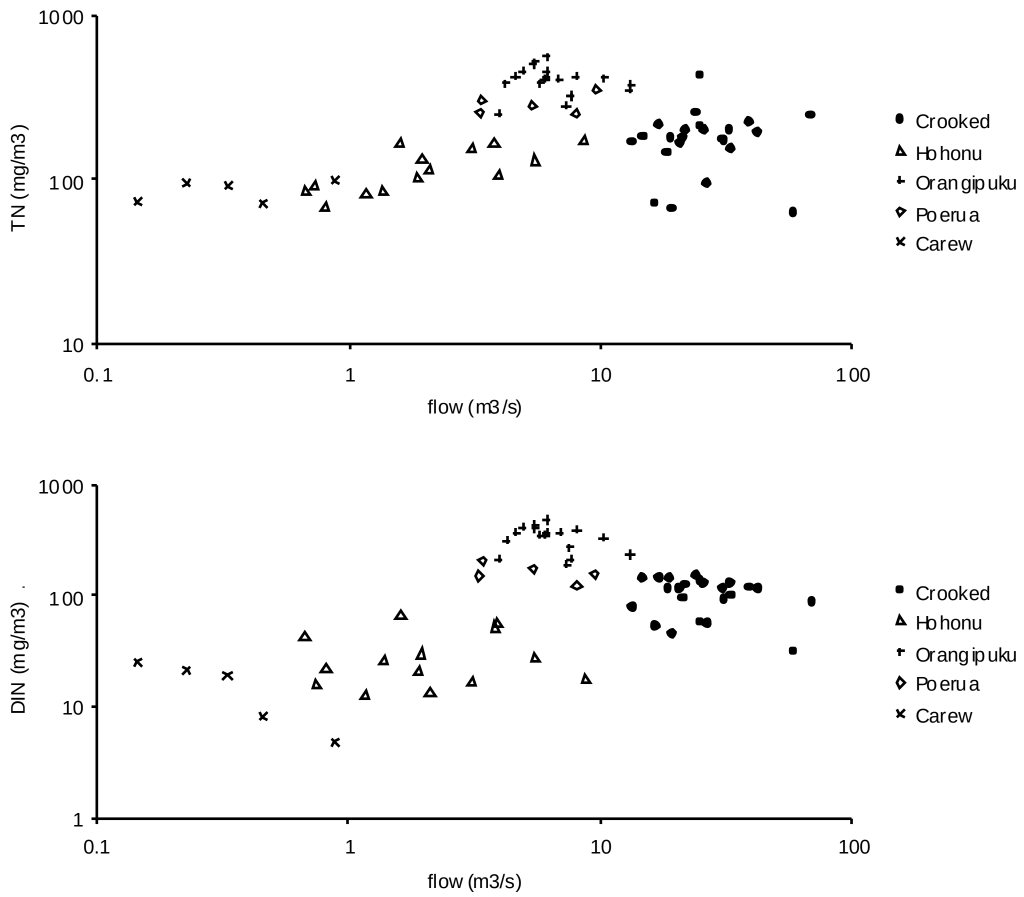
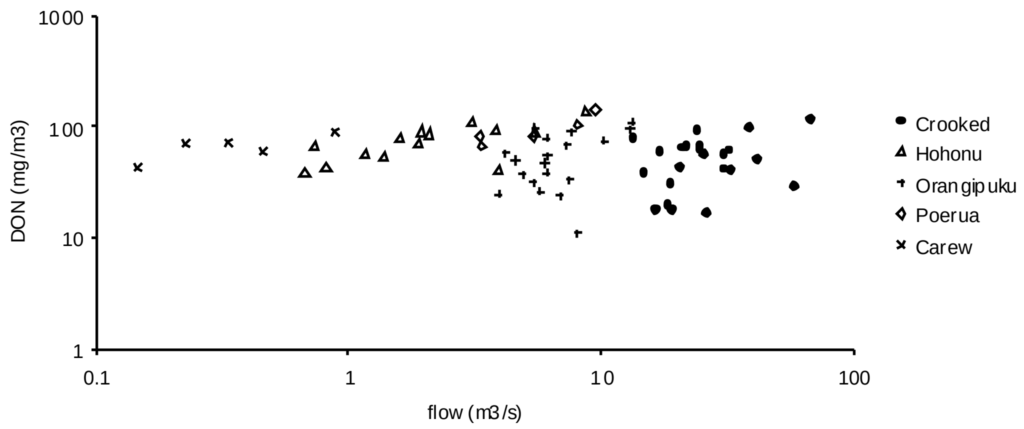
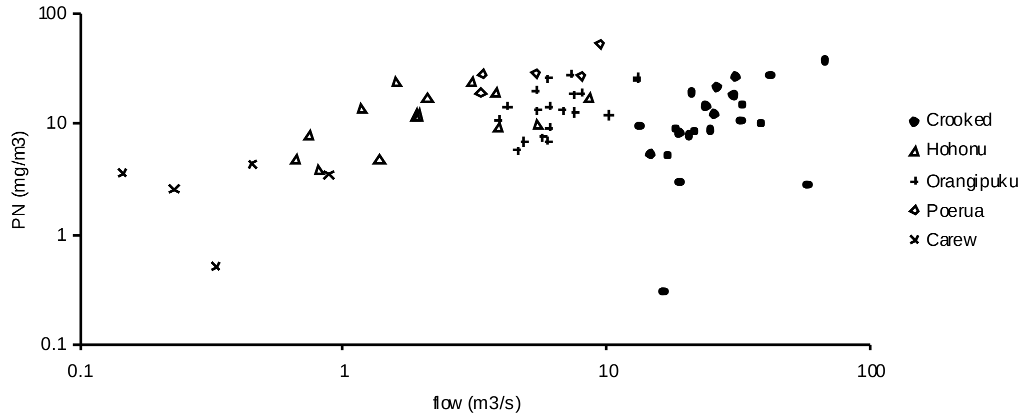


Figure 4: Concentrations of nitrogen compounds in the major tributaries flowing into Lake Brunner.

Figure 4: (cont.)





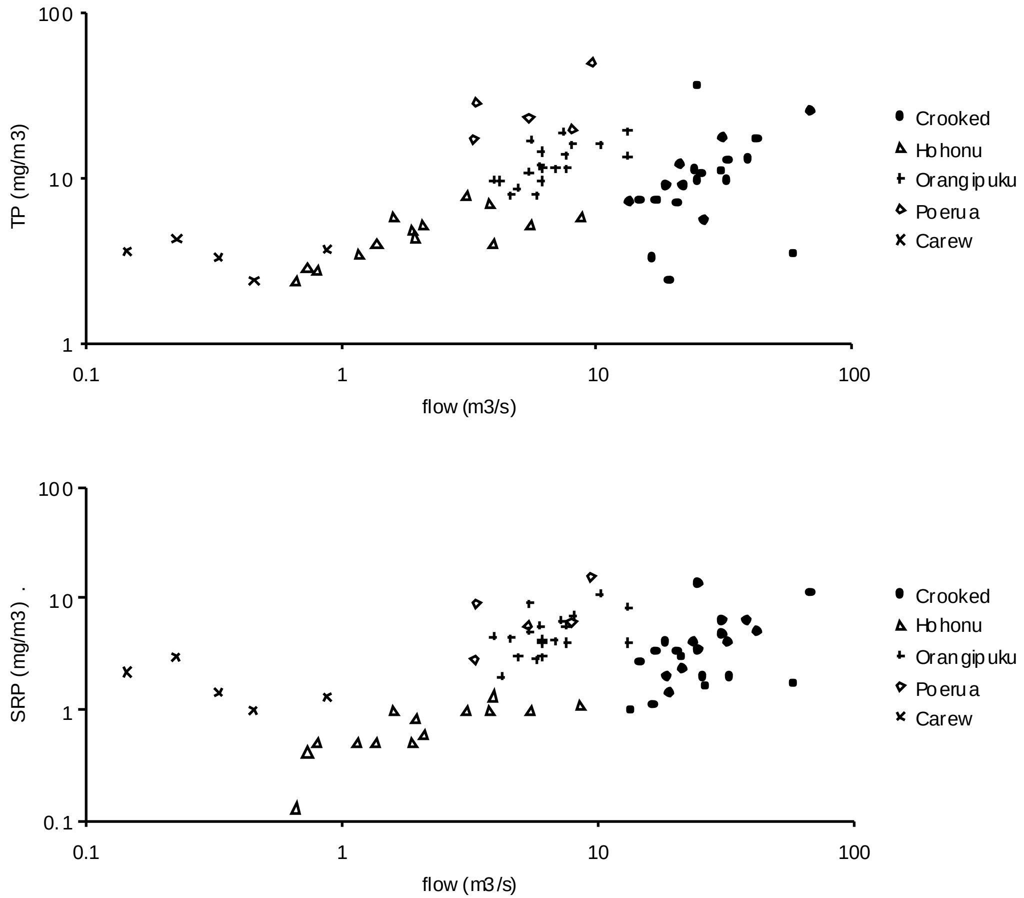
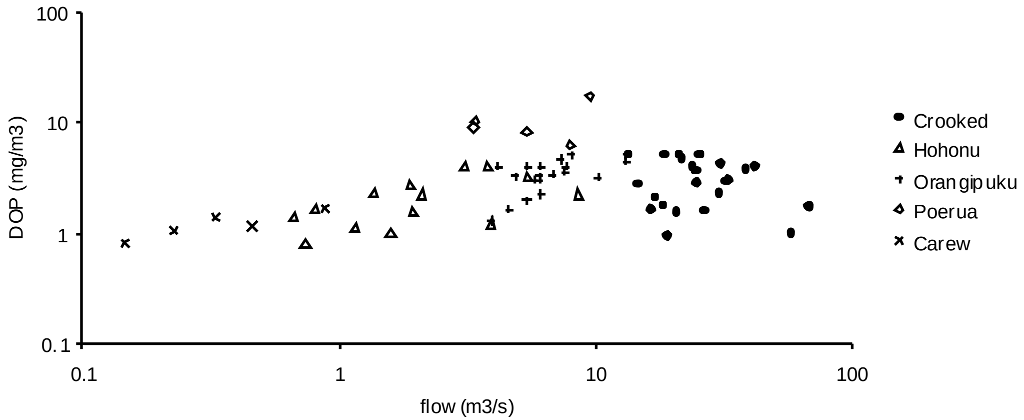
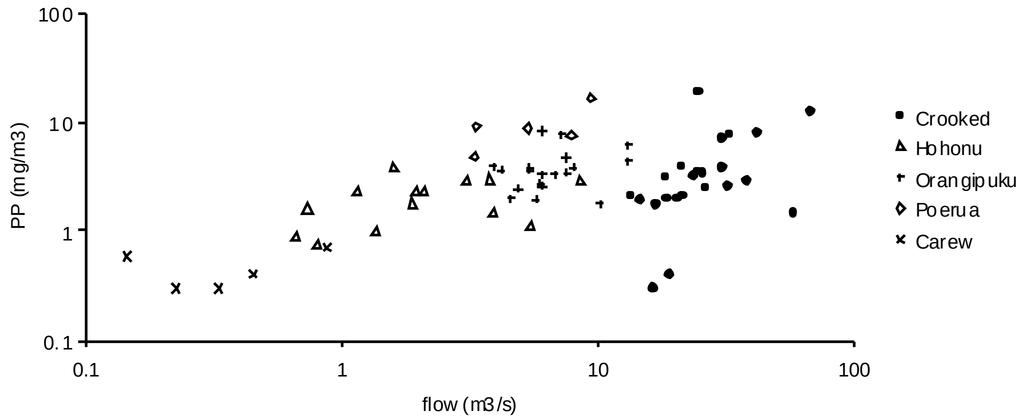


Figure 5: Concentrations of phosphorus compounds in the major tributaries flowing into Lake Brunner.

Figure 5: (cont.)





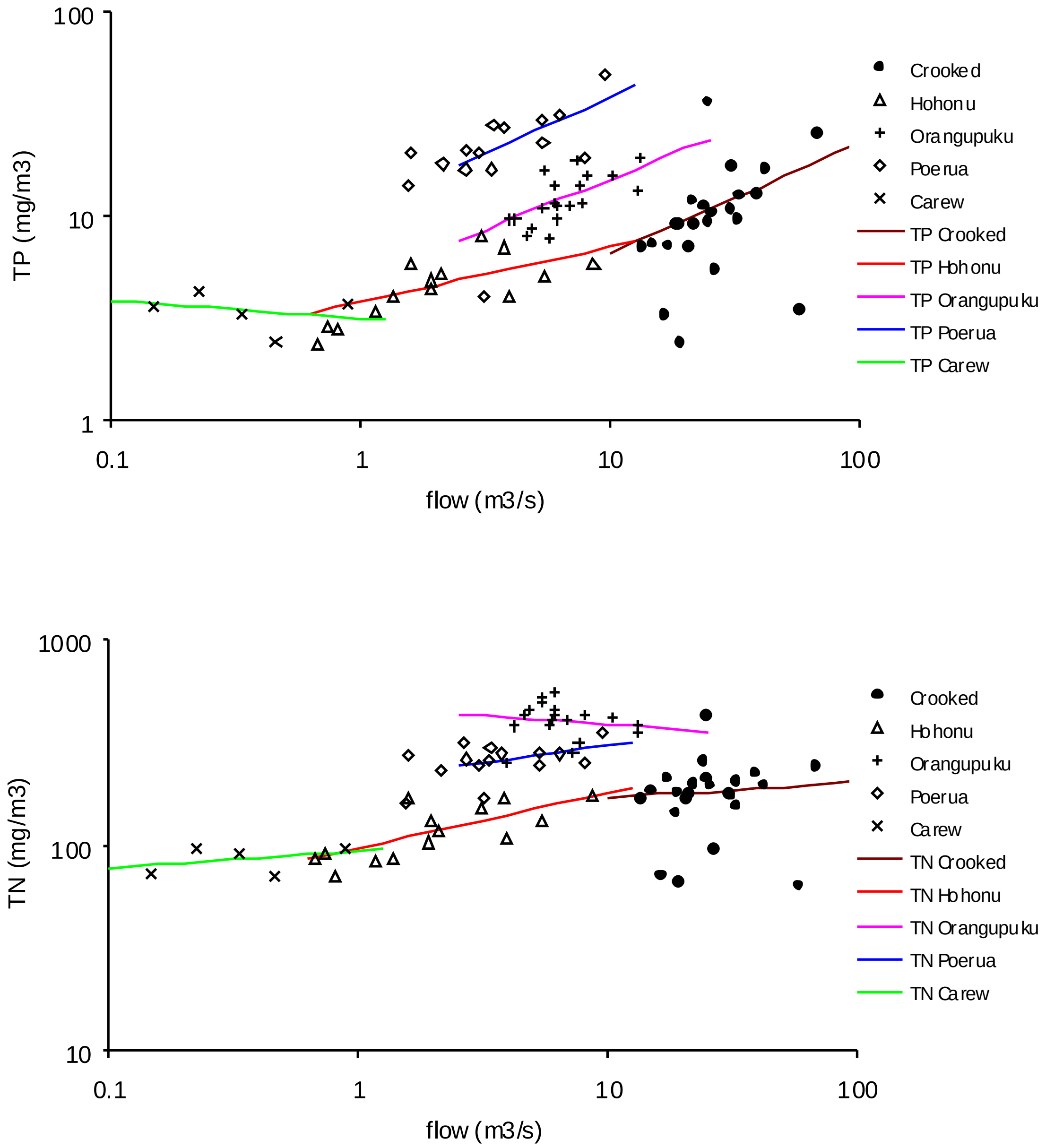


Figure 6: Correlation between flow and total phosphorus (top) and total nitrogen (bottom) in the major tributaries flowing into Lake Brunner. Points = observations, lines = fitted regression models.

2.4 Land use

Table 2 and Figure 7 summarise land cover and use data for the catchment extracted from the Land Cover Database 2 (LCDB2). This GIS layer was derived from satellite imagery with extensive ground truthing in 2003 but it does not capture changes in land use during the study period 1998-2007.

18.9% of the total catchment area is classified as high producing exotic grassland (here denoted Pasture3). 74.6% of the catchment is undeveloped – forest, scrub, undeveloped grassland, rock or water.

The total area in dairy farming is 3432 ha (WCRC data, Appendix 1). This is 54% of the total area of Pasture3 in the catchment. Dairy farms total 2324 ha at Rotomanu (draining to the Crooked) which is 53% of Pasture3 land, and 1108 ha at Inchbonnie (draining to the Orangipuku) which is 69% of Pasture3 land.

The Orangipuku is the most intensively developed catchment (Table 2, Figure 7) and this is reflected in it having the highest TN concentrations (Figure 6). The Orangipuku has the highest TN concentrations but not the highest TP concentrations (Figure 6). Based on LCDB2 35% of the Orangipuku catchment area is Pasture3 while the Crooked/Poerua and Hohonu contain 18% and 10% Pasture3, respectively. It is noteworthy that LCDB2 indicates 10% Pasture3 in the Hohonu which is generally regarded as a forested catchment – there are no dairy farms on the western side of the lake.

Table 2: Land use in the major catchments. Source: LCDB2 (2003).

	ExoticForest ha	GorseBroom Ha	NativeForest ha	NativeGrass ha	NativeScrub ha	Pasture1 ha	Pasture2 ha	Pasture3 ha	Rock ha	Water ha	Total ha
Carew			385		62			2	4		454
Hohonu	673		3011		255	77		463	51	32	4563
Orangipuku	41	11	2552		279	44		1598	25	14	4565
Crooked	154	45	12541	201	1545	1772	193	3455	197	384	20487
Poerua	47		2316	10	197	105		895	23	214	3807
Crooked & Poerua	201	45	14857	212	1742	1877	193	4350	220	597	24294
Total	915	55	20806	212	2337	1999	193	6414	301	644	33876
					% of sub-catchment						
Carew			85%		14%			1%	1%		
Hohonu	15%		66%		6%	2%		10%	1%	1%	15%
Orangipuku	1%	0%	56%		6%	1%		35%	1%	0%	1%
Crooked & Poerua	1%	0%	61%	1%	7%	8%	1%	18%	1%	2%	1%
					% of total catchment area						
Carew			1.1%		0.2%			0.0%	0.0%		1.3%
Hohonu	2.0%		8.9%		0.8%	0.2%		1.4%	0.2%	0.1%	13.5%
Orangipuku	0.1%	0.0%	7.5%		0.8%	0.1%		4.7%	0.1%	0.0%	13.5%
Crooked & Poerua	0.6%	0.1%	43.9%	0.6%	5.1%	5.5%	0.6%	12.8%	0.6%	1.8%	71.7%
Total	2.7%	0.2%	61.4%	0.6%	6.9%	5.9%	0.6%	18.9%	0.9%	1.9%	100.0%

Pasture3 = high producing exotic grassland. Pasture2 = low producing exotic grassland. Pasture 1 = tussock.

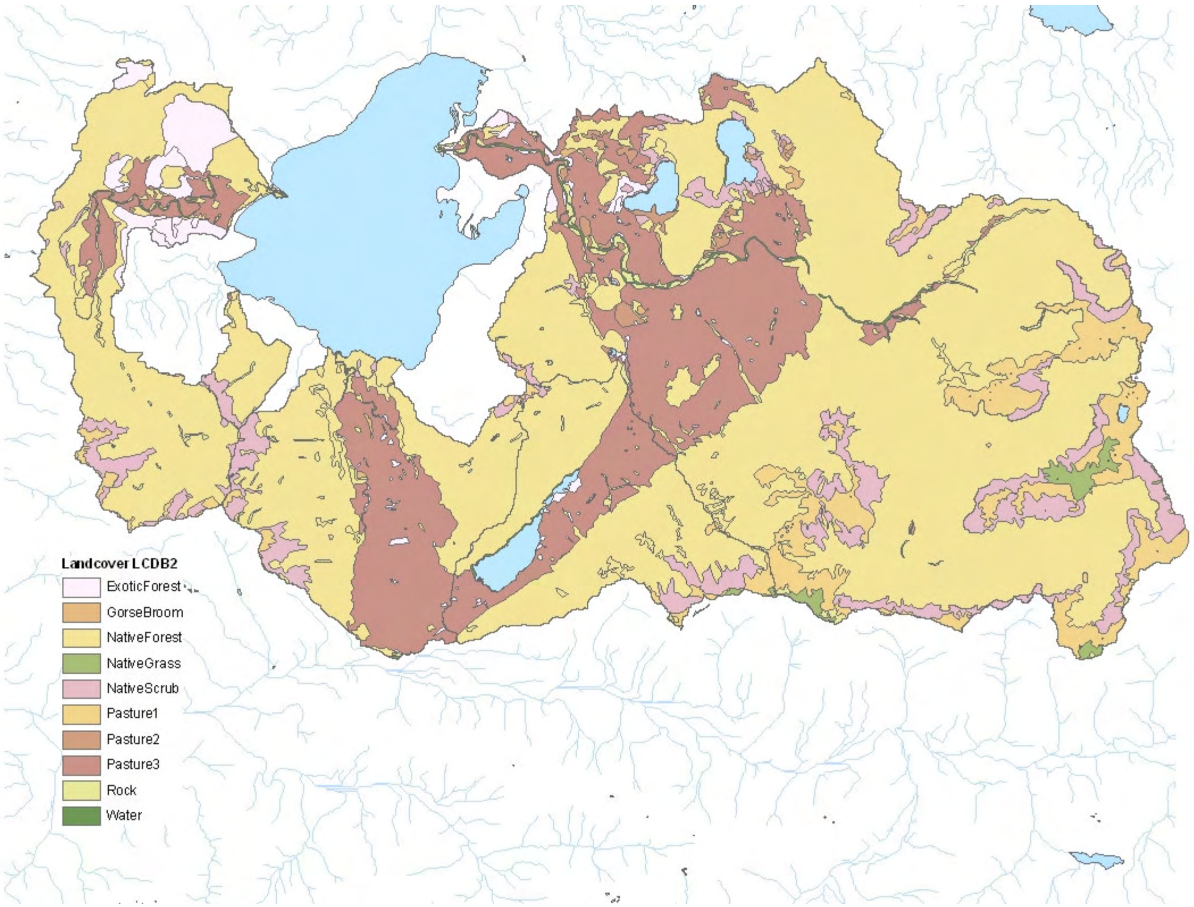


Figure 7: Land cover and land use in the Brunner catchment. Source LCDB2 (2003).

2.5 Nutrient yield

Daily nutrient mass flows in the three major tributaries for the period 1998-2007 were estimated as follows.

1. daily total inflow was estimated from measured outflow and lake level using a daily water balance (see Figure 2);

2. daily flow in each tributary was estimated by multiplying total inflow by the %flow for that tributary – assumed constant (see Table 1);

3. daily TP and TN concentrations were estimated from the regression equations shown in Figure 6 using daily flows from the previous step;

4. daily mass flows were calculated as the product of estimated daily concentration and estimated daily flow;

5. annual average mass flow was the sum of the daily mass flows divided by the number of years in the study period; and

6. annual specific yield for each catchment was the annual mass flow divided by the catchment area.

TP and TN specific yields are highest in the Orangipuku (0.93 kg P ha^{-1} yr^{-1} and 21 kg N ha^{-1} yr^{-1}). This is consistent with it being the most intensively farmed catchment with 35% of the catchment being Pasture3. The rankings of TP and TN yield match the rankings of %Pasture3.

TN/TP ratios are similar in the Orangipuku and Hohonu (23-25) but significantly lower in the Crooked/Poerua. The reasons for the difference are not clear but may include differences in soil type and the effect of Lake Poerua.

2.6 Relationship between yield and land use

A simple model was developed based on Table 3. It was assumed that the annual average nutrient yield can be described by three yield coefficients for: Pasture3, Pasture2, and Other (viz., all other land uses). The yield for Pasture2 was assumed to equal the average of the yield for Pasture3 and Other.

The model was then used to estimate the yield for each sub-catchment given the yield coefficients for Pasture3 and Other, and the area of Pasture3, Pasture2 and Other in each catchment. Values of yield coefficients for Pasture3 and Other were estimated by fitting to the yields for each sub-catchment in Table 3. Fitting was done using SOLVER within EXCEL by minimise the root mean square error. Table 4 summarises the derived yield coefficients.

Table 3: Catchment nutrient yields estimated from daily flow and concentration predictions.

	Crooked	**Hohonu**	**Orangipuku**	**Crooked**	**Hohonu**	**Orangipuku**
Area km^2	243	45.6	45.7	243	45.6	45.7
%Forest	62%	81%	57%	62%	81%	57%
%Pasture0	1%	0%	0%	1%	0%	0%
%Pasture1	8%	2%	1%	8%	2%	1%
%Pasture2	1%	0%	0%	1%	0%	0%
%Pasture3	18%	10%	35%	18%	10%	35%
%Scrub	7%	6%	6%	7%	6%	6%
%Other	3%	2%	1%	3%	2%	1%
	TP yield			**TN yield**		
$t\ yr^{-1}$	14	0.86	4.2	180	21	98
$kg\ ha^{-1}\ yr^{-1}$	0.59	0.19	0.93	7.4	4.7	21
TN/TP				13	25	23

Table 4: Nutrient yields as a function of land use.

Fitted average yields						
Pasture3	2.4			50.4		
Pasture2	(Pasture3+Other)/2			(Pasture3+Other)/2		
Other	0.1			2.0		
Observed catchment yields (see Table 4)						
kg/ha/yr	0.59	0.19	0.93	7.4	4.7	21
Predicted catchment yields						
kg/ha/yr	0.53	0.34	0.92	10.9	6.9	18.9
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr
Forest	0.1	0.1	0.1	2.0	2.0	2.0
Pasture0	0.1	0.1	0.1	2.0	2.0	2.0
Pasture1	0.1	0.1	0.1	2.0	2.0	2.0
Pasture2	1.3	1.3	1.3	26.2	26.2	26.2
Pasture3	2.4	2.4	2.4	50.4	50.4	50.4
Scrub	0.1	0.1	0.1	2.0	2.0	2.0
Other	0.1	0.1	0.1	2.0	2.0	2.0

RMS errors: TP = 0.2 kg/ha/yr and TN = 4.8 kg/ha/yr.

The fitting process produced a TN yield for Pasture3 of 50.4 kg N ha^{-1} yr^{-1}. This value matches closely the yield of 50 kg N ha^{-1} yr^{-1} for a typical New Zealand dairy farm as predicted by the Overseer model. The TP yield for Pasture3 of 2.4 kg P ha^{-1} yr^{-1} is higher than the typical yield of 1 kg P ha^{-1} yr^{-1} found elsewhere in New Zealand (R.J. Wilcock, NIWA, pers. comm.). Alternatively, if the Orangipuku is 35% dairy pasture and has yields of 0.93 kg TP ha^{-1} yr^{-1} and 21 kg TN ha^{-1} yr^{-1}, and we assume the non-farmed yields are 0.2 for TP and 5 for TN, then the dairy components are 2.3 kg TP ha^{-1} yr^{-1} and 51 kg TN ha^{-1} yr^{-1}.

The average nutrient specific yields across the whole catchment were estimated from the specific yields in Table 3 using the land use data in Table 2. This produced average specific yields for the whole catchment of 11.3 kg N ha^{-1} yr^{-1} and 0.54 kg P ha^{-1} yr^{-1}.

An independent estimate of specific yield for the whole catchment can be made from measured lake concentrations. For the period 2003-2007 the average TN and TP concentrations in the lake were 196 mg N m^{-3} and 6.7 mg P m^{-3}, respectively. Multiplying by the average outflow rate (61.5 m^3 s^{-1}) and dividing by the total catchment area (440 km^2) gives specific yields of 8.6 kg N ha^{-1} yr^{-1} and 0.3 kg P ha^{-1} yr^{-1}. However, these estimates neglect any nitrogen and phosphorus retention in the lake. All lakes retain nutrient (viz., the long-term average mass outflow is less than the inflow). The fraction retained increases with lake residence time. Vant (1987) gives the relationship between phosphorus retention and hydraulic load/lake area derived by

Nurnberg (1984). Applying this relationship to Lake Brunner (where the outflow averages 61.5 m^3 s^{-1} and the lake area is 40.6 km^2) gives a retention R of 23%. When corrected for retention, lake inflows are 11.2 kg N ha^{-1} yr^{-1} and 0.38 kg P ha^{-1} yr^{-1}.

The two estimates of specific yield for TN (11.3 kg N ha^{-1} yr^{-1} from tributary sampling and 11.2 kg N ha^{-1} yr^{-1} from lake sampling) are indistinguishable. The two estimates for TP (0.54 kg P ha^{-1} yr^{-1} from tributary sampling and 0.38 kg P ha^{-1} yr^{-1} from lake sampling) are also similar within the likely errors of estimation. Overall, the available tributary monitoring data are consistent with our expectations of the likely nutrient yields from intensive agriculture.

2.7 Predicting lake inflows

In the future it is intended to develop a model for lake water quality in order to predict the effects of land use changes. The details of the lake water quality model have not been finalised yet. Possible models range in complexity from: (1) an annual average nutrient model with empirical relationships between nutrient concentration, chlorophyll and clarity through to (2) a daily timestep coupled hydrodynamic-lake ecosystem model.

The former type of model (hereafter called Vollenwider-type) has the advantage of being simple to develop, operate and calibrate. However, it does not attempt to simulate the details of lake processes. Such models have been used successfully in Rotorua (e.g., Hoare 1980). They rely on having good monitoring data for calibration which is the case for Brunner.

The latter type of model (hereafter called Ecosystem) have the advantage of directly simulating the hydrodynamics, optics and nutrient-plant interactions that determine lake water quality. Such models have been used successfully in Taupo (e.g., DYRESM-CAEDYM). They rely on having a skilled operator and the necessary data for calibration and input.

There are merits in both types of model and further discussion is desirable with WCRC before making a choice. If an Ecosystem model is chosen there are merits in also developing a Vollenweider-type model because this adds very little to the effort but helps guide Ecosystem model development.

Regardless of which model is chosen, the findings of this report are relevant. Namely that:

1. tributary flows can be estimated from available outflow and lake level data;

2. estimated annual specific nutrient yields of TN and TP for different land use classes in the Brunner catchment are internally consistent and match estimates from elsewhere in New Zealand;

3. effects of land use change on annual nutrient inflow to the lake can be estimated with some confidence.

There are four possible shortcomings of the methods outlined in this report.

First, daily flows (especially flood flows) may not be estimated precisely by the daily water balance model and this may affect predicted nutrient loads. It may be desirable to conduct further hydrological analysis of flood flows.

Second, while flow concentration correlations have been developed in this report it is conceivable they are biased because few samples were collected during floods. However, recent flood sampling did not significantly increase estimated specific yields in Pigeon Creek, a tributary of the Orangipuku (Dr R.J. Wilcock, NIWA, pers. comm.).

Third, the Ecosystem model may require estimates of suspended solids, colour and dissolved inorganic nutrients which would entail further analysis of the tributary monitoring data.

Fourth, the Ecosystem model may also require information about carbon inflows. These are not currently monitored but it may be possible to conduct additional fieldwork and then derive an empirical relationship between carbon and other monitored variables.

Once a choice has been made of lake water quality then a decision can be made about what additional analysis of current monitoring data and/or additional sampling (e.g., during floods) are required. Notwithstanding this, the available monitoring data will provide a good basis for the development of a lake water quality model.

3. References

Hall, J.; Hawes, I.; Payne, G.W. (2006). Dissolved organic nitrogen in Lake Taupo. *NIWA Client Report HAM2005-084*. August 2005.

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

Livingston, M.E.; Biggs, B.J.; Gifford, J.S. (1986). Inventory of New Zealand lakes. *Water & Soil Miscellaneous Publication No. 81.* NWASCo. Wellington.

Menneer, J.C.; Ledgard, S.F.; Gillingham, A.G. (2004). Land use impacts on nitrogen and phosphorus loss and management options for intervention. *AgResearch Client Report*, June 2004.

Nurnberg, G.K. (1984). The prediction of internal phosphorus load in lakes with anoxic hypolimnia. *Limnology &. Oceanography 29*: 111-124.

Vant, W.N. (1987). *Lake Managers' Handbook.* NWASCA, Wellington.

4. Appendix 1: Dairy farms in the Brunner catchment. Source WCRC.

Farm	Name	Area	Consent	Stock	ha	kg N/ha/yr	kg P/ha/yr	Standoff pads	Stock crossings	Stock access %
342/05	Harvey	Inchbonnie	RC01026	420	220	150	0	1	Pigeon Creek	0
338/02	Gault	Inchbonnie	RC00162	440	208	160	54	1	Pigeon Creek	90
339/01	Shaffrey	Inchbonnie	RC07212	290	190	120	45	0	Pigeon Creek	0
346/01	Keeney	Inchbonnie	Permitted	470	250	110	40	1	used infrequently	30
348/02	Harris	Inchbonnie	RC02018	340	170	120	0	0	0	0
349	Perkins	Inchbonnie	Permitted	100	70	0	0	0	0	0
341/04	Keeney & Rooney	Rotomanu	Permitted	480	300	180	0	1	Orangipuku	50
350/03	Marley	Rotomanu	RC02019	400	220	200	46	2		10%
352/06	Coleman	Rotomanu	RC00183	Retiring	130	60	0	0	0	0
353/03	Ruessink	Rotomanu	RC07029	200	96	100	0	1	Thirsty Creek	50
357/03	Kersten	Rotomanu	RC01078	230	100	200	46	2	Slaty Creek	50%
360/01	Condon	Rotomanu	RC00082	150	93	100	0	1	Pigeon Creek	50%
61/03	McLeod	Rotomanu	RC00090	130	105	0	0	1		10%
362/02	Opie	Rotomanu	RC06282	375	200	180	37	1	Puzzle Creek	0%
363/01	McLellan	Rotomanu	RC02216	200	150	0	0	0	0	0
367/02	Kersten	Rotomanu	RC00184	280	150	200	46	2		60%
368/01	Marley	Rotomanu	RC00266	500	350	200	46	1		15%
369/02	Young	Rotomanu	Permitted	160	80	9	0	0	0	0
371/02	Whitmore & Milne	Rotomanu	Permitted	187	100	135	40	1	0	15
372/01	Lowry	Rotomanu	RC02233	450	250	70	0	0		50%
377/04	Kersten	Rotomanu								