Water Quality Study: Lindis 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 previously carried out a targeted, short-term monitoring investigation in the Lindis River (2004-2005). This study repeats this work ten years later.

Why was this targeted investigation deemed necessary

This investigation was undertaken to:

1. Assess spatial and temporal patterns in water quality in order to assess the effects of land-use on water quality in the Lindis catchment.
2. Get a representative background level for an unimpacted site (upstream of Pass Burn).
3. Assess water quality in the Lindis catchment against water quality standards in the Regional Plan: Water.
4. Assess habitat quality, periphyton and macroinvertebrate communities in the Lindis catchment.
5. Provide a water quality and ecological baseline for comparison with in the future prior to a minimum flow being in place and further irrigation development.

What has this study found?

- Water abstraction in the lower part of the river has significant effects on the water quality and ecology of the lower Lindis River. Flows in the middle and lower reaches of the Lindis River are heavily influenced by water abstraction as well as losses to groundwater. Much of the abstraction from the Lindis River occurs as large surface water takes from near Cluden Stream, downstream.

1. Water quality in the upper Lindis River is generally very good, but the lower catchment has high concentrations of total nitrogen (TN) and nitrate-nitrite nitrogen (NNN). TN and NNN concentrations at sites downstream of Archies Flat are likely to exceed Schedule 15 standards for NNN at present. However, given that 80th percentiles for most of the sites were calculated from only one year of data (the exceptions being the SoE sites at Lindis Peak and Ardgour Road), these results should be interpreted with caution. This deterioration in water quality coincides with the location of the major water takes from the Lindis River and is likely to be a result of nitrogen-enriched (relative to surface water) groundwater entering the river.

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- Over the period 2005-2014, TN and NNN increased and dissolved reactive phosphorus (DRP) decreased at the Ardgour Road hydrological site, while *E. coli* concentrations at Lindis Peak decreased over the period 2003-2014.

- Water quality in the two tributaries sampled in this study (Cluden and Wainui Streams) was generally poorer than most mainstem sites, with relatively high TN, TP and DRP concentrations. Concentrations of NNN and *E. coli* were relatively low in both tributary sites.

- Water temperatures in the Lindis River at the Ardgour Road hydrological site are generally suitable for the native and introduced fish present, although temperatures at Lindis Peak may be too warm for rainbow trout at times.

- Coarse gravels, cobbles and fine gravels dominated the bed at all sites. 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, broom and rank grass.

- The periphyton community at sites in the upper Lindis catchment (above Lindis Peak) were generally indicative of unenriched conditions, with low chlorophyll *a* concentrations and cover by long filamentous algae. Much greater periphyton growths were observed at Ardgour Road Bridge and the Ardgour Road hydrological site, most likely as a result of a combination of more enrichment and/or lower flows at these sites.

- Macroinvertebrate communities collected from the Lindis River (2006-2014) were consistent with good water quality. However, macroinvertebrate samples collected as part of this study in October indicated good to excellent water quality throughout the catchment, while samples collected in February were consistent with good water quality upstream of Lindis Peak and good- fair water quality downstream. This may reflect a combination of low, stable flows, the presence of the invasive diatom *Didymosphenia geminata* and/or water quality in the lower sites.

- Macroinvertebrate communities in Cluden stream indicated good-fair water quality in October 2014, but fair-poor water quality in February 2015. Macroinvertebrate communities in Wainui stream in October 2014 indicated good-fair water quality.

- Common and upland bullies, brown and rainbow trout and longfin eels have been collected from the lower Lindis River.

Technical summary

The Lindis River is a major tributary of the upper Clutha River, with the confluence a short distance upstream of Lake Dunstan. The river is fed by high rainfall (>1 m per annum) in the steep upper catchment, while the lower Lindis catchment and the Tarras Basin receive very low levels of rainfall (<450 mm per annum). Flows in the middle and lower reaches of the Lindis River are heavily influenced by water abstraction as well as losses to groundwater. Much of the abstraction from the Lindis River occurs as large surface water takes from near Cluden Stream, downstream. Water abstraction in this lower part of the river has significant effects on the water quality and ecology of the lower Lindis River.

The objectives of this water quality study were to:

1. Assess spatial and temporal patterns in water quality in order to assess the effects of land-use on water quality in the Lindis catchment.
2. Get a representative background level for an unimpacted site (upstream of Pass Burn).
3. Assess water quality in the Lindis catchment against water quality standards in the Regional Plan: Water.
4. Assess habitat quality, periphyton and macroinvertebrate communities in the Lindis catchment.
5. Provide a water quality and ecological baseline for comparison with in the future prior to a minimum flow being in place and further irrigation development.

Water quality in the upper Lindis River is generally very good, but the lower catchment has high concentrations of total nitrogen (TN) and nitrate-nitrite nitrogen (NNN). Long-term increasing trends (2005-2014) in TN and NNN and decreasing trend for dissolved reactive phosphorus (DRP) were detected for the Ardgour Road hydrological site, while a decreasing trend in *E. coli* concentrations was detected at Lindis Peak over the period 2003-2014.

TN and NNN concentrations at sites downstream of Archies Flat were markedly higher than at sites upstream and are currently likely to exceed Schedule 15 standards for NNN. However, given that 80th percentiles for most of the sites were calculated from only one year of data (the exceptions being the SoE sites at Lindis Peak and Ardgour Road), these results should be interpreted with caution. This deterioration in water quality coincides with the location of the major water takes from the Lindis River and is likely to be a result of nitrogen-enriched (relative to surface water) groundwater entering the river. Water quality in the two tributaries sampled in this study (Cluden and Wainui Streams) was generally poorer than most mainstem sites, with relatively high TN, TP and DRP concentrations. Concentrations of NNN and *E. coli* were relatively low in both tributary sites.

Comparison of 80th percentiles of water quality parameters with receiving water quality limits in the Regional Plan: Water (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	NH_4-N 0.1 mg/l	DRP 0.01 mg/l	*E. coli* 260 cfu/100 ml	Turbidity 5 NTU
Lindis R. - u/s Pass Burn	2013-2014	0.001	0.005	0.004	30	-
Lindis R. - Black Bridge	2013-2014	0.024	0.005	0.002	51	-
Lindis R. - Lindis Peak	2013-2014	0.012	0.005	0.002	170	0.9
	2008-2013	0.013	0.005	0.002	130	0.8
Lindis R. - u/s Cluden	2013-2014	0.061	0.005	0.002	100	-
Lindis R. - Archies Flat	2013-2014	0.032	0.005	0.002	55	-
Lindis R. - Ardgour Road bridge	2013-2014	0.310	0.005	0.002	114	-
Lindis R. - Ardgour Road hydrological site	2013-2014	0.220	0.005	0.002	120	0.6
	2008-2013	0.212	0.005	0.002	128	1.1
Lindis R. - SH8	2013-2014	0.124	0.005	0.002	75	-
Cluden Stream	2013-2014	0.001	0.005	0.004	72	-
Wainui Stream	2013-2014	0.001	0.005	0.004	72	-

Water temperatures at the Ardgour hydrological site and Lindis Peak are generally suitable for the native and introduced fish present, although temperatures at Lindis Peak may be too warm for rainbow trout at times.

Coarse gravels, cobbles and fine gravels dominated the bed at all sites. 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, broom and rank grass.

The periphyton community at sites in the upper Lindis catchment (above Lindis Peak) were generally indicative of unenriched conditions, with low chlorophyll a concentrations and low cover by long filamentous algae. Much greater periphyton growths were observed at Ardgour Road Bridge and the Ardgour Road hydrological site, most likely as a result of a combination of more enrichment and/or lower flows at this downstream site

Macroinvertebrate communities collected from the Lindis River (2006-2014) were consistent with good water quality. However, macroinvertebrate samples collected as part of this study in October indicated good to excellent water quality throughout the catchment, while samples collected in February were consistent with good water quality upstream of Lindis Peak and fair or good water quality downstream. This may reflect a combination of low, stable flows, the presence of the invasive diatom Didymosphenia geminata and/or water quality in the lower sites.Macroinvertebrate communities in Cluden stream indicated good-fair water quality in October 2014, but fair-poor water quality in February 2015. Macroinvertebrate communities in Wainui stream in October 2014 indicated good-fair water quality.

Common and upland bullies, brown and rainbow trout and longfin eels have been collected from the lower Lindis River.

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1 Introduction

The Lindis River is a major tributary of the upper Clutha River, with the confluence a short distance upstream of Lake Dunstan. The river is fed by high rainfall (>1 m per annum) in the steep upper catchment, while the lower Lindis catchment and the Tarras Basin receive very low levels of rainfall (<450 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 lower Lindis River drying 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). However, land-use in the Lindis catchment has changed since that study was conducted. Despite the lack of any additional water takes within the Lindis catchment due to the catchment being over-allocated, conversion of pasture that had previously been flood or border-dyke irrigated to more efficient spray irrigation has led to an increase in the area of land being irrigated within the catchment (see Section 2.1.3). This change in irrigation method also has the potential to improve water quality in the Lindis 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 increasing faecal contamination of receiving waters (ORC 2006b) as well as having a higher rate of nitrogen leaching relative to spray irrigation (Lilburne *et al.* 2010).

1.1 Purpose

The objectives of this water quality study are to:

1. Assess spatial and temporal patterns in water quality in order to assess the effects of land-use on water quality in the Lindis catchment.
2. Get a representative background level for an unimpacted site (upstream of Pass Burn).
3. Assess water quality in the Lindis catchment against water quality standards in the Regional Plan: Water.
4. Assess habitat quality, periphyton and macroinvertebrate communities in the Lindis catchment.
5. Provide a water quality and ecological baseline for comparison with in the future prior to a minimum flow being in place and further irrigation development.

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

2 Background

2.1 Catchment description

The Lindis River rises in the low ranges to the north of the Lindis Pass, bounded to the east by the Ahuriri catchment and to the west by Timaru River and Dingle Burn catchments (Figure 2.1). The highest point in the Lindis catchment (982 km^2) is Mount Martha (1906 m a.s.l.), while the lower reaches at the confluence with the Clutha River, just upstream of Lake Dunstan has an elevation of approximately 220 m a.s.l..

The Tarras Basin (80 km^2) sits immediately to the west of the lower Lindis catchment. Surface water bodies within this area do not discharge into the Lindis River at low flows and groundwater studies suggest that groundwater from this area discharges to the Clutha River and so waterways in the Tarras area are not considered part of the Lindis catchment for the purposes of this report (Figure 2.1). However, considerable amounts of water from the Lindis River are transferred into this area by the Lindis Irrigation race.

2.1.1 Climate

Most (80%) of the Lindis catchment is classified as having a 'cool, dry' climate (mean annual temperature <12°C, mean effective precipitation ≤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 500-1500mm) (River Environment Classification, Ministry for the Environment & NIWA, 2004). Rainfall is highest in the upper catchment (>1300 mm) and declines in a downstream direction, with parts of the lower catchment receiving less than 400 mm of rainfall (Figure 2.2).

The Lindis catchment has a continental climate, reflecting 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 Lindis catchment (approximately 10 km from the nearest point in the Lindis catchment), show that air temperatures vary markedly through 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**

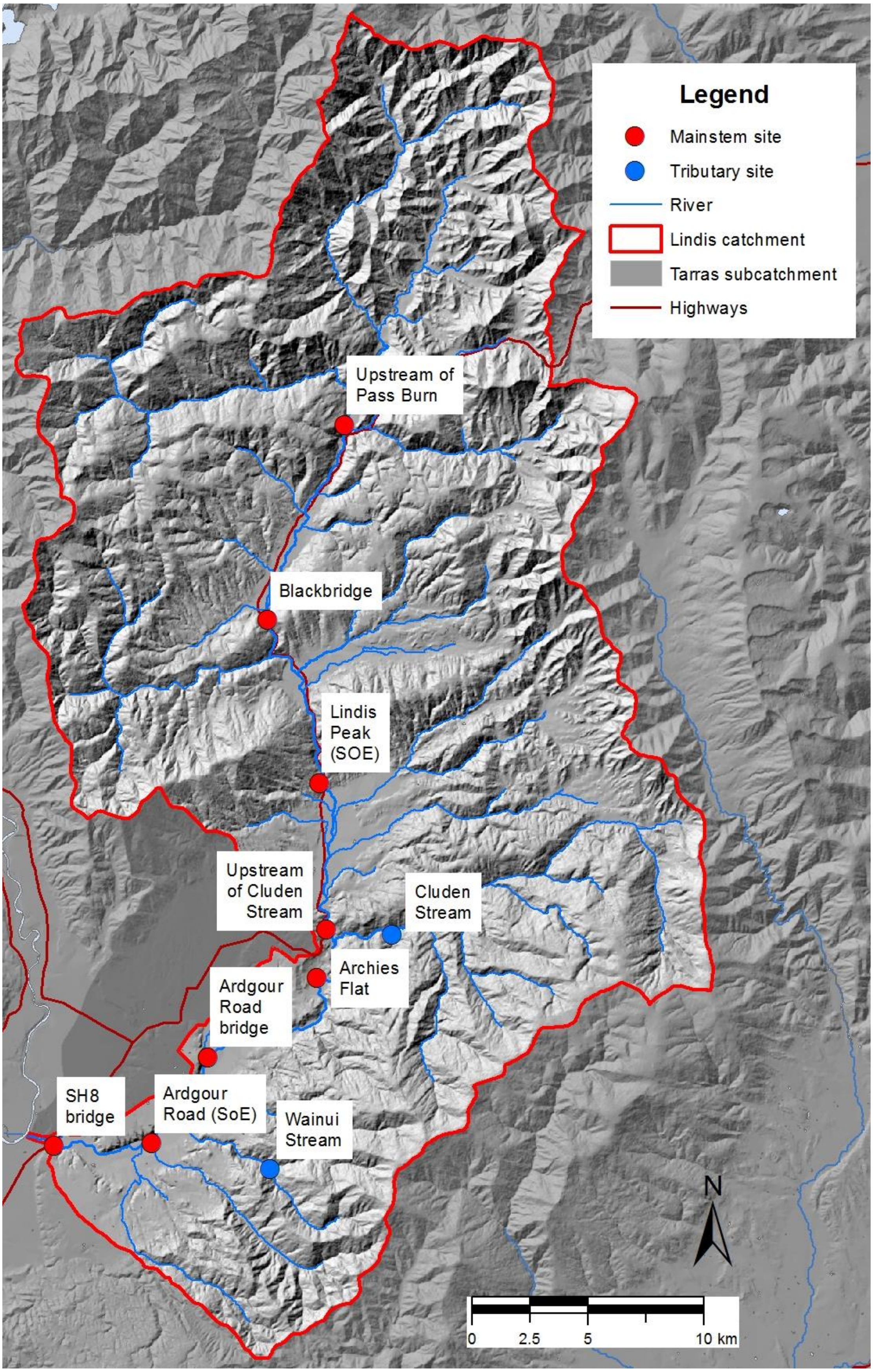

Figure 2.1 **Lindis catcment showing water quality monitoring sites. The Lindis Peak and Ardgour Road sites are also hydrological monitoring sites.**

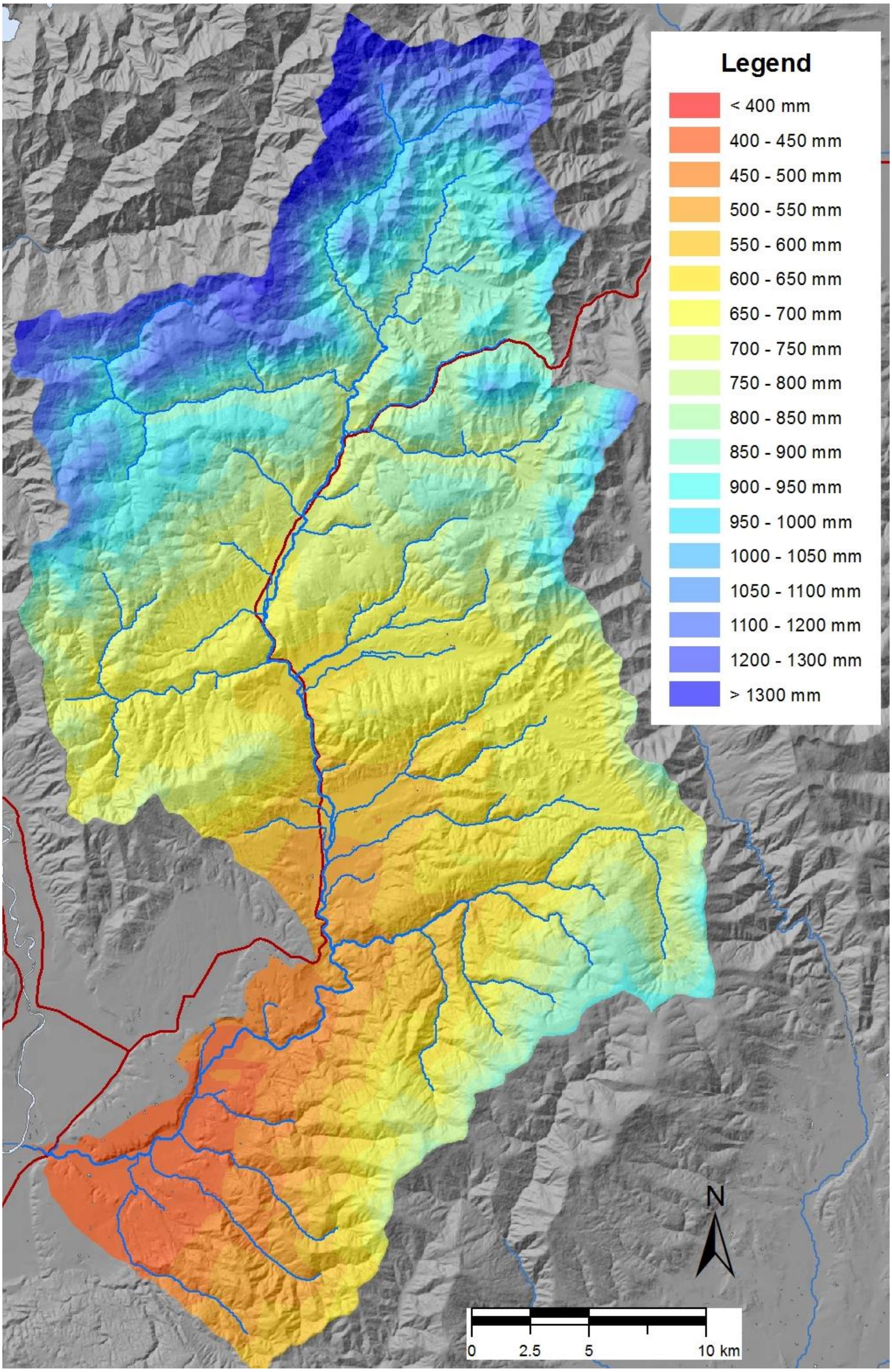

Figure 2.2 **Mean annual rainfall (mm) in the Lindis catchment (Source: growOTAGO).**

2.1.2 Geology and geomorphology

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

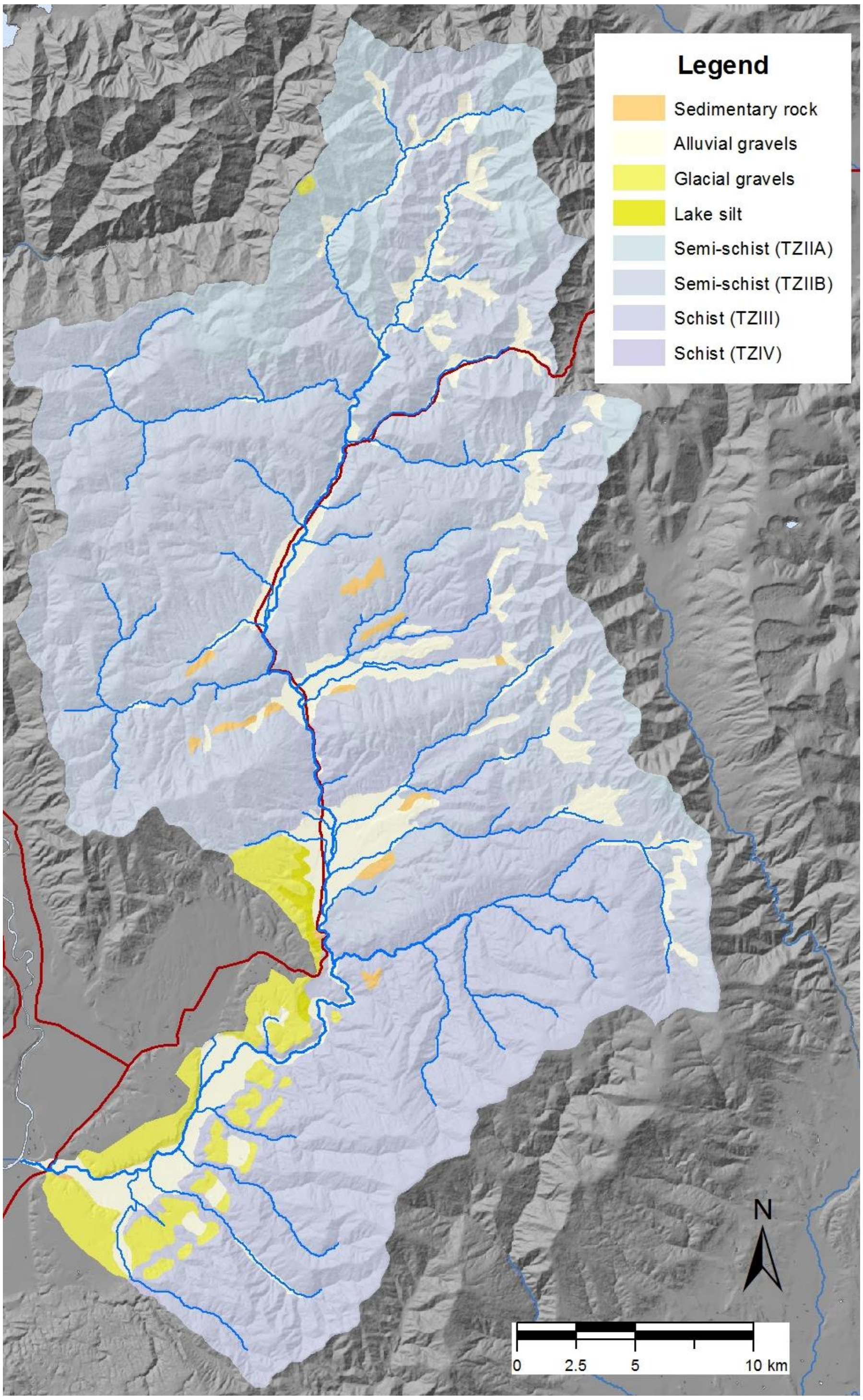

Figure 2.3 **Geology of the Lindis catchment (Source: QMAP seasmless digital data 2012. GNS Science).**

2.1.3 Catchment land use

The majority of the Lindis catchment consists of agricultural grasslands with low producing grassland (45%) and tall tussock grasslands (28%) dominating the hill country, while areas of high producing pasture grasslands (9%) are mostly found on river flats and in the lower part of the catchment, along with some areas of short-rotation cropping (Table 2.2, Figure 2.4).

The area of irrigated land in the Lindis catchment has increased in recent years with the shift from flood irrigation to more efficient spray irrigators. Analysis based on aerial photographs taken on 6 April 2005 (upper catchment) and 26 February 2006 (lower catchment) estimated that approximately 1607 ha of the catchment was irrigated, with the predominant irrigation method being flood irrigation (79%), with some spray irrigation (20%) and a small area of drip irrigation (1%), mostly for viticulture and olive groves (Figure 2.5).

Analysis of satellite imagery (Pleiades, Airbus Defence & Space) from December 2013 estimated that approximately 2328 ha was irrigated, representing an increase of 45% from 2005/2006 (Figure 2.5). Of this irrigated area, approximately 26% was flood irrigated and 74% spray irrigated.

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

Vegetation type	Area (km^2)	% cover
Alpine/sub-alpine vegetation	6.0	1
High Producing Exotic Grassland	84.4	9
Low Producing Grassland	438.6	45
Depleted Grassland	70.8	7
Short-rotation Cropland	3.5	0.4
Tall Tussock Grassland	277.3	28
Exotic Forest	0.8	0.1
Native forest	10.6	1
Scrub	73.8	8

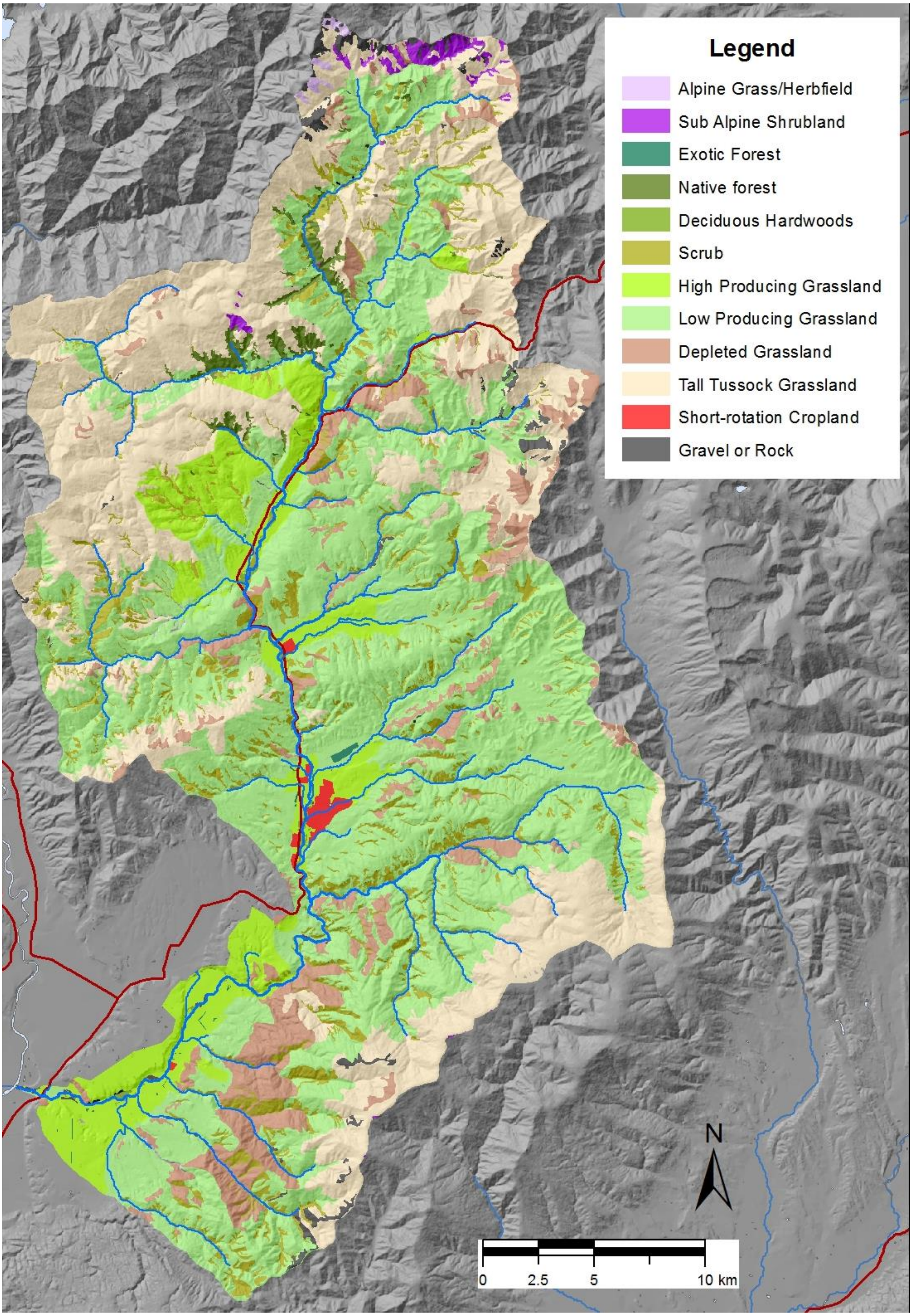

Figure 2.4 **Land cover of the Lindis catchment based on the Land Cover Database (v.4)**

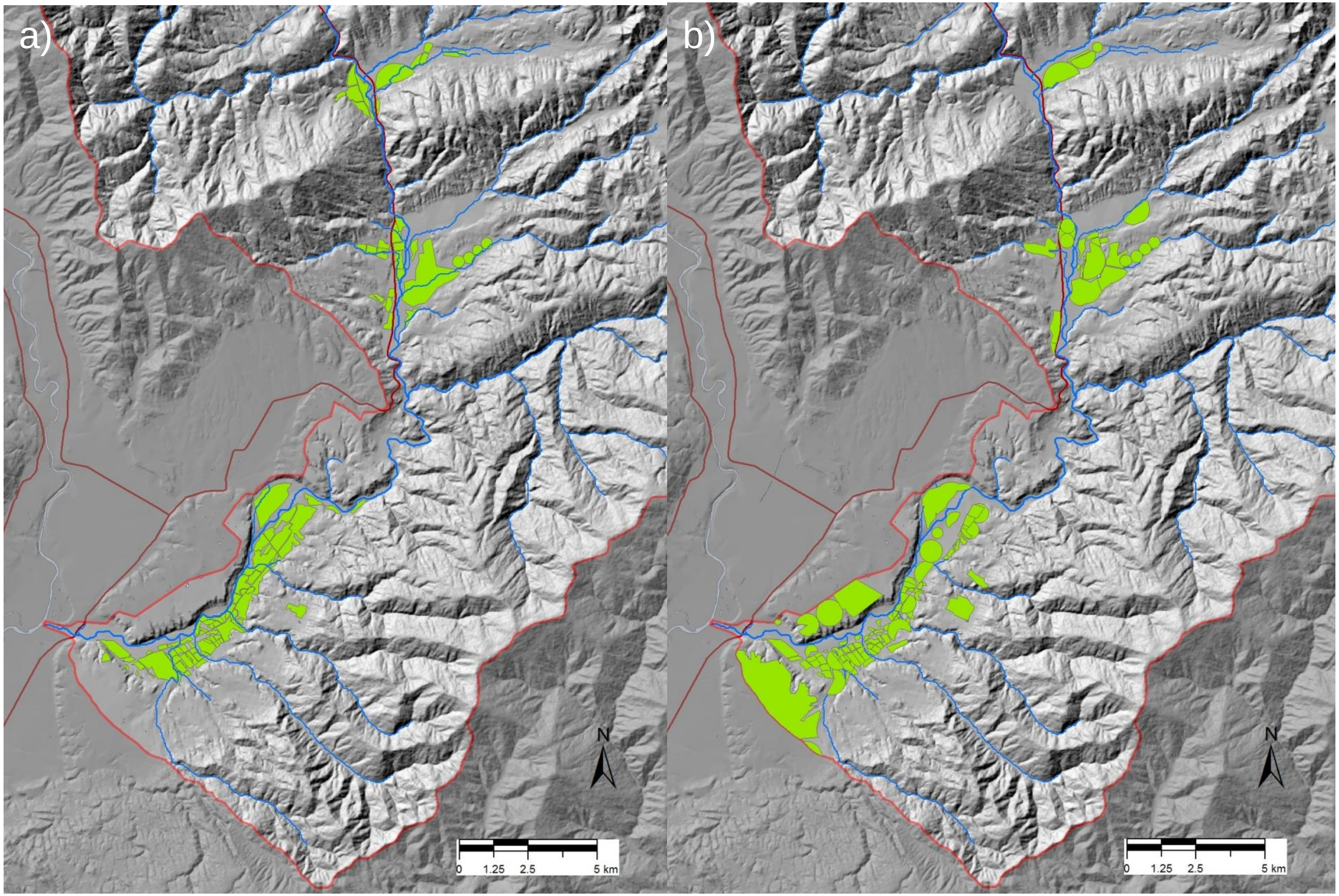

Figure 2.5 **Irrigated area in the Lindis catchment in a) 2005-2006, and b) 2013.**

2.2 Hydrology and water use

The hydrology of the Lindis catchment was reviewed in detail in a management flow report prepared in 2008 (Otago Regional Council 2008). Flow statistics for the two permanent flow recorders in the Lindis River are outlined in Table 2.3.

Flows in the middle and lower reaches of the Lindis River are heavily influenced by water abstraction as well as losses to groundwater (ORC 2008). The naturalised mean annual low flow (MALF)[2] at Ardgour Road is estimated at 1,864 l/s (ORC 2014). At low flows, it was estimated that approximately 440 l/s was lost to groundwater between Ardgour Road and the Clutha confluence (ORC 2008), although a more recent study estimates that this loss is approximately 525 l/s (ORC, unpublished data). Total allocation in the Lindis Catchment is 4,268 l/s, although peak actual use is estimated to be 2,300 l/s. Much of the allocation in the catchment is in the form of large surface water takes from the mainstem in the vicinity and downstream of Cluden Stream, while many of the tributaries also have water takes on them (Figure 2.1).

Table 2.3 **Flow statistics for the permanent flow recorders in the Lindis 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
Lindis Peak	186	322,203	6,164	4,195	1,551	38
Ardgour Road	94	260,988	5,403	3,797	262	9

[2] The average of the lowest seven-day low flow period for every year of record.

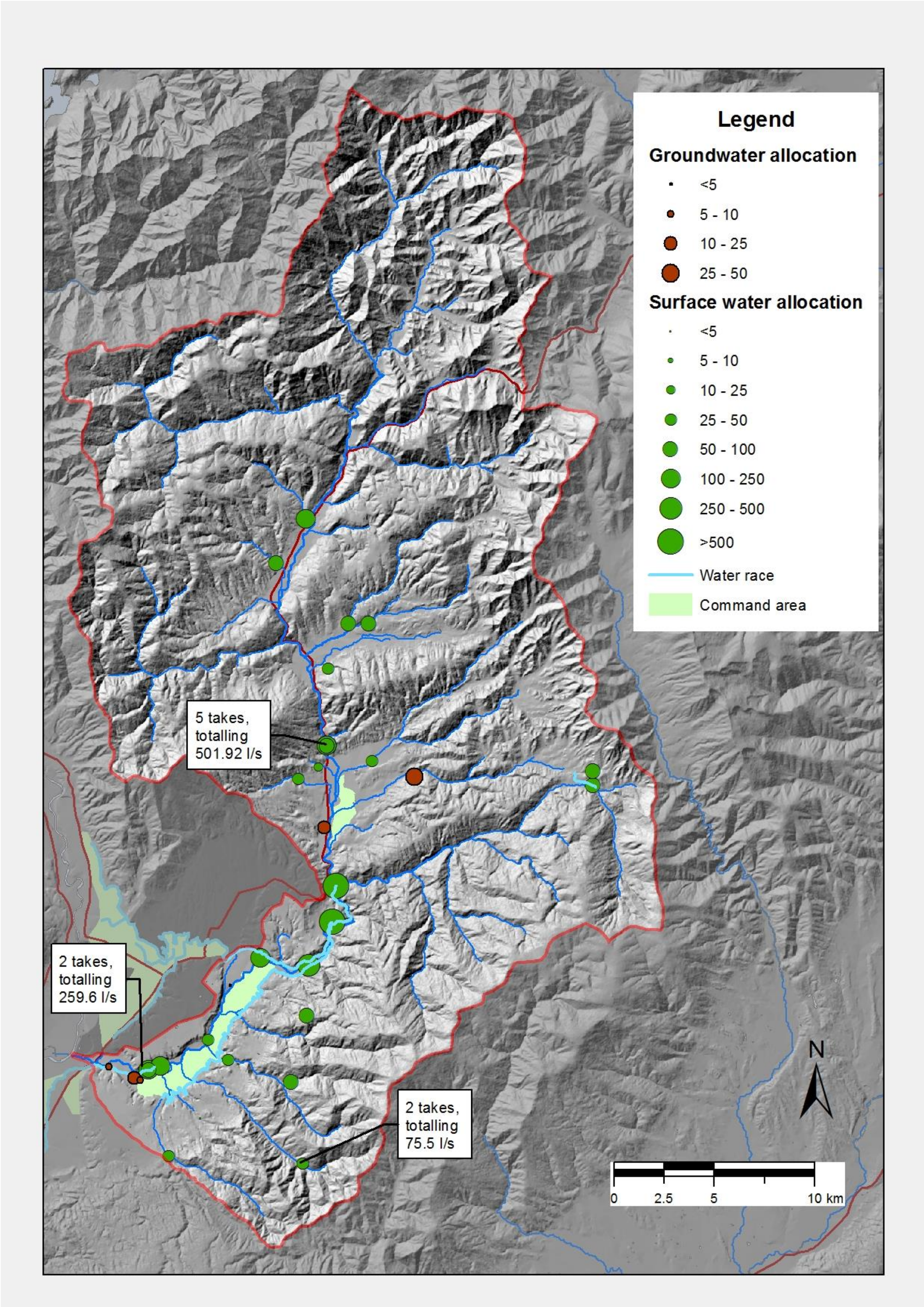

Figure 2.6 **Groundwater and surface water takes, water races and irrigation scheme comand areas in the Lindis River catchment.**

3 Natural values of the Lindis Catchment

3.1 Instream ecological values

Schedule 1A of the Regional Plan: Water for Otago identifies the natural values of Otago's waterways including ecosystem values and significant habitat for indigenous fauna. The Lindis River is recognised as providing habitat for trout spawning, juvenile rearing and adult trout as well as for longfin eel. Both brown trout and rainbow trout have been recorded from the Lindis catchment, although brown trout are more widespread and abundant in the catchment (ORC 2008).

Native fish recorded from the Lindis catchment have included longfin eel, Clutha flathead galaxias, koaro and common and upland bullies (ORC 2008). 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). Both common and upland bullies were classified as "not threatened" (Goodman *et al.* 2014).

3.2 Recreational values

Recreational activities in the Lindis River include swimming and trout fishing. The Lindis River receives a low level of angling effort (Table 3.1), but is a significant spawning tributary of the nationally significant Lake Dunstan fishery (Unwin 2009).

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

Season	Effort
1994/1995	280 ± 100
2001/2002	150 ± 90
2007/2008	330 ± 220

4 Regional planning

4.1 Water quality guidelines

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 Lindis catchment is in receiving water group 2. The numerical water quality limits for this group are outlined in Table 4.1.

For the upper Lindis catchment (upstream of the Lindis Peak monitoring site), the receiving water limits (Schedule 15) outlined in Table 4.1 are applied as 5-year, 80th percentiles when flows are at or below a reference flow of 3,510 l/s at the Lindis Peak hydrological monitoring site (Figure 2.1). For the lower Lindis catchment (downstream of the Lindis Peak monitoring site to the Clutha confluence), the receiving water limits outlined in Table 4.1 are applied as 5-year, 80th percentiles when flows are at or below a reference flow of 3,500 l/s at the Ardgour Road hydrological monitoring site (Figure 2.1).

Table 4.1 Receiving water numerical limits and timeframe for achieving 'good' water quality in the Lindis 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 is undertaken at two sites in the Lindis catchment: Lindis Peak (since 8 October 2003) and Ardgour Road (since 25 October 2005).

5.1.2 Catchment water quality sampling 2012-2013

Water quality samples were collected from each of the seven monitoring sites every fortnight between 30 September 2013 and 15 September 2014. 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 *Escherichia coli* (*E. coli*). These analyses were conducted by Hill Laboratories (Hamilton, www.hill-labs.co.nz), except the samples collected on 14 and 28 August 2014, and 15 September 2014 which were analysed by Watercare Laboratory Services (Auckland, www.watercarelabs.co.nz). The methods employed by each lab are outlined in Appendix A.

5.2 Habitat assessment

Sediment composition was visually assessed using an underwater viewer at five or more 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. Riparian vegetation at each site was noted, as was livestock access to the river channel.

5.3 Periphyton

5.3.1 Long-term monitoring

Periphyton community composition was monitored at two sites as part of SoE monitoring. 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. The scrubbings from the three stones were pooled and transferred to a sample container using river water. The sample was transported to the laboratory and preserved in formaldehyde.

In the laboratory, each sample was thoroughly mixed, and three aliquots were removed to an inverted microscope settling chamber. They were then allowed to settle for 10 minutes. Samples were analysed according to the 'relative abundance using an 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 2014/2015 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 at five points across the river on four transects within a 100 m reach using an underwater viewer. 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).

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		Enrichment 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**

In addition to assessments of periphyton cover, periphyton biomass was assessed using rock scrapes from ten randomly chosen stones in 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 was frozen within 12 hours of collection.

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 on to 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 10 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 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 and Kilroy 2000) and scaled to the number of milligrams of chlorophyll *a* per m^2 of stream bed.

5.4 Macroinvertebrates

Macroinvertebrate communities were sampled at seven sites in the Lindis River and two tributaries (Cluden and Wainui Streams) on 21 October 2014 and 17 February 2015. At each site, one 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).

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 2006 at Lindis Peak and Ardgour Road using a pulsed DC Kainga EFM300 backpack electric fishing machine. Since 2009, these surveys have been undertaken following the New Zealand Freshwater Fish Sampling Protocols (Joy *et al.* 2013). Breifly, 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.

Fish communities at the Ardgour Road bridge were also monitored in 2007 and 2008 by stop-netting and three-pass electric fishing a known area of streambed.

5.6 Data analysis and presentation

5.6.1 Trend analysis

Long-term trends in water quality parameters and macroinvertebrate indices were considered using a seasonal Kendall trend test in Time Trends statistical software (Version 3.00, NIWA). Tests for water quality variables were performed with six seasons per year (fitting with the 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), with the covariate adjustment method used being locally weighted scatterplot smoothing (Lowess) curve with a tension of 0.3 (i.e. 30% of points to fit) and five iterations.

5.6.2 Boxplots

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

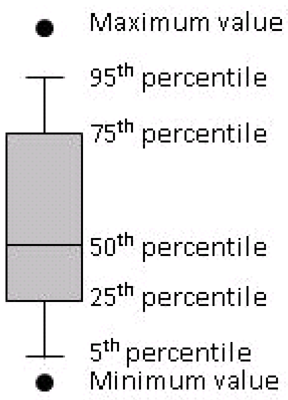

Figure 5.1 **The interpretation of the various components of a box plot, as presented in this report**

6 Results

6.1 Long-term monitoring

6.1.1 Trend analyses

Analysis of trends in water quality parameters at Lindis Peak shows that most parameters had not changed between 2003 and 2014, with the exception of *E. coli* counts, which declined significantly over this period (Table 6.1, Figure 6.1). However, at the Ardgour Road site, there was a significant increasing trend in NNN and TN and a significant decrease in DRP over the period 2005-2014, while the other parameters considered did not show any trend over this period (Table 6.1, Figure 6.2).

Trends in ammoniacal nitrogen were not assessed for either site due to the very low concentrations observed at both sites (Figure 6.1, Figure 6.2).

Table 6.1 Trends in water quality parameters at the SoE sites in the Lindis 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. Trends with a *P*-value of less than 0.05 are considered to be statistically significant.

Site	Variable	*Z*	*P*	Trend
Lindis Peak	NNN	0.84	0.4036	n.s.
(8 Oct 2003 to	TN	-0.58	0.5642	n.s.
23 Apr 2014)	DRP	-0.90	0.3681	n.s.
	TP	0.12	0.9073	n.s.
	E. coli	-3.09	0.0020	Declining
	Turbidity	-1.87	0.0622	n.s.
Ardgour Rd	NNN	3.58	0.0003	Increasing
(25-Oct-2005 to	TN	2.78	0.0087	Increasing
23-Apr-2014)	DRP	-2.77	0.0056	Declining
	TP	-1.61	0.1084	n.s.
	E. coli	0.67	0.5054	n.s.
	Turbidity	-1.24	0.2152	n.s.

6.1.2 Compliance with water quality limits

Schedule 15 of the Regional Plan: Water sets out water quality limits and targets for receiving waters in the Otago region (Section 4). These limits apply as 5-year, 80th percentiles when flows are at or below the reference flow at the appropriate monitoring site. For sites upstream of Lindis Peak, the reference flow is 351 l/s at the Lindis Peak flow monitoring site, while for sites downstream of Lindis Peak, the reference flow is 350 l/s at the Ardgour Road flow monitoring site. Monitoring data collected from Lindis Peak and Ardgour Road sites when flows were below the appropriate reference flow were compared to receiving water limits. None of the variables considered at the Lindis Peak site exceeded the Schedule 15 limit (Figure 6.2). Of the variables considered at the Ardgour Road site, only NNN exceeded the limit (Figure 6.2).

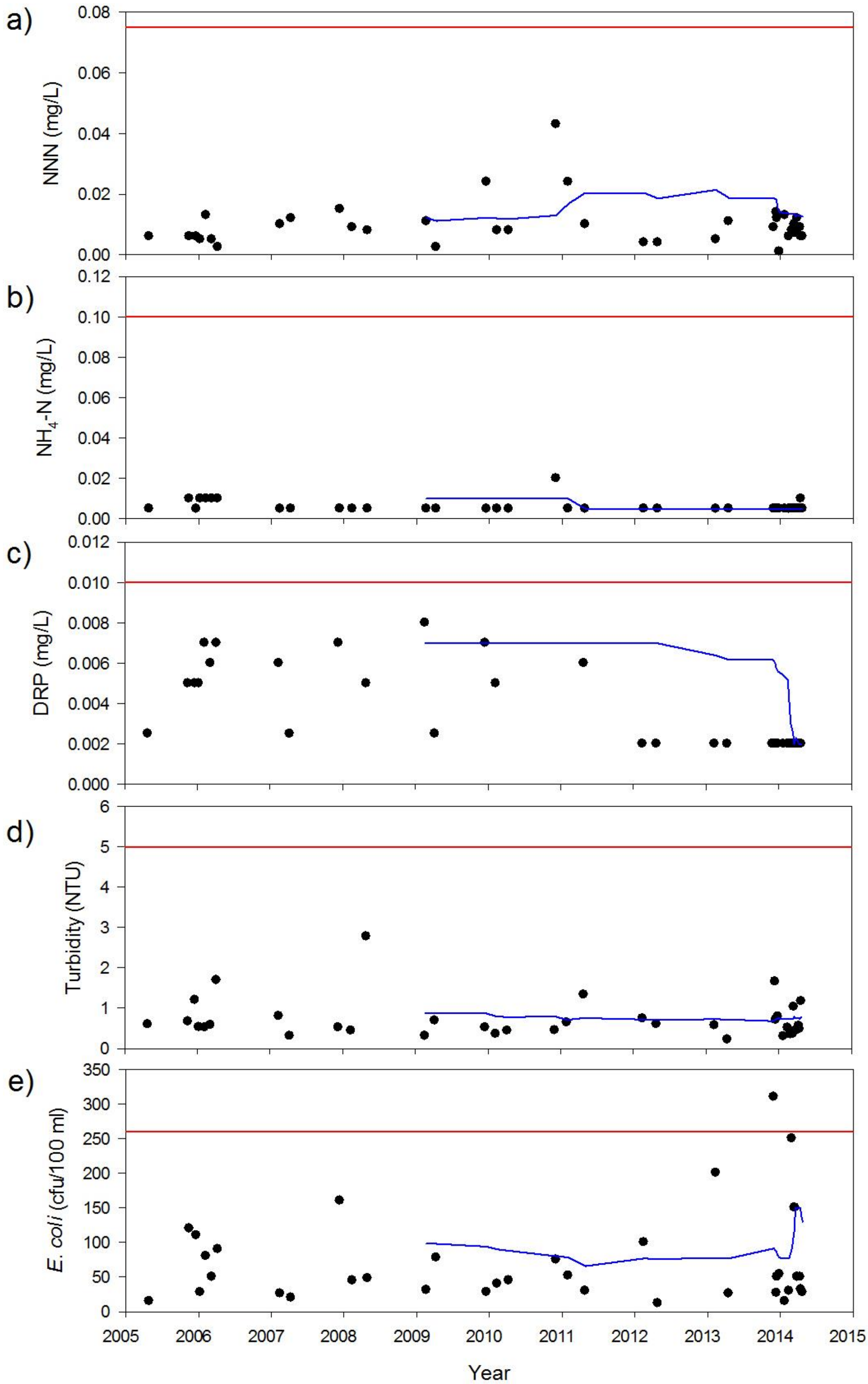

Figure 6.1 **Comparison of a) NNN, b) NH4-N, c) DRP, d) turbidity and e) *E. coli* at the Lindis Peak site when flows are below median flow with Schedule 15 standards (red lines). Blue lines represent 5-year moving 80th percentiles.**

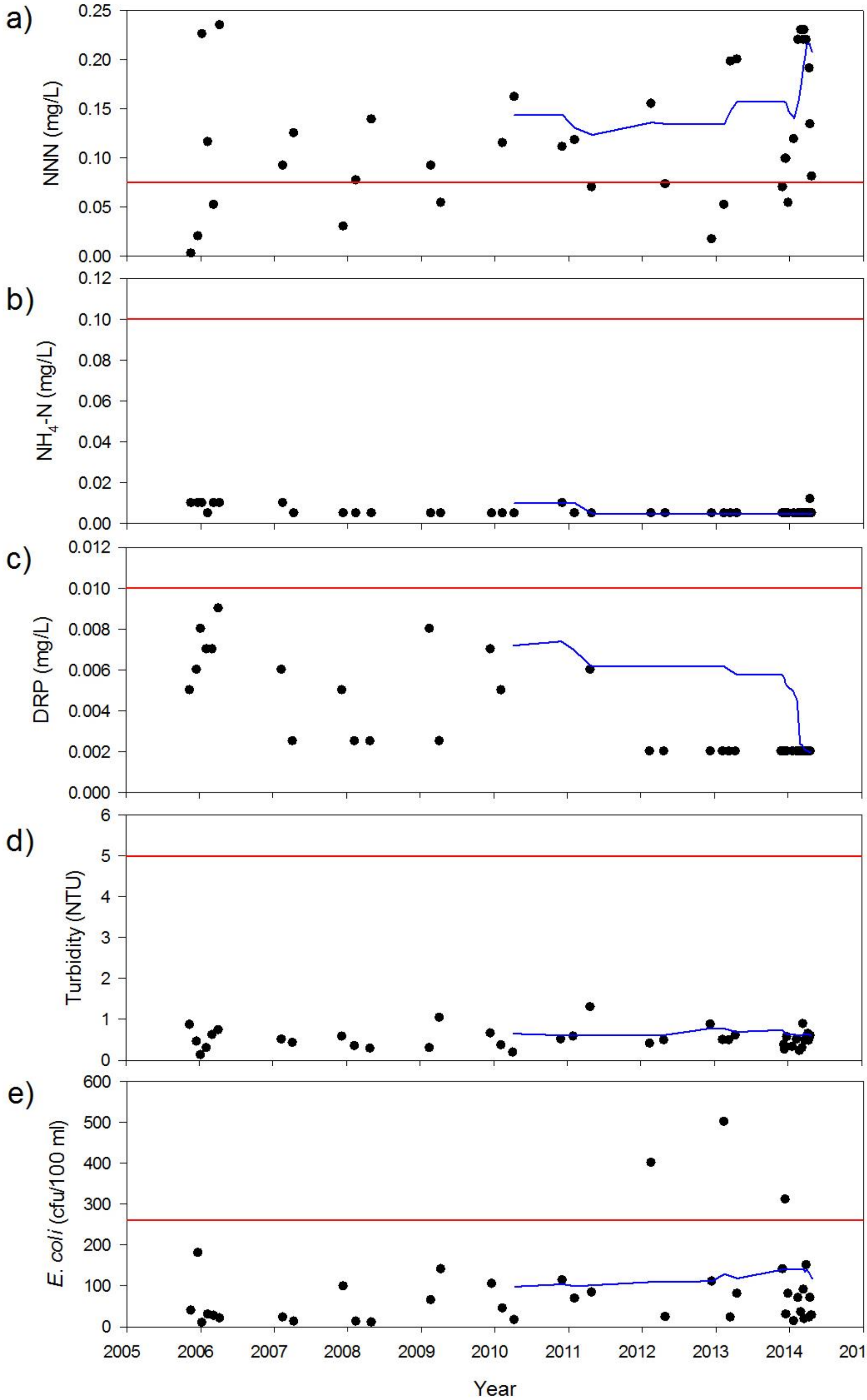

Figure 6.2 **Comparison of a) NNN, b) NH4-N, c) DRP, d) turbidity and e) *E. coli* at the Ardgour Road site when flows are below median flow with Schedule 15 standards (red lines). Blue lines represent 5-year moving 80th percentiles.**

6.2 Water temperature

Extensive water temperature records are available for the two long-term hydrology sites in the Lindis River. Records are available for the Ardgour Road site from 19 January 2006 to 15 July 2014 while records from Lindis Peak span 20 April 2004 to 8 April 2009.

Water temperatures in the Lindis River vary widely, with temperatures close to freezing in winter months, rising to up to 22°C in mid-summer (Table 6.2). Maximum 2-hour and weekly moving averages were calculated for each period for comparison with thermal criteria for the protection of freshwater life. The highest recorded 2-hour average temperatures were 21.9°C at Lindis Peak and 21.9°C at Ardgour Road, while the highest weekly averages were 18.5°C and 17.0°C at Lindis Peak and Ardgour Road, respectively (Table 6.2).

Table 6.2 Water temperature statistics for two sites in the Lindis River.

Site	Hydrological year	Instantaneous temperature			Moving averages	
		Min	Max	Mean	Max. 2 hour	Max. weekly
Lindis Peak	2004-2005	0.0	21.9	8.6	21.9	18.5
	2005-2006	-0.1	20.7	9.5	20.7	17.8
	2006-2007	0.1	20.1	9.1	20.0	16.7
	2007-2008	0.1	20.3	9.8	20.3	17.7
Lindis at Ardgour Road	2006-2007	0.1	20.9	9.9	20.9	16.6
	2007-2008	0.6	20.2	9.7	20.1	16.2
	2008-2009	1.1	21.3	9.9	21.1	17.0
	2009-2010	1.7	20.3	9.6	20.2	16.3
	2010-2011	1.0	21.0	9.9	20.9	16.0
	2011-2012	0.8	21.1	9.5	20.9	16.8
	2012-2013	0.1	21.9	10.4	21.8	17.0

6.3 Catchment water quality survey

6.3.1 Nitrogen

Total nitrogen (TN) concentrations were very low at the upper sites as far downstream as Lindis Peak and increased with distance downstream, with the highest concentrations observed at Ardgour Road and SH8 (Figure 6.3). Generally, these patterns were similar whether considering low flows or all flows, although TN concentrations were much lower during low flows at most sites (Figure 6.3). TN concentrations in the two tributaries sampled were generally low, but were higher in Wainui Stream than Cluden Stream during low flows (Figure 6.3).

NNN showed similar patterns to TN; NNN was low in the upper Lindis River and tributary monitoring sites and increased with distance downstream with highest concentrations observed at the three most downstream sites (Figure 6.4). The increase in NNN concentrations between Archies Flat and the Ardgour Road Bridge was particularly evident during periods of low flow (Figure 6.4).

Concentrations of NH_4-N were very low at all sites on all occasions, with the majority of readings at all sites below the detection limit (0.01 mg/L; Figure 6.3).

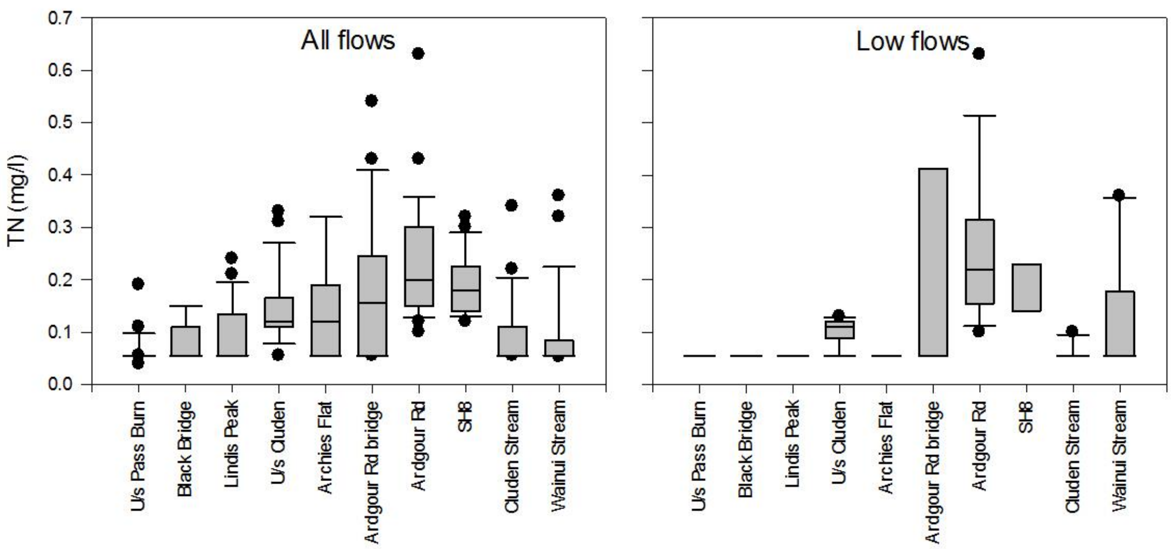

Figure 6.3 TN concentrations in the Lindis River under all flows and low flows.

Schedule 15 of the Regional Plan: Water sets out water quality limits for receiving waters in the Otago region (Schedule 15; Table 4.1). These limits apply as 5-year, 80th percentiles, when flows are at or below the reference flow in Table 16B of plan change 6A. For sites upstream of Lindis Peak, the reference flow is 3,510 l/s at Lindis Peak, while a reference flow of 3,500 l/s at the Ardgour Road flow recorder applies to sites downstream of Lindis Peak. Between seven and thirteen samples were collected from sites in the Lindis River during periods when flows were below median flow between 30 September 2013 and 15 September 2014 and were compared to the Schedule 15 limits. The 80th percentiles of NNN concentrations at the Ardgour Road bridge, Ardgour Road and SH8 exceeded the limit while concentrations at all other sites were well below the Schedule 15 limit (Figure 6.4). Concentrations of NH4-N at all sites were well within the limit (Figure 6.5).

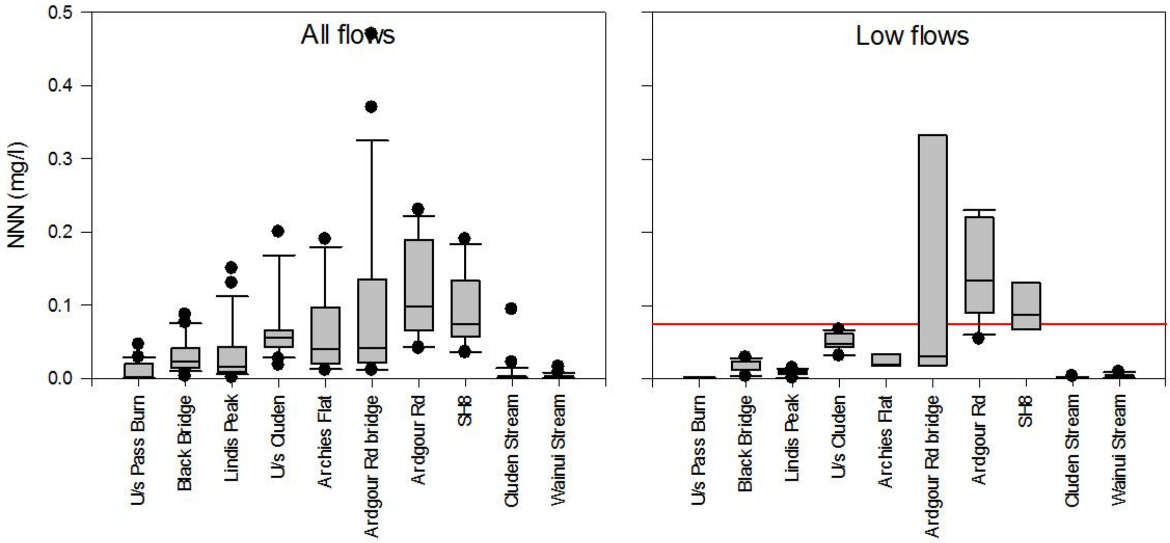

Figure 6.4 **NNN concentrations in the Lindis River under all flows and low flows. The red line represents the Schedule 15 limit from plan change 6a.**

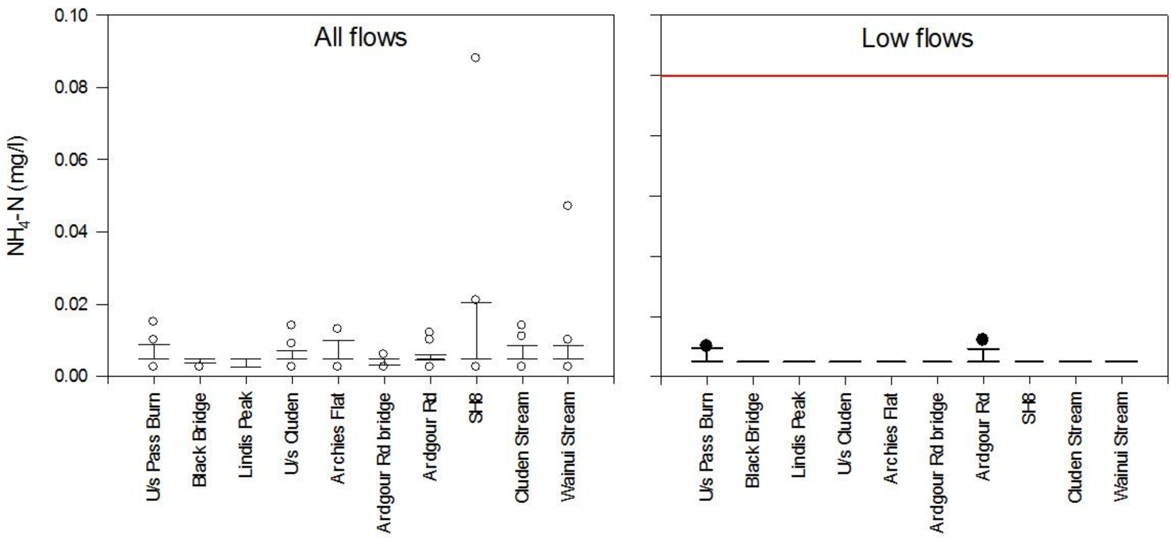

Figure 6.5 **NH_4-N concentrations in the Lindis River under all flows and low flows. The red line represents the Schedule 15 limit from plan change 6a.**

6.3.2 Phosphorus

Total and dissolved reactive phosphorus concentrations were consistently low at all the sites sampled in the Lindis catchment, particularly at low flows, and the majority of values measured at all sites were below the detection limit of 0.004 mg/l (Figure 6.6, Figure 6.7). As a consequence, the 80th percentiles of DRP readings at all sites were within the Schedule 15 limit (Figure 6.7).

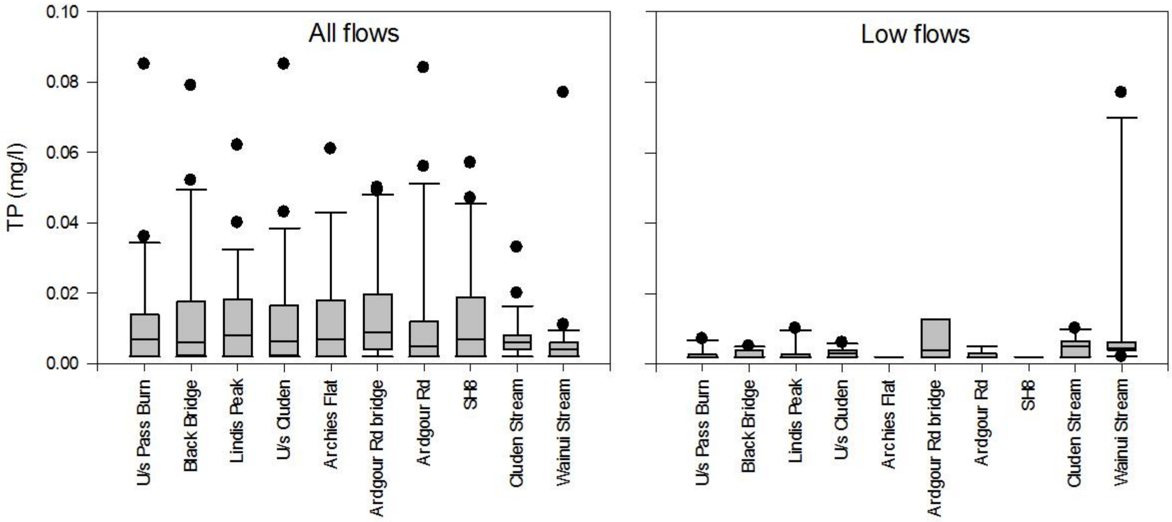

Figure 6.6 **TP concentrations in the Lindis River under all flows and low flows.**

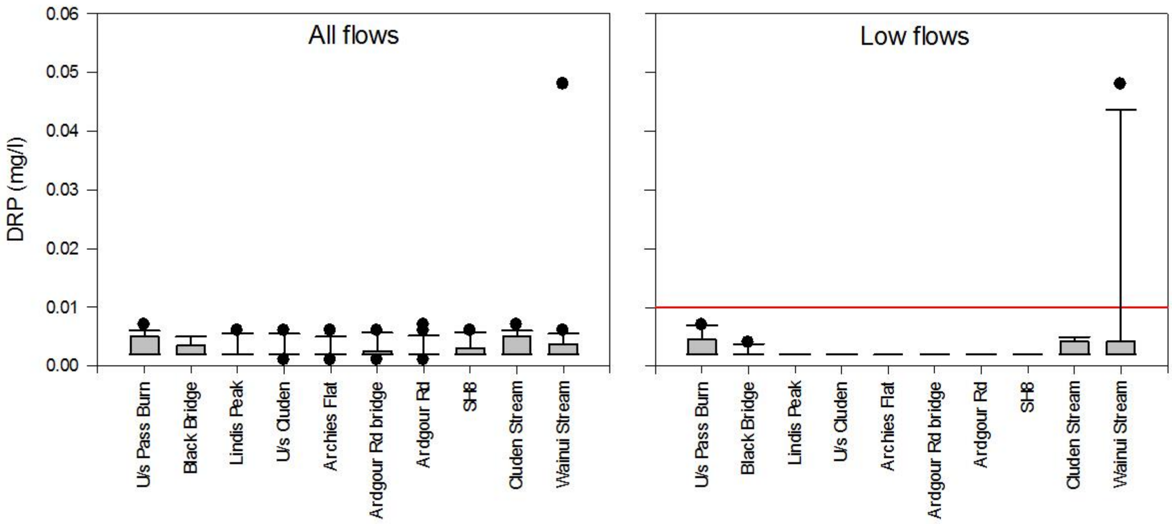

Figure 6.7 **DRP concentrations in the Lindis River under all flows and low flows. The red line represents the Schedule 15 limit from plan change 6a.**

6.3.3 *Escherichia coli*

Concentrations of *E. coli* were low across all sites in the Lindis catchment, with the 80th percentiles during low flows well within the Schedule 15 for *E. coli* at all sites (Figure 6.8).

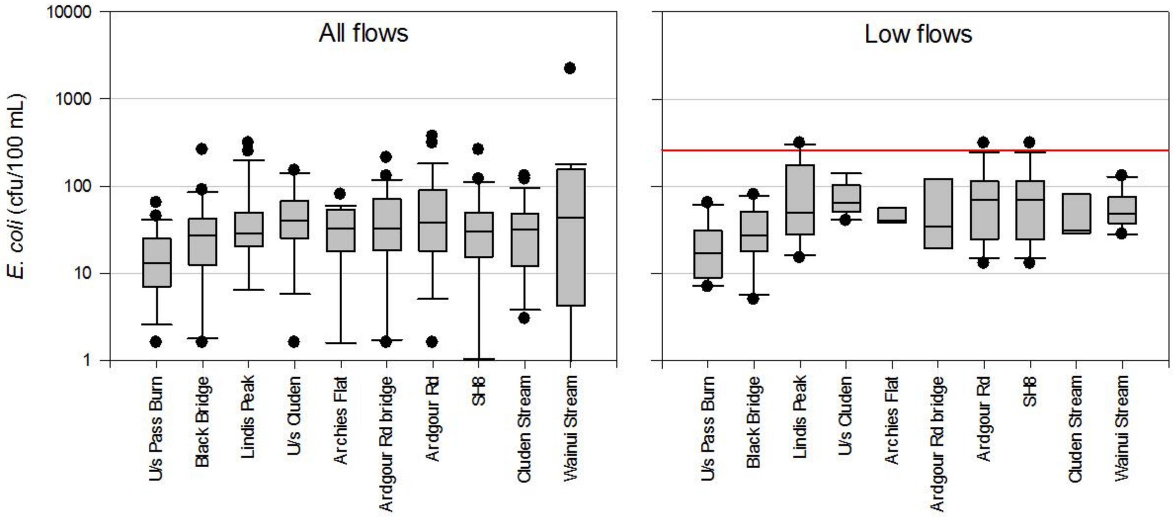

Figure 6.8 ***E. coli*** **concentration in the Lindis River under all flows and low flows. The red line represents the Schedule 15 limit from plan change 6a.**

6.4 Habitat assessments

6.4.1 Riparian management

The riparian vegetation at all sites on the Lindis River was dominated by willows (*Salix* species), exotic pasture grasses and lupins (*Lupinus polyphyllus*). In addition, matagouri (*Discaria toumatou*) and rosehips (*Rosa canina*) were present at the site upstream of the Pass Burn. Most sites were not fenced from surrounding farmland, and stock 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). Cobbles (128-256 mm) dominated riffles at the Ardgour Road bridge and runs were dominated by fine gravels upstream of Cluden Stream, while at the Ardgour Road hydrological monitoring site, riffles had similar cover by cobbles, coarse gravels and fine gravels (2-8 mm), while runs were dominated by coarse gravels (Table 6.3).

Table 6.3 Substrate composition (% cover) at the seven sites in the Lindis catchment on 21 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 pass burn	10	29	38	23	0
	Black Bridge	0	2	75	18	5
	Lindis Peak	15	25	50	10	0
	u/s Cluden	0	8	52	40	0
	Ardgour Road bridge	0	86	6	6	2
	Ardgour Road	21	27	26	26	0
	SH8	-	-	-	-	-
Run	U/s pass burn	-	-	-	-	-
	Black Bridge	0	30	45	13	12
	Lindis Peak	0	0	100	0	0
	u/s Cluden	0	0	20	50	30
	Ardgour Road bridge	0	23	48	28	0
	Ardgour Road	0	0	73	23	4
	SH8	0	0	75	20	5
Pool	Black Bridge	0	0	70	22	8

6.5 Periphyton

6.5.1 Long-term monitoring

Periphyton community composition was monitored at Lindis Peak in 2003, 2004 and 2006 and at the Ardgour Road site since 2006 (Table 6.4). The periphyton community was dominated by the stalked diatom *Gomphoneis* in 2003 and the red alga *Audouinella* in 2004 and 2006, with the cyanobacterium *Phormidium* present in 2003 and all other taxa identified on all occasions being diatoms (Table 6.4).

The green filamentous algae *Stigeoclonium* was the most abundant taxon at the Ardgour Rd site in 2006, with the cyanobacterium *Phormidium* also present along with various diatoms (Table 6.4). In comparison, in 2007, only diatoms were identified at this site, with the most abundant taxa being *Cymbella* and *Nitzschia* (Table 6.4). The invasive, stalked diatom *Didymosphenia geminata* was first detected in SoE monitoring in 2007 and dominated the periphyton community at the Ardgour Road site in 2008, 2009 and 2011 (Table 6.4). The filamentous green alga *Mougoetia* dominated the periphyton in 2010 and 2015, while *Phormidium* was the most abundant taxon in 2011 and 2014 (Table 6.4).

Table 6.4 **Periphyton taxa collected at two sites in the Lindis 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.**

	Lindis @ Lindis Peak			Lindis River @ Ardgour Rd									
Taxa	**2003**	**2004**	**2006**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Green filamentous													
Microspora											1		
Mougoetia								8		1		3	8
Spirogyra							1	4					3
Stigeoclonium				6									
Ulothrix											3		
Green algae													
Gloecystis spp.								3					
Red/Brown Algae													
Audouinella	3	8	5						2				3
Cyanobacteria													
Oscillatoria/Phormidium	2			3				6	4	3	2	8	2
Diatoms													
Achnanthidium spp.								5					
Cocconeis spp.								2					
Cymbella spp.	5		2	2	6	3	2				4	5	2
Diatoma spp.								2					
Didymosphenia geminata						8	8	5	3	8	3		4
Encyonema spp.								7					
Fragilaria spp.								4					
Frustulia spp.			2	1	3		4			2	3		3
Gomphoneis spp.	8	1						4		2	3	2	
Gomphonema spp.	4	2						3					
Hantzschia spp.									2				
Naviculoid diatom			2	1			6			2	1	4	
Navicula spp.								2					
Nitzschia spp.	3		2		6	3	4	4	2		2	2	
Rhoicosphenia spp.								1			2		
Rossithidium spp.								4					
Synedra spp.	2	3		3	3	5	1	3	2	3	1	3	5
Phytoplankton													
Closterium spp.			1								1		
Cosmarium spp.													1
Staurastrum spp.								1					

6.5.2 2014/15 catchment surveys

Periphyton communities in the Lindis 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 (Figure 16). 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 (Clausen & Biggs 1997, 1998). The corresponding flows in the Lindis River are 12,570 l/s at Lindis Peak and 11,769 l/s at the Ardgour Road hydrological site. No events that were expected to substantially reduce periphyton biomass occurred subsequent to the high-flow event in August 2014, with flows dropping to low flow levels by January 2015 and remaining at these levels for the remainder of the study period (Figure 16). Thus, these surveys present an opportunity to consider periphyton accrual (biomass gain) over a period of more than 200 days.

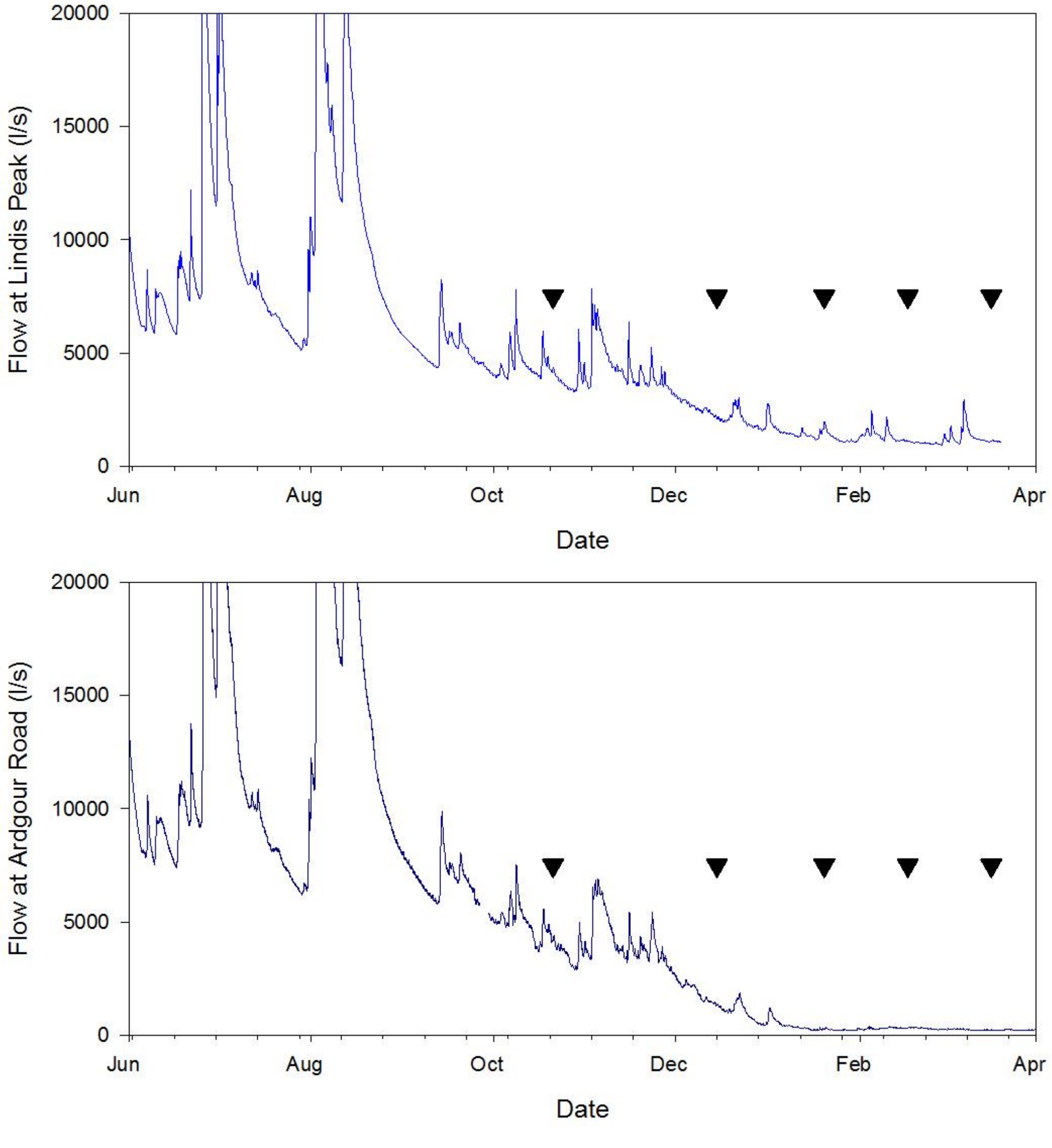

Figure 6.9 **Flows at the two hydrological sites in the Lindis River during and prior-to periphyton surveys undertaken as part of this study. Black triangles represent periphyton survey dates.**

The periphyton community at most sites in the upper Lindis catchment were generally dominated by thin green or light brown (diatom-dominated) films on most sampling occasions, although the colonial cyanobacterium *Nostoc* was the dominant periphyton at the most upstream site (upstream of the Pass Burn) in January, February, and March sampling occasions, but was not observed at the other sites in the catchment (Table 6.5).

The invasive, stalked diatom didymo (*Didymosphenia geminata*) dominated the periphyton community at the Ardgour Road bridge on most sampling occasions, but was observed at most sites in the catchment (Table 6.5).

Benthic cyanobacteria (identified as thin, medium or thick, black/dark brown mats in Table 6.5), most likely *Phormidium* (Figure 6.10), were observed at most sites in the catchment on most occasions (Table 6.5). Medium to thick growths of *Phormidium* were observed at most sites on most occasions (Table 6.5).

Short brown/red filamentous algae was the most abundant periphyton type at Black Bridge and upstream of Cluden Stream in October 2014, but not subsequent occasions, although short brown filaments were evident at Black Bridge in December 2014 and February 2015 (Table 6.5). Short green filamentous algae were recorded at low levels at many of the sites in the Lindis catchment on the survey occasions (Table 6.5). Long green filamentous algae have been present at low levels at many of the sites surveyed on many occasions, but were particularly abundant at the Ardgour Road bridge and Ardgour Road hydrological site from January 2015 (Table 6.5).

Over the course of this study, chlorophyll *a* concentrations observed at the Ardgour Road hydrological site were higher than upstream of the Pass Burn (P=0.03), Black Bridge (P=0.07), Lindis Peak (P=0.04) and Ardgour Road Bridge (P=0.06) (Table 6.5, paired t-tests). Chlorophyll *a* concentrations observed upstream of Cluden Stream were higher than observed upstream of the Pass Burn (P=0.07), Black Bridge (P=0.06) and Lindis Peak (P=0.01) and Ardgour Road Bridge (P=0.06)(Table 6.5). Chlorophyll *a* concentrations at Black Bridge and Ardgour Road Bridge were significantly higher than those observed at Lindis Peak (Table 6.5, P=0.01 and 0.09, respectively).

Chlorophyll *a* concentrations at sites in the upper catchment (upstream of and including Lindis Peak) were well within provisional national periphyton guidelines, with all sites below the maximum chlorophyll *a* biomass to protect benthic biodiversity on all occasions (50 mg/m^2, Biggs 2000) (Table 6.5, Figure 6.11). This guideline was exceeded on one occasion (February 2015) at the site upstream of Cluden Stream and two occasions (December 2014 and January 2015) at the Ardgour Road hydrological site (Table 6.5, Figure 6.11). However, the chlorophyll *a* biomass at all sites and on all occasions except Ardgour Road hydrological site in March was well within the maximum chlorophyll *a* biomass to protect trout angling and habitat (200 mg/m^2 for diatoms/cyanobacteria, 120 mg/m^2 for filamentous algae) and aesthetics and recreation (120 mg/m^2 for filamentous algae) (Biggs 2000) (Table 6.5, Figure 6.11). The high chlorophyll *a* concentration at the Ardgour Road hydrological site (150 mg/m^2) was associated with a community dominated by unconsolidated algae, didymo and long filamentous algae (Table 6.5).

Chlorophyll *a* concentrations generally increased at all sites over the study period (Figure 6.11), although concentrations dropped between February and March at Black Bridge, Lindis Peak and upstream of Cluden (Figure 6.11). This reduction may have been a result of changes in the composition of periphyton at these sites between these occasions or seasonal changes (reduced light intensity, temperature) resulting in a loss of biomass or the vitality of periphyton cells. Much lower chlorophyll *a* concentrations were observed at the Ardgour Road bridge and Ardgour Road hydrological sites in February compared with January and March (Figure 6.11). The reason for this drop is not clear, however overall periphyton cover does not show a similar drop.

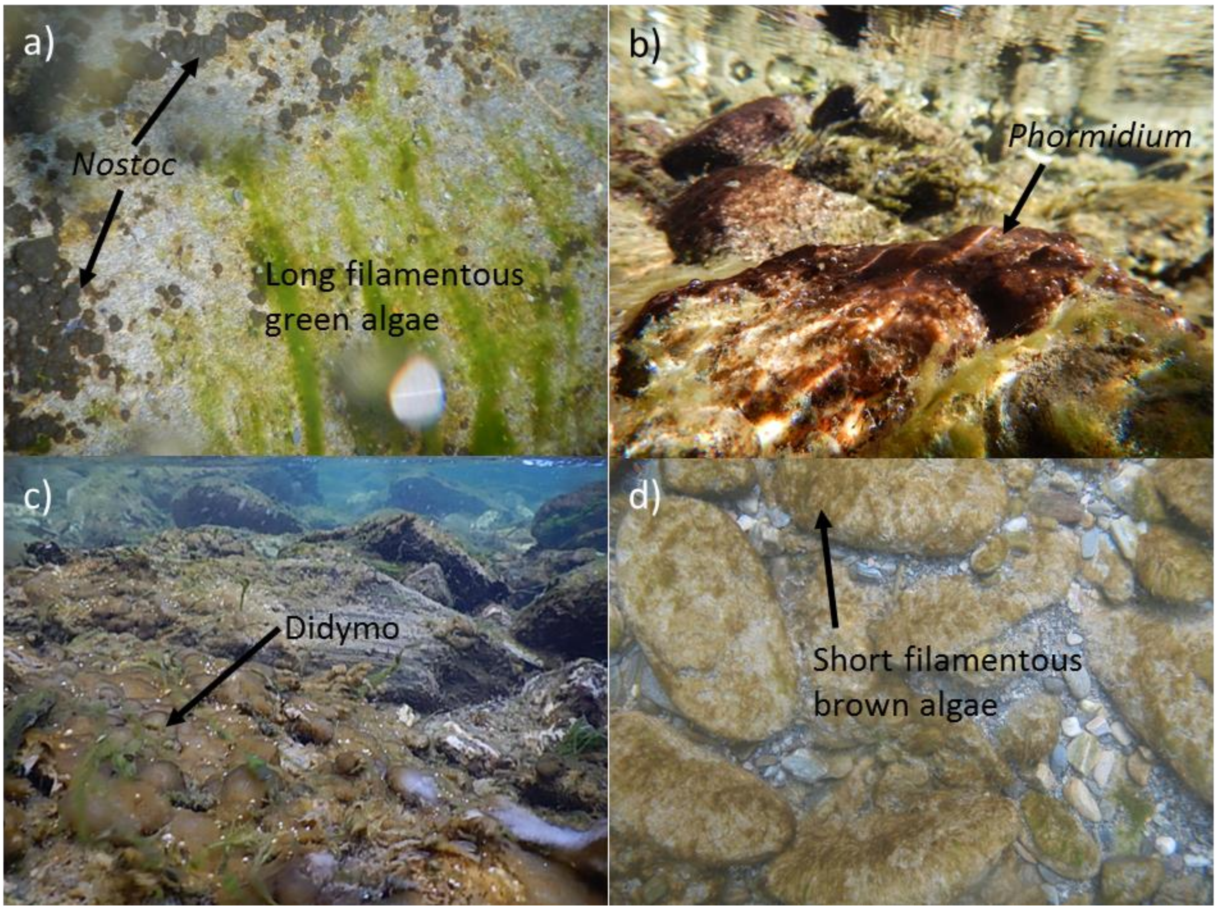

Figure 6.10 Underwater photographs of common periphyton types observed in the Lindis River. a) Thin accumulation of long filamentous green algae and the colonial cyanobacterium *Nostoc*, b) thick mat of the benthic cyanobacterium *Phormidium*, c) mixed periphyton community dominated by the stalked diatom *Didymosphenia geminata*, d) short brown filamentous algae.

Long (>2 cm) filamentous algae cover was much lower at sites in the upper catchment (above Cluden Stream) on all occasions (Table 6.5, paired t-tests, all $P<0.1$), while the maximum recorded cover by long filamentous algae approached guideline levels (30% cover) at the Ardgour Road bridge and Ardgour Road hydrological sites (Figure 6.12). Interestingly cover by long filamentous algae at the upper most site (upstream of Pass Burn) was higher than observed at Lindis Peak and upstream of Cluden Stream (Table 6.5, both $P=0.03$).

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 sites above Cluden Stream, but exceeded the guideline value on three occasions at the Ardgour Road bridge and two occasions at Ardgour Road hydrological site (Figure 6.12). At both sites that exceeded this guideline, periphyton cover was dominated by didymo and unconsolidated algae at both sites on most occasions (Table 6.5). In addition, the cyanobacterium *Phormidium* was also abundant in February and short filamentous green algae in March at the Ardgour Road bridge (Table 6.5).

Table 6.5 Composition of the periphyton communities at seven sites on the Lindis River over the period October 2014-April 2015. The dominant periphyton type(s) on each occasion are highlighted in bold.

Site	Date	Thin mat/film (under 0.5 mm thick)			Sludge	Medium mat (0.5 – 3 mm thick)				Thick mat (over 3 mm		Didymo mat	Short filaments (>1 cm, <2 cm		Long filaments (>2 cm long)		Chlorophyll a
		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	Brown/reddish	Green	Brown/reddish	mg/m^2
Lindis upstream of Pass Burn	21-Oct-14	P	8	P								P	5				3
	15-Dec-14	P	**37**					P				P			P		4
	20-Jan-15				P			**13**					P		P		8
	17-Feb-15						P	**31**							P		19
	17-Mar-15		P					**44**							P		44
Lindis at Black Bridge	21-Oct-14	P	20				P				P			**43**	P		16
	15-Dec-14		**24**						P			P	P	P	P		6
	20-Jan-15	P	**24**	P					P	P		14	P		P		21
	17-Feb-15	7	P	P	P		P		7			6	P	8	P		32
	17-Mar-15	P		7			P		12	P		6			P		26
Lindis at Lindis Peak	21-Oct-14	**91**											P				4
	15-Dec-14	P	**58**						P			P					2
	20-Jan-15	P			5				P								3
	17-Feb-15	**18**			**18**				6								20
	17-Mar-15	P	**67**						5								17
Lindis upstream of Cluden Stream	21-Oct-14		15						P					**24**			16
	15-Dec-14								8								42
	20-Jan-15	15	**29**						15		P						30
	17-Feb-15	11	P	5	P				**35**								**64**
	17-Mar-15	P	**82**	7			P										26
Lindis at Ardgour Rd bridge	21-Oct-14		P						P			**26**					19
	15-Dec-14								P			**28**					11
	20-Jan-15	P	P		**50**							28			16		49
	17-Feb-15	P			17						17	**25**	4		**27**		5
	17-Mar-15				16					8		**29**	11		18		45
Lindis at Ardgour Road hydro site	21-Oct-14		**36**						5		P	P		P	P		42
	15-Dec-14	**35**			13				16			P	P				**64**
	20-Jan-15	**44**	6		18				P			15			P		**53**
	17-Feb-15				24				5		P	**35**			18		8
	17-Mar-15				**48**				P			19			24		151
Lindis at SH8	21-Oct-14	P	**19**				P					P		P	P		10
	15-Dec-14	11			13							12					10
	20-Jan-15	Dry															
	17-Feb-15	Dry															
	17-Mar-15	Dry															

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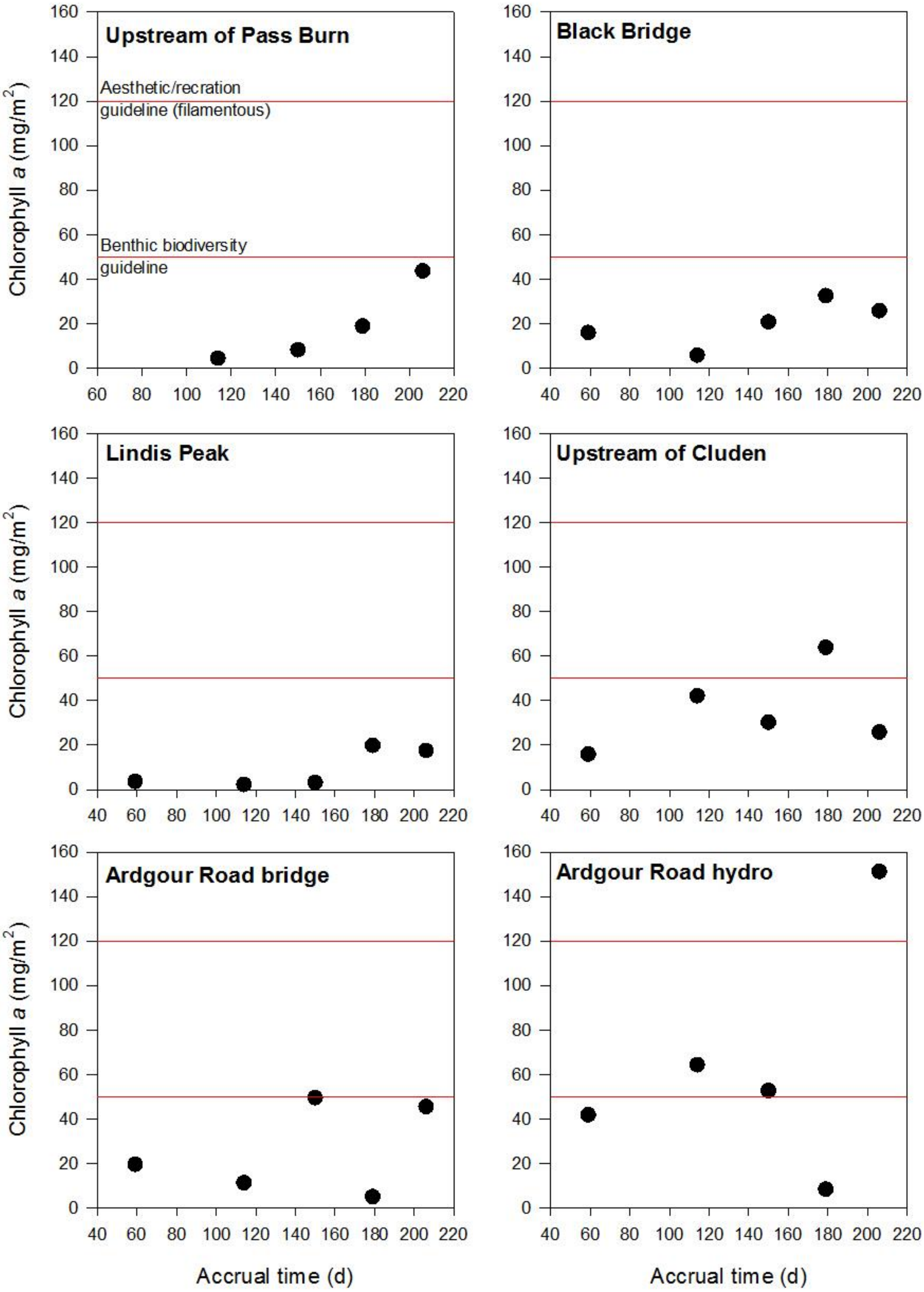

Figure 6.11 **Chlorophyll *a* concentrations over time (accrual time since August 2014 high-flow event) at six sites in the Lindis River. Data from Lindis at SH8 are not shown due to this site being dry on three out of five sampling occasions. Red lines represent provisional national periphyton biomass guidelines for the protection of benthic biodiversity (50 mg/m^2) and aesthetics/recreaton for filamentous algae (120 mg/m^2).**

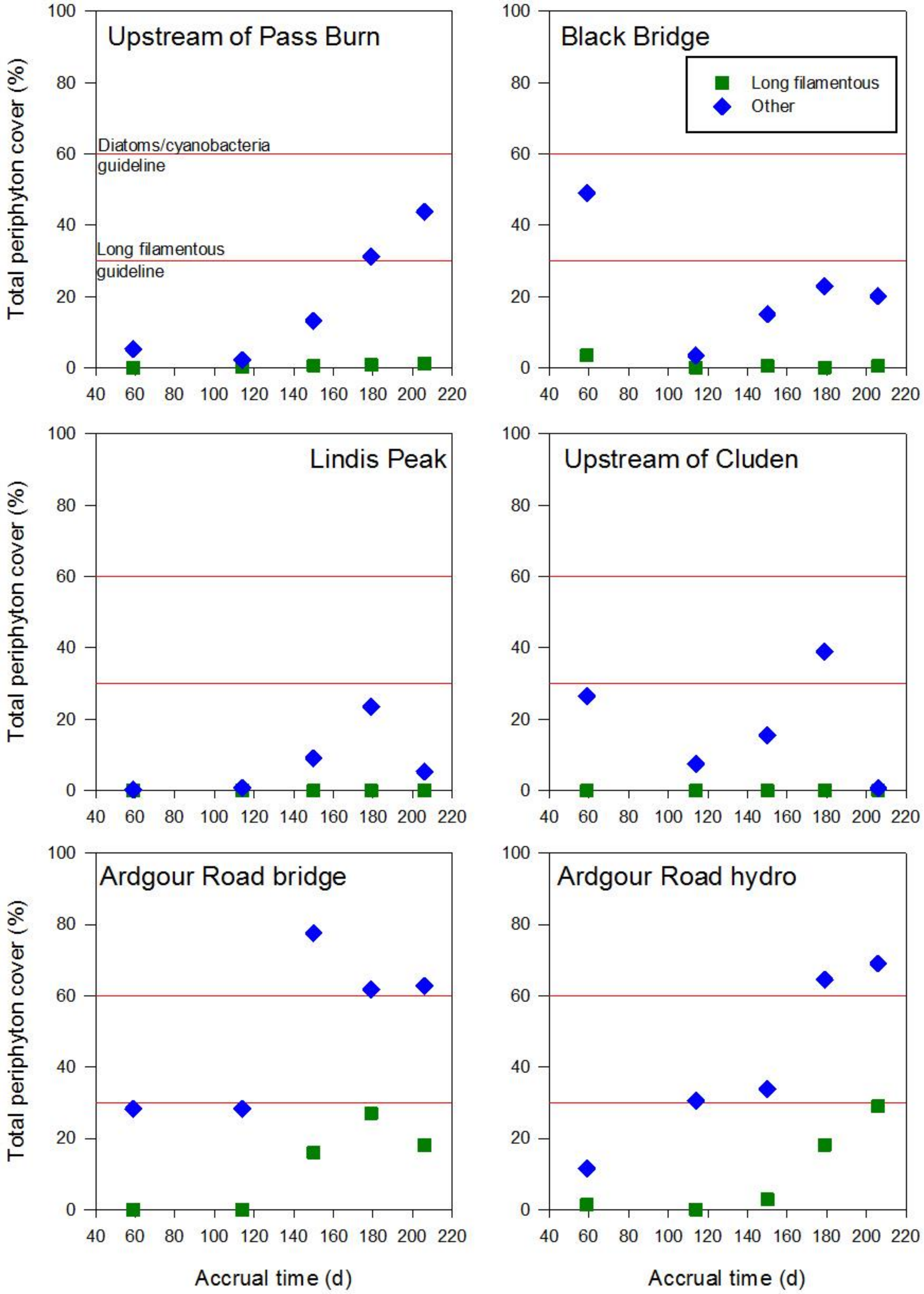

Figure 6.12 **Cover of long filamentous algae (green points) and other periphyton (blue points) over time (accrual time since August 2014 high-flow event) at six sites in the Lindis River. Data from Lindis at SH8 are not shown due to this site being dry on three out of five sampling occasions. Red lines 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 Lindis Peak in 2004 and 2006 and from Ardgour Road since 2006. Larvae of the common mayfly *Deleatidium* and riffle beetles (Elmidae) were among the most abundant macroinvertebrates at Lindis Peak in both 2004 and 2006, although the net-spinning caddis fly *Hydropsyche* (formerly *Aoteapsyche*) and midge (Chironominae) larvae were also among the most abundant taxa in 2006 (Table 6.6). The composition of the macroinvertebrate community at the Ardgour Road site has been more variable, with riffle beetles, midge (Orthocladiinae) larvae and oligochaetes being among the most abundant taxa on three of the nine sampling occasions and *Deleatidium* larvae and larvae of the cased caddisflies *Pycnocentria and Pycnocentrodes* being among the most abundant taxa on two of the nine sampling occasions (Table 6.6).

Macroinvertebrate metrics provide a measure of long-term water and habitat quality in a waterway. The $\%EPT_{taxa}$ ranged from 40-58% over the nine years of macroinvertebrate sampling at the Ardgour Road site and is within the expected range for a rain-fed stream and there was no evidence of a trend in $\%EPT_{taxa}$ at this site over this period (Figure 6.13, Table 6.7). MCI scores ranged from 96 to 109 at the Ardgour Road site, indicating that generally water quality is good (using the criteria in Table 5.2) and no trend in MCI scores was detected (Figure 6.13, Table 6.7). SQMCI scores ranged widely, most likely as a result of the variability in the abundance of chironomid midges (Orthocladiinae) and oligochaete worms (Table 6.6) and, similarly, no trend in SQMCI scores was apparent between 2006 and 2014 (Figure 6.13, Table 6.7).

Table 6.6 **Macroinvertebrate taxa collected from the Lindis River as part of SoE monitoring. Only taxa that were abundant on one occasion or more are shown. See Appendix A for the full table. Relative abundance scores are described in Table 5.2.**

		MCI score	Lindis River at Lindis Peak		Lindis River at Ardgour Rd								
	Taxon		2004	2006	2006	2007	2008	2009	2010	2011	2012	2013	2014
COLEOPTERA	Elmidae	6	VVA	VA	VVA	VVA	A	C	VA	C	C	R	C
DIPTERA	*Austrosimulium* species	3	VA	R		C	C	C	C	R			
	Chironominae	2		VA	C	C	A						
	Orthocladiinae	2		C	VA	VA	A	VA	VA	R	A	VVA	C
	Tanypodinae	5		C	C	C	A	A	A				
	Tanytarsini	3							R		C	VA	C
EPHEMEROPTERA	*Deleatidium* species	8	VVA	VA	VA	A	A	A	VA	A	VA	VA	C
MEGALOPTERA	*Archichauliodes diversus*	7	R	R	A	C	R		A		C	A	C
MOLLUSCA	*Potamopyrgus antipodarum*	4		C	R	A	A						
OLIGOCHAETA		1	A	A	C	VVA		VA	VA		C	C	
TRICHOPTERA	*Hydropsyche* species	4	VA	VA	A	A		R	A	R	A	A	A
	Hudsonema spp.	6	C			R	A	R	R				R
	Hydrobiosidae early instar	5		C	R	A	A	C					R
	Hydrobiosis umbripennis gp.	5		R		C	C	C	A	A	C	A	C
	Olinga species	9	VA	A	VA	C	A	R	A	C	C	A	C
	Oxyethira albiceps	2				C		R	A				R
	Psilochorema species	8	R	R	R	C	R	R	A		R	C	C
	Pycnocentria species	7	VA				A	C	A	R	C	VA	A
	Pycnocentrodes species	5	A	C	VVA	VA	A	R	R	R	R	A	A
Total Richness			**15**	**19**	**15**	**22**	**18**	**19**	**22**	**12**	**16**	**16**	**24**
EPT Richness*			**10**	**10**	**6**	**9**	**10**	**10**	**9**	**7**	**8**	**8**	**11**
%EPT Richness*			**67%**	**53%**	**40%**	**41%**	**56%**	**53%**	**41%**	**58%**	**50%**	**50%**	**46%**
MCI Score			**131**	**108**	**104**	**96**	**109**	**96**	**104**	**113**	**115**	**109**	**106**
SQMCI Score			**6.56**	**4.98**	**5.66**	**3.66**	**5.31**	**2.69**	**4.64**	**6.63**	**6.44**	**3.81**	**5.35**

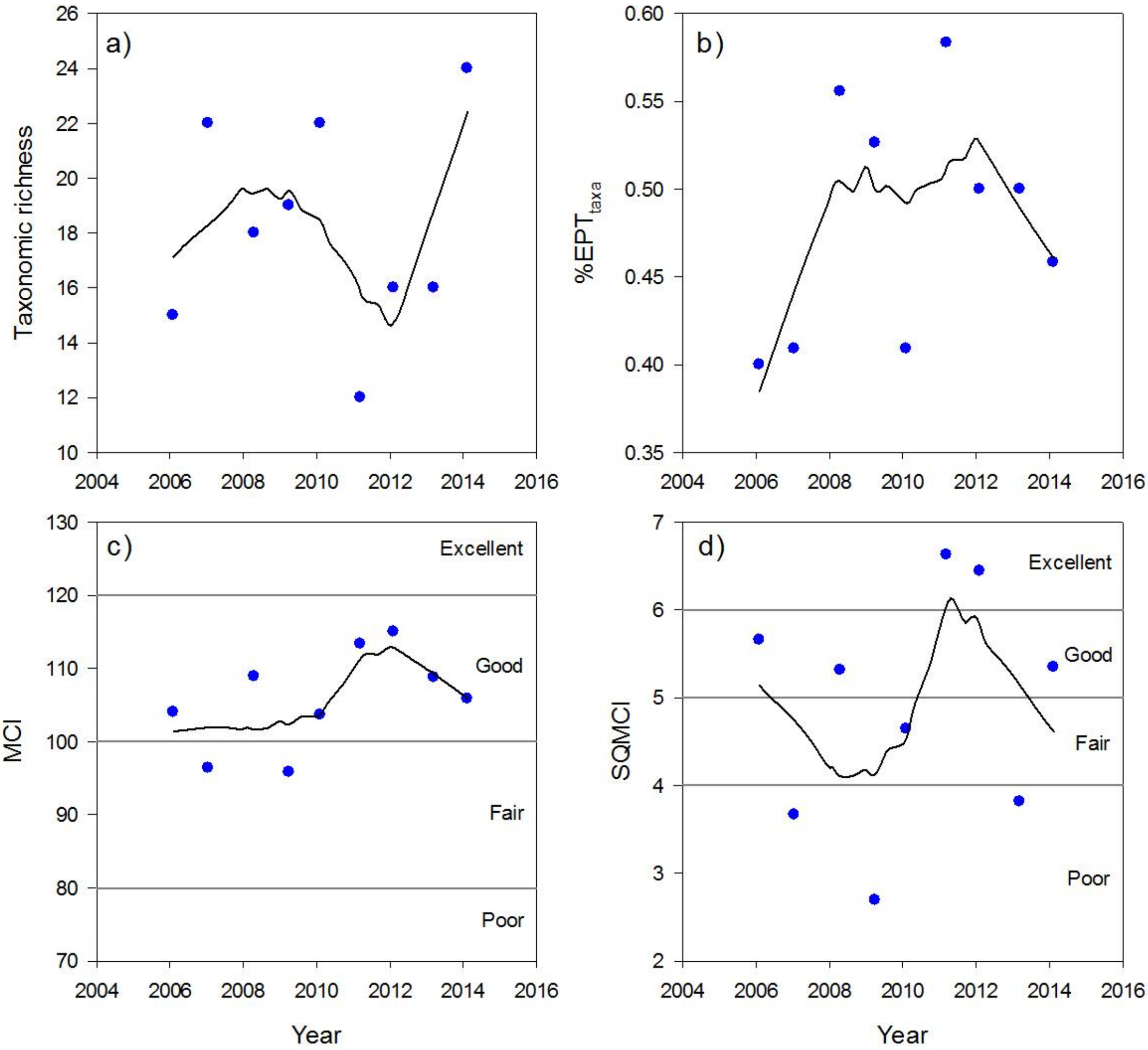

Figure 6.13 **Macroiinvertebrate metrics in the Lindis River at the Ardgour Road SoE site between 2006-2014. a) Taxonomic richness, b) % EPT richness, c) MCI, d) SQMCI. Fitted lines (black) are loess curves (tension = 0.6). Horizontal grey lines in parts c) and d) represent the water quality classes for MCI and SQMCI in Table 5.2.**

Table 6.7 **Summary of trend analyses for macroinvertebrate metrics for the Lindis River at the Ardgour Road SoE site between 2006-2014. N.s. = not significant.**

Metric	*Z*	*P*	Trend
Taxonomic richness	0.316	0.38	n.s.
%EPT	0.527	0.31	n.s.
MCI	0.938	0.18	n.s.
SQMCI	0.313	0.38	n.s.

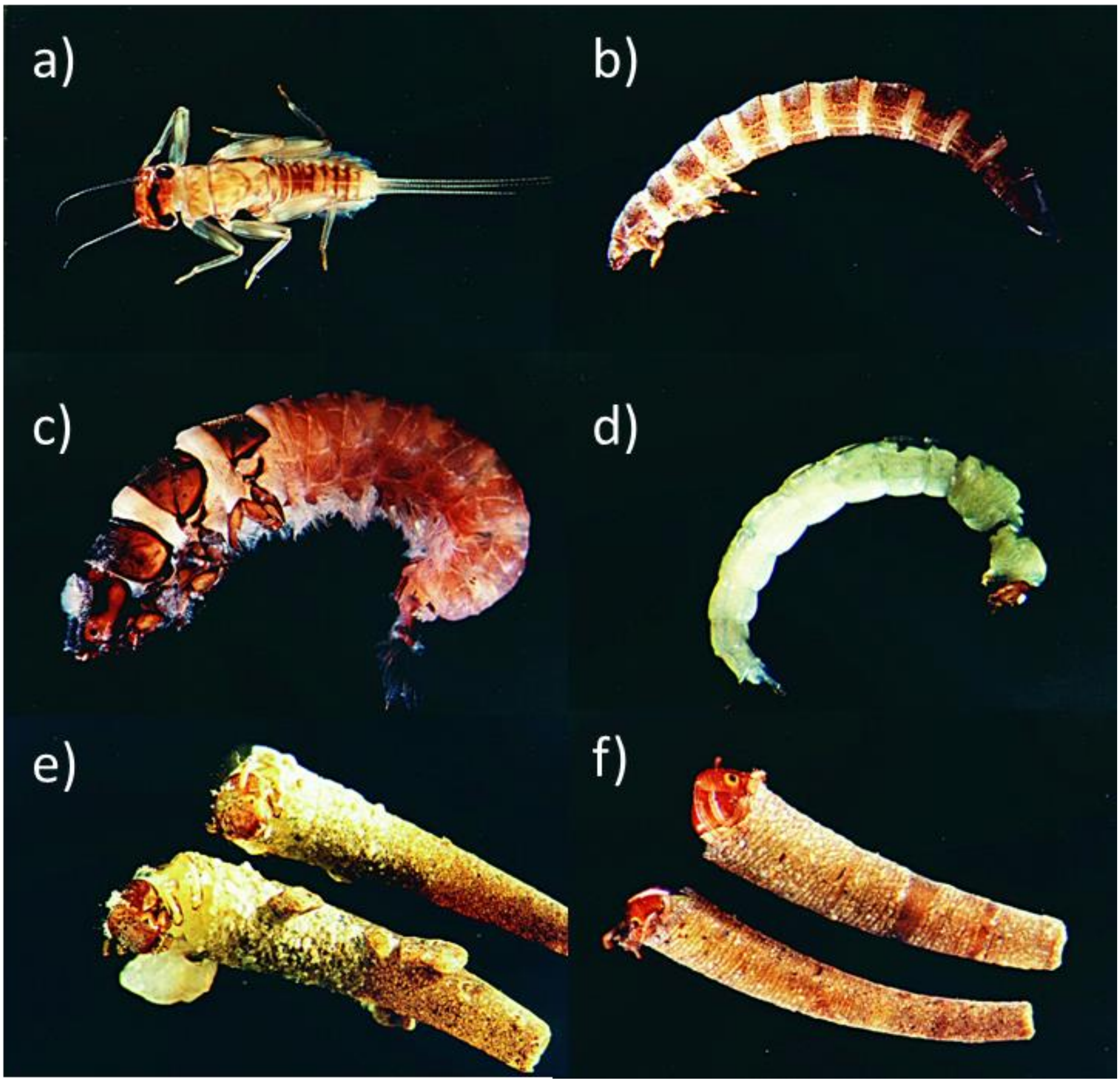

Figure 6.14 **Photographs of common macroinvertebrate taxa in the Lindis River. a) a nymph of the mayfly *Deleatidium*, b) a larval elmid beetle, c) a larva of the net-spinning caddis fly, *Hydropsyche*, d) chironomid midge larvae, e) the larvae of the cased caddis fly *Pycnocentrodes*, and f) the larvae of the cased caddis fly *Pycnocentria*. All photographs by Stephen Moore.**

6.6.2 2014 Catchment survey

Larvae of the common mayfly *Deleatidium* were the most abundant macroinvertebrate at all sites in the Lindis River on 21 October 2014 (Table 6.8). Chironomid midge larvae were abundant at many of the sites and were particularly abundant at the Lindis Peak site (Table 6.8). Chironomid midge larvae are often associated with a higher biomass of periphyton and can become very abundant when periphyton becomes prolific, such as in enriched waterways or after a prolonged period of stable flows, and most chironomids have low MCI tolerance scores as a result. This is likely to be the reason for the low MCI score at the Lindis Peak site, as this site with the highest cover of periphyton on this sampling occasion. Larvae of two cased caddis flies (*Pycnocentrodes* and *Pycnocentria*) were among the most abundant invertebrate taxa at two sites: upstream of Cluden Stream and Ardgour Road hydrological site (Table 6.8).

Larvae of the common mayfly *Deleatidium* were also among the most abundant macroinvertebrate taxa at all sites in the Lindis River on 17 February 2015 (Table 6.9). Chironomid midge larvae (Orthocladiinae and Tanytarsini) were among the most abundant at many of the sites, particularly below the site upstream of Cluden Stream, most likely due to the abundance of periphyton at these lower sites and the prolonged period of stable flows prior to this sampling occasion (Table 6.9). . Larvae of the net-spinning caddis fly were among the most abundant taxa at two sites: Black Bridge and Ardgour Road hydrological site, while the larve of two cased caddis flies (*Pycnocentrodes* and *Pycnocentria*) were among the most abundant invertebrate taxa at three sites: Lindis Peak, Ardgour Road bridge and Ardgour Road hydrological site (Table 6.9).

MCI score and SQMCI scores for all sites in the Lindis River in October 2014 are consistent with very good water quality, with a low level of nutrient enrichment (Table 6.8). In February 2015, MCI and SQMCI scores for the sites upstream of Pass Burn and at Black bridge indicated good water quality, while the MCI and SQMCI for Lindis Peak indicated excellent water quality. Scores for all other sites in the Lindis River were indicative of either fair or good water quality (Table 6.9). These results indicate that while the water quality in the upper Lindis catchment is very good, a combination of low, stable flows, the presence of the invasive diatom *Didymosphenia geminata* and/or water quality in the lower sites result in macroinvertebrate communities that are indicative of fair or good water quality.

The macroinvertebrate community in Cluden Stream on 21 October 2014 was dominated by *Deleatidium,* the mudsnail *Potamopyrgus antipodarum* and oligochaete worms with the MCI score indicating good-fair water quality, while the SQMCI score indicated fair water quality (Table 6.8). Chironomid midges dominated the community of Wainui Stream on 21 October 2014 and as a result, the MCI score indicated that water quality was fair, while the SQMCI score suggested that water quality at this site was poor (Table 6.8).

The macroinvertebrate community in Cluden Stream on 17 February 2015 was dominated by the mudsnail *Potamopyrgus antipodarum*, chironomid midge larvae (Tanytarsini) and the cased caddis fly *Pycnocentria* (Table 6.9). The MCI and SQMCI scores for this site indicated good-fair water quality (Table 6.9). The macroinvertebrate community in Wainui Stream was not sampled in on 17 February 2015 due to a lack of surface flow.

Table 6.8 Macroinvertebrate communities collected at seven sites in the Lindis River and two tributaries on 21 October 2014. Relative abundance scores are described in Table 5.2.

TAXON	MCI score	Lindis River							Cluden Stream	Wainui Stream
		Upstream of Pass Burn	Black Bridge	Lindis Peak	Upstream of Cluden Stream	Ardgour Rd bridge	Ardgour Road hydro site	SH8		
COLEOPTERA (Beetles)										
Elmidae	6	R	R	R		R	R		R	R
DIPTERA (True flies)										
Aphrophila species	5	R	R	R	R	R	C		C	
Austrosimulium species	3	R	C	R	R	A	R	C	A	VA
Eriopterini	9	R	C	C	C	C	R	R		
Hexatomini	5		R			R				
Maoridiamesa (Chironomidae)	3	R	C	C	R	A	A	R	R	VA
Muscidae	3						R			R
Orthocladiinae (Chironomidae)	2	C	A	A	A	C	A	C	A	VA
Tanypodinae (Chironomidae)	5			R	A		A	R		
Tanytarsini (Chironomidae)	3	R	A	VA	A	R	A		A	
EPHEMEROPTERA (Mayflies)										
Coloburiscus humeralis	9								C	
Deleatidium species	8	VA	VA	VA	VA	VA	VA	VA	VA	C
Nesameletus species	9	R			R					
MEGALOPTERA (Dobsonflies)										
Archichauliodes diversus	7		R	R			R		C	
MOLLUSCA (Snails)										
Potamopyrgus antipodarum	4				R				VA	
OLIGOCHAETA (Segmented worms)	1		R	R	C	C	R	C	VA	A
PLECOPTERA (Stoneflies)										
Zelandobius species	5	R	C	C	R		R			
Zelandoperla species	10	R								
TRICHOPTERA (Caddis flies)										
Aoteapsyche species	4	C	C	C	A		C		C	
Confluens species	5				R					
Costachorema species	7			R		R	R			
Helicopsyche species	10				R					
Hudsonema alienum	6		R							
Hudsonema amabile	6			R	R	R	C	R		R
Hydrobiosis species	5	R	R	C	C	C	C	R	C	A
Neurochorema species	6								R	
Olinga species	9	R	C	C	A	C	C		C	
Psilochorema species	8	R	R	R	R		R	R		
Pycnocentria species	7	R	C	A	VA	R	A	R	A	R
Pycnocentrodes species	5		C	A	VA	A	VA	A	C	R
Taxonomic richness		**16**	**19**	**20**	**21**	**16**	**21**	**12**	**17**	**11**
%EPT richness		**56%**	**47%**	**50%**	**57%**	**44%**	**48%**	**50%**	**47%**	**45%**
MCI		**120**	**106**	**108**	**110**	**105**	**106**	**103**	**102**	**89**
SQMCI		**7.41**	**6.21**	**5.36**	**6.10**	**6.19**	**5.67**	**6.85**	**4.39**	**2.82**

Table 6.9 Macroinvertebrate communities collected at seven sites in the Lindis River and two tributaries on 17 February 2015. Relative abundance scores are described in Table 5.2.

TAXON	MCI score	Lindis River: Upstream of Pass Burn	Lindis River: Black Bridge	Lindis River: Lindis Peak	Lindis River: Upstream of Cluden Stream	Lindis River: Ardgour Road Bridge	Lindis River: Ardgour Road hydro site	Cluden Stream
COLEOPTERA (Beetles)								
Berosus species	5					R		
Elmidae	6	A	A	C	C	R	R	R
Hydraenidae	8		R					
CRUSTACEA (crayfish, shrimp)								
Ostracoda	3					R		R
DIPTERA (True flies)								
Aphrophila species	5	R	R	R				
Austrosimulium species	3	R	R	R	R		C	
Ceratopogonidae	3		R					
Chironomus species	1					R		
Empididae	3	C					R	
Ephydridae	4					C	R	
Eriopterini	9	R	C	C	C			
Hexatomini	5		R					
Maoridiamesa species	3		C		A		A	
Muscidae	3	R	R		R	C	A	
Orthocladiinae	2	C	A	A	VA	VA	VA	A
Paralimnophila skusei	6					R		
Polypedilum species	3	R						
Tanypodinae	5			C	C	A	R	R
Tanytarsini	3	VA	A	A	VA	C	VA	VA
EPHEMEROPTERA (Mayflies)								
Austroclima species	9	R	A	R	C		A	
Coloburiscus humeralis	9							R
Deleatidium species	8	VA	VA	VA	VA	VA	VA	A
MEGALOPTERA (Dobsonflies)								
Archichauliodes diversus	7	C	R	C	C	C	C	C
MOLLUSCA (Snails)								
Potamopyrgus antipodarum	4	R	A	R	C		C	VA
OLIGOCHAETA (Segmented worms)	1		C		R	R	A	A
PLECOPTERA (Stoneflies)								
Megaleptoperla species	9			R				
Zelandobius species	5	C				R	C	
Zelandoperla species	10	R						
TRICHOPTERA (Caddis flies)								
Aoteapsyche species	4	A	VA	A	A	R	VA	C
Beraeoptera roria	8		R					
Costachorema species	7						R	
Hudsonema amabile	6	R	R	C	A	A	C	A
Hydrobiosis species	5	C	A	C	A	C	VA	R
Neurochorema species	6	C	R	C	R			
Olinga species	9	A	A	A	A	A	A	A
Oxyethira albiceps	2					C	C	C
Psilochorema species	8	C	C	R	R	A		
Pycnocentria species	7	A	A	A	C	A	VA	VA
Pycnocentrodes species	5	C	A	VA	C	VA	VA	A
Taxonomic richness		**23**	**25**	**20**	**21**	**22**	**23**	**17**
%EPT richness		**52%**	**44%**	**55%**	**48%**	**45%**	**48%**	**53%**
MCI		**113**	**110**	**120**	**108**	**95**	**97**	**101**
SQMCI		**5.71**	**5.75**	**6.04**	**4.77**	**5.37**	**4.86**	**4.80**

6.7 Fish monitoring

6.7.1 Long-term fish monitoring

Long-term monitoring of fish communities has been conducted at the Ardgour Road bridge and at Lindis Crossing following the New Zealand Freshwater Fish Sampling Protocols (Joy *et al.* 2013 – see Section 5.5.1 for more details). Fish communities at the Ardgour Road bridge were also monitored in 2007 and 2008. However, a different sampling methodology was employed on these occasions, the results of these surveys are not considered further, other than to note that brown trout and upland bully being the only species collected on both of these occasions.

Three species were collected from the Ardgour Road site: brown trout, upland bully and longfin eel. A single large longfin eel (1000 mm) was collected from this site in 2010. The density of brown trout collected in this reach has been relatively consistent on most sampling occasions (1.3-3.0 fish/100 m^2), with the exception of 2010, when much higher densities were observed (16.4 fish/100 m^2) (Figure 6.15a). Densities of upland bullies were also relatively consistent over the period 2009-2013 (12.4-31.8 fish/100 m^2), with much higher densities observed in the 2014 survey (89.6 fish/100 m^2) (Figure 6.15b).

Four species have been collected from the Lindis Crossing site: brown and rainbow trout, common and upland bully. The density of brown trout collected from this reach ranged from low (e.g. 2011 and 2014) to moderate (e.g. 2009)(Figure 6.15c) while rainbow trout were collected during the 2010 and 2013 surveys (Figure 6.15c). Upland bully were observed on most occasions, with very high densities in 2009, while common bully were collected in 2009 and 2011 (Figure 6.15d).

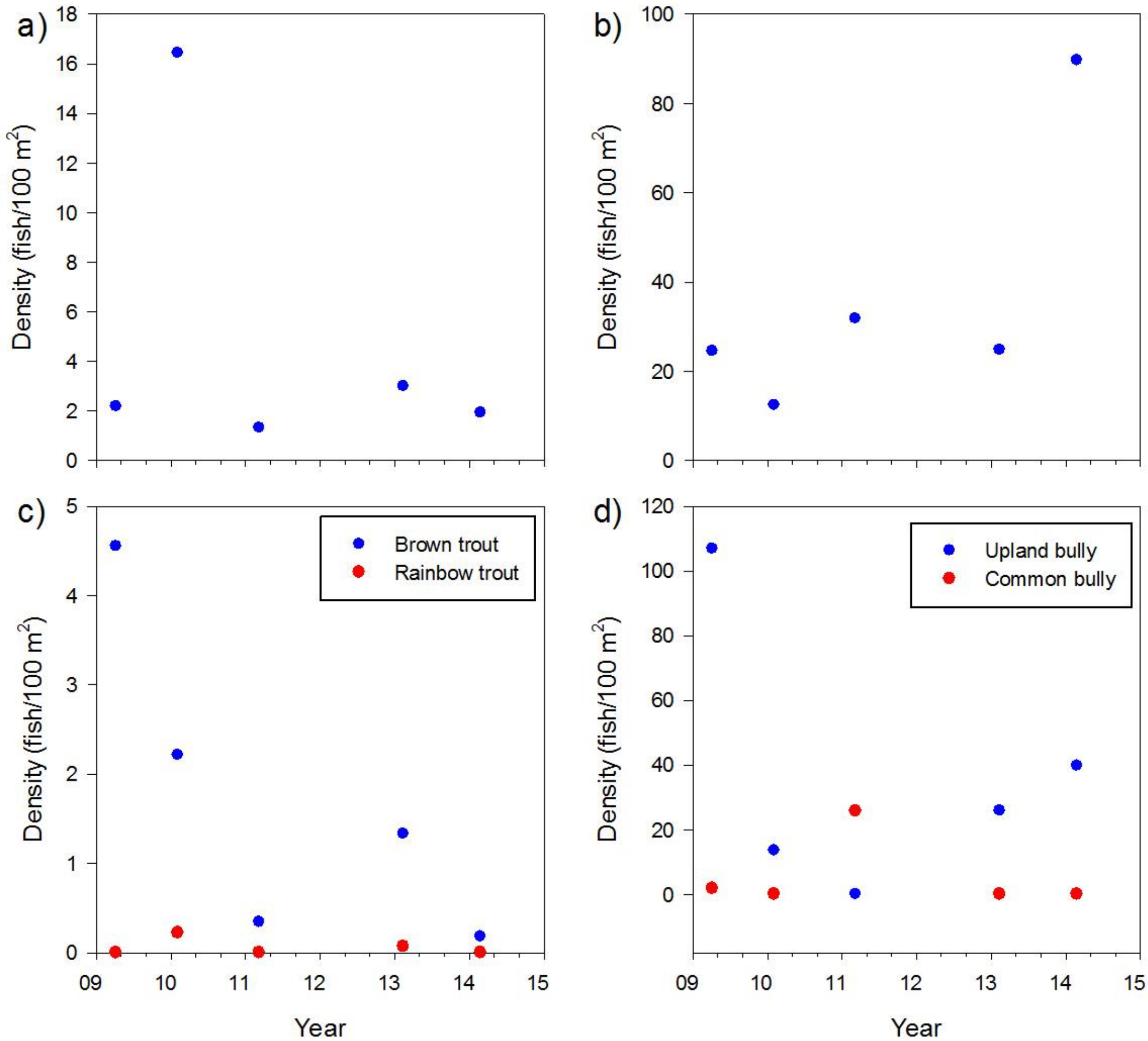

Figure 6.15 **Fish densities observed at the two monitoring sites in the Lindis River during SoE monitoring. a) Brown trout at the Ardgour Road bridge, b) upland bully at the Ardgour Road bridge, c) brown and rainbow trout at Lindis Crossing, d) common and upland bully at Lindis Crossing.**

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 as well as water users (Biggs 2000). Periphyton biomass is determined by the balance between two opposing processes: biomass accrual 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, water velocity and SS) and grazing (mainly by invertebrates). In an unregulated river (lacking major dams or significant water storage), the processes affecting biomass loss are not able to be manipulated, meaning that nutrient management is likely to be among the most practical means of managing periphyton biomass.

Increasing concentrations of TN and NNN and a significant decline in DRP concentrations were detected at the Ardgour Road SoE site. Comparison of nutrient concentrations at low flows during this study with those from the 2005/2006 study suggests that similar increases in TN and NNN are likely to have occurred at all mainstem sites from Archies Flat. These changes may reflect changing irrigation practices in the Lindis catchment, with a shift from flood irrigation to more efficient spray irrigation. Flood irrigation has been shown to detrimentally affect water quality, with the discharge of wipe-off water[3] increasing concentrations of sediment and nutrients (particularly phosphorus) and increasing faecal contamination of receiving waters (ORC 2006b). Flood irrigation is also predicted to have a higher rate of nitrogen leaching relative to spray irrigation (Lilburne *et al.* 2010). However, increased land-use intensity (e.g. stocking rates, rate of fertiliser application) following the conversion to spray may account for the observed increase in NNN and TN at the Ardgour Road site.

The results of the 2013-2014 catchment survey are consistent with the results of long-term monitoring, with markedly higher TN and NNN concentrations observed at sites downstream of Archies Flat (Ardgour Road bridge, Ardgour Road and SH8) compared with those upstream, especially during periods of low flow. There are two possible explanations for this: The first is that irrigation abstraction from the lower Lindis River results in very low flows downstream that are insufficient to dilute N-enriched[4] groundwater entering this lower part of the river (especially upstream of the Ardgour Road SoE site). The second is that there are point-source discharges containing high concentrations of nitrogen entering the Lindis downstream of Archies Flat, with the most likely source of such discharges being excess water from flood irrigation (wipe-off water). However, if the latter was the case, TP and *E. coli* concentrations would also be expected to increase downstream of Archies Flat. Generally, this was not the case, although higher concentrations of TP were observed at the Ardgour Road bridge than at other sites in the lower river, which may indicate the presence of a discharge of wipe-off water in that area.

The results of water quality monitoring in the Lindis catchment suggest that periphyton in the lower Lindis River is likely to be phosphorus-limited. The reduction in DRP observed at the

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

[4] Relative to the low NNN concentrations observed in the river upstream

Ardgour Road hydrological site could reflect a reduction in discharges containing high concentrations of phosphorus, such as wipe-off water, as discussed above. Alternatively, it may reflect increased P-limitation and uptake by periphyton. For most periphyton types, P-limitation would be expected to prevent substantial increases in the biomass of periphyton. However, recent research indicates that benthic cyanobacteria such as *Phormidium* may be able to trap fine sediment within the cyanobacterial mat and transform insoluble forms of P in these trapped fine sediments into soluble forms that are available for use by the mat (Wood et al. 2014). This is would give *Phormidium* a competitive advantage over other periphyton taxa at low P concentrations. Waterways with low P concentrations and high concentrations of dissolved N are likely to provide conditions that allow benthic cyanobacteria to proliferate which may have implications for human and animal health (see Section 7.7.1).

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* at Lindis Peak declined significantly over the period October 2003-23 April 2014. During the 2013-2014 survey, *E. coli* concentrations were consistently low across the sites considered and were well below levels considered to pose a threat to water users.

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 very clear water, high turbidity with very low clarity). Turbidity at both sites in the Lindis River is generally low (i.e. water clarity is high) and there is no evidence of a change in clarity at either long-term monitoring site over the term of monitoring.

7.4 Compliance with water quality limits

Schedule 15 of the Regional Plan: Water outlines the water quality limits for receiving waters (Table 4.1). These limits are applied as 5-year, 80th percentiles, when flows are at or below a reference flow. For sites upstream of Lindis Peak, the reference flow is 3,510 l/s at the Lindis Peak hydrological monitoring site. For the lower Lindis catchment (downstream of the Lindis Peak monitoring site to the Clutha confluence), the receiving water are applied as 5-year, 80th percentiles when flows are at or below a reference flow of 3,500 l/s at the Ardgour Road hydrological monitoring site. For most of the sites sampled (the exceptions being the SoE sites at Lindis Peak and Ardgour Road) data is only available for one year. For these sites, 80th percentiles were calculated based on this limited data and should be interpreted cautiously.

Water quality at the Lindis Peak site complies with all water quality limits, while water quality at the Ardgour Road site complies with the limits for all variables except for NNN (Table 7.2). Given the increasing trend in NNN at the Ardgour Road hydrological site, it is unlikely that this site will comply with the NNN limit in the near future without some change (such as the implementation of a minimum flow or changes to land management practices).

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	NH_4-N 0.1 mg/l	DRP 0.01 mg/l	*E. coli* 260 cfu/100 ml	Turbidity 5 NTU
Lindis R. - u/s Pass Burn	2013-2014	0.001	0.005	0.004	30	-
Lindis R. - Black Bridge	2013-2014	0.024	0.005	0.002	51	-
Lindis R. - Lindis Peak	2013-2014	0.012	0.005	0.002	170	0.9
	2008-2013	0.013	0.005	0.002	130	0.8
Lindis R. - u/s Cluden	2013-2014	0.061	0.005	0.002	100	-
Lindis R. - Archies Flat	2013-2014	0.032	0.005	0.002	55	-
Lindis R. - Ardgour Road bridge	2013-2014	0.310	0.005	0.002	114	-
Lindis R. - Ardgour Road hydrological site	2013-2014	0.220	0.005	0.002	120	0.6
	2008-2013	0.212	0.005	0.002	128	1.1
Lindis R. - SH8	2013-2014	0.124	0.005	0.002	75	-
Cluden Stream	2013-2014	0.001	0.005	0.004	72	-
Wainui Stream	2013-2014	0.001	0.005	0.004	72	-

ORC is currently undertaking consultation with the community as part of the process to set a minimum flow in the Lindis catchment. Whatever the minimum flow that is recommended for the Lindis catchment, it is likely that it will affect water quality in the lower Lindis River, as more water from the upper catchment (where water quality is high) will have to pass the irrigation intakes and flow into the lower catchment to maintain the minimum flow at the Ardgour Road minimum flow site. This increased flow of upper catchment water to the lower catchment will result in more dilution and lower NNN concentrations in the lower catchment.

7.5 Water temperature

Water temperature is a fundamental factor affecting all aspects of stream systems. Water temperature (especially high water temperatures) directly affects fish populations, 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).

Brown trout (*Salmo trutta*) and rainbow trout (*Onchyrhynchus mykiss*) are likely to be the fish that are most sensitive to high water temperatures in the Lindis River, although the thermal requirements of Clutha flathead galaxias are unknown. 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).

Water temperatures recorded at Lindis Peak and Ardgour Road were well within the acute thermal thresholds for brown and rainbow trout (Table 7.2). The maximum weekly average temperatures at Ardgour Road was within the chronic thermal threshold for all species considered, while the maximum weekly average observed at the Lindis Peak was within the chronic thermal thresholds for brown trout and the native species considered but exceeded the chronic threshold for rainbow trout (Table 7.2). These results suggest that thermal conditions in these sections of the Lindis River are generally suitable for brown trout, longfin eel and common bully but that water temperatures in the vicinity of Lindis Peak may be unsuitable for rainbow trout at times.

Table 7.2 Comparison of long-term temperature statistics for two sites in the Lindis River with thermal criteria to protect fish species found in the Lindis River.

	Acute criteria (°C)	Chronic criteria (°C)	Source
Lindis Peak	21.9	18.5	Table 6.2
Ardgour Road	21.8	17.0	Table 6.2
Brown trout	24.6	19.6	Todd *et al.* 2008
Rainbow trout	23.8	18.2	Todd *et al.* 2009
Longfin eel	-	28	Olsen *et al.* 2012
Common bully	-	24	Olsen *et al.* 2012

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 substrate at most sites in the Lindis River was predominantly coarse gravels, although cobbles and fine gravels formed a substantial proportion of the bed at some sites. Riparian buffers were not generally present and there was evidence of direct stock access at most sites surveyed. However, given the generally low stocking rates in areas adjacent to survey sites, this is unlikely to have a substantial effect on water quality. Riparian vegetation generally consisted of exotic species, including willows, lupins, broom and rank grass.

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* that have been recorded from the Lindis 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.

Monitoring of the composition of periphyton communities at the Lindis Peak site up to 2006 is consistent with a low level of nutrient enrichment and/or regular flushing flows. The periphyton community at the Ardgour Road SoE site has been dominated by long filamentous green algae on occasion, which may reflect elevated levels of nutrients, low, stable flows, or both. The invasive, stalked diatom *Didymosphenia geminata* has dominated the periphyton community at this site in several years since it was first detected in SoE monitoring in 2007.

Long-term periphyton monitoring in the Lindis River is undertaken on one occasion per year (usually in mid-late summer), and therefore provides a very limited "snapshot" of periphyton community composition at the two long-term monitoring sites in the Lindis catchment. 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 mainstem sites in the Lindis catchment. These surveys allow for consideration of longitudinal and temporal changes in composition of the periphyton community and for comparison to the results of the water quality sampling as well as river flows.

The dominance of the periphyton at the most upstream monitoring site (upstream of the Pass Burn) by the colonial cyanobacterium *Nostoc* is consistent with its preference for clean, fast-flowing upland streams (Biggs & Kilroy 2000). Mats of the benthic cyanobacterium *Phormidium* were observed on most occasions at all upper sites, except the uppermost site (upstream of Pass Burn). Cover by *Phormidium* was generally low at most sites, although cover at the site upstream of Cluden Stream exceeded 35% in February 2015. This value exceeded the "Alert" threshold (20% cover) for the cover of benthic cyanobacteria in recreational freshwaters, but was within the threshold for "Action" (50%) (MfE & MoH, 2009). The presence of *Phormidium* mats in the upper catchment does not suggest that there are water quality issues in the upper Lindis catchment, due to the due to the ability of *Phormidium* mats to capture fine sediments from the water column and release phosphorus from them (Wood *et al.* 2014 – see Section 7.1 for more information).

The results of the 2014/15 catchment survey indicate that the periphyton community at sites in the upper Lindis catchment (above Lindis Peak) were generally indicative of unenriched conditions, with these sites having the lowest chlorophyll *a* concentrations and cover by long filamentous algae. However, the sites at Ardgour Road Bridge and the Ardgour Road hydrological site supported much greater periphyton growths. This is likely to be a result of a combination of more enrichment (as reflected in higher nitrogen concentrations) and/or lower flows at this downstream site (as evident in Figure 6.9). Enrichment in these lower sites is not likely to be reflected in DRP concentrations, as phosphorus is expected to be the main nutrient limiting periphyton growth, so any phosphorus entering the lower river is expected to be rapidly taken up by periphyton.

7.7.2 Macroinvertebrates

Macroinvertebrates are a diverse group 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, 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 also provide a good indication of the medium- to long-term water quality of a waterway. For this reason, they are used in biomonitoring 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 at the Ardgour Road 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" (based on the criteria in Table 5.2). SQMCI scores were highly variable, most likely reflecting the variability in the abundance of chironomid midge larvae (Orthocladiinae) and oligochaete worms. Analysis of macroinvertebrate indices over time suggests that water and habitat quality have not changed substantially since 2006.

The common mayfly *Deleatidium* was among the most abundant macroinvertebrate collected at all sites in the Lindis River in October 2014. In general, the macroinvertebrate communities in the Lindis River in October 2014 were consistent with very good water quality, with a low level of nutrient enrichment, however, in February suggest that while the water quality in the upper Lindis catchment is very good, a combination of low, stable flows, the presence of the invasive diatom *Didymosphenia geminata* and/or water quality in the lower sites result in macroinvertebrate communities that are indicative of fair or good water quality.

Chironomid midges dominated the community in Wainui Stream in October 2014 and the composition of the macroinvertebrate community indicated that this waterway was moderately to heavily impacted. This may reflect the lack of surface flow in this section of Wainui Stream at times, as the sampling site (at Ardgour Road) was dry in February 2015 and was not sampled on this occasion as a result.

7.7.3 Fish

Two fish species (brown trout and upland bully) have been consistently collected from the Ardgour Road bridge, while a single large longfin eel was collected in 2010. Four species were collected at Lindis Crossing – brown and rainbow trout and common and upland bully. The presence of common bully at this site is likely to reflect its proximity to Lake Dunstan. Common bully are usually diadromous[5], but can form land-locked populations[6]. In this case, the common bully observed in the lower Lindis River are likely to be using Lake Dunstan as a growing habitat during their juvenile phase.

High densities of juvenile brown trout were observed at the Ardgour Road site during the SoE fish survey in 2010 following a prolonged period of low flows. The median flow for the 3 months preceding the fish survey was 848 l/s and maximum flow recorded was 4,612 l/s (*c.f.* the median flow for this site, 3,923 l/s). The most recent fresh[7] occurred on 6 September 2009, some 150 days prior to sampling. Therefore, the high densities of

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[5] Diadromous species spend part of their life-cycle in freshwater and part in saltwater.

[6] In landlocked populations of diadromous species, instead of migrating into the ocean, they migrate into a lake.

[7] A period of high flows that is likely to flush periphyton and fine sediment, but is smaller than the annual flood. A fresh is defined as when flows exceed three times the median flow, in this case, 11,769 l/s.

juvenile brown trout observed on this occasion may reflect high recruitment in the Lindis catchment resulting from the period of stability prior to the survey. Alternatively, it may reflect the aggregation of juvenile trout in the vicinity of the Ardgour Road bridge as they seek refuge from reduced flows and/or drying in the river reaches upstream and downstream of the survey reach.

High densities of upland bullies were observed at the Ardgour Road site during the SoE fish survey in 2014. This survey was conducted on 25 February 2014 during a prolonged period of low flows. The median flow for the 3 months preceding this fish survey was 1,017 l/s and maximum flow recorded was 4,612 l/s. The most recent fresh occurred on 1 November 2013, 115 days prior to sampling. As for the high densities of brown trout observed in 2010, the high densities of upland bullies observed in the 2014 survey may reflect high recruitment resulting from the period of stability prior to the survey or the aggregation of bullies in the vicinity of the Ardgour Road bridge as a result of reduced flows and/or drying in the river reaches upstream and downstream of the survey reach.

8 Summary

1. Flows in the middle and lower reaches of the Lindis River are heavily influenced by water abstraction as well as losses to groundwater. Much of the abstraction from the Lindis River occurs as large surface water takes from near Cluden Stream, downstream. Water abstraction in this lower part of the river has significant effects on the water quality and ecology of the lower Lindis River.

2. Water quality in the upper Lindis River is generally very good, but the lower catchment has high concentrations of TN and NNN. TN and NNN concentrations at sites downstream of Archies Flat are currently likely to exceed Schedule 15 standards for NNN. This deterioration in water quality coincides with the location of the major water takes from the Lindis River and is likely to be a result of nitrogen-enriched (relative to surface water) groundwater entering the river. Given that 80^{th} percentiles for most of the sites were calculated from only one year of data (the exceptions being the SoE sites at Lindis Peak and Ardgour Road), these results should be interpreted with caution.

3. TN and NNN increased and DRP decreased at the Ardgour Road hydrological site over the period 2005-2014, while *E. coli* concentrations at Lindis Peak decreased over the period 2003-2014.

4. Water quality in the two tributaries sampled in this study (Cluden and Wainui Streams) was generally poorer than most mainstem sites, with relatively high TN, TP and DRP concentrations. Concentrations of NNN and *E. coli* were relatively low in both tributary sites.

5. Water temperatures in the Lindis are generally suitable for the native and introduced fish present, although temperatures at Lindis Peak may be too warm for rainbow trout at times.

6. Coarse gravels, cobbles and fine gravels dominated the bed at all sites. 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, broom and rank grass.

7. The periphyton community at sites in the upper Lindis catchment (above Lindis Peak) were generally indicative of unenriched conditions, with low chlorophyll *a* concentrations and cover by long filamentous algae. Much greater periphyton growths were observed at Ardgour Road Bridge and the Ardgour Road hydrological site, most likely as a result of a combination of more enrichment and/or lower flows at this downstream site

8. Macroinvertebrate communities collected from the Lindis River (2006-2014) were consistent with good water quality. However, macroinvertebrate samples collected as part of this study in October indicated good to excellent water quality throughout the catchment, while samples collected in February were consistent with good water quality upstream of Lindis Peak and fair or good water quality downstream. This may reflect a combination of low, stable flows, the presence of the invasive diatom *Didymosphenia geminata* and/or water quality in the lower sites.

9. Macroinvertebrate communities in Cluden stream indicated good-fair water quality in October 2014, but fair-poor water quality in February 2015. Macroinvertebrate communities in Wainui stream in October 2014 indicated good-fair water quality.

10. Common and upland bullies, brown and rainbow trout and longfin eels have been collected from the lower Lindis River.

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Appendix A Water quality laboratory methods

Laboratory analysis methods used by Hills Laboratories (30 September 2013 – 18 July 2014)

Parameter		Method	Method description	Detection limit
TSS	Total suspended solids	APHA 2540D	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination	3 mg/L
Turbidity	Turbidity	APHA 2130	Analysis using a Hach 2100 Turbidity meter.	0.05 NTU
TN	Total nitrogen		Calculation: TKN + Nitrate-N + Nitrite-N	0.05 mg/L
NH4-N	Total ammoniacal nitrogen	APHA 4500-NH_3 F (modified from manual analysis)	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N).	0.010 mg/L
NNN	Nitrate-nitrite nitrogen (or Total oxidised nitrogen)	APHA4500-NO_3- I	Automated cadmium reduction, flow injection analyser	0.002 mg/L
TKN	Total Kjeldahl Nitogen	APHA 4500-Norg D (modified), 4500 NH_3 F (modified)	Phenol/hypochlorite colorimetry after sulphuric acid digestion with copper sulphate catalyst	0.10 mg/L
DRP	Dissolved reactive phosphorus	APHA 4500-P E (modified from manual analysis)	Molybedenum blue coloroimetry. Discrete analyser.	0.004 mg/L
TP	Total phosphorus	APHA 4500-P B&E (modified from manual analysis)	Ascorbic acid colorimetry after acid persulphate digestion. Discrete Analyser. Also modified to include the use of a reductant to eliminate interference from arsenic	0.004 mg/L
E. coli	*Escherichia coli*	APHA 9222 G	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, MUG Confirmation	1 cfu/100 ml

Laboratory analysis methods used by Watercare Laboratory Services (14 August-15 September 2014)

Parameter		Method	Method description	Detection limit
TSS	Total suspended solids	APHA 2540D	Filtration and gravimetry	0.2 mg/L
Turbidity	Turbidity	APHA 2130B (modified)		0.05 NTU
TN	Total nitrogen	APHA 4500-P J, 4500-NO3 F (modified)	Direct method	0.01 mg/L
NH4-N	Total ammoniacal nitrogen	MEWAM, HMSO 1981, ISBN 0117516139	Colorimetry/Discrete Analyser	0.005 mg/L
NO3-N	Nitrate nitrogen	APHA 4110 B (modified)	Ion chromatography (0.45 um filtered)	0.002 mg/L
NO2-N	Nitrite nitrogen	APHA 4110 B (modified)	Ion chromatography (0.45 um filtered)	0.002 mg/L
TKN	Total Kjeldahl Nitogen		Calculated: TN - NO3-N - NO2-N	0.10 mg/L
DRP	Dissolved reactive phosphorus	APHA 4500-P B, F (modified)	Colorimetry/Discrete Analyser	0.002 mg/L
TP	Total phosphorus	APHA 4500-P B, J (modified)	Persulphate digestion and Colorimetry/Discrete analyser	0.004 mg/L
E. coli	*Escherichia coli*	USEPA Method 1603 (2002)	Membrane filtration	2 cfu/100 ml

Appendix B Long-term macroinvertebrate data

Table 9.1 Macroinvertebrate taxa collected from the Lindis River as part of SoE monitoring. Relative abundance scores are described in Table 5.2.

Taxon	MCI score	Lindis River at Lindis Peak		Lindis River at Ardgour Rd								
		2004	2006	2006	2007	2008	2009	2010	2011	2012	2013	2014
ACARINA	5							R				
COLEOPTERA												
Elmidae	6	VVA	VA	VVA	VVA	A	C	VA	C	C	R	C
Scirtidae	8			C								
CRUSTACEA												
Ostracoda	3						R					
DIPTERA												
Aphrophila species	5										R	R
Austrosimulium species	3	VA	R		C	C	C	C	R			
Ceratopogonidae	3											R
Chironominae	2		VA	C	C	A						
Empididae	3							C				R
Ephydridae	4			C								
Eriopterini	9	C	R		R			R	C	C	C	R
Hexatomini	5											R
Lobodiamesa species	5											R
Maoridiamesa species	3				C			R				C
Mischoderus species	4						R					
Muscidae	3				R	C	C	A	R	R	C	C
Orthocladiinae	2		C	VA	VA	A	VA	VA	R	A	VVA	C
Podonominae	8									C		
Tanypodinae	5		C	C	C	A	A	A				
Tanytarsini	3							R		C	VA	C
EPHEMEROPTERA												
Austroclima species	9											R
Coloburiscus humeralis	9	R	R									
Deleatidium species	8	VVA	VA	VA	A	A	A	VA	A	VA	VA	C
Zephlebia species	7					C						
MEGALOPTERA												
Archichauliodes diversus	7	R	R	A	C	R		A		C	A	C
MOLLUSCA												
Potamopyrgus antipodarum	4		C	R	A	A						
NEMATODA	3				C							
OLIGOCHAETA	1	A	A	C	VVA		VA	VA		C	C	

Table 9.1 continued Macroinvertebrate taxa collected from the Lindis River as part of SoE monitoring. Relative abundance scores are described in Table 5.2.

Taxon	MCI score	Lindis River at Lindis Peak		Lindis River at Ardgour Rd								
		2004	2006	2006	2007	2008	2009	2010	2011	2012	2013	2014
PLECOPTERA												
Zelandobius species	5		C				R				R	R
Zelandoperla species	10	C						R				
TRICHOPTERA												
Hydropsyche species	4	VA	VA	A	A		R	A	R	A	A	A
Costachorema species	7								R	R		
Hudsonema amabile	6	C			R	A	R	R				R
Hydrobiosidae early instar	5		C	R	A	A	C					R
Hydrobiosis umbripennis grou	5		R		C	C	C	A	A	C	A	C
Neurochorema species	6	C	R		C	R						
Olinga species	9	VA	A	VA	C	A	R	A	C	C	A	C
Oxyethira albiceps	2				C		R	A				R
Psilochorema species	8	R	R	R	C	R	R	A		R	C	C
Pycnocentria species	7	VA				A	C	A	R	C	VA	A
Pycnocentrodes species	5	A	C	VVA	VA	A	R	R	R	R	A	A
Total Richness		**15**	**19**	**15**	**22**	**18**	**19**	**22**	**12**	**16**	**16**	**24**
EPT Richness (minus Hydroptilidae		**10**	**10**	**6**	**9**	**10**	**10**	**9**	**7**	**8**	**8**	**11**
%EPT Richness (minus Hydroptilida		**67%**	**53%**	**40%**	**41%**	**56%**	**53%**	**41%**	**58%**	**50%**	**50%**	**46%**
MCI Score		**131**	**108**	**104**	**96**	**109**	**96**	**104**	**113**	**115**	**109**	**106**
SQMCI Score		**6.56**	**4.98**	**5.66**	**3.66**	**5.31**	**2.69**	**4.64**	**6.63**	**6.44**	**3.81**	**5.35**

Appendix C Periphyton cover and chlorophyll *a* datasheets from 2014/15 survey

Table 9.2 Periphyton cover (%) and chlorophyll *a* concentration in the Lindis River on 21 October 2014.

Periphyton class		Lindis upstream of Pass Burn	Lindis at Black Bridge	Lindis at Lindis Peak	Lindis upstream of Cluden Stream	Lindis at Ardgour Rd bridge	Lindis at Ardgour Road hydro site	Lindis at SH8
Thin mat/film:	Green	3	2	-	-	-	-	1
(under 0.5 mm thick)	Light brown	8	20	91	15	0	36	19
	Black/dark brown	1	-	-	-	-	-	-
Medium mat:	Light brown	-	4	-	-	-	-	4
(0.5 – 3 mm thick)	Black/dark brown	-	-	-	3	2	5	-
Thick mat: (over 3 mm thick)	Black/dark brown	-	3	-	-	-	3	-
Didymo mat	Brown to white	1	-	-	-	26	1	0
Filaments, short:	Green	5	-	-	-	-	-	-
(>1 cm, <2 cm long)	Brown/reddish	-	43	0	24	-	4	2
Filaments, long (>2 cm)	Green	-	4	-	-	-	1	1
Total periphyton cover (%)		**17**	**75**	**92**	**41**	**28**	**49**	**26**
Chlorophyll *a* concentration (mg/m2)		**3.1**	**15.9**	**3.6**	**15.8**	**19.4**	**41.7**	**9.5**

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Table 9.3 Periphyton cover (%) and chlorophyll *a* concentration in the Lindis River on 15 December 2014.

Periphyton class		Lindis upstream of Pass Burn	Lindis at Black Bridge	Lindis at Lindis Peak	Lindis upstream of Cluden Stream	Lindis at Ardgour Rd bridge	Lindis at Ardgour Road hydro site	Lindis at SH8
Thin mat/film:	Green	1	-	1	-	-	35	11
(under 0.5 mm thick)	Light brown	37	24	58	-	-	-	-
	Black/dark brown	-	-	-	-	-	-	-
Sludge	Loose unconsolidated algae, easily dislodged	-	-	-	-	-	13	13
Medium mat:	Dark green/black bobbles (*Nostoc*)	2	-	-	-	-	-	-
(0.5 – 3 mm thick)	Black/dark brown	-	0	1	8	1	16	-
Didymo mat	Brown to white	0	2	0	-	28	2	12
Filaments, short:	Green	-	0	-	-	-	1	-
(>1 cm, <2 cm long)	Brown/reddish	-	1	-	-	-	-	-
Filaments, long: (over 2 cm long)	Green	0	0	-	-	-	-	-
Total periphyton cover (%)		**40**	**28**	**59**	**8**	**28**	**66**	**36**
Chlorophyll *a* concentration (mg/m2)		**4.3**	**5.7**	**2.2**	**42.1**	**11.2**	**64.2**	**9.9**

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Table 9.4 Periphyton cover (%) and chlorophyll *a* concentration in the Lindis River on 20 January 2015.

Periphyton class		Lindis upstream of Pass Burn	Lindis at Black Bridge	Lindis at Lindis Peak	Lindis upstream of Cluden Stream	Lindis at Ardgour Rd bridge	Lindis at Ardgour Road hydro site	Lindis at SH8
Thin mat/film:	Green	-	4	2	15	0	44	-
(under 0.5 mm thick)	Light brown	-	24	-	29	2	6	-
	Black/dark brown	-	3	-	-	-	-	-
Sludge	Loose unconsolidated algae, easily dislodged	1	-	5	-	50	18	-
Medium mat:	Dark green/black bobbles (*Nostoc)*	13	-	-	-	-	-	-
(0.5 – 3 mm thick)	Black/dark brown	-	1	4	15	-	0	-
Thick mat:	Green/light brown	-	0	-	-	-	-	-
(over 3 mm thick)	Black/dark brown	-	-	-	1	-	-	-
Didymo mat	Brown to white	-	14	-	-	28	15	-
Filaments, short:	Green	0	0	-	-	-	-	-
(>1 cm, <2 cm long)	Brown/reddish	-	-	-	-	-	-	-
Filaments, long: (over 2 cm long)	Green	1	1	-	-	16	3	-
Total periphyton cover (%)		**14**	**46**	**11**	**59**	**96**	**87**	**-**
Chlorophyll *a* concentration (mg/m2)		**8.1**	**20.6**	**3.1**	**30.3**	**49.5**	**52.6**	**-**

Table 9.5 Periphyton cover (%) and chlorophyll *a* concentration in the Lindis River on 17 February 2015.

Periphyton class		Lindis upstream of Pass Burn	Lindis at Black Bridge	Lindis at Lindis Peak	Lindis upstream of Cluden Stream	Lindis at Ardgour Rd bridge	Lindis at Ardgour Road hydro site	Lindis at SH8
Thin mat/film:	Green	-	7	18	11	2	-	-
(under 0.5 mm thick)	Light brown	-	3	-	4	-	-	-
	Black/dark brown	-	1	-	5	-	-	-
Sludge	Loose unconsolidated algae, easily dislodged	-	3	18	4	17	24	-
Medium mat:	Light brown	0.1	0.1	-	-	-		-
(0.5 – 3 mm thick)	Dark green/black bobbles (*Nostoc)*	31	-	-	-	-		-
	Black/dark brown		7	6	35	-	5	-
Thick mat:	Green/light brown	-	-	-	-	-	-	-
(over 3 mm thick)	Black/dark brown	-	-	-	-	17	2	-
Didymo mat	Brown to white	-	6	-	-	25	35	-
Filaments, short:	Green	-	0.4	-	-	4	-	-
(>1 cm, <2 cm long)	Brown/reddish	-	8	-	-	-	-	-
Filaments, long: (over 2 cm long)	Green	1	0.2	-	-	27	18	-
Total periphyton cover (%)		**32**	**33**	**42**	**59**	**91**	**83**	**-**
Chlorophyll *a* concentration (mg/m2)		**18.8**	**32.4**	**19.7**	**63.9**	**4.9**	**8.3**	**-**

Table 9.6 Periphyton cover (%) and chlorophyll *a* concentration in the Lindis River on 20 March 2015.

Periphyton class		Lindis upstream of Pass Burn	Lindis at Black Bridge	Lindis at Lindis Peak	Lindis upstream of Cluden Stream	Lindis at Ardgour Rd bridge	Lindis at Ardgour Road hydro site	Lindis at SH8
Thin mat/film:	Green	-	2	1	1	-	-	-
(under 0.5 mm thick)	Light brown	2	-	67	82	-	-	-
	Black/dark brown	-	7	-	7	-	-	-
Sludge	Loose unconsolidated algae, easily dislodged	-	-	-	-	16	48	-
Medium mat:	Light brown	-	2	-	1	-	-	-
(0.5 – 3 mm thick)	Dark green/black bobbles (*Nostoc)*	44	-	-	-	-	-	-
	Black/dark brown	-	12	5	-	-	2	-
Thick mat:	Green/light brown	-	0	-	-	8	-	-
(over 3 mm thick)	Black/dark brown	-	-	-	-	-	-	-
Didymo mat	Brown to white	-	6	-	-	29	19	-
Filaments, short:	Green	-	-	-	-	11	-	-
(>1 cm, <2 cm long)	Brown/reddish	-	-	-	-	-	-	-
Filaments, long:	Green	1	1	-	-	18	24	-
(over 2 cm long)	Brown/reddish	-	-	-	-	-	5	-
Total periphyton cover (%)		**47**	**29**	**74**	**90**	**81**	**98**	**-**
Chlorophyll *a* concentration (mg/m2)		**43.5**	**25.6**	**17.4**	**25.7**	**45.4**	**151.1**	**-**