CAWTHRON

Nutrient Loading From The Motueka River Into Tasman Bay, 2005

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Nutrient Loading From The Motueka River Into Tasman Bay, 2005

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Prepared for
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Motueka Integrated Catchment Management Programme

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PREFACE

An ongoing report series, covering coastal-sea components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by coastal managers, environmental groups and users of coastal marine resources to address specific questions that may require urgent attention or may fall outside the scope of ICM research objectives. We anticipate that providing access to marine environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

EXECUTIVE SUMMARY

Background

The information provided in this report was collected as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "*ridge top to the sea*" approach. One component of a Cawthron investigation into the effects of freshwater inflow quantity and quality on the productivity of the marine receiving environment is presented here.

Study objective

The aim of this investigation was to estimate the rate of discharge of several dissolved and particulate nutrients into Tasman Bay, via the Motueka River, during the calendar year 2005. In order to accomplish this, it was first necessary to evaluate flow/concentration relationships using various data sets assembled from historical river flow and water quality information.

Overview of results and conclusions

Flow/concentration relationships were assessed for different river states (steady, rising and receding flows) and seasons (summer, winter). In general highest nutrient concentrations were observed during rising flood flows and during winter months.

The calculated mass transport of nutrients into Tasman Bay via the Motueka River during the calendar year 2005 was:

TN (t)	**NO_3(t)**	**NH_4 (t)**	**DIN (t)**	**DRP (t)**	**TP (t)**	**DRSi (t)**
313	212	7	219	5	32	9132

Delivery rates were strongly affected by flood flows and the largest contributions also occurred during the winter months, June – August.

The flow/concentration relationships described here and the resulting 2005 loading estimates are considered to be generally representative of the Motueka River under the present catchment land usage. At these discharge rates, the nutrients delivered into the Bay would likely contribute to coastal production in a beneficial way with little potential for dysfunctional ecosystem enrichment effects. The observed flow/concentration relationships may be re-examined when additional data are collected.

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1. INTRODUCTION

1.1. Background

The information provided in this report has been collated and interpreted as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. For a description of the programme structure and rationale refer to Basher (2003). The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "*ridge top to the sea*" approach.

This report evaluates flow/concentration relationships for several dissolved and particulate nutrients in the Motueka River and their estimated discharge rates into Tasman Bay during 2005. The nutrients were total phosphorus (TP), dissolved reactive phosphorous (DRP), total nitrogen (TN), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and dissolved reactive silica (DRSi). Estimated average daily concentrations and load estimates are reported for each month and for the 2005 calendar year. These data, and the flow/concentration relationships developed, enable ongoing evaluation of short and medium term (e.g. daily, monthly) variation in nutrient discharge rates for investigation of their implications to the river plume ecosystem. Flow/concentration relationships can be reassessed periodically, with the availability of additional data, and used to compare estimated discharge rates for successive years.

1.2. Study area

The Motueka River and its tributaries (Figure 1) drain a catchment of ~2180 km^2 comprised of approximately 35% native bush, 25% planted forest, 19% pasture and 12% scrub by area (Basher, 2003). The River has a mean flow of 59 m^3/s and a measured flow range from about 5.6 m^3/s to greater than 2,100 m^3/s (Basher, 2003). Flow is seasonally variable and is usually high in winter and spring and low in summer. The river is prone to large floods and extended periods of low flow. These temporal flow variations have a significant influence on nutrient concentrations and therefore it is important to consider them when assessing temporal concentration patterns. References containing background information describing the Motueka River catchment and the receiving water of Tasman Bay can be accessed through http://icm.landcareresearch.co.nz.

1.3. Why are nutrients important?

The Motueka River flows into Tasman Bay through an unconfined intertidal and shallow subtidal delta (Gillespie et al. 2004). Nutrients contained in the river nourish delta plant communities (e.g. saltmarsh, eelgrass, macroalgae) and coastal phytoplankton productivity thereby contributing to fish and shellfish production within a large plume-affected region of the western Bay (Gillespie 2003; Mackenzie et al. 2003). The size of the Motueka River outwelling plume varies considerably depending upon flow, however following a moderate rainfall event (i.e. in the order of 200 $m^3 s^{-1}$) the plume can almost completely encompass three designated offshore aquaculture management areas (Figure 2). Excessive nutrient discharge can lead to accelerated eutrophication of coastal environments and adverse symptoms of over enrichment (e.g. problematic algal blooms, oxygen depletion, dysfunctional changes in biotic communities). Significant reduction in nutrient discharge could lead to impoverishment of coastal primary productivity and subsequent diminishment of fish and shellfish resources. Ongoing information describing nutrient discharge rates is therefore required in order to develop a catchment strategy that will enable sustainable management of biological resources within Tasman Bay.

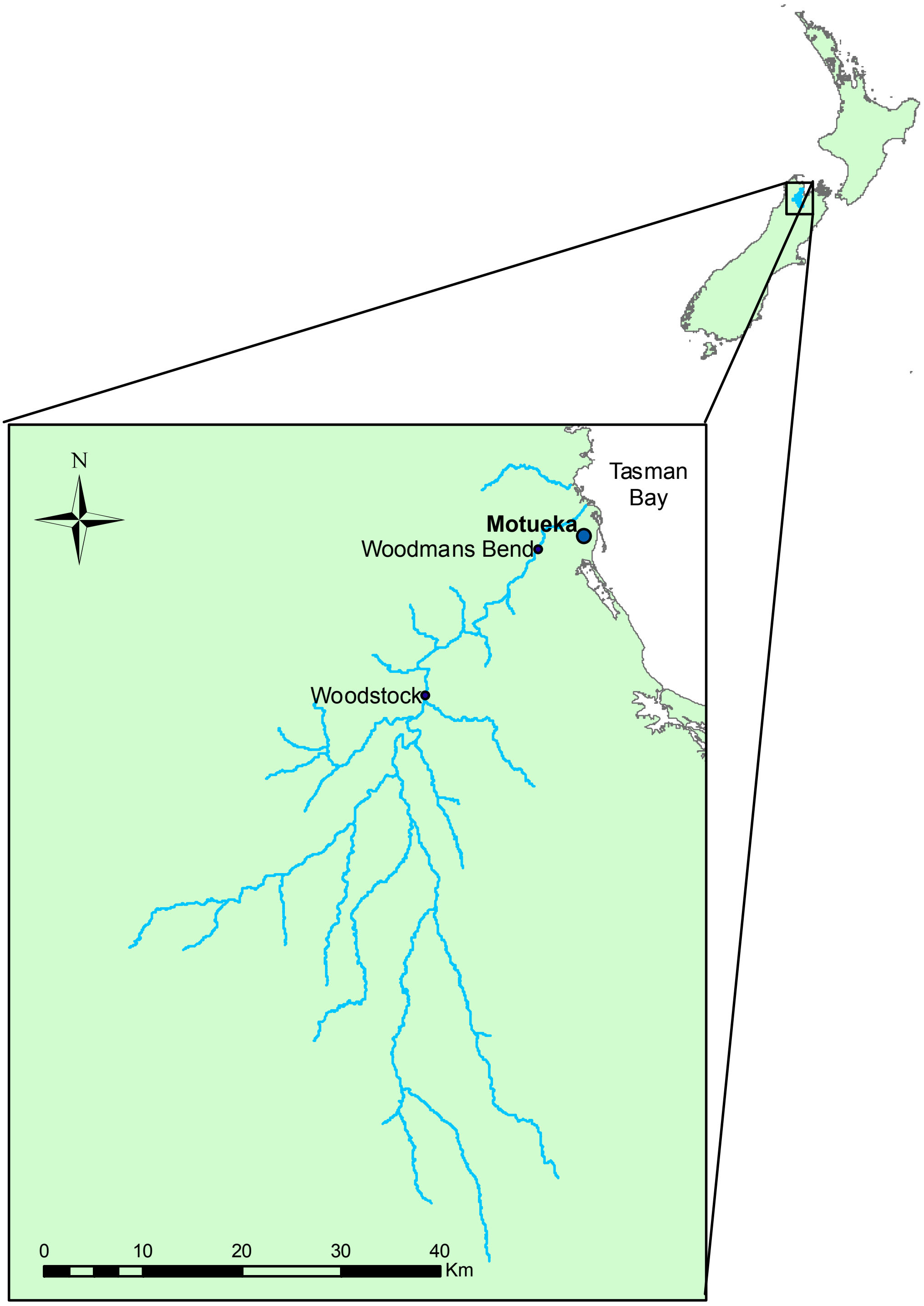

Figure 1. Location map of the Motueka catchment and data collection points.

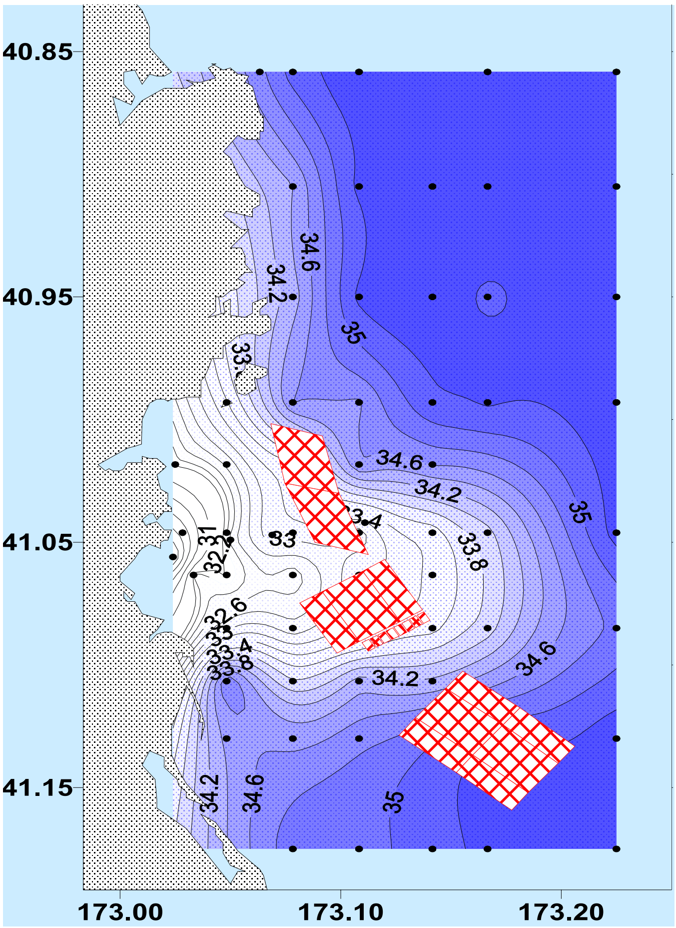

Figure 2. Spatial extent of the Motueka River outwelling plume (surface salinity field) after a moderate rainfall event with flows up to 200 m^3 s^{-1} (from Tuckey et al. 2006).

2. METHODS

2.1. Calculations

Mass loadings of the relevant nutrient species were calculated for 2005 based on observed relationships between average daily flow of the Motueka River and the associated concentration of each nutrient. These relationships and their derivation are described briefly here and more detailed information is provided in Appendix 1.

Silica data were severely limited as they were available for the Woodman's bend site only, including just one flood event (23 measurements) and nine monthly measurements covering flows <80 m^{3}s^{-1}. Because of this, seasonal variation was not possible to deduce but a significant dilution effect was noted during flood flows. Therefore mass transport calculations for this nutrient were based on average concentrations for flows <80 m^{3}s^{-1} and average concentrations >80 m^3s^{-1} and the corresponding loadings during 2005 are rough approximations.

Flow/concentration relationships for the remaining nutrients were calculated from historical records (1989 to 2004) of flow and nutrient concentrations at two sites on the Motueka River (Woodstock and Woodman's bend). The aim was to find correlations with the most representative fit for the catchment as a whole. Two flood events were captured in detail; one large and one small. When plotted against river flow, concentrations of most nutrient species demonstrated a fairly typical response to flood events with differing responses to first flush onset, flood peak and post-peak dilution. Thus samples collected at a similar flow rate could have quite different concentrations (rising versus falling limb). Another factor affecting the flow/concentration relationship was seasonal variation. Concentrations observed during summer were generally lower than those observed during winter; presumably due to higher plant uptake of nutrients during summer. Flow data was therefore split into three flow states (rising, steady or receding) and two seasons (October-March) and (April-September).

The percentage of time that the river was in each category and the average flow while in that category was then used to generate the following equations to estimate monthly average concentrations and mass loadings for each nutrient.

Equation 1

Average concentration ($conc_{avg}$) (mg/L) = ($conc_{steady}$ x t_{steady})+ ($conc_{rise}$ x t_{rise}) + ($conc_{recede}$ x t_{recede})

Where t = time in state/unit of time (e.g. month) and conc = average concentration (mg/L) according to the equation determined from Table 1. The values used in the equation vary according to river state and season and the parameter being tested.

Table 1. Equation characteristics used to calculate average nutrient concentrations for the different data groupings.

Concentration (conc) = a x V_{flow} + c						
	Summer			Winter		
a	Steady	Rising	Receding	Steady	Rising	Receding
TN	0.000002	0.0000004	0.0000008	0.00001	0.000002	0.000001
NH_4-N	-0.00000009	-0.000000005	0.000000005	-0.0000001	0.000000004	0.000000005
NO_3-N	0.000002	0.00000001	0.00000002	0.00002	0.0000003	0.0000003
TP	0.0000007	0.0000005	0.0000004	0.0000001	0.0000007	0.0000004
DRP	0.00000004	0.000000004	0.00000002	0.0000001	0.00000001	0.000000004
	Summer			Winter		
c	Steady	Rising	Receding	Steady	Rising	Receding
TN	0.09	0.165	0.1425	-0.0423	0.2734	0.2507
NH_4-N	0.0075	0.0058	0.0055	0.0071	0.005	0.0048
NO_3-N	0.0214	0.0946	0.1026	-0.1491	0.1609	0.2062
TP	0.0045	0	0	0.0017	0	0
DRP	0.0011	0.0034	0.0026	0.0011	0.0097	0.0034

Equation 2

Mass Load (kg/day) = V_{flow} x $conc_{avg}$

Where V = volume of flow per day and $V_{flow} = (V_{steady} \times t_{steady}) + (V_{rise} \times t_{rise}) + (V_{recede} \times t_{recede})$

3. RESULTS

3.1. Average nutrient concentrations

The highest concentrations of nutrients were discharged into Tasman Bay during the winter months (April - September). Concentrations were especially high in July and August (Figures 3 and 4). These higher concentrations were due to periods of high flows (Figure 5). Of the summer months, January had the highest nutrient concentrations and average flow was also higher than during other summer months.

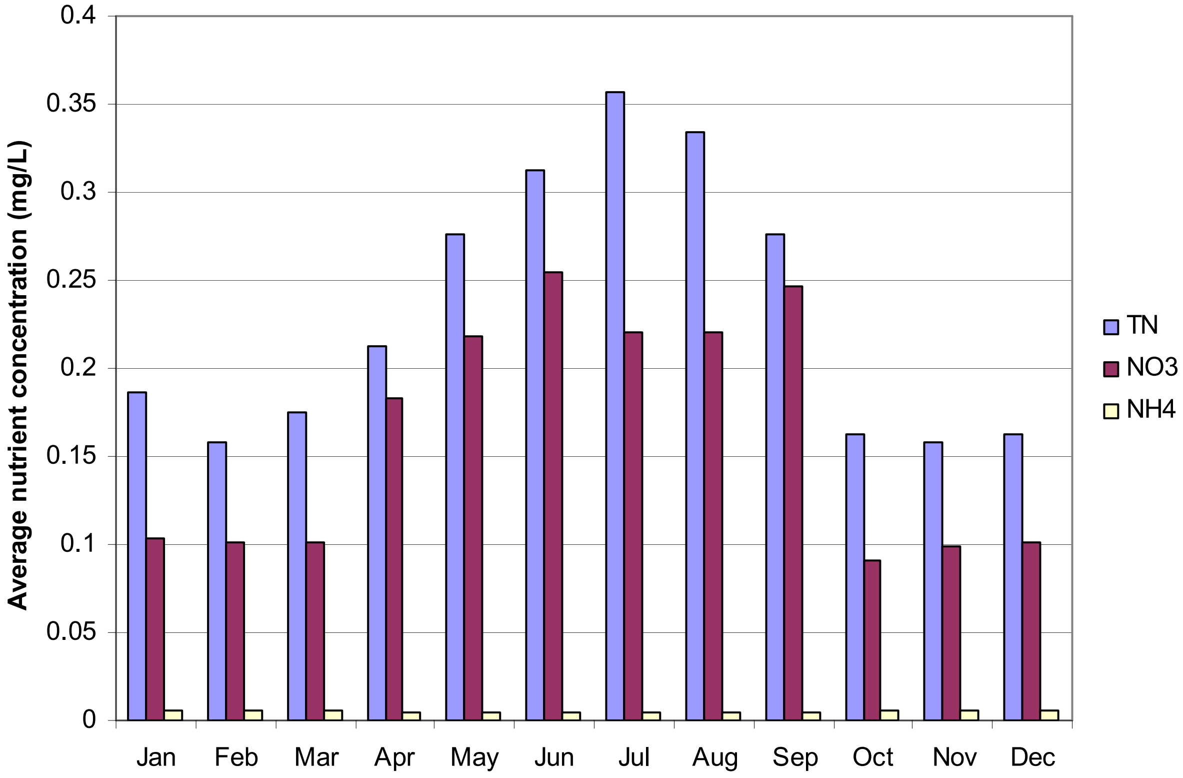

Figure 3. Average daily concentrations of Total Nitrogen (TN), Nitrate (NO_3-N) and Ammonium (NH_4-N) in the Motueka River during 2005.

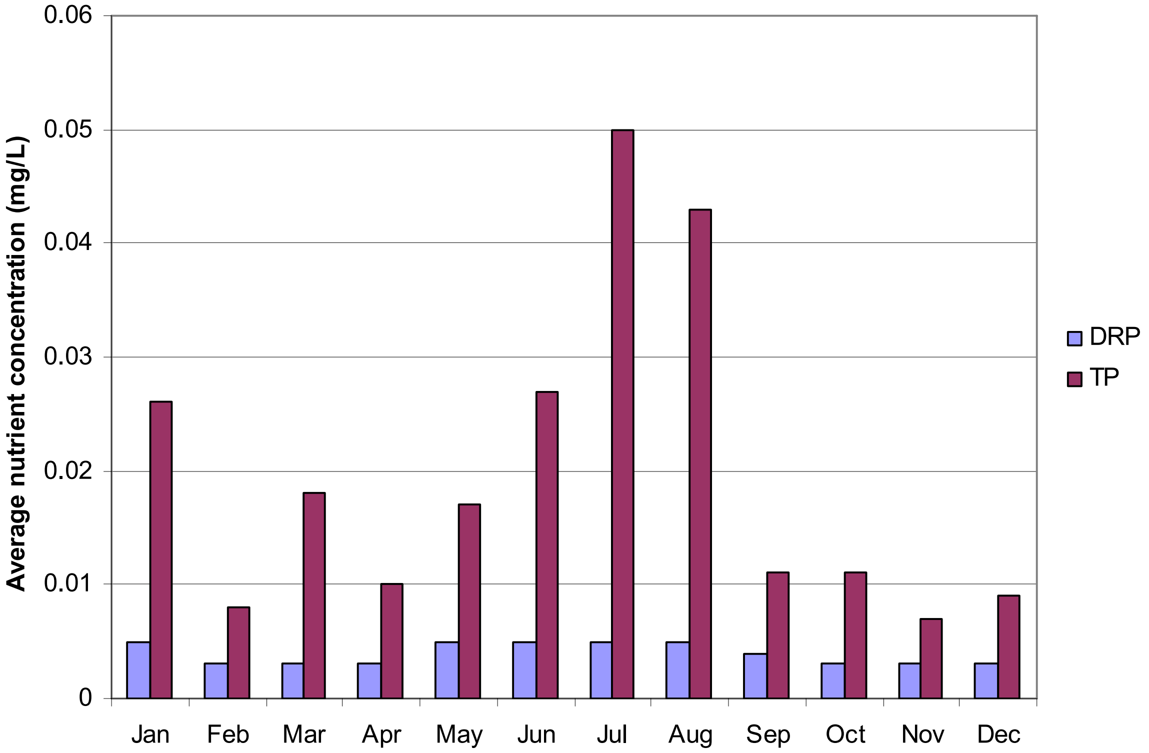

Figure 4. Average daily concentrations of Dissolved Reactive Phosphorus (DRP) and Total Phosphorus (TP) in the Motueka River during 2005.

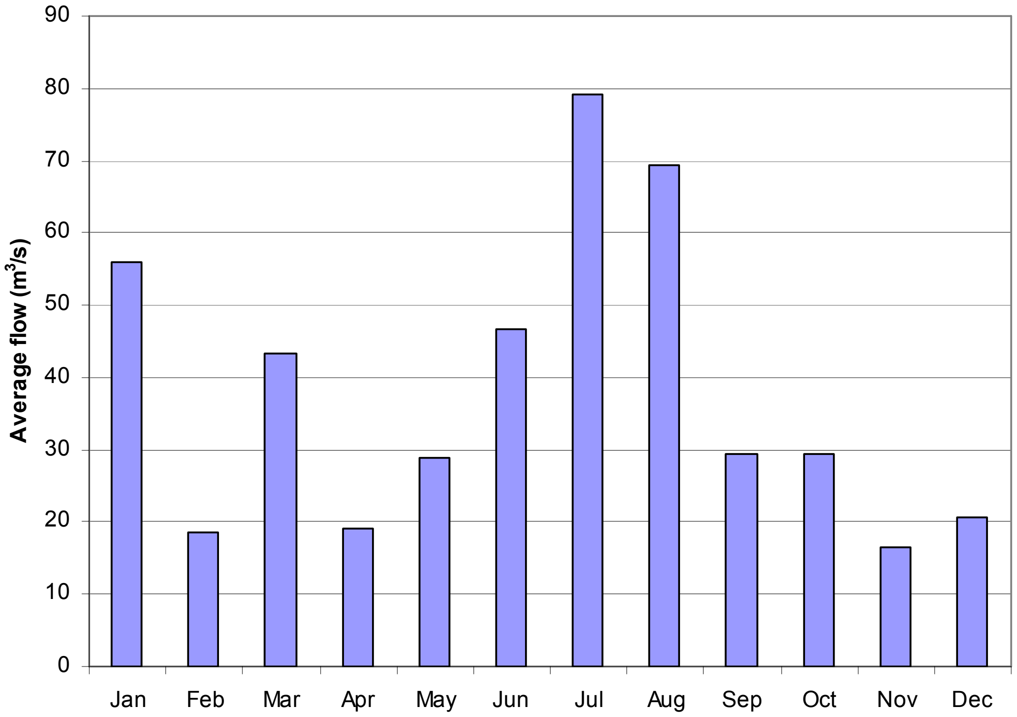

Figure 5. Average flows at Woodman's bend during 2005.

3.2. Mass nutrient loading to Tasman Bay

3.2.1. *Annual load*

The total discharge of each of six nutrient species into Tasman Bay from the Motueka catchment was estimated for the calendar year 2005 (Table 2).

Table 2. Calculated mass discharge of nutrients (tonnes) into Tasman Bay via the Motueka River during 2005

TN	NO_3-N	NH_4-N	DIN	DRP	TP	DRSi
313	212	7	219	5	32	9132

3.2.2. *Average monthly loads*

Monthly nutrient loadings are controlled by the concentration of the nutrient species and the corresponding river flow, resulting in generally higher loadings during the winter months, June – August 2005 (Figures 6 and 7). Higher loading rates for TN and TP were also observed during January corresponding to particularly high summer flows throughout most of that month.

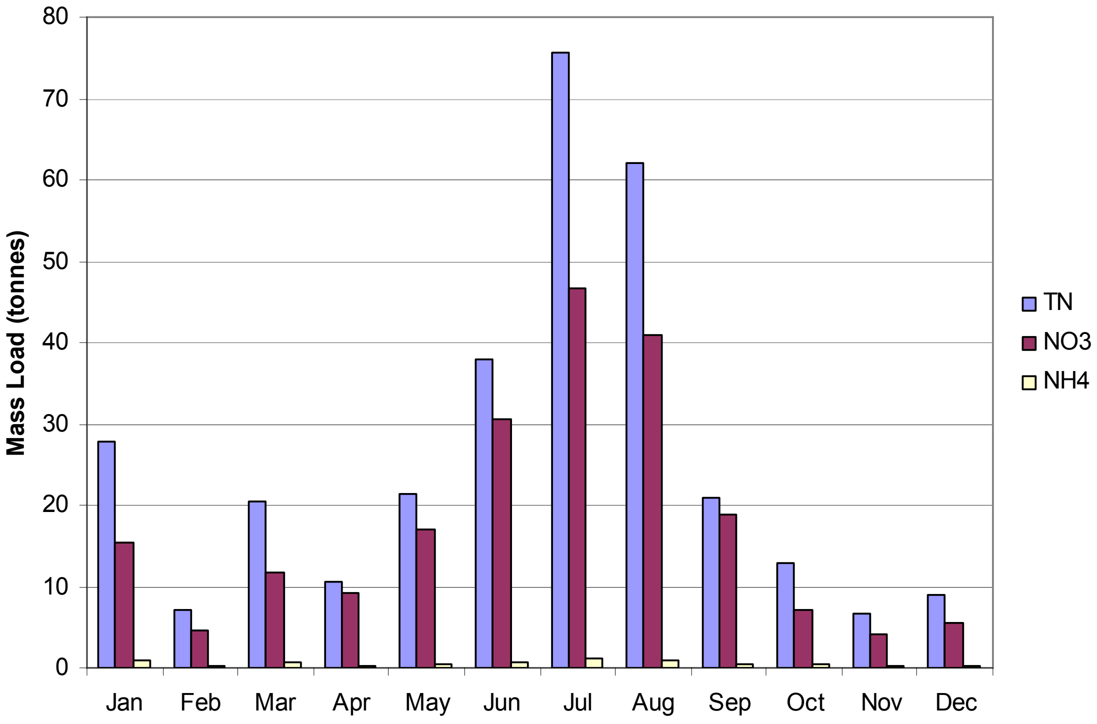

Figure 6. Mass loadings of Total Nitrogen (TN), Nitrate (NO3) and Ammonium (NH4) in the Motueka River during 2005.

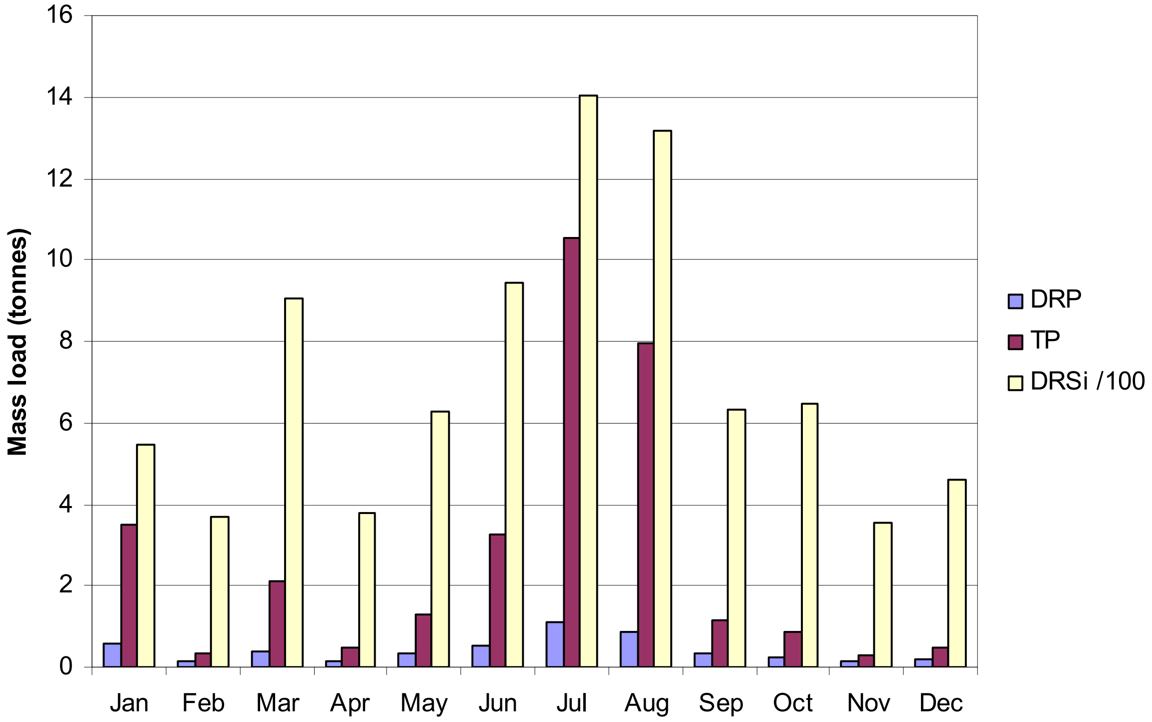

Figure 7. Mass loadings of Dissolved Reactive Phosphorus (DRP), Total Phosphorus (TP) and Dissolved Reactive Silica (DRSi) in the Motueka River during 2005. DRSi values have been divided by 100.

4. DISCUSSION

The results presented here will enable rough comparisons of the various sources of "new" nutrients to Tasman Bay. Although the Motueka River contributes more than 60% of the total freshwater flow into Tasman Bay, it appears that other smaller tributaries (i.e. the Waimea, Maitai, Wakapuaka rivers and a number of smaller streams) may contribute a disproportionate amount (i.e. >50%) of some nutrients (e.g. nitrogen) due to their generally higher concentrations. This assumption, however, is based on a limited amount of water quality data (Gillespie et al. 2001).

MacKenzie (2003) reported DRSi concentrations for Tasman Bay surface waters that were generally far in excess of phytoplankton requirements. He describes strongly increasing shoreward DRSi gradients off the Motueka River mouth, and an inverse relationship of DRSi with salinity as testimony to the importance of freshwater sources of this nutrient. These findings are consistent with the relatively high Si discharge rates observed in the present study. An optimum molar ratio of DRSi to DIN to DRP for phytoplankton production in temperate coastal waters is considered to be approximately 16:16:1 (Redfield et al. 1963). A significant divergence from this ratio could result in an alteration of phytoplankton community structure.

For example, where DRSi is relatively less available than DIN in coastal surface waters, diatom-dominated communities could be displaced by others that are less Si-demanding (e.g. dinoflagellate-dominated communities). The average DRSi to DIN molar ratio calculated from the Motueka River data accessed for the present study was ~20 times greater than the optimum 1:1 requirement, suggesting that the normally recurring winter/spring and autumnal diatom blooms in Tasman Bay (MacKenzie & Gillespie 1986) are nourished with DRSi from freshwater sources to the extent that concentrations are unlikely to be limiting in plume affected regions.

Molar DIN to DRP ratios of inflowing Motueka river waters were high (mean = 97 suggesting that algal growth in the river may have been (at times) phosphorus limited, although N:P ratios generally provide a poor indicator of which nutrient is limiting in rivers and streams (Francoeur et al. 1999). The coastal waters of Tasman Bay, however, are known to be limited to a greater extent by nitrogen with molar N to P ratios typically less than 16 to 1 (MacKenzie et al. 2003). In view of this, we look more closely at known sources and sinks for nitrogen in Tasman Bay and their significance to coastal productivity.

Using TN as an example, the total annual freshwater + wastewater input to Tasman Bay would be approximately 890 tonnes. This total includes 313 tonnes from the Motueka River (this study), 273 tonnes from other tributaries of Tasman Bay (very rough but conservative estimate based on proportional flows and limited available water quality data) and 304 tonnes from the four main point source wastewater discharges (Gillespie et al. 2001). By extrapolating measured Tasman Bay benthic denitrification rates (two sites only, Christensen et al. 2003) to the <30 m depth contour of the Bay, we estimate that about 1800 tonnes TN could be removed per year. Thus it appears that the amount of TN discharged into the Bay during 2005 would have been easily assimilated and would have contributed to coastal production in a beneficial way with little potential for dysfunctional ecosystem enrichment effects.

5. SUMMARY AND CONCLUSIONS

5.1. Study objective

The aim of this investigation was to estimate the rate of discharge of several dissolved and particulate nutrients into Tasman Bay, via the Motueka River, during the calendar year 2005. In order to accomplish this, it was first necessary to evaluate flow/concentration relationships using various data sets assembled from historical river flow and water quality information.

5.2. Overview of results and conclusions

Flow/concentration relationships were assessed for different river states (steady, rising and receding flows) and seasons (summer, winter). In general highest nutrient concentrations were observed during rising flood flows and during winter months.

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The flow/concentration relationships described here and the resulting 2005 loading estimates are considered to be generally representative of the Motueka River under the present catchment land usage. At these discharge rates, the nutrients delivered into the Bay would likely contribute to coastal production in a beneficial way with little potential for dysfunctional ecosystem enrichment effects. The observed flow/concentration relationships may be re-examined when additional data are collected.

6. ACKNOWLEDGEMENTS

Unpublished Motueka River water quality data was provided by Dr Roger Young, Cawthron Institute, Graham Bryers (NIWA, Hamilton) and Trevor James (Tasman District Council, Richmond). River flow data was provided by Martin Doyle, Tasman District Council, Richmond.

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8. APPENDICES

Appendix 1. Data and rationale used for determinations of flow/concentration relationships.

Data from a network of water quality sampling locations was accessed for this study. A summary of the hydrological and sample data is presented in Table A1.

Table A1. Sampling intensity and flow characteristics at sampling locations.

	Woodstock	Woodman's Bend	All Motueka
No. of Sample Occasions	192	94	286
Average Flow (L/s)	56167	296590	135187
Maximum Flow (L/s)	695000	1116800	1116800
Minimum Flow (L/s)	6260	12600	6260

The data from two sampling locations, Woodstock and Woodman's Bend, were used as described in the following sections (refer to Figure 1 in the report).

Sampling location

Woodstock Data
Water quality has been collected at Woodstock monthly by NIWA since 23/1/89 as part of the National River Water Quality Network. This data was accessed through 10/2/04 resulting in long term water quality records of approximately 15 years. The sampling was undertaken irrespective of flow conditions, however for the purpose of this study the state of the river at the time of sampling was recorded as rising, steady or receding.

Woodman's Bend Data
Woodman's Bend was the lowest monitoring site on the Motueka River. It was therefore considered to be representative of the catchment as a whole prior to the river discharging into Tasman Bay. Contributions arising below Woodman's Bend from Brooklyn Stream and some groundwater recharge have not been factored in to calculations of loading rates.

Flow records have only been recorded at Woodman's Bend since January 2001. TDC quarterly sampling has been carried out since 5/7/00 and the most recent data was accessed on 18/5/04. Again, samples were taken irrespective of flow conditions with subsequent documentation as per the Woodstock samplings.

Data sets for Woodman's Bend sampling were available over each of two flood events of differing magnitudes. The first, a small rainfall event between 21/5/02 and 23/05/02, peaking at 137 m^3/s, included eight samples (Figure A1). The second flood event included 30 samples over several flood peaks between 16/6/04 and 24/6/04, the largest being 1117 m^3/s (Figure A2).

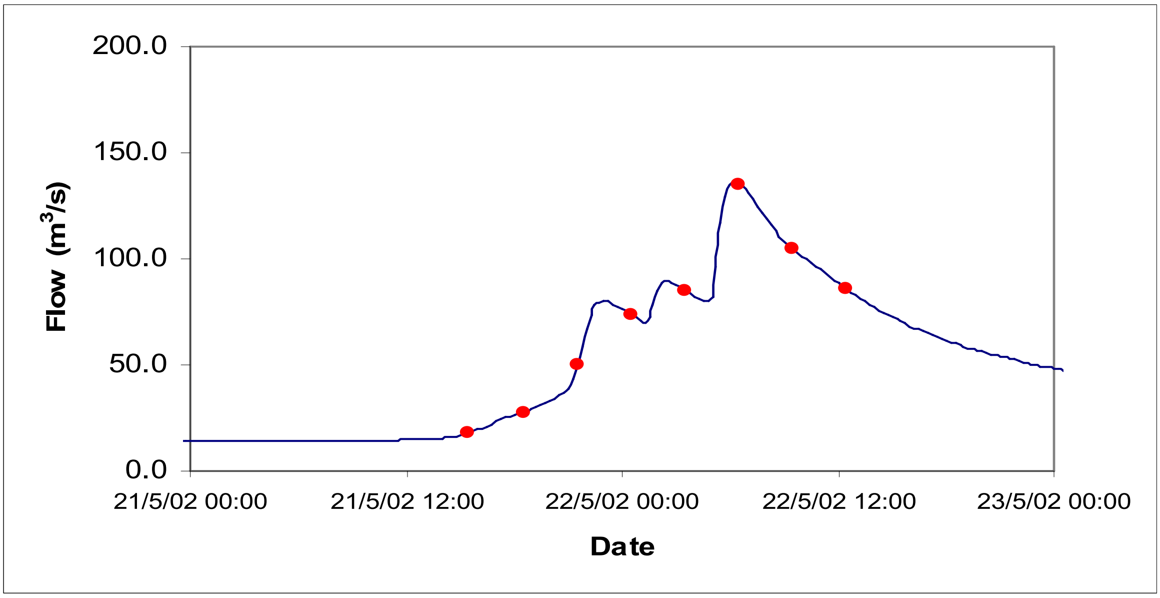

Figure A1. Sampling occasions over the small flood at Woodman's Bend (May 2002).

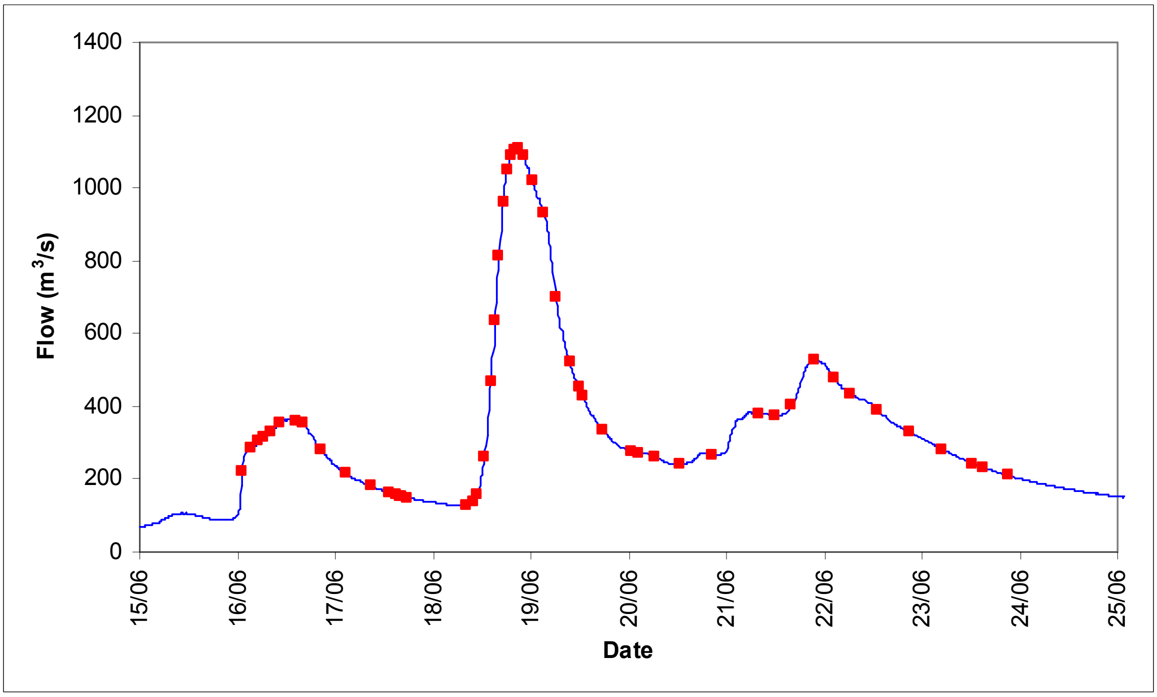

Figure A2. Sampling occasions over the large flood at Woodman's Bend (June 2004).

The Motueka River has peaked at 1117 m^3/s or greater on only 33 occasions in 30 years (i.e. about once per year). Therefore samples from this period, although useful in capturing the maximum flows, may not be entirely representative of the moderate floods that are more common.

Separation of data

Using various data subsets, the aim of this study was to calculate flow/concentration relationships for the Motueka River in order to estimate loading rates to Tasman Bay at various time scales. A schematic diagram of the data evaluation procedure is shown in Figure A3.

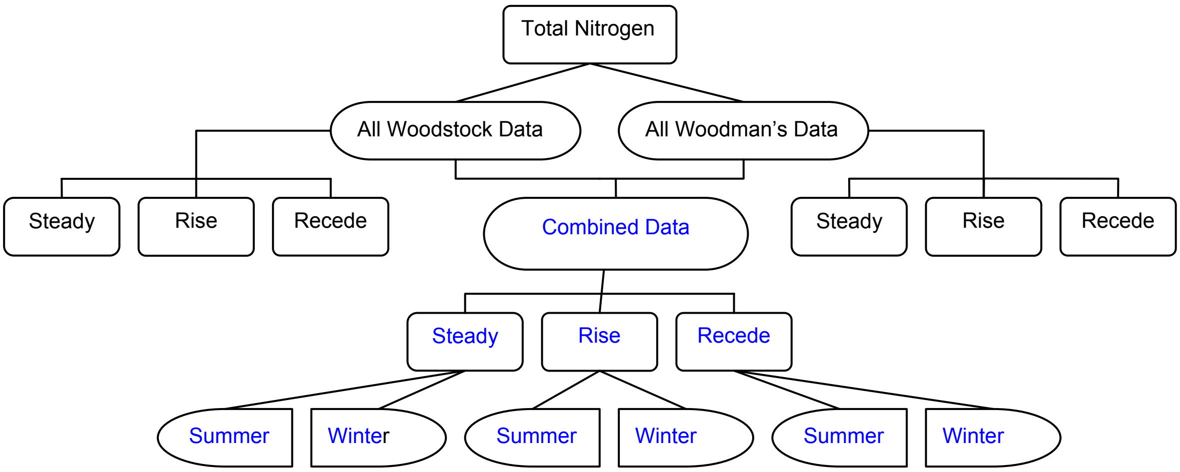

Figure A3. Diagram of the evaluation of data sets for determination of flow/concentration relationships (TN used as an example). Blue font shows the data sets ultimately used for loading estimates.

Average low flow, or steady state, concentrations for most nutrient species were reasonably similar between the two sites. Where there was slight variation, it was not to a significant level. The relationship was stronger for Woodman's Bend as the available low flow data was averaged over only a few samples and collected over a shorter time frame. Greater variation in low flow data due to seasonal/diurnal variation was apparent over the Woodstock record. Therefore, although flow was similar, the Woodstock R^2 value was lower (weaker correlation). Nevertheless, the Woodstock data set was not omitted because it was considerably larger and it was considered representative of the overall state of the river.

When plotted against flow, most nutrients demonstrated a fairly typical flood response with differing concentrations corresponding to first-flush onset, flood-peak and post-peak dilution (hysterisis). For this reason data was grouped according to steady, rising or receding flows (Figure A1).

In order to further improve loading estimates over short (e.g. daily) time scales, the data was also separated into summer and winter flows. Summer includes the months of spring (Oct – March) while winter includes autumn (April – Sept).

Total Nitrogen

Total Nitrogen concentrations varied greatly both seasonally and over shorter time periods. A stronger relationship existed at Woodman's Bend which was skewed by flood data but did not enable determination of seasonal fluctuation. When data sets were combined, the correlation was reasonable ($R^2 = 0.6056$). Because the nature of the two data sets varied, direct comparison between them was difficult however positive correlations existed for all flow states and similar average concentrations existed within each state. When split into seasons, the combined Motueka River data had stronger correlations during the winter period however flood flows were more prevalent during this period. A comparison of the two seasonal estimates for a low flow and small flood flow illustrates the importance of seasonal data separation. The average concentration during low flow (14383 L/s) in summer was 0.128 mg/L or 159 kg/day, compared with 0.102 mg/L or 126 kg/day during winter. For a small flood event (36595 L/s average rise, 82% of time, 788873 L/s average recession, 18% of time) an average concentration of 0.184 mg/L, or 704 kg/day as a load, was observed during summer compared with 0.344 mg/L or 1312 kg/day during winter. These flood estimates, although they seem generally realistic, probably slightly underestimate the actual. This is because the correlations have been made from average data spread across a long time period (15 years) but also influenced (skewed) by short term events. .

Ammonia –N

NH_4-N concentrations were very low throughout all data sets. No strong positive or negative correlation was observed with flow for either data set although seasonal variation was evident for the Woodstock data. With the combined data set split into river state a reasonable correlation was evident during flood recession periods (R^2. 0.5076) while a slight negative correlation existed during steady flow. When split further into season, low flow correlations did not improve, indicating a similar flow/concentration relationship applies irrespective of temporal variation. During the rising limb of flood events concentrations appeared to increase with flow, but an outlier skewed this toward a negative correlation. Again, relationships were weak but, for the most part, positive and slightly increasing with flow. With concentrations averaging 0.006 mg/L flow was clearly the greatest variable with respect to load.

Nitrate-N

NO_3-N concentrations were well below water quality guidelines for both long term records at Woodstock and the flood dominated records of Woodman's Bend. Large variations in the Woodstock data indicate that factors other than flow (e.g. seasonal effects) govern Nitrate-N concentrations. When analysed on a smaller scale, the flood events at Woodman's Bend strongly affected concentrations. Subsequently, data was separated into summer and winter for the combined data set. Although correlations were not particularly strong for each of the three stages of flow, average concentrations within each set did vary, thus highlighting the importance of separating data in preference to using an overall average for low flow data.

Winter correlations were strongest in all flow states probably due to larger concentrations being available for transport (NO_3-N not being removed to the same extent via plant uptake in winter compared with summer). This seasonal variation was reflected in daily low flow averages estimated at 0.05 and 0.139 mg/L for summer and winter respectively or 62 and 172 kg/day.

Total Phosphorus

Being strongly attached to sediment and therefore associated with erosional runoff events, TP was positively and strongly related to flow. The strong trend for both sites was evident throughout the rise and recession stages of the river; however weak relationships existed during low flows for both sites, possibly due to seasonal variation (R^2 0.05 Woodman's Bend and 0.06 Woodstock). The strongest relationships existed when the data was combined (R^2 0.85). When split for seasons, weak positive correlations existed during steady state with little variation in average concentration for summer (0.006 mg/L) or winter (0.003 mg/L) flows. Because strong positive relationships existed when data was not split, these figures were not too dissimilar when the entire data set was considered (due to the fact that TP is highly mobile during elevated flows and less so during steady state). However when rise and recession was separated and split by season even stronger correlations existed indicating the importance of splitting flood events (Otherwise a danger of underestimating flood loads due to low flows “pulling down” actual flood figures). This was the case for estimating small flood loads without forcing the trend line through zero. As it stands, smaller floods less than approximately 150 m^3/s, are still being underestimated and this should be considered. R^2 values for summer rise and recession are 0.9603 and 0.819 respectively and for winter 0.8429 and 0.8782 giving a confident fit of concentration against flow.

Dissolved Reactive Phosphorus

DRP flow versus concentration relationships were weak for all sites and flow conditions, these only marginally strengthened when river states were analysed separately. The Woodstock and Woodman’s Bend data sets were similar and the strongest relationship occurred when they were combined. There was large scatter about the regression lines for all river states however the positive correlation suggested that these should be considered. There was little variation at steady state for either summer or winter flows resulting in exactly the same average concentration for each; 0.002 mg/L or 2 kg/day. This estimate was only slightly higher than reported for the smaller Waimea River (1.1 kg/day, Gillespie et al. 2001). A similar correlation existed during the rising limb of a small flood but the average concentration within each set varied seasonally (summer 0.0039 mg/L and winter 0.0128 mg/L), however the reverse was true during the recession period.

Dissolved Reactive Silica

Silica data were severely limited as they were available for the Woodman’s bend site only, including just one flood event (23 measurements) and nine monthly measurements covering flows <80 m^3s^{-1}. Because of this, seasonal variation was not possible to deduce but a significant dilution effect was noted during flood flows. Therefore mass transport calculations were based on average concentrations for flows <80 m^3s^{-1} and average concentrations >80 m^3s^{-1} and the corresponding loadings during 2005 are rough approximations.

Large flood estimate versus actual

To test the accuracy of the concentration predictions, a calculation of the mass load of total nitrogen was made for the large flood sampled from the 15/06/04 – 24/06/04 at Woodman's Bend. Three methods were used to estimate the mass load over the flood event, a complex event lasting for ten days including four individual peaks (Figure A1).

The first method was a direct correlation using all of the flood data collectively, and then applying it to each 15 minute interval over the ten day event. The second used the same method, but separated the data into rise and recession periods and applied the two new correlations. The third used the actual sample concentration results and applied each sample across the preceding discharge results to the previous sample, effectively "blocking in" the flood hydrograph using an area method. These results were then compared with the predicted result based on the average rise and recession figures from the flood event only and the percentage of time within each flow state. Results are given in Table A2

The predicted result, based on two averages and weighted for time, was just 3,369 kg/day below the actual result. Considering the complexity of this flood event, the estimated average concentration and associated average kg/day were reasonably close. The separated flood results were very similar to the actual results based on real data. This type of flood event is rare (one event per year) and as flood events deliver a disproportionate amount of nutrients, having this reasonably accurate estimate of larger flows is very important. However, when all flood data is used, some over-estimation is likely due lower flood events resulting in larger than actual loadings.

Table A2. Comparison of TN estimates using various methods.

	All Flood Data	Separated Flood Data	Average Actual Data	Predicted Data based in Discharge only
Av mg/L/day	0.66	0.56	0.61	**0.66**
Av kg/day	25,217	20,072	20,987	**17,618**

Smaller flood estimates versus actual

A similar comparison was made for smaller flood flows. It was found that when the river was in a "flood state" (i.e. rising or receding) but was less than ~150 m^3/s, average concentrations and hence loads were underestimated for most nutrient species. This was due to the actual results being highly influenced by the first flush stage. Not sampling the first flush during larger floods results in lower average concentrations through dilution. For example, over the small two day flood event at Woodman's Bend, the actual average concentration for TP was 0.1 mg/L which equates to approximately 546 kg/day. On average the predicted figures for the same period equalled 0.033 mg/L or 133 kg/day. Similarly using NH_4-N as an example 0.008 mg/L or 37 kg/day was actually recorded at Woodman's Bend while for the same period 0.005

mg/L or 23 kg/day was predicted. Therefore over smaller flood events concentrations were underestimated by approximately 1.7 - 3 times. With such a small data set, capturing this initial flush stage (20 – 150 m^3/s) was not possible. However, when periods under inspection fall below (steady state) or above this period (larger floods) figures balance well between actual and predicted.

General remarks

This analysis of nutrient loading focused on the importance of data separation with respect to temporal sampling. Our calculations incorporated both seasonal variation and flow variation. The flow/concentration relationships described here and the resulting 2005 loading estimates are considered to be generally representative of the Motueka River under the present catchment land usage. The observed flow/concentration relationships may be re-examined when additional data are collected. Future monitoring should aim to capture the "first flush" period of flood events in order to increase the accuracy of loading estimates.