IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of applications for resource consent by the Central Plains Water Trust and a notice of requirement for the designation of land by Central Plains Water Limited associated with the construction and operation of the Central Plains Water Scheme

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STATEMENT OF EVIDENCE OF DEAN ANTONY OLSEN ON BEHALF OF THE DIRECTOR GENERAL OF CONSERVATION AND THE NORTH CANTERBURY FISH AND GAME COUNCIL

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1. INTRODUCTION

Qualifications and experience

1.1 My name is Dean Antony Olsen. I reside in Nelson where I work as a freshwater ecologist at the Cawthron Institute. I hold the degrees of B.Sc. (Honours I) in Zoology and Ph.D. in Zoology, both from the University of Otago. I am a member of the New Zealand Freshwater Sciences Society and the North American Benthological Society.

1.2 I worked as a research assistant in the stream ecology group at the Zoology Department of the University of Otago from 1995 until 1997. During this time I worked on a wide range of stream ecology projects including invertebrate studies, electric-fishing surveys, geomorphological surveys, and stable-isotope analyses. Since 1998, my research has focussed on the ecology of the hyporheic zone, invertebrate ecology, and the effects of disturbance on invertebrate community dynamics.

1.3 After completing my Ph.D. in 2003, I worked for two years as a Post-doctoral Research Associate at the University of Vermont in Burlington, Vermont, United States of America working on a United States Department of Agriculture-funded project considering agricultural impacts on stream invertebrates. I have been employed as a freshwater ecologist at the Cawthron Institute in Nelson since September 2005.

1.4 I have been the first author of several scientific articles in the peer-reviewed international journals Archiv für Hydrobiologie, Freshwater Biology, Marine and Freshwater Research, and New Zealand Journal of Marine and Freshwater Research and have been sole or lead author on more than twenty client reports in the area of stream invertebrate ecology.

1.5 I regularly peer-review manuscripts for international scientific journals including Aquatic Sciences, Freshwater Biology, Hydrobiologia, Invertebrate Systematics, Journal of Applied Ecology, Journal of the North American Benthological Society, Marine and Freshwater Research, New Zealand Natural Sciences and Restoration Ecology.

1.6 I reviewed existing information on invertebrate communities in braided rivers and considered the effects of water abstraction on the invertebrates of braided rivers for the resource consent hearing for the hydro-electric power scheme proposed for the Wairau River by TrustPower Limited. This review was published as a Department of Conservation report (Olsen, 2006).

1.7 I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses (31 July 2006). This evidence is within my area of expertise, except where I state that I am relying on facts or information provided by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Scope of evidence

1.8 My evidence concerns the invertebrate communities in the Rakaia and Waimakariri Rivers and the effects of the water takes proposed by Central Plains Water (CPW). I will describe the existing information on the composition and abundance of invertebrate communities in the Rakaia and Waimakariri Rivers, and compare them to those of other braided rivers in New Zealand.

1.9 In this evidence, I view invertebrates as an integral part of the ecosystem of the Waimakariri and Rakaia Rivers, of some intrinsic value but more importantly a key component of the food-web of the rivers. I place particular focus on the relevance of changes in invertebrate community composition and abundance for food availability for predators such as insectivorous birds and fishes.

1.10 In summary, my evidence addresses:

a. Attributes of the invertebrate communities of the Rakaia and Waimakariri Rivers.

b. Comparison of the invertebrate communities of the Rakaia and Waimakariri Rivers with those of other braided New Zealand rivers.

c. Potential effects of the proposed scheme on stream invertebrate communities of the Rakaia and Waimakariri Rivers including:

- changes in flow (including interpretation of weighted usable area (WUA) x flow graphs), sediment and temperature regimes below the proposed intake sites,
- potential for reduced invertebrate habitat quality resulting from "flat-lining" of flows, and
- localised effects of fine sediments from construction of the intakes and sediment flushing from sediment settling basins.

d. Potential effects of the proposed scheme on the invertebrates, hydrology and physical and chemical conditions within the hyporheic zone of the Rakaia and Waimakariri Rivers.

e. Potential effects of the proposed scheme on stream invertebrate communities of foothill streams affected by the scheme, these include the Selwyn River and its tributaries, the Hororata, Hawkins, and Waianiwaniwa rivers, as well as the Kowai River, and their respective tributaries. Effects considered include:

- effects of increased nutrient concentrations and subsequent increases in periphyton, and
- effects of elevated flows resulting from raised water tables.

1.11 In preparing this evidence, in addition to my own work, I have primarily considered:

a. The Assessment of Environmental Effects Report (June 2006) prepared for the CPW;

b. The reports prepared by Kingett Mitchell Limited (subsequently Golder Kingett Mitchell) on the effects of construction and operation of the proposed scheme on benthic ecology (Kingett Mitchell 2006a, c, e, f Golder Kingett Mitchell 2007a,b). To prevent confusion, I have used the same letters to indicate individual Kingett Mitchell Ltd reports as Dr Burrell has used in his evidence in chief;

c. Responses to Section 92 requests and Section 42 officer's reports;

d. Statements of evidence on behalf of CPW;

e. Scientific reports;

f. Peer-reviewed scientific publications.

Summary of findings

1.12 The key conclusions of my evidence are outlined below.

1.13 The Applicant has provided insufficient information to adequately assess the environmental effects of the CPW Scheme on invertebrate communities in the Rakaia and Waimakariri Rivers. Little new empirical invertebrate data from the Rakaia or Waimakariri Rivers is presented by the applicant, and that the most extensive data sets for both these rivers were collected more than 20 years ago. Investigations of potential effects of the proposed scheme on invertebrates in the Waimakariri are reliant on the outputs of an Instream Flow Incremental Methodology (IFIM) model conducted in one reach of this river.

1.14 A key consideration when assessing the effects of the water takes from the Rakaia and Waimakariri Rivers is the reduction in wetted area of the river, and changes in quality of invertebrate habitat and consequent changes in habitat availability for invertebrates. An IFIM analysis conducted in the Waimakariri River predicts that the CPW Scheme will result in a reduction in available *Deleatidium* and food producing habitat of 3–20% compared with the status quo flow allocation in summer/autumn months (December – May) and 0–6% in winter/spring months (June – November), with the greatest reductions evident in December and January.

1.15 Consideration of the cumulative effects of the CPW Scheme and existing flow allocations suggests that 12-31% of *Deleatidium* habitat is lost in the period December-May. Food producing habitat was reduced by 13-24% in the post-CPW scenarios compared with naturalised flows between December and May . I believe that these cumulative effects are more than minor given the high values supported by macroinvertebrates in the Waimakariri River (e.g. birds and sports fish populations). Predicted reductions in food producing and *Deleatidium* habitat are generally minor (>10%) between June and November, with reductions in *Deleatidium* habitat of 9-12% predicted to occur in October and November.

1.16 There is an increased risk of periphyton proliferation and fine sediment inputs during construction and operation of the proposed scheme. Fine sediment and periphyton proliferation are known to cause changes in invertebrate community composition, and such changes are expected to reduce the quality and availability of invertebrate prey for insectivorous birds and drift-feeding fish (such as trout) in areas affected. The effects of fine sediment on invertebrates could be minimised by limiting sluicing of sediment traps to periods of elevated flows when levels of suspended sediment are likely to be naturally elevated and the river has sufficient power to disperse fine sediments.

1.17 The CPW Scheme is expected to result in increased flows resulting from raised water tables, and changes in water quality resulting from land-use intensification in foot-hill streams draining the area affected by the scheme. While increased flow is likely to have a beneficial effect on invertebrate populations, these may be negated by changes in water quality that occur as a result of land-use intensification.

1.18 In my opinion, there is inadequate information on the mitigation options proposed by the applicant to allow for an informed assessment of their likely effectiveness and adequacy to mitigate effects of the scheme that are likely to negatively affect invertebrate populations and the values they support.

1.19 Reduced exchange between the river and the hyporheic zone has the potential to seriously affect macroinvertebrate communities as well as nutrient dynamics, especially in the Selwyn and Waimakariri Rivers. Such changes may affect the availability and suitability of invertebrates as food for drift-feeding fish (especially trout) and insectivorous birds (especially drift-feeders such as black-fronted terns) and have not been assessed by the applicant.

1.20 I believe that the CPW Scheme is likely to significantly affect the productivity and composition of macroinvertebrate communities in the Waimakariri River and foot-hill streams draining the Central Plains area. However, the extent and significance of the effects in the Waimakariri River have not been adequately assessed, leading to considerable uncertainty as to the magnitude of the effects on macroinvertebrates and other components of the ecosystem (e.g. birds and fish) that are reliant on them. I believe that the minimum flows and allocation limits set out by the Water

Conservation (Rakaia) Order are likely to limit the effects of the proposed takes in the Rakaia.

2. ATTRIBUTES OF THE INVERTEBRATE COMMUNITY OF THE RAKAIA AND WAIMAKARIRI RIVERS AND COMPARISON TO OTHER EAST-COAST BRAIDED RIVERS

2.1 Macroinvertebrates (hereafter referred to as invertebrates) are the worms, insects, crustaceans, mites and molluscs that live in and on the streambed. They are an essential link in the transfer of energy from plant matter, fungi and bacteria to the larger animals that live in (e.g. trout, salmon parr, bullies, galaxiids) and around the stream (e.g. spiders, insectivorous birds) (for a simplified braided river foodweb, see Figure 1 attached as Appendix A). Thus, it is important to consider the effects of flow-modification on invertebrates as anything that affects them is likely to have consequences for many other parts of the ecosystem.

2.2 In the Rakaia and Waimakariri Rivers, invertebrates are an important component of the diet of river-bed birds[1] (such as banded dotterel, black-fronted tern, and wrybill), sportsfish[2] (brown and rainbow trout, juvenile quinnat salmon), and native fish. Therefore, it is important to consider likely effects of the proposed scheme on invertebrate populations in order to understand how it will affect bird populations and fisheries in both these rivers. For details on the significance of the riverine bird populations in the Rakaia and Waimakariri Rivers, I refer you to the evidence of Dr Kenneth Hughey, and for information on the significance of the sports fish please refer to the evidence of Dr John Hayes.

2.3 It is important to consider how the proposed scheme will affect the composition of invertebrate communities in addition to densities, as some invertebrates (e.g. mayflies, stoneflies, caddisflies) are of higher value as food for fish and birds than others (e.g. chironomid midges, riffle beetles) due to their size and availability to predators. For example, a change in community composition from one dominated by favoured prey items (e.g. *Deleatidium* mayflies) to one dominated by less valuable

[1] Summarised in Sagar (1983) (p.40-41) and Hughey *et al.* (1989) (p. 35-41).
[2] Sagar & Eldon (1983) found that the diet of juvenile brown trout in the Rakaia River was dominated by *Deleatidium* nymphs and chironomid midges. They also found that the diet of juvenile quinnat salmon was dominated by adult *Deleatidium* and diptera (true flies).

prey (e.g. chironomid midges, beetle larvae) is likely to reduce the energy intake of drift-feeding fish (such as trout), and may affect the growth or condition of fish.

Rakaia River

2.4 The most extensive studies of the invertebrates of the Rakaia River to date were conducted by Dr. Paul Sagar and are summarised in a Fisheries Environmental Report (Sagar 1983a), and three peer-reviewed scientific journal articles (Sagar 1983b, 1986, Sagar & Glova 1992). Quantitative sampling of benthic invertebrates, conducted over a two-year period (1979-1981), found that nymphs of the mayfly *Deleatidium* numerically dominated the invertebrate community of the Rakaia River 2 km upstream of the Rakaia Mouth and just below state highway 1 on all occasions, and at Highbank on all but one occasion (Table 1, attached as Appendix B). Overall, *Deleatidium* represented between 31 and 96% of invertebrates collected. Chironomid midge larvae were the next most abundant taxon at these three sites on most occasions and were the most abundant taxon collected at Highbank on one occasion (20 March 1980) (Table 1, Appendix B).

2.5 Other taxa that were consistently found in the Rakaia include the larvae of the net spinning caddis fly *Aoteapsyche*, the free-living caddis fly *Hydrobiosis*, the riffle beetle *Hydora*, and the crane flies Eriopterini, and *Molophilus.*

2.6 Little new information on invertebrate communities of the Rakaia River is provided in the material supporting the AEE. As a consequence, the only quantitative invertebrate data available for analysis are those of Sagar (1983).

2.7 In my opinion, it is unlikely that this data (collected in 1979-1981) adequately represents existing conditions in the Rakaia River given climatic variations and additional abstraction from the Rakaia since this data was collected. Single, semi-quantitative hand-net samples were collected by Kingett Mitchell from three minor braids of the Rakaia on one occasion.

2.8 Information presented in Kingett Mitchell (2006c) shows that the invertebrate community of two of the minor braids sampled were dominated by the mayfly *Deleatidium* (>70% of invertebrates), while the cased caddisfly *Pycnocentrodes* (33%), *Deleatidium* (28%), and the net-spinning caddis fly (22%) were the three most abundant taxa in the remaining minor braid site (RB2 – Rakaia at SH1 bridge).

2.9 In Paragraph 4.2 of his evidence in chief, Dr Burrell states that:

> "…depths and velocities are generally too great and bed sediments too mobile in most of the habitat within major braids [of the Rakaia and Waimakariri Rivers] to allow periphyton development or invertebrates to colonise."

2.10 I believe that this statement is an oversimplification and is not supported by available information from the Rakaia River. While greater densities of invertebrates have been found in minor braids than major braids in the Rakaia River (Table 1, Appendix B), major braids have been found to contain areas of suitable and productive habitat for invertebrates (Sagar 1983a, b) and contribute significantly to the overall population of invertebrates in the Rakaia River. Thus, I believe that Dr Burrell's assessment is premature and not supported by available information for the Rakaia River.

2.11 Invertebrate densities in the Rakaia River ranged between 83 - 5478 individuals per square metre of stream bed (ind. m^{-2}) on the sampling occasions reported by Sagar (1983). This study found that invertebrate densities were high during periods of stable low flows, while densities were markedly lower following high flow events (Figure 2, attached Appendix). Based on these results, Sagar (1983) concluded that high flows, and subsequent sediment movement, were the main factors governing invertebrate densities in the Rakaia River. This is consistent with the statement in Kingett Mitchell (2006c) that:

> "… invertebrate diversity and biomass are strongly influenced by the high frequency of floods in each of the Rakaia and Waimakariri Rivers" (Section 3.2.1).

2.12 I agree with these assessments, although this is not to say that the effects of the CPW Scheme on invertebrates will be negated by the flood flows in these rivers.

Waimakariri River

2.13 The invertebrate community of the Waimakariri River has been dominated by either *Deleatidium* or chironomid midges at both sites sampled as part of the National River Water Quality Network (NRWQN – data courtesy of NIWA) on all but one sampling occasion (1989-2001). The exception to this was in February 1990 when the community at the old highway bridge site was dominated by oligochaete worms. Collectively, *Deleatidium* and chironomid midges have comprised 65-99% of total invertebrate densities on the 12 sampling occasions at the Gorge site, and 43-99% on the 12 sampling occasions at the highway bridge site (Table 1, Appendix B).

2.14 However, both the NRWQN sites are in areas where the channel of the Waimakariri is constrained to one or two braids, which is not representative of the river form over most of its length below the gorge. In contrast, Hughey *et al*. (1989) sampled invertebrates in major, minor and seepage channels in a heavily braided reach (with up to 10 channels in a cross-section) of the Waimakariri River approximately 10 km upstream of the SH1 bridge. In this study, all three channel types were dominated by *Deleatidium* (68-80% of invertebrates). It is likely that the dominance of chironomids at both of the NRWQN sites results from the greater stability of the single-channel NRWQN sites compared with the highly braided reach sampled by Hughey *et al.* (1989).

2.15 As discussed in paragraph 2.7 with regard to the Rakaia River, Dr Burrell states in his evidence in chief that:

> "…depths and velocities are generally too great and bed sediments too mobile in most of the habitat within major braids [of the Rakaia and Waimakariri Rivers] to allow periphyton development or invertebrates to colonise." (Paragraph 4.2).

2.16 I disagree with this statement with regard to the Waimakariri River also, as it is not supported by either evidence presented by Dr Burrell or available data from surveys. Hughey *et al.* (1989) reported greater densities of invertebrates from major braids than minor braids in the Waimakariri River (Table 1, Appendix A). The applicant has provided no data to substantiate Dr Burrell's assertion that much of the habitat in major braids is unsuitable for invertebrate colonisation and, in fact, the data of Hughey *et al.* (1989) suggests the opposite. Thus, I believe that Dr Burrell is premature in "writing off" much of the habitat in major braids of the Waimakariri River as being unsuitable invertebrate habitat.

Threatened invertebrate species

2.17 No invertebrate species of potential conservation interest (defined as having restricted and/or disjunct ranges or as being uncommonly encountered by Collier

(1992) or listed in Hitchmough 2005) are recorded from the reaches of the Rakaia and Waimakariri Rivers expected to be affected by the CPW Scheme.

2.18 Therefore, we cannot exclude the possibility that species of conservation interest occur within the area to be affected by the proposed scheme. The fact that there are no records of species of potential conservation interest is not all that surprising given the relatively low sampling effort within the Rakaia and Waimakariri Rivers, especially given the highly heterogeneous nature of these habitats. In addition, many researchers do not identify invertebrates to species level. If more comprehensive sampling was conducted and failed to yield any species of conservation interest, we could have more confidence that no such species exist.

Comparison with other braided rivers

2.19 I compared data on invertebrate densities and community composition in the Rakaia and Waimakariri Rivers to data from six other large South Island braided rivers: the Ashley, Grey, Hurunui, Rangitata, Wairau and Waitaki Rivers, as no such review has been presented by other parties to date. I believe that such a review is useful to help assess the significance of the invertebrate communities of the Waimakariri and Rakaia Rivers compared with those of similar rivers in the South Island and to allow us to understand the significance of any reductions in invertebrate populations. For this review I used data from published reports and scientific journal articles as well as unpublished data from the NRWQN.

2.20 The invertebrate community data for two sites in the Waimakariri River (Gorge, old highway bridge) used in these analyses were obtained from the NRWQN. Invertebrate data from three sites (Highbank, State Highway 1 (SH1), Mouth) in the Rakaia River were sourced from Sagar (1983). This information is summarised in Table 1, attached as Appendix B to this evidence.

2.21 Suitable data (quantitative samples from primary channels, with densities or relative abundances for all taxa) was found for the Ashley (Scrimgeour & Winterbourn 1989, Hughey *et al.* 1989), Grey (NRWQN data), Hurunui (NRWQN data), Rakaia (Sagar 1983), Rangitata (Bonnet 1986, Stark 2001), Waimakariri (Hughey *et al.* 1989, NRWQN data), and Waitaki Rivers (Rutledge 1987, Palmer 1989, Rutledge *et al*. 1992, NRWQN data). A summary of this information is included in Table 2, attached as Appendix C to this evidence.

2.22 In collections from the Waimakariri River as part of the NRWQN between 1989 and 2001, 33 taxa (between 6-16 on each occasion) were collected from the gorge site, and 27 taxa (5-14 on each occasion) were collected from the old highway bridge site (Table 1, Appendix B). The number of taxa collected from the gorge site is within the range collected from other braided South Island rivers sampled as part of the NRWQN (28-49 taxa - Table 2), whilst the number collected from the old highway bridge site is lower than observed at other NRWQN sites considered. The sampling effort, taxonomic resolution and methods employed are consistent between all rivers sampled as part of the NRWQN, meaning that these values are directly comparable.

2.23 Average invertebrate densities in the Rakaia and Waimakariri Rivers are low in comparison to many other braided rivers (Figure 3 attached as Appendix E). I believe that this is likely to be a result of the frequent disturbance events in these rivers.

2.24 Quinn & Hickey (1990) reviewed invertebrate data collected from 88 rivers throughout New Zealand and found that most rivers had between 230 (10^{th} percentile) and 6700 (90^{th} percentile) invertebrates per square metre of river bed sampled, with the median value being 1903 invertebrates per square metre. Invertebrate densities recorded from most sites in the Rakaia and Waimakariri Rivers fall below the median value of Quinn & Hickey (Figure 3 attached as Appendix E).

2.25 I compared the invertebrate communities of the Rakaia and Waimakariri Rivers with those from other braided rivers using multi-dimensional scaling (MDS) ordination. This is a multivariate statistical technique that allows complex data (such as community data, which consists of many species) to be presented in a simplified form. The important point to note when interpreting MDS ordination plots is that the relative distance between points in the plot is indicative of the similarity of the community structure at these sites. That is to say that sites with similar invertebrate communities will plot close together, while there will be a greater distance between sites with very dissimilar communities. This analysis is presented in Figure 4, attached as Appendix F to this evidence.

2.26 In a MDS ordination of the invertebrate data from major braids of eight braided rivers, the Rakaia River sites cluster closest to sites from the Rangitata River, and the heavily braided Waimakariri site sampled by Hughey *et al.* (1989), with all of these sites being heavily dominated by the mayfly *Deleatididium* (60-84% of total abundance of invertebrates). These sites fall within a larger cluster that also includes sites from the Ashley, Hurunui, and Wairau Rivers, the communities of which were also *Deleatidium*-dominated but to a lesser extent (Figure 4, attached as Appendix F to this evidence).

2.27 Meanwhile, the two NRWQN sites in the Waimakariri River (gorge and old highway bridge) cluster with sites from the Rangitata (Arundel from Stark 2001) and Wairau (at Tuamarina) Rivers. These four sites are dominated by chironomids with *Deleatidium* sub-dominant (Wairau River at Tuamarina, Rangitata River at Arundel), or are co-dominated by chironomids and *Deleatidium* (Waimakariri River at gorge and old highway bridge). These four sites fall within a larger cluster that also includes sites in the Grey (Dobson and Waipuna) and Waitaki (Kurow) Rivers that are heavily dominated by chironomids (45-69% of total invertebrate abundance).

2.28 The *Deleatidium*-dominated invertebrate community observed in the Rakaia River and in the braided sections of the Waimakariri River has been shown to be more favoured as food by drift-feeding brown trout and insectivorous birds (e.g. Wrybill and black-fronted terns) than the chironomid-dominated community observed in the single-channel sections of the Waimakariri River. Chironomids are expected to be less favoured food for black fronted terns and trout than *Deleatidium* due to their small size (see Table 3 attached as Appendix G to this evidence) which results in lower energy content and availability to predators (since both trout and terns are visual feeders) than larger invertebrates, such as *Deleatidium*.

3. EVALUATION OF CPW'S APPROACH TO THE ASSESSMENT OF ENVIRONMENTAL EFFECTS

3.1 Assessments of the likely effects of the activities proposed by CPW on stream invertebrates require detailed information on changes in hydrology, habitat availability and habitat quality as well as quantitative invertebrate data collected from a range of habitat types (range of water velocity, depth and substrate type). I believe that the information provided by the applicant is inadequate to undertake such assessments for invertebrates in the Rakaia and Waimakariri Rivers as it provides little insight as to how the proposed scheme would affect river productivity and life supporting capacity of the river.

3.2 I believe that in order to understand the effects of flow reduction on the productivity of a river system, it is necessary to have information on the densities of invertebrates in different habitat types and over gradients of flow and water depth. No such data is available in this case.

3.3 The productivity of the invertebrate community of the Waimakariri and Rakaia Rivers is an important consideration because of the values (birds and fish) that rely on aquatic invertebrates as prey. Productivity of the invertebrate community is an important component of the "life-supporting capacity of the rivers. The applicant provides little information on the density of invertebrates in the Rakaia and Waimakariri Rivers, instead relying on the results of a study conducted over 25 years ago in the Rakaia River and on data from the NRWQN, which has very limited usefulness in these assessments (see paragraph 3.11). The lack of quantitative invertebrate sampling makes it difficult to assess the effects of the proposed water takes or to set meaningful in-stream management objectives relating to invertebrate densities.

3.4 The invertebrate samples collected by Kingett Mitchell (2006c) to assess the effects of the proposed water takes from the Rakaia and Waimakariri Rivers were taken using kick-netting from an area of approximately 1 m^2 from minor braids (<5 m^3 s^{-1}). Kick-net sampling is a semi-quantitative method that is widely used in assessments of water quality, but samples collected in this way are of limited use in assessing the effects of reductions in flow resulting from water abstraction.

3.5 Kick-net sampling should not be used to estimate the densities of invertebrates, as in this method the area sampled is not delimited accurately and not all individuals present in the sampling area are likely to be collected. This limits the value of kick-net samples when assessing the effects of a scheme such as that proposed on the productivity of the river system. I believe that the effect of the proposed scheme on the productivity of the invertebrate communities of the Waimakariri and Rakaia Rivers is a key consideration that has not been adequately addressed by the applicant to date.

3.6 In kick-net sampling conducted by Kingett Mitchell (2006c):

> "…run, riffle and pool habitats were sampled in proportion to their occurrence within the reach with a total of approximately 1 m^2 streambed sampled per site."

3.7 The samples from each habitat type (run, riffle, pool) were combined into a single, composite sample for that site. This is routinely done in water quality assessments where invertebrates are usually sampled using kick-netting and are used to calculate the Invertebrate Community Index, or a related index (such as the SQMCI, QMCI). However, water quality is only part of the picture when it comes to understanding the environmental effects of the proposed scheme. In my opinion, a more important consideration in the Waimakariri and Rakaia Rivers is the contribution of different habitat types to the overall productivity of these systems and how each of these habitats are likely to be affected by the proposed scheme.

3.8 In my view, to assess the effects of flow reduction on the productivity of a river system, it is necessary to have information on the densities of invertebrates in different habitat types and over gradients of flow and water depth. Sampling over such physical gradients allows for an assessment of the effects of flow reduction on the productivity of invertebrate communities. Such assessments are critical for determining the likely effects of the scheme on bird and fish populations in the Waimakariri and Rakaia catchments. Because no such data has been presented by the applicant, our assessments must rely entirely on the results of the IFIM modelling of invertebrate habitat.

3.9 IFIM habitat modelling predictions are most sensitive to the habitat suitability criteria (HSC) applied (Jowett 2004) and consideration must be given to the transferability of HSC developed on other rivers to the study river. It seems reasonable to expect that HSC developed on rivers with similar physical characteristics to the study river should be more applicable than HSC developed on physically different rivers. The *Deleatidium* mayfly HSC (Jowett *et al.* 1991) were developed from invertebrate data collected from four rivers that are physically quite different from the Waimakariri (see paragraphs 4.13-4.14).

3.10 I would have more confidence in the results of the IFIM if the applicant had developed *Deleatidium* HSC based on quantitative invertebrate data collected from the Waimakariri River. Because no HSC were developed for the Waimakariri, we are left with no choice but to use HSC developed in other river systems.

3.11 Quantitative samples of benthic invertebrates (allowing estimation of densities) have been taken from two sites in the Waimakariri as part of the NRWQN and were used in assessments by the applicant. The NRWQN samples are taken to assess long-term trends in water quality in New Zealand and are collected and processed in a manner that is appropriate for that research question. The NRWQN data represent a composite of 7 Surber samples (quantitative) taken annually during base flows, not less than 4 weeks following bed-scouring flows.

3.12 These data provide no information on the variation within or between different habitat types (since they are only collected from run habitat), or the effect of variation in water velocity and depth on invertebrate community composition or abundance (since individual Surber samples are combined into a single composite sample). In addition, NRWQN samples are collected annually, so they provide no information on seasonal dynamics of invertebrate communities. Thus, they are of extremely limited value when assessing the consequences of flow reductions expected to result from the proposed scheme.

3.13 I believe that it is important to understand the seasonal dynamics of invertebrate populations when considering the effects of the activities proposed by CPW, since the effects of this scheme will vary seasonally depending on variation in flows in the rivers and out-of-river water demand. Any effects of the proposed scheme on invertebrates are expected to be most evident in summer and autumn months when flows are usually lower and irrigation demand is greatest.

3.14 The lack of quantitative invertebrate data in the Waimakariri River, and the reliance on historical quantitative sampling (e.g. from 1979-1981) in the Rakaia River is unusual in an AEE for a proposal of this magnitude. Table 4 (attached as Appendix G) presents the invertebrate sampling effort conducted as part of some AEEs and development investigations for other projects, for comparison with the sampling conducted as part of assessments for the CPW Scheme. In my opinion, comparison with the amount of quantitative sampling conducted in these other cases shows that the assessments conducted by the applicant are inadequate to allow a thorough and informed assessment of the invertebrate communities in the Waimakariri and Rakaia rivers and the effects of the proposed scheme. We have virtually no quantitative data available for the Waimakariri River (limited to the sampling of Hughey *et al.* (1989) in 1985-1986), and the data available for the Rakaia River was collected over 25 years ago.

3.15 In my view, the reliance on limited historical data from the Rakaia and Waimakariri Rivers is a major short coming of the assessments conducted by CPW. In my opinion, it is unlikely that these data (collected more than 20 years ago in the Waimakariri and more than 25 years ago in the Rakaia) adequately represent existing conditions given the effects of climatic variations and additional abstractions from these rivers since these data were collected.

4. EFFECTS OF THE PROPOSED SCHEME ON INVERTEBRATES IN THE RAKAIA AND WAIMAKARIRI RIVERS

4.1 A key consideration when assessing the effects of the water takes from the Rakaia and Waimakariri Rivers is the reduction in wetted area of the river, and changes in quality of invertebrate habitat and consequent changes in habitat availability for invertebrates. The volumes of proposed abstraction from each of these rivers (up to 40 $m^3 s^{-1}$) are not inconsequential, and given this, I believe that the potential effects of these flow reductions have not been adequately addressed to date. In particular, I believe the assessments of the effects are deficient in the following ways:

i. Lack of quanitative invertebrate sampling to consider spatial and temporal variability in invertebrate populations (in addition to densities).

ii. Use of habitat suitability criteria developed in other systems with no regard to the applicability of these to the Waimakariri River.

iii. No IFIM modelling conducted for the Rakaia River. Therefore, it is very hard to assess how the proposed take will affect the availability of invertebrate habitat in the Rakaia (or indeed, the protection afforded by the water conservation order flow rules).

iv. Little information on the likely effects of the proposed takes on minor and seepage channels and consequential reductions in invertebrate productivity.

v. Limited analysis of the effects of flow variability and time since last flood on invertebrate populations and composition.

vi. Limited analysis of the risks of increased algal proliferation during low, stable flows and the effects that such proliferations may have on invertebrate communities.

Rakaia River

4.2 Most of my comments in subsequent paragraphs focus on the Waimakariri River, rather than the Rakaia. The reason for this is that I believe that the existing rules for water abstraction from the Rakaia, which were set following consideration of a large amount of technical evidence during the hearing of the Water Conservation (Rakaia) Order (1988), result in minor modification of the flow regime (see evidence in chief of Mr de Joux). Because the proposed takes are within the rules of the Water Conservation (Rakaia) Order, and on consideration of the modification of the flows in the Rakaia, I believe that the effects of the proposed water abstraction on invertebrates in the Rakaia River are likely to be minor. This opinion, however, is based on a rather simplistic consideration of the modelled changes to hydrographs, as sufficient information to allow for detailed assessments of habitat availability at a range of flows is not available within the AEE technical documents for the Rakaia River.

4.3 The only source of information on the relationships between flow and habitat availability in the Rakaia River is that of Glova & Duncan (1985), which considered how changes in flow affect available fish habitat. However, this publication did not consider how changes in flow affect the availability of habitat for invertebrates.

Waimakariri River

4.4 In this section, I will present assessments of changes in the availability of invertebrate habitat in the Waimakariri River that predict that the cumulative effect of the CPW Scheme and existing abstractions will reduce habitat for important invertebrate taxa by more than 20% during January-April.

4.5 Instream habitat modelling provides useful insights when considering the effects of reductions in flow on invertebrate habitat in the Waimakariri River. For the analyses I present here, I have used the most recent outputs from the IFIM modelling conducted by NIWA in the Waimakariri River at Crossbank, as presented in Jowett et al. (2008). These are the same modelling outputs used by Dr Burrell (as outlined in paragraph 5.3 of his evidence in chief). Dr. John Hayes discusses the transferability of the results of the modelling reach at Crossbank to the remainder of the affected reach of the Waimakariri in his evidence in chief.

4.6 Generally, when making such assessments for invertebrates, the change in weighted usable area (WUA), the area of suitable habitat for the organism of interest, is assessed by comparing the expected habitat availability at median flow when the scheme is in operation with the status quo or naturalised median flows. I have used modelled monthly median flows under a range of abstraction scenarios (no abstraction, status quo allocation, and two post-CPW scenarios) supplied by Mr Richard de Joux (for the assumptions of the modelling, see his evidence in chief).

4.7 In considering changes in available habitat for invertebrates, I will focus on the change in WUA (expressed as m^2/m) rather than the habitat suitability index (HSI), which is an index of habitat quality and is numerically equivalent to WUA divided by the wetted width of the river channel. My reasoning for this is that WUA incorporates both the quantity and quality of habitat, and consequently is affected by changes in the area as well as the quality of available habitat. I believe that little is to be gained by assessing the HSI for invertebrate taxa, since I believe that the most important factor to be assessed is the overall change in invertebrate productivity resulting from changes in flow, which is best assessed by considering WUA.

4.8 This is contrary to Dr Burrell's opinion in paragraph 5 of his supplementary evidence where he states that *"Dr Meredith has not made the distinction between effects of the CPW take on habitat quantity (expressed as WUA, m^2/m) and habitat quality (expressed as a percentage of total wetted area)."* and goes on to say that *"…I consider that to gain a balanced perspective on habitat effects, it is important to consider both changes in habitat quantity and habitat quality with flow."*. I agree that it is important to consider both habitat quality and quanitity. However, I believe that Dr Burrell has overlooked the fact that WUA integrates both habitat quality and quantity, and is, therefore, the most appropriate metric to assess how the proposed scheme will influence the overall invertebrate productivity in the affected reach of the Waimakariri River. The results of the IFIM suggest that any modest increase in habitat quality at lower flows (as measured by the HSI) fails to compensate for the loss of wetted area occupied by the river under such conditions.

4.9 Part of the argument for considering HSI in addition to WUA is that WUA can be misleading in some circumstances, as the contribution of a large area of low quality habitat can be the same as a small area of very high quality habitat. I accept that for some species (such as large fish) this can be problematic, as small areas of high quality habitat can be masked by large areas of low quality habitat. However, when considering the effects of changes in flow on the invertebrate productivity of a river, I believe that a large area of low quality habitat and a small area of very high quality habitat are likely to be equivalent in their contribution to the overall productivity of the river.

4.10 As outlined in paragraph 2.13, most sites in the Waimakariri River are dominated by the mayfly *Deleatidium* or chironomid midges. Therefore, the invertebrate habitat suitability curves used in the analyses presented in Golder Kingett Mitchell (2007b) (*Deleatidium*, chironomid midges (*Maoridiamesa*, Orthocladiinae) and food producing) are appropriate choices for the Waimakariri River. In addition to these taxa, Dr Burrell also presents IFIM outputs for a number of other invertebrate taxa in his evidence including the net-spinning caddis fly *Aoteapsyche* and the cased caddis fly *Pycnocentrodes,* which can both be relatively abundant in the Waimakariri River.

4.11 When modelling habitat availability for the mayfly *Deleatidium, w*e have the choice of two sets of habitat suitability curves (HSC). The most widely used *Deleatidium* HSC are those of Jowett *et al*. (1991) which were developed from invertebrate data collected from four single-channel rivers: the Clutha (mean flow: 195 m^3s^{-1}), Mangles (mean flow: 10 m^3s^{-1}), Mohaka (mean flow: 40 m^3s^{-1}) and Waingawa (mean flow: 11 m^3s^{-1}). The bed sediments of these four rivers were dominated by gravels (32-64 mm) and cobbles (64-128 mm). The other HSC for *Deleatidium* are those that were developed for the Waitaki River by Jowett (2002).

4.12 The Waitaki River is a large braided river (mean flow: 373 m^3s^{-1}), and had a median particle size of 35 mm (Jowett 2002). Note that for the *Deleatidium* (Waitaki) HSC, all water depths are deemed to be suitable for *Deleatidium* (suitability = 1). These two sets of curves are attached as Figure 5a, in Appendix I.

4.13 In comparison, the Waimakariri River (mean flow: 122 m^3s^{-1}) at Crossbank is heavily braided with a median particle size of 28 mm (Duncan & Bind 2008). Based on the physical characteristics of the Waimakariri River, it could be argued that the *Deleatidium* (Waitaki) curves are more applicable – since these were developed for a braided river (albeit a much larger one) with a similar substrate.

4.14 I present changes in weighted usable area (WUA) calculated both sets of *Deleatidium* HSC in Table 5 and Table 6 (attached in Appendices J and K). Hereafter, I refer to the Jowett et al. (1991) HSC as *Deleatidium* (mayfly), and the

HSC developed for the Waitaki by Jowett (2002) as *Deleatidium* (Waitaki). In doing so, I recognise the inherent uncertainty in applying HSC that were not developed specifically for the system to which they are being applied. Given this uncertainty, I believe that a cautious approach is to make decisions based on the HSC that results in the most conservative estimates of habitat retention.

4.15 IFIM modelling for the Waimakariri River, predicts that WUA (a measure of the area and quality of available habitat) increased with increasing flow for all 15 invertebrate taxa considered for the entire flow range modelled (Figure 6 attached as Appendix L). Meanwhile, HSI (a measure of habitat quality only) is stable or slightly decreases with increased flow. These results suggest that the increase in available invertebrate habitat with increasing flow is primarily a consequence of the increase in wetted area, rather than changes in habitat quality.

4.16 When considering the effects of the CPW Scheme on hydrology and habitat availability, three comparisons are relevant:

a. Flows under the status quo allocation scenario (pre-CPW) versus naturalised flows – this comparison is useful to consider how much habitat is available under status quo flow allocation compared to natural flows.

b. Post-CPW flows versus pre-CPW (status quo) flows – allows assessment of the amount of habitat under the CPW Scheme compared with the existing environment.

c. Post-CPW flows versus naturalised flows – this comparison allows assessment of the cumulative effects of the CPW scheme in addition to status quo water takes. Two post-CPW flow scenarios were considered:

1) 20/25/240 scenario - 20 $m^3 s^{-1}$ maximum abstraction from the Rakaia, 25 $m^3 s^{-1}$ maximum abstraction from the Waimakariri, and a reservoir with a capacity of 240 MCM.
2) 20/40/220 scenario - 20 $m^3 s^{-1}$ maximum abstraction from the Rakaia, 40 $m^3 s^{-1}$ maximum abstraction from the Waimakariri, and a reservoir with a capacity of 220 MCM.

4.17 Comparison of available *Deleatidium* habitat under status quo flow allocation with naturalised flows indicates that the greatest reductions in available invertebrate habitat occur during summer months. The reduction in *Deleatidium* (mayfly) habitat approaches 20% in February (19.3%) and March (19.3%) and exceeds 10% in January (10.9%) and April (12.3%) (Table 5, attached as Appendix J). Very similar results are obtained using the *Deleatidium* (Waitaki) HSC: the estimated reduction in habitat for *Deleatidium* exceeds 20% in February (22.5%) and March (22.5%) and 10% in January (14.3%) and April (14.7%) (Table 5, attached as Appendix J). Similarly, the reduction in food producing habitat exceeds 10% between January and April (Table 5, attached as Appendix J). These analyses indicate that between May and December, the effects of status quo allocation on *Deleatidium* and food producing habitat in the Waimakariri River are relatively minor (<10%).

4.18 Both post-CPW flow scenarios (20/25/240 and 20/40/220) result in further losses of *Deleatidium* habitat in excess of 10% (*Deleatidium* (mayfly): 10.3 – 16.9%, *Deleatidium* (Waitaki): 12.9 – 20.2%) in January, April, May and December when compared with <u>status quo</u> (pre-CPW) flows (Table 6, Appendix K). For both post-CPW scenarios versus status quo flows, available food producing habitat is reduced by more than 10% in January, May and December (Table 6, Appendix K).

4.19 I have also considered the cumulative effects of the water takes proposed by CPW in addition to existing water takes. Dr Burrell does not present such a comparison in his evidence, so I believe that it would be useful to do so here. Between 23 and 26% of *Deleatidium* (mayfly) habitat and 27% and 31% of *Deleatidium* (Waitaki) habitat is lost in the period January – April in both post-CPW scenarios when compared with the habitat available at naturalised flows (Table 5, Appendix J). Similarly, food producing habitat was reduced by 20-24% of in the post-CPW scenarios compared with naturalised flows between January and April in both post-CPW scenarios (Table 5, Appendix J). In both CPW scenarios, reductions in *Deleatidium* exceed 10% between October and May, and reductions in food producing habitat exceed 10% between December and May (Table 5, Appendix J).

4.20 I have been asked to consider an alternative flow scenario, the base post-CPW scenario (20/40/220), but with a minimum flow for B permits of 100 m^3s^{-1}. The details of this scenario are outlined in the evidence of Mr de Joux. This flow scenario results in losses in habitat of less than 10% when compared to existing allocation (the pre-CPW scenario), with maximum habitat losses are evident in September – December

(Table 5, Appendix J). Between January and August, this flow scenario results in losses of less than 2%. I would consider such additional losses (in addition to the losses experienced under existing allocation) to be minor.

4.21 When compared to the habitat available at naturalised flows, up to 20% of *Deleatidium* (mayfly) habitat is lost under this flow scenario (Table 6, Appendix K), while up to 23% of *Deleatidium* (Waitaki) habitat is lost under this flow scenario compared to naturalised flows (Table 6, Appendix K). Under this scenario, up to 18% of food producing is lost compared to naturalised flows (Table 6, Appendix K).

4.22 When determining an acceptable level of habitat retention for invertebrates, it is important to consider the significance of the values supported by invertebrates and whether food is likely to be limiting those values. In both the Waimakariri and Rakaia Rivers, invertebrates, and *Deleatidium* in particular, are an important food source for birds (Sagar, 1983; Hughey *et al*. 1989; but see also Duncan *et al.* 2003) and sports fish (Sagar & Eldon, 1983). The latter include regionally significant trout fisheries, and nationally significant salmon fisheries (see evidence of Dr. John Hayes).

4.23 Choosing an appropriate level of habitat retention is a somewhat subjective process. I believe it is best viewed as a risk-assessment; the greater predicted loss of invertebrate habitat, the greater risk of significant impact on the values that invertebrates support.

4.24 It is my opinion, that the modelled reductions in available invertebrate habitat (up to 32% for *Deleatidium* and 25% for food producing habitat) are more than minor effects given the significance of the values supported by invertebrates in the Waimakariri River. I note that this is consistent with the definition of minor provided on page 56 of Kingett Mitchell (2006f), which defined minor effects as being 10% or less.

4.25 The AEE and evidence by Dr Burrell also failed to recognise that there can also be losses in braided river invertebrate productivity through the loss of sources of recolonists that can reinvade major channels following disturbance. Secondary and tertiary braids can be productive habitats for invertebrates in braided rivers (refer to Table 1 attached as Appendix B, Table 2 attached as Appendix C) and can be an important source of recolonists following disturbance, such as flooding, in large braided rivers (Scrimgeour *et al.* 1988).

4.26 Analyses presented in Kingett Mitchell (2006c) suggest that the invertebrate community of most of the minor braids sampled were dominated by *Deleatidium,* and that greater flow stability resulted in an increase in the relative abundance of less mobile taxa, including the cased caddis fly *Pycnocentrodes* and the net-spinning caddis fly *Aoteapsyche*.

4.27 In my opinion, reduced extent and quality of invertebrate habitat (resulting from warmer temperatures, siltation, periphyton proliferation) may affect invertebrate production in these braids and I expect this to affect the rate at which the invertebrate community can recover following disturbance. I do not believe that the assessments presented to date adequately address the extent of the reduction in wetted area of secondary and tertiary braids and the consequences of changes in habitat quality for invertebrates.

4.28 Similarly, seepage habitats can be among the most productive habitats in braided rivers (Hughey *et al*. 1989, Stark 2001, Ryder 2006), and can contribute significantly to the biodiversity of these systems (Gray *et al*. 2006). The assessments presented by the applicant imply that reductions in flow in the Waimakariri River resulting from the proposed abstraction will have only relatively minor effects on seepage habitats. However, I believe that such an assessment is premature given the state of knowledge of these habitats in the Waimakariri system. The applicant has not quantitatively assessed how reduction in flow might affect groundwater-surface water exchange in these large braided systems, therefore it is difficult to interpret any potential changes to seepage habitats in an adequate manner.

4.29 Periphyton proliferation and sedimentation resulting from extended periods of stable flow can lead to reduced habitat quality for some invertebrate taxa. Water abstraction of the magnitude of the CPW Scheme has the potential to cause flows in the Waimakariri to drop to, and stay at, 41 m^3 s^{-1} (the minimum flow for A class permits) for extended periods of time (see evidence of Mr de Joux). This phenomenon is commonly referred to as “flat-lining”. Whilst the water abstraction proposed by the applicant will not directly result in this flat-lining at 41 m^3s^{-1}, since this relies on A-class permit abstraction, the frequency, duration and magnitude of the take from the Waimakariri River proposed by CPW will increase the frequency and duration of the circumstances when A-class abstraction will result in flat-lining. Therefore, I believe that this cumulative effect of the CPW and A-class permit abstractions is an important consideration in the assessments of the effects of CPW's proposed activities.

4.30 The increase in the duration of low flows in the Waimakariri River is a key effect of the proposed take(s) (as Dr Burrell states in paragraph 6 of his supplementary evidence, and Dr Meredith states in paragraph 55 of his section 42 officer's report). In paragraph 6 of his supplementary evidence, Dr Burrell challenges Dr Meredith's suggestion that:

> "production of macroinvertebrate food sources…will be significantly reduced by the extent of flow reduction and in particular by the duration of low flows"

and suggests that increased flow stability is likely to increase periphyton and invertebrate productivity. However, Dr Burrell has provided no analysis of relationships between flow variability/stability and invertebrate populations within either the Waimakariri or Rakaia Rivers to support his conclusion. In fact, periods of low, stable flow may result in periphyton proliferation, which may reduce the suitability of habitats for some sensitive invertebrate taxa (e.g. mayflies, stoneflies).

4.31 It is evident from the nature of the CPW Scheme that it will not affect the frequency or magnitude of large or even moderate flood events (refer to the evidence of Mr de Joux). Dr Burrell deals with this effect in paragraph 6.10, where he concludes that:

> "…the CPW take will have a negligible effect on the frequency of biologically important flood events, and that the Waimakariri will remain highly flood-disturbed".

4.32 Therefore, the increased stability that Dr Burrell refers to with regard to anticipated productivity increases is not a consequence of any effect of the proposed takes on the frequency or magnitude of disturbance events.

4.33 The CPW take(s) are expected to lead to an increase in periphyton accrual time - the period of time when flows are suitable for periphyton growth (flows of below 3 times the median flow). Dr Burrell predicts that the average accrual time will increase by 9 days compared with the existing flow allocation scenario. This means that with the CPW Scheme in place, the average period between flows of 3 times median flow or greater will be 9 days longer than at present.

4.34 Dr Burrell suggests that the greater flow stability afforded by this increase in accrual time will result in a minor increase in benthic invertebrate productivity (paragraph 6.14 of his evidence in chief). However, I do not expect that such an increase in productivity would compensate for the loss of available habitat area caused by the abstraction reducing flows relative to the natural flow recession.

4.35 I believe the reduction in habitat area is likely to significantly reduce invertebrate productivity (see paragraph 4.25 above), while the predicted increase in accrual time is likely to have only a minor beneficial effect, with the net result being a reduction in productivity rather than the gain that Dr Burrell suggests.

4.36 In addition, the minor beneficial effect of increased flow stability may be negated if periphyton proliferates and makes reduces habitat quality for sensitive species such as *Deleatidium.*

4.37 We do not have empirical data to enable us to assess the extent of any gains in invertebrate production resulting from the predicted increases in accrual time and compare these to the likely reductions caused by reduced wetted area suitable for invertebrates (as measured by WUA). Such an analysis would have been possible if quantitative invertebrate data taken from a range of depths and velocities in the Waimakariri River had been collected by the applicant.

4.38 As mentioned above, the IFIM analysis for the Waimakariri River, predicted WUA (a measure of habitat area <u>and</u> quality) increased with increasing flow for all 15 invertebrate taxa considered for the entire flow range modelled (Figure 6 attached as Appendix L), while the change in HSI (a measure of habitat quality) varies between taxa (Figure 7 attached as Appendix L).

4.39 This suggests that the increase in available invertebrate habitat (as a consequence of the increase in wetted area) with increasing flow exceeds any minor gains resulting from the greater stability afforded by longer accrual periods. Therefore, I do not see much evidence to support Dr Burrell's dismissal of Dr Meredith's suggestion that the proposed CPW take(s) from the Waimakariri River are likely to reduce invertebrate productivity.

4.40 I agree with Dr Meredith's opinion and in the absence of new data or analyses presented by the applicant that demonstrate otherwise, I believe that the reduced flows resulting from the proposed take(s) will reduce the productivity of the invertebrate community in the Waimakariri River.

4.41 The CPW Scheme also has the potential to affect the ability of the invertebrate community of the Waimakariri to recover from disturbance caused by bed-moving flows. Sagar (1983b) showed that small freshes during periods of low flows can play an important role in determining the rate of recolonisation of defaunated areas of sediment in braided rivers and goes on to suggest that this is because of higher drift rates of invertebrates during rising flows. The proposed take by CPW and the cumulative effect of this and other takes are expected to reduce flow variability and the magnitude and duration of these small freshes, which may affect the rate of recolonisation of defaunated sediments following flood events.

4.42 There is a risk that the increased accrual periods resulting from the proposed scheme will lead to increased growths of periphyton. Periphyton proliferation may result in reduced abundances of sensitive invertebrates (EPT[3] taxa) and increased relative abundances of tolerant taxa such as riffle beetles (Elmidae), purse-cased caddis flies (*Oxyethira albiceps*) and chironomids (see Table 3, attached as Appendix G). These tolerant taxa are likely to be less favoured food for black fronted terns and trout due to their small size

4.43 In regulated rivers, such periphyton growths are usually controlled by flushing flows. The CPW Scheme does not allow for water stored in the Waianiwaniwa Reservoir to be released back into the Waimakariri River in sufficient volumes to flush periphyton. Consequently, flushing flows will only occur when the intake structures are shut off by the applicant during naturally occurring high flows. The applicant will have limited capability to manage such flows, as they will rely on the occurrence of naturally elevated flows.

4.44 Inputs of fine sediments during construction and flushing of the sediment traps have the potential to cause short-term, localised effects on the invertebrate communities downstream of the intakes in both the Rakaia and Waimakariri Rivers. Fine sediments can negatively affect stream invertebrates by disrupting feeding or respiration. I expect the relative abundance of sensitive taxa, such as EPT taxa, to

[3] EPT = mayflies (**E**phemeroptera), stoneflies (**P**lecoptera), and caddis flies (**T**richoptera). Taxa in these orders of invertebrates generally are sensitive to reductions in water quality, periphyton proliferation, elevated water temperatures, and siltation.

decrease in areas affected by fine sediments in favour of more tolerant taxa (e.g. chironomids) and this may reduce prey availability for fish and birds. However, any effects of fine sediment on invertebrates could be minimised by limiting sluicing of sediment traps to periods of elevated flows when levels of suspended sediment are likely to be naturally elevated and the river has sufficient power to disperse fine sediments.

5. ADEQUACY OF PROPOSED MITIGATION OPTIONS IN THE RAKAIA AND WAIMAKARIRI RIVERS

5.1 Kingett Mitchell (2006c) identifies potential effects of the proposed scheme on invertebrate communities as well as assessing the effectiveness of various mitigation measures for these effects (Table 7.1). Dr Burrell also addresses mitigation options in his evidence in chief. In this section I will comment on the likely effectiveness of these mitigation options.

5.2 Table 7.1 of Kingett Mitchell (2006c) identifies erosion and sediment effects as one likely consequence of the diversion of water from the Rakaia and Waimakariri Rivers. The mitigation options presented include avoidance of erosion-prone areas and use of flood-protection works. This assessment fails to address the effects of sediment flushing from the sediment traps in the canal system described in section 3.4.2 of the AEE. Periodically, accumulations of fine sediment will be flushed from the canals and back into the Rakaia and Waimakariri Rivers. As discussed above, these fine sediments have the potential to affect stream invertebrate communities, albeit over a restricted area of riverbed below the discharge point.

5.3 Such effects could be minimised by restricting the flushing of the settling basin to periods of elevated flows when concentrations of suspended sediments will be naturally elevated and the transport capacity of the river is sufficient to flush sediments and distribute them over a greater length of river channel than at low flows.

5.4 It is evident from the analyses that I present in paragraphs 4.17 to 4.19 and the analyses presented by Dr Burrell in paragraphs 6.20 to 6.22 that the reduced flows resulting from the CPW Scheme will reduce the available habitat for invertebrates in the Waimakariri River. The CPW Scheme alone (i.e. not accounting for cumulative effects) is expected to reduce the available habitat for the important invertebrate

Deleatidium by up to 20% in several months of the year, yet Dr Burrell states that he believes that no mitigation is necessary. Given the high values supported by invertebrates in the Waimakariri River (birds and fisheries), I believe that mitigation is appropriate. The proposal to limit B-permit abstractions to periods when flows exceed 100 m^3s^{-1} would result in the retention of similar levels of habitat to the existing flow regime in most months (see paragraph 4.20). I believe that such a flow regime would mitigate the effects of the CPW abstraction from the Waimakariri River to being minor.

6. EFFECTS OF THE PROPOSED SCHEME ON FOOT-HILL RIVERS

6.1 The CPW Scheme will also affect several foot-hill rivers within the extent of the proposed scheme, primarily within the Selwyn River and its tributaries (including the Hawkins, Hororata and Waianiwaniwa Rivers). The effects of the CPW Scheme on these systems are substantially different to those in the large braided rivers. The main issues in these foot-hill systems are increased flows resulting from raised water tables, and changes in water quality resulting from land-use intensification. I discuss these issues in the following paragraphs.

6.2 Several foot-hill streams will be affected by the construction of the canals associated with this scheme. These streams include the Selwyn, Kowai, Hawkins, Hororata Rivers in addition to some small tributaries in the vicinity of the upper Waimakariri River intake (Hacketts Creek, Cabbage Tree Flat Stream). I anticipate that any effects of construction of these structures will be minor so long as the culvert/siphon structures are built in an appropriate manner, taking precautions to minimise potential for sediment and stormwater inputs. Such effects could be minimised with the imposition of appropriate conditions of consent for the construction of these structures.

6.3 In assessing the significance of effects of the CPW Scheme on invertebrates in foot-hill rivers, it is important to consider the values that are reliant on invertebrates in these systems. The values in foot-hill rivers that are supported by invertebrates are currently lower than those in the Rakaia and Waimakariri Rivers, with smaller, less significant populations of riverine birds (Kingett Mitchell 2006d), trout and native fish. However, it should be pointed out that many of these systems have previously supported more significant fishery values (see the evidence of Mr Joe Hay) and that the decline of these has been attributed (in part) to land-use intensification and habitat degradation. Consequently, the consequences in any reductions in the quantity or quality of macroinvertebrates are likely to be lower than for these other systems.

6.4 The evidence presented in the AEE states on several occasions that increased flows in foot-hill streams resulting from raised groundwater level to have a beneficial effect on aquatic macroinvertebrate communities as a result of greater flow permanence, reduced flow variability and greater wetted area occupied by the channel. Although I would agree that increased flows could potentially contribute to habitat improvements in some rivers, such benefits depend on the water quality in these systems which will also be affected if the CPW Scheme proceeds. Where waterways in this area are naturally ephemeral or intermittent, so any tendency towards greater flow permanence represents a deviation from the natural state of these systems. The evidence that has been presented by the applicant is clearly a generalization of all of the waterways in the Central Plains region and lacks any quantitative basis or site-specific information in relation to predicted outcomes.

6.5 I am concerned about the potential for increased nutrient run-off resulting from land-use intensification to result in greater growth of periphyton in the foot-hill streams draining the area affected by the CPW Scheme. Periphyton proliferations usually reduce habitat suitability for sensitive macroinvertebrates such as the mayfly *Deleatidium* and result in greater numbers of algae-tolerant species such as chironomids. I expect that this will reduce the amount and quality of invertebrate prey for drift-feeding fish (such as trout) and insectivorous birds in these streams. Although the applicants proposes various non-specific mitigation measures to prevent nutrient run-off, the details of how the mitigation measures will be employed, their effectiveness, and the dismissal of key effects such as phosphorus run-off, leads to a great deal of uncertainty as to the potential environmental outcomes. This is also discussed in the following section.

7. ADEQUACY OF PROPOSED MITIGATION OPTIONS IN FOOT-HILL STREAMS

7.1 Land-use intensification resulting from the proposed scheme has the potential to significantly degrade water quality in several foot-hill rivers within the extent of the CPW Scheme. This is recognised in Table 7.1 of Kingett Mitchell (2006c), where land-use intensification in the Selwyn and Hororata Rivers was identified as having a significant negative effect on water quality as a result of sediment and phosphorus run-off, sedimentation caused by bank erosion, and increased nitrate-N in surface and groundwaters. However, the authors of this report suggest that these effects can be mitigated to being negligible or even a minor improvement by "Sustainable farm management" practices such as fencing waterways to exclude stock, riparian planting, on-farm nutrient budgeting and the use of nitrification inhibitors. This assessment lacks details on how effective such measures are likely to be in the context of the affected area, or indeed, how they would be implemented.

7.2 I do not believe that the assessments presented to date adequately address the potential effect of nutrient-laden groundwater entering foothill streams. The extent to which the CPW Scheme will affect nutrient runoff to waterways is discussed in more detail in the evidence of Dr Scott Larned.

8. EFFECTS OF THE PROPOSED SCHEME ON THE HYPORHEIC ZONE OF THE RAKAIA AND WAIMAKARIRI RIVERS

8.1 The hyporheic zone is the interface between surface water and groundwater, and is generally defined as the sediments of river substrates below the active wetted channel of the river that are influenced to some degree by surface water. It is an important habitat for biological communities such as heterotrophic microbes and invertebrates, and in many streams and can be a very significant site for nutrient transformations. The invertebrate fauna of the hyporheic zone is called the hyporheos and can include species of invertebrates that are normally found at the surface of the stream bed, some taxa that are usually found in groundwater, as well as some species that are specific to the hyporheic zone. Consequently, it can be a hot-spot for biodiversity.

8.2 Braided rivers, such as those found in the alluvial outwash plains of the Rakaia and Waimakariri Rivers have extensive hyporheic zones with high connectivity between the interstitial and surface waters due to their extensive, permeable beds.

8.3 The hyporheic zone has generally been overlooked in AEEs to date. However, given its potential importance in the braided river systems of the Rakaia and Waimakariri Rivers and in the gravel beds of Selwyn, Hawkins and Hororata Rivers I believe that it should receive some consideration in this hearing. Because the hyporheic zone is the transition zone in which inputs of organic material and nutrients from land run-off are taken up and metabolized, they act to cleanse water flowing downstream through its catchment and have been likened to being a "river's liver" (Fisher et al. 2005). As such hyporheic zones provide highly important ecosystem services by maintaining clean water for drinking, recreation, and industrial (e.g. stockwater) uses.

8.4 Significant numbers of 'surface-dwelling' invertebrates are found in the hyporheic zone, and their exploitation of this habitat can vary seasonally (see Table 7, attached as Appendix M to this evidence). Invertebrates in the hyporheic zone may contribute significantly to the abundance, biomass, productivity and diversity of a river's invertebrate community. For example, in samples collected to 50 cm into the stream bed, Olsen & Townsend (2003) found that 70-75% of all invertebrates were collected from sediments more than 10 cm below the sediment surface (Table 7 attached as Appendix M to this evidence). The limited studies of invertebrate production in New Zealand streams have suggested that the hyporheic zone can make a significant contribution to invertebrate production. Collier *et al.* (2004) estimated that 76% of the annual production of the mayfly *Acanthophlebia cruentata* occurred in the hyporheic zone (>10 cm below the sediment surface), while Wright-Stow *et al.* (2006) estimated that 96% of the production of the cased caddisfly *Olinga* occurred in the hyporheic zone. There has been no assessment of the contribution of invertebrate populations found in the hyporheic zones of the Rakaia or Waimakariri Rivers.

8.5 The applicant's AEE included modelling of habitat availability for *Deleatidium* in surface waters under different flow scenarios in the Waimakariri River. However, this is unlikely to give a complete picture of the potential effects of the scheme on this key invertebrate, since a significant proportion of the population is expected to be present in the hyporheic zone (see paragraph 8.3 above). Reductions in flow are unlikely to affect the hyporheic zone in the same way as surface habitats and, in my opinion, hyporheic habitat will be more sensitive to reductions in flow than surface habitat.

8.6 In the absence of hard data, I can only speculate on the likely consequences of reduced in flows on the hyporheic zone of the Rakaia and Waimakariri Rivers based on our current knowledge and will outline these in the following paragraphs.

8.7 Studies have shown that the rate of water exchange between surface and hyporheic water is proportional to the square of stream velocity (Packman & Salehin 2003). Thus, hyporheic exchange is expected to decline more rapidly with a decreased flow than the reduction in the surface water system would suggest. This is of particular concern as the strength and direction of exchange of water between surface water and hyporheic water are key factors affecting the distribution and abundance of invertebrates in the hyporheic zone (Olsen & Townsend 2003) because, among other things, it supplies the hyporheic zone with oxygen and nutrients, creating hot-spots of hyporheic production.

8.8 I expect reduced surface water- groundwater exchange and increased residence time of water in the hyporheic zone to affect the rate and/or type of chemical processes (e.g. nutrient uptake and transformations) and its rate of metabolism. I anticipate that reduced water exchange may result in larger volumes of anoxic sediments, where anaerobic processes such as denitrification (conversion of nitrate-nitrogen to gaseous nitrogen) and methanogenesis (methane production) predominate. Such changes may affect water quality in surface waters and have not been assessed or considered by the applicant to date.

9. CONCLUSIONS

9.1 The macroinvertebrate fauna of the Rakaia and Waimakariri Rivers are an important food source for insectivorous birds, such as black fronted terns and wrybill, and sports fish. Macroinvertebrate communities of both braided rivers are dominated by the mayfly *Deleatidium* at most sites on most occasions. On average, macroinvertebrate densities observed in the Rakaia and Waimakariri Rivers were lower than those reported from most other braided rivers in New Zealand. Given the significance of the values (bird and fish populations) that aquatic invertebrate populations support, it is important to consider how they will be affected by the proposed scheme.

9.2 In my opinion, the assessments conducted by the applicant are inadequate to allow a thorough and informed assessment of the invertebrate communities in the Waimakariri and Rakaia rivers and to adequately assess effects of the CPW Scheme, especially given the high values supported by invertebrates in these systems (threatened bird species, significant sports fisheries). This is evident when the invertebrate sampling effort in the applicant's assessments is compared with the effort conducted in previous large-scale assessments of water abstractions.

9.3 An IFIM analysis conducted in the Waimakariri River indicates that when the status quo flow allocation is compared with naturalised flows, the greatest reduction in available *Deleatidium* and food producing habitat occurs in summer months.

Reductions in *Deleatidium* habitat are predicted to exceed 20% in February and March and 10% in January and April. Reductions in food producing habitat exceed 10% in January and April.

9.4 This IFIM analysis also suggests that both post-CPW scenarios result in a reduction in available *Deleatidium* and/or food producing habitat of a further 10% or more compared with the status quo flow allocation in December, January, April and May.

9.5 Consideration of the cumulative effects of the CPW Scheme and existing flow allocations suggests that 24 - 27% of *Deleatidium* habitat is lost in the period January – April in both post-CPW scenarios. Meanwhile food producing habitat was reduced by 21-25% in the post-CPW scenarios compared with naturalised flows between January and April. I believe that these cumulative effects are more than minor given the high values supported by macroinvertebrates in the Waimakariri River (e.g. birds and sports fish populations).

9.6 The water abstraction proposed by the applicant may result in an increase in periphyton biomass and deposition of fine sediments in some areas. Periphyton proliferation and fine sediment inputs usually result in a shift in the composition of invertebrate communities from dominance by mayflies to dominance by chironomid midges. Such changes may reduce the quality and availability of invertebrate prey for insectivorous birds and drift-feeding fish (such as trout). Effects of sediment flushing could be minimised by limiting the flushing of the settling basin to periods of elevated flows.

9.7 The CPW Scheme is expected to result in increased flows resulting from raised water tables, and changes in water quality resulting from land-use intensification in foot-hill streams draining the area affected by the scheme. While increased flow is likely to have a beneficial effect on invertebrate populations, I believe that these are likely to be negated by changes in water quality that occur as a result of land-use intensification.

9.8 In my opinion, there is inadequate information on the mitigation options proposed by the applicant to allow for an informed assessment of their likely effectiveness and adequacy to mitigate those effects of the CPW Scheme that are likely to negatively affect invertebrate populations and the values they support.

9.9 Reduced exchange between the river and the hyporheic zone has the potential to seriously affect macroinvertebrate communities as well as nutrient dynamics in the Rakaia, Selwyn and Waimakariri Rivers. Such changes will affect the availability and suitability of invertebrates as food for drift-feeding fish (especially trout) and insectivorous birds (especially drift-feeders such as black-fronted terns) and have not been assessed by the applicant.

9.10 I consider that the CPW Scheme has the potential to cause major changes in the abundance and composition of the macroinvertebrate communities in the Waimakariri River and foot-hill streams draining the scheme area. I believe that the existing minimum flows and allocation limits in the Rakaia are likely to limit effects of the proposed takes from that river to being no more than minor. However, the extent and significance of the effects, in particular those occurring in the Waimakariri River, has not been adequately assessed, leading to considerable uncertainty as to the magnitude of the effects on macroinvertebrates and other components of the ecosystem (e.g. birds and fish) that are reliant on them.

D Olsen
May 2008

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Appendix A

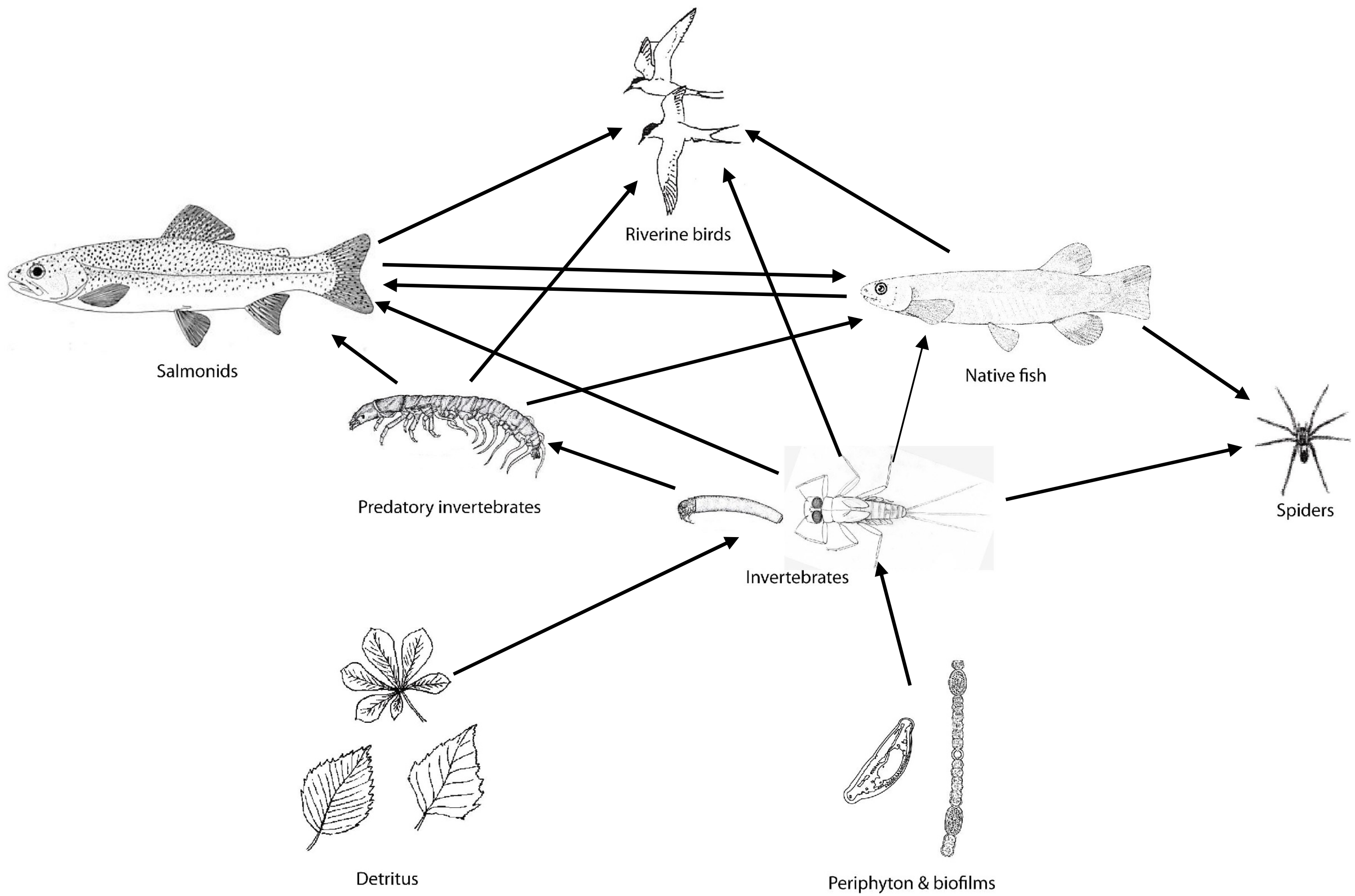


Figure 1 Simplified hypothetical food-web of a braided river showing possible consumptive links between invertebrates and other trophic levels. Arrows indicate the direction of energy flow.

Appendix B

Table 1 Summary of the relative abundance of selected invertebrate taxa, taxon richness and total invertebrate abundance in quantitative collected from the Rakaia (Sagar, 1983) and Waimakariri Rivers (NRWQN – data courtesy of the National Institute of Water and Atmospheric Research). A dash '-' indicates taxa that were not collected.

	Rakaia										**Waimakariri**					
	Sagar (1983) (1979-1980)						**Sagar (1983) (1980-1981)**				**Hughey et al. (1989)**		**NRWQN**			
Site	**Mouth**		**SH1**		**Highbank**		**SH1 Major**		**SH1 minor**		**Major**	**Minor**	**Gorge (CH3)**		**Old HW bridge (CH4)**	
Date	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**			**Mean**	**Range**	**Mean**	**Range**
Ephemeroptera																
Deleatdium	71.1	45.3-90.7	83.3	70.3-97.1	76.3	32.4-93.8	75.1	48.2-92.5	50.2	23.5-86.3	77.6	79.8	29.0	1-62.8	62.2	0-62.2
Plecoptera																
Zelandobius	1.4	0-6.7	1.4	0-9	1.1	0-5.8	0.3	0-1.9	0.8	0-3.0	0.4	0.3	2.4	0-10.8	7.9	0-7.9
Trichoptera																
Pycnocentrodes	1.1	0-6.3	0.3	0-1.4	0.3	0-2.8	0.3	0-2.2	7.6	0-26.2	?	?	0.3	0-2.1	0.3	0-0.3
Olinga	-	-	-	-	-	-	0.3	0-2.5	0.0	0-0.4	?	?	0.1	0-0.8	0.0	0-0
Oxyethira	0.5	0-4.4	-	-	1.4	0-16.9	0.4	0-2	0.2	0-0.8	0.0	0.0	0.3	0-2	5.4	0-5.4
Aoteapsyche	4.1	0-11.4	1.9	0-5.8	0.8	0-4.8	6.4	0.2-34.8	12.4	0.7-42.3	0.6	0.2	1.7	0-6.8	12.1	0-12.1
Hydrobiosis	1.1	0-2.3	2.3	0.4-7.1	2.2	0-6.1	5.3	0-13.4	4.9	1.0-11.2	?	?	1.9	0-7.5	10.7	0-10.7
Coleoptera																
Elmidae	0.6	0-2.1	1.0	0-4.8	0.4	0-4.2	0.9	0-4.7	2.6	0.2-6.9	0.2	0.1	1.7	0-5.6	5.2	0-5.2
Diptera																
Chironomidae	17.2	2.1-43.2	7.6	1.4-18.5	14.4	0-42.4	4.7	0-21.7	12.4	0-52.1	14.5	11.6	29.8	0-68.3	60.6	0-60.6
Austrosimulium	-	-	0.3	0-1	0.1	0-1.2	1.7	0-5.8	0.5	0-4.5	0.2	0.6	0.1	0-0.5	0.4	0-0.4
Eriopterini	1.6	0-4	1.5	0-5.1	0.9	0-6.2	1.6	0-7.4	1.6	0-5.2	?	?	1.6	0-8.8	5.9	0-5.9
Molophilus	0.3	0-1.8	0.4	0-1.2	2.2	0-6.7	0.6	0-4.7	1.0	0-4.7	?	?	0.0	0-0	2.2	0-2.2
Muscidae	-	-	-	-	-	-	0.2	0-1.7	1.4	0-13.0	0.0	0.0	0.0	0-0	0.3	0-0.3
Oligochaeta	0.6	0-2.6	0.2	0-2.5	0.0	0-0.3	0.1	0-1.1	0.7	0-4.6	?	?	0.2	0-2	33.7	0-33.7
Mollusca																
Potamopyrgus	-	-	-	-	-	-	0.1	0-0.5	0.0	0-0.6	?	?	0.0	0-0.2	2.2	0-2.2
Number of taxa	13[#]	3-13	13[#]	3-12	11[#]	3-10	26[#]	5-16	30[#]	8-21	14	14	33	6-16	27	5-14
Density	1393	80-5343	802	173-2863	646	90-2837	754.7	135-1663	1041	0-3363	1626	1074	2061	77-12151	3434	101-3434

? denotes taxa for which insufficient information is given.
Total number of taxa collected at a site (in all samples collected).

Appendix C

Table 2 Comparison of the relative abundance of selected taxa, taxon richness and total invertebrate abundance in the Ashley, Grey, Hurunui, Rangitata, Wairau and Waitaki Rivers. NRWQN data courtesy of NIWA.

	Ashley				**Grey**		**Hurunui**	
	Scrimgeour & Winterbourn (1989)	Hughey et al. (1989)			NRWQN (1989-2001)		NRWQN (1989-2001)	
	Upstream of Makerikeri River confluence	Major	Minor	Seepage	Dobson	Waipuna	Mandamus	SH1
Ephemeroptera								
Deleatidium	59.1	69.2	63.4	45.6	3.7	9.1	28.6	27.7
Plecoptera								
Gripopterygidae	0.5	1.2	0.7	0.7	0.1	0.8	3.9	0.6
Trichoptera								
Aoteapsyche	12.2	2.1	1.4	15.0	14.5	13.6	25.5	13.1
Hydrobiosidae	1.8	1.0	0.6	0.9	1.0	2.3	2.8	0.7
Oxyethira albiceps	0.4	-	-	-	0.2	0.6	0.1	1.7
Pycnocentrodes	1.4	?	?	?	2.2	0.7	9.2	14.7
Coleoptera								
Elmidae	13.8	16.2	25.4	39.3	1.9	1.6	3.8	12.8
Diptera								
Austrosimulium	0.4	0.9	1.2	0.2	0.1	0.5	1.0	*
Chironomidae	4.4	4.1	1.8	2.7	68.7	64.9	16.5	24.4
Tipulidae	?	2.3	2.3	1.2	1.6	1.4	0.6	0.1
Oligochaeta	0.5	?	?	?	3.4	1.7	0.8	1.6
Mollusca								
Potamopyrgus	?	?	?	?	0.9	*	0.4	1.5
Crustacea								
Amphipoda	?	?	?	?	*	*	-	*
Total taxa collected	60	na	na	na	46	49	37	44
Total invertebrate density	2315	2419	3985	9116	4294	4724	1412	4063

* denotes that this taxon was present but represented less than 0.1% of the total invertebrate abundance.
?' denotes taxa for which insufficient information is given.
na indicates that this information was not available.
‡ Includes *Pycnocentria*

Table 2 Continued.

	Rangitata									
	Bonnet (1986)				Stark (2001)					
	Mouth	SH1	Arundel	Above gorge	Mouth Major	Mouth Intermediate	Mouth Minor	Arundel Major	Arundel Intermediate	Arundel Minor
Ephemeroptera										
Deleatidium	72.3	59.9	67.4	70.8	81.7	78.7	84.4	34.2	15.3	18.1
Plecoptera										
Gripopterygidae	8.2	4.0	5.2	1.4	8.6	8.8	6.6	2.5	1.8	1.5
Trichoptera										
Aoteapsyche	0.2	0.2	2.1	1.3	1.7	1.5	1.4	2.2	1.2	1.4
Hydrobiosidae	2.0	4.1	5.7	5.4	2.0	1.6	2.1	3.1	2.4	1.9
Oxyethira albiceps	2.2	0.3	0.7	0.4	-	0.1	-	0.1	0.1	0.1
Pycnocentrodes	-	0.1‡	0.1‡	0.2‡	0.6	0.6	0.2	0.1	0.1	0.2
Coleoptera										
Elmidae	0.3	2.4	0.4	0.2	0.6	0.8	0.7	0.2	0.2	0.5
Diptera										
Austrosimulium	4.7	5.7	6.1	10.7	0.1	0.7	0.8	1.9	1.1	1.6
Chironomidae	8.3	20.5	13.1	10.3	2.0	3.7	1.3	54.0	75.7	73.7
Tipulidae	2.0	4.6	2.1	2.2	2.5	3.2	2.3	1.7	2.4	0.9
Oligochaeta	0.6	0.5	0.1	0.6	-	-	0.1	-	-	0.1
Mollusca										
Potamopyrgus	0.1	-	-	-	0.1	-	-	-	-	-
Crustacea										
Amphipoda	-	-	-	0.1	0.1	-	-	-	-	-
Total taxa collected	17	18	19	27	na	na	na	na	na	na
Total invertebrate density	573	948	692	1917	741	885	2969	1153	1880	8738

* denotes that this taxon was present but represented less than 0.1% of the total invertebrate abundance.
?' denotes taxa for which insufficient information is given.
na indicates that this information was not available.
‡ Includes *Pycnocentria*

Table 2 Continued.

	Wairau									
	Stark 1988	NRWQN (1989-2001)		Ryder (2006)						
	Dip Flat	Dip Flat	Tuamarina	Argyle Major	Argyle Minor	Hillersden Major	Hillersden Minor	Marchburn Major	Marchburn Minor	Renwick Major
Ephemeroptera										
Deleatidium	28.6	38.3	30.1	39.8	22.7	28.1	33.5	40.7	61.9	41.9
Plecoptera										
Gripopterygidae	15.7	12.7	0.1	-	-	-	0.1	-	-	-
Trichoptera										
Aoteapsyche	6.5	13.9	1.9	0.9	3.2	7.8	11.9	14.0	6.7	10.3
Hydrobiosidae	5.1	2.3	0.9	-	-	-	-	-	-	
Oxyethira albiceps	0.2	0.1	0.1	-	0.9	0.5	0.2	-	-	
Pycnocentrodes	3.2	0.3	1.2	4.1	17.7	14.2	12.5	13.2	1.7	2.4
Coleoptera										
Elmidae	1.9	6.6	3.0	11.5	21.5	21.8	25.0	22.1	12.9	8.0
Diptera										
Austrosimulium	0.5	2.7	0.2	0.8	*	0.3	1.9	0.8	1.7	2.7
Chironomidae	13.3	17.7	61.0	36.9	24.4	21.8	7.8	11.1	2.7	28.2
Tipulidae	4.7	1.9	0.7	0.5	2.5	0.2	0.4	0.4	-	0.1
Oligochaeta	0.8	0.6	0.5	-	-	-	-	0.2	0.1	-
Mollusca										
Potamopyrgus	-	-	0.1	-	-	*	-	*	-	-
Crustacea										
Amphipoda	-	-	-	-	-	-	-	-	-	-
Total taxa collected	55	45	37	27	24	26	22	27	18	18
Total invertebrate density	1576	2580	4811	2526	2690	2900	1944	3802	2644	1296.2

* denotes that this taxon was present but represented less than 0.1% of the total invertebrate abundance.
?' denotes taxa for which insufficient information is given.
na indicates that this information was not available.
‡ Includes *Pycnocentria*

Table 2 Continued.

	Waitaki							
	Palmer *et al*. (1989)	Rutledge (1987)				Rutledge *et al.* (1992)	NRWQN (1989-2001)	
		Ferry inner	Ferry outer	Henstridges	Jardines	Near Duntroon	Kurow	SH1
Ephemeroptera								
Deleatidium	16.8	10.9	12.5	6.0	12.7	17.7	9.5	2.5
Plecoptera								
Gripopterygidae	7.6	-	-	0.1	*	10.5	-	*
Trichoptera								
Aoteapsyche	6.7	12.5	4.5	3.0	1.2	8.9	3.8	2.4
Hydrobiosidae	2.0	2.1	1.5	3.4	1.5	1.6	0.3	0.3
Oxyethira albiceps	5.9	*	4.1	0.3	1.1	8.1	12.6	1.7
Pycnocentrodes	1.2	20.1[‡]	7.1[‡]	15.7[‡]	2.5[‡]	-	1.2	22.4
Coleoptera								
Elmidae	35.3	6.6	31.5	3*	5*	26.6	1.8	3.1
Diptera								
Austrosimulium	6.2	0.1	0.5	0.3	0.1	2.4	0.2	*
Chironomidae	10.7	0.6	0.1	3.4	8.8	9.7	45.2	19.6
Tipulidae	0.1	3.2	12.8	13.1	-	-	1.5	*
Oligochaeta	3.0	0.9	10.7	8.3	6.4	3.2	11.7	4.8
Mollusca								
Potamopyrgus	1.8	22.5	8.5	8.9	10.2	7.3	5.7	9.9
Crustacea								
Amphipoda	2.1	1.0	0.7	0.5	0.2	4.0	2.2	31.3
Total taxa collected	16	21	21	21	17	na	28	44
Total invertebrate density	1255	5755	698	1396	976	na	410	4126

* denotes that this taxon was present but represented less than 0.1% of the total invertebrate abundance.
?' denotes taxa for which insufficient information is given.
na indicates that this information was not available.
‡ Includes *Pycnocentria*

Appendix D

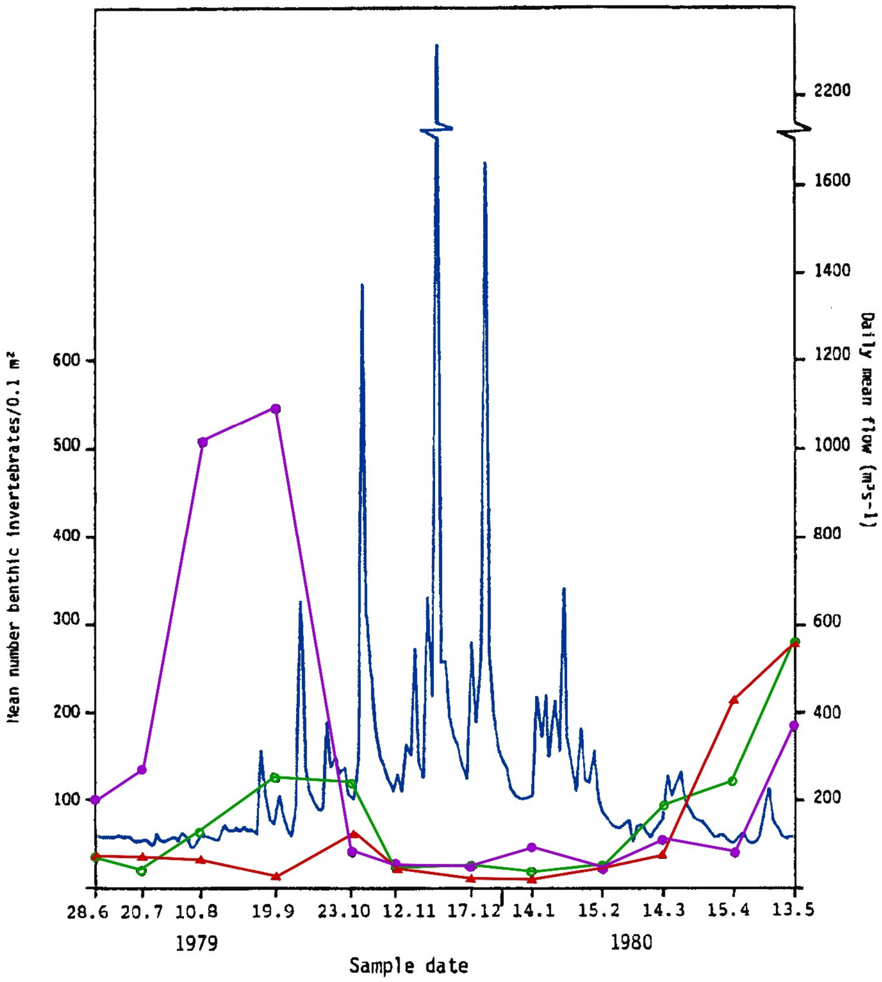


Figure 2 Numbers of benthic invertebrates (mean of triplicate Surber samples) at three stations in the Rakaia River compared with daily mean flow of the Rakaia River (June 1979-May1980). ● = 2km upstream of Rakaia mouth (Station 1), ○ = downstream of SH1 bridge (Station 2), ▲= Highbank (Station 3). Dark blue continuous line is the daily mean flow. Modified (colour added for clarity) from Sagar (1983).

Appendix E

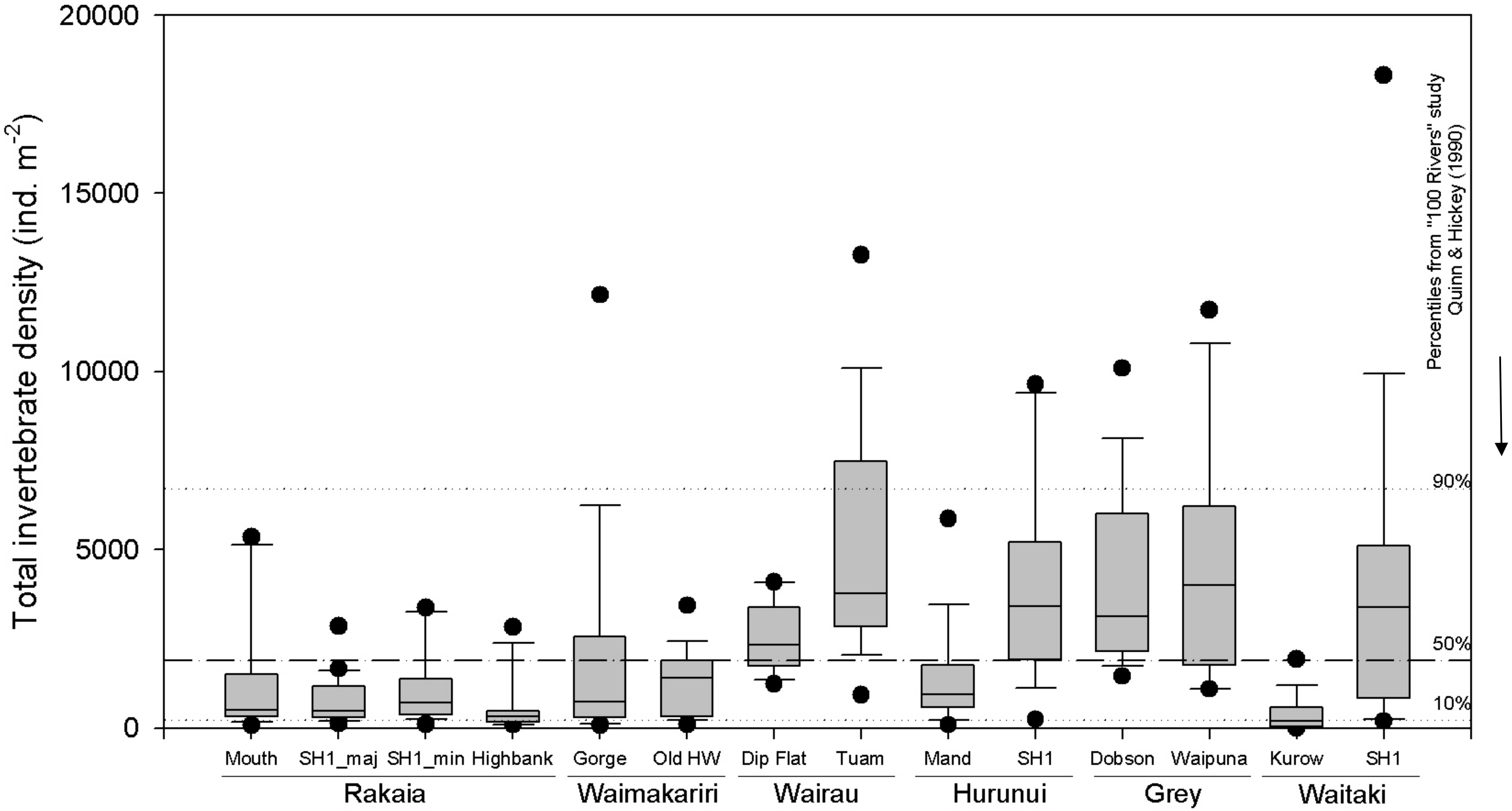


Figure 3 Box & whisker plots showing the distribution of invertebrate densities in the Rakaia and Waimakariri Rivers compared to national river water quality network (NRWQN) sites on four braided rivers (Wairau, Hurunui, Grey and Waitaki Rivers) on an annual basis from 1989-2001. Data courtesy of Mike Scarsbrook of NIWA.

Appendix F

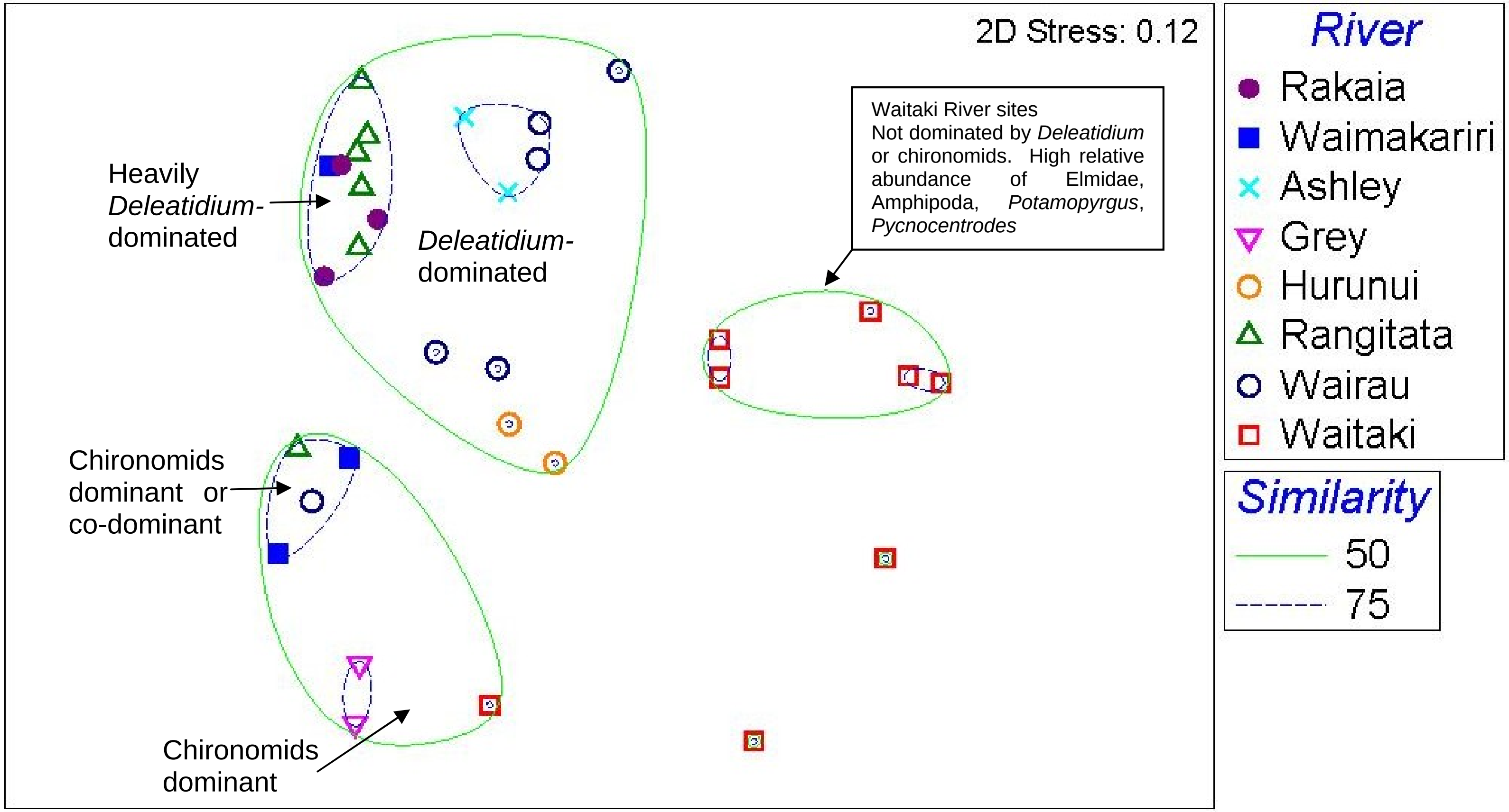


Figure 4 Multi-dimensional scaling ordination of the invertebrate communities of the Wairau (open blue circles), Ashley (cyan crosses), Grey (open pink triangles), Hurunui (open orange circles), Rakaia (violet circles), Rangitata (open green triangles), Waimakariri (blue squares), and Waitaki (open red squares) rivers. Solid green or dashed blue lines represent results of cluster analysis - groups of sites surrounded by green lines cluster at a 50% level of similarity or greater, while groups of sites surrounded by dashed blue lines cluster at a 75% level of similarity or greater.

Appendix G

Table 3 Ranges in length and dry mass of *Deleatidium*, chironomid midges and riffle beetles (Elmidae) used in the study of Towers *et al.* (1994). *n* indicates the number of individuals on which each range is based.

	Range		
Taxon	length (mm)	Dry mass (mg)	*n*
Deleatidium	3.9-10.4	0.3-5.7	53
Chironomidae	2.1-4.1	0.08-0.85	23
Elmidae	2.9-6.9	0.05-1.19	32

Appendix H

Table 4 Number (and type) of invertebrate samples collected for major AEEs and development investigations in comparison to assessments for CPW

River	Purpose	Study	Samples Quantitative	Samples Semi-quantitative
Rakaia River	**AEE – Central Plains Water**	Kingett Mitchell (2006c)	**-**	**3†**
Waimakariri River	**AEE – Central Plains Water**	Kingett Mitchell (2006c)	**-**	**3†**
Lower Clutha River	Power development investigations	Biggs & Shand (1987)	209	-
Wanganui River	AEE - Tongariro Power Development	Stark (1989)	239	-
Rangitata River	Water Conservation Order hearing	Stark (2001)	291	-
Waitaki River	AEE - Project Aqua	Stark & Suren (2002)	222	-
Waitaki River	AEE - North Bank Tunnel Concept	Stark & Suren (2007)	104*	-
Wairau River	AEE - Wairau HEPS	Ryder (2006)	110	82

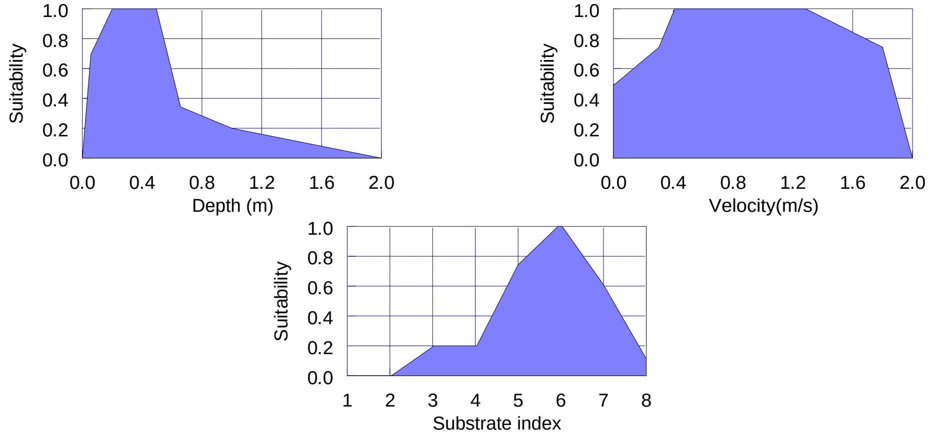
† Samples collected from minor braids only.

* indicates that these samples are in addition to those collected by Stark & Suren (2002).

Appendix I

a)

Deleatidium (mayfly) (Jowett et al. 1991)



b)

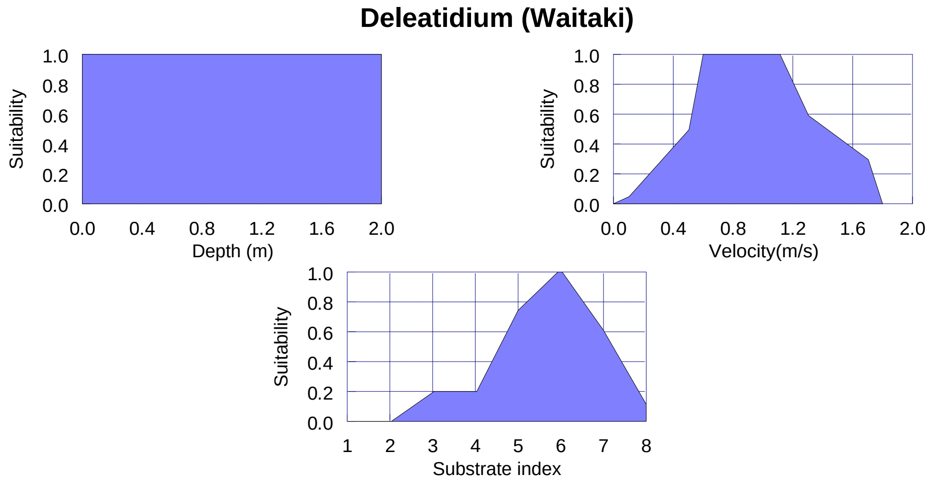


Figure 5 Habitat suitability curves for the mayfly *Deleatidium*. a) *Deleatidium* (mayfly) curves of Jowett *et al.* (1991), and b) *Deleatidium* (Waitaki) curves of Jowett (2002).

Appendix J

Table 5 Percentage of habitat retention for *Deleatidium* and food producing habitat based on WUA (m^2 m^{-1}) at monthly median flows expected under status quo allocation compared with naturalised flows, and post-CPW scenarios compared with naturalised flows. WUA information courtesy of Maurice Duncan of NIWA. Cells highlighted in yellow indicate 80-90% habitat retention, orange cells indicate 70-80% habitat retention, and pink cells indicate <70% habitat retention.

		Month									
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Naturalised vs. status quo	*Deleatidium*	89.1%	80.7%	80.7%	87.7%	97.5%	97.6%	97.6%	98.1%	98.4%	91.7%
	Deleatidium (Waitaki)	86.7%	77.5%	77.5%	85.3%	96.8%	97.0%	97.0%	97.4%	98.0%	89.9%
	FPW	88.8%	83.3%	83.3%	88.5%	97.3%	97.5%	97.4%	97.9%	98.6%	92.6%
Naturalised vs post-CPW 20/25/240	*Deleatidium*	74.1%	76.6%	76.6%	77.2%	86.7%	93.3%	93.6%	95.2%	97.8%	90.6%
	Deleatidium (Waitaki)	69.2%	72.5%	72.5%	72.9%	84.1%	91.6%	92.0%	93.8%	97.2%	88.6%
	FPW	76.2%	79.6%	79.7%	79.6%	87.0%	92.8%	93.2%	94.9%	98.0%	91.6%
Naturalised vs post-CPW 20/40/220	*Deleatidium*	74.1%	76.6%	76.6%	77.2%	87.4%	92.1%	93.8%	96.1%	97.5%	90.5%
	Deleatidium (Waitaki)	69.2%	72.5%	72.5%	72.9%	84.8%	90.1%	92.3%	94.9%	96.8%	88.4%
	FPW	76.2%	79.6%	79.7%	79.6%	87.6%	91.6%	93.4%	95.9%	97.7%	91.5%
Naturalised vs Post CPW 20/40/220 "B" take above 100 m3/s	*Deleatidium*	88.1%	79.7%	79.7%	86.6%	96.6%	96.9%	96.9%	97.5%	91.1%	88.5%
	Deleatidium (Waitaki)	85.5%	76.2%	76.2%	84.1%	95.7%	96.1%	96.1%	96.7%	89.2%	85.9%
	FPW	88.0%	82.4%	82.4%	87.6%	96.4%	96.7%	96.7%	97.4%	91.8%	89.7%
Naturalised vs post-CPW 20/40/220 with 1:1 flow share	*Deleatidium*	81.2%	78.2%	78.1%	82.2%	91.8%	94.0%	93.6%	93.9%	94.8%	90.2%
	Deleatidium (Waitaki)	77.6%	74.4%	74.3%	78.9%	89.9%	92.4%	92.0%	92.1%	93.7%	88.0%
	FPW	82.3%	81.0%	81.0%	84.0%	91.5%	93.6%	93.2%	93.5%	95.4%	91.2%

Appendix K

Table 6 Percentage of habitat retention for *Deleatidium* and food producing habitat based on WUA (m^2 m^{-1}) at monthly median flows expected under post-CPW scenarios compared with flows under status quo allocation. WUA information courtesy of Maurice Duncan of NIWA. Cells highlighted in yellow indicate 80-90% habitat retention.

		Month									
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Pre-CPW vs post-CPW 20/25/240	*Deleatidium*	83.1%	94.9%	94.9%	88.0%	89.0%	95.5%	95.9%	97.1%	99.3%	98.8%
	Deleatidium (Waitaki)	79.8%	93.5%	93.6%	85.4%	86.8%	94.4%	94.9%	96.3%	99.2%	98.5%
	FPW	85.8%	95.6%	95.6%	90.0%	89.5%	95.2%	95.7%	96.9%	99.4%	99.0%
Pre-CPW vs post-CPW 20/40/220	*Deleatidium*	83.1%	94.9%	94.9%	88.0%	89.7%	94.3%	96.1%	98.0%	99.0%	98.7%
	Deleatidium (Waitaki)	79.8%	93.5%	93.6%	85.4%	87.6%	92.9%	95.2%	97.4%	98.8%	98.3%
	FPW	85.8%	95.6%	95.6%	90.0%	90.0%	93.9%	95.9%	97.9%	99.1%	98.8%
Pre-CPW vs Post CPW 20/40/220 "B" take above 100 m3/s	*Deleatidium*	98.9%	98.7%	98.7%	98.8%	99.1%	99.2%	99.3%	99.5%	92.6%	96.5%
	Deleatidium (Waitaki)	98.7%	98.4%	98.4%	98.6%	98.9%	99.0%	99.1%	99.3%	91.0%	95.6%
	FPW	99.0%	98.9%	98.9%	99.1%	99.1%	99.2%	99.2%	99.4%	93.1%	96.8%
Pre-CPW vs post-CPW 20/40/220 with 1:1 flow share	*Deleatidium*	91.1%	96.8%	96.8%	93.7%	94.1%	96.2%	95.9%	95.7%	96.3%	98.3%
	Deleatidium (Waitaki)	89.5%	96.0%	95.9%	92.4%	92.8%	95.3%	94.9%	94.6%	95.6%	97.9%
	FPW	92.7%	97.2%	97.2%	95.0%	94.0%	96.0%	95.7%	95.5%	96.7%	98.5%

Appendix L

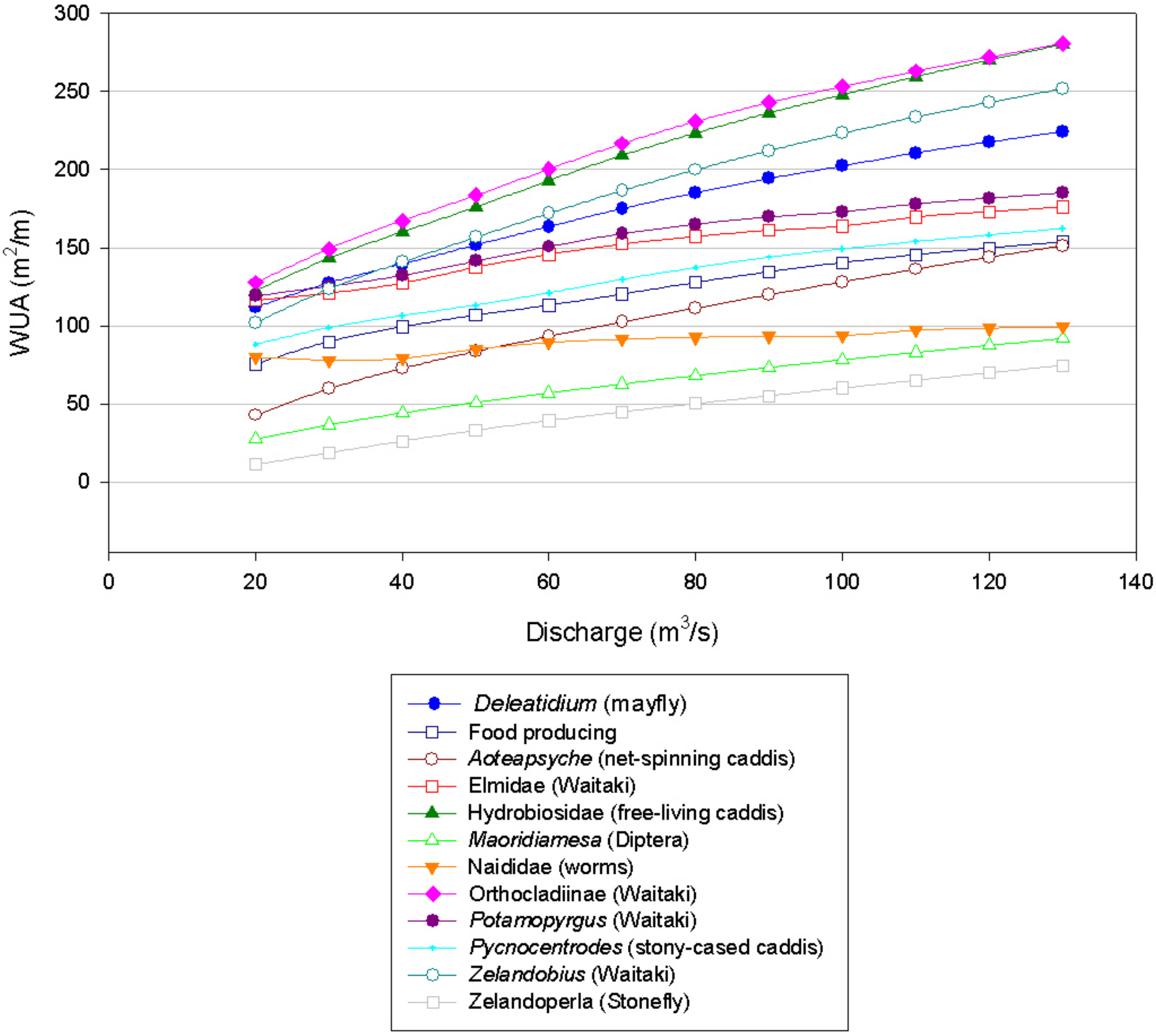


Figure 6 Relationship between discharge (m^3/s) and habitat availability, as measured by weighted usable area (WUA, m^2/m), for 12 invertebrate taxa in the Waimakariri River.

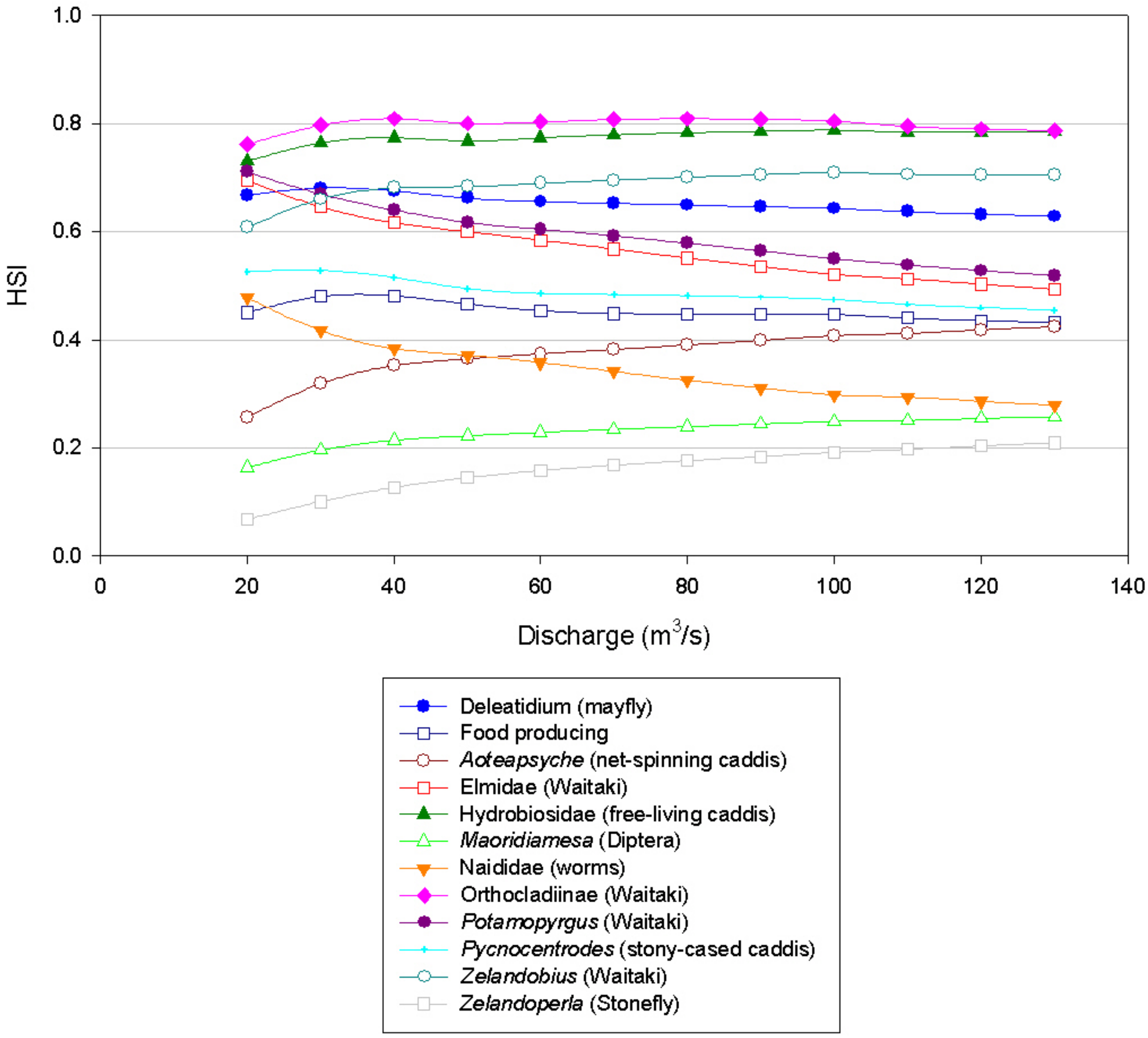


Figure 7 Relationship between discharge (m^3/s) and habitat quality, as measured by the habitat suitability index (HSI, %), for 12 invertebrate taxa in the Waimakariri River.

Appendix M

Table 7 Percentage of the total densities of common taxa found in the surficial sediments (to 10 cm below the sediment surface) of freeze cores taken to a depth of 50 cm into the bed of the Kye Burn, North Otago (modified from Olsen & Townsend, 2003). An asterisk indicates that this taxon was not abundant on this sampling occasion.

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