Waituna Catchment Loads

Report for Environment Southland

Prepared by

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Executive Summary

Catchment runoff containing sediments and nutrients threaten the ecological integrity of Waituna lagoon. There are fears that land intensification will exacerbate the observed decline in the lagoon. Environment Southland (ES) commissioned Diffuse Sources and NIWA to develop a robust methodology for calculating nutrient loads for the streams discharging to the Waituna Lagoon, which can be used to estimate loads across different time scales (e.g, season, years) and compare these through time.

Three regression approaches for estimating contaminant loads are recommended for both future and historical estimates of contaminant loads. These regressions are based on the fact that concentrations vary significantly with flow rate, and so regressions employ rating curve for load calculations.

We recommend that the SedRate software (NIWA, Christchurch) be used for these load calculations because it is fairly easy to use, it allows for LOWESS curves in the future if necessary, is defensible, and provides uncertainty estimates. Loads can estimated for different time periods (years and seasons) by applying the relevant period of flow record to the rating curve.

We concluded that it is not necessary at this stage to take account of long-term trends in concentration for TN or TP when establishing measured loads over the period of the historical monitoring record. We also concluded that it was not necessary to include seasonal effects (most of which is caused by flow) or hysteresis (although the latter needs to be checked by further sampling of storms). A caveat to this conclusion is the possible influence of climate change on flows, which may have a small effect on load trend analysis.

We concur with the bimonthly sampling strategy. We recommend that additional storm sampling be conducted, because the dataset has only limited storm monitoring. There is a need to confirm that the concentration predictions made by the recommended regression approach reasonably describe other storm events. We have not been prescriptive about number of samples and storm size, because this should be determined by achieving adequate coverage of the flow duration curve.

We have, however, made recommendations on flow 'triggers' within the various subcatchments and methods for determining appropriate sampling frequency.

We suggest that flow monitoring at Waituna @ Marshalls coupled with sufficient gauging at other sites (covering the flow range, and is ongoing to check for consistent runoff behaviour) is adequate given the response of the catchments. However, continuous flow recording should be installed if significant land use changes occur or are predicted to (e.g., significant change in proportion of farm types, farm drainage systems, drain management) of if the gauging programme shows changing flow characteristics or unstable relationships.

The present sampling method does not represent particulate P and N. This may turn out to be insignificant for loads given relatively small concentration range and relatively low responsiveness to flow. However, this should be checked with a field study (including measuring TDP and DON) and calculation of the true particulate loads for P and N.

There are inconsistencies in sediment load and proposed impacts in the estuary. This should be reassessed. Sediment loads are very low, but probably consistent with runoff from catchments of this type.

The present parameter list could be expanded to include colour (to help understand these peat catchment responses to rainfall – the present 'measure of colour" – black disk - also responds to suspended particulate matter). TDP and DON should also be measured.

The analysis in this report shows how monitoring to date can be used to derive load estimates and their uncertainty, and describes how other factors, such as seasonality and time trends can be incorporated in the future if necessary. It also points to some future refinements involving accurate flow estimation, additional sampling to confirm the behaviour at high flows and ensure coverage of flow duration curves, additional chemical analysis for dissolved and particulate forms, and sampling methods.

Contents

1 Introduction

1.1 Scope

Catchment runoff containing sediments and nutrients threaten the ecological integrity of Waituna lagoon. There are fears that land intensification will exacerbate this decline in the lagoon. Environment Southland (ES) commissioned Diffuse Sources and NIWA to develop a methodology for calculating nutrient and sediment loads for the streams contributing to the Waituna Lagoon:

1) based on the data collected pre May 2011, when the continuous water level sites were established in the catchment and water quality data was collected monthly as part of the regional water quality network,

2) based on the data collected post May 2011 when the continuous water level sites were established in the catchment and water quality data has been collected semi-monthly with some storm chasing.

In addition to recommendations on load methodologies, ES requested recommendations on the type of sampling regime and flow data required to capture adequate data into the future.

1.2 Catchment Characteristics

The upper catchment has free-draining brown soils, while the lower catchment has peat soils. The Moffett subcatchment is all peat soils and of fairly intensive land use, while the Carran Creek Tributary subcatchment has high proportion of reserve (DOC) peat lands.

The mid catchment has severe bank erosion on the main Waituna River.

There are major issues with no dairy shed effluent storage in some older farms that need to irrigate effluent at high rates during rainfall.

Peat soils are quite reducing, which are expected provide conditions for nitrate reduction and hence denitrification (conversion through to N_2 gas), and elevated ammonia concentrations. The water quality is strongly affected by peat staining. Note this peat characteristic is reflected in the pH of the waters, which are low (especially in the Carran tributary - typically pH 4 – 5).

2 Water quality and flow data

2.1 Data Collection and Calculation Methods

Flows are available from Marshall Rd 2001-2007, plus good correlations with Waihopai Rd after that. In September, flow recording was restored at Waituna at Marshall Road with a continuous water level/flow recorder, and two less accurate trutrack recorder sites on Carran Creek and Moffat Creek. These are typically within 20 mm of measured water level but can be as much as 50 mm out. Flow data is therefore less reliable at these sites, but ascertaining the timing of flood peaks is good.

The long-term water quality data for the Waituna @ Marshalls site was collected from July 1995 and consists of monthly samples prior to April 2011 and bimonthly after that date. However, TN, TP, and turbidity were only measured from 1998-99. Samples were collected monthly at Moffat Ck, Carran Creek and Carran Creek tributary from 2001.

Total annual surface water loads were modelled for 2010 using over 10 years of water quality data (including a recent flood event) at three sites in the catchment and current flow relationships. Flow data has been modelled from the Waihopai catchment and the relationship between water quality measurements, modelled flow and season have been expressed as four typical seasonal flow/concentration curves. Nutrient concentrations were interpolated from continuous flow measurements and day of the year and applied to the flow in each catchment to give a load.

Samples for baseflow and stormflow are collected in midstream with 9 litre bucket, letting the bucket sink to about 2/3rd depth.

2.2 Exploratory Data Analysis

We carried out an exploratory data analysis has been carried out to guide any enhancement of the current monitoring programme and ensure that robust estimates can be made of nutrient and sediment loads to the lagoon. There are three types of information: 1) detailed information from a major storm 2) long-term monitoring data as described above 3) sediment and nutrient loads.

This EDA (in the following 3 chapters) is a summary of plots and calculations, and does not make definitive conclusions about contaminant behaviour, but only suggests possible interpretations.

This analysis adds to the findings of a technical comment "Surface Water Quality – Waituna Catchment" by Kristen Meijer (27 June 2011).

3 Behaviour of Particulate Matter

The data

Total Suspended Solids (TSS) monitoring is limited to recent times, whereas Black Disk (BD) and turbidity have been measured often through the monitoring periods. There is also some Volatile Suspended Solids (VSS) data from recent times. Table 3.1 summarise basic statistics. Long-term trends were included where available (Meijer 2011) and are based on a Seasonal-Kendall test with flow adjustment for the period July 2000/August 2001 to 30 June 2010.

Table 3.1 Summary Statistics for Particulates. Data, except trends, includes the large storm of May 2011.

A: Water Quality Sampling Flows

Site	Waituna at Marshalls	Waituna at Mokohau	Moffat	Carran Ck	Carran Ck tributary
Mean	3845	-	580	1019	380
Median	1223	-	196	385	122
Minimum	56	-	9	29	6
Maximum	22167	-	4453	5352	1769
Number	250	-	176	175	175

B: TSS

Site	Waituna at Marshalls	Waituna at Mokohau	Moffat	Carran Ck	Carran Ck tributary
Mean	25	35	17	16	<3
Median	11	9.4	8	8	<3
Minimum	<3	<3	<3	<3	<3
Maximum	250	510	133	100	10
Number	91	26	92	90	90

C: Turbidity

Site	Waituna at Marshalls	Waituna at Mokotua	Moffat	Carran Ck	Carran Ck tributary
Mean	15.1	7.8	14.4	16.8	2.6
Median	8.2	4.8	7.9	12	2.0
Minimum	1.7	1.67	2.5	3.8	0.8
Maximum	90	69	110	190	24
Number	190	109	161	160	160

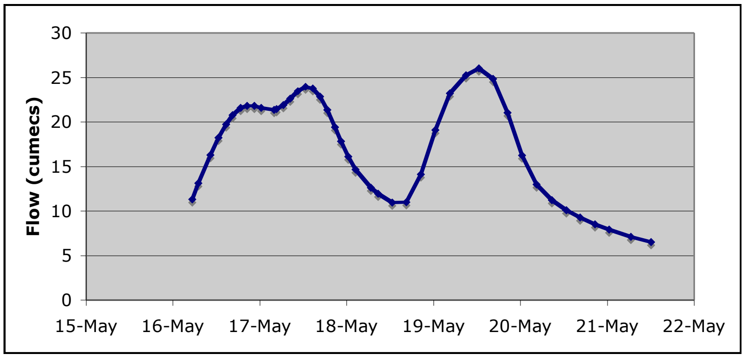
D: Black disk

Site	Waituna at Marshalls	Waituna at Mokotua	Moffat	Carran Ck	Carran Ck tributary
Mean	0.67	1.2	0.49	0.38	0.41
Median	0.62	1.13	0.5	0.37	0.39
Minimum	0	0	0	0	0
Maximum	1.5	3	0.97	0.84	0.93
Number	190	109	118	105	110
Trend	Improving (4.5%)	No trend	No trend	No trend	No trend

TSS and turbidity medians are similar across all catchments except for the “natural” Carran Ck Tributary. Mean and median TSS and turbidity are very low for the developed catchments, and are reflected in very low specific yields (Section 8). The effect of peat soils can be seen in the black disk measurements for the lower catchments sites; clarity was higher in the Waituna at Mokotua, where there is expected to be a much lower proportion of peat soils.

At present there is only one monitored storm. This very large storm was monitored over 5 days in May 2011.

Figure 3.1 Flows for storm of May 2011 at Waituna at Marshalls



Flow relationships

There are poor relationships between flow and particulate matter as measured by TSS, turbidity and black disk (Figure 3.2 - 3.3).

There is marked hysteresis in TSS (and all particulate-related parameters) in the large storm of 16^{th} – 21^{st} May 2011 for all catchments (Figure 3.2).

Concentrations of TSS are relatively low, even at high flows compared with most NZ catchments. This is especially true for the Carran tributary (the "natural" catchment) (Figure 3.2). Turbidity can also be relatively low at high flows (Figure 3.3). However, high flows are associated with poor transparency (Figure 3.3).

The water can be highly turbid during low flows (Figure 3.3) and have a wide range in black disk transparency (Figure 3.3).

The three major catchments have a strong TSS/turbidity relationship (Figure 3.4).

There is a large variability in the optical characteristics of the water during low flows (Figure 3.4). Black disk visibility appears to be very affected by the colour of the water (it is strongly peat stained) as well as particle concentrations.

Catchment sources

The discussion above supports the idea of limited sources and very low catchment loads (although apparently, there is some severe bank erosion in the mid catchment. Finger printing sediment sources will be subject of future study). The relatively low slope of the catchment may also allow more settling and have less erosional energy than in more typical NZ hilly streams.

Nature of particulates

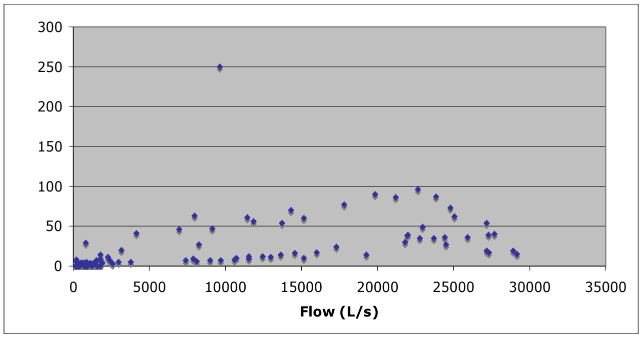
The particulate matter is organic-rich – possibly reflecting the high proportion of peat soils, and the low slope.

Table 3.2 Particulate organic content

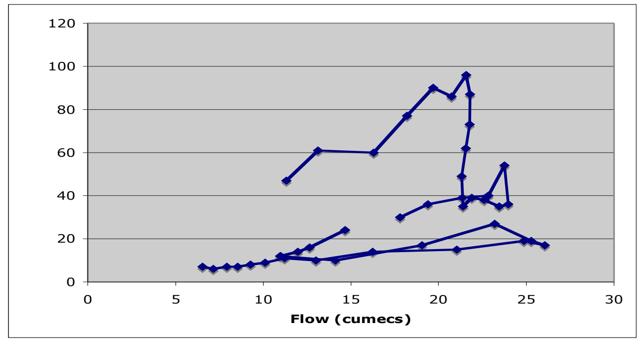
Site	VSS/TSS (%)
Waituna @ Marshalls	35
Moffat	32
Carran	55

Figure 3.2 TSS versus Flow. TSS concentrations are in mg/L.

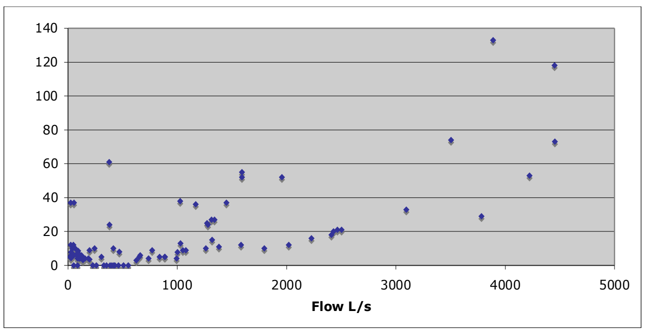
Waituna @ Marshalls



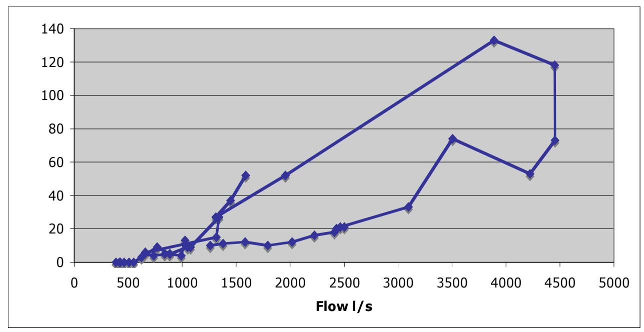
Waituna @ Marshalls Storm 16 – 21 May 2011



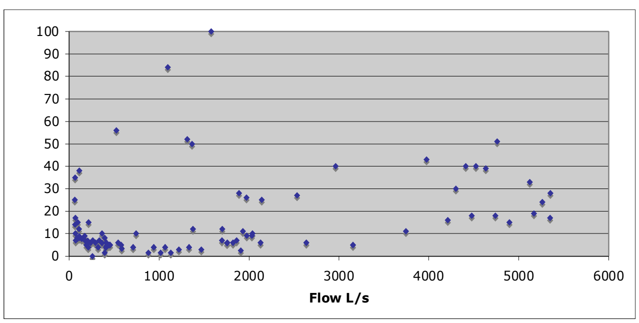
Moffat Creek



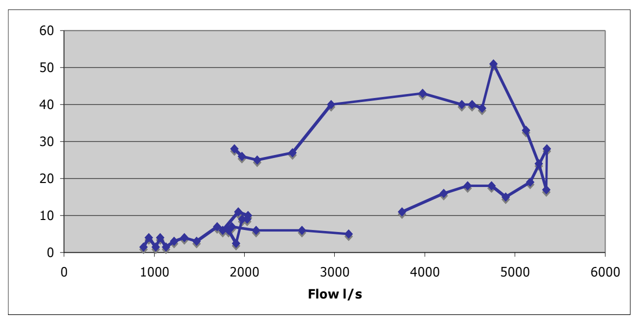
Moffat Creek Storm 16 – 21 May 2011



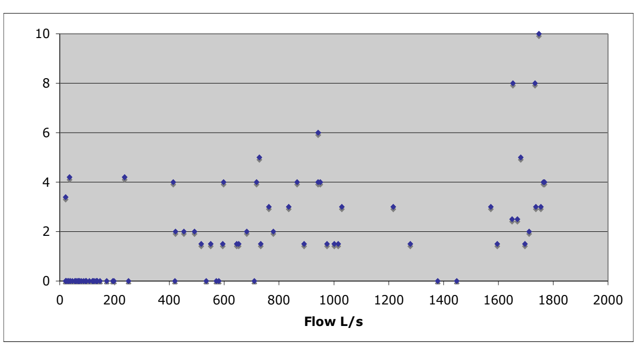
Carran Creek



Carran Creek Storm 16 – 21 May 2011



Carran Creek Tributary



Carran Creek Tributary Storm 16 – 21 May 2011

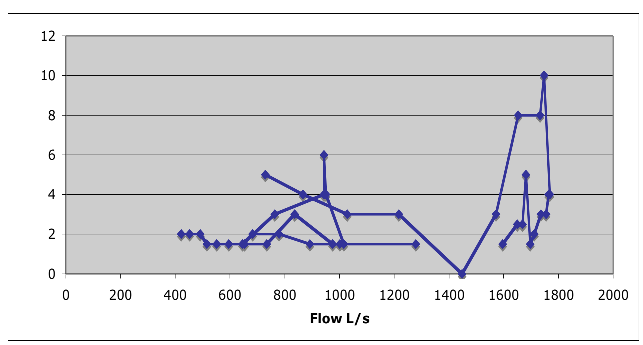


Figure 3.3 Turbidity and Black Disk versus Flow

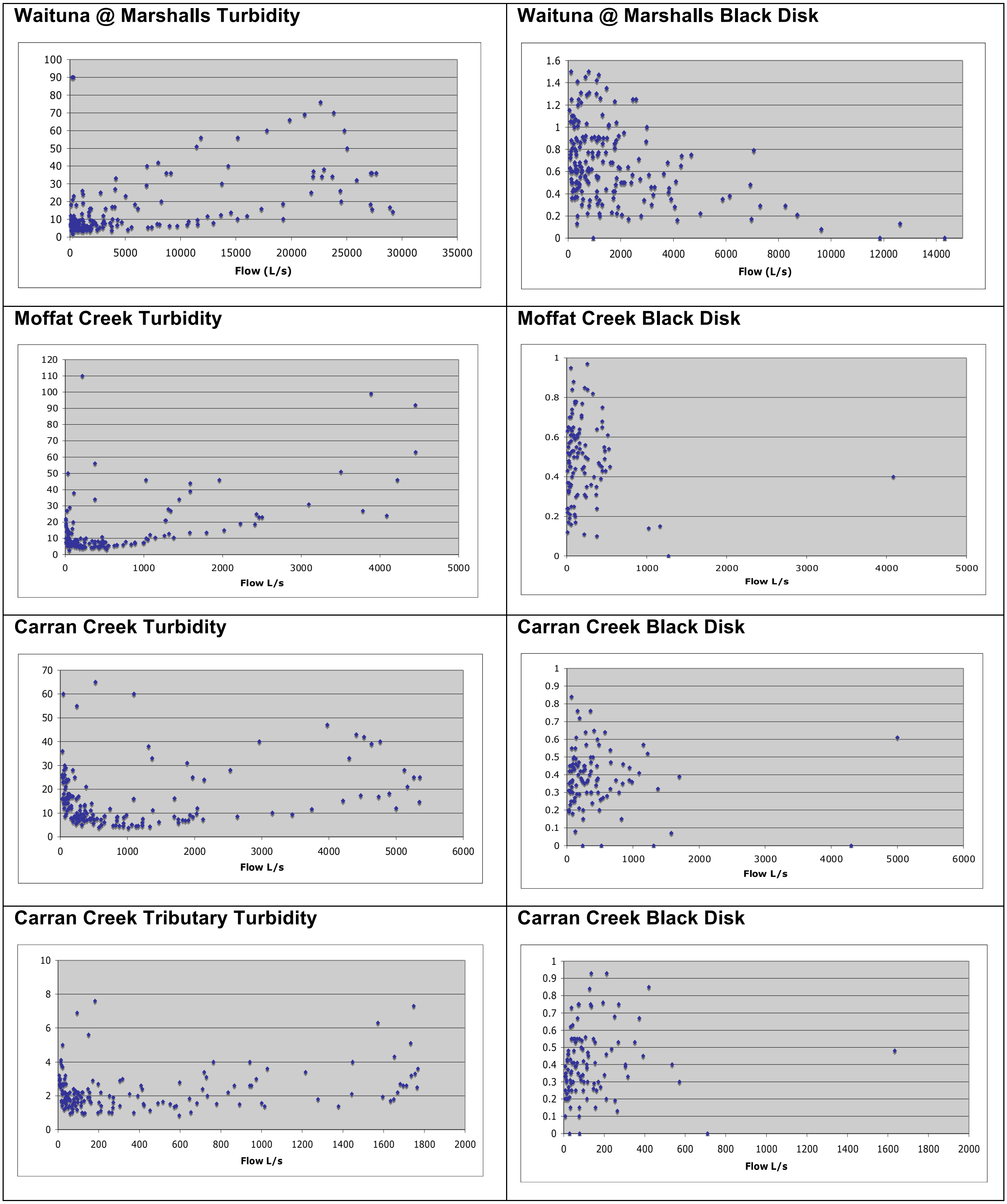
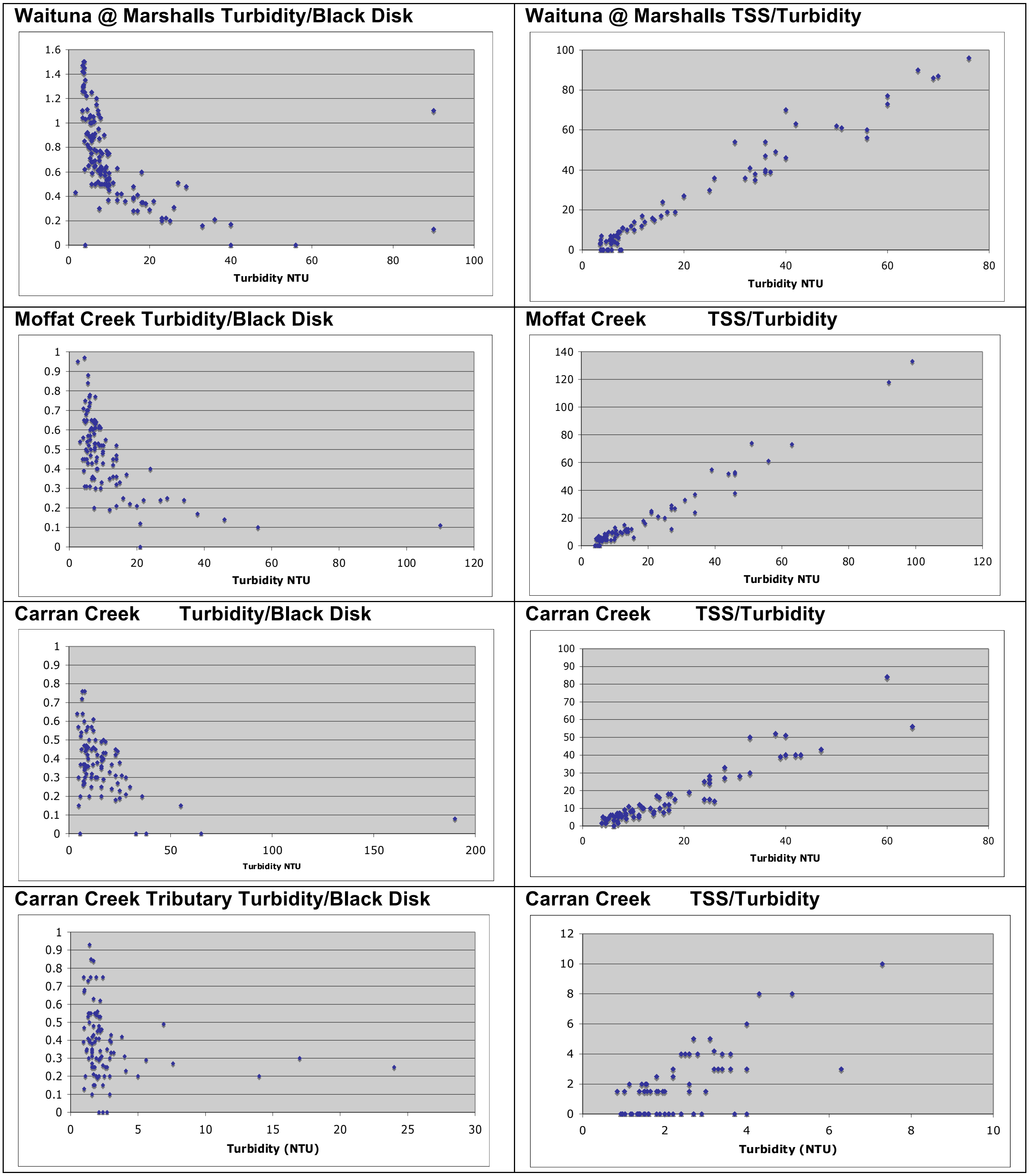


Figure 3.4 Turbidity versus Black Disk and TSS



Sediment load

The sediment load calculated by Environment Southland (Meijer 2011) is very low in the NZ context. The specific yields from Waituna, Moffat and Carran were 111, 122 and 71 kg/ha/yr, which places then in amongst the lowest yields measured in New Zealand and equivalent to sediment loads from low hill-country native catchments (Williamson 1993).

The estimate is based on monthly sampling, and this does not include many high flows. So the load could be higher, although the large storm had relatively small increases in TSS concentrations (compared with many other NZ catchments). (We note that the Lagoon Technical Group (LTG) reported a similar issue with reconciling low sediment inputs). These preliminary estimates of catchment sediment loads are at least 40 times less than that needed to explain observed lagoon sediment deposition rates (SDR). It is difficult to believe that sediment loads have been underestimated to that extent (40x), and it may point to large increase in sand inputs into the estuary from the bar and ocean (the apparent SDR increase observed in the cores was associated with coarser sediments) associated with artificial opening. Alternatively (or in addition to) the high SDR may be due to:

- large bedload of coarse sands – which would be surprising in this low gradient catchment)
- large inputs during, and subsequent to, drain-maintenance activities

Table 3.3 Sediment Deposition Rate calculations

Sediment load	1517 t/yr
Bulk density	1.5 t/m^3
Amount of sediment load settling in lagoon	100%
Volume of sediment	1011 m^3
Area of lagoon	1350 ha
Area of wetland	2200 ha
Increase in sediment depth	0.075 mm/yr**
Prior 1960 rate in estuary	0.05 – 0.06 mm/yr (LTG 2011)
Post 1960 rate in estuary	2.8 mm/yr (LTG 2011)

**Less if assume <100% settled and no settling in wetlands

4 The Behaviour of Nitrogen Forms

The data

Nitrate + nitrite-N, ammonium-N, and total nitrogen concentrations were measured, with TN only from 1989-99. Particulate+organic nitrogen (PON) shown in the following plots was calculated from TN-DIN. PON statistics have not been summarised; it is not useful parameter because it contains both particulate and dissolved organic matter. It was plotted, however, in the following figures to check that it did not exhibit unusual responses to flow, season or time.

Table 4.1 Summary Statistics (trends from Meijer 2011). Data, except trends, includes the large storm of May 2011.

A: Nitrate-nitrogen

Site	Waituna at Marshalls	Waituna at Mokotua	Moffat	Carran Ck	Carran Ck tributary
Mean	1.69	2	0.77	0.76	0.032
Median	1.50	1.87	0.43	0.55	0.023
Minimum	0.01	0.15	<0.002	0.01	0.004
Maximum	4.5	4.4	2.9	2.0	0.77
Number	247	123	176	175	173
Trend	Deteriorating (2.5%)	Deteriorating (3.2%)	No trend	No trend	Improving (16.5%)

B: Ammonium-nitrogen

Site	Waituna at Marshalls	Waituna at Mokotua	Moffat	Carran Ck	Carran Ck tributary
Mean	0.141	0.082	0.088	0.102	0.022
Median	0.077	0.056	0.052	0.082	0.016
Minimum	<0.01	<0.01	<0.01	<0.01	<0.01
Maximum	2.4	0.48	0.43	0.50	0.10
Number	249	124	176	175	174
Trend	Improving (16%)	No trend	Deteriorating (9.4%)	No trend	No trend

C: Total Nitrogen

Site	Waituna at Marshalls	Waituna at Mokotua	Moffat	Carran Ck	Carran Ck tributary
Mean	2.8	2.7	2.06	1.85	0.74
Median	2.5	2.5	1.6	1.46	0.72
Minimum	0.6	0.57	0.55	0.53	0.32
Maximum	6.0	9.5	5.1	4.4	1.70
Number	206	123	176	175	175
Trend	Deteriorating (0.9%)	Deteriorating (1.5%)	No trend	No trend	No trend

Nitrate concentrations are increasing slightly (about 1% per year – and see Figure 4.9) in the Waituna but not in Moffat or Carran Creeks. Concentrations are highest in the Upper Waituna. Nevertheless, nitrate is relatively high in the three developed catchments, but very low in the partially-developed catchment (Carran Creek Tributary).

The picture that is emerging is that land development has increased nitrate, but the peat soils are attenuating that increase. This effect is least in the upper Waituna, where mineralised soils dominate. Dairying intensification has had little impact on nitrate levels in the peat-dominated Moffat catchment.

Ammonia is a minor component of the total N load, and shows complex behaviour across the 5 catchment sites.

Concentrations

Nitrate is the dominant nitrogen species in the Waituna catchment (Figure 4.1, 4.2). In the other developed catchments, nitrate concentrations are roughly comparable to organic+particulate nitrogen. Concentrations of nitrate and ammonia are very low in the partially-developed Carran Creek tributary – Figure 4.1, 4.7.

Some very high concentrations of ammonium nitrogen (NH_4-N) have also been recorded at low flow (including 2.4 mg/L not shown for Waituna @ Marshalls), possibly due to the washoff of dairy shed effluent to the stream. While the soils are reducing, it is doubtful that reduction could cause such high ammonium concentrations because NH_4^+ is attenuated in soils due to adsorption. High NH_4-N concentrations are consistent with effluent disposal problems within the catchments with some older farms having insufficient effluent storage and needing to irrigate at high rate during rainy periods. The high ammonium nitrogen is related to high concentrations of indicator bacteria and DRP, which is also consistent with it being an effluent disposal issue.

Flow effects

Nitrate concentrations show an increase with flow at low flows and then a "levelling off" with wide variability (Figure 4.1). This increase is consistent with the proposed ground water flushing mechanism and was also observed during the large storm (see next section). This no doubt contributes to part of the seasonality observed with nitrate and total nitrogen (TN), with higher flows in winter having higher nitrate concentrations (see later Figure 4.3). The relationship is weakest with the Carran Creek Tributary, which has also very low nitrate+nitrite concentrations.

Ammonium nitrogen shows a weak flow relationship for the Waituna and Moffat Creek (but not for Carran Creek).

TN shows a similar relationship with flow for Waituna, Moffat and Carran and this would be expected (as it is a combination of particulate N and nitrate – both of which increase with flow). However, the relationship with O+PN is relatively weak and more linear. TN and O+PN concentrations only increase slightly with flow for the "natural" catchment (Carran Creek Tributary).

Seasonality and time trends

Long term time trends are not readily apparent from visual examination of the data (Figures 4.3 – 4.7), but may occur for some parameters for some catchments when flow adjustments are made.

Nitrate concentrations show a strong seasonality with low nitrates in summer (Figure 4.3-4.7) in the developed catchments, but not for Carran Creek tributary. This is consistent with flow data, which shows higher nitrate with higher flows. This supports the idea of a flushing effect (from soil profile) and/or nitrate removal effect (at low flows) by peat soils or wetlands. Conductivity is largely invariant with flow (see Box next page). This also supports the idea of a flushing mechanism (Figure 4.1).

Ammonium-N sometimes shows a seasonal effect, although less pronounced than nitrate (Figure 4.3-4.7). This is also, at least partly, related to increases in concentrations with increases in flow (Figure 4.1). Nitrate is probably being reduced in soils or wetlands, which depending on the mechanism (denitrification or dissimilatory nitrate reduction) may result in production of nitrite and ammonia. Ammonium-N is lowish, but do increase in winter and does seem to increase with flow (Figure 4.1). Ammonium is relatively immobile in mineral soils (due to adsorption) so any flushing effects will not be pronounced as with nitrate.

TN sometimes shows a seasonal effect, due to nitrate. PON (TN - NO_xN - NH_4N) does not show a seasonal variation.

The seasonal effects were investigated further, in the following plots (Figure 4.8). There is winter effect on nitrate concentrations, but not for TN or ammonium-N concentrations. This probably reflects less efficient denitrification in winter from sustained groundwater flows. (Note that the autumn data has the highest flows and nitrate concentrations because it contains the very large May 2011 storm).

Conductivity behaviour

Conductivity shows no decrease with flow in the catchments. This is shown for the Waituna @ Marshalls site below. This is surprising, because most catchments show dilution effects from direct rainfall and overland flow. However, very similar behaviour is seen in Bog Burn in Northern Southland, which also has peat soils (B. Wilcock, NIWA, pers. com.).

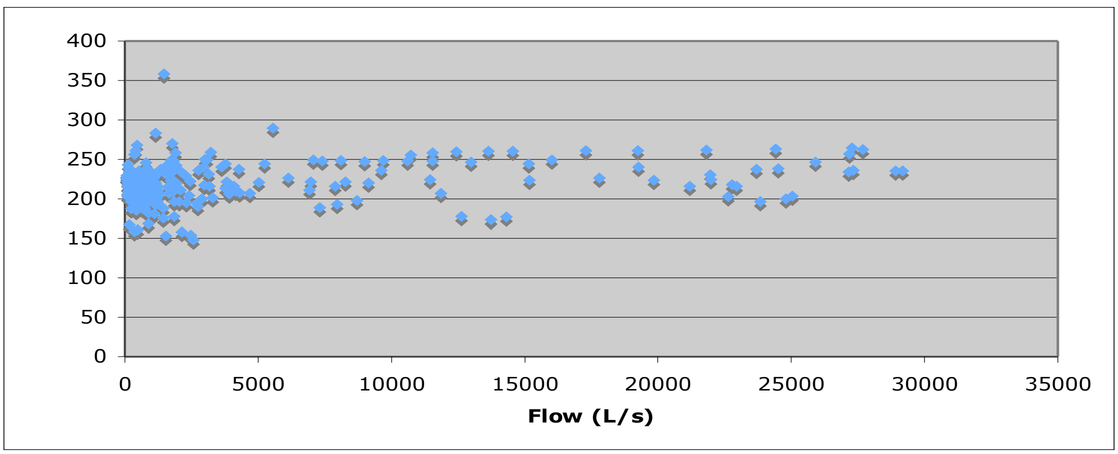
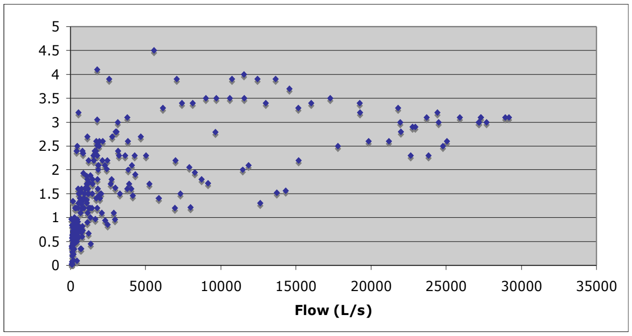
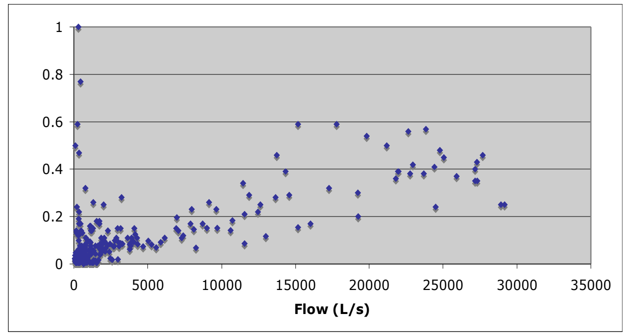


Figure 4.1 Nitrate+Nitrite Nitrogen and Ammonium Nitrogen versus Flow

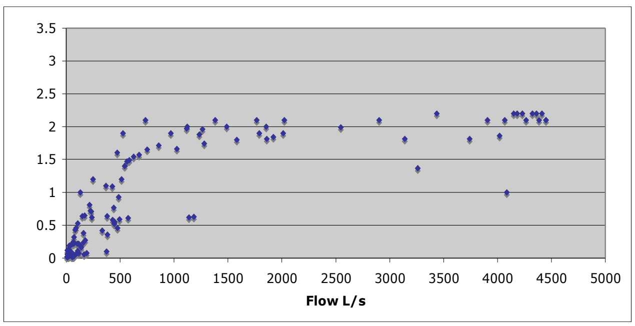
Waituna @ Marshalls NO_x-N



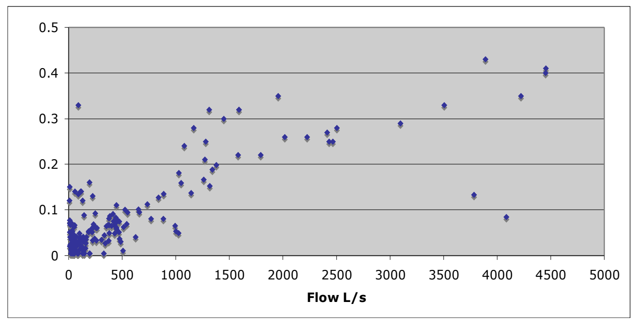
Waituna @ Marshalls NH_4-N



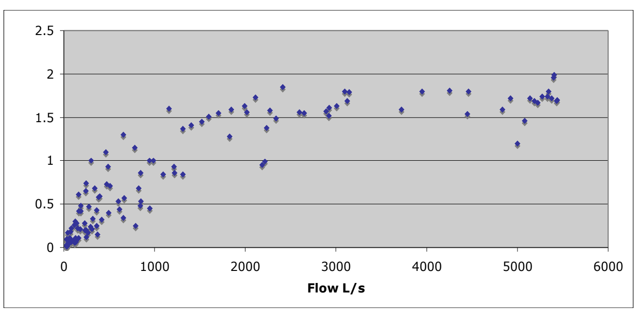
Moffat Creek NO_x-N



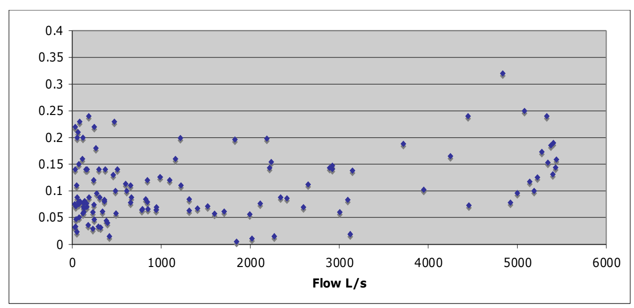
Moffat Creek NH_4-N



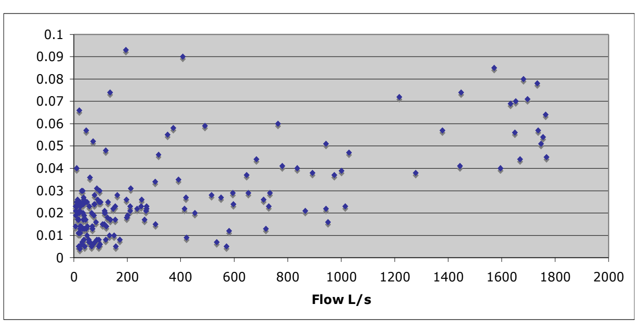
Carran Creek NO_x-N



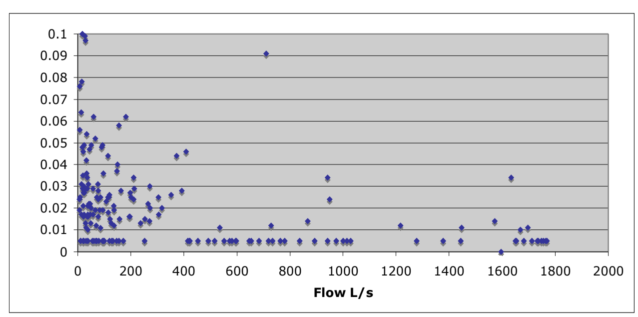
Carran Creek NH_4-N



Carran Creek NO_x-N



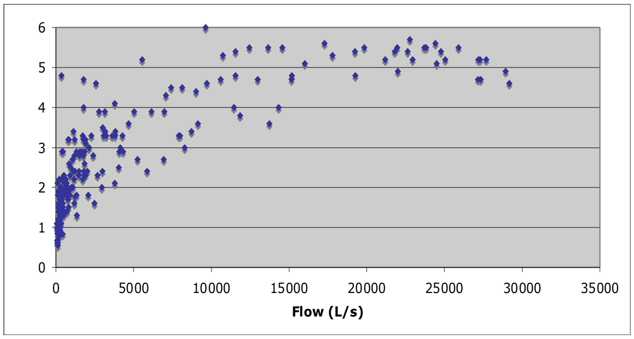
Carran Creek Tributary NH_4-N



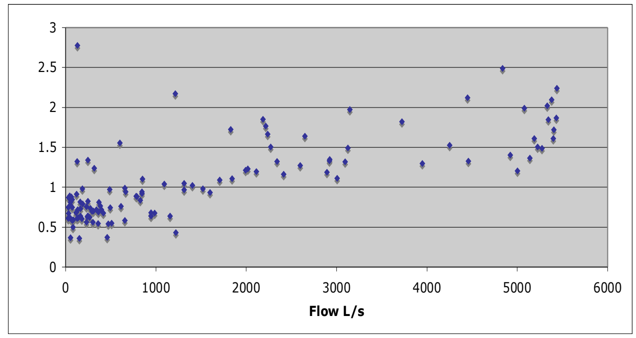
Note: Dropped a few high outlier values, especially for NH_4-N.

Figure 4.2 Total Nitrogen and Organic/Particulate Nitrogen versus Flow

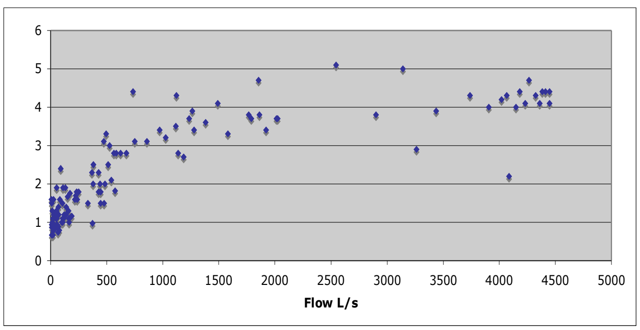
Waituna @ Marshalls TN



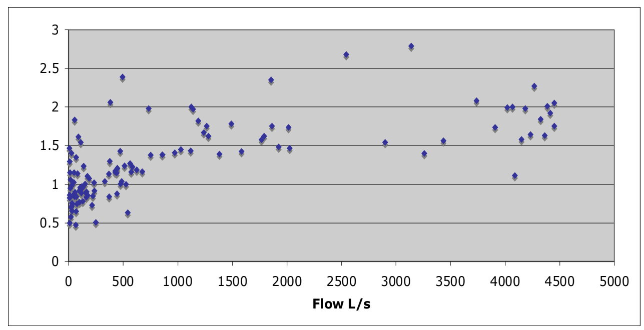
Waituna @ Marshalls O+PN



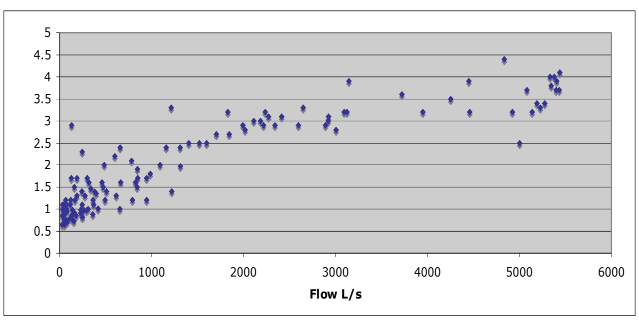
Moffat Creek TN



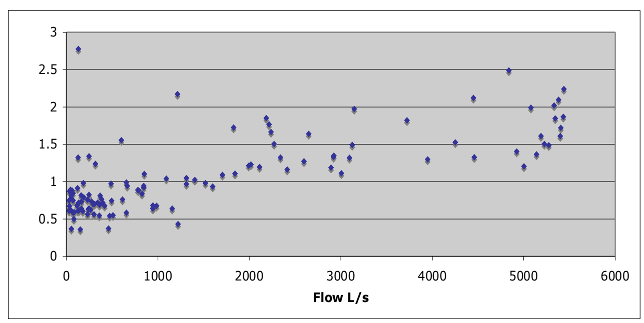
Moffat Creek O+PN



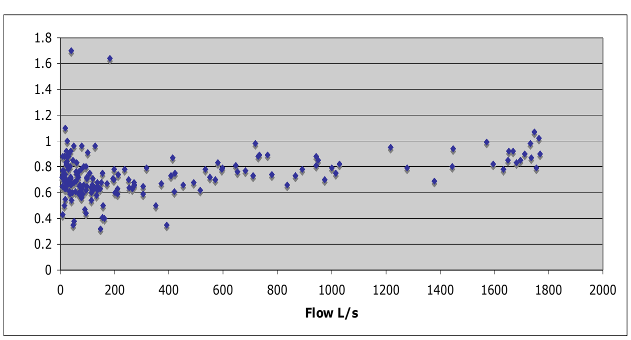
Carran Creek TN



Carran Creek O+PN



Carran Creek Tributary TN



Carran Creek Tributary O+PN

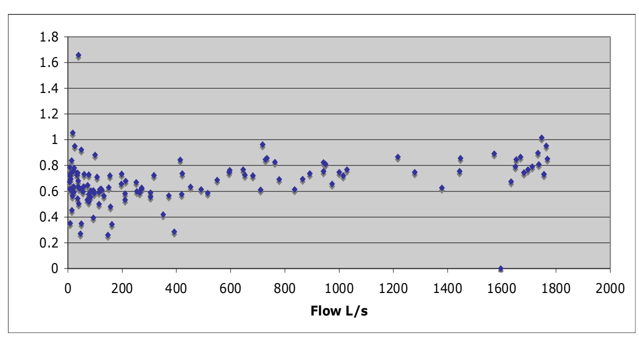
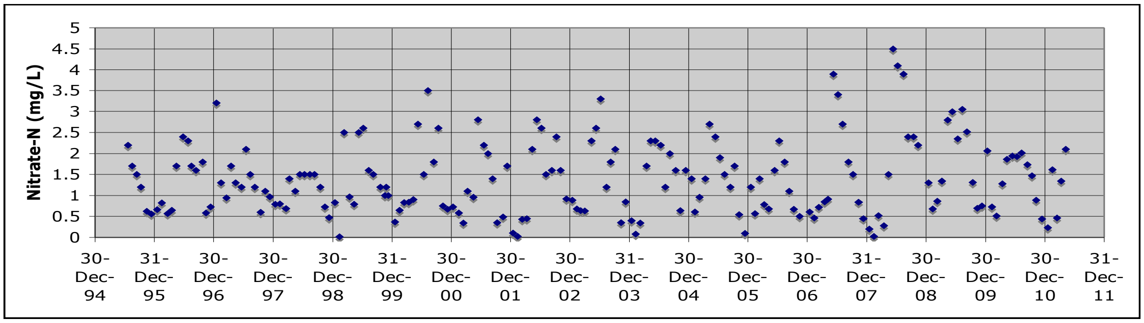
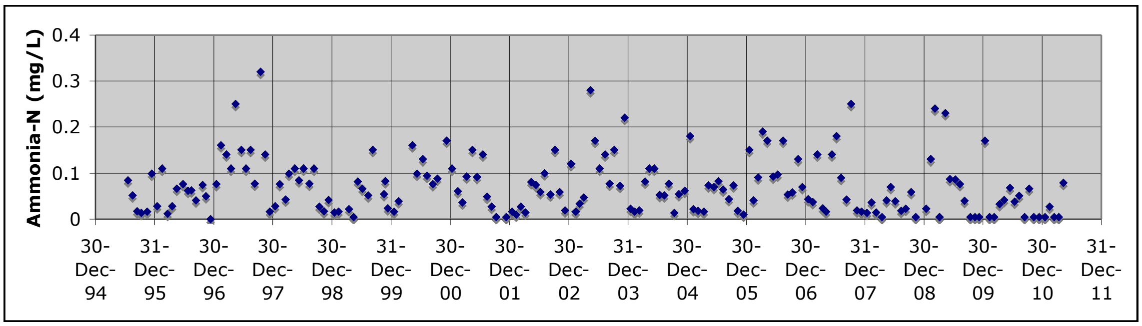


Figure 4.3 Waituna @ Marshalls Nitrogen Forms over Time

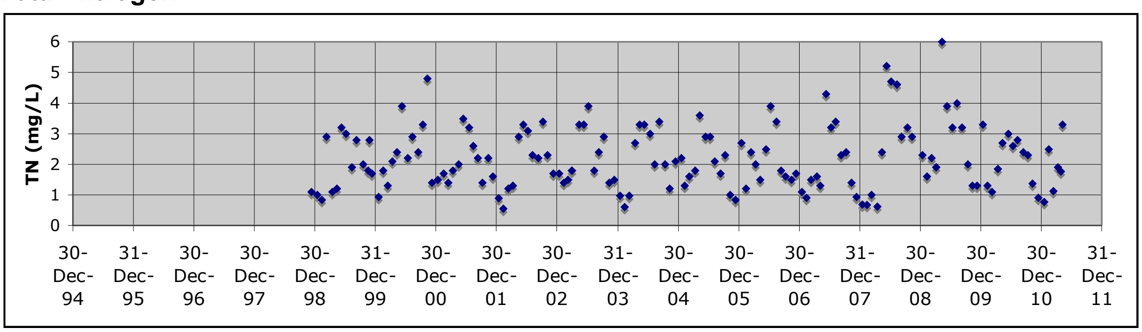
Nitrate+Nitrite-N



Ammonium-N



Total Nitrogen



Organic+Particulate-N

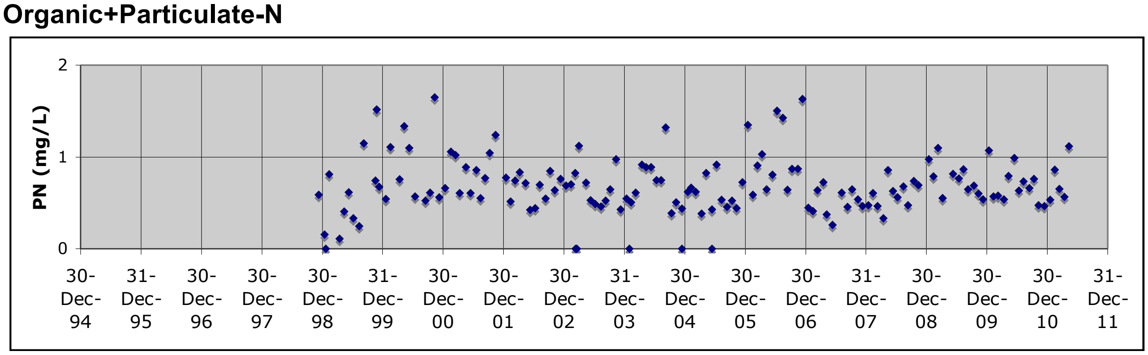
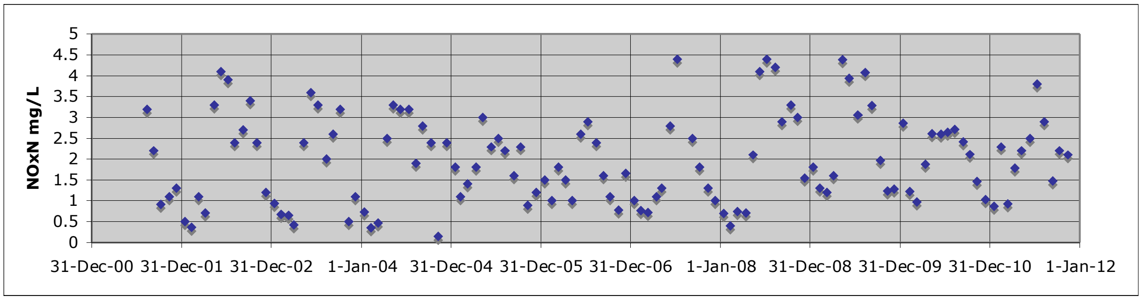
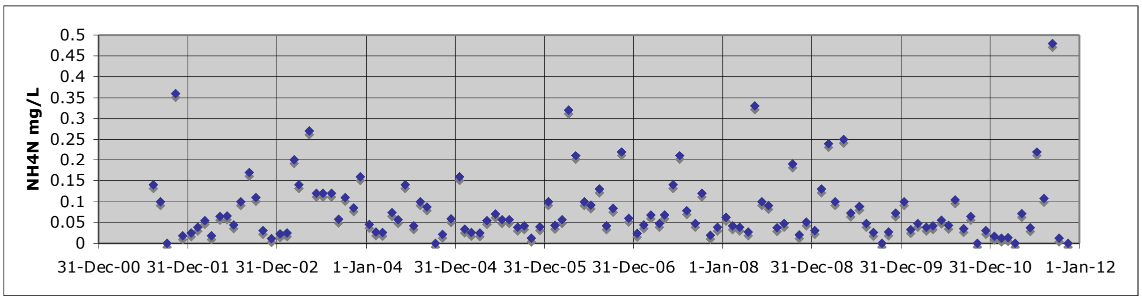


Figure 4.4 Waituna at Mokotua Nitrogen Forms over Time

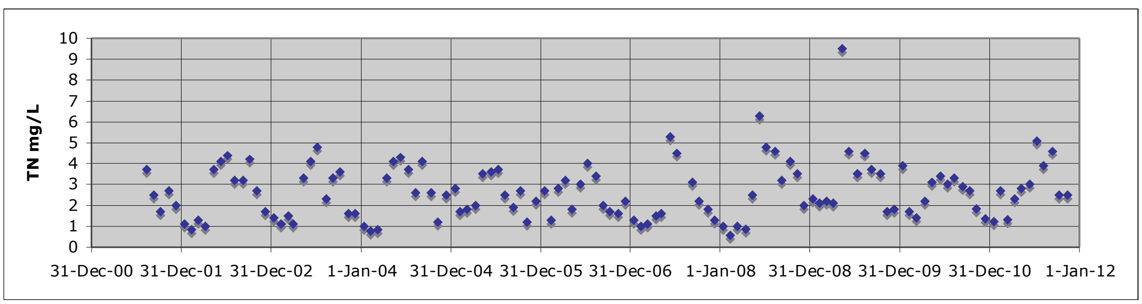
Nitrate+Nitrite-N



Ammonium-N



Total Nitrogen



Organic+Particulate-N

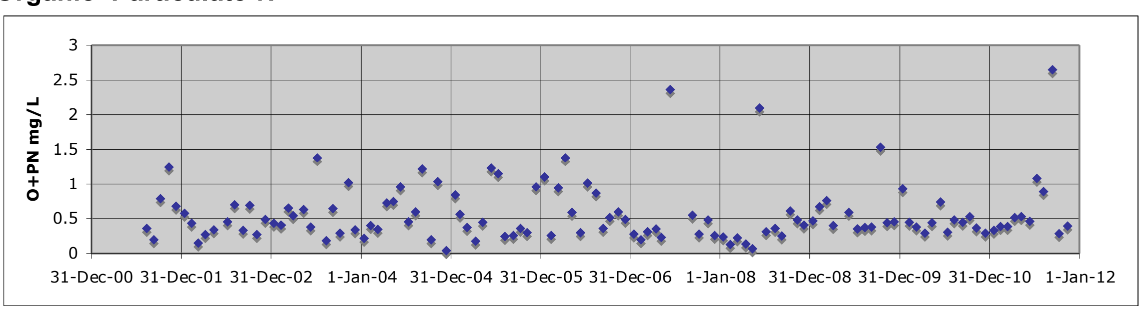
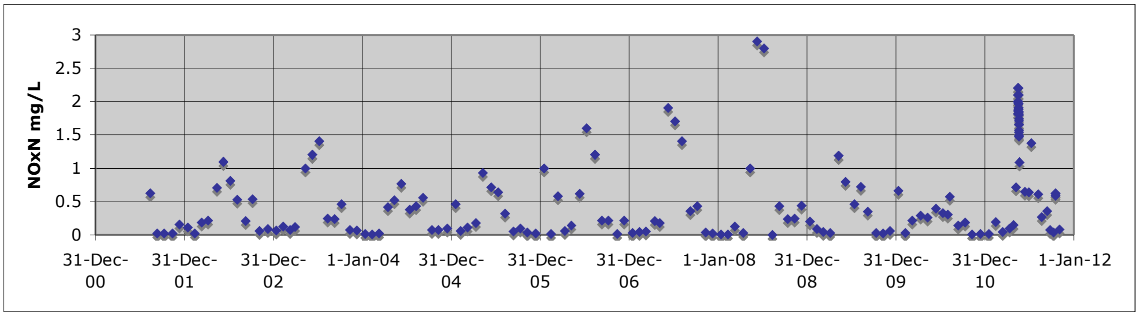
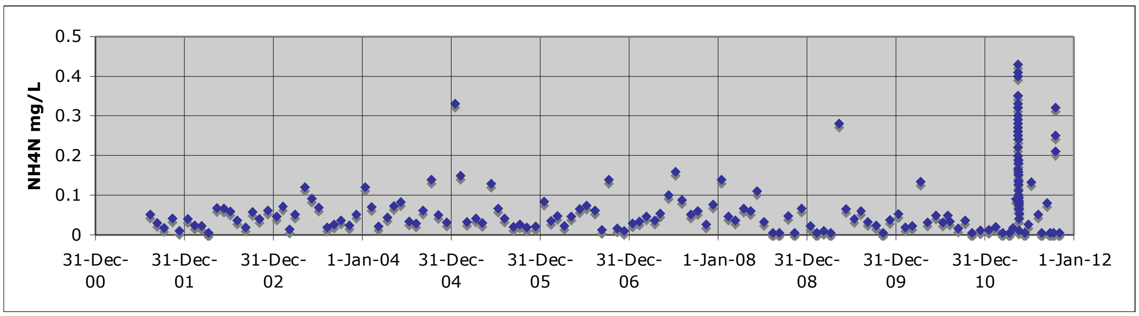


Figure 4.5 Moffat Creek Nitrogen Forms over Time

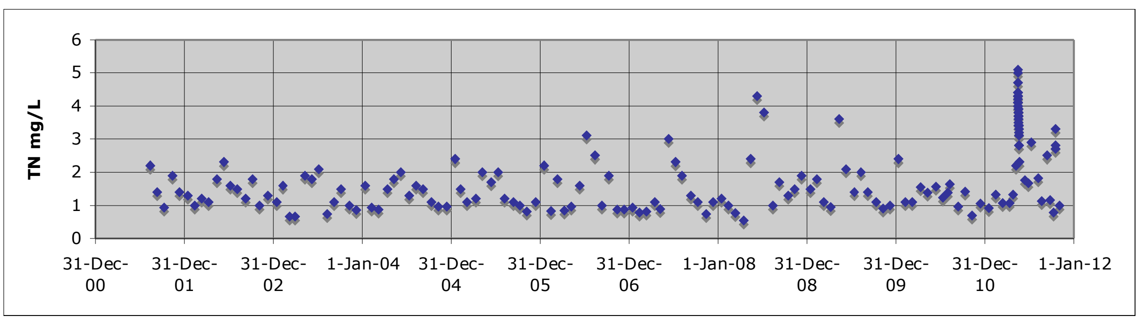
Nitrate+Nitrite-N



Ammonium-N



Total Nitrogen



Organic+Particulate-N

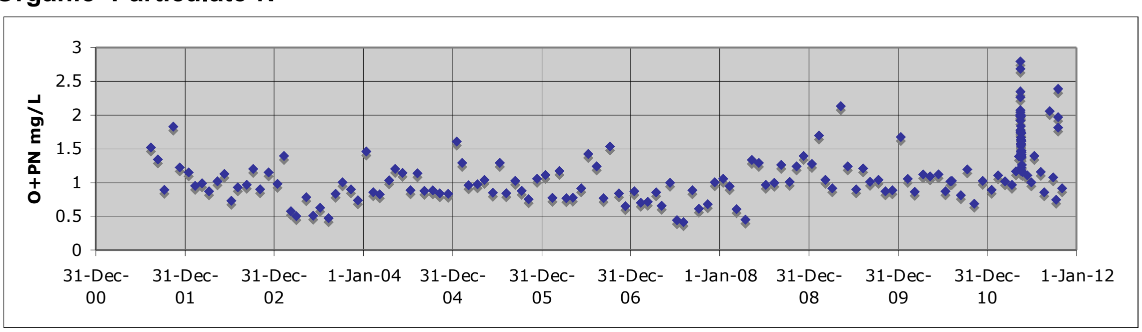
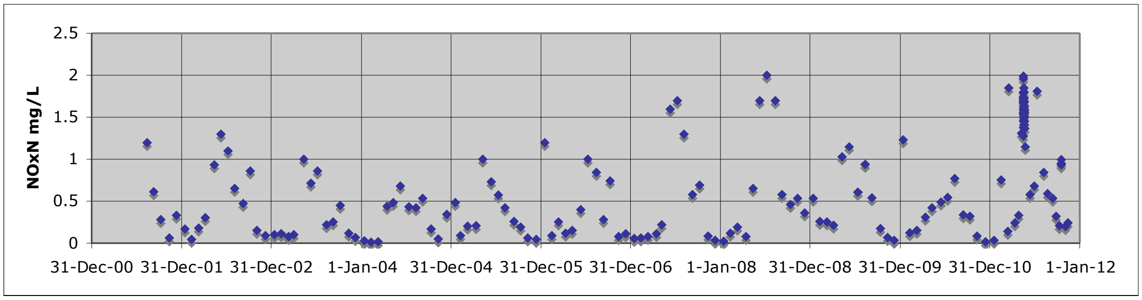
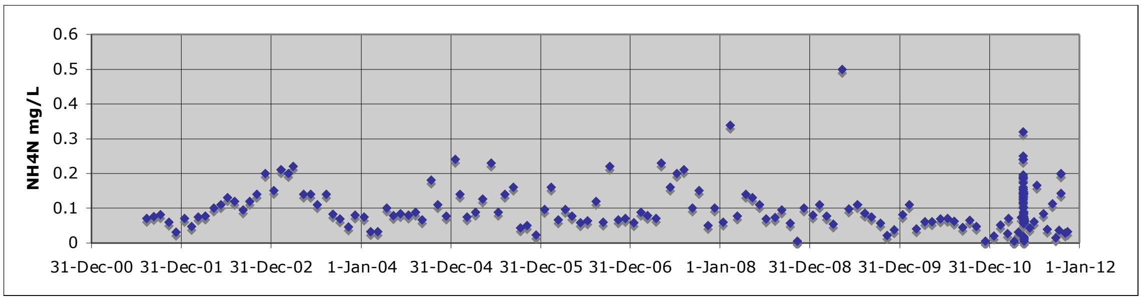


Figure 4.6 Carran Creek Nitrogen Forms over Time

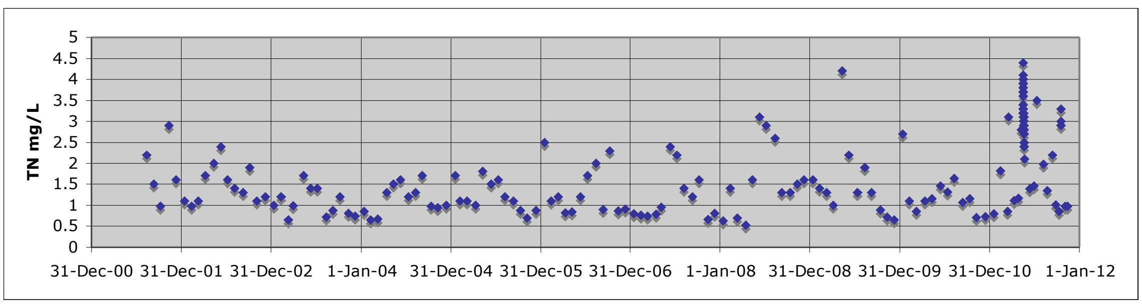
Nitrate+Nitrite-N



Ammonium-N



Total Nitrogen



Organic+Particulate-N

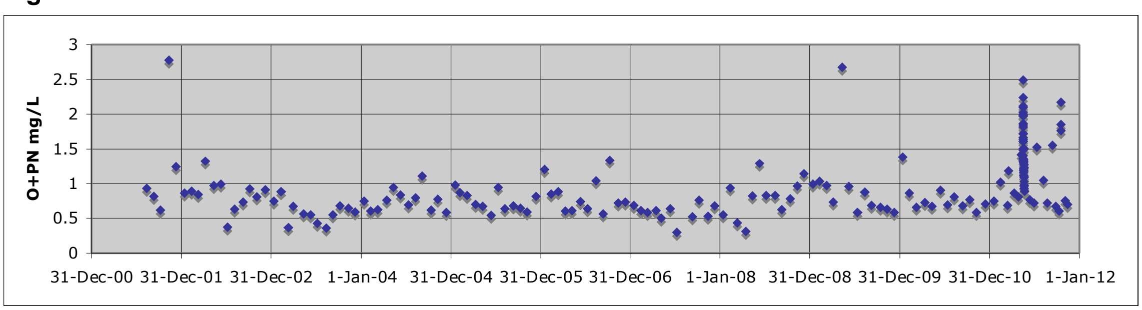
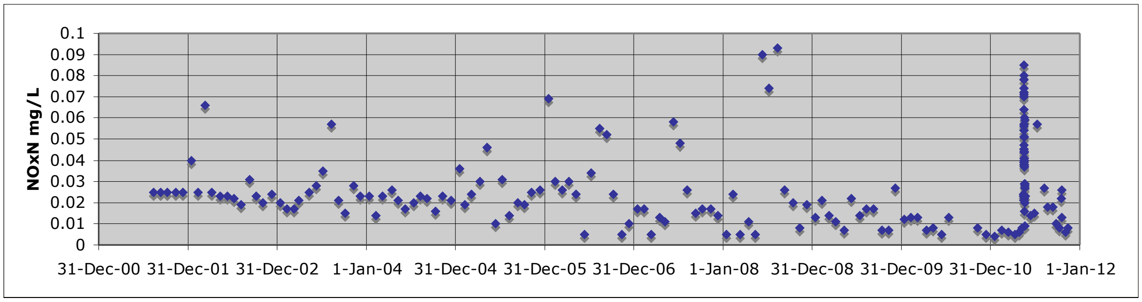
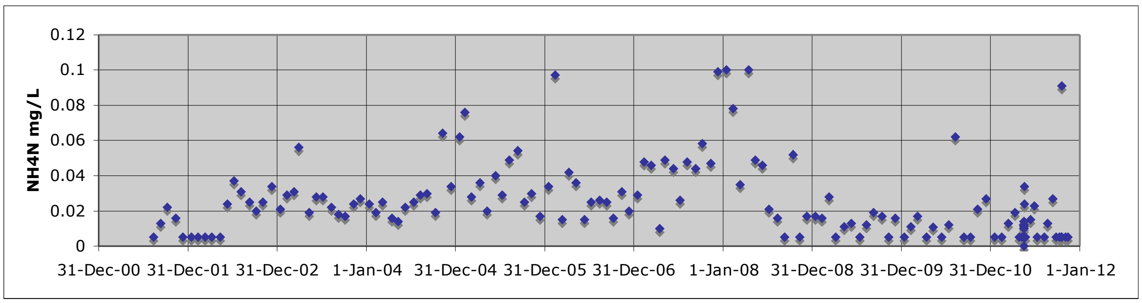


Figure 4.7 Carran Creek Tributary Nitrogen Forms over Time

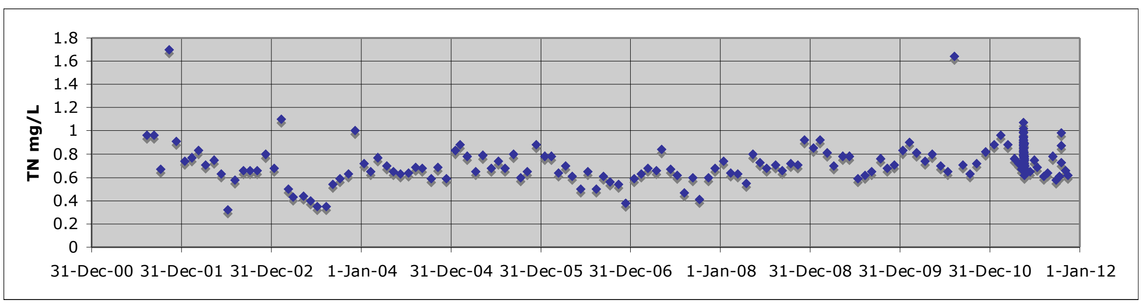
Nitrate+Nitrite-N



Ammonium-N



Total Nitrogen



Organic+Particulate-N

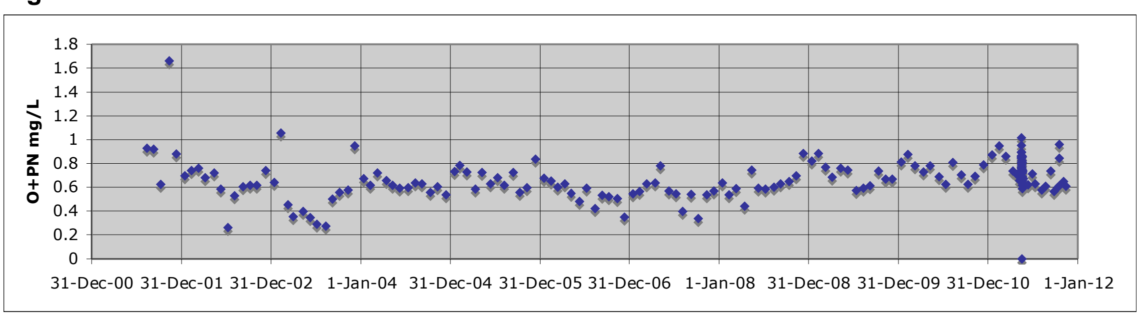
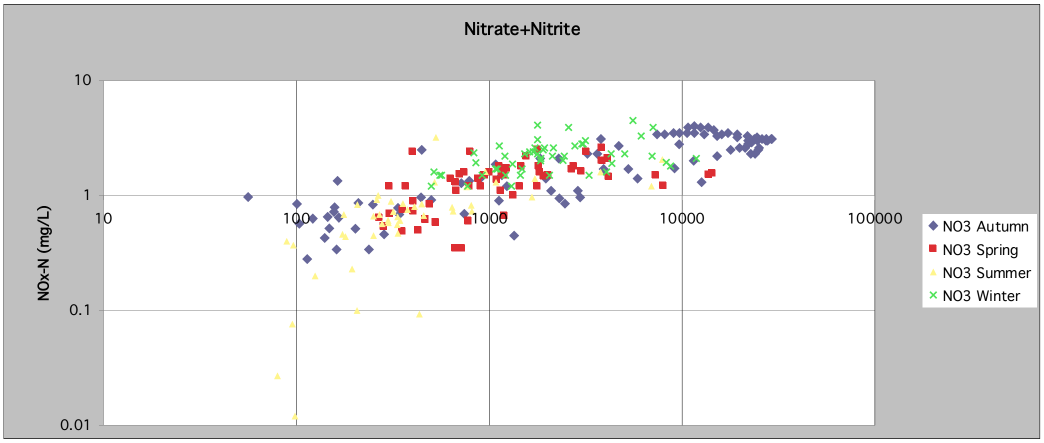
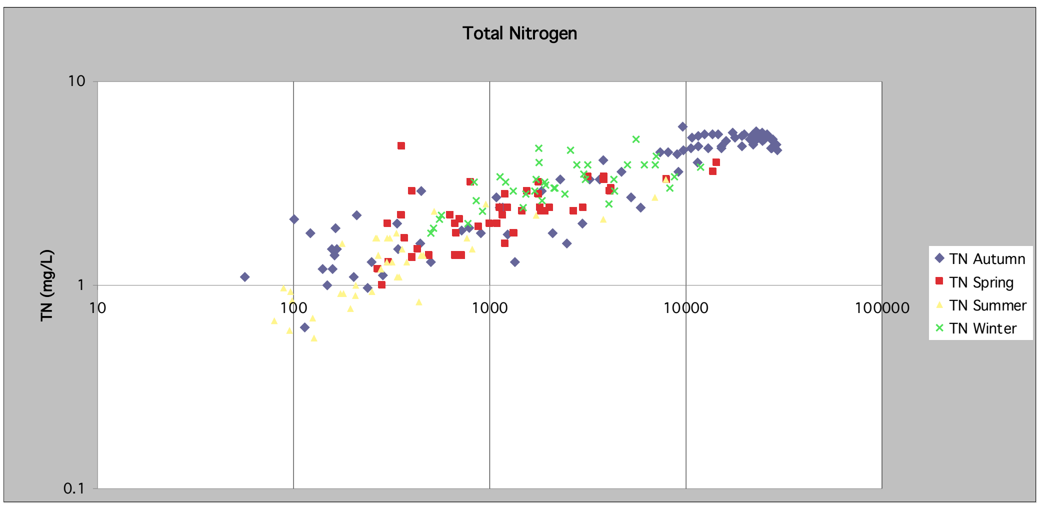
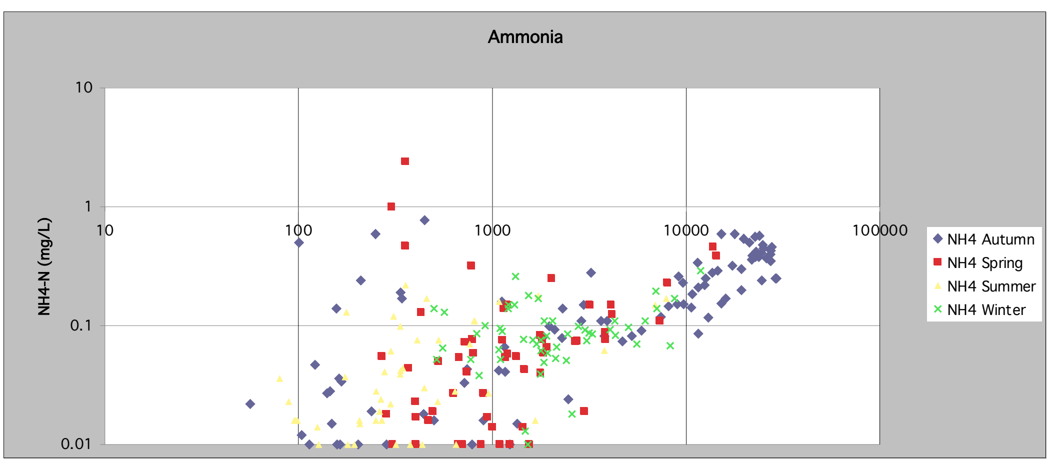


Figure 4.8 Concentration versus flow for the separate seasons.







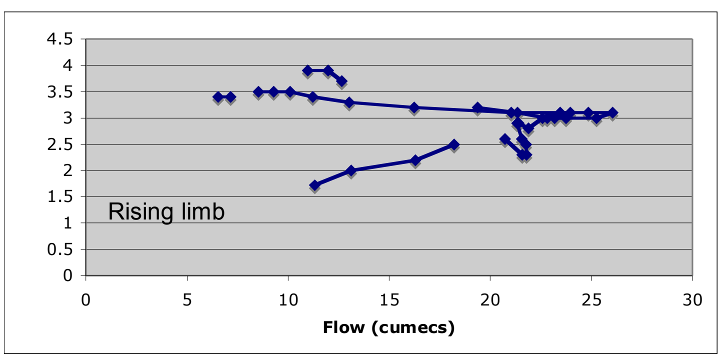
Implications for load estimation

Seasonal effects are probably largely driven by flow differences, although there is an additional seasonal effect for winter nitrate concentrations, perhaps reflecting a sustained flushing of nitrate from soils by the higher winter rainfall and flows.

The flow relationship is very important for nitrate concentrations and for particulate nitrogen (however, we were only able to look at particulate + dissolved organic nitrogen). However, there may be some other factors. At least one of these is flow hysteresis; in the large storm of May 2011, nitrate concentrations were higher on the falling limb – consistent with a groundwater flushing effect (Figure 4.9, also see left hand side of plots in Figure 4.8 for the same storm data). Lowest nitrates were observed during the rising stage of the storm (direct inputs of rainfall + flushing of old (denitrified) groundwater) but relatively high nitrates were observed throughout the rest of the storm.

The hysteresis effect is opposite for particulate and dissolved nitrogen. It is probably least important for TN (e.g., as evident in the tighter grouping of data on the right hand side of Figure 4.8 for TN), as the two hysteresis effects cancel out (dissolved nitrate increases , P+ON decreases), which may be fortuitous for concentration predictions.

Figure 4.9 Nitrate concentrations during a large storm (May 2011) at the Waituna @ Marshalls site.



5 Behaviour of Phosphorus Forms

DRP and TP were measured and summary statistics and trends are given in Table 5.1.

Table 5.1 Summary Statistics of Phosphorus Forms. Data, except trends, includes the large storm of May 2011.

A: TP

Site	Waituna at Marshalls	Waituna at Mokohau	Moffat	Carran Ck	Carran Ck tributary
Mean	0.110	0.058	0.240	0.176	0.102
Median	0.067	0.034	0.160	0.130	0.085
Minimum	0.023	0.012	0.054	0.057	0.005
Maximum	0.530	0.88	1.090	1.300	2.400
Number	200	115	168	167	167
Trend	No trend	No trend	Improving (6.1%)	No trend	Jump (16.5%)

B: DRP

Site	Waituna at Marshalls	Waituna at Mokohau	Moffat	Carran Ck	Carran Ck tributary
Mean	0.028	0.012	0.123	0.056	0.063
Median	0.023	0.009	0.067	0.045	0.050
Minimum	0.003	<0.004	0.010	0.008	0.003
Maximum	0.088	0.093	0.53	0.185	0.187
Number	241	105	168	166	167
Trend	Improving (4.5%)	Improving (9.3%)	No trend	No trend	No trend

Concentrations

During low flows, TP concentrations were very low in Carran Creek Tributary, concentrations have increased in recent years in a stepwise fashion (Figure 5.1, 5.6). TP concentrations at low flows were also relatively low in the Waituna Creek (Figure 5.1, 5.2), especially at Mokotua (Figure 5.1, 5.3).

Total phosphorus concentrations are higher in the developed catchments compared with the partially-developed Carran tributary. DRP shows no change or declining concentrations in all catchments except the partially-developed Carran Creek subcatchment where very low DRP concentrations have increased in recent years.

DRP concentrations are highest in the Moffat Creek – substantially higher than the other sites. It is somewhat higher than in the other peat catchment (Carran), and lowest in the upper and lower Waituna. This may reflect poor adsorption qualities of peat compared with mineral soils in the upper catchment; or may be simply a result of differing tile drainage practices/intensities. While phosphorus 'release' from reducing sediments is a known phenomenon, we do not think it likely that difference in redox potential between the different catchments is the cause of the difference in DRP concentrations. We note that the behaviour of phosphorus in peat soils is poorly understood and is currently being investigated by AgResearch.

The picture that emerges is that intensification of land use over the last decade has had little effect on P concentrations already elevated by land development. There are, however, some unexplained results, such as the increase in DRP in the Carran Creek tributary, which has higher concentrations than the developed Waituna catchment (e.g., Waituna @ Marshalls).

Flow

Both TP and DRP show some increase in concentration with flow, but with wide variability (Figure 5.1). The biggest effect is for Moffat Creek.

Speciation

DRP is a large proportion of TP for the Carran Creek Tributary (Figure 5.6) and for Moffat Creek (Figure 5.4), but is less so for Carran Creek (Figure 5.5), and a minor portion for the Waituna (Figure 5.2, 5.3).

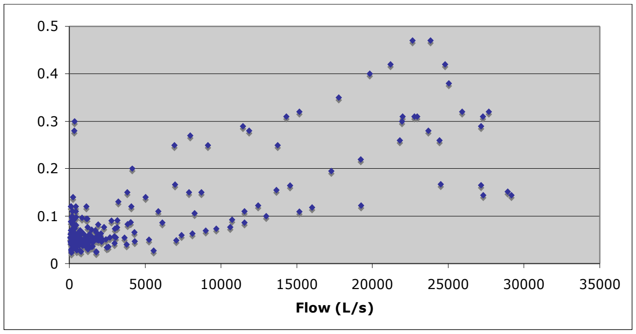
The higher TP at low flows in Carran Creek and Moffat Creek are probably due to higher DRP – which suggests some differences in these catchments leading to more DRP in base flow. This may be due to soil mineralisation processes, mole drains, or both.

Seasonal effects

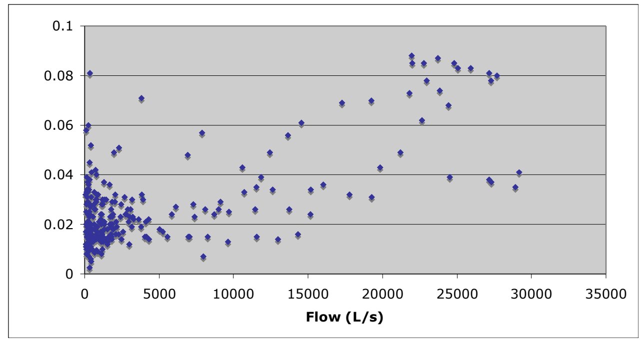
There is no visual time trend (Figures 5.2 – 5.6) in the long-term data, although Waituna at Marshalls shows reductions in P concentrations when allowance is made for flow (Table 5.1). There are no discernible seasonal effects

Figure 5.1 Total Phosphorus and Dissolved Reactive Phosphorus versus Flow

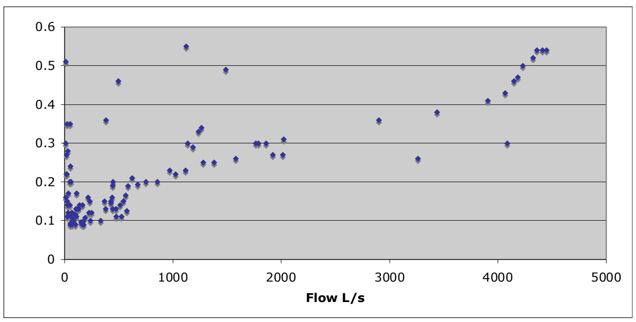
Waituna @ Marshalls TP



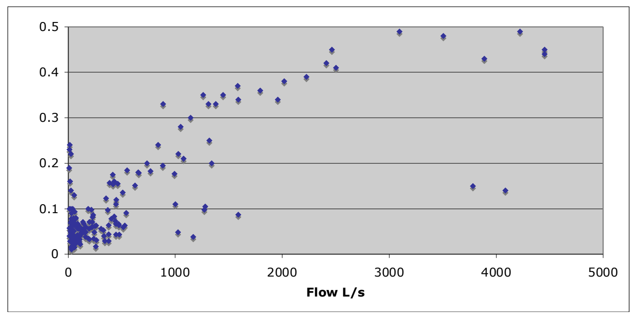
Waituna @ Marshalls DRP



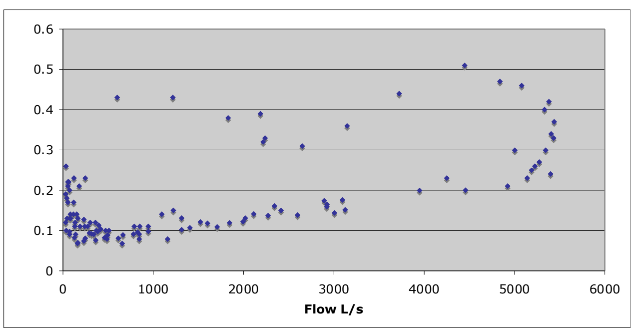
Moffat Creek TP



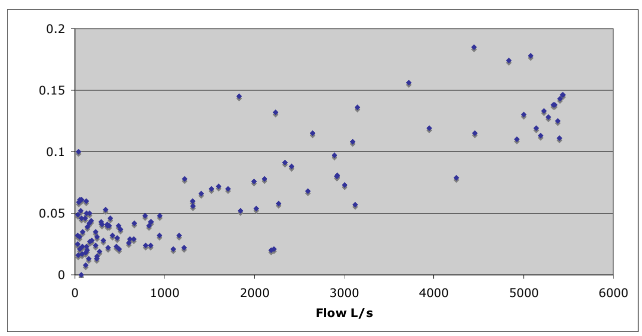
Moffat Creek DRP



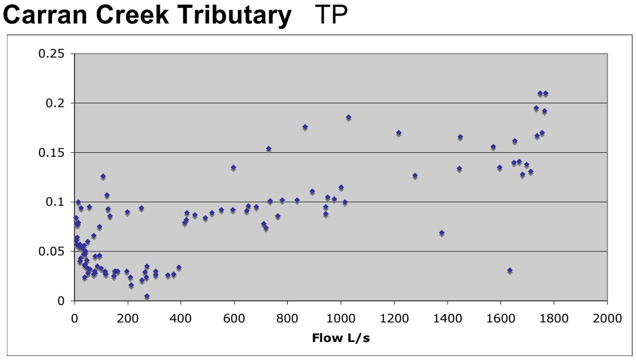
Carran Creek TP



Carran Creek DRP



Carran Creek Tributary TP



Carran Creek Tributary DRP

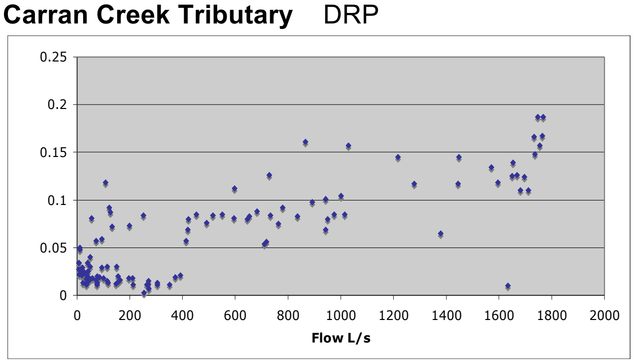
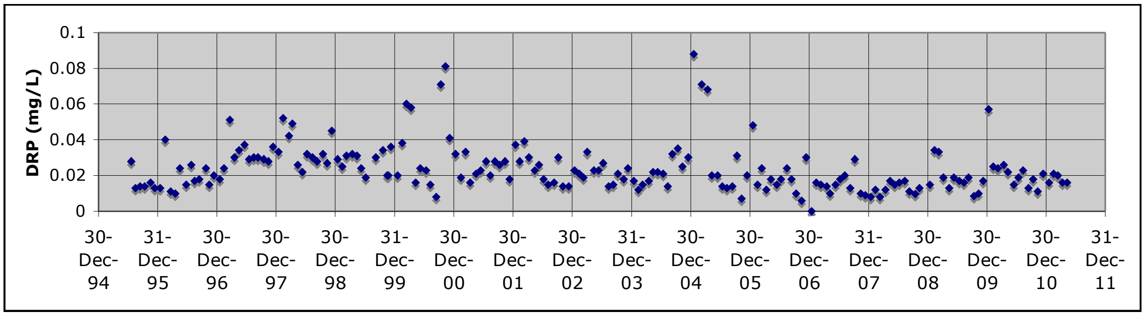


Figure 5.2 Waituna @ Marshalls

Dissolved Reactive Phosphorus



Total Phosphorus

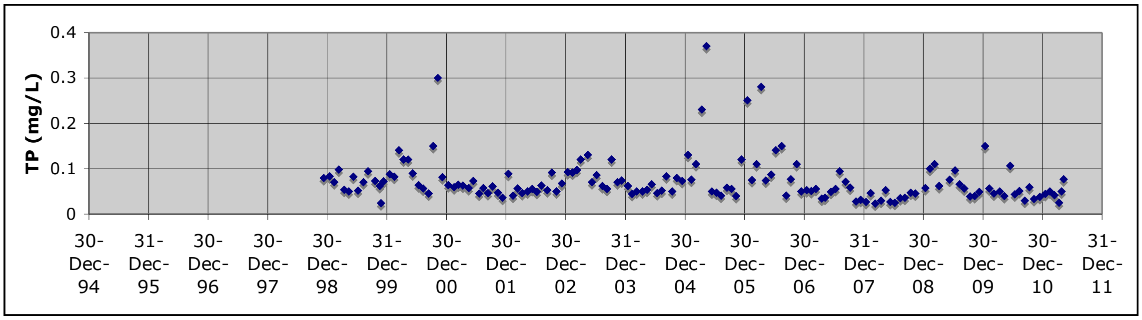
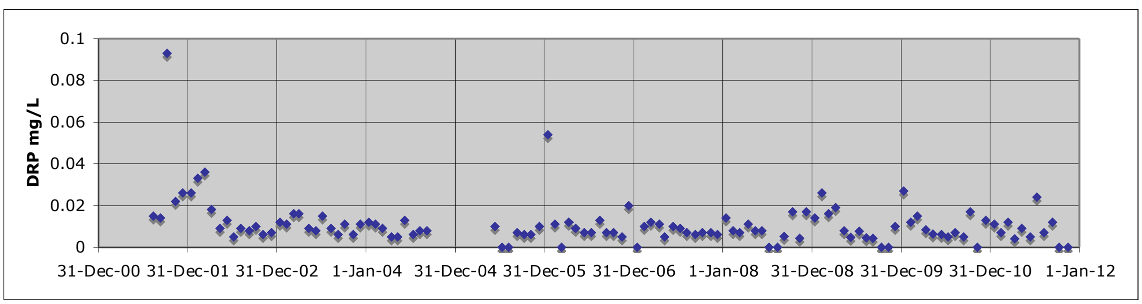


Figure 5.3 Waituna @ Mokotua

Dissolved Reactive Phosphorus



Total Phosphorus

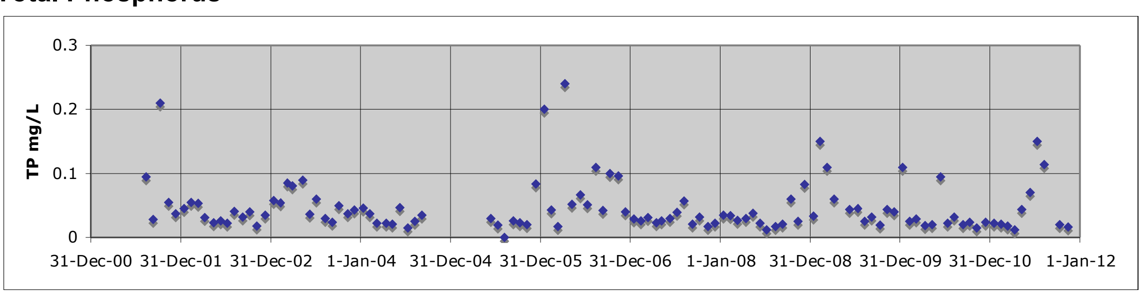
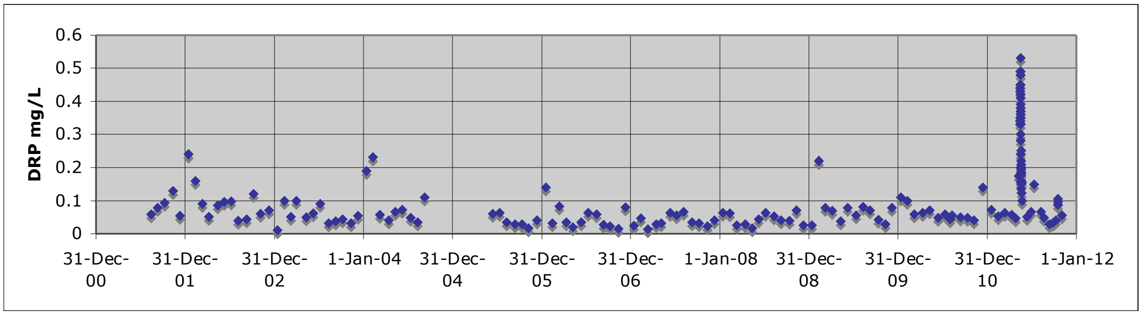


Figure 5.4 Moffat Creek

Dissolved Reactive Phosphorus



Total Phosphorus

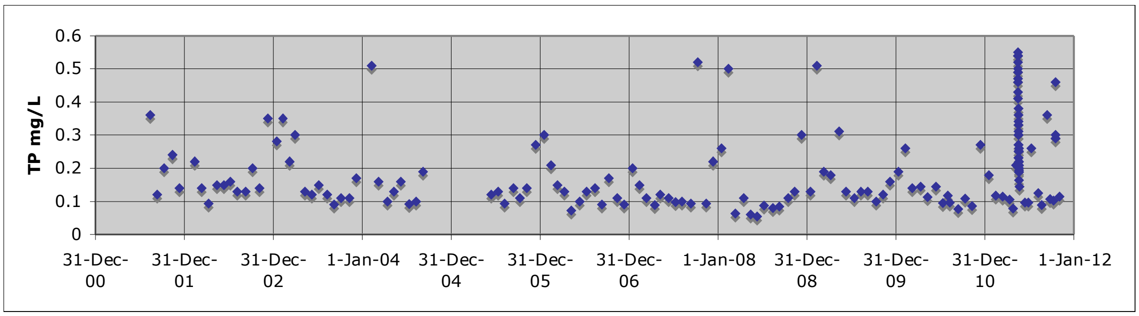
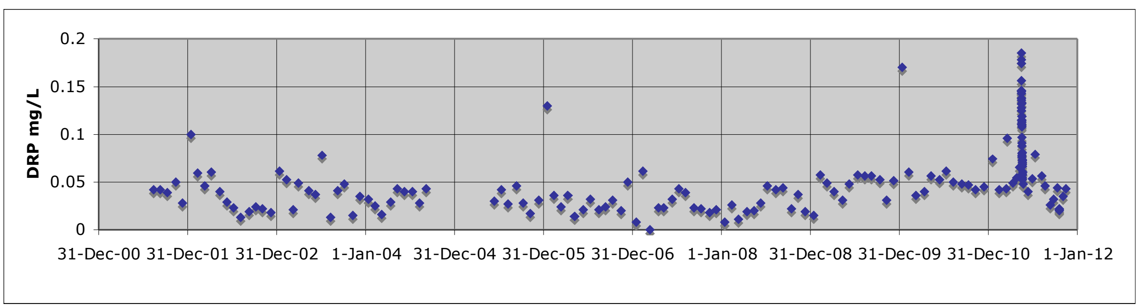
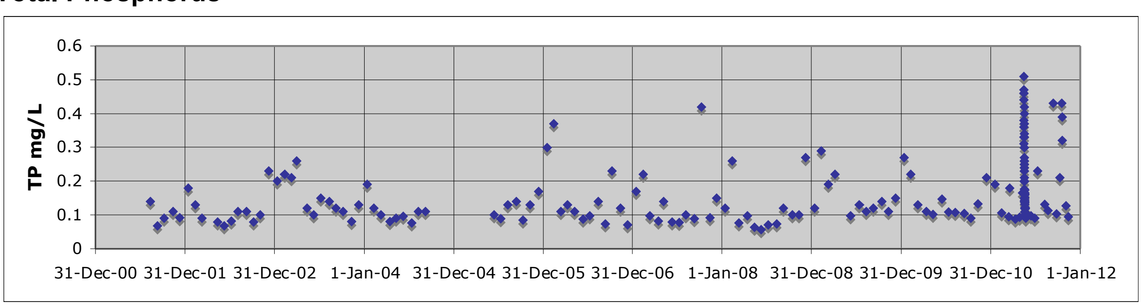


Figure 5.5 Carran Creek

Dissolved Reactive Phosphorus



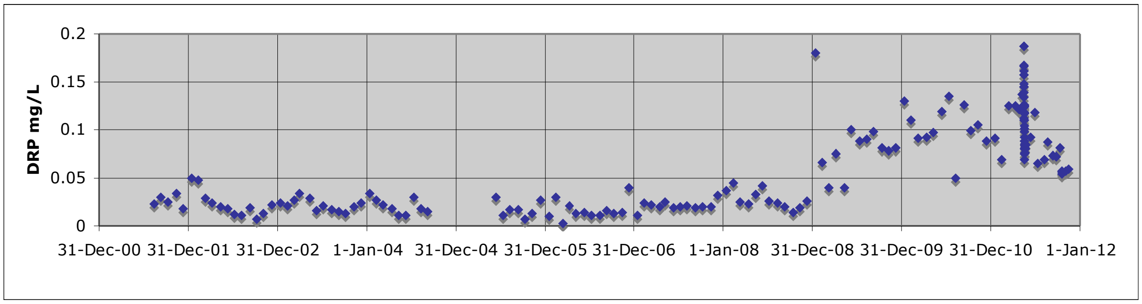
Total Phosphorus



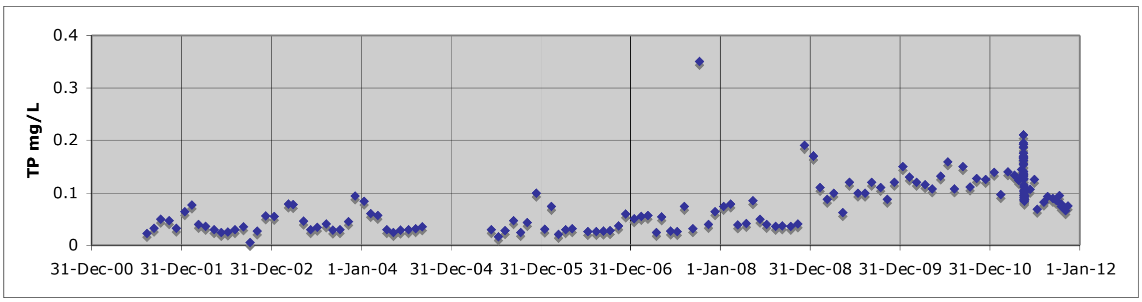
Dropped 0.7, 1.1 mg/L

Figure 5.6 Carran Creek Tributary

Dissolved Reactive Phosphorus

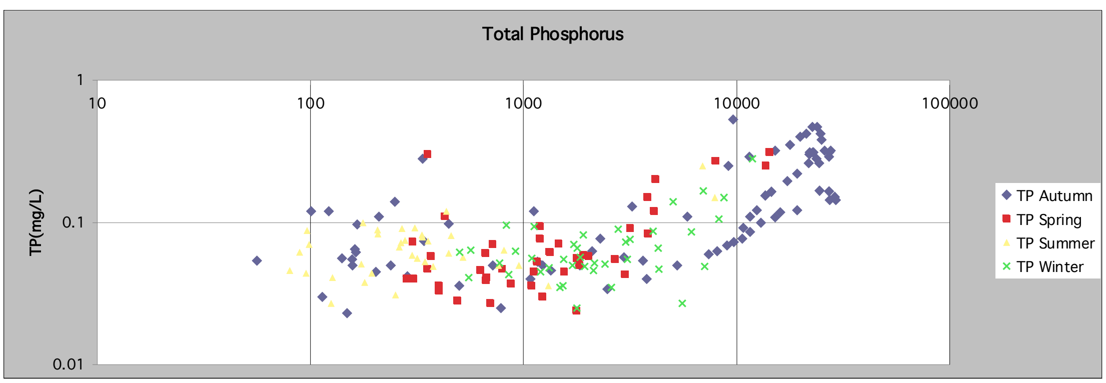


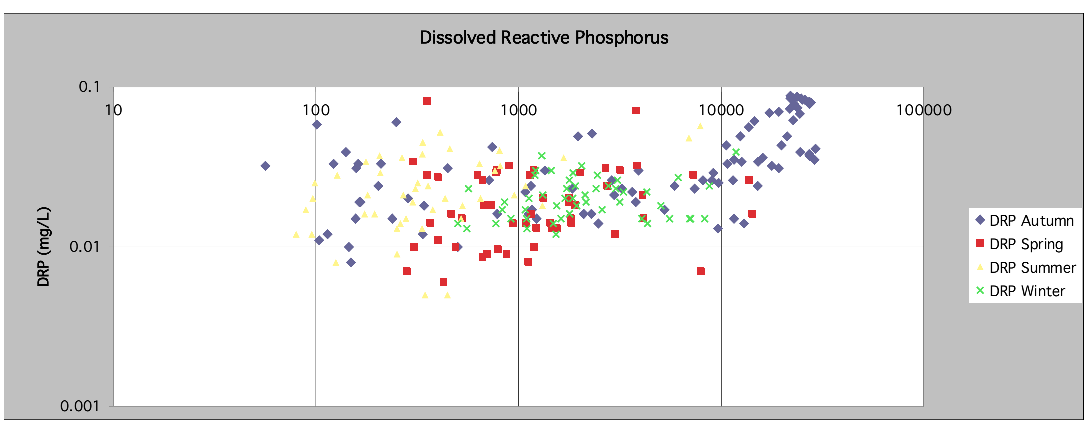
Total Phosphorus



Note: One high outlier of 0.55 mg/L not shown

Figure 5.8 Concentration versus flow for the separate seasons.





6 Methods for calculating mass loads

6.1 Review of methods

There is a wide range of methods available for calculating the mass loads of river contaminants. These can generally be categorised into two broad approaches: interpolation techniques and extrapolation techniques (Littlewoood 1992; Degens & Donohue 2002). Interpolation techniques involve estimating loads using instantaneous discharge and contaminant concentration data taken at fixed points, whereas extrapolation techniques combine data collected over representative flow periods to generate relationships from which continuous contaminant concentration data is derived for available discharge data (Degens & Donohue 2002). The derived contaminant concentration data are combined with collected concentrations to estimate overall load (Degens & Donohue 2002).

1) Interpolation techniques

Interpolation techniques calculate loads by assuming that the fluxes estimated from field samples are representative of the fluxes in the un-sampled time period between samples. The simplest of these use averages of discharge and concentration data or load data to provide estimates of continuous load (Degens & Donohue 2002). The three main types of interpolation methods are:

a) Linear interpolation

Linear interpolation is based on determining time-weighted contaminant concentration data for flow measurements between times that field measurements of contaminant concentrations were taken (Kronvang & Bruhn 1996). Linear interpolation is appropriate in situations where field sampling produces contaminant concentration data that represents the true temporal patterns of contaminant concentrations for the sampling interval (Degens & Donohue 2002). Kronvang & Bruhn (1996) tested 13 different load estimation methods and found the following linear interpolation method produced the "best and most reproducible" method for estimating annual transport of various species of N and P:

$$Load = \sum_{i=1}^{n+1} \sum_{t_i < t \leq t_{i+1}}^{i} q_t \frac{C_{t_i}(t_{i+1} - t) + C_{t_{i+1}}(t - t_i)}{t_{i+1} - t_i}$$

Where C_{t_i}= concentration measured at time t_i, $C_{t_{i+1}}$= concentration measured at the next time, t_i and t_{i+1}= are the times at the beginning and end of each interval when concentrations were measured (from times *0* to *n*) and t is the time at any time between i and $i+1$ when concentrations were sampled and discharge data was recorded. q_i is the discharge recorded at each time step.

The linear interpolation method is simple and easily applied. However, depending on the nature and quality of the measured contaminant concentration data, it may not be appropriate to use in all situations. This is because, although river discharge data is often sampled frequently (or continuously), contaminant concentration data is collected at much less frequent intervals (i.e. weekly or monthly). Loads estimated using data with a wide sampling interval or with data that does not adequately capture the variability in contaminant concentrations experienced under a range of flow conditions (including flood events), are likely to be unreliable (Letcher et al. 1999)

b) Averaging estimators

Averaging estimators, which are based on the same principle as linear interpolation, are amongst the simplest load estimation methods available (Degens & Donohue 2002). Contaminant loads are estimated as the sum of loads for each sampled interval weighted by the number of samples taken across the period of measurement. A large number of averaging estimators are reported in the literature (e.g., Walling & Webb 1981; Preston et al. 1989). Letcher et al. (1999) suggested that averaging estimators are often used because of the lack of more appropriate techniques. The main difference between these various methods is that they average loads over differing time periods (e.g., daily, monthly, quarterly, yearly). Selection of a suitable estimator depends upon the frequency of the collected data and the required resolution of the contaminant loads. They are, however, similar in form to the following:

$$Load = K\left[\sum_{i=1}^{n}\frac{C_i Q_i}{n}\right]$$

Where K = a conversion factor to account for differences in units and periods of time, Q_i=flow for interval i, C_i= concentration for interval i.

c) Ratio estimators

Ratio estimators are a further development of averaging estimators. Ratio estimators account for the inter-relationships (i.e. co-variance) between load and stream discharge (Letcher et al. 1999; Quilbé et al. 2006). The most basic form of the ratio estimate is:

$$Load = \left(\frac{\bar{y}}{\bar{x}}\right)X$$

Where $\bar{x}$and $\bar{y}$ are the sample means of the discharge data (x_i) and contaminant load data (y_i), respectively, and X is the discharge. If the ratio of y_i to x_i is similar for all samples, then the ratio estimate will be highly precise (Degens & Donohue 2002). Ratio estimators are considered to be well suited for cases when there is a good flow record (i.e. continuous) but only a few concentration data are available (Quilbé et al. 2006).

A number of ratio estimators have been developed for contaminant load estimation (Preston et al. 1989), however, the Beale Ratio estimator has been shown to perform well (Johnes 2007) and is one of the most widely used ratio estimators (Degens & Donohue 2002). The Beale Ratio estimator estimates annual loads using estimates of instantaneous loads at sampling times, with annual flow data and a ratio factor being used to account for co-variance between instantaneous load and flow (Degens & Donohue 2002).

2) Extrapolation techniques

The main and most widely used extrapolation technique is that of the rating curve method. The rating curve method is based on extrapolating contaminant concentration measurements over the entire period of interest by developing a relationship between contaminant concentration and stream discharge (at the time of sampling) (Letcher et al. 1999). This relationship is then applied to the entire discharge record. Rating curves describe the average relation between discharge and contaminant concentration for a specific location (Asselman 2000). The relationship between contaminant concentration and discharge is typically log-log in nature, i.e. the relationship between the log of the contaminant concentration and the log of discharge is linear. Therefore the most commonly used rating curve is a power function:

$C = aQ^b$

Where C is the contaminant concentration (usually in mg/l), Q is the discharge (usually in m^3/sec), a and b are regression coefficients. The relationship between TN and discharge at Environment Southland's Marshall Road site (interpolated from Waihopai discharge data) is an example of a reasonable linear relationship in log-log space (Figure 6.1).

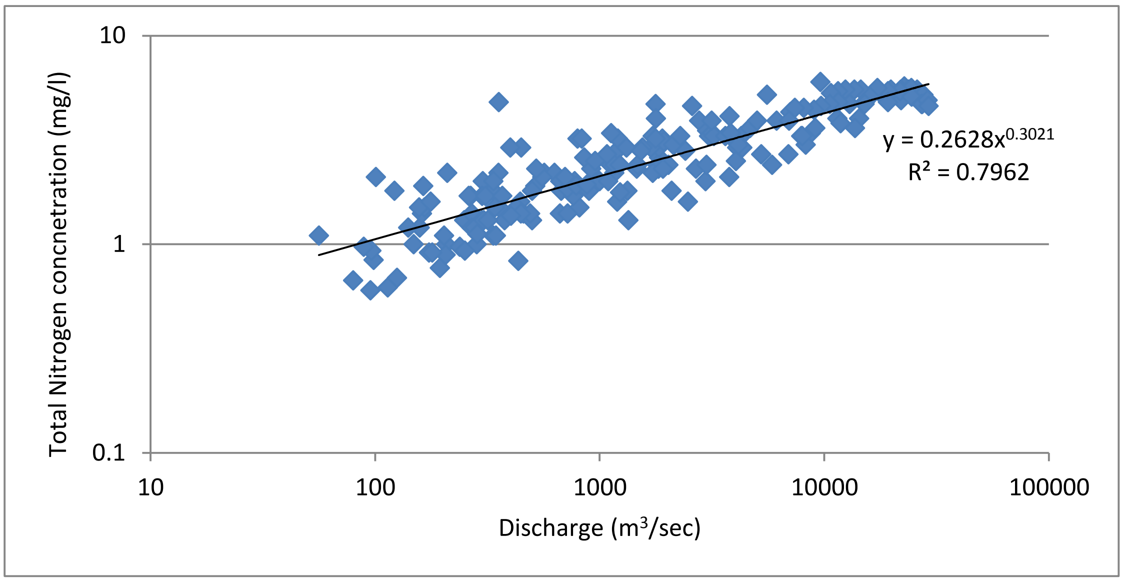


Figure 6.1 Total nitrogen/ discharge relationship for the Marshall Road site.

Care must be taken to not use rating curves in inappropriate situations, such as when the relationship between discharge and contaminant concentration is poor or when a small number of observations are used to develop a relationship and range of flow conditions are not well represented (Letcher et al. 1999).

The use of a rating curve approach also allows data to be stratified to develop a number of relationships based on when the contaminant concentration data was collected, such as by season and/or hydrograph position (i.e. rising or falling stage) (Letcher et al. 1999). Data stratification should be exercised carefully with small datasets or with datasets that are biased towards a particular flow period (e.g., low flow monitoring or winter storm monitoring).

Other extrapolation methods include non-linear regression (e.g. Smith et al. 1997) and non-parametric techniques such as locally weighted scatterplot smoothing (LOWESS). The basic premise of non-linear regression is the same as linear regression except that non-linear regression is characterised by the fact that the prediction equation depends non-linearly on one or more unknown parameters (Smyth 2002). LOWESS is a modern regression method that is designed to be used in situations when ordinary least squares regression does not perform well. LOWESS fits simple models to localised subsets of the data to build up a function that describes the deterministic part of the variation in the data, point by point (NIST 2003).

6.2 Which method is best?

There are many examples of researchers trying to determine whether there is an optimal load estimation method (e.g. Preston et al. 1989; Letcher et al. 1999; Phillips et al. 1999; Zamyadi et al. 2007; Marsh & Waters 2009). However, it is clear from these studies that there is no clear "best" load estimation method. Letcher et al. (1999) suggested that the selection of a load estimation technique will depend on a number of factors including: data resolution, operator ability, and the relationships within the data and between various contaminant concentrations. Although it often not the case, field data collection programmes should be designed taking into account the characteristics of particular rivers and the load estimation method to be used (Letcher et al. 1999).

For this study, it recommended that several load estimation techniques are applied to the data. It is not possible know what the 'true' contaminant loads actually are. However, applying several methods and assessing the variability between the estimations gives some indication of adequacy of the collected data to date. Depending on the variability of load estimates from the different methods, having results from several methods would also provide confidence in the contaminant loads estimates. That is, if there is only a small amount of variability between the load estimates we can have confidence that the estimates are reasonable. Alternatively, if there is a wide range in the estimated loads we can have less confidence in the results or we must be more judicious about choosing the appropriate method.

The methods used to calculate contaminant loads for the four Waituna tributary sites are:

Method 1

Method 1 is a simple averaging estimator as described by Preston et al. (1989):

$$Load = KQ_{MA}\left[\sum_{j}^{n}\frac{C_j}{n}\right]$$

where K is a conversion factor to account for differences in units and periods of time, Q_{MA} is the mean annual flow (Ml y^{-1}), C_j is the concentration (mg l^{-1}) for suspended sediment sample j, and n is the number of samples.

Method 2

Method 2 is the Beale ratio estimator:

$$Load = Q_a\left(\frac{\bar{l}}{\bar{q}}\right)\left(\frac{1+\frac{1}{N}\frac{cov(l,q)}{\bar{l}\bar{q}}}{1+\frac{1}{N}\frac{var(q)}{\bar{q}^2}}\right)$$

Where Q_a = annual flow, $\bar{l}$ = average load for times when samples were collected, $\bar{q}$ = average flow for times when samples were collected, N = number of samples collected over the year, $cov(l,q)$ = covariance between sampled loads and flow at time of sampling, and $var(q)$ = variance of the flows at the time of sampling.

Methods 3-5

Methods 3, 4 and 5 are regression (or rating curve) methods. Method 3 is an ordinary least squares regression approach that fits a power relationship through the data. Method 4 is the LOWESS approach outlined above. Methods 3 and 4 were determined utilising the SedRate load estimation software that was developed by Murray Hicks of NIWA (Christchurch). Measures of uncertainty (standard error) were also determined using these two rating curve approaches. Method 5 is identical to Method 3 (ordinary least squares regression). The key difference between the two methods is that Method 3 was calculated using the SedRate software while Method 5 was semi-manually applied in an Excel spreadsheet. Method 5 was also calculated on a yearly basis, so that the inter-annual variability of contaminant loads can be assessed. Retransformation bias for all three methods was corrected using the non-parametric smearing estimate of Duan (1983).

6.3 Model performance

Quilbé et al. (2006) reviewed previous uses of averaging estimators, ratio estimators and rating curve approaches. Their review concluded that:

1) averaging estimators are accurate only when contaminant concentration data are available for the entire flow range;
2) ratio estimators are less sensitive to river and contaminant characteristics than rating curve methods but requires more data to achieve the same level of precision
3) rating curve methods give the best results if there is a good correlation between flow and contaminant concentration for a wide range of flow values.

Quilbé et al. (2006) suggested that what may be considered a "good relationship" is somewhat subjective. Quilbé et al. (2006) proposed that a coefficient of determination (r^2) of >0.5 (i.e. >50% of the variability in contaminant concentration can be explained by flow) is a reasonable threshold. However, for data that follow a power relationship the r^2 value is not appropriate, except when the power relationship is applied to log-transformed data (McCuen 2003). Even when it is applied to log-transformed data, the numerical value applies to the prediction of the logarithms and not the dependent variable (i.e. contaminant concentration) for which estimates are required (McCuen 2003).

A more appropriate measure of model performance is the coefficient of efficiency (E) as outlined in Nash & Sutcliffe (1970). The coefficient of efficiency represents a form of noise to signal ratio, comparing the average variability of model residuals to the variability of the target output (Schaefli & Gupta 2007). Coefficient of efficiency values of between 0 and 1 are considered acceptable with higher positive values indicating superior model performance (Chiew & McMahon 1993; Schaefli & Gupta 2007). A negative E value indicates a poorly performing model (Schaefli & Gupta 2007). The coefficient of efficiency is defined by:

$$E = \frac{(\sum_{i=1}^{n}(OBS_i - \overline{OBS})^2 - \sum_{i=1}^{n}(EST_i - OBS_i)^2)}{\sum_{i=1}^{n}(OBS_i - \overline{OBS})^2}$$

Where OBS_i and EST_i are the observed and estimated parameter, respectively, and $\overline{OBS}$ is the mean value of all the observations.

In the case of the data from the four Waituna tributaries there are reasonably long water quality sampling records (apart from TSS). Moffat Creek, Carran Creek and Carran Creek tributary have been monitored on a monthly basis since 2001, while the Marshall Road site has been monitored since 1996. Because monthly monitoring is most likely to occur during non-event flow conditions, there is the risk that this dataset is biased towards lower flows. Despite this potential sampling bias, a reasonable range of flows has been sampled. Furthermore, some recent storm monitoring has augmented the dataset (to date only one relatively large event (May 2011) has been sampled). The E values for each of the water quality parameters at each of the Waituna sites are presented in Table 6.1. The results show that for 24 out of the 26 instances, the E values are >0 and hence can be considered to be acceptable models. The only two parameters with negative E values are NH4-N and DRP at the Marshalls Rd site. As loads of NH_4-N and DRP are not a specific requirement of this study, their poor performance is of little concern. Accordingly, we consider the rating curve approach to be suitable for most of the data from the four Waituna sites. However, we were not able to establish relationships for TDP or PP; these were not measured in the sampling programme.

Table 6.1 Regression (power law) outputs and coefficient of efficiency (E) values for each site. E values in bold indicate poorly performing models.

	TSS	NO_3-N	NH_4-N	TN	DRP	TP
Marshall Rd						
Coefficient	-0.95	-0.92	-2.70	-0.59	-2.18	-1.95
Exponent	0.562	0.336	0.489	0.305	0.171	0.268
r^2	0.63	0.63	0.43	0.80	0.22	0.39
E	0.42	0.41	**-0.26**	0.81	**-0.11**	0.46
Carran Creek						
Coefficient	0.569	-2.253	-1.343	-0.65	-2.112	-1.245
Exponent	0.1520	0.7041	0.0975	0.3193	0.2828	0.1167
r^2	0.07	0.70	0.04	0.74	0.38	0.10
E	0.07	0.17	0.05	0.77	0.49	0.08
Carran Creek tributary						
Coefficient	-0.063	-2.130	-1.186	-0.214	-1.899	-1.406
Exponent	0.147	0.222	-0.296	0.031	0.249	0.119
r^2	0.21	0.23	0.24	0.04	0.19	0.06
E	0.11	0.26	0.19	0.04	0.31	0.01
Moffatt Rd						
Coefficient	0.347	-2.484	-2.232	-0.478	-1.918	-1.124
Exponent	0.216	0.827	0.400	0.300	0.343	0.166
r^2	0.09	0.71	0.41	0.76	0.41	0.17
E	0.10	0.29	0.49	0.81	0.53	0.21

7 Catchment loads

7.1 Catchment loads determined by the 5 methods

The results for each of the load estimation methods for the four Waituna sites are illustrated in Tables 7.1 to 7.4. There are three general comments of note from the tabulated results:

1) The results from the three regression methods (Methods 3-5) are very similar for all parameters at all four sites. Given the similarity of the methods this is not surprising. Of particular note is that the more sophisticated LOWESS approach does not have much of an effect on the estimated loads (except for some influence on TP, as discussed later),

indicating the power relationships (methods 3 and 5) probably adequately describe the current datasets.

2) Although they tend to be slightly higher, the averaging estimator results are similar to regression methods. However, given the reasonable quality and length of the record this method is somewhat redundant, therefore the results from this method will not be considered further.

3) Although they are within the same order of magnitude, the results from the Beale ratio estimator are consistently higher than the other four approaches. This disparity, in itself, does not indicate that the results of the Beale ratio estimator are less accurate than the other methods presented; the disparity is largely related to inclusion of the May 2011 data. When the storm event is excluded, the loads decrease for TN and TP as the May 2011 data have consistently high concentrations during higher flows (Table 7.1). The TSS load increases because the concentrations do during the event during the May 2011 are low. This suggests that including the event introduces a significant bias to the Beale method. As noted by Richards (1998) a stratified Beale method (whereby loads are calculated for different flow ranges) can be used to deal with this situation.

We recommend that regression approaches be used for the Waituna Lagoon sites because:

- Dickinson (1981) found that the Beale ratio estimator tended to overpredict as sampling frequency increased.
- The Beale ratio estimator is useful in cases where there are few concentration data (Quilbé et al. 2006), but we do have a considerable number of samples.
- A key advantage of the ratio estimator approaches is that they are least affected by sources of bias (Kronvang & Bruhn 1996), however they do tend to be imprecise (Quilbé et al. 2006; Preston et al. 1989).
- If the Beale method were used, a stratified method would be required which introduces additional complexity.
- With the regression model, is the degree to which the data meet the model assumptions can be assessed (by determining E values and standard errors).
- In the case of the Waituna catchments the regression curve fits are reasonably good and the levels of uncertainty are low.

Consequently, we consider a regression approach the most suitable for the Waituna Lagoon catchments.

Table 7.1 Mean annual contaminant loads (tonnes/year) for Marshall Road as determined by the five load estimation methods. Unless otherwise stated, the flood event of May 2011 has been included.

	TSS	**NO_3-N**	**NH_4-N**	**TN**	**DRP**	**TP**
Method 1						
Averaging estimator (t/y)	1268	85.4	7.1	143.8	1.4	5.5
Method 2						
Beale ratio estimator (t/y)	2001	134.7	14.4	232.3	2.8	11.0
Beale ratio estimator without 2011 event (t/y)	2512	-	-	159.6	-	6.6
Method 3						
Regression (t/y)	894.9	112.0	11.3	165.8	1.5	6.0
SE (%)	*9.9*	*5.8*	*9.1*	*2.4*	*4.5*	*5.4*
Method 4						
Regression (LOWESS) (t/y)	867.7	105.1	11.4	167.0	1.4	5.3
SE (%)	*10.0*	*5.6*	*9.1*	*2.4*	*4.6*	*5.6*
Method 5						
Regression (t/y)	807.9	107.7	11.3	166.2	1.5	6.2
SD (t/y)	208.8	24.9	2.8	37.8	0.3	1.4

Table 7.2 Mean annual contaminant loads (tonnes/year) for Carran Creek as determined by the five load estimation methods.

	TSS	NO_3-N	NH_4-N	TN	DRP	TP
Method 1						
Averaging estimator (t/y)	183.1	8.7	1.2	21.1	0.6	2.0
Method 2						
Beale ratio estimator (t/y)	233.4	16.3	1.4	34.0	1.1	2.7
Method3						
Regression (t/y)	166.4	9.3	1.2	21.3	0.6	2.0
SE (%)	*12.6*	*7.0*	*6.5*	*2.7*	*5.2*	*4.9*
Method 4						
Regression(LOWESS) (t/y)	137.4	9.2	1.1	21.3	0.6	1.8
SE (%)	*12.9*	*6.7*	*6.5*	*2.7*	*5.3*	*5.1*
Method 5						
Regression (t/y)	166.6	9.3	1.2	21.3	0.6	2.0
SD (t/y)	31.6	2.3	0.2	4.4	0.1	0.4

Table 7.3 Mean annual contaminant loads (tonnes/year) for Carran Creek tributary as determined by the five load estimation methods.

	TSS	NO_3-N	NH_4-N	TN	DRP	TP
Method 1						
Averaging estimator (t/y)	8.3	0.1	0.1	2.6	0.2	0.4
Method 2						
Beale ratio estimator (t/y)	11.1	0.2	0.0	2.9	0.4	0.5
Method3						
Regression (t/y)	7.6	0.1	0.1	2.5	0.2	0.4
SE (%)	*5.6*	*6.3*	*7.5*	*2.1*	*8.6*	*6.9*
Method 4						
Regression(LOWESS) (t/y)	7.1	0.1	0.1	2.5	0.2	0.3
SE (%)	*5.7*	*6.4*	*7.4*	*2.1*	*8.9*	*7.1*
Method 5						
Regression (t/y)	7.4	0.1	0.1	2.6	0.2	0.4
SD (t/y)	1.4	0.0	0.0	0.5	0.0	0.1

Table 7.4 Mean annual contaminant loads (tonnes/year) for Moffat Rd as determined by the five load estimation methods.

	TSS	NO_3-N	NH_4-N	TN	DRP	TP
Method 1						
Averaging estimator (t/y)	131.3	6.1	0.7	16.2	1.0	1.9
Method 2						
Beale ratio estimator (t/y)	191.7	13.1	1.4	27.5	2.0	3.2
Method3						
Regression (t/y)	97.4	7.8	0.7	17.3	0.9	1.7
SE (%)	*14.7*	*9.3*	*8.3*	*2.8*	*7.2*	*6.2*
Method 4						
Regression(LOWESS) (t/y)	118.2	7.7	0.8	17.3	1.1	2.0
SE (%)	*14.2*	*9.5*	*7.9*	*2.8*	*6.9*	*5.9*
Method 5						
Regression (t/y)	109.2	5.1	0.8	13.2	0.4	1.3
SD (t/y)	21.1	1.3	0.1	2.8	0.1	0.3

7.2 Uncertainty in load estimation

It is apparent from the uncertainty levels (standard error) determined by Methods 3 and 4 that load estimations are reasonably precise. The highest levels of uncertainty are for the TSS loads from Marshall Road, Carran Creek and Moffat Creek. These higher uncertainty levels are probably due to the fact that TSS has only been sampled since 2008; hence fewer data have been used to construct the regression relationships. It is important note here that highly precise load estimations do not necessarily equate to highly accurate load estimations. This issue is described succinctly by Richards (1998):

> *'Precision and accuracy measure two related but different aspects of the behaviour of a measurement system. If repeated measurements are made of an object, the measurement process is called precise if the difference among the measurements is small, and it is called accurate if the average measurement is close to the true value. Bias is the lack of accuracy; a measurement system which is unbiased is highly accurate.'*

In effect the true contaminant loads of a river can never actually be known for sure. However, if we reduce elements that might introduce bias (e.g., infrequent frequency, sampling only during base-flow conditions, poor sampling protocols) and use a load estimation method that produces precise estimates, we can have a high degree of confidence in the results.

7.3 Total contaminant loads from the three main tributaries to the Waituna Lagoon

The total annual loads (Method 3) for the three main Waituna Lagoon tributaries are presented in Table 7.5. Clearly the Marshall Rd site contributes the vast majority of contaminants to Waituna lagoon. This is not unexpected, given that the Marshall Road site has the largest contributing area to the lagoon. The total loads are clearly of importance with regards to any potential effects within the Waituna Lagoon receiving environment. However, a more useful measure of the relative contribution of each of the tributaries would be the specific yields (i.e. the total load divided by the catchment area). Not only would this provide a useful measure of the relative importance of the three tributaries but it would also put the contaminant loads into some sort of context with other rivers in the region and throughout New Zealand. We do not have the catchment area information for these catchments but the specific yields could be easily calculated once this information is determined.

Table 7.5 Total annual loads and relative contributions of the three main catchments discharging into the Waituna Lagoon (as determined by load estimation Method 3).

	TSS	**NO_3-N**	**NH_4-N**	**TN**	**DRP**	**TP**
Marshall Rd (t/y)	894.9	112.0	11.3	165.8	1.5	6.0
Marshall Rd (%)	77.2	86.7	85.4	81.1	50.1	62.0
Carran Creek (t/y)	166.4	9.3	1.2	21.3	0.6	2.0
Carran Creek (%)	14.4	7.2	9.0	10.4	20.9	21.0
Moffat Creek (t/y)	97.4	7.8	0.7	17.3	0.9	1.7
Moffat Creek (%)	8.4	6.1	5.6	8.4	29.0	17.1
Total	**1158**	**129.1**	**13.2**	**204.4**	**3.1**	**9.7**

8 Factors influencing loads

The effect of storm events

As stated above, the datasets for all four sites are sourced primarily from monthly monitoring. To date only one storm event has been measured. Ordinarily, this would be a significant issue as contaminant concentrations generally peak during flood events and therefore most contaminants tend to be transported during the largest events. However, analysis of the data from the May 2011 event (Marshall Rd) indicates that the concentrations of TSS and TN remain on the same regression trajectory and do not increase markedly during flood events (Figure 8.1). The concentration of TN remains in the same order of magnitude and TSS only increases by one order of magnitude over three orders of magnitude of flow. Consequently, if the May 2011 event data is removed from the regression analysis, the mean annual TSS load increases by ~11% and the TN load increases by ~1%. The small increase in TSS concentrations during events is probably related to the flat nature of the catchment and hence there is likely to be very little input of sediment from hillslope sources. Small relative increases in storm TN concentrations are likely to be related to the fact that TN concentrations are already elevated in low flow conditions.

In contrast to TSS and TN, the May 2011 event data suggests the TP concentrations increase above a certain flow level (~8000 l/s; Figure 8.2), although the concentrations remain within the same order of magnitude. Accordingly, a power function does not fit this data very well. Also, if the May 2011 event data is removed from the regression analysis the loads decrease by ~36% suggesting that the behaviour at high flows is different. The reason for this is unknown, and it might be due to non-typical TP dynamics during the one flow event sampled to date. We therefore recommend that more event sampling be conducted, especially for TP.

At the Marshall Road site, the top 1% of flow transports ~13% of the flow volume. Only around 16-19% of the annual TN load is transported by the top 1% of the flow (Table 8.1). The fraction is similar for TP, although this varies somewhat depending on the method used (Table 8.1). Although this may not necessarily be the case for TP, it appears that large flow events are not especially important for transporting contaminant loads (when compared to many other New Zealand catchments). A similar pattern is also apparent at the Carran Creek and Moffat Road sites.

Figure 8.1 Flow/TN data for Marshall Road. Solid symbols are monthly monitoring data. Hollow diamonds are data from May 2011 event.

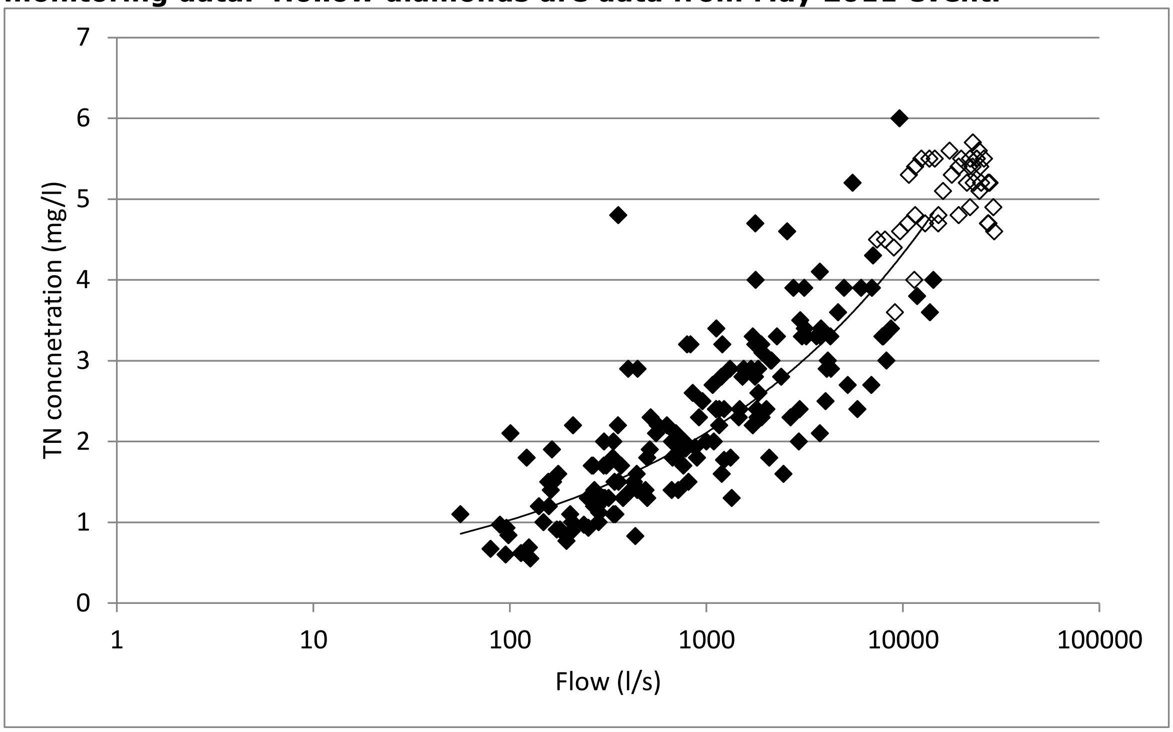


Figure 8.2 Flow/TP data for Marshall Road. Solid symbols are monthly monitoring data. Hollow diamonds are data from May 2011 event.

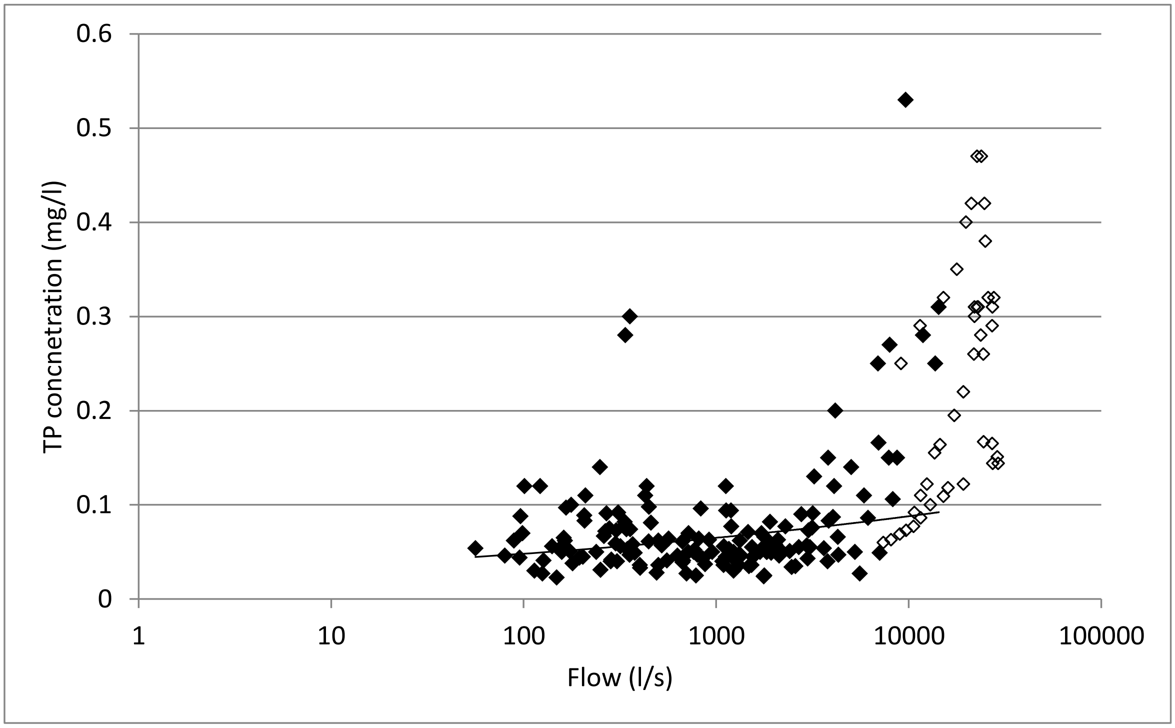


Table 8.1 Fraction of TP and TN load derived from top 1% of low at Marshall Road using differing regression relationships.

	Fraction of load from >99 percentile flow
TN	
Power relation	0.19
LOWESS	0.18
TP	
Power relation	0.18
LOWESS	0.28

Annual variability of contaminant loads

The yearly estimated contaminant loads (1995-2011) for each of the sites (as determined by Method 5) are presented in Tables 8.2 to 8.5. It is clear from the yearly load estimates that there is considerable inter-annual variability. For example, at the Marshall Rd site estimated TN loads vary from 92 t/y in 2000 to 226 t/y in 2004. Because the contaminant loads are calculated using a single rating curve for each contaminant (for each site) all of this variability is due to variability in flow, hence any trends in the data would be attributable to flow. At any rate, no significant trends are apparent in the data.

Table 8.2 Total contaminants exported from Marshall Road (tonnes) (1995-2011) as determined by Method 5

Year	TSS	NO_3-N	NH_4-N	TN	DRP	TP
1995	840.8	114.1	11.8	176.4	1.6	6.5
1996	743.5	102.5	10.5	158.7	1.4	5.9
1997	1067.2	138.8	14.8	213.4	1.9	7.9
1998	771.4	109.8	11.0	170.8	1.6	6.4
1999	739.9	93.3	10.1	143.2	1.3	5.3
2000	404.8	59.0	5.8	92.2	0.9	3.5
2001	891.3	115.0	12.3	176.8	1.6	6.5
2002	1097.0	139.7	15.1	214.2	1.9	7.9
2003	599.1	82.4	8.4	127.7	1.2	4.8
2004	1156.5	147.6	15.9	226.3	2.0	8.3
2005	765.2	102.8	10.7	159.0	1.4	5.9
2006	908.4	122.7	12.7	189.6	1.7	7.0
2007	594.4	82.9	8.4	128.8	1.2	4.8
2008	515.1	73.4	7.3	114.3	1.1	4.3
2009	723.1	95.9	10.1	147.9	1.3	5.5
2010	905.4	116.1	12.4	178.4	1.6	6.6
2011	1010.6	134.6	14.1	207.6	1.9	7.7
mean	***807.9***	***107.7***	***11.3***	***166.2***	***1.5***	***6.2***
SD	***208.8***	***24.9***	***2.8***	***37.8***	***0.3***	***1.4***

Table 8.3 Total contaminants exported from Carran Creek (tonnes) (1995-2011) as determined by Method 5

Year	TSS	NO_3-N	NH_4-N	TN	DRP	TP
1995	176.2	9.7	1.3	22.6	0.7	2.1
1996	161.6	8.6	1.2	20.5	0.6	2.0
1997	206.2	12.2	1.5	26.8	0.8	2.5
1998	181.2	9.0	1.3	22.6	0.7	2.2
1999	138.4	8.3	1.0	17.9	0.5	1.7
2000	105.0	4.8	0.8	12.6	0.4	1.3
2001	173.0	10.1	1.2	22.3	0.7	2.1
2002	201.4	12.4	1.4	26.6	0.8	2.4
2003	134.2	6.9	1.0	16.7	0.5	1.6
2004	213.1	13.1	1.5	28.1	0.8	2.6
2005	162.8	8.8	1.2	20.5	0.6	2.0
2006	191.0	10.5	1.4	24.4	0.7	2.3
2007	138.1	6.9	1.0	17.0	0.5	1.7
2008	124.2	6.0	0.9	15.2	0.5	1.5
2009	148.8	8.3	1.1	18.9	0.6	1.8
2010	173.2	10.3	1.2	22.4	0.7	2.1
2011	204.3	11.6	1.4	26.4	0.8	2.5
mean	***166.6***	***9.3***	***1.2***	***21.3***	***0.6***	***2.0***
SD	***31.6***	***2.3***	***0.2***	***4.4***	***0.1***	***0.4***

Table 8.4 Total contaminants exported from Carran Creek tributary (tonnes) (1995-2011) as determined by Method 5

Year	TSS	NO_3-N	NH_4-N	TN	DRP	TP
1995	7.9	0.1	0.1	2.8	0.2	0.4
1996	7.2	0.1	0.1	2.6	0.2	0.4
1997	9.2	0.1	0.1	3.2	0.3	0.5
1998	8.1	0.1	0.1	2.9	0.2	0.4
1999	6.2	0.1	0.1	2.2	0.2	0.3
2000	4.7	0.1	0.1	1.8	0.1	0.2
2001	7.7	0.1	0.1	2.7	0.2	0.4
2002	8.9	0.1	0.1	3.1	0.3	0.4
2003	6.0	0.1	0.1	2.2	0.2	0.3
2004	9.5	0.1	0.1	3.3	0.3	0.5
2005	7.3	0.1	0.1	2.6	0.2	0.4
2006	8.6	0.1	0.1	3.0	0.3	0.4
2007	6.2	0.1	0.1	2.2	0.2	0.3
2008	5.5	0.1	0.1	2.0	0.2	0.3
2009	6.7	0.1	0.1	2.4	0.2	0.3
2010	7.7	0.1	0.1	2.7	0.2	0.4
2011	9.1	0.1	0.1	3.2	0.3	0.4
mean	***7.4***	***0.1***	***0.1***	***2.6***	***0.2***	***0.4***
SD	***1.4***	***0.0***	***0.0***	***0.5***	***0.0***	***0.1***

Table 8.5 Total contaminants exported from Moffatt Creek (tonnes) (1995-2011) as determined by Method 5.

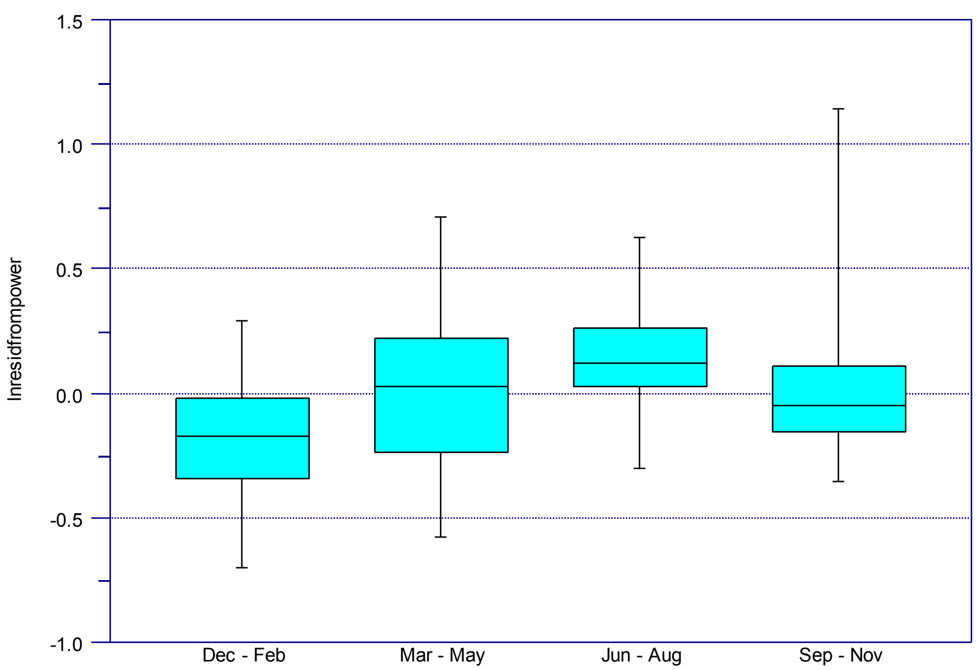
Year	TSS	NO_3-N	NH_4-N	TN	DRP	TP
1995	115.7	5.3	0.8	14.0	0.4	1.4
1996	105.9	4.7	0.8	12.7	0.4	1.3
1997	135.7	6.7	1.0	16.7	0.5	1.7
1998	118.3	4.9	0.9	13.9	0.4	1.5
1999	90.9	4.6	0.7	11.2	0.3	1.1
2000	67.9	2.6	0.5	7.7	0.2	0.8
2001	113.6	5.6	0.8	13.9	0.4	1.4
2002	132.9	6.9	1.0	16.6	0.5	1.6
2003	87.5	3.8	0.6	10.3	0.3	1.1
2004	140.7	7.3	1.0	17.6	0.5	1.7
2005	106.5	4.8	0.8	12.7	0.4	1.3
2006	125.3	5.7	0.9	15.1	0.5	1.5
2007	89.9	3.8	0.7	10.5	0.3	1.1
2008	80.8	3.3	0.6	9.4	0.3	1.0
2009	97.5	4.6	0.7	11.7	0.4	1.2
2010	113.8	5.7	0.8	14.0	0.4	1.4
2011	134.3	6.4	1.0	16.4	0.5	1.6
mean	***109.2***	***5.1***	***0.8***	***13.2***	***0.4***	***1.3***
SD	***21.1***	***1.3***	***0.1***	***2.8***	***0.1***	***0.3***

Effect of seasonal variations

In Meijer (2011) seasonal variations in concentration and loads were identified, so is it natural to consider taking account of the effect of this seasonality in load calculations. Indeed, in the load estimation method used by Environment Southland to date (C. Jenkins, pers. comm., reviewed in Meijer 2011), the relation between flow and concentration was established for each season.

In the exploratory data analysis section of this report (Section 5 and 6) seasonal differences could be seen for nitrate, but not easily seen for other nutrients. Part of the seasonal variation in concentration could simply be a result of seasonal flow variations (in conjunction with the relation between concentration and flow). However, there is still a small seasonal variation after the flow effect is taken into account (Figure 8.3).

Figure 8.3 Seasonal boxplot of residual concentrations for TN at the Waituna at Marshall Rd site, after fitting a power type rating curve. The vertical axis is the natural logarithm of the residual concentration. We first fitted a power rating to the full dataset (excluding the samples over large event in May 2011). The box plot was prepared using the Time Trends software.



To investigate the influence of this residual seasonality on loads, a load estimation was prepared using a rating curve of the form:

$$\ln(C) = s(Q) + a\cos(2\pi T) + b\sin(2\pi T)$$

Where s is a LOWESS smoothing curve calculated with the gam procedure in the R statistical software and T is the time in years from the start of some arbitrary reference year. The resulting rating curve was applied to the full flow record. Taking account of seasonality in this fashion resulted in less than 1% difference in the mean annual TN load for the Marshall Road Site, and less than 3% difference to the TP load at that site. This result applied whether or not the May 2011 result was removed, and also if a power rating curve was used. When seasonality is taken into account, the sensitivity to flow is reduced; these two factors counter each other, giving rise to only a negligible influence on mean annual load. Also, taking account of the effect of this seasonality in concentrations had little effect on the proportion of load arising in different seasons (Table 11).

Table 8.6 Fraction of load attributable to different seasons for TN at the Marshall Rd site.

Season	With seasonal term in regression	Without seasonal term in regression
summer	0.12	0.16
autumn	0.40	0.38
winter	0.32	0.28
spring	0.15	0.18

Considering these results, we conclude that it is not necessary to take account of seasonality in the rating curve, because it has only a minor influence on the load or the seasonal distribution of load.

Event hysteresis

Environment Southland identified differences in rising and falling limbs of the hydrograph (C. Jenkins, pers. comm.). Such hysteresis effects have been taken into account in their load estimations. Sections 4 – 6 in the exploratory data analysis reproduce this hysteresis for TSS and nutrients.

We have not included this approach in our load estimations because:

- there is only one storm and there is insufficient data to be confident of the effect
- the storm was a major one, and prolonged high flows may have led to source exhaustion which may not be observed in other storms
- because event contaminant concentrations (particularly for TSS and TN) do not increase greatly (i.e. they remain in the same order of magnitude), the difference between the concentrations on the rising and falling limbs is not large
- there is little evidence in literature that it is an important approach

However, with more storm data, the importance of hysteresis should be reassessed.

Long-term temporal trend

If there were a long-term increase or decrease in concentration, then it would be useful to consider making load predictions for a particular year of interest or a reference year, rather than a long-term average. However, as noted above in the yearly breakdown of loads, there is considerable inter-annual variability in load due to flow rates, and developing a rating curve for each year would involve considerable prediction uncertainty given the small number of samples. Hence a longer-term view is required.

To investigate the effect of time trends, we applied a regression of the form:

$$\ln(C) = s(Q) + a\cos(2\pi T) + b\sin(2\pi T) + cT$$

Where T is time in years from the start of 1996. This rating curve was then applied to the full flow record with a) the time term varying and b) the year in the time trend term fixed at 2011 (that is, the long-term average load that would apply if the rating curve relevant to 2011 is applied, not the actual load in 2011). In this analysis, the large May 2011 event was removed to avoid the confounding influence of a large number of high-concentration samples taken toward the end of the water quality monitoring record.

Inclusion of the temporal trend term made less than 1% difference to the long-term predicted load for TN or TP at Marshall Rd. Also the load for 2011 conditions (option b above) was slightly less than the long-term average. This second term is caused by a small (and statistically insignificant) negative trend in concentration (after flow variation is taken into account). This result was a little puzzling considering that concentration trend analysis by Environment Southland showed an increase in TN concentration over time (Meijer 2011). However, we have conducted a trend analysis of the water quality record for total nitrogen in the Waituna Creek at Marshall Road, which suggests that there is no statistically significant trend over the period 1999-2011. This analysis was conducted with TimeTrends version 3.2 using a seasonal Kendall test with LOWESS flow adjustment, for all 13 years of the water quality record, excluding a large rainfall event in 2011. The reason that we obtained a non-significant trend in contrast to the increasing trend (1.5% per year) that Environment Southland found is due to the different time periods analysed (ES: 2000-2010). We note that while there was no trend in TN there was still a trend in nitrate-N of 1.3% increase per year (with 5-95 percentile limit range of 0.6-2.1% per year).

Considering these results, we concluded that it is not necessary at this stage to take account of long-term trends in concentration for TN or TP when establishing measured loads over the period of the historical monitoring record. The flow-associated fluctuations in load can still be assessed for different years by applying the relevant period of flow record to the rating curve (without the trend term). In the future, if significant concentration trends become apparent, then the load estimation method could be modified to include a temporal term or, if there is sufficiently long record, by applying the rating curve method to different periods of concentration and flow record.

Influence of climate change/variability

The role of climate on short-term trends in water quality variables in New Zealand rivers has been discussed by Scarsbrook et al. (2003), who concluded that trends in conductivity, clarity and TP were influenced by climate, while climatic effects were not so apparent on trends in nitrogen and dissolved reactive phosphorus. Over the ten years 1999-2009 there was a declining national trend in flow; a trend that almost certainly is linked to climate change as flow was found to be associated with Southern Oscillation Index by Scarsbrook et al. (2003). The increases and decreases in flow may have some influence on trends in selected water quality variables. While we found no appreciable trends in loads of nutrients over the period 1995-2011, this overlapped with a period in which there was a declining national trend in flow. Whilst we cannot say with any certainty whether the national trend in declining flows also applied to these catchments, it could in theory be influencing the our lack of observed trends in loads. If, for example, flows were increasing over the period of record (as they were nationally from 1989-1999) then it is likely that our trend analysis of loads (flow x concentration) would be positive (i.e. increasing loads with time).

9 Recommendations for future monitoring and load estimation

Load estimation

Three regression approaches for estimating contaminant loads have been presented in this report and are recommended for both future and historical estimates. Concentrations vary significantly with flow rate, so that we consider that it is appropriate to apply a rating curve for load calculations. In most cases, the power function describes the low/contaminant relationships reasonably well, so there is no need to use the more sophisticated LOWESS approach. In the case of TP, LOWESS curve produces slightly different load estimates, but considering that this result is based on only one storm and the difference in loads is not large, the regression approach is satisfactory. This approach could be revised, if future monitoring shows a more curvature in the rating curve (in the log-log plots). We recommend that the SedRate software be used for the load calculations because it is fairly easy to use, it allows for LOWESS curves in the future, is defensible, and provides uncertainty estimates. The proposed method is sufficiently simple, however that it could be implemented in a spreadsheet or other software.

Historical period

We concluded that it is not necessary at this stage to take account of long-term trends in concentration for TN or TP when establishing measured loads over the period of the historical monitoring record. The flow-associated fluctuations in load can still be assessed for different years by applying the relevant period of flow record to the rating curve (without the trend term). There is insufficient data to confidently include hysteresis effects. We also conclude that it is not necessary to make the regressions for each season, because the both the load and the seasonal breakdown of load are insensitive to addition of seasonality.

A potential important issue affecting historical load predictions is the lack of a comprehensive and accurate flow record from each of the Waituna tributaries, with flow records having to be interpolated from the neighbouring Waihopai catchment. This incomplete flow record will increase the uncertainty of the results. This uncertainty is not quantifiable, but we can argue that it will not matter as much as it would in many other catchments. On average, the flow predictions seem quite good (high R^2). For many other catchments, a high R^2 does not mean that flows can be predicted adequately during rapid changes in flow, e.g., at the start of a storm runoff event, i.e., it is hard to predict the timing. However, from the above data analysis, the precise timing does not seem that important, because concentrations do not respond dramatically to flows.

An area of uncertainty in respect to accuracy for predicting past loads of nutrient and sediments, is the lack of water quality monitoring from storm events. However, for TSS and TN the concentrations do not increase markedly during events and the limited storm sampling to date suggests that a power-type relation provides a reasonable prediction of concentrations at high flows. The high flows are still important, because they carry a large volume. For example, the top 1% of flows carry 13% of the flow volume at Marshall Road. However, the proportion of TN load associated with these flows is only 16-18%, indicating the limited importance of higher concentrations during high flows. For TP, the concentrations seems to rise more with high flows, so that the top 1% of flow carry up to 18-28% of the load. Without including the large monitored event for TP in May 2011, the load estimate would have been significantly different (36% difference). These findings are based on a dataset that includes only limited storm monitoring. We therefore recommend that some additional storm sampling be conducted to confirm the behaviour at high flows. There is a need to confirm that the concentration predictions made by the recommended regression approach reasonably describe other storm events, any seasonal influence, and any hysteresis in contaminant concentrations.

We concur with the bimonthly sampling strategy. We recommend that additional storm sampling be conducted, because the dataset has only limited storm monitoring. There is a need to confirm that the concentration predictions made by the recommended regression approach reasonably describe other storm events and investigate hysteresis in contaminant concentrations. We have not been prescriptive about number of samples and storm size, because this should be determined by achieving adequate coverage of the flow duration curve. On the basis of present information, we would expect to be about 3 storms or about 12 samples per year.

Another finding is that nutrient concentrations are not changing dramatically over the historical period with changing land use. This creates uncertainty in our understanding, and to some extent load predictions, because dairying is expected to increase nitrogen (especially nitrate) levels. Groundwater pathways clearly play an important role in stormwater runoff in this flat terrain, and denitrification is probably an important process in the peat soils. These pathways and processes should be a major focus of research efforts. In the future, we recommend measurement of DON and TDP to improve the understanding of the proportion of nutrient load being carried by different nutrient species/fractions (see below). Given the importance of mole and tile drains in the catchment and drain-clearance operations, a focussed process study on the role of drainage in regulating denitrification rates (and hence NO_3-N loads to the lagoon) may be justified.

Sediment loads are very low and cannot account for the higher sedimentation rate observed in the estuary. However, we do not believe that these loads are grossly underestimated because of load prediction methodology inadequacies. It is more likely that sedimentation rates are incorrect or sediment is input from other sources besides typical catchment runoff. These other sources might include short-term localised sources that arise from the flat nature of the catchment and the likelihood of weed infestation and removal. We support Environment Southland’s concerns for drain maintenance effects and the need to monitor these.

Future load estimation and sampling

In the future, in addition to the comments above (use the 3 interpolation methods, check for long term trends, check for significant hysteresis) we recommend the following:

Accurate flow measurements are required to ensure accurate load predictions. The best way to do this is to install flow recorders at all sites. However, setting up and maintaining new hydrometric stations can be expensive and it can be argued that due to the relatively small sensitivity of concentrations to flow rate and the flat hydrographs, flow recorders are not essential. If not installed, this means there will need to be comprehensive gauging at all the sites, and across a wide range of flows, for correlation to Waituna @ Marshalls. However, continuous flow recording should be installed if significant land use changes occur or are predicted to occur (e.g., large changes in farm drainage systems, drain management) of if the gauging programme shows changing flow characteristics or unstable relationships.

Whilst sampling to date has shown that flow doesn't have a large effect on the concentration of suspended sediment and particulate-nutrient forms (parameters that are usually responsive to flow increases) this is based on limited sampling, with only one large storm event. Sampling more events would give Environment southland greater confidence that the relationships established to date are similar over all seasons and storm sizes. It may be, for example, that events pre- or post-drain clearing operations are particularly important.

We recommend that for the purposes of sampling, events are defined as follows:

1) Marshall Rd >5000 l/s
2) Moffat Creek >500 l/s
3) Carran Creek >1200 l/s
4) Carran Creek tributary >450 l/s.

Automatic samplers should be set to trigger once the above flows are exceeded. There is little value in sampling below these flow thresholds as there is already a wealth a data at these lower flows. We note that it will be difficult to 'trigger' samplers Moffat, Carrans and Carran Creek Tributary without installing flow recorders.

The number of samples required to adequately calculate load is catchment dependent and will depend on how river concentrations respond with flow, which in turn is dependent of catchment processes. It is therefore an iterative process. We recommend that flow duration curve analysis (load duration curves is better still) be used to make decisions on the sampling frequency required to characterize a particular event. Again we note the difficulty in doing this for other than the Marshall Road site without installing flow recorders. Even if this were done it would take some time to get the record necessary to do flow duration analysis. However by interpolating the Marshall Road site with some adjustments utilizing local knowledge of the individual catchments it should be possible to estimate of the required sampling frequency, without having to wait for a flow record to be established. We recommend setting the water samplers to sampler at time or flow intervals more frequent than may be necessary and then using the event flow record to make decisions on which samples should be analysed and/or composited.

In any year, detailed flow analysis should be conducted – e.g., including flow duration curves. Flow is having the largest effect on loads and should receive the greatest attention for understanding changes of loads through time.

We recommend that the present parameter suite is continued, but colour is added. Conductivity, pH, black disk and colour behaviour all help interpret the behaviour of other parameters. In addition, for nutrients, samples should be analysed for TDP and DON, to characterise the proportion of particulate versus dissolved/colloidal nutrients. It is not possible to estimate particulate or total dissolved nutrient loads until that information is obtained. VSS should only be carried out when TSS exceed adequate concentrations (probably >20 mg/L).

The present sampling method is known to be inaccurate for measuring average cross-section particulate matter concentrations in other catchments. Strong gradients can occur for suspended particulate matter (SPM) in the water column cross section during storm runoff. If this occurs then bucket sampling will add to the uncertainty in the accuracy of TSS, TP and TN loads, although should be adequate for the dissolved component. The situation in the Waituna tributaries is unknown, but strong gradients would not be expected. This is because:

1. low stream slopes and low concentrations of SPM
2. the high concentration of peat-derived organic matter may result in relatively high proportion of organic matter in SPM and lower particle densities, and a potentially high proportion of TDP, DON and low density particulate nitrogen.

There is a need to investigate the concentration and characteristics of the nitrogen and phosphorus forms (the PON and POP described in this report). If high-density particulate phosphorus and nitrogen are identified as important parameters in estuary management (i.e., they form a significant and important part of nutrient load that may be influenced by land management), then sampling methods may need to be re-assessed. This would need to be done by a field study assessing integrative forms of sampling.

When comparing loads through time, it is really important that a consistent approach is used, due to the differences in loads calculated with different methods. In the future, if concentration trends become apparent, then the load estimation method could be modified to include a temporal term or, if there is sufficiently long record, by applying the rating curve method to different periods of concentration and flow record.

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