Water quality and ecosystem health in the Upper Taieri

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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 upper Taieri River catchment.

The Upper Taieri is well known for its natural values, including the regionally significant scroll plain wetland, endangered native fish and its trout fishery. However, water quality and ecology of the area is being put under pressure because of changing agricultural use, especially increasing use of irrigation and the intensification of land use.

By using both regulatory and non-regulatory approaches, the ORC must ensure that the water quality in the region is maintained or if necessary 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 policy decisions. They will also be shared with the community and other stakeholders to promote good practice to maintain and enhance water quality in and around the upper Taieri catchment.

Executive summary

The Upper Taieri is known for its numerous natural values, including the regionally significant scroll plain wetland, endangered native fish and a regionally significant trout fishery.

The 2012 State of Environment Water Quality Report (ORC, 2012a) showed that water quality in the Upper Taieri River catchment is generally good; there have been improvements at Waipiata, but Tiroiti and Sutton have shown deterioration. The improvements are probably due to a wide array of changes occurring in the Upper Taieri, ranging from improved irrigation methods and efficiency, the fencing of an increasing number of waterways, better management of wetland complexes and better effluent management on dairy farms. However, they are offset by more intensive farming in the catchment.

The objectives of this investigation were to:

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

In September 2010, the Otago Regional Council (ORC) initiated a water-sampling programme whereby water samples were collected from 18 sites fortnightly for 12 months. During the summer of 2011/2012, all ten tributary sites were also sampled for habitat condition, macroinvertebrate community composition and fish abundance.

This investigation has found that:

- water quality in the Taieri River in the Upper Taieri catchment was found to be 'good'. Concentrations of bacteria, nitrogen and sediment were below the effects-based guidelines' during low flows.
- nitrite-nitrate-nitrogen concentrations were low in the main stem, but exceeded guideline values at some of the tributary sites.
- Dissolved reactive phosphorus concentrations exceeded guidelines at most sites for all-flow conditions. Very few sites exceeded the guidelines' when flows were low.
- bacteria and suspended solid levels were generally very low. Suspended solids did exceed guidelines at six sites during all-flow conditions.
- some tributary sites (lower Gimmer Burn, lower Pig Burn, lower Sheppard's Drain and Sow Burn) had enough fine sediment build-up on the bed to have a detrimental impact on ecological values.
- where exceedences in water-quality parameters occurred, they can probably be explained by the presence of dead stock, stock access to waterways or to irrigation run off.
- in general, 'good' ecological values were found, (as indicated by trout and macroinvertebrate population) in sites with good water quality and good habitat. Central Otago Roundhead galaxiids were present where trout populations were limited by low flow.

- where ecological degradation had occurred, it was attributed to a lack of stock exclusion, irrigation run off and prolonged low flows (over-allocation of water).

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1. Introduction

The Upper Taieri is known for its numerous natural values, including the regionally significant scroll plain wetland, endangered native fish and a regionally significant trout fishery.

However, land-use intensification has affected water quality in a number of catchments around New Zealand (Riley *et al*., 2003; Buck *et al*., 2004; Townsend *et al*., 2008). These changes can occur quickly as farming technology and changing markets allow intensive farming practices to be used in areas where they formerly were not.

The 2012 State of Environment Water Quality Report (ORC, 2012a) showed that water quality in the Upper Taieri River catchment is generally 'good'; there have been some improvements at Waipiata, but Tiroiti and Sutton have shown some deterioration. The improvements are probably the result of a wide array of changes occurring in the area, ranging from improved irrigation methods and efficiency, an increasing number of waterways fenced, better management of wetland complexes and better effluent management on dairy farms. However, they are offset by more intensive farming in the catchment.

The objectives of this investigation are to increase the understanding of the ecological health of the Upper Taieri River catchment by considering water quality, physical habitat, macroinvertebrate communities and fish populations. This knowledge will assist decision making by all stakeholders in the area.

2. Background information

2.1 Topography and Soils

The Taieri River rises in the Lammerlaw and Lammermoor Ranges at 1,150 m above sea level and traces a 318 km horse-shoe to reach the Pacific Ocean about 30 km south of Dunedin. The Upper Taieri has two major catchments that are greater than 1000 km^2: Logan Burn and Kye Burn. The north-eastern boundary of the catchment is formed by the Ida Range and Kakanui Mountains. These are the highest mountains in the catchment and are snow-capped for several months. Mount Ida is 1,691 m and Mount Pisgah in the Kakanui Range is 1,643 m. To the east, the Rock and Pillar Range, a prominent feature in the catchment, divides the Upper Taieri and the Strath Taieri. The Taieri River collects tributaries from its western, northern and eastern slopes. The range extends north-east from the Lammermoors for about 45 km, is about 20 km in width and reaches 1,450 m above sea level at Summit Rock. The summit is generally flat topped and contains large and extensive swamp areas and tarns. Snow usually lies for several months in winter. The eastern slopes are steep and tower over Middlemarch on the Strath Taieri.

Other well-known features in the Upper Taieri include Serpentine Flat (the Styx) and the Maniototo Plain. Serpentine Flat is about 540 m above sea level and has an area of approximately 38 km^2. It is about 10 km long, from north to south, and 5 km across the centre. On these flat areas, the river's channel meanders, and has many oxbows and swampy areas. The Maniototo Plain covers an area of about 660 km^2. It is 36 km long - 20 km at its widest point; 300 m at its lowest - and varies in height from 600 m, at the foot of the Kakanui Mountains, to 450 m, near Ranfurly. High river flows in winter and spring spread out over the meander belt and remain ponded for several months. Many tributaries flow from the surrounding high ranges through gorges and down alluvial fans on the Maniototo to the Taieri River, including the Linn Burn and Totara Creek, from Rough Ridge, in the west; the Logan Burn, Sow Burn and Pig Burn, from the Rock and Pillar Range, in the south; the Wether Burn and Hog Burn, from the Ida Range, in the north; and the Kye Burn, from the Ida Range, in the north, and the Swin Burn, from the Kakanui Mountains, in the north-east.

The Upper Taieri has a range of soil types, depending on their topographic position and relationship with climate and vegetation. The main types are the upland and high country yellow-brown earths, characterised by a horizon of weakly developed fine-crumb structure and silt-loam texture over a friable silt-loam subsoil. These soils are formed in areas that are subject to intense ground frosts and low rainfall, under a vegetative cover of tall tussock, subalpine shrubland and alpine herbfield. Other types that are common, but not as dominant, include brown-grey earths and recent alluvial soils, which are found around the historical channels and flood plains that surround the main tributaries.

2.2 Vegetation

Indigenous vegetation communities in the Upper Taieri were once dominated by grasslands and some native scrubland. Grassland communities would have consisted of short tussock grasslands, such as the fescue tussock (*Festuca novae-zelandiae*) and the silver tussock (*Poa laevis*). High altitude short tussocks now occupy much of the summit of the Rock and Pillar Range, which was once covered with slim snow tussock (*Chionochloa macra*). Tall tussock grasslands would have had extensive coverings of narrow-leaved snow grass (*C. rigida*) and red tussock, (*C. rubra*) and blue tussock (*Poa colensoi*). Scrublands would have been dominated by manuka (*Leptosperum scoparium*) kanuka (*L. ericoides*) and matagouri (*Discaria toumatou*). However, due to burning and grazing, scrublands are not common today, especially on the flat. There is also more farmland today, which is dominated by high producing exotic grasses. On the steeper slopes and in the backcountry, short tussocks are still common, but are top-dressed and over-sown with exotic pasture grasses.

2.3 Land-use

Land-use in the upper Taieri is dominated by low intensity mixed sheep and beef farming (Figure 2.1). Deer farming is present in the catchment and makes up 4,126 ha (1.5% of the catchment). Dairy farming is present and clustered around Patearoa and comprises 1.4% (3,964 ha) of the catchment area (Figure 2.1).

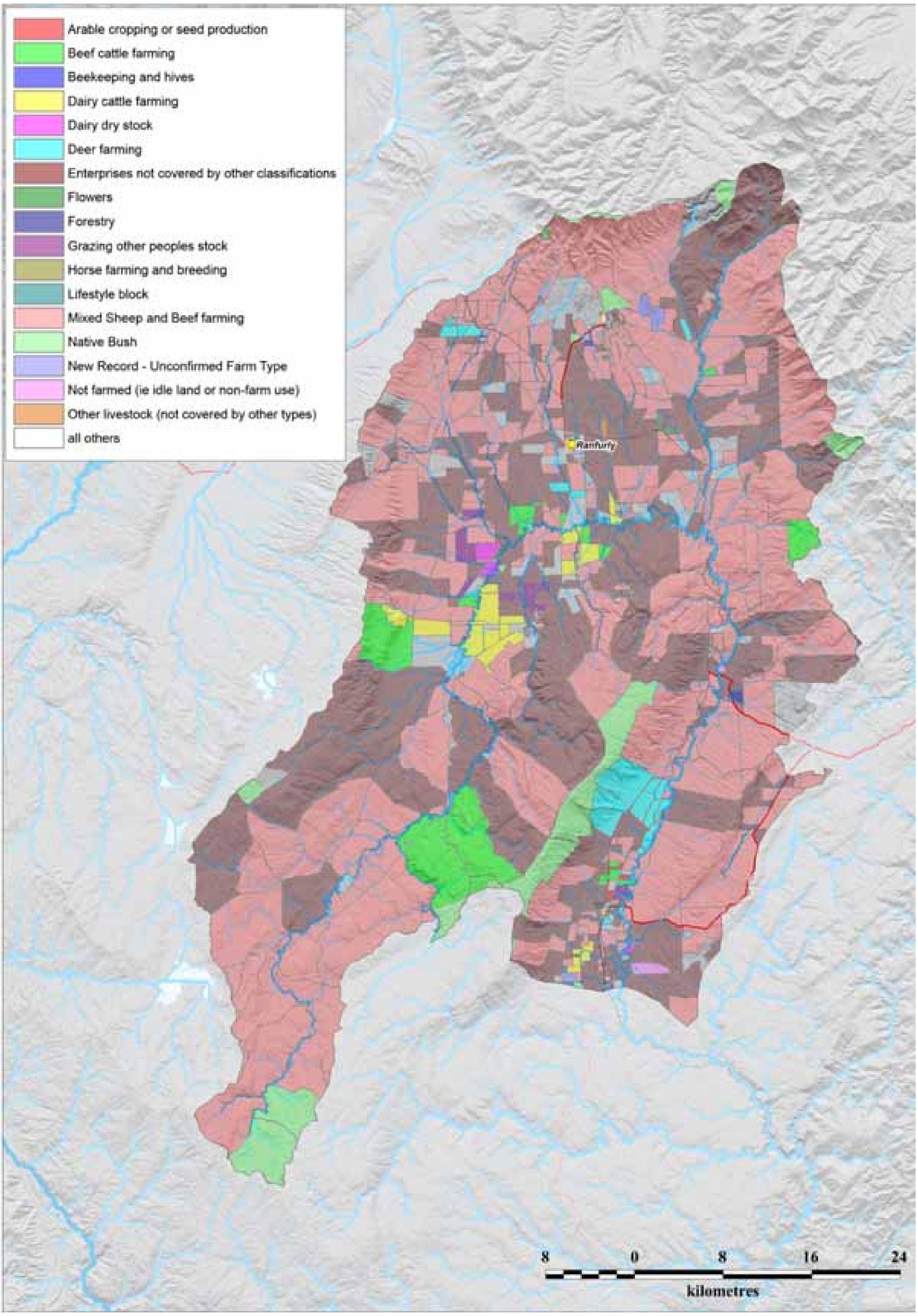


Figure 2.1 Land-use classifications for the upper Taieri catchment (above Sutton) based on data provided in the Agribase database.

2.4 Climate

The Upper Taieri is one of the driest, coldest and hottest areas in New Zealand. Maximum temperatures greater than 30ºC are common in summer and minimum temperatures as cold as -15ºC have been recorded near Nasbey. Waipiata has an annual average of 2,046 sunshine hours per year.

Patearoa has the lowest mean annual rainfall, at 396 mm. In contrast, Dansey's Pass, which is influenced by orographic rainfall from the east, has a mean annual rainfall of 758 mm. The lowest rainfall experienced in any year was 262 mm, recorded at Patearoa in 1997. All sites tend to experience their lowest mean monthly rainfall during winter and early spring (Figure 2.2). The highest rainfall months occur in December, while Dansey's Pass gets most of its annual rain in summer, between November and February.

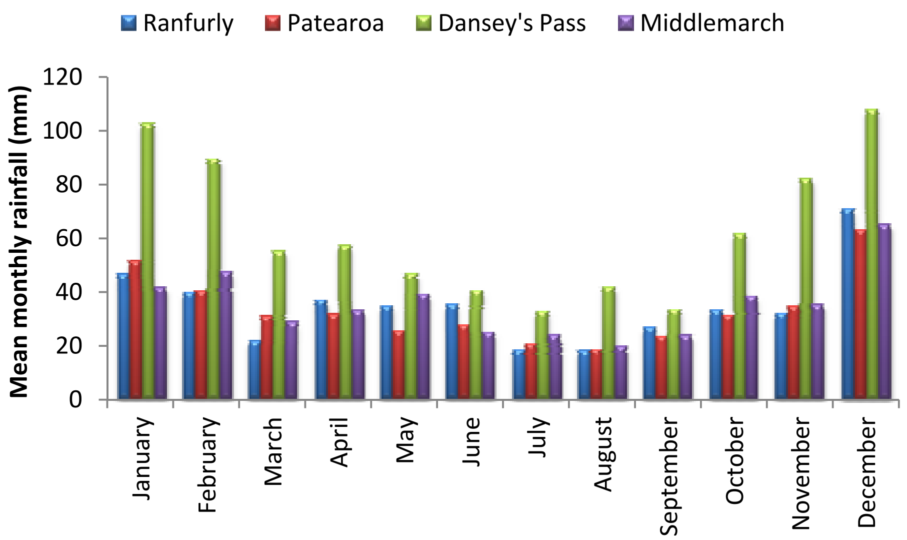


Figure 2.2 Mean monthly rainfall for four sites in the Upper and Strath Taieri catchments.

2.5 Hydrology

Figure 2.3 displays the hydrographs for the daily average flow for the 2006-2011 hydrological years at the four flow sites in the Upper Taieri catchment. Flows are often at their lowest towards the end of summer (February to March) and in winter. Highest flows occur during the spring snowmelt. Flow peaks are relatively sharp at Canadian Flat as this site is above the wetlands, which buffer peak flows. The wetlands have most holding capacity during the drier period, from February to March.

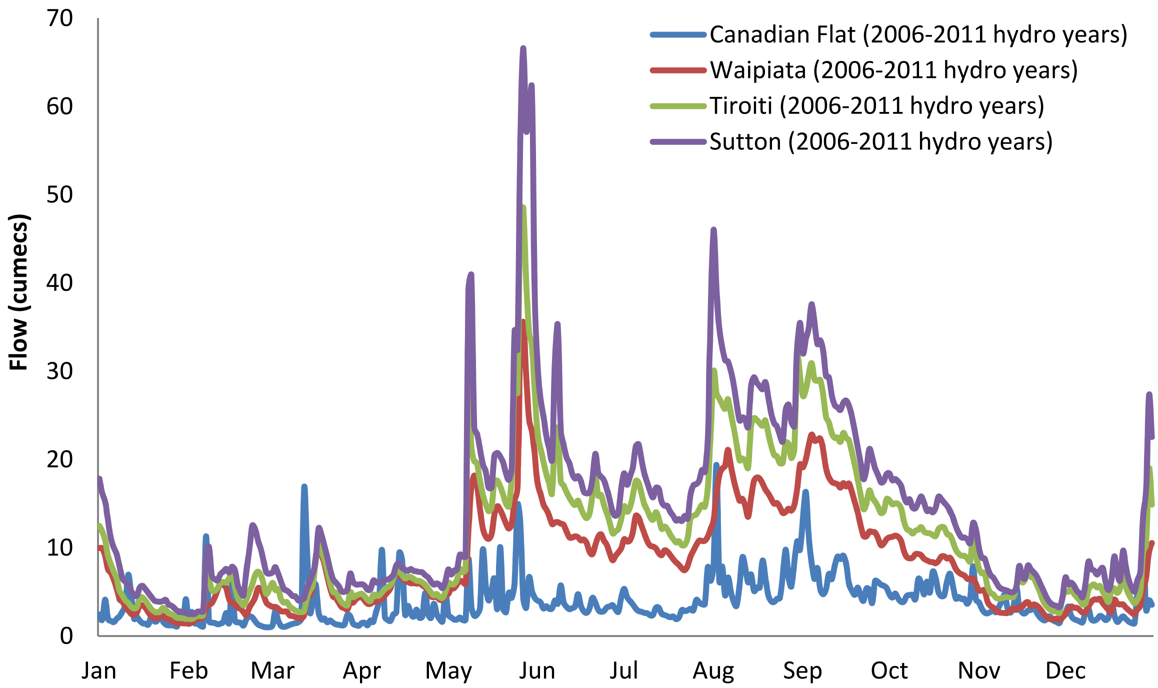


Figure 2.3 Hydrograph summary of the main hydrological monitoring sites.

2.6 Natural values

Twelve species of fish are present within the Upper Taieri catchment. Of these, four have been introduced as sports fish and have successfully naturalised (Table 2.1). Of the eight remaining native fish, five species are of conservation concern, including two species, Eldon's and Dusky galaxiids, which are considered nationally endangered.

Table 2.1 Fish species present within the Upper Taieri catchment (Sources: New Zealand Freshwater Fish Database, ORC records and Fish and Game Otago records).

Common name	Species name	Conservation status
Chinook salmon	*Oncorhynchus tshawytscha*	Introduced and naturalised
Brown trout	*Salmo Trutta*	Introduced and naturalised
Brook char	*Salvelinus fontinalis*	Introduced and naturalised
Perch	*Perca fluvialtilis*	Introduced and naturalised
Longfin eel	*Angullia dieffenbachia*	Declining
Lamprey	*Geotia australis*	Declining
Eldon's galaxias	*Galaxias eldoni*	Nationally endangered
Roundhead galaxias	*Galaxias anomalus*	Nationally vulnerable
Flathead galaxias	*Galaxias deprecsiceps*	Not threatened
Dusky galaxias	*Galaxias pullus*	Nationally endangered
Common Bully	*Gobiomorphus cotidianus*	Not threatened
Upland Bully	*Gobiomorphus breviceps*	Not threatened

Schedule 1A of the Regional Plan: Water for Otago (RPW) (ORC, 2004) lists many natural values for the Upper Taieri, including trout, spawning and juvenile habitat for trout and salmon, rare native fish and macroinvertebrates. Table 2.2 summarises the significant values, as listed in the RPW.

Table 2.2 Natural values of sampling sites in the Upper Taieri taken from Schedule 1A of the RPW.

Water body	Ecosystem value	Significant indigenous vegetation and significant habitat of indigenous fauna
Taieri River (*upstream of Tiroiti*)	• Spawning habitat (trout and salmon) • Juvenille habitat • Eels • Trout (downstream of Paerau weir) • Rare fish (upstream of Paerau weir	• Significant habitat for flathead galaxiid, including tributaries upstream of Paerau weir • Significant habitat for lamprey
Sow Burn	• Spawning habitat • Juvenille habitat • Adult salmon and trout	
Pig Burn	• Spawning habitat • Juvenille habitat • Adult trout	
Kye Burn (including Little Kye Burn)	• Habitat spawning (trout) • Juvenille habitat • Eels • Trout • Rare fish	• Significant habitat for roundhead and flathead galaxiids

2.7 Recreational values

Schedule 1A of the RPW acknowledges the importance of the spawning and juvenile habitats and adult populations in the Upper Taieri catchment's trout fishery. The Otago region experienced a slight decrease in river-angling days of recreational salmonid fishing between 2001/2002 and 2007/2008. Over the same period, there was a slight increase in the number of angler days in the Upper Taieri, above Kokonga, from 3660 ± 730 days in 2001/2002 and 4050 ± 1130 days in 2007/2008 (Unwin, 2009).

2.8 Irrigation

Irrigation accounts for 85% of water abstraction in Otago and is likely to remain the primary use of this resource in the region. Currently, 73% of consented water takes from the Taieri River are used for irrigation, with most of the water being used for pasture production. There are three major irrigation schemes in the Taieri catchment: the Maniototo Irrigation Company (MIC), the Hawkdun-Idaburn Irrigation Company and the Ida Valley Irrigation Company. The Hawkdun-Idaburn Irrigation Company takes up to 0.41 cumecs from the Eweburn/Wetherburn catchments, which includes water augmented from the Mt Ida Race (sourced from the upper Ida Burn, Manuherikia catchment) and stored in the Eweburn Dam. The Ida Valley Irrigation Company takes up to 0.556 cumecs from Totara Creek to augment the Poolburn Reservoir in the Manuherikia catchment. The MIC takes up to six cumecs from the main stem of the Taieri River, augmented by water stored in Logan Burn Reservoir. This take supplies approximately 60 farms with irrigation and stock water and has a command area of approximately 9,300 hectares. There are five minimum flow sites in the main stem of the Taieri River: Outram (2.5 cumecs), Sutton (1.25 cumecs), Tiroiti (1.1 cumecs), Waipiata (1 cumecs) and Paerau (0.85 cumecs).

Table 2.3 shows that spray irrigation has the most efficient rates of water application compared to flood/contour/border-dyke irrigation. The main reason for low efficiency in flood irrigation is that the high rate of application causes a significant proportion of the 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 (McDowell and Rowley, 2008; Monaghan *et al*., 2009) conducted in catchments dominated by flood/border-dyke irrigation have shown that agricultural pollutants, such as nutrients, bacteria and sediment, are significantly elevated because they are entrained and transported over the paddock and back in water races or water ways. Due to the greater application efficiency of spray irrigation, there is a reduction in irrigation run off. However, this benefit to water quality is often offset by an increase in contaminants associated with diffuse discharges from land-use intensification, as result of improved irrigation techniques.

Table 2.3 Approximate application efficiency (Ea) for various irrigation methods (Irrigation New Zealand Inc., 2007).

System type	Average E_a (%)	Efficiency range (%)
Linear move	85	80-93
Centre-pivot	85	85-94
Border-dyke	60	50-80
Wild flood	25	5-50

3. Methods

This section outlines the methods that were followed to collect the water chemistry, physical habitat, and ecological values in the Tokomairiro River catchment. The physico-chemistry section outlines the analytes that were sampled, the sampling frequency and guidelines that were used for the study. The physical assessment used key measures from the Fine sediment assessment protocols (Clapcott *et al.* 2011). The macroinvertebrate and fishery values section outlines the methods for selecting habitat to sample and methods for the collection of data and interpretation of data.

3.1 Physico-chemical assessment

Between September 2010 and September 2011, 17 streams (Figure 3.1) 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). Flow monitoring was also carried out at most sites on permanent or temporary recorders. For sites where there was 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.

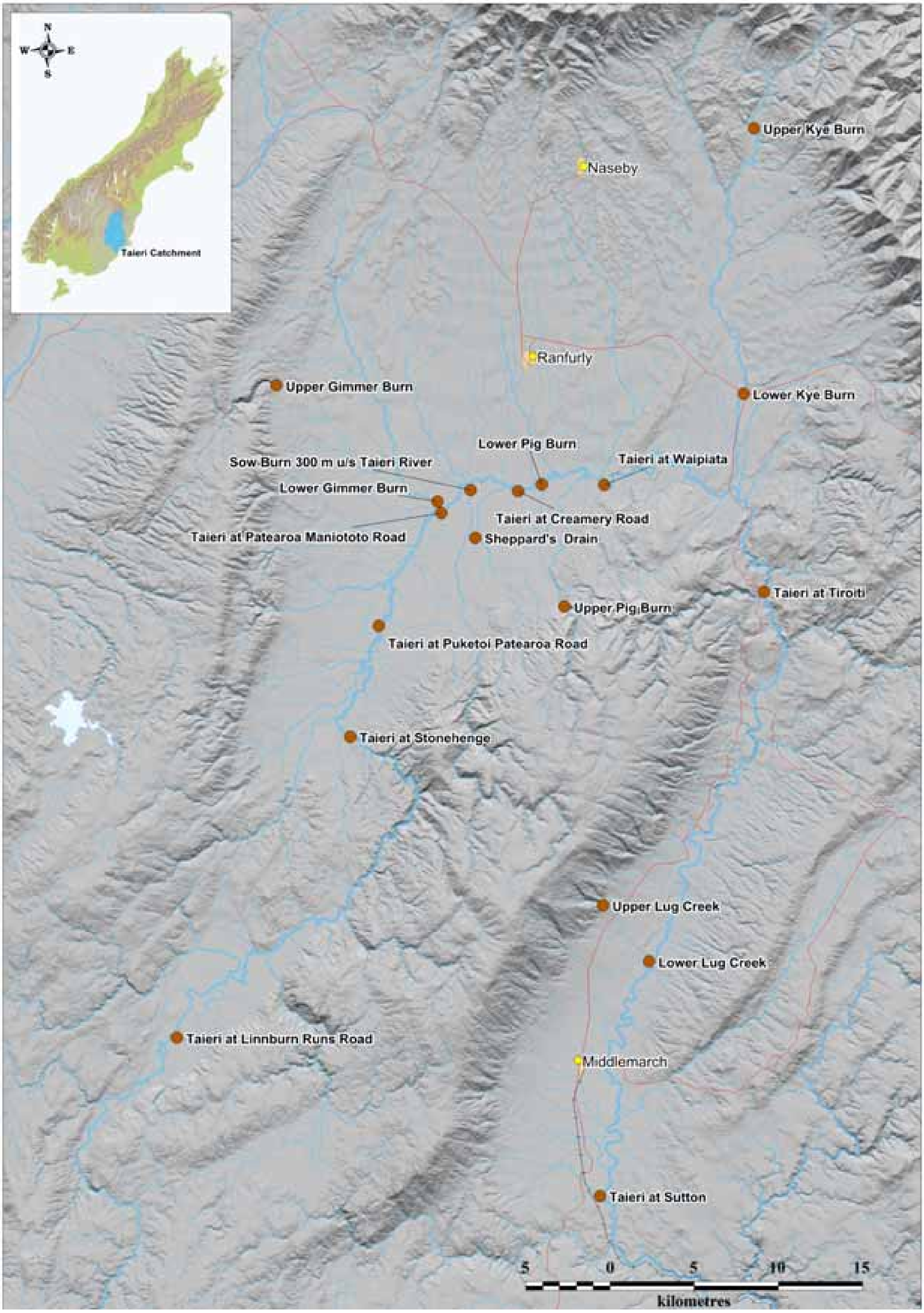


Figure 3.1 **The Upper Taieri River catchment and water-quality sampling sites.**

3.2 Water quality guidelines

The guideline values in this report have been chosen to reflect the nature of the Upper Taieri River catchment (Table 3.1). Where possible, guideline standards reflecting discernible effects on ecological, angling and contact recreation have been used. The ANZECC (2000) guidelines are referenced for NH_4, TN and TP guideline values, while the biologically available nutrients (DRP and NNN) were referenced against the New Zealand Periphyton Guidelines (Biggs, 2000) for angling. The guideline values for the Upper Taieri River catchment are based on a N-limited system with an accrual period of greater than 30 days. Accural periods were calculated by working out the average number of days between flow events that were three times median flow (Biggs, 2000).

Bacteria guidelines were drawn from the MfE/MoH microbiological water-quality guidelines (2003) for human health. SS guidelines were taken from the Cawthron Institute (Hay *et al.* 2006), where 5 NTU was found to be the maximum turbidity value before there was an effect on drift-feeding trout's growth potential. A regression between SS and turbidity data (R^2=0.93) on long-term monitoring data from Taieri River at Sutton gave a SS guideline value of 8.75 mg/l.

Table 3.1 Physico-chemical and microbiological analytes and guideline values.

Analyte	Guideline value	Ecological effect
NH_4	≤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	≤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	≤0.075 mg/l**	The biologically available component of TN, an excess of this nutrient may cause nuisance algal growths.
TP	≤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	≤0.006 mg/l**	An excess of this nutrient, which is the biologically available component of TP, 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 (e.g. from human or animal faeces).
SS	≤8.75 mg/l^^	SS smother larger substrate, reducing available habitat for macroinvertebrates and fish. Nutrients may attach to sediments. High levels may affect clarity and photosynthesis and 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 Hay *et al.* (2006) 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 Taieri River at Sutton.

3.3 Water quality analysis procedures

3.3.1 Water quality index

In this investigation, the water quality index (WQI) (Table 3.2) was used to allow inter-site comparisons between each monitoring site. The WQI for each site was derived from the median values for the following six variables: TP; DRP, TN; NNN; *E coli* and; SS. The median values were then assessed against water quality guidelines (Table 3.1).

Table 3.2 Water Quality Index Classification.

WQI Classification	Definition
Excellent	Median values for all six variables comply with guideline values.
Good	Median values for five of the six variables comply with guideline values.
Fair	Median values for three or four of the six variables comply with guideline values.
Poor	Median values for two or less of the six variables comply with guideline values.

3.3.2 Flow adjustment

Annual loads

Annual loads were calculated for monitoring site using the interpolation method provided by Johnes (2007) for all parameters. The output was in kg/ha/year. However, it should be noted that this method under estimates both SS and *E. coli* loads. This is because most of the SS load is exported during storm events and it is recommended that SS loads are calculated with data collected weekly (Johnes, 2007). This was difficult to achieve in this investigation due to logistics and cost, so calculations were done on fortnightly data. For *E. coli*, storm loads are know to export over 90% of the annual *E. coli* load (Davis-Colley *et al.* 2008). As a result of the sampling strategy, storm flows were not targeted. While this limitation is noted, annual loading was calculated for comparisons.

3.4 Physical habitat assessment

Assessments of fine sediment were conducted in all sites in December 2011 using the fine habitat assessment methods provided for in Clapcott *et al.* (2011). The specific methods employment included: proportion of fine sediment; particle size; shuffle index and; sediment depth. A brief description of each method is provided below.

Fine sediment estimation:

In a 30m reach comprising run habitat, five transects were established. At the most downstream transect, the proportion of fine sediment (defined as sediment less than 2mm in diameter) was estimated using an underwater viewer. This was repeated another three times along the transect for a total of four estimations per transect.

Particle size:

Wolman particle counts were completed in the same 30m along five random transects. Starting at the bottom of the reach and work across and up, 100 randomly selected substratum were selected. This was achieved by picking up the substrate that was at the front of the foot. Each individual substrate was measured along its longest access.

Shuffle index:
In the same reach, three Shuffle Indexes were completed. This was achieved by placing a white marker in the stream bed, and then moving 3m upstream and disturbing the sediment vigorously. A rank of 1-5 (Figure 3.2) was then applied depending on how long it took the sediment to clear.

Level 1: No or small plume.	**Level 2:** Plume briefly reduces visibility at tile.	**Level 3:** Plume partially obscures tile but quickly clears.
		
Level 4: Plume partially to fully obscures tile but slowly clears.	**Level 5:** Plume fully obscures tile and persists even after shuffling ceases.	
		

Figure 3.2 Visual guidelines for shuffle index grades (proposed guidelines for the assessment of fine sediment).

Sediment depth:
In the 30m reach, five randomly distributed transects were established. At four locations on each transect, a pipe was inserted as far as practical into the stream bed. The depth was then recorded. This was repeated along each transect.

3.5 Biological assessment

3.5.1 Macroinvertebrates

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

Macroinvertebrate communities in 17 streams were sampled in January 2012. At each site, one extensive kick-net sample was collected, following Protocol C2: hard-bottomed, semi-quantitative sampling of stream macroinvertebrate communities (Stark *et al.*, 2001), which requires sampling a range of habitats, including riffles, mosses, wooden debris and leaf packs. Samples were preserved in 90% ethanol in the field and returned to the laboratory to be processed. Following Protocol 1, semi-quantitative coded abundance, macroinvertebrate samples were coded into one of five abundance categories: Rare (1-4), Common (5-19), Abundant (20-99), Very Abundant (100-499) or Very, Very Abundant (500+).

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 macroinvertebrates were indentified under a dissecting microscope (10-40X), using the identification key of Winterbourn *et al.* (2000).

While no guidelines are currently available for macroinvertebrate community indices, the commonly accepted categories are summarised in Table 3.3. 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 terms, 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***: An index that is 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 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 taxa and dividing this total by the number of taxa present at the site.

- ***Semi-quantitative Macroinvertebrate Community Index* (SQMCI)**: A variation of the MCI that accounts for the abundance of pollution sensitive and tolerant species. The SQMCI is calculated from coded count data. (Individual taxa counts are assigned to one of Rare (R), Common (C), Abundant (A), Very Abundant (VA), Very, Very Abundant (VVA) classes.)

Table 3.3 Criteria for aquatic macroinvertebrate health, according to different macroinvertebrate indices. There is no guideline for macroinvertebrate communities; however, these are accepted criteria (Stark et al., 2001).

Macroinvertebrate index	Poor	Fair	Good	Excellent
MCI	<80	80-99	100-119	>120
SQMCI	<4	4-5	5-6	>6

3.5.2 Fish communities

Each site was fished by three-pass downstream electric-fishing, using a pulsed DC Kainga EFM300 backpack electro-shocker. A 15-minute rest period between electric-fishing passes was used to allow fish to 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. Fish from each pass were kept separate, counted and then released after the third electric-fishing pass. At each site, native fish were identified and counted; trout, on the other hand, were counted, weighed in grams, and then measured from the tip of the snout to the caudal fork.

At each site, trout were weighed and measured so that their condition could be assessed. The aim was to collect 20 trout from each site; however, this was not possible at all sites. Calculating trout condition is important as it indicates the relationship between a trout's length and weight, and is unrelated to age.

The formula for trout condition is:

$$K = \frac{10^N W}{L^3}$$

where K is the condition factor; W is the weight of the fish in grams (g); L is the length of the fish in millimetres (mm); N equals 5. This formula produces the K values (condition values) (Table 3.4). A photographic representation is shown in Figure 3.3.

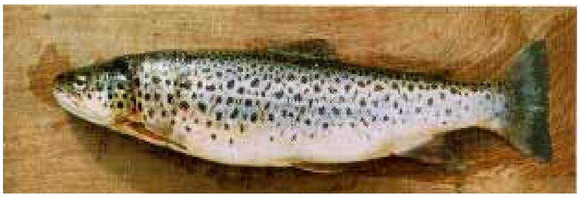
Table 3.4 K-value of fish condition (Barnham and Baxter, 1998).

K value	Condition	Comments
1.6	**Excellent**	trophy-class fish
1.4	**Good**	well-proportioned fish
1.2	**Fair**	acceptable to many anglers
1	**Poor**	long and thin
0.8	**Extremely poor**	resembling a Barracuda, big head and narrow, thin body

Extremely poor K = 0.78

Poor K = 0.95

Fair K = 1.19



Good K = 1.36

Excellent K = 1.66

Exceptional K = 2.02

Figure 3.3 Photo representation of trout with different condition factors (Barnham and Baxter, 1998).

3.5.3 Fish density classes

To rank brown trout density in the Upper Taieri River catchment, we combined the data in NIWA's New Zealand Freshwater Fish Database (NZFFD), which is based on three-pass electric-fishing over a known area (m^2), with ORC and Fish and Game Otago data. All sites were ranked on trout- fish density per square metre (total fish density, brown trout density) and then broken into quartiles. Each quartile was classed as 'Excellent', 'Good', 'Fair' or 'Poor', based on their relative density to the entire upper Taieri River catchment data set.

4. Results

4.1 Water quality

This section provides an assessment of the intensive monitoring of rivers undertaken during the 12-month investigation.

One problem with water-quality data is the confounding effect of varying river flow at the time of sampling. To acknowledge this variable, water-quality data were flow adjusted. Each graph has two bars in this section (in addition to annual loads). The blue bar represents the median value for all samples over all-flow conditions; while the red bar shows the median value for samples collected when flows were below the median value of the flow record. The lower flows represent conditions when the rivers are most susceptible to algal growth and used for recreation.

Because we had problems establishing a site, we could not record flow weighting and load calculations at the lower Gimmer Burn.

4.2 Nutrients

TN concentrations were well below the guideline for all-flows at most sites. The upper and lower Sheppard's Drain sites were above the guideline for all flows, with the lower site recording higher concentrations (Figure 4.1). Concentrations of TN for low flows were below the guideline.

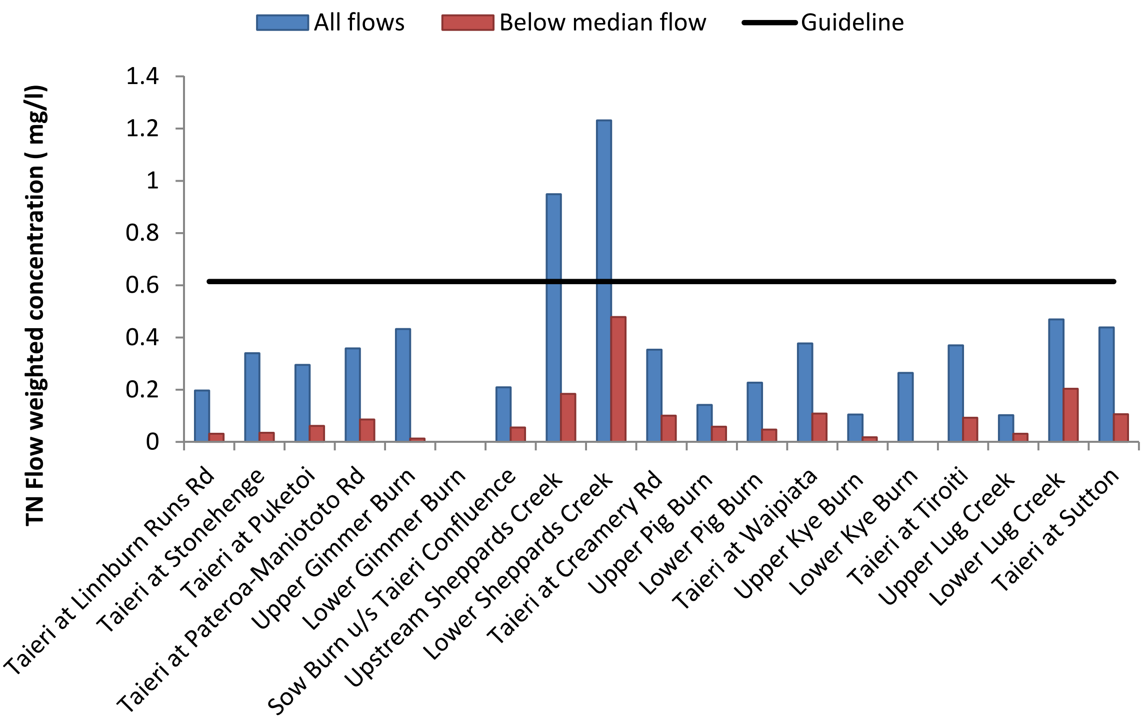


Figure 4.1 Median-flow-weighted concentration of TN for all sampling sites. The lower Kye Burn could not be reported for below-median flows because of missing flow data caused by technical difficulties with the stage-height recorder.

Annual load calculations have shown that on a per hectare basis, lower Sheppard's Drain exports the most TN annually, followed by the lower Pig Burn and lower Lug Creek. When we compared the three tributary sites that had upper and lower sampling points, in general, the lower site exported more TN per hectare than the upper site. The exception was the Kye Burn, where there was no difference between the upper and lower site. TN was slightly lower at Sutton (0.81 kg/ha/year) compared to the top at Linn Burn Runs Road, which had an annual load of 1.04 kg/ha/year (Figure 4.2).

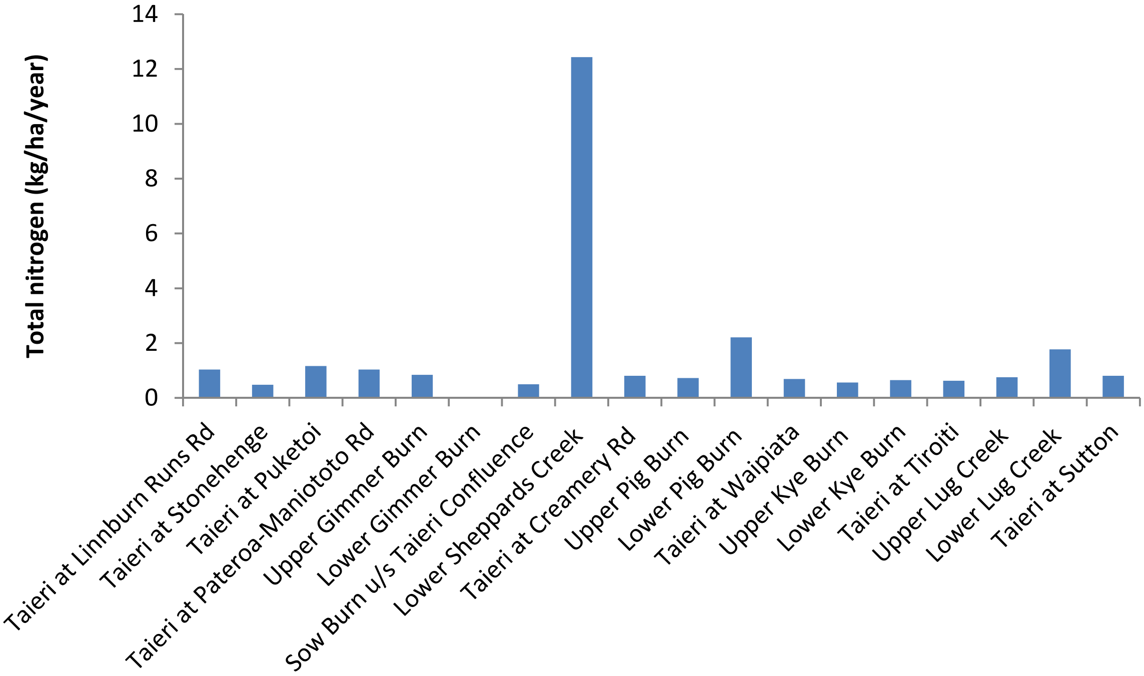


Figure 4.2 **Annual loads of TN for catchment area above each sampling site.**

NNN concentrations were very low throughout most of the catchment (Figure 4.3). Between the main-stem sites of Lin Burn Runs Road and Creamery Road, the tributary sites (Sow Burn and upper and lower Sheppard's Drain) did increase the concentrations (all flows and low flows). Upper and lower Sheppard's Drain had low flow concentrations well above the guideline value. Sites with upper and lower comparisons showed that the lower sites had higher NNN concentrations for all flows and below-median flow, especially lower Lug Creek. There was a noticeable increase in the median concentration of NNN between the Linn Burn Runs Road and Sutton site for both flow conditions (Figure 4.3).

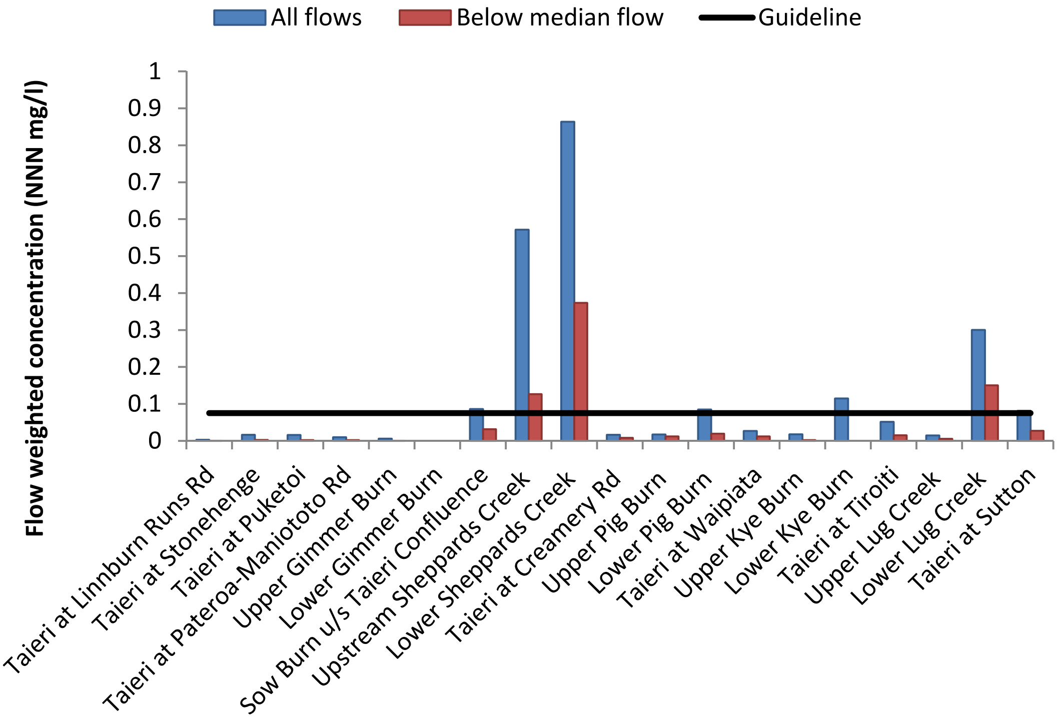


Figure 4.3 Median-flow-weighted concentration of NNN for all sampling sites.

Annual loads of NNN were very low for the main-stem sites between Linn Burn Runs Roads and Waipiata, with tributary sites having the greatest annual loads per hectare (Figure 4.4). Lower Sheppard's Drain had the highest annual load, contributing 8.8 kg/ha/year of NNN. The next closest was lower Lug Creek, which contributed 1.09 kg/ha/year of NNN. There was an increase in the annual load per hectare at Sutton, compared to Linn Burn Runs Road (Figure 4.4).

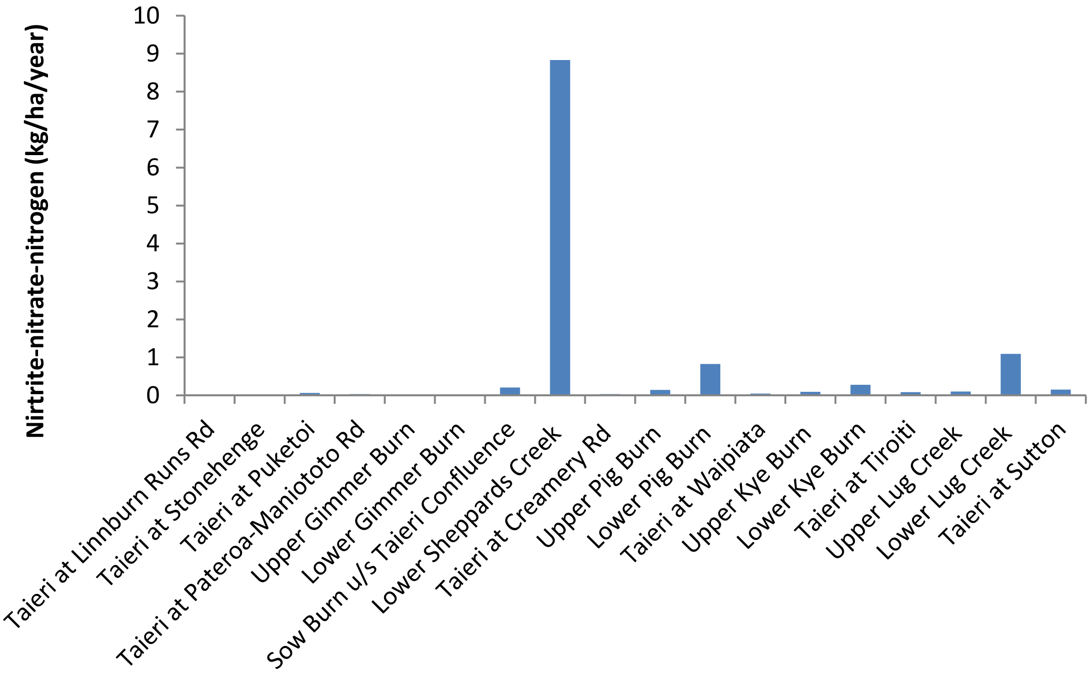


Figure 4.4 Annual loads of NNN for catchment area above each sampling site.

All NH_4 concentrations were well below the guideline (Figure 4.5). Sheppard's Drain had the highest concentrations for all flows and low flows.

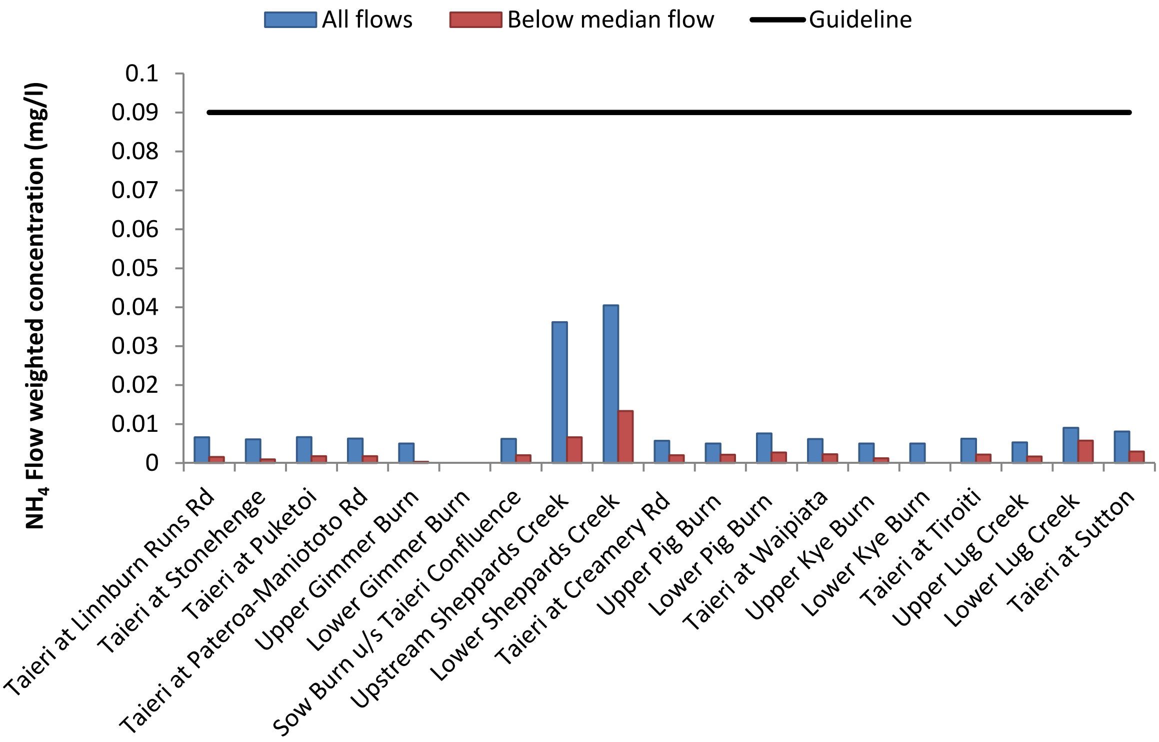


Figure 4.5 **Median-flow-weighted concentration of NH_4 for all sampling sites.**

Lower Sheppard's Drain had the highest annual load of all the sites. Annual loads were variable throughout the catchment, with no evident trend. The NH_4 load for the lower Pig Burn was much higher than the upper site. The reverse was true for Lug Creek (Figure 4.6).

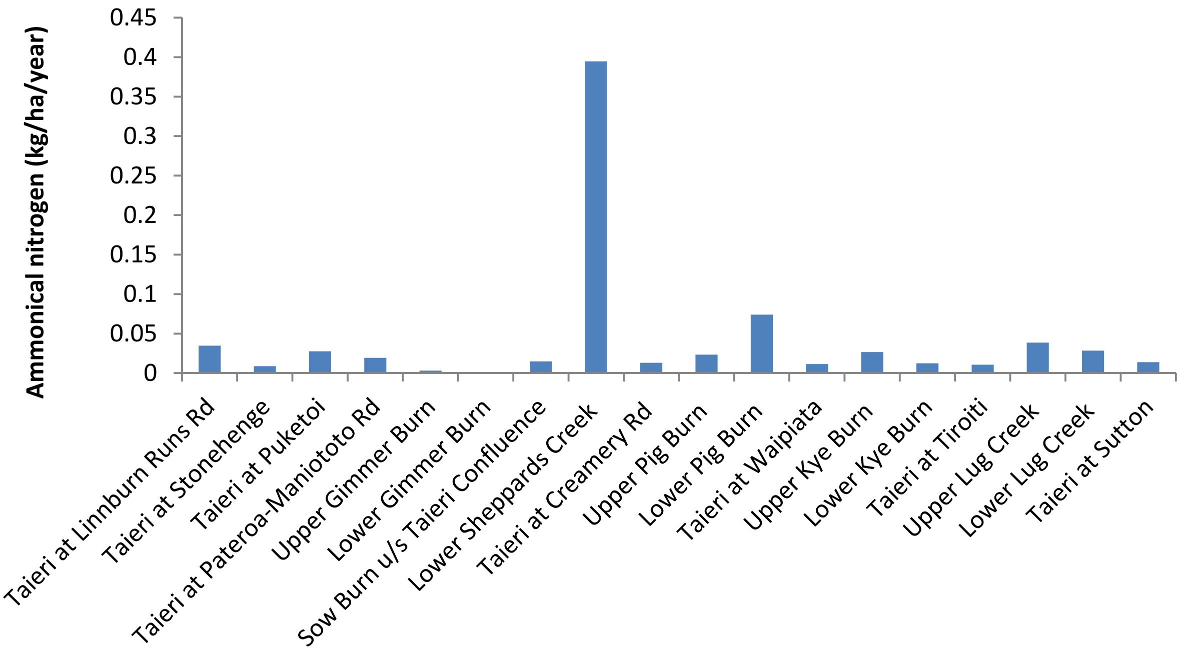


Figure 4.6 **Annual loads of NH_4 for catchment area above each sampling site.**

TP concentrations never exceeded the guideline for low-flow samples, but often exceeded the guideline for all-flow samples, especially in the main-stem sites (Figure 4.7). For all flows, there was a greater increase in TP at the Sutton site.

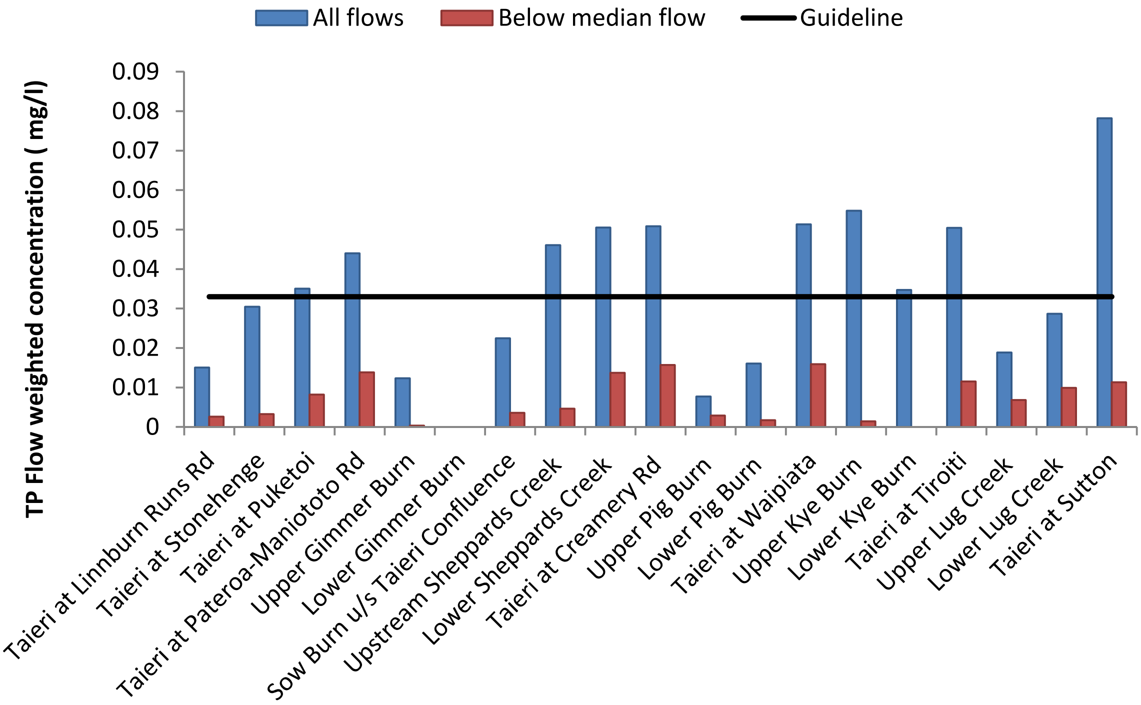


Figure 4.7 Median-flow-weighted concentration of TP for all sampling sites.

TP loads were the highest in the upper Kye Burn, followed by lower Sheppard's Drain. Linn Burn Runs Road had a higher annual load when the flow-weighted concentrations were low (Figure 4.8). There was no difference in the annual load of TP between the upper and lower sites on Lug Creek. There was a small, but distinct, increase in TP loads between Linn Burn Runs Road and Sutton (Figure 4.8).

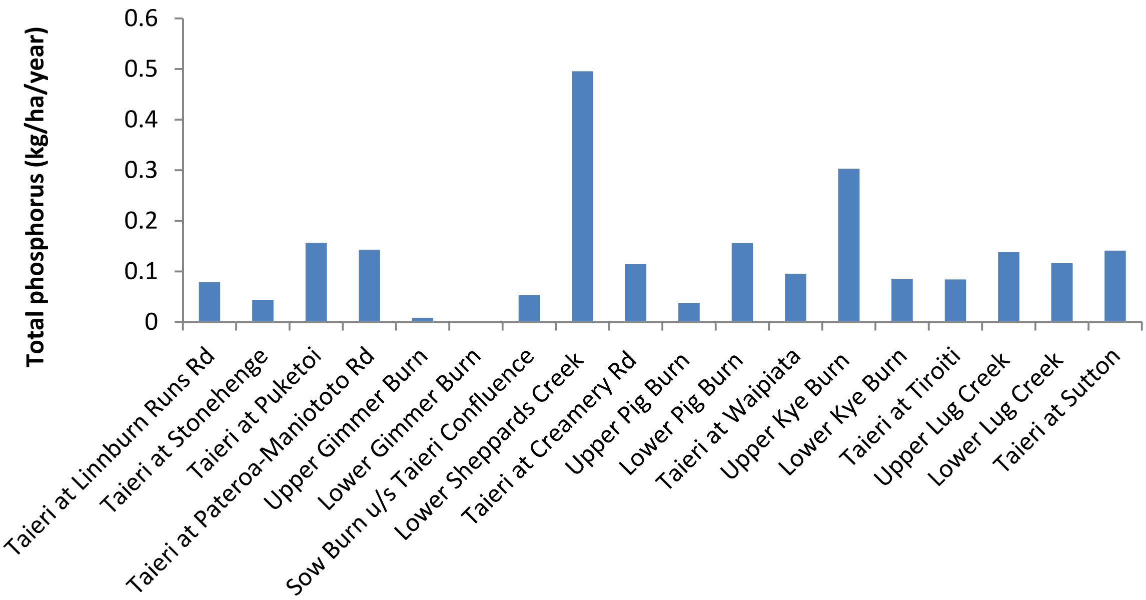


Figure 4.8 Annual loads of TP for catchment area above each sampling site.

DRP concentrations exceeded the guideline at the majority of sites for all-flows. The exceptions were Linn Burn Runs Road, upper Gimmer Burn, upper Pig Burn and the upper Kye Burn (Figure 4.9). Lower Lug Creek and Taieri, at Waipiata, had low flow concentrations that exceeded the guideline, while Taieri, at Patearoa-Maniatoto Road, and Creamery Road were just below the guideline for low flow samples. There was a noticeable increase in DRP concentrations between Linn Burn Runs Road and Patearoa-Maniototo-Road.

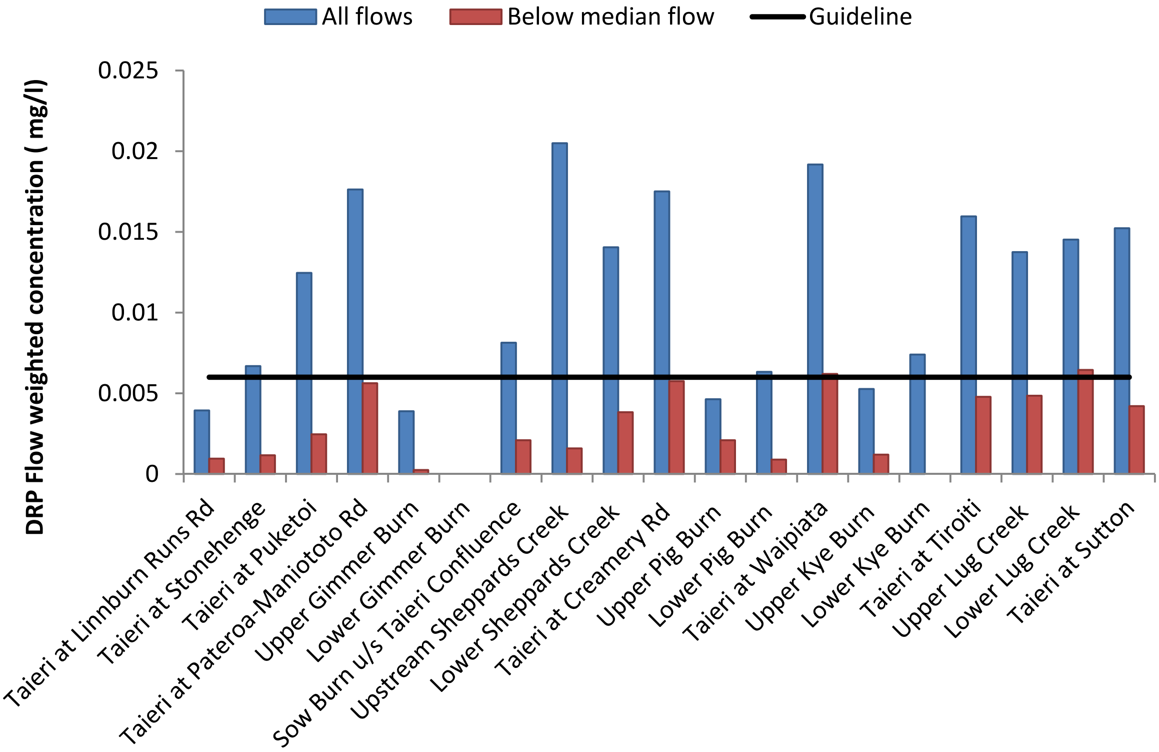


Figure 4.9 Median-flow-weighted concentration of DRP for all sampling sites.

Upper Lug Creek had the highest annual DRP load compared to the other sites, including lower Lug Creek. The next highest load was in the lower Sheppard’s Drain. A similar pattern was also observed in the Kye Burn, but not in the Pig Burn. DRP loads decreased at Waipiata, compared to the main-stem-sampling locations upstream. There was no major increase between the top site, at Linn Burn Runs Road, and the lowest site, at Sutton (Figure 4.10).

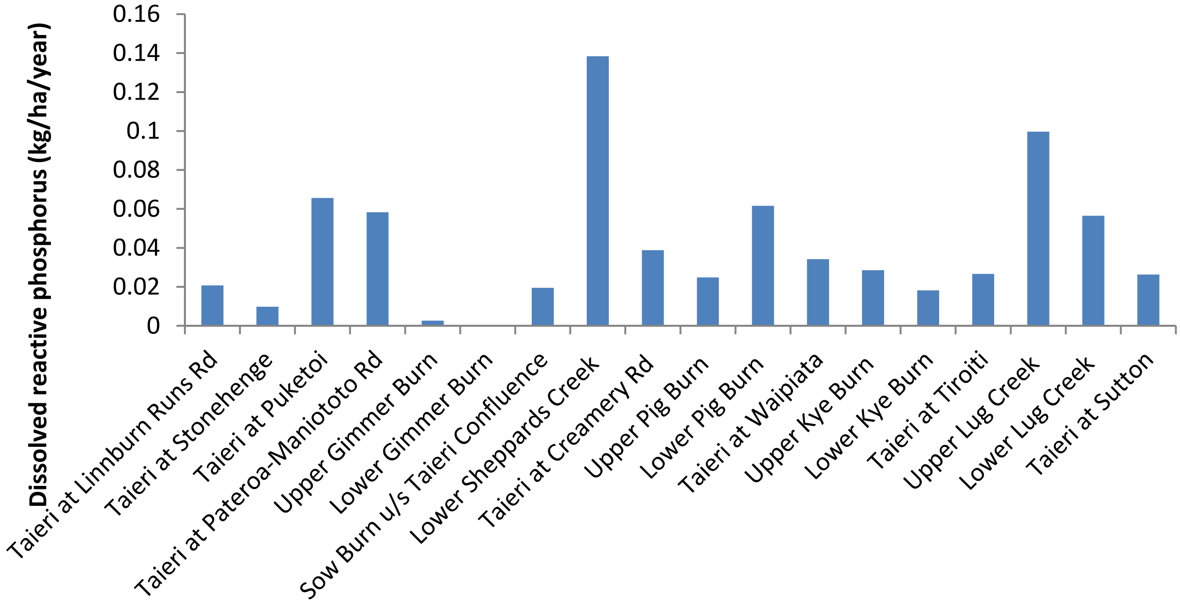


Figure 4.10 Annual loads of DRP for catchment area above each sampling site.

Periphyton growth N or P limited

Redfield (1963) published data that indicated a molar ratio of N:P of 16:1 is required for periphyton growth. NIWA has suggested that a ratio of <4:1 reflects N limitation, while a ratio of >20:1 indicates P limitation (Wilcock *et al.*, 2007). Figure 4.11 shows the NNN:DRP ratio for each site.

Based on the Redfield ratio, Sheppard's Drain is DRP-limited, with a NNN: DRP ratio of 1:103 at the downstream site. Lower Lug Creek is also DRP-limited, while the remaining sites are NNN- limited. Using the NIWA ratios of nutrient limitation, Sow Burn, Sheppard's Drain, lower Pig Burn, lower Kye Burn and lower Lug Creek are all DRP-limited streams, while the remaining sites are all NNN-limited (Figure 4.11).

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*, 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.

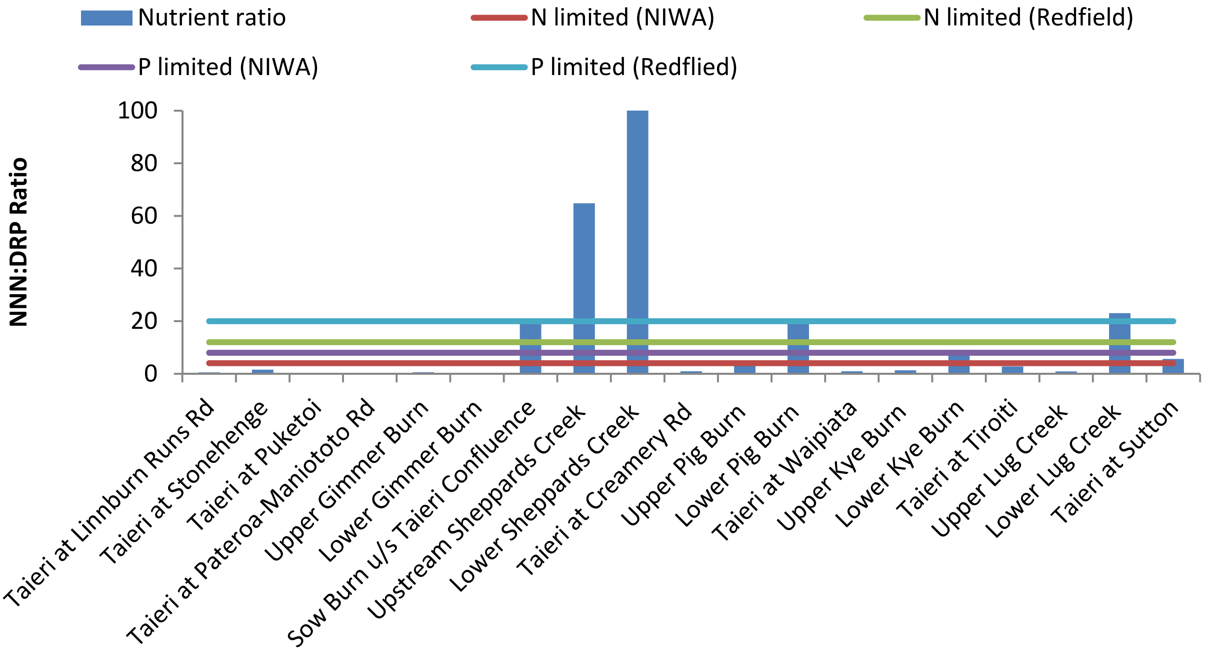


Figure 4.11 Nutrient ratios (NNN: DRP) for all sampled sites.

4.3 Bacteria

Concentrations of *E. coli* were generally very low and exceeded the guideline during all flows. *E. coli* exceeded the guideline during low flows at the Pateroa-Maniototo Road site and lower Lug Creek. The lower Lug Creek site had exceptionally high *E. coli* concentrations, for both flow conditions (Figure 4.12).

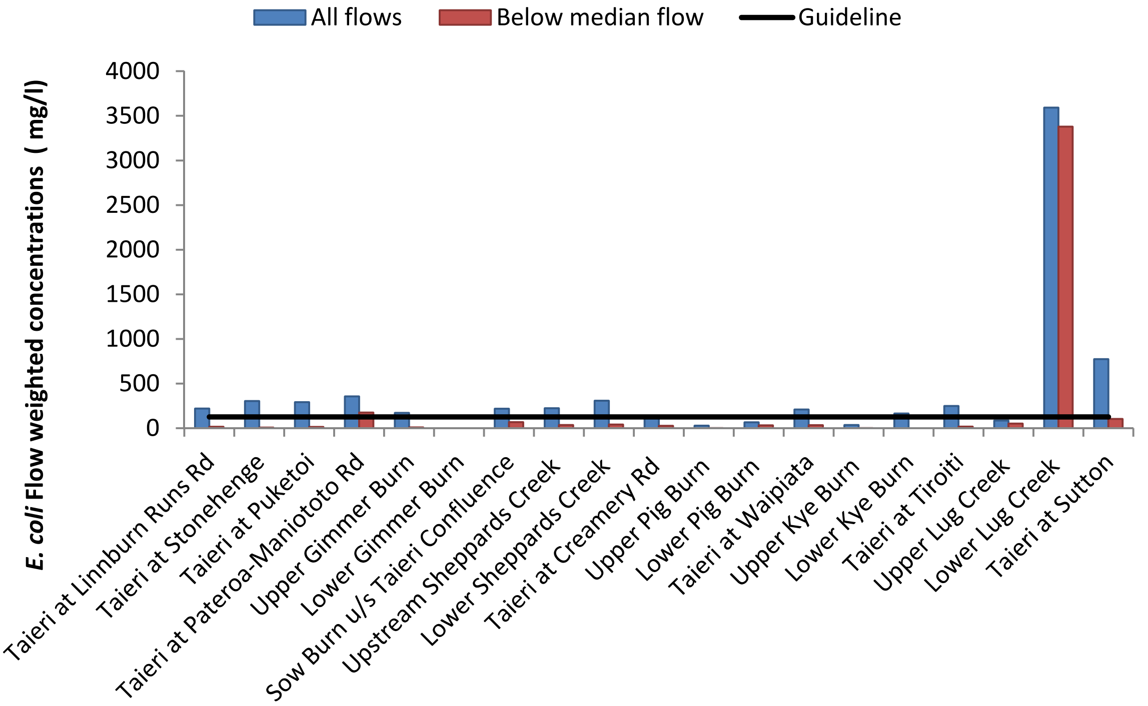


Figure 4.12 Median-flow-weighted concentration of *E. coli* for all sampling sites.

Bacteria loads were relatively low on an annual per hectare basis. Where streams had upstream and downstream comparisons, the downstream site had higher annual *E. coli* counts per hectare than the upper sites, especially for lower Lug Creek, which had a very high annual load (Figure 4.13).

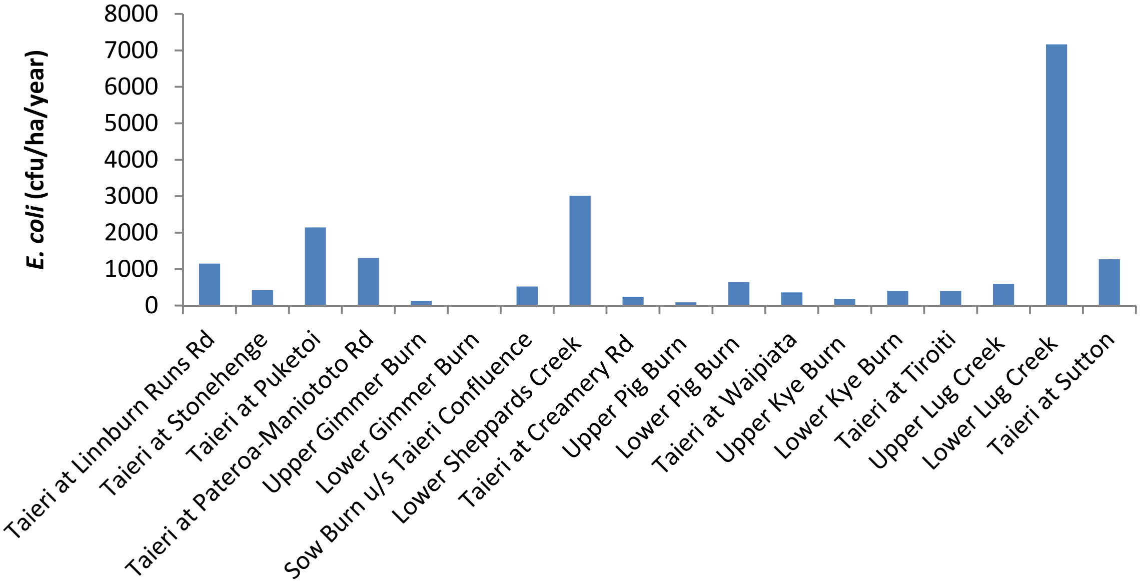


Figure 4.13 Annual loads of *E. coli* for catchment area above each sampling site.

4.4 Sediment

Median-SS concentrations were low on the Taieri River main stem, upstream of Waipiata. SS concentrations spiked at Sutton when all flows were considered. Sow Burn and lower Sheppard's Drain had median concentrations that exceeded the guideline for all flows (Figure 4.14). Both Kye Burn sites had low flow concentrations well above the guideline value. All sites had low flow concentrations that were consistently below the guideline (Figure 4.14).

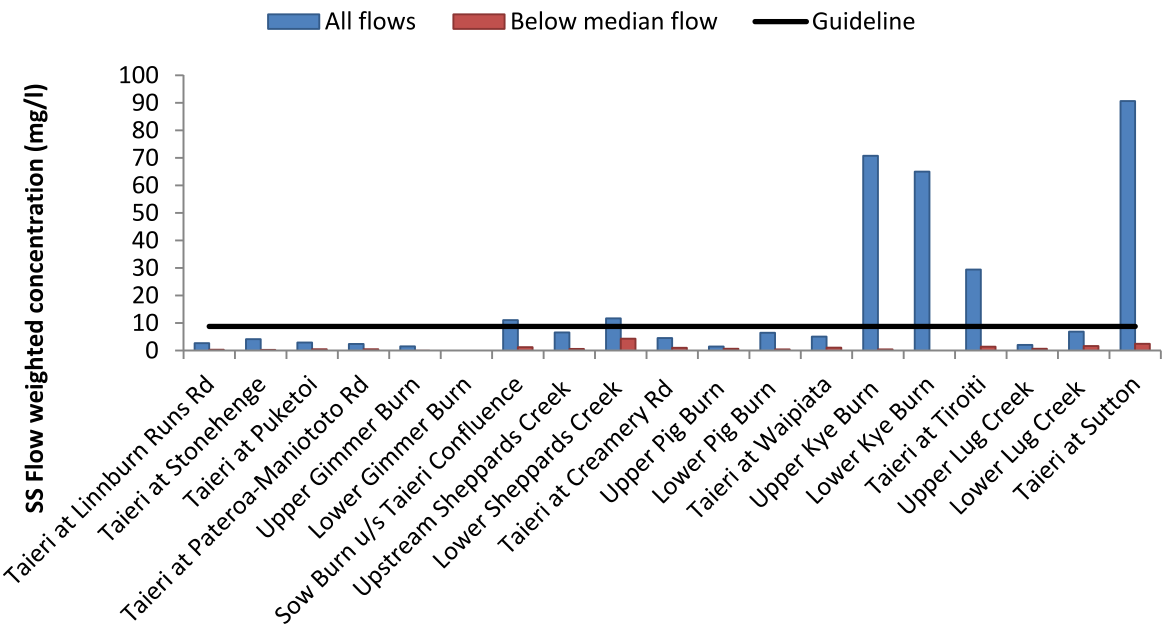


Figure 4.14 Median-flow-weighted concentration of SS for all sampling sites.

Annual SS loads were low at the main-stem sites until Tiroiti, and only spiked substantially at Sutton. Lower Pig Burn had an annual load 114 kg/ha/year. The highest annual loads were observed at the upper Kye Burn (annual load of 392 kg/ha/year), followed by the lower Kye Burn (160 kg/ha/year) (Figure 4.15).

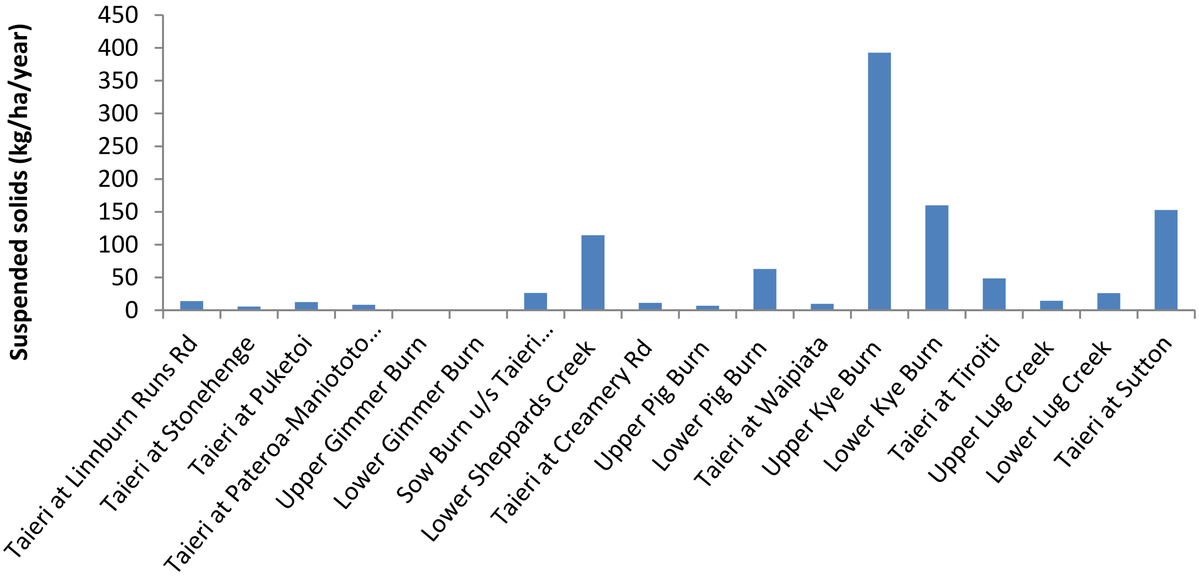


Figure 4.15 Annual loads of SS for catchment area above each sampling site.

The median values for all flows (Table 4.1) and low flows (Table 4.2) were also compared to the water quality guidelines (Table 3.1) chosen to protect local instream standards. NH_4 was not included in this assessment, as all sites passed the guideline value for this parameter. An ‘excellent’ classification meant that the six other variables met guideline values; a score of 4 or 5 was given a ‘good’ classification; 2 or 3 meant the site was classified as ‘fair’, and 1 or less was classed as ‘poor’. The majority of sites had ‘good’ water quality at all flows. Three sites had ‘excellent’ water quality (Taieri at Linn Burn Runs Road, upper Gimmer Burn and the upper Pig Burn. Table 4.1 shows that for all flows, median concentrations of *E. coli* were below the guideline value at all sites, as were SS concentrations. The majority of sites had DRP concentrations that exceeded the guideline, while only four sites exceeded the NNN concentration. Median concentrations for all parameters tended to be higher at the lower Gimmer Burn site than at the upper site (except for NNN where concentrations were the same). DRP and TP exceeded the guideline.

Table 4.1 Median values for each parameter at each site from the entire sampling period for all flows.

	TN	*E. coli*	SS	NNN	DRP	TP	
Parameter and guideline value	**0.614 mg/l**	**126 cfu/100 ml**	**8.75 mg/l**	**0.075 mg/l**	**0.006 mg/l**	**0.033 mg/l**	**Grade**
Taieri at Linn Burn Runs Rd	0.17	42	1.5	0.0025	0.0025	0.013	Excellent
Taieri at Stonehenge	0.23	36	1.5	0.0065	0.007	0.018	Good
Taieri at Puketoi	0.24	23.5	1.5	0.0025	0.0095	0.0325	Good
Taieri at Pateroa-Maniatoto Rd	0.32	43.5	1.5	0.0025	0.016	0.0405	Good
Upper Gimmer Burn	0.26	24	1.5	0.0025	0.005	0.007	Excellent
Lower Gimmer Burn	0.49	61.5	1.5	0.0025	0.0245	0.0565	Good
Sow Burn 300m u/s Taieri confluence	0.20	75	5	0.11	0.007	0.015	Good
Upper Sheppard's Drain	0.91	18	4	0.571	0.015	0.03	Fair
Lower Sheppard's Drain	1.15	16	7	0.871	0.009	0.03	Fair
Taieri at Creamery Road	0.30	49	3	0.0145	0.015	0.0505	Good
Upper Pig Burn	0.11	2	1.5	0.019	0.005	0.007	Excellent
Lower Pig Burn	0.27	25	4	0.069	0.006	0.014	Good
Taieri at Waipiata	0.33	59.5	4	0.0185	0.0175	0.0485	Good
Upper Kye Burn	0.07	7	1.5	0.008	0.006	0.007	Good
Lower Kye Burn	0.18	19	1.5	0.032	0.014	0.0085	Good
Taieri at Tiroiti	0.31	53	6	0.0365	0.014	0.0405	Good
Upper Lug Creek	0.08	16.5	1.5	0.0105	0.013	0.023	Good
Lower Lug Creek	0.38	97.5	4	0.2135	0.013	0.023	Good
Taieri at Sutton	0.34	82	7	0.0495	0.0125	0.038	Good

For low flows, median DRP concentrations were above the guideline at most sites. TP concentrations also exceeded the guideline, but not as many sites as for DRP. NNN concentrations were only above the guideline at Sow Burn, Sheppard's Drain and lower Pig Burn (Table 4.2).

Table 4.2 Median values for all parameters at all sites only for the samples collected when flows were below-median flow for the sampling period.

Parameter and guideline value	TN 0.614 mg/l	*E. coli* 126 cfu/100 ml	SS 8.75 mg/l	NNN 0.075 mg/l	DRP 0.006 mg/l	TP 0.033 mg/l	Grade
Taieri at Linn Burn Runs Rd	0.15	54	1.5	0.0025	0.005	0.13	Good
Taieri at Stonehenge	0.18	32.5	1.5	0.011	0.007	0.018	Good
Taieri at Puketoi	0.235	34	1.5	0.0025	0.0105	0.0335	Good
Taieri at Pateroa-Maniatoto Rd	0.32	63.5	1.5	0.0025	0.0195	0.052	Good
Upper Gimmer Burn	0.195	79.5	1.5	0.0025	0.00425	0.0055	Excellent
Lower Gimmer Burn	0.485	61.5	1.5	0.0025	0.0245	0.0565	Good
Sow Burn 300m u/s Taieri confluence	0.235	103.5	1.5	0.152	0.0075	0.0125	Good
Upper Sheppard’s Drain	0.995	110	4	0.7455	0.0115	0.028	Fair
Lower Sheppard’s Drain	1.14	16	5	0.8835	0.0085	0.0265	Fair
Taieri at Creamery Road	0.3	65.5	3	0.018	0.0195	0.054	Good
Upper Pig Burn	0.11	1.5	1.5	0.0255	0.0055	0.006	Excellent
Lower Pig Burn	0.28	40.5	1.5	0.111	0.0055	0.0085	Good
Taieri at Waipiata	0.32	66	3	0.019	0.0195	0.056	Good
Upper Kye Burn	0.07	7	1.5	0.008	0.006	0.007	Good
Lower Kye Burn	0.16	4	1.5	0.045	0.005	0.006	Excellent
Taieri at Tiroiti	0.31	68	3.5	0.0435	0.0155	0.0415	Good
Upper Lug Creek	0.075	19.5	1.5	0.0125	0.0145	0.017	Good
Lower Lug Creek	0.45	103	2.25	0.2995	0.013	0.021	Good
Taieri at Sutton	0.34	82	3	0.062	0.011	0.032	Good

4.5 Physical habitat

Physical habitat was surveyed in the tributaries for practical reasons. The majority of tributaries sampled had minimal fine sediment, with no sediment build-up (Table 4.3). Three sites had substantial fine sediment: the lower sites of Gimmer Burn, Sheppard’s Drain and Pig Burn. Lower Gimmer Burn had the highest percentage of fine sediment cover (65%) and the lowest median substrate size, although the sediment depth was comparatively low (Table 4.3). The lower Pig Burn had the second highest fine sediment cover (50%) and the deepest sediment depth (140 mm). Sow Burn had no fine sediment on the stream bed, but the median substrate size was small (20 mm) and the average sediment depth was 113 mm (Table 4.3).

Table 4.3 Summary of physical habitat characteristics in tributary sites of the Upper Taieri River.

Site name	Fine sediment cover (%)	Sediment depth (mm)	Median substrate size	Shuffle index
Taieri at Linn Burn Runs Rd	-	-	-	-
Taieri at Stonehenge	-	-	-	-
Taieri at Puketoi	-	-	-	-
Taieri at Pateroa-Maniatoto Rd	-	-	-	-
Upper Gimmer Burn	0	0	60	1
Lower Gimmer Burn	65	19	5	3
Sow Burn 300m u/s Taieri confluence	0	113	20	3
Upper Sheppard's Drain	-	-	-	-
Lower Sheppard's Drain	45	45	5	2
Taieri at Creamery Road	-	-	-	-
Upper Pig Burn	0	0	150	1
Lower Pig Burn	50	140	10	3
Taieri at Waipiata	-	-	-	-
Upper Kye Burn	5	0	48	1
Lower Kye Burn	0	0	100	1
Taieri at Tiroiti	-	-	-	-
Upper Lug Creek	0	0	143	1
Lower Lug Creek	15	0	54	2
Taieri at Sutton	-	-	-	-

4.6 Stream biology

4.6.1 Macroinvertebrates

Eight tributary sites were sampled for macroinvertebrates. The number of taxa ranged between 11 and 23. The lowest numbers of taxa were recorded at Sow Burn and lower Sheppard's Drain, with 11 taxa each, followed by the lower Pig Burn with 12. The upper Gimmer Burn had the highest number (23), followed by 20 each at the upper Pig Burn and upper Lug Creek. The percentage of EPT taxa was highest at the upper Pig Burn, with 65%

of the community dominated by EPT taxa, especially in the stonefly order, with nine genus present (Figure 4.16). Upper and lower Lug Creek also had high proportions of EPT taxa: 65% and 61% of the community, respectively. Lower Sheppard's Drain had the lowest proportion (9%) (Figure 4.16).

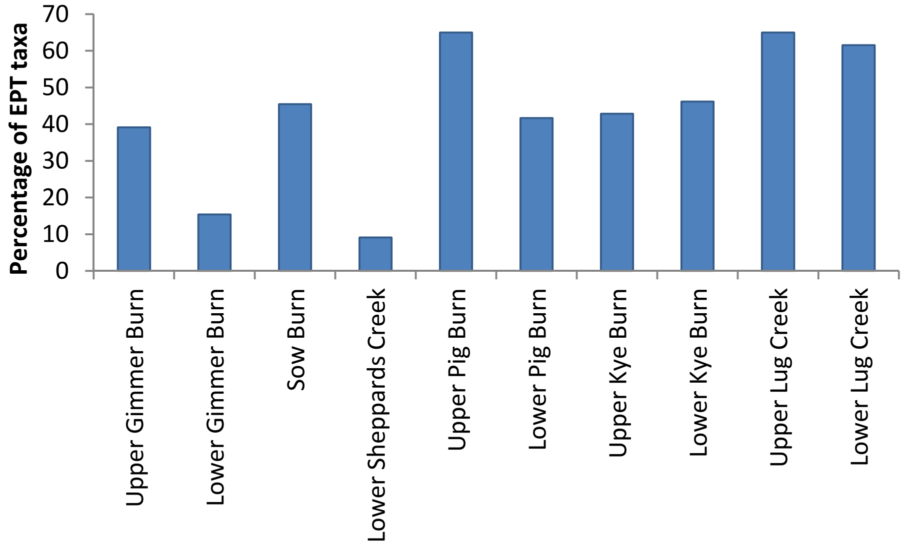


Figure 4.16 Proportion of the macroinvertebrate community comprising EPT taxa.

MCI cores were categorised as 'excellent' in upper Pig Burn (134), upper Lug Creek (125) and lower Lug Creek (120) (Figure 4.17). These sites were dominated by *Deleatidium* mayflies and *Coloburiscus* in both sites on Lug Creek as well as representation from other high scoring caddisflies, such as *Helicopyche* species, *Olinga* species, *Hydrobiosella* species and *Psilochorema* species. Due to the presence of *Nesameletus* and *Plectrocenmia maclachlani*, upper Kye Burn had a higher MCI score (114) than the lower site (98) (Figure 4.17). Lower Sheppard's Drain had the lowest MCI score (60) and was dominated by worms, *Potamopyrgus antipodarum* and *Austrosimilium* species (sand flies) (Figure 4.17).

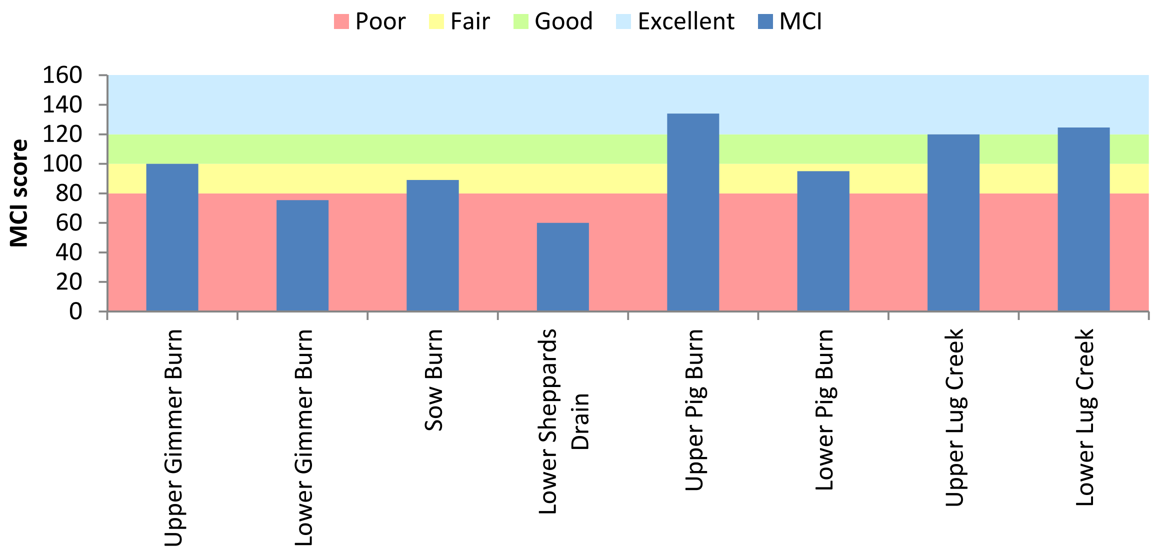


Figure 4.17 MCI scores for eight tributary sites that were sampled.

SQMCI scores showed that the majority of sites have ‘excellent’ macroinvertebrate communities. Both upper and lower sites for the Pig Burn, Kye Burn and Lug Creek had ‘excellent’ SQMCI scores (Figure 4.18). These communities were dominated by an abundance of mayflies (primarily *Deleatidium species*, but also contained *Coloburiscus humeralis* and *Nesameletus species*) and stoneflies (*Olinga*, *Pycnocentrodes* and the *Hydrobiosis umbripennis* group) (Figure 4.18).

Figure 4.18 SQMCI scores for the eight tributary sites that were sampled.

4.6.2 Fish

Electric-fishing was conducted in early January 2012 at ten tributary sites in the Upper Taieri River catchment. Because it was not practical to fish at the main-stem sites, these were not sampled. At all sites, except lower Sheppard’s Drain, brown trout were often the only species caught. Central Otago Roundhead galaxiids were only found in the lower Kye Burn site (a total of six individuals caught in a 155 m^2 area) (Figure 4.19). Long fin eels were caught in only three sites (lower Gimmer Burn (4), Sow Burn (2) and lower Lug Creek (1)). Upper Lug Creek had the highest trout density of all sites, with 1.37 trout per square metre, followed by lower Lug Creek (Figure 4.19). Lower Pig Burn had a relatively intermediate trout density, with 0.66 trout per metre square. Upper Kye Burn had the lowest trout density, but no trout (or any fish) were caught in lower Sheppard’s Drain (Figure 4.19).

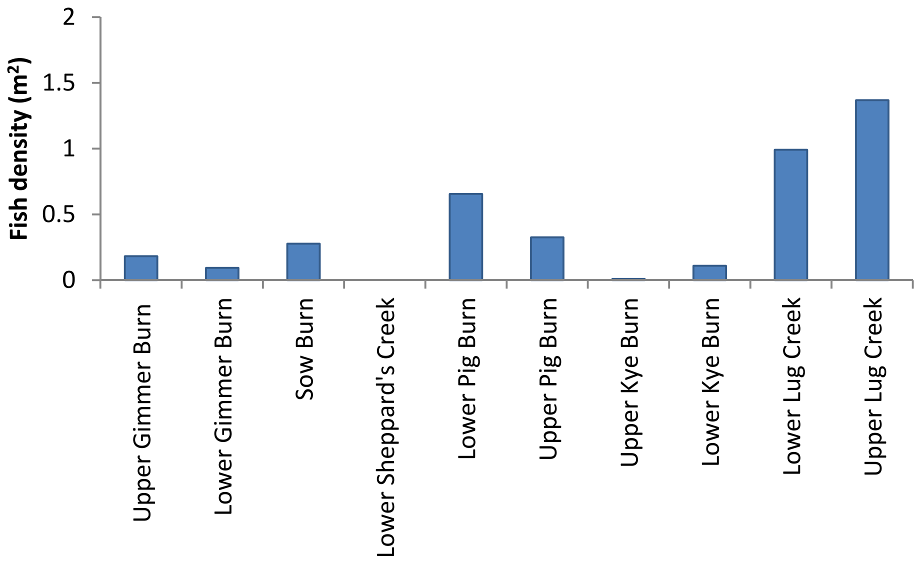


Figure 4.19 Fish density in the eight tributary sites that were surveyed.

The upper Kye Burn had the best-conditioned trout, which were classified as 'good', followed by the upper Pig Burn and then lower Lug Creek. The lower Gimmer Burn was considered 'fair' (Figure 4.20).

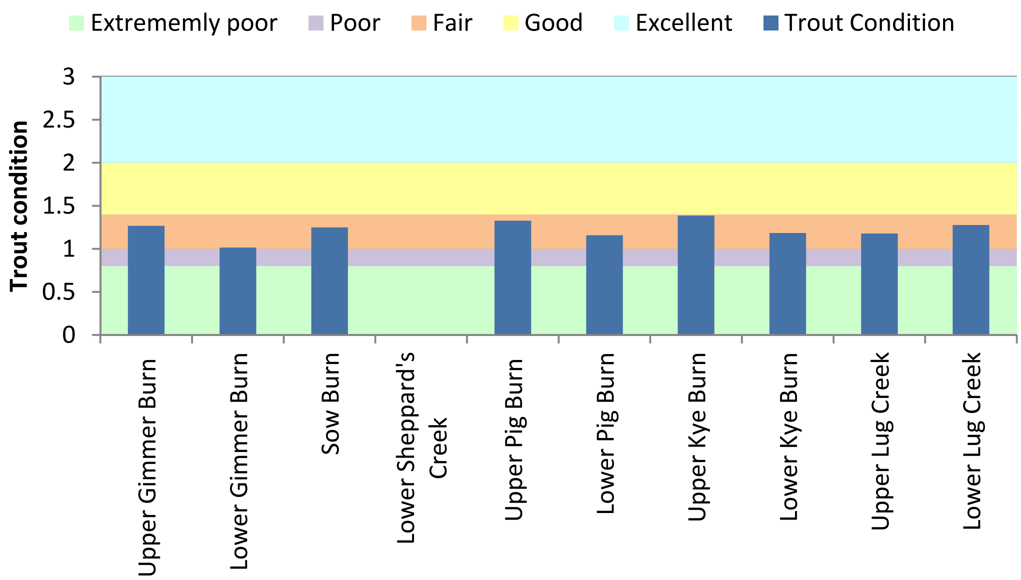


Figure 4.20 Brown trout condition in eight tributary sites.

When trout-condition-density factor was derived for the tributary sites, lower Lug Creek had the highest densities of well-conditioned trout, followed by upper Lug Creek. Upper Kye Burn has the lowest score, followed by lower Gimmer Burn. No fish were caught in lower Sheppard's Drain, so it has a score of zero (Figure 4.21).

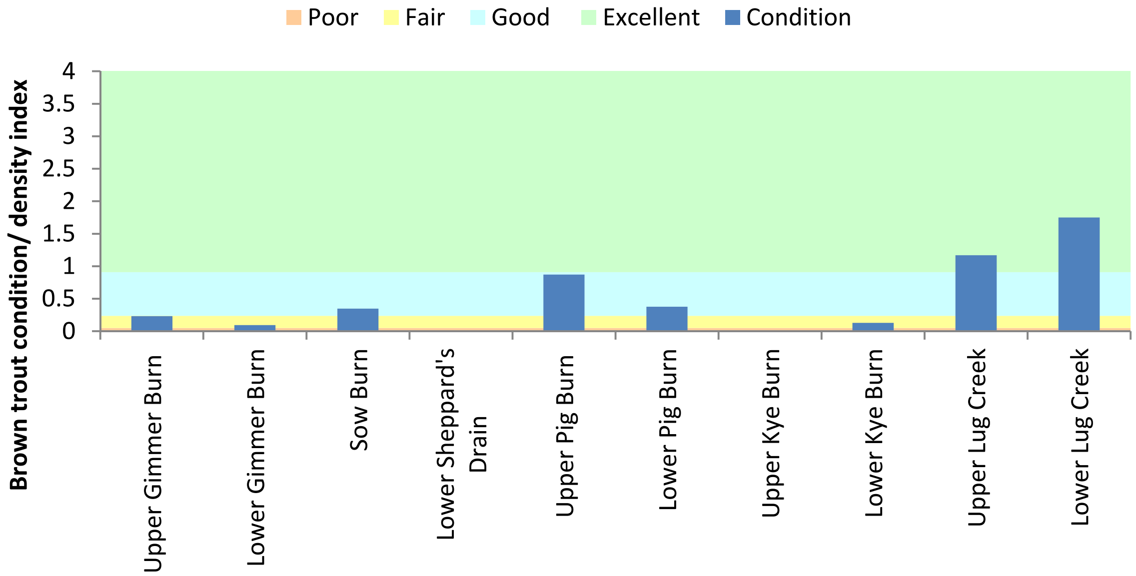


Figure 4.21 Brown trout condition/ density factor in eight tributary sites.

5. Discussion

This section discusses the results from the water quality monitoring, physical habitat assessments and ecological monitoring (macroinvertebrate and fish surveys). Where appropriate, links have been made between water quality, ecological values and catchment activities.

5.1 Stream water quality

Water quality results are frequently reported as being above or below the ANZECC guidelines (2000). The guidelines set default trigger values for slightly disturbed (modified) river ecosystems in New Zealand. An exceedance of the trigger value is an 'early warning' mechanism to alert resource managers of a potential problem (or emerging change) that should be followed up. The ANZECC guidelines cannot be expected to represent a local threshold for water quality and ecosystem impairment.

Therefore, for this investigation, guidelines which are more appropriate for conditions in the Upper Taieri River were adopted, in particular, the New Zealand periphyton guidelines, the Mfe/ MoH (2003) guidelines and a suspended solid guideline to protect fishery values.

Flow-weighted concentrations were calculated and reported in two categories: all flows and below- median flows. Below-median flows represent the period of most recreational use and periphyton growth.

5.2 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.

Nitrogen concentrations in this investigation were low, compared to elsewhere in Otago (ORC 2011, ORC 2012b, ORC 2012c). Nevertheless, NNN concentrations were still above regionally appropriate guideline values for both Sheppard's Drain sties, the lower monitoring sites for the tributaries (only for all flows) and Sutton (only for all flows). Sheppard's Drain had the highest concentrations of NNN and TN for both all flow and low flows. These high concentrations are the result of the drain being spring fed and naturally high in N. However, not all of the N will be from a natural source, and some could be leachate from high intensity dairy farms. The relative contributions are unknown.

TN at low flows made small increases in successive sites between Stonehenge and Maniototo-Pateroa Road Bridge, where concentrations then stabilised down to Sutton. In contrast, NNN was very low between Stonehenge and the Pateroa-Maniototo Road Bridge site and only started to increase at Sutton. This pattern of increasing TN is probably a combined effect of dissolved organic nitrogen leaching from the catchment and particulate N from return irrigation run off. The probable reason for low NNN, relative to TN, is that the catchment is N-limited, and any available NNN would be used for algal and macrophyte growth. After this initial increase, TN concentrations only rose slightly between the Maniototo-Pateroa Road Bridge and Waipiata. This insignificant change is probably the result of good irrigation management, good effluent management and the wetland and the riparian wetland buffers stripping any N that is lost.

DRP concentrations were above the guideline for the main-tributary sites, but only for all flows. Rivers are most susceptible to prolific macrophyte and algal growth during the summer when river flows tend to be below-median flow. However, there is the risk that the elevated DRP can leach from the soil during rainfall events and become retained in stream-bed sediments and used later in the season during high risk periods.

DRP concentrations steadily increased between Linn Burn Runs Road and Patearoa-Maniototo Road Bridge. The increase in TP and DRP is probably due to irrigation run off that flows directly into the Taieri River. Conversations with the Maniototo Irrigation Compnay revealed that there are between two and three streams that capture irrigation run off and flow into the Taieri River all year round. This area (circled in red in Figure 5.1) has a mixture of spray and border-dyke/flood irrigation. Furthermore, the change in median concentration between the Puketoi and Pateroa-Maniototo Bridge Road sites shows that the Gimmer Burn was contributing a significant amount of DRP and TP. The area circled in blue in Figure 5.1 shows most of the irrigated area in the Gimmer Burn catchment is border-dyke irrigation. As irrigation run off has been shown to contain elevated levels of phosphorus (McDowell and Rowley, 2008; Monaghan *et al*., 2009), it can concluded that irrigation run off is causing the water quality degradation in the lower Gimmer Burn and contributing to the degradation between Puketoi and the Patearoa-Maniototo Bridge Road sites.

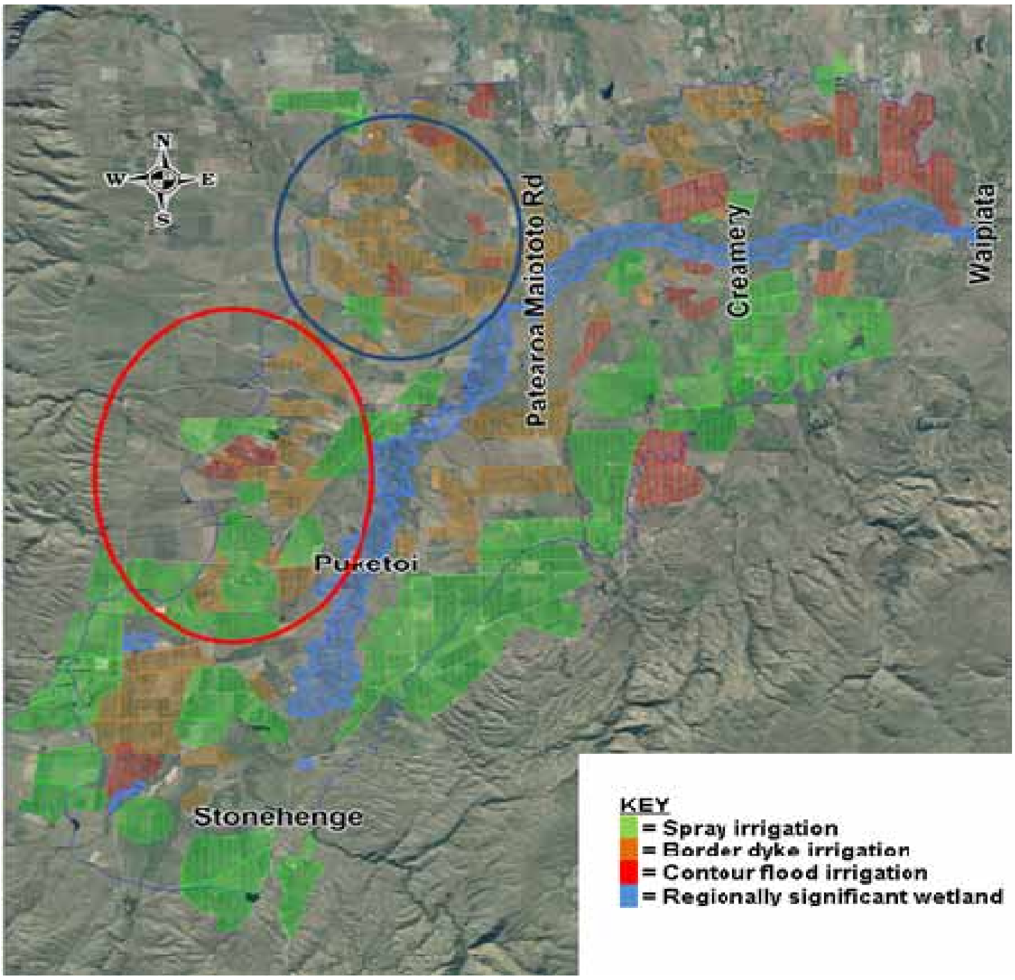


Figure 5.1 Irrigation types and irrigated area above Waipiata.

5.3 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, as it may contain other pathogenic organisms, could pose a threat to human health. 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 an additional measure for rivers in rural catchments.

E. coli concentrations were very low, with only the Taieri at Pateroa-Maniatoto Road Bridge and lower Lug Creek breeching the guideline value during low flows. Small breeches occur at the other sites during all flows. The exceedence of the *E. coli* guideline at the Pateroa-Maniatoto Road Bridge during low flows could be attributed to the irrigation run off that collects in the two or three creeks or drains upstream of this site. On closer inspection of the data for the lower Lug Creek site, we found that there was a period of high *E. coli* readings in early summer of 2010, with one reading recording an *E. coli* concentration of 91,500 cfu/ 100 ml. As there was no significant stock access observed and only spray irrigation in some paddocks, with no obvious signs of irrigation run off, these high *E. coli* readings suggest the presence of a dead animal. Given that direct effluent discharge on a dairy farm on tile-moled country has an *E. coli* concentration of about 53,000 cfu/ 100ml (ORC 2011), this example demonstrates the importance of fencing for stock exclusion.

5.4 Suspended solids

Suspended solids are the concentrations 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, smothering stream-bed habitat, which has a negative effect on instream values such as macroinvertebrates and fish (Townsend *et al.*, 2008). For instance, high levels of suspended sediment can adhere to the gills of trout and native fish, impeding respiration and potentially causing death. Sediment can also reduce fishes' visual recognition of food sources, which affects growth, condition and reproductive success, also potentially leading to death (Parkyn and Wilcock, 2004). Sediment can also harbour *E. coli* and reduce its half-life, thus allowing it to be re-suspended during the summer.

SS concentrations were below the effects-based guideline for low flows at all sites. Only six sites exceeded the guideline value, but only for all flows. The Sow Burn site just exceeded the guideline, probably because of stock access eroding the banks (Figure 5.2). While stock access did not cause significant amounts of sediment to enter the stream directly, future higher river flows and rainfall could entrain the sediment.

The elevated SS concentration at lower Sheppard's Drain was interesting. This site was fenced on both sides, with a reasonable buffer (Figure 5.3), and showed no sign of exposed or collapsing banks, the elevated concentrations could be caused by the depositing of sediment while the creek was unfenced. Finally, historic gold-mine workings could account for the very high concentrations of SS at upper and lower Kye Burn, Tiroiti and Sutton.

Figure 5.2 Unrestricted stock access in Sow Burn allows stock to erode the banks which then act as a sediment source when flows increase.

Figure 5.3 An effective buffer on a dairy platform.

5.5 Summary of stream water quality

- NH_4 concentrations were consistently low at all sites and well below the guideline value.
- NNN concentrations were below the guideline value at all sites, except for both sites at Sheppard's Drain. These high concentrations and exceedances were attributed to the fact the stream is spring fed.
- P increased between Stonehenge and the Pateroa-Maniatoto Road Bridge. These increases were probably the result of cattle having access to the stream and the Styx wetland complex and flood/border-dyke irrigation run off.
- Bacteria concentrations were low at all sites, except for lower Lug Creek. The high readings in lower Lug Creek are probably because of the presence of a dead animal in the stream.
- SS concentrations exceeded the guideline in the Kye Burn and at Tiroiti and Sutton, probably because of high flows moving sediment from historic-gold diggings. SS concentrations were below the guideline level for all sites when flows were below-median flow.

5.6 Physical habitat

Physical habitat is considered to be an important factor affecting 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; however, this does not measure its build-up on the stream bed. It is possible for some systems to have a high SS load but little fine sediment build-up on the bed. Therefore, stream-bed assessments were carried out to determine the extent of habitat degradation. To measure habitat degradation, we calculated the proportion of fine sediment (less than 2 mm) on the stream bed.

As the current methods for assessing physical habitat are only practical in smaller tributary sites, the main stem of the Taieri River was not sampled. Of the sites sampled, most of the sites had little fine sediment build-up and good substrate size. However, there were a few sites with noticeable depth of fine sediment on the bed. Lower Gimmer Burn was of most concern, having 65% of its streambed smothered with fine sediment less than 2mm in diameter. A shuffle index result of 3 also suggests a build-up of fine sediment. This fine sediment was probably caused by stock access and/or irrigation run off. Lower Pig Burn and lower Sheppard's Drain had a fine sediment build-up of 50 and 45%, respectively. It was interesting to note that both of these sites had effective stock exclusion and reasonable buffers (Figure 5.4). The high proportion of fine sediment was probably due to sediment built-up before the streams were fenced off. In the case of the Pig Burn, the sediment may have been sourced from further up the catchment.

Figure 5.4 Two different dairy platforms on Sheppard's Drain (left) and lower Pig Burn (right) both with effective fencing and rank grass buffers.

5.7 Summary of physical habitat

Fine sediment values on the stream bed were low at most of the sites. Only the lower Gimmer Burn, lower Sheppard's Drain and the lower Pig Burn had excessive fine sediment build-up, which we believed to be the result of stock access (current and historic) and the effects of irrigation run off.

5.8 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. While they are based on studies from New Zealand and Australia, they do not always take into account regional differences. Therefore, effects based guidelines were used in this investigation to more accurately reflect when ecosystems maybe impaired. The effects-based guidelines were based on the effects of a regionally significant trout fishery (Biggs, 2000). This investigations 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 'excellent', 'good', 'fair' or 'poor' for chemical, physical habitat, macroinvertebrate and trout fishery values (Table 5.1).

Water quality in the Upper Taieri is generally ‘good’, which has, in turn, maintained healthy ecosystems. Where water quality and physcial habitat were ‘good’, in the case of upper Gimmer Burn, upper Pig Burn and both sites in Lug Creek, ecological values were also ‘good’. Despite having ‘good’ water quality and physical habitat, ecological values were found to be ‘poor’ in the Kye Burn. In the upper Kye Burn, the fish population was ‘poor’, and only one trout was caught in the netted section. However, when spot fishing was undertaken, reasonable-sized resident fish, ranging in size from 167-270 mm, were caught in plunge pools. The low density of brown trout in the upper Kye Burn was probably due to little habitat heterogenity, as this section of the Kye Burn is fast flowing (being within a constricted gorge), which frequently disturbs substrate and blows out fish. Larger fish only reside in the deeper plunge pools, as large immovable boulders upstream provide some refuge.

The brown trout population and macroinvertebrate community in the lower Kye Burn were classed as ‘fair’ (Table 5.1), which contrasted with the ‘good’ water quality and ‘excellent’ habitat measured at the site. This result could be due to water abstraction further upstream, which might limit the trout population through temperature and oxygen stress (Leprieur *et al*., 2006) and affect the macroinvertebrate community (Dewson *et al*., 2007). However, the absence of trout has benefitted the Central Otago Roundhead galaxiids at this site, as they were not subject to predation.

Table 5.1 Summary of categories for water quality, physical habitat, macroinvertebrates and trout populations. Only the tributary sites had habitat and ecological surveys conducted.

Site	Water quality	Physical habitat	Macroinvertebrate community	Brown trout population
Taieri at Linn Burn Runs Rd	Excellent	-	-	-
Taieri at Stonehenge	Good	-	-	-
Taieri at Puketoi	Good	-	-	-
Taieri at Pateroa-Maniatoto Rd	Good	-	-	-
Upper Gimmer Burn	Excellent	Excellent	Good	Good
Lower Gimmer Burn	Good	Poor	Poor	Poor
Sow Burn 300m u/s Taieri confluence	Good	Fair	Fair	Good
Upper Sheppard's Drain	Fair	-	-	-
Lower Sheppard's Drain	Fair	Fair	Poor	Poor
Taieri at Creamery Road	Good	-	-	-
Upper Pig Burn	Excellent	Excellent	Excellent	Excellent
Lower Pig Burn	Good	Fair	Fair	Good
Taieri at Waipiata	Good	-	-	-
Upper Kye Burn	Good	Excellent	Good	Poor
Lower Kye Burn	Good	Excellent	Fair	Fair
Taieri at Tiroiti	Good	-	-	-
Upper Lug Creek	Good	Exceelent	Excellent	Excellent
Lower Lug Creek	Good	Good	Excellent	Excellent
Taieri at Sutton	Good	-	-	-

The lower Gimmer Burn was one of three sites that had 'poor' ecological values. Despite having 'good' water quality, this site had 'poor' physical habitat, macroinvertebrate community and, therefore, a 'poor' fish community. Although the site had heavy sediment deposition, water quality results showed low SS concentrations throughout the investigation, probably because the lower Gimmer Burn is a sluggish meandering stream, and, therefore, susceptible to sedimentation. The sluggish meandering nature of the lower Gimmer Burn means that any naturally occurring bank erosion, stock-induced erosion or irrigation bywash that contributes sediment will be readily deposited and not picked up by water sampling.

Lower Sheppard's drain had 'good' water quality, but the other variables were 'poor'. No fish were caught within the surveyed reach. While these results are of concern, they must seen in context: the drain was constructed to drain border-dyke irrigation run off. It was dug deep and is now a permanently flowing spring-fed stream.

5.9 Summary of instream ecological values

- Where water quality and habitat were ‘excellent’, so generally were the ecological values; the exception was the Kye Burn, where disturbances from floods and drought limited ecological values.
- When fine sediment build-up on the stream bed was considered excessive, ecological values were adversely affected, with fish populations either absent or limited.
- Central Otago Roundhead galaxiids were only present in one site (lower Kye Burn). Their presence was aided by re-occurring low-flow events through the effects of irrigation. These low flows help to limit the survival of trout populations, thus removing the galaxiids from significant trout-predation pressures.
- Fine sediment is considered to be the biggest causes of ecological impairment.

6. Conclusions

- Water quality in the Taieri River in the Upper Taieri catchment was found to be ‘good’. Concentrations of bacteria, nitrogen and sediment were below the effects-based guidelines’ during low flows.
- Nitrite-nitrate-nitrogen concentrations were low in the main stem, but exceeded guideline values at some of the tributary sites.
- Dissolved reactive phosphorus concentrations exceeded guidelines at most sites for all-flow conditions. Very few sites exceeded the guidelines’ when flows were low.
- Bacteria and suspended solid levels were generally very low. Suspended solids did exceed guidelines at six sites during all-flow conditions.
- Some tributary sites (lower Gimmer Burn, lower Pig Burn, lower Sheppard’s Drain and Sow Burn) had enough fine sediment build-up on the bed to have a detrimental impact on ecological values.
- Where exceedences in water-quality parameters occurred, they can probably be explained by the presence of dead stock, stock access to waterways or to irrigation run off.
- In general, ‘good’ ecological values were found, (as indicated by trout and macroinvertebrate population) in sites with good water quality and good habitat. Central Otago Roundhead galaxiids were present where trout populations were limited by low flow.
- Where ecological degradation had occurred, it was attributed to a lack of stock exclusion, irrigation run off and prolonged low flows (over-allocation of water).

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