Water quality and ecosystem health in the Manuherikia catchment

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Foreword

The Otago Regional Council (ORC) carries out regular water quality monitoring as part of its State of Environment programme, as well as short-term targeted water quality monitoring programmes. This report provides the results from a more detailed, short-term investigation carried out in the Manuherikia River catchment between 2009 and 2011.

The Manuherikia catchment is one of the driest in New Zealand, and irrigation water is in high demand. Water quality in the catchment is generally very good, with land use currently dominated by low intensity farming. However, a change to more intensive farming is taking place, and with the development of new irrigation practices and infrastructure, there is likely to be further intensification, which may put pressure on water quality and ecological values.

By using both regulatory and non-regulatory approaches, the ORC must ensure that the water quality in Central Otago is maintained and, where possible, enhanced. In line with this principle, the ORC is currently implementing a Rural Water Quality Strategy and revising its Water Plan, in consultation with the Otago community.

The results of this report will be used to guide future policy decisions. They will also be shared with the community and other stakeholders to promote good practice so that the water quality in the Manuherikia catchment is maintained, if not enhanced.

Executive Summary

The 2007 State of Environment (SOE) report (ORC, 2007) shows that water quality in the Manuherikia catchment is generally good, with three of the four sites monitored, for SOE purposes, having ‘very good’ water quality, and none having ‘poor’ water quality. However, a change to more intensive farming could potentially occur, and with the development of new irrigation practices and infrastructure, there is likely to be further intensification, which may put pressure on water quality and ecological values. To effectively manage water quality and ensure there is no deterioration in the future if land use practises change, an intensive water quality investigation was designed to provide an indication of current water quality in the catchment.

The objectives of this study were to:

- determine the current state of water quality in the catchment
- quantify the current state of the catchment’s instream biological health
- identify the catchment’s sensitivity and susceptibility to land-use change.

At the end of 2009, the ORC initiated a water-sampling programme, in which fortnightly samples were collected from 17 streams over a 12-month period. During the summer of 2010/2011, physical habitat surveys and ecological surveys (macroinvertebrates and fish) were also sampled.

The following conclusions have been drawn from the investigation:

- Catchment-specific instream effects-based guidelines and an ecological value classification have allowed an understanding of the effects of water quality degradation and habitat health.
- Water quality results have shown that the Manuherikia’s main stem has ‘good’ water quality, with a change from ‘excellent’ water quality at the top of the catchment, to ‘good’ at the bottom, at Galloway.
- There are some tributaries to the main stem of the river that have degraded water quality during low flows, and which are probably caused by irrigation run-off.
- Nitrogen was well below effects-based guideline values, especially during the high risk period when flows were low. Analysis suggests this catchment is nitrogen limited.
- In streams such as Dovedale Creek and the lower Ida Burn, where high densities of the threatened Central Otago Roundhead galaxiid are located, it is likely that the low river flows are protecting these populations by excluding trout invasion.
- Improving flood irrigation methods and riparian management to minimise or eliminate irrigation run-off could improve water quality and physical habitat in the degraded tributaries.
- The ecological values in these streams were not just related to water quality issues.

Other factors include natural low flows, hydroelectric dams on the Clutha River/Mata-Au disrupting Longfin eel migration, water abstraction for irrigation, predation and land-use management.

Results from this study will be used to provide baseline data to direct council policy, and keep it in line with the Rural Water Quality Strategy.

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1. Introduction

Land-use intensification has been seen to affect water quality adversely in a number of catchments around New Zealand (Riley *et al*., 2003; Buck *et al*., 2004; Townsend *et al*., 2008). Often these changes occur quite quickly as farming technology and changing markets allow intensive farming practices to become viable in areas where they formerly were not. The 2007 State of Environment (SOE) report (ORC, 2007) shows that water quality in the Manuherikia catchment is generally good, with three of the four sites monitored in this catchment for SOE purposes having 'very good' water quality, and none having 'poor' water quality.

Despite this result, conditions may change with new land-use activities, such as intensive farming. The Council's Rural Water Quality Strategy states that the water quality in the region should not deteriorate into the future whether or not land use changes. A single dairy farm exists in the catchment (as of June 2009), and a dramatic increase in the wintering of dairy cows has been observed in recent times. It is envisaged that there will be a dramatic change in irrigation methods (as land use changes and water permits expire), water distribution and sources of irrigation water over time.

For these reasons, the ORC initiated this study to increase the understanding of the ecological health of the catchment for all stakeholders. This study also provides information to direct policy decisions to ensure that water quality is maintained.

1.1 Background information

The Manuherikia River is located in Central Otago. It extends for approximately 64 km and has a catchment area of approximately 3085 km^2. The river's headwaters are in the Hawkdun Range, and the catchment is surrounded by mountainous terrain, except to the south-west, where it joins the Clutha River/Mata-Au at Alexandra (

Figure 1). The Manuherikia catchment includes two major depressions, the Manuherikia valley and the Ida Valley. These are connected by the Pool Burn gorge. Brown-grey soils dominate the central-southern zone of the catchment, while a yellow-grey soil extends from the middle part up to the Dunstan Valley. The upper Manuherikia Valley is characterised by yellow-brown soil. The hills and the mountains have been coated, in many locations, with a veneer of Pleistocene and recent loess, while the terraces are covered by alluvium and a thin deposit of loess of the same age (Beecroft *et al*., 1986).

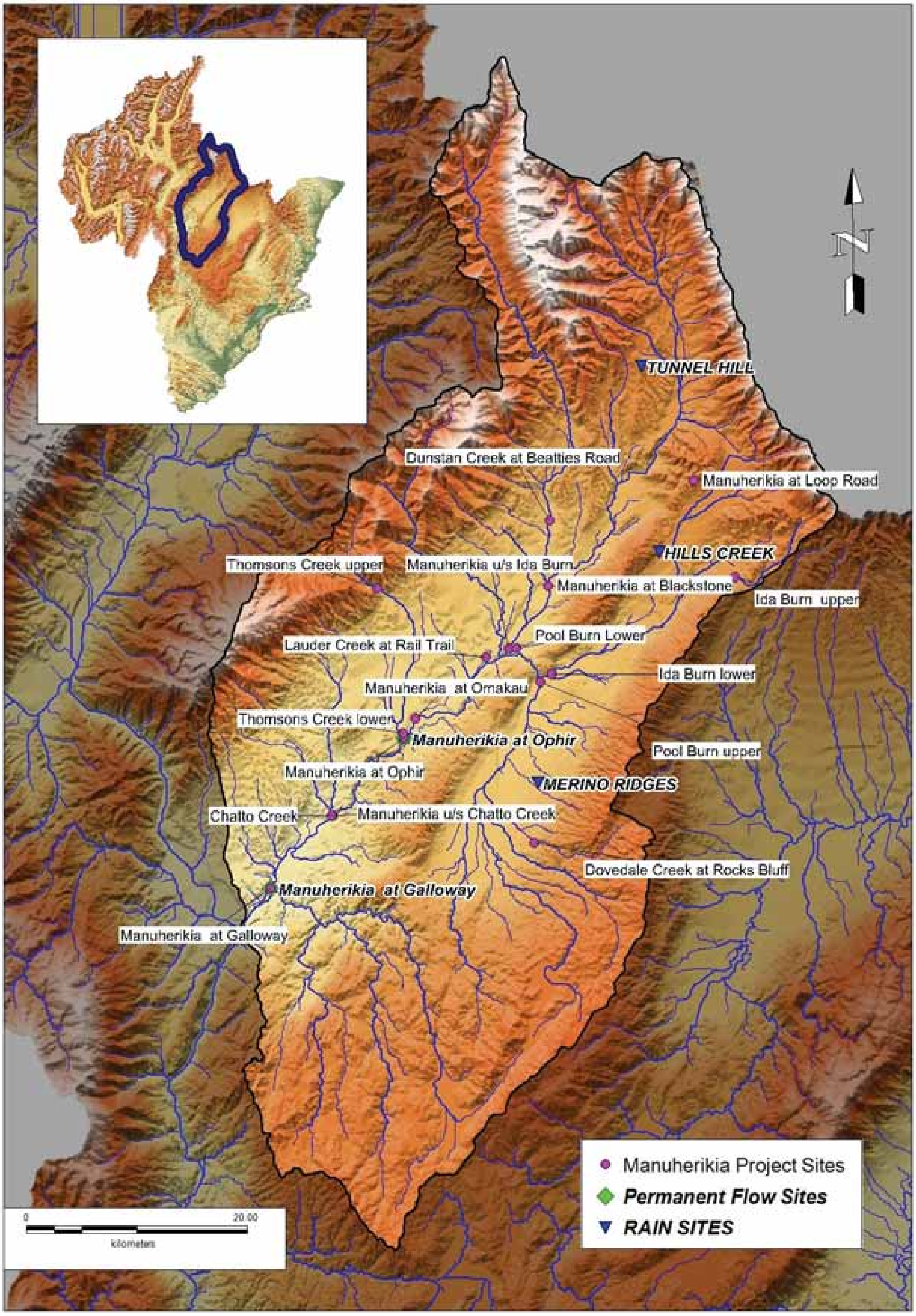

Figure 1. The Manuherikia catchment and sampling sites

1.2 Climate

The Manuherikia climate is considered to be the most continental type in the country (NIWA 2001). The surrounding mountains shelter the catchment from rain-bearing storms, and, due to its location in Central Otago, away from the effects of the sea, the area has cold winters and warm summers, with high diurnal ranges. Average monthly rainfall totals do not have a distinct seasonal pattern. The Tunnel Hill gauge generally has a high average monthly rainfall, while the Merino Ridges site generally has the lowest average monthly rainfall total (Figure 2). On average, the highest monthly average rainfall occurs in the summer months of December/January.

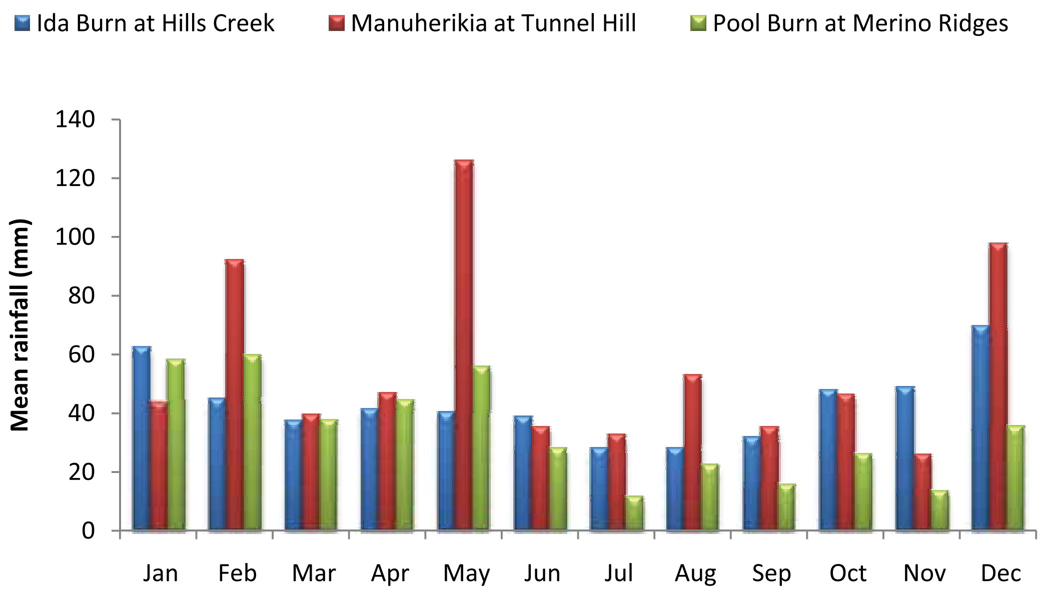

Figure 2. Average monthly record for three permanent rainfall sites in the Manuherikia catchment

Potential evapotranspiration (PET) in the valley is higher than the amount of rainfall occurring in late spring, summer and autumn, resulting in moisture deficiency of about 300 mm near Alexandra, 200 mm around Omakau and 150 mm in the upper valley. PET is at its highest during summer, up to 134 mm/month, and it significantly exceeds the monthly rainfall (39 mm). The annual water requirement for pasture in Otago is about 700 mm, most of which is needed during spring and summer. Wilting point is usually reached during September or October, when water for irrigation is usually needed.

1.3 Land use

The primary land use in the upper catchment of the Manuherikia and Ida valleys is extensive sheep and beef grazing. Relative to the upper catchment, due to irrigation, relatively higher intensity farming dominates the mid and lower reaches of the catchment, with smaller farms and higher stocking rates. In the past few years, there has been an expansion of wintering dairy herds, and in June 2009 the first dairy platform was established near Omakau.

1.4 Hydrology

The main stem of the Manuherikia River has two permanent flow recorders: at Ophir, which contains data dating back to 1971 (catchment area up-stream is estimated at 2196 km^2), and the more recently added site near the Alexandra camping ground, known as the Galloway site, near the bottom of the Manuherikia River (catchment area upstream estimated at 3010 km^2). Flows for the two sites are significantly altered due to numerous abstractions upstream and augmentation from Falls Dam. The hydrographs in Figure 3 highlight this complex hydrology whereby the typical trend increasing flow downstream does not occur.

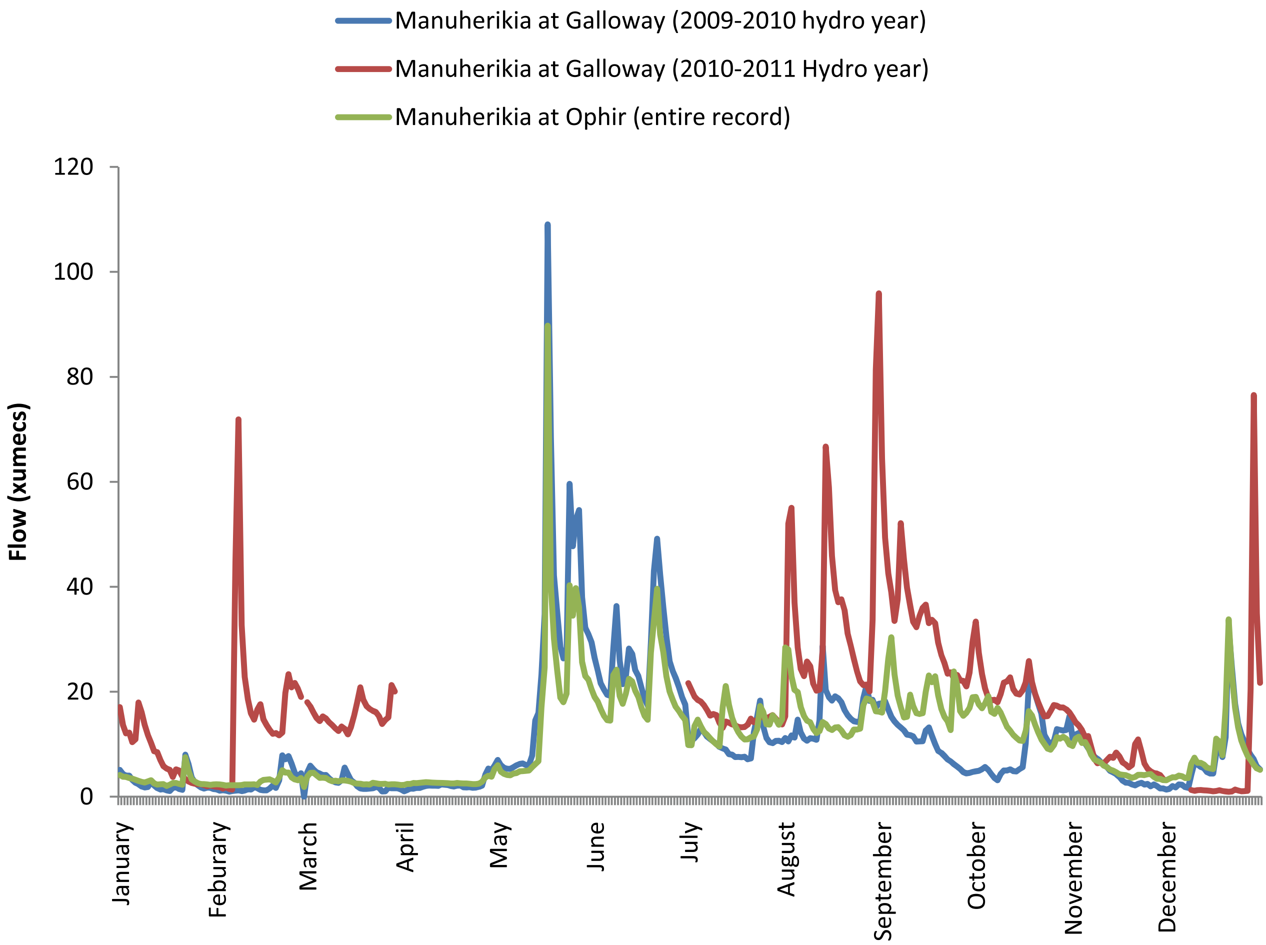

Figure 3. Average daily flow for the Manuherikia River at Galloway and Ophir

1.5 Manuherikia fish values

The Manuherikia River supports a diverse fishery, with 11 species of fish (summarised in Table 1) and one species of freshwater crayfish (*Paranephrops zealandicus*) listed on NIWA's New Zealand Freshwater Fish Database (ORC records).

Table 1. Fish species present within the Manuherikia catchment (Sources: New Zealand Freshwater Fish Database, ORC records and Fish & Game Otago records)

Common name	Species name	Conservation status
Chinook salmon	*Oncorhynchus tshawytscha*	Introduced and naturalised
Brown trout	*Salmo Trutta*	Introduced and naturalised
Rainbow trout	*Oncorhymchus mykiss*	Introduced and naturalised
Brook char	*Salvelinus fontialis*	Introduced and naturalised
Perch	*Perca fluvialtilis*	Introduced and naturalised
Longfin eel	*Angullia dieffenbachia*	Declining
Central Otago Roundhead galaxiids	*Galaxias anomalus*	Nationally vulnerable
Flathead galaxiids	*Galaxias* Sp. D	Nationally vulnerable
Alpine galaxiid	*Galaxias paucispondylus*	Nationally endangered
Koaro	*Galaxias brevipinnis*	Declining
Common Bully	*Gobiomorphus cotidianus*	Not threatened
Upland Bully	*Gobiomorphus breviceps*	Not threatened

The Regional Plan: Water (The Water Plan) (ORC, 2004) identifies significant ecosystem and habitat values for the conservation of indigenous fauna. For the Manuherikia River main stem, ecosystem values include trout spawning habitat, juvenile habitat, adult trout and Longfin eels. Chatto Creek has significant trout spawning and juvenile habitats, as does the Pool Burn downstream of Cobb Cottage. Chatto Creek and Dovedale Creek also provide significant habitat for the Roundhead galaxid, which is considered to be in gradual decline.

1.6 Recreational values

The most significant active recreational pursuit carried out on the Manuherikia River is angling, which is the main focus of this section. Other pursuits, such as kayaking and swimming, also occur within the catchment.

The Water Plan identifies the Manuherikia River and tributaries as having high natural value, particularly for brown trout fry, trout spawning and adult trout habitats. The Manuherikia River is popular with local and visiting anglers, and angling visits increased from an estimated 3,000 in 1984 (Richardson *et al*., 1984) to 3536 in 1996 (Unwin and Brown, 1998) and then to 5,629 in the 2001/2002 season (Urwin and Image, 2003). The Manuherikia River has gone from being the fifth most important trout fishing river in Otago in 1996, to being the fourth, in 2003. It is worth noting that the difference between the third and fourth positions is slight.

Angler observations note that later in the season, fish tend to be harder to catch as they become stressed by low flows and associated warmer water temperatures. Some fish migrate into sections of the river, such as the gorge downstream of Omakau, or into the Clutha River/Matau-Au, to escape the effects of low flows. This can be seen in the angling patterns of guides, who tend to target large sections of the lower river early in the season, but then focus on the gorge section later in the season. The popularity of the fishery was recognised recently, with bag limits for the lower river reduced from six to three per person due to angling pressure (Hollows, 2003).

1.7 Irrigation

Given the comparative dryness of the Manuherikia catchment, irrigation is an important management technique to enhance farm viability in the area. Historically, water allocation in Otago has been dominated by deemed permits (mining privileges). Deemed permits were granted under past mining legislation by the Warden's Court, and provided for the taking, damming and discharging of water. Initially, deemed permits were issued for gold mining; however, most of these takes are now used for irrigation purposes. All of the Crown irrigation schemes constructed in Otago before 1950 rely on the use of deemed permits and a variety of other water permits. Many of these schemes use dams to capture spring snow melt run-off, which is released over the early to mid-summer period for irrigation use.

Figure 4 shows the irrigation schemes' command areas and the surface water irrigation takes. The main irrigation schemes in the Manuherikia are fed from Falls Dam, which services Omakau, in conjunction with takes coming from streams draining the Dunstan Mountains. The Ida Burn scheme is fed by the Ida Burn dam, while the Manorburn, the Greenland and Pool Burn reservoirs feed the Galloway and Ida Valley schemes. The Hawkdun race, which flows along the base of the Hawkdun Range in the upper Manuherikia, distributes water into the Upper Taieri catchment and is not used in the Manuherikia catchment.

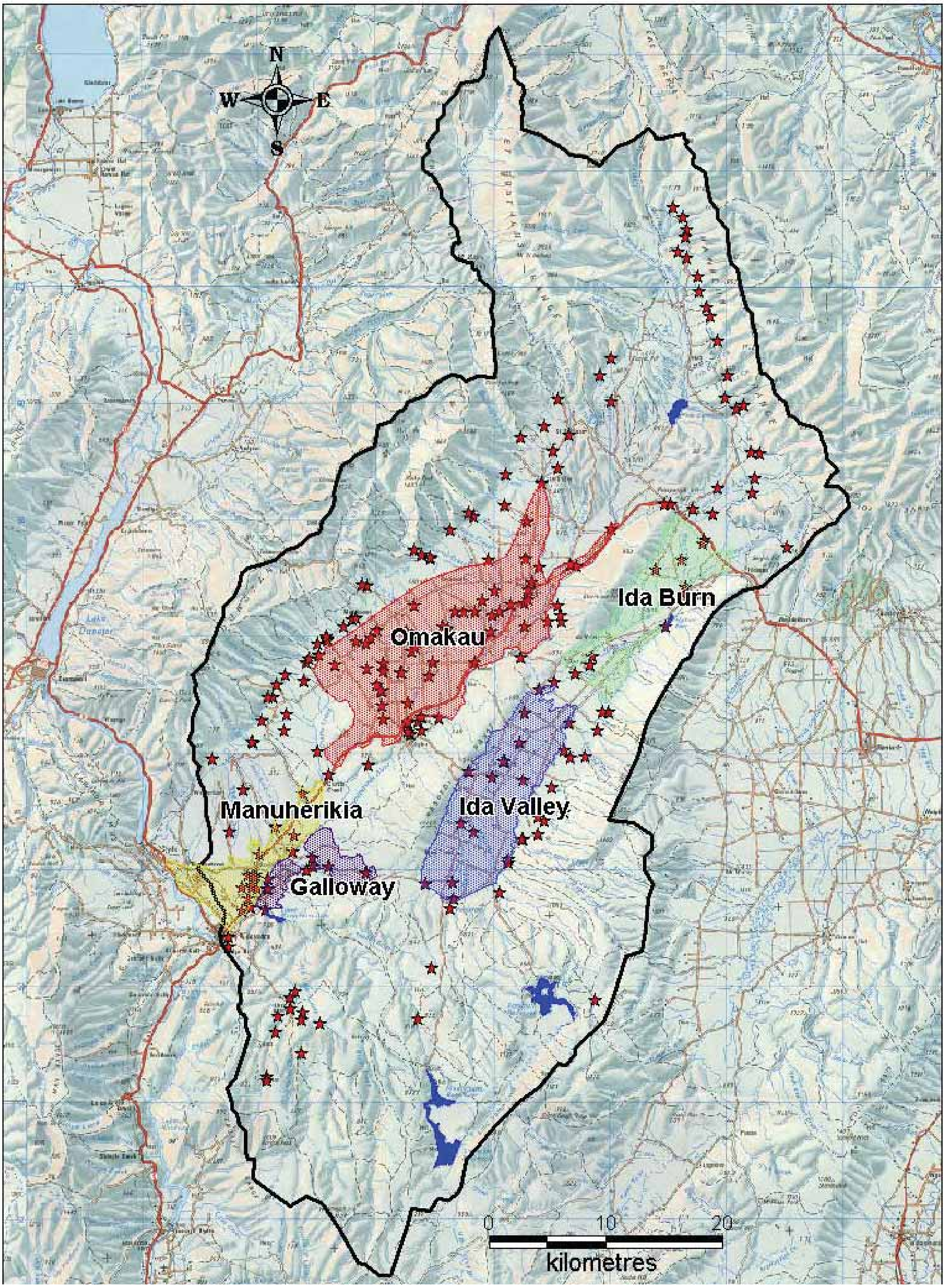

Figure 4. Command areas of different irrigation schemes. Consented surface water takes are highlighted by red stars

In the Manuherikia catchment, a total of 28,681 l/s has been allocated for irrigation and stock-water use, which is made up of 241 consented surface water takes dominated by deemed permits. This makes the Manuherikia catchment heavily over-allocated as there is a primary allocation limit of 3,200 l/s. There are two main methods of irrigation used in the catchment. The first is flood/ border dyke irrigation (whereby water is distributed through a series of races and channels and then spilled over land to irrigate). The other method is spray irrigation, for example, K-line, Roto-Rainers and centre pivot. The irrigation efficiencies of the main methods of irrigation in the Manuherikia are identified in Table 2.

Table 2. Approximate application efficiency (E_a) for various irrigation methods (Irrigation New Zealand Inc., 2007)

System type	Average E_a (%)	Efficiency range (%)
Centre-pivot	85	85-94
Solid set sprinklers	80	75-85
Border-dyke	60	50-80
Wild flood	25	5-50

Spray irrigation has the more efficient rates of water application than flood/contour/border-dyke irrigation. The main reason for the low efficiency in flood irrigation is that the high rate of application causes a significant proportion of the irrigated water to drain to depths greater than 300 mm, which is beyond the root systems of higher producing grass species, or it flows directly back into the stream or irrigation races (Lincoln Environment and Aqualinc, 2005). A number of New Zealand studies (e.g. McDowell and Rowley, 2008; Monaghan *et al*., 2009), which were conducted in catchments dominated by flood/border dyke irrigation, have shown that agricultural pollutants, such as nutrients, bacteria and sediment, are significantly elevated as a result of being entrained and transported over the paddock and back into water races or water ways. Due to the greater application efficiency of spray irrigation, there is a reduction in irrigation run-off. However, this is often offset by an increase of contaminants associated with diffuse discharges from land-use intensification, made possible through improved irrigation techniques.

2. Methods

This section outlines the methods that were followed to collect the water chemistry, physical habitat and ecological values in the Manuherikia catchment. The physico-chemistry section (2.1) outlines the analytes that were sampled, and the sampling frequency and guidelines that were adopted for the study. The physical assessment used key measures from the Physical Habitat Assessment Protocols (Harding *et al.*, 2009). The section on macroinvertebrate and fishery values outlines the methods used for selecting the habitat and for the collection and interpretation of data.

2.1 Physico-chemical assessment

Between September 2009 and September 2010, 17 streams (summarised in Figure 5) were sampled fortnightly with grab samples for physical, chemical and microbiological parameters, using standard collection protocols (APHA, 2006). These parameters included total phosphorus (TP), total nitrogen (TN), nitrite-nitrate nitrogen (NNN), ammoniacal nitrogen (NH_4), dissolved reactive phosphorus (DRP), *Escherichia coli* (*E. coli*) and suspended solids (SS). As well as water quality monitoring, we undertook permanent flow monitoring, by establishing permanent flow sites, or temporary flow recorders, at most sites. For sites where we attempted no flow recording, virtual flows were generated. A virtual flow or synthetic flow is created by spot gauging a site over a period of time and carrying out a regression with a nearby permanent or long-term flow site.

Sites were categorised into 'excellent', 'good', 'fair' and 'poor', according to their water quality. An 'excellent' classification meant that all of the six variables met guideline values; a score of 5 gave a 'good' classification; a score of 3 or 4 meant that the site was classified as 'fair', and 2 or less meant that the water quality at the site was 'poor'.

Manuherikia at Loop Road

Mean flow (cumecs): 4.76
Mean width (m): 15

Dunstan Creek at Beatties

Mean flow (cumecs): 2.73
Mean width (m): 8.9

Manuherikia at Blackstone

Mean flow (cumecs): 7.34
Mean width (m): 19.4

Manuherikia at US Ida Burn

Mean flow (cumecs): 9.31
Mean width (m): 23.5

Ida Burn upper

Mean flow (cumecs): 0.13
Mean width (m): 1.8

Ida Burn lower

Mean flow (cumecs): 0.76
Mean width (m): 6.6

Pool Burn upper

Mean flow (cumecs): 0.5
Mean width (m): 1.8

Pool Burn lower

Mean flow (cumecs): 0.98
Mean width (m): 5.3

Lauder Creek

Mean flow (cumecs): 1.05
Mean width (m): 2.8

Manuherikia at Omakau

Mean flow (cumecs): 11.23
Mean width (m): 15

Thomsons Creek upper

Mean flow (cumecs): 0.73
Mean width (m): 6.9

Thomsons Creek lower

Mean flow (cumecs): 0.96
Mean width (m): 2.1

Manuherikia at Ophir

Mean flow (cumecs): 12.18
Mean width (m):

Chatto Creek

Mean flow (cumecs): 0.96
Mean width (m): 6

Manuherikia US Chatto Creek

Mean flow (cumecs): 11.48
Mean width (m):28

Manuherikia at Galloway

Mean flow (cumecs): 12.43
Mean width (m): 26

Dovedale at Rocks Bluff

Mean flow (cumecs): 0.05
Mean width (m): 0.5

Figure 5. Photographic summary of each sampling site (at the time of ecological surveying), including mean flow (for the investigation period) and mean width for the wetted channel at the time of ecological surveying

2.2 Water quality guidelines

The guideline values in this report have been chosen to reflect the nature of the Manuherikia catchment (Table 3). Where possible, we have used guideline standards that can detect discernable effects on ecological, angling and contact recreation. The ANZECC (2000) guidelines are referenced for NH_4, TN and TP guideline values, while the biologically available nutrients (DRP and NNN) are referenced against the New Zealand Periphyton Guidelines (Biggs, 2000) The guideline values for the Manuherikia catchment are based on an N-limited system, with an accrual period of 33.1 days. Accural periods where calculated by working out the average number of days between flow events that were three times higher than median flow. The appropriate NNN and DRP concentrations were then selected from Biggs (2000), based on the appropriate number of accrual days.

Bacteria guidelines were drawn from the MfE/MoH microbiological water quality guidelines (2003) for human health. Suspended solid (SS) guidelines were drawn from the Cawthron Institute (Rodger and Young, 1999), where 5 NTU was found to be the maximum turbidity value before there was an effect on drift-feeding trout growth potential. A regression between SS and turbidity data (R^2=0.86) on long-term SOE data from the Manuherikia River at Galloway gave a suspended solid value of 10.31 mg/l.

Table 3. Physico-chemical and microbiological analytes and guideline values

Analyte	Guideline value	Ecological effect
NH_4	$\leq$0.9 mg/l*	High levels of ammonia are toxic to aquatic life, especially fish. The level of total ammonia in water should be less than 0.88 grams per cubic metre to be safe for fish. Ammonia in waterways comes from either waste waters or animal wastes (dung and urine).
TN	$\leq$0.614 mg/l*	Encourages the growth of nuisance aquatic plants. These plants can choke waterways and out-compete native species. High levels can be a result of run-off and leaching from agricultural land.
NNN	$\leq$0.075 mg/l**	The biologically available component of TN, an excess of this nutrient may cause nuisance algal growths
TP	$\leq$0.033 mg/l*	Encourages the growth of nuisance aquatic plants, which can choke waterways and out-compete native species. High levels can be a result of either waste water or, more often, run-off from agricultural land
DRP	$\leq$0.006 mg/l**	The biologically available component of TP, an excess of this nutrient may cause nuisance algal growths
E.coli	<126 cfu/100 ml*** (^1) <260 cfu/100 ml (^2) 260-550 cfu/ 100 ml (^3) <550 cfu/ 100 ml	*E. coli* bacteria are used as an indicator of the human health risk from harmful micro-organisms present in water; for example, from human or animal faeces.
SS	$\leq$10.3 mg/l^^	Suspended solids smother larger substrate reducing available habitat for macroinvertebrates and fish. Nutrients may attach to sediments. High levels may affect clarity and photosynthesis. High levels also make it difficult for fish and other animals to see their prey.

*ANZECC & ARMCANZ (2000), **Biggs (2000), ***ANZECC (1992), ^MfE/MoH (2003) - ^1 = acceptable level, ^2 = alert level, ^3 = action level, ^^Cawthron (1999)/ ORC 2010: This value is based on taking the 5 NTU (turbidity) guideline recommended by Rodger and Young (1999) as the value that compromises trout growth potential and then applying the NTU value to a regression equation based on long turbidity and SS data from our SOE sampling site at Manuherikia at Ophir.

2.3 Physical habitat assessment

Habitat availability is an important determinant for ecological values (Death, 2000; Quinn, 2000). Physical habitat condition was assessed at all 17 sites during baseline summer flows in December 2010. Protocol 3c from the Stream Habitat Assessment Protocols (Harding *et al.*, 2009) was used for this investigation. This method requires the establishment of a total of six cross sections (two from each of pools, riffles and runs). From these cross sections, a variety of instream habitat features are measured to calculate the total percentage of the cross section each habitat occupies. Such habitat includes macrophytes, algae, leaf packs, large woody debris (longest axis greater than 20 cm) and the extent of undercut banks. There is also a count for large obstructions to flow, such as boulders and log jams. Along each transect the degree of substrate embeddedness and compactness was noted. The scoring and definitions of embeddedness and compactness are given in Table 4.

Table 4. Scores for the degree of embeddedness and compactness (Harding *et al.*, 2009)

Score	Substrate embeddedness	Substrate compactness
1	Not embedded, the substrate on top of the bed	Loose, easily moved substrate
2	Slightly embedded, >25% of the particle is buried or attached to the surrounding substrate	Mostly loose, little compaction
3	Firmly embedded, approximately 50% of the substrate is embedded or attached to the surrounding substrate	Moderately packed
4	Heavily embedded, >66% of the substrate is buried	Tightly packed substrate

'Embeddedness' is an indication of how much of the dominant substrate is buried by finer sediment. 'Compactness' is a measure of how tightly packed substrate is. Under certain conditions (e.g. frequent flash flows or sedimentation), substrate can become highly compacted. When this happens, bed substrate can become very stable, which adversely affects steam biological health by reducing or eliminating interstitial spaces, the habitat used by macroinvertebrates and fish.

On each transect, ten pieces of substrate were measured along their longest axis, and the total length of deposition and scouring was measured.

For this report, each stream was given a categorical rank of 'excellent', 'good', 'fair' or 'poor', by adding up each stream's respective scores for embeddedness, compactness and fine sediment. For fine sediment, each site was given a rank of between 1 and 4. These ranks were based on the range of fine sediment cover present: 1 = 0-20%, 2 = 21-40, 3 = 41-60, 4 = 61+. 'Excellent' habitat occurred with scores of 3-4; 'good' was between 5 and 7; 'fair' 8-10 and 'poor' between 11 and 12.

2.4 Biological assessment

2.4.1 Macroinvertebrates

Aquatic macroinvertebrates are organisms that live on or within the bottom substrate in rivers and streams (e.g. rocks, gravels, sands, silts, organic matter, such as macrophytes, or organic debris, such as logs and leaves). Examples of aquatic macroinvertebrates include insect larvae (e.g. mayflies, stoneflies, caddisflies and beetles), aquatic oligochaetes (worms), snails and crustaceans (e.g. amphipods and crayfish). These macroinvertebrates are a useful tool to assess the biological health of a river because they are found everywhere and they have different tolerances to temperature, dissolved oxygen, sediment and chemical pollution. Thus, the presence or absence of taxa can provide significant insight into long-term changes in water quality.

Macroinvertebrate communities were sampled in 17 sites in December 2010. At each site, three Surber samples (250µm; 0.062 m^2) were collected, using Protocol c3: Hard-bottomed, quantitative sampling of stream macroinvertebrate communities (Stark *et al*., 2001). We collected samples from riffle habitat by setting the Surber sample, and then vigorously disturbing the stream substrate until the macroinvertebrates were dislodged. Samples were preserved in 90% ethanol in the field and then processed in the laboratory.

In the laboratory, the samples were passed through a 500 µm sieve to remove fine material. The sieve contents were then placed in a white tray, and the macroinvertebrates were identified under a dissecting microscope (10-40X), using the identified key by Winterbourn *et al*., (2000).

While there are no guideline values currently in place for macroinvertebrate community indices, the commonly accepted categories are summarised Table 5. The indices often used to measure stream health are summarised below:

Species richness: The total number of species (or taxa) collected at a sampling site. In general, high species richness may be considered good; however, mildly impacted or polluted rivers, with slight nutrient enrichment, can have higher species richness than un-impacted, pristine streams.

Ephemeroptera Plecoptera and Trichoptera (EPT) Richness: EPT is an index that represents the sum of the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) species collected. These groups of insects are often the most sensitive to organic and mineral pollution; therefore, low numbers of these species might indicate a polluted environment. In some cases, the percentage of EPT species compared to the total number of species found at a site can give an indication of the importance of these species in the overall community.

Macroinvertebrate Community Index **(MCI)**: The MCI uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. Taxa are scored between 1 and 10. One represents taxa that are highly tolerant of organic pollution, while 10 represents taxa that are sensitive to organic pollution. The MCI score is obtained by adding the scores of individual taxon and dividing this total by the number of taxa present at the site.

Quantitative Macroinvertebrate Community Index **(QMCI)**: The QMCI uses the same method as the MCI scores but weighs each taxon score according to the abundance of that taxon in the community. Scores range from 0 (severely polluted) to 10 (very clean).

Table 5. Criteria for aquatic macroinvertebrate health according to different macroinvertebrate indices. There are no guidelines for macroinvertebrate communities; however, these are the accepted criteria (Stark *et al.*, 2001).

Macroinvertebrate index	Poor	Fair	Good	Excellent
Total species	<10	15-20	20-30	>30
Total EPT species	<5	5-15	15-20	>20
MCI	<80	80-99	100-119	>120
QMCI	<4.00	4-4.99	5-5.99	>6

2.4.2 Fish communities

All of the tributary sites of the Manuherikia River were electro-fished to see how fish species composition and density varied between sites. A 100 m^2 reach was fished at each of the water quality sites; the reach was isolated with top and bottom stop nets extending across its width. Unfortunately, flows in the Manuherikia main stem were too high for electric-fishing to be undertaken.

For the tributary sites, each site was fished by three-pass downstream electric-fishing, using a pulsed DC Kainga EFM300 backpack electro-shocker. We allowed a 15-minute rest period between electric passes so that the fish could settle. The backpack operator used a sieve dip net, while another team member used a pole net immediately below the electro-shocker. A third member carried buckets for fish collection. In all, there were three experienced operators at all sites. Fish from each pass were kept separate, counted and released after the third electric-fishing pass. At each site, native fish were identified and counted, while trout were counted, weighed in grams and measured in length from the tip of the snout to the caudal fork.

2.4.3 Fish density classes

We used the following method to compare the relative fish densities recorded from the tributaries of the Manuherikia catchment with those in other Clutha catchment streams. To classify the streams for fish density, we used NIWA's New Zealand Freshwater Fish Database (NZFFD) to obtain fish density data for other sites in the Clutha catchment (based on three pass electric-fishing over a known area (m^2)). We also used data collected by ORC and Fish & Game Otago. All sites were ranked on fish density per square metre (total fish density, brown trout density and non-migratory galaxiid density) and then broken into quartiles. For the purposes of this report, each quartile was classed as 'excellent', 'good', 'fair' or 'poor', based on their relative density to the entire Clutha data set.

3. Results

3.1 Water quality

This section provides an assessment of the intensive water quality monitoring of streams undertaken during the 12 months of this study. The data are also compared to long-term SoE monitoring data.

Water quality results were flow adjusted to take into account flow variability between seasons and that different-sized rivers have different assimilation capacities (e.g. the Manuherikia River has a larger assimilation capacity than the Pool Burn). Each graph contains two columns: the blue column represents the flow-weighted median concentration for all samples; while the red column shows the flow weighted median concentrations for samples taken when flows were below median flow. The following text refers to these as 'all flows' and 'low flows'. This method also allows us to know the relative load that the various tributaries contribute to the main stem.

3.2 Nutrients

NNN concentrations were excessively above the guideline at Ida Burn lower and Pool Burn upper at all flows (Figure 6). Chatto Creek was the only site where NNN concentrations were slightly higher during low flow conditions and where the guideline value was exceeded.

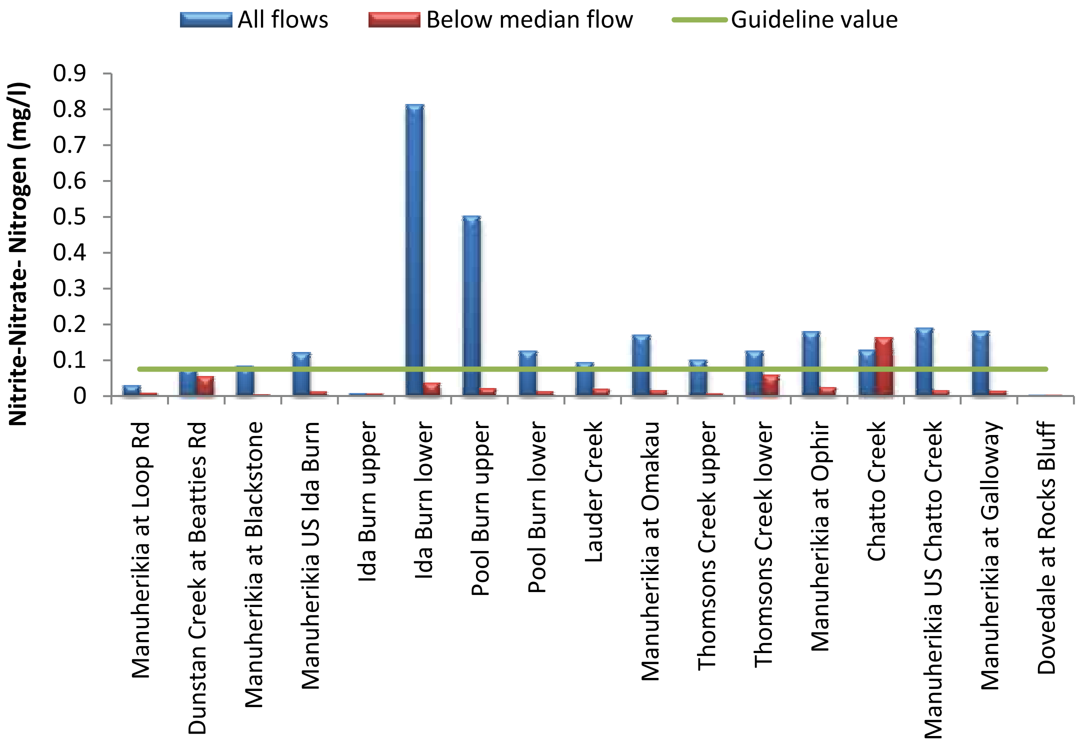

Figure 6. Flow weighted median concentrations of NNN for all flows (blue column) and below median flows (red column)

Load graphs (Figure 7) show how much NNN each sampling site contributes throughout the year of the sampling regime. Figure 7 shows that both of the Pool Burn sites, Ida Burn upper, Dunstan Creek at Beattie's Road, Chatto Creek and Dovedale Creek contribute very little NNN in the way of load. Of the tributaries, Thomsons Creek lower does contribute a substantial volume of NNN. Manuherikia at Ophir had the highest NNN load of all the sites.

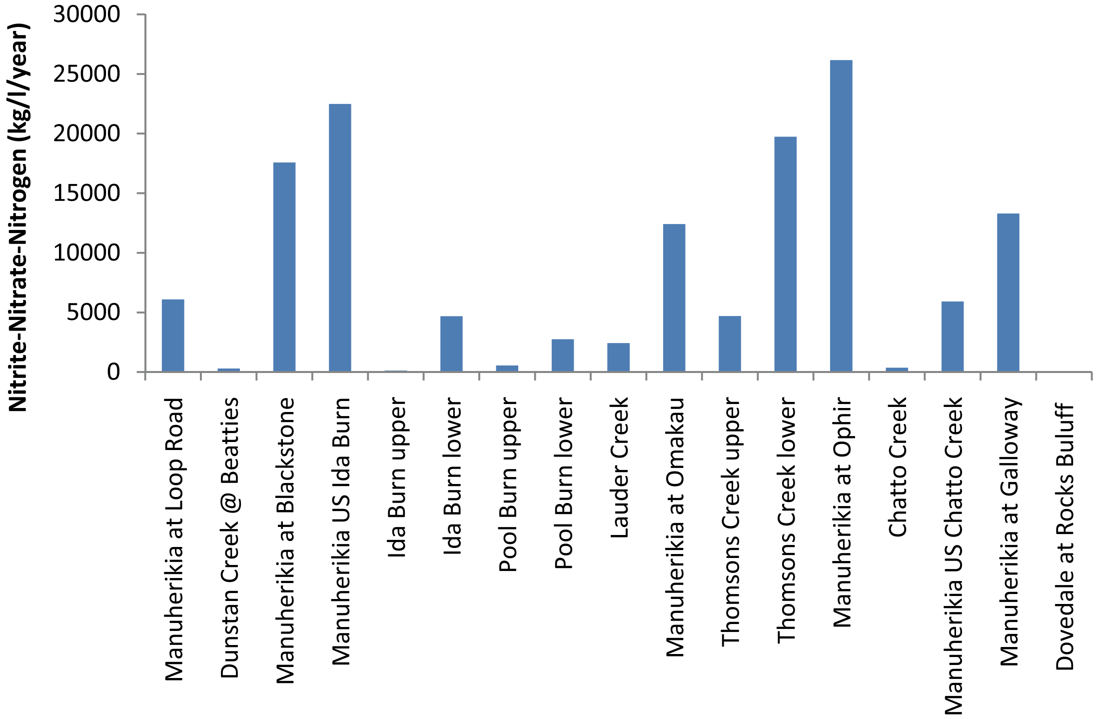

Figure 7. Graph of loads of NNN in the Manuherikia catchment

The lowest DRP concentrations were found in the upper catchment, although the Manuherikia, upstream of the Ida Burn confluence, was above the guideline for both flow conditions (Figure 8). During low flows, concentrations of DRP were very high at Ida Burn lower, both Pool Burn sites and Thomsons Creek lower. There was also a notable increase in DRP concentrations between Manuherikia at Omakau and Manuherikia at Ophir. There was a general increase in DRP concentrations downstream of the Manuherikia River, as different tributaries enter.

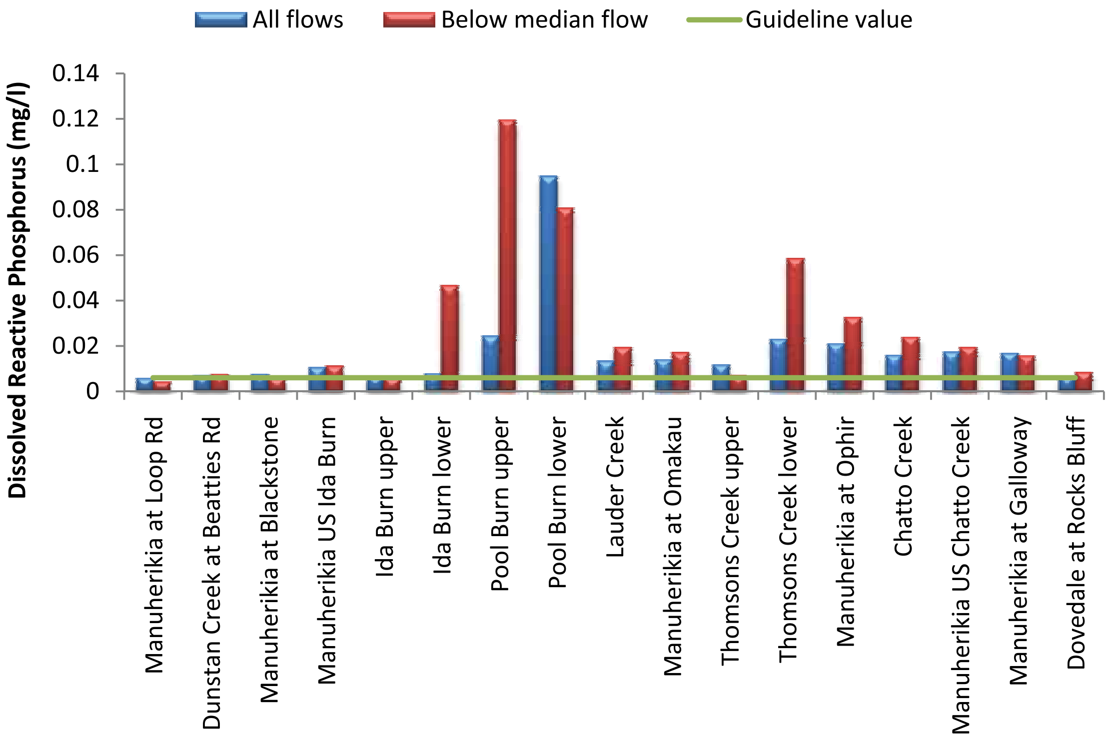

Figure 8. Flow weighted median concentrations of DRP for all flows (blue column) and below median flows (red column)

Total loads of DRP were highest in the Thomsons Creek lower, followed by Manuherikia at Ophir. The remainder of the tributaries had negligible amounts of DRP relative to the main-stem sites (Figure 9).

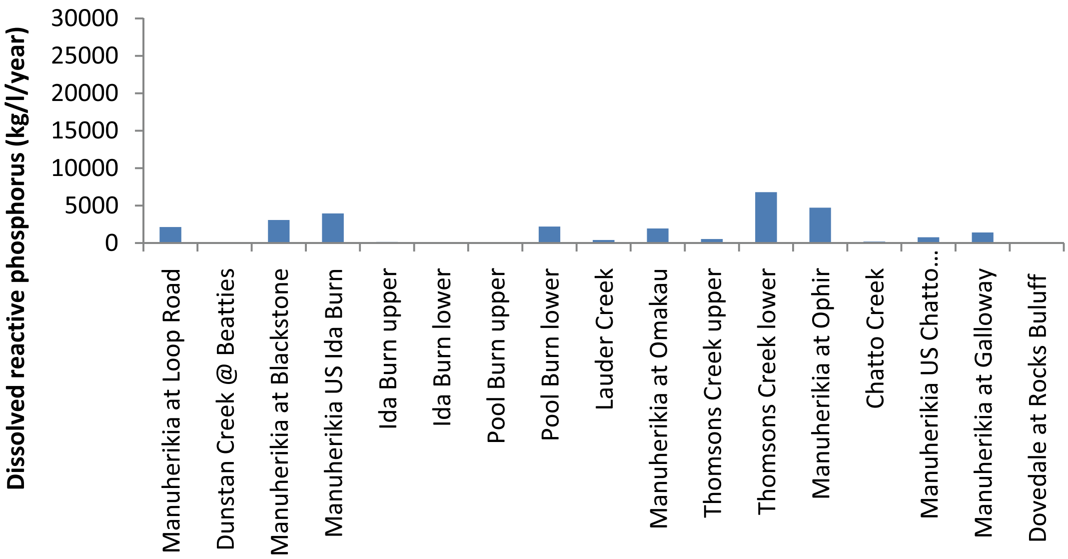

Figure 9. DRP loads for all sampling sites in the Manuherikia catchment

Ratios between NNN and DRP suggest that all streams are N-limited (Figure 10).

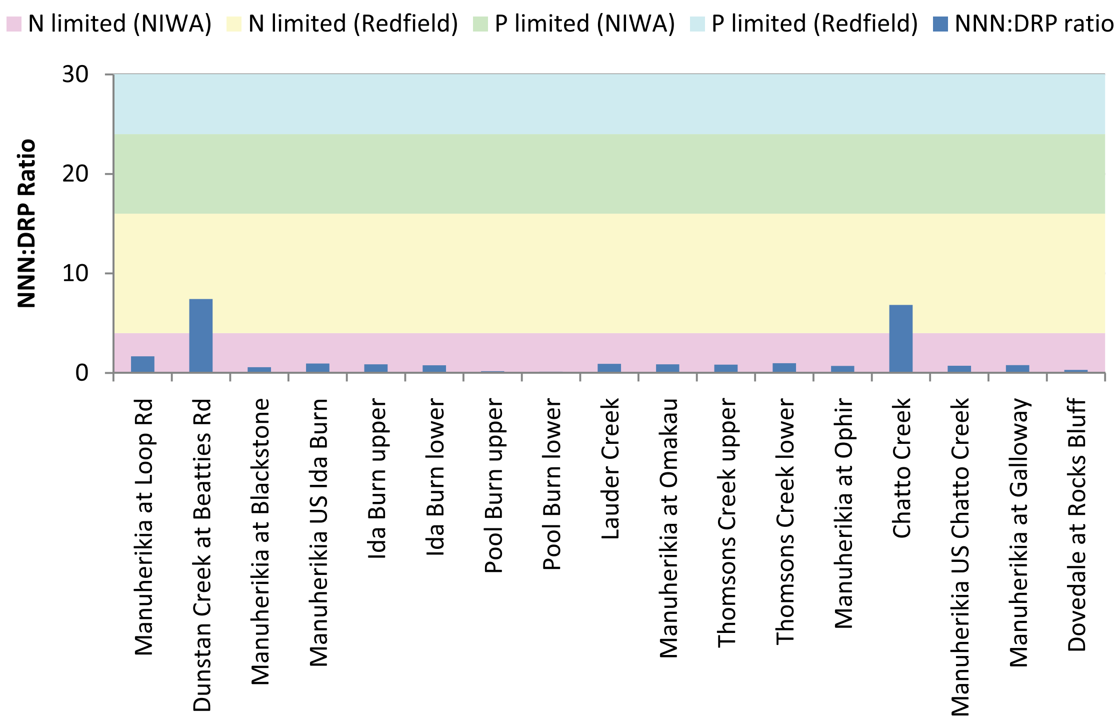

Figure 10. NNN and DRP ratios in the Manuherikia catchment

Definition of 'Redfield ratio':

The optimal N/P ratio for phytoplankton growth, the 'Redfield ratio', is 16:1 (based on molecular concentrations). Large differences from 16 at low N/P ratios can be an indication of potential nitrogen limitation; whereas large differences at high N/P ratios can suggest potential phosphorus limitation of the primary production of phytoplankton.

Definition of 'molar concentration':

Molar concentration = $c_i = n_i / V$, where c_i is defined as the amount of a constituent n_i, divided by the volume of the mixture V

Definition of 'nutrient limitation':

A limiting nutrient is defined as 'that element in shortest supply relative to demands for plant growth'. Adding a limiting nutrient will stimulate plant growth (i.e. net primary productivity) more than adding any other element. Co-limitation by two or more nutrients is possible.

TN concentrations were mostly higher when all flows were considered, as opposed to at low flows only. The exceptions were Lauder Creek lower, Chatto Creek and Thomsons Creek lower (Figure 11). Most sites were below the ANZECC guideline, but Ida Burn lower exceeded the guideline during all flow conditions and both sites on the Pool Burn exceeded it for all flows and low flows. Thomsons Creek lower was the only site to exceed the guideline value at low flows only.

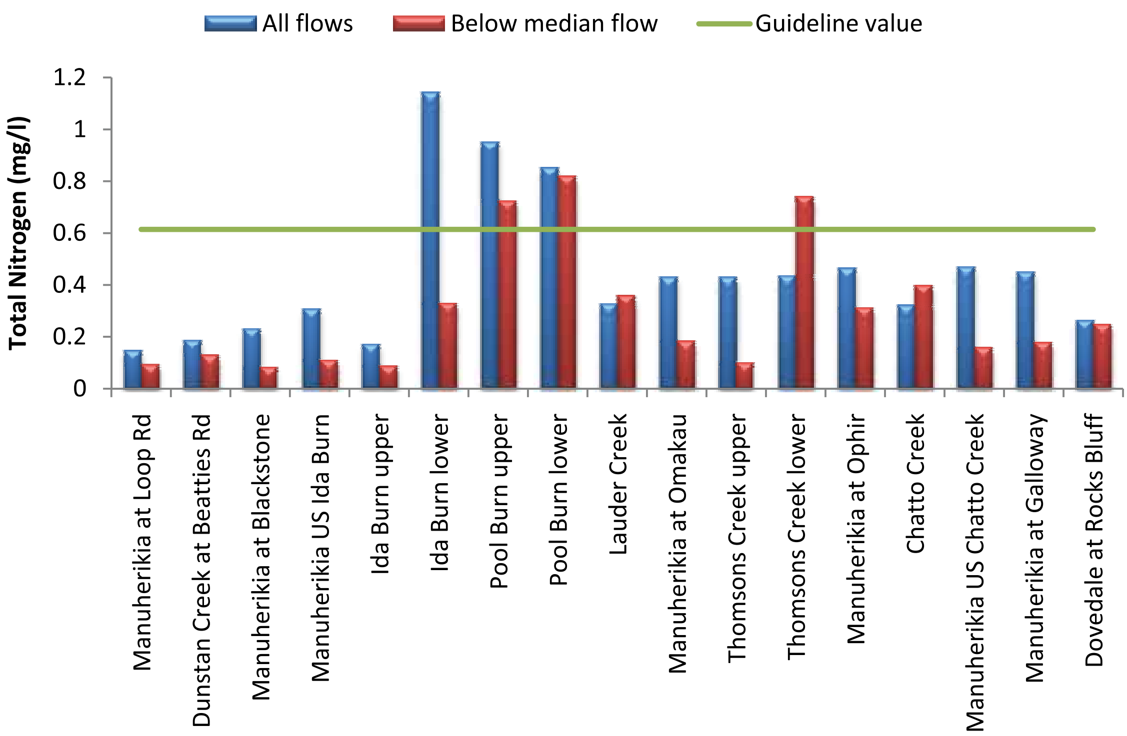

Figure 11. Flow weighted median concentrations of TN for all flows (blue column) and below median flows (red column)

Figure 12 shows that TP exceeded the guideline at most sites during the study period. The upper catchment sites had the lowest concentrations for both all and low flows. The Manuherikia River main-stem sites showed TP to be higher during all flows than at low flows only. In comparison, Ida Burn lower, Pool Burn upper and lower, as well as Thomsons Creek lower, Lauder Creek, Dovedale Creek and Chatto Creek, had higher concentrations during low flows.

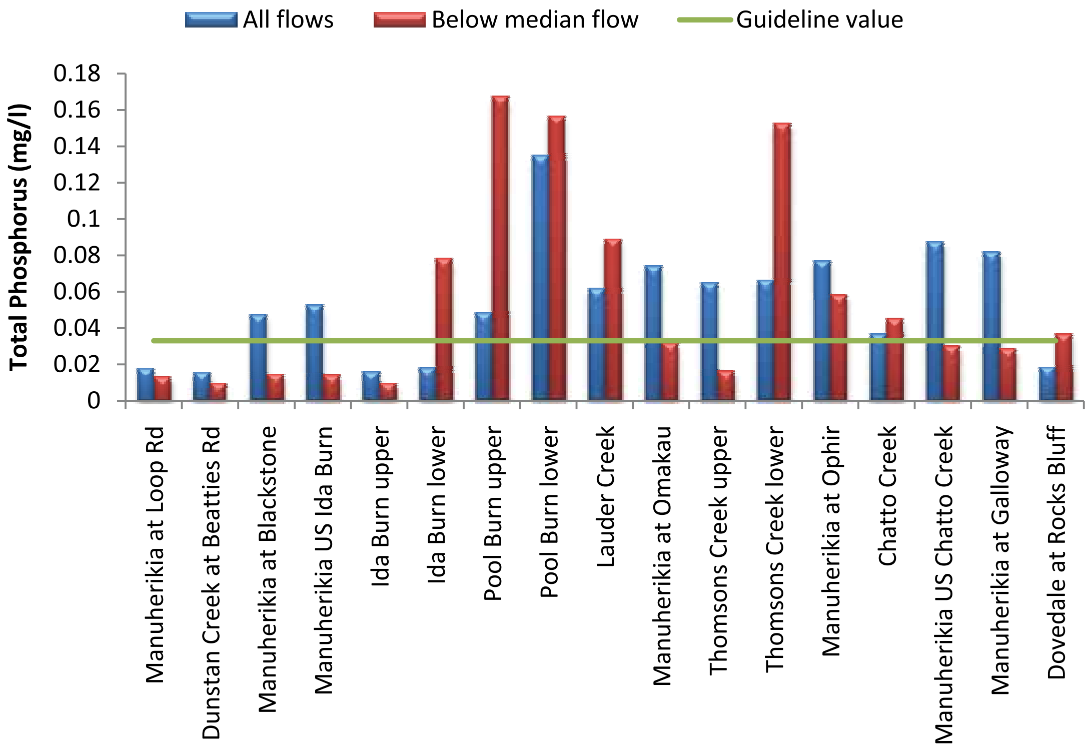

Figure 12. Flow weighted median concentrations of TP for all flows (blue column) and below median flows (red column)

3.3 Bacteria

Concentrations of *E. coli* were below the recommended median value stipulated by the Ministry of Health guideline for the top sites for all flows, except Thomsons Creek upper (Figure 13). The concentration of *E. coli* exceeded the guideline at Ida Burn lower, both the Pool Burn sites, Lauder Creek, Thomsons Creek lower, Chatto Creek, Manuherikia at Ophir and Dovedale Creek during low flows. Manuherikia at Ophir had the highest concentrations for all the Manuherikia River main-stem sites.

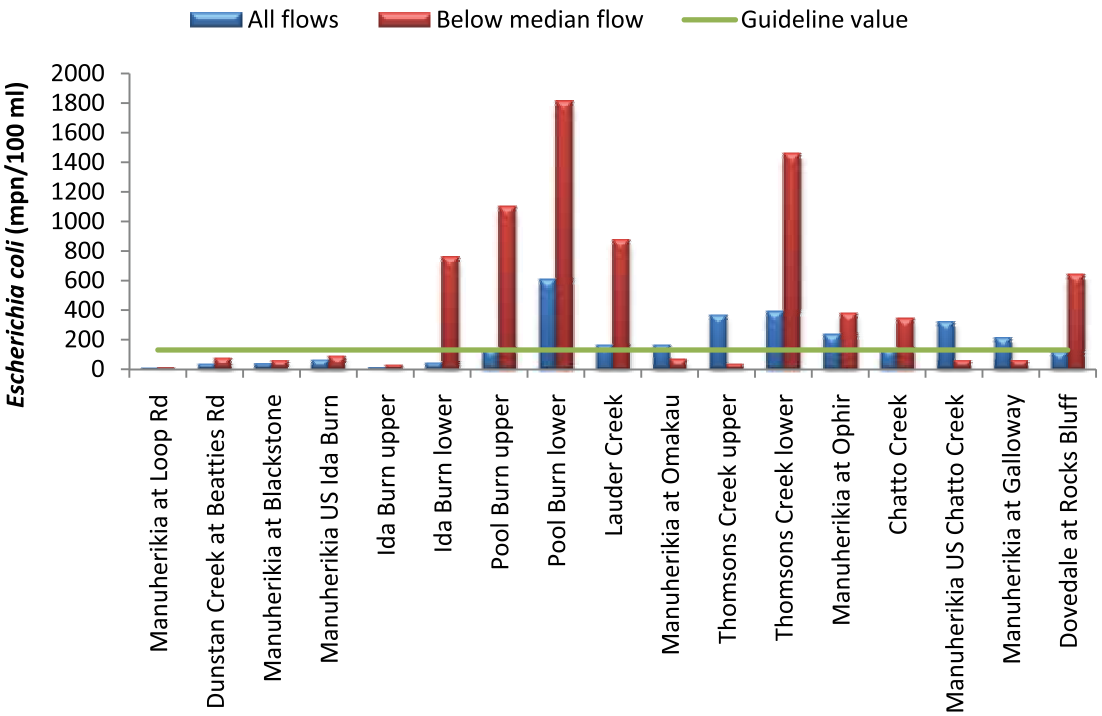

Figure 13. Flow-weighted median concentrations of *E. coli* for all flows (blue column) and below median flows (red column)

Thomsons Creek contributes a considerable amount of *E. coli*, while many of the tributaries (except Pool Burn lower) contribute negligible amounts (Figure 14). Of the main-stem sites, very little was found at the top sampling site (Manuherikia at Loop Road), while the highest load on the main stem (second highest overall) was found on the Manuherikia at Ophir.

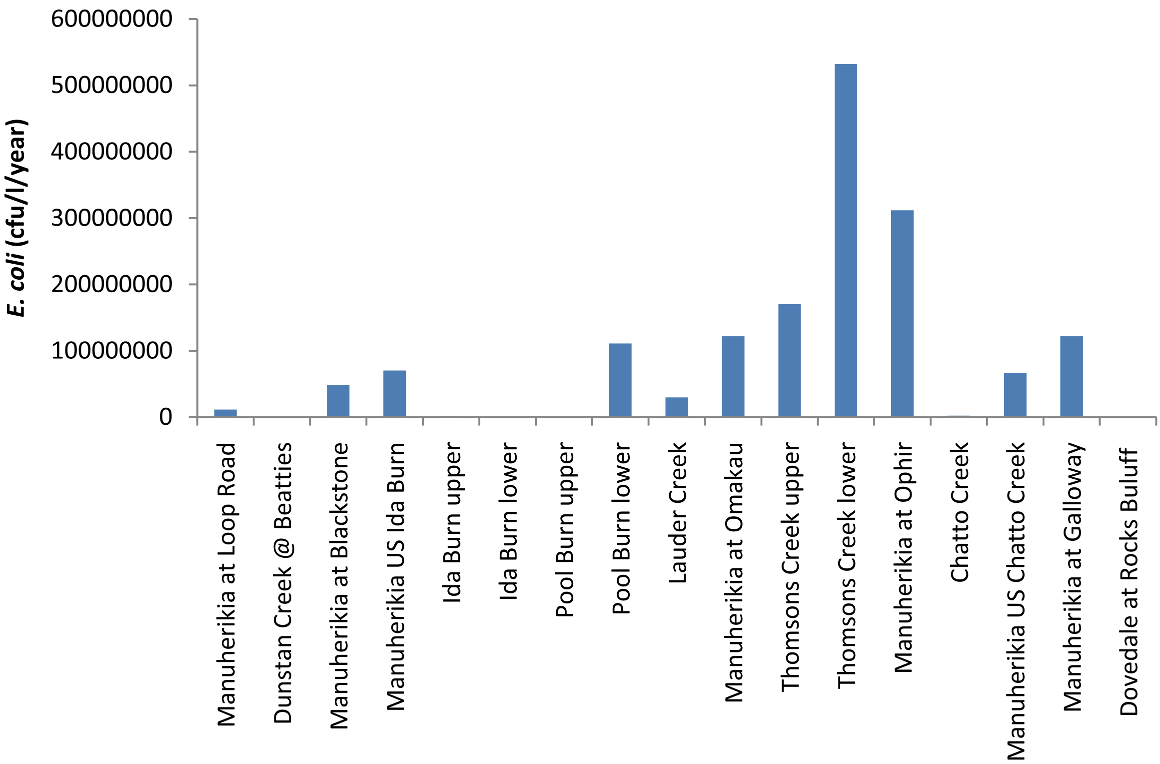

Figure 14. Loads of *E. coli* for all sampling sites in the Manuherikia catchment

3.4 Sediment

SS concentrations often exceeded the guideline value when all flows were considered. SS concentrations were below the guideline for all sites when flows were low, with the exception of Thomsons Creek lower and Lauder Creek (Figure 15).

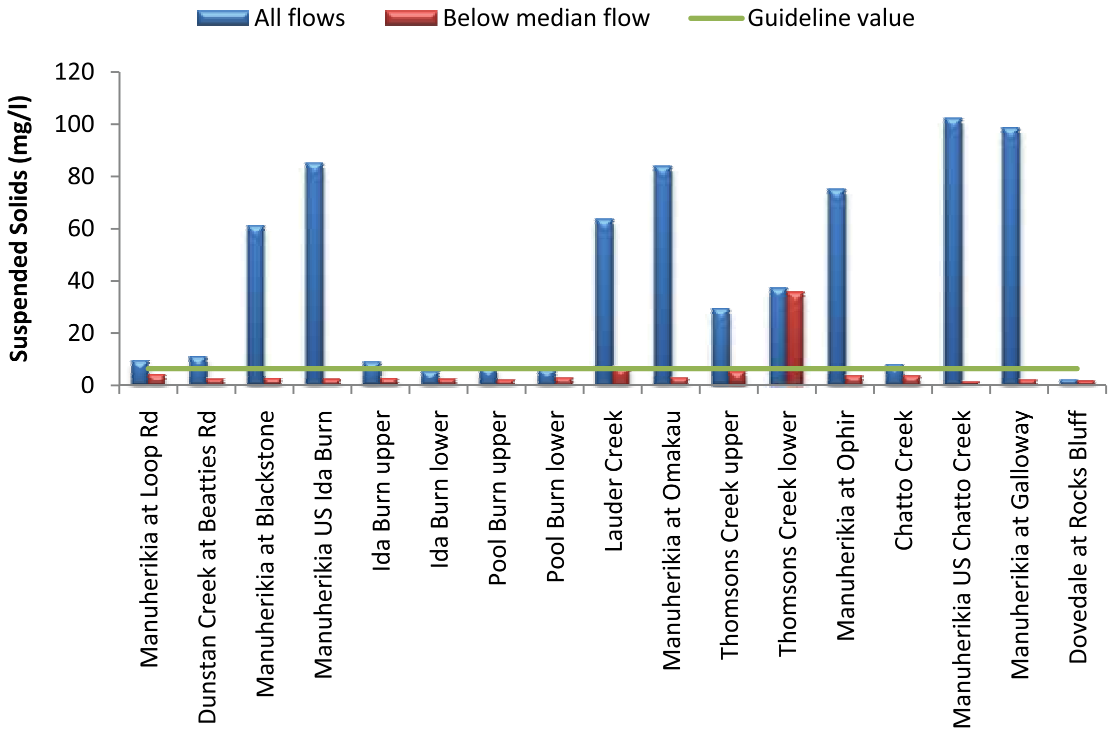

Figure 15. Flow-weighted median concentrations of SS for all flows (blue column) and below median flows (red column)

The median values (only for below median flows) were assessed against water quality guidelines (Table 3) chosen to protect local instream standards. NH_4 was not included in this assessment, as all sites passed the guideline value for this parameter. Table 6 indicates that the majority of sites have 'excellent' or 'good' water quality. Thomsons Creek is the only site to have 'poor' water quality.

Table 6. The median concentration of each contaminant (at below median flows) is compared to the guideline value. The bolded numbers indicate that guideline concentration is exceeded. Sites have then been classified as having 'excellent', 'good', 'fair' or 'poor' water quality.

Guideline	DRP <0.006 mg/l	TP <0.033 mg/l	NNN <0.075 mg/l	TN <0.614 mg/l	*E. coli* <126 cfu/ 100 ml	SS <10.3 mg/l	Grade
Manuherikia River at Loop Road	0.004	0.013	0.007	0.091	9	3.972	Excellent
Dunstan Creek at Beatties Road	**0.007**	0.010	0.054	0.129	73	2.347	Good
Manuherikia River at Blackstone	**0.006**	0.014	0.003	0.083	56	2.670	Excellent
Manuherikia US Ida Burn	**0.011**	0.014	0.010	0.109	86	2.224	Good
Ida Burn upper	**0.006**	0.009	0.005	0.086	27	2.653	Excellent
Ida Burn lower	**0.046**	**0.078**	0.036	0.328	**757**	2.282	Fair
Pool Burn upper	**0.119**	**0.167**	0.021	**0.722**	**1099**	2.031	Fair
Pool Burn lower	**0.080**	**0.156**	0.011	**0.819**	**1816**	2.740	Fair
Lauder Creek	**0.019**	**0.089**	0.017	0.358	**874**	6.961	Fair
Manuherikia River at Omakau	**0.017**	0.032	0.015	0.184	68	2.723	Good
Thomsons Creek upper	**0.007**	0.016	0.006	0.099	30	5.352	Good
Thomsons Creek lower	**0.058**	**0.153**	0.057	**0.739**	**1458**	**35.573**	Poor
Manuherikia River at Ophir	**0.032**	**0.058**	0.023	0.310	**377**	3.575	Fair
Chatto Creek	**0.024**	**0.045**	**0.162**	0.396	**341**	3.537	Fair
Manuherikia US Chatto Creek	**0.019**	0.030	0.014	0.157	57	1.437	Good
Manuherikia at Galloway	**0.016**	0.028	0.012	0.178	59	2.139	Good
Dovedale at Rocks Bluff	**0.008**	**0.037**	0.003	0.247	**643**	1.726	Good

3.5 Comparison of long-term SOE data and project data

There are five long-term SOE monitoring sites in the Manuherikia catchment: Dunstan Creek at Beatties Road (since 2001); Manuherikia at Galloway (since 2000); Manuherikia River at Ophir (since 2006); Pool Burn upper (since 2003) and Ida Burn lower (since 2003). Kruskal-Wallis tests (Appendix 1) were used to detect significant changes between the long-term SOE data and the data from this monitoring programme. The results of significant increases or decreases between the two periods are summarised in Table 7.

Table 7. Summary of significant ($P < 0.05$) differences between two water quality data sets: long-term SoE data and this investigation

Analyte	Dunstan Creek at Beatties Road	Manuherikia River at Ophir	Manuherikia at Galloway	Pool Burn upper	Ida Burn lower
DRP		increase	increase		
TP		increase	increase		
NNN	increase				
TN					
NH_4	decrease	increase	decrease	decrease	decrease
E. coli		increase			
SS				increase	

3.6 Physical habitat

The majority of streams had very little fine sediment build-up on the stream bed; consequently, embeddedness was also low with most sites ranked between 1 and 2 (Table 8). The exception to this was the Pool Burn upper, which was completely covered with fine sediment, and Lauder Creek, which was dominated by small sediment (5-10 mm diameter) (Table 8). The main stem of the Manuherikia River had the highest median substrate size, while Pool Burn upper had the lowest (2 mm) (Table 8).

Table 8. Summary results of physical habitat in 17 streams

Site	Compactness	Embeddedness	Median substrate size (mm)	Percentage of fine sediment
Manuherikia River at Loop Road	3	1	135.5	7
Dunstan Creek at Beatties Road	2	1	74.9	8
Manuherikia River at Blackstone	2	2	80.5	6
Manuherikia US Ida Burn	2	2	87.8	3
Ida Burn upper	1	1	61.7	3
Ida Burn lower	2	1	24.8	8
Pool Burn upper	1	4	2	100
Pool Burn lower	2	1	83.5	4
Lauder Creek	2	4	9.85	90
Manuherikia River at Omakau	2	2	89.3	4
Thomsons Creek upper	2	1	108	3
Thomsons Creek lower	3	1	73.4	4
Manuherikia River at Ophir	2	2	113.05	3
Chatto Creek	2	2	55	5
Manuherikia US Chatto Creek	3	2	80.6	2
Manuherikia at Galloway	3	2	82.8	3
Dovedale at Rocks Bluff	2	2	39.2	10

3.7 Stream biology

3.7.1 Macroinvertebrates

Three replicate Surber samples were collected from each sampling site in December 2010 during base-flow conditions. QMCI scores were the highest in Dunstan Creek at Beatties Road, which was classified as being in 'excellent' condition (Figure 16). This was followed by Chatto Creek and the Manuherikia at Blackstone, which were in 'good' condition. Both Thomsons Creek sites were also 'good'. Ida Burn lower achieved the lowest QMCI score, followed by Pool Burn upper. Out of the 17 sites sampled, eight were classified as having 'poor' QMCI scores.

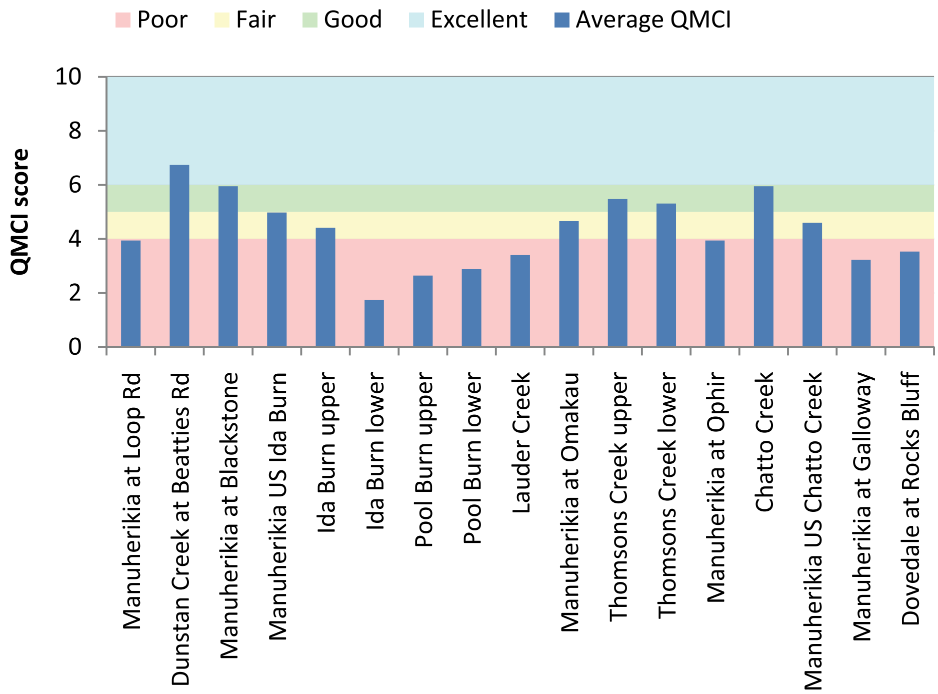

Figure 16. Average QMCI scores for all sampling sites

MCI scores were the highest in Dunstan Creek at Beatties Road, which was the only site to achieve an 'excellent' MCI score (Figure 17). This macroinvertebrate community was dominated by *Deleatidium* mayflies, *Stenoperla* stoneflies and cased caddisflies (primarily *Pycnocentrodes* and *Olinga* species). Pool Burn upper was the only site that fell into the 'poor' category. This site was dominated by worms and snails (*Potamopyrgus antipodarum*). Manuherikia upstream of the Ida Burn confluence and Thomsons Creek upper had 'good' scores, while the remaining sites fell into the 'fair' category. These sites were dominated by the cased caddis *Pycnocentrodes* and *Deleatidium* mayflies.

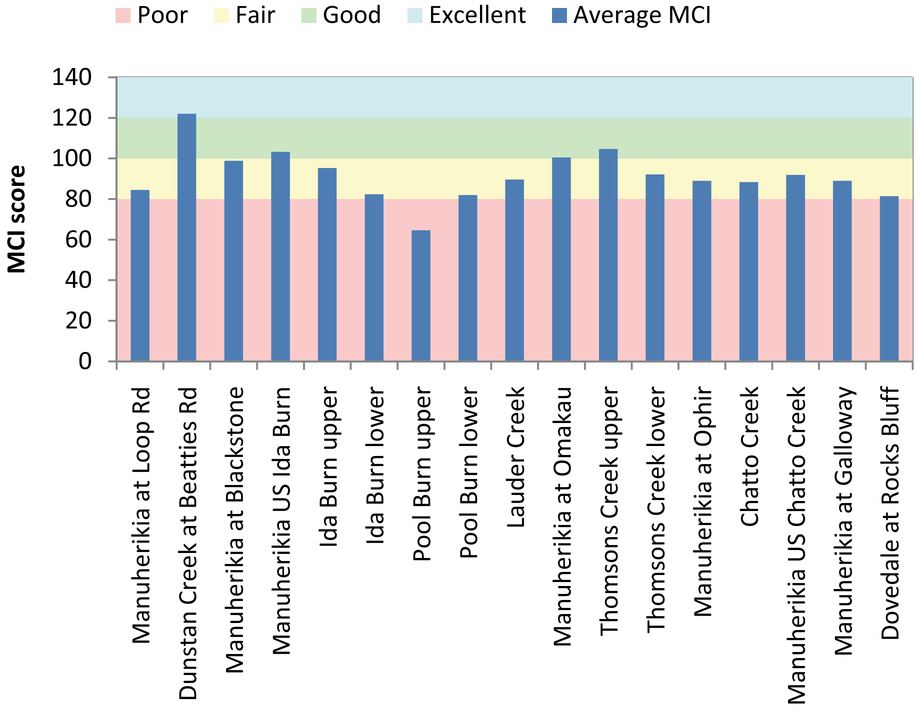

Figure 17. Average MCI scores for all sample sites

The percentage of the macroinvertebrate community consisting of EPT taxa was highly variable (Figure 18). Dunstan Creek at Beatties Road had the highest percentage of EPT taxa (92%), followed by Thomsons Creek lower (78%) and Manuherikia River at Blackstone (78%). The lowest percentage composition was in the Pool Burn upper with 0.4%. The control sites of Ida Burn lower and Dovedale Creek had macroinvertebrate communities consisting of 42% and 13% EPT taxa, respectively.

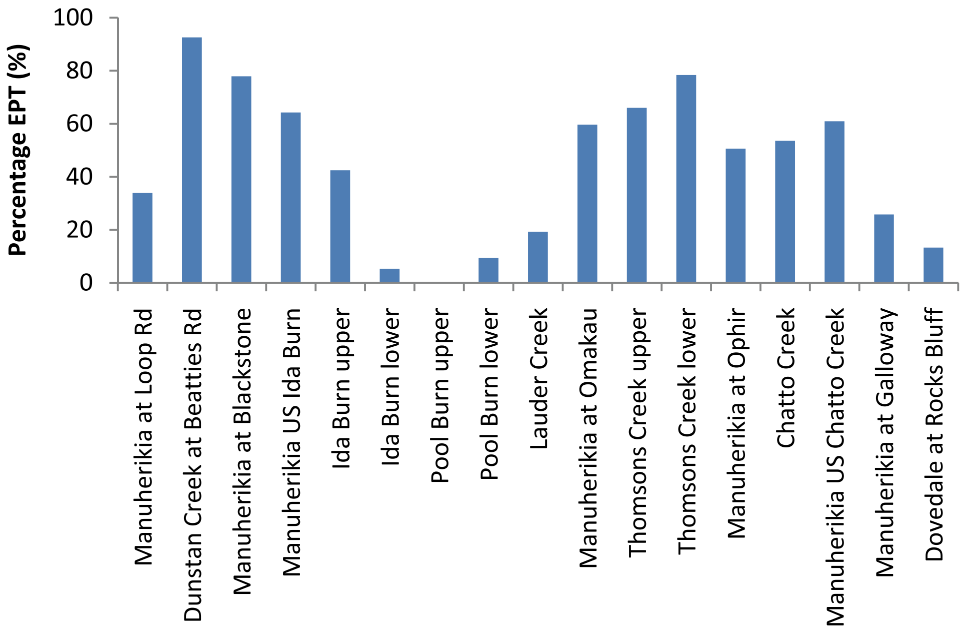

Figure 18. Percentage of the macroinvertebrate community comprising EPT taxa at all sites

3.7.2 Fish

Electric-fishing was undertaken in early January 2011, but due to high river flows, only seven sites were successfully fished. A second attempt was made to fish the remaining sites in late March, but river levels were still too high. Of the sites that were fished, only the Pool Burn upper contained no fish (Figure 19). The most common fish present throughout the sampled streams were Brown Trout. This was followed by Roundhead galaxiids, Upland Bullies and freshwater crayfish. One Perch was caught, as were two Longfin eels. The highest number of species was found in the Ida Burn lower, with four species present, two of which were native (Long Fin eels and Roundhead galaxiid). Only Brown Trout were caught in both the Ida Burn upper and Chatto Creek, while Dovedale Creek at Rocks Bluff had only native fish present: the Roundhead galaxiid and freshwater crayfish.

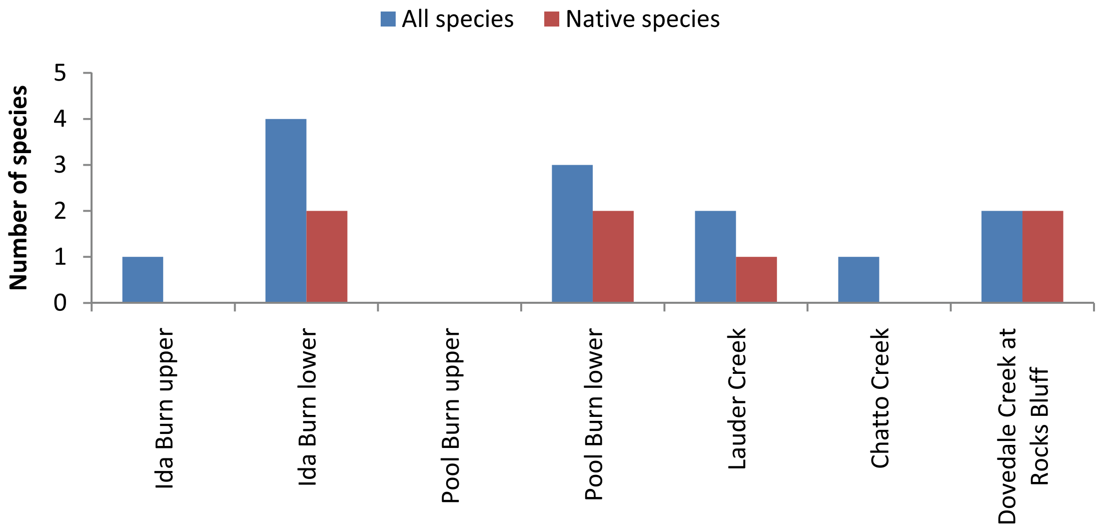

Figure 19. Total number of fish species present. (Only sites that were fished are included)

Brown Trout densities were 'excellent' in the Ida Burn upper (Figure 20). Both the Pool Burn lower and Chatto Creek had 'fair' Brown Trout populations. No Trout were caught at either Dovedale Creek or Pool Burn upper.

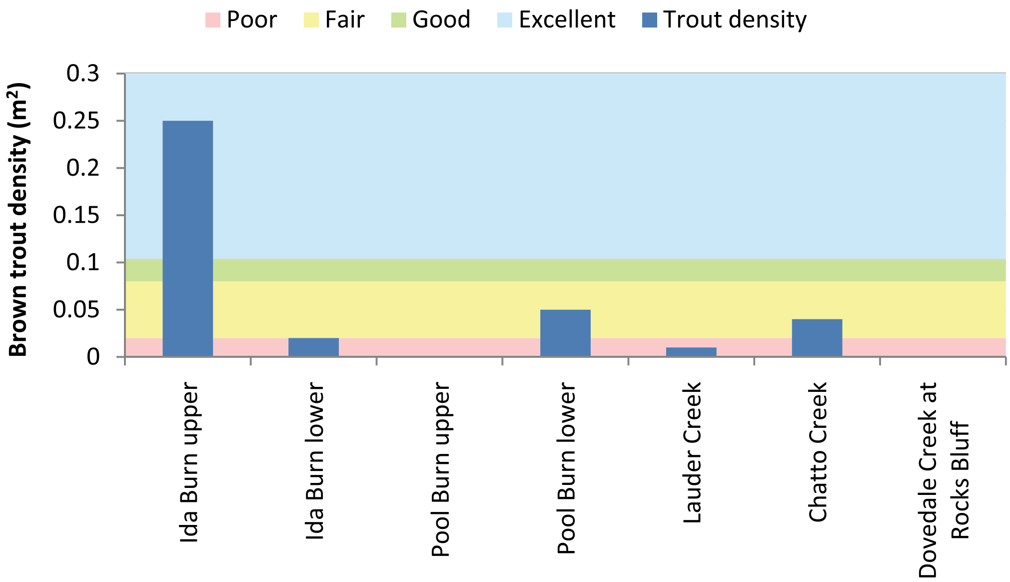

Figure 20. Brown trout density. (Only sites that were fished are included.) Density rankings have also been included.

Native fish densities are classified as ‘excellent’, when compared to the rest of the Clutha catchment in Dovedale Creek, followed by Ida Burn lower (Figure 21). The Pool Burn lower and Lauder Creek had brown trout densities that placed them in the ‘good’ category.

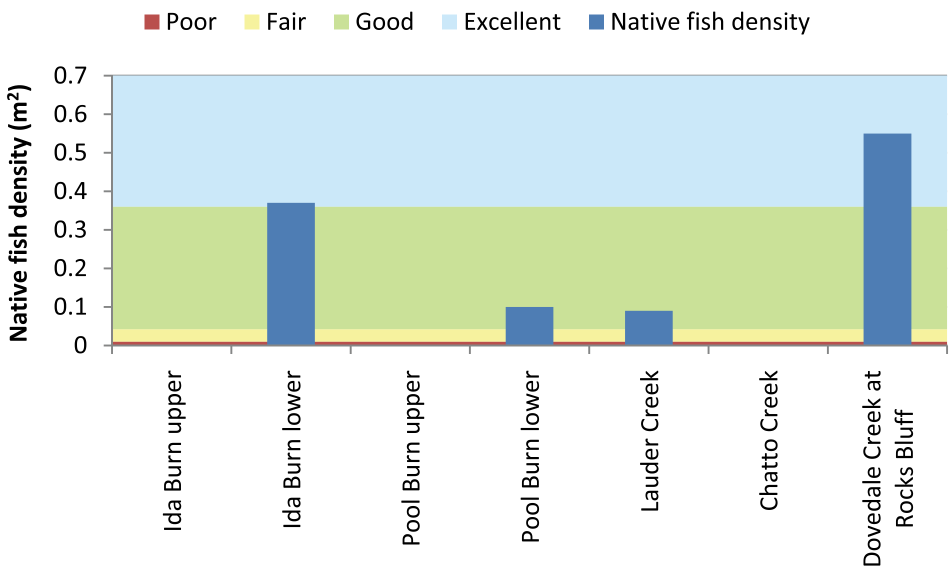

Figure 21. Native fish density in sampling sites. (Only the sites that were able to be fished have been included.) Density classes have also been presented.

Roundhead galaxiid densities were found to be ‘excellent’ in both Dovedale Creek and Ida Burn lower (Figure 22).

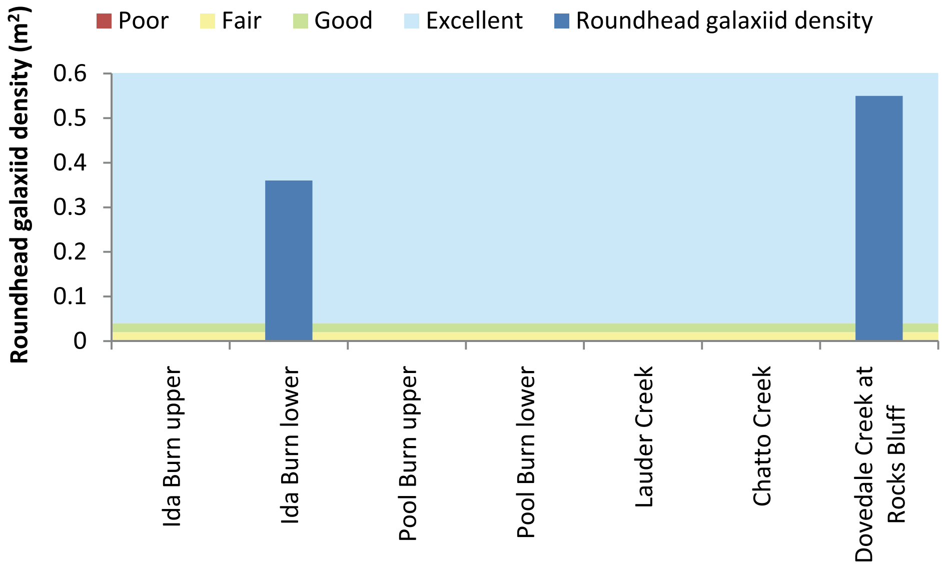

Figure 22. Central Otago Roundhead galaxiid density with density classes. (Only the sites that were able to be fished are included.)

4. Discussion

This section discusses the results from the water quality monitoring, physical habitat assessments and ecological monitoring, macroinvertebrate surveys and fish sampling. Where appropriate, we have linked the degraded water quality and physical habitat with agricultural development and the impact on instream values.

4.1 Stream water quality

In this study, we compared nutrient concentrations for all flows and when rivers were at median flow or below (low flows). Flows below median flow generally occur at times when rivers and streams are most likely to be used for recreation and more susceptible to nuisance algal growth. Flows exceeding median flow generally occur after rainfall events.

Water quality in the Manuherikia catchment was generally ‘good’, with most sites recording pollutant concentrations below guideline values; these values, in fact, showed little difference from the upstream control sites. There was a marginal increase in pollutant concentrations at the lowest site in the Manuherikia (Manuherikia at Galloway) compared to that at the top Manuherikia site (Manuherikia River at Loop Road). This is probably due to contributions from Thomsons Creek, the Pool Burn (supplemented by Ida Burn) and Lauder Creek, which were the three sites that consistently had relatively degraded water quality.

4.2 Nutrients

Nutrients are an important component in river systems, as they control algal and instream plant growth. Slight nutrient enrichment can be positive as it can increase algal and plant growth, which provides greater food and habitat resources for macroinvertebrates. However, nutrient concentrations can become so elevated that they promote nuisance algal and weed growth, which has a negative impact on the river’s ecosystem.

The main nutrients of concern are NNN and DRP, as these are the two nutrients that are biologically active. NNN concentrations were generally low compared to intensively farmed catchments with higher stocking rates and higher fertiliser inputs (e.g. the Pomahaka catchment). The sites that exceeded the NNN guideline substantially were the lower Ida Burn and upper Pool Burn, with the latter site contributing very little NNN to its total load. All of the remaining sites (except Manuherikia at Loop Road, Ida Burn upper and Dovedale Creek) were marginally above the guideline (again the latter two sites contributed very negligible amounts of NNN). All of these exceedances were in the ‘all flows’ category, which suggests that these high NNN concentrations primarily occur in winter and early spring. Higher NNN concentrations for ‘all flows’ is probably due to NNN being exported out of the catchment once it is saturated. NNN is highly soluble and mobile. Thus, when soils are saturated, NNN can be readily exported out of the soil profile and into streams and rivers. NNN concentrations are likely to be low at the other sites due to the underdeveloped nature of the Manuherikia catchment. Where agricultural activity does exist, it is of low intensity; also the soils tend to be dry, which limits the movement of NNN.

DRP concentrations are above the guideline value at most sites. The highest concentrations, especially those during low flow conditions (high risk for nuisance algal growth), are found in Ida Burn lower, both Pool Burn sites and Thomsons Creek lower. The tributaries, Lauder Creek and Chatto Creek, also have elevated DRP concentrations, but these are not as high as at Ida Burn lower, both Pool Burn sites and Thomsons Creek lower (which had the highest loading of DRP compared to all the other sites). All these tributaries are likely to increase the DRP load at the main-stem Manuherikia sites, such as Omakau, Ophir (upstream of the Chatto Creek confluence) and Galloway. While this study has not directly investigated the effects of irrigation run-off, all the tributaries do receive inputs from irrigation run-off, which is probably transporting agricultural pollutants. A number of New Zealand research papers have demonstrated that irrigation run-off from flood irrigation can adversely affect water quality (McDowell and Rowley, 2008; Monaghan *et al*., 2009).

Analysis of nutrient ratios (Figure 10) has shown that all the streams and rivers sampled in this study are NNN-limited. The fact that several sites were above the DRP guideline, but no prolific algal growth was observed (except weed growth in both Pool Burn sites), supports this observation. As land use intensifies, particularly with the introduction of intensive dairy farming, there tends to be a significant increase in the amount of NNN in waterways. If more intensive land use becomes widespread in the Manuherikia catchment, there is the potential for NNN concentrations to increase, and waterways will no longer be N-limited. However, this has not been observed in other intensive dairy catchments in Otago. In the Washpool Stream in the Pomahaka River catchment, south-west Otago, it was estimated that dairy farming consisted of 79% of the catchment land area; however, the stream was still N-limited. While there are no tile and mole drains in the Manuherikia catchment, there is the risk (albeit, low) that NNN concentrations may increase as more intensive farming moves into the catchment, which may reduce the NNN: DRP ratios and potentially lead to more algal and macrophyte growth.

The guideline values selected for NNN (0.075 mg/l) and DRP (0.006 mg/l) were very low compared to those applied in the Pomahaka and the Catlins ORC catchment water quality studies (ORC, 2010; ORC, 2011). The current project’s guideline values were selected from 30 days of algae accrual in those guidelines provided by Biggs (2000). This accrual period figure was calculated by working out the average number of days between flow events that were higher than three times the median flow. Flows that are greater than three times the median flow are considered to be high enough to disturb the stream bed and re-set periphyton growth. These low guideline values mean that the Manuherikia River and its tributaries are at high risk of having prolific algal blooms. However, as this catchment is NNN-limited and NNN concentrations are very low, there are currently no prolific algal blooms. Limited NNN may also explain why DRP concentrations increase downstream: the available DRP is not being used in growing algal growth due to insufficient levels of NNN. While conducting these ecological surveys, we observed that all the sites had a thin layer of algae on the substrate, which is typical of wide rivers with exposure to direct sunlight. While the guideline values are low and possibly restrictive, in reality the river network is relatively steep as it is still in the high country; thus, water velocities are much greater than in a lowland stream. Consequently, flows lower than three times the median flow may be sufficient for creating a flushing flow. As long as NNN concentrations remain low and do not breach the guideline value, especially during summer, the risk of prolific algal growths should remain low.

4.3 Bacteria

The suitability of water for recreational activities (such as swimming) is typically assessed by the level of *E. coli* bacteria in a water sample. Although most *E. coli* are harmless, elevated levels are used to indicate the presence of faecal pollution, which may pose a threat to human health as it contains other pathogenic organisms. The suitability for stock drinking water is assessed in a similar way. The same bacteria are used as indicators, but at a different threshold (1000 *E. coli* per 100 ml water, as recommended by the ANZECC (1992)). This provides a useful measure for the rivers in rural catchments, as such catchments are more likely to provide drinking water for stock.

E. coli concentrations were below the recreational guideline value in the upper part of the catchment. Sites with high *E. coli* were the Ida Burn lower, both the Pool Burn sites, Lauder Creek and Dovedale Creek. However, these results need to be put into context. While as discrete units, the *E. coli* concentrations are of concern, in terms of their overall contribution to the Manuherikia River, they are negligible (Figure 14). Thomsons Creek lower also had high *E. coli* levels (and contributed the most *E. coli* in respect to load, even when compared to the main-stem sites of the Manuherikia River). The site is different to the previously listed sites, as most of the *E. coli* is probably sourced from irrigation by-wash, as this section of the creek always has some flow. These results are concerning because they are occurring during low-flow conditions, when there has been no rain and when people are more likely to be using the rivers and streams for recreation. These high values at low flows suggest direct inputs of bacteria. Ida Burn, Pool Burn, Lauder Creek and Thomsons lower all have flood irrigation inputs that wash agricultural pollutants (in this case, animal effluent) into the waterways. Dovedale Creek also had *E. coli* concentrations that exceeded the guideline value during low flows. This sampling site was located within a deer farm, and as deer have a tendency to wallow in water, direct animal contamination is likely. Most streams that were sampled had little stream fencing to prevent animal access.

4.4 Suspended Solids

SS is the concentration of inorganic and organic matter held in the water column of a stream. SS typically consist of fine particulate matter, such as clay particles, and all streams carry SS loads under natural conditions. However, when SS concentrations are increased through the erosion of the stream banks or other catchment erosion, there is a risk that this elevated SS can fall out of suspension and settle on the stream bed. This settled sediment can smother stream bed habitat, which has a negative effect on the instream values such as macroinvertebrates and fish (Townsend *et al.*, 2008). High levels of suspended sediment can also have negative effects on trout and native fish by adhering to gills, thereby impeding respiration, and potentially causing death. Sediment can also reduce fishes' visual recognition of food sources, which affects their growth, condition, reproductive success, also potentially leading to death (Parkyn and Wilcock, 2004 and references within). What's more, sediment harbours *E. coli* and reduces its half-life, thus allowing it to be re-suspended during the summer.

SS concentrations were elevated above guideline values at a number of sites, when all flows were taken into account. However, this was to be expected, as high flows and significant rainfall events wash land surfaces through overland flow. Such high flow events will skew the median. When SS concentrations were considered for only low flows, concentrations did not exceed the guideline value, except at Thomsons Creek lower. This could have been the result of sediment contributions from flood irrigation run-off.

4.5 Summary of stream water quality

- If NNN concentrations increase, the lack of flushing flows during the summer could make the Manuherikia catchment high risk of an increase in potentially prolific algal growth.
- DRP concentrations were above the guideline value (particularly for low flows) in many of the tributaries of the Manuherikia River, which contributed to the increase in DRP in the lower part of the Manuherikia River.
- *E. coli* levels were low for the upper catchment sites and most of the Manuherikia main stem, with the exception of Ophir, which is influenced by Thomsons Creek.
- Elevated *E. coli* levels in Dovedale Creek were probably the result of deer accessing the stream.
- SS levels were below effects-based guideline vales.
- The Manuherikia River is NNN-limited, which currently prevents algal proliferation.
- Elevated DRP, TP, TN and *E. coli* in Thomsons Creek lower, Pool Burn and Lauder Creek are consistent with what is to be expected from flood irrigation. It is possible that DRP levels increase downstream because all the DRP cannot be fully utilised, due to low NNN concentrations limiting algal growth.
- Elevated *E. coli*, TP and DRP at Ophir during low flows are possibly due to contributions from Thomson's Creek.

4.6 Physical habitat

Physical habitat is an important factor influencing the ecological health of a river system, as it provides refuge for macroinvertebrates and fish, as well as providing breeding grounds for a number of fish species (McDowall, 2000). When physical habitat is degraded, primarily through the input of fine sediment, instream habitat (particularly larger substrate) can be smothered, thereby reducing the amount of available habitat for macroinvertebrates and fish (Death, 2000; Riley *et al*., 2003; Buck *et al*., 2003).

SS has traditionally been the measure of how much sediment is present within a river system. The inherent weakness of this is that it does not measure its build-up on the stream bed. As it is possible for some systems to have a high SS load and have little fine sediment build-up on the bed, we undertook stream-bed assessments to determine the extent of habitat degradation. The main measure of habitat degradation used in this study is the proportion of fine sediment (less than 2 mm) on the stream bed.

The majority of the sample sites had almost no fine sediment build-up. This was particularly so for the main stem of the Manuherikia River and the sampling sites in the upper part of the catchment (such as Dunstan Creek) or upper sites in the river network (such as Ida Burn upper and Thomsons Creek upper). The sites with the highest proportion of fine sediment were in the Pool Burn upper and Lauder Creek lower. Most of these fine sediment sources could probably be eliminated by fencing of streams on the Ida Valley floor. These fences would exclude stock from creating tracks to the stream, which then becomes a sediment source during higher flows. Fencing would also allow riparian buffers to form, which would filter out pollutants entering waterways through overland flow of excess water.

The Pool Burn upper had a high percentage of fine sediment build-up on the stream bed; however, the Pool Burn lower had little build-up. This is possibly the result of greater and cleaner flow (in terms of sediment load) coming from the Ida Burn.

4.7 Summary of physical habitat

- The majority of sampling sites had little to no build-up of fine sediment. The most concerning sites for fine sediment build-up are in the Pool Burn upper site.

4.8 Instream ecological values

Water quality results are frequently reported as being above or below ANZECC guidelines. However, these guidelines do not necessarily represent a threshold for detecting ecological effects. They have limitations because they are based on studies from New Zealand and Australia and do not always take into account regional differences. For this present study, effects-based guidelines were used for nutrients and sediment and national health guidelines for bacteria. Regionally derived guidelines were used for fishery values. This latter approach looks at mutiple stressors (chemical, physical and community structure) and therefore provides a more relevant ecological impact assesment. Each site has been graded as either ‘excellent’, ‘good’, ‘fair’ or ‘poor’, for chemical, physical habitat, macroinvertebrate and trout fishery values (Table 9).

The relationships observed between water quality, physical habitat, trout and fish values in this study are more complicated than in other areas where similar studies have been conducted (for example, the Pomahaka catchment and Catlins region). Confounding factors include: the hydroelectric dams on the Clutha River/Mata-Au, which impede Longfin eel migration; sport fish competition, mainly from brown trout, which predate on rare non-migratory native fish; and natural low flows, which are often exacerbated by water abraction for irrigation.

In the upper part of the catchment, we found ‘excellent’ water quality, habitat and macroinvertebrate communities, but we obtained no fish data, due to the abnormally high river flows when electric-fishing was planned (Table 9). Manuherikia River at Loop Road had a ‘poor’ macroinvertebarte community, which is probably due to a didymo invasion smothering substrate and excluding the healthy invertebrate taxa (EPT taxa). In one site (Ida Burn upper), we found ‘good’ water quality (not ‘excellent’, due to the stringent DRP standard), ‘excellent’ habitat, ‘fair’ macroinvertebrates and an ‘excellent’ trout population. The ‘poor’ native fish ranking at this site is probably due to the predatory effects of brown trout.

Conversely, the Pool Burn upper had ‘poor’ water quality, physical habitat and macoroinvertebrate communities; furthermore, no fish were found (Table 9). At this site, the stream bed was covered in fine silt, which was possibly the result of flood irrigation run-off and stock access introducing fine sediment. However, we noted that the stretch of river immediately above the sampling site had been cleaned out by a digger during the study (Figure 23). Stock access creates tracks along the stream banks that are more susceptible to being eroded into the Pool Burn. The macroinvertebrate community was also dominated by snails, which suggests the presence of organic pollution in the form of nutrient enrichment. Consequently, this site has little in the way of habitat and food resources for fish. The likely cause of these pollutants is direct access to waterways by stock and run-off from flood irrigation. Lauder Creek lower also had ‘fair’ water quality, ‘poor’ physical habitat, a ‘poor’ macroinvertebrate community and a ‘poor’ trout population. The native fish population was dominated by Upland Bullies, and this ‘excellent’ population is again probably the result of the limited predatory pressure by brown trout.

Figure 23. Pool Burn upper looking up from the Auripo Road bridge

Table 9. Summary of categories for chemical, physical, macroinvertebrate, sports fish (trout) and native fish for all 17 sites in this investigation. N/A denotes sites that were unable to be fished as flows were too high.

Site	Water quality	Habitat	Macroinvertebrates	Trout	Native fish
Manuherikia at Loop Road	Excellent	Excellent	Poor	N/A	N/A
Dunstan Creek at Beatties	Good	Excellent	Excellent	N/A	N/A
Manuherikia at Blackstone	Excellent	Excellent	Good	N/A	N/A
Manuherikia US Ida Burn	Good	Excellent	Fair	N/A	N/A
Ida Burn upper	Excellent	Excellent	Fair	Excellent	Poor
Ida Burn lower	Fair	Good	Poor	Fair	Excellent
Pool Burn upper	Fair	Poor	Poor	Poor	Poor
Pool Burn lower	Fair	Good	Poor	Good	Excellent
Lauder Creek	Fair	Fair	Poor	Poor	Excellent
Manuherikia at Omakau	Good	Excellent	Fair	N/A	N/A
Thomsons Creek upper	Good	Excellent	Good	Excellent	Poor
Thomsons Creek lower	Poor	Good	Good	N/A	N/A
Manuherikia at Ophir	Fair	Excellent	Poor	N/A	N/A
Chatto Creek	Fair	Good	Good	N/A	N/A
Manuherikia US Chatto Creek	Good	Excellent	Fair	N/A	N/A
Manuherikia at Galloway	Good	Excellent	Poor	N/A	N/A
Dovedale at Rocks Bluff	Good	Fair	Poor	Poor	Excellent

Dovedale Creek and Ida Burn lower all had ‘excellent’ densities of Central Otago Roundhead galaxiids, which are a threatened species. The high density of these fish was probably due to the absence of trout at Dovedale Creek and the ‘poor’ densities of trout in the lower Ida Burn. In the latter case, irrigation possibly restricted flow, causing trout to die because of the high temperatures and low oxygen levels; the more hardy Central Otago Roundhead galaxiids are more tolerant of low flow conditons, and thus are able to persist.

In the sites that were electric-fished, the absence of Longfin eels from many of the streams was praticularly evident. Single, large (700 mm plus) Longfin eels were only caught in the Pool Burn lower, Ida Burn lower and Lauder Creek lower. It was also concerning that no smaller individuals, indicating recruitment, were caught. This is consistent with reported effects of hydro dams (Jellyman, 1987), which suggested that the Clutha River/Mata-Au dams would have a significant effect on the longfin eel population in the Manuherikia catchment. This was observed after the Roxburgh Dam was constructed and predicted around the time the

Clyde Dam was to be built (Jellyman, 1987). Scientific opinion in the early 1980s was that the Clutha hydroelectric dams had, or would, almost totally exclude young eels from migrating upstream (Glova and Davis, 1981, Jellyman, 1984). This study indicates that this has occurred, as only large (500 mm plus) Longfin eels, and no juvenile eels, have been caught. During the electric-fish survey at the Pool Burn upper, a local farmer commented that there were numerous eels resident in the stream 10-15 years ago, but that now there are none. There are new consent conditions on Contact Energy requiring the company to collect juveniles migrating upstream and re-locate them above the dams; however, the success of this requirement is yet to be investigated.

4.9 Summary of instream ecological values

This study suggests that this catchment has a complex ecosystem, with a variety of compounding factors potentially influencing its ecological values; these factors range from natural low flows, hydroelectric dams, water abstraction for irrigation, predation effects and the potential impact of land-use management.

Where there is ‘good’ water quality, permanent flows and ‘good’ physical habitats, there are healthy macroinvertebrate communities, and where fish surveys have been conducted, either high trout or native fish densities exist. Conversely, in the degraded sites, water quality is generally ‘fair’, but when physical habitat is degraded and flows are very low, or streams have dried up, there are obvious effects on both macroinvertebrate communities and fish populations.

Where electric-fish surveys have been conducted and dense fish populations found, sites have either been dominated by native fish, or by trout, suggesting that these two species do not co-occur and that trout had excluded native fish by predating upon them. The concerning absence of eels is likely to be caused by migration barriers being blocked by the Clutha River/Mata-Au hydroelectric dams.

5. Conclusions

- This 12-month targeted water quality and ecological health study provides a baseline of water quality and ecological data.

- Catchment-specific instream effects-based guidelines and an ecological value classification have allowed an understanding of the effects of water quality degradation and habitat health.

- Water quality results have shown that the Manuherikia main stem has ‘good’ water quality, with a change from ‘excellent’ water quality at the top of the catchment to ‘good’ at the bottom site at Galloway.

- There are some tributaries to the main stem of the Manuherikia River that have degraded water quality during low flows, probably caused by irrigation run-off.

- Nitrogen was well below effects-based guideline values, especially during the high risk period when flows were low. Analysis suggests this catchment is NNN-limited.

- In streams such as Dovedale Creek and the lower Ida Burn, where high densities of the threatened Central Otago Roundhead galaxiid are located, it is likely that the low river flows are protecting these populations by excluding trout invasion.

- Water quality and physical habitat could be improved in the degraded tributaries by improving flood irrigation methods to minimise or eliminate irrigation run-off and through better riparian management.

- The ecological values in these streams were not just related to water quality issues. Other factors include natural low flows, hydroelectric dams on the Clutha River/Mata-Au disrupting Longfin eel migration, water abstraction for irrigation, predation and land-use management.

Results from this study will be used to provide data that will help to direct Council policy, in line with its Rural Water Quality Strategy.

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Appendix 1: Kruskall-Wallis test

The Kruskal-Wallis test is a non-parametric test (distribution-free) used to compare independent groups of sampled data. If there are only two groups, the test is called the Mann-Whitney U test. The test is carried out on one or more variables measured from two or more populations defined by the grouping variable.

Unlike the parametric independent group analysis of variance (one way ANOVA), this non-parametric test makes no assumptions about the distribution of the data (e.g. normality). However, the test does assume identically shaped and scaled distributions for each group, except for any difference in medians.

This test is an alternative to the independent group ANOVA, when the assumption of normality or equality of variance is not met. This, like many non-parametric tests, uses the ranks of the data rather than their raw values to calculate the statistic. Since this test does not make a distributional assumption, it is not as powerful as the ANOVA. It is identical to a one-way analysis of variance, with the data replaced by their ranks.

Appendix 2: Raw water quality data for all sampling sites

Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia at Omakau							
07-Sep-09	0.005	0.005	10	0.011	5	0.09	0.015
23-Sep-09	0.005	0.011	23	0.019	3	0.14	0.019
06-Oct-09	0.005	0.011	330	0.014	1.5	0.13	0.023
20-Oct-09	0.005	0.01	66	0.012	20	0.19	0.035
03-Nov-09	0.005	0.009	84	0.008	36	0.14	0.046
19-Nov-09	0.005	0.022	62	0.013	3	0.11	0.032
01-Dec-09	0.005	0.014	14	0.016	6	0.15	0.029
15-Dec-09	0.005	0.014	14	0.014	1.5	0.07	0.024
06-Jan-10	0.005	0.016	8	0.014	1.5	0.12	0.029
18-Jan-10	0.005	0.02	180	0.011	1.5	0.2	0.033
01-Feb-10	0.005	0.021	68	0.01	1.5	0.27	0.04
17-Feb-10	0.005	0.015	22	0.013	1.5	0.18	0.026
02-Mar-10	0.005	0.016	48	0.015	1.5	0.19	0.034
16-Mar-10	0.005	0.015	24	0.024	1.5	0.2	0.023
30-Mar-10	0.005	0.016	32	0.016	1.5	0.22	0.023
14-Apr-10	0.005	0.014	40	0.013	1.5	0.21	0.025
27-Apr-10	0.01	0.032	270	0.032	8	0.48	0.08
10-May-10	0.005	0.009	2	0.009	1.5	0.12	0.013
25-May-10	0.005	0.012	2900	0.013	134	0.8	0.244
08-Jun-10	0.02	0.03	300	0.266	142	0.69	0.135
22-Jun-10	0.01	0.016		0.278	207	0.61	0.129
14-Jul-10	0.005	0.008	4	0.41	4	0.63	0.014
27-Jul-10	0.005	0.007	2	0.306	4	0.58	0.015
25-Aug-10	0.005	0.008	24	0.228	14	0.42	0.02
08-Sep-10	0.005	0.01	24	0.214	59	0.44	0.051
21-Sep-10	0.005	0.005	11	0.174	12	0.34	0.024
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia at Loop Road							
08-Sep-09	0.005	0.005	0.5	0.0025	3	0.09	0.01
23-Sep-09	0.005	0.005	10	0.0025	1.5	0.08	0.009
06-Oct-09	0.005	0.0025	8	0.0025	3	0.06	0.008
20-Oct-09	0.005	0.0025	13	0.0025	4	0.1	0.009
03-Nov-09	0.005	0.006	4	0.0025	15	0.09	0.012
19-Nov-09	0.005	0.006	4	0.0025	3	0.05	0.006
01-Dec-09	0.005	0.0025	10	0.0025	3	0.07	0.01
15-Dec-09	0.005	0.005	4	0.0025	3	0.05	0.009
06-Jan-10	0.005	0.0025	2	0.0025	3	0.05	0.015
18-Jan-10	0.005	0.006	6	0.0025	1.5	0.1	0.009
01-Feb-10	0.005	0.0025	8	0.0025	3	0.11	0.012
17-Feb-10	0.005	0.0025	16	0.0025	4	0.12	0.013
02-Mar-10	0.005	0.0025	6	0.0025	8	0.15	0.024
16-Mar-10	0.005	0.0025	10	0.0025	3	0.14	0.016
30-Mar-10	0.005	0.006	8	0.0025	7	0.2	0.025
14-Apr-10	0.005	0.007	6	0.0025	6	0.21	0.04

27-Apr-10	0.005	0.008	52	0.043	17	0.19	0.041
10-May-10	0.005	0.005	2	0.02	1.5	0.1	0.011
25-May-10	0.005	0.005	16	0.04	12	0.15	0.019
08-Jun-10	0.01	0.01	27	0.126	29	0.32	0.048
22-Jun-10	0.005	0.009		0.06	20	0.25	0.029
14-Jul-10	0.005	0.006	2	0.043	1.5	0.05	0.01
27-Jul-10	0.005	0.0025	2	0.008	2	0.15	0.009
25-Aug-10	0.005	0.005	1	0.0025	1.5	0.12	0.007
08-Sep-10	0.005	0.006	2	0.011	3	0.15	0.013
21-Sep-10	0.005	0.0025	1	0.0025	1.5	0.13	0.013
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia at Ophir							
08-Sep-09	0.005	0.009	9	0.031	4	0.17	0.017
23-Sep-09	0.01	0.016	61	0.033	5	0.21	0.032
06-Oct-09	0.005	0.02	210	0.027	5	0.19	0.039
20-Oct-09	0.005	0.017	260	0.033	32	0.28	0.059
03-Nov-09	0.005	0.01	160	0.019	31	0.18	0.045
19-Nov-09	0.01	0.04	250	0.021	4	0.24	0.064
01-Dec-09	0.02	0.025	198	0.02	4	0.24	0.044
15-Dec-09	0.01	0.034	250	0.022	3	0.23	0.057
06-Jan-10	0.02	0.042	237	0.012	3	0.3	0.073
18-Jan-10	0.02	0.034	310	0.014	3	0.28	0.053
01-Feb-10	0.01	0.04	420	0.021	4	0.4	0.077
17-Feb-10	0.01	0.041	280	0.008	1.5	0.36	0.07
02-Mar-10	0.005	0.027	92	0.014	3	0.28	0.05
16-Mar-10	0.01	0.026	84	0.018	1.5	0.32	0.047
30-Mar-10	0.02	0.026	130	0.013	1.5	0.31	0.044
14-Apr-10	0.02	0.02	76	0.018	1.5	0.25	0.033
27-Apr-10	0.02	0.053	1500	0.057	10	0.67	0.114
10-May-10	0.005	0.011	20	0.034	1.5	0.19	0.019
25-May-10	0.02	0.027	860	0.117	149	1	0.265
08-Jun-10	0.02	0.056	1000	0.356	119	0.85	0.163
22-Jun-10	0.01	0.017		0.252	155	0.56	0.101
14-Jul-10	0.005	0.01	3	0.397	4	0.63	0.018
27-Jul-10	0.005	0.007	6	0.272	4	0.51	0.016
25-Aug-10	0.005	0.009	18	0.227	121	0.41	0.024
08-Sep-10	0.01	0.013	12	0.211	69	0.46	0.06
21-Sep-10	0.005	0.006	20	0.185	38	0.38	0.038
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia at Blackstone							
07-Sep-09	0.005	0.0025	2	0.0025	5	0.06	0.016
23-Sep-09	0.005	0.007	30	0.0025	1.5	0.12	0.023
06-Oct-09	0.005	0.005	4	0.0025	1.5	0.05	0.01
20-Oct-09	0.005	0.006	34	0.0025	30	0.11	0.026
03-Nov-09	0.005	0.008	35	0.0025	40	0.12	0.045
19-Nov-09	0.005	0.009	22	0.0025	3	0.05	0.013
01-Dec-09	0.005	0.006	14	0.0025	1.5	0.06	0.011
15-Dec-09	0.005	0.007	44	0.0025	4	0.05	0.012

06-Jan-10	0.005	0.005	16	0.0025	3	0.05	0.015
18-Jan-10	0.005	0.007	140	0.0025	3	0.07	0.015
01-Feb-10	0.005	0.005	140	0.0025	1.5	0.09	0.012
17-Feb-10	0.005	0.0025	38	0.0025	1.5	0.1	0.009
02-Mar-10	0.005	0.005	76	0.0025	7	0.14	0.021
16-Mar-10	0.005	0.005	120	0.0025	1.5	0.11	0.012
30-Mar-10	0.005	0.006	38	0.0025	3	0.18	0.019
14-Apr-10	0.005	0.006	50	0.0025	4	0.18	0.027
27-Apr-10	0.005	0.008	180	0.017	8	0.17	0.031
10-May-10	0.005	0.005	82	0.0025	5	0.09	0.014
25-May-10	0.005	0.008	83	0.006	12	0.1	0.031
08-Jun-10	0.01	0.012	130	0.159	207	0.45	0.125
22-Jun-10	0.01	0.012		0.183	188	0.44	0.121
14-Jul-10	0.005	0.007	10	0.311	5	0.49	0.013
27-Jul-10	0.005	0.005	14	0.171	9	0.37	0.013
25-Aug-10	0.005	0.006	4	0.135	5	0.27	0.01
08-Sep-10	0.005	0.008	12	0.111	28	0.27	0.035
21-Sep-10	0.005	0.0025	1	0.094	6	0.22	0.018
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia at Galloway							
08-Sep-09	0.005	0.008	2	0.016	10	0.13	0.015
23-Sep-09	0.005	0.009	7	0.011	13	0.14	0.02
06-Oct-09	0.005	0.012	22	0.005	3	0.12	0.027
20-Oct-09	0.005	0.017	270	0.033	19	0.25	0.049
03-Nov-09	0.005	0.011	86	0.015	65	0.17	0.042
19-Nov-09	0.005	0.021	190	0.018	4	0.17	0.038
01-Dec-09	0.01	0.023	84	0.021	1.5	0.24	0.038
15-Dec-09	0.005	0.021	62	0.019	3	0.17	0.035
06-Jan-10	0.005	0.017	64	0.01	1.5	0.18	0.035
18-Jan-10	0.005	0.018	174	0.006	1.5	0.22	0.03
01-Feb-10	0.005	0.019	3	0.009	1.5	0.27	0.036
17-Feb-10	0.005	0.014	13	0.006	1.5	0.24	0.032
02-Mar-10	0.005	0.017	20	0.006	1.5	0.22	0.031
16-Mar-10	0.005	0.014	37	0.013	1.5	0.25	0.027
30-Mar-10	0.005	0.015	48	0.01	1.5	0.25	0.027
14-Apr-10	0.005	0.018	110	0.018	1.5	0.25	0.03
27-Apr-10	0.005	0.044	570	0.078	19	0.69	0.113
10-May-10	0.005	0.012	16	0.015	1.5	0.16	0.019
25-May-10	0.005	0.012	75	0.049	29	0.43	0.091
08-Jun-10	0.02	0.04	1100	0.291	161	0.75	0.173
22-Jun-10	0.01	0.017		0.271	263	0.64	0.152
14-Jul-10	0.005	0.01	1	0.386	6	0.59	0.016
27-Jul-10	0.005	0.008	12	0.294	4	0.54	0.016
25-Aug-10	0.005	0.009	8	0.226	16	0.41	0.025
08-Sep-10	0.01	0.011	17	0.208	78	0.44	0.059
21-Sep-10	0.005	0.006	12	0.177	20	0.37	0.042
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Dunstan Creek @ Beatties							

07-Sep-09	0.005	0.005	1	0.021	1.5	0.08	0.008
23-Sep-09	0.005	0.006	12	0.01	1.5	0.1	0.009
06-Oct-09	0.005	0.005	3	0.019	1.5	0.05	0.007
20-Oct-09	0.005	0.006	34	0.016	7	0.12	0.011
03-Nov-09	0.005	0.006	24	0.013	8	0.09	0.011
19-Nov-09	0.005	0.009	160	0.012	1.5	0.05	0.009
01-Dec-09	0.005	0.007	140	0.019	1.5	0.08	0.01
15-Dec-09	0.005	0.008	38	0.022	1.5	0.05	0.009
06-Jan-10	0.005	0.008	8	0.029	1.5	0.07	0.013
18-Jan-10	0.005	0.01	22	0.024	1.5	0.07	0.008
01-Feb-10	0.005	0.006	42	0.04	1.5	0.13	0.012
17-Feb-10	0.005	0.007	54	0.025	1.5	0.1	0.007
02-Mar-10	0.005	0.008	41	0.029	1.5	0.12	0.011
16-Mar-10	0.005	0.008	30	0.045	1.5	0.12	0.01
30-Mar-10	0.005	0.008	10	0.035	1.5	0.13	0.007
14-Apr-10	0.005	0.008	68	0.054	1.5	0.12	0.006
27-Apr-10	0.005	0.008	130	0.085	7	0.22	0.017
10-May-10	0.005	0.006	44	0.065	1.5	0.13	0.007
25-May-10	0.005	0.009	87	0.043	21	0.19	0.036
08-Jun-10	0.005	0.01	74	0.283	13	0.46	0.024
22-Jun-10	0.005	0.009		0.132	41	0.3	0.036
14-Jul-10	0.005	0.005	4	0.124	1.5	0.23	0.005
27-Jul-10	0.005	0.005	6	0.032	2	0.15	0.006
25-Aug-10	0.005	0.006	8	0.073	1.5	0.16	0.006
08-Sep-10	0.005	0.007	12	0.102	9	0.23	0.012
21-Sep-10	0.005	0.005	1	0.072	1.5	0.17	0.012
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Ida Burn lower							
08-Sep-09	0.005	0.011	3	0.016	1.5	0.23	0.019
23-Sep-09	0.005	0.014	7	0.007	1.5	0.21	0.026
06-Oct-09	0.005	0.015	12	0.013	1.5	0.2	0.028
20-Oct-09	0.005	0.022	160	0.01	1.5	0.32	0.039
03-Nov-09	0.01	0.039	28	0.011	1.5	0.37	0.067
19-Nov-09	0.01	0.061	5100	0.024	6	0.59	0.113
01-Dec-09	0.02	0.035	84	0.035	5	0.25	0.064
15-Dec-09	0.005	0.048	130	0.019	1.5	0.29	0.083
06-Jan-10	0.005	0.046	408	0.02	1.5	0.33	0.1
18-Jan-10	0.01	0.049	3800	0.023	1.5	0.31	0.069
01-Feb-10	0.005	0.082	470	0.023	1.5	0.51	0.132
17-Feb-10	0.01	0.062	330	0.015	1.5	0.35	0.12
02-Mar-10	0.005	0.05	49	0.014	3	0.24	0.075
16-Mar-10	0.005	0.04	500	0.01	1.5	0.32	0.062
30-Mar-10	0.005	0.038	84	0.009	8	0.33	0.053
14-Apr-10	0.005	0.034	260	0.008	1.5	0.35	0.052
27-Apr-10	0.005	0.047	280	0.019	1.5	0.75	0.09
10-May-10	0.005	0.031	22	0.005	1.5	0.2	0.042
25-May-10	0.01	0.043	79	0.112	1.5	0.35	0.067
08-Jun-10	0.01	0.035	210	0.265	19	0.58	0.052

22-Jun-10	0.01	0.024		0.841	123	1.32	0.104
14-Jul-10	0.005	0.008	40	1.56	1.5	1.92	0.011
27-Jul-10	0.005	0.006	30	1.12	2	1.55	0.015
25-Aug-10	0.005	0.007	24	1.05	1.5	1.46	0.013
08-Sep-10	0.005	0.01	24	1.02	13	1.41	0.028
21-Sep-10	0.005	0.0025	74	0.841	1.5	1.2	0.015
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Pool Burn lower							
08-Sep-09	0.005	0.022	14	0.005	1.5	0.63	0.044
23-Sep-09	0.005	0.019	10	0.008	1.5	0.55	0.047
06-Oct-09	0.02	0.029	16	0.023	9	0.56	0.069
20-Oct-09	0.01	0.06	380	0.053	5	1.01	0.128
03-Nov-09	0.005	0.053	48	0.005	4	0.66	0.118
19-Nov-09	0.005	0.1	180	0.005	7	0.67	0.216
01-Dec-09	0.01	0.018	76	0.005	3	0.66	0.16
15-Dec-09	0.005	0.155	2400	0.005	1.5	0.66	0.209
06-Jan-10	0.005	0.153	110	0.005	1.5	0.56	0.21
18-Jan-10	0.02	0.131	310	0.005	3	0.94	0.193
01-Feb-10	0.005	0.169	220	0.005	1.5	0.76	0.255
17-Feb-10	0.005	0.099	190	0.005	1.5	0.6	0.124
02-Mar-10	0.005	0.065	94	0.005	1.5	0.53	0.085
16-Mar-10	0.005	0.1	180	0.005	1.5	0.58	0.122
30-Mar-10	0.005	0.041	46	0.005	1.5	0.52	0.051
14-Apr-10	0.005	0.087	130	0.005	1.5	0.63	0.109
27-Apr-10	0.005	0.145	5300	0.026	4	1.33	0.222
10-May-10	0.005	0.041	14	0.005	1.5	0.49	0.051
25-May-10	0.005	0.04	31	0.023	1.5	0.64	0.069
08-Jun-10	0.04	0.338	2400	0.418	15	1.79	0.435
22-Jun-10	0.005	0.041		0.081	3	0.76	0.073
14-Jul-10	0.005	0.018	10	0.209	1.5	0.75	0.026
27-Jul-10	0.005	0.009	4	0.047	2	0.67	0.02
25-Aug-10	0.005	0.02	8	0.026	1.5	0.59	0.038
08-Sep-10	0.005	0.026	76	0.015	6	0.63	0.061
21-Sep-10	0.005	0.013	20	0.006	1.5	0.6	0.036
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Thomsons lower							
08-Sep-09	0.005	0.01	52	0.059	7	0.24	0.025
23-Sep-09	0.01	0.028	320	0.058	11	0.37	0.067
06-Oct-09	0.005	0.028	300	0.056	15	0.31	0.066
20-Oct-09	0.005	0.018	230	0.045	42	0.32	0.065
03-Nov-09	0.005	0.01	110	0.026	31	0.2	0.046
19-Nov-09	0.02	0.08	600	0.042	7	0.74	0.153
01-Dec-09	0.02	0.045	830	0.039	5	0.56	0.096
15-Dec-09	0.02	0.079	1800	0.043	7	0.74	0.151
06-Jan-10	0.02	0.076	2900	0.008	20	0.87	0.168
18-Jan-10	0.02	0.063	560	0.021	9	0.62	0.127

01-Feb-10	0.02	0.089	3400	0.058	14	0.88	0.182
17-Feb-10	0.01	0.076	450	0.009	4	0.73	0.15
02-Mar-10	0.005	0.059	510	0.022	4	0.6	0.117
16-Mar-10	0.005	0.06	110	0.008	1.5	0.7	0.113
30-Mar-10	0.005	0.046	270	0.009	1.5	0.64	0.099
14-Apr-10	0.005	0.027	130	0.023	1.5	0.41	0.059
27-Apr-10	0.02	0.111	3400	0.098	10	1.17	0.201
10-May-10	0.005	0.021	76	0.146	3	0.44	0.044
25-May-10	0.02	0.037	2900	0.196	286	1.58	0.42
08-Jun-10	0.02	0.095	2100	0.489	86	1.1	0.198
22-Jun-10	0.01	0.018		0.227	82	0.5	0.076
14-Jul-10	0.005	0.01	29	0.355	4	0.55	0.021
27-Jul-10	0.005	0.008	8	0.207	4	0.48	0.023
25-Aug-10	0.005	0.009	31	0.223	12	0.39	0.025
08-Sep-10	0.005	0.015	58	0.204	80	0.49	0.061
21-Sep-10	0.005	0.007	34	0.194	49	0.4	0.069
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia US Ida Burn							
07-Sep-09	0.005	0.0025	2	0.006	4	0.06	0.013
23-Sep-09	0.005	0.007	7	0.006	1.5	0.09	0.011
06-Oct-09	0.005	0.006	16	0.006	1.5	0.06	0.011
20-Oct-09	0.005	0.007	74	0.009	21	0.13	0.024
03-Nov-09	0.005	0.008	80	0.007	39	0.13	0.032
19-Nov-09	0.005	0.011	24	0.008	1.5	0.05	0.012
01-Dec-09	0.005	0.01	18	0.005	1.5	0.09	0.016
15-Dec-09	0.005	0.01	48	0.01	1.5	0.05	0.015
06-Jan-10	0.005	0.008	22	0.005	1.5	0.2	0.015
18-Jan-10	0.005	0.009	270	0.005	1.5	0.08	0.01
01-Feb-10	0.005	0.007	64	0.005	1	0.14	0.017
17-Feb-10	0.005	0.006	130	0.005	1.5	0.11	0.013
02-Mar-10	0.005	0.007	64	0.007	3	0.13	0.017
16-Mar-10	0.005	0.008	88	0.011	1.5	0.13	0.012
30-Mar-10	0.005	0.009	34	0.007	1.5	0.15	0.013
14-Apr-10	0.005	0.08	82	0.012	1.5	0.13	0.014
27-Apr-10	0.005	0.01	280	0.04	10	0.28	0.034
10-May-10	0.005	0.006	96	0.016	1.5	0.1	0.008
25-May-10	0.005	0.008	130	0.025	5	0.12	0.018
08-Jun-10	0.01	0.019	220	0.243	165	0.59	0.126
22-Jun-10	0.01	0.013		0.184	216	0.45	0.088
14-Jul-10	0.005	0.007	24	0.318	4	0.49	0.012
27-Jul-10	0.005	0.005	4	0.198	4	0.4	0.013
25-Aug-10	0.005	0.006	4	0.14	8	0.29	0.014
08-Sep-10	0.005	0.009	34	0.138	30	0.32	0.045
21-Sep-10	0.005	0.0025	6	0.128	7	0.27	0.019
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Manuherikia US Chatto Creek							
08-Sep-09	0.005	0.007	5	0.018	4	0.13	0.016

23-Sep-09	0.005	0.01	23	0.022	6	0.16	0.022
06-Oct-09	0.005	0.017	46	0.008	1.5	0.14	0.033
20-Oct-09	0.005	0.015	300	0.021	24	0.23	0.047
03-Nov-09	0.005	0.01	120	0.013	34	0.11	0.023
19-Nov-09	0.005	0.024	26	0.014	1.5	0.13	0.035
01-Dec-09	0.005	0.019	12	0.015	1.5	0.17	0.027
15-Dec-09	0.005	0.025	64	0.012	1.5	0.12	0.04
06-Jan-10	0.005	0.021	60	0.011	1.5	0.12	0.034
01-Feb-10	0.005	0.032	100	0.023	1.5	0.31	0.048
18-Jan-10	0.01	0.028	280	0.03	1.5	0.26	0.048
02-Mar-10	0.005	0.024	56	0.009	1.5	0.2	0.033
17-Feb-10	0.005	0.025	30	0.009	1.5	0.19	0.031
16-Mar-10	0.005	0.018	40	0.01	1.5	0.2	0.029
30-Mar-10	0.005	0.019	32	0.012	1.5	0.17	0.023
14-Apr-10	0.01	0.027	110	0.012	1.5	0.22	0.031
27-Apr-10	0.005	0.052	1500	0.068	8	0.69	0.11
10-May-10	0.005	0.011	27	0.021	1.5	0.15	0.016
25-May-10	0.025	0.01	64	0.03	3	0.12	0.019
08-Jun-10	0.01	0.042	1600	0.3	209	0.84	0.212
22-Jun-10	0.005	0.017		0.273	238	0.66	0.151
14-Jul-10	0.005	0.009	46	0.418	5	0.61	0.017
27-Jul-10	0.005	0.008	26	0.311	2	0.56	0.014
25-Aug-10	0.005	0.009	54	0.231	17	0.44	0.022
08-Sep-10	0.01	0.011	29	0.219	86	0.45	0.065
21-Sep-10	0.005	0.005	26	0.185	21	0.38	0.035
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Lauder Creek							
07-Sep-09	0.005	0.0025	10	0.008	10	0.06	0.017
23-Sep-09	0.005	0.006	19	0.01	8	0.12	0.062
06-Oct-09	0.005	0.006	300	0.01	8	0.14	0.033
20-Oct-09	0.005	0.007	240	0.01	31	0.19	0.041
03-Nov-09	0.005	0.006	88	0.0025	22	0.14	0.03
19-Nov-09	0.005	0.017	2300	0.0025	5	0.23	0.076
01-Dec-09	0.005	0.01	160	0.0025	1.5	0.15	0.045
15-Dec-09	0.005	0.021	1600	0.0025	4	0.4	0.113
06-Jan-10	0.005	0.011	74	0.025	1.5	0.15	0.066
18-Jan-10	0.005	0.025	290	0.0025	3	0.49	0.108
01-Feb-10	0.005	0.044	340	0.0025	4	0.64	0.212
17-Feb-10	0.01	0.017	140	0.0025	1.5	0.44	0.105
02-Mar-10	0.005	0.022	330	0.01	1.5	0.42	0.114
16-Mar-10	0.005	0.013	380	0.0025	2	0.34	0.073
30-Mar-10	0.005	0.014	170	0.0025	1.5	0.28	0.064
14-Apr-10	0.005	0.013	430	0.0025	1.5	0.25	0.055
27-Apr-10	0.01	0.045	2000	0.076	21	0.9	0.193
10-May-10	0.005	0.008	55	0.0025	1.5	0.2	0.036
25-May-10	0.005	0.01	430	0.0025	9	0.26	0.07
08-Jun-10	0.02	0.042	290	0.325	113	0.8	0.137
22-Jun-10	0.01	0.011		0.109	89	0.35	0.072
14-Jul-10	0.005	0.005	10	0.109	6	0.25	0.017

27-Jul-10	0.005	0.005	32	0.082	7	0.3	0.025
25-Aug-10	0.005	0.006	30	0.056	15	0.17	0.02
08-Sep-10	0.005	0.008	20	0.069	162	0.33	0.065
21-Sep-10	0.005	0.0025	6	0.057	29	0.2	0.051
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Chatto Creek							
08-Sep-09	0.005	0.012	9	0.048	1.5	0.17	0.021
23-Sep-09	0.005	0.017	7	0.021	1.5	0.2	0.036
06-Oct-09	0.01	0.024	250	0.161	7	0.38	0.046
20-Oct-09	0.005	0.017	140	0.084	13	0.34	0.047
03-Nov-09	0.005	0.014	98	0.039	9	0.19	0.036
19-Nov-09	0.005	0.029	210	0.087	7	0.34	0.059
01-Dec-09	0.01	0.063	950	0.2	6	0.62	0.098
15-Dec-09	0.005	0.033	250	0.217	5	0.58	0.074
06-Jan-10	0.005	0.031	1300	0.176	4	0.49	0.064
01-Feb-10	0.005	0.026	330	0.152	4	0.46	0.059
18-Jan-10	0.02	0.039	700	0.258	7	0.67	0.087
02-Mar-10	0.005	0.031	1500	0.386	3	0.69	0.063
17-Feb-10	0.005	0.045	540	0.283	1.5	0.63	0.081
16-Mar-10	0.005	0.035	500	0.36	3	0.73	0.061
30-Mar-10	0.005	0.039	200	0.305	1.5	0.66	0.069
14-Apr-10	0.005	0.025	350	0.299	1.5	0.58	0.046
27-Apr-10	0.005	0.03	480	0.133	1.5	0.53	0.064
10-May-10	0.005	0.02	100	0.21	1.5	0.38	0.031
25-May-10	0.01	0.025	1000	0.115	95	0.73	0.186
08-Jun-10	0.005	0.017	110	0.304	22	0.6	0.06
22-Jun-10	0.005	0.014		0.113	4	0.25	0.027
14-Jul-10	0.005	0.011	31	0.148	3	0.27	0.014
27-Jul-10	0.005	0.009	30	0.12	2	0.27	0.018
25-Aug-10	0.005	0.012	24	0.145	3	0.29	0.017
08-Sep-10	0.005	0.011	32	0.111	11	0.3	0.029
21-Sep-10	0.005	0.008	26	0.139	13	0.31	0.031
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Pool Burn upper							
07-Sep-09	0.005	0.023	22	0.031	1.5	0.44	0.041
23-Sep-09	0.005	0.033	250	0.024	3	0.43	0.062
06-Oct-09	0.005	0.057	410	0.051	3	0.56	0.093
20-Oct-09	0.005	0.043	340	0.042	4	0.75	0.09
03-Nov-09	0.005	0.03	220	0.02	4	0.45	0.068
19-Nov-09	0.03	0.27	400	0.057	4	0.85	0.332
01-Dec-09	0.04	0.071	150	0.02	1.5	0.58	0.109
15-Dec-09	0.02	0.059	260	0.037	1.5	0.61	0.097
06-Jan-10	0.04	0.217	280	0.018	3	1.28	0.295
18-Jan-10	0.04	0.135	290	0.01	1.5	0.96	0.189
01-Feb-10	0.03	0.159	480	0.018	4	0.98	0.243
17-Feb-10	0.03	0.124	190	0.037	1.5	0.77	0.19
02-Mar-10	0.01	0.124	470	0.0025	1.5	0.78	0.178

16-Mar-10	0.005	0.099	450	0.006	2	0.74	0.145
30-Mar-10	0.02	0.201	480	0.008	1.5	1.03	0.265
14-Apr-10	0.01	0.077	2100	0.011	1.5	0.53	0.111
27-Apr-10	0.01	0.095	500	0.022	3	0.79	0.143
10-May-10	0.005	0.036	110	0.012	1.5	0.31	0.053
25-May-10	0.005	0.033	320	0.024	1.5	0.42	0.055
08-Jun-10	0.01	0.085	1000	0.283	14	0.83	0.13
22-Jun-10	0.02	0.027		0.743	127	1.32	0.128
14-Jul-10	0.005	0.012	29	1.27	1.5	1.7	0.017
27-Jul-10	0.005	0.008	18	0.91	2	1.46	0.025
25-Aug-10	0.005	0.013	26	0.722	3	1.16	0.025
08-Sep-10	0.005	0.014	34	0.759	11	1.2	0.038
21-Sep-10	0.005	0.006	28	0.617	1.5	1.06	0.024
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Dovedale Creek at Rocks Bluff							
08-Sep-09	0.005	0.006	3	0.0025	1.5	0.27	0.011
23-Sep-09	0.005	0.006	12	0.0025	5	0.27	0.021
06-Oct-09	0.005	0.006	27	0.0025	1.5	0.21	0.02
20-Oct-09	0.005	0.007	62	0.0025	1.5	0.28	0.014
03-Nov-09	0.005	0.008	290	0.0025	1.5	0.27	0.03
19-Nov-09	0.005	0.009	370	0.0025	1.5	0.15	0.035
01-Dec-09	0.01	0.008	100	0.0025	5	0.43	0.091
15-Dec-09	0.005	0.009	92	0.0025	1.5	0.13	0.039
01-Feb-10	0.005	0.007	3200	0.0025	1.5	0.33	0.034
Date	NH4 g/m3-N	DRP g/m3-P	*E. coli* cfu/100ml	NNN g/m3-N	SS g/m3	TN g/m3-N	TP g/m3-P
Ida Burn upper							
08-Sep-09	0.005	0.005	0.5	0.0025	1.5	0.18	0.019
23-Sep-09	0.005	0.0025	22	0.0025	1.5	0.07	0.006
06-Oct-09	0.005	0.0025	4	0.0025	1.5	0.025	0.005
20-Oct-09	0.005	0.0025	4	0.0025	1.5	0.07	0.005
03-Nov-09	0.005	0.005	30	0.0025	1.5	0.06	0.0025
19-Nov-09	0.005	0.007	19	0.0025	1.5	0.025	0.005
01-Dec-09	0.005	0.005	30	0.0025	1.5	0.06	0.007
15-Dec-09	0.005	0.006	12	0.0025	1.5	0.025	0.007
06-Jan-10	0.005	0.005	8	0.008	1.5	0.025	0.01
01-Feb-10	0.005	0.0025	150	0.0025	1.5	0.08	0.009
17-Feb-10	0.005	0.005	24	0.007	1.5	0.07	0.01
02-Mar-10	0.005	0.006	13	0.007	1.5	0.06	0.007
16-Mar-10	0.005	0.006	8	0.008	1.5	0.1	0.008
30-Mar-10	0.005	0.007	18	0.006	1.5	0.1	0.007
14-Apr-10	0.005	0.006	10	0.005	1.5	0.06	0.006
27-Apr-10	0.005	0.006	6	0.008	1.5	0.1	0.008
10-May-10	0.005	0.005	1	0.0025	1.5	0.06	0.0025
25-May-10	0.005	0.023	88	0.018	21	0.5	0.055
08-Jun-10	0.005	0.006	30	0.008	7	0.21	0.018

22-Jun-10	0.005	0.007		0.024	55	0.28	0.048
14-Jul-10	0.005	0.01	1	0.0025	1.5	0.22	0.016
27-Jul-10	0.005	0.0025	1	0.0025	2	0.15	0.007
25-Aug-10	0.005	0.005	4	0.0025	1.5	0.11	0.0025
08-Sep-10	0.005	0.005	1	0.0025	1.5	0.13	0.007
21-Sep-10	0.005	0.0025	2	0.0025	1.5	0.11	0.01