Before the Hearings Commissioners
at Christchurch

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in the matter of: a submission on the proposed Hurunui and Waiau River Regional Plan and Plan Change 3 to the Natural Resources Regional Plan under the Resource Management Act 1991

to: **Environment Canterbury**

submitter: **Meridian Energy Limited**

Statement of evidence of John William Hayes

Dated: 12 October 2012

REFERENCE: JM Appleyard (jo.appleyard@chapmantripp.com)
TA Lowe (tania.lowe@chapmantripp.com)

Chapman Tripp
T: +64 3 353 4130
F: +64 3 365 4587

245 Blenheim Road
PO Box 2510, Christchurch 8140
New Zealand

www.chapmantripp.com
Auckland, Wellington, Christchurch

1. **QUALIFICATIONS AND EXPERIENCE**

1.1 My full name is John William Hayes. I hold the degrees of B.Sc (Hons) and a PhD in zoology, specialising in freshwater ecology and fisheries.

1.2 I have 32 years experience as a freshwater fisheries scientist, and I have been employed by the Cawthron Institute in that capacity since 1994. I have special expertise in trout ecology and recreational fisheries, instream habitat modelling and bioenergetics modelling.

1.3 Other relevant information concerning my education, work experience and expertise is attached in **Appendix 1**.

1.4 In preparing my evidence I have drawn from the following Cawthron reports, commissioned by Meridian Energy for the assessment of effects of hydropower development options on the Waiau and Hurunui rivers, two of which I have co-authored:

a. Doehring & Maxwell (2011) Freshwater fish distribution and salmonid fishery values in the Waiau catchment;

b. Olsen *et al*. (2011) Assessment of the Amuri Hydro Project on the Waiau River;

c. Hayes *et al*. (2012) Periphyton, macroinvertebrates and fish in the Waiau River, North Canterbury – January – February 2012 surveys;

d. Doehring (2012). Freshwater fish distribution in the Hurunui River between the Mandamus River confluence and State Highway 7.

1.5 I have visited the Waiau River in the Amuri and Hanmer plains areas for surveying fish and macroinvertebrate communities, and have fished in the lower and upper parts of the catchment for trout and salmon.

1.6 In preparing my evidence I have reviewed:

a. The evidence of the following witnesses:

i. Mr Woods;

ii. Mr Jowett;

iii. Dr Olsen;

iv. Dr Mabin;

v. Mr Greenaway; and

b. Meridian's resource consent application, and Assessment of Environmental Effects (AEE) for the AHP.

1.7 I have read the Environment Court's Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note (2011) and I agree to comply with it. I have complied with it in the preparation of this statement of evidence. I have not omitted material facts known to me that might alter or detract from the opinions expressed.

2. SCOPE OF EVIDENCE

2.1 I have been asked by Meridian Energy Limited ("Meridian") to present evidence on fish in the Waiau River, North Canterbury, in respect of the Proposed Hurunui Waiau River Regional Plan (the "Proposed Plan") and Meridian's proposed Amuri Hydro Project (AHP).

2.2 My evidence addresses the following points:

a. Fish communities and distribution in the Waiau and Hurunui rivers;

b. Fish values;

c. Fish migrations;

d. Fish diversity and abundance in the Amuri and Hanmer plains river segments:- results of the 2012 summer survey;

e. Effects of the flow and allocation regime for the Waiau River in the Proposed Plan on fish populations and salmon angling opportunities.

2.3 I have assessed the effects of the minimum flow and allocation regime in the Proposed Plan relative to the current minimum flow and allocation regime (Status Quo) and the naturalised flow regime. The latter addresses cumulative effects. The Status Quo includes current irrigation and other water takes as described by Mr Mathamo in his evidence. The AHP (called the modelled proposal) and Status Quo flow regimes are the river flows below all Amuri Plains irrigation and other takes.

2.4 In my assessment of effects, I have used the modelled proposal, as described in the evidence of Mr Woods as a surrogate for the Environmental Flow and Allocation Regime for the Waiau River in the Proposed Plan. The two flow regimes are similar except for the 2 m^3/s "gap" between the "A" and "B" allocation blocks in the Proposed Plan which Mr Wood's has not taken into account in his modelling. By not including the 2 m^3/s gap the amount of abstraction under the AHP flow regime (the modelled proposal) is slightly higher than under the Proposed Plan but this difference is not of any consequence for assessment of ecological effects. I note also that the modelling undertaken represents full allocation of "A", "B" and "C" blocks and takes into account all existing known abstractions, and likely future irrigation abstractions.

2.5 While my evidence is focussed on fish it also draws on information on habitat and abundance of macroinvertebrates in the Waiau River because this is relevant in respect of food resources for fish. I had a key role in collecting, analysing and documenting information on periphytyon, macroinvertebrates and fish from the Waiau River undertaken for effects assessment of the AHP (Hayes *et al*. 2012). The periphtyon and macroinvertebrate information is presented by Dr. Dean Olsen.

2.6 All of the issues covered by this scope of evidence are within my area of expertise.

3. KEY FACTS AND OPINIONS

Fish diversity, distribution and conservation status in the Waiau and Hurunui rivers

3.1 A total of 14 freshwater fish species are known from the Waiau and Hurunui rivers of which 12 are common to both, and they have the same complement of native species. The most frequently occurring species in the middle and upstream parts of the two rivers are brown trout, upland bully, longfin eel, and Canterbury galaxias koaro, with alpine galaxias also relatively common in the upper Hurunui. Inanga and common smelt will be common in the lower reaches of both rivers but are under-represented in fish records.

3.2 Longfin eels, koaro, inanga, and torrentfish have national threat classifications as 'declining'. Despite this classification, all four fish species are still widespread and common, although there is concern over recruitment failure in longfin eels. All four species will be relatively resilient to flow alteration because they colonise from the ocean, and there is no evidence that they home to natal rivers. The remaining species are not of conservation concern.

Fish values

3.3 Of the native fish species that occur in the Waiau and Hurunui rivers, longfin and shortfin eel, inanga and koaro have fisheries values. The other native fish species have intrinsic value and also provide food for top predators such as eels, trout and birds.

3.4 Trout and salmon support recreational sports fisheries in both the Waiau and Hurunui rivers. On the basis of angler usage, at the entire river level the Hurunui salmonid fishery (salmon and trout fishing combined) is potentially nationally important (angler use ≥ 10,000 angler days / year) and the Waiau fishery is regionally important. The upper Hurunui trout fishery is potentially nationally important. The salmon fisheries in both rivers are regionally important. The trout and salmon fisheries in the Amuri Plains segment of the Waiau River are locally important.

Fish diversity and density in the Amuri Plains segment of the Waiau River

3.5 A similar number of fish species was recorded in a reach of the Waiau River in the Amuri Plains as has been recorded from inland reaches of other South Island braided rivers. However, fish density recorded in the Waiau was lower than in other rivers, which is consistent with flood disturbance suppressing fish densities. Over a flow/sediment stability gradient for South Island braided rivers, the Waiau River's flow regime is near the lower end of the gradient (*i.e.*, highly unstable).

3.6 In braided rivers higher fish diversity and density has been reported in seepage and minor channels than in major channels, probably because major channels experience more frequent flood disturbance. This was found to be the case for density but not diversity in the Amuri reach.

Effects of proposed flow alteration on fish in the Amuri Plains segment of the Waiau River

3.7 I have assessed the effects of the Proposed Plan flow regime as it would be implemented by the Amuri Hydro Project ("the Modelled Proposal") with respect to the Status Quo and natural flow regimes. Comparisons against the base line of the Status Quo assess the effects of the new environmental flow and allocation regime in the Proposed Plan. Comparisons against the base line of the natural flow regime assess cumulative effects. My assessment is based largely on Mr Jowett's hydraulic-habitat modelling for assessing effects of the Amuri Hydro Project (AHP).

3.8 Hydrological modelling undertaken for the AEE for the AHP complies with the environmental flow and allocation regime in the Proposed Plan, except that the 2 m^3/s "gap" between the 'A' and 'B' allocation blocks in the Plan is omitted. In my opinion the 2 m^3/s gap will have no material benefit on fish or benthic invertebrate habitat so its omission from effects assessment of the AHP is inconsequential.

3.9 When habitat retention is referenced to the MALF the Modelled Proposal retains similar percentages of fish and invertebrate habitat to the Status Quo because the AHP MALF (20 m^3/s) is very similar to the Status Quo MALF (21.5 m^3/s). The Modelled Proposal MALF retains on average 98% (94 – 100%) of fish habitat and 97% of habitat for *Deleatidium* (mayfly) and food production relative to the Status Quo MALF. It retains about 90% (range 70 – 107%) of the fish habitat available at the natural MALF and about 83% of habitat for *Deleatidium* and food production.

3.10 The biggest reductions in habitat availability are for torrentfish, because it is a fast-water species, whereas habitat gains are predicted for large longfin eels (> 300 mm) and juvenile salmon (> 55 mm) because they prefer slower, deeper water.

3.11 A high level of adult trout habitat is predicted to be retained at both the Status Quo and Modelled Proposal MALFs (98%). A similar level of juvenile trout habitat is retained relative to the Status Quo (97%) but 14% habitat loss (86% retention) is predicted relative to the natural flow regime.

3.12 Monthly habitat retention analysis showed that the adverse effects of the Status Quo regime on fish and invertebrate habitat are confined mainly to the summer (January – April). The worst effects are in dry years, with lesser effects in typical years and none in wet years. The Modelled Proposal extends effects, both negative and positive, over most of the year compared with the Status Quo.

3.13 The greatest differences between habitat provided by the Status Quo versus the Modelled Proposal occur in typical and dry months. Eight of the ten fish species/life stages modelled are predicted to experience neutral habitat effects or net gain in habitat over typical years, averaging 115% retention. Six species/life stages are predicted to exhibit a net loss in habitat in dry years averaging 90% retention.

3.14 Both the Status Quo and the Modelled Proposal have a net overall benefit for adult trout drift-feeding habitat especially in spring in dry months, winter - spring in typical months and summer in wet months.

3.15 Cumulative effects of the Modelled Proposal on fish are modest and not substantially different to effects relative to the Status Quo.

3.16 The habitat losses predicted for fish, including torrentfish, under the modelled proposal do not threaten the viability of the species, and probably won't result in population decline, because they currently occur at low densities in the Amuri Plains segment of the Waiau. That is, habitat is unlikely to be limiting the total population.

3.17 Compared to the Status Quo the Modelled Proposal is predicted to result in an average loss of benthic invertebrate habitat of 14 - 17% across all dry and typical months (*i.e.*, 83 - 86% habitat retention). Predicted average cumulative habitat loss (*i.e.*, Modelled Proposal relative to the natural flow regime) is 18 - 21% (*i.e.*, 79 - 82% retention). Predicted habitat losses for wet years average 16% and 22% for the Modelled Proposal referenced to the Status Quo and natural flow regimes, respectively.

3.18 Frequent flood disturbance in the Waiau naturally suppresses invertebrate food resources for fish and the predicted invertebrate habitat losses may reduce them further. This may reduce growth and abundance of trout and juvenile salmon that rely on drift feeding, but probably not of benthic feeding native fish.

3.19 The effect of the above changes to flow related habitat for trout and benthic invertebrates on trout was assessed with an empirical trout abundance model developed by Mr Jowett on 59 sites in rivers throughout New Zealand. The model predicted that the Modelled Proposal regime would support about 20% fewer trout than the Status Quo and natural flow regimes in the Amuri Plains segment of the Wairau River. However, the model predictions have a high level of uncertainty. Predicted abundance under the Status Quo and the Modelled Proposal flow regimes (20.8 and 16.3 trout/km; respectively) could differ from actual abundance by up to 1.9 times higher and 0.3 times lower. This range of uncertainty, which is measure of the natural variability in trout abundance, is greater than the difference in predicted mean abundance between the two flow regimes.

Flows for maintaining fish passage

3.20 The 20 m^3/s minimum flow in the Proposed Plan will allow salmon passage in the Amuri Plains segment of the Waiau whereas the Status Quo summer minimum flow (15 m^3/s) would impede passage.

3.21 The natural frequency of floods > 210 m^3/s will be retained under the Modelled Proposal so salmon will continue to benefit from freshes that stimulate, and facilitate, upstream migration.

Salmon angling

3.22 The Modelled Proposal will substantially reduce salmon angling lies in the Amuri Plains segment of the Waiau but this alone is unlikely to significantly adversely affect salmon angling opportunities because lies are probably underutilised over most the segment. The truncation of flow recessions resulting from flow diversion under the AHP has greater potential to adversely affect salmon fishing opportunities but this can be easily mitigated by managing flows into any intake immediately following floods.

Water quality

3.23 Chemical water quality is generally high in the Amuri segment under the Status Quo flow regime owing to the low percentage of the catchment intensively farmed. Chemical water quality (including dissolved oxygen) will continue to fall well within the tolerance ranges of fish under the Modelled Proposal regime.

3.24 Water temperature modelling indicates that compared to the Status Quo flow regime the full irrigation with hydro flow regime will increase water temperatures through the braided Amuri Plains river segment (Leslie Hills Bridge to Sanderson's Road – below Waiau Township) by about 1 ^{o}C. The resulting water temperatures will continue to be below lethal temperatures for fish but will be high enough to cause infrequent behavioural effects on trout and salmon, including reduced feeding and growth of trout and disruption of migration by salmon. These conditions will occur only on hot sunny days at low flow. Mean daily water temperature occasionally exceeds the threshold for feeding and growth of trout under the status quo flow regime (19^{o}C).

4. FISH DIVERSITY, DISTRIBUTION AND CONSERVATION STATUS IN THE WAIAU AND HURUNUI RIVERS

4.1 Historical records of fish species distribution in flowing water in the Waiau and Hurunui rivers (excluding ponds, lakes and wetlands) were sourced from the New Zealand Freshwater Fish Database (NZFFD, National Institute for Water and Atmospheric Research (NIWA)). These were complemented by fish distribution predictions from a spatial database based on a model developed by Leathwick *et al*. (2008). The model is built around the river network developed originally as the River Environment Classification (REC; Snelder *et al*. 2004) and predicts the probability of presence for each species at all rivers and streams throughout New Zealand.

4.2 A total of 14 freshwater fish species are known from the Waiau and Hurunui rivers, of which 12 are in common to both rivers (Table 1). They also have the same complement of native species (Table 1). A further two species, lamprey and bluegill bully are probably present in both rivers.

4.3 According to the NZFFD the most frequently occurring species in the two rivers are brown trout, Canterbury galaxias, and upland bully; and also longfin eel in the Waiau River, and Alpine galaxias and koaro in the Hurunui River (Table 1). However, occurrence of the various species will depend on the spatial distribution of sampling which is not evenly distributed across the catchments. With this in mind, based on occurrence elsewhere, brown trout, upland bully, longfin eel and Canterbury galaxias will probably be the most frequently occurring species, especially in the middle and upper reaches. Inanga and common smelt are underrepresented in the records for both rivers owing to low sampling effort in the lower reaches and difficulty of capture.

4.4 The distribution of the native species is strongly influenced by the high incidence of migratory species in the fauna. Seventy percent of the native fish species in the Waiau and Hurunui rivers are diadromous (*i.e.* they have to migrate between the sea and freshwater to complete their life cycle). Of the exotic species, chinook salmon are also obligatory sea-going fish while a proportion (probably small) of the brown trout population will also go to sea, but their ocean-migratory behaviour is not necessary for survival. Brown trout often move extensively in freshwater and so are widespread in both catchments.

4.5 The migratory species vary in their ability to penetrate upstream and this is the main influence on the distribution of the fauna. Only the strongest swimming or climbing migratory species (*e.g.*, longfin eel, koaro and salmon) and resident species (upland bully, Canterbury galaxias, alpine galaxias, brown trout) occur in the Waiau River above about 400 m altitude or more than 100 km from the ocean (Figure 1). A similar pattern can be expected in the Hurunui River.

4.6 Longfin eels, koaro, inanga, and torrentfish have national threat classifications as ‘declining’ (Allibone *et al*. 2010). Allibone *et al*. defined “decline” as a reduction in the total adult population size, or total area occupied, between 10 % and 70 % for a period of ten years, or in the case of populations a reduction of the same magnitude over three generations. Despite this classification, all four fish species are still widespread and common, and all but torrentfish are exploited by fisheries. Moreover, all four species will be relatively resilient to flow alteration because they colonise from the ocean, and there is no evidence that they home to natal rivers. The remaining species in Table 1 are not of conservation concern.

5. FISH VALUES

5.1 Of the native fish species that occur in the Waiau and Hurunui rivers, longfin and shortfin eel, inanga and koaro have fisheries values. The eels contribute to commercial, recreational and Maori cultural harvests, and inanga and koaro mainly to recreational harvest of whitebait, although some fishers may sell some of their catch. The other native fish species have intrinsic value and provide food for top predators such as eels, trout and birds.

5.2 Trout and salmon support recreational sports fisheries in both the Waiau and Hurunui rivers. In the 2007-2008 National Angler Survey (NAS) the following angler usage estimates (angler days per year) were made for the Waiau and Hurunui Rivers: Waiau 6297 ± 1986 of which 4343 ± 1016 were on the Waiau mainstem; Hurunui 12598 ± 2480, of which 4401 ± 802 were above Mandamus.

5.3 A rule of thumb used for ranking the importance of rivers based on NAS angling usage alone is that rivers with 10,000 or more angler days per year are potentially nationally important. This was used by the Ministry for the Environment in its analysis of national significance for freshwaters (MFE 2004). On this basis the above angler usage estimates suggest that the Hurunui salmonid fishery is potentially nationally important and the Waiau fishery regionally important. Features other than angling usage alone are also taken into account when considering importance of fisheries. Teirney *et al*. (1982) considered that the upper Hurunui trout fishery (above Mandamus) was a nationally important back country fishery on the basis of its remoteness, high scores for scenic beauty, and comparatively high angling usage for a backcountry fishery (approximately 5000 visits annually).

5.4 Regionally significant salmon fisheries are characterised by annual spawning runs which generally number a few thousands but rarely if ever exceed ten thousand; angling effort is usually between two and 10,000 angler-days per year; and are mostly fished by anglers travelling within their home Fish and Game region (Unwin 2006). The Hurunui salmon fishery has been ranked as regionally important (Teirney *et al*. 1982; Teirney *et al*. 1987; Bonnett *et al*. 1991).

5.5 Mr Greenaway undertook a recreational use study of the Waiau River over the 2011 – 2012 spring – summer. He concluded that the Waiau salmon fishery in total was of regional importance, and in the Amuri Plains segment of the Waiau River it is of local importance (see Mr Greenaway's evidence).

5.6 The Hurunui River has a modest salmon run estimated by North Canterbury Fish and Game at between about 100 and 5000 fish. This places it 5th in terms of run size of the known 24 salmon fisheries in New Zealand (North Canterbury Fish & Game 2010). The annual counts for the Hurunui between 2001 and 2009 (when the fishery was in a low phase) ranged from 20 to 151 fish, with a mean of 96 fish (North Canterbury Fish & Game 2010). Fish and Game's estimates of harvest (between 1995 and 2009) suggest that the catch is relatively high in relation to the numbers of spawning fish (range 15-826 fish, mean = 357).

5.7 The Waiau River salmon run is smaller than the Hurunui's. The Waiau has the eighth best salmon run of the South Island salmon rivers; the average run is about 600 fish per year and the catch is about 200 fish per year (Fish & Game 2010; North Canterbury Fish & Game (2010). Salmon counts have been made by aerial survey since 1995 (North Canterbury Fish & Game 2010). These counts were one day snapshots of the spawning population, not total spawning population counts, so they provide only an indication of the spawning population trend. The annual counts for the Waiau between 1995 and 2010 were variable and modest (range 66-614 fish, mean = 233). Fish and Game's estimates of harvest were also highly variable and modest over the same period (range 0-496 fish, mean = 108). Salmon counts and harvest estimates in the four major Canterbury salmon rivers (Waimakariri, Rakaia, Rangitata and Waitaki) can be 10 or more times the estimates for the Waiau River.

6. FISH MIGRATIONS

6.1 As already mentioned, a high proportion of the New Zealand freshwater fish fauna is sea-migratory. Allibone *et al*. (2010) list 51 native freshwater fish species now recognised in New Zealand of which 19 (37%) are sea-migratory. Most of the migratory native species spawn in freshwater or tidal reaches, their larvae are swept out to sea where they grow for a few months before returning to freshwater as juveniles and grow into adults. Examples include: whitebait species (*e.g*. inanga and koaro), some bullies (*e.g*., common bully) and torrentfish. Eels have a different life history. They spawn in the ocean (in the tropics) and return to freshwater as juveniles (glass eels then elvers) where they grow into adults. Sea-migratory salmon and brown trout, are different again; they spawn in freshwater and their juveniles rear there for a few months, or in the case of brown trout even years, and then all salmon and some trout migrate to the ocean where they grow to maturity and then return to freshwater.

6.2 An understanding of life history migration patterns is important for allowing for fish passage, and screening to mitigate entrainment of fish when flow is abstracted or diverted. Table 2 shows the periods of the year when the different life stages of various fish species are migrating in the Waiau and Hurunui rivers. The critical months for upstream migrating juveniles of most native fish species are August to April but torrentfish also migrate over the winter months (Table 2). When all species are included, juvenile fish may be migrating during all months of the year. Larvae of most native fishes disperse downstream from September to July, but juvenile lamprey can be moving downstream in any month of year (Table 2). Mature eels move downstream in February to May. The critical months for upstream migrating adult salmonids are January to June and for downstream migrating juveniles are September to January (Table 2). Juvenile brown trout can also exhibit a pulse of downstream movement in April and May.

6.3 Increasing flows (*e.g.*, floods & freshes) are an almost universal factor in promoting fish movement. High flows stimulate upstream migration (*e.g.*, of whitebait, salmon and trout), for reasons such as attractant flows cuing migration through the river mouth, and provision of passage depths upstream. Mature eels migrate downstream on floods – probably to ensure adequate passage depths and easy, fast travel. However, it is less likely that mid range flow variability is critical for migration, especially where flows are altered over a segment of a river rather than affecting the river down to the river mouth, providing passage depths are maintained. Native fish and trout occur in a wide range of rivers and streams differing greatly in flow variability so it is unlikely that they are finely attuned to subtle flow variation.

6.4 Snelder *et al*. (2011) reviewed the migratory life histories of fish in the Waiau River and commented on the potential influence of mid range flows on migration. They were not able to prescribe mid-range flows that will achieve set outcomes for the fish populations because there is insufficient understanding of the threshold levels to trigger migrations and stop them.

6.5 Provision of passage depth is a key issue when considering flow variation for river segments. Salmon, being the largest, deepest bodied species, have the highest passage depth requirement of all the fish species in the Waiau and Hurunui rivers. Because adult salmon do not feed on their upstream spawning migration they rely entirely on their energy reserves built up in the ocean. Impediments to migration such as swift water, and shallow reaches that may delay upstream passage deplete their energy reserves so they have less energy for spawning. This is especially so when the water is warm because energy costs increase exponentially with increasing temperature.

6.6 In braided rivers of the East Coast of the South Island, salmon spawn mainly in cool, usually spring-fed, tributaries in the headwaters. In the Waiau catchment most salmon spawning occurs in the upper Waiau

River. In the Hurunui River most salmon spawning occurs in the South Branch and upper North Branch (Unwin 2006; North Canterbury Fish & Game 2010).

6.7 Brown trout have variable migratory life history patterns. Some fish can be largely stream resident, undergoing only small movements, while in other rivers, especially those with large catchments, trout may move extensively with some migrating to the ocean at various ages and for varying lengths of time. Life-history movement patterns can be driven by feeding opportunities. River trout feed predominantly on aquatic invertebrates, because these are usually the most available prey, but they can grow three times faster feeding on fish prey and small forage fish are most abundant in the lower reaches of rivers and in the ocean.

6.8 The upper Waiau catchment has a reputation for high quality fishing for large trout (North Canterbury Fish & Game 2010). It is possible that at least some of these large trout have moved from the headwaters to the lower river over their lifetime where they ought to benefit from the growth advantage offered by warmer waters, and greater abundance of small fish prey, in the lower river and ocean than in the cold headwaters.

6.9 Waiau headwater trout may supplement their diet with juvenile salmon. However, it is unlikely that this potential seasonal feeding opportunity encourages residency by all of the trout in the headwaters. As found in other rivers a substantial proportion of the brown trout population in the Waiau catchment can be expected to move extensively within the river system.

6.10 The same applies to the Hurunui River, although the moderating influence of Lake Sumner on water temperature potentially supports residency by trout in the North Branch. This was a conclusion of a study that I carried out on the scope for trout growth over longitudinal water temperature gradients in the Hurunui River, later augmented by more research by Dr Young (Cawthron Institute) and an otolith microchemistry study (Hayes & Quarterman 2003; Bickel & Olley 2009; all summarised in North Canterbury Fish & Game (2010)).

6.11 Accordingly provision of adequate depths for upstream passage for adult trout, at least during the spawning run (March – June (Table 2)) is important, as is mitigating entrainment of juveniles moving downstream (September – January and possibly also April – May).

6.12 Adult brown trout have the second highest depth passage requirement to salmon, so their requirements will be met by provision of passage for adult salmon.

6.13 Of the native fish that are recorded from the Waiau and Hurunui rivers, all but adult eels are small bodied and can migrate through very shallow water. Provision of salmon passage would also accommodate passage for large adult eels.

7. FISH DIVERSITY AND DENSITY IN THE AMURI PLAINS SEGMENT OF THE WAIAU RIVER

Methods

7.1 Cawthron staff undertook periphyton, macroinvertebrate and fish electrofishing surveys in late January - early February 2012 to augment the sparse existing information for the Amuri Plains segment of the Waiau River aimed at better informing Meridian's AEE of the proposed AHP. The surveys were undertaken on one reach in the Amuri Plains segment and a comparative ('control') reach in the Hanmer Plains segment. The location of the reaches is shown in Figure 2. Both survey reaches (and segments) were braided. Details on sampling are provided in Appendix 2.

7.2 The flow regime prior to our surveys was very unstable (Figure 4). There were four freshes/floods with a maximum daily flow greater than 200 m^3/s in the three months preceding sampling, the second of which (in late November) was 1256 m^3/s, and the last (over 300 m^3/s) occurred just nine days prior to sampling. A FRE3 (3 x median) flood for the Waiau is 219 m^3/s and is predicted to have surface and deep flushed 70% and 55% of the natural median flow (73.5 m^3/s) channel, respectively (Olsen et al. 2011 – citing Duncan & Bind 2009). The late November flood is predicted to have surface and deep flushed about 88% and 82% of the median flow channel.

7.3 The frequency of freshes/floods > 200 m^3/s over the three months prior to sampling is typical of an average year in the Waiau over the same period (Olsen *et al*. 2011, Appendix 4). However, the magnitude of the November flood may tip the November 2011 – February 2012 flow record in Figure 4 toward a wet year.

Diversity

7.4 The electrofishing survey confirmed seven fish species in the Amuri Plains segment of the Waiau River and the same seven species were present in the Hanmer Plains segment. The introduced species were juvenile brown trout and chinook salmon (adults are also present). The native species were: upland bully and Canterbury galaxias, which are non-migratory, and longfin eel, torrentfish and koaro, which are migratory.

7.5 The koaro were juveniles, probably moving up through the survey reaches on their way from the ocean to adult habitat in headwater tributaries. Similarly, juveniles of longfin eel, another migratory species which penetrates to high altitudes and far inland (even more so than koaro), were frequently caught in both the Amuri and Hanmer survey reaches. Adult longfin eel will also be present in both reaches associated with instream cover in the form of tree debris and rock rip-rap flood protection works. Elsewhere the substrate is too fine and embedded to provided sufficient cover for large eels.

7.6 As expected Canterbury galaxias and upland bully were frequently caught, consistent with them being widely distributed in the Waiau River, including the Amuri and Hanmer plains segments. Canterbury galaxias is widespread and common in eastern- and northern-draining rivers in the South Island north of Waitaki River. Upland bully is even more widespread and common in the South Island.

7.7 A similar number of fish species was found in the Amuri Plains segment of the Waiau as has been recorded from surveys of inland reaches in other South Island braided rivers (7 versus 5-8) (Table 3). Of the rivers listed in Table 3 the Hurunui is the most comparable with the Waiau (at Amuri and Hanmer Plains) in terms of proximity and distance inland of the sampling sites. The Hurunui was sampled immediately upstream of the SH7 bridge. The same seven species were recorded from this location (by Glova *et al*. 1985) as Cawthron recorded in the Amuri and Hanmer Plains reaches in the Waiau River.

7.8 As already mentioned, fish diversity is influenced by the distance from the ocean and altitude owing to the large proportion of sea-migratory species in the fauna. The Waiau sampling reaches were approximately 64 km (Amuri reach) and 87 km (Hanmer reach) from the ocean. The weakest swimming migratory species (*e.g.*, inanga and smelt) will not be able to penetrate that far upstream, and those with moderate swimming ability may be present only in low abundance (Figure 1). Snelder *et al*. (2011) thought that bluegill and common bully might penetrate 70 km and 80 km up the Waiau River, respectively, but neither of these species were recorded in our survey.

7.9 Species richness, which is a measure of diversity, was similar between the Amuri and Hanmer survey reaches, and also between the channel and mesohabitat types.

Density

7.10 Fish densities in the Waiau River are compared with densities recorded from other South Island east coast rivers in Table 3. For the comparison fish density from the Amuri and Hanmer Plains reaches was averaged since total fish density did not differ significantly between the two reaches. Because sampling methodology and meso-habitat type can influence density estimates, the comparative data presented in Table 3 was confined to electrofishing data obtained from only riffles, although fish density and diversity in riffles and runs in the Waiau River was not significantly different.

7.11 Fish density in the Waiau was at the bottom end of the range recorded for the braided rivers (Table 3). Fish density in the Hurunui was second highest in the range. These results are consistent with relative flow and bed stability between the rivers and the distance inland of the sampling locations. Of the rivers listed in Table 3, fish densities were highest in the Ashley River, which has the lowest flows and lowest frequency of flooding. The flow regime in the Hurunui River is partly stabilised by the lakes in the catchment of the North Branch. The second lowest fish densities were recorded in the Rakaia River which has the most variable flow regime. These results are consistent with flood disturbance suppressing fish densities, and that over a flow/sediment stability gradient for South Island braided rivers the Waiau River's flow regime is amongst the most unstable.

7.12 In braided rivers, higher fish diversity and density has been reported in seepage and minor channels than in major channels (Jellyman *et al*. 2003). Our fish density, but not diversity, data from the Amuri reach were consistent with this pattern (Figure 5) and was mostly due to upland bully and Canterbury galaxias preferring minor and seepage channels (Figure 6).

7.13 Highest fish densities were recorded from seepage channels in both Amuri and Hanmer reaches, but densities were highly variable. Clearly not all seepage channels, or meso-habitats within them, are created equal. Fish diversity and density at any location will be a legacy of flood disturbance and connectivity with other channels. Diversity and density is highest in seepage channels because they receive the least flood disturbance. Intermittent connections with the larger channels may contribute to the variation in density. Most of the available habitat, mainly shallow runs, in the seepage channels was silted owing to low water velocities associated with the small channel discharges. Silt is detrimental to the habitat of most fishes and macroinvertebrate EPT[1] taxa. Only the riffles and faster portions of the runs in seepage channels had clean substrate and these were the habitats that supported the highest fish densities and diversity.

7.14 While the differences found in fish density between small and large channels in the Amuri survey reach, whether density (and diversity) is higher in seepage and minor channels than in the larger channels in the wider Amuri river segment is not proven by our data. The sampling design did not include replication at the channel level and reach level within the two river segments (Amuri and Hanmer plains). The inference domain of the data is thus limited to the channels that were sampled in the two reaches, (Amuri and Hanmer sampling reach). That is, because of the lack of channel type and reach replication statistical inferences cannot be made that apply to the entire Amuri and Hanmer plains braided segments. Braided rivers are highly variable habitats for fish and macroinvertebrates and in order to demonstrate patterns at the river, or river segment level, with statistical confidence a very large sampling effort is required.

7.15 There is support from other studies that have found higher fish diversity and density in seepage and minor channels than major channels of South Island braided rivers (e.g. Jellyman *et al*. 2003). This matter is relevant to flow alteration because flow reduction could redistribute available suitable habitat. Fish (and macroinvertebrate) habitat in seepage and minor channels will decrease with flow reduction but this might be compensated by more habitat becoming available in the larger channels with reduction in water velocity. On the other hand, the substrate in the major channels will continue to be unstable because most of the bedload is transported down major channels. So habitat quality, in terms of stability, may not be

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[1] EPT refers to Ephemeroptera (may flies), Plecoptera (stoneflies) and Trichoptera (caddis flies) which are aquatic invertebrate orders. They comprise the prey items preferred by fish and river birds.

equivalent in major and minor/seepage channels. Furthermore, just how minor and seepage channels will respond to flow reduction is difficult to predict. The apportioning of flows down minor channels is dependent on the height of the hydraulic controls, and, during floods, also on their degree of armouring. The flow in seepage channels is also dependent on variation in the porosity of the riverbed and the groundwater level. Hence, the response of water level and flow in seepage channels to flow in the mainstem will vary between channels.

7.16 Another relevant point not yet addressed by research is whether the lower densities observed in major channels is offset by the large area of available habitat in those channels and results in greater total numbers of fish than in seepage and minor channels, which have higher densities but lower total area. Intuitively though, it does make sense that seepage and minor channels should be important as refuges from at least moderate floods and therefore sources of colonists too. Knowledge of the relative areas of channel types and their substrate stability history (in relation to floods) would be required to better inform these issues.

7.17 The points raised in the above paragraphs are relevant for appreciating uncertainties in effects assessment of flow alteration in braided rivers, particularly in relation to interpreting hydraulic-habitat model predictions. Applications of these models traditionally involve averaging predictions of habitat availability over all channel- and meso-habitat types, as was done by Mr Jowett in his habitat modelling on the Amuri reach of the Waiau River.

8. VERIFICATION OF FISH HABITAT SUITABILITY CRITERIA

8.1 During the 2012 summer fish survey of the Waiau River water depths and velocities where fish were sampled were measured. This enabled me to verify the habitat suitability curves used by Mr Jowett for habitat modelling. Such verification provides more confidence in habitat modelling results than assuming the habitat suitability curves available from other rivers apply to the Waiau River.

8.2 The sampling largely covered the full range of suitable water depths and velocities for most of the species/lifestages of fish captured. This included mean water depths (in lanes) up to 0.7 m and velocities up to of 1.3 m/s. In intermediate and major channels fish were mainly confined to near the margins because it is too fast for them in mid channel. Fish density was highest in minor and seepage channels (in the Amuri reach), with fish distributed across the entire channel width, even in the fastest riffle habitats.

8.3 The depth and velocity use distributions of most of the fish species found in the Waiau River survey reaches matched fairly well with the published habitat suitability curves, allowing for the sparse data from the Waiau River (Figure 7). Canterbury galaxias and upland bully were exceptions, favouring slower water than predicted by Jowett & Richardson's (2008) habitat suitability curves. This was probably because most were caught in seepage and minor channels, which are slower flowing than larger channels.

8.4 The consequences of the apparent differences between habitat used by Canterbury galaxias and upland bully for habitat modelling predictions are that the Jowett & Richardson suitability curves, when used in habitat modelling, will overestimate the flow requirements of these species in the Waiau River (*i.e.*, environmental flow predictions based on them will be environmentally conservative). Taking this into consideration, and the better matches for the other species, Jowett & Richardson's (2008) habitat suitability criteria are appropriate for habitat modelling the range of species that were recorded in the Amuri Plains segment of the Waiau River.

9. EFFECTS OF PROPOSED FLOW ALTERATION ON FISH IN THE AMURI PLAINS SEGMENT OF THE WAIAU RIVER

9.1 Mr Jowett has undertaken one dimensional (1D) habitat modelling on the Amuri Plains segment of the Waiau River, superseding the 2D habitat modelling undertaken by Duncan and Bind (2009) for the low to median flow range. Mr Jowett's model was applied to flows in the range 10 - 60 m^3/s whereas Duncan and Bind's model was applied to the range 10 – 100 m^3/s. I base my instream habitat effects assessment on Mr Jowett's modelling. My assessment complements his. I provide some additional information on the ecological rationale underpinning effects assessment on fish using habitat modelling and discuss uncertainties.

Concepts underpinning assessment of effects of flow alteration on fish

Ecologically relevant features of the hydrograph

9.2 Assessment of the effects of flow alteration on fish needs to be placed in the contexts of the ecologically relevant features of the hydrograph and space, food and passage requirements of fish.

9.3 The Ministry for the Environment's (MfE) Flow Guidelines state that there are two critical aspects of a flow regime for sustaining the instream values of river ecosystems. These are: 1) a minimum flow to fulfil minimum water quality and habitat requirements, and 2) flow variability.

9.4 These guidelines are based on the concept of environmental flow regimes rather than just a minimum flow regime. Environmental flow regimes include the key minimum flow and flow variability features that maintain a river's physical and natural character, structure and function of its ecosystem and dependent values.

9.5 The minimum flow is intended to provide minimum life supporting conditions for instream values (*e.g.*, fish and invertebrates) such as they would usually experience during natural low flows. The mean annual low flow is a relevant reference flow for assessing minimum flow options.

9.6 Flow variability is at least as important as the minimum flow because this influences habitat availability, water quality and flushing above that minimum. Setting a minimum flow with insufficient provision for flow variability risks the river being held at the minimum flow for long periods of time with potential adverse effects on habitat and water quality, periphyton proliferation, competition, and predation risk for fish.

9.7 Floods and freshes are necessary to maintain the channel form and for flushing fine sediment and periphyton, while mid-range flows may contribute to invertebrate productivity, fish and bird feeding opportunities and fishing opportunities.

9.8 I understand that the policy framework in the Proposed Plan promotes retention of flow variability.

Space and food

9.9 Space refers to habitat for fish to feed and hide from predators. Hiding habitat is often referred to as cover. In braided rivers hiding habitat for small fish is provided mainly by spaces in the substrate, instream debris, and deep water with turbulent surface. The relative importance of these types of hiding habitat depends on the species and size of fish. The main hiding habitats for larger fish (*e.g.*, eels, trout and adult salmon) are deep water with a turbulent surface, instream debris, and big boulders (including rock rip-rap bank protection works). Species such as bullies, torrentfish and Canterbury galaxias forage on benthic invertebrates directly off the substrate – so their feeding habitat may be similar, and in close proximity, to their hiding habitat. Canterbury galaxias may also drift feed, which is the predominant feeding behaviour of trout and juvenile salmon in most rivers. Drift-feeding refers to fish feeding in the water column, usually from a focal point, on invertebrates drifting past.

9.10 Cover provided by substrate and instream debris is usually insensitive to flow change unless it is mostly distributed along channel margins and flow reduction results in it being dewatered. This is unlikely in braided rivers, which provide little bank cover (*e.g.*, overhanging banks and vegetation). Hence habitat modelling focuses on feeding habitat. The habitat suitability curves used by Mr Jowett for benthic fishes (*e.g.*, bullies, torrentfish, Canterbury galaxias) describe a mix of feeding habitat and hiding habitat because the data were obtained by electrofishing over lanes, with a lane consisting of several metres of similar depth and velocity. The fish caught in these lanes would have been both hiding in the substrate and feeding on benthic invertebrates in the vicinity of their hiding refuges. The habitat suitability curves for juvenile salmonids were also based on fish caught by electrofishing, but these fish would have been foraging in the water column – on invertebrate drift, but also probably close to cover, such as instream debris or coarse substrate. The habitat suitability curves for adult trout were based on depth and velocity selection by individual drift feeding fish, so these describe only feeding habitat.

9.11 All fish in inland parts of braided rivers feed mainly on aquatic invertebrates, with some supplementing their diet with terrestrial invertebrates, and large fish such as adult trout and eels also eating small fish. The effects of flow alteration on invertebrate food for fish are usually assessed by examining the relationship between benthic invertebrate habitat and flow predicted by hydraulic-habitat modelling.

Assessing space and food habitat with respect to ecologically relevant flow statistics

9.12 Habitat modelling produces continuous relationships between flow and fish or invertebrate habitat. In order to compare the flow regimes in terms of how well they maintain habitat it is helpful to interpret the habitat – flow relationships with respect to ecologically relevant flow statistics. Habitat levels maintained at the ecological flow statistic are compared between alternative flow regimes.

9.13 The mean annual low flow (MALF) is ecologically relevant for annual spawning fish because it defines the minimum living space (habitat) available each year. Mr Jowett has previously found that trout abundance in New Zealand rivers was correlated with the quality of adult trout habitat (indexed by adult trout combined habitat suitability index (CSI or HSI)) at the mean annual low flow (MALF) (Jowett 1992). He also found that the quality of benthic invertebrate habitat (indexed by "food producing" CSI) at the median flow, was strongly correlated with trout abundance. The correlation was even stronger with aquatic invertebrate biomass, highlighting the importance of the food resource in influencing trout numbers.

9.14 The MALF is also relevant to native fish species with generation cycles longer than one year, at least in small rivers where the amount of suitable habitat declines at flows less than MALF. Research in the small, braided Waipara River[2], where native fish habitat is limited at low flow, showed that the detrimental effect on fish abundance increased with the magnitude and duration of low flow (Jowett *et al*. 2005; Jowett *et al*. 2008). Research on the small Onekaka River[3] in Golden Bay also showed that, when habitat availability was reduced by flow reduction, abundance of native fish species responded in accord with predicted changes in habitat availability in both direction and magnitude (Jowett *et al*. 2008). However, densities of fish in the Waipara and Onekaka rivers are much higher than in the Waiau River. Fish are unlikely to be space limited in the latter because densities are low.

9.15 Aquatic invertebrates have much faster colonisation times than annual spawning, and multi-aged fishes. Denuded habitat is quickly recolonised by invertebrates drifting from refugia and by winged adults

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[2] The Waipara River has a median flow of 900 l/s

[3] The Onekaka River has a median flow of 218 l/s

laying eggs, and some taxa have more than one generation per year. Benthic invertebrate communities have been found to recolonise river braids within about 30 days after drying – probably mainly by drift of colonists from permanently flowing braids upstream. Recovery may take longer after big floods.

9.16 The median flow is considered an ecologically relevant flow statistic for referencing benthic invertebrate habitat because this represents typical flow conditions (Jowett *et al*. 2008). Unlike the mean flow the median flow is not strongly influenced by floods. The habitat on the margins inundated by flows higher than the median flow does not remain wet for long enough to contribute significantly to benthic production, particularly in braided rivers. Because of their faster rate of recovery from flow disturbance, invertebrate populations will respond to typical flow conditions whereas most fish populations will be influenced by annual limiting flow conditions.

9.17 Provision for seasonal flow variation may also allow for seasonally varying food requirements of fish and birds and nesting requirements of the latter. Fish have higher food requirements in summer because their metabolic and consumption rates are higher at warmer water temperatures. If space and or food is limiting, then flows higher than the MALF ought to give some respite from limiting conditions, especially feeding conditions, at the MALF. This is the rationale for also assessing fish habitat, but particularly benthic invertebrate habitat with respect to monthly flow statistics. Sometimes monthly median flows are used, or in the case of Mr Jowett's habitat modelling on the Waiau, also the 90th and 10th percentile flows for the month. However, as already noted fish are unlikely to be space limited in the Amuri Plains segment of the Waiau River because densities are low.

Habitat retention levels

9.18 The effects of a proposed flow regime are assessed by expressing the habitat retained at the ecologically relevant flow statistic as a percentage of that retained at the natural flow.

9.19 Choosing acceptable levels of habitat retention is a value judgment. If a significant instream value is very high then the level of habitat protection ought to be high in order to manage the risk that a reduction in habitat might pose to the maintenance of that value. This approach is consistent with the MfE' Flow Guidelines. Some account should also be given to whether the fish (or invertebrate) populations are likely to be space or food limited.

9.20 If habitat is limiting then a predicted reduction in habitat is assumed to correspond to reduction in abundance. However, this will not be the case if other factors unrelated to flow suppress the population below carrying capacity. This point is relevant to the Waiau River where fish and invertebrate densities have been found to be low, consistent with floods suppressing populations. In this case there is less risk associated with lower levels of habitat retention than with rivers in which fish densities are high. This is particularly so for seasonal habitat retention analysis which for fish is more environmentally conservative than habitat retention at the MALF.

Passage

9.21 In addition to space and food, the dependence of fish passage on flow also needs to be considered. This requires identifying those fish species which have the greatest depth requirements for passage and locations (riffles) where passage will be most critical.

Flow regimes

9.22 Mr Jowett assessed the effects of the modelled proposal with respect to the Status Quo regime and he also provided a comparison with the natural flow regime. My assessment does the same.

9.23 Comparisons of the modelled proposal against the Status Quo assess the incremental effects of the minimum flow and allocation rules in the

Proposed Plan. Comparisons of the modelled proposal against the natural flow regime assess the cumulative effects (*i.e.*, of proposed takes added to all existing takes).

9.24 The flow regimes that I compare are the following modelled and described by Mr Woods:

a. The natural flow (with no consented takes) – recorded at Marble Point.

b. The Status Quo – with the current seasonal minimum flow rules (15 – 25 m^3/s) and current estimated irrigation demand along the Amuri Plains Reach ('A' Block only).

c. The modelled proposal – with full irrigation and hydro-power development. This involves:

   i. the 20 m^3/s minimum flow and 'A' and 'B' Block flow allocation rules, and irrigation demand, in the Proposed Plan, and

   ii. the additional abstraction of up to 50 m^3/s of water for hydro generation taken from the 'C' Block, and from the 'A' & 'B' Blocks when these are not required for irrigation.

9.25 As pointed out by Mr Woods, the modelled proposal is the maximum practical use of the flow and allocation regime in the Proposed Plan along the Amuri reach.

9.26 Mr Woods' modelled proposal complies with the environmental flow and allocation regime in the Proposed Plan except for the 2 m^3/s "gap" between the 'A' and 'B' Blocks in the Plan. In my opinion the 2 m^3/s gap will have no material benefit on fish or benthic invertebrate habitat so its omission from effects assessment for the modelled proposal (and so the AHP) is inconsequential.

9.27 Mr Wood's hydrological modelling predicts that the modelled proposal, along with water abstracted for existing and future irrigation, will substantially alter the natural hydrological regime in the Amuri Plains segment. Up to 29 km of the river will be affected – from near the existing irrigation intake at Mouse Point to just upstream of Sanderson's Road, below Waiau township.

9.28 Compared with the Status Quo the mean annual flow will reduce from 88.9 m^3/s to 55.1 m^3/s. The median flow (66.4 m^3/s) and mean annual 7-day low flow (MALF) (21.5 m^3/s) will both reduce to 20 m^3/s.

9.29 Under the Status Quo, the minimum flow is seasonal, being 15 m^3/s in February and March, 20 m^3/s in January and April, and 25 m^3/s in all other months. The irrigation season typically occurs between September/October and April, which is when the river usually has both its highest (Sept-Oct) and lowest (February- March) natural flows. Under the Proposed Plan the minimum flow will be 20 m^3/s in all months resulting in a higher minimum flow in February and March. However, the minimum flow will occur more frequently and for longer than under the Status Quo. Mr Jowett has estimated that the number of low flow events ≤ 20 m^3/s will increase from 2 to 21 events per year with the modelled proposal and their median duration will increase from 4 to 5 days per year.

9.30 The modelled proposal has little effect on the duration of low flow events because floods are frequent in the Waiau and the hydro-power take will shut off at 210 m^3/s. As Mr Jowett has shown this also retains the main flushing flows. Smaller freshes could also be retained if necessary by allowing these to by-pass any intake.

Habitat – flow relationships

9.31 Mr Jowett has found that the habitat – flow relationships for most native fish and salmonids, and benthic invertebrates in the Amuri Plains segment show a similar pattern, with the amount of habitat increasing with flow up to about 30 m^3/s. Exceptions are torrentfish and juvenile brown trout (< 100 mm). Habitat for torrentfish increases over the entire flow range modelled (10-60 m^3/s) and for juvenile trout it is maximised at 55 m^3/s (see Figures 2 & 3 in Mr Jowett's evidence). Torrentfish are a fast-water species and usually follow this same pattern in habitat modelling applications. The water velocity suitability curve that Mr Jowett used to model juvenile trout habitat also has a relatively high optimum (at 0.6 – 1.0 m/s) (Jowett 2012a Appendix 1). This is higher than other juvenile trout habitat suitability curves that are sometimes used in habitat modelling in New Zealand. Hence they may overestimate the flow requirements of juvenile trout in the Waiau River.

9.32 Habitat for benthic invertebrates is generally more flow sensitive than habitat for fishes as was also the case for the Waiau River. Mr Jowett found that habitat for both *Deleatidium* mayflies and general food producing habitat increases over the flow range modelled, beginning to level out at 60 m^3/s indicating maximum habitat would be attained at about the natural median flow (73.5 m^3/s) (see Figure 4 in Mr Jowett's evidence).

Habitat retention

9.33 Mr Jowett summarised the effects of the modelled proposal with habitat retention analysis referenced to the Status Quo and natural MALFs, and 50th (median), 90th and 10th percentile flows for each month. These percentile flows represent 'typical', dry, and wet months, respectively.

9.34 When habitat retention is based on the MALF the modelled proposal retains similar percentages of fish and invertebrate habitat to the Status Quo because the modelled proposal MALF (20 m^3/s) is very similar to the Status Quo MALF (21.5 m^3/s). The modelled proposal MALF retains on average 98% (94 – 100%) of fish habitat and 97% of habitat for *Deleatidium* and food production relative to the Status Quo MALF.

9.35 The modelled proposal retains about 90% (range 70 – 107%) of the fish habitat available at the natural MALF (31.5 m^3/s) and about 83% of habitat for *Deleatidium* and food production. The biggest reductions in habitat are for torrentfish, because it is a fast-water species, whereas habitat gains are predicted for large longfin eels (> 300 mm) and juvenile salmon (> 55 mm) because they prefer slower, deeper water.

9.36 A high level of adult trout habitat will be retained at both the Status Quo and modelled proposal MALFs (98%). This occurs because the habitat – flow relationship for adult brown trout drift feeding habitat varies little with flow change in the Amuri habitat modelling reach (see Figure 3 in Mr Jowett's evidence). A similar level of juvenile trout habitat is retained relative to the Status Quo (97%) but 14% habitat loss (86% retention) is predicted relative to the natural flow regime (86%).

9.37 The seasonal habitat retention analysis showed that the adverse effects of the Status Quo regime on fish and invertebrate habitat are confined mainly to the summer (January – April) (see Tables 8-16 in Mr Jowett's evidence). The worst effects are in dry years with lesser effects in typical years and none in wet years.

9.38 A comparison of the 'Status Quo' and 'Full irrigation with hydro' columns in Mr Jowett's Tables 8 – 12 provides an overview of the differences in monthly pattern of effects of the modelled proposal. The modelled proposal extends effects, both negative and positive, over most of the year compared with the Status Quo.

9.39 The higher minimum flow in February and March under the modelled proposal mitigates the adverse habitat effects of the Status Quo in February and March in dry years. However, adverse effects are greater in some other months, including in typical years with the modelled proposal.

9.40 Mr Jowett's analysis shows that the greatest differences between habitat provided by the Status Quo and the modelled proposal occur in typical and dry months. Eight of the ten fish species/life stages modelled are predicted to experience neutral habitat effects or net gain in habitat overall in typical years, averaging 115% retention. Six species/life stages are predicted to exhibit a net loss in habitat in dry years averaging 90% retention.

9.41 Monthly habitat retention is greatest for adult longfin eels and salmon > 55 mm (up to 152% and 140%, respectively, in typical years). Habitat retention is lowest for torrentfish (50% in typical years).

9.42 Both the Status Quo and the modelled proposal have a net overall benefit for adult trout drift-feeding habitat especially in spring in dry months, winter - spring in typical months and summer in wet months (see Table 13 in Mr Jowett's evidence).

9.43 Cumulative effects of the modelled proposal on fish are modest and not substantially different to effects relative to the Status Quo. Compared to the natural flow regime seven of the ten fish species/life stages modelled are predicted to experience neutral habitat effects or net gain in habitat over typical years under the modelled proposal, averaging 118% retention. Six species/life stages are predicted to exhibit a net loss in habitat in dry years averaging 85% retention.

9.44 The habitat losses predicted for fish, including torrentfish, under the modelled proposal do not threaten the viability of the species, and they may not result in population decline, because the species occur at low densities in the Amuri Plains segment of the Waiau. That is, habitat is unlikely to be limiting the population.

9.45 The modelled proposal has greater effects on benthic invertebrate habitat than on fish habitat. Relative to the Status Quo monthly habitat losses are predicted for *Deleatidium* and food producing habitat in all months and years except for February and March in dry years (see Tables 6 & 7 in Mr Jowett's evidence). Predicted average habitat loss across all dry and typical months is 17% (*i.e.*, 83% habitat retention). Average cumulative habitat loss (*i.e.*, modelled proposal relative to the natural flow regime) is 21% (*i.e.*, 79% retention).

9.46 The monthly habitat retention analysis for benthic invertebrates based on flow percentiles does not account for the effects of preceding floods and periodic drying disturbance on benthic invertebrates. BITHABSIM, a model that I devised and co-developed with Dr Olsen and others, accounts for these processes in assessing effects of flow alteration on benthic invertebrates (Olsen *et al*. 2011). Dr Olsen presents the results of a BITHABSIM analysis on *Deleatidium* in the Amuri habitat modelling reach (see Tables 15 and 16 of Dr Olsen's evidence).

9.47 Relative to the Status Quo, average habitat loss predicted by BITHABSIM across all months in dry, typical and wet years is 9%, 19% and 16%, respectively. Average cumulative habitat loss (*i.e.*, AHP relative to the natural flow regime) in dry, typical and wet years is 11%, 25% and 22%, respectively. Average habitat retention across all dry and typical months for the modelled proposal referenced to the Status Quo is 86%, and referenced to the natural flow regime is 82%, respectively, slightly higher than for the seasonal habitat analysis based on flow percentiles.

9.48 Flood disturbance in the Waiau River suppresses invertebrate food resources for fish and the above invertebrate habitat losses will reduce them further. This may reduce growth and abundance of trout and juvenile salmon that rely on drift feeding. It is less likely to adversely affect benthic feeding native fish species because they crop benthic invertebrates from the bottom close to where they live, and they occur at low densities. Drift feeding fish crop drifting invertebrates recruited from larger areas upstream of their feeding positions. Hence, although trout and juvenile salmon also occur at low densities in the Waiau, they ought to be more sensitive to contraction of the food producing area, especially given that invertebrate densities are also low.

9.49 This point emphasises the relevance of assessing the effects of flow alteration on benthic invertebrate habitat since it is critically important to fish – particularly to drift feeding trout and juvenile salmon. In the Amuri segment of the Waiau, the effects of flow alteration on benthic invertebrate habitat are more important than the effects on fish habitat, especially since habitat probably is not limiting fish populations.

Trout abundance modelling

9.50 Mr Jowett developed a model of the relationship between trout and invertebrate habitat quality and trout abundance (Jowett 1992). The model predicts adult brown trout abundance, based on empirical relationships between physical and catchment variables and trout abundance at 59 sites in clear-water rivers in New Zealand. The flow related habitat variables included in the model are: the quality of trout habitat (CSI) at the MALF and quality of invertebrate food producing habitat at the median flow. Trout abundance can be predicted for an altered flow regime and expressed as percent change from that predicted for the status quo or natural flow regimes.

9.51 The model predicts that the Status Quo and natural flow regimes would support 20.8[4] trout/km in the Amuri Plains segment of the Waiau River. Twenty percent fewer trout (16.3[5] trout/km) are predicted for the modelled proposal (the AHP flow regime). However, the model predictions are subject to a high level of uncertainty. Predicted abundance (16.3 and 20.8 trout/km) could differ from actual abundance by up to 1.9 times higher and 0.3 times lower. (Figure 8). This range of uncertainty, which is measure of the natural variability in trout abundance, is greater than the difference in predicted mean abundance between the two flow regimes.

9.52 The implications of flow alteration under the modelled proposal for trout and salmon abundance and growth are uncertain. This is because there is insufficient understanding of the relationships between fish populations and their food and space resources, particularly in braided rivers. This is discussed further in Appendix 4.

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[4] Corresponding to 2.0 and 1.8 trout/hectare for the status quo and naturalised flow regimes, respectively.

[5] Corresponding to 1.6 trout/hectare

Flows for maintaining fish passage

9.53 I said earlier that salmon are the critical species for defining minimum passage flow. Mr Jowett determined adult salmon upstream passage flow requirements on a critical, shallow riffle in the Amuri Plains hydraulic-habitat modelling reach. The salmon passage criteria he used were a minimum of 3 m wetted width with a depth ≥ 0.24 m and velocity < 2 m/s. I agree that these criteria are appropriate. Salmon can negotiate shallower water, as they do in the shallow, headwater spawning tributaries but over relatively short riffles.

9.54 Mr Jowett concluded that a flow of 20 m^3/s would allow salmon passage at the critical riffle and that 16 m^3/s would be an impediment to passage.

9.55 The natural frequency of floods > 210 m^3/s will be retained under the proposed AHP so salmon will continue to benefit from freshes that stimulate, and facilitate, upstream migration. However, the truncation of flow recessions by the AHP take will mean that migrating salmon will face shallow water more often in the Amuri segment. The more shallow water that salmon encounter on their upstream migration, the greater will be the difficulty of passage and associated energy expenditure and risk of injury and infection (from abrasion).

Salmon angling lies

9.56 Mr Jowett modelled the relationship between salmon angling lies (analogous to angling 'habitat') and flow for the Amuri Plains segment of the Waiau River. I agree with his use of salmon angling suitability curves developed on the Waimakariri River for this analysis because of the similar geomorphology and flow regimes of the two rivers. I assisted the North Canterbury Fish and Game Council in developing these suitability curves. The curves were based on depth and water velocities collected from locations where experienced salmon anglers considered salmon would lie and likely to be caught.

9.57 Mr Jowett found that salmon angling lies increased with flow over the modelled flow range (see Figure 3 in Mr Jowett's evidence). This pattern of response is expected for shallow, moderate-sized braided salmon rivers since salmon like deep, slower flowing water in which to rest and anglers prefer to fish such water. Deep, slower flowing water is uncommon in braided sections of braided rivers.

9.58 The higher minimum flow with the modelled proposal will retain more salmon habitat (by up to 151%) in the key months of February and March than the Status Quo during low flow conditions.

9.59 However, salmon fishing is generally poor at low flows owing to the water being too clear and often too warm. Best salmon angling occurs on flow recessions following floods when the water is slightly discoloured. A water clarity rule of thumb is that conditions are best when anglers can barely see their feet in knee deep water. The monthly habitat retention analysis is therefore more appropriate for assessing effects on salmon angling habitat. Relevant months are January – April when anglers fish for salmon.

9.60 Relative to both the Status Quo and naturalised flow regimes the modelled proposal has greatest adverse effect on salmon angling lies in typical flow months (average retention 37% and 46%, respectively) (see Table 17 in Mr Jowett's evidence). Under the modelled proposal salmon angling lies are predicted to increase relative to the Status Quo (average retention 119%) but decrease relative to the natural flow (average retention 52%). In wet years average habitat retention relative to both the Status Quo and natural flow regimes is 83%.

9.61 The modelled proposal will reduce the duration of ideal salmon angling conditions following floods because it will truncate flow recessions. This will add to the effect of reduction in salmon angling lies. The significance of this cumulative effect on salmon angling depends on angling usage in the Amuri Plains segment. In that regard Mr Greenaway has found that angling use in the Amuri Plains segment, mainly by local anglers, is low and concentrated at the Twin Bridges (above the proposed hydro-diversion intake) and Waiau township bridge. Concentrations of angling effort at these locations probably are related to ease of access. The angling lies in between these locations probably are under utilised. Hence a reduction in number and area of salmon angling lies probably will not adversely affect angling opportunities at current usage levels.

9.62 The main effect of the modelled proposal on salmon angling opportunities will be the reduction in duration of ideal fishing conditions during flood recessions. Water clarity is unlikely to be significantly reduced by the flow diversion given that the affected segment is only 29 km, and this is a primary factor in determining salmon angling success. Flow and water temperature are co-correlates that may also influence angling success. Water temperature will not change appreciably under the modelled proposal (see Water Quality section below). Elevated flow may influence salmon angling success by encouraging greater migratory activity in salmon. Anglers have identified preferred flow ranges for salmon angling on other rivers (*e.g.*, Rakaia, Rangitata and Waimakariri) and this information has influenced flow decisions and resource consent decisions. However, the relative importance of water clarity, flow and temperature, and interactions between these variables, in influencing salmon angling success is still not adequately understood.

9.63 Provision of prime salmon angling opportunities offered by flow recessions can, if appropriate, be pragmatically accommodated in resource consent conditions that stipulate that following floods, say greater than the FRE3, large-scale diversion or abstraction must be delayed for up to 12 hours per day over a specified period (*e.g.*, 2 days) such that natural flows are maintained during daylight hours when the water clears sufficiently for salmon angling (> 0.4 m black disc). Resource consents for Central Plains Water irrigation takes are subject to such a condition.

Water quality

9.64 Chemical water quality will be generally high in the Amuri segment of the Waiau River under the Status Quo flow regime owing to the low percentage of the catchment intensively farmed. Chemical water quality (including dissolved oxygen) will continue to fall well within the tolerance ranges of fish under the AHP flow regime.

9.65 Water temperature is the water quality parameter of most interest in respect of fish. Trout and salmon have lower temperature tolerances and preferences than all native fishes that have been studied.

9.66 The upper incipient[6] lethal temperature for brown trout is about 25 ^{o}C (Elliott 1994). The optimal temperature for growth of brown trout fed on an invertebrate diet is 14°C while this increases to 17°C in trout fed on a fish diet. Brown trout may stop feeding and stop growing when temperature rises above 19 ^{o}C.

9.67 The upper incipient lethal temperature for chinook salmon is also about 25 ^{o}C.

9.68 Temperatures exceeding 21^{o}C block upstream migration of adult salmon (McCullough 1999), because this places too great a metabolic demand on the fish for them to have any energy available for migration. Temperatures > 15.5 ^{o}C greatly increase the incidence of disease and mortality. Temperatures greater than only 12.8 ^{o}C have resulted in increased mortality in female salmon prior to spawning in North America (Raleigh *et al*. 1986).

9.69 Adult salmon need access to deep, slow water holding areas with low temperatures to reduce metabolic demand and pre-spawning mortality. When females are in holding pools and their eggs are nearing maturation, they need temperatures below 16 ^{o}C for their eggs

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[6] The incipient lethal temperature is usually defined as the temperature at which 50% mortality occurs in experiments conducted over a set period of time.

to successfully mature prior to spawning. Temperatures < 12.8 ^{o}C, and declining, provide best spawning conditions.

9.70 Optimum growth of juvenile chinook salmon occurs between 10 and 15.6 ^{o}C. Growth declines to zero at about 21 ^{o}C, but considering increasing mortality rate with temperature, zero net growth of populations occurs at 19 ^{o}C. The physiological transition of juvenile salmon into migrant smolts, and their downstream migration, proceeds best at temperatures < 12.2 ^{o}C and can be inhibited by temperatures exceeding 18.3 ^{o}C.

9.71 Following from the above points there are energetic imperatives for salmon to reach the cold headwaters before their energy reserves are drawn too low for successful spawning and before their eggs are vulnerable to the higher temperatures encountered lower down the river.

9.72 Mr Jowett has modelled the effect of flow regime change on water temperature in the Amuri Plains segment of the Waiau River – from Leslie Hills Bridge to Sanderson's Road (Jowett 2012b). The model predicted that the modelled proposal will increase daily mean water temperatures at Sanderson's Road by about 1 ^{o}C relative to the Status Quo flow regime.

9.73 Maximum daily mean water temperatures at Waiau Bridge and Sanderson's Road over the period September 2011 to April 2012 were 19 – 20 ^{o}C under the Status Quo regime; occurring in December and April (Figure 9). These would have increased to 20 – 21 ^{o}C under the modelled proposal. These temperature ranges will cause behavioural effects in trout and salmon but are not lethal to them. The increase in temperature will have a small adverse effect on trout feeding and growth and on salmon migration when temperatures are already naturally high, (*i.e.*, on sunny days at low flow). These occasions will be infrequent. Mean daily water temperature occasionally exceeded the threshold for feeding and growth of trout under the status quo flow regime (19^{o}C) in 2011-2012 (Figure 9). Most of the time water temperature at Waiau Bridge and Sanderson's road was lower than the thresholds that cause behavioural changes in trout and salmon under the Status Quo flow regime and the same will be true under the modelled proposal. This is illustrated by the average daily mean temperatures recorded at the above sites which under the Status Quo did not exceed 17 ^{o}C (Figure 10).

10. CONCLUSIONS

10.1 The Amuri Plains segment of the Waiau River has low diversity and densities of freshwater fish species, the latter consistent with high frequency of flood disturbance. Benthic invertebrate densities are low for the same reason.

10.2 About half of the ten fish species/life stages modelled in the Amuri Plains section of the Waiau are predicted to lose habitat on average over dry and typical years and half gain habitat. Habitat losses are small to modest for most species (< 20 %) but high for torrentfish (up to 50 %). However, these habitat losses probably won't result in population decline because densities are low (*i.e.*, habitat is unlikely to be limiting).

10.3 However, fish may be adversely affected by reduced benthic invertebrate habitat. Compared to the Status Quo benthic invertebrate habitat under the modelled proposal is predicted to decline over all months in dry and typical years, by an average of 14 - 17%. Predicted average cumulative habitat loss (*i.e.*, the modelled proposal relative to the natural flow regime) is 18 - 21% (*i.e.*, 79 - 82% retention). Predicted habitat losses for wet years average 16% and 22% for the modelled proposal compared to the Status Quo and natural flow regimes, respectively. The greatest habitat reductions will occur in typical flow years. Flood frequency naturally appears to suppress invertebrate populations in the Waiau River and the predicted habitat losses may reduce total invertebrate abundance further.

10.4 The implications for fish are uncertain. The reduction in invertebrate food resources may have adverse consequences for abundance and growth of drift feeding trout and juvenile salmon in particular. A trout abundance model predicts 20% fewer trout under the modelled proposal relative to the Status Quo and natural flow regimes. Benthic feeding native fish probably won't be adversely affected by the reduction in invertebrate food resources.

10.5 The 20 m^3/s minimum flow in the Proposed Plan will allow salmon passage in the Amuri Plains segment of the Waiau whereas the Status Quo summer minimum flow (15 m^3/s) would impede passage.

10.6 The natural frequency of floods > 210 m^3/s will be retained under the modelled proposal (and Proposed Plan) so salmon will continue to benefit from freshes that stimulate, and facilitate, upstream migration.

10.7 The modelled proposal will substantially reduce the area and quality of salmon angling lies in the Amuri Plains segment of the Waiau but this alone is unlikely to significantly adversely affect salmon angling opportunities because lies are probably underutilised over most the segment. The truncation of flow recessions resulting from flow diversion under the modelled proposal has greater potential to adversely affect salmon fishing opportunities but this can be easily mitigated by a condition that limits takes immediately following floods.

10.8 Chemical water quality will be generally high in the Amuri segment of the Waiau River under the Status Quo flow regime owing to the low percentage of the catchment intensively farmed. Chemical water quality (including dissolved oxygen) will continue to fall well within the tolerance ranges of fish under the modelled proposal regime.

10.9 Compared to the Status Quo the modelled proposal will increase water temperatures through the braided Amuri Plains river segment (Leslie Hills Bridge to Sanderson's Road – below Waiau Township) by about 1 ^{o}C. The resulting water temperatures will continue to be below lethal temperatures for fish but will be high enough to cause infrequent behavioural effects on trout and salmon, including reduced feeding and growth of trout and disruption of migration by salmon.

12 October 2012

John William Hayes

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APPENDICES

Appendix 1.

11. **Education, work experience and expertise of John William Hayes**

11.1 I have the following qualifications: BSc Honours and PhD in zoology from the University of Canterbury. I am a member of the New Zealand Freshwater Sciences Society and the American Fisheries Society.

11.2 My expertise includes instream habitat modelling, river and fish ecology, especially of trout and salmon, and recreational fisheries. After graduating with my PhD in 1984 I worked as a fisheries research scientist at the Freshwater Fisheries Centre of the Ministry of Agriculture and Fisheries until 1992. Between then and 1994 I held a similar position with the National Institute of Water and Atmospheric Research (NIWA). I have been employed as a senior fisheries scientist with the Cawthron Institute, Nelson since July 1994.

11.3 I have special expertise in recreational trout and salmon fisheries, fish bioenergetics modelling, habitat suitability analyses, and instream habitat modelling. I also have experience with native fish ecology and distribution. My interests and research experience extend to aquatic macroinvertebrates, in respect to their importance as food for fishes, and in particular invertebrate drift.

11.4 Since the mid 1990s I have managed research programmes developing and testing bioenergetics models for predicting brown trout growth, movement within rivers, and flow related carrying capacity[7,8].

11.5 In the late 1990s and early 2000s I managed a research programme on angler usage and satisfaction, trout age and growth, and trout

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[7] Hayes, J. W., Stark, J. D., Shearer, K. A. 2000: Development and test of a whole-lifetime foraging and bioenergetics model for drift-feeding brown trout. Transactions of the American Fisheries Society 129: 315-332.

[8] Hayes JW, Hughes NF, Kelly LH 2007. Process-based modelling of invertebrate drift transport, net energy intake and reach carrying capacity for drift-feeding salmonids. Ecological Modelling 207: 171-188.

catchability and behavioural response to anglers on backcountry rivers in New Zealand[9].

11.6 I have 47 years fishing experience for trout and salmon, throughout New Zealand and also in Australia and North America. I regularly publish feature articles for trout fishing magazines and have co-authored a book on trout fishing, trout habitat requirements, and trout fisheries management in New Zealand[10].

11.7 I also have extensive experience providing consulting advice to regional councils, energy companies, fish and game councils and the Department of Conservation on the flow, habitat, and water quality requirements of trout and native fishes; I have written over 80 such reports for clients.

11.8 Examples of recent hearings in which I have presented freshwater fisheries and instream habitat evidence include the:

- Buller River Water Conservation Order Hearing;
- Motueka River Water Conservation Order Hearing;
- Rangitata River Water Conservation Order Hearing;
- Genesis Energy's Tongariro Power Development Resource Consents Hearing;
- Otago Water Plan Appeal Environment Court Hearing;
- Waitaki Water Allocation Board Hearing;
- Trustpower's Wairau Valley Hydro Electric Scheme Resource Consents Hearing;
- The Oreti River Water Conservation Order Hearing;
- Meridian Energy's lower Waitaki North Branch Tunnel Concept Water Resource Consents Hearing;
- TrustPower's Wairau Hydropower Proposal Appeals Hearing;
- Central Plains Water Scheme Resource Consents Hearing.

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9 Hayes, J.W. 2002: Backcountry River fisheries: seminar proceedings & update of research. Cawthron Report No. 727. Prepared for Foundation of Research, Science and Technology, and Fish & Game New Zealand. 62p. plus appendices.

10 Hayes J, Hill L 2005. The artful science of trout fishing. Canterbury University Press, Christchurch.

- Horizon's One Plan Hearing.
- Meridian Energy's Mokihinui Hydropower Proposal Resource Consent Hearing.

11.9 In 2010 I gave advice to the Land and Water Forum on the state of New Zealand's freshwater fisheries.

Appendix 2.

1. **Sampling methods for the summer 2012 fish survey of the Waiau River in the braided Amuri and Hanmer Plains segments**

1.1 One reach was sampled in each of the Amuri and Hanmer Plains segments. Sampling was undertaken by single pass electrofishing using two electrodes fished in tandem. Single pass electrofishing provides semi-quantitative density data. Figure 3 illustrates the sampling design. In each reach, three riffles and three runs (mesohabitats) were fished in each of a major, intermediate and minor channel. In addition, two seepage channels were fished in the Amuri reach and one in the Hanmer reach. In the major, intermediate and minor channels 3-4 replicate 20 m^2 lanes (10 m long x 2 m wide) were sampled systematically per mesohabitat, totalling 60 - 100 m^2 per mesohabitat. Lanes were chosen to cover a range of mean water depths and velocities from shallow, slow margins to deep, fast water at the extreme of safe wading and efficient electrofishing (< 0.7 m deep and 1.3 m/s).

1.2 Water depths and velocities within the lanes were measured and were reasonably homogenous. In addition to demonstrating that we sampled a broad range of depths and velocities, with the physical and efficiency limitations of electrofishing, these data also served to verify the habitat suitability curves used by Mr Jowett for habitat modelling.

1.3 Sampling was less regimented in the seepage channels, being largely opportunistic and dependent on mesohabitat availability. Two riffles, three runs and two backwaters were sampled in the seepage channels in the Amuri reach and a riffle and four runs were sampled in the seepage channel in the Hanmer reach. Lanes were fished where the channel geometry suited; otherwise areas of various shapes and sizes were fished. As for the larger channels, water depths and velocities within the areas fished were relatively homogenous. In total 96 m^2 of riffle, 105 m^2 of run, and 280 m^2 of backwater were sampled in the two seepage channels in the Amuri reach, and 6 m^2 of riffle and 24 m^2 of run were fished in the seepage channel in the Hanmer reach.

1.4 Additional electrofishing sampling was conducted in some Waiau River tributaries between Waiau township and about 14 km upstream from the Hanmer reach; these included Cow Creek, Counting Crow Stream, Home Stream and Manson River (Figure 2). The aim of the tributary survey was to determine whether additional species were present that were not found in the main river. Therefore, sampling was not structured according to a similar design as that for the main river, but rather it was opportunistic in nature, depending on access, and involved prospecting the streams with single electrofishing machines to assemble a species list.

1.5 We sampled channels of different size because flow alteration potentially affects the channels differently. When flow is reduced, the shallow, minor, and possibly seepage, channels will loose proportionally more habitat for small fish, and macroinvertebrates, than the major channels. Hence some understanding of comparative diversity and density of seepage and minor channels versus major channels is necessary to assess effects.

Appendix 2: Tables

Table 1. Fish species occurrence (% of NZFFD records for the river) in the Waiau and Hurunui rivers. NZFDD search criteria excluded wetlands, lakes, lagoons and ponds. A total of 80 records were retrieved for the Waiau River between 1965-2010, of which 75 included fish, and 83 records for the Hurunui River between 1963 – 2010 of which 71 included fish. National conservation threat classification (Allibone *et al*. 2010) and migratory/non-migratory behaviour are also listed.

Common name	**Scientific name**	**Occurrence**		**Threat classification**	**Migratory**
		Hurunui[1]	**Waiau**		
Longfin eel	*Anguilla dieffenbachii*	5.6	9.8	Declining	Y
Shortfin eel	*Anguilla australis*	4.5	2	Not threatened	Y
Alpine galaxias	*Galaxias paucispondylus*	9.6	6.5	Not threatened	N
Canterbury galaxias	*Galaxias vulgaris*	16.3	27.5	Not threatened	N
Inanga	*Galaxias maculatus*	-*	2	Declining	Y
Koaro	*Galaxias brevipinnis*	11.8	2.6	Declining	Y/N
Upland longjaw galaxias	*Galaxias prognathus*	0.6	0.7	Nationally vulnerable	N
Torrentfish	*Cheimarrichthys fosteri*	0.6	0.7	Declining	Y
Common bully	*Gobiomorphus cotidianus*	0.6	0.7	Not threatened	Y
Upland bully	*Gobiomorphus breviceps*	18.5	24.2	Not threatened	N
Common smelt	*Retropinna retropinna*	-*	0.7	Not threatened	Y
Brown trout	*Salmo trutta*	22.5	16.3	Introduced and naturalised	Y/N
Rainbow trout	*Onchorhynchus mykiss*	-	-*	Introduced and naturalised	Y/N
Chinook/quinnat salmon	*Onchorhynchus tschawytscha*	2.2	5.9	Introduced and naturalised	Y
Perch	*Perca fluviatilis*	0.6	-	Introduced and naturalised	N
Fish absent		6.7	0.7		
TOTAL species recorded in NZFFD		12	13		
***TOTAL** species known to be present		14	14		

[1]Occurrence totals are subject to ounding error causes

*Common smelt and inanga are present in the lower Hurunui River, especially in the lagoon above the river mouth because they are caught by whitebaiters and are frequently seen from the banks. Rainbow trout are occasional caught by anglers in the upper Waiau River

Table 2. Probable fish migration (black bars) in the affected reaches of the Waiau River over a year, and, for reference, timing of koaro whitebait, glass eels, juvenile bullies and torrentfish migrating from the sea into the river mouth. Progressive colonisation upstream is represented by green bars; dark green over the warmer periods when active upstream movement occurs, and light green for cooler periods when less movement occurs. Reproduced from Snelder et al. (2011).

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Longfin eel	glass eel	from sea												
	elver	gradual upstream												
	adult	downstream												
Shortfin eel	glass eel	from sea												
	elver	gradual upstream												
	adult	downstream												
Koaro	whitebait	from sea												
	post-whitebait	upstream												
	larvae	downstream												
Lamprey	adult	upstream												
	ammocete	gradual downstream												
	macropthalmia	out to sea												
Torrentfish	juvenile	from sea												
	growing adult	gradual upstream												
	larvae	downstream												
Bluegill bully	juvenile	from sea												
	growing adult	gradual upstream												
	larvae	downstream												
Common bully	juvenile	from sea												
	growing adult	gradual upstream												
	larvae	downstream												
Chinook salmon	adult	upstream												
	juvenile	downstream												
Brown trout	adult	upstream												
	juvenile	downstream												

Table 3. Fish species density (per 100 m^2) sampled by single pass electro-fishing in riffles in five east coast South Island rivers. Adapted from Jellyman *et al*. (2003).

	Waitaki[1]	**Ashley**[2]	**Hurunui**[2]	**Rakaia**[2]	**Waiau**[3]
Bluegill bully	1.0	81.0	0.0	1.0	0.0
Common bully	0.0	5.0	0.0	0.0	0.0
Upland bully	25.0	25.0	23.0	3.0	1.7
Koaro	0.0	1.0	1.0	0.0	0.0[4]
Longfin eel	1.0	72.0	9.0	2.0	1.4
Shortfin eel	0.0	8.0	0.0	0.0	0.0
Torrentfish	1.0	389.0	5.0	15.0	0.8
Brown trout	15.0	1.0	1.0	1.0	2.0
Chinook salmon	0.0	1.0	1.0	2.0	0.5
Rainbow trout	1.0	0.0	0.0	0.0	0.0
Canterbury galaxias	0.0	12.0	20.0	0.0	3.8
Total density/100m^2	44.0	595.0	60.0	24.0	10.1

[1] Jellyman et al. (2003)
[2] Glova et al. (1985) – sampling undertaken immediately upstream of SH 7 Bridge.
[3] February 2012 sampling in Amuri and Hanmer Plains
[4] Koaro were caught in runs in Waiau River.

Appendix 3: Figures

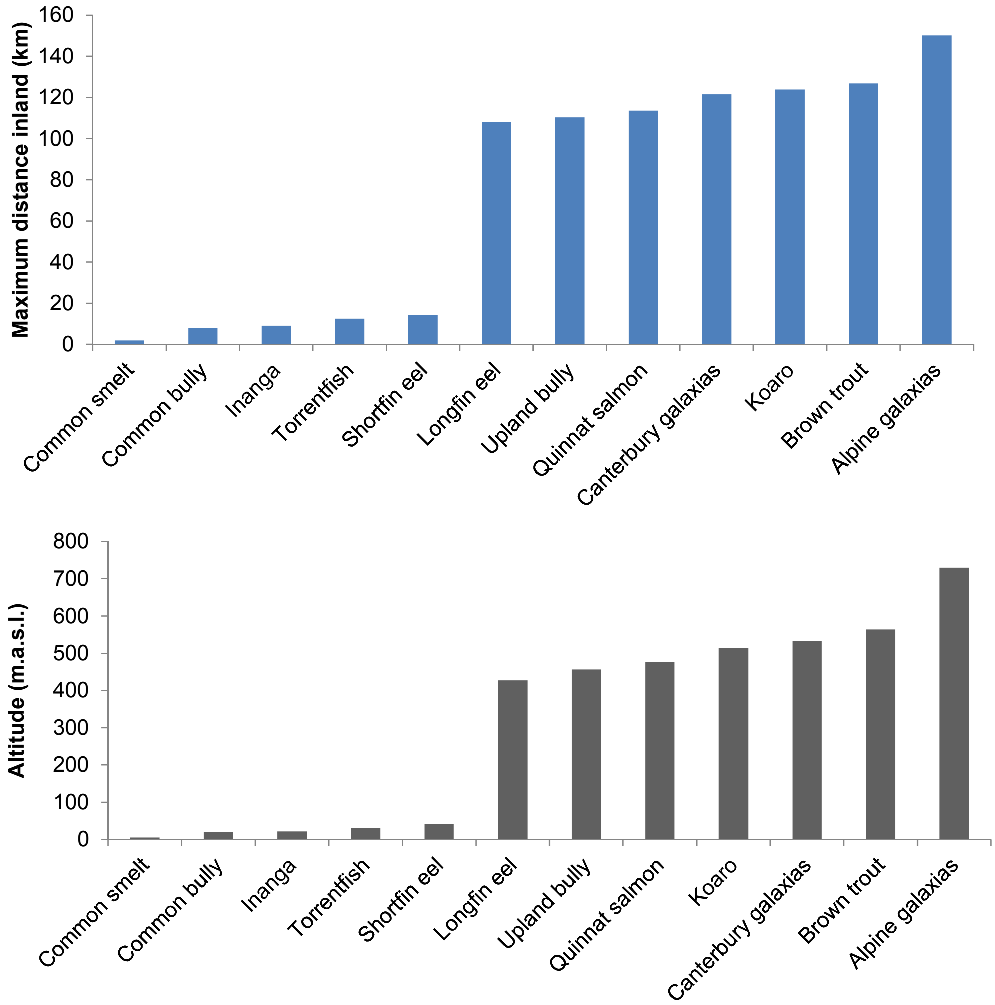

Figure 1. Maximum distance inland (km) and altitude (meters above sea level) for 12 fish species in the Waiau Catchment. Data were sourced from the NZFFD (NIWA).

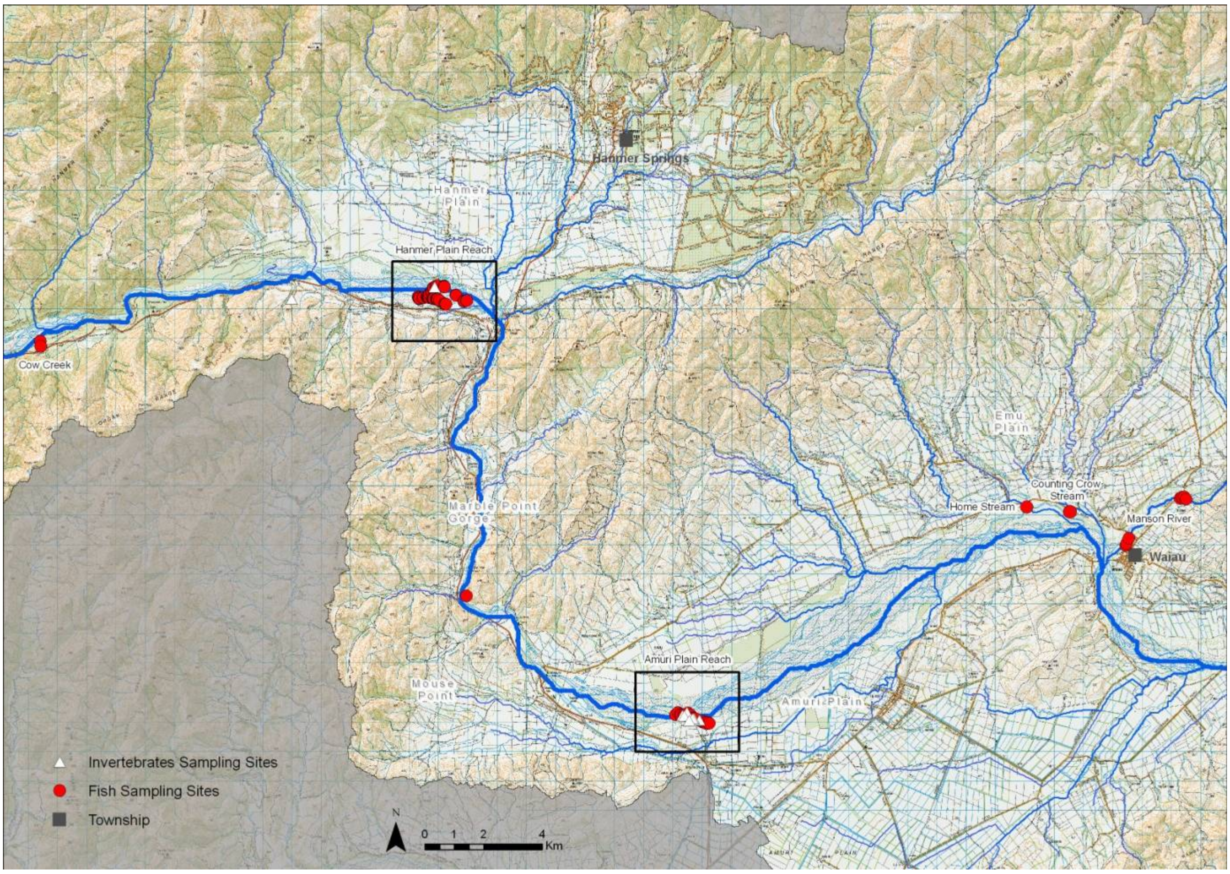

Figure 2. Location of sampling sites for the periphyton, macroinvertebrate and freshwater fish surveys conducted in January – February 2012.

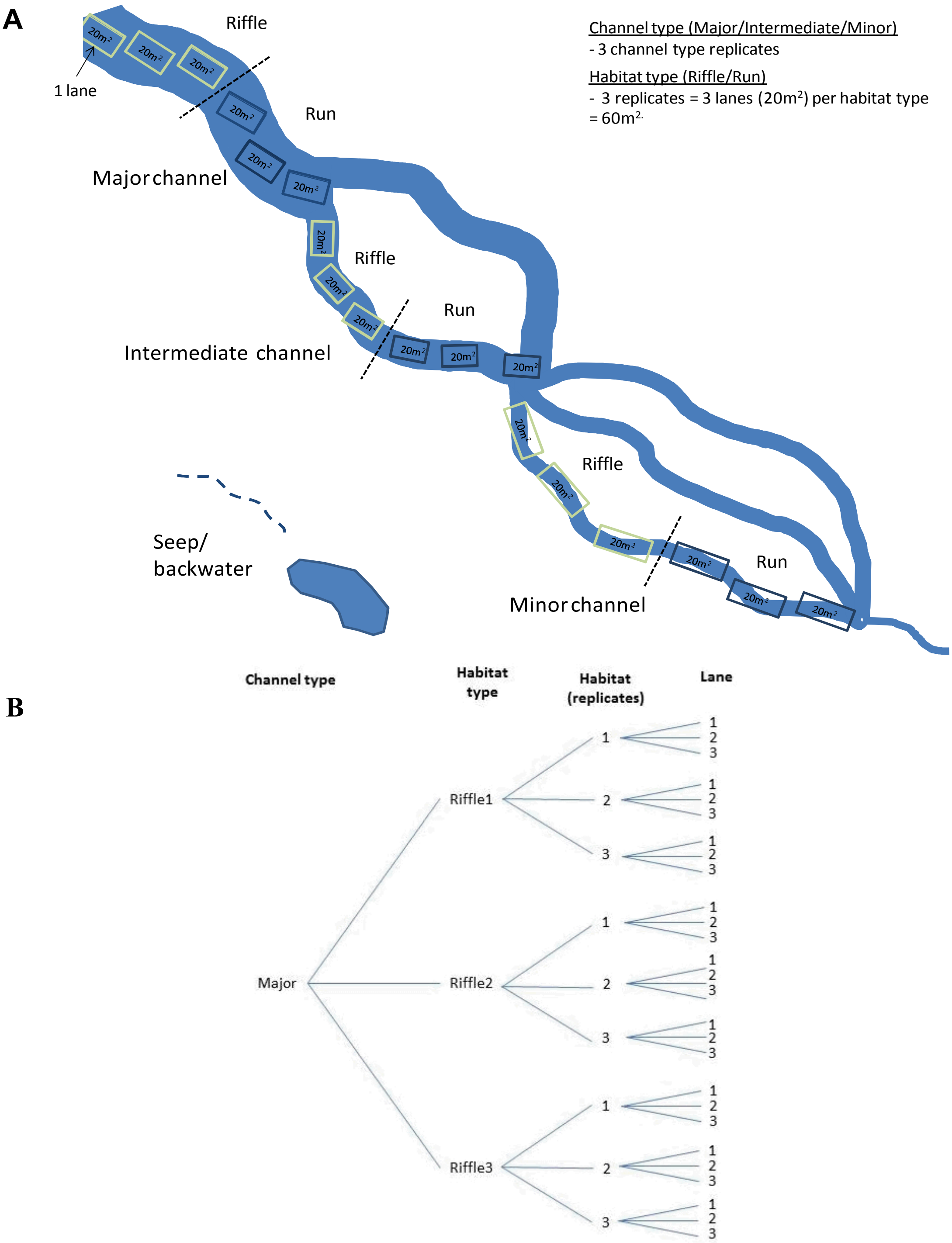

Figure 3. Sampling design for the February 2012 freshwater fish survey. (**A**) Sampling design for both the Hanmer (control) reach and the Amuri Plains (affected) reach. (**B**) Sampling design for one channel type (in this case a major channel) and one habitat type (in this case a riffle).

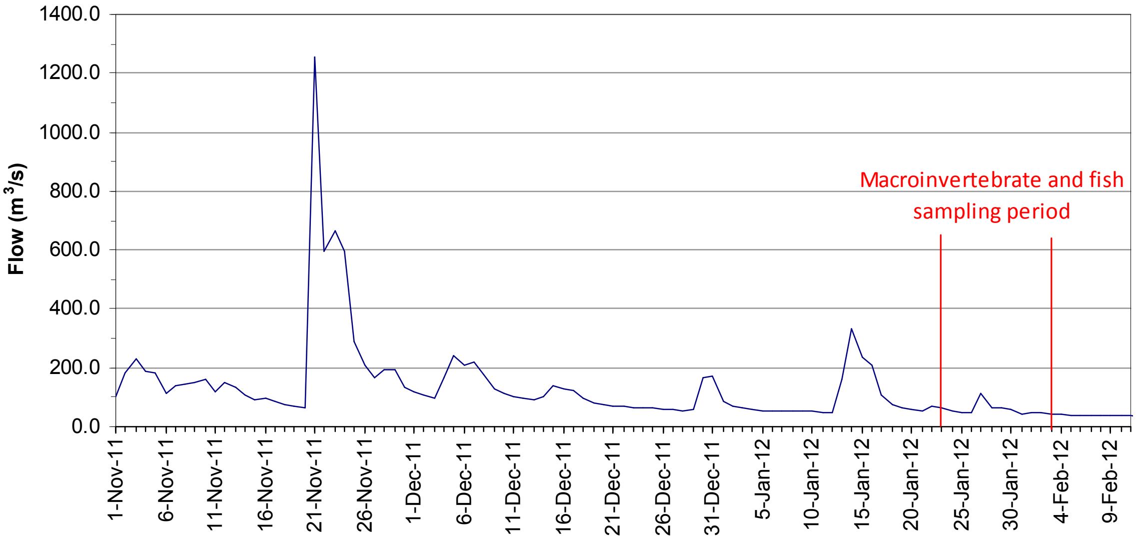

Figure 4. Timing of the freshwater fish surveys in relation to the maximum daily river flow calculated from continuous flow data from the Waiau River at Marble Point between November 2011 and February 2012.

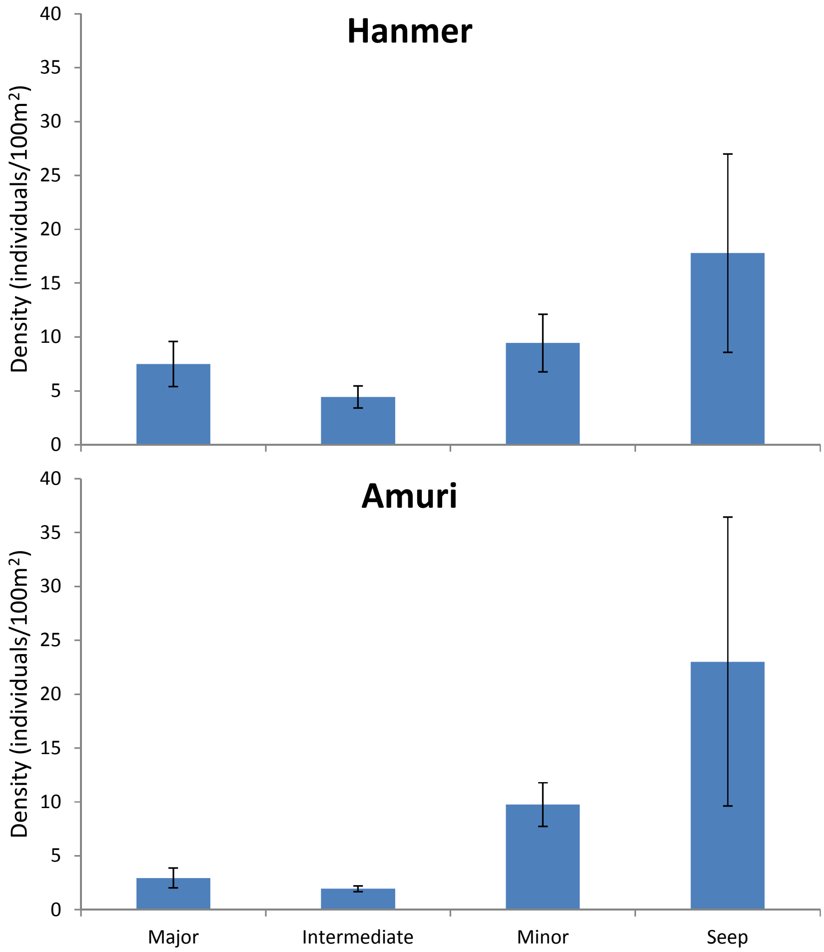

Figure 5. Comparison of total fish density (per 100m^2) (± SE) between different channel types for the Hanmer and Amuri reaches.

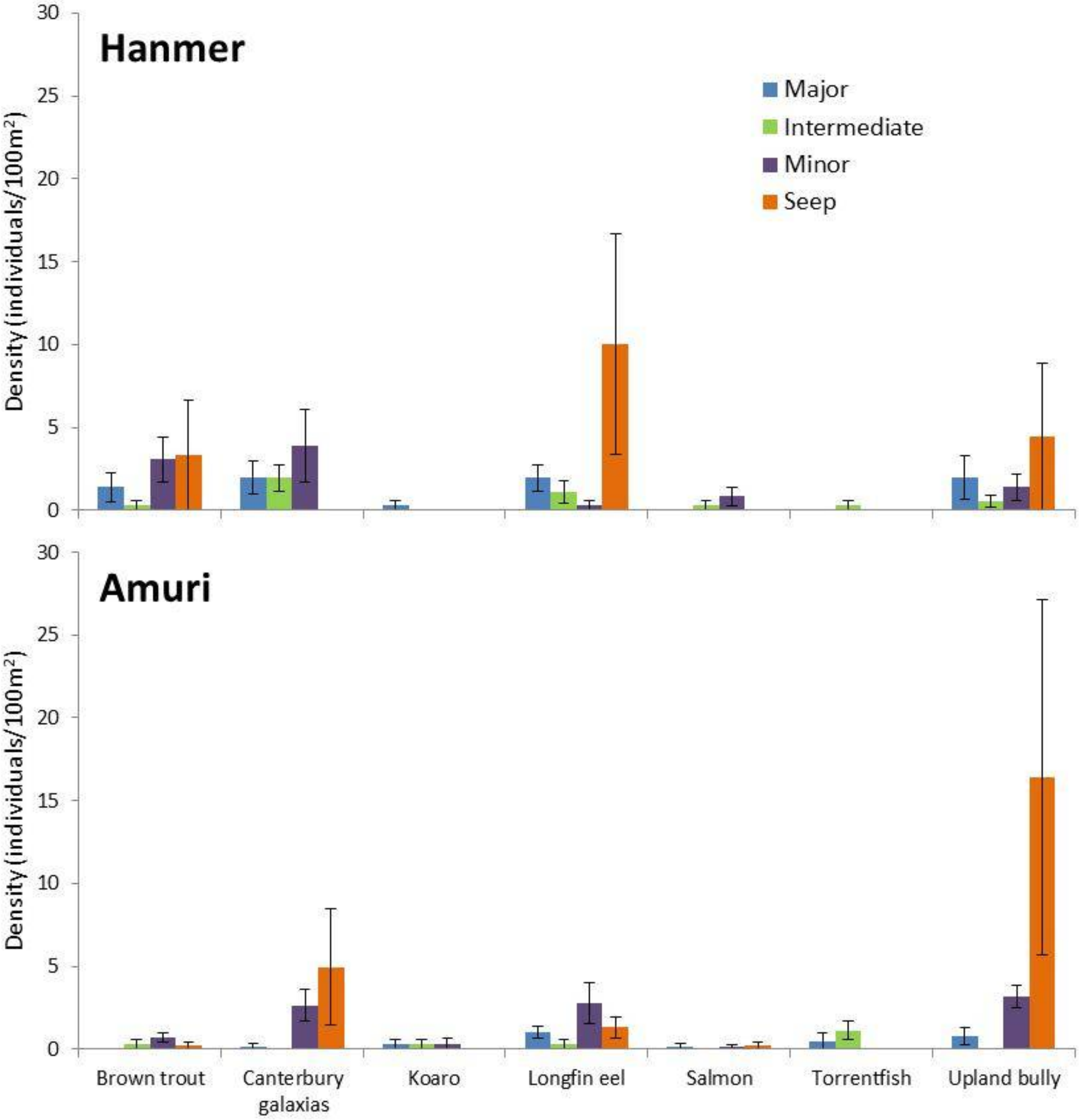

Figure 6. Comparison of individual fish species density (per $100m^2$) (± SE) between different channel types for the Hanmer and Amuri reaches.

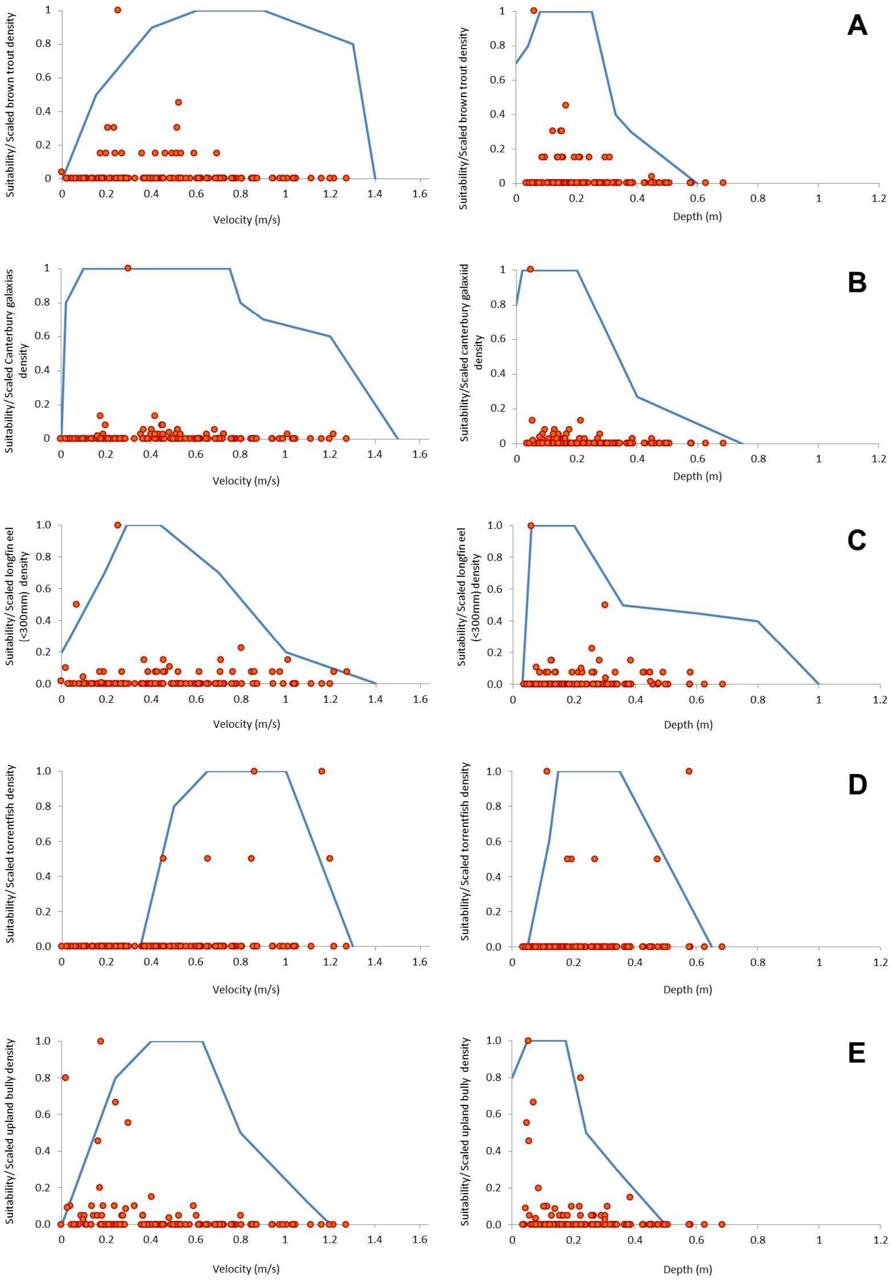

Figure 7. Water velocity and depth suitability curves (blue lines) developed by Jowett & Richardson (2008) for brown trout (A), Canterbury galaxias (B), longfin eel (C), torrentfish (D) and upland bully (E) overlaid with density data from the Waiau River (orange dots). The density data for each lane fished was scaled to between 0-1 by dividing by the maximum density.

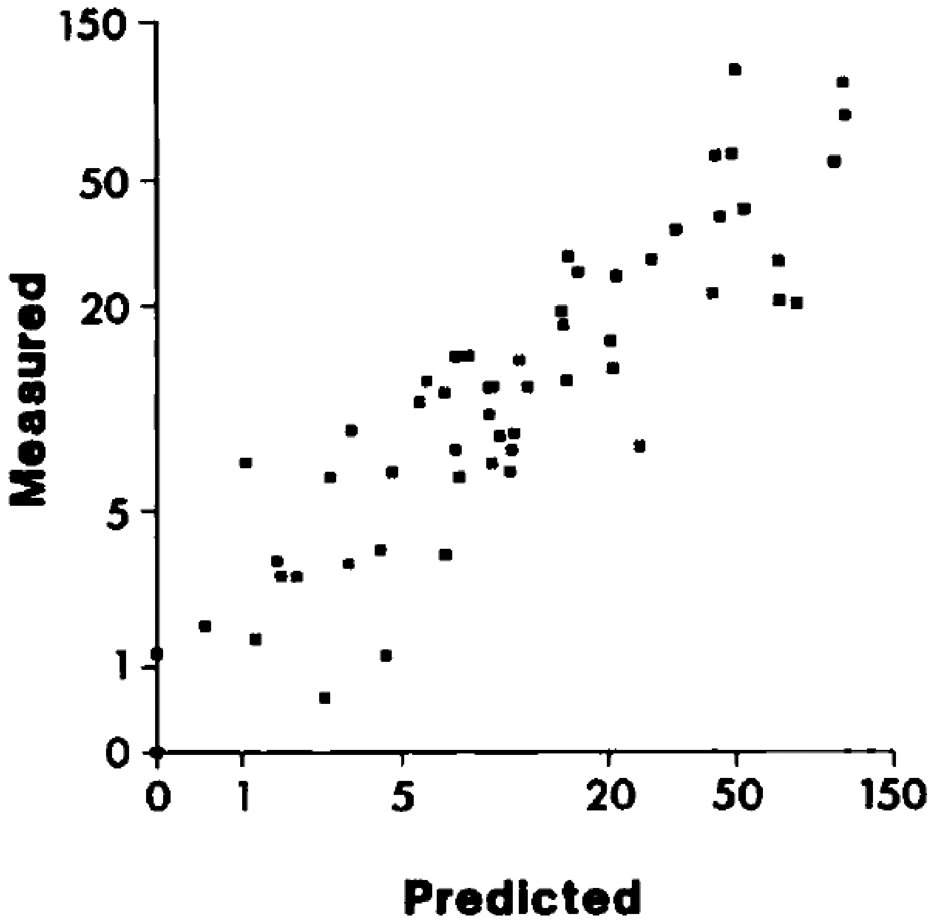

Figure 8. Comparison of measured and predicted brown trout abundance (numbers / hectare) for 59 New Zealand rivers according to model C in Jowett (1992).

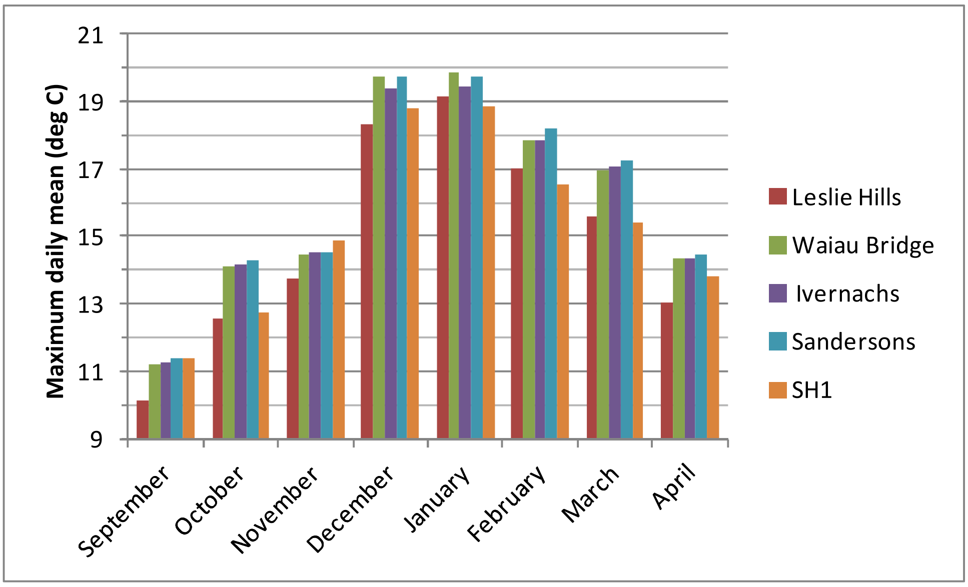

Figure 9. Maximum daily mean water temperatures September 2011 to April 2012 for sites between Leslie Hills Bridge and the SH1 Bridge (from Jowett 2012b).

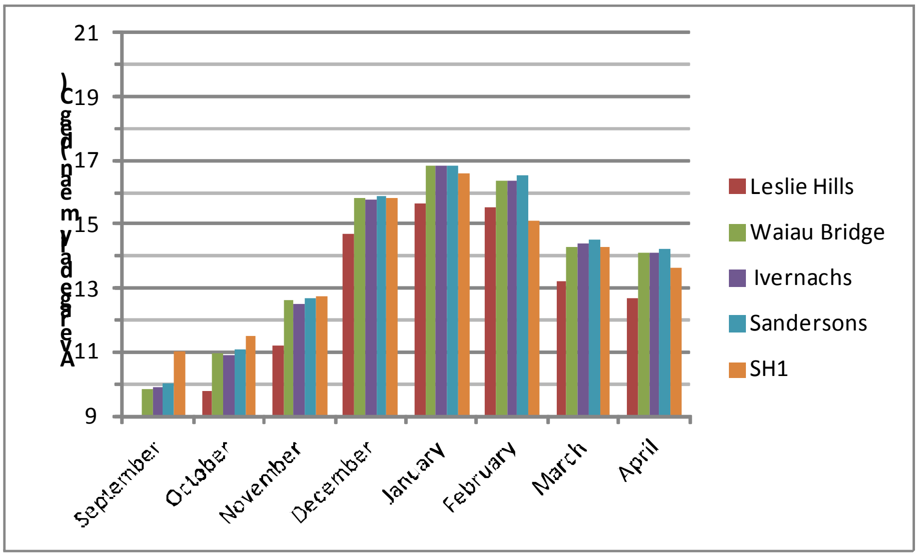

Figure 10. Average daily mean water temperatures September 2011 to April 2012 for sites between Leslie Hills Bridge and the SH1 Bridge (from Jowett 2012b).

Appendix 4.

1. **Fish habitat – food relationships and uncertainties in braided rivers.**

1.1 I have already pointed out the uncertainties in hydraulic-habitat modelling arising from averaging habitat across all channel types and not accounting for the fact that invertebrate and fish densities are higher in minor channels owing to them experiencing less flood disturbance (paragraphs 7.15 – 7.17). Mr Jowett's hydraulic-habitat modelling in the Amuri reach indicates that there is not much reduction in the number of braids over the median – low flow range. He counted an average of 5.5 braids at 50 m^3/s and 4.4 braids at 15.1 m^3/s. So fish will not be forced to move from minor braids due to drying under the modelled proposal. The available habitat area in minor braids will decline – probably at a greater rate than indicated by Mr Jowett's predictions for all channels combined, but because fish are presently at low densities it is unlikely that they would experience habitat limitation under the modelled proposal. The result will probably simply be higher densities (*i.e.*, the same number of fish in a smaller area). While densities of benthic invertebrates in minor channels might also increase for the same reason, the total abundance is more likely to decline – owing to the reduction in area of their habitat and that of their periphtyon food (the latter being unable to move with the drying margin).

1.2 The second area of uncertainty is whether predicted reductions in benthic invertebrate habitat will translate to less food for fish. If fish forage by browsing over large areas of the river bed (say like sheep in a paddock) then the predicted reduction in area of benthic invertebrate habitat might result in diminished food intake. Extending the sheep analogy this represents a reduction in paddock size and therefore less grass production – hence less sheep can be supported. Most of the native fish in the Amuri Plains segment of the Waiau feed by browsing invertebrates off the river bed, although Canterbury galaxias may also forage on invertebrates drifting in the current (as trout and juvenile salmon do). However, unlike sheep benthic foraging native fish do not forage widely, most probably occupy a home range of a few meters, close to cover, or move between a riffle and a nearby run or pool. Hence the food availability at the patch scale rather than reach scale is probably more relevant to them.

1.3 Fish that swim in the water column, such as trout and salmon, are predominantly invertebrate drift feeders. They visually forage from a focal point, in relatively deep water, on invertebrates drifting past in the water column or on the water surface. The focal point can be somewhat loose in the case of juvenile salmon schooling with others of their kind, but the drift feeding concept still applies. Invertebrate drift is the process by which benthic invertebrates produced in extensive shallow, moderately fast-water (riffles and runs) habitats are transported to where trout and juvenile salmon lie in wait in deeper, slow-moderately flowing water. Trout and juvenile salmon like deeper, slower locations because these allow them to maximise their drift foraging area. The larger the trout, the deeper the water it likes to feed, and live, in. Because deep water is comparatively uncommon in braided rivers prime drift foraging locations, with cover nearby, are uncommon and patchy in distribution.

1.4 What matters to drift feeding fish is the concentration of invertebrates in the water column; the higher the drift concentration the higher the rate of drift delivery through their foraging area (at least 2 body lengths in cross sectional radius around the fish but this can be greater in slower water). They prefer locations that are deep enough, with moderate water velocities to ensure a large three dimensional foraging area and fast enough to ensure a high rate of drift delivery (drift rate being the product of drift concentration and water velocity through the cross-sectional foraging area). Therefore, in respect of the effects of flow change on benthic invertebrate habitat, the relevant question to ask is "how might the reduction in area of invertebrate habitat affect drift concentration?"

1.5 The answer to this question depends on two key points, both poorly understood: 1/ how big is the drift catchment area upstream of the fish (*i.e.*, how far and wide do the invertebrates passing through a fishes foraging area recruit from)?; 2/ are there flow related processes by which drift can concentrate?.

1.6 Invertebrates are known to remain in suspension for 10 – 60 m, depending on water velocity and the behaviour of the invertebrate (Keup 1988). But they periodically re-enter the drift. Hence, invertebrates can move downstream considerable distances in a saltatory fashion, and adults that emerge from the water can accumulate on the water surface in eddies and back-waters.

1.7 The area of the food producing catchment upstream will be critical in determining the carrying capacity of deep-water feeding refuges that adult trout in particular prefer. If flows are insufficient to maintain the food producing area, and drift flux, to support the fish population in a deep-water refuge then the longer the flow is at the minimum flow, the greater will be the adverse effect on energy reserves, or growth potential, of the fish. This highlights the interplay between the magnitude of the minimum flow and its duration – the latter being sensitive to the allocation volume and the frequency of freshes/floods.

1.8 Once in the water column invertebrates cannot concentrate by any hydraulic process (*e.g.*, the merging of lines of current) because water cannot be appreciably compressed, at least not at depths common in rivers. However, the variable depth to volume ratio in a river can serve to vary the drift concentration (no. invertebrates/m^3). Drift concentration will be highest where the flow is spread over shallow riffles – because there is a large surface area of river bed contributing invertebrates to the water column. Drift concentration will be lowest where the river is narrow and deep owing to dilution (*i.e.*, low area of wetted bed to volume ratio), and where invertebrates settle to the bed. Therefore, it is not surprising that drift feeding salmonids are commonly found in transition zones where waters flowing over shallow riffles merge at the heads of runs and pools. Whether a flow reduction substantially alters the drift concentration emanating from the shallow food producing areas depends on the how the ratio of populated food producing habitat area varies with depth. This also depends on the historical stability of the channel. The longer that the bed of a channel (or zone in a channel) remains undisturbed by floods the longer time there is for periphyton and benthic invertebrate colonisation (*i.e.*, for densities to increase). Bed stability versus flow dynamics and its outcome for benthic colonisation (and hence productivity) at spatial scales relevant to fish is poorly understood. Research to tackle this important question is expensive and beyond the resources commonly available for effects assessment of flow alteration proposals in New Zealand.

1.9 The forgoing discussion focussed on aquatic invertebrates in the water column. As I said, once in the water column invertebrates can't be concentrated owing to the incompressibility of water. However, hydraulic processes can concentrate invertebrates on the water surface. This happens where surface "seams" occur where lateral down-welling meets with slower flowing water, and in eddies and backwaters where floating debris and invertebrates accumulate. Invertebrates from the water's surface (of aquatic and terrestrial origin) feature predominantly in the diet of juvenile salmon in braided rivers.

1.10 Even if the reductions in invertebrate habitat predicted for the modelled proposal, when compared with the Status Quo and natural flow regimes do not appreciably alter the drift concentration in the water column in transition zones, they will lead a reduction in total mass transport of drift. This could reduce the density (no./m^2) of surface drifting aquatic invertebrate adults, but given the high temporal and spatial variation of invertebrate drift large research efforts would be required in order to have any hope of detecting this.

1.11 At a conceptual level though, ultimately it is the total mass transport of drift that ought to influence the abundance and biomass of drift feeding fish. Drift that bypasses one fish, either through or past its foraging area, is available for other fish downstream. Dispersion processes distribute drifting invertebrates from the fast thalweg to the margins, where they settle, through the zone where water velocities and depths are suitable for drift feeding fish. Dispersion also equalises drift concentrations after local depletion by a drift feeding fish. Providing there is sufficient drift feeding habitat, the more drift food that is transported will allow more fish to be spaced along the margins of large channels and throughout runs and pools in minor channels.

1.12 Given the low benthic invertebrate densities, average drift concentrations in the Amuri Plains segment of the Waiau River will also be low. The food requirements of fish increase as they grow, hence the likelihood of growth limitation increases with body size. It is very likely that low drift concentrations presently limits the growth of trout (at least after their first year) and larger juvenile salmon in the Amuri Plains segment. Dirty water from frequent flooding will add to growth limitation by reducing drift foraging efficiency. The predicted reductions in invertebrate habitat under the modelled proposal risk exacerbating growth limitation, particularly of these species.

1.13 Farmers can measure grass growth and production of dry matter to estimate carrying (stocking) capacity. It is then a simple matter to estimate the reduction in carrying capacity that will occur with a reduction in paddock size. This is much more difficult to do in rivers and the task is even more challenging because one needs to consider interactions between three trophic levels – periphyton, invertebrates and fish. However, this is the very information that we need in order to really understand the effects of flow reduction on the productivity of fish populations supporting fisheries. It is very difficult and expensive to undertake studies to provide this information; they are beyond the budgets available for assessments of effects for resource consents and planning hearings.

1.14 It is also very difficult to monitor effects of flow change on fish populations and hence learn by experience. It is highly unlikely that actual effects of flow alteration on fish populations in the Waiau River could be detected with realistic monitoring budgets, owing to high spatial and temporal variability in benthic invertebrate and fish habitat and densities. Although detection of flow effects on fish populations is unlikely, this does not mean effects can be ruled out. This is more a commentary of our inability to harness enough monitoring and research effort to detect effects.