Water quality study: Cardrona River catchment

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Overview

Background

The Otago Regional Council (ORC) is responsible for managing Otago's groundwater and surface-water resources. ORC carries out regular and extensive long-term monitoring as part of its State of the Environment (SoE) programme and carried out a targeted, short-term monitoring investigation of the Cardrona River in 2004-2005. This study repeated this work ten years later.

Why was this targeted investigation done?

The objectives of this water quality study are to:

1. assess spatial and temporal patterns in water quality to assess the effects of land-use on water quality in the Cardrona catchment
2. get a representative background level for an unimpacted site (Cardrona River, upstream of Cardrona township)
3. assess water quality in the Cardrona catchment against water-quality standards in the Regional Plan: Water (RPW) Change 6A
4. assess habitat quality and macroinvertebrate communities in the Cardrona catchment
5. provide an assessment for future comparison once minimum flows are in place and if large-scale irrigation development occurs.

What has this study found?

1. Water quality in the upper Cardrona River is generally very good, but the lower catchment below the State Highway (SH) 6 bridge has high concentrations of total nitrogen (TN) and nitrate-nitrite nitrogen (NNN). Concentrations of NNN at both these sites are currently likely to exceed Schedule 15 standards. This deterioration in water quality coincides with the location of nitrogen-enriched (relative to surface water) groundwater entering the river. Compliance with Schedule 15 standards is based on calculation of 80th percentiles of water-quality data collected at flows less than median flow over a five-year period. Given that the 80th percentiles for most of the sites were calculated from only one year of data (the exceptions being the SoE site at Mount Barker), these results should be interpreted with caution in relation to Schedule 15 compliance.

2. No trend was evident for the Mount Barker SoE site over the period 2000-2015 for most water-quality variables. *Escherichia coli* (*E. coli*) and suspended solids (SS) concentrations decreased over this period.

3. Water quality in two of the tributaries sampled in this study (Boundary Creek and Branch Burn) was generally good. However, elevated NNN concentrations and *E. coli* counts were observed in Spotts Creek and were particularly evident during periods of low flow.

4. Water temperatures in much of the main stem of the Cardrona River and most of its tributaries are generally suitable for brown and rainbow trout and native fish, but water temperatures in the vicinity of Ballantyne Road and in the lower Branch Burn may be unsuitable for brown and rainbow trout at times. All four main-stem sites exceeded the acute thermal criterion for the common mayfly, *Deleatidium*, which suggests that water temperatures may affect macroinvertebrate community structure in the lower Cardrona at times.

5. Coarse gravels dominated the bed at most sites in the Cardrona River. Riparian buffers were not generally present, and there was evidence of direct stock access at most sites surveyed. Riparian vegetation generally consisted of exotic species, including *Salix* species (willows), *Lupinus polyphyllus* (lupins) and exotic grasses.

6. The results of the 2014/2015 catchment periphyton survey were consistent with the results of water-quality sampling undertaken at the same time, with the periphyton community at sites in the upper Cardrona catchment (above Ballantyne Road) indicating low-nutrient conditions, with low chlorophyll-a concentrations and generally sparse periphyton cover. However, the site at the SH6 bridge supported much greater periphyton growths, a finding that is consistent with the much higher nitrogen concentration observed at this site, resulting from the resurgence of nitrate-enriched groundwater, immediately upstream of the bridge.

7. Macroinvertebrate communities collected from Mount Barker between 2001 and 2015, as part of the SoE monitoring programme, were consistent with good to excellent water quality, and trend analysis indicated that macroinvertebrate metrics at this site had been stable over this period. Macroinvertebrate communities sampled in the upper Cardrona River and tributaries (all upstream of Mount Barker) in October 2014 were consistent with very good water quality. However, macroinvertebrate communities in February 2015 generally included a greater abundance of taxa that are tolerant of poor water quality, probably the result of the low, stable flows and warmer water temperatures before this sampling occasion. The reduced number of macroinvertebrate taxa collected from the Ballantyne Road site in February is probably the result of this site drying in the weeks before this sampling occasion.

8. Six fish species, including brown and rainbow trout, longfin eel, koaro, Clutha flathead galaxias and upland bully, have been collected from the Mount Barker monitoring site.

Technical summary

The Cardrona River is a major tributary of the upper Clutha River, with the confluence a short distance downstream of the outlet of Lake Wanaka. The river is fed by high rainfall (>1 m per annum) in the steep western portion of the catchment, while the lower catchment receives low levels of rainfall (<700 mm per annum). As a result, there is heavy demand for water abstraction in the lower catchment, and existing levels of allocation contribute to the drying of the lower Cardrona River in most years.

The objectives of this water quality study are to:

1. assess spatial and temporal patterns in water quality to assess the effects of land-use on water quality in the Cardrona catchment
2. get a representative background level for an unimpacted site (Cardona River upstream of Cardrona township)
3. assess water quality in the Cardrona catchment against water quality standards in RPA Change 6A
4. assess habitat quality and macroinvertebrate communities in the Cardrona catchment
5. provide an assessment for future comparison once minimum flows are in place and if large-scale irrigation development occurs.

Water quality in the upper Cardrona River is generally very good, but the lower catchment below the SH6 bridge has high concentrations of TN and NNN, and concentrations of NNN at both these sites are currently likely to exceed Schedule 15 standards for NNN. This deterioration in water quality coincides with the location of nitrogen-enriched (relative to surface water) groundwater entering the river. Given that the 80th percentiles for most of the sites were calculated from only one year of data (the exceptions being the SoE site at Mount Barker), these results should be interpreted with caution.

No trend was evident for the Mount Barker SoE site over the period 2000-2015 for most water-quality variables. The exception was *E. coli* and suspended solid (SS) concentrations, which decreased over this period.

Water quality in two of the tributaries sampled in this study (Boundary Creek and Branch Burn) was generally good. However, elevated NNN concentrations and *E. coli* counts were observed in Spotts Creek and were particularly evident during periods of low flow.

Water temperatures in much of the main stem of the Cardrona River and most of its tributaries are generally suitable for brown and rainbow trout and native fish, but water temperature maxima in the vicinity of Ballantyne Road and in the lower Branch Burn may be unsuitable for brown and rainbow trout at times, particularly during the height of summer. All four main-stem sites exceeded the acute thermal criterion for the common mayfly, *Deleatidium*, which suggests that high water temperatures may affect macroinvertebrate community structure in the lower Cardrona at times.

Comparison of the 80th percentiles of water-quality parameters with receiving water-quality limits in Plan Change 6A (Schedule 15,Table 4.1). Values that exceeded the limit are highlighted in red. All values calculated using samples collected when flows were at, or below, the appropriate reference flow.

Site	Period	NNN 0.075 mg/l	NH4-N 0.1 mg/l	DRP 0.01 mg/l	*E. coli* 260 cfu/100 ml	Turbidity 5 NTU
Upstream of Cardrona	2014-2015	0.002	0.012	0.004	38	-
Waiorau bridge	2014-2015	0.019	0.010	0.004	51	-
Upstream of Boundary Ck	2014-2015	0.017	0.007	0.004	216	-
James Road bridge	2014-2015	0.015	0.007	0.004	85	-
Stockyards Ford	2014-2015	0.013	0.007	0.004	66	-
Mount Barker (SoE)	2014-2015	0.070	0.010	0.004	40	-
	2010-2015	0.066	0.010	0.004	72	0.87
Ballantyne Road	2014-2015	0.059	0.014	0.005	21	-
SH6	2014-2015	0.380	0.009	0.004	26	-
Clutha confluence	2014-2015	0.752	0.005	0.003	48	-
Boundary Creek	2014-2015	0.016	0.011	0.004	99	-
Branch Burn	2014-2015	0.019	0.005	0.004	33	-
Spotts Creek	2014-2015	0.342	0.016	0.006	372	-

Coarse gravels dominated the bed at most sites in the Cardrona River. Riparian buffers were not generally present, and there was evidence of direct stock access at most sites surveyed. Riparian vegetation tended to consist of exotic species, including willows, lupins and exotic grasses.

The results of the 2014/15 catchment periphyton survey were consistent with the results of water-quality sampling undertaken at the same time with the periphyton community at sites in the upper Cardrona catchment (above Ballantyne Road), which indicated low-nutrient conditions, with low chlorophyll-a concentrations and cover by long, filamentous algae. However, the site at the SH6 bridge supported much greater periphyton growths, a finding that is consistent with the much higher nitrogen concentration observed at this site, resulting from the resurgence of nitrate-enriched groundwater, immediately upstream of the SH6 bridge.

Macroinvertebrate communities collected from Mount Barker between 2001 and 2015 were consistent with good to excellent water quality, and trend analysis indicated that macroinvertebrate metrics at this site had been stable over this period. Macroinvertebrate communities in the upper Cardrona River and tributaries (all upstream of Mount Barker) in October 2014 were consistent with very good water quality. However, macroinvertebrate communities in February 2015 generally included a greater abundance of taxa that are tolerant of poor water quality, probably the result of the low, stable flows and warmer water temperatures before this sampling occasion. The reduced number of macroinvertebrate taxa collected from the Ballantyne Road site in February is probably the result of this site drying in the weeks before the February sampling occasion. Six fish species (brown and rainbow trout, longfin eel, koaro, Clutha flathead galaxias and upland bully) have been collected from the Mount Barker monitoring site.

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1. Introduction

The Cardrona River is a major tributary of the upper Clutha River, with the confluence located a short distance downstream of the outlet of Lake Wanaka. The river is fed by high rainfall (>1 m per annum) in the steep western portion of the catchment, while the lower catchment receives low levels of rainfall (<700 mm per annum). As a result, there is heavy demand for water abstraction in the lower catchment, and existing levels of allocation contribute to the drying of the lower Cardrona River in most years.

A targeted water quality study was carried out in the Lindis and Cardrona catchments in 2004-2005, which confirmed that water quality was very good in both catchments (Otago Regional Council (ORC) 2006a). Since that study was conducted, the area of irrigated land within the Cardrona catchment has increased, and the method of irrigation has also been changing. Such changes have the potential to affect water quality in the Cardrona catchment. Flood irrigation has been shown to detrimentally affect water quality, with the discharge of wipe-off water[1] increasing concentrations of sediment and nutrients and faecal contamination of receiving waters (ORC 2006b). Flood irrigation has also been shown to have a higher rate of nitrogen leaching relative to spray irrigation (Lilburne *et al.* 2010), although this is associated with higher recharge of groundwater relative to spray irrigation. The higher recharge associated with flood-irrigation methods may dilute nitrogen concentrations in groundwater, resulting in lower groundwater nitrogen concentrations than under spray irrigation. Conversion of flood or border-dyke irrigation to more efficient spray irrigation has the potential to improve surface-water quality in the catchment, especially concentrations of suspended sediment, phosphorus and *Escherichia* coli (*E. coli*), which may result in higher nitrogen concentrations in groundwater.

1.1. Purpose

The objectives of this study are to:

1. assess spatial and temporal patterns in water quality to assess the effects of land-use on water quality in the Cardrona catchment
2. get a representative background level for an unimpacted site (Cardona River, upstream of Cardrona township)
3. assess water quality in the Cardrona catchment against water-quality standards in the Regional Plan: Water (RPW) Change 6A
4. assess in-stream habitat quality and macroinvertebrate communities in the Cardrona catchment
5. provide an assessment of ecological health and water quality for future comparison once minimum flows are in place and if large-scale irrigation development occurs.

[1] Excess irrigation water that is discharged back into a race and/or waterway

2. Background

2.1. Catchment description

The Cardrona River starts in the Crown Range and flows through alluvial flats bounded on both sides by steep valley walls. The river flows for almost 9 km over the upper Clutha plains before entering the Clutha River just downstream of Albert Town (Figure 2.1). The catchment encompasses an area of 339 km^2. The highest point in the Cardrona catchment is Mount Cardrona (1934 m ASL), while the lower reaches, just upstream of the confluence of the Clutha, have an elevation of about 280 m.

2.1.1. Climate

Just over half (55%) of the Cardrona catchment is classified as having a ‘cool, dry’ climate (mean annual temperature <12°C, mean effective precipitation[2] ≤500 mm), with the remainder of the catchment, mostly in the upper reaches and high country, classified as ‘cool, wet’ (mean annual temperature <12°C, mean effective precipitation 500-1500 mm) (River Environment Classification, Ministry for the Environment & NIWA, 2004). This reflects the effect of elevation on rainfall, with highest rainfall occurring in the elevated western portion of the catchment (>1400 mm), while low elevation areas receive less than 700 mm of rainfall per annum (Figure 2.2).

The Cardrona catchment has a continental climate, due to its distance from the moderating influence of the ocean. Long-term air temperature records from the Wanaka aerodrome (NZTM 1302550E 5040843N), the closest long-term weather station to the Cardrona catchment (about 3 km from the nearest point in the Cardrona catchment), show that air temperatures vary markedly throughout the year, with the average summer maximum temperatures being almost 24°C, while the average maximum in July is 7.6°C (Table 2.1).

Table 2.1 Long-term average temperature statistics (mean, minimum daily, maximum daily) for Wanaka aerodrome between 1981 to 2010

	Month												Annual
	J	F	M	A	M	J	J	A	S	O	N	D	
Mean	17.2	17	14.2	10.6	7.2	4.1	3.3	5.5	8.3	10.5	13	15.3	**10.5**
Max.	23.8	23.7	20.5	16.3	12	8.2	7.6	10.4	13.6	16.3	19.2	21.5	**16.1**
Min.	10.6	10.3	7.9	4.8	2.3	-0.1	-0.9	0.5	2.9	4.7	6.9	9	**4.9**

[2] Mean effective precipitation is calculated by subtracting the mean annual precipitation from the mean annual potential evapotranspiration.

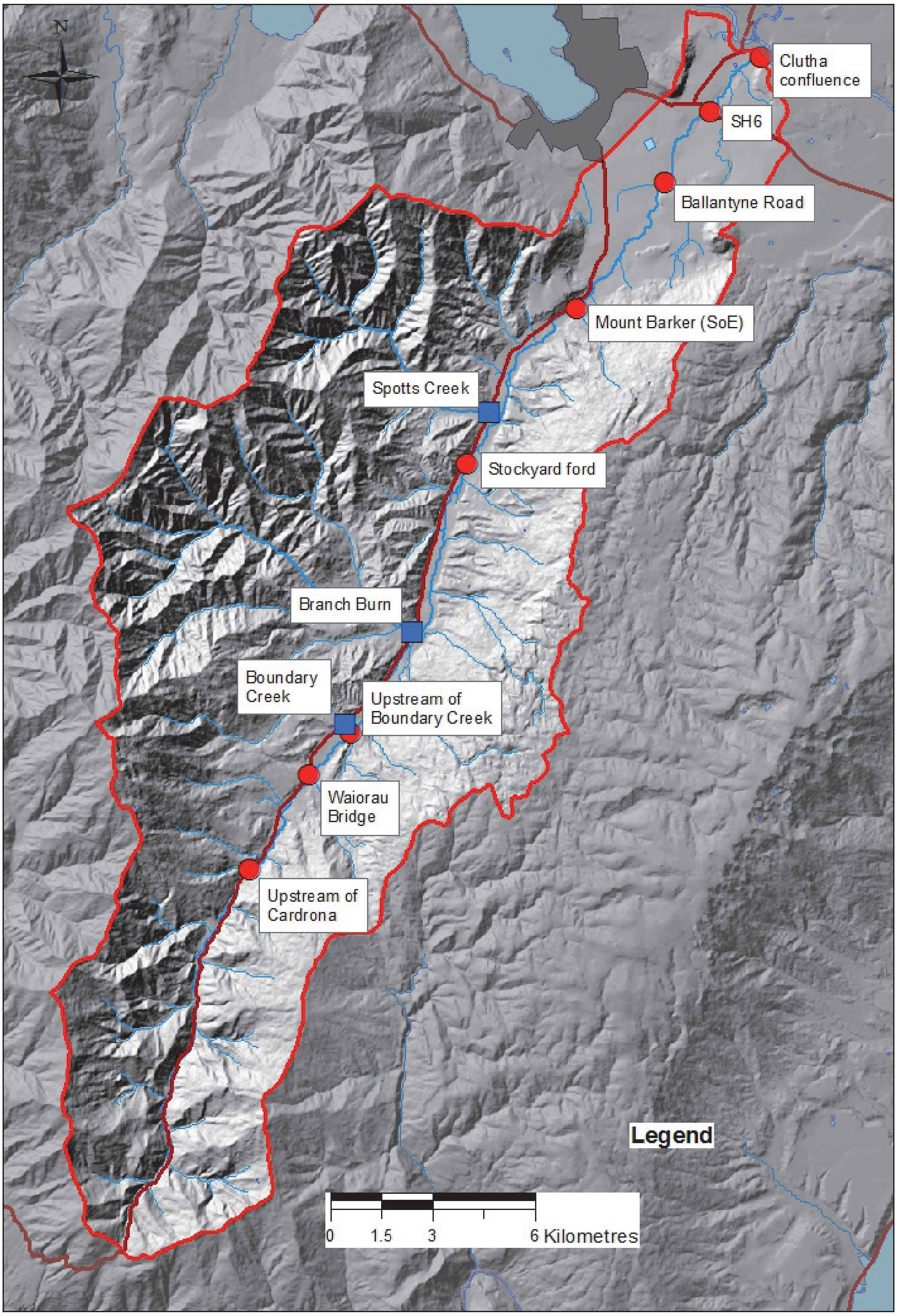

Figure 2.1 Cardrona catchment, showing water-quality monitoring sites

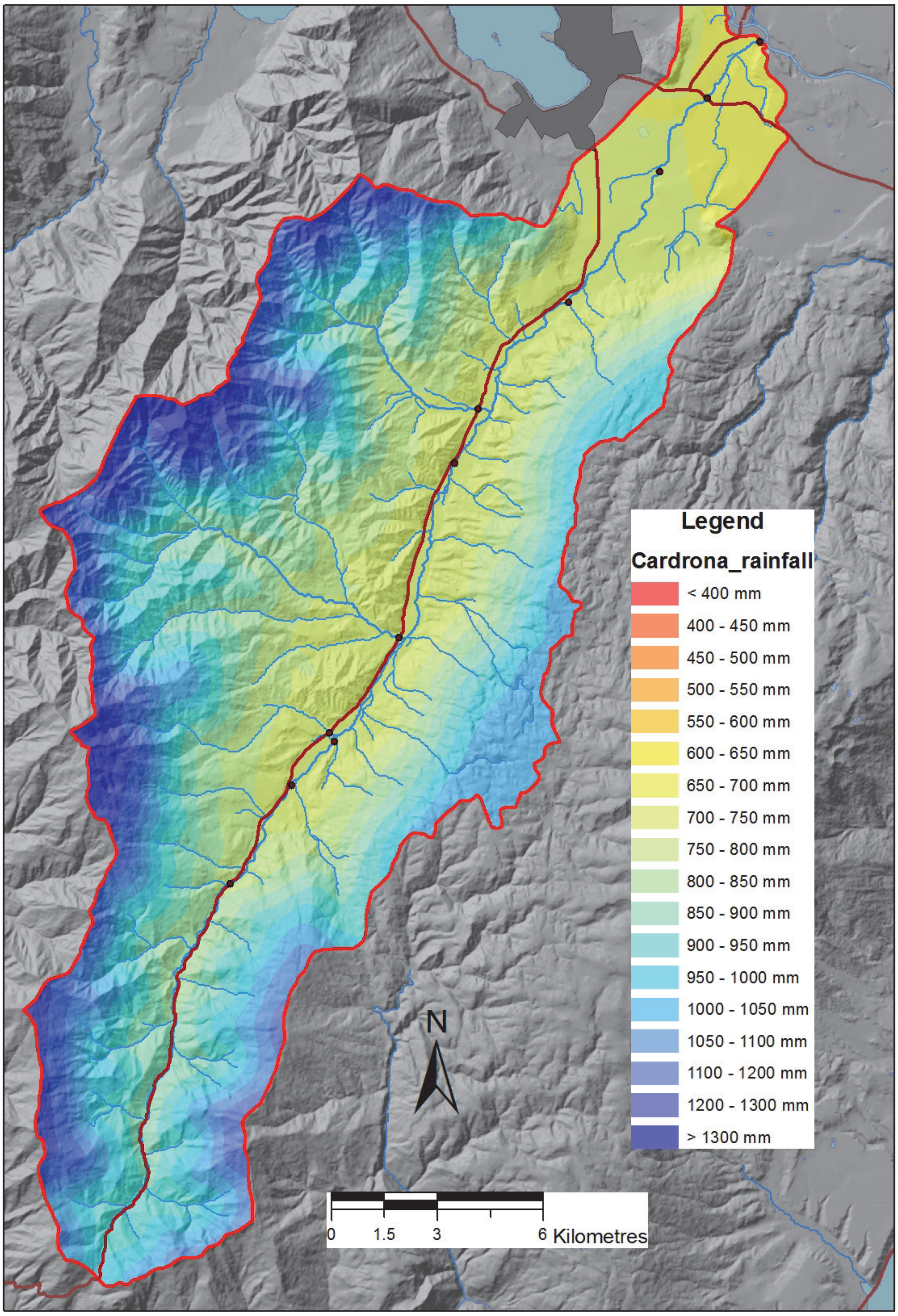

Figure 2.2 **Mean annual rainfall (mm) in the Cardrona catchment. Source: grow Otago**

2.1.2. Geology and geomorphology

Most of the catchment lies on an underlying geology of schist, with some areas of sedimentary rock (quartz sand and gravel and conglomerate) scattered throughout the catchment. Much of the lower portion of the catchment sits on alluvial or glacial gravels (Figure 2.3).

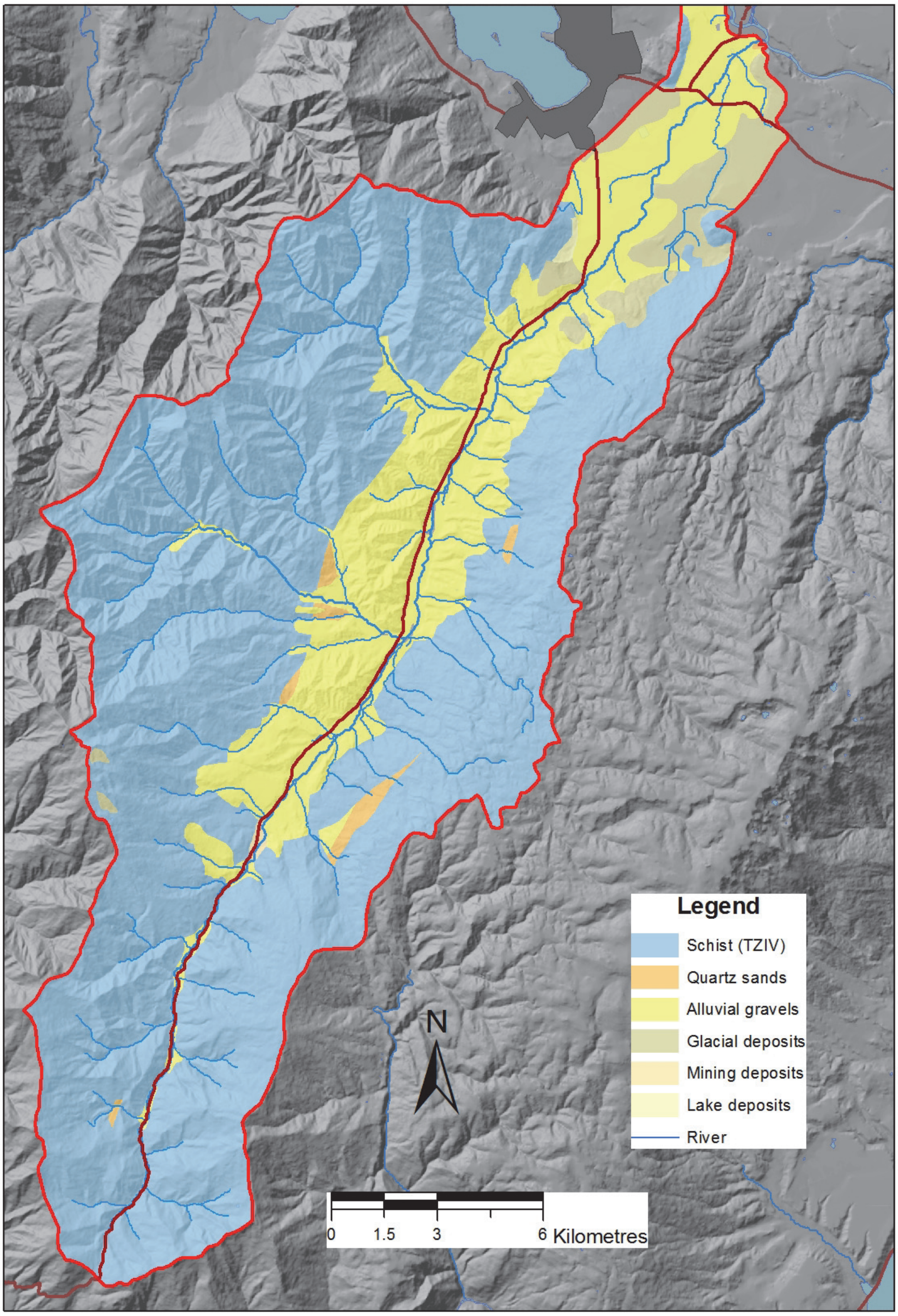

Figure 2.3 **Geology of the Cardrona catchment. Source: QMAP seamless digital data 2012, GNS Science)**

2.1.3. Catchment land use

Most of the Cardrona catchment consists of agricultural grasslands, with tall tussock grasslands (44%) and low-producing grassland (37%) dominating the hill country, while areas of high-producing pasture grasslands (10%) are mostly found on river flats in the lower part of the catchment (Table 2.2, Figure 2.4).

A total area of about 2,850 ha in the Cardrona catchment is irrigated, with most of this area on the extensive area of flat land between the Criffell Range and Mount Roy and the Clutha River, although much of the floor of the Cardrona Valley and areas near tributaries are also irrigated (Figure 2.5).

Table 2.2 Cover by different vegetation types in the Cardrona catchment, based on the Land Cover Database (v.4)

Vegetation type	Area (km^2)	% cover
Indigenous scrub	8	2%
High-producing exotic grassland	34	10%
Low-producing grassland	127	37%
Mixed-exotic shrubland	6	2%
Tall tussock grassland	148	44%
Other	17	5%

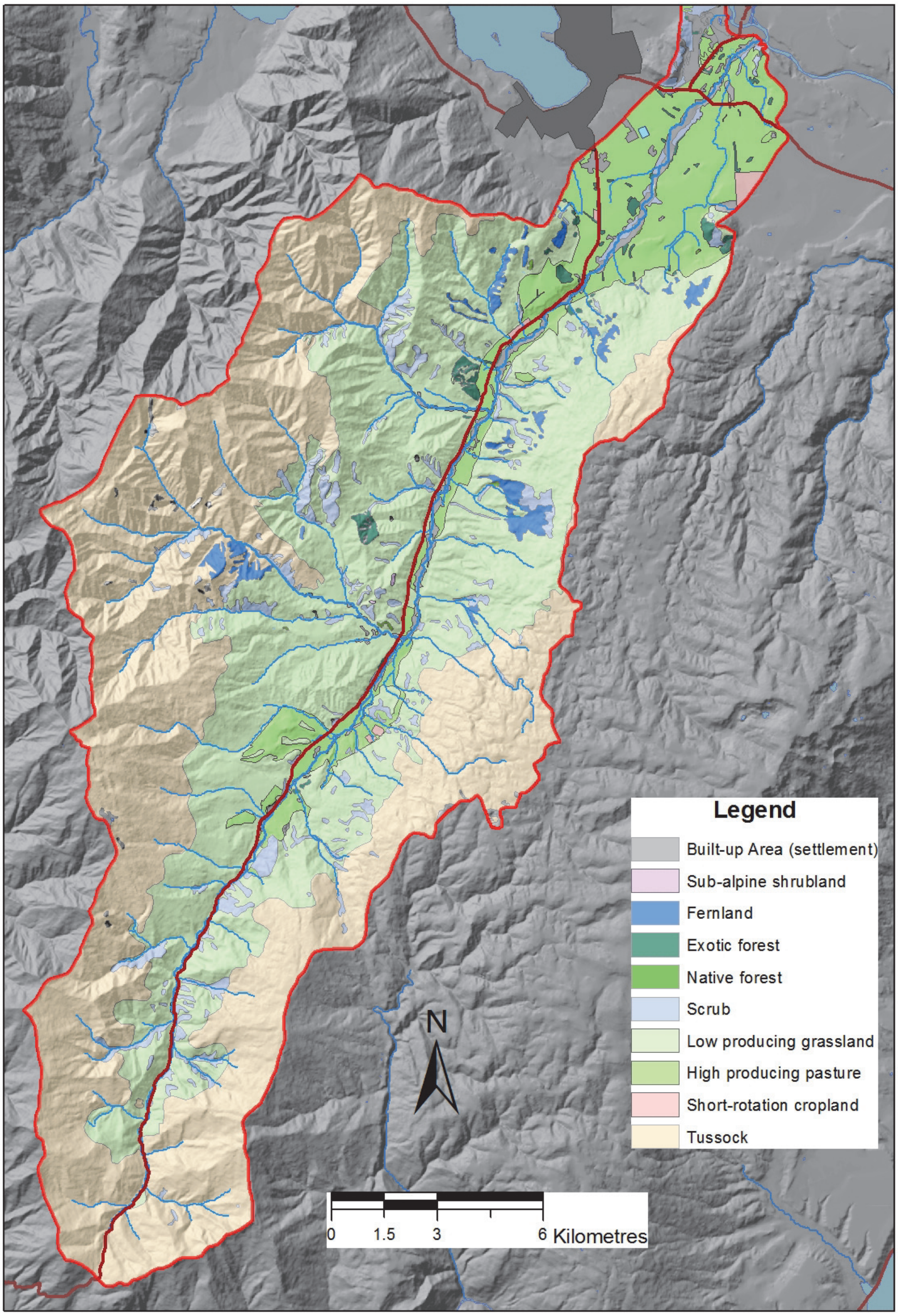

Figure 2.4 **Land cover of the Cardrona catchment, based on the Land Cover Database (v.4)**

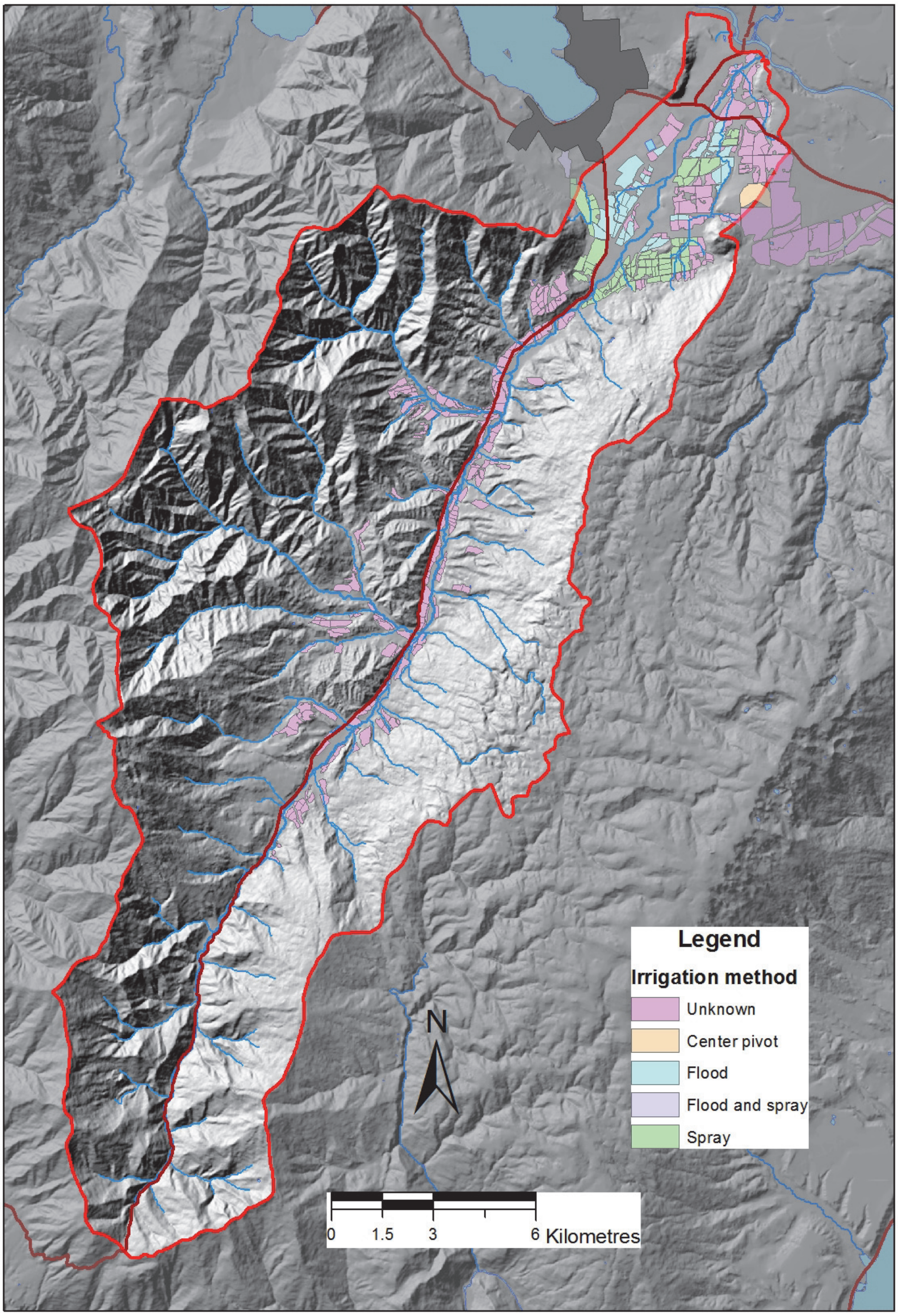

Figure 2.5 **Irrigated area and irrigation method (where known) in the Cardrona catchment in 2014. Based on analysis of satellite imagery (Pleiades, Airbus Defence & Space)**

2.2. Hydrology and water use

The hydrology of the Cardrona catchment was reviewed in detail in a report prepared in 2011 (Dale & Rekker 2011). Flow statistics for the permanent flow recorders in the Cardrona River are outlined in Table 2.3.

Flows in the lower reaches of the Cardrona River are heavily influenced by water abstraction, as well as losses to groundwater (Dale & Rekker 2011). At low flows, it was estimated that about 700 l/s was lost to groundwater between Mount Barker and the State Highway (SH) 6 bridge, while the river gains about 300 l/s from groundwater between SH6 and the Clutha confluence (Dale & Rekker 2011). Total primary allocation in the Cardrona catchment is 2,217 l/s, while there is 19.8 l/s of supplementary allocation and 332 l/s of consented groundwater takes. Much of the allocation in the catchment is in the form of large surface-water takes from the main-stem river. Most of these are in the vicinity of Mount Barker, while many of the tributaries also have water takes on them (Figure 2.6).

Table 2.3 Flow statistics for the permanent flow recorders in the Cardrona River. N.B. these flow statistics do not account for water abstraction (i.e. they are not naturalised).

Site Name	Min. recorded flow (l/s)	Max. recorded flow (l/s)	Mean flow (l/s)	Median flow (l/s)	7-d MALF (l/s)	Complete hydrological years
Mount Barker	308	145,299	3,665	2,312	881	15
Clutha confluence	253	121,840	1,996	1,551	-	1

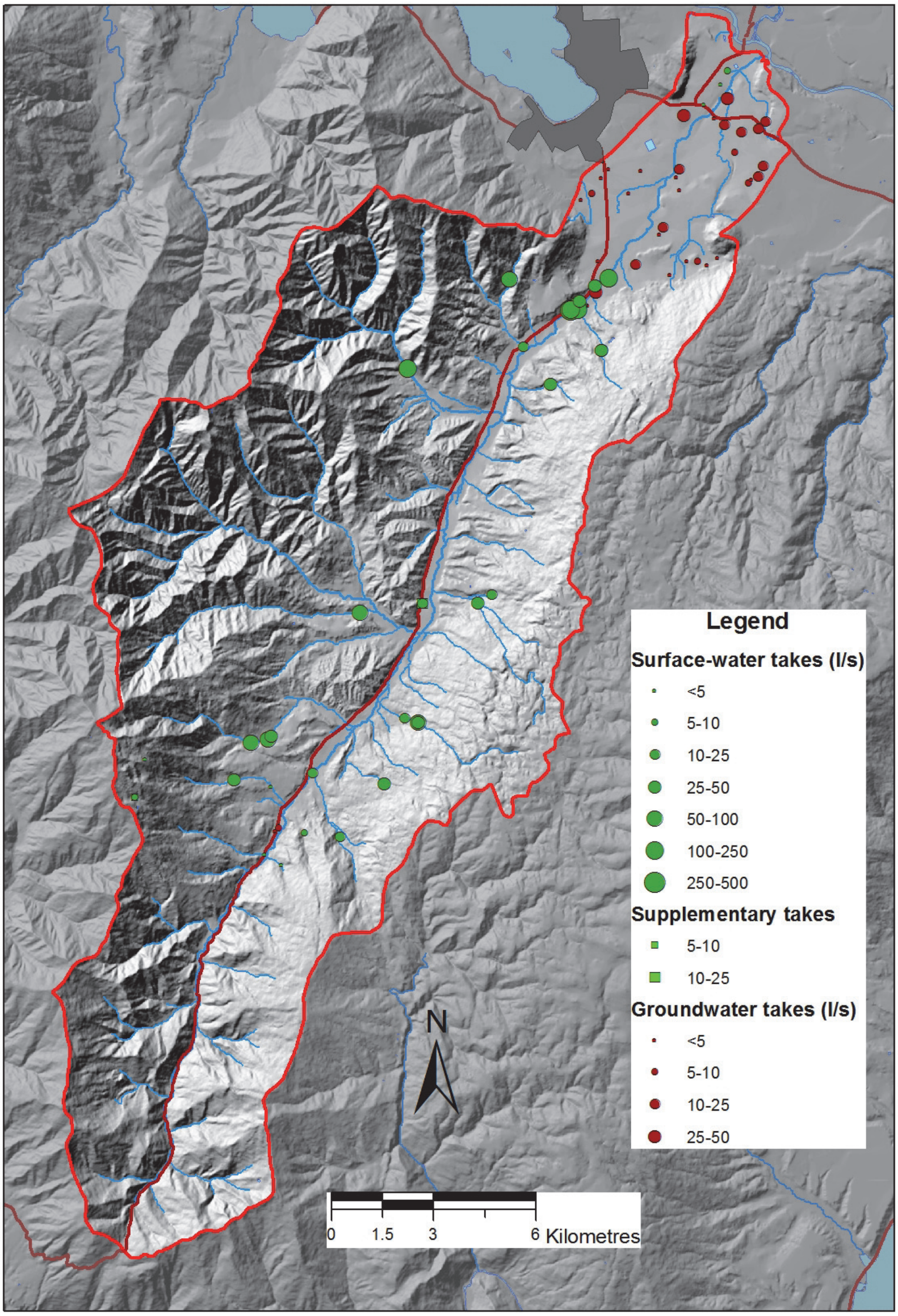

Figure 2.6 **Groundwater and surface-water takes in the Cardrona River catchment**

3. Natural values of the Cardrona catchment

3.1. Instream ecological values

Schedule 1A of the RPW for Otago identifies the natural values of Otago's waterways, including ecosystem values and significant habitat for indigenous fauna. The Cardrona River is recognised as providing habitat for trout spawning, juvenile rearing and adult trout, as well as for longfin eel and rare native fish (Clutha flathead galaxias). Both brown trout and rainbow trout have been recorded from the catchment, although brown trout are more widespread, while rainbow trout have generally been recorded from the tributaries (Dale & Rekker 2011). The catchment is considered an important recruitment source for the upper Clutha and Lake Dunstan fisheries.

Native fish recorded from the catchment have included longfin eel, Clutha flathead galaxias, koaro and upland bully (Dale & Rekker 2011). The significant presence of Clutha flathead galaxias is listed as a value of the catchment in Schedule 1A of the RPW. Clutha flathead galaxias are classified as 'nationally critical' (the highest threat classification in the New Zealand threat classification system, Townsend *et al.* 2008) in the most recent assessment of the conservation status of freshwater fish in New Zealand, while longfin eel and koaro were classified as 'declining' (Goodman *et al.* 2014). Upland bullies are classified as 'not threatened' (Goodman *et al.* 2014).

Schedule 1A of the RPW also recognises that the Cardrona has a high degree of naturalness above 900 m and is free of pest macrophytes, although the invasive diatom *Didymosphenia geminata* (didymo) is now found in much of the catchment.

3.2. Recreational values

Recreational activities in the Cardrona River include swimming and trout fishing. The Cardrona River is considered a locally significant fishery (Dale & Rekker 2011) and receives little angling effort (Table 3.1), but is a significant spawning tributary of the nationally significant upper Clutha River fishery (Unwin 2009).

Table 3.1 Angler effort (angler days ± standard error) estimated for the Cardrona River as part of the National Angler Survey (Unwin 2009)

Season	Effort
1994/1995	30 ± 30
2001/2002	none
2007/2008	30 ± 30

4. Regional planning

4.1. Water-quality guidelines – Plan Change 6A

Plan Change 6A was adopted on 1 May 2014 and sets out numerical water-quality limits for all catchments in the Otago region (Schedule 15). It establishes water-quality thresholds for all discharges to lakes, rivers, wetlands, and drains into two discharge threshold areas (Schedule 16). The Cardrona catchment is in receiving water group 2. The numerical water-quality limits for this group are outlined in Table 4.1.

For the Cardrona catchment, the receiving water limits outlined in Table 4.1 are applied as five-year, 80th percentiles when flows are at or below a reference flow of 1.95 m/s at the Mount Barker hydrological monitoring site (Figure 2.1).

Table 4.1 Receiving water numerical limits and timeframe for achieving good water quality in the Cardrona catchment

	Nitrate-nitrite nitrogen	Dissolved reactive phosphorus	Ammoniacal nitrogen	*Escherichia coli*	Turbidity
Numerical limit	0.075 mg/L	0.01 mg/L	0.1 mg/L	260 cfu/100 ml	5 NTU
Target date	31 March 2025	31 March 2025	31 March 2012	31 March 2012	31 March 2012

5. Sampling and analysis methods

5.1. Water-quality sampling

5.1.1. Long-term monitoring

Long-term ('State of the Environment') monitoring has been undertaken at one site in the Cardrona catchment (Mount Barker (also known as 'The Larches')) since December 1989.

5.1.2. Catchment water-quality sampling 2012-2013

Water-quality samples were collected from each of the eight monitoring sites every fortnight between 18 September 2014 and 14 September 2015. These samples were analysed for total nitrogen (TN), nitrate-nitrite nitrogen (NNN), ammoniacal nitrogen (NH_4-N), total phosphorus (TP), dissolved reactive phosphorus (DRP), suspended solids (SS) and *E. coli* by Watercare Laboratory Services (Auckland, www.watercarelabs.co.nz). Water-quality parameters measured as part of this study included: nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), NH_4-N, TN, DRP, TP, total suspended solids (TSS) and *E. coli*. NNN was calculated by adding NO_3-N and NO_2-N, while total Kjeldahl nitrogen (TKN) was calculated by subtracting NNN from TN.

5.2. Habitat assessment

Sediment composition was visually assessed using an underwater viewer from at least five locations in each mesohabitat type (run/pool/riffle) at each site, with the proportion of bedrock, boulders (>256 mm), cobbles (64-256 mm), coarse gravels (16-64 mm), fine gravels (2-16 mm) and fines (>2 mm) noted. Characteristics and extent of riparian vegetation at each site were noted, as was livestock access.

5.3. Periphyton

5.3.1. State of the Environment (SoE) monitoring

Periphyton community composition was measured at two sites as part of the SoE monitoring programme. Algal samples were collected by selecting three stones at each site, taken from one-quarter, one-half and three-quarters of the stream width. At each collection point, a stone was randomly selected and removed to the river bank. A 5 cm x 5 cm (0.0025 m^2) area of each stone surface was scrubbed with a small brush into a tray and rinsed with river water. Using river water, the scrubbings from the three stones were pooled and transferred to a sample container. The sample was transported to the laboratory and preserved in formaldehyde.

In the laboratory, each sample was thoroughly mixed, and three aliquots were removed and placed in an inverted microscope settling chamber. They were then allowed to settle for ten minutes. Samples were analysed according to the 'relative abundance using the 'inverted microscope' method, outlined in Biggs and Kilroy (2000). Samples were inspected under 200-400x magnification to identify algal species present using the keys of Biggs and Kilroy (2000), Entwisle *et al.* (1988) and Moore (2000). Algae were given an abundance score ranging from 1 (rare) to 8 (dominant), based on the protocol of Biggs and Kilroy (2000). Internal quality assurance procedures were followed.

5.3.2. 2014 Catchment survey

The percentage cover of the stream bed by different categories of periphyton was assessed using the Rapid Assessment Method 2 (RAM-2), described by Biggs & Kilroy (2000). This method, which is recommended for general surveys and assessing broad-scale effects of perturbations, involves estimating the periphyton percentage cover five points across the river on four transects within a 100 m reach, using an underwater viewer (bathyscope). Thus, 20 estimates of periphyton percentage cover (to the nearest 5%) are obtained with the periphyton classified into 12 categories (Table 2). Note that some periphyton taxa are found in several categories because it is not only their presence, but also the thickness of the mat, that is important for the evaluation of water quality (Table 2).

As well as assessments of periphyton cover, periphyton biomass was assessed, using rock scrapes taken from ten randomly chosen stones at each site to estimate chlorophyll-*a* biomass (QM-1b). Periphyton was completely removed from a circular area of 52 mm diameter (21.2 cm^2), using a tooth brush, with all periphyton washed into a plastic jar for chlorophyll-*a* analysis, kept on ice in a cooler and frozen within 12 hours of collection.

Laboratory analysis of chlorophyll-*a* concentration was undertaken by Ryder Consulting Ltd. In the laboratory, each sample was thawed and tipped into a glass beaker and blended for about 30 seconds or until the mixture was free of obvious clumps of material. The blended liquid was then made up to a known volume (e.g. 100 ml). Each sample was then shaken, and three 5 ml aliquots were withdrawn, using an automatic pipette, and filtered onto a Microscience MS-GC 47 mm glass-fibre filter. The filter was placed in a tube containing 20 ml of 90% ethanol, immersed in a water bath (78°C for five minutes) and then put into a refrigerator overnight. The tube was centrifuged for ten minutes at 6000 rpm before the absorption of a 13.5 ml aliquot of the ethanol homogenate was measured at 665 nm and 750 nm, using a 4 cm cuvette in a Shimadzu UV-120-01 spectrophotometer. The ethanol homogenate was then acidified with 0.375 ml of 0.3 M HCl, and then, following a 30-second delay, absorbances at 665 nm and 750 nm were re-read. The total amount of chlorophyll *a* was calculated, using a standard formula (Biggs & Kilroy 2000), and scaled to the number of milligrams of chlorophyll *a* per m^2 of stream bed.

Table 5.1 Periphyton categories used in periphyton assessments (following RAM-2), with enrichment indicator scores. (* Diatom epiphytes give the green filaments a brown colouring) (from Biggs & Kilroy 2000).)

Periphyton category		Periphyton enrichment indicator score	Typical taxa
Thin mat/film: (under 0.5 mm thick)	Green	7	*Cymbella*, *Achnanthidium*, *Cocconeis*, *Ulothrix*, *Stigeoclonium* (basal cells), young *Spirogyra*
	Light brown	10	Assorted diatoms and cyanobacteria (*Cocconeis*, *Fragilaria*, *Synedra*, *Cymbella*, *Lyngbya*, *Amphithrix*)
	Black/dark brown	10	Assorted cyanobacteria (*Schizothrix*, *Calothrix*, *Lyngbya*)
Medium mat: (0.5 – 3 mm thick)	Green	5	*Stigeoclonium*, *Bulbochaete*, *Chaetophora*, *Oedogonium*, *Spirogyra*, *Ulothrix*
	Light brown (± dark green/black bobbles)	7	*Gomphonema*, *Gomphoneis*, *Synedra*, *Cymbella*, , *Fragilaria*, *Navicula*, *Nostoc*
	Black/dark brown	9	*Tolypothrix*, *Schizothrix*, *Phormidium*, *Lyngbya*, *Rivularia*
Thick mat: (over 3 mm thick)	Green/light brown	4	*Navicula*, *Gomphoneis*, *Synedra*, *Rhoicosphenia*, *Ulothrix*, *Oedogonium*, *Microspora*, *Spirogyra*, *Vaucheria*
	Black/dark brown	7	*Phormidium*, *Schizothrix*, *Audouinella*, *Batrachospermum*, *Nostoc*
Filaments, short: (under 2 cm long)	Green	5	*Ulothrix*, *Oedogonium*, *Microspora*, *Spirogyra*, *Cladophora*
	Brown/reddish	5	*Cladophora**, *Oedogonium**, *Rhoicosphenia*, *Navicula*, *Batrachospermum*, *Diatoma*
Filaments, long: (over 2 cm long)	Green	1	*Ulothrix*, *Oedogonium*, *Microspora*, *Zygnema*, *Spirogyra*, *Cladophora*, *Rhizoclonium*
	Brown/reddish	4	*Melosira*, *Cladophora**, *Rhizoclonium**

5.4. Macroinvertebrates

On 22 October 2014 and 18 February 2015, macroinvertebrate communities were sampled at eight sites in the Cardrona River and three sites in tributaries. 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 a laboratory for processing. Following Protocol P1, '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 onto a white tray, and the macroinvertebrates were identified under a dissecting microscope (10-40X), using the identification key of Winterbourn *et al.* (2006). Macroinvertebrate samples were processed by Ryder Consulting Ltd.

The indices commonly used to measure stream health are summarised below:

- Species richness is 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 unimpacted, pristine streams.

- Ephemeroptera plecoptera and trichoptera (EPT) richness is the sum of the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) species collected. These insects are often the most sensitive to organic pollution; therefore, low numbers might indicate a polluted environment. Comparing the percentage of EPT species (%EPT_{taxa}) to the total number of species found at a site can give an indication of the importance of these species in the overall community. For this report, purse-cased caddisflies (Hydroptilidae: *Oxyethira* and *Paroxyethira*) were excluded from the EPT count, due to their tolerance of enriched conditions.

- Macroinvertebrate community index (MCI) uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. Taxa are assigned scores of between 1 and 10, depending on their tolerance. A score of 1 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 the total by the number of taxa present at the site and multiplying this figure by 20 (a scaling factor). MCI scores can be interpreted based on the water-quality classes proposed by Stark & Maxted (2007) (Table 5.2).

- Semi-quantitative macroinvertebrate community index (SQMCI) is a variation of the MCI that accounts for the abundance of pollution sensitive and tolerant species. The SQMCI is calculated from coded-abundance data. Individual taxa counts are assigned to one of the following abundance classes: rare (R, 1-4 individuals), common (C, 5-19 individuals), abundant (A, 20-100 individuals), very abundant (VA, 100-500 individuals), very, very abundant (VVA, >500 individuals). SQMCI scores can be interpreted based on the water-quality classes proposed by Stark & Maxted (2007) (Table 5.2).

Table 5.2 Criteria for aquatic macroinvertebrate health, according to different macroinvertebrate indices (following Stark & Maxted 2007)

Macroinvertebrate index	Poor	Fair	Good	Excellent
MCI	<80	80-99	100-119	>120
SQMCI	<4.00	4-4.99	5-5.99	>6

5.5. Fish

5.5.1. Long-term monitoring

Fish populations have been surveyed annually since 2009 at the Mount Barker monitoring site, using a pulsed DC Kainga EFM300 backpack electric-fishing machine and following the New Zealand Freshwater Fish Sampling Protocols (Joy *et al.* 2013). Briefly, this entails dividing a 150 m reach into ten 15 m-long sub-reaches, and each section is electric fished in a single pass from downstream to upstream. When each section is fished, all fish caught are measured using a fish board and recorded. When 50 individuals of an individual species have been measured, individuals in subsequent sections are counted and recorded. An additional monitoring site at SH6 was monitored in 2009, following the protocol outlined above.

Fish communities at Mount Barker were also monitored in 2008 by stop-netting and three-pass electric fishing about 60 m^2 of streambed.

5.6. Data analysis and presentation

5.6.1. Trend analysis

Long-term trends in water-quality parameters were considered, using a seasonal Kendall trend test in Time Trends statistical software (Version 5.0, Jowett 2015). Tests for water-quality variables were performed with six seasons per year (fitting with the historic bimonthly SoE sampling), and the median value for each season was used in the analysis. All water-quality data were flow-adjusted (flow was used as a covariate in the analysis). The covariate adjustment method was a locally weighted scatterplot smoothing (Lowess) curve, with a tension of 0.3 (i.e. 30% of points to fit) and five iterations.

Long-term trends in macroinvertebrate metrics (taxonomic richness, %EPT, MCI and SQMCI) were considered, using a Mann-Kendall trend test in Time Trends (Version 5.0, Jowett 2015).

5.6.2. Box plots

Where sufficient water-quality data were available, they were presented as box plots, as these provide information on data distribution (Figure 5.1).

Monitoring sites included in the water-quality box plot summaries are ordered from upstream main stem (left of plot) to downstream main stem. Main-stem river-monitoring sites are listed first, followed by the three tributary sites. The tributary sites, like the main-stem sites, are listed from left to right with the most upstream tributary site listed first. The location of water-quality monitoring sites are shown in Figure 2.1.

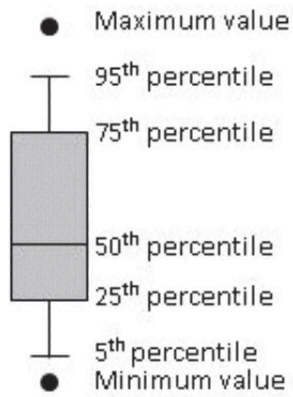

Figure 5.1 The interpretation of the various components of a box plot, as presented in this report

6. Results

6.1. Long-term monitoring

6.1.1. Trend analyses

Analysis of trends in water-quality parameters at the Mount Barker (The Larches) SoE site shows that most had not changed between January 2000 and December 2015, with the exception of *E. coli* and SS, which declined significantly over this period (Table 6.1).

Table 6.1 **Trends in water-quality parameters at Mount Barker (The Larches) SoE monitoring site in the Cardrona catchment. The *Z*-statistic indicates the direction and strength of any trend detected, while the *P*-value indicates the probability of that trend occurring by chance. The PAC is the percent annual change of the variable in quesiton. Trends with a *P*-value of less than 0.05 are considered to be statistically significant.**

Variable	*Z*	*P*	PAC (% / yr)	Trend
NH_4-N	-1.98	0.048	0	Stable
NNN	-0.07	0.949	n.s.	n.s.
TN	1.23	0.219	n.s.	n.s.
DRP	-1.53	0.125	n.s.	n.s.
TP	0	1	n.s.	n.s.
E. coli	-2.22	0.026	-5.7	Decreasing
Turbidity	-0.49	0.626	n.s.	n.s.
SS	-2.05	0.040	-2.9	Decreasing

6.1.2. Compliance with Plan Change 6A limits

Schedule 15 of the RPW sets out water-quality limits and targets for receiving waters in the Otago region (Section 4). These limits apply as running five-year, 80^{th} percentiles when flows are at, or below, the reference flow at the appropriate monitoring site. For the Cardrona catchment, the reference flow is 1,950 l/s at the Mount Barker flow-monitoring site (also the site that water-quality data is collected for the SoE monitoring programme). Water-quality monitoring data collected from the Mount Barker SoE and flow-monitoring site, when flows were below the reference flow, were compared to receiving water limits. None of the variables considered at the Mount Barker site exceeded the Schedule 15 limit (Figure 6.1).

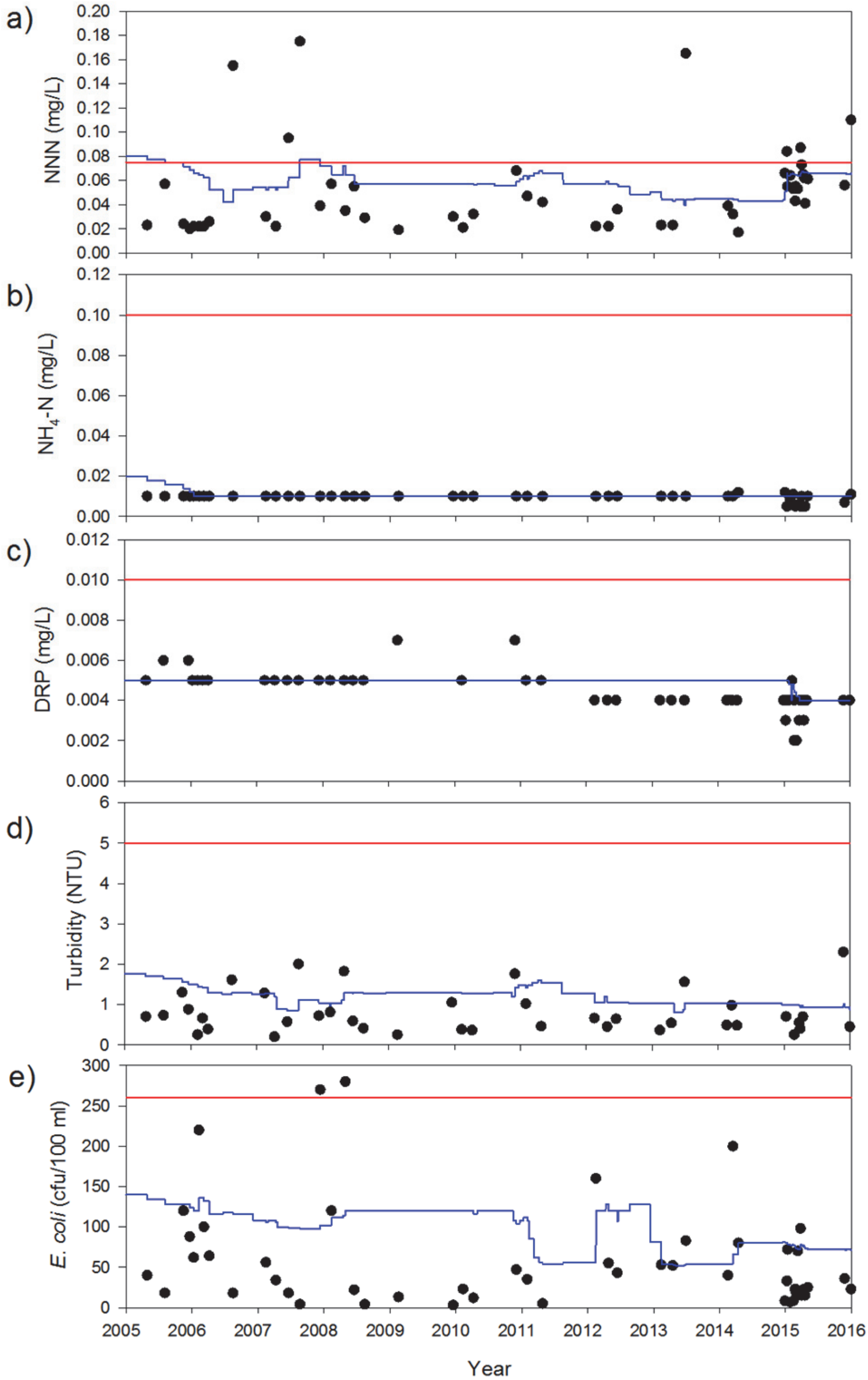

Figure 6.1 **Comparison of a) NNN, b) NH4-N, c) DRP, d) turbidity and e) *E. coli* at the Mount Barker site when flows are below median flow with Schedule 15 standards (red lines). Blue lines represent five-year moving 80th percentiles.**

6.2. Water temperature

Water temperature records were available for four sites in the main stem of the Cardrona River, as well as for four tributaries (Table 6.2). Temperature records for Ballantyne Road suggest that surface flow ceased at this site in mid-late December, while the temperature record at SH6 was consistent with groundwater dominance moderating instream temperature fluctuations from 5 December 2015 to 2 January 2016. The logger was dry at this site from 2 January 2016.

From the continuous record of temperature from each site (recorded at 15-minute intervals), maximum two-hour and weekly moving averages were calculated for each period for comparison, with thermal criteria for the protection of fish species recorded from the Cardrona catchment, as well as a common mayfly (Table 6.2).

Brown trout (*Salmo trutta*) and rainbow trout (*Onchyrhynchus mykiss*) are likely to be the fish species most sensitive to high water temperatures in the Cardrona River, and their thermal requirements are relatively well understood. Todd *et al*. (2008) calculated acute and chronic thermal criteria for both of these species, with acute criteria applied as the highest two-hour average water temperature measured within any 24-hour period, while chronic criteria are expressed as the maximum weekly average temperature (Todd *et al*. 2008).

Most native fish species are more tolerant of high temperatures than trout. Olsen *et al*. (2012) developed interim thermal criteria for native species for which there was sufficient information. No acute criteria are available for the native fish species present in the Cardrona River, but chronic thermal criteria were available for longfin eels (34ºC for adults, 28ºC for elvers (juveniles)) and common bully (24ºC in upland sites) (Olsen *et al*. 2012). Temperature records from the Cardrona catchment suggest water temperatures do not reach levels that are likely to affect these native fish species detrimentally (Table 6.2).

The common mayfly, *Deleatidium*, which is usually the most abundant macroinvertebrate species in the Cardrona River (Section 6.6) are likely to be more sensitive to high temperatures than any of the fish species present. Therefore, the suitability of the temperatures observed in the Cardrona catchment for *Deleatidium* was also considered (Table 6.2).

Water temperatures in the main stem of the Cardrona at Mount Barker, SH6 and the Clutha confluence were suitable for all fish species considered, but exceeded the acute thermal criterion for *Deleatidium* at times (Table 6.2). Water temperatures at Ballantyne Road exceeded acute thermal criteria for brown and rainbow trout and *Deleatidium* before surface flows ceased in January 2016 (Table 6.2).

Water temperatures observed in Deep Creek, Spotts Creek and Boundary Creek during the period temperature loggers were deployed and were suitable for all species considered (Table 6.2). However, water temperatures observed in the Branch Burn exceed acute thermal criteria for rainbow trout, brown trout and *Deleatidium* and chronic criteria for rainbow and brown trout (Table 6.2).

Table 6.2 **Summary of continuous water-temperature records from four sites in the lower Cardrona River and four tributaries. Included are the maximum 2-h average temperature, weekly average temperature and the number of days in excess of acute and chronic criteria for the protection of sensitive aquatic species**

Site	Start date	End date	Length of record (days)	Max 2-h average (°C)	Weekly average (°C)	Number of days exceeding thermal criteria				
						Acute (max. 2-h average)			Chronic (weekly average)	
						Rainbow trout 23.8°C	Brown trout 24.6°C	*Deleatidium* (mayfly) 21°C	Rainbow trout 18.2°C	Brown trout 19.6°C
Cardrona at Mt Barker	7/10/2015	17/03/2016	162	23.4	17.7	-	-	28	-	-
Cardrona at Ballantyne Road	13/11/2015	19/12/2015	36	25.9	16.5	5	1	15	-	-
Cardrona at SH6	7/10/2015	2/01/2016	88	21.6	14.3	-	-	3	-	-
Cardrona at Clutha confluence	3/04/2008	5/02/2014	779	22.4	15.6	-	-	4	-	-
Cardrona at Clutha confluence	7/10/2015	2/03/2016	147	19.7	14.7	-	-	-	-	-
Boundary Creek at Top Race u/s	17/09/2015	3/03/2016	168	16.5	12.0	-	-	-	-	-
Branch Burn at Cardrona Valley	11/08/2015	3/03/2016	205	26.3	19.7	10	16	33	16	2
Deep Creek at Cardrona Valley	28/07/2015	3/03/2016	219	19.6	15.6	-	-	-	-	-
Spotts Creek at Race Intake u/s	13/11/2015	3/03/2016	111	20.6	15.7	-	-	-	-	-

6.3. Catchment water quality survey

6.3.1. Nitrogen

TN concentrations were very low at the upper sites in the Cardrona catchment and increased with distance downstream, with the highest concentrations observed downstream of the SH6 bridge (Figure 6.2). Generally, whether considering low flows or all flows, these patterns were similar, although TN concentrations were much lower during low flows at most sites (Figure 6.2). At the tributary sites, TN concentrations in Boundary Creek and the Branch Burn were low, but substantially higher concentrations were observed in Spotts Creek (Figure 6.2).

NNN showed similar patterns to TN; NNN was low in the upper Cardrona River and in the Boundary Creek and Branch Burn monitoring sites and increased with distance downstream, with the highest concentrations observed at the two most downstream main-stem sites and in Spotts Creek (Figure 6.3). The increase in NNN concentrations from the SH6 bridge downstream was particularly evident during periods of low flow (Figure 6.3), a time when groundwater inflows would have been the primary or only source of baseflow.

Concentrations of NH_4-N were very low at all sites on all occasions (Figure 6.4).

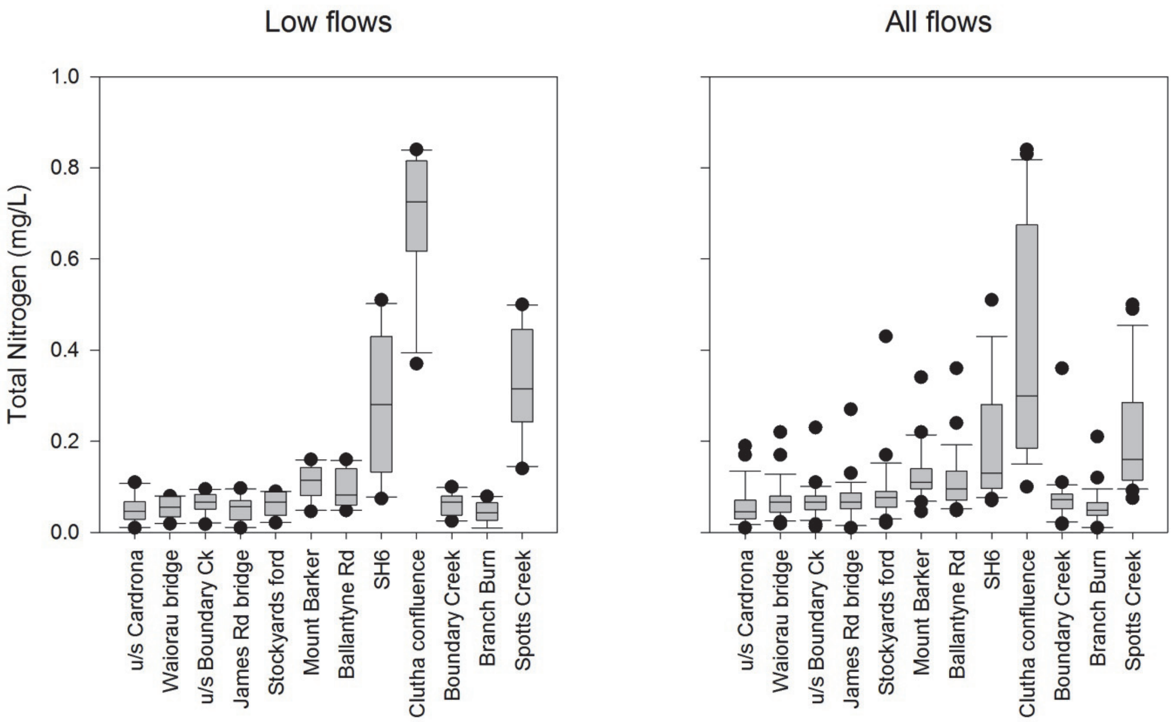

Figure 6.2 **TN concentrations in the Cardrona River and tributaries under all flows and low flows**

Schedule 15 of the RPW sets out water-quality limits for receiving waters in the Otago region (Table 4.1). These limits apply as five-year, 80th percentiles, when flows are at or below the reference flow in Table 16B of Plan Change 6a (1,950 l/s at Mount Barker for the Cardrona catchment). Ten sampling occasions coincided with periods when flows were below median flow between 18 September 2014 and 14 September 2015 and compared to the Schedule 15 limits of 0.075 mg/L NNN. The 80th percentiles of NNN concentrations at the SH6 bridge (0.380 mg/l), Clutha confluence (0.752 mg/l) and Spotts Creek (0.342 mg/l) exceeded the limit, values for Mount Barker (0.696 mg/l) and Ballantyne Road (0.059 mg/l) approached the limit, while the 80th percentile of concentrations at sites upstream of the Stockyards Ford site (0.002 – 0.020 mg/l) were well below the Schedule 15 limit (Figure 6.3). Concentrations of NH_4-N at all sites were well below the Schedule 15 limit (Figure 6.4).

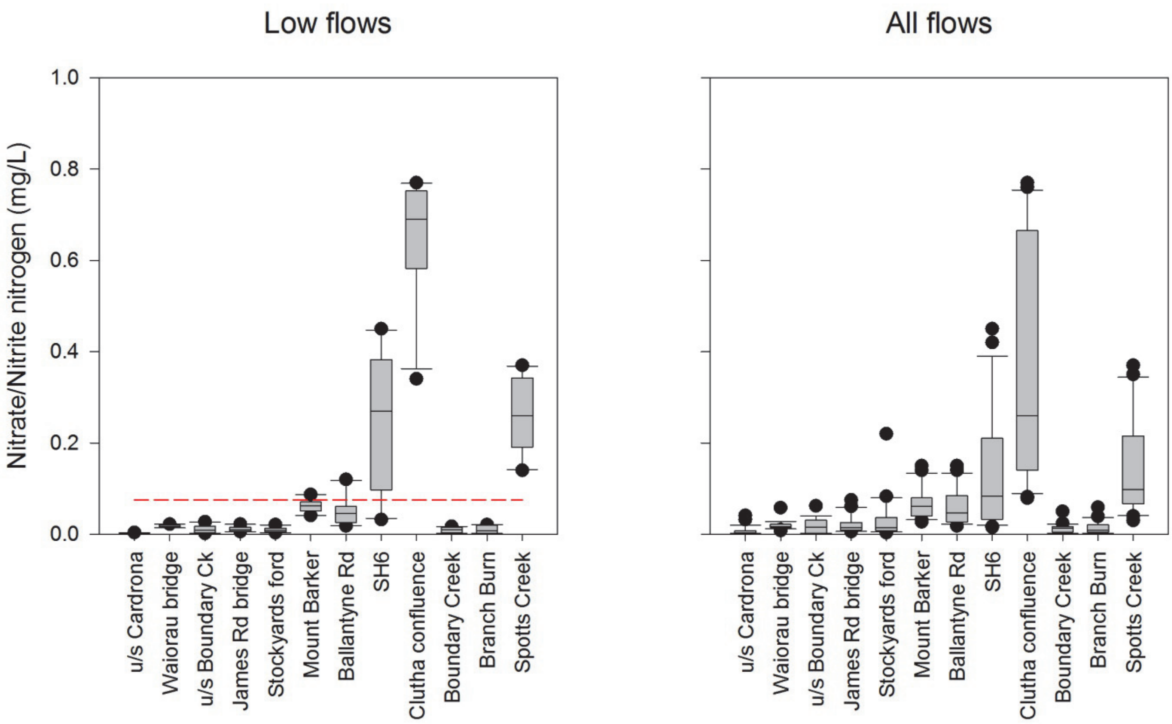

Figure 6.3 **NNN concentrations in the Cardrona River and tributaries under all flows and low flows. The red line represents the Schedule 15 limit from Plan Change 6a.**

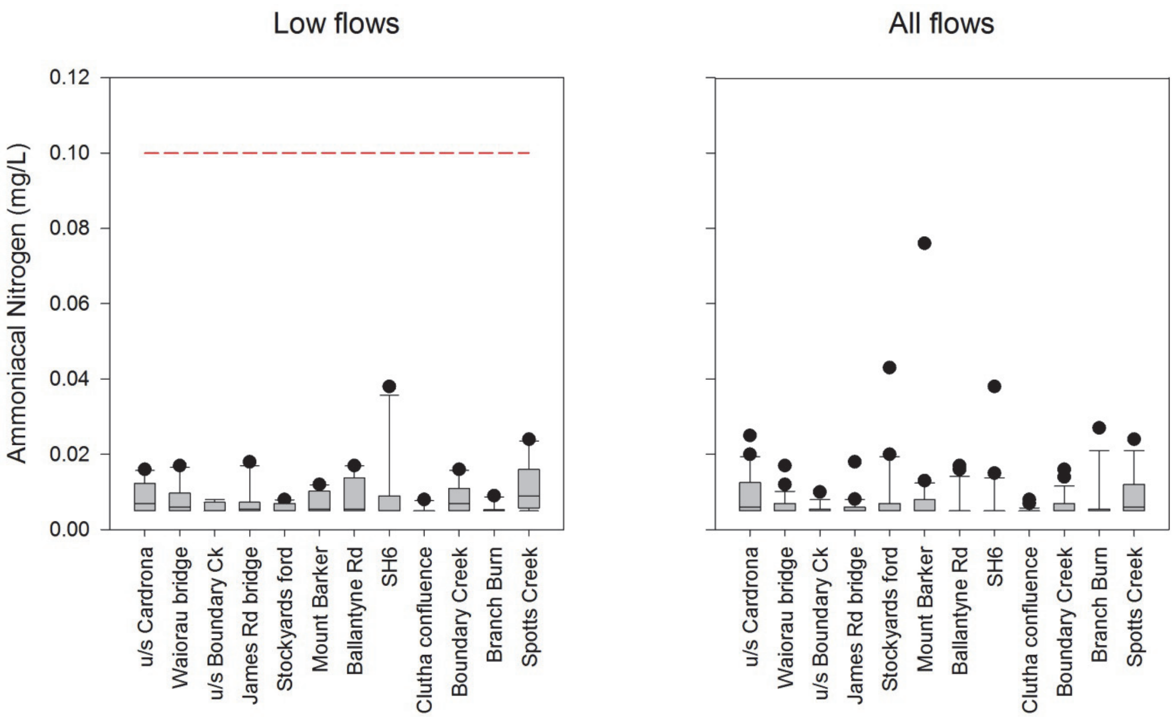

Figure 6.4 **NH_4-N concentrations in the Cardrona River and tributaries under all flows and low flows. The red line represents the Schedule 15 limit from Plan Change 6a.**

6.3.2. Phosphorus

TP and DRP concentrations were consistently low at all the sites sampled throughout the Cardrona catchment, particularly at low flows (Figure 6.5, Figure 6.6). As a consequence, the 80th percentiles of DRP readings at all sites were within the Schedule 15 limit (Figure 6.6).

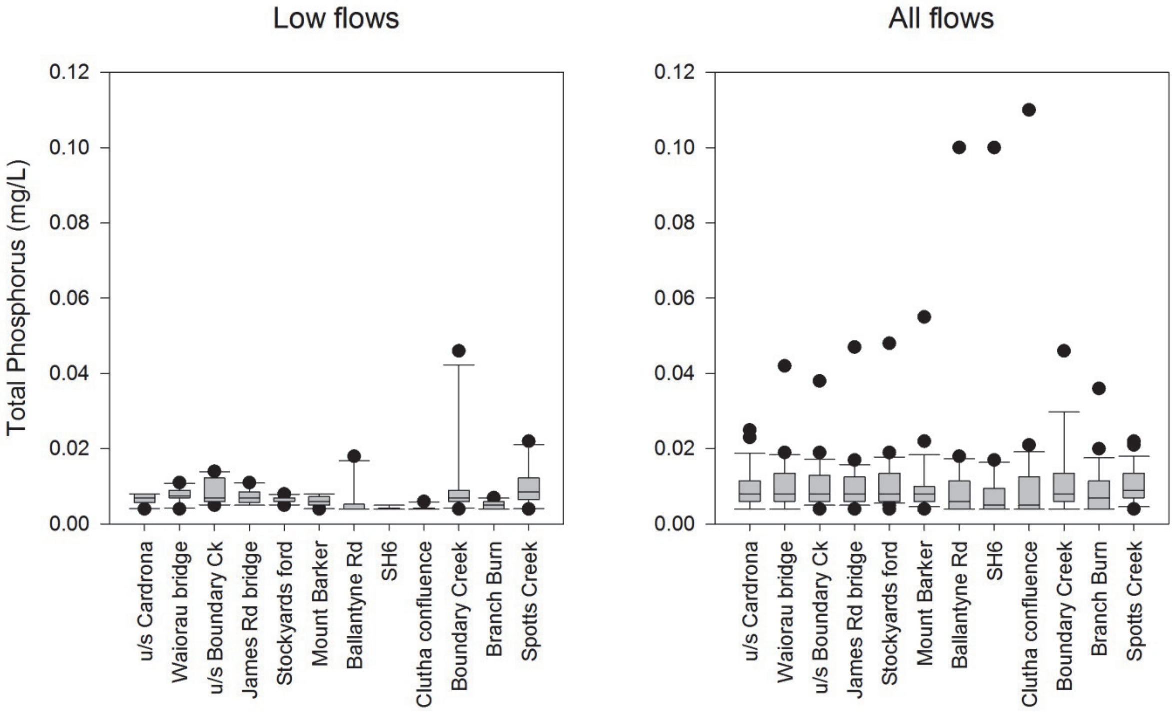

Figure 6.5 **TP concentrations in the Cardrona River and tributaries under all flows and low flows**

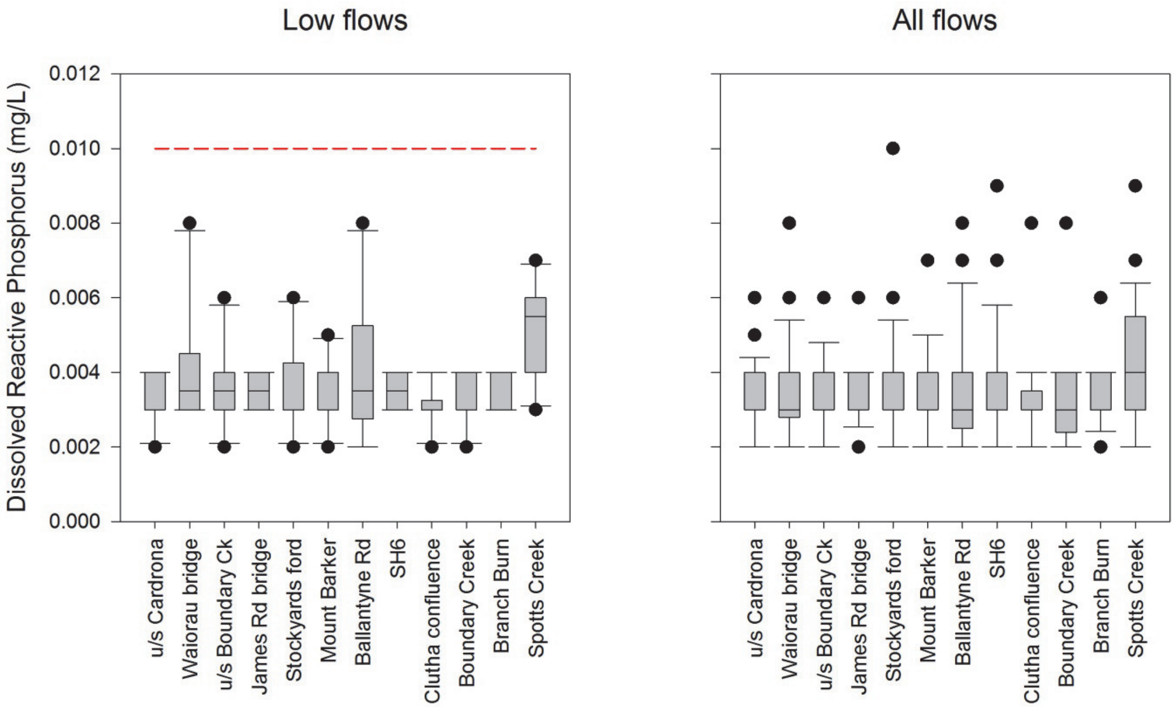

Figure 6.6 **DRP concentrations in the Cardrona River and tributaries under all flows and low flows. The red line represents the Schedule 15 limit from Plan Change 6a.**

6.3.3. Escherichia coli

Concentrations of *E. coli* were low across all sites in the Cardrona catchment, with the 80th percentiles during low flows well within the Schedule 15 limits for *E. coli* at all sites. The exception was Spotts Creek that returned an 80th percentile value of 372 cfu/100 ml (Figure 6.7).

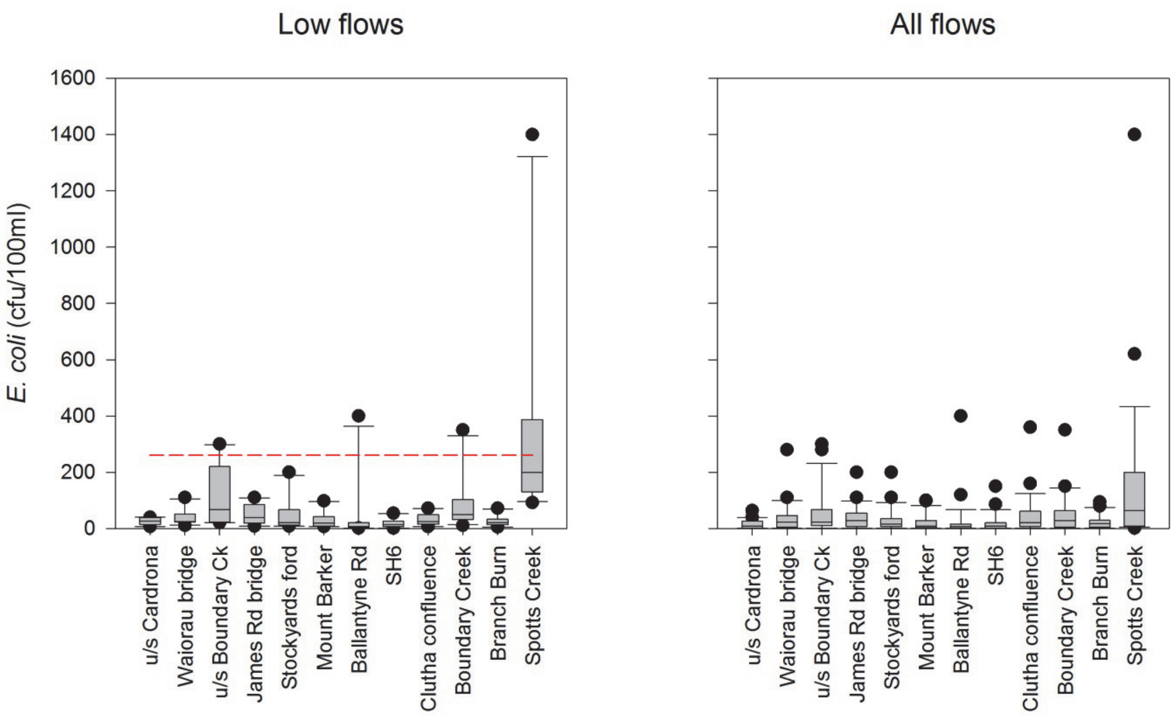

Figure 6.7 ***E. coli*** **concentration in the Cardrona River and tributaries under all flows and low flows. The red line represents the Schedule 15 limit from Plan Change 6a.**

6.4. Habitat assessments

6.4.1. Riparian vegetation

The riparian vegetation at all sites was dominated by *Salix* species (willows), exotic pasture grasses and *Lupinus polyphyllus* (lupins). Most sites were not fenced from surrounding farmland, and stock generally had access to the stream channel.

6.4.2. Substrate composition

The riffles and runs of most sites were dominated by coarse gravels (8-64 mm) (Table 6.3). However, riffles at the site upstream of Boundary Creek had similar proportions of coarse and fine gravels (2-8 mm) and runs at both SH6 and the Clutha confluence were dominated by fine gravels (Table 6.3).

Table 6.3 Substrate composition (% cover) at the eight sites in the Cardrona catchment on 22 October 2014

		Boulder >256 mm	Cobble 64-256 mm	Coarse gravel 16-64 mm	Fine gravel 2-16 mm	Fines <2 mm
Riffle	u/s Cardrona	0	37	45	16	3
	Waiorau bridge	18	33	44	7	0
	u/s Boundary Creek	5	28	33	34	0
	Stockyards Ford	0	23	72	6	0
	Mount Barker	0	24	66	10	0
	Ballantyne Road	0	15	82	4	0
	SH6	0	0	60	40	0
	Clutha confluence	0	17	56	26	1
Run	u/s Cardrona	-	-	-	-	-
	Waiorau bridge	-	-	-	-	-
	u/s Boundary Creek	4	13	51	30	2
	Stockyards Ford	0	0	100	0	0
	Mount Barker	0	13	51	36	0
	Ballantyne Road	0	19	66	15	0
	SH6	0	6	24	71	0
	Clutha confluence	0	5	25	69	1

6.5. Periphyton

6.5.1. Long-term monitoring

Periphyton community composition was monitored at the Waiorau Road bridge on one occasion in 2001. At the Mount Barker monitoring site, periphyton community composition has been monitored annually since 2001 (Table 6.4).

Cyanobacteria dominated the periphyton community at the Mount Barker monitoring site in 2003, 2008, 2009, 2011 and 2014, while diatoms were dominant in 2002, 2006 and 2012. Filamentous green algae dominated in 2001 and 2010 (Table 6.4). The periphyton community at the Waiorau Road bridge was dominated by the stalked diatom *Gomphonema* in 2001 (Table 6.4).

The method used in long-term monitoring is based on scrapes of three stones at each site (total area 75 cm^2) and is unlikely to provide a reliable estimate of the community composition of periphyton across the entire stream bed at each site.

Table 6.4 **Periphyton taxa collected at two sites in the Cardrona River as part of the SoE monitoring programme. Abundance codes are based on Biggs & Kilroy (2000): 1 = rare, 2 = rare-occasional, 3 = occasional, 4 = occasional-common, 5 = common, 6 = common-abundant, 7 = abundant, 8 = dominant.**

Site	Cardrona @ Waiorau Rd Br	Cardrona @ Mt Barker												
Code	**7/03/2001**	**7/03/2001**	**2002**	**12/03/2003**	**2004**	**6/02/2006**	**16/01/2007**	**18/04/2008**	**2/04/2009**	**7/02/2010**	**15/03/2011**	**8/02/2012**	**13/03/2013**	**12/02/2014**
Green filamentous														
Chaetophora												2		
Microspora						6								
Mougeotia sp.					3				3					
Oedogonium			3							8				
Spirogyra		8	2											
Stigeoclonium			5											2
Ulothrix						4								
Green, non-filamentous														
Ankistrodesmus										2				
Gloecystis	3													
Scenedesmus										3				
Filamentous Red Algae														
Audouinella						3							2	4
Diatoms														
Achnanthidium		3												
Cocconeis							2			2				
Cymbella			6	4	4	6	2	2			2			
Diatoma										1				
Didymosphenia geminata								3	3	8		6		2
Encyonema		4	8	3	4					5				
Frustulia						5		1	2	3	2	4		
Gomphoneis		5	7	2			2		4	4		4		2
Gomphonema	7		4	2		4				5			2	
Melosira							2			4	2	2		2
Navicula										3				
Naviculoid diatom						4		1	3		3		1	
Nitzschia			5		3	3				4	2	3	3	
Pinnularia							2				1	1		
Reimeria										2				
Rossithidium										3				
Synedra		3		2	4	3	1			3	2	4	1	
Cyanobacteria														
Oscillatoria/Phormidium			5	8		3		7	6		6			
cf. *Merismopedia*				2										
cf. *Lyngbya*					8									
Rivularia							4						3	5

6.5.2. 2014/2015 catchment survey

Periphyton communities in the Cardrona River were surveyed on five occasions between October 2014 and March 2015. Flows over this time were generally receding from a series of winter high-flow events, with some minor variability in flow associated with rainfall events occurring during the sample period (Figure 6.8). High-flow events in June and August were in excess of three times the median flow (referred to as the 'FRE3'), the magnitude of flows generally considered to be effective at flushing periphyton from the river bed (Clausen & Biggs 1997, 1998). The corresponding FRE3 flow in the Cardrona River at Mount Barker is 6,894 l/s. Two short-lived, high-flow events greater than the FRE3 threshold occurred in November 2014 after the high-flow event of August 2014 (peak flow ~74,000 l/s), with flows dropping to low-flow levels (<1000 l/s) by February 2015 and remaining at these levels for the remainder of the study period (Figure 6.8). Given the relatively stable and low flows in the Cardrona River from October 2014, these surveys present an opportunity to consider periphyton accrual (biomass gain) over a period of more than 130 days, which represents an extended biomass-accrual period.

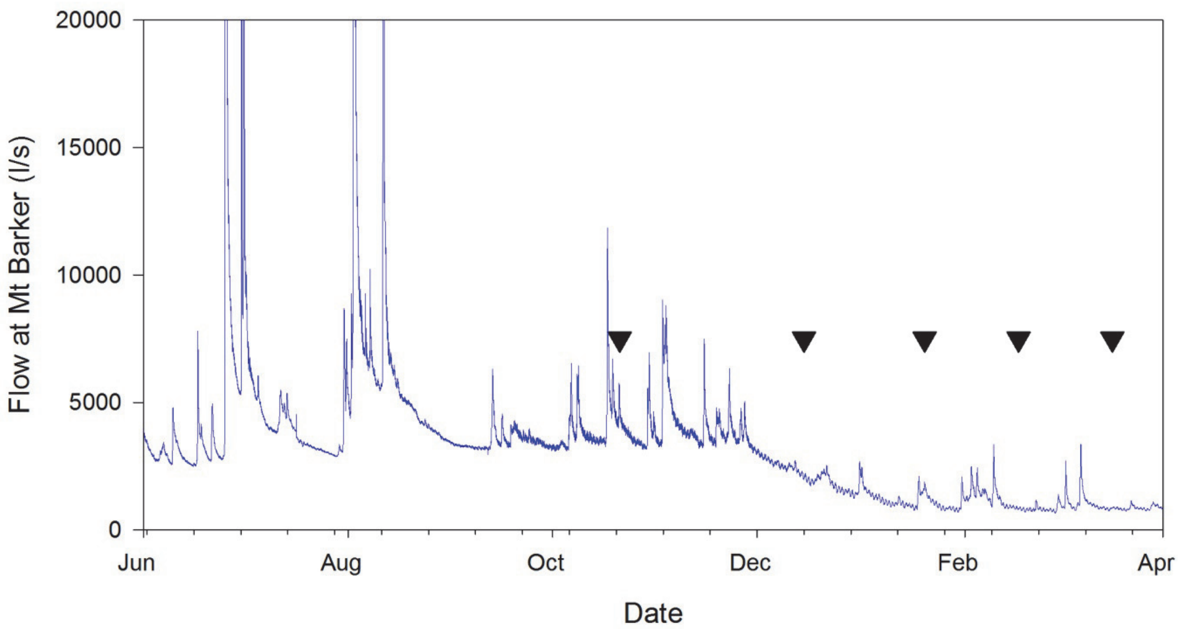

Figure 6.8 **Flows in the Cardrona River at Mount Barker during and before periphyton surveys undertaken as part of this study. The black triangles represent periphyton survey dates.**

The periphyton community at monitoring sites upstream of Ballantyne Road were generally sparse, with thin green or light brown (diatom-dominated) films dominating, although the invasive, stalked diatom, didymo, dominated the periphyton community at the Waiorau bridge, upstream of Boundary Creek and at the Stockyards Ford on some sampling occasions (Table 6.5). Didymo was observed at all sites during the course of this study (Table 6.5).

The periphyton community at the SH6 bridge was sparse on the October and December sampling occasions but was dominated by long, filamentous green algae in January, while diatoms dominated in February and March (Table 6.5)

The periphyton community at the Clutha confluence was also sparse on most occasions, with little or no periphyton present in the October, December and January sampling occasions. Thin films of diatoms and some didymo were present in February, and a mix of short, filamentous green algae and didymo were present in March (Table 6.5).

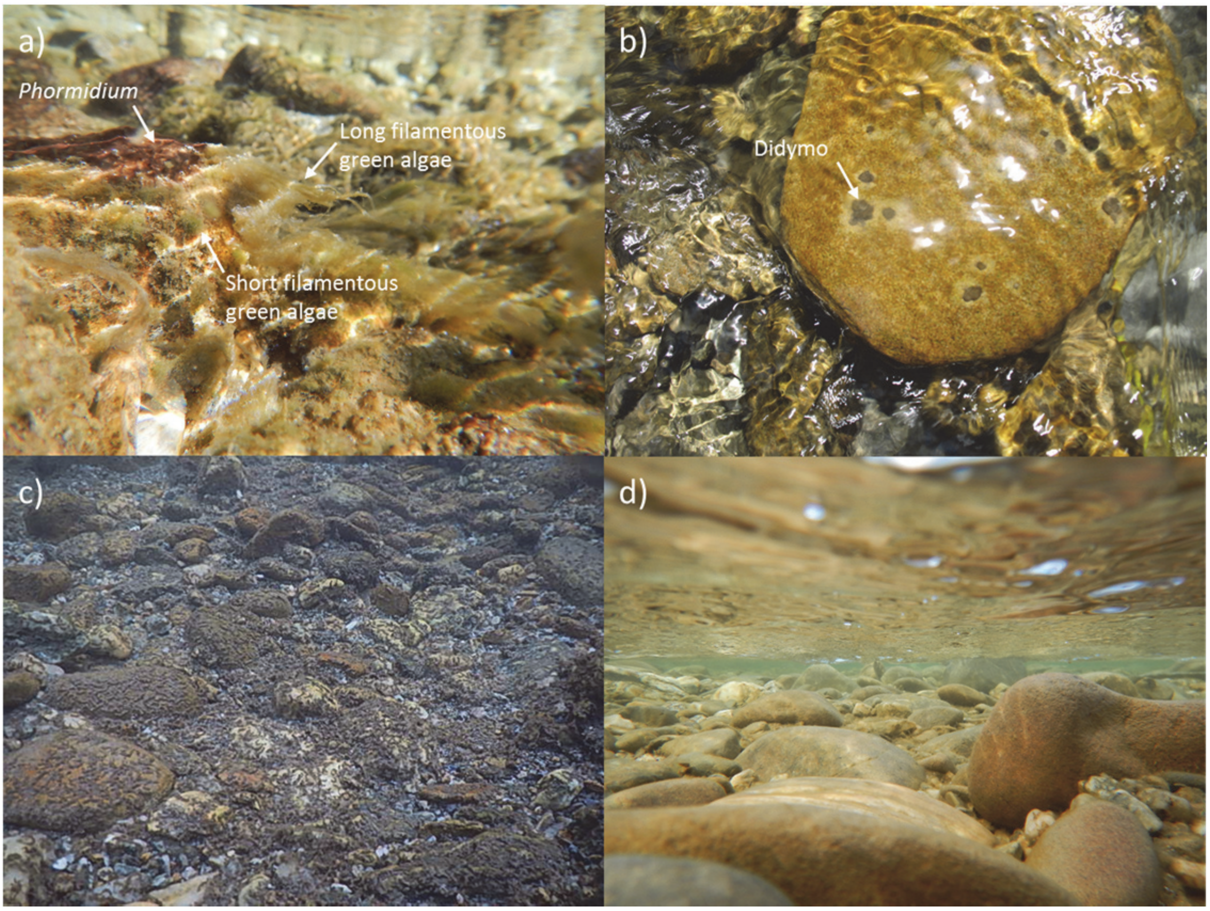

Figure 6.9 **Underwater photographs of periphyton types commonly observed in the Cardrona River. a) Thick cyanobacterial mat (*Phormidium*), and short and long, filamentous green algae, b) small colonies of didymo (*Didymosphemia geminata*), c) fine sediment coating loose, unconsolidated algae and chironomid (midge) tubes and d) bare stones, with no visible periphyton**

Over the course of this study, the highest chlorophyll-*a* concentrations were observed at the Waiorau bridge and SH6 bridge monitoring sites (Table 6.5). The chlorophyll-*a* concentrations observed at the Waiorau bridge were significantly higher than upstream of Cardrona (P=0.008), Stockyard Ford (P=0.02), Mount Barker (P=0.01) and Ballantyne Road (P=0.01) monitoring sites, while concentrations observed upstream of Boundary Creek were significantly higher than upstream of Cardrona (P=0.04) and Ballantyne Road (P=0.04).

Concentrations at the Stockyards Ford were significantly higher than upstream of Cardrona (P=0.02), Mount Barker (P=0.02) and Ballantyne Road (P=0.02) (Table 6.5, paired t-tests).

Chlorophyll-*a* concentrations at most sites in the Cardrona were well within the maximum chlorophyll-*a* biomass to protect benthic biodiversity on all occasions (50 mg/m^2, Biggs 2000) (Table 6.5, Figure 6.10). Chlorophyll-*a* concentrations at two sites (Waiorau bridge in February and upstream Boundary Creek in March) exceeded 50 mg/m^2 on one occasion, while concentrations at the SH6 bridge exceeded it on two occasions (January and March) (Table 6.5, Figure 6.10). The high values measured at the Waiorau bridge and upstream of Boundary Creek were associated with a community dominated by didymo, while the March value at the SH6 bridge was associated with long, filamentous algae, diatoms and unconsolidated algae (Table 6.5).

The high concentration of chlorophyll *a* observed at the SH6 bridge in January (127 mg/m^2) was associated with a community dominated by filamentous green algae (Table 6.5). This value exceeded the guideline value for the maximum chlorophyll-*a* biomass to protect trout angling and habitat and aesthetics and recreation (120 mg/m^2 for filamentous algae) (Biggs 2000). However, the chlorophyll-*a* biomass at all other sites on all occasions (except the SH6 bridge site in January) was well within these guideline values (Table 6.5).

Chlorophyll-*a* concentrations generally increased at all sites over the study period, although concentrations dropped between December and January at the Waiorau bridge and between January and February at the SH6 bridge (Figure 6.10). The reduction at the Waiorau bridge may have been a result of reduced cover by didymo between these occasions (Table 6.5). The marked reduction in chlorophyll *a* at the SH6 bridge probably reflected the decline in long, filamentous green algae between these sampling occasions (Table 6.5).

Long (>2 cm), filamentous algae cover was generally low at most sites, with a slight increase in cover in March at the site upstream of Cardrona, Waiorau bridge and Clutha confluence (Table 6.5). The highest cover by long, filamentous algae occurred at the SH6 bridge and the maximum recorded cover at this site exceeded guideline levels (30% cover) (Table 6.5, Figure 6.11).

The percentage of the bed covered by other periphyton types (including unconsolidated algae, medium and thick mats, didymo and short, (<2 cm) filamentous algae) was well within guideline levels (60% total cover) at most sites on most occasions, but reached the guideline value at the SH6 bridge site in March (Figure 6.11). Periphyton cover at this site was mixed with green and light brown (diatom-dominated) mats, unconsolidated algae and the cyanobacterium, *Phormidium*, the most abundant periphyton types on this occasion (Table 6.5).

Table 6.5 Composition of the periphyton communities at eight sites on the Cardrona River over the period October 2014-April 2015. The dominant periphyton type(s) on each occasion are highlighted in bold. P = present (>5% cover)

		Thin mat/film (<0.5 mm thick)			Sludge	Medium mat (0.5 – 3 mm thick)				Thick mat (>3 mm thick)		Didymo mat	Short filaments (>1 cm, <2 cm long)	Long filaments (>2 cm long)	Chlorophyll *a*
Site	**Date**	Green	Light brown	Black/dark brown	Unconsolidated algae	Green	Light brown	Bobbles (*Nostoc*)	Black/dark brown	Green/light brown	Black/dark brown	Brown to white	Green	Green	mg/m²
Cardrona upstream of Cardrona	22-Oct-14		**40**									P			1
	16-Dec-14	**15**	12			P	P	P				P	P	P	3
	21-Jan-15	17	**38**		P	P						P		P	2
	18-Feb-15	**11**	P									P			7
	18-Mar-15	**17**	P			14				P		8		6	8
Cardrona at Waiorau bridge	22-Oct-14	P	**33**			7			P					P	10
	16-Dec-14	P	5						P			**44**	P	P	29
	21-Jan-15	P	5		**39**				P			P			22
	18-Feb-15	P	16							P		**21**			**57**
	18-Mar-15	P					**26**					P		12	44
Cardrona upstream of Boundary Creek	22-Oct-14		**22**									P	P		5
	16-Dec-14				5	P	P					**19**	P		12
	21-Jan-15	**18**	P		9							P			10
	18-Feb-15	P	P		**12**				P			6			29
	18-Mar-15					P	10				P	**24**		P	**54**
Cardrona at Stockyard ford	22-Oct-14		**20**										P		3
	16-Dec-14		P									6	P		5
	21-Jan-15	**44**			P				P			P	P	P	18
	18-Feb-15	6	5	P	5							**11**			16
	18-Mar-15		P			P	P		P			6		P	21
Cardrona at Mount Barker	22-Oct-14		P												1
	16-Dec-14											P			1
	21-Jan-15		**35**	P						P		P		P	8
	18-Feb-15	**25**	6	6		P			P	P	P	P			9
	18-Mar-15		**18**												4
Cardrona at Ballantyne Road	22-Oct-14	**18**	**17**												4
	16-Dec-14											P			1
	21-Jan-15		P									P		P	1
	18-Feb-15		**100**									P			1
	18-Mar-15		**74**									P			5
Cardrona at SH6	22-Oct-14		P												1
	16-Dec-14											P		P	1
	21-Jan-15		P						P		P		10	**41**	**127**
	18-Feb-15	7	**45**	P		P	14		9	11			P		38
	18-Mar-15	P	P	7	10	10	**17**		P	9	5		P	13	**69**
Cardrona at Clutha confluence	22-Oct-14														0
	16-Dec-14											P	P	P	1
	21-Jan-15	P	**8**		P				P			P	P	P	22
	18-Feb-15	5	**22**						P			8			20
	18-Mar-15	P										11	**13**	6	46

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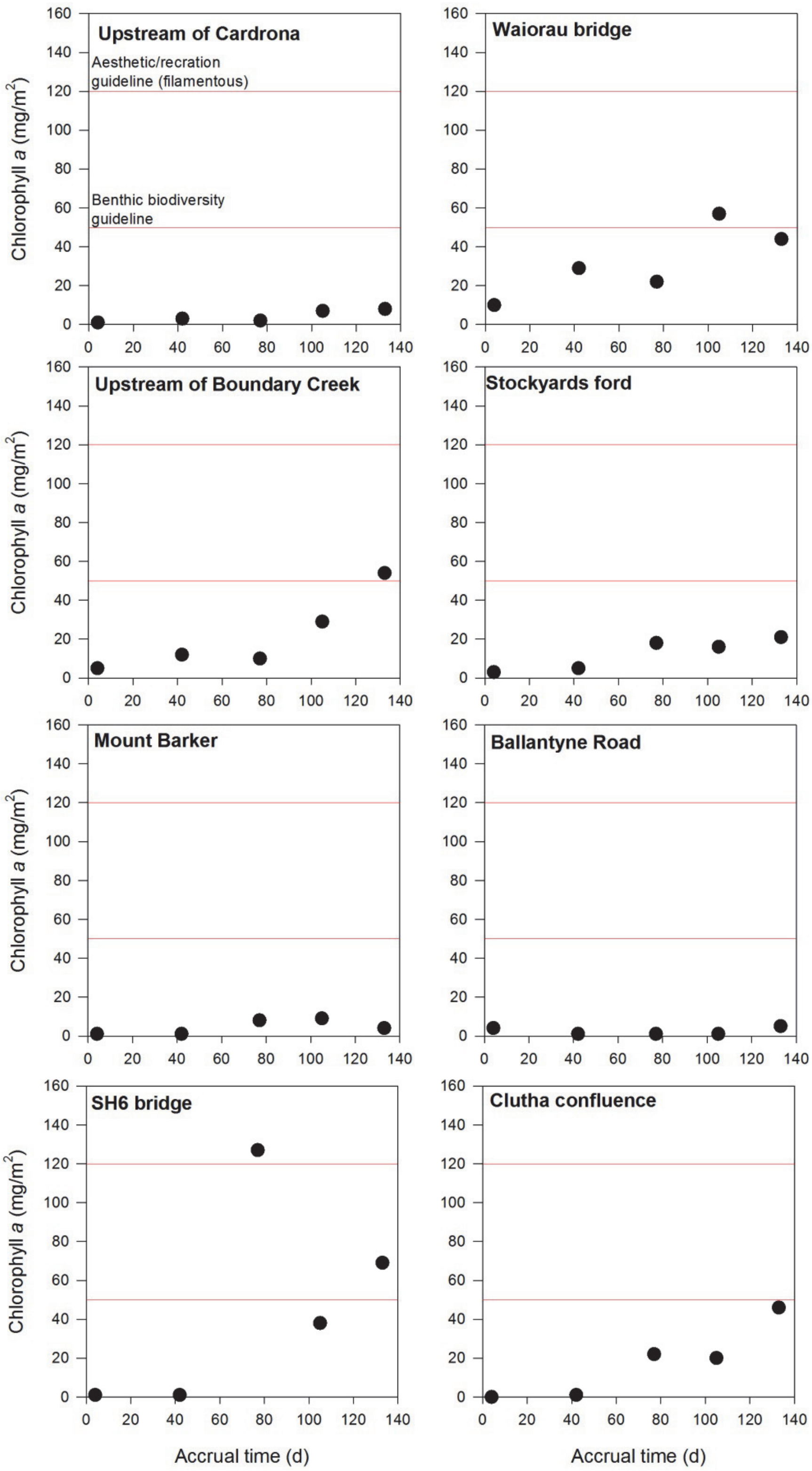

Figure 6.10 **Chlorophyll-*a* concentrations over time (accrual time since the last high-flow event) at six sites in the Cardrona River. Red lines represent provisional national periphyton biomass guidelines for the protection of benthic biodiversity (50 mg/m^2) and aesthetics/recreaton for filamentous algae (120 mg/m^2).**

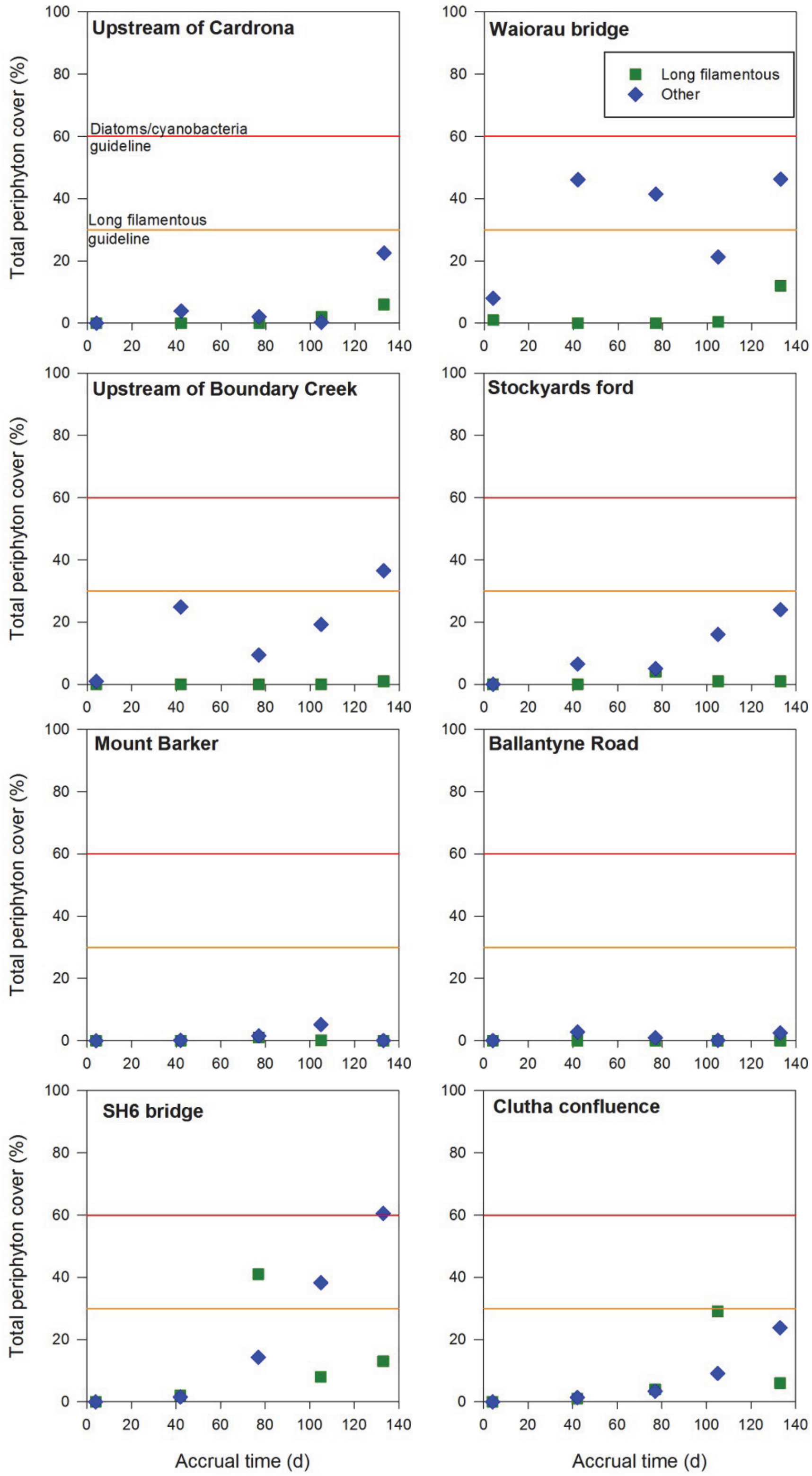

Figure 6.11 **Cover of long, filamentous algae (green points) and other periphyton (blue points) over time (accrual time since the last high-flow event) at six sites in the Cardrona River. The red lines represent provisional national periphyton cover guidelines for long, filamentous algae (30%) and diatoms/cyanobacteria (60%).**

6.6. Macroinvertebrates

6.6.1. Long-term monitoring

Macroinvertebrate samples have been collected from the Waiorau Road bridge in 2001 and annually from Mount Barker since 2001 to the present. Larvae of the common mayfly, *Deleatidium*, were the most abundant macroinvertebrates at the Mount Barker site on ten of the fourteen sampling occasions (Table 6.6). Riffle beetles (Elmidae) were the most abundant species on six of the 14 sampling occasions (2001, 2006-2010). Other taxa that have occasionally been abundant are the net-spinning caddisfly, *Aoteapsyche*, and the cased caddis fly, Pycnocentrodes (Table 6.6).

Macroinvertebrate metrics provide a measure of long-term water and habitat quality in a waterway. The %EPTtaxa ranged from 23-60% over the 14 years of macroinvertebrate sampling at the Mount Barker site, and is within the expected range for a rain-fed stream. There was no evidence of a trend in %EPTtaxa at this site over this period (Figure 6.12, Table 6.7). MCI scores ranged from 96 to 120 at Mount Barker, indicating that generally water quality is good (using the criteria in Table 5.2), and no trend in MCI scores was detected (Figure 6.12, Table 6.7). SQMCI scores ranged widely (5.12 - 7.38), probably as a result of the variability in the abundance of chironomid midges (Chironominae, Orthocladiinae or Tanytarsini) (Table 6.6), and, similar to %EPTtaxa and MCI, no trend in SQMCI scores was apparent between 2001 and 2015 (Figure 6.12, Table 6.7).

Table 6.6 **Macroinvertebrate taxa collected from the Cardrona River as part of SoE monitoring. Only taxa that were abundant on one occasion or more are shown. See Appendix B for the full table. Relative abundance scores: R = rare (1-4 individuals), C = common (5-19 individuals), A = abundant (20-99 individuals), VA = very abundant (100-499 individuals), VVA = very, very abundant (500+ individuals)**

Taxa	MCI Score	Cardrona at Waiorau	Cardrona River at Mount Barker													
		7/03/2001	7/03/2001	2002	12/03/2003	2004	6/02/2006	16/01/2007	18/04/2008	2/04/2009	7/02/2010	15/03/2011	8/02/2012	13/03/2013	12/02/2014	14/01/2015
COLEOPTERA																
Elmidae	6	A	VVA	VA	A	A	VVA	VVA	VVA	VVA	VVA	C	C	A	C	C
DIPTERA																
Austrosimulium	3				C			C	A	R		A		C	C	A
Chironominae	2				A	R	VA		C			C				
Eriopterini	9		C	C	A	A	C	C	A	A	A	R	R	C	C	R
Maoridiamesa	3		A	C			A			R	R	R	C	R	C	
Orthocladiinae	2	R	VA	VA	A	C	VA		C	R	A	C	A	C	C	C
Tanytarsini	3										VA		A		C	C
EPHEMEROPTERA																
Deleatidium	8	A	VVA	VVA	VA	VA	VA	A	VA	VVA	VA	VVA	VA	VA	VA	VA
OLIGOCHAETA	1	R	R	C	A	C	A	C	A	A	R	C	A	R	C	R
PLECOPTERA																
Zelandobius	5	A	A	C		R				A	A	C				
TRICHOPTERA																
Aoteapsyche	4	R	R	C	A	A	A		A	A	VA	A	A	A	A	C
Costachorema xanthopterum	7									R		R		R	R	
Hudsonema	6	R	R						C					R	R	
Hydrobiosidae early instar	5			A	A	R	C	R	C	R	C		R			
Hydrobiosis	5	R	C	C		R	R	R	C	R	R		C	R		R
Neurochorema forsteri	6				R											
Olinga	9										C	R		A	C	R
Oxyethira albiceps	2			C							C					
Plectrocnemia maclachlani	8												R			R
Psilochorema	8	R	R		C	C	C	C	A	C	C	R	R		R	
Pycnocentrodes	5				R	C	C	A	VVA	A	VA	A	R	C	C	R
Pycnocentria	7		R	C					A	C				C	R	
Taxonomic richness		**9**	**12**	**12**	**12**	13	**12**	**9**	**14**	**15**	**15**	**14**	**13**	**14**	**15**	**13**
EPT richness		**6**	**7**	**6**	**6**	7	**6**	**5**	**8**	**9**	**8**	**7**	**7**	**8**	**8**	**6**
%EPT richness		**67%**	**58%**	**50%**	**50%**	23%	**50%**	**56%**	**57%**	**60%**	**53%**	**50%**	**54%**	**57%**	**53%**	**54%**
MCI		**118**	**120**	**101**	**104**	108	**100**	**111**	**101**	**101**	**96**	**108**	**101**	**106**	**109**	**111**
SQMCI		**6.41**	**6.46**	**6.69**	**5.74**	6.96	**5.12**	**6.01**	**5.66**	**6.79**	**5.51**	**7.38**	**5.51**	**6.99**	**6.56**	**6.70**

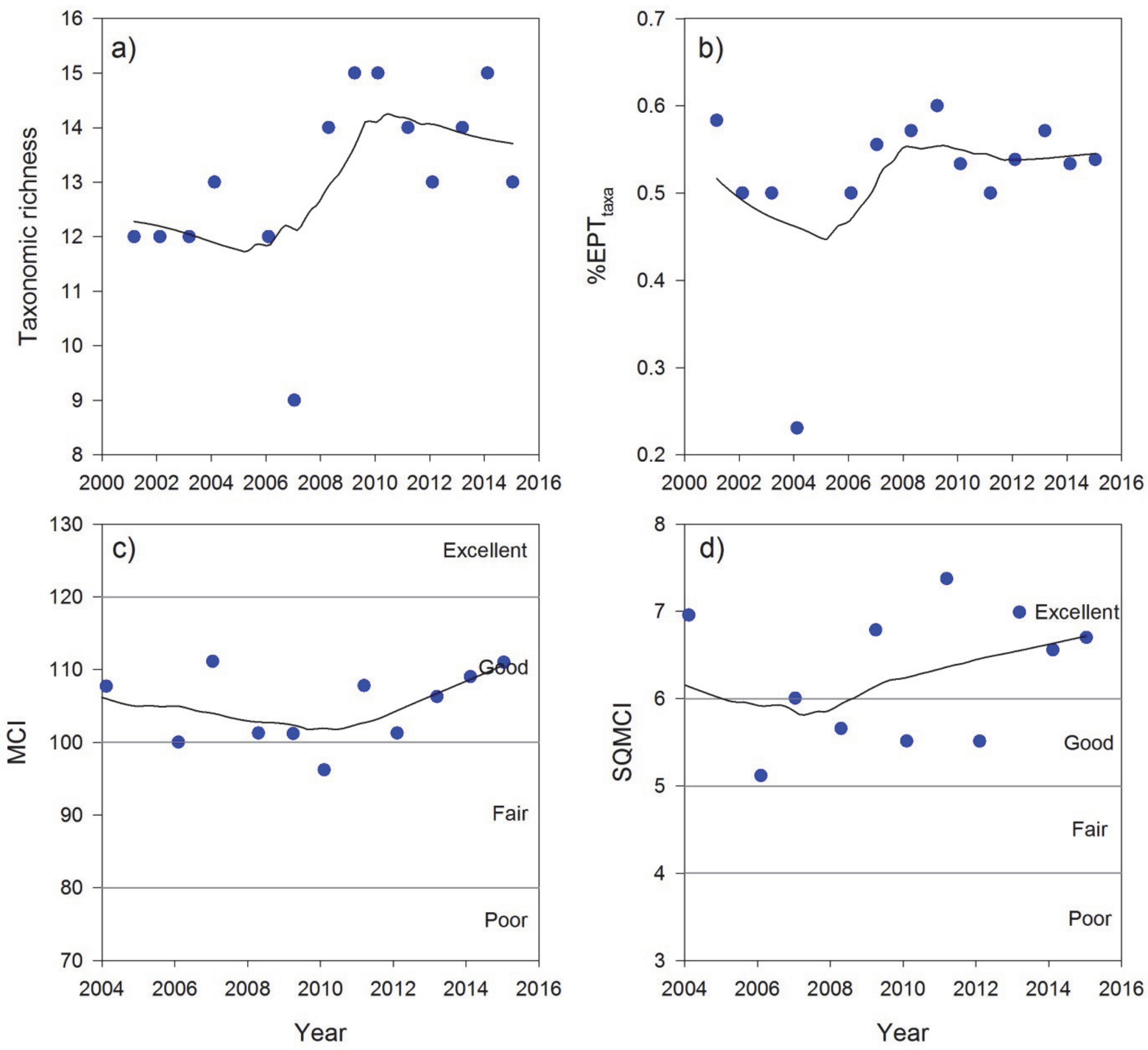

Figure 6.12 **Macroinvertebrate metrics in the Cardrona River at the Mount Barker SoE site between 2001-2015. a) Taxonomic richness, b) %EPT richness, c) MCI and d) SQMCI. Fitted lines (black) are loess curves (tension = 0.6). Horizontal grey lines in parts c) and d) represent the water-quality classes for MCI and SQMCI in Table 5.2.**

Table 6.7 **Summary of trend analyses for macroinvertebrate metrics for the Cardrona River at the Mount Barker SoE site between 2001 and 2015. N.s. = not significant**

Metric	*Z*	*P*	Trend
Taxonomic richness	1.98	0.05	Positive
%EPT	0.72	0.47	N.s.
MCI	0.16	0.87	N.s.
SQMCI	0.44	0.66	N.s.

6.6.2. 2014/2015 catchment survey

Larvae of the common mayfly, *Deleatidium*, were the most abundant macroinvertebrate at all sites in the Cardrona River on 22 October 2014, with larvae of the cased caddis fly *Pycnocentrodes* co-dominant at the Clutha confluence site and the second most abundant taxon at Mount Barker (Table 6.8).

Larvae of the common mayfly, *Deleatidium*, were also among the most abundant macroinvertebrate taxa at all sites except Ballantyne Road on 18 February 2015 (Table 6.9). Chironomid midge larvae (*Maoridiamesa*, Orthocladiinae and Tanytarsini) were among the most abundant at many of the sites, probably due to the prolonged period of stable flows before this sampling occasion (Table 6.9). Larvae of the net-spinning caddis fly, *Aoteapsyche*, were among the most abundant taxa at several sites (Waiorau bridge, upstream of Boundary Creek, Stockyards Ford, Clutha Confluence), while the larvae of the cased caddis fly, *Pycnocentrodes*, were among the most abundant invertebrate taxa at the Stockyards Ford site (Table 6.9).

In October 2014, MCI scores for all sites in the Cardrona River from Mount Barker upstream were consistent with having good or excellent water quality, with a low level of enrichment (Table 6.8). However, MCI scores for Ballantyne Road, SH6 bridge and the Clutha confluence sites indicated fair water quality (Table 6.8).

In February 2015, MCI scores for the sites in Stockyards Ford upstream and the Clutha confluence indicated good water quality, while scores for Mount Barker, Ballantyne Road and SH6 were indicative of fair water quality (Table 6.9).

On average, SQMCI scores in February were 1.9 points lower than the score for the same site in October (Table 6.9). This difference reflects the greater abundance of chironomids in samples collected in February, which is probably the result of the low, stable flows and warmer water temperatures before this sampling occasion.

The macroinvertebrate fauna at the Ballantyne Road site in February had less than half the number of taxa found at other sites.

The macroinvertebrate community of Boundary Creek was dominated by the mayfly, *Deleatidium*, on 22 October 2014, while in February *Deleatidium*, chironomid midges (Orthocladiinae) and net-spinning caddis flies dominated the community (Table 6.9). MCI scores on both sampling occasions indicated good water quality (Table 6.9).

Similarly, the macroinvertebrate community of the Branch Burn was dominated by the mayfly, *Deleatidium*, on 22 October 2014, while in February chironomid midges (Orthocladiinae, Tanytarsini) and net-spinning caddis flies were most abundant (Table 6.9). MCI scores on both sampling occasions indicated good water quality (Table 6.9).

The macroinvertebrate community of Spotts Creek was dominated by the mayfly, *Deleatidium*, and the cased caddis fly, *Pycnocentrodes*, on 22 October 2014, while, in February, the community was dominated by *Deleatidium* and net-spinning caddis flies (Table 6.9). MCI scores on both sampling occasions indicated good water quality (Table 6.9).

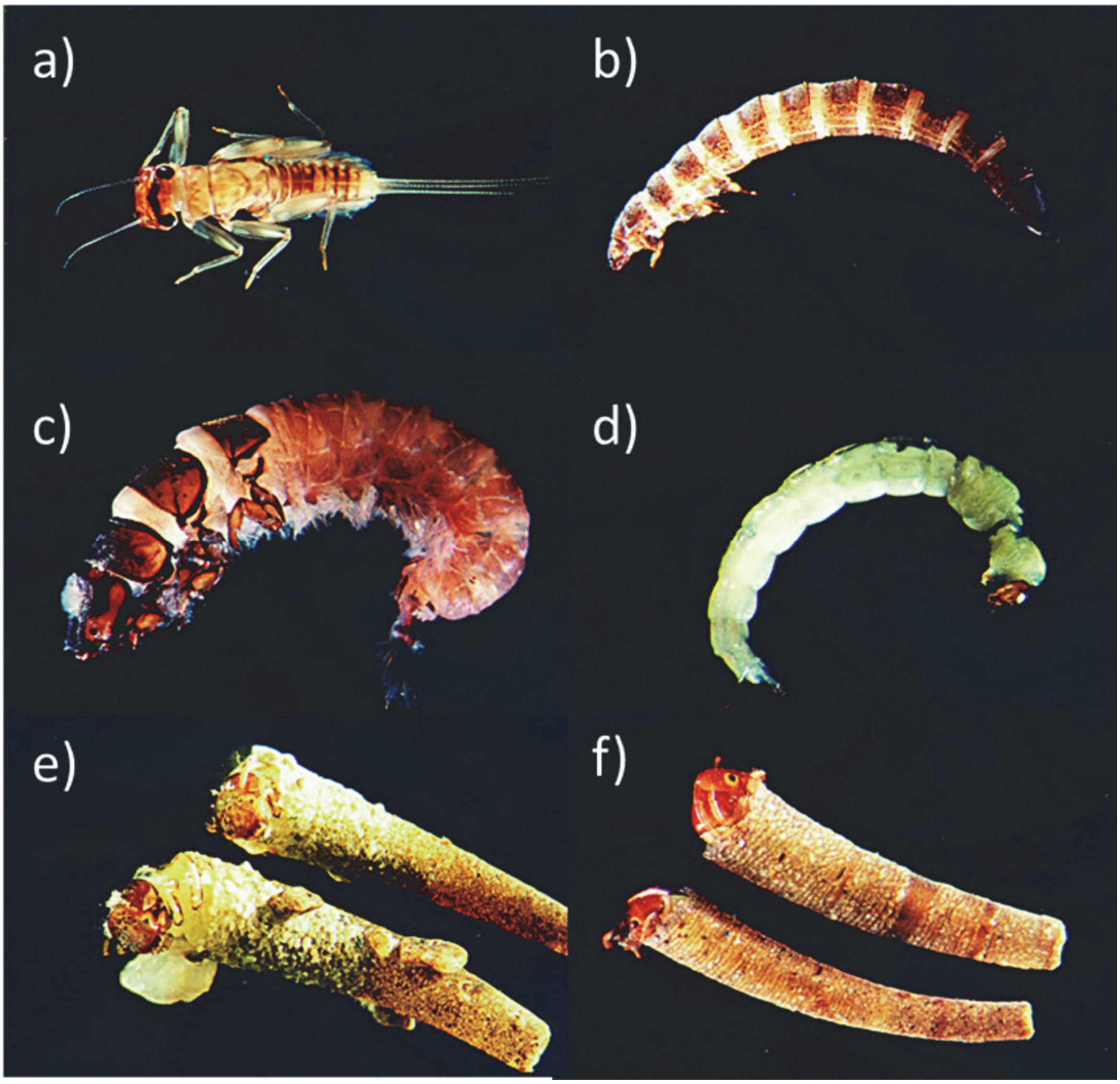

Figure 6.13 **Photographs of common macroinvertebrate taxa in the Cardrona River. a) A nymph of the mayfly, *Deleatidium*, b) a larval elmid beetle, c) a larva of the net-spinning caddis fly, *Hydropsyche*, d) chironomid midge larvae, e) the larvae of the cased caddis fly, *Pycnocentrodes*, and f) the larvae of the cased caddis fly, *Pycnocentria*. All photographs by Stephen Moore.**

Table 6.8 **Macroinvertebrate communities collected at eight sites in the Cardrona River and three tributaries on 22 October 2014. See Appendix B for the full table. Relative abundance scores are described in the caption of Table 6.6.**

TAXON	MCI score	Upstream of Cardrona	Waiorau bridge	Upstream of Boundary Ck	Stockyards Ford	Mount Barker	Ballantyne Rd	SH6	Clutha confluence	Boundary Creek	Branch Burn	Spotts Creek
DIPTERA (True flies)												
Austrosimulium species	3	R		R	R	C	A	C	C	R	R	R
Maoridiamesa species	3	R			R		C	R	A			C
Orthocladiinae	2	C	A	C	C	A	A	C	A	R	C	A
Tanytarsini	3	A	A	A	C	A	C	R	C		C	A
EPHEMEROPTERA (Mayflies)												
Deleatidium species	8	VA	VA	VA	VA	VVA	VA	VA	VA	VA	VA	VA
OLIGOCHAETA (Segmented worms)	1	R	A	C		R	R	R	R	C		C
TRICHOPTERA (Caddis flies)												
Aoteapsyche species	4	C	C	C	C	A	R	R	R	C	C	A
Olinga species	9	R		R		C			R	R	R	A
Pycnocentria species	7		R	R	C	A			C	R	R	C
Pycnocentrodes species	5	R	C	A	A	VA	C	C	VA	A	C	VA
Taxonomic richness		**18**	**16**	**17**	**16**	**18**	**11**	**13**	**15**	**13**	**18**	**16**
EPT taxa		**9**	**9**	**9**	**9**	**8**	**5**	**4**	**6**	**7**	**9**	**8**
%EPT taxa		**50%**	**56%**	**53%**	**56%**	**44%**	**45%**	**31%**	**40%**	**54%**	**50%**	**50%**
MCI		**106**	**119**	**112**	**110**	**110**	**89**	**86**	**97**	**114**	**119**	**109**
SQMCI		**6.66**	**5.73**	**6.39**	**6.98**	**7.07**	**6.13**	**7.22**	**5.78**	**6.97**	**7.25**	**5.87**

Table 6.9 **Macroinvertebrate communities collected at eight sites in the Cardrona River and three tributaries on 18 February 2015. See Appendix B for the full table. Relative abundance scores are described in the caption of Table 6.6.**

TAXON	MCI score	Upstream of Cardrona	Waiorau bridge	Upstream of Boundary Ck	Stockyards Ford	Mount Barker	Ballantyne Rd	SH6	Clutha confluence	Boundary Creek	Branch Burn	Spotts Creek
COLEOPTERA (Beetles)												
Elmidae	6		A	A	A	C	R	C	C	C	A	C
Scirtidae	8	A										
DIPTERA (True flies)												
Austrosimulium species	3	A	C	R	A	C				A	A	C
Eriopterini	9	C	C	C	A	R			C		C	
Maoridiamesa species	3	A	VA	A	A	R		C	C	R	C	
Muscidae	3		C		A	C		A	C		C	
Orthocladiinae	2	A	VA	A	VA	A		VA	A	VA	VA	A
Tanytarsini	3	VVA	VVA	VA	VVA	VA	R	VA	A	A	VA	R
EPHEMEROPTERA (Mayflies)												
Deleatidium species	8	VA	VA	VA	VA	VA	R	VA	VVA	VA	A	VA
OLIGOCHAETA (Segmented worms)	1	R	C	C	C	C	R	C	A	C	R	R
PLECOPTERA (Stoneflies)												
Megaleptoperla species	9	C	A			R						R
Zelandoperla species	10	A	C	R						R	C	
TRICHOPTERA (Caddis flies)												
Aoteapsyche species	4	A	VA	VA	VA	A	R	A	VA	VA	VA	VA
Hydrobiosis species	5	A	A	A	A	A	R	A	A	A	A	A
Olinga species	9	C	C	R	VA	C		R	R	C	A	A
Oxyethira albiceps	2					R	A	C				
Psilochorema species	8	C	C	C	C	C	R	C	C	C	C	R
Pycnocentria species	7	R	R	R	A	R			R	A	A	A
Pycnocentrodes species	5	R	A	C	VA	A		A	C	R	A	C
Taxonomic richness		**23**	**23**	**21**	**20**	**26**	**10**	**21**	**22**	**19**	**23**	**17**
EPT taxa		**11**	**12**	**11**	**9**	**9**	**5**	**9**	**11**	**10**	**10**	**10**
%EPT taxa		**48%**	**52%**	**52%**	**45%**	**35%**	**50%**	**43%**	**50%**	**53%**	**43%**	**59%**
MCI		**111**	**104**	**112**	**103**	**97**	**96**	**95**	**105**	**109**	**109**	**114**
SQMCI		**4.20**	**3.86**	**4.90**	**4.41**	**5.04**	**3.21**	**4.34**	**6.70**	**4.75**	**4.18**	**5.92**

6.7. Fish monitoring

6.7.1. SoE fish monitoring

Long-term monitoring of fish communities has been conducted at Mount Barker since 2009, following the New Zealand Freshwater Fish Sampling Protocols (Joy *et al.* 2013 – see Section 5.5.1). Fish communities in the Cardrona River at SH6 were also monitored in 2009 using the same method. Mount Barker was monitored in 2008, following a different sampling methodology, and the results of this survey are not considered further, other than to note that koaro, brown trout, rainbow trout and upland bully were collected at the Mount Barker site on this occasion.

In total, six species were collected from the Mount Barker site (Table 6.10). Large longfin eels were collected in 2011 (1800 mm) and 2013 (1300 mm) (Table 6.10). Densities of brown trout collected in this reach have been relatively low on most sampling occasions (0.1-1.9 fish/100 m^2), while densities of rainbow trout were generally higher (Table 6.10).

The four fish species collected from the SH8 site in 2009 included brown and rainbow trout, koaro and upland bully. Similar densities of brown and rainbow trout were observed on this occasion (Table 6.10). Brown trout densities at the SH8 were at least twice those found at the Mount Barker site.

Table 6.10 Fish densities (fish/100m^2) observed at the two monitoring sites in the Cardrona River

Species	Cardrona at Mount Barker						Cardrona at SH6
	9/04/09	2/02/10	8/03/11	21/03/12	11/02/13	24/02/14	8/04/09
Brown trout	1.3	0.7	1.9	1.6	0.1	0.1	4.2
Rainbow trout	1.9	0.9	0.9	1.6	7.1	4.0	4.7
Upland bully	21.3	3.8	2.9	10.1	9.1	11.6	15.8
Koaro	2.4	1.4	0.4	0.4	0.3	0.2	1.2
Clutha flathead galaxias	-	-	-	-	1.3	0.1	-
Juvenile galaxias	-	1.0	-	-	-	0.1	-
Longfin eel	-	-	0.1	-	0.1	-	-

7. Discussion

7.1. Nutrients

Nutrient concentrations affect the growth of algae and other periphyton, and high biomasses of periphyton can affect a wide range of instream values, including aesthetics, biodiversity, recreation and water quality (Biggs 2000). Periphyton biomass is regulated by the balance between two opposing processes: biomass accrual (growth) and biomass loss (Biggs 2000). Biomass accrual is driven by the availability of nutrients, light and water temperature, while biomass loss is driven by disturbance (substrate instability, increased or varying water velocity and suspended particles capable of scouring periphyton from the bed of the river) and grazing (mainly by invertebrates). In an unregulated river like the Cardrona, the processes affecting biomass loss (flow variability and grazing) are not able to be manipulated, meaning that, in areas where periphyton biomass reaches nuisance levels, nutrient management is the only practical means of managing periphyton biomass to maintain instream values. In most rivers, nitrogen and phosphorus are the main nutrients that potentially limit periphyton growth. Understanding the amount of these growth-limiting nutrients that are available to periphyton is important, particularly in rivers and streams where high periphyton biomass is a problem.

Concentrations of nitrogen (TN, NNN) and phosphorus (TP, DRP) have not significantly changed at the long-term monitoring site in the Cardrona catchment (Mount Barker). Nitrogen concentrations (TN and NNN) in the upper Cardrona catchment (from the Stockyards Ford upstream) were very low throughout this study. Slightly higher concentrations were evident at Mount Barker and Ballantyne Road, while much higher concentrations were evident at SH6 and the Clutha confluence. This probably reflects nitrogen-rich groundwater entering the lower Cardrona River. The Cardrona River loses approximately 700 l/s of water to the underlying groundwater between Mount Barker and just upstream of the SH6 bridge and regains about 300 l/s over a gaining reach stretching from just above the SH6 bridge to the Clutha confluence (Dale & Rekker 2011).

Nitrogen concentrations in Boundary Creek and the Branch Burn were low, while much higher concentrations were observed in Spotts Creek.

Concentrations of DRP observed during this study were very low at all sites sampled.

Inorganic nitrogen or NNN concentrations observed in the upper Cardona (from the Stockyards Ford upstream) were low enough to limit the growth rate of algae, typically being well below the Biggs (2000) 30-day accrual threshold concentration of 0.075 mg/L. DRP concentrations were also very low at these sites, typically being 0.003 to 0.004 mg/L. Algal growth rate at these sites would be strongly nutrient limited, based on the Biggs (2000) thresholds. The increase in NNN concentration at monitoring sites in the lower Cardona River to 0.30 to 0.40 mg/L would reduce nitrogen limitation of algal growth rate. Presently, DRP concentrations at these sites remain low, and would probably be the growth-limiting nutrient in the lower Cardona River. Maintaining low DRP concentrations in the lower catchment would be important in limiting the risk of increased algal growth rate and problematic algal blooms.

7.2. Faecal contamination

Water contaminated with faecal matter poses a range of possible health risks to recreational users, including serious gastrointestinal and respiratory illnesses. Counts of the bacterium *E. coli* are commonly used as an indicator of faecal contamination and a measure of the probability of the presence of other disease-causing agents, such as the protozoa, *Giardia*, and *Cryptosporidium*, the bacterium, *Campylobacter*, and various other bacteria and viruses.

The concentration of *E. coli* declined significantly over the period January 2000-December 2015, based on data collected and the long-term SoE monitoring site at Mount Barker. This change is encouraging and may reflect changing irrigation practices in the Cardrona catchment, with a shift from flood to spray irrigation that would be expected to result in reduced discharges of wipe-off water[3]. Should there have been a significant shift in irrigation practices in the Cardrona catchment over this time, this would probably result in a significant reduction in faecal contamination of waterways (ORC 2006b). All samples collected from the Mount Barker site at flow less than median flow were well below the Schedule 15 limit of 260 cfu/100ml. Water of this quality reflects very low risk to recreational water users.

Sampling conducted during 2014-2015 shows concentrations of *E. coli* to be very low on most sampling locations. However, this sampling identified two ‘hot spots’ for faecal contamination: *E. coli* counts upstream of Boundary Creek were higher than other sites in the upper Cardrona, and *E. coli* concentrations observed in Spotts Creek during low flows were markedly higher than other locations sampled as part of this study. The *E. coli* levels recorded in the Cardrona River upstream of Boundary Creek, although elevated when compared to other main-stem sites, were still below alert levels and therefore pose minor risk to recreational water users. *E. coli* levels recorded in Spotts Creek, on the other hand, reached red alert levels on a number of occasions. Further investigation would be required to be able to comment on the likely source of bacterial contamination at these sites.

7.3. Turbidity

Turbidity is a measure of the ‘cloudiness’ of water and is inversely related to how clear water appears (i.e. low turbidity is associated with good water clarity and very clear water, high turbidity with very low clarity and ‘dirty’ or cloudy water). Turbidity at Mount Barker is generally low, and there is no evidence of a change in turbidity between January 2000 and-December 2015. However, over the same period a significant decline in SS was detected.

[3] Excess irrigation water that is discharged back to a water race or waterway

7.4. Compliance with Plan Change 6A limits

Plan Change 6a outlines the water-quality limits for receiving waters (Schedule 15, Table 4.1) and discharge thresholds (Schedule 16). Receiving water limits are applied as five-year, 80th percentiles, when flows are at, or below, a reference flow. For the Cardrona catchment, the reference flow is 1,950 l/s at the Mount Barker flow-monitoring site. For most of the sites sampled (the exception being the SoE site at Mount Barker), data is only available for one year. For these sites, 80th percentiles were calculated based on this limited data and should be interpreted with caution.

Water quality at the Mount Barker site complied with all Plan Change 6A limits (Table 7.1). Similarly, based on data collected in 2014-2015, all sites upstream of Mount Barker and Ballantyne Road complied with Schedule 15 limits (Table 7.1). Sites from the SH6 bridge downstream did not comply with the Schedule 15 limit for NNN, but did comply for all other variables (Table 7.1).

The limited samples collected over the 2014-2015 period indicate that sites in Boundary Creek and Branch Burn were likely to comply with all Plan Change 6A limits (Table 7.1). In comparison, data collected from Spotts Creek over the 2014-2015 period suggest that this site was unlikely to comply with Schedule 15 limits for NNN and *E. coli* (Table 7.1).

Table 7.1 Comparison of 80th percentiles of water-quality parameters with receiving water-quality limits in Plan Change 6A (Schedule 15,Table 4.1). Values that exceeded the limit are highlighted in red. All values calculated using samples collected when flows were at or below the appropriate reference flow.

Site	Period	NNN 0.075 mg/l	NH4-N 0.1 mg/l	DRP 0.01 mg/l	E. coli 260 cfu/100 ml	Turbidity 5 NTU
Upstream of Cardrona	2014-2015	0.002	0.012	0.004	38	-
Waiorau bridge	2014-2015	0.019	0.010	0.004	51	-
Upstream of Boundary Ck	2014-2015	0.017	0.007	0.004	216	-
James Road bridge	2014-2015	0.015	0.007	0.004	85	-
Stockyards ford	2014-2015	0.013	0.007	0.004	66	-
Mount Barker (SoE)	2014-2015	0.070	0.010	0.004	40	-
	2010-2015	0.066	0.010	0.004	72	0.87
Ballantyne Road	2014-2015	0.059	0.014	0.005	21	-
SH6	2014-2015	0.380	0.009	0.004	26	-
Clutha confluence	2014-2015	0.752	0.005	0.003	48	-
Boundary Creek	2014-2015	0.016	0.011	0.004	99	-
Branch Burn	2014-2015	0.019	0.005	0.004	33	-
Spotts Creek	2014-2015	0.342	0.016	0.006	372	-

7.5. Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. Water temperature (especially high water temperatures) affects fish populations directly, by affecting their survival, growth, spawning, egg development and migration, but it can also affect fish populations indirectly, through effects on physicochemical conditions and food supplies (Olsen *et al*. 2012).

Of the fish species present in the Cardrona River, brown trout (*Salmo trutta*) and rainbow trout (*Onchyrhynchus mykiss*) are likely to be the fish that are most sensitive to high water temperatures. The thermal requirements of brown trout are well understood (Elliott 1994). Significant mortality of brown trout is expected to occur in relatively short time periods at temperatures above 25°C, and growth is retarded when temperatures exceed 19°C. The growth optimum for brown trout feeding on invertebrates is 14°C, but it becomes 17°C for trout fed on a fish diet (Elliott & Hurley 1998, 1999, 2000). Todd *et al*. (2008) calculated acute and chronic thermal criteria for a range of fish species, and Olsen *et al*. (2012) estimated thermal criteria for some native fish species using the same approach. The acute thermal threshold is calculated as the highest two-hour average water temperature measured within any 24-hour period, while the chronic thermal threshold is expressed as the maximum weekly average temperature (Todd *et al*. 2008).

The common mayfly, *Deleatidium*, which is usually the most abundant macroinvertebrate species in the Cardrona River (Section 6.6), are more likely to be more sensitive to high temperatures than any of the fish species present. Therefore, the suitability of the temperatures observed in the Cardrona catchment for *Deleatidium* was also considered.

Analysis of available water temperature records for three sites in the Cardrona River (Mount Barker, SH6, Clutha confluence) were suitable for all fish species considered, but exceeded the acute thermal criterion for *Deleatidium* at times. Water temperatures in the Cardrona River at Ballantyne Road exceeded acute thermal criteria for rainbow trout, brown trout and *Deleatidium* before the cessation of surface flow.

Water temperatures observed in Deep Creek, Spotts Creek and Boundary Creek in 2015-2016 were suitable for all species considered, but temperatures observed in the Branch Burn exceed acute thermal criteria for rainbow trout, brown trout and *Deleatidium* and chronic criteria for rainbow and brown trout.

These results suggest that thermal conditions in much of the main stem of the Cardrona River and most of its tributaries are generally suitable for brown and rainbow trout and native fish, but that water temperatures in the vicinity of Ballantyne Road and in the lower Branch Burn may be unsuitable for brown and rainbow trout at times. All four main-stem sites exceeded the acute thermal criterion for the common mayfly, *Deleatidium*, which suggests that water temperatures may affect macroinvertebrate community structure in the lower Cardrona at times.

7.6. Substrate and riparian cover

The quantity and quality of habitat are important factors that can affect many instream values, among which composition of the streambed is particularly important because it provides the attachment substrate for periphyton and the habitat for macroinvertebrates and fish.

The riparian vegetation at all sites surveyed in the Cardrona catchment was dominated by exotic species: willows, exotic pasture grasses and lupins. Most sites were not fenced from surrounding farmland, and stock generally had access to the stream channel.

Coarse gravels generally dominated the bed of the Cardrona River, although there was some variation within the catchment: riffles at the site upstream of Boundary Creek had similar proportions of coarse and fine gravels, and runs at both SH6 and the Clutha confluence were dominated by fine gravels. These differences in the physical habitat affect the habitat provided for periphyton, macroinvertebrates and fish. Coarse substrate provides a more stable substrate for periphyton to attach and grow on, which will increase the risk of periphyton biomass reaching nuisance levels relative to finer substrates. However, coarse substrate can be more favourable for macroinvertebrates to move around on and can offer native fish large interstitial spaces as refuge from flows and predators.

7.7. Biological monitoring

7.7.1. Periphyton

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters. This community can include green (Chlorophyta), yellow-green (Xanthophyta), golden brown (Chrysophyta) and red (Rhodophyta) algae, blue-greens (Cyanobacteria), diatoms (Bacillariophyta), bacteria and fungi. Periphyton is an integral part of stream food webs; it captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

The most extreme case of periphyton affecting instream values is toxin-producing benthic cyanobacteria. Some cyanobacteria, including *Phormidium* and *Oscillatoria*, which have been recorded in the Cardrona River, may produce toxins that pose a health risk to humans and animals. These include toxins that affect the nervous system (neurotoxins), liver (hepatotoxins) and dermatotoxins that can cause severe irritation of the skin. The presence of potentially toxic cyanobacteria can affect the suitability of a waterway for drinking, recreation (swimming), dogs, stock drinking water and food-gathering (by affecting palatability or through accumulation of toxins in organs such as the liver). Cyanobacteria-produced neurotoxins have been implicated in the deaths of numerous dogs in New Zealand (Hamill 2001, Wood *et al.* 2007). Cyanobacterial mats can be dislodged from the riverbed and wash to the bank where dogs, attracted by their distinctive musty smell, may eat them. Death occurs rapidly, following the ingestion of a lethal dose.

In February 2016, a dog died as a result of ingesting algal material near Mount Barker. Subsequent observations by ORC staff confirmed the presence of benthic cyanobacteria in the area. Testing for toxins in the cyanobacterial material confirmed the presence of high levels of the potent neurotoxins Anatoxin-a and homo-Anatoxin-a.

Long-term monitoring of the composition of periphyton at Mount Barker shows that the community has generally been dominated by cyanobacteria or diatoms, which both typically dominate systems with low nutrient availability (especially phosphorus), such as the conditions evident at Mount Barker. *Phormidium* mats can capture fine sediments from the water column and release phosphorus from them (Wood *et al.* 2014), which may give *Phormidium* a competitive advantage over other types of periphyton in low-phosphorus environments. The green filamentous algae, *Spirogyra*, that dominated the community at Mount Barker on two occasions (2001, 2010) may be associated with long periods of stable flows. The 7 February 2010 occasion was preceded by a period of 158 days without a high-flow event of sufficient magnitude to reduce periphyton biomass, such as a flow greater than the FRE3 threshold. Flow records were not available before the 7 March 2001 sampling occasion to determine if a lack of flushing flows is likely to account for the dominance of *Spirogyra*. The invasive, stalked diatom, *Didymosphenia geminata*was first detected at Mount Barker in 2008.

Long-term periphyton monitoring in the Cardrona River is undertaken on one occasion per year (usually in mid-late summer) at one site only, and therefore provides a very limited ‘snapshot’ of periphyton community composition at the sole long-term monitoring site in the Cardrona catchment at Mount Barker. In addition, the method previously used in long-term monitoring does not provide information on the bed cover by, or biomass of, periphyton. As part of this study, monthly periphyton surveys were carried in the summer of 2014/2015, with periphyton cover and biomass measured at all of the main-stem sites in the Cardrona catchment. These surveys allow consideration of longitudinal and temporal changes in composition of the periphyton community and comparison with the results of the water-quality sampling and antecedent river flows.

Mats of the benthic cyanobacterium, *Phormidium*, were observed at most sites, except the uppermost site (upstream of Cardrona) and Ballantyne Road. Cover by *Phormidium* was generally low at most sites and was well within the ‘Alert’ threshold (20% cover) for the cover of benthic cyanobacteria in recreational freshwaters (MfE & MoH, 2009). The presence of *Phormidium* mats in the upper catchment does not suggest that there are water-quality issues in the upper Cardrona catchment, as discussed previously.

The results of the 2014/15 catchment survey indicate that the periphyton community at sites in the upper Cardrona catchment (above Ballantyne Road) tended to have unenriched nutrient conditions, with these sites having the lowest chlorophyll-*a* concentrations and cover dominated by thin films of green or light brown algae and didymo. These types of algae are typically dominant at sites with low nutrient concentrations. However, the site at the SH6 bridge supported much greater periphyton growths. This is consistent with the much higher nitrogen concentration observed at this site when compared to the upper Cardrona River monitoring sites and results from the resurgence of enriched groundwater that occurs immediately upstream of the SH6 bridge.

7.7.2. Macroinvertebrates

Macroinvertebrates are a diverse group of animals and include insects, crustaceans, worms, molluscs and mites. They are an important part of stream-food webs, linking primary producers (periphyton and terrestrial leaf litter) to higher trophic levels (fish and birds). Because of the length of the aquatic part of their life-cycles, which generally range from a few months up to two years, macroinvertebrates provide a good indication of the medium- to long-term water quality of a waterway. For this reason, they are used as a biomonitoring tool around the world. In New Zealand, the MCI (Stark, 1985) and its derivatives (SQMCI, QMCI: Stark 1998) are used as a measure of organic enrichment and sedimentation in gravel-bed streams.

Long-term monitoring of the macroinvertebrate community in the Cardona River at the Mount Barker site indicates that the community is dominated by taxa that are sensitive to pollution (i.e. EPT taxa), and MCI scores indicate that water quality is good, while SQMCI scores indicate that water quality is generally excellent (based on the criteria in Table 5.2). Analysis of macroinvertebrate indices over time suggests that water and habitat quality have not changed substantially since 2001.

The common mayfly, *Deleatidium*, was among the most abundant macroinvertebrate collected at all sites in the Cardrona River and tributaries in October 2014. Macroinvertebrate communities in the upper Cardrona River (from Mount Barker upstream) and tributaries in October 2014 reflected very good water quality, with a low level of organic enrichment. However, macroinvertebrate communities in February generally included a greater abundance of taxa that are tolerant of poor water quality, probably the result of the low, stable flows and warmer water temperatures before this sampling occasion. The reduced number of macroinvertebrate taxa collected from the Ballantyne Road site in February is probably the result of this site drying in the weeks before the February sampling occasion.

7.7.3. Fish

Six fish species (brown and rainbow trout, longfin eel, koaro, Clutha flathead galaxias and upland bully) have been collected from the Mount Barker site, although single, large, individual eels have been collected on only two occasions, probably reflecting the lack of recruitment of eels to the upper Clutha since the construction of Roxburgh and Clyde dams. Four species were collected at SH8 in 2009: brown and rainbow trout, koaro and upland bully.

8. Summary

1. Water quality in the upper Cardrona River is generally very good, but the lower catchment below the SH6 bridge has high concentrations of TN and NNN, and concentrations of NNN at both these sites are currently likely to exceed Schedule 15 standards for NNN. This deterioration in water quality coincides with the location of nitrogen-enriched (relative to surface water) groundwater entering the river. Given that the 80th percentiles for most of the sites were calculated based on only one year of data (the exceptions being the SoE site at Mount Barker), these results should be interpreted with caution.

2. No trend was evident for the Mount Barker SoE site over the period 2000-2015 for most water-quality variables. *E. coli* and SS concentrations decreased over this period.

3. Water quality in two of the tributaries sampled in this study (Boundary Creek and Branch Burn) was generally good. However, NNN concentrations and *E. coli* counts were observed in Spotts Creek and were particularly evident during low flows.

4. Water temperatures in much of the main stem of the Cardrona River and most of its tributaries are generally suitable for brown and rainbow trout and native fish, but water temperatures in the vicinity of Ballantyne Road and in the lower Branch Burn may be unsuitable for brown and rainbow trout at times. All four main-stem sites exceeded the acute thermal criterion for the common mayfly, *Deleatidium*, which suggests that water temperatures may affect macroinvertebrate community structure in the lower Cardrona at times.

5. Coarse gravels dominated the river bed at most sites in the Cardrona River. Riparian buffers were not generally present, and there was evidence of direct stock access at most sites surveyed. Riparian vegetation generally consisted of exotic species, including willows, lupins and exotic grasses.

6. The results of the 2014/15 catchment periphyton survey were consistent with the results of water-quality sampling, with the periphyton community at sites in the upper Cardrona catchment (above Ballantyne Road) indicating low-nutrient conditions, with low chlorophyll-*a* concentrations and cover dominated by thin films of green or light brown algae and didymo. However, the site at the SH6 bridge supported much greater periphyton growths, a finding that is consistent with the increased nitrogen concentrations observed at this site, resulting from the resurgence of nitrate-enriched groundwater, immediately upstream of the SH6 bridge.

7. Macroinvertebrate communities collected from Mount Barker between 2001 and 2015 were consistent with good to excellent water quality, and trend analysis indicated that macroinvertebrate metrics at this site had been stable over this period, with the exception of taxon richness that appears to have increased over time. Macroinvertebrate communities in the upper Cardrona River (from Mount Barker upstream) and tributaries in October 2014 were consistent with very good water quality. However, macroinvertebrate communities in February generally included a greater abundance of taxa that are tolerant of poor water quality, probably the result of the low, stable flows and warmer water temperatures before this sampling occasion. The reduced number of macroinvertebrate taxa collected from the Ballantyne Road site in February is probably the result of this site drying in the weeks before the February sampling occasion.

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Appendix A Laboratory analysis methods

Table 9.1 Laboratory analysis methods and detection limits for water-quality parameters used in this water quality study

Analyte	Method	Method reference	Detection limit
Nitrate-N (NO_3-N)	Ion chromatography (0.45 µm filtered)	APHA (online edition) 4110 B (modified)	0.002 mg/l
Nitrite-N (NO_2-N)	Ion chromatography (0.45 µm filtered)	APHA (online edition) 4110 B (modified)	0.002 mg/l
Nitrate-nitrite nitrogen (NNN or TON)	Ion chromatography (0.45 µm filtered)	APHA (online edition) 4110 B (modified)	0.002 mg/l
Ammoniacal-N	Colorimetry/discrete analyser	MEWAM, HMSO 1981, ISBN 0117516139	0.005 mg/l
Total Kjeldahl nitrogen	By calculation (TN-NNN)		0.02 mg/l
Total nitrogen	Persulphate digestion and flow analysis	APHA (online edition) 4500-P J, 4500-NO3 F (modified)	0.01 mg/l
Dissolved reactive phosphorus	Colorimetry/discrete analyser	APHA (online edition) 4500-P B, F (modified)	0.002 mg/l
Total phosphorus	Colorimetry/discrete analyser after persulphate digestion	APHA (online edition) 4500-P B, J (modified)	0.004 mg/l
Total suspended solids	Gravimetry	APHA (online edition) 2540 D	0.2 mg/l
Escherichia coli	Membrane filtration	USEPA Method 1603 (2002)	2 cfu/100 ml

Appendix B Macroinvertebrate data

Table 9.2 **Macroinvertebrate taxa collected from the Cardrona River as part of SoE monitoring. Relative abundance scores: R = rare (1-4 individuals), C = common (5-19 individuals), A = abundant (20-99 individuals), VA = very abundant (100-499 individuals), VVA = very, very abundant (500+ individuals)**

Taxa	MCI Score	Cardrona at Waiorau	Cardrona River at Mount Barker													
		7/03/2001	7/03/2001	2002	12/03/2003	2004	6/02/2006	16/01/2007	18/04/2008	2/04/2009	7/02/2010	15/03/2011	8/02/2012	13/03/2013	12/02/2014	14/01/2015
ACARINA	5										C					
COLEOPTERA																
Berosus	5										R					
Elmidae	6	A	VVA	VA	A	A	VVA	VVA	VVA	VVA	VVA	C	C	A	C	C
CRUSTACEA																
Ostracoda	3										R					
DIPTERA																
Austrosimulium	3				C			C	A	R		A		C	C	A
Blephariceridae	7	R	R													
Ceratopogonidae	3										C					
Chironominae	2				A	R	VA		C			C				
Hexatomini	5			C												
Mischoderus	4			R											R	
Eriopterini	9		C	C	A	A	C	C	A	A	A	R	R	C	C	R
Maoridiamesa	3		A	C			A			R	R	R	C	R	C	
Molophilus	5				R					R		R			R	
Muscidae	3				R				R	R		R	R	R	R	
Orthocladiinae	2	R	VA	VA	A	C	VA		C	R	A	C	A	C	C	C
Tanypodinae	5						C									
Tanypodinae																
Tanytarsini	3										VA		A		C	C

Table 9.2 **Macroinvertebrate taxa collected from the Cardrona River as part of SoE monitoring. Relative abundance scores: R = rare (1-4 individuals), C = common (5-19 individuals), A = abundant (20-99 individuals), VA = very abundant (100-499 individuals), VVA = very, very abundant (500+ individuals)**

Taxa	MCI Score	Cardrona at Waiorau	Cardrona River at Mount Barker													
		7/03/2001	7/03/2001	2002	12/03/2003	2004	6/02/2006	16/01/2007	18/04/2008	2/04/2009	7/02/2010	15/03/2011	8/02/2012	13/03/2013	12/02/2014	14/01/2015
EPHEMEROPTERA																
Deleatidium	8	A	VVA	VVA	VA	VA	VA	A	VA	VVA	VA	VVA	VA	VA	VA	VA
Nesameletus	9	C														
MEGALOPTERA																
Archichauliodes diversus	7				R		C		C		R	R	R	C	R	
MOLLUSCA																
Gyraulus	3										C					
Potamopyrgus antipodarum	4												R			
OLIGOCHAETA	1	R	R	C	A	C	A	C	A	A	R	C	A	R	C	R
PLECOPTERA																
Megaleptoperla	9		R		R										R	R
Zelandobius	5	A	A	C		R				A	A	C				
Zelandoperla	10	R	R	C		R						R				
TRICHOPTERA																
Aoteapsyche	4	R	R	C	A	A	A		A	A	VA	A	A	A	A	C
Costachorema xanthopterum	7									R		R		R	R	
Hudsonema	6	R	R						C					R	R	
Hydrobiosidae early instar	5			A	A	R	C	R	C	R	C		R			
Hydrobiosis	5	R	C	C		R	R	R	C	R	R		C	R		R
Neurochorema forsteri	6				R											
Olinga	9										C	R		A	C	R

Table 9.2 **Macroinvertebrate taxa collected from the Cardrona River as part of SoE monitoring. Relative abundance scores: R = rare (1-4 individuals), C = common (5-19 individuals), A = abundant (20-99 individuals), VA = very abundant (100-499 individuals), VVA = very, very abundant (500+ individuals)**

Taxa	MCI Score	Cardrona at Waiorau	Cardrona River at Mount Barker													
		7/03/2001	7/03/2001	2002	12/03/2003	2004	6/02/2006	16/01/2007	18/04/2008	2/04/2009	7/02/2010	15/03/2011	8/02/2012	13/03/2013	12/02/2014	14/01/2015
Oxyethira albiceps	2			C							C					
Plectrocnemia maclachlani	8												R			R
Psilochorema	8	R	R		C	C	C	C	A	C	C	R	R		R	
Pycnocentrodes	5				R	C	C	A	VVA	A	VA	A	R	C	C	R
Pycnocentria	7		R	C					A	C				C	R	
Taxonomic richness		**14**	**17**	**15**	**16**	**13**	**14**	**9**	**16**	**17**	**21**	**18**	**16**	**16**	**20**	**13**
EPT richness		**4**	**4**	**3**	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**4**	**3**	**7**
%EPT richness		**29%**	**24%**	**20%**	**13%**	**23%**	**14%**	**22%**	**19%**	**18%**	**14%**	**17%**	**13%**	**25%**	**15%**	**54%**
MCI		**118**	**120**	**101**	**104**	**108**	**100**	**111**	**101**	**101**	**96**	**108**	**101**	**106**	**109**	**111**
SQMCI		**6.41**	**6.46**	**6.69**	**5.74**	**6.96**	**5.12**	**6.01**	**5.66**	**6.79**	**5.51**	**7.38**	**5.51**	**6.99**	**6.56**	**6.70**

Table 9.3 **Macroinvertebrate communities collected at eight sites in the Cardrona River and three tributaries on 22 October 2014. Relative abundance scores are described in the caption of Table 6.6.**

TAXON	MCI score	Upstream of Cardrona	Waiorau bridge	Upstream of Boundary Ck	Stockyards ford	Mount Barker	Ballantyne Rd	SH6	Clutha confluence	Boundary Creek	Branch Burn	Spotts Creek
COLEOPTERA (Beetles)												
Elmidae	6	C	C	C	R	R		R	R	C	R	R
DIPTERA (True flies)												
Aphrophila species	5	R	C	R	R	R					R	
Austrosimulium species	3	R		R	R	C	A	C	C	R	R	R
Ceratopogonidae	3	R							R			
Empididae	3					R						
Ephydridae	4							R				
Eriopterini	9	R	R	R	C	C	R	C	C	R	C	C
Hexatomini	5					R						
Maoridiamesa species	3	R			R		C	R	A			C
Muscidae	3							R				
Orthocladiinae	2	C	A	C	C	A	A	C	A	R	C	A
Tanypodinae	5								R		R	
Tanytarsini	3	A	A	A	C	A	C	R	C		C	A
EPHEMEROPTERA (Mayflies)												
Austroclima species	9		R									
Coloburiscus humeralis	9				R						R	R
Deleatidium species	8	VA	VA	VA	VA	VVA	VA	VA	VA	VA	VA	VA
MEGALOPTERA												
Archichauliodes diversus	7		R	R		R				C	R	R
MOLLUSCA												
Potamopyrgus antipodarum	4											R
OLIGOCHAETA (Segmented worms)	1	R	A	C		R	R	R	R	C		C
PLECOPTERA												
Megaleptoperla species	9					R						
Zelandobius species	5	C	C	C	R			R			R	R
Zelandoperla species	10	R	R	R								
TRICHOPTERA (Caddis flies)												
Aoteapsyche species	4	C	C	C	C	A	R	R	R	C	C	A
Hudsonema alienum	6				R		R					
Hydrobiosis species	5	R		R	R	R	R		R	C		R
Neurochorema species	6	R	R	R								
Olinga species	9	R		R		C			R	R	R	A
Psilochorema species	8	R	R		R	R				R	R	R
Pycnocentria species	7		R	R	C	A			C	R	R	C
Pycnocentrodes species	5	R	C	A	A	VA	C	C	VA	A	C	VA
Taxonomic richness		**18**	**16**	**17**	**16**	**18**	**11**	**13**	**15**	**13**	**16**	**18**
EPT taxa		**9**	**9**	**9**	**9**	**8**	**5**	**4**	**6**	**7**	**8**	**9**
%EPT taxa		**50%**	**56%**	**53%**	**56%**	**44%**	**45%**	**31%**	**40%**	**54%**	**50%**	**50%**
MCI		**106**	**119**	**112**	**110**	**110**	**89**	**86**	**97**	**114**	**119**	**109**
SQMCI		**6.66**	**5.73**	**6.39**	**6.98**	**7.07**	**6.13**	**7.22**	**5.78**	**6.97**	**7.25**	**5.87**

Table 9.4 Macroinvertebrate communities collected at eight sites in the Cardrona River and three tributaries on 18 February 2015. Relative abundance scores are described in the caption of Table 6.6.

TAXON	MCI score	Upstream of Cardrona	Waiorau bridge	Upstream of Boundary Ck	Stockyards Ford	Mount Barker	Ballantyne Rd	SH6	Clutha confluence	Boundary Creek	Branch Burn	Spotts Creek
COLEOPTERA (Beetles)												
Dytiscidae	5					R						
Elmidae	6		A	A	A	C	R	C	C	C	A	C
Hydraenidae	8										R	
Scirtidae	8	A										
Staphylinidae	5						C					
COLLEMBOLA (Springtails)	6							C				
CRUSTACEA (Shrimps, crayfish)												
Ostracoda	3								R			
DIPTERA (True flies)												
Austrosimulium species	3	A	C	R	A	C				A	A	C
Ceratopogonidae	3	C			C	C		R	C		R	
Chironomus species	1		R			R						
Empididae	3	R	C			C						
Eriopterini	9	C	C	C	A	R			C		C	
Hexatomini	5	R										
Maoridiamesa species	3	A	VA	A	A	R		C	C	R	C	
Molophilus species	5	R		R	R				R		R	
Muscidae	3		C		A	C		A	C		C	
Orthocladiinae	2	A	VA	A	VA	A		VA	A	VA	VA	A
Paralimnophila skusei	6									R		
Psychodidae	1							R				
Stratiomyidae	5					R						
Tanypodinae	5			R		R		R		R		R
Tanytarsini	3	VVA	VVA	VA	VVA	VA	R	VA	A	A	VA	R
EPHEMEROPTERA (Mayflies)												
Coloburiscus humeralis	9											C
Deleatidium species	8	VA	VA	VA	VA	VA	R	VA	VVA	VA	A	VA
MEGALOPTERA (Dobsonflies)												
Archichauliodes diversus	7	C		C	R	C		R	R	C	C	C
MOLLUSCA (Snails, bivalves)												
Potamopyrgus antipodarum	4		R			R						
NEMATODA (Roundw orms)	3										R	
OLIGOCHAETA (Segmented w orms)	1	R	C	C	C	C	R	C	A	C	R	R
PLECOPTERA (Stoneflies)												
Megaleptoperla species	9	C	A			R						R
Zelandobius species	5	R	C	R	C							
Zelandoperla species	10	A	C	R						R	C	
TRICHOPTERA (Caddis flies)												
Aoteapsyche species	4	A	VA	VA	VA	A	R	A	VA	VA	VA	VA
Costachorema species	7			R	R			R	R		R	
Hudsonema alienum	6		R	R		C	R	R		R	R	R
Hudsonema amabile	6								R			
Hydrobiosidae early instar	5								C			
Hydrobiosis species	5	A	A	A	A	A	R	A	A	A	A	A
Neurochorema species	6	C	R					R	R	R		
Olinga species	9	C	C	R	VA	C		R	R	C	A	A
Oxyethira albiceps	2					R	A	C				
Psilochorema species	8	C	C	C	C	C	R	C	C	C	C	R
Pycnocentria species	7	R	R	R	A	R			R	A	A	A
Pycnocentrodes species	5	R	A	C	VA	A		A	C	R	A	C
Taxonomic richness		**23**	**23**	**21**	**20**	**26**	**10**	**21**	**22**	**19**	**23**	**17**
EPT taxa		**11**	**12**	**11**	**9**	**9**	**5**	**9**	**11**	**10**	**10**	**10**
%EPT taxa		**48%**	**52%**	**52%**	**45%**	**35%**	**50%**	**43%**	**50%**	**53%**	**43%**	**59%**
MCI		**111**	**104**	**112**	**103**	**97**	**96**	**95**	**105**	**109**	**109**	**114**
SQMCI		**4.20**	**3.86**	**4.90**	**4.41**	**5.04**	**3.21**	**4.34**	**6.70**	**4.75**	**4.18**	**5.92**