Macroinvertebrates of the Wairau River and the likely consequences of proposed hydroelectric development

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ABSTRACT

A hydroelectric scheme is currently being proposed for the Wairau River, Marlborough, New Zealand. This report reviews macroinvertebrate data for the Wairau and compares its macroinvertebrate community to those in other medium-to-large braided rivers in the South Island of New Zealand. It also considers the likely effects of the proposed scheme on macroinvertebrates in the Wairau. The diversity and abundance of the macroinvertebrate community of the Wairau was within the range found in other large South Island braided rivers, and provided much of the food needed by local populations of drift-feeding fish, such as brown trout (*Salmo trutta*), and insectivorous birds, such as the black-fronted tern (*Sterna albostriata*), an endangered species. Nymphs of the mayfly *Deleatidium* were abundant and numerically dominated communities at most sites. Elmid beetles and the sandy-cased caddis fly *Pycnocentrodes* were also abundant in the affected reach. Reduced flows would decrease the available habitat for stream macroinvertebrates and could degrade remaining habitat through periphyton proliferation, accumulation of fine sediments, and increased water temperatures. Reduced exchange between the river and groundwater also had the potential to seriously affect macroinvertebrate communities as well as nutrient dynamics and thermal patterns in the residual river.

Keywords: macroinvertebrates, hyporheic zone, Wairau River, braided rivers, South Island, New Zealand, hydroelectric power, environmental effects, residual river, freshwater fish, riverine birds

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1. Introduction

A hydroelectric scheme is currently being proposed by TrustPower Ltd for the Wairau River, Marlborough, South Island, New Zealand. It will affect approximately 49 km of the main stem of the Wairau, from upstream of the Branch River confluence to the Marchburn River confluence approx. 20 km east of Blenheim. The scheme will result in a residual flow of between 10 and 20 m^3/s immediately downstream of the intake structure (compared with an estimated natural flow of approximately 40 m^3/s), with lowest flow occurring between January and July and highest flows in October–November. Of particular concern are the effects that the construction and operation of the proposed scheme will have on the brown trout (*Salmo trutta*) fishery and bird populations of the Wairau, including a significant population of black-fronted terns (*Sterna albostriata*), a threatened species.

To consider the effects of the proposed scheme on fish and bird populations, it is important to consider the effects that the scheme will have on the production of prey species. Macroinvertebrates are the worms, insects, crustaceans, mites and molluscs that live on and in the streambed and are an important part of stream food webs as they provide an energetic link between plants (algae, macrophytes), detritus (leaves, woody debris) and microbes (bacteria, fungi) and larger predatory animals such as fish and birds. Macroinvertebrates are affected by a wide range of physical and chemical factors and, for this reason, are commonly used as indicators of water quality, e.g. the Macroinvertebrate Community Index (MCI) of Stark (1985). Changes in water quality are expected to result in changes in the composition of the macroinvertebrate community, which may affect the availability and quality of food for fish or bird predators.

1.1 OBJECTIVES

1. Review existing macroinvertebrate data for the Wairau and compare its macroinvertebrate community to those of other medium-to-large braided rivers in the South Island for which data are available, particularly with regard to its ability to support fish and bird populations.
2. Consider the likely effects of the proposed hydroelectric power scheme on the macroinvertebrate community of the Wairau and its tributaries.

2. Macroinvertebrate community of the Wairau

2.1 SPECIES COMPOSITION

The Wairau supports a diverse and abundant macroinvertebrate fauna. Previous collections have yielded between 45 (9.1 m^2—National River Water Quality Network (NRWQN) data, 1989–2001, courtesy of the National Institute of Water and Atmospheric Resesearch (NIWA)) and 55 macroinvertebrate taxa (5.7 m^2—Stark 1987) from the upper reaches of the Wairau, at Dip Flat, and 37 taxa from towards the river mouth, at Tuamarina (8.4 m^2—NRWQN). Ryder & Keesing (2005) collected 43 taxa from 66 kick-net samples (c. 33 m^2) from four sites, one upstream of the proposed scheme intake (Argyle), one downstream of the proposed scheme outlet (Hillersden), and two within the reach of river that will experience reduced flows as a result of the scheme (Marchburn and Wratts Road). Caution should be exercised when comparing the total number of taxa between these different studies since sampling effort (e.g. sampling technique, sample volume, number of samples taken) and taxonomic effort varied considerably.

The macroinvertebrate community of the Wairau is dominated numerically by nymphs of the mayfly *Deleatidium* (Table 1, Ryder & Keesing 2005) at most sites. At Dip Flat, other abundant taxa included the stoneflies *Zelandobius furcillatus*-group and *Zelandoperla decorata*, the caddis fly *Aoteapsyche*, and blephariceridand orthocladine midges (Table 1). Elmid beetles and *Pycnocentrodes* were also abundant within the reach that will be affected by the proposed hydroelectric power scheme (Table 1). Further downstream, at Tuamarina, chironomid midges dominated the community (59.1%), although *Deleatidium* also was very abundant (30.1% of total invertebrate abundance, equivalent to c. 1450 individuals/m^2), even more so than at Dip Flat, where it was numerically dominant (constituting 22.9–38.3% of the total invertebrate abundance). Together chironomids and *Deleatidium* made up almost 90% of the total macroinvertebrate community at Tuamarina (Table 1). Dip Flat, in the upper reaches of the Wairau, typically has cool water and low periphyton growth (Close & Davies-Colley 1990; Biggs 1990), the likely result of shading by native forest and surrounding mountain ranges. Growth of periphyton also probably is limited by low nutrient concentrations. Water temperature and nitrate-N concentrations are higher at Tuamarina than at Dip Flat (NRWQN data—in Ryder & Keesing 2005) and both these factors probably contribute to the observed differences in macroinvertebrate community between these sites.

The fauna of the south-bank tributaries of the Wairau is composed of similar taxa to the mainstem, although the relative abundance of these taxa reflects the lower flows and higher stability of these streams. Communities varied from stream to stream but often were dominated by *Deleatidium*, cased caddis flies (especially *Helicopsyche*, *Olinga* and *Pycnocentrodes*), chironomids (Orthocladiinae and *Maoridiamesia* (Diamesinae)), *Austrosimulium* and/or *Potamopyrgus antipodarum*. Although there is little indication of the presence of distinct macroinvertebrate communities in the lower reaches of these tributaries, they

TABLE 1. RELATIVE ABUNDANCE OF MACROINVERTEBRATES AT DIFFERENT LOCATIONS ALONG THE WAIRAU RIVER, MARLBOROUGH.

Relative abundance of common (> 1% of total abundance at one or more sites) macroinvertebrate taxa, taxon richness and total invertebrate abundance collected from the Wairau River at: Dip Flat in July, September, and November by Stark (1987); Dip Flat (DIP) and Tuamarina (TUA) from NRWQN (data courtesy of the National Institute of Water and Atmospheric Research); Argyle (ARG), Hillersden (HIL), Marchburn (MAR), and Wratts Road (WRA) by Ryder & Keesing (2005). – indicates taxa that were not collected, * denotes a taxon for which the relative abundance was ≤ 0.5% of total abundance), and 'na' indicates that this information was not available. EPT = Ephemoptera/Plecoptera/Trichoptera.

	STARK (1987)			NRWQN		RYDER & KEESING (2005)					
	JUL	SEP	NOV	DIP	TUA	ARG	HIL		MAR		WRA
						2003	2003	2004	2003	2004	2003
Ephemeroptera											
Austroclima spp.	1.0	0.7	1.6	*	–	–	–	–	–	–	–
Deleatidium spp.	22.9	26.3	36.7	38.3	30.1	60.1	71.8	43.0	38.6	42.3	57.1
Nesameletus	1.4	3.7	0.8	*	*	0.7	*	1.0	–	–	*
Plecoptera											
Zelandobius furcillatus	16.4	9.7	2.3	*	*	*	*	–	*	–	–
Zelandoperla decorata	10.3	5.4	0.6	12.5	*	–	–	*	–	–	–
Megaloptera											
Archichauliodes diversus	–	*	1.0	*	*	—	—	—	*	*	—
Coleoptera											
Elmidae	1.9	2.0	1.9	6.5	2.9	21.6	3.0	37.5	16.9	17.0	12.9
Diptera											
Aphrophila neozelandica	3.1	1.7	2.2	1.4	*	*	–	1.1	*	*	*
Eriopterini	1.6	1.3	1.7	0.6	*	*	–	*	*	1.4	–
Diamesinae	2.2	1.8	3.5	2.3	0.8	–	1.2	*	*	1.4	*
Orthocladiinae (Chironomidae)	5.1	11.1	5.2	14.7	26.8	*	3.4	1.2	1.1	1.3	6.6
Tanytarsini (Chironomidae)	*	4.1	3.1	0.7	32.3	–	–	–	–	–	–
Simuliidae	*	*	*	2.7	*	3.4	4.5	*	*	*	*
Blephariceridae	8.7	10.7	11.1	*	–	–	–	–	–	–	–
Empididae	1.0	0.8	0.8	–	–	–	–	*	–	*	–
Trichoptera											
Aoteapsyche sp.	8.2	4.4	6.8	13.9	1.9	1.4	0.5	3.3	*	4.9	*
Costachorema spp.	0.9	*	1.6	*	*	*	*	*	*	*	*
Hydrobiosis spp.	1.7	1.0	2.0	*	–	*	0.6	1.0	*	3.0	0.7
Neurochorema spp.	1.0	1.0	*	*	*	–	–	*	*	*	–
Psilochorema spp.	0.8	1.0	0.6	1.1	*	1.4	1.5	0.8	*	1.5	1.0
Pycnocentria spp.	–	–	2.0	*	*	–	–	–	*	–	*
Beraeoptera roria	1.6	1.2	0.7	*	–	–	–	–	–	–	–
Pycnocentrodes sp.	2.2	2.5	2.9	*	1.1	10.1	10.0	6.7	38.1	22.0	11.8
Confluens hamiltoni	–	–	1.0	*	*	–	–	–	–	–	–
Olinga	1.3	*	2.1	*	*	0.6	1.5	–	0.8	–	–
Mean taxon richness (per 0.1 m^2)	13.1	14	12.7	na	na	na[#]	na[#]	na[#]	na[#]	na[#]	na[#]
Total taxa collected		36	42	41	45	37	28	37	34	29	
Total abundance (individuals/m^2)	1533	1905	1290	2580	4811	na[#]	na[#]	na[#]	na[#]	na[#]	na[#]
% EPT	73.3	61.0	67.2	69.7	34.3	75.5	86.7	57.1	79.8	74.7	71.7

[#] Not available because samples were collected using a semi-quantitative method.

are likely to support higher densities of some taxa (e.g. *P. antipodarum*) that are rare in the mainstem. The lower reaches of some of these tributaries (particularly that referred to as the Excell/Huddleston mix (Mill Road)) may also support significant populations of freshwater mussels (N. Deans, pers. comm.).

2.2 MACROINVERTEBRATES OF POTENTIAL CONSERVATION INTEREST

The only macroinvertebrate species of potential conservation interest found in the Wairau is *Neurochorema* sp. A reported in Stark (1988), which was previously only known from streams near the Heaphy Track in the northwest of the South Island. This identification is based on larval material collected in the Surber samples of Stark (1988). Given the uncertainty when separating species of *Neurochorema* as larvae, the presence of *Neurochorema* sp. A should be confirmed by collecting adults in this area.

2.3 COMPARISON WITH OTHER SOUTH ISLAND BRAIDED RIVERS

2.3.1 Taxon richness

In collections between 1989 and 2001, as part of the NRWQN (data courtesy of NIWA), a total of 45 taxa were collected from the Wairau at Dip Flat and 37 taxa from Tuamarina. These values are within the range collected from other braided South Island rivers sampled as part of the NRWQN (27–49 taxa—Table 2). Comparisons within the NRWQN data are appropriate because the sampling protocols and taxonomy are consistent within this dataset. However, sampling effort (e.g. sample volume, number of samples taken) and taxonomic effort varied considerably between other studies summarised in this report, and caution should be exercised when comparing the total number of taxa between the various studies.

2.3.2 Invertebrate abundance

The abundance of macroinvertebrates observed in the Wairau ranged from 1533 to 2580 individuals/m^2 at Dip Flat and was 4811/m^2 at Tuamarina (Table 1). Because this review was conducted using existing quantitative data, caution should be made when interpreting patterns. For example, seasonal data were available for most locations, but not for some. For clarity in Fig. 1 and space in Table 2, where seasonal data were available, data were averaged over all seasons. Densities at Dip Flat were within the range observed in the Ashley, Hurunui, Rangitata, Waimakariri, and Waitaki Rivers, but, on average, samples from Dip Flat contained far fewer invertebrates than samples from the Grey River, although this difference is largely accounted for by the large numbers of chironomid midges in the Grey River (Table 2). Invertebrate densities at Tuamarina were higher than those observed in most other rivers reviewed, except the Waitaki (Table 2), although mean invertebrate abundances in excess

TABLE 2. RELATIVE ABUNDANCE OF MACROINVERTEBRATES AT DIFFERENT LOCATIONS ALONG THE ASHLEY, GREY, HURUNUI, RAKAIA, RANGITATA, WAIMAKARIRI, AND WAITAKI RIVERS.

Relative abundance of common macroinvertebrate taxa, taxon richness and total invertebrate abundance collected from the Ashley (A: Scrimgoeur & Winterbourn 1989; B: Hughey et al. 1989, Grey and Hurunui (NRWQN), Waimakariri (C: Hughey et al. 1989; D: Gorge, E: Old Bridge, both NRWQN), Rakaia (Sagar 1986), Rangitata (F: Bonnet 1986; G: Stark 2001), and Waitaki (H: Palmer et al. 1989; I: Rutledge 1987; J: Rutledge et al. 1992; K NRWQN) Rivers. NRWQN data courtesy of the National Institute of Water and Atmospheric Research. – indicates taxa that were not collected, * denotes a taxon for which the relative abundance was ≤ 0.5% of total abundance), '?' denotes taxa for which insufficient information is given, and 'na' indicates that this information was not available. EPT = Ephemoptera/Plecoptera/Trichoptera.

	ASHLEY		GREY		HURUNUI		WAIMAKARIRI		
	A	B	Dobson	Waipuna	Mandamus	SH1	C – SH1	D	E
Deleatidium	59.1	69.2	3.7	9.1	28.6	27.7	78.7	23.1	36.1
Zelandobius	*		*	*	*	*		*	*
Zelandoperla	–	*[†]	*	*	*	*	*[†]	*	*
Aoteapsyche	12.2	*	14.5	13.6	25.5	13.1	*	*	*
Hydrobiosis	*	?	*	*	*	*	?	*	*
Oxyethira albiceps	*	?	*	*	*	*	?	*	*
Pycnocentrodes	*	?	*	*	9.2	14.7	?	*	*
Elmidae	13.8	16.2	*	*	*	12.8	*	*	*
Austrosimulium	*	*	*	*	*	*	*	*	*
Chironomidae	4.4	*	68.7	64.9	16.5	24.4	13.1	70.3	46.2
Oligochaeta	*	?	*	*	*	*	?	*	6.8
Potamopyrgus	*	?	*	*	*	*	?	*	*
Mean taxon richness (per 0.1 m^2)	na	9.3[#]	na	na	na	na	7.4[#]	na	na
Total taxa collected	60	na	46	49	37	44	na	33	27
Mean total abundance (individuals/m^2)	na	2419	4294	4724	1412	4063	1350	2061	1257
% EPT	77.4	73.5	23.4	29.7	76.4	59.4	81.5	27.9	45.2

	RAKAIA			RANGITATA – F				RANGITATA – G	
	Mouth	SH1 bridge	Below gorge	Mouth	SH1 bridge	Arundel	Above gorge	Mouth	Arundel
Deleatidium	67.7	78.2	60.7	72.3	59.9	67.4	70.8	80.2	24.8
Zelandobius	*	*	*	8.2	*	5.0	*	8.7	*
Zelandoperla	–	–	–	–	–	–	–	?	?
Aoteapsyche	5.8	*	*	*	*	*	*	*	*
Hydrobiosis	*	*	*	*	*	*	*	*	*
Oxyethira albiceps	*	*	*	*	*	*	*	*	*
Pycnocentrodes	*	*	*	*[‡]	*[‡]	*[‡]	*[‡]	*	*
Elmidae	*	*	*	*	*	*	*	*	*
Austrosimulium	–	*	*	4.7	5.7	6.1	10.7	*	*
Chironomidae	16.6	12.9	30.6	8.3	20.5	13.1	10.3	2.8	64.8
Oligochaeta	*	*	*	*	*	*	*	?	?
Potamopyrgus	–	–	–	*	–	–	–	?	?
Mean taxon richness (per 0.1 m^2)	na	na	na	7.2	8.0	8.4	12.4	na	na
Total taxa collected	na	33	na	17	18	19	27	32	30
Mean total abundance (individuals/m^2)	1462	824	666	573	948	692	1917	813	1517
% EPT	80.3	83.7	67.1	85.0	68.6	81.2	79.5	84.4	29.4
n				18	21	21	21		

[#] Major channels only.

[†] Identified to family only—Gripopteryrigidae.

[‡] Includes *Pycnocentria*.

(*continued on next page*)

Table 2—continued.

	WAITAKI							
	H	I - Ferry in	I - Ferry out	I - Henstridge	I - Jardines	J - Near Duntroon	K - Kurow	K - SH1 bridge
Deleatidium	16.8	10.9	12.5	6.0	12.7	17.7	9.5	*
Zelandobius	7.6	*	*	*	*	10.5	–	*
Zelandoperla	–	–	–	–	–	–	–	–
Aoteapsyche	6.7	12.5	*	*	*	8.9	*	*
Hydrobiosis	*	*	*	*	*	*	*	*
Oxyethira albiceps	5.9	*	*	*	*	8.1	12.6	*
Pycnocentrodes	*	20.1[‡]	7.1[‡]	15.7[‡]	*[‡]	–	*	19.8
Elmidae	35.3	6.6	31.5	30.0	50.0	26.6	*	*
Austrosimulium	6.2	*	*	*	*	*	*	*
Chironomidae	10.7	*	*	*	8.8	9.7	45.2	19.6
Oligochaeta	*	*	10.7	8.3	6.4	*	11.7	*
Potamopyrgus	*	22.5	8.5	8.9	10.2	7.3	5.7	9.9
Mean taxon richness (per 0.1 m^2)	12.5	14.6	9.5	10.6	8.3	na	na	na
Total taxa collected	16	21	21	21	17	na	28	44
Mean total abundance (ind./m^2)	1255	5755	698	1396	976	na	410	4126
% EPT	40.7	56.7	32.3	31.0	20.5	46.8	27.8	29.5

[#] Major channels only.

[†] Identified to family only—Gripopteryrigidae.

[‡] Includes *Pycnocentria.*

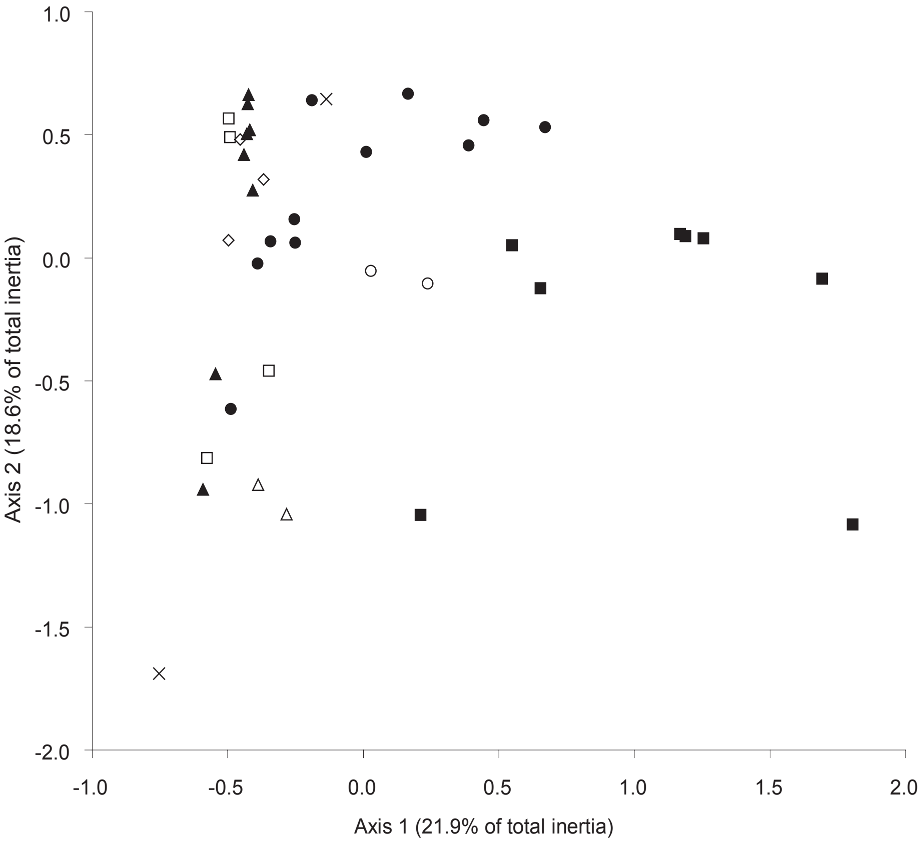

Figure 1. Macroinvertebrate communities of some South Island rivers. Correspondence analysis ordination of the macroinvertebrate communities of the Wairau (closed circles), Ashley (crosses), Grey (open triangles), Hurunui (open circles), Rakaia (open diamonds), Rangitata (closed triangles), Waimakariri (open squares), and Waitaki (closed squares) Rivers.

of 4000/m^2 have also been observed in the Hurunui and Grey Rivers (Table 2). Mean macroinvertebrate densities at Dip Flat and Tuamarina generally were higher than those observed in the Rakaia (Table 2).

Macroinvertebrate samples to provide a basis from which to assess the effects of the proposed scheme were collected using kick-netting from an area of approximately 0.5 m^2. Density estimates for these samples from the main channel of the Wairau varied widely and were generally lower than estimates from other locations in the Wairau (22–478/m^2 at Argyle, 230–1800/m^2 at Hillersden, 218–1770/m^2 at Marchburn and 68–560/m^2 at Wratts Road—data courtesy of Greg Ryder).

It is difficult to determine the reliability of density estimates derived in this way, since kick-netting is only a semi-quantitative method (at best) and may not collect all individuals from the sampling area. It should be noted, too, that macroinvertebrate densities can vary over several orders of magnitude, from less than 100/m^2 to more than 10 000/m^2, not only between rivers but also between times at the same sampling sites, and should be compared with caution. Densities are lowest immediately after large floods and highest after several weeks of stable flow.

2.3.3 Community composition

The composition of the macroinvertebrate communities of the eight braided rivers investigated were compared using a correspondence analysis conducted on untransformed (% composition) macroinvertebrate data. On an ordination plot, communities with similar composition plot close together.

Axis 1 (Fig. 1) is a gradient of increasing relative abundance of elmid beetles, amphipods, *Potamopyrgus antipodarum* and/or the caddis flies *Pycnocentrodes/Pycnocentria* (Table 3). Axis 2 is primarily a gradient in the relative abundance of chironomid midges and *Deleatidium*, with high scores corresponding to *Deleatidium*-dominated communities whilst lower scores represent communities that are dominated by chironomids (Table 3). In the ordination plot, the faunal composition of the Rakaia overlaps with those from most sites in the Rangitata and Waimakariri, indicating that invertebrate communities in these rivers are similar (Fig. 1), largely due to the dominance of *Deleatidium* (Tables 2 and

TABLE 3. PROPORTIONAL CONTRIBUTIONS AND COORDINATES OF SELECTED INVERTEBRATE TAXA TO THE INERTIA OF EACH AXIS OF THE CORRESPONDENCE ANALYSIS.

SPECIES	AXIS 1		AXIS 2	
	INERTIA	COORD	INERTIA	COORD
Chironomidae	0.10	–0.3	0.45	–0.9
Deleatidium	0.09	–0.4	0.29	+0.5
Elmidae	0.18	0.9	0.02	+0.3
Amphipoda	0.14	2.3	0.06	–1.4
Potamopyrgus	0.17	1.9	0.01	–0.4
*Pycnocentrodes**	0.13	1.0	0.01	+0.2

* Combination of *Pycnocentrodes* and *Pycnocentria*.

3). However, some locations in the Rangitata and Waimakariri have low scores on this second axis and are dominated by chironomids (Fig. 1; Tables 2 and 3). Both sites within the Grey are similar to each other and are dominated by chironomids (Fig. 1; Tables 2 and 3). Similarly, the communities from both sites in the Hurunui were similar and occupy an intermediate position on both dimensions (Fig. 1). The invertebrate community of the Waitaki is distinct from all other rivers investigated, with the main distinction being lower dominance by *Deleatidium* and greater relative abundances of elmid beetles, amphipods, *Potamopyrgus*, and *Pycnocentria* and/or *Pycnocentrodes* (Table 3).

Samples from Dip Flat in the Wairau generally had low scores on Axis 1 and an intermediate position on Axis 2, indicating the moderate relative abundance of *Deleatidium* and chironomids compared to the communities of the other rivers examined. Data from the three sampling occasions (July, September, and November) of Stark (1988) and the NRWQN from this site fall in close proximity to each other, indicating that community composition at this site varied little between the different sampling occasions of Stark (1988) and between the two data sources. The invertebrate community from the Wairau at Dip Flat is in a similar position to samples from the Hurunui, Rakaia, Rangitata, and Waimakariri (Fig. 1), most likely due to the moderate relative abundance of *Deleatidium* and chironomids and the abundance of *Aoteapsyche* at these sites (Table 2). In comparison, the Tuamarina NRWQN sample falls within the ranges of samples from the Waimakariri and Rangitata, with a lower score on Axis 1 and low score on Axis 2, most likely as a result of the higher relative abundance of chironomids at this site. The sites in the reach to be affected by the proposed scheme (data courtesy of Greg Ryder) are most similar to the community of the Ashley collected by Hughey et al. (1989) and have moderate scores on Axis 1 and high scores on Axis 2 ordination plot, indicating the higher abundance of *Deleatidium,* elmid beetles, and *Pycnocentrodes* at these sites than in other sites in the Wairau.

A notable distinction between the macroinvertebrate community of the Wairau and those of other rivers considered in this review is the relative abundance of the net-wing midges (Blephariceridae; including *Neocurupira hudsoni*-group and *Peritheates turrifer*—Stark 1988) at Dip Flat (Table 1) compared with the complete absence in all other rivers investigated, except the Rangitata (Table 2). Within the Wairau, Blephariceridae were only collected at Dip Flat and their relatively high numbers there was likely to reflect the more stable nature of the substrate and the comparatively fast water velocities relative to other sites in the Wairau and the other rivers investigated. It is likely that samples collected from the upper reaches of the other braided rivers would also yield blephariceridis.

2.4 SIGNIFICANCE TO FISH AND BIRDS

Twenty-seven fish species (21 native, 6 exotic) and 18 species of river-bed birds are known to be associated with the mainstem of the Wairau (TrustPower Ltd 2005). All these fish species and many of the bird species rely, to some degree, on stream macroinvertebrates for food. Drift-feeding fish, such as brown trout, and insectivorous birds, such as black-fronted terns, which gain a large proportion of their energy from stream invertebrates, are expected to be sensitive to changes in the number, type and size of invertebrates living in the river.

The macroinvertebrate community of the Wairau contains a high proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa (Table 1), which are likely to be favoured food items for trout and insectivorous birds. Similarly EPT-rich communities were found in the Ashley, Hurunui, Rakaia and Rangitata and at some sites in the Waimakariri (Table 2).

Brown trout are visual drift-feeders; they feed preferentially on larger invertebrates (McLennan & MacMillan 1984; Glova & Sagar 1991), and prey size is an important factor affecting growth rates (Hayes et al. 2000), by affecting foraging radius, foraging efficiency, and the energy intake of trout. Thus, trout in a stream dominated by numerous small invertebrates (e.g. chironomids) are expected to grow more slowly than those in a stream where the drift contains a larger proportion of larger insects. Galaxiids feed more at night, especially in the presence of trout, and feed on a wide variety of macroinvertebrates (McIntosh 2000). The composition of their diet usually reflects prey availability (McIntosh 2000), with small prey making up a greater proportion of their diet than for trout in the same stream (Glova & Sagar 1991), indicating that they are generalist feeders.

Black-fronted terns feed on emerging and adult aquatic insects, flying above the water surface and intercepting any drifting adult insects, particularly mayflies. This is a high energy-cost feeding strategy that makes them susceptible to changes in prey availability (O'Donnell 2004). *Deleatidium* is by far the most abundant mayfly in the Wairau (Table 1), and it is anticipated that any reduction in its abundance will affect the population of black-fronted terns in the Wairau catchment.

3. Effects of the proposed hydroelectric development

3.1 FLOW

The flow regime for the proposed scheme will see a minimum flow immediately below the intake of 10 m^3/s from January to July, 12–15 m^3/s from August to September, 20 m^3/s from October to November and 15 m^3/s in December (TrustPower Ltd 2005). This compares with an estimated mean flow at the site of the proposed intake of 39.4 m^3/s.

The primary effect of the proposed reduction in flows in the residual river is a reduction in the area of wetted habitat available to support macroinvertebrate production. Models have been used to predict the effects of different flow regimes in the Wairau on the extent of habitat for various aquatic species (Ryder & Keesing 2005). For *Deleatidium* they indicate that habitat declines gradually as flows reduce to 20 m^3/s but more rapidly below 15 m^3/s (Ryder & Keesing 2005). These models suggest that, of the *Deleatidium* habitat available at 35 m^3/s (approximately the mean flow at the proposed intake—TrustPower Ltd 2005), 51%–65% will be available at 10 m^3/s and 65%–75% at 15 m^3/s (Ryder & Keesing 2005). It should be noted that these models do not take into account other changes in habitat, other than flow, depth, and substrate availability. For example, the estimate of 51%–65% of current *Deleatidium* habitat being available at flows of 10 m^3/s does not account for any reduction in the suitability of this habitat resulting from increased water temperatures at reduced flows (see section 3.3).

The proposed scheme is also likely to alter the flow variability within the residual river by removing small to moderate increases in flow, since these flows are likely to be the primary source of water for generation during the drier months. Effectively, the diversion of any water in excess of the minimum flow (up to the scheme's capacity of 40 m^3/s) will result in extended periods of stable, low flows and will reduce the frequency of higher flows. Large floods can cause widespread mobilisation of the substrate (Matthaei et al. 1999) and major changes to channel structure (Wondzell & Swanson 1999), and may cause major invertebrate mortality (e.g. Scrimgeour et al. 1988; Scrimgeour & Winterbourn 1989; Olsen & Townsend 2005). In contrast, spates, which are increases in flow that are below bank-full, can have significant roles in maintaining habitat quality, by removing excess growths of periphyton and flushing fine sediments (see section 3.2), either of which may have beneficial effects on benthic invertebrate communities. The accumulation of thick periphyton mats can lead to changes in the invertebrate community from one dominated by clean-water animals (e.g. mayflies, stoneflies, and most caddis flies), which are favoured prey of drift-feeding fish, to one with a greater proportion of dipterans (e.g. chironomids, craneflies (Tipulidae)).

3.2 SEDIMENT

Reduced flows within the residual river may allow fine sediments that would usually be flushed away during higher flows to accumulate on the stream bed. This is of particular concern if significant amounts of sediment are discharged into the river from catchment erosion upstream of the scheme or, during the scheme's construction, repair or alteration of the semi-permanent and temporary structures associated with the intake. It is important to ensure that inputs of fine sediment are minimised during construction and operation of the proposed scheme, as these have the potential to have major negative effects on macroinvertebrates and higher trophic levels.

Sediment size affects macroinvertebrate community composition through the preferences of individual taxa, with most New Zealand macroinvertebrates preferring substrates of coarse gravel (32–64 mm) or larger size (Quinn & Hickey 1990; Jowett et al. 1991). Inputs of fine sediments and reduced flows may increase the accumulation of fine sediments on the stream bed, which may in turn affect feeding by stream macroinvertebrates. In laboratory experiments, addition of fine sediments to mats of periphyton reduced the rate at which the grazers *Potamopyrgus antipodarum* and *Deleatidium* could assimilate food, although the growth rate of *P. antipodarum* was highest at intermediate sediment:food ratios (5:1, 10:1—Broekhuizen et al. 2001). Thus, if increased accumulation of fine sediments occurs as a result of the reduced flows under the operation of the proposed scheme, growth of grazers such as *Deleatidium* could decline, which may reduce invertebrate production or lead to a change in community composition to taxa that are more tolerant of fine sediments (e.g. chironomids).

Deposition of fine sediments in the stream bed can restrict exchange of water between the river and underlying aquifer (Brunke 1999), and this may affect thermal patterns within the river, and the rate and/or type of chemical processes (e.g. nutrient uptake and transformations) occurring in the stream bed, as well as the distribution of invertebrates on and within the stream bed (see section 3.5). The operation of the scheme, as currently proposed, may reduce the frequency of small spates (as discussed in section 3.1), which will increase the likelihood of the formation and persistence of such impermeable layers of fine sediments (Brunke 1999). Periods of higher flows ('flushing flows') have been suggested to reduce the accumulation of periphyton mats and fine sediments (TrustPower Ltd 2005). It is difficult to conceive a situation where the operation of the proposed scheme will not reduce the frequency and/or magnitude of naturally-occurring flushing flows, since any flows in excess of the minimum flow for the residual river (between 10 and 20 m^3/s, depending on the season) will be diverted to the canal (up to 40 m^3/s) for generation, except during flood flows > 200 m^3/s. It is important to ascertain whether or not artificial flushing flows would even be required and the ability (or not) of the scheme to provide releases of sufficient magnitude (at least 6 times the flow in the residual river, but preferably 10–12 times to be effective) and duration to have any effect. The limited storage capacity of the proposed scheme also raises uncertainty as to whether the flushing flows possible under it will be sufficient to fulfil their intended purpose.

3.3 THERMAL REGIME

The residual river below the intake may become more susceptible to having high water temperatures as a consequence of the proposed scheme, as a result of reduced water depth (and thereby, increased potential for solar heating), reduced thermal buffering capacity, as a consequence of the reduced volume of water in the residual river, and altered groundwater dynamics. Therefore, it is important to consider how the macroinvertebrate community could change in response to increased water temperatures.

The upper thermal tolerances of 12 common New Zealand stream invertebrates were examined by Quinn et al. (1994). In these experiments, *Deleatidium* was found to be the most sensitive species studied, with half of the experimental animals dying after exposure to 22.6°C for 96 h (Table 4). The next most sensitive species was *Zelandobius furcillatus* (Table 4). Elmid beetles were the most tolerant of high temperatures, with over half of the experimental individuals surviving temperatures of 34°C for up to 48 h. Quinn et al. (1994) suggested that maximum water temperature may be an important factor determining the abundance and distribution of *Deleatidium* and *Zelandobius* in New Zealand rivers.

Cox & Rutherford (2000) extended the work of Quinn et al. (1994) by addressing the effects of diurnally fluctuating temperatures (diel range: 10°C). They found that the mean daily temperature at which 50% mortality of *Deleatidium autumnale* occurred within 96 h (21.9 ± 0.7°C) was lower than that in constant-temperature

TABLE 4. THERMAL TOLERANCES OF FRESHWATER MACROINVERTEBRATES KNOWN FROM THE WAIRAU RIVER.

	24 h LT_{50}*	48 h LT_{50}*	96 h LT_{50}*
Deleatidium	26.8	24.5	22.6
	25.9	-	-
Zelandobius furcillatus	26.0	25.5	-
	c.28	26.5	-
Aoteapsyche colonica	27.8	27.0	25.9
Pycnocentrodes aureola	32.4	32.4	32.4
Pycnocentria evecta	30.4	26.8	25.0
Hydora (Elmidae)	>34	>34	32.6
Potamopyrgus antipodarum	32.4	32.4	32.4

* LT_{50} values are the temperature at which half of the animals died after a given exposure time (24, 48, or 96 h) from the laboratory experiments of Quinn et al. (1994).

experiments (24.2 ± 0.9°C), although the daily maximum temperature at which 50% of individuals died within 96 h (26.9 ± 0.7°C) was higher than for constant temperature experiments (Cox & Rutherford 2000).

The results of these experimental studies are consistent with the results of a survey of the benthic macroinvertebrate communities of 88 New Zealand streams, where the distribution and abundance of stoneflies were restricted by maximum temperatures of > 19°C and those for mayflies at maximum temperatures of > 21.5°C (Quinn & Hickey 1990).

After prolonged low flows during summer, temperatures in the residual river may approach levels that may reduce the suitability for *Deleatidium* (c. 22–25°C). This is of particular concern, as *Deleatidium* is very abundant at all sites in the Wairau (Table 1) and is likely to represent a significant food source for trout and insectivorous birds, in particular black-fronted terns. The macroinvertebrates that were most tolerant of elevated temperatures, i.e. the snail *Potamopyrgus antipodarium* and elmid beetle larvae (Table 1), are not significant prey for trout and are not available as prey for insectivorous birds. Currently water temperatures at the Tuamarina site range as high as 24°C (NRWQN data—in Ryder & Keesing 2005) and this, in combination with periodic periphyton proliferation, may account for the abundance of chironomids at this site. However, since *Deleatidium* is still very abundant at this site, it is unlikely that the temperatures currently experienced there are limiting for this taxon. Temperature increases resulting from the proposed scheme may reduce the suitability of some habitats for *Deleatidium* within the residual river. Data collected from sites downstream of the proposed intake yielded few stoneflies (Ryder & Keesing 2005), and this may indicate that temperatures at these sites already exceed those that stoneflies can tolerate (c. 19°C), since stoneflies are commonly encountered further upstream, at Dip Flat (Table 1).

It is likely that reduced flows will cause some increase in temperatures in the residual river and that, during the warmer months, they could approach levels that will reduce the abundance of sensitive taxa, including *Deleatidium*. The resultant reduction in prey (*Deleatidium*) availability may compound the thermal stress on trout. However, it may be possible for the proposed scheme to be operated in a manner that avoids temperatures reaching critical levels, e.g.

by intensively monitoring water temperatures and releasing greater amounts of water to the residual river when temperatures reach predetermined levels. It is important to recognise the potential effect of changes in thermal patterns in the residual river and to formulate appropriate operational responses to ensure that high habitat quality is retained in the residual river.

3.4 INVERTEBRATE DRIFT TO CANAL INTAKE

The intake of the proposed scheme will consist of semi-permanent and temporary structures to divert water into the permanent intake structure. Consequently a considerable proportion of the invertebrate drift (where invertebrates enter the water column and drift with the current) passing the intake structure will also be diverted into the canal and will not pass downstream into the residual river. Drift is the primary way stream invertebrates escape unfavourable conditions (physical or biotic) and colonise new habitats (Brittain & Eikeland 1988) and drifting invertebrates are an important food source for drift-feeding fish such as trout. Drift distances range widely depending on the species and life-stage as well as physical conditions, particularly current velocity, but vary from centimetres to several hundred metres (Brittain & Eikeland 1988).

It is difficult to know what effect the interception of drift by the intake structure will have on invertebrate dynamics and fish production in the residual river. However, the diversion of invertebrates drifting from upstream of the intake into the canal will reduce the number of invertebrates entering the residual river, which may moreover have less capacity for colonisation by drifting individuals (due to reduced habitat availability). In addition, fewer individuals drifting into the residual river directly below the intake and the reduced flow in the residual river may result in reduced invertebrate drift from this area. In any case, any effect is expected to be limited to a relatively short reach of river directly downstream of these structures.

3.5 EFFECTS ON THE HYPORHEIC ZONE

The hyporheic zone, defined as the saturated interstitial spaces beneath the streambed and in the stream banks that contain some proportion of channel water (White 1993), forms the link between surface waters and groundwater and plays an important role in the interaction between these bodies of water. Gravel-bed rivers, such as the Wairau, can have extensive hyporheic zones and this zone plays an important role in the nutrient dynamics (Grimm & Fisher 1984; Triska et al. 1990, 1993; Findlay 1995; Jones & Holmes 1996) and the temperature regime, particularly where there is high connectivity between the interstitial and surface waters.

The hyporheic zone is a significant habitat for invertebrates in many streams in New Zealand (Scarsbrook 1995; Boulton et al. 1997; Adkins & Winterbourn 1999; Burrell 2001; Fowler & Death 2001; Olsen et al. 2001, 2002; Fowler & Scarsbrook 2002; Scarsbrook & Halliday 2002; Olsen & Townsend 2003) and overseas (reviewed in Brunke & Gonser 1997; Boulton 2001). Significant numbers of 'surface-dwelling' (called epigean) invertebrates are found to penetrate beyond the surficial sediments (Table 5), and there is evidence that some of these taxa may exploit this habitat seasonally (Table 5—Elmidae; Marchant 1995; Olsen & Townsend 2003). In addition to these epigean invertebrates, other invertebrates (particularly crustaceans and water mites) live their entire lives within the hyporheic zone or in the groundwater system and are rarely encountered in surface sediments (e.g. asellotan isopods, Table 5). While inconspicuous to casual observation, invertebrates in the hyporheic zone may contribute significantly to the abundance, biomass, productivity and diversity of the macroinvertebrate community of a river. The hyporheic zone is attractive for many epigean invertebrates because it provides additional food resources, such as wood and leaf fragments, bacteria, fungi, and other invertebrates, and may act as a refuge from competition, predation, and disturbance (i.e. low flows and floods). Consequently, significant numbers of invertebrates that are usually associated with surface sediments are found within the hyporheic zone (Table 5).

The hyporheic zone may also be a refuge for macroinvertebrates during unfavourable conditions at the sediment surface. The only field study assessing its role as a refuge from flooding in a New Zealand stream found limited evidence for the hyporheic zone acting as a significant refuge (Olsen & Townsend 2005). However, studies from overseas have had mixed results. In some cases, invertebrates have been found to move to deeper sediments (Dole-Olivier et al. 1997) whereas in others no such movements were evident (Palmer et al. 1992). In laboratory experiments using some common New Zealand invertebrate taxa, Holomuzki & Biggs (2000) found that all the species studied (which included taxa that are common in the surface sediments of the Wairau, namely *Deleatidium* and *Pycnocentrodes*), moved into deeper sediments in response to high flows. It is likely that there is inter-system variability (and possibly intra-system variability, as indicated by Dole-Olivier et al. (1997)) in the use of the hyporheic zone as a refuge by invertebrates, further illustrating the need to consider the role it could play in the Wairau catchment. In any case, disturbance is likely to decrease with depth into the sediments and invertebrates with a greater proportion of individuals living in deeper sediments may recolonise

TABLE 5. PERCENTAGE OF TOTAL DENSITIES OF COMMON TAXA FOUND IN SURFICIAL SEDIMENTS (TO 10 cm BELOW THE SEDIMENT SURFACE) IN THE KYE BURN, NORTH OTAGO.

Modified from Olsen & Townsend (2003).

TAXON	WINTER	SUMMER
Aoteapsyche (Trichoptera, Hydropsychidae)	*	76
Leptophlebiidae (Ephemeroptera)	48	45
Elmidae (Coleoptera)	4	51
Eriopterini (Diptera, Tipulidae)	31	21
Isopoda (Asellota, Janiridae)	5	0
Total invertebrates	25	30

* Not abundant on this sampling occasion.

disturbed surface sediments faster than if the population is restricted to surface sediments (Olsen & Townsend 2005).

In the absence of data, the likely consequences of the reduction in flows on the hyporheic zone of the Wairau are speculative. However, decreased discharge will almost certainly reduce the amount of exchange between surface water and the hyporheic zone (Packman & Salehin 2003), and increase the time water spends in the hyporheic zone (residence time), while the hyporheic zone is likely to reduce in volume. Exchange with surface waters is crucial for supplying the hyporheic zone with oxygen and nutrients, and reductions in this are likely to make the hyporheic zone less suitable for surface-dwelling invertebrates. Reduced surface water–groundwater exchange and increased residence time of water in the hyporheic zone are also expected to affect nutrient dynamics (Findlay 1995; Jones & Holmes 1996), and may increase the volume of anoxic sediments where anaerobic processes (such as methanogenesis) predominate. Reduced surface water–groundwater exchange is also expected to affect thermal patterns in the residual river, the likely results of which are higher surface water temperatures and reduced thermal refuge in upwelling zones.

The direct effects of reduced discharge on the hyporheic zone are likely to be further compounded by an increase in the amount of silt entering this zone (which is expected under prolonged low flows—see section 3.2) and will almost certainly reduce its suitability as a habitat for stream invertebrates (Olsen & Townsend 2003). Olsen & Townsend (2003) found that the proportion of fine sediments was the predominant factor determining the abundance of invertebrates in the hyporheic zone of the Kye Burn and the abundance of most invertebrate taxa was negatively associated with the amount of fine sediments. This pattern was particularly evident for most epigean taxa, indicating reduced penetration of the hyporheic zone by epigean taxa as the amount of fine sediments increased (Olsen & Townsend 2003). Prolonged periods of stable low flows may lead to siltation such as colmation (the establishment of a clogging layer of fine sediments) or depth-filtration of fine sediments (Brunke 1999). These effects are expected to be compounded by any increase in siltation resulting from the construction and maintenance of the scheme (section 3.2) and from the reduced frequency of periods of elevated flows (section 3.1).

3.6 EFFECTS ON TRIBUTARY STREAMS

The proposed hydro scheme may lower the water table, since the affected reach of the Wairau is likely to be closely connected to the unconstrained alluvial aquifer (TrustPower Ltd 2005). A reduction in the level of the water table will result in reduced groundwater flow into the lower reaches of some of the tributaries, which may compound the existing problems of reduced summer flows. Tributaries that receive a significant proportion of their base-flow from the groundwater (TrustPower Ltd 2005, fig. 5.4.4A) are expected to be particularly affected by any lowering of the water table, with reductions in the extent and/or quality of available habitat and habitat suitability for some macroinvertebrate taxa (e.g. freshwater mussels).

A reduction in flow in the lower reaches of tributaries may also reduce the connectivity between tributaries and the mainstem of the Wairau. This is of particular concern after disturbance, when tributaries may be a significant source of recolonists to the mainstem. Disturbed areas may be recolonised by invertebrates drifting from tributary streams or by ovipositing adult insects (Williams & Hynes 1976). Connectivity between tributaries and the mainstem of the Wairau is essential for recolonisation via invertebrate drift.

Also of concern are the proposed spillways associated with the scheme that discharge to tributaries (Table 6). Whilst many of these are deemed to rarely be used, several are deemed to be 'operational', meaning that they will operate on an annual or near-annual basis. It is difficult to gauge the likelihood of flows of this magnitude under natural conditions in the absence of historical flow information. However, it is likely that such flows occur infrequently in the tributaries that drain low-rainfall south-bank catchments, but that they will represent a significant disturbance to the invertebrates of these small streams and have the potential to have significant, long-term effects on the macroinvertebrate communities of these streams.

TABLE 6. OPERATIONAL SPILLS TO TRIBUTARIES OF THE WAIRAU RIVER.

Locations, volume and estimated frequency under the proposed scheme (TrustPower Ltd 2005, table 5.5.3.3A).

LOCATION OF DISCHARGE	SPILL LOCATION	SPILL (m^3/s)
Saltwater Creek	Canal 4, Ch.200	10–20
Wye River	Canal 5, Ch. 2650	5
Boundary Creek	Canal 7, Ch. 1700	15–20
	Canal 7, Ch. 2000	10–15

4. Conclusions

The hydroelectric power scheme proposed for the Wairau has the potential to cause significant changes in its ecology. The primary effect of the proposed scheme will be to reduce flows over a 49 km stretch of the river from upstream of the Branch River confluence to the Marchburn River confluence, which will affect habitat availability, sedimentation, periphyton communities, temperature patterns, surface water–groundwater exchange and connectivity of the Wairau with south-bank tributaries. It is anticipated that these changes could cause significant changes in the abundance and composition of the macroinvertebrate community. Such changes are expected to reduce the relative abundance of EPT taxa that are particularly sensitive to changes in water quality and increase the relative abundance of more tolerant taxa (e.g. elmids, *Pycnocentrodes*, and chironomids). Of the sensitive taxa, *Deleatidium* is the most abundant macroinvertebrate within the proposed residual river, and any reduction in its abundance is expected to have significant consequences for the ability of the residual river to support current populations of drift-feeding fish (brown trout) and insectivorous birds if food is a limiting factor in the Wairau. Black-fronted terns in particular are heavily reliant on adult stream invertebrates as prey, of which *Deleatidium* is almost certainly the most significant in the Wairau, so will be particularly sensitive to reductions in its abundance.

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